TABLE OF CONTENTS

CHAPTER 1 – EC & STORMWATER REGULATIONS 1
1.1 Manual Overview 1
A. Administration 1
B. Accepted Hydrologic Methods 1
C. Fees 3
D. Enforcement 3
E. National Pollutant Discharge Elimination System (NPDES) 3
1.2 Site and Regional Planning 4
A. Identify and Avoid Sensitive Areas 4
B. Minimize Impervious Surfaces 5
C. Low-Impact Development (LID) and Conservation Subdivision Design 7
D. Regional Stormwater Management 7
1.3 Manual Applicability and Performance Standards 9
A. Erosion Control 9
B. Post-Construction Stormwater Management 10
1.4 Required Components in Permit Application Submittal 14
A. Erosion & Sediment Control 12
B. Post-Construction Stormwater Management 16
C. Flow Charts 17
CHAPTER 2 – EROSION & SEDIMENT CONTROL 21
2.1 Definition / Understanding 21
A. The Erosion Process 21
B. Factors Affecting Erosion 23
C. Sediment Transportation 24
D. Erosion Control 24
E. Sediment Removal 25
2.2 Soil Loss from Construction Sites 26
2.3 Erosion Control BMP's 27
A. General 27
B. Flow Control 27
C. Erosion Control 27
D. Sediment Control 27
E. Runoff Reduction 27
F. Flow Diversion 27
G. Selecting Control Measures 27
H. Rapid and Temporary Stabilization 27
I. Polymers 28
CHAPTER 3 – STORMWATER 31
3.1 Understanding Stormwater 31
A. The Hydrologic Cycle 31
B. Hydrographs 32
C. Management of Stormwater Quality and Quantity 33
3.2 Stormwater Modeling Parameters 35
A. Rainfall Frequency Analysis 35
B. Runoff Curve Number 35
C. Time of Concentration 39
3.3 Calculating and Modeling Performance Standards 47

A. Channel Protection Volume (CPv) 47
B. Water Quality Volume (WQv)..... 47
C. Infiltration 50
D. Recharge Volume Requirements (Rev) 58
3.4 Stormwater BMP's (Structural and Non-Structural) 62
A. Goals of Stormwater BMP's 62
B. Structural BMP's 63
C. Structural Control Categories 63

CHAPTER 4 – DUBUQUE COUNTY STORMWATER AND EROSION CONTROL ORDINANCE 64
Definitions**……64**
General Provisions……...68
Site and Regional Planning……..69
Ordinance Applicability, Performance Standards, and Management Practices……69

APPENDIX A – Erosion & Sediment Control BMP Design Standards
APPENDIX B – Stormwater BMP Design Standards
APPENDIX C – Dubuque County Soils Map and Properties Table
APPENDIX D – Map of Cold Water Streams in Dubuque County
APPENDIX E – References

CHAPTER 1 – EC & Stormwater Regulations

1.1 Manual Overview

The Erosion & Sediment Control and Stormwater Management Manual was designed to help protect Dubuque County's lakes, streams, *wetlands*[1] and quality of life by reducing the negative impacts of *sediment*, rainfall, melting snow and other water *runoff*.

The Manual establishes countywide standards for the quantity and quality of water that runs off land under construction in urban and rural areas, including farms. It also provides flexibility in meeting those standards, recognizing the unique characteristics of each project and site.

Construction site erosion and uncontrolled stormwater runoff from land disturbing and land development activities have significant adverse effects upon regional water resources including the health, safety, property and general welfare of the community, diminishing the public enjoyment and use of natural resources. Effective erosion control, sediment and stormwater management depends on proper planning, design, timely installation and continued maintenance of erosion control and stormwater management practices. Specifically, soil erosion and stormwater runoff can:

- Carry sediment, nutrients, pathogens, organic matter, heavy metals, toxins and other pollutants to regional lakes, streams and wetlands;
- Diminish the capacity of water resources to support recreational and water supply uses and a natural diversity of plant and animal life;
- Clog existing storm drainage systems, increasing maintenance problems and costs;
- Cause bank and channel erosion;
- Increase downstream flooding;
- Reduce groundwater recharge, which may diminish stream base flows and lower water levels in regional lakes, ponds and wetlands;
- Contaminate drinking water supplies;
- Increase risk of property damage and personal injury, and;
- Cause damage to agricultural fields and crops.

A. Administration

The Manual sets countywide standards and gives the necessary flexibility to local governments and developers so they can administer and meet those standards effectively and efficiently.

- The Manual is administered by Dubuque County.
- The Dubuque County stormwater ordinance shall be available for adoption to any city or municipality within Dubuque County, via a 28E agreement.

B. Accepted Hydrologic Methods

The practice of urban stormwater *hydrology* is not an exact science. While the hydrologic processes are well understood, the necessary equations and boundary conditions required to solve them are often quite complex. In addition, the required data is often not available. There are a number of empirical hydrologic methods that can be used to estimate runoff characteristics for a site or drainage sub-watershed:

[1] The use of *italics* indicates the first appearance of a term whose definition appears in Section 1.4 of this chapter.

- NRCS Urban Hydrology for Small Watersheds (TR-55, 1986)
- U.S. Geological Survey (USGS) regression equations (for stream flows only).
- Small storm hydrology methods using volumetric runoff coefficients (Rv) (Schueler, 1987 and Pitt, 1994)
- Rational Method or Modified Rational Method (for storm sewers only – not approved for detention/retention basin design)

These methods are well documented in urban stormwater hydrology design practice, and have been verified for accuracy in duplicating local hydrologic estimates for a range of design storms. Table 1-1 lists the hydrologic methods and circumstances for their use in various analysis and design applications. Table 1-2 includes some limitations on the use of several of the methods.

Table 1-1: Applications of Hydrologic Methods

Application	NRCS	USGS	Small Storm	Rational
Water quality volume (WQv)			X	
Channel protection volume (CPv)	X			
Overbank flood protection (Qp)	X	X		
Extreme flood protection (Qf)	X	X		
Storage facilities	X		X	
Outlet structures	X			
Storm sewer piping	X			X
Culverts	X	X		X
Small ditches	X			X
Open channels	X	X		X
Energy dissipation	X	X		X

Table 1-2: Limitations of Hydrologic Methods

Method	Limitations
NRCS TR-55	Can be used for watershed sizes of 0-2000 acres. Method can be used for estimating peak flows and hydrographs only for storms producing more than 0.5” of runoff. Can be used for low-impact development hydrologic analysis.
Small Storm Hydrology	Only applicable to storms with rainfall of ~1.25” or less. Produces only peak runoff, total volume, and limited hydrograph information. Results of method can only be used for small rainfall applications such as water quality or recharge.
USGS	Can be only used for watersheds having characteristics similar to the watersheds used to develop the equations (generally 2 square miles or more, and may be limited by stream slope and/or location within the Des Moines lobe landform). Only produces peak flow values for larger, more infrequent storm events than the 2-year storm, no hydrograph. Cannot be used where urbanization or channelization has affected stream characteristics.
Rational	Can be used for watershed sizes of 0-60 acres. Only produces peak flow rate, no hydrograph. Parameters used require wide latitude of subjective judgement by user. Cannot be used for detention basin design.

C. Fees

Fees are set by Dubuque County, and are as follows:

- For any site with 2 acres or more of disturbed area, the fee is $285 plus $100 per acre for every acre or portion of an acre over two acres.
- Any development that is considered a subdivision, or requires a plat would be charged the fee's stated above.

Fees may be modified by time to time by the County Engineer.

D. Enforcement

Dubuque County will work with municipalities for consistent enforcement of the county minimum standards.

- The Manual requires builders, developers and other site planners to submit erosion & sediment control and stormwater management plans. If a site is not in compliance with its plan as determined by inspection, a stop-work order may be issued and the administrator may levy fines.

E. Violations

A violation by any person of any provision of this Manual, including the commencing, constructing, causing, or permitting the commencement of any land disturbing activity without submittals as described herein will be subject to abatement, a stop work order, and/or a fine of $750.The County Engineer may order compliance by written notice of violation setting forth the time within which remediation or restoration must be completed and that if the person fails to complete such remediation or restoration within such time, the County shall cause such remediation or restoration work to be done and the person shall be liable for such costs. The County Engineer may issue an order to stop all construction activities on any property where land disturbing activity is being conducted until conditions of non-compliance are corrected. Construction activity, other than that which is required to correct a condition of non-compliance, prior to the correction of the conditions of non-compliance, shall constitute a further violation.

F. National Pollutant Discharge Elimination System (NPDES)

The Clean Water Act established a set of requirements called the National Pollutant Discharge Elimination System (NPDES). The NPDES regulates stormwater discharges associated with industrial activities, municipal storm sewer systems, and construction sites. The purpose of these regulations is to reduce pollution of the nation's waterways by the implementation of *Best Management Practices (BMPs)*.

NPDES Stormwater Permit Requirements:

Phase I areas (large urban areas and major industries)

- Under permit since early 1990s
- Individual municipal permits all include a program element for new development or "post-construction" BMPs

Phase II areas (small urban areas and additional industries)

- Under Iowa Individual MS4 Permit since early 2003
- Permit includes new development requirements

New development BMP's are required under NPDES permits. The intent of incorporating BMPs in new private development and public capital projects is to prevent any net detrimental change in runoff quantity or quality resulting from new development and

redevelopment. Typical permit requirements that are now being included in all Phase I MS4 permits and are incorporated in the Phase II Iowa General Permits include:

- Specific thresholds for "priority projects" that must include both source and treatment control BMPs in the completed projects.
- A list of source control (both non-structural and structural) BMPs and treatment control BMPs to be included or considered
- Specific water quality design volume and/or water quality design flow rate for treatment control BMPs
- A requirement for flow control BMPs when there is potential for downstream erosion
- Adopt a standard model or template for identifying and documenting selected BMPs, including a plan for long-term operations and maintenance of BMPs.

Additional information regarding projects that require an NPDES permit can be obtained from the Iowa DNR's website at http://www.iowadnr.com/water/stormwater/index.html

1.2 Site and Regional Planning

Good stormwater management does not begin with site disturbance and construction. Decisions about lot layout, building density, location of public rights-of-way, protection of sensitive areas, and preservation of open space all have an impact on the quality and quantity of stormwater runoff.

When using site-planning techniques to control stormwater, designers should keep local zoning, land division and building codes in mind. Many communities have adopted site design or land division criteria to serve a variety of land use goals that may or may not directly relate to stormwater runoff.
Examples include:

- Preserving neighborhood or rural character
- Protecting specific natural or scenic resources
- Promoting smooth traffic flow
- Allowing for future land division
- Ensuring adequate pedestrian, bicycle or emergency vehicle access

Usually, such goals complement or reinforce good design for stormwater control. However, in some cases, such as choosing between grid-pattern or cul-de-sac street layouts, the designer may need to strike a balance between competing land use goals. For example, in a community seeking to promote traditional neighborhood design, engineered stormwater basins may be preferable to a curvilinear street layout.

Many techniques can be employed during the site planning and design stage of development to reduce the volume of runoff, thus reducing the need for structural practices to store and treat stormwater. Design and location of stable outlets for site runoff is also important to consider at this time, to avoid causing problems for downstream neighbors. Consider implementing the following techniques (which are listed in order of priority) and manage runoff as close to the source as possible to minimize the volume of stormwater runoff.

A. Identify and Avoid Sensitive Areas

Local variations in topography, soil types, vegetation and hydrology can have a significant influence on the nature and amount of stormwater runoff. The first step in site planning for stormwater management should be identification and mapping of areas that:

- Contain features that could be adversely impacted by stormwater runoff (such as wetlands, floodplains, lakes, streams, and shallow fractured bedrock);
- In their natural state, contribute to *infiltration*, soil and water retention, *groundwater recharge* or temperature control (such as highly pervious soils, native grasslands, woodlands or hydric soils);
- Provide natural drainage ways for surface water runoff (such as *intermittent or perennial streams*, natural or artificial drainage ways); or
- Could be a source of sedimentation, channelized flow or erosion if disturbed (such as steep slopes or easily eroded soils).
- Contain cultural resources, which are protected by federal law. Cultural resources can be found at: http://www.ia.nrcs.usda.gov/technical/culturalresources.html

Development should be designed and construction operations planned to avoid disturbing these areas wherever possible. Federal, state or local regulations protect some natural features, such as wetlands or navigable waterways. Changes in volume and direction of stormwater flow resulting from development or other stormwater practices should be carefully designed and controlled to avoid secondary impacts to natural areas. For example, increased runoff volume can erode streambeds and banks or damage natural wetlands without careful consideration early in the planning process.

Working around sensitive areas should be incorporated as part of the preliminary design, which not only avoids these areas but also highlights them as natural amenities that add value to the development. These sensitive areas complement the functions and values provided by the countywide network of open space corridors.

B. Minimize Impervious Surfaces

Impervious surfaces are the primary source of runoff in both small and large storm events. Hence, the single most effective means of reducing runoff volume is by minimizing the site's impervious surface area.

1. Preserve and Reproduce Pre-Development Hydrologic Conditions

- *Utilize natural drainage flow paths*. Dubuque County strongly recommends the use of grass waterways, vegetated drainage channels and/or water quality swales along street right-of-ways or back lots to channel runoff without abrupt changes in the direction of flow.
- *Restore soil permeability*. Use practices such as deep tilling, chisel plowing and incorporating organic matter into the upper soil layer to restore soil infiltration capacity on heavily disturbed sites. When soil is compacted, its capacity to infiltrate water is greatly diminished. On heavily disturbed sites where practices are used to restore soil permeability, the county may waive the requirement to lower the soil permeability class rating in hydrologic calculations (see 3.2.B, Chapter 3, below).
- *Minimize directly connected impervious area*. Any impervious surface that drains into a catch basin, area drain, or other conveyance structure is a "*directly connected impervious area (DCIA)*." Impervious surfaces also increase the runoff rate (reducing the runoff time of concentration) and runoff volume, which may cause higher peak flows downstream, and increase flood and erosion potential. To minimize directly connected impervious areas, downspouts and driveways should be directed to pervious areas, where feasible. This promotes infiltration and reduces the velocity of runoff water. Other strategies for minimizing connected impervious area include

directing sheet flow through vegetated areas and locating impervious areas so they drain to vegetated buffers or other pervious areas.

- *Use bioretention and other practices to increase infiltration*. *Bioretention basins* are engineered practices that use natural processes, including microbial soil processes, infiltration, and evapotranspiration to improve stormwater quality. *Rain gardens*, often very attractive, are one type of practice commonly designed for residential lots to soak up rainwater from roofs, driveways, and lawns.
- *Include green infrastructures***.** Developed areas may provide self-treatment of runoff via the use of green infrastructures if properly designed and drained. Green infrastructures may consist of conserved natural spaces, large landscaped areas (including parks and lawns), grass/vegetated swales, and turf block paving areas. The infiltration and bio-treatment inherent to such areas may provide the treatment control necessary. These areas therefore act as their own BMP, and no additional BMPs to treat runoff should be required.

2. Site and Lot Vegetation

- *Predevelopment vegetation*. Maintain as much predevelopment vegetation as possible. Vegetation prevents erosion and absorbs water and, therefore, reduces runoff volume.
- *Swales*. Use shallow grassed roadside swales, boulevards and sunken parking lot islands with check dams instead of curb and gutter storm drain systems to handle runoff, wherever possible.
- *Natural buffers and drainage ways*. Maintain natural buffers between development sites and water bodies. Buffers slow runoff, remove sediment and enhance infiltration. Natural depressions and channels should be maintained to slow, store, and infiltrate water.

3. Streets and Roads

- *Road length.* Minimize subdivision roadway length by using a roadway layout with the least pavement length suitable for the site's topography and other planning goals.
- *Road width*. Work within local zoning requirements and planned unit development provisions to minimize road width by narrowing road sections and/or reducing on-street parking. On-street parking may be restricted to one side of the street or eliminated altogether. Pavement and right of-way width must still meet minimum standards described in local land division and zoning ordinances, and should allow for safe vehicular travel and emergency vehicle access.
- *Design road patterns to match landforms*. In rolling terrain, for example, local streets should branch from collector streets and end in short loops or cul-de-sacs, where consistent with other local ordinances and land use goals. Some local ordinances and plans seek to create traditional grid patterns or limit the use of cul-de-sacs to address traffic, neighborhood character or other design objectives.

4. Lot Layout

- *Rooftops*. Reduce the impervious rooftop area by minimizing the building footprint of houses or utilizing green roof technology. Use vertical space rather than horizontal house layouts. Sod or vegetative "green roofs" rather than conventional roofing materials.

- *Driveways*. Where permitted under local driveway, zoning or land division ordinances, reduce impervious driveway area by using shared driveways, limiting driveway width, using pervious pavement, and using reduced building setbacks.
- *Parking lots*. For commercial sites, reduce overall impervious area by providing compact car spaces, eliminating excessive or unnecessary spaces, utilizing shared parking, minimizing stall dimensions, incorporating efficient parking lands, and using pervious materials in spillover parking areas.

C. Low-Impact Development (LID) and Conservation Subdivision Design

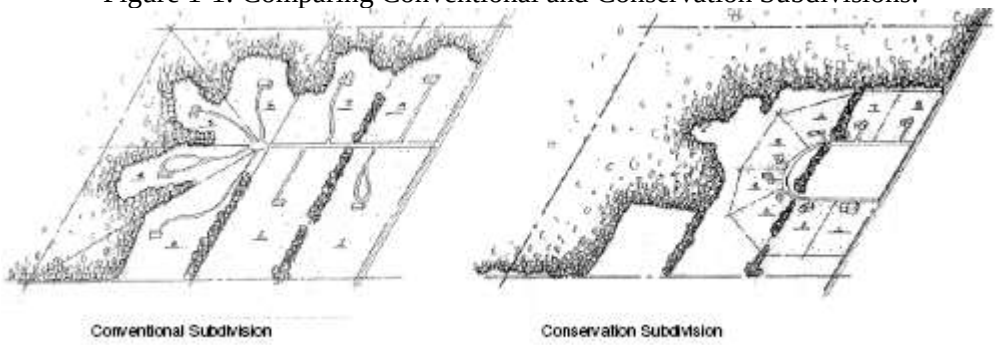
Many of the practices and techniques discussed above are commonly referred to as "low-impact design" or "conservation subdivision design". Both low impact designs and conservation subdivisions have common goals; however, they have different strategies in obtaining that goal.

Low Impact Development is a site design strategy with a goal of maintaining predevelopment hydrologic conditions by managing runoff at the source using uniformly distributed stormwater management facilities. Instead of conveying and treating stormwater in large facilities located at the bottom of drainage areas, LID addresses stormwater through small, cost-effective landscape features located at the lot level. The low-impact analysis and design approach focuses on the following hydrologic analysis and design components:

i. *Runoff curve number (RCN)*: Minimizing change in post-development hydrology by reducing impervious areas and preserving more trees and meadows to reduce the storage requirements to maintain the pre-development runoff volume.
ii. *Time of concentration (Tc)*: Maintaining the pre-development Tc in order to minimize the increase of the peak runoff rate after development by lengthening flow paths and reducing the length of the runoff conveyance systems.
iii. Infiltration: Manage water quality volume through infiltration.
iv. *Retention*: Providing permanent pool storage for volume and peak control, as well as water quality control, to maintain the same storage volume as the pre-development condition.
v. *Detention*: Providing additional storage above permanent pool levels, if required, to maintain the same peak runoff rate and/or prevent flooding for storm recurrence intervals ≥ 5-10 years.

Conservation subdivision designs are characterized by common open space and clustered compact lots. The purpose of a conservation subdivision is to protect sensitive and valuable open space, habitat and other environmental resources while allowing for the maximum number of residences under current community zoning and subdivision regulations. Figure 1-1 compares a conventional subdivision layout with a subdivision incorporating conservation design practices.

Figure 1-1: Comparing Conventional and Conservation Subdivisions.



Source: Ordinance for a Conservation Subdivision, UWEX, Brian Ohm.

During plan review, LID and conservation subdivision design and other practices may need to be evaluated to ensure that the land division meets or exceeds subdivision ordinance requirements or planned-unit development (PUD) approval procedures.

D. Watershed-Wide Planning for Stormwater Management

The Dubuque County Manual, while focusing on plans and practices to meet the erosion control and stormwater needs of particular sites, encourages watershed-wide planning. Ideally, stormwater management should be conducted as part of a watershed plan.

In watershed-wide planning, communities can work together across municipal boundaries to identify potential locations for regional stormwater treatment facilities, and coordinate on-site basins and outlets to reduce the effect of combined peak discharges after storm events. They can also collectively identify areas where stormwater treatment facilities should not be located, e.g. in hydric or alluvial soils, and target areas where they are preferred, e.g. deep sandy soil. Such a collaborative approach may result in significant cost savings from economies of scale and shared responsibility.

E. Regional Stormwater Management

Using individual, onsite structural stormwater management facilities for each development is the typical approach for downstream flood control. The developer finances the design and construction of these management facilities, and is initially responsible for all operation and maintenance. A potential alternative approach is for a community to install strategically-located regional stormwater management facilities in a sub-watershed rather than require onsite management facilities. Regional stormwater management facilities are designed to manage stormwater runoff from multiple projects and/or properties through a local jurisdiction-sponsored program, where the individual properties may assist in the financing of the facility, and the requirement for onsite management facilities is either eliminated or reduced. Table 1-3 lists some advantages and disadvantages of regional facilities as compared to individual on-site facilities.

Table 1-3: Advantages and Disadvantages of Regional Stormwater Management Facilities

Advantages	Disadvantages
Reduced construction costs	Determining an effective location can be difficult
Reduced operation and maintenance costs	Initial capital costs can be high
Ability to serve as a recreational and aesthetic amenity for a community	Substantial planning, financing and permitting are required.
Ability to maximize the intent of the proposed project. (The area set aside for stormwater management facilities is minimized)	The local government may need to establish a stormwater utility or alternative program to fund and implement stormwater control.
Higher assurance of maintenance	
Mitigates existing developments with insufficient stormwater management facilities while also providing for future development	

If a community decides to implement a regional stormwater control, it must ensure that the conveyances between the individual upstream developments and the regional facility can handle the design peak flows and volumes without causing adverse impact or property damage. Full build-out conditions in the regional facility drainage area should be used in the analysis. In addition, unless the system consists of completely man-made conveyances (i.e. storm drains, pipes, concrete channels, etc.); onsite structural management facilities for water quality and downstream channel protection will be required for all developments within the facility's drainage area.

Federal water quality provisions do not allow the degradation of water bodies from untreated stormwater discharges, and it is U.S. EPA policy to not allow regional stormwater management facilities that would degrade stream quality between the upstream development and the regional facility. Without onsite water quality and channel protection, regional management facilities do not protect smaller streams upstream from the facility from degradation and stream bank erosion. Upstream inundation from a regional facility impoundment can eliminate floodplains, wetlands, and other habitat. Further, without adequate channel protection, aquatic habitats and water quality in the channel network upstream of a regional facility may be degraded by stream bank erosion if they are not protected from bank-full flows and high velocities. Based on these concerns, both the EPA and the U.S. Army Corps of Engineers have expressed opposition to in-stream regional stormwater control facilities. In-stream facilities should be avoided if possible, and will likely be permitted on a case-by-case basis only.

1.3 Manual Applicability, Performance Standards, & Management Practices

A. Construction Site Erosion Control

1. Applicability:

Construction site erosion control plans and permits are required for any of the following:

- Land disturbance of 4,000 square feet or more.

- Land disturbance on a slope more than 6%.
- Land disturbance involving excavation and/or filling more than 200 cubic yards of material.
- Land disturbance of more than 100 lineal feet of road ditch, grass waterway, or other area where surface drainage flows in open channels.
- New public or private roads or access drives longer than 150 feet.
- Development that requires a land division.
- Land disturbance less than 2,000 square feet that has a high risk of soil erosion or water pollution, as determined by local ordinance administration.
- Land disturbance of any size within any of the following areas:
  - Within the watershed of a cold water stream.
  - Within 300 feet of the *ordinary high-water mark* of any navigable water or 1000 feet of a lake or pond.
  - Within the 100 year *floodplain*.
  - Within 75 feet of a shoreland wetland or inland wetland.

2. Performance Standards:
   - Acceptable Soil Loss Limits: Maximum rate of off-site sediment yield permitted from projects requiring an erosion control plan and permit is 5 tons per acre per year leaving the site as determined by the Revised Universal Soil Loss Equation 2 (RUSLE-2) Worksheet or by other methods as approved by the County Engineer.

3. Management Practices:

A comprehensive guide to managing erosion on construction sites has been developed by the Iowa Department of Natural Resources. The "Iowa Construction Site Erosion Control Manual" can be found on the Internet at
http://www.iowadnr.gov/water/stormwater/forms/construction_man.pdf

Stabilization control measures listed in this guide include grass channels, dust control, mulching, seeding and fertilizing, silt fence, sod, surface roughening, vegetative filter strip, compost blankets, compost filter tubes, rolled erosion control products (RECPs), wattles, flocculants, and turf reinforcement mats (TRMs).

Structural control measures listed in this guide include benches, compost filter berms, check dams, temporary slope drains, energy dissipaters, flotation silt curtains, rock chutes and flumes, gabions, inlet protection, jetties, level spreaders, rock outlet protection, retaining walls, stabilized construction entrances, rip-rap, sediment barriers, sediment basins, streambank protection, stream channel enhancement, subsurface drainage, and diversion structures.

The guide contains figures and tables summarizing the appropriate use of each of the measures listed, as well as providing specifications and installation guidelines for each. The use of this guide is strongly encouraged when choosing management practices for a construction site.

B. Post-Construction Stormwater Management and Water Quality Protection

1. Applicability:

Stormwater management plans and permits are required for any of the following:

- Required for new development and redevelopment site with 1-acre or more of land disturbing area.
- Development requiring a subdivision plat.
- Commercial or industrial development that requires a certified survey map.
- Any new development or redevelopment, regardless of size, with a Standard Industrial Classification (SIC) code that falls under the NPDES Industrial Stormwater Permit program or a *hotspot land use*.

2. <u>Performance Standards:</u>

- Post-development runoff shall be infiltrated such that a rainfall depth of 1.25 inches is recharged to the ground *(Recharge Volume, Rev)*. Infiltration shall be limited to the volume infiltrated in 24 hours.
    - Exclusion: If the site is unsuitable for infiltration as determined by the County Engineer, the *applicant* may submit engineering evidence such as clay soil or karst that may suggest that the site may require alternative infiltration practices such as a treatment train.
- If the above infiltration standard cannot be met due to an exclusion permitted by the County Engineer, provide water quality treatment for the runoff resulting from a rainfall depth of 1.25 inches *(Water Quality Volume, WQv)*.
- If the above infiltration standard cannot be met due to an exclusion permitted by the County Engineer, provide no increase in runoff temperature originating from sites in cold-water community watersheds using a thermal impact model approved by the Dubuque County Engineer. Affected sites are those located within the watershed of the following rivers and streams:
    1. Upper Portions of Catfish Creek
    2. Monastery Creek
    3. Hogan's Branch
    4. Point Hollow Creek (aka White Pine Hollow)
    5. Bloody Run
    6. Cloie Branch
    7. Little Maquoketa River, Middle (aka Bankston Creek) and South Forks

    Maps of these areas are located in Appendix D of this manual.
- If during construction the plans require a spring to be crossed or encroached upon, a stormwater conveyance system may be installed; however, the natural course of the spring must not be redirected or altered.
- Post-development peak runoff rates for 24-hour storm events must not exceed the following peak runoff rates for the same event:
    - Exclusion: Sites where 1-year post-development peak discharge is less than 2.0 cfs.
    - *Channel Protection Volume (CPv)*: Provide 24 hours of extended detention of the runoff from the 1 and 2-year, 24-hour *design storm event* to reduce bank-full flows and protect downstream channels from erosive velocities and unstable conditions. To avoid excessively small outlet restrictions, the minimum peak outflow need not be less than 0.25 cfs. Ownership for all detention basin areas (wet or dry) will be the responsibility of the homeowners association. In conjunction with ownership, any maintenance responsibilities regarding detention basin falls under the responsibility of the homeowners association.
    - *Overbank Flood Protection (Qp)*: Post-development peak runoff rates for the 2-, 10-, and 25-year, 24-hour storm event must not exceed the pre-settlement peak runoff

rate for the same event. Post-development peak rates may be further restricted by available capacity of downstream drainage systems.

- *Extreme Flood Protection (Qf):* Post-development peak runoff rates for the 100-year, 24-hour storm event must not exceed the pre-development peak runoff rate for the same event. Post-development peak rates may be further restricted by available capacity of downstream drainage systems.

