CHAPTER 2

Post Construction
Stormwater Management Practices

Post-construction stormwater management practices treat runoff from a development site *after* construction is complete. Their objectives range from capturing and treating pollutants in runoff to managing the increased frequency, volume and energy of stormwater runoff so that water resources are not degraded.

Historically, stormwater ponds were used to reduce downstream flooding. Today post-construction stormwater ponds add pollution control and stream protection as important design elements. Apply the structural practices found in this chapter to reduce pollutants, meet state and local permits and reduce downstream erosive effects of runoff. While all structural practices require maintenance, those provided here emphasize lower maintenance and generally self-sustaining processes. Other structural practices are available for use; yet all should be examined for their effectiveness, maintenance requirements and ability to function if maintenance is delayed.

Treatment occurs primarily through the processes of settling, adsorption, and biological uptake, while detention is utilized to curb the impact of increased runoff. Where soils are appropriate, infiltration provides substantial hydrologic benefits.

Structural practices treat runoff, but more is needed to effectively prevent and minimize impacts. Therefore additional management practices are strongly encouraged. Practices such as stream setbacks or reduction of impervious areas influence the layout and design of a development site so that important hydrologic areas are maintained and runoff is limited. Many of the management practices provided have more exhaustive reference sources given that should be consulted as they are applied. Note that while each of the management practices is beneficial, some community zoning or building standards may limit your ability to use a particular practice.

MANAGEMENT PRACTICES

STRUCTURAL PRACTICES

2.1 Reduction of Impervious Areas

Description

Impervious area is the largest cause of increased stormwater runoff as a result of development. Any type of surface that does not allow water to penetrate it is considered impervious. Impervious areas do not allow precipitation to infiltrate into the ground or be absorbed by vegetation, thus increasing the quantity of stormwater runoff and all of its associated problems. Impervious areas consist of asphalt or concrete used in roads, parking lots, drive ways, sidewalks and roofs.

Condition Where Practice Applies

Almost every development project includes the construction of some type of impervious surface, which will contribute to the increase in stormwater runoff. Opportunities to reduce the amount of impervious area exist on practically every project.

Planning Considerations

Although the developers have the ability to incorporate alternative designs that reduce the amount of impervious area in their project, it is the local-governmental agency(ies) that will actually determine what can and will be used. It is in the best interest of communities to allow some alternative design options, especially with Phase II stormwater regulations.

- Parking Lots

  Local community officials may change or modify the zoning ordinance pertaining to parking lots. The number of required parking spaces can be reduced.

"Green space" can be added to or increased within the parking lot. Additional overflow parking can utilize non-paved areas. The minimum number of trees required in parking lots can be increased. Some types of grass reinforcement can be used to provide maintenance and emergency access instead of traditional hard surfaces.

- Decrease Pavement Connectivity

  Another proven method to reduce and slow down stormwater runoff is to provide breaks in the connectivity of pavement. Instead of having large paved areas, provide a grass area for water to flow to and then into the storm sewer system. This slows down runoff, and provides other environmental benefits.

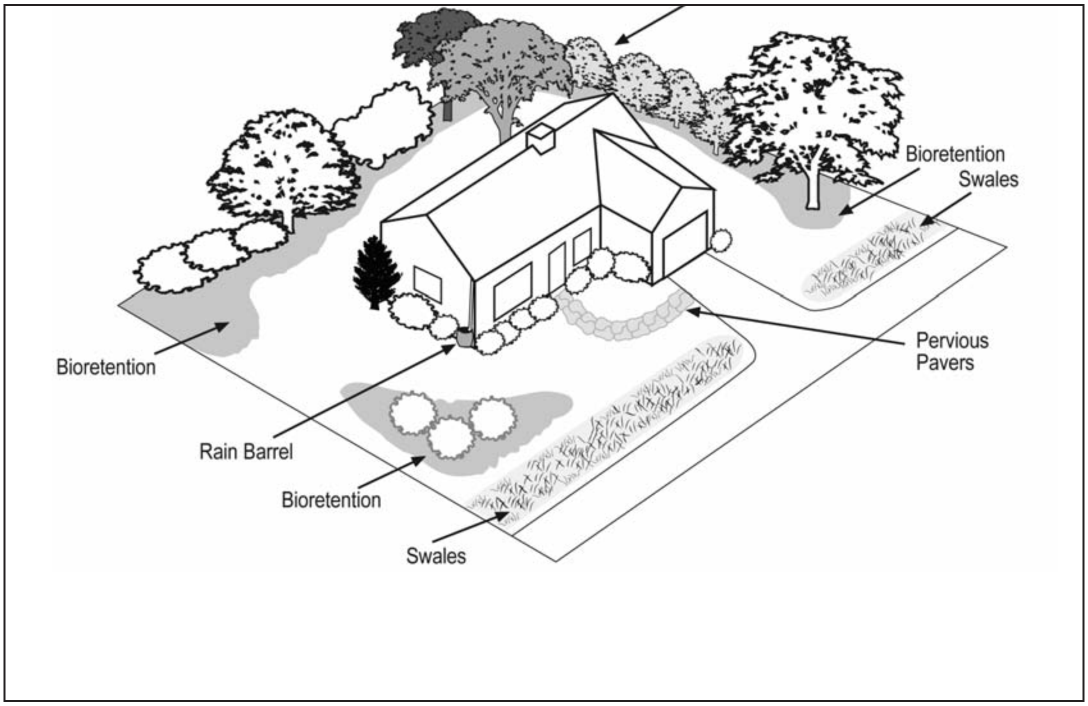
- Sidewalks

  The width of sidewalks may be reduced to reduce the amount of impervious area. Or some type of stepping stones can be used as a walk way. Pavers with permeable bases allow water to infiltrate between the individual stones, instead of increasing runoff.

- Buildings

  Buildings can also be designed to reduce the amount of impervious area. Instead of having a large floor plan, buildings can be built higher reducing the amount of impervious area added by its roof. The amount of runoff created by its roof can be reduced by using a "green" roof. These are typically planted with grass, ground cover, and even small trees and bushes. They are very popular in large cities where land is not available. Green rooftops can serve as a park-like setting open to the people in the building. They may also be used solely to provide stormwater benefits. However, if there is flexibility in the local and state codes that permit green roofs, few developers will proceed with the concept. Once again it would be in the community's best interest to include green roofs as an acceptable design alternative in their standards.

2.2 Low Impact Development



Description

Low-impact development (LID) is a site design approach, which seeks to integrate hydrologically functional design with pollution prevention measures to compensate for land development impacts on hydrology and water quality. LID's goal is to mimic natural hydrology and processes by using small-scale, decentralized practices that infiltrate, evaporate, detain, and transpire stormwater. LID stormwater controls are uniformly and strategically located throughout the site.

LID is achieved by:

- Minimizing stormwater runoff impacts to the extent practicable through preservation of existing landscape features and their hydrologic functions.
- Maintaining predevelopment time of concentration through strategic routing of flows using a variety of site design techniques.
- Dispersing runoff storage measures through a site's landscape through the use of a variety of detention, retention, and runoff practices.

LID practices manage stormwater at its source. LID measures reduce impervious cover, minimize disturbance, preserve and recreate natural landscape features, increase hydrologic disconnects and facilitate infiltration and detention opportunities. LID creates a multifunctional landscape which relies on natural features and processes and emphasizes simple, nonstructural, low-tech methods.

Conditions Where Practice Applies

LID can be used in a broad range of land use situations. Due to maintenance considerations, LID may be most appropriately utilized on institutional, industrial, commercial and governmental developments. However, LID in tandem with conventional stormwater control features can be successfully integrated into any development. LID has been demonstrated to work in new developments and constrained sites involving urban infill or retrofit to reduce combined storm sewer inflows.

Planning Considerations

LID is a design approach and represents a collection of stormwater management practices that may be utilized together to manage stormwater. LID measures are often used as a supplement to conventional stormwater practices to meet the state critical storm criteria and provides post construction water quality benefits.

Nine steps in the LID Site Planning Process.

1. Determine the applicable zoning, land use, and subdivision regulations,
2. Define development envelope (total areas that affect hydrology on site),
3. Use drainage/hydrology as a design element,
4. Reduce total site impervious areas,
5. Integrate preliminary site layout plan,
6. Minimize directly connected impervious areas,
7. Modify/increase drainage flow patterns,
8. Compare pre and post development hydrology and identify Integrated Management Practices (IMP's),
9. Complete LID site plan.

The LID principals are designed to minimize disturbance and manage the stormwater as close to its source as possible. Specific low impact development controls called Integrated Management Practices (IMP's) are tools for developers to utilize to manage stormwater at its source rather than relying solely on centralized BMP's such as detention basins. Common IMP's are detailed below under Design Criteria. Each IMP will have specific planning considerations; however the following details several of the common planning considerations.

- **Clay Soils:** Higher proportions of clay particles in the soil (greater than 27%) will reduce the effectiveness of infiltration-based measures and require greater use of surface depression measures.
- **High Water Table:** High water table, even high seasonal water tables, may restrict the use of some IMP's. Provide at least 2 to 4 feet of separation between the bottom of the IMP and the top of the seasonally high water table elevation. On-site soil evaluation by a qualified professional is highly recommended.
- **Building Foundation and Structures:** IMPs should not be located near foundations of buildings or other structures.
- **Deed Restrictions:** Maintaining distributed depression storage measures within residential subdivisions will require deed restrictions on individual parcels as well as homeowner education programs to ensure measures are maintained.

- **Zoning Variances:** Variances from zoning, subdivision, building, stormwater management, and drainage regulations may be required unless LID is permitted.
- **Snow:** Snowbelt areas of Ohio may find that parking lot LID measures will need to consider snow storage and the effects of road salt on plant material.
- **Design Costs:** Up-front design costs may increase over design of conventional stormwater management approaches due to the need to "fingerprint" the site and complete microscale design of the integrated management practices. However, construction and maintenance costs often decrease.
- **Public Health:** Public health concerns exist about West Nile Virus and other mosquito borne diseases. Brackish water pools may serve as the breeding ground for the mosquitos that carry West Nile Virus. Proper design and construction of stormwater management facilities are necessary to minimize or eliminate this issue.
- **Maintenance Access:** Easements may be necessary to give the community access for maintenance on IMPs.
- **Contractor Guarantees:** Obtaining contractor guarantees for some integrated management measures may not be possible due to lack of standard construction and material specifications.
- **Public Education:** Public education materials are essential for long term management of IMP's.

LID is a relatively new approach to stormwater management in the U.S and has not been used extensively in Ohio because of historic focus on water quality control, climatic factors, lack of regional design standards and cost. However, many of the IMPs, including bioretention, vegetated swales, filter strips and porous pavers, have been utilized individually. LID may also be an important tool to reduce the effects of land use changes near ecological sensitive areas.

Design Criteria

The goal of LID is to mimic the predevelopment hydrology through runoff volume control, peak runoff rate control, flow frequency/duration control, and water quality control. To effectively manage stormwater using LID, the developer must define the hydrologic control (runoff, groundwater recharge, infiltration), evaluate the site constraints (slopes, soils), evaluate and select IMP's that are appropriate considering the hydrologic scheme and site constraints. The addition of some conventional controls may be necessary to complete the stormwater management scheme for the developed site.

See other sections of the Rainwater and Land Development Manual for applicable design criteria on grassy swales, and bioretention. There is no limit to the number of IMP's which may be implemented as part of a low impact development.

Some additional integrated management practices include:

- Biofiltration
- Dry Wells
- Filter/Buffer Strips
- Vegetated Swales
- Cistern & Rain Barrels
- Infiltration Trench
- Green Roof
- Wetland Channels
- Soil Amendment
- Impervious Surface Reduction

Pervious Paver installation

Bioretention

Maintenance

LID may be most appropriately used in institutional, industrial, commercial and governmental developments, as these facilities are more likely than residential developments to receive maintenance on LID features over residential developments. When maintenance is required, additional easements may be necessary to facilitate maintenance access. In residential developments the landowners or homeowners association are often responsible for any required maintenance. Regular inspections, by or for the responsible party, must be completed to ensure LID and conventional stormwater control features continue to operate properly.

Plans and Specifications

See other sections of the Rainwater and Land Development or the resources below for applicable specifications for integrative management measures.

References

Natural Resources Defense Council. 2001. NRDC's Storm Water Strategies (CD-ROM). Washington, D.C.

Prince George's County. 2000. Low-Impact Development Design Strategies: An Integrated Design Approach. Department of Environmental Resources, Maryland.

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SCS. 1985. National Engineering Handbook. Section 4 Hydrology (NEH-4). U.S. Department of Agriculture, Washington, D.C.

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Tyne, Ron. 2000. Bridging the Gap: Developers Can See Green Land Development. Spring/Summer 2000: 27-31.

Web Site References

Low Impact Development, Urban Design Tools http://www.lid-stormwater.net/

Low Impact Development Center http://www.lowimpactdevelopment.org/

U.S. EPA http://www.epa.gov/owow/nps/urban.html

Prince George's County, Maryland http://www.goprincegeorgescounty.com

NAHB Research Center Toolbase Services http://www.toolbase.org/

2.3 Conservation Development

Photo by Kirby Date

Description

Conservation Development refers to development practices that allow land to be developed while conserving a sense of rural character, protecting natural resource features, and insuring water quality. In the process, property rights are protected, the community retains its unique identity and resources, the developer benefits with a high-quality project, and the environmental impacts of development are reduced.

Conservation Development typically allows higher density on a portion of the site in order to leave the rest of the site undeveloped. This results in the same number of structures that would be allowed in a traditional development on a particular parcel of land being located with more flexibility while requiring that a substantial (over 40%) of the land be set aside as permanent open space. The resulting protected open space provides room for conservation practices that serve to buffer the impacts of the development. The conservation practices selected and used can:

1. Reduce stormwater flow through retention and detention basins.
2. Reduce impervious surface area.
3. Increase the filtering of stormwater runoff.
4. Reduce heat reflectance.
5. Retain the original vegetation.
6. Retain historic structures.
7. Allow for the continuation of economically viable agriculture.
8. Allow for the protection of other environmental benefits.

Conservation Development vs. Low Impact Development

Conservation Developments should not be confused with Low Impact Developments. The basic difference is:

- **Conservation Development** involves the overall layout of the property to retain open space. It may or may not include Low Impact Development measures in its site plan.
- **The Low Impact Development** concept applies to how a development is laid out with on-site measures being taken for stormwater retention and management. Low Impact Developments are discussed earlier in this section of the manual.

Conditions Where Practice Applies

This concept is appropriate in all communities regardless of its current development pattern. Each community, large or small, can use the Conservation Development concept as it develops current open space and redevelops existing built-up areas.

Planning and Design Criteria

Ultimately, communities meeting with the most success at achieving a balance of conservation and development will be those that implement a range of tools for different zoning purposes. Outright purchase, use of conservation easements, purchase of development rights, and conservation zoning are all examples of tools that communities can use for land preservation. Each tool has a different set of circumstances under which it works best; and each community will have a unique set of situations of which it can take advantage. Conservation Development techniques are implemented at the planning, zoning and project levels to soften the impact of development on community resources. Conservation Development is one of several tools communities should utilize if they desire to achieve a balance of Conservation and Development that is critical to their long-term quality of life.

Conservation Development vs. Conventional Development

Conventional development patterns result in uniformity despite differences in terrain, climate or site features. Much of this is the result of uniform zoning standards dating to the 1940s. Many of these codes also required practices that are damaging to the rural and natural environment. For example, wide road pavements multiply stormwater problems through increased impervious area and flow-concentrating curb and gutter systems that often send large quantities of untreated stormwater into local streams.

Applying conservation development concepts to a development site utilizes the uniqueness of each site. By preserving significant areas of open space, original woodlands, wetlands, or stream corridors, the site maintains natural and cultural values. Some agricultural uses can be continued; rock outcroppings, old barns, heritage trees, and windrows can be focal points. Open space areas also serve to reduce stormwater runoff and improve its quality. Conservation developments also provide the flexibility to buffer views of development from the road, retaining a sense of openness.

A Typical Conservation Development Project

1. Decisions on site layout and character depend upon the land itself, the community in which it is located, and the intended market of the project. While each conservation development project is unique, there are several characteristics common to most projects.
2. Flexible lot layouts: Within a development, the permitted number of structures are placed on somewhat smaller lots, and the remaining land is set aside as open space. For example, providing one acre lot sizes in a two acre zoned area allows half the land to be preserved.
3. Retain significant amounts of open space: Forty percent (40%) of land area or greater is retained in large, contiguous parcels appropriate to the conservation objective for the area - whether it is a stream corridor, a hillside meadow, a woodland, or farmland.
4. Competitive economic return to property owner and developer: Studies have shown that homes in Conservation Development subdivisions sell for the same, or even greater value and appreciate faster than homes in comparable traditional layouts. This is associated with each home's view and access to permanent open space.
5. Open space is retained permanently in private ownership: Typically these projects have a properly structured homeowners association conservation easement agreement, which includes legal and financial provisions to ensure preservation of open space and to secure its management and maintenance. Usually, the homeowners' association retains ownership and maintenance responsibilities; a conservation easement dedicated to a third party conservation organization ensures the land will not be developed.
6. Retention of rural character: Large open space acreage allows flexibility to buffer views of the development from the road, and to preserve historic structures and landscapes.
7. Reduced length and size of roads and utilities: Sometimes private roads and shared driveways are provided. This aspect is a benefit both to the community, which has less to maintain, and the developer, who has less to build. Environmental impacts related to increased impervious surfaces are reduced. Consideration needs to be made for police, fire and other public vehicles that need to use the road.
8. Alternative septic/sewer arrangements: Areas without urban sewer and water sources may be restricted to lots of a size that support a septic leach field. Alternatives are being explored which should yield lot-reduction options over time. In the meantime, areas in which the zoned lot size is larger than the minimum required for septic leach fields have potential for flexible zoning. For example, areas zoned 3 acres may reduce lot sizes to the 2 acres required by a county health department, and retain 33% of the land in permanent open space. Consultation needs to be made with the local health department for regulations pertaining to septic/sewer arrangements.
9. Commercial development projects also have an emphasis on compatibility with rural aesthetics, reduction of pavement and other impervious surfaces, and providing a community enhancing experience for the customer and passerby.

10. Conservation Easements: A conservation easement is a legal agreement where some of the property rights are transferred from the landowner to an organization that is dedicated to protecting the land rights being transferred. This allows the landowner to continue to own and use the land and sell it or pass it on to heirs while permanently protecting the land. Future landowners are bound by the agreement and the conservation easement holder is responsible for making sure that the agreement is upheld. Conservation easements are discussed in the appendix of this manual.

Steps To Conservation Development in Your Community:

1. Comprehensive Plan: Identify important natural, agricultural and cultural resources, and the priorities for conservation on a site or in the community. Determine, based on these priorities and resources, which of the above planning and development tools will be appropriate for conservation of each area or natural resource. Conservation development is applied best where surrounding open space and development is suitable.

2. Evaluate your zoning code: Make sure the zoning codes will help and not hinder your purpose. The overall comprehensive plan should have codes that correspond and help to implement it. Adopt code change to encourage the kind of development identified as a priority in the comprehensive plan.

3. Encourage quality development projects: The best projects result from a cooperative atmosphere, with developers and community members working together in both design and construction. Identify the developers in your community, discuss some of these ideas with them, and see how you can work together to create exemplary projects that will be an asset to your community.

Reference

For additional resources contact:

The Countryside Program
Kirby Date, Director
P.O. Box 24825
Lyndhurst, Ohio 44124
Phone: 216.295.0511 fax: 216.295.0527
http://www.countrysideprogram.org/main_frameset.html

“The Countryside Program Resource Manual” by the Countryside Program, a project of the Western Reserve Resource Conservation and Development Area. P.O. Box 24825, Lyndhurst OH 44124

2.4 Wetland Setback

Description

Wetland Setbacks are areas retained around existing or created wetlands in order to protect the natural functions of the wetland. Wetland Setbacks left in or restored to a “natural” vegetated state provide an enhanced level of wetland protection not currently afforded by state and federal wetland regulations.

This practice recognizes the valuable services that wetlands provide, while acknowledging that these wetlands have been formed under conditions of less stormwater pollution and imperviousness. Wetland Setbacks reduce wetland degradation associated with development by treating surface runoff for pollutants, transferring surface runoff to subsurface flow and providing a vegetated buffer from more intensive landuses.

By maintaining functional wetlands within their community, local governments and landowners ensure that the natural services provided by wetlands are not lost or transferred out of their watershed.

Conditions Where Practice Applies

Wetland Setbacks are appropriate on all lands surrounding wetlands which receive runoff from development or redevelopment areas. Wetland Setbacks can be utilized in a low impact or conservation development design plan, as part of the regulatory permitting process or normal site design planning. Wetland Setbacks may be most appropriate on those wetlands that are hydrologically connected to other water sources such as springs or streams.

Wetland Setbacks are an appropriate best management practice in a community's Storm Water Program (e.g., NPDES Phase II) or as part of their land use planning. Wetland Setbacks can be incorporated into local zoning codes.

Wetland Setbacks are applicable where the site designer has the objective of mimicking the predevelopment hydrology, reducing the amount of stormwater and maintaining natural features. Establishing wetland setbacks and the associated protection of wetland resources may also be used to demonstrate avoidance of impacts as part of a wetland permitting process.

Wetland Setbacks are also appropriate for ponds, lakes and Water Quality Ponds; however, these features may need to have maintenance access incorporated into any setback area.

Wetland Definition and Value

Generally, wetlands are those areas near streams and in uplands that are inundated or saturated by enough water to be dominated by vegetation adapted for life in saturated soil. In Ohio, wetlands include swamps, marshes, fens, bogs and similar areas.

Wetlands are legally defined in section 40 Code of Federal Regulations (CFR) 232. The U.S. Army Corps of Engineers also has specific regulations covering activities in wetlands as well as technical guidance on determining the extent of wetlands.

Wetlands provide a variety of services to communities and landowners, including:

- **Flood Control:** Wetlands reduce peak flood flows, store floodwaters, and maintain stream base flows.
- **Erosion Control:** Wetlands minimize stream bank and bed erosion by regulating water volume and velocity. Note: natural wetlands are not to be utilized for construction site runoff control.
- **Ground Water Protection:** Wetlands minimize impacts on ground water quality by filtering pollutants from stormwater runoff. Many wetlands recharge ground water reserves.
- **Surface Water Protection:** Wetlands minimize impacts on surface water quality by reducing sediment pollution from stream bank erosion, and by trapping sediments, chemicals, salts and other pollutants from runoff.
- **Habitat:** Wetlands provide essential habitat, particularly for nesting and breeding for many aquatic and terrestrial organisms.

Planning Considerations

Existing Local Requirements

Some counties, townships and municipalities across Ohio have already adopted wetland setbacks. In the event that these setbacks differ from those described here, the larger of these requirements should be used.

Adjustments to the Setback Width

The **setback widths** given in this practice offer minimum protection and should be considered for expansion if any of the following conditions apply:

- Areas crucial to the hydrology of the wetland such as springs, floodplains or streams extend beyond the standard wetland setback. These areas should be considered for incorporation in the setback area, since maintaining the hydrologic support for the wetland is critical to its continuing function.
- The wetland is a rare, sensitive or high value wetland system. These systems need greater buffer widths to ensure protection of the current quality.
- Habitat protection, either of wetland species or species that utilize the wetland, is a major objective. Greater than 100 feet is recommended, but wildlife expertise may be necessary to determine the conditions and width needed for the particular species.
- Larger setbacks may be appropriate for drainage from a commercial or industrial facility that may require pretreatment and flow attenuation.
- Areas that are steep or sparsely vegetated will have lower effectiveness in providing water quality protection for adjacent wetlands and therefore should be expanded.

Storm water management and site planning needed in addition to setbacks

Wetland setbacks will help protect wetland systems, but more is needed as development occurs. Storm water controls will still be needed to control high-energy flows and to mitigate for increased pollution.

Encourage wetland protection through community support and planning

Wetland setbacks are a tool that can be used to protect water quality and water resources. Local planning officials should consider how to facilitate wetland setbacks through wetland identification tools (soils, wetland and land use maps), landowner assistance, zoning code and land acquisition.

Utilizing publicly available resources to produce planning or land use maps can help communities identify where wetlands and wetland setbacks are most likely to be applied. The Natural Resource Conservation Service and the local Soil and Water Conservation District provide soils maps and a list of hydric soils. National Wetlands Inventory (U.S. Fish and Wildlife Service) and Ohio Wetlands Inventory (Ohio DNR) maps may also be useful in finding wetland locations for planning purposes. Note these maps are not appropriate for making wetland delineations. Wetland delineation information is available from the Ohio EPA and the U.S. Army Corps of Engineers.

Finally protect wetland setbacks and the wetlands they surround by placing these areas under a conservation easement. Note that deed restrictions are much less protective since a judge can abolish them at the request of a landowner without public notice.

Landowner Assistance

Several publicly funded organizations are available to assist interested landowners in managing wetlands on their properties, including:

- Soil and water conservation districts,
- Natural Resource Conservation Service
- Ohio Environmental Protection Agency
- Ohio Department of Natural Resources, and
- Ohio State University Extension Service.

These organizations can advise landowners on what to plant near wetlands, where to locate soil disturbing activities to minimize short and long term damage to these services, and any applicable local, state, or federal regulations that may apply to an activity the landowner wishes to undertake. The Ohio Environmental Protection Agency (Ohio EPA) and the U.S. Army Corps of Engineers are available to assist landowners in understanding specific regulations that may apply to proposed activities.

Communities can facilitate wetland setbacks and other wetland management by connecting interested landowners to available county, state, and federal conservation services. A list of conservation agencies is available in the Appendix Section. Conservation funding may be available for purchase of easements or for public land acquisition.

Land Acquisition

Communities may acquire properties that include wetlands that are providing flood control, erosion control, water quality protection, or habitat services either through direct purchase of land, conservation easements, or some other form of permanent preservation. This approach is appealing to communities because it is non-regulatory and enables direct community control over local wetland resources.

Incorporating Wetland Setbacks into Zoning

Zoning regulations that direct the location of development away from wetlands must detail the public health and safety functions of the community's wetlands including flood control, erosion control, and water quality protection, and must be built on technical information supporting these services from the lands being regulated.

Zoning for Wetland Setbacks, unlike landowner assistance or land acquisition, allows communities to directly influence the location of new development and redevelopment. The goal of any zoning code that incorporates Wetland Setbacks is to ensure lots remain buildable and subdivision lot yields are maintained to the extent possible, while pulling soil-disturbing activities back from wetland areas. Thus zoning setbacks should be flexible incorporated to allow variances to other zoning setbacks, such as front and side yard setbacks, to allow site designers to maintain development lot yields. The disadvantages of implementing Wetland Setbacks through zoning controls are that it is an additional regulation and requires community staff to develop and implement.

Regional planning agencies and watershed organizations may also be able to offer assistance in establishing local ordinances and resolutions that maintain wetlands within developing communities.

Permitting For Wetland Impacts

In Ohio, the regulatory permits required to impact "Waters of the State," including lakes, wetlands and streams, may involve both the Army Corps of Engineers (Corps) and Ohio EPA through 404 Permits, 401 Water Quality Certification or Isolated Wetland Permits. Additional information regarding these permits can be found in the Appendix section.

The Corps and Ohio EPA both utilize a three-tier approach to proposals to impact water resources that consist of avoidance, minimization and mitigation. Wetland setbacks can and should be a vital part of these proposals.

Design Criteria

Define the Wetland Boundary

Wetland boundaries are determined by utilizing the delineation protocols acceptable to the U.S. Army Corps of Engineers at the time. Delineations must be submitted to the U.S. Army Corps of Engineers for concurrence. Wetland setbacks should be measured in a perpendicular direction from the defined wetland boundary.

Evaluate Wetland Quality Category

Ohio EPA wetland categories are used to determine the width of the wetland setback. These are general characterizations of a wetland's quality and are determined using the most recent version of the Ohio Rapid Assessment Method as guidance (www.epa.state.oh.us/dsw/401/401.html).

Ohio EPA wetland categories are defined in the Ohio Administrative Code (OAC) 3745-1-54 (www.epa.state.oh.us/dsw/rules/01-54.pdf). They are:

Category 3 - wetlands are considered to be the highest quality;

Category 2 - wetlands are those of moderately high quality and may be good candidates for wetland enhancement;

Category 1 - wetlands are considered low quality wetlands and provide the least public health, habitat or safety services.

Maintain Hydrology

Determine the hydrologic inputs to the wetland, whether overland flow, streams, lakes, or springs. These inputs must either be maintained or substituted for other hydrologic inputs. Incorporating wetland hydrologic sources into the setback may be necessary to protect the integrity of the wetland resources.

Setback Width

The setbacks width differs with the functional capacity of the wetlands. See the Planning Considerations above for adjustments to the setback width. For most situations, Ohio EPA has concurred with the following guidelines.

- A minimum of 120 feet surrounding all Ohio EPA Category 3 wetlands, or current equivalent Ohio EPA classification,

- A minimum of 75 feet surrounding all Ohio EPA Category 2 wetlands, or current equivalent Ohio EPA classification, and
- A minimum of 25 feet surrounding all Ohio EPA Category 1 wetlands or current equivalent Ohio EPA classification.

NOTE: Category 1 wetlands often provide minimal habitat, hydrologic and recreational functions. Often times the degradation of these resources is due to the lack of setback, thus establishing setbacks from these resources may promote the restoration of these wetlands.

Vegetation

The Wetland Setback should be preserved in a natural state and established prior to any soil-disturbing activities. This area should not be mowed or disturbed in any way. If planting occurs within the setback, only native species should be utilized.