Table 1-4: Summary of Dubuque County unified stormwater sizing criteria for management of stormwater quality and quantity

Sizing Criteria	Recommended Method
Recharge Volume Rev	The runoff resulting from a rainfall depth of 1.25 inches or less. Equal to WQv. Goal is to recharge groundwater and maintain stream baseflow and temperature. Goal may be reduced or eliminated if site conditions warrant. Rev = (Rv)(A)(P)/12 Rv = site runoff volume coefficient A = site drainage area (acres) P = design rainfall depth = 1.25 inches
Water Quality Volume WQv	The runoff resulting from a rainfall depth of 1.25 inches or less. Equal to Rev. Goal is to reduce average annual post-development total suspended solids loadings by 80%. Goal is met if Rev is completely infiltrated. WQv = (Rv)(A)(P)/12 Rv = site runoff volume coefficient A = site drainage area (acres) P = design rainfall depth = 1.25 inches
Channel Protection Storage Volume Cpv	Provide 24 hours of extended detention of the runoff from the 1-year and 2-year 24-hr duration storm event to reduce bank-full flows and protect downstream channels from erosive velocities and unstable conditions.
Overbank Flood Protection Qp	Provide peak discharge control of the 2-, 10-, and 25-year storm events through detention controls and/or additional infiltration measures. Downstream conveyance capacity may require additional peak discharge control.
Extreme Flood Protection Qf	Evaluate the effects of the 100-year storm on the stormwater management system, adjacent property, and downstream facilities and property. Manage the impacts of the extreme storm event through detention controls and/or floodplain management.

- *Intakes:* Storm sewer intake points (inlet grates, endwalls, etc.) should have a minimum capacity to convey the post-development condition 10-year peak flow rate.
- *Storm sewers:* Storm sewers should have a minimum capacity to convey the post-development condition 10-year peak flow rate. Provisions should be made for the 25- and 100-year peak flow rate when overland flow is not allowed or available. A minimum cleaning velocity of 3 fps should be used for the design storm. Storm sewer and surface water conveyance easements should be dedicated to the associated homeowners associations for each site. For those storm sewers that will handle footing drains, the following additional discharge (Q) values should be used:
    a. For less than 50 houses, Q = 5.0 gpm (0.011 cfs) per house.
    b. For greater than 50 houses, Q = 250 gpm (0.556 cfs) plus 2.5 gpm (0.0056 cfs) per house for each additional house over 50.
- *Culverts:* Culverts should have capacity to convey the following:

a. Post-development condition 25-year peak flow rate without the headwater depth exceeding the diameter of the culvert.
b. Post-development condition 50-year peak flow rate without the headwater depth exceeding one foot over the top of the culvert.
c. Post-development condition 100-year peak flow rate without the headwater depth exceeding one foot below the low point of the roadway/embankment, unless there are other, more restrictive elevations.

- *Ditches:* Ditches should have capacity to convey the post-development condition 50-year peak flow rate within the ditch banks. Provisions should be made for the post-development condition 100-year peak flow rate to flow overland. Surface water flowage easements should be provided to the general public for all designed drainage ways and overland flow paths.
- *Outlet Stabilization:* Stable outlets must have the capacity to handle the designed outflow from the pond outlet or pipe conveyance structures they serve. If the outlet is to be vegetated, it should be constructed and established before installation of other stormwater or erosion control structures. Outlet stabilization shall be designed based on the expected outlet discharge from the 10-year, 24-hour storm event.
- *Open Channel Stabilization:* To prevent channels from eroding, the channel lining must be adequate to carry the design velocity and volume. Where velocities are higher than 5 ft/sec or where the channel must carry prolonged flow, the channel should be lined with riprap or other armoring material. Channel linings shall be designed based on the expected channel velocity from the 10-year, 24-hour storm event.

3. Management Practices:

A comprehensive guide to managing stormwater on post-development sites has been developed by the Iowa Department of Natural Resources. The "Iowa Stormwater Management Manual" can be found on the Internet at http://www.ctre.iastate.edu/pubs/stormwater/index.cfm

Rate control measures listed in this guide include dry detention basins, wet detention basins, low-impact development (LID) and DCIA minimization strategies, infiltration systems, and constructed wetlands.

Conveyance design measures listed in this guide include street flow, intake capacity, storm sewer sizing, culvert hydraulics and sizing, open channel flow design, groundwater barriers, and stormwater swale systems.

Stormwater infiltration measures listed in this guide include infiltration basins, bioretention systems, infiltration trenches, soil quality restoration, and native landscaping.

Stormwater quality measures listed in this guide include wet detention basins, stormwater swale systems, bioretention systems, constructed wetlands, and native landscaping.

The guide contains figures and tables summarizing the appropriate use of each of the measures listed, as well as providing specifications and installation guidelines for each. The use of this guide is strongly encouraged when choosing management practices for post-development stormwater.

Other guides may be used to design outlet stabilization measures. Acceptable guidelines include the Denver Urban Drainage and Flood Control District publication "Design of Low Tailwater Riprap Basins for Storm Sewer Pipe Outlets", the FHWA publication HEC-14, and other practices found in Iowa, Wisconsin, Nebraska, and Minnesota Department of Transportation design standards.

1.4 Submittal Requirements

***PLEASE NOTE** A DNR issued General Permit #2 will continue to be necessary prior to the beginning of any construction activity that disturbs more than one or more acres or which is part of a larger project that disturbs one or more acres in total.*

A. Construction Site Erosion Control

The submittal of an erosion control plan will require a descriptive narrative of the site, a site plan, and other supporting documents. Note that many of the items coincide with the Iowa DNR's Storm Water Pollution Prevention Plan (SWPPP) requirements.

1. Site Description including the following items:
   a. The nature of the construction activity (e.g. roadway construction, utility construction, single family residential construction, etc.) and major soil-disturbing activities (i.e. clearing, grading, utility work, paving, home building, etc.).
   b. An estimate of the total area of the project site and the total disturbed area.
   c. Watershed size for each drainage area to determine how much of the area to be developed is affected by other drainage flowing through the construction site; to design culvert sizes and drainage channels' to determine the sediment produced by the site under construction.
   d. A summary of available information describing the existing soil and soil properties (e.g. type, depth, infiltration, erodibility, etc.). A Dubuque County soils map and properties table is located in Appendix C.
   e. Information describing the quality of the stormwater runoff currently discharged from the site (required only if data exists, it is not necessary to collect and analyze runoff).
   f. The name of the receiving waters and ultimate receiving waters of runoff from the site. If the site drains into a municipal storm sewer system, identify the system, and indicate the receiving waters to which the system discharges.
   g. List the anticipated sequence of major construction activities and clearly describe the order for implementation of the control measures.
   h. Describe the temporary and permanent stabilization control measures used.
   i. Describe the maintenance procedures required to keep the controls functioning in an effective manner. For each type of erosion or sediment control practice utilized, a description of the proper methods for maintenance must be provided. In addition, maintenance should include removal of sediment from streets, ditches, or other off-site areas.
   j. Describe practices for preventing hazardous materials that are stored on the site from contaminating stormwater.

k. When there is a possibility for non-stormwater related discharges from the site, they must be identified and include a description of the measures that will be implemented to prevent these flows from becoming contaminated by hazardous materials or sediment. Allowable non-stormwater related flows include flows from sump pumps, fire hydrant and potable waterline flushing, vehicle washing, external building washdown, pavement washwater, air conditioning condensate, springs, and footing drains, provided that they are not contaminated by detergents or spills/leaks of toxic/hazardous materials.
l. Describe a method to limit the off-site tracking of sediment by vehicles.

2. A site map (or maps) including the following items:
   a. Limits of soil-disturbing activities – define construction boundaries to limit the disturbance to the smallest area possible. Identify areas to be preserved or left as open space, existing drainage patterns, drainage areas for each discharge location (including off-site drainage), proposed grading, *surface waters* and wetlands, and locations where stormwater is discharged to surface water.
   b. Plan drawing of site to show the location of property lines, lot dimensions, limits of impervious area, land cover type, natural and artificial water features, 100-yr flood plain boundaries, wetland boundaries, and locations of proposed erosion controls.
   c. A plan note stating that areas not subject to construction activity for 21 days or more must have stabilizing measures initiated within 14 days after construction activity has ceased.
   d. A plan note stating that any waste materials from the site must be properly disposed of.
   e. In conformance with IDNR General Permit #2 Part IV D.2.A(2)(a), for disturbed drainage areas smaller than 10 acres, a sediment basin or sediment control along the sideslope and downslope boundaries of the construction area is required. For sites with 10 acres or more of disturbed drainage areas that drain to a common location, a sediment basin providing 3600 cf of storage per acre drained is required where attainable. The storage requirement does not apply to flows from undisturbed areas or stabilized areas that have been diverted around the sediment basin. When sediment basins of the size required are not attainable, other methods of sediment control that provide an equivalent level of protection are required.

3. Other supporting materials:
   a. Revised Universal Soil Loss Equation 2 (RUSLE-2) Worksheet or computations from other approved methods to show that 5.0 ton/Ac/yr soil loss standard is being met.
   b. Section 161A.64 of the Code of Iowa requires that prior to performing any "land disturbing" activity (not including agricultural activities), a signed affidavit must be filed with the local Soil and Water Conservation District stating that the project will not exceed the soil loss limits stated. (Note: this requirement is not a condition of the NPDES General Permit No. 2.)
   c. List additional state or local regulations that apply to the project.
   d. List any applicable procedures or requirements specified on plans approved by state or local officials.
   e. A fee will be required to cover the cost for reviewing the erosion control plans and for performing two site visits. A financial guarantee to ensure that the project will be completed may also be required.

f. Inspections are required every seven calendar days, and within 24 hours of the end of a 0.5 inch or greater storm. A sample inspection form must be submitted. The inspections must include the following:
   i. Inspect disturbed areas and areas used for storage of materials for evidence of pollutants leaving the site and/or entering the storm drainage system.
   ii. Inspect erosion and sediment control measures identified in the written site description and plan to ensure they are functioning correctly.
   iii. Inspect discharge locations to ascertain if the current control measures are effective in preventing significant impacts to the receiving waters.
   iv. Inspect locations where vehicles enter/exit the construction site for signs of sediment tracking. All entrances and exits shall be stabilized with a tracking pad. In addition, any roads where construction tracking leaves gravel, dust or sediment, must be swept at the end of every workday.
   v. Prepare an inspection report that lists the date, the name of the inspector, and the inspector's qualifications. The report must summarize the inspection and note any maintenance of the controls or changes to the written site description and plan that are required.
   vi. Implement required maintenance or changes to the written site description and plan identified during the inspection within seven calendar days following the inspection.
   vii. Inspections should be held to Iowa DNR SWPPP requirements.
   viii. The County, at their sole discretion, may perform spot checks and inspections at any time without warning.

g. A certification statement by responsible parties. The owner shall sign a certification statement substantially similar to that found in Iowa DNR General Permit #2 Part IV D.7.B. Additionally, the designer, contractor(s) and/or subcontractor(s) shall sign the certification statement if they are responsible for implementing, inspecting, and/or maintaining any measure in the plan. Under many circumstances, the identity of the contractor and any subcontractors implementing the pollution prevention measures may not be known at the time of plan submittal, therefore, additional space should be left on the certification form in order to add responsible parties. The contractor responsible for maintaining the measures in the plan can then complete this information, as it becomes available. Note that many owners will contractually assign all responsibility for implementing, inspecting, and/or maintaining any measure in the plan to the contractor. Under this situation, any fines levied against the owner will normally be passed along to the contractor.

B. Post-Construction Stormwater Management and Water Quality Protection

The submittal of site development project will require a descriptive narrative of the site, a site plan, and other supporting documents. They are provided as a minimum guide and are not to be construed as the specific information to be supplied on every project drainage report, and other information may be required. Pre-settlement, pre-development, and post-development conditions for any given site will require analysis unique to that area.

1. Project Report Narrative including the following items:
   a. A cover sheet with project name and location, name of firm or agency preparing the report, Professional Engineer's signed and sealed certification, and table of contents. Number each page of the report.

b. The nature of the construction activity (e.g. roadway construction, utility construction, single family residential construction, etc.), an estimate of the total area of the project site, and the total anticipated impervious area.
c. Watershed size for each drainage area (both onsite and offsite) to determine how much of the area to be developed is affected by other drainage flowing through the site and to design appropriately sized storm sewer, culverts, and drainage channels.
d. Describe pre-settlement/pre-development land use, topography, drainage patterns (including overland conveyance of the 100-year storm event), and natural and manmade features. Describe pre-development ground coverage, soil type, and physical properties, such as *hydrologic soil group* and infiltration. Pre-settlement ground coverage should be assumed as open prairie in any non-wooded area.
e. Describe post-developed land use and proposed grading, change in percent of impervious area, and change in drainage patterns. If an existing drainage way is filled, the runoff otherwise stored by the drainage way will be mitigated with stormwater detention, in addition to the post-development runoff.
f. Describe contributing off-site drainage patterns, land use, and stormwater conveyance. Identify undeveloped contributing areas with development potential and list assumptions about future development runoff contributed to the site.
g. Discussion of soils located on site and their suitability for infiltration. If infiltration meets the exclusion criteria, state why.
h. Describe the features that will be installed to control rate of runoff, pollutants in stormwater, and infiltration in the post-development condition.
i. Indicate what permits have been applied for and received, including but not limited to IDNR Notice of Intent, Dubuque County flood permit for sites affecting FEMA FIRM Zone A, ACOE Section 401 and/or 404 permits for work in waterways or wetlands.
j. Pre-settlement and pre-development runoff analysis, including:
    - Describe overall watershed area and relationship between other watersheds or sub-areas. Include a pre-settlement/pre-development watershed map in the report appendix.
    - The typical method used to predict runoff and peak discharge is the NRCS TR-55 method. Other methods may be used only with the preapproval of the County Engineer. If other methods are used, describe the method and provide documentation of correspondence with County Engineer regarding the method.
    - Describe method used to calculate the time of concentration. Describe runoff paths and travel times through sub-areas. Show and label the runoff paths on the pre-settlement/pre-development watershed map. Pre-settlement runoff paths should be assumed to match pre-development with respect to location and slope.
    - List runoff coefficients or curve numbers applied to the drainage areas. The RCNs listed in Table 1-4a shall be used in all hydrologic calculations for pre-settlement conditions required for determining Qp limits (2-, 10-, and 25-year events). These RCNs have been selected with the intent to mimic hydrologic conditions that existed in Iowa prior to settlement and farming. The RCNs listed in Table 1-4b shall be used in all hydrologic calculations for pre-development conditions required for determining Qf limits (100-year event). These RCNs have been selected with the intent to reflect hydrologic conditions that exist after settlement and farming. If a geotechnical study of

the site was used to determine HSG, provide boring logs and locations in the appendix of the report. If a soil survey was used to determine HSG, cite it in the references.

Table 1-5a: RCNs for Projects in Dubuque County (Pre-settlement Conditions, 2- thru 25-year events)

Cover Type	Curve Numbers for Hydrologic Soil Group			
	A	B	C	D
Non-wooded Areas[1]	30	58	71	78
Wooded Areas[2]	30	55	70	77

[1] RCNs are equivalent to the TR-55 listed values for meadow in good condition with the intent to mimic pre-settlement conditions. Apply to any pre-development condition area which is not wooded.
[2] RCNs are equivalent to the TR-55 listed values for woods in good condition.

Table 1-5b: RCNs for Projects in Dubuque County (Pre-development 100-year events and all Post-development storm events)

Cover Type	Curve Numbers for Hydrologic Soil Group			
	A	B	C	D
Continuous Cropped Agricultural Use[1]	55	69	78	82
Continuous Mature Wooded Area[2]	30	55	70	77
Continuous Meadow Area[3]	30	58	71	78
Lawn and Pasture Areas[4]	39	61	74	80
Impervious Area[5]	98	98	98	98

[1] RCNs are equivalent to mid-range TR-55 listed values for row crops and legume crops (excluding crops mown for hay) were conservation practices are used.
[2] RCNs are equivalent to the TR-55 listed values for woods in good condition.
[3] RCNs are equivalent to the TR-55 listed values for meadow (ungrazed and unmowed) in good condition.
[4] Areas include residential lawns, golf courses, cemeteries, grazed or mowed farm pasture, and other areas with short grass.
[5] Areas include roofs, sidewalks, paved streets and roads (excluding right-of-way), curbs, paved parking lots and driveways.

- The typical precipitation model and rainfall duration used for the design storm is the NRCS Type II 24-hour distribution. Total 24-hour rainfall amounts for given frequency shall reflect data from Bulletin 71, "Rainfall Frequency Atlas of the Midwest" as displayed in Table 1-5 below. Other methods (such as a user-defined model based on collected precipitation data) or durations (such as a critical duration analysis) may be used only with the preapproval of the County Engineer. If other methods are used, describe the method and provide documentation of correspondence with County Engineer regarding the method.

Table 1-6: Dubuque County 24-hour Rainfall Depth for Various Storm Events

Return Period	Rainfall Depth (in)
1-yr	2.32
2-yr	2.91
5-yr	3.67
10-yr	4.31
25-yr	5.11
50-yr	5.73
100-yr	6.36

- Provide summary table(s) of model results including drainage area, time of concentration, frequency, peak discharge, and accumulative routed flows at critical points within the development (if any) and at development boundaries. At a minimum, flow rates for pre-settlement 2-, 10-, and 25-year storms and pre-development 100-year storm must be provided.

k. Post-Development runoff analysis, including:
   - Describe overall watershed area and sub-areas. Discuss if the post development drainage area differs from the pre-development drainage area. Include a post development watershed map in the report appendix.
   - The method used to predict runoff and peak discharge will be the same as used in the pre-development analysis, except for variables changed to account for the developed conditions.
   - The time of concentration method used will be the same as used in the pre-development analysis. Describe change in times of concentration due to development (i.e. change in drainage patterns). Show and label the runoff paths on the post-development watershed map.
   - List runoff coefficients or curve numbers applied to the drainage areas. The RCNs listed in Table 1-4b (above) shall be used in all hydrologic calculations for post-development conditions. Include an analysis of the proposed increase in impervious area and describe the change in runoff volume due to development. Directly connected impervious area (roads, front of houses, etc) shall be separated out from pervious area and unconnected impervious areas (backs of houses, etc) in the determination of a weighted RCN. Provide a summary of the total directly connected impervious area and the total unconnected impervious area for each sub-watershed/catchment.
   - The precipitation model storm event, total rainfall, and total storm duration will be the same as used for the pre-development model.
   - Provide summary table(s) of model results including drainage area, time of concentration, frequency, peak discharge, and accumulative routed flows at critical points within the development (if any) and at development boundaries. At a minimum, flow rates for 1-, 2-, 10-, 25-, and 100-year storms must be provided.
   - Summary of post-development runoff:
     1) Description of BMP including water quality practices (methodology).
     2) Provide table(s) including drainage area, time of concentration, frequency, duration, and peak discharge. Summarize in narrative form the change in hydrologic conditions due to the development.
     3) Post-developed discharge should take into account any upstream offsite detention basins and undeveloped offsite areas assumed to be developed in the future with stormwater detention.

l. Rate control structure and conveyance system analysis, including:
   - Describe any detention basin locations by discussing existing topography and relationship to basin grading. Determine if rock deposits will affect construction and if a high water table precludes basin storage. Floodplain locations should be avoided.
   - The detention basin size in final design should be based upon actual hydrograph routing for the design storms controlled by the basin. Note the

TR-55 approximate method of sizing detention basins (TR-55 Chapter 6) may result in storage errors of 25%, and should not be used in final design.

- The top of any dike used in forming a detention basin should be a minimum of one foot above the 100-year storage elevation. Large detention basin design may require IDNR approval (See Iowa Administrative Code Title V, Chapter 70).
- Discuss the basin outlet design in terms of performance during low and high flows and downstream impact. Note that a single-stage outlet (i.e. one culvert pipe) may not be appropriate because of its inability to detain post-developed runoff from storms less than the 10-year interval. A more desirable outlet has two or more stages (such as a riser structure with an orifice) which will serve to detain runoff for low-flow events of a 2-year storm, and pass greater storm events via the riser outlet.
- Design the spillway for high flows using weir and/or spillway design methods. The steady-state open channel flow equation is not intended for use in spillway design.
- Describe methods to protect the basin during overtopping flow.
- Describe channel protection/lining and velocity dissipation at outlets.
- Provide a summary table of the respective volumes and discharge rates for the project area after routing though rate control structures, and a comparison to the calculated allowable release rate from the site for the 2-, 10-, 25-, and 100-yr storm events.

m. Infiltration basin analysis, including:
   - Describe any basin locations by discussing existing topography and relationship to basin grading. Floodplain, high groundwater, and high bedrock locations should be avoided.
   - The available infiltration rate and resulting footprint size and depth of basin required to capture the Water Quality Volume.

n. Wet detention (retention) basin analysis, if the site conditions do not allow for infiltration of the WQv.

o. Extended detention basin analysis. Discuss the basin outlet design in terms of extended detention during 1- and 2-year post-development condition rainfall events. Note that a single-stage outlet (i.e. one culvert pipe) may not be appropriate because of its inability to detain post-developed runoff from storms less than the 10-year interval. A more desirable outlet has two or more stages (such as a riser structure with an orifice) which will serve to provide extended detention via the orifice and pass greater storm events via the riser outlet.

p. Thermal impact analysis, if the site is in a thermally-sensitive watershed. If the WQv is infiltrated, it is assumed that thermal impacts are zero.

2. A site map (or maps) including the following items:

   a. A preliminary plat (with pre-and post-development topography) may be used to show the proposed development. Minimum scale of 1 inch = 500 feet or larger to ensure legibility should be used for all drainage areas. (Drawings no larger than 24 inches by 36 inches should be inserted in 8-1/2 inch by 11-inch sleeves in the back of the bound report). The plat is to show street layout and/or building location on a contour interval not to exceed 2 feet. The map must show on- and off-site conditions. Label flow patterns used to determine times of concentration. Drainage plans (preliminary plat or topography map) must extend a minimum of

250 feet from the edge of the proposed preliminary plat boundary, or a distance specified by Jurisdiction. The limits of swale and ditch easements should be established based upon the required design frequency. This includes 100-year overflow easements from stormwater controlled structures.

b. Identify areas of the site located within the floodway or floodplain boundaries as delineated on flood insurance rate maps, or as determined by other engineering analysis. Identify wetland areas on the site, as delineated by the National Wetlands Inventory, or as determined by a specific wetland study.
c. Soil map or geotechnical information.
d. Location and elevations of Jurisdictional benchmarks. All elevations should be on Jurisdictional datum.
e. Proposed property lines (if known).
f. Existing drainage facilities and structures, including existing roadside ditches, drainage ways, gutter flow directions, culverts, etc. All pertinent information such as size, shape, slope location, 100-year flood elevation, and floodway fringe line (where applicable), should also be included to facilitate review and approval of drainage plans.
g. Proposed drainage facilities and structures, including storm sewers and open drainage ways, right-of-way and easement width requirements, 100-year overland flow easement, proposed inlets, manholes, culverts, erosion and sediment control, water quality (pollution) control, infiltration basins, energy dissipation devices, and other appurtenances.
h. Cross sections and profiles of road ditches, designed to carry storm flows and to ensure non-erosive velocities.
i. Proposed outfall point(s) for runoff from the study area.
j. The 100-year flood elevation and major storm floodway fringe (where applicable) are to be shown on the plans, report drawings, and plats (preliminary and final). In addition, the report should demonstrate that the stormwater system has adequate capacity to handle a 100-year storm event, or provisions are made for overland flow.
k. Show the critical minimum lowest opening elevation of buildings for protection from major and minor storm runoff.

3. Supporting computations. Computations may be done by hand or with computer software. If software was used, attach computer-generated reports and output and underline and label results, such as the peak discharge. Provided computations must include:
   a. Runoff coefficients and curve numbers for each sub-watershed
   b. Total impervious area (ft^2 and % of total drainage area)
   c. Times of concentration for each sub-watershed
   d. Storm sewer design summaries
   e. Peak runoff calculations – Show results in tabular format and pre- and post-developed hydrographs
   f. Detention basin design – Show tabular stage-storage-discharge results and inflow/outflow hydrographs. Include both extended-detention and rate control results.
   g. Water Quality Volume calculations
   h. Infiltration basin design calculations
   i. Open channel flow calculations. For ditches that drain areas over two square miles in urban areas and over ten square miles in rural areas, design may require

the Iowa Department of Natural Resources (IDNR) approval (See Iowa Administrative Code Chapter 567.71).

j. Culvert design calculations or nomographs. For culverts that drain areas over two square miles in urban areas and over ten square miles in rural areas, design may require the Iowa Department of Natural Resources (IDNR) approval (See Iowa Administrative Code Chapter 567.71).

k. Erosion protection design.

Chapter 2 – Erosion & Sediment Control

2.1 – Definition/Understanding

Erosion and sedimentation are naturally occurring processes. However, human activities have accelerated these processes well beyond the rate desired by nature. The removal of large volumes of soil from the land, and their deposition in waterways, has destroyed ecosystems and degraded the environment.

In order to minimize and control erosion and sedimentation, it is important to understand the process and cause of each.

The Erosion Process

1. **Water.** Erosion from water typically occurs in the following ways:

    a. **Raindrop splash and sheet erosion.** The first step in the erosion process begins as raindrops impact the soil surface. Raindrops typically fall with a velocity of 20-30 feet per second. The energy of these impacts is sufficient to displace soil particles as high as two feet vertically. In addition, the impact of rainfall on bare soil can compact the upper layer of soil, creating a hard crust that inhibits plant establishment and infiltration.

    Sheet erosion occurs as runoff travels over the ground, picking up and transporting the particles dislodged by raindrop impacts. The process of sheet erosion is uniform, gradual, and difficult to detect until it develops into rill erosion. If runoff is maintained as sheet flow, the velocity remains low and there is little potential that the flow will remove particles that have not been dislodged by other means (i.e. raindrop splash).

    The method used to prevent erosion from raindrop splash and sheet erosion is stabilization. Stabilizing techniques such as temporary and permanent vegetation, sodding, mulching, compost blankets, and rolled erosion control products absorb the impact of raindrops and protect the ground surface. By protecting the surface, soil particles are not dislodged and transported by sheet flow. Typically, sheet flow does not have sufficient volume or velocity to dislodge soil particles from a bare surface by itself. It is dependent on raindrop impacts to disturb the surface. Therefore, stabilizing a surface protects the ground from both raindrop and sheet erosion.

    b. **Rill erosion.** Rill erosion occurs as runoff begins to form small concentrated channels. As rill erosion begins, erosion rates increase dramatically due to the resulting higher velocity concentrated flows. Construction sites that show signs of rill erosion need to be re-evaluated and additional erosion control techniques employed. Rilling can be repaired by tilling or disking (filling in the rills and discouraging concentrated flows) and should be repaired as soon as possible in order to prevent gullies from forming.

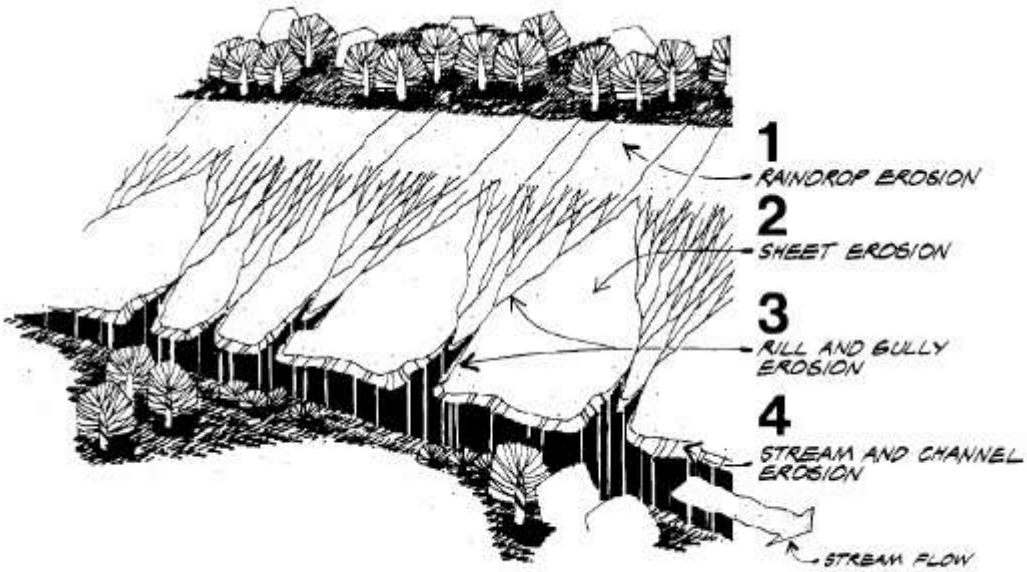
    c. **Gully erosion.** Gully erosion results from water moving in rills, which concentrates to form larger channels. When rill erosion can no longer be repaired by merely tilling or disking, it is defined as gully erosion. Gullies must typically be repaired with

earthmoving equipment. Gully erosion can be prevented by quickly repairing rill erosion and addressing the cause of the rill erosion.

d. **Stream channel erosion.** Stream channel erosion consists of both streambed and streambank erosion. Streambed erosion occurs as flows cut into the bottom of the channel, making it deeper. This erosion process will continue until the channel reaches a stable slope. The resulting slope is dependent on the channel materials and flow properties.

As the streambed erodes and the channel deepens, the sides of the channel become unstable and slough off, resulting in streambank erosion. Streambank erosion can also occur as soft materials are eroded from the streambank or at bends in the channel. This type of streambank erosion results in meandering waterways. One significant cause of both streambed and streambank erosion is the increased frequency, volume, and duration of runoff events that are a result of urban development.

Figure 2-1: Types of Soil Erosion Caused by Water



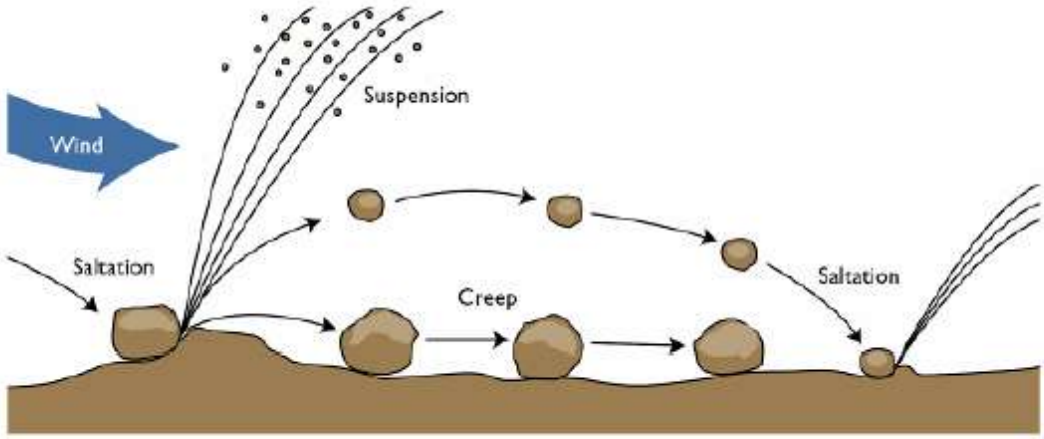
Source: USDA NRCS, 2002.

2. **Wind.** Wind can also detach soil particles. Detached soil is moved by wind in one of three ways:
   a. **Suspension.** Very fine silt and clay particles (smaller than 0.002 inches in diameter) may be picked up by the wind and carried in suspension. Suspended dust may be moved great distances, but does not drop out of the air unless rain washes it out or the velocity of the wind is dramatically reduced.

   b. **Saltation.** Fine silts up to medium sand particles (0.002 to 0.02 inches in diameter) move in the wind in a series of steps, raising into the air and falling after a short flight. This movement is called saltation. A vast majority of wind erosion is a result of the saltation process.

c. **Creep.** Soil particles larger than medium sands (greater than 0.02 inches) cannot be lifted into the wind, but particles up to 0.04 inches (coarse sand) may be pushed along the soil surface by saltating grains or direct wind action. This action is called creep.

Figure 2-2: Movement of Soil Particles by Wind Erosion



Source: McCauley & Jones, 2005.

Factors Affecting Erosion

The extent of erosion that occurs is dependent on a number of factors including soil erodibility, climate, vegetative cover, topography, and season.

1. **Soil erodibility.** The erodibility of a soil depends on its texture and physical properties. The characteristics that influence the potential for erosion are those related to the infiltration capacity of the soil and its ability to resist detachment. Soil properties that affect erodibility include texture, organic matter content, soil structure, and permeability.

   In general, soils with a high percentage of fine sand and silt are the most erodible. These particles are easily detached and carried away by rainfall and runoff. As the clay and organic content of a soil increases, the erodibility of the soil tends to decrease.

   Clay particles have the ability to bind together, reducing the potential for detachment by raindrop splash. However, they are also more impermeable, resulting in increased runoff. The increase in runoff increases the erosion potential (especially rill and gully), offsetting some of the benefit that the binding effect has against resisting erosion. The problem with clay particles is that once they have eroded, they are easily transported by water and are very difficult to remove.

   Soils that are high in organic matter content have a more stable texture and increased permeability. This allows the soil to resist detachment and infiltrate more precipitation. Well draining sands and gravels are the least erodible soils. Soils with high infiltration rates such as these significantly reduce the amount of runoff, thereby reducing the potential for erosion.

The USDA county soil surveys provide an indication of soil erodibility. This value (K) ranges from 0 to approximately 0.7. Higher values indicate a greater potential for erosion.

2. **Precipitation.** The rate of erosion is directly related to the amount and type of precipitation that occurs. High intensity storms increase particle detachment. In addition, frequent or lengthy storms can saturate the soil, reducing infiltration and increasing runoff. Increased detachment and runoff both contribute to erosion. Erosion risks are high where precipitation is frequent, intense, or lengthy. In Iowa, the wettest months occur between May and August, when construction activities are at their peak.

3. **Ground cover.** Ground cover can significantly reduce erosion potential. Vegetative residue, mulch, and compost, as well as the he leaves and branches of vegetation, intercept precipitation and shield the ground from raindrop impacts. The roots of vegetation help hold soil particles together and prevent them from becoming detached. Ground cover slows runoff velocity, increases infiltration, and can even filter sediment out of runoff.

4. **Topography.** Areas with long and/or steep slopes increase the potential for erosion. Long slopes increase the potential for runoff to accumulate and develop into erosive concentrated flow near the bottom of the slope. On steep slopes, high-velocity flows can develop quickly and cause significant erosion.

5. **Season.** The potential for erosion varies throughout the year. In winter months when the ground surface is frozen, there is little chance of water erosion. As spring approaches, the surface soils begin to thaw, but the ground below remains frozen. This creates a high potential for erosion. An early spring rain at this time cannot infiltrate into the frozen subsoils. However, the newly thawed surface can be easily washed away, even by a light rain. Erosion potential is also high in the summer months, due to the high-intensity thunderstorms that occur during this period.

Sediment Transportation

Once soil particles are detached from the surface and suspended in runoff waters, they will remain there until the velocity of the water is reduced. Flowing waters create turbulence that constantly churns and mixes the flow, holding the particle in suspension. In order for the particles to be removed, the velocity of the flow must be reduced sufficiently to allow the particle to settle out by gravity. This process is discussed in further detail in Section 7D-1. Once sediment reaches a natural waterway or stream, it is nearly impossible to remove. As discussed above, the flowing nature of the stream holds the particles in suspension until the flow velocity is reduced. For natural waterways, this reduction in flow velocity does not normally occur until the waterway empties into a water body. At this point, the sediment settles out and is deposited on the bottom of the pond or lake. Over time, this sediment accumulates, forming large deposits, and can eventually fill in a water body completely. Sediment is the largest pollutant (by volume) in stormwater runoff. The resulting deposits can destroy ecosystems and are difficult and expensive to remove.

Erosion Control

The key to successful erosion and sediment control on construction sites is the prevention of erosion. The simplest way to keep sediment from leaving a site is to keep it in place. The

following site management methods should be implemented on all sites to help prevent erosion from occurring:

1. **Limit exposed area.** Existing well-vegetated areas are usually stable and nearly erosion-proof. The simplest and cheapest way to prevent erosion on a site is to prevent the existing vegetation from being disturbed. Obviously, this cannot be done for areas that must be graded and some ground must be exposed. However, by carefully planning the construction, controlling staging and equipment storage areas, and marking construction limits, the exposed area can be minimized.

2. **Limit exposure time.** Leave existing vegetation in place as long as construction operations allow reducing the amount of time that a disturbed surface is exposed. If possible, stage construction so that one area is stabilized before grading activities begin on another area. After areas are disturbed, they should be stabilized as soon as possible. The NPDES permit contains specific requirements for initiating stabilization procedures once construction activities are completed or temporarily suspended. Stabilization activities may include temporary or permanent seeding, sodding, rolled erosion control products, turf reinforcement mats, compost blankets, or mulching.

3. **Divert runoff**. Sheet or concentrated flow over a disturbed area can cause severe erosion. For sites that receive upland runoff, diversion should be constructed to protect bare slopes until vegetation or stabilization is established. Methods of diverting runoff away from or over disturbed areas include diversion structures (berms and swales), slope drains, rock chutes, and flumes. Diverted runoff must be discharged to a stable outlet. A level spreader can be used to convert concentrated diverted flows to sheet flow before they are released onto stable ground.

4. **Limit velocity.** As runoff travels down a bare slope, its velocity increases. Limiting slope lengths will help prevent high-velocity flows. Where it is not practical to reduce the height of a slope by grading, the slope length can effectively be broken up into several smaller slopes by installing silt fence, filter berms, filter socks, and wattles. In ditches and channels, check dams should be used.

5. **Protect concentrated flow areas.** Concentrated flows will occur on most sites. As sheet flows converge and the volume increases, the flow eventually becomes concentrated and provisions must be made to prevent erosion. Grass channels can carry some concentrated flow. Rolled erosion control products and turf reinforcement mats can provide additional reinforcement when required. At discharge points, rock outlet protection or flow transition mats can be provided to dissipate energy and prevent scour at the outlet.

Sediment Removal

Eroded soil particles that are suspended in flowing runoff waters will be transported offsite unless they are removed. The simplest and most efficient way to remove suspended particles from runoff is by detaining the runoff to slow the flow velocity; thereby allowing the suspended soil particles to settle out. This is most commonly accomplished with a sediment control device.

The most important factor in designing a sediment control device is selecting the appropriate size. The ideal situation would be to collect and retain all runoff in a large retention structure, preventing any contaminated water from leaving the site. However, this is not practical in most situations. First, to retain all water onsite would require large

storage areas and volumes. In addition, the retained runoff would be required to infiltrate into the ground or evaporate. These processes may not be sufficient to remove all of the runoff before the next storm occurs. A more practical approach is to size a device to detain the runoff for a sufficient time to remove a significant portion of the suspended material, yet allow the structure to outlet excess runoff, rather than retaining it. Since the device is allowed to drain both during and after the storm event, the size can be reduced, and the danger of being flooded out by a subsequent storm event is also reduced.

2.2 – Soil Loss from Construction Sites

Calculating soil loss

Regardless of the stabilizing and vegetative practices employed, inevitably some soil erosion will occur. Over the years, a variety of different models have been developed to estimate the amount of erosion that occurs on a given site. The current model utilized by the National Resource Conservation Service (NRCS) is the second revision of the Uniform Soil Loss Equation (USLE), which is called RUSLE2 (Revised Universal Soil Loss Equation). RUSLE2 is a semi-empirical model that considers the erodibility factors discussed in the previous section. The RUSLE2 model utilizes the following equation to determine sediment delivery rate:

$$A = R \times K \times L \times S \times C \times P \qquad \text{Equation 1}$$

Where:

A	=	Estimated average annual soil loss in tons/acre/year
R	=	Rainfall-runoff erosivity factor
K	=	Soil erodibility factor
L	=	Slope length factor
S	=	Slope steepness factor
C	=	Cover management factor
P	=	Support practice factor

Manually calculating soil loss with the RUSLE2 model is a time-consuming process that requires extensive weather, soils, and other support information. In order to simplify the use of RUSLE2, NRCS has developed a RUSLE2 software program. The RUSLE2 program utilizes the concept described above to estimate soil loss, sediment yield, and sediment characteristics from sheet and rill erosion. This program is available for download from NRCS at: http://fargo.nserl.purdue.edu/rusle2_dataweb/RUSLE2_Index.htm.

While the RUSLE2 model was originally developed to analyze conservation practices on agricultural land, it can also be used to estimate sediment delivery rates from construction sites. This is an especially useful tool for designing erosion and sediment control systems for large sites. It is also useful for estimating sediment delivery rates to both temporary and permanent sediment basins. This information can be used to estimate the required cleanout frequency for sediment control structures, and for identifying sites that are highly susceptible to erosion, so potential problems can be addressed prior to construction.

2.3 – Erosion Control BMP's

General

The following sections provide design information for a variety of erosion and sediment control measures. Each section describes the measure, how to properly design and implement it, and the benefits that it provides. Each measure's benefits are shown on the first page and a rating (high, medium, or low) is given for each; a summary of the individual measures and their benefits is shown in Table 2-1. The benefits have been divided into five categories that directly affect erosion or sediment transportation. The following are descriptions of each of the benefits shown in Table 2-1.

Flow Control

Flow control refers to the ability of a practice to reduce flow velocity (either sheet or concentrated flow). Reducing flow velocity helps reduce erosion and transportation of sediment. Controlling velocity is important on long or steep slopes. High-velocity flows can quickly cause severe erosion.

Erosion Control

Erosion control is the measure's ability to stabilize the surface and prevent soil particles from becoming displaced. Erosion control should be utilized on all disturbed surfaces. Preventing erosion from taking place is the simplest and most cost-effective method of keeping sediment from leaving a site.

Sediment Control

Sediment control is the ability of a practice to remove suspended soil particles from runoff after erosion has taken place. Sediment control measures are the last line of protection against releasing sediment laden runoff into water bodies or waterways.

Runoff Reduction

Runoff reduction is the ability to reduce the volume of runoff from a site. Reducing the volume from an area also reduces the potential for both erosion and sediment transportation. These methods utilize absorption or increase the potential for infiltration of stormwater into the soil.

Flow Diversion

Flow diversion consists of routing upland runoff around disturbed areas. By reducing the amount of runoff over a disturbed area, the potential for erosion and sediment transportation are also reduced.

Selecting Control Measures

To simplify the process of selecting erosion and sediment control measures, a web-based database has been developed. This database narrows the list of practical measures based upon site conditions and other selection criteria. This database is available at: http://dhn.iihr.uiowa.edu/runoff/. The database and the following table may be used to select a system of both erosion control and sediment control measures. No single measure should be relied upon as the sole method of erosion control and sediment control.

Rapid and Temporary Stabilization

Temporary seeding is applicable on any area of the site that will remain inactive for at least 21 days but less than 1 year. It is often used to prevent erosion between construction activities and during the winter months if established early enough. Due to its short-term nature, temporary seeding may be ineffective on its own and should be used in conjunction with other management practices.

For rapid stabilization, all seed will be installed by the hydroseed method. The plan must indicate areas for rapid stabilization, and an estimate of the number of mobilizations based on staging or phase. Critical areas of special concern should be designated on the plan as special emphasis zones. If a hydroseeder is used to apply hydromulching, it must be applied at the rate of 2,000 lbs per acres and as the final operation. It is not permitted to apply seed and fertilizer with the mulching.

Polymers

Polymers (PAM), or anionic polyacrylamides, are non-toxic, organic chemicals that can be applied to soil or water and will temporarily bond soil aggregates. The resulting soil surface is significantly more resistant to erosion than untreated soil. Water application of polymers promotes sediment flocculation and coagulation, thereby increasing settling velocity.

PAM is applicable on a wide variety of sites, especially those with steep slopes where traditional practices, such as mulching, are rendered ineffective when used by themselves. PAM may also be used to improve the efficiency of devices that rely on settling of particles in water. This practice is usually used during and after site grading activities, prior to and during the establishment of seed, or in situations where other practices are unavailable or ineffective due to weather conditions. The use of additional practices, such as mulching, may significantly increase the effectiveness of the practice.

For water application, polymers may only be applied to runoff that has been captured in sediment control devices. Application of polymers in these devices helps sediment suspended in the water to settle out. Polymers may not be applied directly to any surface waters of the state, such as lakes, rivers, streams, wetlands or springs. When used for a temporary sediment basin, detention basin or man-made control facility, polymers should be approved by Dubuque County with regard to the location of application, product type, application method, dates of application and rate of application.

Advantages:

- Effective in preventing erosion
- Cost effective
- May reduce turbidity
- Reduces erosion during winter months, when vegetation cannot be established
- Prevents crust formations

Disadvantages:

- Must be reapplied whenever the soil is disturbed and after large storm events
- May increase the pH of runoff
- Limited life span

- Does not provide protection for seed in the summer months
- Over application may result in negative effects on plants and wildlife
- Must be approved by Dubuque County before use
- Cannot be used within 30 feet of state water bodies

1. Selection

Polymers are available commercially in both granular and liquid forms in a wide variety of formulations. However, Dubuque County must approve the polymer before it may be used. Polymers shall be utilized following all manufacturers' instructions and specifications.

2. Application

As application rates will vary depending upon the product used, the time of year, and the individual site characteristics, PAM shall be applied following Dubuque County's and the manufacturer's specifications. Excessive application may result in reduced effectiveness and may have adverse effects on local plant and wildlife communities. As a result, land applied PAM may not be applied within 30 feet of any state water bodies. Reapplication is required after any site disturbance and after large storm events. In addition, because PAM breaks down over time, reapplication, based on manufactures specifications, is required for the practice to remain effective.

Additional practices, such as mulching, are strongly encouraged for use with polymers. The combination of these practices results in enhanced erosion protection, while increasing the success of germination by providing protection for seed.

3. Documentation

Those utilizing PAM as an erosion control practice must maintain an inspection log that is readily attainable by Dubuque County Erosion Control Inspectors. Documentation requirements include:

- Date of application
- Rate of application
- Type of PAM applied (including manufacturer, product name and concentration)
- Specific area of the site that the practice has been applied
- Dates of inspection
- Date of construction activities on the application site
- Dates and amounts of rainfall on the site

4. Maintenance

Applied areas shall be inspected weekly and after each rainfall event for evidence of rill and gully formation PAM shall be reapplied necessary per manufactures' specifications PAM shall be reapplied after any site disturbance and after large rainfall events

5. Method to Determine Practice Efficiency

The efficiency of PAM is dependant upon the individual site characteristics, the type of polymer used, the rate of application, the time of year applied, and the use of additional

practices. PAM efficiency is also dependant upon site disturbance. Any disturbance to the application area, such as vehicle traffic, grading, large storm events, etc., greatly reduces the efficiency of the practice and requires reapplication to prevent soil loss. However, when properly applied, PAM has the ability to reduce soil loss by 40%.

Table 2-1: Summary of Erosion and Sediment Control Measures and Benefits

Control Measure	Benefits				
	Flow Control (Velocity)	Erosion Control (Stabilization)	Sediment Control (Removal)	Runoff Reduction (Volume)	Flow Diversion
L = Low, M = Medium, H = High					
Vegetative & Soil Stabilization Erosion Control Measures					
Compost Blanket	M	M	L	M	
Dust Control		M			
Grass Channel	L	H	L	L	
Mulching	L	M	L	L	
Permanent Seeding	M	H	M	M	
Temporary Rolled Erosion Control Products	L	H			
Sodding	M	H	M	M	
Surface Roughening	L	L		L	
Temporary Seeding	M	H	M	L	
Turf Reinforcement Mats	L	H			
Vegetative Filter Strip	L	L	M	L	
Polymers		H			
Structural Erosion Control Measures					
Check Dam	H		L		
Diversion Structure					H
Level Spreader	H				M
Rock Chutes and Flumes	M	H			
Rock Outlet Protection	H	H			
Flow Transition Mat	L	H			
Temporary Slope Drain					H
Sediment Control Measures					
Filter Berm	L		L		L
Filter Sock	L		L		L
Wattle	L		L		
Flocculents			H		
Floatation Silt Curtain			M		
Inlet Protection			L		
Sediment Basin	H		H	L	
Sediment Trap	H		H	L	
Silt Fence	L		M		M
Stabilized Construction Entrance			L		

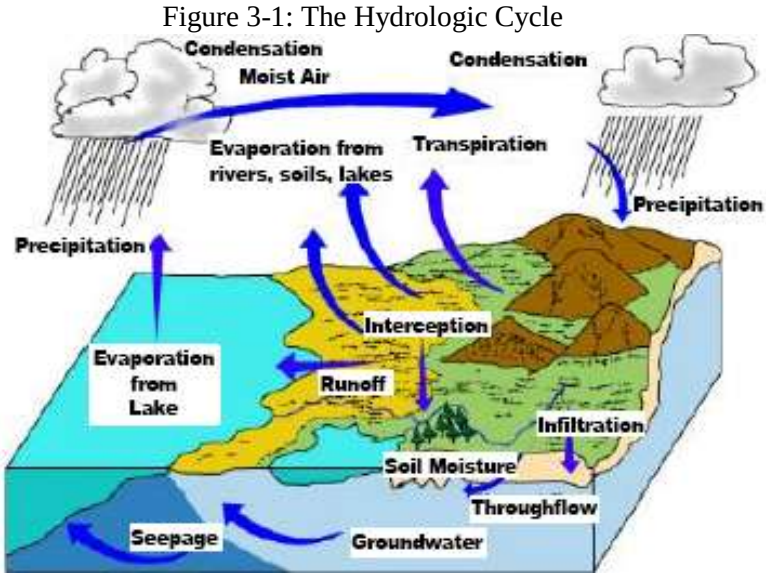
Chapter 3 – Stormwater

3.1 Understanding Stormwater

A. The Hydrologic Cycle

The hydrologic cycle, illustrated in Figure 3-1, is the movement of water from the atmosphere to the earth's surface. Water moves through one or more components of the cycle including evaporation, transpiration, runoff, precipitation, infiltration, percolation and its eventual return to the atmosphere. In an undeveloped area, with natural ground cover such as forest or meadow, a significant portion of precipitation infiltrates into the soil. This water is filtered and cooled as it travels underground. Some infiltrated water is subsequently discharged into rivers and streams as baseflow. Baseflow provides a steady contribution of high quality water to lakes, streams and rivers. Other infiltrated water descends deeper underground to the water table and recharges aquifers. Groundwater recharge replenishes the supply of underground water that can be extracted for domestic use and irrigation. Another portion of precipitation is returned to the atmosphere through a combination of evaporation and plant transpiration called evapotranspiration. Where there is natural ground cover, all of these processes together serve to minimize the percentage of precipitation that becomes runoff, the water that flows over that land surface into streams and other surface water bodies.

Figure 3-1: The Hydrologic Cycle

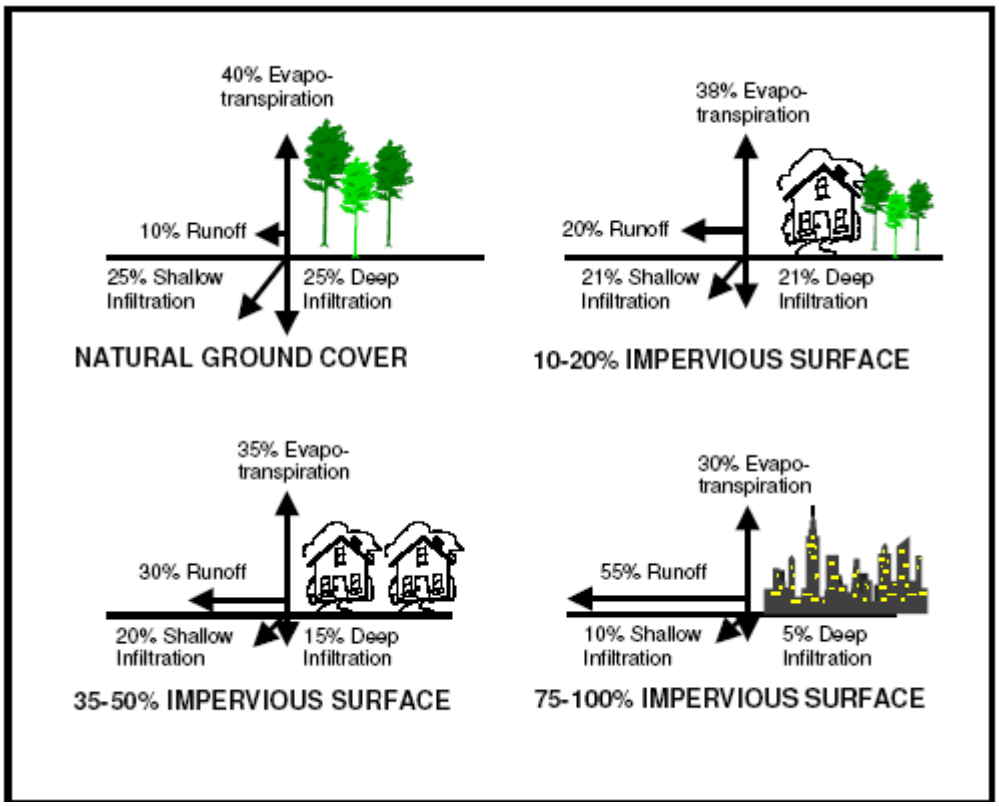


Adapted from: The Physical Environment: An Introduction to Physical Geography

Urbanization dramatically affects the hydrologic cycle by altering the relative percentage of precipitation that contributes to groundwater, evapotranspiration, and runoff relative to the natural ground cover. Specifically, urbanization increases runoff by decreasing the amount of water that infiltrates into the ground and is taken up and transpired by plants. This is because water cannot infiltrate into, and plants cannot grow on, impervious surfaces such as pavement and rooftops. Figure 3-2 illustrates how watershed imperviousness affects the magnitude of each of the hydrologic cycle components. Increased stormwater runoff not only decreases baseflow and groundwater recharge, but also increases the amount of water that runs off the surface, picking up and carrying pollutants to lakes, streams, rivers and wetlands. The

increased surface runoff increases flooding frequency and severity while the increased input of pollutants degrades water quality and aquatic habitat.

Figure 3-2: Impact of Impervious Area on the Hydrologic Cycle Fluxes

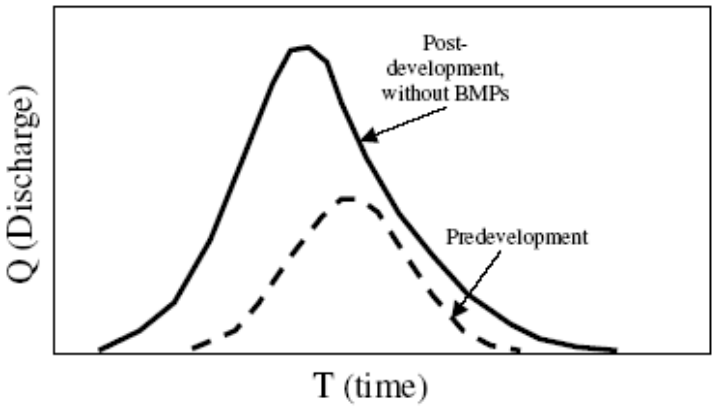


Adapted from: Prince Georges County Department of Environmental Resources Programs and Planning Division, 1999. *Low-impact Development Design Strategies: An Integrated Design Approach*. Department of Environmental Resources, Prince Georges County, Maryland.

B. Hydrographs

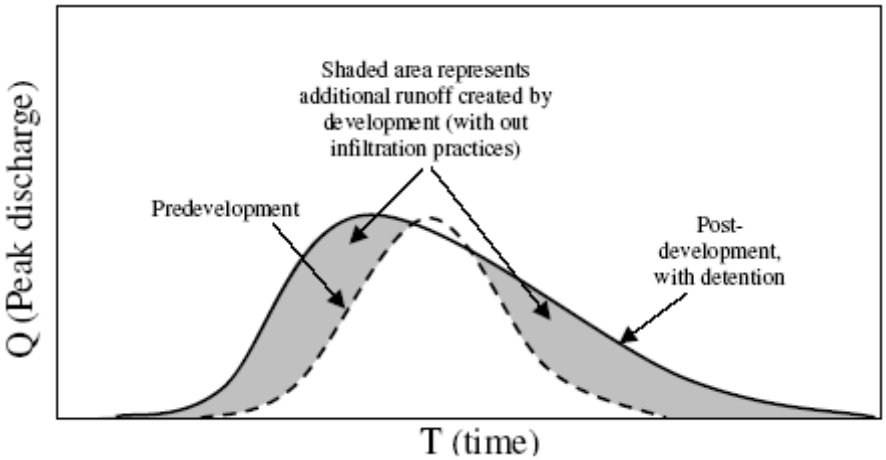
Stormwater hydrographs are plots of runoff discharge versus time. They illustrate a site's response to a storm event. The highest point on a hydrograph represents the peak flow rate following a storm, and the area under the graph represents the total volume of runoff generated by the storm. Figure 3-3 shows the significant difference between a pre- and post-development hydrograph, specifically, the figure displays that development increases the volume, peak flow rate and duration of stormwater runoff following a storm event.