Maintenance

Wetland Setbacks should be inspected regularly to ensure that the Wetland Setbacks are being maintained in a natural state and have not been mowed, treated with herbicide (except as used to control invasive species), or developed. Wetland Setbacks and the wetlands they surround should be placed in a conservation easement to protect these resources in perpetuity. Easements should be regularly monitored and violations of easement agreements addressed in order to insure long-term protection.

References

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U.S. Army Corps of Engineers (ACOE). 1987. Corps of Engineers Wetlands Delineation Manual. Technical Report Y-87-1, Final Report, January 1987, Wetlands Research Program, U.S. Army Corps of Engineers, Waterways Experiment Station, Vicksburg, MI.

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Castelle, A.J., C. Conolly, M. Emers, E.D. Metz, S. Meyer, M. Witter, S. Mauermann, T. Erickson, S.S. Cooke. 1992. Wetland Buffers: Use and Effectiveness. Adolfson Associates, Inc., Shorelands and Coastal Zone Management Program, Washington Department of Ecology, Olympia, WA. Publication. No. 92-10. www.ecy.wa.gov/pubs/92010.pdf

2.5 Stream Setback Area

Description

Stream setbacks (also known as streamways or riparian buffer areas) minimize property damage and protect water quality by providing areas where over bank flooding, meander migration, and stream processes freely occur and thereby encourage stability, habitat, and water quantity and quality functions. On high quality creeks and rivers these areas represent the most biologically diverse and active areas where in-stream and riparian habitat abounds, sediments are exported to floodplain areas, pollutants are assimilated and stormwater is stored and conveyed. On more impacted or lower quality creeks and rivers, stream setbacks represent areas where meander migration or floodplain redevelopment is likely to occur and where natural stream adjustments are predicted to occur.

This practice establishes the setback area based on the predicted belt width of stream, the lowest elevation ground in the valley and the stream location. The streamway is determined at intervals using the stream's drainage area and regional or locally developed stream data. Ideally, local government should map these areas so that they are centered on the areas most subject to flooding. In lieu of this mapping, individual parcels shall have stream setbacks located on site plans as this practice describes.

Note: This practice reflects the site development scale. Additional resources should be consulted when developing a model ordinance or implementing stream setbacks throughout a watershed or community.

To provide the greatest benefits, riparian areas should be predominately native vegetation, preferably forested. However, passive uses such as trails and picnic areas may be maintained.

Stream setbacks are strongly linked to the protection of public health or safety of watershed residents by setting aside areas that:

- Reduce flood hazards resulting from high flows and high velocities;
- Recharge groundwater;
- Reduce pollution in stream flows and surface water by filtering, settling and chemical transformation in floodplain areas and stream side soils;
- Reduce sediment loads from stream bank erosion; and allow recovery of previously degraded or channelized streams;
- Provide adequate room for stream meander patterns or channel migration;
- Provide high quality habitats for wildlife;
- Limit the need for costly measures such as channel armoring that would otherwise be necessary to protect structures and reduce property damage;
- Protect natural aesthetics and the environmental quality of stream corridors and the value of nearby property.

Conditions Where Practice Applies

Setbacks are appropriate for all sizes of stream channels from ephemeral or intermittent streams up to large rivers. The importance of these areas increases as a watershed is developed. Streams and associated corridors most subject to encroachment or modification (drainage areas less than 10 square miles) are most in need of established protection. These size channels are small enough that they can be more easily modified and are less likely to have adequately mapped or protected floodplain areas.

The width of the setback area is based on empirical stream data and the predicted belt width of the stream, but setback areas on sites with existing development must be implemented to minimize potential conflicts between current landuses and the stream setback. For example, setback shall be implemented to ensure that development gets no closer to the stream, thus effectively setting the setback for that parcel at the line of the existing foundation/structure. Still the recommended setback area provides the zone where channel movement is predicted and stream processes are most beneficial and should be sustained as much as possible.

Planning Considerations

The Stream Setback is Based Primarily on Stream Processes

The stream setback is based on the most critical land area needed to sustain natural stream processes. These processes are responsible for the common meandering pattern that streams exhibit and for channel and floodplain forms that are dynamically stable and beneficial to water quality and overall stream integrity. With this in mind, it should be noted that many Ohio streams are not in the condition of "best potential". Many have been altered directly by straightening or channelization or degraded in response to landuse changes within the watershed. Thus the existing meander pattern (the stream's plan form) is often narrower than it was historically and erosion and deposition may be working to re-establish a wider pattern along with a more dynamically stable channel form. A stream setback establishes the area in which these processes can continue to occur.

While this area provides many benefits it may need to be expanded to accomplish additional objectives. For instance, some communities may require more extensive preservation of floodplain or upland wildlife areas.

Existing Local Requirements

Some counties, townships and municipalities across Ohio have already adopted riparian setbacks. In the event that these setbacks differ from those described here, the larger of these is suggested. Please note when comparing distances that this practice predicts the full meander belt width that contains the stream, while other local stream protection setbacks may utilize a setback distance from each bank of the stream. To compare this practice to a setback distance from each bank, the latter should be doubled and added to the width of the stream for proper comparison (see Figure 2.5.1).

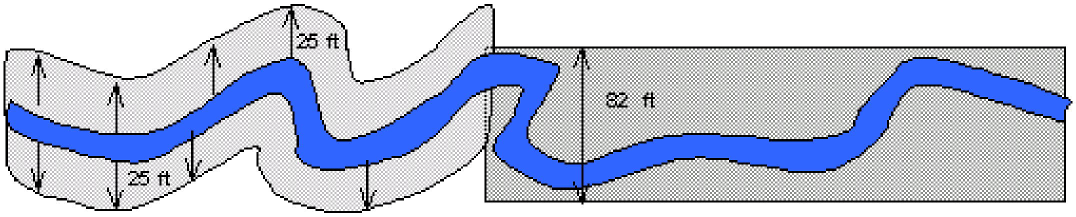


Figure 2.5.1 Comparing a traditional stream setback to the streamway-based setback.

Encourage Rehabilitation of Streams in the Stream Setback –

Because so many Ohio streams have been channelized or have degraded it is advantageous to promote channel and floodplain rehabilitation activities that provide channels with greater access to an active floodplain. This will insure more natural stability and higher function. General grading that occurs during development may provide an opportunity to rehabilitate an entrenched stream and therefore provide a higher quality stream corridor. Applicable practices may be floodplain rehabilitation, primarily lowering of high banks. This setback practice does not limit rehabilitation activities.

Adjustments to the Setback Width

In some circumstances, site conditions justify altering the width of the setback area. These may be situations of narrow, confined valleys smaller than the setback width, floodplains that extend beyond the area, wetlands contiguous to the area, or adjacent hillsides prone to slippage or being undercut as a result of stream flows. This is best accomplished with GIS or other more regional tools that can be used to incorporate adjustments to the setback area width.

For large rivers with extensive setback areas, further refinement of acceptable land uses within the area may be necessary. After maintaining a forested riparian area immediately adjacent to the river, other uses such as open fields or recreation areas are appropriate provided that the floodplain characteristics are not impaired.

Design Criteria

Calculating the Setback Area Width

The setback area width is a total width, which crosses the channel and is calculated according to the drainage area (square miles).

Size:

The setback area shall combination of two overlapping areas, one Streamway based and the other based on a minimum distance from the channel bank, equivalent to 1 channel width as illustrated in Figure 2.5.2.

The Streamway size appropriate to accommodate the meander belt is:

Streamway width = 147 (Drainage Area in square miles)$^{0.38}$

(Approximately 10 channel widths)

In addition, at no point shall the distance between the setback boundary and the channel be less than:

Minimum distance from channel = 14.7 (Drainage Area in square miles)$^{0.38}$

(Approximately 1 channel width)

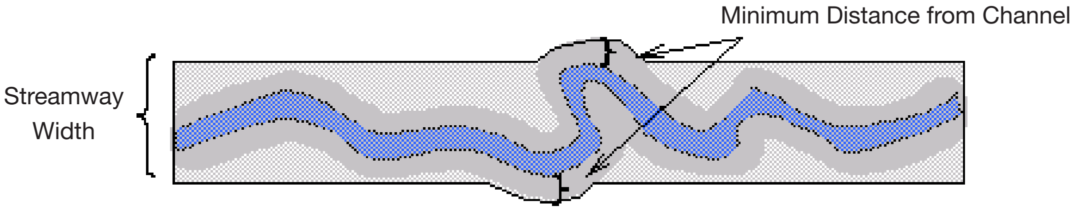


Figure 2.5.2 Setback areas combine the streamway and a minimum distance from the channel.

Location

A Streamway is more a feature of a valley than individual bends or the present location of a channel , thus the setback area may not always be exactly centered over the stream, especially as streams meander.. It is more aptly visualized as a flood path or roughly the flood way. Thus, setback areas should be fit to the valleys. They shall be positioned so that corresponding left and right boundary elevations match and the setback area incorporates the lowest elevations in the valley.

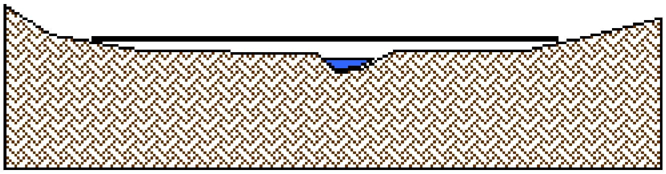


Figure 2.5.3 Center setback areas over the floodway with matching elevations at either boundary.

Avoid concentrating flow into the setback area

Maintaining diffuse sheet flow into the setback area maximizes the treatment processes that occur in riparian and floodplain areas. Convert concentrated flows from storm drains and swales (with limited drainage areas) to uniform shallow sheet flow as it enters the stream setback area. Grading and constructing level spreaders can help accomplish this. Ditches and streams with access to an active floodplain will better utilize these areas than deep entrenched channels.

Insure long-term protection of the area

Zoning, conservation easements and public ownership are options to consider long-term protection of the area. Local government may utilize zoning to set appropriate landuses for the stream setback area. In addition, many local governments will accept ownership of such properties if deeded in fee simple to the community. In this case, a credit may be applicable toward local open space or parkland set aside requirements.

Conservation easements offer one of the best ways to protect riparian areas. These maintain private ownership, while maintaining the limitations on the uses and actions that can be taken in the setback area. Easements can be held by a legally qualified conservation organization (such as a land trust) or a government agency. Easements should be regularly monitored and violations of easement agreements addressed in order to insure long-term protection.

Clearly identify the setback area boundaries on the plat map, construction plans and the site

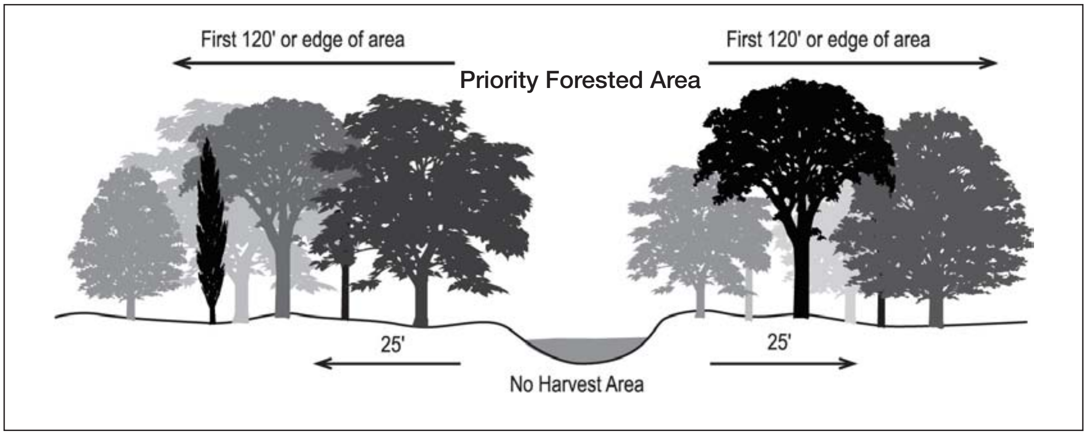
Install temporary fencing and best management practices appropriately to prevent encroachment during construction.

Following construction erect a fence or visual barrier identifying the area or portions of the area, which are to be no-mow zones or permanently forested areas. Sections of split rail or similar unobtrusive fencing provide a visual marker that will allow the area to remain distinct of other landuses.

Vegetative Goals

Setback areas are to be established in native vegetation, which for most Ohio streams is forest. Areas may also be divided into primary (closest to the stream) and secondary areas with different vegetative targets that allow for surrounding landuses. Forested areas should be maintained for a minimum of the first 50 feet of the area on either bank.

Harvesting on privately held areas should not be done within 25 feet of either bank. Removal of invasive species is allowable at anytime and is highly recommended for maintenance of the setback as a natural area.



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2.6 Water Quality Ponds

Wet extended detention pond

Description

Water quality ponds are stormwater ponds designed to treat runoff for pollutants and control increases in stream discharge and bedload transport. Water quality ponds may be predominantly dry between storm events, or have a permanent pool or even have wetland features. Water quality ponds remove pollutants by settling, chemical interaction and biological uptake by plants, algae and bacteria. The efficiency of settling suspended solids and the ability to treat dissolved pollutants is improved with the addition of wetlands and permanent pools. Water quality ponds are often designed to provide flood control by including additional detention storage above the volume specified in this practice.

Conditions Where Practice Applies

Water quality ponds are applicable to most urbanizing areas where pollutant loads are predominantly particulates and control is needed to address increased erosion potential in down stream channels.

Water quality ponds are appropriate for residential, commercial and industrial areas and are easily incorporated on sites where a stormwater pond is to be constructed to control potential flooding. Even where detention ponds are not necessary for flood control, water quality ponds can be used to address water quality and stream stability concerns.

Water quality ponds are most appropriate for larger sites, greater than 20 acres for wet or wetland ponds or greater than 10 acres for extended detention ponds. Ponds may be beneficial for smaller areas, yet have greater problems sustaining permanent pools, or issues of maintenance such as potential blocking of the outlet (due to small orifices) by trash and debris.

Existing flood control ponds may be retrofitted to meet the water quality and stream stability objectives of these stormwater ponds.

Planning Considerations

Water quality ponds may not be appropriate for ultra-urban areas where adequate space is not available or for heavy industrial areas that require extensive pollution treatment.

Water quality ponds may cause stream warming and may need additional design considerations or may not be appropriate for coldwater streams.

Ponds with dams are regulated under the Ohio Revised Code 1501: 21 Dam Safety Administrative Rules. A dam is exempt from the state's authority (ORC Section 1521.062) if it is 6 feet or less in height regardless of total storage; less than 10 feet in height with not more than 50 acre-feet of storage, or not more than 15 acre-feet of total storage regardless of height. Check with the Ohio Dept. of Natural Resources, Division of Water, for the most current requirements.

Additional upland practices may be needed to reduce nutrient loads that cause problems common to eutrophic ponds (excess algae, low oxygen levels, and odor).

For wet ponds, soils and site conditions must be appropriate to maintain a permanent pool during dry weather. Permanent pools may be difficult to maintain if the contributing watershed area is less than 20 acres and if the ratio of drainage area to water surface area is less than 6:1.

Suitable soils must be available for constructing the embankment and insuring sufficient impermeability to prevent seepage losses. A trained professional shall conduct an on-site evaluation of the proposed pond site and borrow areas prior to final design to characterize the adequacy of the site and the excavated soils for use as core trench or embankment fill. The evaluation should include a test pit at each abutment, along the centerline of the proposed embankment, the emergency spillway, the borrow area and the pool area. As a general rule, one test pit should be placed for every 10,000 square feet of area examined. All explorations shall be logged using the Unified Soil Classification System.

Treatment goals, watershed characteristics and site constraints should drive designs towards one of 3 main pond configurations:

1. *Extended Detention,*
2. *Wet Extended Detention*
3. *Wetland Extended Detention.*

Pond volume and depth characteristics depend on the type of pond being designed. In all instances, an extended detention volume (portion of the water quality volume, WQv) must be determined and treated.

Table 2.6.1 Pond types and appropriate characteristics and treatment goals

Pond Type	Minimum Drainage Area (acres) *	Drainage Area: Surface Area:	Suspended Solids Estimated Effectiveness	Dissolved Pollutants Estimated Effectiveness	Stream Warming Potential	Target Depth (apply % to surface area)
Extended Detention	≥10		Low to Moderate	Low	Moderate	3’
Extended Detention with Forebays and Micropool	≥10		Low to Moderate (improve over ED)	Low	Moderate	3’
Wet Extended Detention	≥20 or sufficient baseflow to support permanent pool	<6:1	Moderate-high	Moderate-High	High	Generally not deeper than 6-8’
Wet Extended Detention with wetland fringe	≥20 or sufficient baseflow to support permanent pool	<6:1	Moderate-high	Moderate-High	High	Generally not deeper than 6-8’ – 20% at 6-8”
Wetland	≥20 or sufficient baseflow to support permanent pool	>50:1	Moderate-high	Moderate-High	Moderate	5-20% 1.5-6’ wetland areas range from 0 – 18’ with avg of 6 – 12”
Wetland (pocket)	Dependent upon baseflow	>100:1	Variable	Variable	Moderate	5-20% 1.5 – 6’ Wetland areas range from 0 – 18” with avg of 6 –12”

***Note: Extended detention basins are appropriate for areas less than 10 acres, if the outlet is designed to prevent clogging.**

Advantages of Wetland Features – Wetland vegetation, in addition to promoting settling, stabilizes deposited sediment. Wetlands can further treat stormwater in ways most other treatment practices cannot, by plant uptake, adsorption, physical filtration, microbial decomposition and shading. Wetland plants readily absorb heavy metals, and other toxic wastes.

Microorganisms that thrive in wetland plant root systems consume and decompose pollutants. These microorganisms that live among the plants are very good at breaking down poisonous organic compounds such as benzene, toluene and PCBs into harmless elements that the microorganisms and plants can digest.

Mosquito Concerns – Water quality ponds have extended detention times less than the time needed for common vector mosquitoes to hatch (generally 72 hours). But it is still important to design and maintain stormwater ponds in order to prevent conditions most favorable to mosquitoes. When designing and maintaining stormwater ponds apply the following considerations:

- Avoid stagnant water by assuring there is sufficient flow to support a wet or wetland ponds.
- Maintain the outlets so that detention does not occur beyond the extended detention period.
- Design wet ponds with wetland benches and wetlands with varying depths (mix of deeper water and wetland areas) in order to have improved habitats for natural mosquito predators like small fish, birds, dragonflies and aquatic insects.
- For areas that will have standing water without wave action or deeper water, consider aeration to prevent stagnation.

Design Criteria (Applicable to Each Pond Type)

Water Quality Volume (Applicable to all pond configurations)

The water quality volume (WQv) is the volume of runoff that is treated in a water quality pond. Depending upon the type of pond (dry extended detention, wet or wetland) all or a portion of this volume is stored above wetland or permanent pool features and drained over a 24-48 hour period. Detaining this volume has two stream protection objectives: reducing the pollutants suspended in the runoff and reducing the energy of common storm events responsible for most channel erosion. The water quality volume is calculated using equation 1 below, adapted from Urban Runoff Quality Management (ASCE/WEF, 1998). This is required by the Ohio EPA NPDES general permit for construction activities.

$$\text{WQv (ac-ft)} = C * 0.75 * A / 12 \qquad \text{(Equation 1)}$$

Where:

C = runoff coefficient

A = area draining into the BMP in acres

The runoff coefficient, C, is calculated using the following equation or alternatively values provided in the current Ohio EPA NPDES general permit for construction activities.

$$C = 0.858i^3 - 0.78i^2 + 0.774i + 0.04 \qquad \text{(Equation 2)}$$

Where:

i = watershed imperviousness ratio, the percent imperviousness divided by 100

Note: The Ohio EPA NPDES stormwater general permit for construction activities requires that the water quality volume be increased by 20% for capacity lost over time due to sediment accumulation.

Pond Configuration

Configure the pond so that water quality treatment is optimized through pond shape and flow length. Improved settling of pollutants occurs as the flow length is maximized. Optimally, designs will avoid the problems of dead storage or incoming water short-circuiting through the pond and the resuspension of deposited sediments.

Forebays and micropools, pool water at the inlets and outlet of a pond in order to improve the effectiveness and ease of maintenance of water quality ponds. The shape and grade of pond side slopes also strongly influence pond effectiveness and potential safety.

1. Length to Width Ratio

Wedge shaped or ponds that are longer than wide will prevent flow from short-circuiting the main body of water. The ratio of flow length to pond width should be at least 3:1. To increase a pond's flow length, the contours of the pond may be configured to form baffles or an extended flow path. Constructing submerged aquatic benches to form cells will enhance flow routing (Figure 2.6.1).

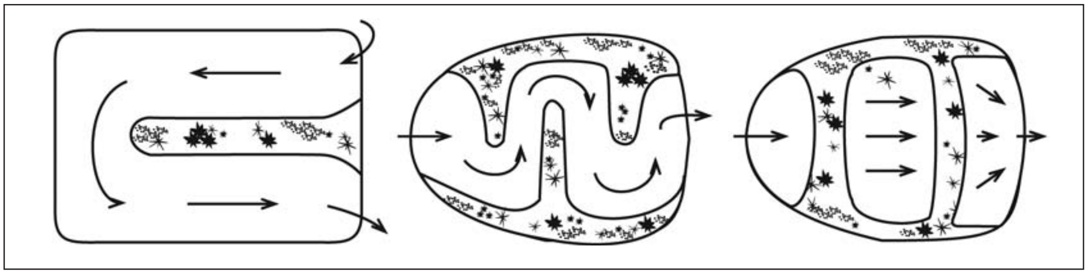

Figure 2.6.1 **Flow Routing to Enhance Water Quality Treatment**

2. Side Slopes

Varying the slope to create benches above and below waterlines increases safety and stability and can create water quality features such as wetland benches in permanent pools. Slopes should not be steeper than 3:1 or shallower than 12:1.

3. Forebay(s)

A forebay is a settling pool located at the inlet to a pond. It is separated from the rest of the pond by a level dike often planted with emergent wetland vegetation. Forebays are primarily used to improve the settling efficiency of a pond but they also reduce maintenance by promoting settling in a confined, easily accessible location.

Forebays promote settling by: segmenting or dividing the pond into cells which reduce mixing and promote plug flow; by converting the high velocity concentrated inflow from a pipe to a wide uniform slow flow to the normal pool area; and by dissipating flows through emergent vegetation. See Figure 2.6.2.

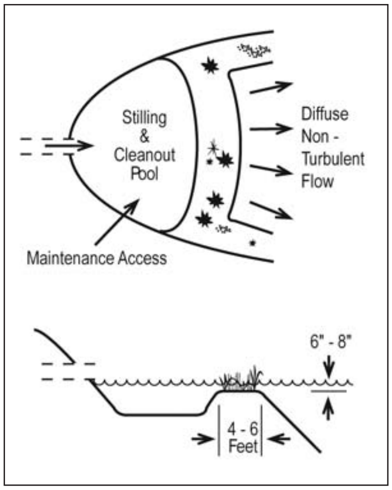

Figure 2.6.2 **Forebay**

Forebay Size – forebay for a single inlet should occupy from 8-25% of the normal pool area. Forebays should be large enough to avoid scour and resuspension of trapped sediment and sized for ease of construction and cleanout. Forebays should have a water depth of at least 3 ft.

Forebay Outlet – Provide an outlet to the main pond, consisting of a level spreader or submerged level dike. A submerged dike separating the forebay from the rest of a wet pool or wetland should be 6-12 in. below the normal water surface elevation and provide a non-erosive overflow. It should also be planted with hardy emergent wetland vegetation. See the wetland extended detention pond section below for more information on planting.

Forebay Maintenance Access – To accommodate relatively frequent sediment cleanout, easy equipment access should be provided to the forebay. This should include gradual slopes without obstructions and an access easement. Additionally a drain should be installed under the dike so that the forebay can be drained during maintenance operations.

4. Micropool

For wetland and predominantly dry extended detention stormwater ponds, a micropool is recommended in front of the outlet. The micropool allows a reverse slope pipe or other non-clogging outlet to be used. The micropool should be 4-6 feet deep and equal to 10% of the volume of the water quality volume.

5. Non-clogging Outlet

Extended detention outlets often require small orifices or controls and must be designed to be non-clogging. A reverse flow pipe is one way to configure an outlet to better trap floating pollutants and to be less clogging (see figure 2.6.3). Reverse flow pipes draw water from below the water surface to trap floating debris that would otherwise clog the outlet.

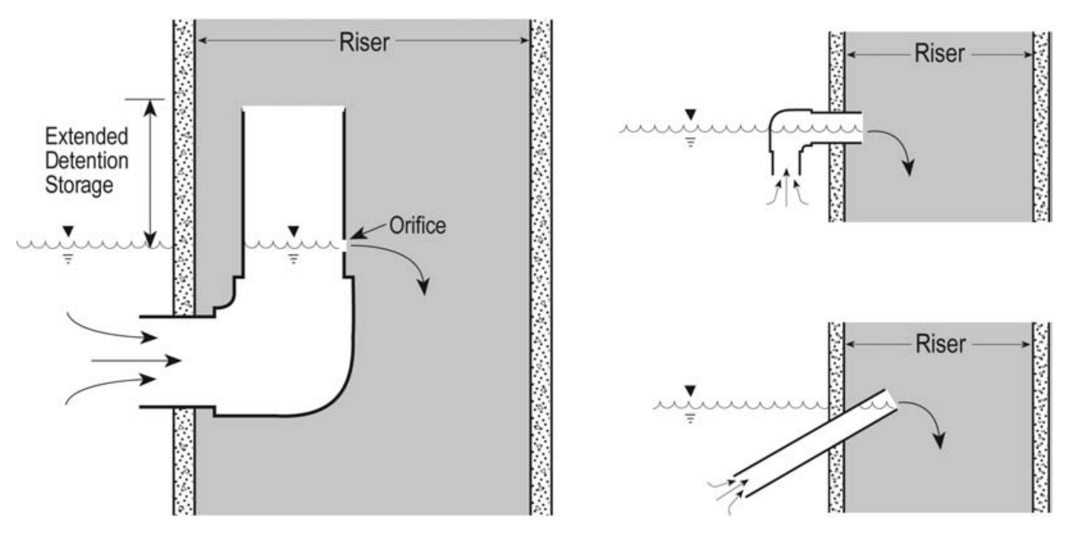

Figure 2.6.3 **Reverse Flow Structures Reduce Clogging and Trap Floating Pollutants**

A reverse flow pipe is designed to draw water below the pond's surface and above the midpoint of the normal permanent pool elevation. They may be constructed with a pipe on a negative slope or with a turned pipe elbow. Reverse flow outlets may be constructed with a straight pipe set on a negative slope. A pipe with a 90-degree elbow also may be used either inside the riser and facing upward or outside the riser facing down (see figure 2.6.3).

6. Pond Drain

It is recommended that a drain be installed such that the entire pond can be drained for maintenance or repair purposes.

7. Additional Specifications for Pond Construction

Embankment ponds must be well constructed and built according to NRCS Conservation Practice Standards 378 (Pond) addressing issues such as:

- Ponds must incorporate emergency spillways designed to safely convey flows exceeding design storm flows.
- Outlet structures should be built to withstand floatation and incorporate anti-vortex and debris or trash rack devices.
- Embankments and principal spillway shall utilize adequate soils and compaction, core trenches and anti-seep collars.

Dry Extended Detention Basin – Design Criteria

Detention Volumes

The extended detention volume is equal to the water quality volume (WQv) found in equation 1. An additional capacity of 20% must be provided within the water quality volume for sediment accumulation. This additional volume may be utilized in forebays at inlets and in a micropool at the outlet, which will improve the maintenance and efficiency of the pond.

Local government may require additional detention volumes for peak discharge control (flood control). Appropriate design procedures, including routing design storms through the basin, shall be used to insure the pond and outlet geometry meet local and state requirements. See the figure below.

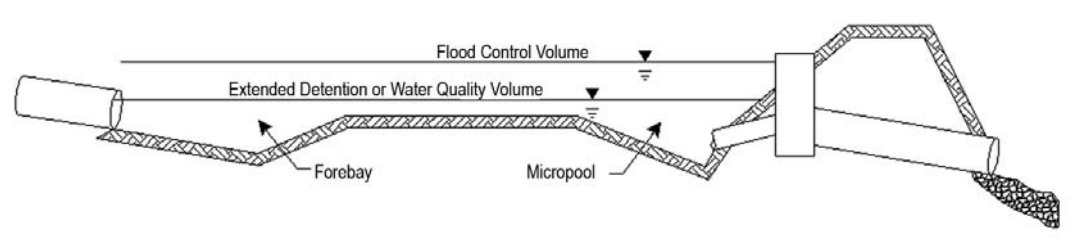

Fig 2.6.4 **Storm Water Pond with Extended Detention and Flood Control Volumes**

Outlet Design

Design the outlet structure (principal spillway) to draw down the extended detention volume over a 48-hour period. The outlet should empty less than 50% of this volume in the first 16 hours.

Peak discharge control (flood control) required by local government can be incorporated into the spillway with additional control devices (e.g. orifices or weirs) above the extended detention outlet. This type of multiple outlet spillway incorporates outlet controls for each attenuation goal.

Permanent Pool

Dry extended detention basins do not have a permanent pool except for the establishment of forebays at inlets and a micropool at the outlet. While these are not required, they increase the effectiveness of the pond and the ease of maintenance. More information is provided on these in the design criteria applicable to all ponds above.

Wet Extended Detention Basin – Design Criteria

Detention Volumes

Wet extended detention ponds detain a volume equal to 75% of the WQv found with equation 1 (0.75 WQv) above a permanent pool. See figure 2.6.5.

Local government may require additional detention volumes for peak discharge control (flood control). Appropriate design procedures, including routing design storms through the basin, shall be used to insure the pond and outlet geometry meet local and state requirements. See the figure below.