Figure 3-3: Pre- and Post-Development Storm Hydrograph



The increase in impervious surfaces increases the volume of runoff produced because it reduces infiltration, thus reducing baseflow. The impacts of these changes include increased flooding, erosion, channel widening, habitat loss, and streambed erosion.

Figure 3-4: Hydrograph with Stormwater Detention Practices Installed



Note from Figure 3-4 that conventional, stormwater detention practices can affect the timing and magnitude of the peak flow rate, but do not equate the volume of pre- and post-development runoff. This is because these management practices retain water and release it at a peak rate equal to predevelopment conditions, but do not facilitate infiltration and evapotranspiration. In order to decrease runoff and partially mitigate the adverse impacts of increased imperviousness, infiltration standards are implemented.

C. Management of Stormwater Quality and Quantity

By utilizing site design techniques that incorporate on-site storage and infiltration and reduce the amounts of directly connected impervious surfaces, the amount of runoff generated from a site can be significantly reduced. This can reduce the necessity for traditional structural BMPs to manage runoff from newly developed areas. There are a number of practices that can be used to promote on-site storage and infiltration and to limit the amount of impervious surfaces that are generated. However, the use of on-site infiltration can be limited in certain areas due to factors such as slope, depth to the water table, and geologic conditions.

1. Site design features such as providing rain barrels, dry wells or infiltration trenches to capture rooftop and driveway runoff, maintaining open space, preserving stream buffers

and riparian corridors, using porous pavement systems for parking lots and driveways, and using grassed filter strips, bioswales, vegetated swales, and other green infrastructures in place of traditional curb-and-gutter type drainage systems can greatly reduce the amount of stormwater generated from a site and the associated impacts.

2. Street construction features such as placing sidewalks on only one side of the street, limiting street widths, reducing frontage requirements, installing curb cuts to redirect flow from impervious surfaces to pervious areas and eliminating or reducing the radius of cul-de-sacs have the potential to significantly reduce the amount of impervious surfaces and therefore the amount of rainfall that is converted to runoff.

3. Construction practices such as minimizing disturbance of soils and avoiding compaction of lawns and greenways with construction equipment can help to maintain the infiltrative capacity of soils.

In areas that are already developed, flow control can be more complicated. Since a drainage infrastructure already exists, retrofitting these systems to provide flow control can be prohibitively expensive. Regional stormwater management systems can be used to manage runoff in these areas, but space considerations and high capital costs can limit their application.

Depending on site-specific constraints, however, there are a number of practices that can be incorporated on-site to reduce runoff volumes from these areas. Down spouts can be disconnected from the storm drain system and this rainfall can instead be collected and stored on a property in rain barrels to be used for watering lawns and landscaping during periods between events.

Infiltration and retention practices such as bioretention areas and infiltration trenches can be constructed to capture runoff from rooftops, lawns, and driveways and reduce the volume of runoff discharged to storm sewers. Alternatives such as using vegetated swales in place of traditional curb and- gutter piped conveyance systems can be considered to provide treatment and infiltration of small storm runoff. Stormwater from commercial areas and golf courses can be collected and stored in ponds and subsequently used for irrigation.

Stormwater reuse can help to maintain a more natural, pre-development hydrologic balance in the watershed (Livingston et al, 1998). Parking lots can also be used as short-term storage areas for ponded stormwater, and bioretention facilities placed around the perimeter of parking lots can be used to infiltrate this water volume.

In order to reduce the impacts to receiving waters from the high concentrations of pollutants contained in the runoff, BMPs can be implemented to remove these pollutants. Where the generation of runoff cannot be avoided, end-of-pipe structural BMPs may be implemented to decrease the impacts of stormwater discharges to receiving streams. However, BMPs are limited in their ability to control impacts, and frequently cause secondary impacts such as increased temperatures of discharges to receiving streams. BMPs that can be designed to provide significant flow attenuation include grassed swales, vegetated filter strips, detention and retention basins, wetland basins, and wetland channels and swales. These BMPs can also provide the added benefit of removing pollutants such as suspended solids and associated nutrients and metals from stormwater runoff.

The environmental aspects of stormwater quantity control must be carefully balanced against the hazard and nuisance effects of flooding. Large or intense storm events or rapid snowmelt can produce significant quantities of runoff from urban areas with high levels of imperviousness. This runoff must be rapidly transported from urbanized areas in order to prevent loss of life and property due to flooding of streets, residences, and businesses. This is frequently accomplished by replacing natural drainage paths in the watershed with paved gutters, storm sewers, or other artificial means of drainage. These drainage systems can convey runoff at a faster rate than natural drainage paths, allowing rapid transport of runoff away from areas where flooding is likely to occur. However, as large quantities of runoff are conveyed rapidly from the urban landscape and discharged to receiving streams, downstream areas can flood. Following urbanization, large volumes of runoff can be produced from even small storm events due to the high amounts of impervious surfaces. The increased volume and rate of runoff to local urban streams often occurs much more frequently following urbanization. Therefore, design of stormwater drainage systems must always balance flood protection with ecological concerns.

3.2 Stormwater Modeling Parameters

A. Rainfall Frequency Analysis:

Frequency analysis techniques are used to develop relationships between the average intensity, storm duration, and return period from rainfall data. Often, the rainfall depth is used in place of the average intensity. The Rainfall Frequency Atlas of the Midwest – Bulletin 71 (Huff and Angell, 1992), published by the Midwest Climate Center and the Illinois Water Survey, includes rainfall depth, duration, and return period frequency analysis in tabular format for Dubuque County. The Bulletin 71 data includes the additional rainfall data for the additional period or record since 1960, and is recommended as the primary source for single-event design procedures. Table 3-1 lists the rainfall depths for various storm events as published by Bulletin 71.

Table 3-1: Dubuque County 24-hour Rainfall Depth for Various Storm Events

Return Period	Rainfall Depth (in)
1-yr	2.32
2-yr	2.91
5-yr	3.67
10-yr	4.31
25-yr	5.11
50-yr	5.73
100-yr	6.36

B. Runoff Curve Number

The principal physical watershed characteristics affecting the relationship between rainfall and runoff are land use, land treatment, soil types, and land slope. The NRCS method uses a combination of soil conditions and land uses (ground cover) to assign a runoff factor to an area. These runoff factors, called runoff curve numbers (CN), indicate the runoff potential of an area. The higher the CN, the higher the runoff potential. Soil properties influence the relationship between runoff and rainfall since soils have differing rates of infiltration. Based on infiltration rates, the NRCS has divided soils into four hydrologic soil groups:

1. Group A soils have a low runoff potential due to high infiltration rates. These soils consist primarily of deep, well-drained sands and gravels.

2. Group B soils have a moderately low runoff potential due to moderate infiltration rates. These soils consist primarily of moderately deep to deep, moderately well- to well-drained soils with moderately fine to moderately coarse textures.
3. Group C soils have a moderately high runoff potential due to slow infiltration rates. These soils consist primarily of soils in which a layer exists near the surface that impedes the downward movement of water or soils with moderately fine to fine texture.
4. Group D soils have a high runoff potential due to very slow infiltration rates. These soils consist primarily of clays with high swelling potential, soils with permanently high water tables, soils with a clay pan or clay layer at or near the surface, and shallow soils over nearly impervious parent material.

Runoff curve numbers vary with the soil moisture conditions. Average antecedent runoff conditions (ARC II) are recommended for most hydrologic analysis, except in the design of state-regulated Category I dams where ARC III may be required. Areas with high water table conditions or are heavily irrigated may want to consider using ARC III antecedent runoff condition. Refer to Chapter 6 of the US Army Corps of Engineers engineering manual EM 1110-2-1417 for ARC adjustments.

The maximum runoff curve numbers listed in Table 3-2 shall be used in all pre-development hydrologic calculations subject to stormwater standards. In post-development conditions and pre-redevelopment conditions, developers are required to lower one HSG class from the native soil class to account for compaction, for all hydrologic calculations where disturbance has occurred, unless practices such as deep tilling, chisel plowing and incorporating organic matter into the upper soil surface have successfully restored the soil structure. If disturbance has not occurred, the post-development runoff curve number should be the same as in pre-development conditions. The maximum runoff curve numbers listed in Table 3-2 shall be used in all hydrologic calculations subject to stormwater standards.

Table 3-2: Maximum Runoff Curve Numbers for Projects in Dubuque County

Cover Type	Curve Numbers for Hydrologic Soil Group			
	A	B	C	D
Ag Use & Natural Open Space[1]	30	58	71	78
Mature Wooded Area[2]	30	55	70	77
Lawn Areas[3]	39	61	74	80
Impervious Area[4]	98	98	98	98

All runoff curve numbers were derived from TR-55.
[1] Runoff curve numbers are equivalent to the values for meadows in good condition with the intent to mimic pre-settlement conditions. Areas include pasture land, ranges, meadows, row crops and other open areas that do not have short grass similar to that found in residential lawns.
[2] Woods in good condition.
[3] Areas include residential, golf courses, cemeteries and other areas with short grass.
[4] Areas include roofs, sidewalks, paved streets and roads (excluding right-of-way), curbs, paved parking lots and driveways.

When a drainage area has more than one land use, directly connected impervious area (DCIA) (roads, front of houses, etc) shall be separated from pervious area and unconnected impervious areas (backs of houses, etc). A composite curve number may be calculated by combining pervious and unconnected impervious areas. It should be noted that when composite curve numbers are used, the analysis does not take into account the location of the specific land uses, but sees the drainage area as a uniform land use represented by the

composite curve number and therefore, this method shall be used only in cases where uniformity is present. An example of performing runoff curve number calculations is described below.

EXAMPLE:
Using the figures below, determine the pre-development and post-development runoff curve numbers for a 90.0 acres residential project site. Assume the site has hydrological soil group B and antecedent runoff conditions II. This site is proposed to have 50 lots with 6,400 sf of impervious area per lot, 2/3 directly connected and 1/3 indirectly connected (assume the 6,400 sf includes rooftops, sidewalks and driveways).

Figure 3-5: Pre-Development Land Use

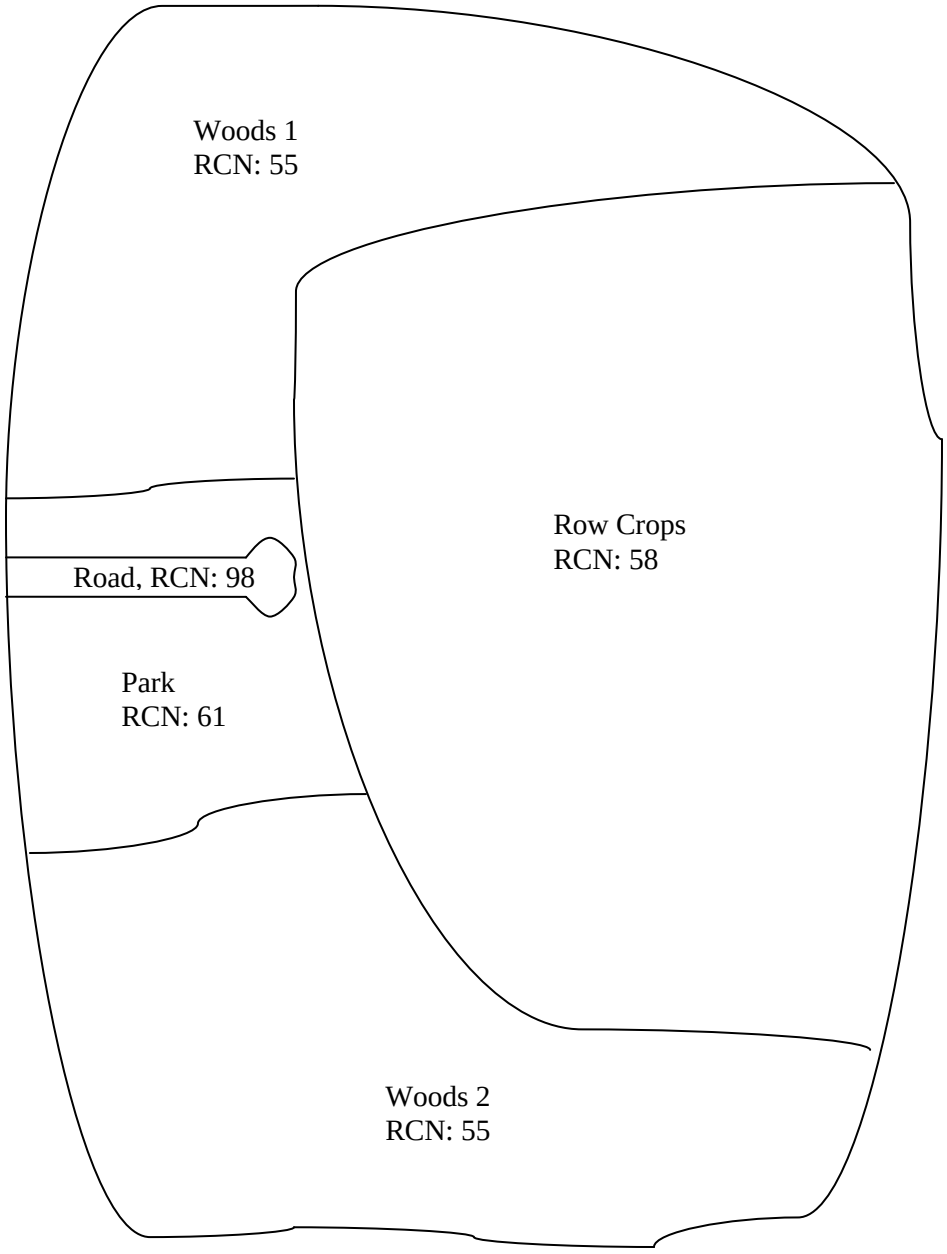
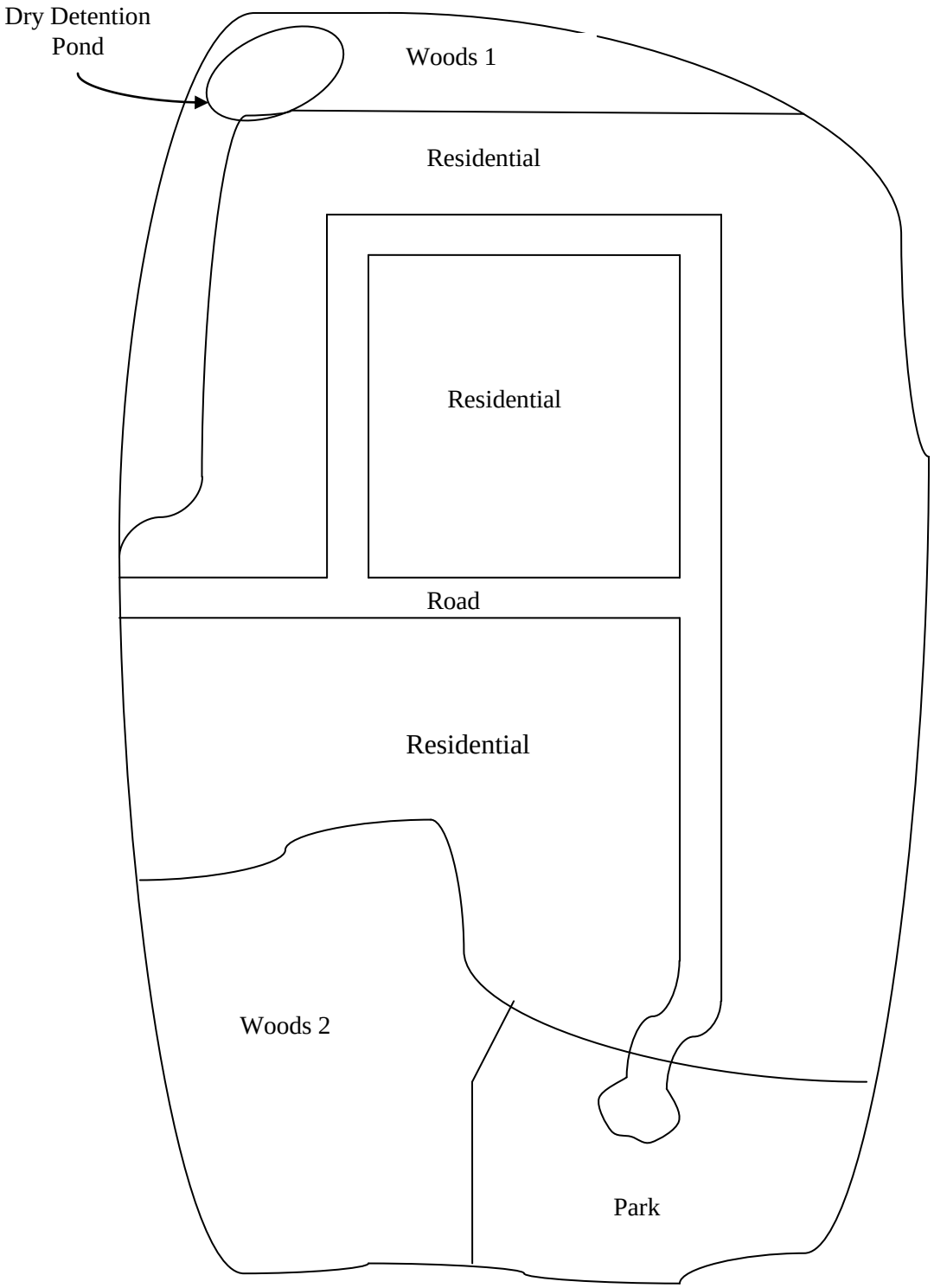


Table 3-3: Pre-development Runoff Curve Number Calculation

Watershed	**Land Area (Ac)**	**Land Area (%)**	**Curve Number**	**Weighted Curve Number (% Area x CN)**
Woods 1	15.0	16.67	55	9.17
Woods 2	24.5	27.22	55	14.97
Row Crops	45.4	50.44	58	29.26
Park	5.0	5.56	61	3.39
Road	0.1	0.11	98	0.11
Total	90.0	100	-	56.9

Figure 3-6: Post-Development Land Use



Note: See following page for RCN computations (Tables 3-4 and 3-5)

Table 3-4: Post-development Areas

Watershed	**Land Area (Ac)**	**Watershed 1***	**Watershed 2***	
		DCIA	**Unconnected Imperv. Area**	**Pervious Area**
Woods 1	2.5	0	0	2.5
Woods 2	16.0	0	0	16.0
Residential	61.6	4.9	2.5	54.2
Park	8.5	0	0	8.5
Road	0.9	0.9	0	0
Dry Detention Basin	0.5	0	0	0.5
Total	90.0	5.8	2.5	81.7

* DCIA watershed will have a RCN of 98.

**May be combined with weighted average (See Table 3-5)

Table 3-5: Indirectly Connected Post-development Runoff Curve Number Calculation

Watershed	**Land Area (Ac)**	**Land Area (%)**	**Curve Number**	**Weighted Curve Number (% Area x CN)**
Woods 1	2.5	2.97	55[A]	1.63
Woods 2	16.0	19.00	55[A]	10.45
Residential (Imperv. Area)	2.5	2.97	98	2.91
Residential (Pervious Area)	54.2	64.37	74[B]	47.63
Park	8.5	10.10	74[B]	7.47
Dry Detention Basin	0.5	0.59	74[B]	0.44
Total	84.2	100	-	70.5

[A] CN reflects woods in HSG B because this area was not disturbed in post-development conditions; therefore, the runoff curve number remains the same as in pre-development conditions.

[B] CN reflects HSG C values. As mentioned above, the permeability class is to be lowered by one for post-development calculations in disturbed areas to account for compaction.

The different land uses within the drainage basin should reflect a uniform hydrologic group, represented by a single curve number. Any number of land uses can be included, but if their spatial distribution is important to the hydrologic analysis, then subbasins should be created

and separate hydrographs developed and routed to the study point. Case-in-point, DCIA should be separated from the rest of the watershed.

C. Time of Concentration

The time of concentration is defined as the time required for water falling on the most remote point of a drainage basin to reach the outlet where remoteness relates to time of travel rather than distance. Probably a better definition is that it is the time after the beginning of rainfall excess when all portions of the drainage basin are contributing simultaneously to flow at the outlet.

The time of concentration (Tc) is used in numerous equations to calculate discharge. In most watersheds, it is necessary to add the many different time of concentrations resulting from different field conditions that runoff flows through to reach the point of investigation. Water moves through a watershed as sheet flow, shallow concentrated flow, swales, open channels, street gutters, storm sewers, or some combination of these. This section describes the many conditions and corresponding solutions that need to be considered when estimating the total time of concentration (Tc) (sum of runoff travel time).

There are also many methods utilized to estimate the time of concentration. Examples are the Kinematic Wave Method, Kirpich formula, Kerby formula, and the NRCS Velocity Method. The NRCS Velocity Method is one of the most common, is easily understood, has continuity with many computer programs, and is considered as accurate as other methods. It is for these reasons the NRCS Velocity Method is used in this manual. If there is a desire to use a different method in determining the time of concentration, the Engineer needs to be contacted for approval.

Using an appropriate value for time of concentration is very important, although it is hard sometimes to judge what the correct value is. DCIA should be analyzed separately from pervious area. In other words, the DCIA's should have its own time of concentration (typically 5 minutes) and CN (typically 98).

1. Factors affecting time of concentration:
   a. Surface roughness: One of the most significant effects of urban development on flow velocity is a decrease in retardance to flow. That is, undeveloped areas with very slow and shallow overland flow through vegetation become modified by urban development; the flow is then delivered to streets, gutters, and storm sewers that transport runoff downstream more rapidly. Travel time through the watershed is generally decreased.
   b. Channel shape and flow patterns: In small non-urban watersheds, much of the travel time results from overland flow in upstream areas. Typically, urbanization reduces overland flow lengths by conveying storm runoff into a channel as soon as possible. Since channel designs have efficient hydraulic characteristics, runoff flow velocity increases and travel time decreases.
   c. Slope: Slopes may be increased or decreased by urbanization, depending on the extent of site grading or the extent to which storm sewers and street ditches are used in the design of the water management system. Slope will tend to increase when channels are straightened and decrease when overland flow is directed through storm sewers, street gutters, and diversions.

2. Estimating time of concentration (NRCS velocity method)
   Travel time (T_t) is the ratio of flow length to flow velocity

$T_t = L / 3600(v)$

Equation 3-1

T_t = travel time (hrs)
L = flow length (ft)
V = average velocity (ft/s)
3600 = conversion factor from seconds to hours

Time of concentration (T_c) is the sum of T_t values for the various consecutive flow segments:

$T_c = T_{t1} + T_{t2} + T_{t3} \ldots\ldots\ldots\ldots T_{tm}$

Equation 3-2

T_c = time of concentration (hr)
T_t = travel time for flow component
m = number of flow segments

a. Sheet Flow:
The maximum sheet flow length to be used is 100 feet. Sheet flow is flow over plane surfaces (parking lots, farm fields, lawns). It usually occurs in the headwater of streams. With sheet flow, the friction value (Manning's n) is an effective roughness coefficient that includes the effect of raindrop impact; drag over the plane surface; obstacles such as litter, vegetation, crop ridges, and rocks; and erosion and transportation of sediment. These n values are for very shallow flow depths of about 0.1 foot. Table 3-6 gives Manning's n values for sheet flow for various surface conditions.

For sheet flow of less than 100 feet, use Manning's kinematic solution (Overton and Meadows, 1976) to compute Tt. Equation 3-3 displays Manning's kinematic equation.

Equation 3-3

$$T_t = \frac{0.007[(n)(L)]^{0.8}}{\sqrt{P_2}S^{0.4}}$$

T_t = travel time (hours)
n = Manning's roughness coefficient (Table 3-6)
L = flow length (ft)
P_2 = the 2-year, 24-hour rainfall (inches)
S = slope of hydraulic grade line (land slope, ft/ft)

This simplified form of Manning's kinematic solution is based on the following:
• Shallow steady uniform flow
• Constant intensity of rainfall excess (that part of a rain available for runoff)
• Rainfall duration of 24 hours
• Minor effect of infiltration on travel time

Table 3-6: Roughness Coefficients (Manning's n) for Sheet Flow

Surface Description	*n*[1]
Smooth surfaces (concrete, asphalt, gravel, or bare soil)	0.011
Fallow (no residue)	0.05
Cultivated soils:	
Residue cover <20%	0.06
Residue cover >20%	0.17
Grass:	
Short grass prairie	0.15
Dense grasses[2]	0.24
Bermuda grass	0.41
Range (natural)	0.13
Woods[3]:	
Light underbrush	0.40
Dense underbrush	0.80

[1] The n values are a composite of information compiled by Engman (1986).
[2] Includes species such as weeping lovegrass, bluegrass, buffalo grass, blue grama grass, and native grass mixtures.
[3] When selecting n, consider cover to a height of about 0.1 ft. This is the only part of the plant cover that will obstruct sheet flow.

b. Shallow concentrated flow (urban/suburban areas):
After a maximum of 100 feet, sheet flow (gutter, swales, etc.) usually becomes shallow concentrated flow. The average velocity (V) for this flow can be determined from Figure 3-7, in which average velocity is a function of watercourse slope and type of channel surface. For slopes less than 0.005 ft/ft, use equations given below for Figure 3-7. Tillage can affect the direction of shallow concentrated flow. Flow may not always be directly down the watershed slope if tillage runs across the slope. After determining average velocity in Figure 3-7, use Equation 3-4 to estimate travel time for the shallow concentrated flow segment.

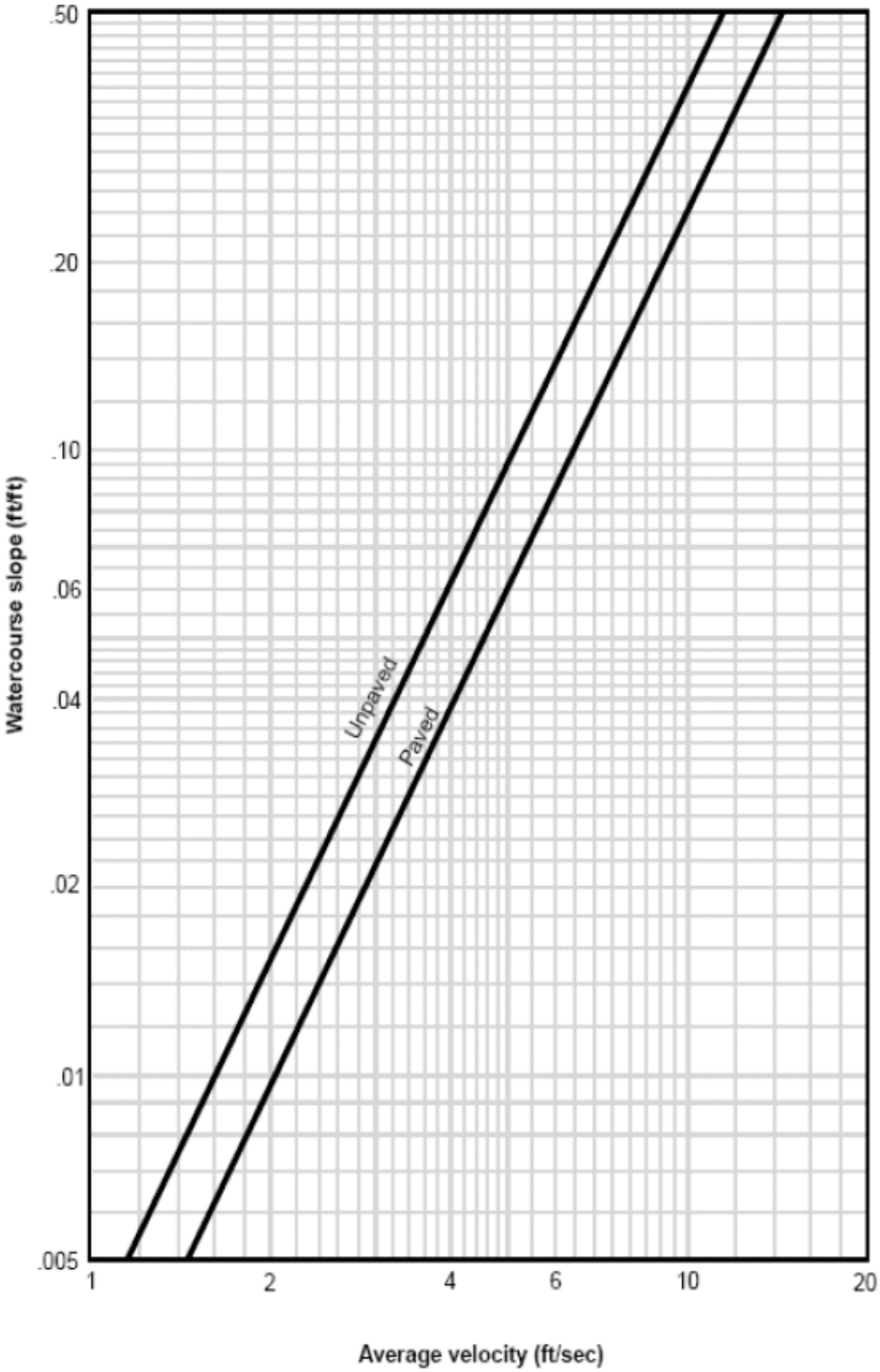
Unpaved V = 16.1345 (s) 0.5
Paved V = 20.3282 (s) 0.5

where:
V= average velocity (ft/s)
s = slope of hydraulic grade line, (watercourse slope, ft/ft)

These two equations are based on the solution of Manning's equation (Equation 3-4) with different assumptions for *n* (Manning's roughness coefficient) and *r* (hydraulic radius, ft). For unpaved areas, *n* is 0.05 and r is 0.4; for paved areas, *n* is 0.025 and r is 0.2.

Tillage and vegetation surfaces can affect the direction of shallow concentrated flow. Flow may not always be directly down the watershed slope if tillage runs across the slope. After determining average velocity (V) in Figure 3-7, use Equation 3-1 to estimate travel time for the shallow concentration flow segment.

Figure 3-7: Shallow Concentrated Flow



Source: NRCS Urban Hydrology for Small Watersheds, v 2.1, 1986

c. Open channels (open swales, ditches, and storm sewer piping under gravity flow): Open channels are assumed to begin where surveyed cross section information has been obtained, where channels are visible on aerial photographs, or where blue lines (indicating streams) appear on United States Geological Survey (USGS) quadrangle sheets. Manning's equation or water surface profile information can be used to estimate average flow velocity. Average flow velocity is usually determined for bankfull elevation.

Manning's equation:

Equation 3-4

$$V = \frac{1.49(R^{2/3})(S^{1/2})}{n}$$

V = average velocity (ft/s)
R = hydraulic radius (ft) and is equal to A/WP
A = cross sectional flow area (ft^2)
WP = wetted perimeter (ft)
S = slope of the hydraulic grade line (channel slope, ft/ft)
n = Manning's roughness coefficient for open channel flow (see Table 3-6)

Manning's n values for open channel flow can be obtained from standard textbooks such as Chow (1959) or Linsley et al. (1982). After average velocity is computed using Equations 3-3 and 3-4, T_t for the channel segment can be estimated using Equation 3-1

d. Notes:

- Manning's kinematic solution should not be used for sheet flow longer than 100 feet. Equation 3 was developed for use with the four standard rainfall intensity-duration relationships.
- The minimum Tc to use is 5 minutes.

Worksheet 1: Time of Concentration (T_c) or Travel Time (T_t)

Project _____ By _____ Date _____

Location _____ Checked _____ Date _____

Circle one: Present Developed

Circle one: T_c T_t through sub area

Notes: Space for as many as two segments per flow type can be used for each worksheet.

Include a map, schematic, or description of flow segments.

Sheet flow (Applicable to T_c only)	Segment ID					
. Surface description (Table 2)……						
:. Manning's roughness coeff., n (Table 2)……..						
:. Flow Length, L (Total L less than or equal to 300')…	ft					
:. Two-year 24-hour rainfall, P_2…….	in					
:. Land slope, s……	ft / ft					
i. $T_t = \frac{0.007(nL)^{0.8}}{(\sqrt{P_2})(s^{0.4})}$ Compute T_t……..	hr		+		=	

Shallow concentrated flow	Segment ID					
'. Surface description (paved or unpaved)……..						
:. Flow length, L……	ft					
'. Watercourse slope, s……..	ft / ft					
0. Average velocity, V (Figure 1)……	ft / s					
1. $T_t = \frac{L}{3600V}$ Compute T_t……..	hr		+		=	

Open channel flow	Segment ID					
2. Cross sectional flow area, a……..	ft^2					
3. Wetted perimeter, P_w……..	ft					
4. Hydraulic radius, $r = \frac{a}{P_w}$ Compute r……	ft					
5. Channel slope, s……..	ft / ft					
6. Manning's roughness coeff., n……..						
7. $V = \frac{1.49r^{2/3}s^{1/2}}{n}$ Compute V……..	ft / s					
8. Flow length, L……	ft					
9. $T_t = \frac{L}{3600V}$ Compute T_t……..	hr		+		=	

:0. Watershed or subarea T_c or T_t (add T_t in steps 6, 11 and 19)…… hr

Worksheet 2: Time of Concentration (T_c) or Travel Time (T_t)

Project *Example* By _____ Date _____

Location _____ Checked _____ Date _____

Circle one: Present Developed

Circle one: T_c T_t through subarea

Notes: Space for as many as two segments per flow type can be used for each worksheet. Include a map, schematic, or description of flow segments.

	Sheet flow (Applicable to T_c only)	Segment ID	AB			
1.	Surface description (Table 2)……		Dense Grass			
2.	Manning's roughness coeff., n (Table 2)……..		0.24			
3.	Flow Length, L (Total L less than or equal to 300')…	ft	100			
4.	Two-year 24-hour rainfall, P_2…….	in	3.6			
5.	Land slope, s…….	ft / ft	0.01			
6.	$T_t = \frac{0.007(nL)^{0.8}}{(\sqrt{P_2})(s^{0.4})}$ Compute T_t……..	hr	0.30	+	=	0.30

	Shallow concentrated flow	Segment ID	BC			
7.	Surface description (paved or unpaved)……..		Unpaved			
8.	Flow length, L……	ft	1400			
9.	Watercourse slope, s……...	ft / ft	0.01			
10.	Average velocity, V (Figure 1)……	ft / s	1.6			
11.	$T_t = \frac{L}{3600V}$ Compute T_t……..	hr	0.24	+	=	0.24

	Open channel flow	Segment ID	CD			
12.	Cross sectional flow area, a……...	ft^2	27			
13.	Wetted perimeter, P_w……..	ft	28.2			
14.	Hydraulic radius, $r = \frac{a}{P_w}$ Compute r……	ft	0.957			
15.	Channel slope, s……..	ft / ft	0.005			
16.	Manning's roughness coeff., n……...		0.05			
17.	$V = \frac{1.49 r^{2/3} s^{1/2}}{n}$ Compute V……...	ft / s	2.05			
18.	Flow length, L……	ft	7300			
19.	$T_t = \frac{L}{3600V}$ Compute T_t……..	hr	0.99	+	=	0.99
20.	Watershed or subarea T_c or T_t (add T_t in steps 6, 11 and 19)……				hr	1.53

3.3 Calculating and Modeling Performance Standards

A. Channel Protection Volume (CPv)

To protect channels from erosion, 24-hour extended detention of the 1-year, 24-hour storm event should be provided. The rationale for this criterion is that runoff will be stored and released in such a gradual manner that critical erosive velocities during bank-full and near-bank-full events will seldom be exceeded in downstream channels. The following represent the minimum basis for designing for channel protection storage volume:

- The models TR-55 and TR-20 (or approved equivalent) are used for determining peak discharge rates.
- Off-site areas are modeled as present land use in good condition for the 1-year storm event.
- The length of overland flow used in time of concentration (tc) calculations is limited to no more than 100 feet and should use the manning's n factor for short grass for post development conditions.
- A Cpv orifice diameter (do) of less than 3 inches is subject to approval by the appropriate review authority and is not recommended unless an internal control for orifice protection is used.
- Cpv is calculated for the entire site. If a site consists of multiple drainage areas, Cpv may be distributed proportionately to each drainage area.
- The stormwater storage needed for Cpv may be provided above the WQv storage in stormwater ponds and wetlands; thereby meeting all storage criteria except Rev in a single facility with appropriate hydraulic control structures for each storage requirement.
- Infiltration is not recommended for Cpv control because of large storage requirements.

B. Water Quality Volume (WQv)

The water quality volume (WQv) is the storage needed to capture and treat the runoff from 90% of the average annual rainfall. In numerical terms, it is equivalent to the rainfall depth in inches (the 90% cumulative frequency rainfall depth) multiplied by the volumetric runoff coefficient (Rv) for the site, and the site drainage area. The design rainfall depth to be used for determining the WQv in Iowa is 1.25 inches. (Note: this depth is determined based on the long-term rainfall record; rainfall events less than 0.1 inch were not included in the total number of events. An explanation of how this design rainfall depth was calculated is located in Section 2C-2 of the Iowa Stormwater Manual.) The 3-month recurrence interval rainfall depth for a particular climate region can be used as an initial approximation.

1. Basis for determining water quality treatment volume:
   As a basis for design, the following assumptions may be made:
   a. Measuring impervious cover: The measured area of a site plan that does not have vegetative or permeable cover shall be considered total impervious cover. DCIA should be analyzed separately from unconnected impervious area and pervious area.
   b. Multiple drainage areas: When a project contains or is divided by multiple drainage areas, the WQv is addressed for each drainage area.
   c. Offsite drainage areas: The WQv is based on the impervious cover of the proposed site. Offsite existing impervious areas may be excluded from the calculation of the WQv requirements.

d. Subtraction for structural practices: Where structural practices for treating the Rev are employed upstream of a BMP, the recharge volume requirements (Rev) may be subtracted from the WQv used for design.

2. Methods for Determining Water Quality Treatment Volume:
   Two methods can be utilized to estimate the WQv. Both rely on computing a volumetric runoff coefficient (Rv) and multiplying this by the rainfall volume to obtain a runoff volume in watershed inches.

   Short cut method.
   The first method uses Equation 3-6 to estimate the volumetric runoff coefficient, Rv (Schueler, 1987). It is recommended that the short cut method be used where the site consists of predominately one type of land surface or for quick calculations to obtain a reasonably accurate estimate of the water quality treatment volume.

   The following equations are used to determine the storage volume, WQv (in acre-feet of storage):
   - Water Quality Volume (WQv):

$$WQv = \frac{[(P)(Rv)(A)]}{12} \qquad \text{Equation 3-5}$$

P = rainfall depth in inches (1.25)
A = Area in acres

- Volumetric Runoff Coefficient for the Project Site (Rv):

$$Rv = 0.05 + 0.009(I) \qquad \text{Equation 3-6}$$

I = Impervious Area (%)

<u>Example calculation of the short cut method:</u>
Assume a 5-acre commercial (business park) development that is 64% impervious. The design rainfall depth, P, (90% cumulative rainfall frequency) is 1.25 inches.

$Rv = 0.05 + 0.009(64\%)$
$Rv = 0.63$

$$WQv = \frac{(1.25\text{ in})(0.63)(5\text{ Ac})}{12\text{ in/ft}}$$

$WQv = 0.328\text{ Ac-ft} * 43560\text{ ft}^2/\text{acre} = 14{,}293\text{ ft}^3$

Small storm hydrology method:
The second method utilizes the work done by Pitt and others to compute an Rv based on the specific characteristics of the pervious and impervious surfaces of the drainage catchment. This method presents a relatively simple relationship between rainfall amount, land surface, and runoff volume. The Rv's used to compute the runoff volumes are identified in Table 3-7. The small storm hydrology model involves the following:

i. For a given rainfall depth, the runoff coefficients for land surfaces present on the subject site are selected. Rainfall coefficients for open space shall be lowered by one permeability class (HSG) for all post-development hydrologic calculations where disturbance has occurred, unless practices such as deep tilling, chisel

plowing, and incorporating organic matter into the upper soul surface have successfully restored soil structure. If disturbance has not occurred, the post-development runoff coefficient should be the same as in pre-development conditions.

ii. A weighted runoff coefficient for the entire site is computed.

iii. If a portion of the site has disconnected impervious surfaces, reduction factors are applied to Rv. The reduction factors (from Table 3-8) are multiplied by the computed Rv for connected impervious areas to obtain the corrected value.

iv. For the given rainfall, the runoff volume (in watershed inches) is computed. WQV is equal to the rainfall times the Rv (same as Equation 3-5 above).

Table 3-7: Volumetric Runoff Coefficient Rv for DCIA's

Impervious Area	Precipitation (in)
Flat roofs and large unpaved parking lots	0.86
Pitched roofs and large impervious areas (large parking lots)	0.98
Small impervious areas and narrow streets	0.74
Sandy soils (HSG A)	0.03
Silty soils (HSG B)	0.13
Clayey soils (HSG C and D)	0.22

Source: Pitt, 1994

Table 3-8: Reduction Factors to Volumetric Runoff Coefficient Rv for Unconnected Impervious Surfaces

Impervious Area	Precipitation (in)
Strip commercial shopping center	0.99
Medium to high density residential with paved alleys	0.48
Medium to high density residential without alleys	0.22
Low density residential	0.22

Source: Pitt, 1994

The small storm hydrology method has the advantage of evaluating the precise elements of a particular site and can be utilized for most design applications to estimate accurate runoff volumes. The method requires somewhat more effort to identify the specific land surface area ratios and additional effort is needed to assess the disconnections of impervious areas. The method rewards site designs that utilize disconnections of impervious surfaces by lowering the computed Rv and the required WQv. An example calculation for the small storm hydrology method is below:

<u>Example calculation of the small storm hydrology method:</u>
Assume a 5-acre shopping center having a 1.8-acre flat roof, 2.2-acres of parking, and a 1-acre open space (HSG-B soil), for a 1.25-inch rainfall event and no disconnection of impervious surfaces.

The average weighted volumetric runoff coefficient (using Table 3-7):

Flat roof:	1.8 Ac	x	0.86 in	= 1.55 Ac-in
Parking:	2.2 Ac	x	0.98 in	= 2.16 Ac-in
Open Space:	1.0 Ac	x	0.13 in	= 0.13 Ac-in
Total:	5.0 Ac			= 3.84 Ac-in

The weighted volumetric runoff coefficient:

Rv = 3.84 Ac-in / 5.0 Ac = 0.77 in

$$WQv = \frac{(1.25\ in)(0.77\ in)(5.0\ Ac)}{12\ in/ft}$$

$$WQv = 0.401\ Ac\text{-}ft * 43560\ ft^2/acre = 17{,}469\ ft^3$$

For a major sediment control device such as sediment basin or sediment trap to perform efficiently, it must be large enough to detain the contaminated runoff for a sufficient time to allow suspended particles to settle out, allow a sufficient flow of water through the system to prevent flooding, and be small enough that it is cost-effective to construct. In order to size an efficient basin, an understanding of Stoke's Law is required. An explanation of Stokes Law is located in Section 7D of the SUDAS Manual.

Infiltration

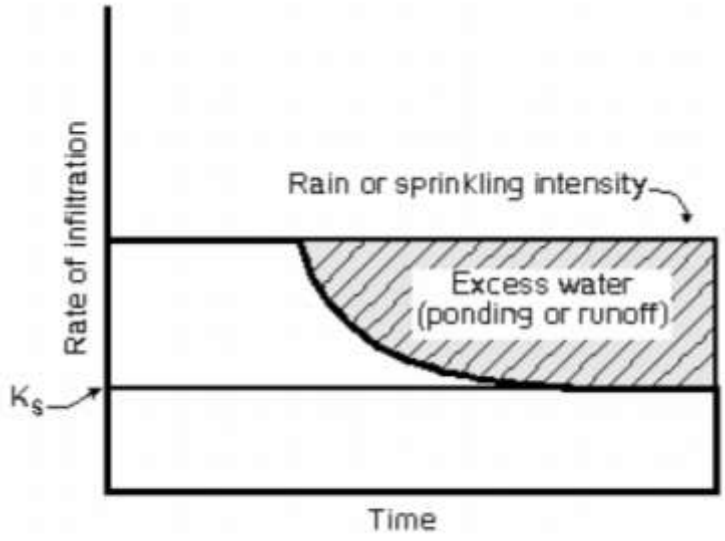
1. Infiltration Fundamentals:

   Infiltration is the downward movement of water from the land surface into the soil profile. Infiltration can occur naturally following precipitation, or can be induced artificially through structural modifications in the ground surface. Some water that infiltrates will remain in the shouldow soil layer, where it will gradually move vertically and horizontally through the soil and subsurface material. Eventually, it might enter a stream by seepage into the stream bank. Some of the water may continue to move deeper (percolate), recharging the local groundwater aquifer. A dry soil has a defined capacity for infiltrating water. The capacity can be expressed as a depth of water that can be infiltrated per unit time, such as inches per hour. If rainfall supplies water at a rate that is greater than the infiltration capacity, water will infiltrate at the capacity rate, with the excess either being ponded, moved as surface runoff, or evaporated. If rainfall supplies water at a rate less than the infiltration capacity, all of the incoming water volume will infiltrate. In both cases, as water infiltrates into the soil, the capacity to infiltrate more water decreases and approaches a minimum capacity. When the supply rate is equal to or greater than the capacity to infiltrate, the minimum capacity will be approached more quickly than when the supply rate is much less than the infiltration capacity.

   As precipitation infiltrates into the subsurface soil, it generally forms an unsaturated (vadose) zone and a saturated (phreatic) zone. In the unsaturated zone, the voids (spaces between grains of gravel, sand, silt, clay, and cracks within rocks) contain both air and water. Although a lot of water can be present in the unsaturated zone, this water cannot be pumped by wells because capillary forces hold it too tightly. The upper part of the unsaturated zone is the soil-water zone. The soil zone is crisscrossed by roots, openings left by decayed roots, and animal and worm burrows, which allow the precipitation to infiltrate into the soil zone. Water in the soil is used by plants in life functions and leaf transpiration, but it also can evaporate directly to the atmosphere. Below the unsaturated zone is a saturated zone where water completely fills the voids between rock and soil particles.

   Generally, soil-water infiltration has a high rate in the beginning, decreases rapidly, and then slowly decreases until it approaches a constant rate. As shown in Figure 3-8, the infiltration rate will eventually become steady and approach the value of the saturated hydraulic conductivity.

Figure 3-8: Decrease of Infiltration Rate



Source: Hillel, 1982

The slope of the land can also indirectly impact the infiltration rate. A steep slope will result in runoff, which will impact the amount of time the water will be available for infiltration. In contrast, gentle slopes will have less of an impact on the infiltration process due to decreased runoff. When compared to the bare soil surface, vegetation cover tends to increase infiltration by retarding surface flow, allowing time for water infiltration. Plant roots may also increase infiltration by increasing the hydraulic conductivity of the soil surface through the creation of additional pore space. Due to these impacts, infiltration may vary widely under different types of vegetation.

2. Infiltration Systems:
   Surface infiltration can be achieved through the use of grass buffer strips, vegetated swales, and porous pavement systems. Infiltration systems such as infiltration trenches, infiltration basins, and bioretention areas (including rain gardens) are designed specifically to capture a defined volume of storm runoff and transfer it directly to the soil profile. Several integrated practices, such as soil quality restoration and native landscaping, can be used in conjunction with these practices to improve the infiltration capacity of compacted urban soils. An infiltration BMP is designed to capture a volume of stormwater runoff, retain it, and infiltrate all or part of that volume into the ground. Infiltration of stormwater has a number of advantages and disadvantages. The advantages of infiltration include both water quantity control and water quality control.
   a. Water quantity control can occur by capturing and retaining surface runoff and infiltrating the water into the underlying soil, reducing the volume of water discharged directly to receiving streams. Infiltration systems can be designed to capture the volume of stormwater from the smaller, more frequent storm events (water quality volume) and infiltrate this water into the ground over a period of several hours or days. Infiltration can provide a secondary benefit by increasing recharge of underlying aquifers and increasing baseflow levels of nearby streams.
   b. Water quality treatment can be attained when pollutant removal occurs as water percolates through the various soil layers. As the water moves through the soil,

particles can be filtered out. In addition, microorganisms in the soil can degrade organic pollutants that are contained in the infiltrated stormwater.

There are two general types of situations where infiltration practices may be used:

a. For determining the dimensions of an infiltration device that is required to provide storage of the WQv, Cpv, and/or Qp.
b. Site conditions may dictate the layout and capacity of infiltration measures, and one might be interested in determining the level of control provided by such a layout. In the latter case, control may not be sufficient. Additional control, possibly from other BMPs, may be needed.

The same principles of design apply to both situations. Although infiltration of stormwater has many benefits, it also has some drawbacks:

a. Infiltration may not be appropriate in areas where groundwater is a primary source of drinking water, due to the potential for contaminant migration. This is especially true if the runoff is from a commercial or industrial area where there may be contamination from organics or metals.
b. The performance of infiltration BMPs will also be limited in areas with low-permeability soils.
c. In addition, infiltration BMPs can experience reduced infiltrative capacity, and even clogging, due to excessive sediment accumulation. Frequent maintenance may be required to restore the infiltrative capacity of the system. Care must also be taken during construction to limit sediment generation and compaction of the soil layers underlying the BMP, to avoid reducing the infiltrative capacity.

3. Soils Testing Requirements for Infiltration Practices

The requirements in this section define the site evaluation procedures to:

a. Perform an initial screening of a development site to determine its suitability for infiltration.
b. Evaluate each area within a development site that is selected for infiltration.
c. Prepare a site evaluation report.

<u>Purpose</u>

a. Establish methodologies to characterize the site.
b. Establish requirements for siting an infiltration device and the selection of design infiltration rates.
c. Define requirements for a site evaluation report that ensures appropriate areas are selected for infiltration and an appropriate design infiltration rate is used.

These requirements are intended for development sites being considered for stormwater infiltration devices. Additional site location requirements may be imposed by other stormwater infiltration device technical standards.

Criteria

The site evaluation consists of four steps for locating the optimal areas for infiltration and properly sizing infiltration practices. Steps 1 and 2 are completed as soon as possible in the approval process.

- Step 1: Initial screening
- Step 2: Field verification of information collected in Step 1
- Step 3: Evaluation of specific infiltration areas
- Step 4: Soil and site evaluation reporting

The steps should coincide, as much as possible, for when the information is needed to determine the following:
- Potential for infiltration on the site
- Optimal locations for infiltration devices
- Final design of the infiltration device(s)

a. Step 1: Initial screening.
   The initial screening identifies potential locations for infiltration devices. The purpose of the initial screening is to determine if installation is limited by any of the general restrictions for infiltration practices, and to determine where field work is needed for Step 2. Optimal locations for infiltration are verified in Step 2. Information collected in Step 1 will be used to explore the potential for multiple infiltration areas versus relying on a regional infiltration device. Smaller infiltration devices dispersed around a development are usually more sustainable than a single regional device that is more likely to have maintenance and groundwater mounding problems. The initial screening should determine the following:
   i. Site topography and slopes greater than 20%.
   ii. Site soil infiltration capacity characteristics as defined in NRCS county soil surveys.
   iii. Soil parent material.
   iv. Regional or local depth to groundwater and bedrock. Use seasonally high groundwater information where available.
   v. Distance to sites identified as closed remediation sites within 500 feet from the perimeter of the development site.
   vi. Presence of endangered species habitat.
   vii. Presence of floodplains and flood fringes.
   viii. Location of hydric soils based on the USDA county soil survey and wetlands within or adjacent of the project area.
   ix. Sites where the installation of stormwater infiltration devices would not be recommended due to the potential for groundwater contamination as described below:
      1) An area within 250 feet of a private well.
      2) An area within 1000 feet of a municipal well.
      3) An area within 300 feet upslope or 100 feet downslope of karst features.
      4) A channel with a cross-sectional area equal to or greater than 3 ft^2 that flows to a karst feature.
      5) An area where the soil depth to groundwater or bedrock is less than 2 feet.
      6) Potential impact to adjacent property.

b. Step 2: Field verification of the initial screening.
   i. Field verification is required for areas of the development site considered suitable for infiltration. This includes verification of Steps ai to aiv, aix3, aix4 and aix5.

i. Sites should be tested for depth to groundwater, depth to bedrock and percent fines information to verify any exemption and exclusion. The following is a description of the percent fines expected for each type of soil textural classification: Several textural classes are assumed to meet the percent fines limitations for both 3- and 5- foot soil layers. These classifications would include the sandy loams, loams, silt loams, and all the clay textural classifications. Coarse sand is the only soil texture that, by definition, will not meet the limitations for a 3-foot soil layer consisting of 20% fines. Other sand textures and loamy sands may need the percent fines level verified with a laboratory analysis.

ii. Borings and pits should be dug to verify soil infiltration capacity characteristics and to determine depth to groundwater and bedrock.

iii. The following information should be recorded for Step 2:

1) The date or dates the data was collected.

2) A legible site plan/map that is presented on paper that is no less than 8 ½ x 11 inches in size and:
   - Is drawn to scale or fully-dimensional
   - Illustrates the entire development site
   - Shows all areas of planned filling and/or cutting
   - Includes a permanent vertical and horizontal reference point
   - Shows the percent and direction of land slope for the site or contour lines. Highlight areas with slopes over 20%.
   - Shows all floodplain information that is pertinent to the site
   - Shows the location of all pits/borings included in the report
   - Location of wetlands as field delineated and surveyed
   - Location of karst features, private wells within 100 feet of the development site, and public wells within 400 feet of the development site

3) Soil profile descriptions are written in accordance with the descriptive procedures, terminology and interpretations found in the Field Book for Describing and Sampling Soils, USDA, NRCS, 1998. Frozen soil material must be thawed prior to conducting evaluations for soil color, texture, structure and consistency. In addition to the data determined in Step B, soil profiles must include the following information for each soil horizon or layer:
   - Thickness, in inches or decimal feet
   - Munsell soil color notation
   - Soil mottle or redox feature color, abundance, size, and contrast
   - USDA soil textural class with rock fragment modifiers
   - Soil structure, grade size, and shape
   - Soil consistence, root abundance, and size
   - Soil boundary
   - Occurrence of saturated soil, groundwater, bedrock, or disturbed soil

c. Step 3: Evaluation of specific infiltration areas.
This step is to determine if locations identified for infiltration devices are suitable for infiltration, and to provide the required information to design the device. A minimum number of borings or pits should be constructed for each infiltration device (Table 3-9). The following information should be recorded for Step 3:

i. All the information under Step 1.

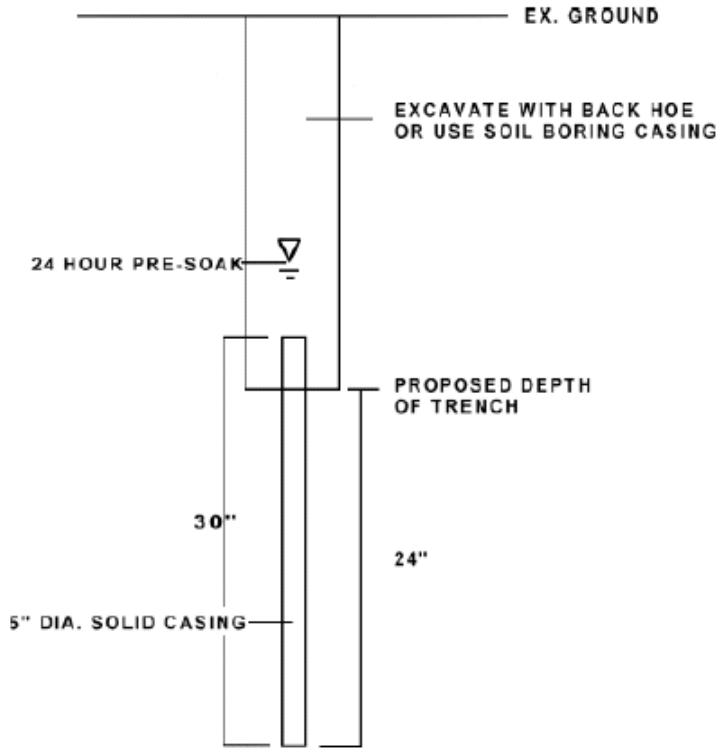
ii. A legible site plan/map that is presented on paper no less than 8 1/2 x 11 inches in size and:
   - Is drawn to scale or fully dimensional
   - Illustrates the location of the infiltration devices
   - Shows the location of all pits and borings
   - Shows distance from device to wetlands

iii. An analysis of groundwater mounding potential is required as per Table 3-9. The altered groundwater level, based on mounding calculations, must be considered in determining the vertical separation distance from the infiltration surface to the highest anticipated groundwater elevation. References include, but are not limited to Bouwer (1999), Guo (1998, 2001), Hantuch (1967).

iv. One of the following methods should be used to determine the design infiltration rate:
   1) Infiltration rate not measured. Table 3-10 should be used if the infiltration rate is not measured. Select the design infiltration rate from Table 3-10 based on the least-permeable soil horizon 5 feet below the bottom elevation of the infiltration system.
   2) Measured infiltration rate. The tests should be conducted at the proposed bottom elevation of the infiltration device. Two procedures are recommended for the infiltration testing: Infiltration test column and double ring infiltrometer. The procedure of the infiltration test column is summarized below. If the infiltration rate is measured with a double-ring infiltrometer, the requirements of ASTM D3385 should be used for the field test.

v. Procedure for infiltration test column.
   1) Install casing (solid 5-inch diameter, 30-inch length) to 24 inches below proposed BMP bottom (see Figure 3-9).
   2) Remove any smeared soiled surfaces, and provide a natural soil interface into which water may percolate. Remove all loose material from the casing. Upon the tester's discretion, a 2-inch layer of coarse sand or fine gravel may be placed to protect the bottom from scouring and sediment. Fill casing with clean water to a depth of 24 inches, and allow to pre-soak for 24 hours.
   3) After 24 hours, refill casing with another 24 inches of clean water, and monitor water level (measured drop from the top of the casing) for 1 hour. Repeat this procedure (filling the casing each time) three additional times, for a total of four observations or until there is no measurable change in the readings. Upon the tester's discretion, the final field rate may either be the average of the four observations, or the value of the last observation. The final rate should be reported in inches per hour.
   4) May be done through a boring or open excavation.
   5) The location of the test should correspond to the BMP location.
   6) Upon completion of the testing, the casings should be immediately pulled, and the test pit should be backfilled.