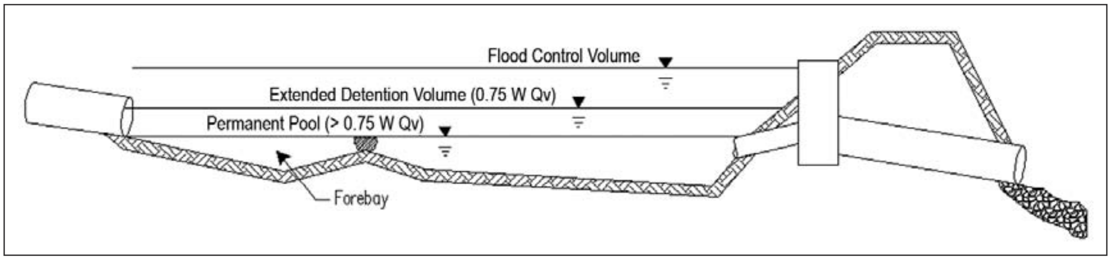

Figure 2.6.5 **Wet Storm Water Pond with Extended Detention and Flood Control Volumes**

Outlet Design

Design the outlet structure (principal spillway) to draw down the extended detention volume over a 24-hour period. The outlet should empty less than 50% of this volume in the first 8 hours.

Peak discharge control (flood control) required by local government can be incorporated into the spillway with additional control devices (e.g. orifices or weirs) above the extended detention outlet. This type of multiple outlet spillway incorporates outlet controls for each attenuation goal.

Permanent Pool Volume

The permanent pool of a wet extended detention pond is equal to three fourths of the WQv (0.75 WQv) found with equation 1 plus an additional volume equal to 20% of the WQv (0.2 WQv) added for sediment accumulation. Thus the original capacity of the permanent pool shall be equal to 0.95 of the water quality volume. This volume may include forebays, cells created within the permanent pool for increasing efficiency.

Permanent Pool Depth

The mean depth of the permanent pool should be between 3 and 6 feet in order to optimize settling of suspended particles. This is calculated by dividing the permanent pool's storage volume by the pool's surface area. A pool that varies in depth will allow diverse conditions for wetland vegetation and portions, which are deep enough for fish. If fish are to be maintained in the pool, approximately 25% of the pool should be at least 6 to 8 feet deep.

Overly shallow pools will have increased problems with algae and the re-suspension of deposited sediments by wind or as runoff enters the pond. Overly deep pools may encourage thermal stratification and anaerobic conditions at the bottom, which allow pollutants (e.g. metals and phosphorus) to be released from sediments. Deep pools are often associated with short flow paths from inlet to outlet, allowing runoff to short-circuit treatment provided by flow through the main volume of the pool.

Wetland Benches

Wet extended detention ponds may include wetland environments that greatly enhance water quality treatment by establishing a shallow aquatic bench around the main pool. These areas also improve safety by creating a vegetative barrier to discourage children from venturing into deeper water and reducing the hazard of steep grades at the pond edge.

When used as one water quality design feature within a wet extended detention pond pond, wetland vegetation should occupy at least 20% of the wet pool's water surface. It is also recommended that benches be at least 6 feet wide and have depths of 6 to 12 inches on average and not exceed 18 inches. See the Design criteria for wetland extended detention ponds for guidance on establishing wetland plants.

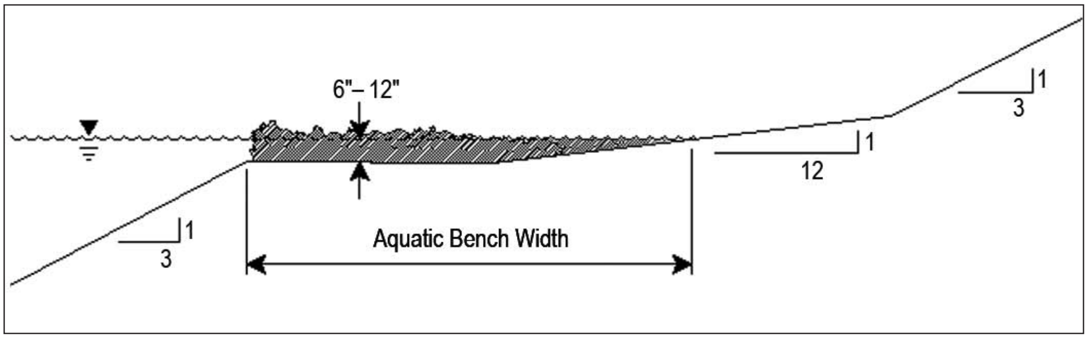

Figure 2.6.6 **Grading of Side Slope to form a Wetland Bench**

Reducing Thermal Impacts Through Shading

Warm water released from a permanent pool may adversely impact the thermal regime of receiving streams, particularly if the receiving water is a cold-water fishery. The pool acts as a heat sink between storm events during the summer months. Water released downstream from the pond can be as much as 10 F warmer than naturally occurring base flow. Large impervious surfaces also warm surface runoff significantly which can be critical to stream systems where fish and other aquatic life are threatened by high summertime water temperatures.

Add Shading – Shading a pond can significantly reduce thermal impacts. Trees planted around the pond, particularly on the south and west sides offer the most protection from the summer sun. Trees planted on islands or peninsulas should also be considered. Because tree roots can damage dams, trees must not be planted on the embankment itself. Wetland vegetation also contributes to shading and reduces thermal impacts.

Leaf litter introduces nutrients to the pond and adds to the accumulation of sediment. While nutrients and sediment are pollutants, nutrients in plant material or detritus are more readily utilized by aquatic insects and incorporated into the food chain. Fallen leaves are a vital part of aquatic environments, whereas soluble nutrients and nutrients attached to fine sediments easily wash through a pond system or promote algal growth.

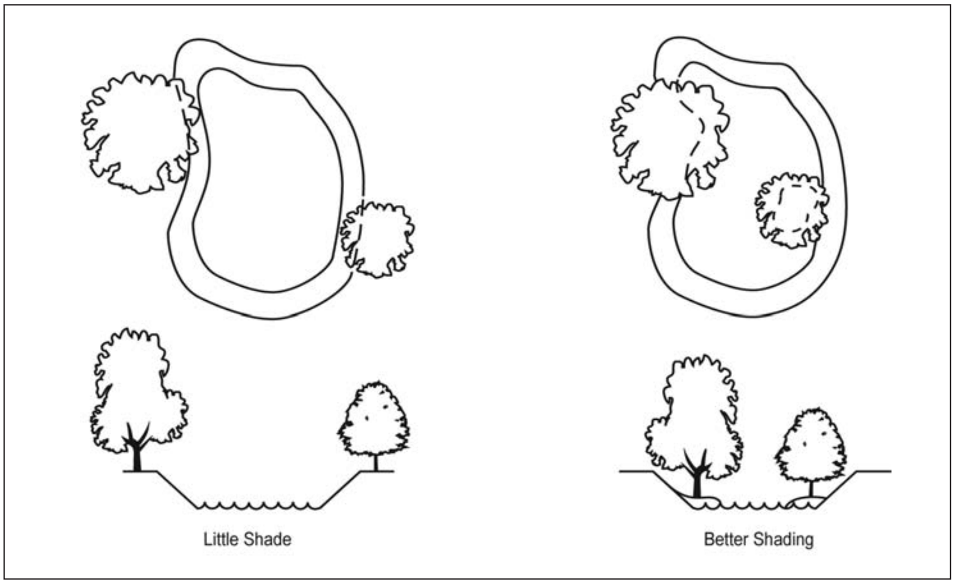

Figure 2.6.7 Tree Placement to Shade Ponds and Reduce Thermal Impacts

Wetland Extended Detention Basin – Design Criteria

Detention Volumes

Wetland extended detention ponds detain a volume equal to the water quality volume (1.0 WQv) found in equation 1 above the permanent wetland pool.

Local government may require additional detention volumes for peak discharge control (flood control). Appropriate design procedures, including routing design storms through the basin, shall be used to insure the pond and outlet geometry meet local and state requirements. See the figure below.

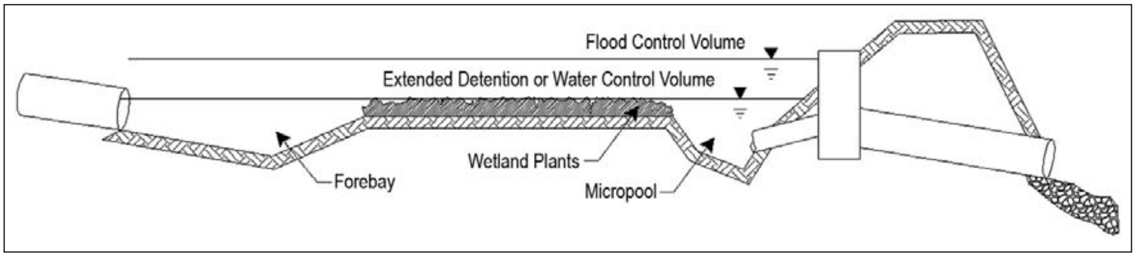

Figure 2.6.8 Wetland Storm Water Pond with Extended Detention and Flood Control Volumes

Outlet Design

Design the outlet structure (principal spillway) to draw down the extended detention volume over a 24-hour period. The outlet should empty less than 50% of this volume in the first 8 hours.

Peak discharge control (flood control) required by local government can be incorporated into the spillway with additional control devices (e.g. orifices or weirs) above the extended detention outlet. This type of multiple outlet spillway incorporates outlet controls for each attenuation goal.

Permanent Wetland Pool Volume

The permanent pool volume is based on the designer's assessment of sufficient runoff and base flow to sustain a wetland pool. The designer should assess the change in storage volume over time based on water entering and leaving the wetland. This water budget should include water entering from precipitation, runoff, base flow, groundwater and any water to be pumped. Water leaving should include evaporation, expected plant transpiration, stormwater outflow, and seepage or percolation. Greater guidance on wetland creation and water budgets can be found in the Natural Resource Conservation Service Engineer Field Manual Chapter 13.

Add a volume equal to 20% of the water quality volume to the permanent wetland pool volume for accumulation of sediment overtime. This total volume should include forebays, cells and micropools graded within the permanent pool for increasing efficiency.

Wetland Depth

Wetland pool depths should generally range between 6-18 inches. The average depth should be between 6 and 12 inches. This depth may vary but must accommodate 1) the depth appropriate for the type of wetland vegetation planted, and 2) adequate volume of runoff stored within the wetland. Wetland diversity and stability will be improved if a variety of depths are created with complex subsurface contours and irregular shapes to provide more edge effect.

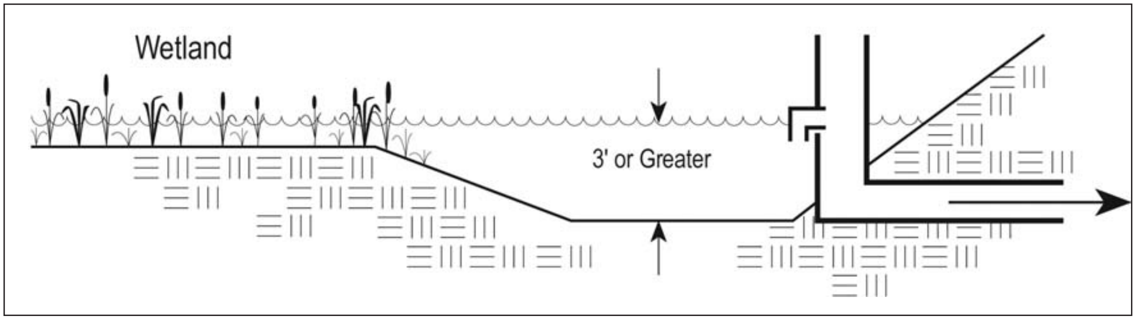

Figure 2.6.9 Micropool: Open Water Around Outlet Structure of Wetland

A micropool, that is a deep area, greater than 3 feet, should be created at the outlet structure so that vegetation and sediment buildup do not interfere with outflow from the basin. Incorporating a deep pool at the inlet to the pond may be used to promote initial settling and dissipate concentrated inflow.

Establishing Wetland Vegetation

Six to eight species of wetland plants should be planted. Species that have worked well in constructed urban wetlands include: common three square, arrowhead, soft stem bulrush, wild rice, pickerelweed, sweetflag, smartweeds, spike rush, soft rush, and a number of other sedges.

Vegetation may be established one or a combination of the following methods: planting nursery stock (plants or rhizomes), mulching with soils from an existing wetland or allowing volunteer establishment. Using only volunteer establishment is discouraged since it often leads to mono-typical stands of invasive or undesirable species.

Planting Layout – Initial planting should cover at least 30% of the wetland area, concentrated in several portions of the pond and have densities of four to five plants/square yard. Planting clusters of single species will improve the quality and diversity plantings. Plants should be planned for their appropriate depth within the permanent wetland pool.

Grading or Disking the Basin – The basin substrate should be soft enough to permit relatively easy insertion of the plants into the soil. If the basin has been recently graded or excavated, the soil should be sufficiently soft. However, if the basin soil is compacted or hard subsoil is encountered, planting will be difficult. In these cases, it is recommended that the basin soil be disked or otherwise loosened before planting.

Flood and Drain Prior to Planting – If nursery stock will be used, it is recommended that the wetland area be flooded for a period of time (6-9 monthes, USEPA) prior to draining and planting.

Treatment of Plant Material – For successful establishment of wetland vegetation the nursery stock must be correctly handled prior to planting. For growing plants, this consists of keeping the roots moist at all times, and in keeping the plants out of direct sunlight as much as possible. Vegetation should be planted as soon as possible to avoid damage during on-site storage. Dormant plant material should be stored under conditions similar to those under which the material was stored at the nursery.

When planting container plants dig holes about one third bigger to allow root systems an un-compacted area in which to develop.

Mulching with Wetland Soils – If an area is mulched with soil from an existing wetland, plants should be allowed to germinate and grow for a period prior to fully inundating the wetland pool. Care should be taken not to allow the newly germinated plants to dry out.

Transition from temporary sediment control basin to permanent stormwater quality pond.

Often permanent stormwater management ponds are used for sediment control during construction. In most cases, these facilities will need dewatering and sediment removal in order to insure that the pond has the appropriate volume for permanent stormwater design. This includes removal of temporary risers used for sediment control and reseeding bare soil or establishing wetland vegetation in designated areas within the pond.

Maintenance of Water Quality Ponds

While maintenance is inevitable, the amount of maintenance required and its cost can vary considerably depending on the initial design of a pond. A number of design features are helpful in this regard:

Sediment Storage – Reduce the frequency of sediment cleanout easily by increasing the volume available for sediment storage. Increasing the permanent pool volume by 20% or according to the predicted sediment loads is recommended. Ponds used for sediment control during construction should be cleaned out when the site is stabilized, as the cost of cleanout will be considerably less expensive during construction than in the future.

On-Site Disposal – Transporting dredged sediment is often the largest cost associated with pond cleanout. This can be avoided by providing an area on-site for future sediment disposal. A disposal site should be designated during site design.

Forebay – Trapping most sediment in a confined, easily accessible forebay can reduce maintenance costs.

Maintenance Easements – Maintenance easements must be established to allow access to the pond, particularly to the forebays, embankment, outlet structure and sediment disposal areas.

Disposal of Pollutants – Water quality treatment practices are intended to trap pollutants. The fate of these pollutants must be considered. Trapped sediment is usually clean enough for on-site use. The large volume of sediment poses the most common disposal problem. Sediments may also have high concentrations of hydrocarbons, nutrients and heavy metals. Soil tests should be done if the pond has received spills, is in a highly industrial area, or if the watershed has intensive traffic.

Sediment should be spoiled in areas, which will keep pollutants bound in the sediment (e.g., metals and phosphorous). To avoid these pollutants from becoming soluble, acid and anaerobic conditions, such as wetlands, should be avoided.

Table 2.6.3 Typical Maintenance Activities For Water Quality Ponds (USEPA) Adapted from WMI, 1997 and SMRC

Schedule	Activity
Monthly	Mow embankment and clean trash and debris from outlet structure. Address any accumulation of hydrocarbons.
Annually	Inspect embankment and outlet structure for damage and proper flow. Remove woody vegetation and fix any eroding areas. Monitor sediment accumulations in forebay and main pool.
Semi-Annually	Inspect wetland areas for invasive plants.
3-7 years	Remove Sediment from forebays.
15-20 years	Monitor sediment accumulations in the main pool and clean as pond becomes eutrophic or pool volume is reduced significantly.

References

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2.7 Infiltration Trench

Description

An infiltration trench is a rock-filled trench that receives stormwater runoff, allowing it to infiltrate into the ground. These structures provide temporary underground storage in the form of a trench or other storage chamber filled with uniform graded stone. Infiltration trenches are used in conjunction with sediment removal practice so that most suspended solids are removed before passing runoff into the infiltration trench. This is typically accomplished by passing runoff through a forebay (see water quality ponds), a grass filter strip or a water quality swale prior to the trench.

Infiltration is the single most efficient post-construction stormwater practice, providing several benefits other control practices don't. Most notably, infiltration tends to reverse the hydrologic consequences of urban development by reducing peak discharge and increasing base flow to local streams. Unfortunately, infiltration trenches must be very carefully constructed to ensure they will continue to function, and they often have high long-term maintenance requirements. Infiltration practices also are limited by site constraints, particularly soils, which must be within a narrow range of permeability.

Conditions Where Practice Applies

Smaller Sites – Infiltration trenches are generally not considered practical for sites larger than 5 acres. Used in small areas they offer flexibility in incorporating water quality treatment into a site's drainage system. They may be used prior to runoff entering the site's drainage system, such as along parking lot perimeters. They can be located in small areas, which cannot readily accommodate wet ponds or similar facilities.

Soil Hydraulic Conductivity – Hydraulic conductivity describes the ability of water to move through a soil. Hydraulic conductivity should be at least 0.52 inches per hour but not more than 2.4 inches per hour for infiltration trenches. These rates represent average or saturated soil conditions, not dry conditions. Rates slower than the minimum will lead to trench sizes that are unreasonably large and are more prone to failure. Higher infiltration rates will not provide adequate runoff treatment or protection against ground water contamination. Higher hydraulic conductivity will not provide adequate runoff treatment and protection against groundwater contamination. Trenches should not be constructed on undisturbed soils that have been filled. On-site evaluation of soil parameters related to hydraulic conductivity and groundwater by a trained professional is recommended..

Industrial or Other Areas of Potential Ground Water Contamination – This practice should not be used in heavy industrial developments, areas with chemical storage, pesticide storage or fueling stations.

Stable Slope – Trenches should not be used in slip prone areas where they may cause slope instability.

Hydrologic Recharge – Infiltration practices help reduce runoff and may help support recharge of groundwater and baseflow to streams. This practice may be a particularly desirable option when the receiving stream is a cold water habitat.

Planning Considerations

Sediment Clogging – The principle threat to infiltration trenches and a common reason for their failure is sediment clogging and sealing off of the permeable soil layer. An effective sediment trapping system is an essential part of all infiltration trench designs. Vegetated swales, buffer strips or sediment settling ponds should be planned so that most sediment is removed from runoff prior to reaching the infiltration trench. Additionally infiltration trenches may not be installed until disturbance from construction has ended and soils are stabilized.

Groundwater Protection – Precautions must be taken to guard against the facility introducing contaminants into water supply aquifers. Excessively permeable soils will not effectively stop pollutants and should not be used for infiltration practices Infiltration trenches should be used with caution in well-head protection areas, i.e., areas of the state where the public water supply comes from ground water. At a minimum, infiltration structures should not be located within 100 feet of an active water supply well. A minimum vertical separation of 3 feet between the bottom of the infiltration trench and the seasonal high water elevation of the ground water must be maintained, although larger separations are recommended where achievable. Normally, infiltration through soil is a highly effective and safe means of removing pollutants and protecting groundwater from contamination. Removal mechanisms involve sorption, precipitation, trapping, and bacterial degradation or transformation and are quite complex.

Considerations for Cold Climates – The design volume of the infiltration trench may need to be increased in order to treat snowmelt. In addition, if the practice is used to treat roadside runoff, it may be desirable to divert flow around the trench in winter to prevent infiltration of chlorides from road salt. Finally, a minimum setback of 20 feet from road subgrade is required to ensure that the practice does not cause frost heaving.

Design Criteria

Diversion – Storm water runoff should be directed to the infiltration trench via dispersed sheet flow wherever possible. A grass filter strip of at least 25 feet must precede the infiltration trench in these situations. Where runoff is directed to the infiltration trench as concentrated flow (via a swale, storm sewer or other discrete conveyance), the infiltration trench must be designed "off-line" such that flows in excess of the Water Quality Volume (WQv) are diverted around the infiltration trench.

In addition, a diversion that allows the trench to be bypassed when the pretreatment system becomes clogged or otherwise fails should be included in the design. This can be accomplished by providing a drain valve.

Soil Hydraulic Conductivity – Soil infiltration rates within the trench must be between 0.52 and 2.4 inches per hour. The soil should have no greater than 20 percent clay content and less than 40 percent silt/clay content.

The list of soils in Ohio that meet the required infiltration rates and are potentially suitable for the installation of infiltration trenches can be found in Appendix E. However, do not use this or county soil surveys to determine final suitability. Site-specific soil tests should be performed to confirm that the hydraulic conductivity falls within the required range. A certified Soil Scientist or other trained professional shall perform one test hole per 5000 feet, with a minimum of two borings within the planned facility location. This evaluation shall include an evaluation of the normal and seasonal high groundwater levels.

Pretreatment – The potential for failure of infiltration practices due to clogging by sediments is high. Failure will result if sediment is not trapped before runoff enters the trench. Thus, it is imperative that the facility design includes a durable, maintainable pretreatment system for removing sediment from stormwater before the trench. This can be accomplished by installing a plunge pool. Where infiltration trenches are used to treat rooftop runoff with drainage areas of 1 acre or less, pretreatment can be accomplished by providing an underground trap with a permanent pool between the downspout and the infiltration trench (Fig 2.7.1). The trap must be accessible, but sealed tightly so that it does not become a breeding ground for mosquitoes.

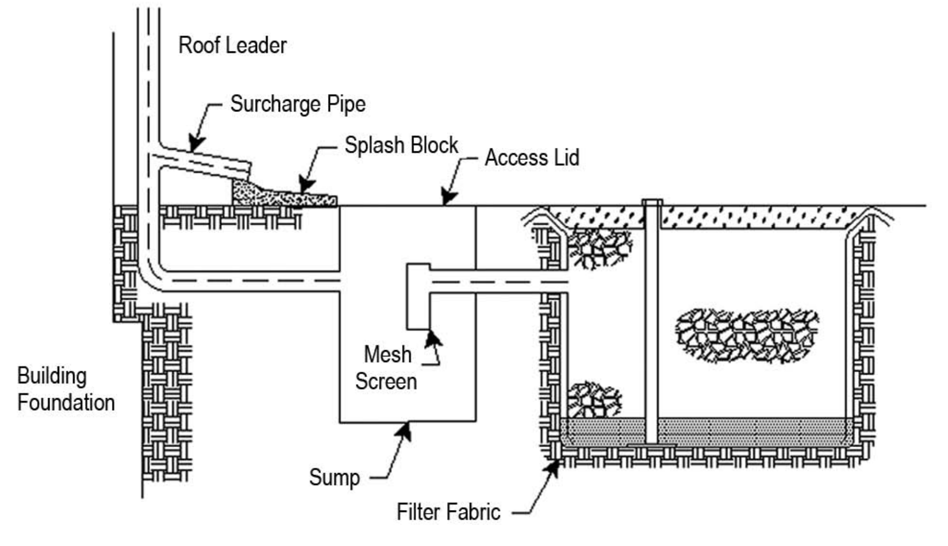

Figure 2.7.1 **Underground pretreatment facility and infiltration trench for treating rooftop runoff.**

Sizing the Pretreatment Facility – The size of the pretreatment facility is based on the infiltration rate of the soil in which the infiltration trench is built. For soils with infiltration rates of 2.0 inches per hour or less, the pretreatment facility shall be sized to contain 25% of the WQv. For infiltration rates greater than 2.0 inches per hour, the pretreatment facility shall be sized to contain 50% of the WQv.

Exit Velocity from Pretreatment Facility – The velocity of runoff as it exits from the pretreatment device must be non-erosive.

Drain Time Requirements – The practice is to be designed to infiltrate the Water Quality Volume (WQv, see page 30 of this chapt.) through the bottom floor of the structure in 24 to 48 hours. Drain times in excess of 72 hours should be avoided to prevent mosquito-breeding habitat from forming. Flows in excess of the WQv are to be diverted around the trench.

Dimensions – The dimensions of the storage reservoir (infiltration trench) are made by fitting the length, width and depth into a configuration, which satisfies drain time and storage volume requirements. The trench dimensions shall be sized by accepted engineering methods such as those outlined below:

1. Determine Initial Storage Depth – The bottom of the infiltration trench must be deeper than 2 feet to avoid freezing and shallow enough to leave at least 3 feet between the seasonal high-water table or bedrock and the trench bottom. Soil morphology also must be considered in determining the dimensions of the storage reservoir to utilize the optimum horizons or strata. The presence of a thin, slowly permeable soil horizon may require a trench depth which completely penetrates it to more permeable underlying material. Long trenches may need to be curved parallel to the topographic contour in order to keep the trench bottom elevation within the optimum depth in the soil profile.

2. Determine Area of Trench Bottom – The bottom of the trench is to be completely flat so as to allow runoff to infiltrate through the entire surface.

$$A_{\min} = \frac{WQ_v}{Porosity * (E * T)}$$

Where: A_{min} = Minimum area of the bottom of the trench (ft^2);
WQ_v = Water Quality Volume (ft^3); (Trench volume less stone volume).
E = Exfiltration Rate (ft/hr); (Soil infiltration rate at trench bottom)
T = Drain Time (hr) (Must be 24 to 48 hrs per Ohio EPA requirements)

The excavated volume of the trench is the WQ$_v$ divided by porosity or the void space of the stone.

Determine Length and Width – A long, narrow trench is less affected by water table mounding. If depth to seasonal high-water table or bedrock is within 5 feet of the trench bottom, it is advisable to design the trench as long and narrow as possible. Otherwise, the configuration of the trench is not restricted and is only limited by site design constraints.

Stone – The infiltration trench is filled with clean, washed aggregate. Stone with a diameter of between 1 and 3 inches should be used.

Geotextile – The sides and top of the trench must be lined with a non-woven geotextile to restrict the amount of sediment entering the structure. The top layer of the geotextile should be covered by 6-to-12 inches of smaller sized gravel (0.75-inch diameter). This top layer of gravel and geotextile must be replaceable. The bottom of the trench must NOT be covered with geotextile to prevent clogging with sediment. The geotextile should meet the following specifications:

Table 2.7.1 Geotextile specification

Specification	Criteria
Material	ASTM D-3776
Weight, oz/yd2	4
Grab tensile strength, lb/min (ASTM D4632)	90
Elongation at break, % (ASTM D4632)	30
Toughness, lb/min	6000

Bottom Sand Filter – To promote continued infiltration, the bottom of the trench should be covered with a clean layer of sand, approximately 6 inches deep.

Observation Well – An observation well, consisting of a perforated vertical 6-inch diameter PVC pipe with lockable cap should be installed in the trench to monitor performance. The original depth of the well must be marked on the top of the well.

Overflow – Infiltration trenches, like all stormwater facilities, must be designed to handle storms, which exceed their storage capacity without damage. Discharges must be non-erosive and overflow must always pass around the infiltration trench without being restricted by sediment filters. For example, the infiltration trenches that accept concentrated runoff from a subsurface pipe must have an overflow structure that collects overflow from within the structure rather than forcing runoff up and out through the geotextile cover.

Construction Sediment – Due to their sensitivity to sediment, infiltration trenches should not receive runoff from disturbed areas of the site. It is advisable to construct the infiltration trench only after the contributing drainage area has been stabilized.

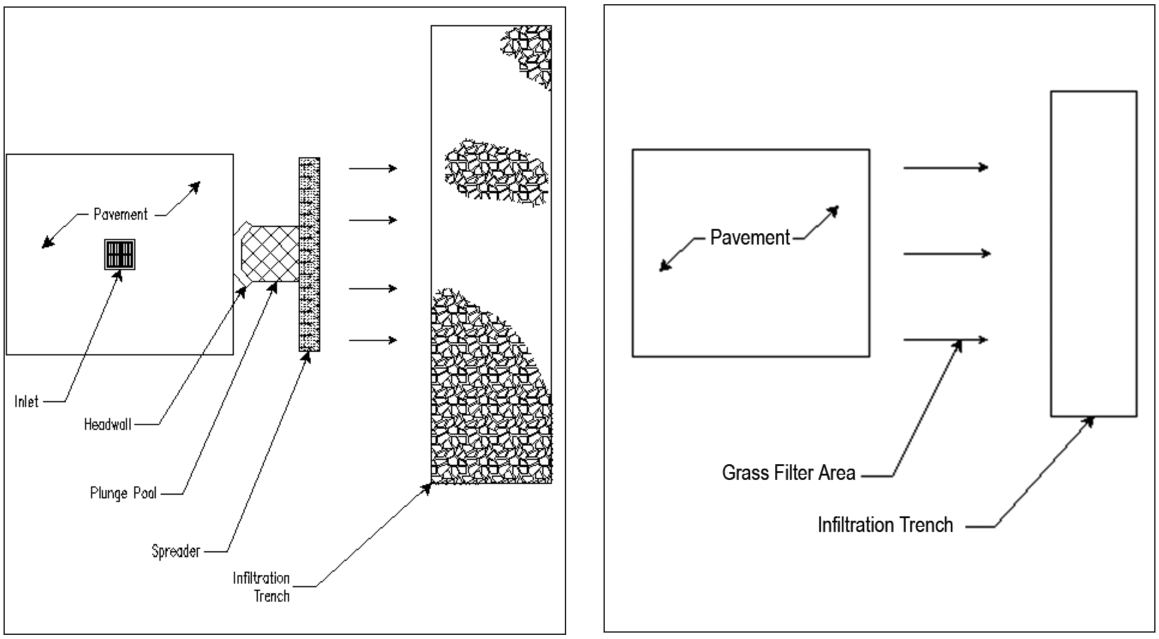

Figure 2.7.2 Typical Infiltration Trench with Plunge Pool

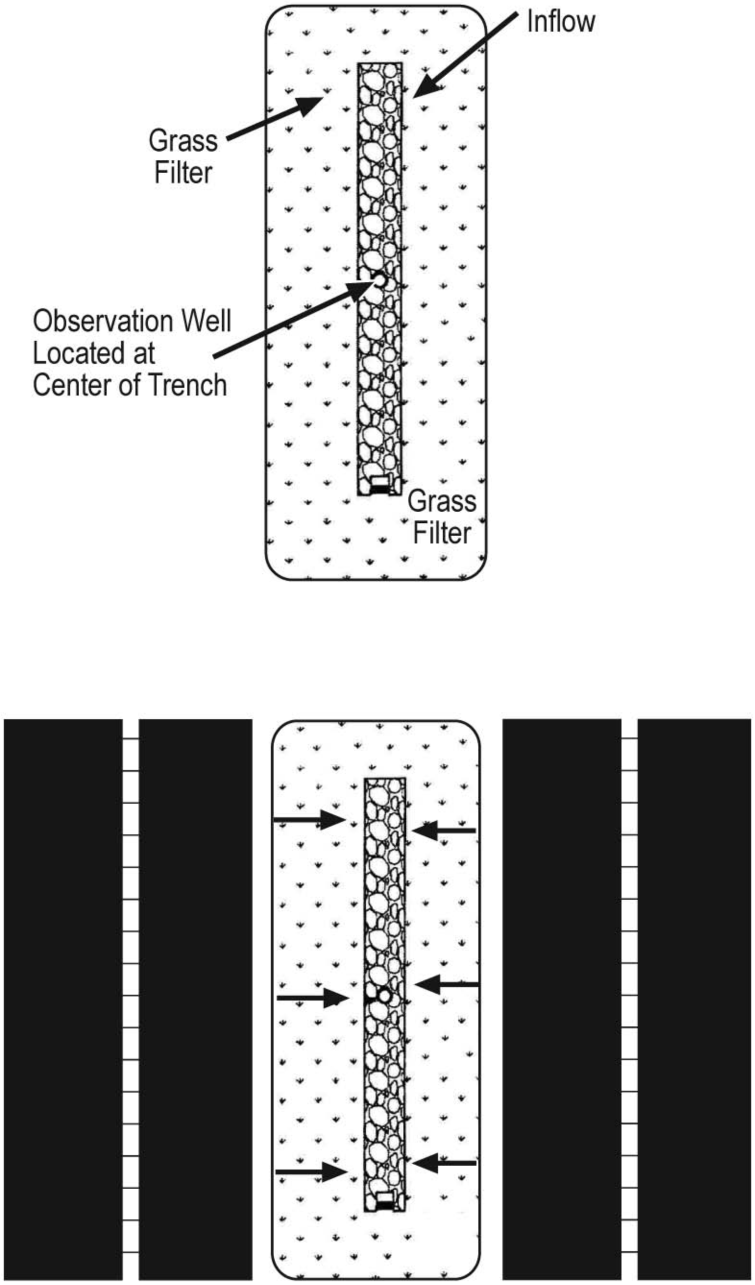

Figure 2.7.3 Illustration of a median strip trench design

Infiltration trenches have a high rate of failure. In one study in Prince George's County, Maryland (Galli, 1992), less than half of the trenches investigated were still functioning properly and less than one third still functioned properly after 5 years. However, many of these structures did not incorporate pretreatment of runoff. Thus, it is critical to ensure that proper pretreatment of runoff has been provided.

Maintenance

The following regular maintenance and inspection protocol is recommended:

Table 2.7.2 Typical Maintenance for Infiltration Practice

Schedule	Activity
Twice per year	Check observation wells following 3 days of dry weather. Failure to percolate within this timeCheck observation wells following 3 days of dry weather. Failure to percolate within this time period indicates clogging. Inspect pretreatment devices and diversion structures for sediment build-up and structural damage.
Standard maintenance	Remove sediment and oil/grease from pretreatment devices as well as overflow structure.
Upon failure	Total rehabilitation of the trench should be conducted to maintain storage capacity within 67% of the design treatment volume and 72-hour exfiltration rate limit. Trench walls should be excavated to expose clean soil.
Annually	Trim adjacent trees to assure that drip-line does not extend over the surface of the infiltration trench.

Adapted from WMI, 1997 and SMRC

References

ASCE/WEF (American Society of Civil Engineers/Water Environment Federation), 1998. Urban Runoff Quality Management, WEF Manual of Practice No. 23, ASCE Manual and Report on Engineering Practice No. 87, Alexandria and Reston, VA.

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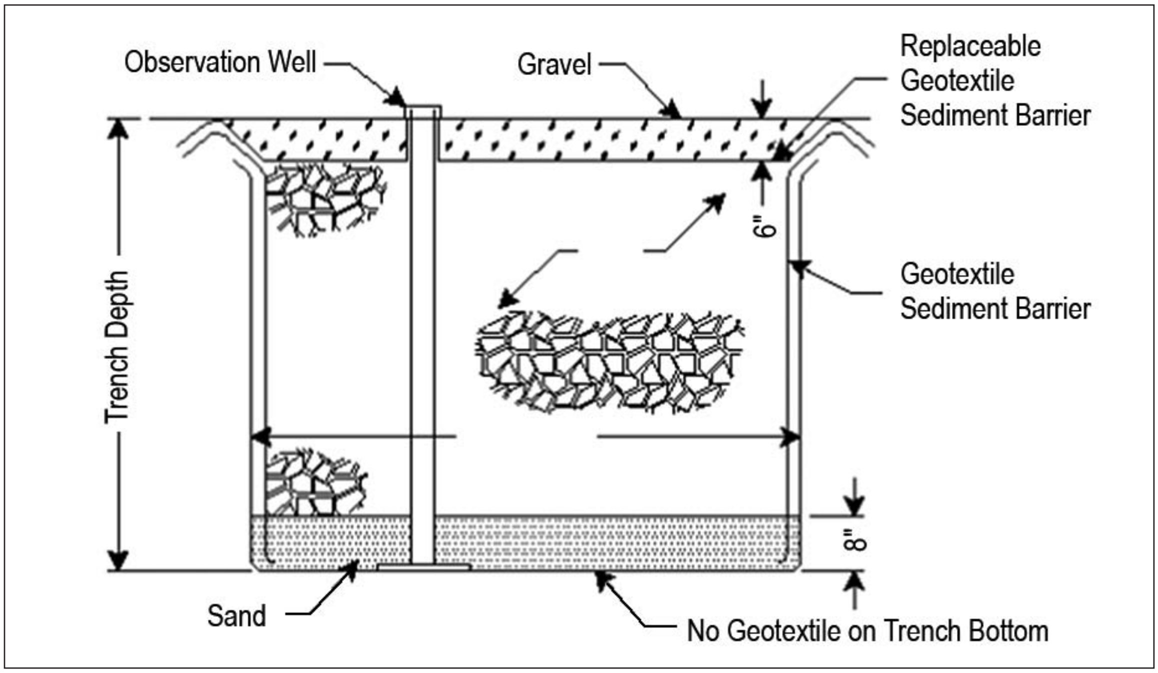
Specifications
for

Infiltration Trench



1. SEDIMENT SHALL BE PREVENTED FROM ENTERING THE INFILTRATION TRENCH. Sediment clogging and sealing off the permeable soil is the most common cause of infiltration trench failure. Runoff from the construction site shall NOT be allowed to flow to the trench until construction is complete and upslope areas have been stabilized. If storm drains enter the infiltration trench directly and cannot be rerouted, they shall be sealed with a masonry plug until all contributing drainage areas are stabilized.
2. The infiltration trench design shall include a system for removing sediment from stormwater before it enters the infiltration structure. However, this system shall NOT be used to control sediment during construction.
3. Trench excavation and backfilling of sand and rock shall be done when the soil moisture is low enough to allow the soil to crack or fracture. No trench excavation or fill shall occur on wet soil to prevent compaction and maintain soil permeability.
4. Bottom Sand Filter - The bottom of the trench shall be covered with an 8-inch layer of clean sand. The sand layer shall be placed the same day excavation is completed.
5. Observation Well - A 4-inch diameter, rigid perforated vertical pipe shall be installed in the trench. The vertical pipe shall be securely and permanently attached to a base to prevent upward movement. The top of the vertical pipe shall have a secure removable cap. The original depth shall be permanently marked on the top of the observation well.
6. Geotextile - The sides and top of the trench shall be lined with geotextile. The bottom of the trench shall NOT be covered with geotextile.
7. Rock - Rock fill shall be clean, poorly-graded, uniform size crushed washed rock. Well-graded rock has less void space available for runoff storage and shall not be accepted.
8. Gravel Top Layer - The top layer of the geotextile shall be covered by 6 inches of gravel (0.75-inch diameter).

2.8 Sand and Organic Filters

Above-ground Austin Sand Filter and sand filtration chamber.

Description

Sand filters utilize a sedimentation chamber and a filtration chamber to treat stormwater. The first chamber (sedimentation) removes large particles from stormwater by allowing them to settle out of suspension, while the second chamber (filtration) removes finer particles by filtering stormwater through a bed composed of sand or a combination of sand and organic material overlying a drain system.

Sand filters provide good treatment for pollutants except nitrates. Since these facilities attenuate the peak flows of common storm events, they are expected to reduce the potential for downstream channel erosion.

Conditions Where Practice Applies

Sand filters can be applied on most types of sites, but are most often implemented on ultra-urban sites dominated by impervious area or where space is a consideration. Sand filters also achieve a relatively constant effluent concentration of 7.5 mg/L TSS regardless of influent concentration. Therefore, sand filters, if maintained frequently enough to prevent clogging, are effective at treating stormwater "hot spots" with atypically high particulate loads, such as commercial parking lots, fueling stations, auto recycling facilities, industrial rooftops, commercial nurseries, outdoor loading/unloading facilities, and vehicle or equipment washing facilities.

Sand filters are appropriate on sites where contamination of groundwater may be a concern. In most instances, sand filters are constructed with impermeable basin or chamber bottoms that help to collect, treat, and release runoff to a storm drainage system or directly to surface water with no contact between runoff and groundwater. Sand filters can be used in areas where a permanent pool cannot be maintained for a wet pond. Sand filters should not receive runoff from active construction areas and are not appropriate for continuously disturbed areas that could cause premature clogging of the sand/media bed.

The two most common types of sand filters used in the United States, the Austin Sand Filter (Figure 2.8.3) and the Delaware Perimeter Sand Filter (Figure 2.8.4). The Austin Sand Filter is built at or below grade and is most commonly used for larger drainage areas that have both impervious and pervious surfaces. Delaware sand filter systems are installed underground, and thus are most commonly used for highly impervious areas where land available for structural controls is limited.

Planning Considerations

Size and Condition of Contributing Drainage Area – Sand filters are best suited to treat drainage areas of up to 25 acres for Austin aboveground sand filters and up to 1 acre for Delaware perimeter or underground units. Aboveground sand filters have been used for drainage areas up to 100 acres, but require larger pretreatment basins, additional distribution of water across the filter bed, and/or more frequent maintenance to prevent clogging. Because of clogging concerns, sand filters should not be used on sites where soils are permanently disturbed, and no stormwater should enter the filter system while the site is under construction.

Slopes – Sand filters can be used on sites with up to 6 percent slope. Austin aboveground sand filters require an elevation drop (head) of about 4 to 8 feet to allow runoff to flow through the system, while Delaware Perimeter Sand Filters typically require only 2 feet of head. The top of the filter bed must be completely level and stormwater must enter the filtration chamber as sheet flow.

Climate – The filter bed and internal conveyance structures may freeze in aboveground and perimeter sand filters unless the filter bed is placed below the frost line. Alternative conveyance systems such as a weir system between the sediment chamber and the filter bed may prevent the filter bed from freezing in more mild cold climates.

Design Criteria

The design of sand filters can be altered to fit a variety of site constraints or community preferences. Due to this flexibility, several sand filter designs have been developed. This manual provides the design criteria for two common configurations of sand filters: the Austin Aboveground Sand Filter and the Delaware Perimeter Sand Filter. Other manuals should be consulted for other design variations. The design steps will generally follow those laid out in Figure 2.8.1 for both aboveground and perimeter sand filters.

1) Determine overall treatment volume (WQv)
2) Divert flows exceeding treatment volume
3) Size and configure sedimentation chamber
4) Size and configure filtration chamber
5) Size outlet structure

Figure 2.8.1 Overall Design Process

Sand filters are usually constructed inside a concrete shell or built directly into the terrain over an impermeable liner. Where possible, the filter bed should be constructed below the frost line to prevent freezing. Although most Austin Sand Filters are open, they have been installed underground in parking areas, along the perimeter of parking lots, and in medians or landscaped areas.

1. Determine the Treatment Volume (Water Quality Volume)

The water quality volume (WQv) is the volume of runoff that is treated by a sand filter system. The sand filter should be designed to capture and store the entire WQv within the sedimentation chamber with a weir, perforated riser, or other outlet structure used to gradually release the captured runoff into the filtration basin over a 24-hour period. The filtration basin is designed to provide a filtration time of no less than 24 hours (when the filter media is new) and no more than 40 hours (when the filter media is clogged and requires maintenance). A total drawdown time of 40 hours is used for facility design. The water quality volume is calculated using equation 1 below, adapted from Urban Runoff Quality Management (ASCE/WEF, 1998). This is required by the Ohio EPA NPDES general permit for construction activities.

$$\text{WQv (ac-ft)} = C * 0.75 * A / 12 \qquad \text{(Equation 1)}$$

Where:

C = runoff coefficient

A = area draining into the BMP in acres

The runoff coefficient, C, is calculated using the following equation or alternatively values provided in the current Ohio EPA NPDES general permit for construction activities.

$$C = 0.858i^3 - 0.78i^2 + 0.774i + 0.04 \qquad \text{(Equation 2)}$$

Where:

i = watershed imperviousness ratio, the percent imperviousness divided by 100

Note: The Ohio EPA NPDES stormwater general permit for construction activities requires that the water quality volume be increased by 20% for capacity lost over time due to sediment accumulation.

2. Divert Flows Exceeding Treatment Volume

In most cases flows into the sand filter are limited to the water quality volume (WQv). Therefore other measures may be necessary to meet flood control detention requirements either (1) by diverting all runoff exceeding the water quality volume to separate facilities or (2) by increasing the size of the sedimentation basin and placing a second outlet sized to meet flood control requirements above the stage of the water quality volume. Figure 2.8.2 shows a device that utilizes a weir to divert the water quality volume to a sand filter.

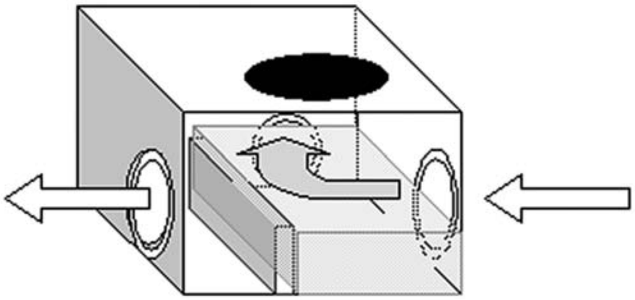


Figure 2.8.2 A weir inside the junction box of the storm sewer system diverts initial flows to sand filter.

3. Designing the Sedimentation Chamber (Basin)

The sedimentation chamber is the first stage of treatment within a sand filter. The chamber provides pretreatment of runoff by settling out coarser particles from runoff in order to prevent clogging and to reduce regular maintenance of the sand filter.

a) The Austin Sand Filter - Sedimentation chamber

The sedimentation chamber within an Austin Sand Filter is designed to completely empty between storms. This requires a somewhat larger size in order to minimize re-suspension of settled material, but also minimizes potential mosquito breeding conditions that exist within Delaware Perimeter Sand Filters and other designs that retain water between storms.

Basin Dimensions – The volume of the sedimentation basin equals the WQv plus an additional 20% of the WQv for sediment storage. The water depth in the sedimentation basin when full should be at least 2 feet and no greater than 10 feet. The minimum surface area of the sedimentation basin is determined by using the equation:

$$As = (1.2 * WQv)/(ds + freeboard) \qquad \text{(Equation 3)}$$

Where:

As = Minimum surface area of sedimentation chamber (cubic feet)
WQv = Water Quality Volume (cubic feet)
ds = Basin depth (feet)
freeboard = 0.5 feet

The sedimentation chamber should be configured so that it has a minimum length-to-width ratio of 2:1 between inlet(s) and the outlet, otherwise baffles may be necessary within the sedimentation chamber. A fixed vertical sediment depth marker should be installed in the sedimentation basin to indicate when 20% of the basin volume has been lost because of sediment accumulation.

Sedimentation Chamber Inlet – The WQv should be discharged uniformly into the sedimentation chamber at a velocity of no more than 2 ft/sec in order to maintain near quiescent conditions. A drop inlet structure is recommended to allow more efficient collection of sediment and other suspended solids that settle out within the sedimentation chamber. Energy dissipation devices may be necessary in order to reduce inlet velocity to 2 ft/sec or less.

Sedimentation Chamber Outlet – The outlet of the sedimentation basin conveys the WQv into the filtration chamber. The outlet structure should consist of a weir or a perforated riser pipe with a trash rack discharging to a weir acting as the inlet to the filtration chamber (Figure 2.8.3):

- Any weirs shall extend across the full width of the facility such that no short-circuiting of flows can occur.
- The riser pipe shall have a minimum diameter of 6 inches with four 1-inch perforations per row. The vertical spacing between rows should be 4 inches (on centers). To prevent clogging, it is recommended that the bottom half of the riser pipe be wrapped with geotextile fabric and that a cone of 1 to 3 inch diameter gravel be placed around the riser pipe.
- If a riser pipe is used to connect the sedimentation and filtration basins a valve shall be included to isolate the sedimentation basin in case of a hazardous material spill in the watershed. The control for the valve must be accessible at all times, including when the basin is full.
- Openings in the trash rack should not exceed one-third the diameter of the riser pipe.

Liners – For sedimentation basins built directly on the terrain of the site, they must be built on an impermeable liner, particularly in areas where groundwater protection is of primary importance. The liner may consist of either compacted clay with a hydraulic conductivity of 1 x 10-6 cm/sec or less, or nonwoven geotextile fabric meeting the specifications of ASTM D-751 and ASTM D-1682 and a minimum US Standard Sieve size of 80.

b.) The Delaware Perimeter Sand Filter Sedimentation Chamber

The sedimentation basin within the Delaware Perimeter Sand Filter system is usually a narrow 24” deep trough parallel to; and the same length and width as, the filtration basin, separated by a weir that runs the entire basin width with an elevation equal to the elevation of the top of sand in the filtration basin (see Figure 2.8.4). This weir results in a permanent pool 24 inches deep, the depth of the filtration bed, within the sedimentation basin. Although this dead storage serves to prevent the re-suspension of settled particulates, it may serve as a breeding ground for mosquitoes.

Sedimentation Chamber Surface Area – To meet Ohio EPA permit requirements, the WQv must fit within the volume of the sedimentation basin and the filtration basin between the top of the filter media and an overflow weir designed to divert flows in excess of the WQv to conveyance and/or detention facilities sized to meet local drainage criteria. The following equation may be used to calculate the surface area of the sedimentation basin:

$$A_s = WQv/2h - A_f \qquad \text{(Equation 4)}$$

Where:

A_s = Surface area of the sedimentation basin (square feet)
WQ_v = Water quality volume (cubic feet)
$2h$ = Maximum allowable depth of water over the filter (feet)
A_f = Surface area of the filtration basin (square feet)

The surface area of the sedimentation basin and the filtration basin are usually equal in a Delaware Perimeter Sand Filter, allowing the following equation to be used to determine the maximum allowable depth of water over the filter:

$$2h = WQv / 2{*}A_f \qquad \text{(Equation 5)}$$

Solve this equation simultaneously with Equation 4 to calculating the surface area of the filter bed.

Establishing Basin Width and Length – Once the area of each chamber is calculated, the dimensions of the facility must be established. Although typical sediment trenches and filter trenches are 18 to 30 inches wide, site constraints dictate the width. In addition, other factors such as available grate widths also may dictate final widths. Standard grate width is 26 inches.

Floatable Control – The standard Delaware Sand Filter design does not provide a means to prevent floatables or hydrocarbon sheens from passing through to the filtration chamber. If installing a Delaware Sand Filter in a situation where floatables or hydrocarbons are a concern, long-term maintenance plans should reflect the increased maintenance needs of the sand filter. In addition, large storm overflow weirs should be equipped with a 10-gauge aluminum hood or commercially available catch basin trap. The hood or trap covers should extend a minimum of 1 foot into the permanent pool.

Dewatering Drain – A 6-inch diameter dewatering drain with gate valve should be installed at the top of filter bed elevation through the partition separating it from the clear-well chamber.

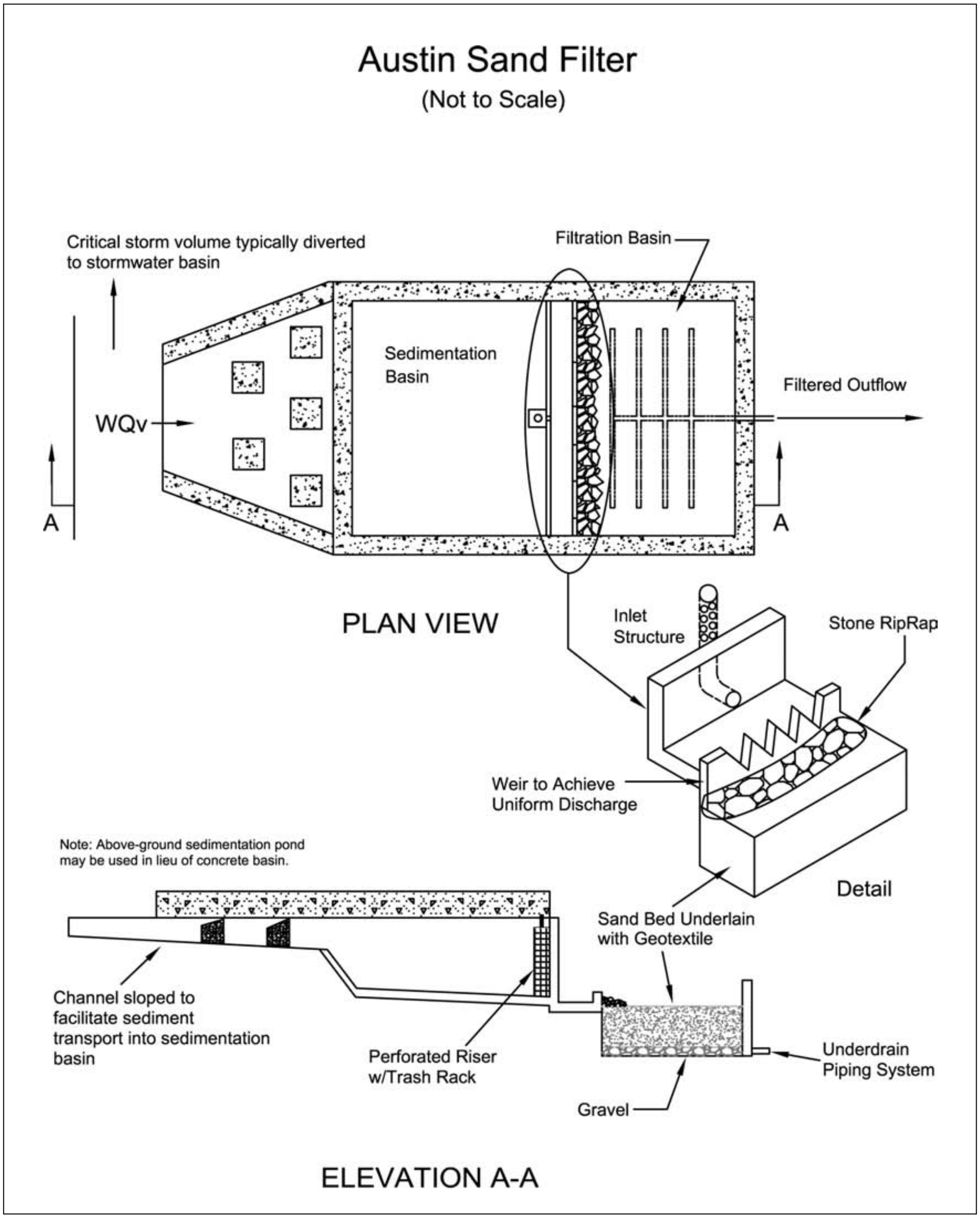


Figure 2.8.3 Austin Sand Filter, (City of Austin, TX. 1996).

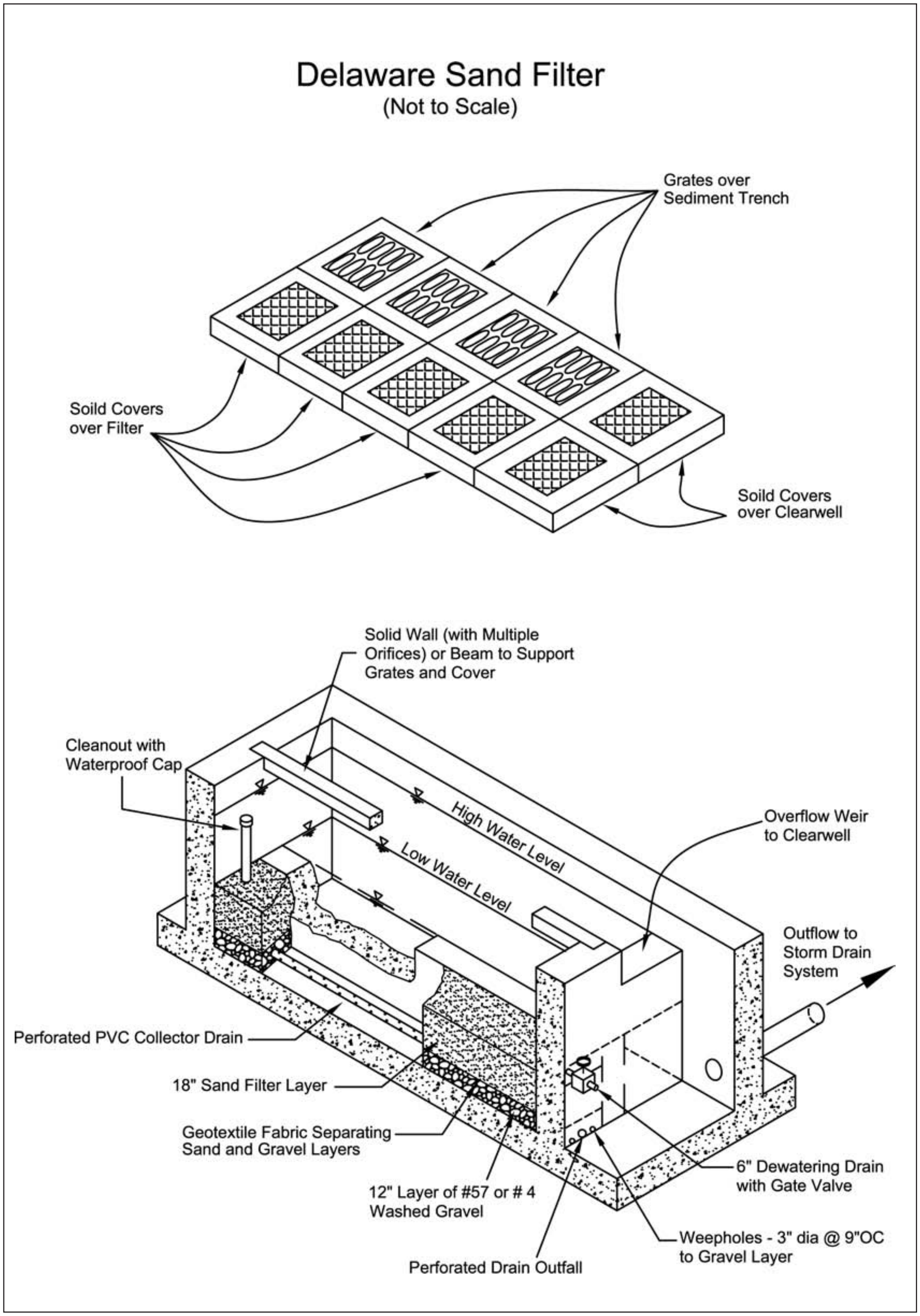


Figure 2.8.4 Delaware sand filter (City of Austin, TX. 1996).

4. Designing the Filtration Chamber

Once the WQv passes through the sedimentation chamber, it enters the filtration chamber where the stormwater passes through a sand filter for treatment. Surface area is the primary design parameter.