Figure 3-9: Infiltration Testing Requirements



The measured infiltration rate should be divided by a correction factor selected from Table 3-11. The correction factor adjusts the measured infiltration rates for the occurrence of less permeable soil horizons below the surface and the potential variability in the subsurface soil horizons throughout the infiltration site.

A less-permeable soil horizon below the location of the measurement increases the level of uncertainty in the measured value. Also, the uncertainty in a measurement is increased by the variability in the subsurface soil horizons throughout the proposed infiltration site.

To select the correction factor from Table 3-11, the ratio of design infiltration rates must be determined for each place an infiltration measurement is taken. The design infiltration rates from Table 3-10 are used to calculate the ratio. To determine the ratio, the design infiltration rate for the surface textural classification is divided by the design infiltration rate for the least-permeable soil horizon. For example, a device with loamy sand at the surface and a least-permeable layer of loam will have a design infiltration rate ratio of about 6.8 and a correction factor of 4.5. The depth of the least-permeable soil horizon should be within 5 feet of the proposed bottom of the device or to the depth of a limiting layer.

Table 3-9: Evaluation Requirements Specific to Proposed Infiltration Devices

BMP type	Design manual reference	Tests required [1]	Minimum number of borings/pits required	Minimum drill/test depth required below the infiltration surface (bottom of BMP)
Rain garden	2E-4	Pits or borings	NA [2]	5 feet or depth to limiting layer, whichever is less.
Infiltration trenches (<2000 ft^2 impervious drainage area)	2E-2	Pits or borings	1 test/100 linear feet of trench with a minimum of 2, and sufficient to determine variability	5 feet or depth to limiting layer, whichever is less
Infiltration trenches (>2000 ft^2 impervious drainage area)	2E-2	Pits or borings Mounding potential	1 pit required and an additional 1 pit or boring per 100 linear feet of trench, and sufficient to determine variability	Pits to 5 feet or depth to limiting layer Borings to 15 feet or depth to limiting layer
Bioretention systems	2E-4	Pits or borings	1 test per 50 linear feet of device with a minimum of 2, and sufficient to determine variability	5 feet or depth to limiting layer, whichever is less
Swales used for infiltration (dry or enhanced swale)	2I-3	Pits or borings	1 test per 1000 linear feet of swale with a minimum of 2, and sufficient to determine variability	5 feet or depth to limiting layer, whichever is less

[1] Continuous soil borings should be taken using a bucket auger, probe, split-spoon sampler, or Shelby tube. Samples shall have a minimum 2-inch diameter. Soil pits must be of adequate size, depth, and construction to allow a person to enter and exit the pit and complete a morphological soil profile description.
[2] Information from Step 2 is adequate to design rain gardens.

d. Step 4: Soil and site evaluation report contents.
The site's legal description and all information required in Steps 2 and 3 should be included in the Soil and Site Evaluation Report. These reports are completed prior to the construction plan submittal.

Table 3-10: Design Infiltration Rates for Soil Textures Receiving Stormwater

Soil Texture[1]	Design infiltration rate without measurement[2] (inches/hr)
Coarse sand or coarser	3.60
Loamy coarse sand	3.60
Sand	3.60
Loamy sand	1.63
Sandy loam	0.5
Loam	0.24
Silt loam	0.13
Sandy clay loam	0.11
Clay loam	0.09
Silty clay loam	0.06[3]
Sandy clay	0.05
Silty clay	0.04
Clay	0.02

1 Use sandy loam design infiltration rates for fine sand, loamy fine sand, very fine sand, and loamy fine sand soil textures.
2 Infiltration rates represent the lowest value for each textural class presented in Table 2 of Rawls, 1998.
3 Infiltration rate is an average based on Rawls, 1982.

Table 3-11: Total Correction Factors Divided into Measured Infiltration Rates

Ratio of design infiltration rates[1]	Correction factor
1	2.5
1.1 to 4.0	3.5
4.1 to 8.0	4.5
8.1 to 16.0	6.5
16.1 or greater	8.5

1 Ratio is determined by dividing the design infiltration rate (Table 2) for the textural classification at the bottom of the infiltration BMP by the design infiltration rate (Table 2) for the textural classification of the least permeable soil horizon. The least permeable soil horizon used for the ratio should be within five feet of the bottom of the BMP facility or to the depth of the limiting layer.

D. Recharge Volume Requirements (Rev)

The criteria for maintaining recharge is based on the average annual recharge rate of the hydrologic soil groups (HSG) present at a site, as determined from USDA, NRCS soil surveys, or from detailed site investigations. More specifically, each specific recharge factor is based on the USDA average annual recharge volume per soil type divided by the average annual rainfall in Iowa (32 inches per year) and multiplied by 90%. This keeps the recharge calculation consistent with the WQv methodology. The annual recharge volume requirement is specified for a site as follows:

a. Percent volume method:

$$Rev = \frac{(S)(Rv)(A)}{12} \qquad \text{Equation 3-7}$$

where: Rv = 0.05 + 0.09(I)
I = impervious cover (%)
A = site area (acres)
S = soil-specific recharge factor (from HSG)

b. Percent area method:

$$Rev = \frac{(S)(Ai)}{12} \qquad \text{Equation 3-8}$$

Ai = measured impervious area
S = soil-specific recharge factor (from HSG)

Table 3-12: Soil Specific Recharge Factors

Hydrologic Soil Group	Average Annual Recharge Volume (in/yr)	Soil Specific Recharge Factor (*S*)
A-Sandy	18	0.51
B-Silty	12	0.34
C-Clayey	6	0.17
D-Clayey	3	0.08

The recharge volume is considered part of the total WQv that must be provided at a site and can be achieved either by a structural practice (e.g., infiltration, bioretention), a nonstructural practice (e.g., buffers, disconnection of rooftops), or a combination of both. Drainage areas having no impervious cover and no proposed disturbance during development may be excluded from the Rev calculations. Designers are encouraged to use these areas as non-structural practices for Rev treatment. Note: Rev and WQv are inclusive. When treated separately, the Rev may be subtracted from the WQv when sizing the water quality BMP.

The intent of the recharge criteria is to maintain existing groundwater recharge rates at development sites. This helps to preserve existing water table elevations, thereby maintaining the hydrology of streams and wetlands during dry weather. The volume of recharge that occurs on a site depends on slope, soil type, vegetative cover, precipitation, and evapotranspiration. Sites with natural ground cover, such as forest and meadow, have higher recharge rates, less runoff, and greater transpiration losses under most conditions. Because development increases impervious surfaces, a net decrease in recharge rates is inevitable. The relationship between Rev and site imperviousness is shown in graphical form in Figure 3-8.

Figure 3-10: Relationship Between Groundwater Recharge, Rev, and Site Impervious Cover

Source: MDE, 2000

1. Procedures for determining recharge volume, Rev:
   If more than one HSG is present at a site, a composite soil specific recharge factor must be computed based on the proportion of total site area within each HSG. The recharge volume provided at the site should be directed to the most permeable HSG available.

   The percent volume method is used to determine the Rev treatment requirement when structural practices are used to provide recharge. These practices include infiltration and exfiltration structures (i.e., infiltration, bioretention, dry swales, or sand filters with storage below the underdrain). In this method, the volume of runoff treated by structural practices must meet or exceed the computed Rev.

   The percent area method is used to determine the Rev treatment requirements when non-structural practices are used. Under this method, the recharge requirement is evaluated by mapping the percent of impervious area that is effectively treated by an acceptable non-structural practice and comparing it to the minimum recharge requirements. Acceptable non-structural practices include filter strips that treat rooftop or parking lot runoff, sheet flow discharge to stream buffers and grass channels that treat roadway runoff.

   The recharge volume criteria does not apply to any portion of a site designated as a stormwater hotspot or any project considered as redevelopment. If the Rev is treated by structural or nonstructural practices separate and upstream of the WQv treatment, the WQv is adjusted accordingly.

2. Design criteria for infiltration practices
   a. Infiltration conveyance criteria.
      The design of all infiltration practices includes an analysis of the site runoff conveyance configuration to ensure that excess flow is discharged at non-erosive velocities.

i. The overland flow path of surface runoff exceeding the capacity of the infiltration system is configured to preclude erosive concentrated flow. If computed flow velocities do not exceed the non-erosive threshold, overflow may be accommodated by natural topography.
ii. Infiltration systems are designed to fully de-water the entire WQv within 48 hours after the storm event.
iii. If the infiltration practice is used to control the CPv or Qp, the truncated hydrograph method can be used to determine the required detention volume.
iv. If runoff is delivered by a storm drain pipe or along the main conveyance system, the infiltration practice should be designed as an off-line practice.
v. Stormwater outfalls with capacity for the overflow associated with the 10-year design storm event are included and configured to prevent non-erosive velocities on the downslope.

b. Infiltration pre-treatment criteria
   i. Pre-treatment techniques to prevent clogging. The purpose of pre-treatment is to protect the long-term integrity of the infiltration rate. The following techniques, at least three for infiltration trenches and two for infiltration basins, are installed in every infiltration practice:
      - Grass channel (see Appendix for design requirements and example computation)
      - Grass filter strip (minimum 20 feet and only if sheet flow is established and maintained); see Appendix for design requirements and example computation
      - Bottom sand layer
      - Upper sand layer (6-inch minimum) with filter fabric at the sand/gravel interface
      - Use of washed bank run gravel as aggregate
   ii. Pre-treatment volume. A minimum of 25% of the WQv is pre-treated prior to entry to the infiltration practice. If the infiltration rate for the underlying soils is greater than 2 inches per hour, 50% of the WQv is pre-treated prior to entry into an infiltration facility. This can be provided by a sedimentation basin, stilling basin, sump pit, or other acceptable measures. Exit velocities from pre-treatment should be non-erosive during the two-year design storm.
c. Infiltration treatment criteria.
   i. The infiltration practice is designed to exfiltrate the entire WQv less the pre-treatment volume through the floor of each practice, using the design methods outlined in the subsequent design procedures for each practice.
   ii. Infiltration practices are best used in conjunction with other BMPs, and downstream detention is often still needed to meet the CPv and Qp sizing criteria.
   iii. A porosity value, n (n=Vv/Vt), of 0.40 is used in the design of stone reservoirs for infiltration practices.
d. Infiltration landscaping criteria.
   i. A dense and vigorous vegetative cover is established over the contributing pervious drainage areas before runoff can be accepted into the facility.
   ii. Infiltration trenches are not constructed until all of the contributing drainage area has been completely stabilized.
e. Infiltration maintenance criteria.
   i. Infiltration practices may not serve as a sediment control device during the site construction phase. In addition, the erosion and sediment control plan for

the site must clearly indicate how sediment will be prevented from entering the infiltration site.

ii. An observation well for monitoring the water level is installed in the infiltration practice, consisting of an anchored six-inch diameter perforated PVC pipe with a lockable cap.

iii. Consideration should be given in the infiltration design to include a dewatering method in the event of failure. This can be done with subdrain pipe systems to provide drawdown capability.

iv. Direct access is provided to all infiltration practices for maintenance and rehabilitation.

3.4 Stormwater BMP's (Structural and Non-structural)

A stormwater best management practice (BMP) is a technique, measure, or structural control that is used for a given set of conditions to manage the quantity and improve the quality of stormwater runoff in the most cost-effective manner. BMPs can be either:

- Non-structural BMPs. Include a range of pollution prevention, education, or institutional management and development practices designed to limit the conversion of rainfall to runoff and to prevent pollutants from entering runoff at the source of runoff generation.
- Structural BMPs. Engineered and constructed systems that are used to treat the stormwater at either the point of generation or the point of discharge to either the storm sewer system or to receiving waters (e.g. detention ponds or constructed wetlands).

No single BMP can address all stormwater problems. Each type has certain limitations based on drainage area served, available land space, cost, and pollutant removal efficiency; as well as a variety of site-specific factors such as soil types, slopes, depth of groundwater table, etc. Careful consideration of these factors is necessary in order to select the appropriate BMP(s) for a particular location. Regardless of the type, stormwater BMPs will be most effective when implemented as part of a comprehensive stormwater management program that includes proper selection, design, construction, inspection, and maintenance. Descriptions of commonly-used BMPs, along with important factors for design, advantages, disadvantages, and maintenance considerations for each BMP can be found in Part 2D.

A. Goals of Stormwater BMP's

In existing urbanized areas, BMPs can be implemented to address a range of water quantity and water quality considerations. The applicability of individual practices will vary depending on the needs of the practitioner. For new urban development, BMPs should be designed and implemented so that the post-development peak discharge rate, volume, and pollutant loadings to receiving waters are as close as possible to pre-development values. In some instances, the application of BMPs can improve water quality and or reduce runoff volume when the watershed had been altered from its natural condition. In order to meet these goals, BMPs are typically implemented to address three factors:

1. Flow rate control (peak flow reduction)
2. Reduction of runoff volume from urbanizing areas
3. Pollutant removal and pollutant source reductions

Properly designed, constructed, and maintained structural BMPs can effectively remove a wide range of pollutants from urban runoff. Pollutant removal in stormwater BMPs can be accomplished through a number of physical and biochemical processes. The efficiency of a given BMP in removing pollutants is dependent upon a number of site-specific variables, including the size, type, and design of the BMP; the soil types and characteristics; the geology and topography of the site; the intensity and duration of the rainfall; the length of antecedent dry periods; climate factors such as temperature, solar radiation, and wind; the size and characteristics of the contributing watershed; and the properties and characteristics of the various pollutants.

B. Structural BMP's

Structural BMPs include engineered and constructed systems that are designed to provide control for water quantity and/or water quality of stormwater runoff. Structural BMPs can be grouped into several general categories. For purposes of this document, and to be consistent with the definitions and terminology used in the ASCE National Stormwater BMP Database, structural BMPs have been grouped and defined as follows:

1. Infiltration systems capture a volume of runoff and infiltrate it into the ground.
2. Detention systems capture a volume of runoff and temporarily detain (withhold) that volume for subsequent release. Traditional detention systems do not retain a significant permanent pool of water between runoff events. Detention systems do not reduce the total volume of surface runoff from a storm event since the entire captured volume is eventually released after the period of detention. The main goal of traditional detention systems is to reduce the peak discharge rate to the downstream conveyance. A variant of the traditional dry detention basin is designed as an "extended dry detention pond" providing 24-48 hours of holding time for the runoff from the water quality design storm.
3. Wet-detention systems (stormwater ponds) capture a volume of runoff and retain that volume until it is displaced in part or in total by the next runoff event. These systems are better defined as "extended detention" or "wet pond" systems since the runoff volume is eventually released to the downstream conveyance after an extended period of storage (usually 24-48 hours). A true retention system would *permanently* retain all or part of the captured runoff volume and prevent its release to the downstream conveyance. The retained volume is either lost to evaporation, infiltrated into the soil profile and then to the water table, or is subsequently withdrawn for consumptive non-potable re-use. These systems typically maintain a significant permanent pool volume of water between runoff events.
4. Constructed wetland systems (stormwater wetlands) are similar to detention systems, except that a major portion of the BMP water surface area (in pond systems) or bottom (in shallow marsh-type systems) contains wetland vegetation. This group also includes wetland channels.
5. Filtration systems use some combination of a granular filtration media such as sand, soil, organic material, carbon, or a membrane to remove constituents found in runoff.
6. Vegetated systems (biofilters) such as swales and filter strips are designed to convey and treat either shallow flow (swales) or sheet flow (filter strips) runoff.

C. Structural Control Categories

The structural stormwater control practices recommended in this section have been placed into one of two categories based upon their applicability and ability to meet stormwater management goals:

1. General application structural controls. General application structural controls are recommended for use with a wide variety of land uses and development types. These structural controls have a demonstrated ability to effectively treat the WQv, and are presumed to be able to remove 80% of the annual average TSS load in typical post-development urban runoff when designed, constructed, and maintained in accordance with recommended specifications. Several of the general application structural controls can also be designed to provide water quantity control, i.e. downstream channel protection (CPv), over-bank flood protection (Qp) and/or extreme flood protection (Qf).

2. Limited application controls. Limited application structural controls are recommended only for limited use for specific site or design conditions. Generally, these practices:
   - Cannot individually achieve the 80% TSS removal target
   - Are intended to address hotspot or specific land use constraints or conditions
   - May have high or special maintenance requirements that may preclude their use
3. Conventional detention structural controls. Table 3-15 lists the conventional detention structural stormwater control practices that have been used in Iowa for many years. These structural controls are recommended only for providing water quantity control, i.e. channel protection, overbank flood protection, and/or extreme flood protection in a stormwater ponds in series. Due to the potential for pollutant re-suspension and outlet clogging, conventional detention structural controls are not intended to treat stormwater runoff, and should be used downstream of other water quality structural controls or for downstream regional detention for peak discharge control for major storm events (>25-yr RI).

Table 3-13: General Applications Structural Controls

Structural Control	Description and Rationale for Use
Infiltration • Infiltration trench • Infiltration basins	*Infiltration trench*: An excavated trench filled with stone aggregate, used to capture and allow infiltration of stormwater runoff into the surrounding soils from the bottom and sides of the trench. *Infiltration basins*: Shallow detention basins constructed over permeable soils. Suspended solids are removed through sedimentation and the detained runoff is allowed to infiltrate through the bottom of the basin.
Enhanced Swales • Dry swale • Wet swale/wetland channel	Enhanced swales are vegetated open channels that are explicitly designed and constructed to capture and treat stormwater runoff within dry or wet cells formed by check dams or other means.
Bioretention • Bioretention area • Rain gardens	Bioretention areas are shallow stormwater basins or landscaped areas that utilize engineered soils and vegetation to capture and treat stormwater runoff. Runoff may be returned to the conveyance system, or allowed to partially or fully infiltrate into the soil.
Sand Filters • Surface sand filter • Perimeter sand filter	Sand filters are multi-chamber structures designed to treat stormwater runoff through filtration, using a sand bed as its primary filter media. Filtered runoff may be returned to the conveyance system, or allowed to partially or fully infiltrate into the soil.
Stormwater Ponds • Wet pond • Wet extended detention pond • Micro-pool extended detention pond • Multiple pond systems	Stormwater ponds are constructed stormwater retention basins that have a permanent pool (or micropool) of water. Runoff from each rain event is detained and treated in the pool.
Stormwater Wetlands • Shallow wetland • Extended detention shallow wetland • Pond/wetland systems • Pocket wetland	Stormwater wetlands are constructed wetland systems used for stormwater management. Stormwater wetlands consist of a combination of shallow marsh areas, open water, and semi-wet areas above the permanent water surface.

Table 3-14: Limited Application Structural Controls

Structural Control	Description and Rationale for Limited Use
Vegetative practices • Filter strip • Grass channel	Both filter strips and grass channels provide biofiltering of stormwater runoff as it flows across the grass surface. However, by themselves, these controls cannot meet the 80% TSS removal performance goal. Consequently, both filter strips and grass channels should only be used as pretreatment measure or as part of a treatment train approach.
Filtering practices • Organic filter • Underground sand filter	*Organic filters:* Organic filters are surface sand filters where organic materials such as a leaf compost or peat/sand mixture are used as the filter media. These media may be able to provide enhanced removal of some contaminants, such as heavy metals. Given their potentially high maintenance requirements, they should only be used in environments that warrant their use. *Underground sand filters*: Underground sand filters are systems located in an underground vault. These systems should only be considered for extremely high-density or space-limited sites.
Wetland systems • Submerged gravel wetlands	Submerged gravel wetlands systems use wetland plants in submerged gravel or crushed rock media to remove stormwater pollutants. These systems should only be used in mid- to high-density environments where the use of other structural controls may be precluded. The long-term maintenance burden of these systems is uncertain.
Pavement systems • Portland cement pervious concrete • Porous asphalt concrete • Modular porous paver systems	Porous pavements are permeable pavement surfaces with an underlying stone reservoir to temporarily store surface runoff before it infiltrates into the subsoil. *Portland cement pervious concrete* is the term for a mixture of course aggregate, Portland cement, and water that allows for rapid infiltration of water. *Modular porous paver systems* consist of open void paver units laid on a gravel subgrade. Pervious concrete, porous asphalt, and porous paver systems provide water quality and quantity benefits, but have high workmanship and maintenance requirements. They have a high failure rate if off-site sediment loads are not controlled.

Table 3-15: Conventional Detention Structural Controls

Structural Control	Description
Dry detention/dry extended detention basins	Dry detention basins and dry extended detention (ED) basins are surface facilities intended to provide for the temporary storage of stormwater runoff to reduce downstream water quantity impacts (peak discharge control).
Multi-purpose detention areas	Multi-purpose detention areas are site areas used for one or more specific activities, such as parking lots and rooftops, and are also designed for the temporary storage of runoff.
Underground detention	Underground detention tanks and vaults are an alternative to surface dry detention for space-limited areas where there is not adequate land for a dry detention basin or multi-purpose detention area.

Table 3-16: Selection and Applicability of General Application Controls

General Application Controls									
Structural Control Category	Structural Control	Stormwater Treatment Suitability				Expected Water Quality Performance			
		Water Quality	Channel Protection	Overbank Flood Protection	Extreme Flood Protection	TSS / Sediment Removal Rate	Nutrient Removal Rate (TP/TN)	Bacteria Removal Rate	Hotspot Application
Stormwater ponds	Wet pond	✓	✓	✓	✓	80%	50% / 30%	70%	✓
	Wet ED pond	✓	✓	✓	✓				✓
	Micro-pool ED pond	✓	✓	✓	✓				✓
	Multiple ponds	✓	✓	✓	✓				✓
Stormwater wetlands	Shallow wetland	✓	✓	✓	✓	80%	40% / 30%	70%	✓
	Shallow ED wetland	✓	✓	✓	✓				✓
	Pond wetland	✓	✓	✓	✓				✓
	Pocket wetland	✓	✓						✓
Bioretention	Bioretention areas	✓	✱			80%	60% / 50%	ID	✓
Sand Filters	Surface sand filter	✓	✱			80%	50% / 25%	40%	✓
	Perimeter sand filter	✓	✱						✓
Infiltration	Infiltration trench	✓	✱			80%	60% / 60%	90%	
Enhanced Swales	Dry swale	✓	✱			80%	50% / 50%	ID	✓
	Wet swale	✓	✱			80%	25% / 40%	ID	✓
✓ Meets suitability criteria		✱ Can be incorporated into the structural control in certain situations						ID Insufficient data	

Source: Georgia Stormwater Manual, Vol. 2, 2001

Table 3-17: Selection and Applicability of General Application Controls (continued)

Structural Control Category	Structural Control	Site Applicability					Implementation Consideration			
		Drainage Area (acres)	Space Required (% of tributary Impervious Area)	Site Slope	Minimum Head Required (feet)	Depth to Water Table	Residential Subdivision Use	High Density / Ultra Urban	Capital Cost	Maintenance Burden
Stormwater ponds	Wet pond	25 min	2-3%	15% Max	6-8 ft	2 ft if hotspot or aquifer	✓		Low	Low
	Wet ED pond						✓		Low	Low
	Micropool ED pond	10 min					✓		Low	Moderate
	Multiple ponds	25 min					✓		Low	Low
Stormwater wetlands	Shallow wetland	25 min	3-5%	8% Max	3-5 ft	2 ft if hotspot or aquifer	✓		Moderate	Moderate
	Shallow ED wetland						✓		Moderate	Moderate
	Pond wetland				6-8 ft		✓		Moderate	Moderate
	Pocket wetland	5 min			2-3 ft	Below WT	✓		Moderate	High
Bioretention	Bioretention areas	5 max	5%	6% Max	5 ft	2 feet	✓	✓	Moderate	Moderate
Sand filters	Surface sand filter	10 max	2-3%	6% Max	5 ft	2 feet		✓	High	High
	Perimeter sand filter	2 max			2-3 ft			✓	High	High
Infiltration	Infiltration trench	5 max	2-3%	10% Max	1 ft	4 feet	✓	✓	High	High
	Infiltration basin	10 max			3-ft		✓			
Enhanced swales	Dry swale	5 max	10-20%	4% Max	3-5 ft	2 feet	✓		Moderate	Low
	Wet swale	5 max			1 ft	Below WT	✓		High	Low

Source: Georgia Stormwater Manual, Vol. 2, 2001

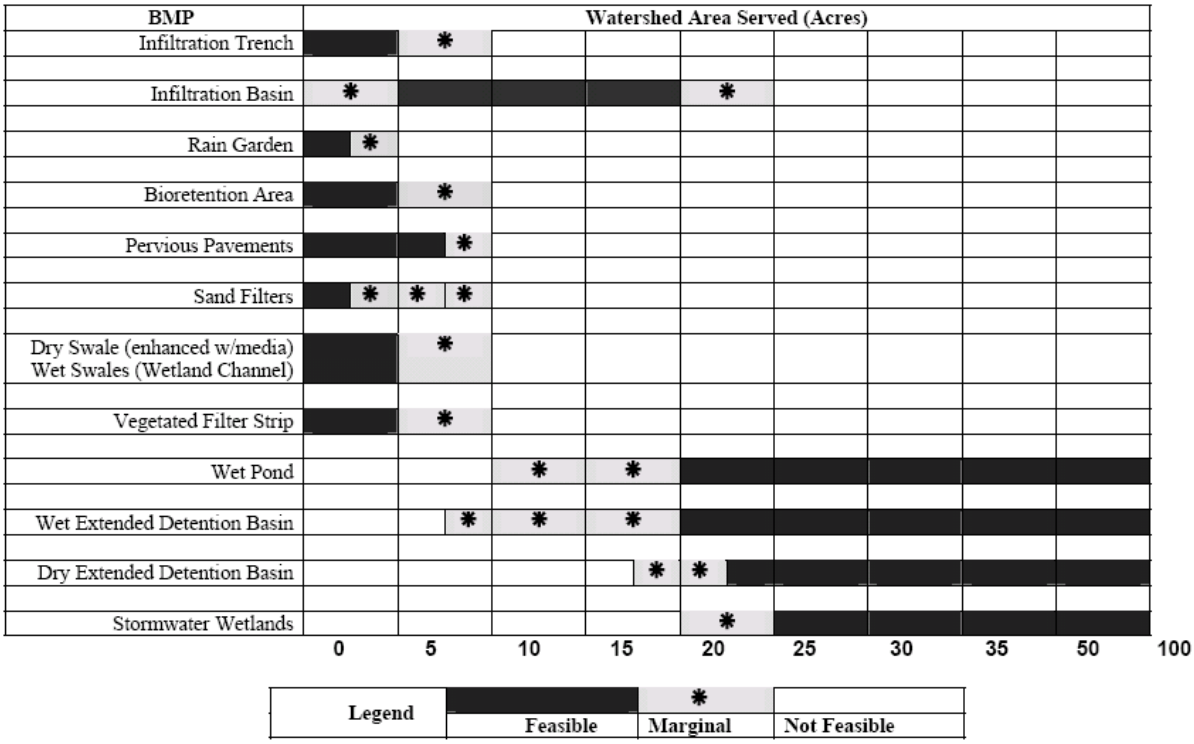
Table 3-18: Selection of Limited Application Control Screening

Structural Control Category	Structural Control	Water Quality	Site Applicability		Implementation Considerations					
		Meets 80% TSS Reduction Goal	Drainage Area (acres)	Space Required (% of tributary impervious area)	Pretreatment Control	Residential Subdivision Use	High Density Ultra-Urban	Capital Cost	Maintenance Burden	Commercially Manufactured Systems Available
Biofilters	Filter strip	No*	2 max	20-25%	✓	✓		Low	Moderate	
	Grass channel	No*	5 max	10-20%	✓	✓		Low	Low	
Filtering practices	Organic filter	Yes	10 max**	2-3%			✓	High	High	
	Underground sand filter	Yes	5 max	None			✓	High	High	Yes
Wetland systems	Submerged gravel wetland	Yes	5 max**	2-3%			✓	High	High	
Hydro-dynamic devices	Gravity (oil-grit) separator	No*	1 max**	None	✓		✓	High	High	Yes
Porous surfaces	Pervious concrete [1]	No [2]	5 max	Varies			✓	Medium	High	
	Modular porous paver systems[1]	No [2]	5 max	Varies		✓	✓	High	High	Yes
Chemical treatment	Alum treatment systems	Yes	25 min	None				High	High	

✓ -- Meets suitability criteria
* Provides less than 80% TSS removal efficiency. May be used in pretreatment and as part of a treatment train.
** Drainage area can be larger in some instances.
[1] Porous surfaces provide water quantity benefits by reducing the effective impervious area.
[2] Due to potential for clogging, porous surfaces should not be used for the removal of sediment or other course particulate pollutants.