Filter Surface Area – The filter surface area is calculated using the following formula:

$$A_f = \frac{WQv * d_f}{k* (h+df) * t_f} \qquad \text{(Equation 6)}$$

Where:

A_f = Filter surface area (feet^2)
d_f = Sand bed depth (feet)
k = Coefficient of permeability for sand filter (feet/day)
= 3.5 ft/day for clean concrete sand (0.02” to 0.04” diameter) satisfying AASHTO M-6 or ASTM C-33
h = One-half the maximum allowable water depth over filter (feet)
t_f = Time required for runoff volume to pass through filter (days) or 1.67 days (40 hours) per Ohio EPA requirement

Filter Basin Inlet – Storm water must be spread uniformly across the surface of the filter media. To assure a uniform flow, stormwater must enter the filtration chamber using flow spreaders, weirs or multiple orifice openings, and the receiving end of the sand filter protected (splash pad, riprap, etc.) such that erosion of the sand media does not occur.

Sand Bed – The sand filter is constructed with at least 18 inches of sand overlying at least 6 inches of very coarse gravel (0.5 to 2 inch diameter). The sand and gravel media shall be separated by a permeable geotextile fabric meeting ASTM D-751 and ASTM D-1682, and the gravel layer shall be placed on drainage matting made of geotextile fabric meeting ASTM D-2434, ASTM D-1682, and ASTM D-1117. Figures 2.8.3, 2.8.4 and 2.8.5 present schematic representations of a standard sand beds.

Underdrain and Outlet Requirements – The underdrain piping consists of 4 inch diameter perforated PVC pipe (Schedule 40 PVC or greater), configured as a main collector pipe and, for Austin Sand Filters, two or more lateral branch pipes placed no more than 10 ft apart or 5 ft from the basin wall. Perforations should be 3/8 inch in diameter, with at least 6 holes per row and a maximum spacing between rows of perforations of no more than 6 inches. Each underdrain pipe should be wrapped in a geotextile fabric meeting ASTM D-751 and ASTM D-1682, with a minimum of 2 inches of gravel covering the top surface of the PVC pipe. Each pipe must have a minimum slope of 1% (1/8 inch per foot), and each individual underdrain pipe shall have a cleanout access location.

Weepholes – Weepholes between the filter chamber and the shell may be provided as a backup in case of underdrain pipe clogging. If used, weepholes should be 3 inches in diameter with a minimum spacing of 9 inches center to center. The openings on the filter side of the dividing wall should be covered to the width of the trench with 12-inch high plastic hardware cloth of 1/4-inch mesh or galvanized steel wire, minimum wire diameter 0.03-inch, number 4 mesh hardware cloth anchored firmly to the dividing wall structure and folded 6 inches back under the bottom stone.

Maintenance of Sand Filters

Filter systems require frequent maintenance. Two design considerations that can help reduce maintenance problems are:

1. Providing access to the filtering system
2. Addressing confined space issues for underground systems

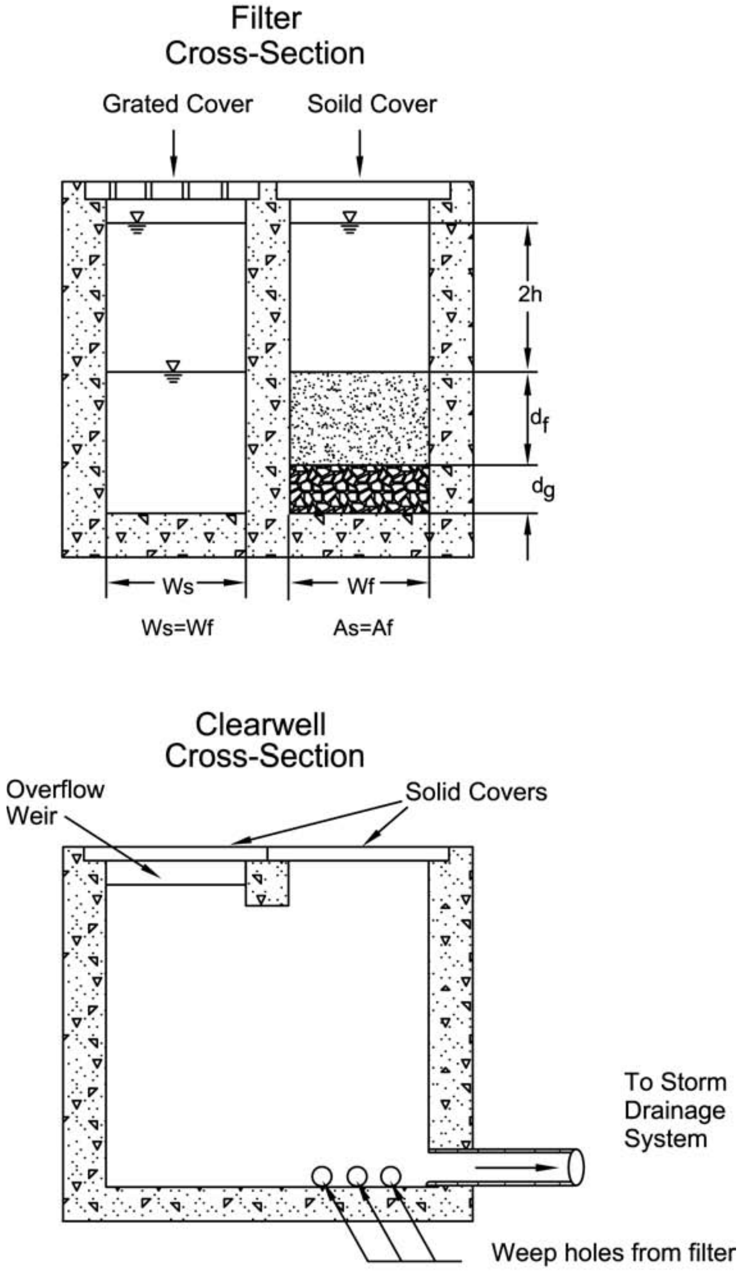
Where observation wells and grates are used, lifting rings or threaded sockets should be provided to allow for easy removal by lifting equipment. Access for the lifting equipment must be provided. Any long-term maintenance plan for sand and organic filters should include regular inspections for each of the following items:

Table 2.8.2 Typical maintenance activities.

Schedule	Activity
Monthly	Debris Removal Check for clogging and sediment accumulation on the filter surface – remove and place areas where clogging is occurring or likely If sediment chamber is more than half full of sediment, clean out Vegetation Control for surface systems (if applicable) • Mowing • Fertilization • Repair erosion
Semi-annual	Check for cracks and leakage Inspect, repair grates Replenish media
Annual and/or after major storms	Remove accumulated sediment from sedimentation chamber Rake and/or remove sediment from surface of filter bed Inspect spillways and repair if necessary

Delaware Sand Filter

(Not to Scale)



Where: Ws = Width of sediment chamber
Wf = Width of filter
As = Area of sediment chamber
Af = Area of filter
2h = Maximum ponding depth over filter
df = Depth of sand layer
dg = Depth of gravel layer

Figure 2.8.5 Delaware filter cross sections.

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2.9 Grass Filter Strip

Description

Grass filter strips, also known as vegetated filter strips, treat the water quality of small sheet flows from developed areas. They are uniform strips of dense turf or meadow grasses with minimum slope, best suited to accept diffuse flows from roads and highways, roof downspouts, and very small parking lots, usually prior to runoff being collected by swales, ditches or storm drains. They are also an ideal component of stream buffers or as pretreatment to a structural practice.

Dense turf creates a thick porous mat, which slows runoff velocity from small flows causing deposition and filtration of particulates. Other pollutant removal mechanisms are nutrient uptake, adsorption and infiltration. Grass filter strips are generally not very effective for treating soluble pollutants. Their overall effectiveness is highly variable depending on slope, the quality of turf, and flow rates. It is critically important to maintain sheet flow through the filter strip; otherwise the practice provides little to no treatment.

Conditions Where Practice Applies

Grass filter strips are an adaptable practice that often can be incorporated throughout a development site, allowing multiple use from turf areas. Grass filter strips, should not be used as the primary control practice to provide water quality treatment for a development site, particularly hot spots such as gas stations and junkyards, but can be used as a supplemental practice or as pretreatment when combined with another structural treatment practice.

Natural meadow areas also may be used for grass filter strips. Grass filter strips are most often located in landscaping areas around building and parking lot perimeters, in greenbelts or along conservation easements, and median strips in parking lots and streets. The site's topography must allow shallow slopes and sheet flow runoff through the filter strip.

Filter strips are a suitable practice to protect cold-water habitats as they typically do not warm runoff.

Filter strips are impractical in ultra-urban settings because they consume a large amount of space when compared to other practices. Filter strips typically consume an equal width to the impervious drainage area they treat.

Planning Considerations

Grass Filter Strips at the Source vs. Buffer Strips at the Resource

Grass filter strips are used as close as possible to the source of the runoff. They are integrated throughout a development site such as along the edges of parking lots. Buffer strips, on the other hand, are used adjacent to perennial and intermittent stream channels. Grass filter strips are planted to turf while buffer strips have diverse forest vegetation. Grass filter and buffer strips both treat sheet flow runoff but buffer strips also provide many additional functions important to the riparian system: shading, bank stability, leaf litter and detritus.

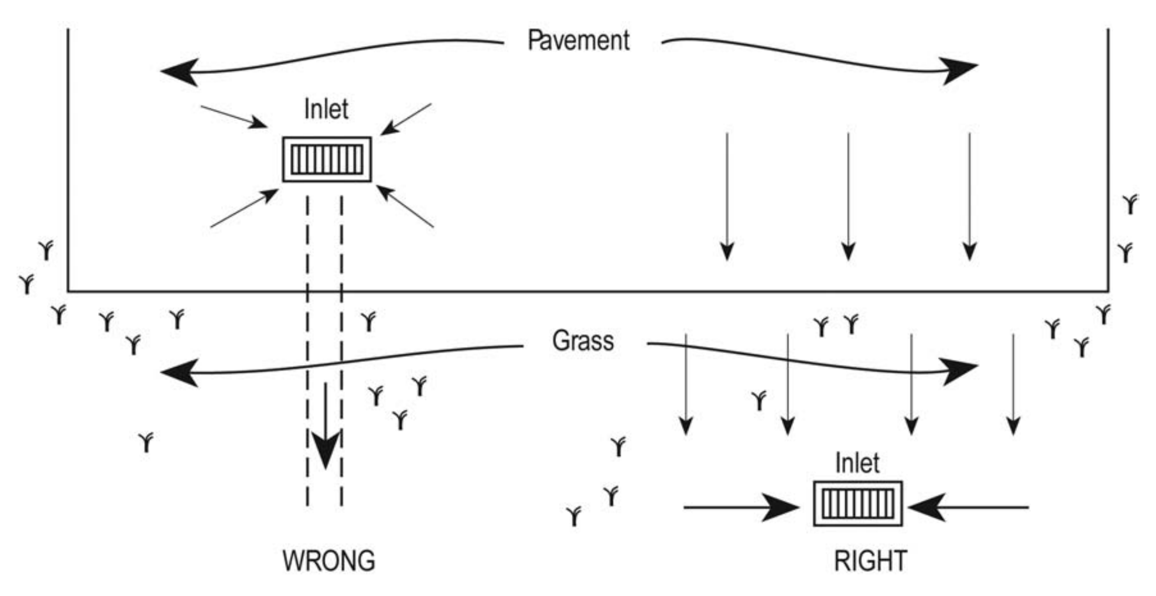

Figure 2.9.1 Runoff routed through grass filter strip before entering drainage system

Design Criteria

Siting Criteria

The filter strip should abut the contributing drainage area. If placed abutting a parking lot, devices that channelize flows into the filter, such as curb cuts and gutters should be avoided. In order to minimize soil compaction and to maintain quality dense vegetation, filter strips should not be located in areas expected to receive heavy pedestrian or vehicular traffic once the site is developed.

Drainage Area

The limiting design factor for grass filter strips is not the drainage area to the practice, but rather the length of flow leading to it. The length of flow cannot exceed the length at which sheet flow concentrates. As a rule of thumb, sheet flow from impervious surfaces will concentrate within a maximum of 75 feet, and 150 feet from pervious surfaces (Center for Watershed Protection, 1996). Thus, as a rule of thumb, a filter strip can treat 1 acre of impervious area per 580-foot length and 1 acre of pervious area per 290-foot length.

Slope

The slope of a grass filter strip should be as flat as possible. However, if standing water may create a nuisance, slopes should be sufficient to provide positive drainage. To avoid runoff converging into concentrated flows, slopes must be less than 5%. Filter strips that are 1% slope or flatter should be avoided unless they are built on very sandy or gravely soils. The top and toe of the slope should be as flat as possible to encourage sheet flow and prevent erosion.

Slope Length

A higher level of pollutant removal is achieved the longer the slope length (the distance water flows through a filter strip). Grass filter strips must have a minimum slope length of 25 feet, but should be designed to provide a slope length based on their slope within the ranges noted in the table below:

Table 2.9.1 Filter Strip Flow Length

Slope of Filter Strip	75% Particulate Trap Efficiency	90% Particulate Trap Efficiency
1%	25 ft	50 ft
2%	30 ft	120 ft
3%	40 ft	135 ft
4%	60 ft	170 ft
5%	75 ft	210 ft

Ground Water

Filter strips should be separated from ground water by at least 2 to 4 feet to prevent contamination and to assure that the filter strip does not remain wet between storms.

Soils

Filter strips will be less effective as the clay fraction of the soil increases, since this limits the infiltration of runoff associated with proper treatment. Filter strips are not suitable in very poor soils that cannot sustain a grass cover.

Assuring Sheet Flow

To assure that runoff remains as sheet flow through the filter strip, a grass or rock trench level spreader shall be used at the top of the slope. The level spreader must have a minimum depth and a minimum width of 1 foot. The level spreader shall be placed on a level contour. In addition to assuring sheet flow, the level spreader acts as a pretreatment device to settle out some sediment particles.

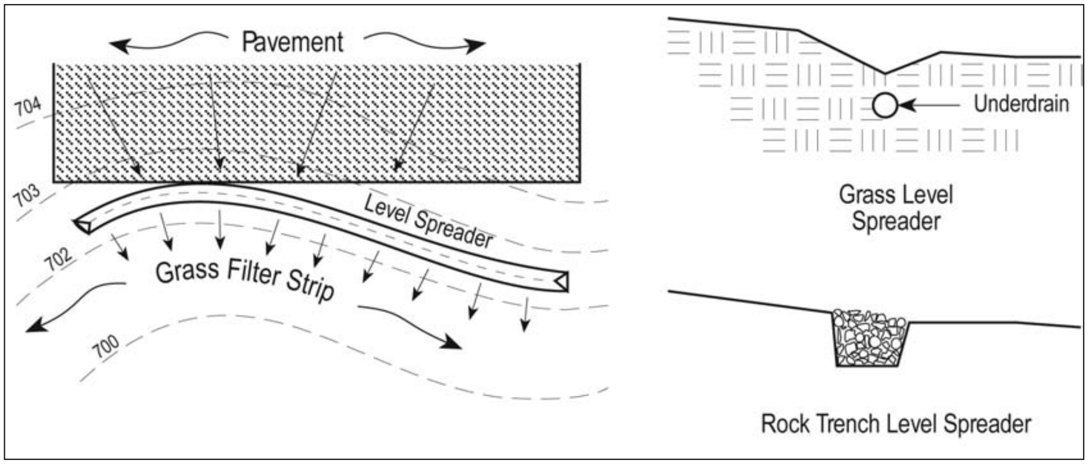

Figure 2.9.2 Grass filter strip with level spreader to distribute flow

Establishing Vegetation

Dense vegetation is critical to effective filter strips. Poor stands of vegetation may even result in a grass filter strip eroding and becoming a source of pollution. Soil preparation and planting is deserving of special attention (see Specifications for Permanent Seeding). When selecting vegetation for grass filter strips, select species that can withstand relatively high velocity flows and both wet and dry periods. A tool to select the appropriate vegetation based on site specific conditions is available on the internet from the USDA Natural Resource Conservation Service at: http://ironwood.itc.nrcs.usda.gov/Netdynamics/Vegspec/pages/HomeVegspec.htm

Some common grasses suitable for use in Ohio include perennial ryegrass, tall fescue, red fescue and kentucky bluegrass as well as canada wildrye, chinese silvergrass, orchardgrass, smooth brome, switchgrass, timothy and western wheatgrass. Filter strips can even provide a convenient area for snow storage and treatment. If used for this purpose, salt-tolerant vegetation such as creeping bentgrass should be selected.

Seeding of the filter strip should be completed no later than September 30th to assure sufficient vegetation by October 31st. Vegetation should be inspected within 30 days of seeding to assure that an adequate stand of vegetation has established. If an adequate stand has not been established by October 31st, temporary measures must be installed to divert stormwater flows around the filter strip until adequate vegetation and stabilization occurs. No stormwater flows should be directed to a filter strip with established vegetation until the contributing drainage area has been stabilized.

Pedestrian and Vehicular Traffic

Heavy use should be avoided to minimize soil compaction and maintain quality dense vegetation.

Maintenance

– Only a minimum amount of maintenance should be necessary to ensure continued functioning of grass filter strips.

– The most significant concern is gully formation from unexpected concentrated flows. If rills and gullies occur, they must be repaired and stabilized with seed or sod. Measures must be taken to eliminate the concentrated flow.

– Filter strips should be inspected annually to assure that the level spreader is not clogged and to remove built-up sediment.

– Grass within the filter strip should be maintained as lawn. Grass height should be about 3 to 4 inches.Vegetation must be kept healthy.

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Specifications
for

Grass Filter Strip

NOTE: See Specifications for Permanent Seeding.

1. Filter strips shall be graded to prevent runoff from concentrating. Depressions, ridges and swales shall be graded out to achieve a uniform slope having a level grade across the slope.

2. To assure that runoff remains as sheet flow through the filter strip, a level spreader shall be used at the top of the slope. The rock or grass level spreader must be placed on a contour, and shall have a minimum width and depth of 1 foot.

3. Soil compaction shall be minimized in the filter strip area. Work shall be performed only when the soil moisture is low.

4. A subsoiler, plow or other implement shall be used to decrease soil compaction and allow maximum infiltration. Subsoiling shall be done when the soil moisture is low enough to allow the soil to crack or fracture.

5. Because a dense vegetation is critical for effective filter strips, only a dense stand of vegetation without rills or gullies shall be acceptable. If rills or gullies form or if vegetative cover is not dense, a new seedbed shall be prepared and replanted.

6. The filter strip shall be seeded no later than September 30th to assure that vegetation establishes prior to the onset of winter weather.

2.10 Bioretention

Description

Bioretention practices are stormwater practices that utilize a soil media, mulch and vegetation to treat runoff and improve water quality for small drainage areas. Bioretention practices can provide effective treatment for many runoff quality problems such as total suspended solids, heavy metals, organic compounds, bacteria and nutrients (phosphorous and nitrogen) by promoting settling, adsorption, microbial breakdown, and nutrient assimilation by plants. Outlet configurations of bioretention practices can be altered in order to encourage exfiltration, enhance nitrogen removal and mitigate discharge temperatures.

A bioretention area consists of a depression that allows shallow ponding of runoff and gradual percolation through a soil media, after which it either exfiltrates through underlying soils or enters the storm sewer system through an underdrain system. Bioretention practices are sized to fully capture and treat common storm events (the water quality volume) whereas runoff volumes from larger events may be designed to bypass these practices.

Condition Where Practice Applies

A bioretention practice is generally applicable for:

- Limited contributing drainage areas, generally less than 2 acres.
- Broad water quality treatment, including temperature, suspended solids, metals and depending upon design characteristics, nutrients. A comparison of practices is provided in Chapter 1.
- Various land uses including highly impervious areas such as roadways, commercial areas, or parking areas, especially in traditionally landscaped areas such as cul-de-sacs or park-

ing lot islands.

- Sites with soils of sufficient hydraulic conductivity or a suitable outlet for an underdrain system to fully drain the practice in a period of 12 to 48 hours.
- Sites with sufficient fall between inflow point and outlet for the underdrain, (generally exceeding 3.5 feet). Shallower facilities are expected to reduce the effectiveness of treatment.

Bioretention practices are not applicable where:

- Continuous groundwater flow will prevent the basin from draining between storm events.
- Groundwater pollution potential is high due to high pollution loads or a high groundwater table.

Planning Considerations

Groundwater Concerns – There is an increased risk of groundwater pollution if there is not adequate separation between bioretention facilities and the groundwater table.

High groundwater may impede the proper functioning of the practice by consuming storage capacity or slowing drainage of the practice. Karst areas, shallow bedrock, a high groundwater or seasonally high groundwater table, or soils that allow surface water to bypass treatment through the soil media all increase the potential for groundwater pollution. A minimum 2ft of separation is recommended and a minimum 1ft of separation is required between the top of the water table and the bottom of the excavated bioretention practice. Separation may also be achieved by using an impermeable liner or a layer of compacted earth. Seasonal high groundwater should also be evaluated so it is sufficiently below (see above) the excavated bottom of the practice or able to be lowered sufficiently with perimeter drains.

Off-line or In-line with Major Flow – Bioretention practices may be designed off-line or in-line with runoff flow. Off-line facilities fill to capacity, and then are bypassed by additional runoff. Off-line design minimizes the potential for eroding mulch or other material from the practice during high flows. Off-line bioretention is typically surrounded by an earth berm to capture the required volume of runoff and utilizes the same opening for flow entering and exiting the practice. Figure 2.10.1 shows an example of such a facility. Numerous installed off-line bioretention facilities have shown how poor design or poor construction may cause the initial treatment volume to bypass inlets to the practice. Therefore careful design must be used to insure that runoff enters and fills the practice before bypassing.

In-line (also called on-line) facilities fill with the required volume of runoff then discharge excess flows through an overflow or outlet structure such as a drop inlet or weir. These facilities must be designed to safely route large storms through the practices without erosion in the facility or at the discharge location.

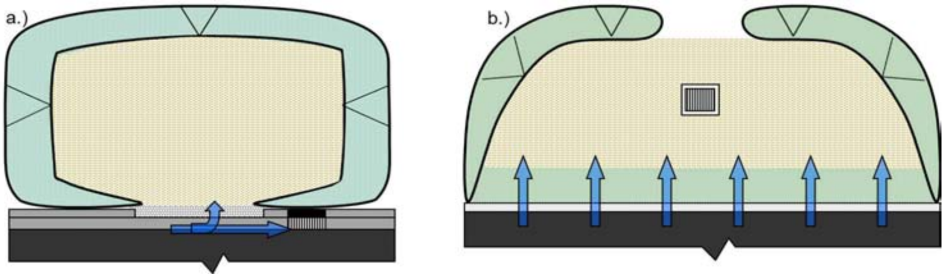


Figure 2.10.1. Flow into a.) offline versus b.) in-line facilities. Offline facilities receive flow then are bypassed by runoff, while in-line facilities receive all contributing runoff.

Suitable Soils for Infiltration and Establishing Need for a Designed Underdrain System – The bioretention practice must be designed so that the treatment volume will be drained between 12 and 48 hours either through infiltration into the soils under the facility, through an underdrain system, or through a combination of in-situ soils and an underdrain system. Facilities designed without an underdrain system shall have a qualified professional certify in-situ soils have the capacity to fully infiltrate the treatment volume within 48 hours. This certification shall include a description of the soil depth and horizons that correspond to the design elevations of the bioretention practice.

Setbacks to Prevent Water Damage - Appropriate setbacks from property lines, wells, septic systems, basements and building foundations shall be maintained to prevent damage to these systems or offsite areas. The following table provides recommended minimum setbacks.

Table 2.10.1 Minimum setbacks from important infrastructure.

	Setback Distance	
Feature protected by setback	Bioretention Utilizing Underdrain System	Bioretention Utilizing Suitable Soils For Infiltration
Property Line	2’ (check with local requirements)	
Well	100’	
Septic System (including perimeter drain)	50’	
Building Foundations or Basements	10’	25’
Asphalt (parking, drives or roadways)	2’ (check with local requirements)	

Long Term Maintenance and Easements - Since bioretention combines plant materials with the temporary storage and filtering of stormwater, more frequent regular maintenance is required than for other more traditional stormwater facilities. Designs shall include easy access for maintenance as well as an appropriate plan of operations and maintenance that considers the spectrum of activities described later in this standard. A legal and enforceable maintenance agreement shall be in place and executed. Although many bioretention facilities are located on private property and will be privately maintained, the area shall be placed in a drainage easement to permit public access if maintenance should be necessary. For residential developments, additional measures such as educational materials and deed restrictions may be necessary to prevent alterations that would affect the use or diminish the effectiveness of the bioretention practice.

Filter Bed Area - Bioretention facilities may require more area than some other stormwater treatment practices. Generally the surface area of the filter bed will be between five and ten percent of the contributing impervious area.

Slope and Effect of Curbing - Designers must consider the effect of curbing around the bioretention area on the design and construction of side slopes and the filter bed. Curbing may steepen side slopes in some areas and compel contractors to fill areas of the filter bed. Consider wheel stops that allow sheet flow, lower curbing or detailing exact grading on plans to prevent problems.

Construct Bioretention after Site Stabilization - Bioretention facilities shall be constructed after all other areas of the drainage area have been constructed and finally stabilized. That is, sediment-laden runoff from construction shall not be allowed to pass through the practice. Runoff from actively eroding sites will cause the premature failure of bioretention facilities. Avoid using a bioretention facility as a sediment trap or basin. If they must be used to capture construction site sediments, excavation should leave the trap or basin bottom at least 12 inches higher than the planned bioretention bottom elevation. After construction is finalized they may be excavated down to the final elevation after water and sediments have been removed. These measures will help to protect the infiltration capacity of the underlying soils.

Design Criteria

Water Quality Volume - All bioretention practices shall be designed to treat the water quality volume (WQv) by initially ponding that volume and allowing it to infiltrate through soil media within the practice. Bioretention practices have a target drawdown time of 24 hours for the surface ponding area. Drawdown time may be controlled by the soil media (typically), by an orifice on the underdrain or by the the rate of infiltration into in-situ soils under the practice.

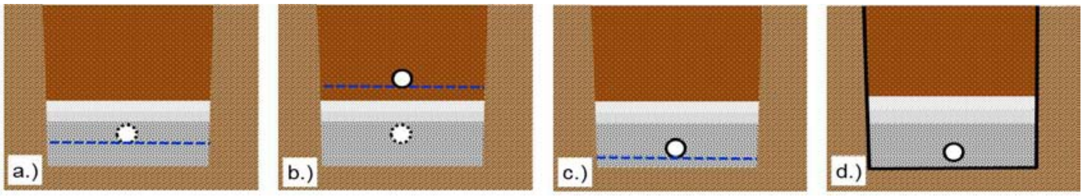
Incorporating Additional Objectives - Design of bioretention practices will vary depending on the water quality objectives, the potential for groundwater recharge, and the potential for groundwater pollution. While all bioretention practices provide filtration through the soil media, the following conditions and design variations may enhance or limit the infiltration of water into in-situ soils, or enhance denitrification at the bottom of the practice.

In-situ Soils Suitable for Infiltration – Where in-situ soils can fully infiltrate the water quality volume within 48 hours and where groundwater pollution potential is low, exfiltration may be used as the primary drainage for the bioretention practice. Although this situation may be designed without an underdrain (Figure 2.10.2a), an internal water storage layer provided with a drain near the top serves as a backup to natural exfiltration (Figure 2.10.2b). Systems designed without an underdrain may not be used where extensive ponding of water above the practice will cause damage. Infiltration capacity of the soils shall be tested by a qualified professional.

Limited Infiltration and/or Enhanced Nitrogen Treatment - (Limited infiltration soils = $0.05 \leq Kfs \leq 0.5$ in/hr.) This design provides an internal water storage (IWS) layer below the upturned outlet of the underdrain pipe. This standing water zone (see Figure 2.10.2b and option 1 of 2.10.3) holds water and extends opportunity (both in time and quantity) for exfiltration. This layer also acts as a anoxic zone that encourages denitrification, that is, the conversion of nitrate to nitrogen gas, reduction in nitrogen discharge, and thus is an aid in preventing eutrophication of receiving waters. This design is expected to provide better than 40% and perhaps as high as 80% mass removal of nitrogen from surface runoff.

Low Infiltration In-situ Soils – For sites having in-situ soils with low permeability (clayey subsoils with $Kfs < 0.05$ in/hr), a standard underdrain bedded in a gravel layer provides the primary drainage for the practice (Figure 2.10.2c and Figure 2.10.3c). This configuration may be most appropriate for hydrologic soil group (HSG) D soils.

Impermeable Liner – For areas with a high water table, karst, shallow bedrock or high pollution loads, an impervious liner separates the entire practice from in-situ soils and the water table (Figure 2.10.2c). This design also relies on the underdrain system as the primary drainage. This is appropriate where heavy pollution is expected and/or where groundwater must be protected.



For sand, loamy sand, and sandy loam subgrade soils with $K_{fs} \geq 0.5$ in/hr.

For loamy or silty soils with $0.05 \leq Kfs \leq 0.5$ in/hr.

For clayey soils with $K_{fs} \leq 0.05$ in/hr. Some added sump volume may be acceptable on soils with K_{fs} = 0.02 - 0.05 in/hr.

For situations, where interaction with groundwater and surrounding soils must be limited.

Figure 2.10.2 Underdrain configurations in typical bioretention cross-sections (blue dashed line designates water available for infiltration. From left to right:

a.) Bioretention with soils suitable for infiltration (underdrain optional).

b.) Bioretention with an internal water storage (IWS) layer that has been raised into the soil media for denitrification. An IWS will provide extra storage for infiltration.

c.) Underdrain placed for poorly drained soils.

d.) Lined bioretention cell.

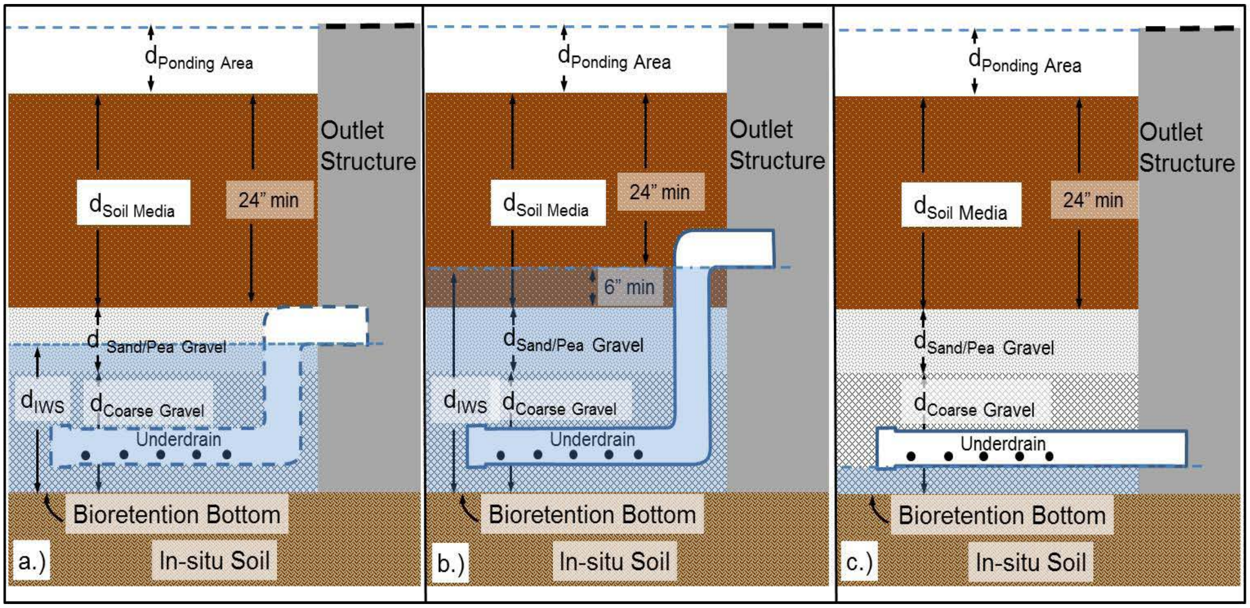


Figure 2.10.3 Comparison of different underdrain and internal water storage configurations. These should be based on the soil properties and the design objectives. The figures labeled a.), b.) and c.) correspond to the same labels in figure 2.10.2.

a.) A bioretention area with soils suitable for infiltration may or may not require an underdrain. The internal water storage (IWS) layer should be sized to hold a volume that is equal or greater than the water quality volume.

b.) Bioretention with an internal water storage (IWS) layer for increased infiltration or for treating nitrogen. Raising the upturned elbow so that at least 6 inches of the IWS is in the soil media creates conditions for denitrification.

c.) Underdrain placed with a minimum of three inches of cover and three inches of bedding. This design still allows some minimal water storage for infiltration even on poorly drained soils.

Area Dimensions – The filter bed area typically will have a minimum 10 foot width though there are scenarios, especially in densely urban areas, where narrower bioretention areas make sense in order to take advantage of available space in parking lot islands, curb bump-outs, or landscape planters. Basin sides slopes, and pretreatment and conveyance areas, may increase the overall area dedicated to the practice and may affect slope of the filter area.

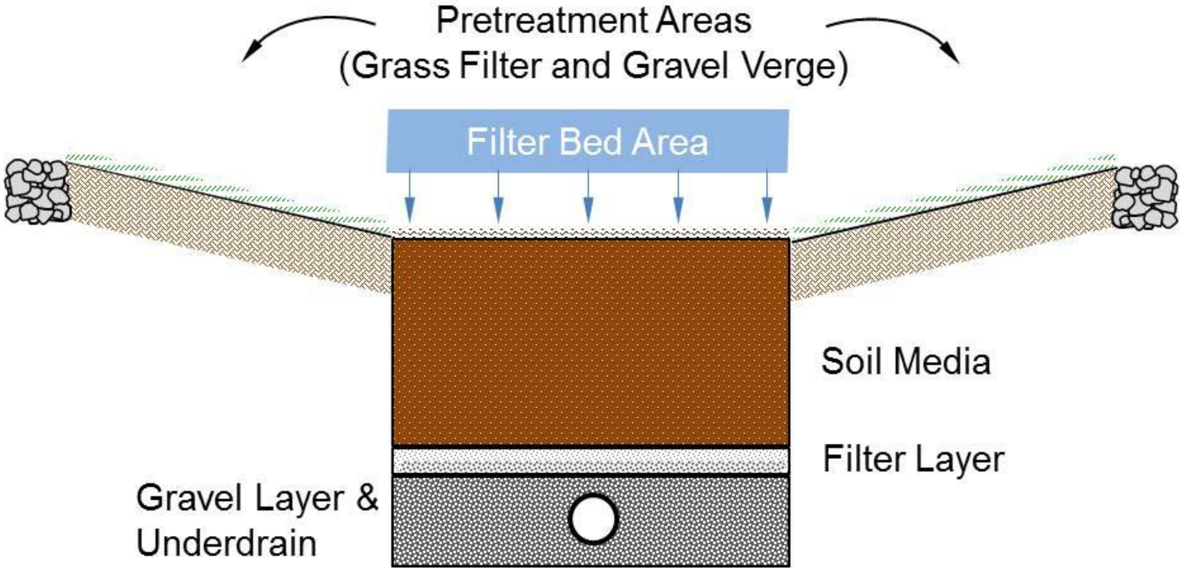


Figure 2.10.4 Components of Bioretention

General Components of Bioretention Practices

1. *Pretreatment Area* – Pretreatment is necessary to ensure long-term function of bioretention practices. High sediment loads cause clogging of the bioretention surface and failure of the practice. Pretreatment is designed to capture excessive sediment before it reaches the filter bed area and to dissipate energy so that flows into the practice don't erode adjacent soils or scour the filter bed. Pretreatment options vary based on whether flow is concentrated or enters the practice as sheet flow. Ideally, paved areas will be directed to the bioretention practice as sheet flow. For many bioretention areas, both types of pretreatment are necessary. The following pretreatment requirements apply:
   a. Sheet flows from paved areas shall use a gravel verge (a shallow stone-filled trench) at the edge of the pavement to dissipate energy and spread flow onto a grassed filter at least 10 feet long with 4:1 or flatter sideslopes (see Figure 2.10.4).
   b. For concentrated flows, the discharge must pass through either a grass swale or a pretreatment forebay. The grass swale must be at least 20 ft in length with a discharge of 1 fps or less for the 1-year 24-hour storm event. The forebay(s) must be sized to capture at least 20% of the WQv. Concentrated flows into the grass swale or forebay shall have an apron stabilized with appropriately sized riprap/stone.

2. *Filter Bed and Ponding Area* - The bioretention practice is designed to capture and temporarily store the entire water quality volume (WQv) so that it will infiltrate through the filter media. The ponding depth for the WQv should be less than or equal to 12 inches to ensure the WQv drains in a timely fashion (~24 hr) in preparation for the next runoff event. The depth of ponding is controlled by the height of the overflow structure or the berm containing runoff. [Note: Additional storage can be included above the WQv, with appropriate outlet, to achieve additional volume reduction or to help meet peak discharge requirements - see sections below.]

   Minimum size of the filter bed:

   For situations **where impervious areas exceed 25% of the contributing drainage area**, the filter bed area shall be a minimum of 5% of the contributing impervious area.

   Example -

   Contributing Drainage Area, A_{da} = 1.49 Ac = 65,000 ft^2
   Impervious Area, A_{imp} = 0.57 Ac = 24,800 ft^2
   Impervious Percentage, $I = (A_{imp}/A_{da})*100 = (24{,}800\ ft^2/65{,}000\ ft^2)*100 = 38.2\%$
   Since I = 38.2% is greater than 25%, then
   $A_{filter\ bed} = 0.05*A_{imp} = 0.05*24{,}800\ ft^2 = 1240\ ft^2$ (the minimum filter bed area)

   For situations **where impervious areas are less than 25% of the contributing drainage area,** the filter bed area shall be at least equal to the WQv divided by the one foot maximum ponding depth.

   Example -

   Contributing Drainage Area, A_{da} = 1.49 Ac = 65,000 ft^2
   Impervious Area, A_{imp} = 0.28 Ac = 12,200 ft^2
   Impervious Percentage, $I = (A_{imp}/A_{da})*100 = (12{,}200\ ft^2/65{,}000\ ft^2)*100 = 18.8\%$
   Because I = 18.8% is less than 25%, then $A_{filter\ bed}$ = WQv/1 ft
   $WQv = C*P*A = 0.164*(0.75\ in)*(65{,}000\ ft^2)*(1\ ft/12\ in) = 666\ ft^3$
   $A_{filter\ bed} = WQv/1\ ft = 666\ ft^3/1\ ft = 666\ ft^2$ (the minimum filter bed area)

3. *Mulch* – If the bioretention area is not vegetated with dense turf, a minimum 3 inch layer of coarse shredded hardwood mulch shall be placed around plants and over the planting soil. Besides protecting the filter bed surface from erosion, the mulch creates an organic layer conducive to filtering, capturing and degrading pollutants, and promoting biological growth. Pine mulches and fine or chipped hardwood mulches may not be used since they will float and move, blocking drainage or leaving the area with high flows.

4. *Planting Soil* – The planting soil filters the treatment volume, detains runoff in the available void space and provides a media for plant growth and a biological community. Much of the pollutant removal occurs in this zone due to filtering, microbial activity, ion exchange, adsorption and plant uptake. The planting soil (an engineered soil media) shall be at least two feet deep and up to four feet in depth (settled) depending upon the planned vegetation. Greater depth is necessary to accommodate the root ball of trees planted in bioretention facilities. Soils and soil mixes must be certified by a qualified laboratory (1 test per 100 yd^3 of soil) and have the following attributes:

    - Texture class: loamy sand. Having no less than 80% sand and no greater than 10% clay considering only the mineral fraction of the soil.
    - pH range: 5.2 - 8.0
    - Soluble Salts: 500 ppm maximum.
    - Decomposed organic matter: 3-5% by weight [Note: this translates to 8-20% organic matter by volume. See note on "Creating a Suitable Soil Media" below.]
    - Phosphorus: phosphorus of the planting media should fall between 15 and 60 mg/kg (ppm) as determined by the Mehlich III test. For sites in watersheds with a phosphorus TMDL or sites with high phosphorus loads, the phosphorus content of the planting media should fall between 10 and 30 mg/kg as determined by the Mehlich III test.
    - Sand added shall be clean and meet AASHTO M-6 or ASTM C-33 with a grain size of 0.02-0.04" inches.

Creating Suitable Soil Media - To meet the above soil media criteria, the following mix (by volume) is recommended as a starting point:

Sand: 7.5 parts clean sand (i.e., ASTM C-33 or equivalent, < 1% passing No. 200 sieve)

Native Soil: 1.5 part (loam, silt loam or clay loam texture)

Decomposed Organic Matter: 1 part (leaf compost, pine bark fines, mulch fines, etc.)

Based on testing, experience and native soil characteristics the sand, soil or organic matter content can be adjusted to achieve the desired mix. The soil mix supplier should pre-test the sand, native soil and organic matter to evaluate their phosphorus content. The soil mix supplier must present a soil test showing the planting media meets the criteria above.

5. *Filter Layer* - The filter layer is composed of a layer of sand over a layer of pea gravel and is required to prevent fines from the planting soil migrating down through to the underdrain or to the subsoil below the practice.

    - Three inches of clean medium concrete sand (ASTM c-33) over three inches of #8 or #78 stone (pea gravel).

6. *Gravel Layer and Underdrain System* - A gravel bed consisting of # 57 washed stone (excluding recycled concrete) shall be provided as drainage media and bedding material for underdrain pipes and as the water storage reservoir in whole or as a part (with 6 inches of soil media) for the purpose of denitrification. The gravel layer shall generally be 10-12" thick with a minimum of 3-in. of gravel provided above and below underdrain pipes. The thickness of the gravel layer (or sump) below the drain may be increased to promote infiltration into the underlying soil.

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Underdrains shall be a perforated pipe capable of withstanding the expected load above and exceeding the drainage capacity of the planting soil layer. The following requirements apply to underdrains:

- The underdrain system shall be placed level or on a positive slope.
- Underdrain pipes shall be a minimum 4-in. diameter perforated PVC pipe with the holes oriented downward.
- Underdrains are placed within a layer of # 57 washed gravel, having a minimum of 3-in. of gravel above and 3-in. below the pipe.
- Underdrains shall be placed depending upon the purpose of the reservoir created:
    - o For promoting infiltration into appropriate in-situ soils, underdrains are outletted at a higher elevation from the gravel layer either by raising the underdrained or utilizing an upturned elbow. Provide suitable gravel thickness to create an internal water storage (IWS) layer (temporary storage sump) capable of storing the entire water quality volume. See the figure below.
    - o For treating nitrogen, an upturned elbow is also used to raise the outlet of the underdrain and thus create an anoxic zone for denitrification. Ponding water into the bottom six inches of soil media is necessary for this to occur and will increase nitrogen removal by the practice. Gravel depth is determined by the volume of water targeted for anaerobic treatment. See the figure below.
- Underdrain pipes shall end with an elbow or a capped tee with a vertical pipe providing observation and/or cleanout at the elevated end of the pipe. Observation/cleanout pipes shall consist of a minimum 4 inch diameter vertical non-perforated PVC pipe extending to the surface of the practice and sealed with a removable watertight cap.
- Underdrains shall drain to an existing drainage system or other suitable stable outlet having positive drainage.

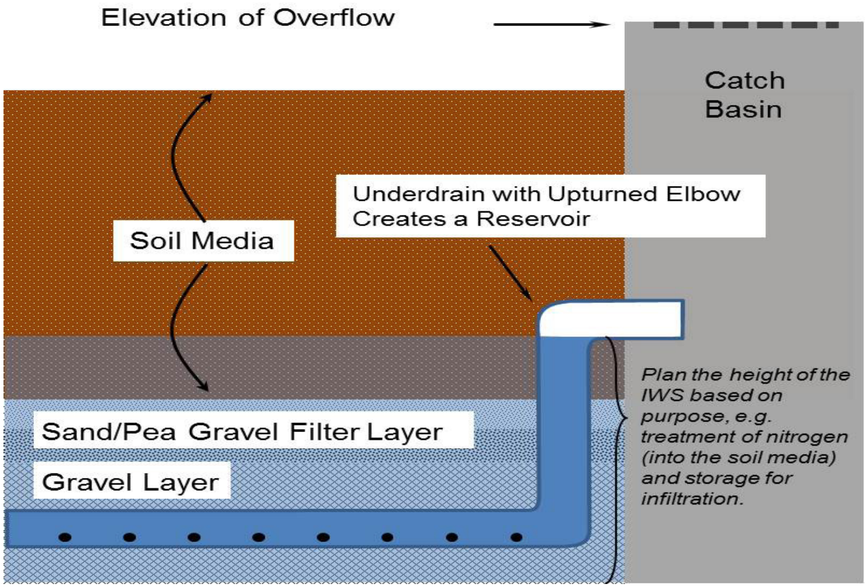

Figure 2.10.5 Bioretention with an underdrain and reservoir for increased infiltration. The reservoir or internal water storage (IWS) is created by using an upturned elbow. An orifice can also be added to modify the drain time through the filter media.

7. *Overflow, Tailwater and Routing* - Bioretention facilities shall have a means of discharging runoff that exceeds the capacity of the practice (in a non-erosive manner). This will be a drop inlet or weir set at the maximum ponding elevation of the treatment volume (WQv). In contrast, off-line facilities collect runoff until the ponding area fills, then are bypassed by additional storm flows. As with all stormwater practices, the designer must evaluate and account for potential tailwater conditions in the storm sewer or receiving stream.

   The bioretention practice is going to perform as intended, and most predictably, when the underdrain outlet is free draining (i.e., not subject to tailwater conditions where the underdrain outlet would be fully or partially submerged). However, bioretention practices are part of the larger stormwater management or drainage network of the development site. Having the outflow rate of the bioretention practice reduced due to increased head at the outlet is likely to have minimal negative impacts. However, any scenario in which water from the larger drainage network (such as a detention basin, a receiving stream or lake, or a storm sewer) is backed into the bioretention cell by having a higher head at the outlet than is present in the bioretention practice should be avoided. From a practical standpoint, the engineer might use the following rules of thumb when checking for back flow into the bioretention practice from tailwater/surcharge in the drainage network:

   - the bioretention practice should be designed such that the tailwater elevation does not exceed the elevation of the internal water storage zone for the 1-year, 24-hour event;
   - the bioretention practice should be designed such that the tailwater elevation does not enter the top 12 inches of planting media for the 10-year, 24-hour event.

8. *Planting Materials* – Species planted in bioretention practices should be adapted to the region, pollution tolerant, and able to survive the variable moisture conditions. Most plants should be facultative (found equally in wetland or upland conditions) though some species found in either environment may be acceptable. Native and non-invasive plants shall be used. Turf is an option if it can withstand the duration of ponding.

   Select plants that in a mature condition will be appropriate to the depth of soil and the underdrain system. For examples, trees may be selected if the planting soil will be at least 4 inches deeper than the root ball of the selected trees. Trees and large shrubs will require staking to prevent being dislodged by wind. It is recommended that a qualified landscape architect, horticulturalist, or native plant dealer be consulted during the design of the planting plan.

Design Checklist

1. Compute water quality volume (WQv). _____

WQv = C * P * A / 12, where:

WQv= water quality volume in acre-feet

C = runoff coefficient (Use formula below or coefficient from Ohio EPA NPDES permit)

Planned Site Imperviousness (i) _____ (e.g. for 80% imperviousness use 0.8)

$C = 0.858i^3 - 0.78i^2 + 0.774i + 0.04$

C = _____

P = 0.75 inch precipitation depth

A = area draining into the BMP in acres _____

2. Compute critical storm detention requirements. Substitute local requirements if they differ from the critical storm method.

Design Storm	Peak Discharge Rate (cfs)	24-hour Runoff Volume (show units)		Percent Increase	Design Discharge (cfs)
		Pre-Development	Post- Development		
1-year					
2-year					
5-year					
10-year					
25-year					
50-year					
100-year					

Critical Storm _______ Design Discharge ________

3. Determine whether bioretention is an appropriate stormwater practice for the area.

- Limited drainage area (generally <2 acres)
- Outlet for an underdrain and or soils of sufficient hydraulic conductivity to fully drain the practice in a period of 12 to 48 hours.
- Sites with sufficient fall between inflow elevation to outfall (generally exceeding 3.5 feet). Shallower facilities are expected to reduce the effectiveness of treatment.
- Consider whether peak discharge requirements will be managed at the bioretention practice and whether these stormwater detention needs make bioretention infeasible.
- No continuous groundwater flow or seasonal high groundwater table above the practice bottom, or perimeter drains are sufficient to lower seasonal high groundwater table.
- Low potential for groundwater pollution (high pollution loads or high groundwater table). A liner may be used in areas with high pollutant loads or high groundwater table.
- Can meet setback requirements found in Table 2.10.1

4. Additional local conditions or criteria affecting design:

5. Determine the size of the bioretention filter bed area. The surface area of the filter bed is determined based upon site imperviousness and the ponded area needed to capture the water quality volume (WQv). For sites where impervious areas are greater or equal to 25% of the total drainage area, then the minimum filter bed area is equal to 5% of the contributing impervious area. For sites where impervious areas are less than 25%, then the filter bed area shall be at least equal to the WQv divided by the maximum ponding depth (≤ one foot). The WQv divided by the design depth provides the minimum surface area of the filter bed. Actual ponding of the WQv will be shallower as side slopes allow ponding over a larger bowlvolume.

Where the drainage area is ≥ 25% impervious area, the filter bed area shall be at least 5% of the contributing impervious area.

Where $A_{da} \geq$ 25% impervious, then $A_{filter\ bed} = 0.05 * A_{imp}$

Where the drainage area is < 25% impervious area, the filter bed area shall be the WQv divided by the maximum ponding depth (1 foot).

Where A_{da} = < 25% impervious then $A_{filter\ bed}$ = WQv/1 ft max. depth or other desired depth

6. Check to see that drain time is within the required parameters (12-48 hours):

7. Determine practice dimensions and design depths/elevations. The landscaped ponded area shall be a minimum of 10 feet wide with the length generally exceeding 2:1 (length:width).

- Width _____ • Length _____ • Ponding depth ______
- Overflow catch basin or weir
- Mulch depth 3”
- Soil media depth (generally 2 – 4 feet deep)
- Sand layer _______ • Pea gravel _______
- Gravel layer _____ • Cover over underdrain _____ • Diameter of underdrain ____
  - Underdrain invert elevation (at catch basin) ______
  - Depth of gravel layer beneath underdrain ______
- Liner (only for potential groundwater pollution)

8. Design stable conveyances into the practice. Off-line practices will need to have flow diverted.

- Flow diversion structure.
- Curb cuts or openings, rock channel protection.
- Slotted curb diversion in which flows exceeding WQv bypass the bioretention practice and are routed to other required stormwater detention practices.
- Overflow catch basin inlet.
- Other.

9. Pretreatment. Depending upon whether flow is concentrated or sheet flow, specify the devices used to dissipate runoff energy and to capture excessive sediment or other pollutants/trash before water is ponded. The plan and cross-section should show these devices and their dimensions.

- Stone trench/gravel verge.
- Grass filter strip.
- Grass channel.
- Forebay.
- Other.

10. Gravel layer and underdrain system

- No underdrain. On-site soils are suitable for infiltration. Tested rate of infiltration or hydraulic conductivity at the excavated depth ____.
- Upturned elbow or underdrain above gravel for internal water storage volume.

  Available water storage volume = volume of gravel x porosity (assumed 0.35 for #57 gravel)
- Standard gravel layer and underdrain system. Minimum 3” of gravel above and below the underdrain.

11. Emergency overflow. Conveys larger flows by or safely through the practice without erosion.

12. Landscaping plan. Show locations of plantings on a plan view and the associated quantities of suitable native plants.

Construction Issues

1. **Timing of Construction -** Construction of bioretention practices shall take place after land grading is complete and the contributing drainage area has been stabilized. Construction may take place if the entire contributing area can be effectively diverted until construction is complete and fully-vegetated cover protects all soil areas. Construction shall not occur during periods of precipitation since clogging of soils, bedding, filter or planting media may occur.
2. **Excavation, Soils and Liners -** Excavate the trench to plan dimensions being careful to protect in-situ soils by avoiding compaction of the trench with equipment or foot traffic. An initial 2-3" layer of uniform construction sand will help to avoid this impact. Some smearing of soils at the final grade will occur if a bucket without teeth is used. If this smearing occurs, it shall be remediated by fracturing a few inches deep with an appropriate tool. Bioretention lined with plastic shall use a minimum 30-mil liner and take measures to avoid puncture of the liner.
3. **Planting Soils -** Soils must be tested by a certified laboratory to insure they meet required specifications. Documentation of certification/testing shall be available onsite to site inspectors. The planting soil shall be placed in 12 inch lifts and lightly settled by gentle soaking with water (to promote settling). Planting soil should be placed to a depth approximately 5% higher than finish grade to allow for settling.
4. **Mulch -** Place mulch once sufficient settling of the planting soil has occurred in order to avoid excess compaction. Bioretention vegetated with turf shall be sodded or planted and provided with straw mulch cover as soon as final grade is reached.
5. **Vegetation -** Grassed filter strips should be sodded rather than seeded. Trees and tall shrubs subject to being thrown by wind must be staked to remain upright.

Maintenance

Proper functioning of a bioretention practice is dependent on the planting soil continuing to drain and plant survival. Most maintenance activities influence these goals. Maintaining the pretreatment area and minimizing erosion will extend the function of the planting soil. Bioretention areas are a landscaped feature of a site and regular attention to the plants is necessary. Take measures to insure winter snow plowing does not pile snow on trees or shrubs in the landscaped ponding area.

Over time (3-10 years); fine sediments may accumulate in the top few inches of planting soil. This is expected and can be corrected by replacing a portion of the planting soil or replacing all the planting soil and the filter layer until better permeability is achieved.

Activity	Schedule
Water Plants	As necessary during first growing season
Prune and weed plants for appearance	As needed
Inspect & replace poorly suited or diseased plants	As needed
Check for erosion or deposition in pretreatment and bioretention areas; Clean out and repair damaged areas	Semi-annually
Inspect facility for salt damages	Monthly
Remove litter and debris	Monthly
Add and/or replace mulch	Annually
Test soil and adjust as necessary to maintain in 5.2- 8.0 pH range	Biannually
Check planting soil and filter layer for clogging, replacing nec. portions	2 –10 years/ As needed

Table 2.0.2 These maintenance activities are suggested as a minimum.

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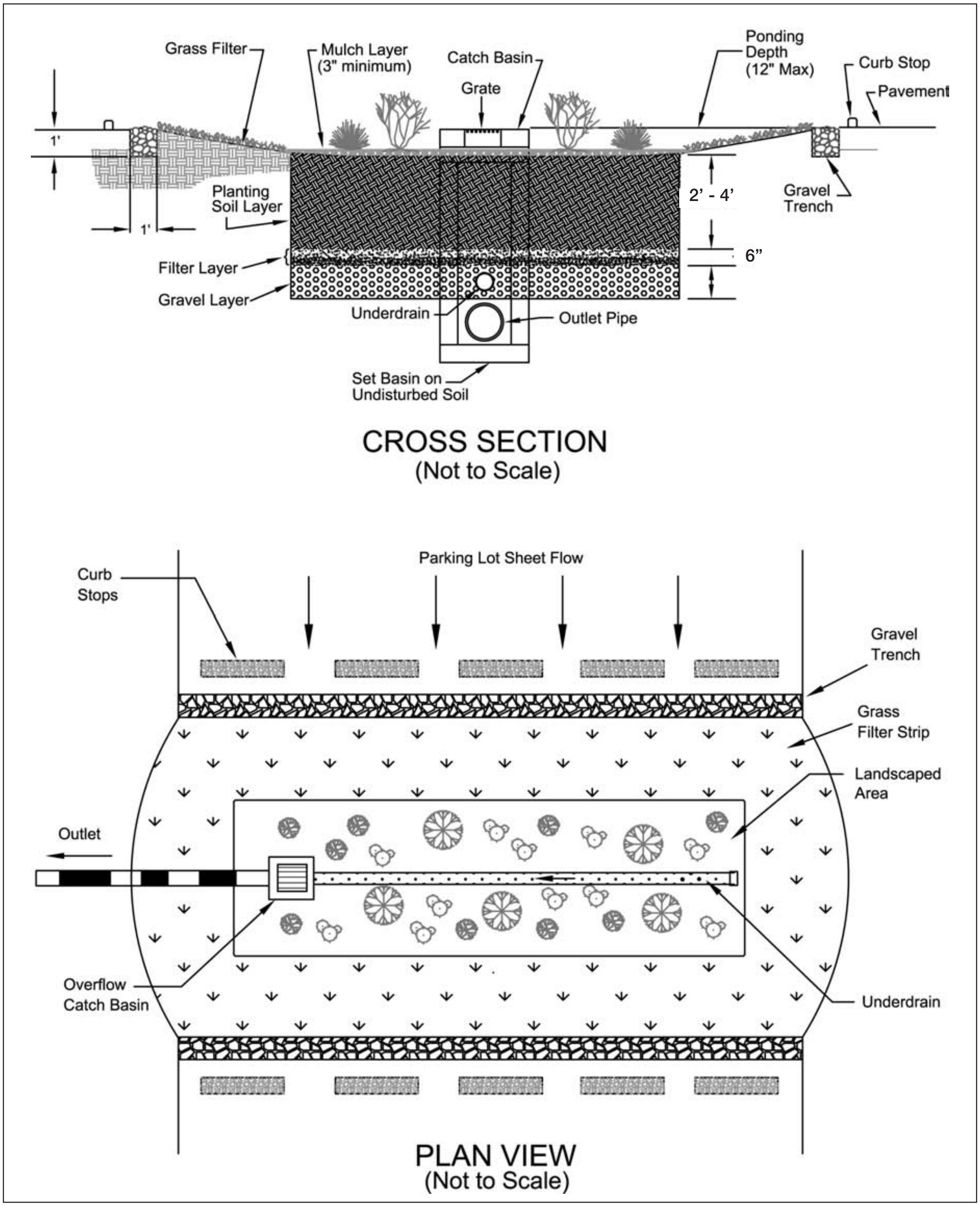
Specifications
for

Bioretention Areas



2.11 Pervious Pavement

Figure 2.11.1 Porous Concrete at Indian Run Park in Dublin, Ohio.

Description

Pervious pavement systems consist of a permeable pavement surface layer and one or more underlying aggregate layers designed to temporarily store stormwater. Most pervious pavement systems are designed to infiltrate stormwater into the underlying soil, reducing the volume of runoff leaving the site. Where the underlying soil will not permit full infiltration of runoff, outlets and/or underdrains are used to remove excess runoff and discharge it to an appropriate outlet[1].

Research has shown that pervious pavement can be a very effective component of a stormwater management system, mitigating many of the water quality and quantity impacts associated with runoff from impervious pavements. Pervious pavements reduce suspended solids, metals and petroleum hydrocarbons in runoff, and significantly reduce runoff volumes and peak flow rates.

Pervious pavements perform water quality functions by filtering suspended solids and hosting microbial organisms known to biodegrade pollutants. Depending upon the construction of the pavement, soil infiltration, transpiration (vegetated open celled grids), and increased soil adsorption may all contribute to reducing offsite runoff and associated adverse impacts. Additionally pervious pavements provide some moderating of water temperatures compared to traditional pavements.

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[1] Note that pervious pavements and their drainage strucures must be considered as part of the larger site and stormwater system when meeting local peak discharge requirements.