Source: Georgia Stormwater Manual, Vol. 2, 2001

Table 3-19: Watershed Area Restriction for BMP's



Source: Adapted from Schueler, 1987

CHAPTER 4 - EROSION & SEDIMENT CONTROL AND STORMWATER MANAGEMENT ORDINANCE OF DUBUQUE COUNTY, IOWA

PART 1
INTRODUCTION

4-1 TITLE. An ordinance establishing countywide standards for the quantity and quality of water that runs off land under construction in urban and rural areas, including farms.

4-2 PURPOSE. The purpose of this Ordinance is to help protect Dubuque County's lakes, streams, wetlands and quality of life by reducing the negative impacts of sediment, rainfall, melting snow and other water runoff.

4-3 through 4-10 Reserved

PART 2
DEFINITIONS

4-11 DEFINITIONS. For the purpose of this Ordinance all words shall carry their customary meanings, except where specifically defined herein. The use of the present tense shall include the past and future tenses, and the future the present; the word "shall" is mandatory, while the word "may" is permissive; the singular number shall include the plural and the plural the singular.

4-11.1 **Best management practice" (or "BMP")** means structural and non-structural measures, practices, techniques or devices employed to avoid or minimize sediment or other pollutants carried in runoff.

4-11.2 **"Bioretention"** means a storm water infiltration device consisting of an excavated area that is backfilled with an engineered soil, covered with a mulch layer and planted with a diversity of woody or herbaceous vegetation.

4-11.3 **"Channel Protection Volume" (CPv)** is the volume of runoff produced from a 1-year, 24-hour design storm on a post-development site, which is detained for an extended period of time (24 hours or more).

4-11.4 **"Design storm"** means hypothetical depth of rainfall that would occur for the stated return frequency (i.e. once every 2 years or 10 years), duration (i.e. 24-hours) and timing of distribution (i.e. type II). All values are based on the historical rainfall records for the area.

4-11.5 **"Detention basin"** means a stormwater management facility designed to protect against flooding and, in some cases, downstream erosion by storing water for a limited period of a time. Detention basins do not retain a significant permanent pool of water between runoff events.

4-11.6 **"Directly connected impervious area"** means an impervious surface that is directly connected to a storm sewer or water of the state via an impervious flow path.

4-11.7 **"Development"** means construction of buildings, other structures, impervious surfaces, and/or soil disturbance to the extent that peak runoff rates and volumes are increased, in a location where no such features currently exist.

4-11.8 **"Erosion"** means the process of detachment, transport and deposition of soil, sediment or rock fragments by action of water, wind, ice or gravity.

4-11.9 **"Erosion control plan"** means a written description and detailed site plan of best management practices designed to meet the requirements of this ordinance submitted by the applicant for review and approval by Dubuque County.

4-11.10 **"Extreme Flood Protection (Qf)"** means the controlling of post-development runoff 100-year peak flows to prevent flood damage from large storm events, maintain the boundaries of the pre- development 100-year Federal Emergency Management Agency (FEMA) and/or locally designated floodplain, and protect the physical integrity of BMP control structures.

4-11.11 **"Floodplain"** means a flat or nearly flat land adjacent to a stream or river that experiences occasional or periodic flooding.

4-11.12 **"Groundwater recharge"** means a hydrologic process where water moves downward from surface water to groundwater.

4-11.13 **"Hotspot land use"** means a site that produces higher concentrations of trace metals, hydrocarbons or other priority pollutants than are normally found in urban stormwater runoff. Examples of hotspots include gas stations, vehicle service and maintenance areas, salvage yards, material storage sites, garbage transfer facilities, and commercial parking lots with high-intensity use.

4-11.14 **"Hydrologic soil group (HSG)"** has the meaning used in the runoff calculation methodology promulgated by the United States Natural Resources Conservation Service Engineering Field Manual for Conservation Practices

4-11.15 **"Hydrology"** means the study of the movement, distribution, and quality of water throughout the Earth.

4-11.16 **"Impervious surface"** means an area that releases all or a large portion of the precipitation that falls on it, except for frozen soil. Conventional rooftops and asphalt or concrete sidewalks, driveways, parking lots and streets are typical examples of impervious surfaces. For purposes of this manual, typical gravel driveways and other examples listed shall be considered impervious unless specifically designed to encourage infiltration or storage of runoff.

4-11.17 **"Infiltration"** means the entry of precipitation or runoff into or through the soil.

4-11.18 **"Intermittent Stream"** means a stream that only flows for part of the year.

4-11.19 **"Karst features"** means an area or surficial geologic feature subject to bedrock dissolution so that it is likely to provide a conduit to groundwater, and may include caves, enlarged fractures, mine features, exposed bedrock surfaces, sinkholes, springs, seeps or swallets.

4-11.20 "**Land disturbing activity" (or "disturbance")** means any man-made alteration of the land surface that may result in a change in the topography or existing vegetative or non-vegetative soil cover, or may expose soil and lead to an increase in soil erosion and movement of sediment. Land disturbing activity includes clearing and grubbing for future land development, excavating, filling, grading, building construction or demolition, and pit trench dewatering.

4-11.21 **"Ordinary high water mark (OHWM)"** means the highest level reached by a body of water that has been maintained for a sufficient period of time to leave evidence on the landscape.

4-11.22 **"Overbank Flood Protection (Qp)"** means the controlling of post-development runoff peak flows to prevent an increase in the frequency and magnitude of out-of-bank flooding generated by development (e.g., flow events that exceed the bank-full capacity of the channel and therefore must spill over into the floodplain).

4-11.23 **"Peak flow"** means the maximum rate at which a unit volume of storm water is discharged.

4-11.24 **"Perennial Stream"** means a stream that has continuous flow in parts of its bed all year round during years of normal rainfall.

4-11.25 **"Post-development condition"** means the extent and distribution of land cover types anticipated to occur under conditions of full development that will influence rainfall, runoff and infiltration.

4-11.26 **"Pre-development condition"** means the extent and distribution of land cover types present before the initiation of land development activity.

4-11.27 **"Pre-settlement condition"** means the extent and distribution of land cover types likely present before European settlement.

4-11.28 **"Rain garden"** means a depression area, designed and constructed as a landscape feature, that is used to improve water quality and enhance infiltration.

4-11.29 **"Recharge Volume (Rev)"** means the volume of rainfall that is captured on a post-development site and directed through the soil to the groundwater table.

4-11.30 **"Redevelopment"** means any construction, alteration, or improvement performed on sites where the existing site is already predominantly developed.

4-11.31 **"Regional storm water management facility"** means a storm water management facility for an entire drainage area or watershed, including future land development activities within the watershed, serving multiple developments and/or land owners.

4-11.32 **"Retention basin"** means a stormwater management facility designed to prevent flooding, erosion and improve water quality in adjacent waters by temporarily storing water for an extended period of a time and in addition generally retains a significant permanent pool of water between runoff events.

4-11.33 **"Runoff"** means water from rain, snow or ice melt, or dewatering that moves over the land surface via sheet or channelized flow.

4-11.34 **"Sediment"** means solid earth material, both mineral and organic, that is in suspension, is being transported, or has been moved from its site of origin by air, water, gravity or ice, and has come to rest on the earth's surface at a different site.

4-11.35 **"Runoff curve number (RCN)"** has the meaning used in the runoff calculation methodology promulgated by the United States Natural Resources Conservation Service Technical Release 55, "Urban Hydrology for Small Watersheds" (commonly known as TR-55).

4-11.36 **"Site"** means the entire area included in the legal description of which the land disturbing or land development activity will occur.

4-11.37 **"Stabilized"** means that all land disturbing activities are completed and that a uniform, perennial vegetative cover has been established over the entire surface with a density of at least 70%, or other surfacing material is in place and the risk of further soil erosion is minimal, as determined Dubuque County.

4-11.38 **"Storm drainage system"** means a publicly-owned facility by which storm water iscollected and/or conveyed, including but not limited to any roads with drainage systems, municipal streets, gutters, curbs, inlets, piped storm drains, pumping facilities, retention and detention basins, natural and human-made or altered drainage channels, reservoirs, and other drainage structures.

4-11.39 **"Stormwater"** has the same meaning as the term "runoff".

4-11.40 **"Surface waters"** means all lakes, bays, rivers, streams, springs, ponds, wells, impounding reservoirs, marshes, watercourses, drainage systems and other surface water or groundwater, natural or artificial, public or private, within Dubuque County.

4-11.41 **"Time of concentration (Tc)"** means the time needed for water to flow from the most remote point in a watershed to the watershed outlet. It is a function of topography, geology and land use within the watershed.

4-11.42 **"Volumetric Runoff Coefficient (Rv)"** means the fraction of rainfall during small storm events that becomes runoff, and can be determined by the methodologies described by Scheuler (1987) or Pitt (1994).

4-11.43 **"Water Quality Volume (WQv)"** is the storage needed to capture and treat the runoff from 90% of the average annual rainfall. In numerical terms, it is equivalent to the rainfall depth in inches multiplied by the volumetric runoff coefficient (Rv) for the site, and the site drainage area.

4-11.44 **"Wetlands"** means an area where water is at, near or above the land surface long enough to be capable of supporting aquatic or hydrophytic vegetation and which has soils indicative of wet conditions.

4-12 through 4-20 Reserved

PART 3
GENERAL PROVISIONS

4-21 ADMINISTRATION. The Erosion and Sediment Control and Stormwater Ordinance shall be administered by Dubuque County through an administrator to be designated by the Dubuque County Board of Supervisors. Said administration shall be under the terms and provisions of the Dubuque County Erosion and Sediment Control and Stormwater Management Manual. Said document shall hereafter be referred to as the Dubuque County

Manual for purposes of this Ordinance. This Ordinance shall be available for adoption to any city or municipality within Dubuque County, via a 28E Agreement.

4-22 HYDROLOGIC METHODS. This Ordinance adopts the accepted hydraulic methods referred to in Section 1.1(B) of the Dubuque County Manual.

4-23 FEES. Fees are set by Dubuque County as follows:

(1) For any one site with two acres or more of disturbed area, the fee is $285.00 plus $100.00 per acre for every acre or portion of an acre over two acres.

(2) Any development that is considered a subdivision, or requires a plat, would be charged the fees stated above.

(3) Fees may be modified by the County by resolution.

4-24 ENFORCEMENT AND PENALTIES. Dubuque County will work with municipalities for consistent enforcement of the County minimum standards. The Dubuque County Manual requires builders, developers and other site planners to submit erosion and sediment control and stormwater management plans. If a site is not in compliance with its plan as determined by inspection, a stop work order may be issued and the County may levy fines. A violation by any person of any provision of this Ordinance, including the commencing, constructing, causing or permitting the commencement of any land-disturbing activity without submittals as described within this Ordinance and the Dubuque County Manual, will be subject to abatement, a stop work order, and/or a fine of $750.00. The County may order compliance by written notice of violation setting forth the time within which remediation or restoration must be completed and that if the person fails to complete such remediation or restoration within such time, the County shall cause such remediation or restoration work to be done and the person shall be liable for such costs. The County may issue an order to stop all construction activities on any property where land-disturbing activity is being conducted until conditions of non-compliance are corrected. Construction activity, other than that which is required to correct a condition of non-compliance, prior to the correction and the conditions of non-compliance, shall constitute a further violation.

4-25 THE NATIONAL POLLUTANT DISCHARGE ELIMINATION SYSTEM (NPDES). This Ordinance specifically

adopts the National Pollutant Discharge Elimination System (NPDES) permit requirements as outlined in paragraph 1.1(f) of the Dubuque County Manual.

4-26 MANUAL. The Dubuque County Erosion and Sediment Control and Stormwater Management Manual shall be available for inspection and/or copying during regular business hours at the Dubuque County Secondary Roads Department and at the Dubuque County Courthouse.

4-27 through 4-30 Reserved

PART 4
SITE AND REGIONAL PLANNING

4-31 IMPLEMENTING STORMWATER MANAGEMENT. In order to effectively implement good stormwater management, certain techniques shall be utilized. These techniques are detailed in Section 1.2 of the Dubuque County Manual and, in order of priority are as follows:

(a) Identify and avoid sensitive areas

(b) Minimize impervious surfaces.

(c) Utilize low-impact development (LID) and conservation subdivision design.

(d) Watershed-wide planning for stormwater management.

4-32 through 4-40 Reserved

PART 5
ORDINANCE APPLICABILITY, PERFORMANCE STANDARDS AND MANAGEMENT PRACTICES

4-41 APPLICABILITY. Construction site erosion plans and permits are required under any of the conditions listed under Section 1.3(A)(1) of the Dubuque County Manual.

4-42 PERFORMANCE STANDARDS. Acceptable soil loss limits are established at Section 1.3(A)(2) of the Dubuque County Manual.

4-43 MANAGEMENT PRACTICES. Dubuque County hereby adopts by reference the guide to managing erosion on construction sites developed by the Iowa Department of Natural Resources and detailed under Section 1(3)(A)(3) of the Dubuque County Manual.

4-44 POST-CONSTRUCTION STORMWATER MANAGEMENT AND WATER QUALITY PROTECTION. Dubuque County hereby adopts in total Section 1.3(B)(1)(2)(3) of the Dubuque County Manual relating to the applicability, performance standards and management practice for stormwater management and water quality protection.

4-45 through 4-50 Reserved

PART 6
SUBMITTAL REQUIREMENTS

4-51 CONSTRUCTION SITE EROSION CONTROL. Dubuque County hereby adopts Section 1(4)(A) of the Dubuque County Manual relating to construction site erosion control.

4-52 POST-CONSTRUCTION STORMWATER MANAGEMENT AND WATER QUALITY PROTECTION. Dubuque County hereby adopts Section 1(4)(B) of the Dubuque County Manual relating to post-construction stormwater management and water quality protection.

4-53 through 4-60 Reserved.

PART 7
ENACTMENT

4-61 This Ordinance shall be in effect after its final passage approval and publication as provided by law.

By order of the Dubuque County Board of Supervisors on this 29th day of March, 2010.

Denise M. Dolan
Dubuque County Auditor

Definitions

1. "**Best management practice" (or "BMP")** means structural and non-structural measures, practices, techniques or devices employed to avoid or minimize sediment or other pollutants carried in runoff.

2. **"Bioretention"** means a storm water infiltration device consisting of an excavated area that is backfilled with an engineered soil, covered with a mulch layer and planted with a diversity of woody or herbaceous vegetation.

3. **"Channel Protection Volume" (CPv**) is the volume of runoff produced from a 1-year, 24-hour design storm on a post-development site, which is detained for an extended period of time (24 hours or more).

4. **"Design storm"** means a hypothetical depth of rainfall that would occur for the stated return frequency (i.e. once every 2 years or 10 years), duration (i.e. 24-hours) and timing of distribution (i.e. type II). All values are based on the historical rainfall records for the area.

5. **"Detention basin"** means a stormwater management facility designed to protect against flooding and, in some cases, downstream erosion by storing water for a limited period of a time. Detention basins do not retain a significant permanent pool of water between runoff events.

6. **"Directly connected impervious area"** means an impervious surface that is directly connected to a storm sewer or water of the state via an impervious flow path.

7. **"Development"** means construction of buildings, other structures, impervious surfaces, and/or soil disturbance to the extent that peak runoff rates and volumes are increased, in a location where no such features currently exist.

8. **"Erosion"** means the process of detachment, transport and deposition of soil, sediment or rock fragments by action of water, wind, ice or gravity.

9. **"Erosion control plan"** means a written description and detailed site plan of best management practices designed to meet the requirements of this ordinance submitted by the applicant for review and approval by Dubuque County.

10. **"Extreme Flood Protection (Qf)"** means the controlling of post-development runoff 100-year peak flows to prevent flood damage from large storm events, maintain the boundaries of the pre- development 100-year Federal Emergency Management Agency (FEMA) and/or locally designated floodplain, and protect the physical integrity of BMP control structures.

11. **"Floodplain"** means a flat or nearly flat land adjacent to a stream or river that experiences occasional or periodic flooding.

12. **"Groundwater recharge"** means a hydrologic process where water moves downward from surface water to groundwater.

13. **"Hotspot land use"** means a site that produces higher concentrations of trace metals, hydrocarbons or other priority pollutants than are normally found in urban stormwater runoff. Examples of hotspots include gas stations, vehicle service and maintenance areas, salvage yards, material storage sites, garbage transfer facilities, and commercial parking lots with high-intensity use.

14. **"Hydrologic soil group (HSG)"** has the meaning used in the runoff calculation methodology promulgated by the United States Natural Resources Conservation Service Engineering Field Manual for Conservation Practices

15. **"Hydrology"** means the study of the movement, distribution, and quality of water throughout the Earth.

16. **"Impervious surface"** means an area that releases all or a large portion of the precipitation that falls on it, except for frozen soil. Conventional rooftops and asphalt or concrete sidewalks, driveways, parking lots and streets are typical examples of impervious surfaces. For purposes of this manual, typical gravel driveways and other examples listed shall be considered impervious unless specifically designed to encourage infiltration or storage of runoff.

17. **"Infiltration"** means the entry of precipitation or runoff into or through the soil.

18. **"Intermittent Stream"** means a stream that only flows for part of the year.

19. **"Karst features"** means an area or surficial geologic feature subject to bedrock dissolution so that it is likely to provide a conduit to groundwater, and may include caves, enlarged fractures, mine features, exposed bedrock surfaces, sinkholes, springs, seeps or swallets.

20. "**Land disturbing activity" (or "disturbance")** means any man-made alteration of the land surface that may result in a change in the topography or existing vegetative or non-vegetative soil cover, or may expose soil and lead to an increase in soil erosion and movement of sediment. Land disturbing activity includes clearing and grubbing for future land development, excavating, filling, grading, building construction or demolition, and pit trench dewatering.

21. **"Ordinary high water mark (OHWM)"** means the highest level reached by a body of water that has been maintained for a sufficient period of time to leave evidence on the landscape.

22. **"Overbank Flood Protection (Qp)"** means the controlling of post-development runoff peak flows to prevent an increase in the frequency and magnitude of out-of-bank flooding generated by development (e.g., flow events that exceed the bank-full capacity of the channel and therefore must spill over into the floodplain).

23. **"Peak flow"** means the maximum rate at which a unit volume of storm water is discharged.

24. **"Perennial Stream"** means a stream that has continuous flow in parts of its bed all year round during years of normal rainfall.

25. **"Post-development condition"** means the extent and distribution of land cover types anticipated to occur under conditions of full development that will influence rainfall, runoff and infiltration.

26. **"Pre-development condition"** means the extent and distribution of land cover types present before the initiation of land development activity.

27. **"Pre-settlement condition"** means the extent and distribution of land cover types likely present before European settlement.

28. **"Rain garden"** means a depression area, designed and constructed as a landscape feature, that is used to improve water quality and enhance infiltration.

29. **"Recharge Volume (Rev)"** means the volume of rainfall that is captured on a post-development site and directed through the soil to the groundwater table.

30. **"Redevelopment"** means any construction, alteration, or improvement performed on sites where the existing site is already predominantly developed.

31. **"Regional storm water management facility"** means a storm water management facility for an entire drainage area or watershed, including future land development activities within the watershed, serving multiple developments and/or land owners.

32. **"Retention basin"** means a stormwater management facility designed to prevent flooding, erosion and improve water quality in adjacent waters by temporarily storing water for an extended period of a time and in addition generally retains a significant permanent pool of water between runoff events.

33. **"Runoff"** means water from rain, snow or ice melt, or dewatering that moves over the land surface via sheet or channelized flow.

34. **"Sediment"** means solid earth material, both mineral and organic, that is in suspension, is being transported, or has been moved from its site of origin by air, water, gravity or ice, and has come to rest on the earth's surface at a different site.

35. **"Runoff curve number (RCN)"** has the meaning used in the runoff calculation methodology promulgated by the United States Natural Resources Conservation Service Technical Release 55, "Urban Hydrology for Small Watersheds" (commonly known as TR-55).

36. **"Site"** means the entire area included in the legal description of which the land disturbing or land development activity will occur.

37. **"Stabilized"** means that all land disturbing activities are completed and that a uniform, perennial vegetative cover has been established over the entire surface with a density of at least 70%, or other surfacing material is in place and the risk of further soil erosion is minimal, as determined Dubuque County.

38. **"Storm drainage system"** means a publicly-owned facility by which storm water is collected and/or conveyed, including but not limited to any roads with drainage systems, municipal streets, gutters, curbs, inlets, piped storm drains, pumping facilities, retention and detention basins, natural and human-made or altered drainage channels, reservoirs, and other drainage structures.

39. **"Stormwater"** has the same meaning as the term "runoff".

40. **"Surface waters"** means all lakes, bays, rivers, streams, springs, ponds, wells, impounding reservoirs, marshes, watercourses, drainage systems and other surface water or groundwater, natural or artificial, public or private, within Dubuque County.

41. **"Time of concentration (Tc)"** means the time needed for water to flow from the most remote point in a watershed to the watershed outlet. It is a function of topography, geology and land use within the watershed.

42. **"Volumetric Runoff Coefficient (Rv)"** means the fraction of rainfall during small storm events that becomes runoff, and can be determined by the methodologies described by Scheuler (1987) or Pitt (1994).

43. **"Water Quality Volume (WQv)"** is the storage needed to capture and treat the runoff from 90% of the average annual rainfall. In numerical terms, it is equivalent to the rainfall depth in inches multiplied by the volumetric runoff coefficient (Rv) for the site, and the site drainage area.

44. **"Wetlands"** means an area where water is at, near or above the land surface long enough to be capable of supporting aquatic or hydrophytic vegetation and which has soils indicative of wet conditions.

APPENDIX A – EROSION & SEDIMENT CONTROL BMP DESIGN STANDARDS INDEX

SECTION	DESCRIPTION
7E-2	Compost Blanket
7E-3	Dust Control
7E-4	Grass Channel
7E-5	Mulching
7E-6	Permanent Seeding
7E-7	Temporary Rolled Erosion Control Product (RECP)
7E-8	Sodding
7E-9	Surface Roughening
7E-10	Temporary Seeding
7E-11	Turf Reinforcement Mats (TRM)
7E-12	Vegetative Filter Strip
7E-13	Check Dam
7E-14	Diversion Structure
7E-15	Level Spreader
7E-16	Rock Chutes and Flumes
7E-17	Rock Outlet Protection
7E-18	Flow Transition Mat
7E-19	Temporary Slope Drain
7E-20	Filter Berm
7E-21	Filter Sock
7E-22	Wattle
7E-23	Flocculents
7E-24	Flotation Silt Curtain
7E-25	Inlet Protection
7E-26	Sediment Basin
7E-27	Sediment Trap
7E-28	Silt Fence
7E-29	Stabilized Construction Exit

7E-2 Compost Blanket

Source: Soil-Tek

BENEFITS

	L	M	H
Flow Control	■	■	□
Erosion Control	■	■	□
Sediment Control	■	□	□
Runoff Reduction	■	■	□
Flow Diversion	□	□	□

Description: A 1 to 4 inch surface application of compost/mulch or a blend of both to protect areas with erosive potential

Typical Uses: Used to protect bare soil surfaces from raindrop impact, prevent/reduce sediment loss, reduce surface water runoff, and promote seed growth for establishment of ground cover.

Advantages:

- Immediately protects 100% of the ground surface upon application.
- Conforms to any terrain.
- Reduces rill erosion and the volume of stormwater runoff.
- Allows for natural infiltration and percolation of water into underlying soil.
- Can be combined with seed and placed in a one-step process with pneumatic blower truck.
- Can be used when projects have begun too late in the growing season to establish erosion control vegetation.
- Has high water retention properties, thereby reducing watering requirements during dry weather periods.
- Can be used in areas with poor quality soils (low organic matter) that do not support vigorous growth of vegetation.

Limitations:

- Not suitable for areas of concentrated water flow unless used in conjunction with other control measures that slow velocities.
- Erosion control benefit of compost is eliminated if material is incorporated (tilled) into soil.
- Susceptible to wind erosion.

Longevity: One year.

SUDAS Specifications: Refer to Section 9040, 1.08, C, 2.03, and 3.04

A. Description/uses

A compost blanket consists of a layer of compost/mulch or a blend of both placed on denuded areas to help prevent initiation of runoff and erosion. Apply compost blanket to a depth of 2 to 4 inches, depending on slope steepness. When a pneumatic blower truck is utilized, a compost blanket can be installed and seeded simultaneously for permanent vegetation establishment.

A compost blanket is both an erosion control and stormwater quality practice. Compost blankets stabilize the soil, prevent splash, sheet, and rill erosion, and remove suspended soil particles and contaminants from water moving offsite and into adjacent waterways or stormwater conveyance systems.

B. Design considerations

Compost quality and screen size is important. Coarse compost tends to provide more protection than fine material. The coarser compost includes particles which are large enough to prevent them from being washed away or displaced by the rainfall. Fine compost particles can be dislodged and washed away, eliminating any potential protection.

For full erosion control benefits, compost should not be incorporated (tilled) into underlying soil. In order to prevent water from sheeting between the compost blanket material and soil surface on a slope, a minimum 3-foot wide band of blanket material should be placed behind the top of the slope, along the shoulder. Alternatively, a compost berm or filter sock may be placed at the top of the slope.

Compost can be seeded for temporary and/or permanent vegetation during or immediately after installation. For vegetated compost blankets (pneumatic seeding), a maximum blanket depth of 2 inches is recommended. Deeper compost depths can prevent the roots of the vegetation from growing down into the underlying soil. This process is important in developing long term slope stability. With turf or sod, compost can replace topsoil requirements – 1 inch of compost is equivalent to 3 inches of topsoil.

C. Application

Application rates should be between 2 to 3 inches in depth (270 to 405 cubic yards per acre) with greater depths for steeper slopes.

Table 1: Compost blanket thickness on slopes

Slope	Compost Thickness
2:1 (see comments below)	4”
3:1	3”
4:1	2”

Compost blankets may be used to stabilize steep slopes (up to 2:1) if additional measures are provided. For these severe applications, the slope length should be reduced through the installation of silt fence, filter berms or filter socks. A maximum spacing of 25 feet between slope reduction practices should be provided. In addition, lightweight mulch control netting should be placed under the compost and anchored into place. These additional practices help stabilize the blanket and prevent the material from sliding down steep grades.

D. Maintenance

The disturbed ground under the blanket should be checked in spots for failure. Common failures, due to concentration of water flows or the improper type of compost used, will result in splash, sheet or rill erosion of the underlying soil. Damage should be repaired immediately to prevent further erosion.

E. Time of year

Compost blankets are effective on a year-round basis. Unlike other erosion control measures, installation is possible when the ground is wet or frozen, especially if a pneumatic blower truck is utilized for placement.