There are a variety of pervious pavement surfaces available in the commercial marketplace, including pervious concrete, porous asphalt, permeable interlocking concrete pavers, clay pavers, concrete grid pavers, and plastic grid pavers. While the design specifics vary for each product, pervious pavements have the same general structural components detailed in this practice.

There are several examples of pervious pavement installations that are still functioning well after 15 or 20 years (see e.g., Adams, 2003). If designed, constructed, and maintained according to the following guidelines, pervious pavements should have life spans comparable to traditional pavements.

Condition where practice applies and settings to avoid

Pervious pavement can be used in most settings where traditional pavements are used. It is especially well suited to parking lots, sidewalks, playgrounds and plazas. Pervious pavement can be used in driveways if the homeowner is aware of the stormwater management function and subsequent maintenance requirements of the pavement.

Areas of Heavy Traffic - Pervious pavement typically is not suitable for areas that experience high traffic loads or high vehicle weight traffic such as busy roadways or travel lanes in heavily used parking lots. However, pervious pavement is suited for parking lanes on roadways and in parking lots. When it is necessary to use traditional pavement for traffic lanes, runoff can be directed as sheet flow to pervious pavement areas.

Areas of Potential Groundwater Contamination – Pervious pavements should not be used in heavy industrial developments, areas with chemical storage, fueling stations or areas with significant risk of spills that might contaminate groundwater. Pervious pavements should not be used for sites located over contaminated soils without placing an impermeable liner between the pavement structure and soils.

Other Sites to Avoid

Unstable slope areas – pervious pavement should not be used in slip prone areas where concentrated infiltration may exacerbate slope instability

Steep slopes - areas with slopes steeper than 10 percent present design challenges that are difficult to overcome

Sediment sources - sites with sources of sediment (from vehicles, bare soils, spoil piles, sand storage, etc.) should be separated from pervious pavements with filter strips or other sediment removal practices.

Anticipated Performance

Pervious pavements are projected to perform well in reducing the annual load of suspended solids, metals and hydrocarbons in runoff, and significantly reduce runoff volumes and peak flow rates. Pervious pavements filter solids in the pavement layer and may completely remove them in the matrix of the sub-pavement layers depending upon the nature of the subgrade and designed drainage of the system. Though this varies with design; filtering, detention, adsorption processes all contribute to some degree in reducing pollutants in contributed flows and offsite runoff. Pervious pavements also buffer water temperatures. Increased infiltration into the subgrade soils contributes to the highest removal of pollutants from site runoff, although some pollutants such as soluble nutrients, chlorides or sodium raise concern for groundwater pollution.

Table 2.11.1 Anticipated performance of pervious pavements.

Category	Subcategory	Full WQv Infiltration	Partial Infiltration	No Infiltration
Runoff Water Quality	Suspended Solids*	>90%	80-90%	80%
	Phosphorus*	Medium	Medium	Medium
	Nitrogen/Nitrates*	Low	Low	Low
	Heavy Metals	High	High	High
	Bacteria	Not clear at this time. Other practices using media filtration do treat bacteria. Using a sand layer may enhance this.		
	Thermal	Pervious pavements with a reservoir storing the WQv or most of that volume are expected to provide good thermal attenuation, but this will vary based on the particular design (i.e. material, the storage volume, outlet configuration etc.)		
	Oil and Grease	High	High	High
	Poly Aromatic Hydrocarbon	Reduced compared to runoff from traditional ashalt		
	Chlorides & Sodium**	Not controlled.		
Runoff Volume Reduction		85-90%	%WQv-captured * 85%	
Recharge		High	Medium	Not at all.
Runoff Time of Concentration		Improved lag time, but varies with design.		
Peak Flow Attenuation		Significant peak flow attenuation, but varies with design.		

*** There would be an expected improvement with the addition of sand layers and/or vegetative systems.**
**** May be a significant groundwater concern depending upon winter application practices.**

Planning Considerations

Preliminary Site Evaluation - The overall site should be evaluated for potential pervious pavement/infiltration areas early in the design process, as effective pervious pavement design requires consideration of soils, grading, outlets, groundwater, and other site infrastructure.

Size of Project – Small projects such as walkways, or driveways with limited traffic may not have associated requirements for treating or storing stormwater. Therefore small scale projects may not need the depth of stone reservoir described in this practice. There are still numerous benefits to applying pervious pavements even with less stone subbase than this practice describes. For small scale practices where local or state regulations do not require treating the water quality volume, manufacturer recommendations should be consulted.

Soils - Pervious pavements may be used on any soil type, although soil conditions determine whether an underdrain is needed. Less permeable soils (most Hydrologic Soil Group C or D soils, some HSG B soils) usually require an underdrain, whereas soils with higher permeability (HSG A, and some HSG B soils) often do not. Estimates of soil permeability are available based on soil type, but designers should verify underlying soil permeability rates before proceeding with site and stormwater system design (see discussion below). Special measures may be needed when pervious pavement will overlay high shrink-swell soils in order to limit moisture or to stabilize these soils.

Subgrade Compaction - One of the major benefits of pervious pavement is runoff volume reduction from infiltration into underlying soils. Subgrade compaction severely limits the infiltration capacity of the underlying soil. For pervious pavement systems with an infiltration component, the subgrade should not be compacted according to traditional pavements. Structural integrity of pervious pavements is ensured through several mechanisms other than subgrade compaction (see discussion below). If the structural design of the pavement section requires subgrade compaction to achieve the required design strength or to minimize the possibility of pavement failure, then soil permeability should be measured based on the required subgrade design.

Separation Distances - Pervious pavements should not be located or used where their installation would: create a significant risk for basement seepage or flooding; interfere with public or private wells, septic or sewage disposal systems; or cause problematic groundwater issues. These issues should be evaluated and potential problems avoided by the designer.

Horizontal Separation Distances

- separation from buildings - pervious pavement systems should be installed at least 10' away from up-gradient building foundations and 100' from down-gradient foundations, unless an acceptable barrier is provided or the building foundation can adequately handle additional water;
- sanitary sewers - care should be taken to minimize infiltration of runoff into sanitary sewers and building laterals;
- septic systems - pervious pavement should be installed no closer than 100' from a septic system or leach bed; when this or any infiltration BMP is located up-gradient, appropriate perimeter drainage should be used to prevent flows from reaching the septic system;
- drinking water wells - pervious pavement should not be located within 25' of a private drinking water well or within the sanitary isolation radius of a public drinking water supply well. (The isolation radius ranges from 50 to 300 feet, and is based on the well's average daily pumpage; see the chart below.) If it is necessary to pave within the sanitary isolation radius, use of an impermeable bottom liner and an underdrain discharging beyond the isolation radius is recommended, especially if the pavement will support motorized vehicles.

<table>
<tr><th>Feature protected by setback</th><th colspan="2">Setback Distance (feet)</th></tr>
<tr><td>Building Foundations or basements</td><td colspan="2">At least 10’ downgradient or 100’ upgradient of foundations</td></tr>
<tr><td>Septic Systems</td><td colspan="2">At least 100’ separation</td></tr>
<tr><td>Private Well</td><td colspan="2">At least 25’ (See OAC 3701-28-10)</td></tr>
<tr><td>Public Well</td><td colspan="2">50 – 300 ft minimum depending upon Average Daily Water Demand (based upon sanitary isolation distance found in OAC 3745-9-04)</td></tr>
<tr><td></td><td>Average Daily Pumpage (Q) (gal/day)</td><td>Sanitary Isolation Radius (feet)</td></tr>
<tr><td></td><td>0-2500</td><td>50</td></tr>
<tr><td></td><td>2501-10,000</td><td>Square root of Q</td></tr>
<tr><td></td><td>10,001 – 50,000</td><td>50 + Q/200</td></tr>
<tr><td></td><td>Over 50,000</td><td>300</td></tr>
<tr><td>Source Water Protection Area</td><td colspan="2">See Ohio EPA Source Water Protection Area. Each area may have its own specific requirements.</td></tr>
</table>

Table 2.11.2 Horizontal separation distances.

Vertical Separation Distances - Give special consideration to the following situations:

- Infiltrating pervious pavement systems with recharge layers located over soils with ground water tables that reach within 2 feet of the subgrade infiltration bed.
- Infiltrating pervious pavement systems with recharge layers located over impermeable bedrock within 2 feet of the subgrade infiltration bed.

These situations are likely to result in mounding of stormwater to the level of the infiltration bed for extended periods, especially during the spring. These systems may still help meet watershed management goals - for example, baseflow maintenance and temperature moderation during summer low-flow periods. However, a more thorough mapping and modeling of surface and subsurface hydrology is necessary to prevent unintended consequences. The pavement system configuration and drainage system should be modified to achieve stormwater management goals while minimizing unintended consequences.

Soil surveys can be used as rough guidance during initial planning and site layout to identify areas where shallow water tables or shallow bedrock may be a concern. However, in areas where these concerns are known, a professional geotechnical engineer and/or professional soil scientist should be contracted to take core samples to a depth of 6 ft below the proposed subgrade depth and report: depth to bedrock, any layering of the subgrade representing significant changes in texture or structure, the particle size distribution of the subgrade soil, the particle size distribution of any deeper layers, and depth to water table (ideally the water table will be checked between late March to early May when the water table is highest).

Groundwater Concerns – Pervious pavement, as with any infiltrating practice, requires the designer to consider the potential for adversely impacting groundwater. Elevated pollution sources or areas with high risk of toxic spills should not be directed to pervious pavement without appropriate pretreatment.. Examples include maintenance yards where salt storage or distribution takes place, airport areas where deicing occurs, fueling stations and composting facilities.

Development sites that include both relatively clean runoff (e.g., rooftop runoff) and dirtier runoff (e.g., from a maintenance yard or material storage area) should consider separate stormwater management systems appropriate to the specific runoff source. In such a scenario, rooftop runoff or runoff from office parking could be safely directed to an infiltrating BMP without pretreatment, whereas runoff from a maintenance yard should be treated in a separate facility designed to minimize potential negative impacts to groundwater. Such areas should be separated with physical barriers (fence, curb, etc.) to minimize tracking of pollutants into “clean” runoff areas.

Karst Terrain - Active karst regions are found in parts of Ohio (Hull, 1999; ODNR, 1999), and complicate development and stormwater system design. The use of permeable pavement or other infiltration BMPs in karst regions may promote the formation of sinkholes. In karst regions, a detailed geotechnical survey should be conducted to the satisfaction of the local approval authority. Permeable pavement designs in karst should exceed the minimum vertical separations recommended above and consider the use of an impermeable bottom liner and an underdrain. Additionally they should not receive runoff from other (external) impervious areas.

Freeze-Thaw - Water entrapped in the pavement course during freezing and thawing cycles will result in cracking, scaling and/or deterioration of the pavement (NRMCA, 2004). Therefore, the pavement structure and drainage system should be designed to ensure free drainage of the pavement surface and to prevent ponding into the pavement structure.

Frost Heave - Frost heave occurs when underground water accumulates in ice formations or ice "lenses", expanding and pushing the pavement structure upward resulting in uneven pavement (Leming et al., 2007) . Unlike their traditional counterparts, pervious pavements are specifically designed to introduce water below the pavement surface. Therefore, the pavement structure and drainage system should be appropriate for the subgrade soils (Leming et al., 2007; UNH, 2009).

One recommendation is to increase pavement thickness to accommodate the extra load carried by the surface course during spring thaw (Leming et al., 2007). This is reflected in some guidance for specific pavement surfaces (see e.g., ORMCA, 2009).

Frost heave is a serious concern for finer textured soils. Sands and coarser aggregates are much less susceptible to frost heave. One straightforward approach to minimize frost heave is to provide a base aggregate course thickness to minimize the formation of ice in the underlying subgrade. The University of New Hampshire Stormwater Center (UNH, 2009) recommends that the thickness of the pervious pavement structure (i.e., pavement plus sub-base thickness) be a minimum of 0.65 x design frost depth for the location. Local maximum frost penetration depth oftentimes can be provided by the local building authority. In the absence of locally available information, the following table can be used.

Located North of Latitude	Max. Frost Depth (inches)	Min. Recommended Thickness (0.65 x Max Frost Depth in inches)
38.3	24	16
38.7	26	17
39.0	28	18
39.3	30	20
39.7	32	21
40.0	34	22
40.3	36	24
40.7	38	25
41.0	40	26
41.3	42	27
41.7	44	29
42.0	46	30

Table 2.11.3 Frost depth and minimum recommended pavement system (pavement + sub-base) thickness by latitude (interpolated from Fig. 13 in Floyd, 1978; http://www.ngs.noaa.gov/PUBS_LIB/GeodeticBMs/#figure13)

Grading – The bottom of the infiltration bed should be level or nearly level. Sloping bed bottoms will lead to poor distribution and reduced infiltration. It is recommended pervious pavement slopes be less than 5% to optimize the ponding depth under the pavement surface. If pavement slopes cannot be reduced, infiltration beds may be placed along a slope by benching or terracing the subsurface infiltration beds to promote more uniform infiltration.

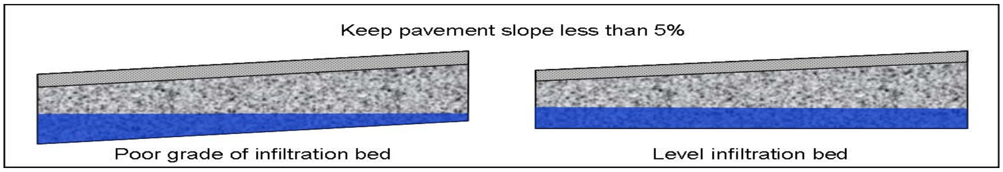

Figure 2.11.2 A level infiltration bed and limited pavement slope will maximize stormwater treatment and storage.

Figure 2.11.3 Terrace sloping areas to limit the pavement slope (photo credit: Brandon Andreson).

Runoff from External Areas - Drainage from traffic lanes or other impervious surfaces (e.g., sidewalks) can be directed to pervious pavement surface as sheet flow. The impervious area contributing runoff should be less than twice the area of pervious pavement receiving the runoff. Roof drains and leaders may connect directly to the subbase reservoir, but should be provided a means of trapping sediment prior to the subbase reservoir. Runoff from pervious areas (lawns or landscaping) or other sediment sources should not be directed onto pervious pavement.

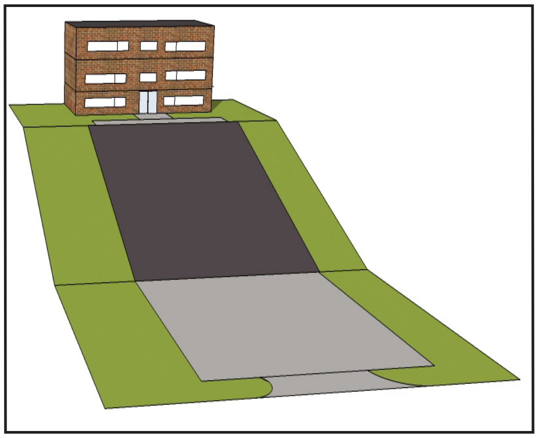

Figure 2.11.4 Calculate "run-on" from impervious areas, making sure it does not exceed twice the pervious pavement (infiltration bed) area.

Sites to Use or Consider Use of an Impermeable Liner

A liner should be used for pervious pavement systems for sites:

- all sites over contaminated (or potentially contaminated) soils
- sites with high pollution potential source areas
- sites with slip prone soils
- sites in source water protection areas

A liner may be considered for pervious pavement systems for sites with:

- subgrade soil infiltration rates less than 0.02 in/hr
- depth to bedrock or seasonal high water table less than 2 ft below subgrade infiltration bed
- karst geology

If the site requires a liner, the designer should consider whether a different BMP (e.g., bioretention, constructed wetland, wet swale) may be more appropriate.

Stormwater Detention - Sub-pavement infiltration beds are typically sized to manage the water quality volume and to convey stormwater without allowing ponding into the pavement itself. These sub-pavement aggregate “reservoirs” also may be designed to mitigate the peak discharge of less-frequent, more intense storms (such as the critical storm or 100-yr event). Discharge control typically is provided by an outlet control structure. The specific design of these structures may vary, depending on factors such as rate and storage requirements.

Construction Sequencing - The pervious pavement system is most susceptible to failure during construction, and therefore it is important that the construction be undertaken in such a way as to prevent:

- Compaction of underlying soil
- Clogging the subgrade soil or geotextile with sediment and fines
- Tracking of sediment onto pavement
- Drainage of sediment laden waters onto pervious surface or into aggregate base

Pervious pavement will be prone to failure if it is not protected from sources of sediment. For this reason, insure that nearby areas or areas contributing runoff are completely stabilized prior to construction of the pervious pavement system. Sediment on the subgrade infiltration bed will greatly reduce the infiltration capacity of the final practice. Therefore special measures are needed to avoid this situation. Quick succession from excavation to placement of materials during dry weather is ideal for protecting the practice’s long term functioning. Planned pavement areas that will be exposed for a period of time while other site construction occurs may be excavated within twelve (12) inches, but no closer than six (6) inches, of the final subgrade elevation. Following construction and site stabilization, sediment should be removed and final grades established when materials can be placed in a timely manner.

Maintenance - Pervious pavements have different maintenance requirements than traditional pavements, discussed in some detail below. The use of pervious pavement must be carefully considered in all areas where the pavement potentially could be seal coated or paved over due to lack of awareness by a new owner, such as individual home driveways. In those situations, a system that is not easily altered by the property owner may be more appropriate. Educational signage at pervious pavement installations may promote its prolonged use. Maintenance is critical to the long-term performance of pervious pavement, especially those activities that prevent clogging of the surface pavement and subsequent clogging of the subsurface layers by accumulated sediments and organic matter. The most important activities to protect the long term function of pervious pavement include periodic vacuum sweeping to remove accumulated sediments and organic materials, monitoring of the drainage functions of the pavement and maintenance/cleanup of landscaped areas contiguous to the parking area (CSN, 2010).

Cost Considerations - The primary added cost of a pervious pavement/infiltration system lies in the underlying aggregate bed, which is generally deeper than a conventional pavement subbase. However, this additional cost may be offset by a significant reduction in the number of inlets and pipes. Pervious pavement systems may eliminate or reduce the need (and associated costs, space, etc.) for surface detention basins. When all these factors are considered, pervious pavement with infiltration is increasingly competitive with traditional pavement for the pavement and associated stormwater management costs.

Types of Pervious Pavement

Porous Asphalt - Porous asphalt is very similar to standard bituminous asphalt except the fines have been removed to maintain interconnected void space. Research has led to improvements in porous asphalt through the use of additives and higher-grade binders. Porous asphalt is similar in appearance to standard asphalt and is suitable for use in any climate where standard asphalt is appropriate. Guidance specific to the design, installation and maintenance of porous asphalt is available from the National Asphalt Pavement Association (NAPA, 2008) and the University of New Hampshire Stormwater Center (UNHSC, 2009).

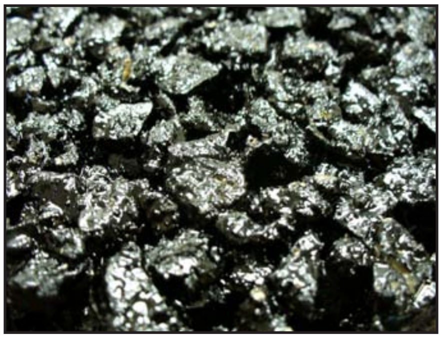

Figure 2.11.5 Porous Asphalt

Pervious Concrete - Pervious concrete is produced by reducing the fines in the mix to maintain interconnected void space for drainage. Pervious concrete has a coarser appearance than its conventional counterpart but may be colored similar to traditional decorative concrete. In northern climates such as Ohio, pervious concrete should always be underlain by a stone subbase designed for proper drainage and stormwater management, and should generally not be placed directly on a soil subbase. Special care must be taken during the placement of the pervious concrete to avoid overworking the surface and creating an impervious pavement. Guidance on the design, installation and maintenance of pervious concrete is available from the Ohio Ready Mix Concrete Association (ORMCA, 2009). ORMCA also offers installer training and certification for pervious concrete.

Figure 2.11.6 Pervious Concrete

Block or Brick Pavement - A number of concrete or clay paver products are available, providing either a traditional brick pavement look or more complex designs and configurations. Block or brick pavements maintain drainage through gaps between the pavers filled with small, uniformly-graded gravel. The pavers are bedded on a stone or sand layer that provides uniform support and drainage. Pavers are especially well suited for plazas, patios, small parking areas, parking stalls in larger lots, and streets.

Pervious interlocking concrete pavement (PICP) are one commonly used product that consist of 3 1/8” thick concrete units or pavers with various shapes, patterns, and colors. The size and complexity of the project determines whether PICP may be placed by machine or by hand. Guidance for design, installation and maintenance of concrete pavers is available from the manufacturer and the Interlocking Concrete Pavement Institute (ICPI, 1995).

Figure 2.11.7 Pervious Interlocking Concrete Pavement

Reinforced Turf and Gravel Filled Grids - Grid-type pervious pavements consist of open-celled concrete or plastic structural units filled with small, uniformly-graded gravel or turf that allows infiltration through the pavement surface. The structural units are underlain by a stone and/or sand drainage system for stormwater management. Reinforced turf applications are excellent for fire access roads, overflow parking, occasional use parking (such as at religious facilities and athletic facilities). Reinforced turf is also an excellent application to reduce the required standard pavement width of paths and driveways that must occasionally provide for emergency vehicle access.

Figure 2.11.8 Vegetatated Grid System utilitized for fire access.

Figure 2.11.9 Vegetated Grid System with established turf grass.

Design Criteria - General/Introduction

Pervious pavements typically will be designed to address two types of design criteria:

- Minimum specifications should be met to ensure the long-term structural performance appropriate to the specific use of the pavement (pavement type, location, type of traffic, traffic load, etc.). The pavement should meet all design, construction and maintenance requirements of the local approval authority.
- Secondly, pervious pavement typically will be part of the stormwater management infrastructure of the development site. Therefore, meeting specific design criteria should allow the pervious pavement system to receive credit toward meeting water quality treatment performance requirements of the NPDES Construction General Permit (OEPA, 2008) and/or receive appropriate credit toward meeting local peak discharge requirements.

Design Criteria - Stormwater Requirements

The Ohio DNR and Ohio EPA mandate is to ensure post-construction stormwater performance over the long-term. This means the pervious pavement system must show equivalent WQ performance to the structural BMPs listed in Table 2 of the NPDES Construction General Permit (Ohio EPA, 2008), or be part of a larger stormwater system that collectively meets those requirements. Pervious pavement can be used to meet the WQv requirement for either new development or re-development.

Full infiltration of WQv - Pervious pavement, without prior OEPA approval, may be used to meet the WQv requirements of the Construction General Permit (CGP) as long as the practices designed to fully infiltrate the WQv and follows the design, construction and maintenance protocols outlined in this section.

No infiltration - If the site is not suitable for deep infiltration (e.g., lined system or compacted subgrade), pervious pavement may be considered for WQv on a case-by-case basis with prior approval from OEPA and the local MS4. This scenario will require an appropriately designed outlet control to release runoff over a 24 hour period; however, no additional sediment storage volume (=0.2*WQv) is required. The volume of runoff detained shall drain over 24 hours, releasing no more than one half the volume in the first eight hours. Until further notice, monitoring of system function/performance is likely to be required.

Partial infiltration of WQv - If the site is capable of partially infiltrating the WQv, the volume infiltrated may be subtracted from the WQv when determining detention requirements. As for the no infiltration scenario, an appropriately designed outlet will be needed to release runoff over 24 hours, releasing no more than one half the volume in the first eight hours.. This scenario requires prior approval from OEPA and the local MS4.

Redevelopment Projects - For redevelopment projects, the area of pervious pavement receives a 1:1 credit toward the 20% reduction in impervious area requirement of the CGP. All areas draining to the pervious pavement receive credit toward the impervious area reduction as long as the storage layer is designed to hold and either infiltrate (within 48 hours) or release (with a drain time of 24 hours, releasing no more than half the WQv in the first 8 hours) the water quality volume AND the pervious pavement system meets all other requirements outlined in this guidance.

Inspection and Maintenance - Pervious pavement must be inspected and cleaned regularly to maintain the hydrologic performance of the pavement system. Therefore, Ohio EPA will consider pervious pavement as meeting the requirements of the CGP only if the property owner has a maintenance agreement approved by the local MS4 that includes the minimum practices outlined under the section titled “Maintenance” below.

Water Quality Calculations -

Calculate the **total water quality volume** (WQv) using the following equation:

$$\text{WQv (ac-ft)} = C*P*A \qquad \text{(Equation 1)}$$

Where:
C = volumetric runoff coefficient
P = 0.75” rainfall
A = drainage area (acres)
For the pervious pavement surface, C = 0.89.

For other contributing drainage area, determine C according to guidance in the NPDES Construction General Permit (Ohio EPA, 2008). Either look up the C value in Table 1 of the CGP, or use the following equation:

$$C = 0.858i^3 - 0.78i^2 + 0.774i + 0.04 \qquad \text{(Equation 2)}$$

Where: i = watershed imperviousness ratio, the percent imperviousness divided by 100

If the additional contributing drainage area is entirely impervious surfaces (traditional pavements and/or roofs), i = 1 and C = 0.89.

No additional storage is required for sediment accumulation.

Converting Storage Volume to Storage Depth - The sub-pavement volume available for temporary storage of stormwater will typically be filled with aggregate (washed, uniformly-graded stone or gravel). The volume occupied by the aggregate itself is unavailable for water storage. The remaining volume of voids is available for storage of water:

$$V_T = V_S + V_V \qquad \text{(Equation 3)}$$

Where:
V_T = Total Volume
V_S = Solids Volume
V_V = Voids Volume

A more common way to communicate about the volume available for water storage is the aggregate porosity, φ, the ratio of void-space volume to the total volume:

$$\varphi_{aggregate} = V_V / V_T$$

Aggregate porosity can range from 0.30 to 0.40 (Ferguson, 2005). However, some percentage of the voids will be unavailable for additional stormwater storage because of previous wetting and entrapped air resulting in a lower usable or effective porosity. We recommend using an aggregate porosity of φaggregate = 0.30 in the following calculations[2][3].

The aggregate thickness required to meet the WQv objective can be calculated:

$$D_{agg}\text{-WQv} = \text{WQv}/(A_{reservoir} * \varphi_{aggregate})$$

Where:
D_{agg}-WQv = required aggregate thickness (L)
WQv = water quality volume (L^3)
$A_{reservoir}$ = basal area of aggregate reservoir (L^2)
$\varphi_{aggregate}$ = aggregate porosity

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[2] Note that the proosity of the pavement itself typically is substantially lower than the aggregate base; when needed for calculations, porosities for the pavement should be taken from guidance provided by the specific industry association.

[3] A number of underground storage chambers have been developed and designed to provide both sturctural support for pavements and temporary stormwater storage. Because the void space within the chambers approaches 100%, these chambers may provide a cost-effective alternative to a sub-pavement reservoir consisting entirely of aggregate. Guidance for both the chambers and the industry association for the desired pavement should be consulted to ensure sturctural performance.

Drawdown Calculation - Ideally, the water quality volume will be drained within 48 hours in preparation for the next runoff event. The approach to determine drawdown characteristics is different depending on whether the pervious pavement is an infiltrating or non-infiltrating system.

The entire area under both pervious (e.g., parking lanes or pull-in parking) and traditional pavement (e.g., traffic lanes) may be used as infiltration or storage area as long as the WQv/sub-base gravel layer is fully interconnected and the soil infiltration capacity is adequate throughout the area. A minimum of 33% of the infiltration bed should be covered with pervious pavement.

For non-infiltrating systems, the drawdown calculation should follow the procedure used for surface detention basins with the depth and head adjusted for the porosity of the aggregate. For WQv detention under pervious pavement, a 24 hour drawdown time is recommended, with no more than ½ of the water quality volume draining from the facility in the first 8 hours. The drawdown control device should have a minimum orifice diameter of 1".

For infiltrating systems, the WQv should be infiltrated into the subgrade soil within 48 hours. The design infiltration rate of the subgrade soil will be based on field measurements at the appropriate depth, and be verified during construction (see section on measurement and verification of subgrade infiltration rate). The infiltration rate shall be based on the final, after-compaction subgrade properties, if compaction is required[4].

There are a number of factors - including soil compaction, surface smearing, aggregate "masking", sedimentation, and air entrapment - that typically mean the actual infiltration rate under real-world, post-construction conditions will be substantially lower than the measured infiltration rate. To increase the likelihood of achieving design performance over the long-term, it is recommended that an infiltration rate equal to one-half the measured infiltration rate of the subgrade be used for the design:

$$f_{design} = 0.5*f_{measured}$$

Where: f_{design} = design subgrade infiltraion rate (L/T)

$f_{measured}$ = field measured subgrade infiltration rate (L/T)

The following table presents estimates of design infiltration rate that can be used for initial planning considerations until field measurements can be collected[5].

Soil Texture of Subgrade Soil	Clay Content (%)	Clay + Silt Content (%)	Preliminary f_{design} (in/hr)	Soil Texture of Subgrade Soil	Clay Content (%)	Clay + Silt Content (%)	Preliminary f_{design} (in/hr)
Sand	< 8	< 15	3.0	Sandy Clay Loam	20 - 35	<55	0.05
Loamy Sand	< 15	< 30	2.0	Clay Loam	27 - 40	54 - 80	0.02
Sandy Loam	< 20	< 60	0.9	Silty Clay Loam	27 - 40	>80	0.02
Loam[5]	7 - 27	48 - 80	0.2	Silty Clay	40 - 60	>80	0.02
Silt Loam[5]	< 27	48 - 100	0.1	Sandy Clay	35 -55	<55	<0.01
Silt[5]	<12	80 - 92	0.1	Clay	> 40	>55	<0.01

Table 2.11.4 Estimated infiltration rate based on soil texture.

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[4] If the subgrade will be compacted to meet structural design requirements of the pavement section, the design infiltration rate of the subgrade soil shall be based on measurement of the infiltration rate of the subgrade soil subjected to the compaction requirements.

[5] For silt, silt loam and loam subgrade textures, check for the presence of a fragipan, which can severely limit permeability.

For infiltrating systems, the drawdown calculation shall be determined using the following equation. The infiltration area A_{inf} shall be the bottom area of the infiltration bed.

$$T_d = WQv / (f)(A_{inf})(\varphi_{aggregate})$$

Where

T_d = drawdown time (T)
WQv = water quality volume (L^3)
f = infiltration rate of subgrade soil (L/T)
A_{inf} = area of infiltration bed (L^2)
$\varphi_{aggregate}$ = porosity of aggregate base

WQv Sample Problem

A site in Columbus proposes to install 1 acre of pervious pavement that will also receive sheet flow from 2 acres of traditional asphalt. The subgrade infiltration area is equal to the area of the pervious pavement. The measured subsurface infiltration rate (fmeasured) of the native soil is 0.5 in/hr. The aggregate base is composed of No. 57 aggregate. Calculate the WQv, the depth of the WQv, the porosity adjusted WQv depth, and the time necessary for the WQv to drain into the native soil.

Calculate the WQv:

$WQv = C*P*A$
i = 100% impervious = 1.0
$C = 0.89$
$P = 0.75$ inches
$A = 3$ acres
$WQv = (0.89)(0.75 \text{ in})(3 \text{ ac}) = 2.0 \text{ ac-in} = 0.17 \text{ ac-ft} = 7300 \text{ ft}^3$

Calculate the WQv "depth":

$DWQv = WQv/A_{inf} = 2.0 \text{ ac-in}/1.0 \text{ ac} = 2.0 \text{ inches}$

Calculate the porosity adjusted WQv depth:

$\varphi_{aggregate} = 0.30$
$D_{agg}\text{-}WQv = WQv /(A_{inf})(\varphi_{aggregate}) = DWQv /(\varphi_{aggregate}) = 2.0 \text{ in}/0.30 = 6.7 \text{ inches}$

Calculate the WQv drain time:

$f_{design} = 0.5\ f_{measured} = 0.5\ (0.5 \text{ in/hr}) = 0.25 \text{ in/hr}$
$T_d = WQv / (A_{inf})(f_{design}) = 2.0 \text{ ac-in}/(1.0 \text{ ac} * 0.25 \text{ in/hr}) = 8 \text{ hr}$
$T_d = 8 \text{ hr} < 48 \text{ hr}$

Water Quantity (incl. Peak Discharge) Credits - The peak rate of runoff from a site is radically altered by development. The addition of impervious surfaces, the hardening of pervious areas, and the improved hydraulic efficiency of the drainage network all contribute to greatly increased flow peaks, as well as extended periods of elevated discharge. Pervious pavements have been shown to considerably reduce flow peaks, when compared with traditional pavements, through several mechanisms including subgrade infiltration (also called exfiltration), temporary storage and increased flow path resistance.

Pervious pavement can be encouraged by appropriately crediting the stormwater management benefits provided. The ways that pervious pavement potentially can receive credit include:

- infiltration or extended detention of the WQv (described above)
- stormwater utility credit or fee reduction
- critical storm adjustment
- peak discharge attenuation

The ways that pervious pavement may be used to fulfill the WQv requirement are discussed in the previous section. The other three quantity "credits" are discussed here.

Stormwater Utility Credit - [Note: All credits are at the discretion of the local stormwater management authority.] All contributing drainage area for which the pervious pavement system fully infiltrates the WQv should receive full credit for runoff volume reduction and water quality purposes, and partial to full credit for peak flow reduction. Pervious pavement systems with partial or no infiltration should be considered for a partial credit because of the combination of water quality benefits, runoff volume reduction, and flow peak reduction.

Critical Storm Adjustment - The State of Ohio does not regulate stormwater discharges for large, infrequent rainfall events (e.g., 1-year to 100-year events). However, controlling discharge for these events is an important consideration toward protecting public safety and minimizing damage to property and infrastructure. Many Ohio communities have peak discharge or "flood control" regulations aimed at reducing the impacts of large events. Many of those communities have adopted the Critical Storm criteria for peak discharge control (ODNR, 1980). The following recommendations are designed to encourage consideration of pervious pavement while still protecting the public interest.

For pervious pavement systems, the CN for Critical Storm determination should be based on the abstraction potential, which is a function of infiltration capacity of the underlying soil and the elevation at which underdrains are placed above subgrade. Until more definitive research is developed by NRCS or another research entity, it is recommended that the Critical Storm CN for the pervious pavement system be based on TR-55 guidance (USDA, 1986) for "newly graded areas" or "open space in poor condition" based on the hydrologic soil group (HSG) of the in-situ soil and the measured subgrade infiltration rate upon completion of excavation of the underground reservoir.

Soil HSG (in/hr)	Measured Infiltration Rate	CN
A	> 1.0	68
B	> 0.02	79
C	> 0.05	86
D	> 0.02	89

Table 2.11.5 Recommended Critical Storm CN for A_{inf} for No Underdrains or Underdrains Placed D_{agg}-WQv or Higher above Subgrade.

Soil HSG (in/hr)	CN
A	77
B	86
C	91
D	94

Table 2.11.6 Recommended Critical Storm CN for A_{inf} for Underdrains Placed Directly on Subgrade.

Modeling Stormwater Detention and Peak Discharge Attenuation - The aggregate subbase “reservoir” can be used as a detention basin to temporarily store stormwater. Outfitted with an appropriate outlet, the aggregate reservoir may be able to meet local peak discharge requirements for the area that drains to the pervious pavement system. Otherwise, the aggregate reservoir and outlet become part of the overall drainage network that needs to be properly “routed” to determine inflow to an end-of-pipe facility.

The following guidelines will help ensure the pervious pavement system achieves long-term structural and stormwater management goals:

- Peak discharge requirements are set by local regulations. All stormwater systems that incorporate pervious pavement require review and approval from the local stormwater authority. Preliminary approach, plans and calculations should be discussed as early as possible with the plan reviewer to facilitate communication and avoid delays in review and approval.
- The available storage volume is equal to area*depth*effective porosity of the aggregate layer(s).
- though porosities for washed, uniformly-graded aggregate may approach 0.4, some percentage of the voids will be unavailable for storage because of previous wetting and entrapped air resulting in a lower usable or effective porosity; for consideration of intense design events such as a NRCS type II distribution, use of a conservative effective porosity of 0.3 for clean, uniformly-graded aggregate is merited.
- the porosity of the pavement course typically will be substantially lower than the aggregate base; when needed for calculations/routing, porosities for the pavement should be taken from guidance provided by the specific industry association.
- For infiltrating systems, the modeler should assign a steady discharge (often termed exfiltration rate) equal to the final (or minimum) infiltration rate.
- The aggregate reservoir should be designed to prevent the (routed) 10-yr, 24-hr design event from entering the pavement course.
- The site design should include a secondary, surface drainage network that will pass the 100-yr, 24 hr event without damage to property assuming failure of the pervious pavement system. The model should show flow paths and elevations for the 100-yr, 24-hr design event with the pervious pavement treated as impervious.

Subgrade Infiltration Capacity - The hydrologic performance of infiltrating pervious pavement systems requires special attention to the subgrade soil (i.e., soil at the bottom of the aggregate reservoir) and the infiltration bed surface throughout planning, design and construction. The following guidelines will help ensure the pervious pavement system achieves long-term stormwater management goals:

- The bottom surface area of the infiltration bed should not be less than the surface area of the pervious pavement. The designer should consider increasing the infiltration bed surface area by extending the infiltration bed under adjacent traditional pavement. Such an expansion of the infiltration bed may be necessary to achieve the required drawdown time for the WQv.
- The bottom surface area of the infiltration bed should be at least 33% of the sum of the area of the pervious pavement surface plus all contributing impervious surfaces (parking lot, roads, driveways, sidewalks, roofs, etc.), that is Ainf > 0.33*(Aperv-pave + Aimpervious).
- The bottom of the infiltration bed should be level or nearly level. Sloping bed bottoms will lead to poor distribution and reduced infiltration.
- For infiltrating systems, the subgrade should not be compacted as it would be for traditional pavements. If the structural design of the pavement section requires subgrade compaction to achieve a required design strength, then subgrade infiltration should be measured based on the required subgrade design.
- The design infiltration rate of the subgrade soil should be based on field measurements at the appropriate depth and verified during construction (see section on measurement and verification of subgrade infiltration rate).

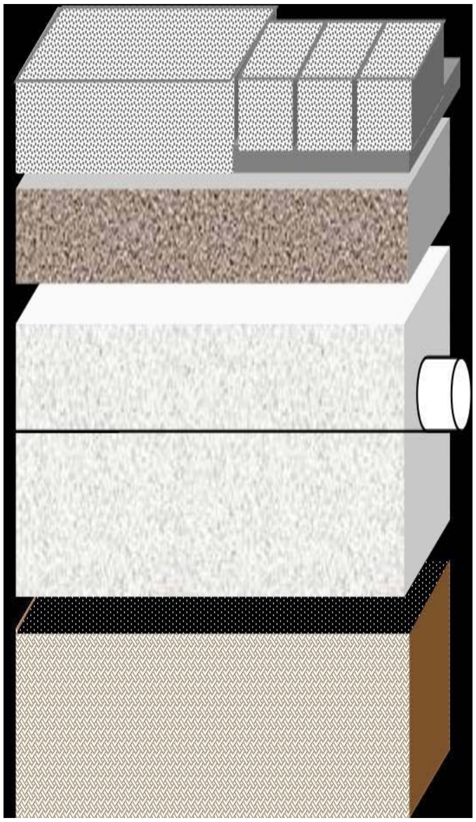
Design Criteria - Pavement Structure Design

Structural Design – The designer shall refer to the appropriate industry association or manufacturer’s specifications for structural design of the pervious pavement system.

Table 2.11.7 Reference appropriate specifications for structural design.

Pavement Type	Guidance	Website
Porous Asphalt	Porous Asphalt Pavements for Stormwater Management: Design, Construction and Maintenance Guide. Info Series 131, Revised November, 2008. National Asphalt Pavement Association, Lanham, MD.	www.asphaltpavement.org
Pervious Concrete	Specifier’s guide for Pervious Concrete Pavement with Detention. Revised October, 2009. Ohio Ready Mixed Concrete Association, Columbus, OH.	http://www.ohioconcrete.org
Concrete Pavers	Structural Design of Interlocking Concrete Pavement for Roads and Parking Lots. ICPI Tech Spec Number 8. Interlocking Concrete Pavement Institute, Washington, DC.	http://www.icpi.org
Grid Pavements	Concrete Grid Pavements. ICPI Tech Spec Number 8. Interlocking Concrete Pavement Institute, Washington, DC.	http://www.icpi.org
Vegetated Grid Pavements	See various manufacturer specifications	

Infiltrating Systems:



Pavement & bedding material - see industry association guidance.

Filter/choker course - minimum 2” of AASHTO #57 if larger aggregate is used for reservoir course or AASHTO #7, #8 or #9 if the reservoir course uses #57.

Underdrains - 4”-6” dia. PVC placed at top of recharge layer.

Recharge course - sized to infiltrate the WQv from the contributing drainage area (minimum 3” depth). Typically AASHTO #57 or larger.

Permeable geotextile fabric or sand layer equivalent

Subgrade - uncompacted subgrade

Closed Systems:

Pavement & bedding material - see industry association guidance.

Filter/choker course - minimum 2” of AASHTO #57 if larger aggregate is used for reservoir course or AASHTO #7, #8 or #9 if the reservoir course uses #57.

Reservoir course - clean, uniformly-graded coarse aggregate, typically #57, #4, #3 or #2.

Underdrains - 4”-6” dia. PVC placed placed on subgrade.

Impermeable liner (if necessary)

Compacted subgrade graded with positive slope toward outlet (minimum slope - 1%?)

Figure 2.11.10 Types of materials used in infiltrating and closed pervious pavement systems.

Subgrade Preparation - The subgrade shall be designed to carry the desired traffic load. Check the appropriate industry association or manufacturer's specifications for compaction requirements. Design infiltration rates must be adjusted to account for intended and unintended subgrade compaction.

Subgrade Soil/Aggregate Base Interface - For open (infiltrating) systems on fine-textured soils a geotextile should be placed between the native soil and the aggregate base[6]. The geotextile limits the migration of fines, limits the settling of aggregate into the underlying soil, and helps to distribute surface loads.

For infiltrating systems, given the soil characteristics of the native soil, alternative materials such as a layer of clean sand may be placed in lieu of a geotextile on top of the native soil layer to provide adequate separation between the native soil and aggregate base in an open system (UNHSC. 2009).

For closed systems, an impermeable liner shall be placed between the native soil and the aggregate base using standard measures to prevent puncture of the geomembrane (e.g., smooth subgrade, sand bedding, geotextile). Prevent lateral flow by bringing the impermeable liner to the surface or by securing the liner to a cut-off or perimeter wall making sure that the outlet pipe and any other penetrations of the liner are adequately sealed. An impermeable liner should be used for pervious pavement systems for:

- all sites over contaminated (or potentially contaminated) soils
- sites with high pollution potential source areas
- sites with slip prone soils
- sites in source water protection areas

A closed system may also be used to prevent saturation of the underlying soil for structural reasons; consult a geotechnical engineering or pavement design engineer to determine whether a closed system is required based on soil conditions.

Perimeter Barrier: Some paving materials will be prone to lateral movement unless secured against a perimeter barrier. This may be a cut stone or concrete barrier or a manufactured edge restraint. Concrete barriers at the surface grade or as a raised curb can also serve as a way to secure the impermeable liner in non-infiltrating systems to prevent lateral flow between cells in a sloping situation. Where open graded subbase material will be place against conventional road base material or soils, some type of barrier is probably needed to prevent migration of fines into the permeable pavement subbase and movement of water into the conventional road base.

Aggregate Bed - The underlying aggregate bed is typically 8-36 inches deep and is a function of structural requirements, stormwater storage requirements, frost depth considerations, site grading, and anticipated loading. Several sizes of aggregate may be required for pavement bedding, choker courses, or stormwater storage. It is critical the aggregate be uniformly graded, clean washed, and contain a significant void content. A range of aggregate sizes has been used successfully in pervious pavement projects. Choice of aggregate(s) will depend on structural requirements, local availability, and cost. Check the appropriate industry association or manufacturer's specifications for specific aggregate requirements.

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[6] UNHSC, 2009. UNHSC Design Specifications for Porous Asphalt Pavement and Infiltration Beds. Revised October, 2009. University of New Hampshire Stormwater Center, Durham, NH. http://www.unh.edu/erg/cstev/pubs_specs_info.htm.

Underdrains and observation well - Most pervious pavement systems should be designed with an underdrain system to efficiently drain the system during larger events. To avoid damage to the pavement layer, water within the subsurface stone storage bed should only rise to the level of the pavement surface in extremely rare events based on the risk tolerance of the engineer, owner or MS4 (we recommend a minimum of the 10-yr, 24-hr event). Underdrains should be installed with a minimum slope of 1% and capped at dead ends of drains. For pervious pavement areas of at least 10,000 square feet, at least one observation/cleanout standpipe should be installed near the center of the pavement and shall consist of rigid 4 to 6 inch non-perforated PVC pipe. This should be capped flush with or just below the top of pavement elevation and fitted with a screw or flange type cover. Portions of the underdrain system within 1 foot of the outlet structure should be solid and not perforated.

Figure 2.11.11 Commonly used stone for choker and reservoir layers (not to scale).

Construction

Any non-traditional stormwater practice presents challenges during the construction phase that require extra attention to plan detail (both for the design engineer and the contractor) and benefit from construction oversight by the design engineer or others with intimate knowledge of system design and function. Infiltrating pervious pavement systems increase complexity by striving to maintain infiltration capacity while ensuring structural integrity. For these systems, the design engineer should provide additional detail or requirements that protect or assure design infiltration capacity, and this capacity should be confirmed with field measurements during construction.

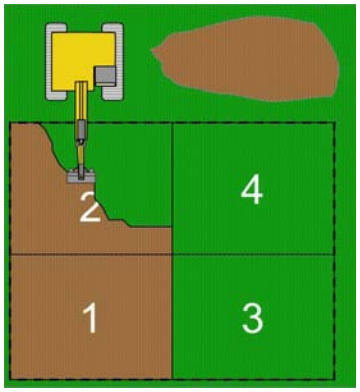
Acceptable Conditions for Initiating Construction - Construction of the pervious pavement shall begin only after all the contributing drainage area has been stabilized with vegetation or the planned cover in order to prevent contamination with sediments. Do not construct the pervious pavement practice in rain or snow. Construction of any infiltration BMP should be completed during a window of dry weather - excess compaction or smearing of the subgrade will ensure failure of the stormwater functions of the practice and threaten non-compliance with local or state requirements.

Erosion, Sediment and Runoff Controls - Keeping sediment out of this practice is critical. Rigorous installation and maintenance of erosion, sediment and runoff control measures should be provided to divert runoff and to prevent sediment deposition on the pavement surface, the subgrade or within the stone bed. A non-woven geotextile may be folded over the edge of the pavement to reduce the likelihood of sediment deposition. Any construction materials that are contaminated by sediments must be removed and replaced with clean materials (CSN, 2010). Surface sediment should be removed as soon as possible using a vacuum sweeper.

Clearing and Excavation - Clear and excavate the area for pavement and base courses in a manner that maintains the infiltrative capacity to the greatest extent possible (Brown, 2010). First insure plans detail staging of work in order to maintain the infiltrative capacity of the subgrade soils. Compaction of the subgrade soils will be increased by working in wet conditions, allowing construction equipment to work or travel across the area and by smearing the final soil surfaces during excavation. Final grade of the bed should be level for infiltrating systems, while closed or lined systems should have positive drainage to the outlet. To protect and maintain subgrade infiltrative capacity (adapted from Brown, 2010):

- Do not all allow excavation in wet conditions or if wet weather is forecasted for the construction period or before the area can be filled. Excavate in dry soil moisture conditions and avoiding excavating immediately after storms without a sufficient drying period.
- Do not allow equipment or haul routes to cross the planned pavement area, especially once excavation has begun.
- Station and operate excavating equipment from outside the planned pavement area or from unexcavated portions of the area using an excavation staging plan (see figure 2.11.12).
- Leaving 6 to 12 inches of undisturbed soil above the subgrade elevation if geotextile and base material placement will be delayed.
- Dig the final 9-12 inches by using the teeth of the excavator bucket to loosen soil so as not to smear the sub grade soil surface. Grading of the bottom (subgrade) surface of the practice with construction equipment should be avoided. Final grading or smoothing of the bottom should be done by hand.
- Avoid allowing water to pond in bottom of cuts.

Figure 2.11.12 Stage excavation in order to avoid compaction.



- Areas that have been allowed to trap sediment must have sediment removed and be allowed to dry before final excavation down to the subgrade elevation. Any accumulation of sediments on the finished subgrade should be removed with light equipment and the subgrade surface lightly scarified with hand tools. *Very important note: limit breaking natural soil structure (especially for clayey-silty soils) or risk adversely impacting the infiltrative capacity of the subgrade.
- Finally, before placing geotextile and base aggregate, the final subgrade infiltration rate must be measured for infiltrating systems and reported to the local stormwater authority.

Place geotextile or planned filter material on the uncompacted subgrade and place geotextile up and over the sides of the excavated area. Place geotextiles so that there is a minimum of 16 inches of overlap between subsequent rolls of fabric (see manufacturers recommendation) and a minimum of four feet of material beyond the sides of the excavation. Secure geotextile so that it will not move or wrinkle as aggregate is placed. Some designers may use an alternative filter material such as sand and/or pea gravel between the base aggregate (reservoir layer) and the subgrade soils instead of geotextile (see e.g., UNHSC, 2009). Non-infiltrating designs may compact the subgrade and replace the geotextile with a suitable impermeable lining. Excess fabric (beyond the excavation) should not be trimmed until there is no possibility of sediment entering the pavement area.

Place reservoir course of aggregate and underdrain system. For infiltrating systems, plans will dictate the depth of aggregate to be placed beneath the underdrain system, although this generally exceeds 3 inches. Underdrains should be installed with a minimum slope of 1%. Dead ends of pipe underdrains shall be closed with a suitable cap placed over the end and held firmly in place. For pervious pavement areas of at least 10,000 square feet, at least one observation/cleanout standpipe shall be installed near the center of the pavement and shall consist of rigid 4 to 6 inch non-perforated pvc pipe. This should be capped flush with or below the top of pavement elevation and fitted with a screw or flange type cover. Portions of the underdrain system within 1 foot of the outlet structure should be solid and not perforated.

Moisten and spread 4-12 inch lifts of the washed stone aggregate comprising the reservoir layer. Place and spread lifts of stone without driving on the subgrade and being careful not to damage drainpipes, connections or observation wells. Place at least 4 inches of additional aggregate above the underdrain. The aggregate layer should be lightly compacted, although industry references vary on the degree and number of passes with a roller. The Interlocking Concrete Pavement Institute (ICPI, 2007; LID,) specifies making 2 passes with a roller in vibratory mode and at least 2 passes in static mode until there is no movement of the stone, while the National Asphalt Pavement Association recommends compacting each lift with a light roller or vibratory plate compactor. Do not crush the aggregate with the roller.

Install filter/choker layer (and bedding layer if used). This course transitions from a larger aggregate size of the subbase to a size that will fill large voids and provide a smooth surface for the pavement layer. Its use depends upon the size of the aggregate course below. For pervious concrete and porous asphalt, AASHTO No. 57 may be used for the reservoir layer and in the layer transitioning to pavement. For interlocking pavers, a smaller size aggregate will be used as a filter layer and also as a bedding layer. These layers should be spread, leveled and compacted to their designed thicknesses.

Install paving materials. Install the planned paving materials in accordance with manufacturer or industry specifications for the particular type of pavement, whether pervious concrete, porous asphalt (Hansen, 2008; Jackson, 2007), interlocking pavers or grid pavers.

Maintenance

Pervious pavements require maintenance to provide stormwater benefits over a long time period. Because pervious pavements convey water through the pavement and also effectively trap fine materials, the majority of maintenance efforts will be to keep the system permeable (unclogged) and to manage pollutants such as salts that might effect groundwater. Therefore regular inspection will evaluate whether the surface and the bed of the pavement are functioning as intended. In other words, water should continue to move through the pavement, not pond into the pavement layer, and drain from the reservoir layer in sufficient time. Maintenance of the pavement will remove fine materials as they collect in the surface and prevent winter deicing materials from being overused or clogging the system.

Effective management includes educating the property owner, landscapers, maintenance staff, snow removal personnel and general users. In this regard, an operation and maintenance plan, signage, maintenance agreements, and contracts will serve as important points of reference for these audiences. Each document should reflect the appropriate actions to take and those to avoid for the appropriate audience. For example, landscaping personnel that work adjacent to the pavement area should be required to keep landscaping materials, such as soil, mulch or plants off the pavement and to use adequate sediment control and/or stabilization for bare areas. Snow removal, pavement repair and similar contracts should include notes regarding appropriate and inappropriate actions regarding the pervious pavement area. Because pervious pavements will be maintained and managed differently than traditional pavements, signage at pervious pavement installations is recommended. This will promote its prolonged use and prevent conventional pavement management from damaging the system. An example of this includes preventing seal coating of porous asphalt or allowing snow to be stockpiled on a pervious pavement.

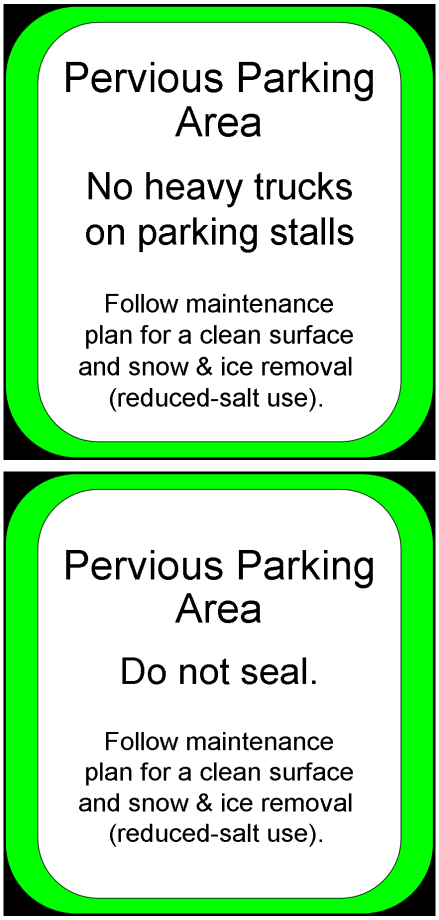


Figure 2.11.13 Examples of signage that might be used to protect pervious pavements.

An operation and maintenance plan should be prepared by the designer and provided to the owner and the stormwater authority as well as the property manager and maintenance personnel. An operation and maintenance plan for pervious pavement should detail specific actions that must be performed and their timing and/or frequency. It also describes potential damaging actions and measures to take to prevent damage to the pervious pavement. The operation and maintenance plan should also provide detailed information regarding the observation well and the depth or elevations of the underdrain system and outlet, so that the water levels under the pavement can be monitored and compared to the designed function of the system. The operation and maintenance plan should provide the normal drain time (hours) of the pavement.

Three main strategies dominate pervious pavement operation and maintenance:

Prevent clogging of the pavement and regularly remove accumulated fines. Vacuum sweeping is necessary to remove grit, leaves and other debris collecting at the pavement surface. This should be done two to four times a year. Times that especially will have an accumulation of material include after winter snow melt and after leaf drop in the fall. Vacuums used on paver systems with bedding material should be able to remove sediments and organic matter without removing the bedding aggregate. If bedding aggregate is removed, it should be replaced. Preventing clogging also involves managing adjacent vegetated and landscaped areas. These area should be maintained in healthy vegetation. Soil, mulch and other landscaping materials should never be stored or stockpiled directly on the pavement. Construction equipment should not be driven over or stored on the pavement.

Snow and Ice Removal. No sand or cinders should be used on pervious pavements. Instead winter maintenance should focus on timely snow plowing and judicious use of deicing materials. Deicing materials present a problem in any pavement system due to their solubility and history of building up to levels that are toxic to plant and animal life. In pervious pavements, high salt use has an increased potential of reaching groundwater sources, but case studies of pervious pavements have shown a reduced need for deicing material to be applied to pervious pavements due to the effects of a warmer subbase. The operation and maintenance plan should provide guidelines for reduced salt use responsive to the actual ice on the pavement rather than typical rates applied on conventional pavements in the Midwest. Snow should not be stockpiled on the pavement. The operation and maintenance plan should show where snow will be pushed or stockpiled during plowing. The operation and maintenance plan should detail the blade depth that plow operators should use, because in some instances, such as grid pavements, snow plow operators may need to raise the blade slightly to avoid dislodging the surface. In every case, care should be taken with snow plowing to keep from gouging the pavement or dislodging aggregate or pavers.

Repair pervious pavements appropriately. Areas may be repaired using the same treatment as the original pervious pavement application or, in the case of porous asphalt or pervious concrete, small areas (not the lowest area on a sloping section) can be replaced with standard (impermeable) pavement. In that case the stone bed of the entire pavement will continue to provide storage and infiltration as designed. In no case should seal coats or new impermeable pavement layers be applied, as is typical in traditional asphalt pavements.

Inspection Items. The following are suggested items for inspection and are adapted from CSN, 2010:

- Using the observation well, observe the rate of drawdown in the practice. Measure the water level in the observation well following a storm event exceeding one half inch of rainfall. This should be done immediately after the storm, recording the precipitation amount, the time of the measurement and the water level in the well. Observe and record the water level after 24, 48 and 72 hours. Actual expected performance will depend on the soils and the intended performance of the design. If the subgrade soils were hydrologic soil group D, there may still be water standing in the reservoir layer after 48 or 72 hours. There should not be standing water above the elevation of the underdrain, and this would indicate problems with the outlet or underdrain system being clogged. Assess potential clogging of the subgrade soils and geotextile by comparing the actual drawdown rate to the intended or design performance of the reservoir layer.
- Observe the pavement surface during and after rain for evidence of ponding, deposited sediments, leaves or debris. Address any signs of clogging or accumulated fine material

by performing vacuum maintenance.

- Inspect the structural integrity of the pavement surface for damage such as missing infill material or broken pavers, spalling, rutting, or slumping of the surface. Any adversely affected areas should be repaired as soon as possible.
- Check contributing impervious areas and their associated pretreatment or runoff control structures for sediment buildup and structural damage. Remove sediment as needed.
- Inspect adjacent and contributing drainage area for sources of sediment or areas that may need better stabilization with erosion control.

Typical Maintenance Activities	Anticipated Schedule
Avoid sealing with construction sediments	During construction & long-term
Water vegetated grid pavement areas and adjacent vegetated areas to ensure good growth	As necessary during first growing season
Avoid sealing or repaving with non-porous materials	Long-term
Clean pavement to ensure pavement is free of debris and sediments	As needed (at least twice a year)
Check to see that pavement dewaters during large storms and does not pond into surface (check observation well for appropriate water levels)	After large storms
Inspect upland and adjacent vegetated areas. Seed & straw bare areas.	As needed
Inspect pavement surface for structural integrity and areas in need of repair. Repair as needed.	Annually

Table 2.11.7: Typical maintenance activities for permeable pavement (adapted from WMI, 1997)

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