F. Regional location

The availability of compost blankets are affected by regional location, due to adequate supplies of compost and composting facilities.

7E-3 Dust Control

Source: Jerico Services, Inc.

BENEFITS

	L	M	H
Flow Control			
Erosion Control	■	■	
Sediment Control			
Runoff Reduction			
Flow Diversion			

Description: Dust control is the practice of controlling fugitive dust that results from grading, demolition, hauling, and traffic on construction sites. Fugitive dust may cause offsite damage, health hazards, and traffic problems if preventive measures are not taken.

Typical Uses: Used in open, windy areas such as the tops of hills and on construction sites with exposed soil in open areas due to tree clearing. Also used in locations where construction traffic is high, such as the entrance to the site. Dust control may also be applied to soil stockpiles.

Advantages:

- Low visibility conditions caused by airborne dust are minimized.
- Dust control methods are widely applicable.
- Most dust control methods are inexpensive and promote the growth of stabilizing vegetation.
- Most dust control methods are easy to install/apply and maintain.

Limitations:

- Some temporary dust controls must be reapplied or replenished on a regular basis.
- Some controls are expensive (e.g., chemical treatment), may be ineffective under certain conditions, or have their own associated impacts.
- If chemical dust control treatment is over-applied, excess chemicals could potentially cause both surface and groundwater contamination.
- Petroleum products should not be used for dust control as there is potential for stormwater pollution and groundwater contamination.

Longevity: Usually short term. Actual time varies by method and weather conditions.

SUDAS Specifications: Refer to Section 9040, 1.08, D, 2.06, and 3.08

A. Description/uses

Earth-moving activities comprise the major source of construction dust emissions, but traffic and general disturbance of the soil also generate significant dust emissions. Therefore, dust control should be used when open dry areas of soil are anticipated on the site.

Dust control measures include minimization of soil disturbance, spray-on adhesives, tillage, chemical treatment and water spraying, and ensuring trucks are tarped upon leaving the

construction site. In many cases, measures incorporated into the project to prevent soil erosion by water will indirectly prevent wind erosion.

While there are a number of temporary alternatives for dust control, one option is to permanently modify the site to eliminate dust generation. Modifications could include measures such as covering exposed areas with vegetation, mulch, stone or concrete. For the purpose of this standard, the focus is on temporary dust control measures.

B. Design considerations

While several different products and practices are available for dust prevention, the most important tool is proper planning. During the design phase, the site should be analyzed for potential dust problems and the work coordinated to minimize dust problems.

The first step is to identify construction entrances and haul roads and provide a stable surface by paving, providing rock, or by chemical stabilization. Construction traffic on unstabilized haul roads should be limited as much as possible. When necessary, construction traffic on unstabilized ground should be limited to low speed operations (15 mph or less).

Existing vegetation or crop residue should be left in place as long as possible. When possible, existing tree lines should be left in place to act as a windbreak.

When dust problems are anticipated or are occurring during construction, there are a number of methods and products available to temporarily stabilize the surface and suppress the dust. Selection of these products or practices depends on several factors, including soil type, climate, and the necessary duration of treatment.

1. **Watering.** Spraying the surface of the ground with water is a readily available and highly effective method of suppressing dust, though very a short term one. Water trucks can provide onsite control of fugitive dust on haul roads and disturbed surfaces on an as-needed basis. The frequency of watering depends on several factors, including weather, soil type, and construction traffic. Water treatment is typically only effective for one-half hour to 12 hours. Water should be applied at a rate so that the soil surface is wet, but not saturated or muddy. If watering is to be employed at a construction site, it should be used in conjunction with a temporary gravel rock entrance, created to prevent mud from being spread on local streets.

2. **Tillage**. (See Surface Roughening, Section 7E-9). Large, open, disturbed areas should be deep plowed to bring dirt clods to the surface. As the wind blows across smooth disturbed ground, the entire surface is exposed to the wind, creating a high potential for suspending dust particles.

When the surface is roughened, only the peaks of the surface are exposed to the wind. In addition, the clods lying on top of the ground help stabilize the surface. This is a temporary emergency measure that can be used as soon as dust generation starts. Plowing should begin on the windward side of the site and leave 6-inch furrows, preferably perpendicular to the prevailing wind direction, to gain the greatest reduction in wind erosion. Tillage is only applicable to flat areas.

3. **Soil stabilizers and dust suppressants.** These are chemicals applied on or mixed into the soil surface that maintain the moisture levels in exposed soils, or chemically bind the surface material to reduced fugitive dust emissions from the site. These products include:

1) **Calcium chloride.** Maintains water levels in the surface layer by absorbing humidity out of the air. May be applied by mechanical spreader as loose, dry granules or flakes, or as a liquid solution. Generally requires one or two treatments per season. Calcium chloride treated soils can inhibit the growth of vegetation and runoff from these areas can pollute water bodies. Therefore, calcium chloride should not be applied to large areas for site-wide dust control. When used, calcium chloride applications should be restricted to haul roads, and small areas.

2) **Lignosulfonate.** Derived from wood pulp, lignosulfonate is a byproduct of the pape industry and is often referred to as "tree sap." It is applied as a liquid to the ground surface, and binds the surface particles together. Generally requires one or two treatments per season.

3) **Soybean oil (Soapstock).** Acidulated soybean oil soapstock is a by-product of the refining process of soybean oil. It is applied as an undiluted liquid to the ground surface and binds the surface particles together. Proper storage and transportation of soybean oil require that the material be kept at a constant temperature of 155 degrees Fahrenheit and continuously agitated. Application of the material may require special pumping equipment. These restrictions may limit the use of soybean oil for dust control. Generally requires one treatment per season.

4. **Track-out control** (See Chapter 7, Section 7E-28, Stabilized Construction Entrance). Soil tracked out onto streets by construction vehicles eventually dries and creates a fugitive dust. A stabilized construction entrance should be provided to aid in removing soil from vehicles before they enter the roadway.

C. Application

Apply chemical controls at the manufacturer's specified rates and according to all federal, state, and local regulations governing their use. If a chemical dust control treatment is over-applied, excess chemicals could potentially cause both surface and groundwater contamination. Recommended application rates are listed in the table below. Chemical products must be stored, handled, and disposed of according to all applicable regulations and department policies.

Table 1: Recommended application rates for dust suppression products

Product	Mixture	Application Rate[1]
Calcium chloride	Dry flake or liquid solution	1 lb./SY on anhydrous basis
Lignosulfanate	Diluted with water to 25% solids	1 gal/SY
Soybean oil (soapstock)	Undiluted	0.70 gal/SY

[1]Application rates are approximate and may need to be adjusted based upon site conditions

Source: Bolander, 1999 and Morgan, 2005

D. Maintenance

All dust control methods are temporary and require periodic maintenance. Wetting the ground surface with water may be necessary several times a day during hot and dry weather. Other methods provide longer effectiveness, and may only need to be applied once or twice per year.

7E-4 Grass Channel

Source: NRCS Photo Gallery.

BENEFITS

	L	M	H
Flow Control	■		
Erosion Control	■	■	■
Sediment Control	■		
Runoff Reduction	■		
Flow Diversion			

Description: Grass channels consist of ditches, swales, or waterways that are lined with vegetation to stabilize the surface from erosion.

Typical Uses: Used to carry intermittent, low to moderate concentrated flows of surface runoff.

Advantages:

- Low cost method of conveying surface runoff.
- Highly effective for controlling channel erosion for low to moderate flows.
- Aesthetically pleasing.
- Reduces flow velocity and removes sediment.

Limitations:

- Cannot withstand forces from high flows.
- There may be some difficulty establishing vegetation.
- Not suitable for channels that carry constant flows, or that remain submerged for extended periods of time.

Longevity: Permanent.

SUDAS Specifications: Refer to Section 9010 (Seeding) or 9020 (Sodding).

A. Description/uses

Grass channels consist of swales, ditches, and waterways that are lined with permanent vegetation. The purpose of the vegetation is to stabilize the surface of the channel and prevent erosion from concentrated stormwater flow.

Because these structures are lined with vegetation, they cannot be used for channels which have constant flow, or which will be submerged for extended periods of time.

Grass channels are the least costly and most aesthetically pleasing option for lining channels.

B. Design considerations

As water flows through any conduit or channel, the surface of the conduit or channel imparts drag on the flowing water. The amount of drag a particular surface will create is related to the

commonly known Manning's "n" coefficient. This drag force not only slows the flow of the water, but also imparts a corresponding force onto the lining of the channel. This force is known as shear stress.

The ability of a channel to withstand shear stress is dependent on the properties of the lining. If the shear stress imposed on the bottom and sides of a channel by the flowing stormwater exceeds the ability of the channel lining to withstand it, the lining will be moved or damaged. Various types of vegetation provide different levels of resistance to shear. Table 1 lists the various classifications of vegetation that have been established and analyzed.

Prior to movement of the lining, the underlying soil is protected from the erosive forces of the flowing water. Therefore, the erodibility of the underlying soil has little effect on the permissible shear stress of the lining. However, if the grass lining is moved or damaged, the underlying soil properties become a significant factor in determining the degree of erosion that will occur.

Calculating shear stress in a channel is a two-step process. First, the depth of flow in the channel is determined with Manning's equation. For temporary stabilization, the channel liner should be designed to carry a two-year storm event. For permanent stabilization, the liner should be designed for a 10-year event.

For most channel lining materials, Manning's n value does not vary significantly as the depth of flow varies, and is normally assumed to be constant. For grass channels however, the n value varies greatly with the depth of flow. This variation is caused by the reaction of the grass to the flow. As flow depth increases, the grass is bent over, thereby reducing its height and changing the resistance it imparts on the flow.

The following equations, along with the vegetation data listed in Table 2, can be used to calculate the Manning value for a given depth of flow and vegetation type. For vegetated conditions, NRCS has determined that actual Manning's n values range only from 0.02 to 0.5. When calculated values fall outside of this acceptable range, the designer should use the upper or lower limit of the range. If the denominator of Equation 1 is zero or less than zero, a Manning's n value of 0.5 should be used.

$$n = \frac{R^{1/6}}{19.97\left(\log\left(44.8 \times h^{0.6} \times MEI^{-0.4}\right) + \log\left(R^{1.4} \times S^{0.4}\right)\right)}$$ **Equation 1**

Where:

n	=	Manning's coefficient (dimensionless)
R	=	Hydraulic radius (ft.)
h	=	Average height of vegetation; from Table 1 (ft)
MEI	=	Stiffness factor; from Table 2 (lb.· ft^2)
S	=	Channel slope (ft/ft)

Source: Chen & Cotton, 1988 (HEC-15).

Because the Manning coefficient changes with depth, calculating the depth of flow is an iterative process. Once the flow depth is determined, the shear stress on the channel liner is determined by the following equation:

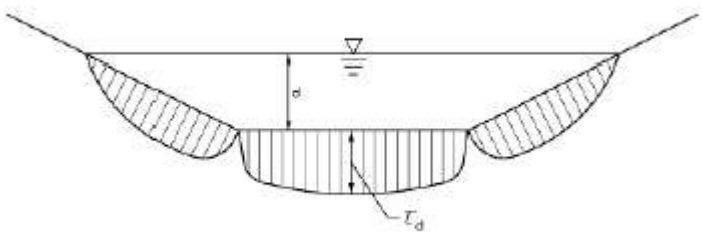
$$\tau_d = \gamma \times d \times S$$ **Equation 2**

Where:

τ_d	=	Shear stress in channel at maximum depth (lbs/ft^2)
γ	=	Unit weight of water (62.4 lbs/ft^3)
d	=	Depth of flow (ft)
S	=	Channel slope (ft/ft)

The shear stress distribution along the wetted perimeter of a channel is not uniform, as indicated in Figure 1. In a trapezoidal channel, the peak shear stress in a straight channel occurs at the center of the bottom of the channel. The stress in the corners of the channel approaches zero. The peak shear stress along the sides of a straight channel occur near the bottom third of the channel.

Figure 1: Stress distribution in a trapezoidal channel

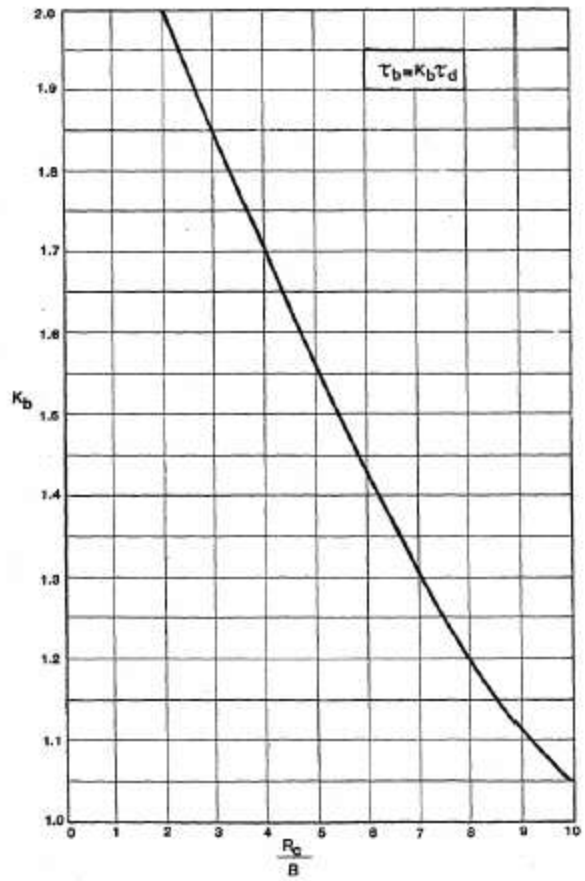


Source: Adapted from Chen & Cotton, 1988 (HEC-15).

If the flow travels around a bend, the current imposes additional forces on the channel as the flow is redirected. These forces result in increased shear stress on the bottom and sides of the channel. The additional shear stress imposed on the channel is related to the ratio of the radius of the bend, R_c, and the bottom width of the channel, b. As the bend becomes sharper, the shear stress increases. The maximum shear stress in the bend is determined by multiplying the calculated shear stress in a straight section of channel by the bend coefficient, K_b (Equation 3). K_b is determined from Figure 2.

$\tau_b = K_b \tau_d$ **Equation 3**

Figure 2: Bend coefficient for maximum shear stress in channel bends



Source: Chen & Cotton, 1988 (HEC-15).

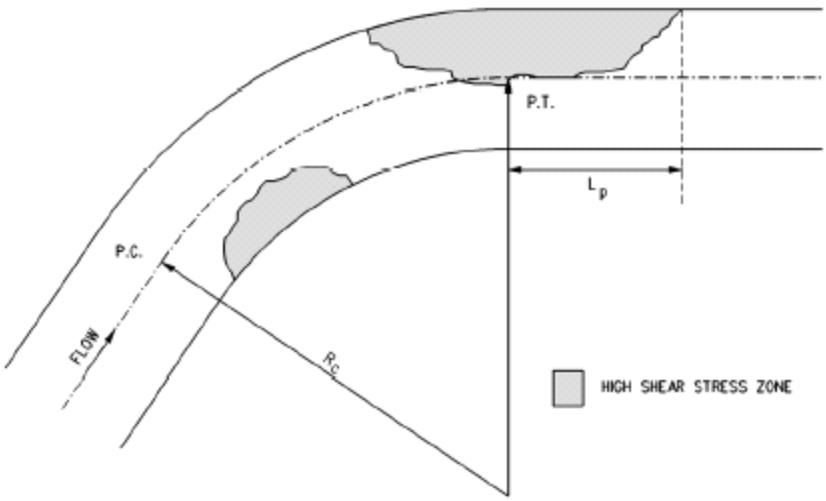
As flow travels around a bend, the increased shear stresses begin along the inside radius and move toward the outside. These increased stresses are also transmitted down the channel for a distance L_p, due to the turbulence created in the flow as it traveled around the bend (see Figure 3). This distance can be determined by Equation 4. When additional channel protection is provided in the bend, it should also be extended through this length.

$$L_p = 0.604 \frac{R^{7/6}}{n}$$ **Equation 4**

Where:

L_p	=	Length of protection required downstream of bend, ft
R	=	Hydraulic radius
n	=	Manning's coefficient

Figure 3: Shear stress distribution in a channel bend



Source: Adapted from Chen & Cotton, 1988 (HEC-15).

Once the anticipated shear stress on the channel liner is determined, it is compared to the allowable shear stress values of the proposed vegetation. If the calculated shear stress value exceeds the allowable shear stress of the liner, additional protection may be required. Depending on the level of shear stress anticipated, additional protection may be provided by an alternate type of vegetation, by reinforcing the vegetation with a turf reinforcement mat, lining the channel with rip-rap, or modifying the geometrics of the channel.

For channels where establishment of vegetation may be difficult, a rolled erosion control product may be considered. A complete discussion on RECPs can be found in Section 7E-7.

A more complete discussion on channel stabilization is provided in Chapter 2.

Table 1: Classification of vegetation

Vegetation Class	Cover	Condition
A	**Weeping lovegrass**	Excellent stand, tall (average 30")
	Yellow bluestem ischaemum	Excellent stand, tall (average 36")
B	Kudzu	Very dense growth, uncut
	Bermuda grass	Good stand, tall (average 12")
	Native grass mixture (**little bluestem**, bluestem, **blue grama,** other long and short Midwest grasses)	Good stand, unmowed
	Weeping lovegrass	Good stand, tall (average 24")
	Lespedeza serices	Good stand, not woody, tall (average 19")
	Alfalfa	Good stand, uncut (average 11")
	Weeping lovegrass	Good stand, unmowed (average 13")
	Kudzu	Dense growth, uncut
	Brome, smooth	Good stand, mowed (average 12" to 15")
	Tall fescue	Good stand, uncut (average 18")
	Tall fescue with birdsfoot trefoil	Good stand, uncut (average 18")
	Grass – Legume mixture – Timothy, Smooth bromegrass, or Orchardgrass	Good stand, uncut (average 20")
	Blue grama	Good stand, uncut (average 13")
C	Crabgrass	Fair stand, uncut (10" to 48")
	Bermuda grass	Good stand, mowed (average 6")
	Red top	Good stand, headed (15" to 20")
	Common lespedeza	Good stand, uncut (average 11")
	Grass-legume mixture - Summer (**orchard grass, redtop,** Italian ryegrass, and common lespedeza)	Good stand, uncut (6" to 8")
	Centipedegrass	Very dense cover (average 6")
	Kentucky bluegrass	Good stand, headed (6" to 12")
D	Bermuda grass	Good stand, cut to 2.5" height
	Common lespedeza	Excellent stand, uncut (average 4.5")
	Buffalo grass	Good stand, uncut (3" to 6")
	Grass-legume mixture fall, spring (**orchard grass, redtop,** Italian ryegrass, and common lespedeza)	Good stand, uncut (4" to 5")
	Kentucky bluegrass or Lespedeza sericea	Good stand, cut to 2" height. Very good stand before cutting.
	Red fescue	Good stand (headed (12" to 18")
E	Bermuda grass	Good stand, cut to 1.5" height
	Bermuda grass	Burned stubble

Note: covers classified have been tested in experimental channels. Covers were green and generally uniform
Items shown in **Bold** are seed varieties included in the SUDAS Specifications.

Source: Chen & Cotton, 1988 (HEC-15) and USDA NRCS, 1986.

Table 2: Vegetation properties

Vegetation Class	Permissible Shear Stress (lb/ft^2)	Average Height, h (ft)	Stiffness, MEI ($lb \cdot ft^2$)
A	3.7	3.0	725
B	2.1	2.0	50
C	1.0	0.66	1.2
D	0.6	0.33	0.12
E	0.35	0.13	0.012

Source: Chen & Cotton, 1988 (HEC-15)

C. Application

Grassed channels are an excellent low-cost stabilizing method for swales and ditches that carry intermittent low to moderate concentrated flows.

D. Maintenance

Proper maintenance of the channel is critical. For designs where vegetation is assumed to be unmowed or at a minimum height, it is important to ensure that the vegetation in the channel is maintained in the manner intended. Mowing a channel, which was not designed to be kept at a short height, could result in failure of the grass channel. If there is a possibility that the channel could be mowed, it should be designed as such.

Newly seeded or sodded areas should be maintained and watered as required to ensure establishment of the grass. See Sections 7E-6 and 7E-8.

E. Time of year

Grass channel liners require the vegetation to be well-established in order to provide maximum protection from erosion. Seeding a channel near the end of the annual seeding window may not allow enough time for the vegetation to develop sufficiently to resist flows from winter snowmelt or spring rains.

F. Design example

Assume a grass channel with a 3-foot bottom, 4:1 side slopes, and a slope of 1% is designed to carry 24 cfs. Determine if the proposed Class C vegetation is adequate.

Solution:

First, use Manning's equation to find the depth of flow. This can be done through a trial and error process, or by using various tables and charts. For grass channels, Manning's n value varies, and must be calculated based upon the depth of flow. From Table 2, the average height, h, for Class C vegetation is 0.66 ft, the stiffness, MEI, is 1.2 lb·ft$_2$, and the permissible shear stress is 1.0 lbs/ft$_2$.

Trial 1 – Assume a trial depth of 1.2 feet.

Area of Flow, $A = (b + Z \times d) \times d = (3 + 4 \times 1.2) \times 1.2 = 9.4\ ft^2$

Wetted Perimeter, $P = b + 2 \times \sqrt{d^2 + (Zd)^2} = 3 + 2 \times \sqrt{1.2^2 + (4 \times 1.2)^2} = 12.9\ ft$

Hydraulic Radius, $R = A/P = 9.4/12.9 = 0.73\ ft$

Manning coefficient (from Equation 1):

$$n = \frac{0.73^{1/6}}{19.97\left(\log\left(44.8 \times 0.66^{0.6} \times 1.2^{-0.4}\right) + \log\left(0.73^{1.4} \times .01^{0.4}\right)\right)} = 0.092$$

Solving Manning's yields: $Q = \frac{1.49}{n} AR^{2/3} S^{1/2} = \left(\frac{1.49}{0.092}\right)(9.4)(0.73)^{2/3}(0.01)^{1/2} = 12.2\ cfs$

Since 12.2 cfs is lower than the design value of 24 cfs, a larger depth should be assumed.

Trial 2 – Assume a depth of 1.5 feet.

Following the procedure for Trial 1: A = 13.5; P=15.4; R=.88; n= 0.077; Q= 24 cfs
Now that the depth of flow is known, the shear stress on the channel bottom can be determined by Equation 2.

$$\tau_{max} = \gamma \times d \times S = 62.4 \times 1.5 \times 0.01 = 0.94\ lbs/ft^2$$

Since the maximum shear stress of 0.94 lbs/ft^2 is less than the capacity of the grass channel liner (1.0 lbs/ft^2), the design should be adequate to protect the channel from erosion.

7E-5 Mulching

Source: Iowa DNR, 2005.

BENEFITS

	L	M	H
Flow Control	■		
Erosion Control	■	■	
Sediment Control	■		
Runoff Reduction	■		
Flow Diversion			

Description: Mulching is the application of organic material over soil that is bare or immediately over soil that has been seeded. Mulch prevents erosion by preventing the detachment of soil particles, slows runoff velocity, and retains moisture to improve germination and establishment of vegetative cover.

Typical Uses: This practice may be applied on exposed soils as a temporary control where soil grading or landscaping has taken place or in conjunction with temporary or permanent seeding. When time constraints prevent the establishment of vegetation (seeding), mulch such as wood chips, straw, or compost can be used independently as a temporary soil stabilization practice that protects the soil surface until vegetation establishment can be completed.

Advantages:

- Provides immediate surface protection.
- Suppresses weed growth.
- Conserves soil moisture.
- Acts as a thermal layer for seed.
- If used in conjunction with seed, allows seed growth through the mulch.
- Useful for dust control.

Limitations:

- If applied too thick, it may inhibit seed germination.
- Can blow or wash away if not anchored properly.

Longevity: Varies by material (three months to one year).

SUDAS Specifications: Refer to Section 9040, 1.08, E, 2.07, and 3.10.

A. Description/uses

Used alone or applied over seed, mulch provides immediate erosion protection. Mulching without seeding may be considered for very short-term protection. Mulch protects the disturbed soil surface by absorbing the impact of raindrops, thereby preventing detachment of the soil particles. It also retains and absorbs water, slowing runoff. These properties allow for greater infiltration of water into soil; help to retain seeds, fertilizer and lime in place; and improve soil moisture and temperature conditions for seed germination. Mulch is essential in establishing good stands of

grasses and legumes. In order to prevent movement by wind or water, it is important that the mulch be anchored to the soil.

B. Design considerations

The plans and specifications should address the type of mulch used, application rate, timing of the application, method of anchoring, and schedule for installation, inspection, and maintenance.

1. **Site preparation.** The soil surface shall be prepared prior to the application of mulch in order to achieve the desired purpose and to ensure optimum contact between soil and mulch.

2. **Material considerations.**

a. **General:**

1) Mulching should not be performed during periods of excessively high winds that would preclude the proper placement of mulch.
2) Concentrated flows should be diverted around areas where mulch is applied.
3) If ground is seeded, mulching should be completed during or immediately after seeding.
4) Depending on the seeding period, a heavier application of mulch may be needed to prevent seedlings from being damaged by frost.
5) In areas where lawn-type turf will be established, the use of tackifiers is the preferred anchoring method. Crimping tends to leave an uneven surface and netting can become displaced and entangled in mowing equipment.
6) The use of mulch behind curb and gutter may not be desirable unless anchored by netting, because air turbulence from nearby traffic can displace mulch. Consider the use of erosion mat or sod as an alternative.
7) The product longevity should match the length of time the soil will remain bare or until vegetation occurs.

b. **Straw:**

1) Straw mulch should be applied in conjunction with temporary or permanent seeding, except when applied for short-term (less than three months) stabilization prior to the allowable seeding date.
2) To prevent straw from being wind blown, it is anchored to the soil surface using tackifiers, nets, or a mulch-crimping machine. Mechanical anchoring or crimping is recommended only for slopes flatter than 2:1. Mulch on slopes steeper than 2:1 should be anchored to the soil with netting, or other alternatives, such as a rolled erosion control product considered.
3) Expected longevity is less than three months.

c. **Wood chips/grindings:**

1) Do not use wood chips/grindings over newly seeded areas.

2) Chips may be produced from vegetation removed from site.
3) Chips are effective on slopes up to 3:1.
4) Wood chips decompose over an extended period of time. This process may take nitrogen from the soil. To prevent nitrogen deficiency in the soil, the wood mulch should be treated with a nitrogen rich fertilizer.
5) Do not use in areas where fine turf will be established.
6) Expected longevity is less than 12 months.

d. **Hydromulch.** Hydromulching is normally conducted in conjunction with hydroseeding, but can also be applied as a stand-alone practice. Several different types of hydromulch are available, and each has different material properties and typical uses:

1) **Wood cellulose fiber hydromulch:**
   a) Produced from wood pulp and recycled paper
   b) Most commonly used hydromulch
   c) Use is limited to slopes 6:1 or flatter.
   d) Typically require 24 hours to dry before rainfall occurs in order to be effective against erosion.
   e) Expected longevity is 3-12 months.

2) **Bonded fiber matrix (BFM) hydromulch:**
   a) Produced from strands of elongated wood fibers and a binding agent
   b) May be used on slopes up to and including 2:1.
   c) Typically requires 24 hours to dry before rainfall occurs in order to be effective against erosion.
   d) Expected longevity is 3-12 months.
   e) Provides significantly superior erosion protection than straw mulch or wood cellulose hydromulch.

3) **Mechanically bonded fiber matrix (MBFM) hydromulch:**
a) Produced from strands of elongated wood fibers and crimped synthetic fibers to create an interlocking mechanism between the fibers. Material is combined with additional binding agents.
b) May be used on slopes up to and including 2:1.
c) Provides immediate protections against erosion. No cure time is required to develop surface protection.
d) Expected longevity is 12 months or greater.
e) Provides significantly superior erosion protection than straw mulch or wood cellulose hydromulch.

e. **Compost:**
1) Compost may be used as mulch, either with or without seeding for erosion protection.
See Compost Blankets, Section 7E-2.
2) Expected longevity is less than 12 months.

C. Application

1. **Mulching without seeding.** Wood mulch and compost applied without seed, should be applied to a uniform depth of 1 to 3 inches depending on slope. Straw mulch should be applied at a rate of 2 tons per acre to achieve the specified coverage rate. Wood cellulose fiber hydromulch should be applied at a rate of 2600 lb. per acre. BFM and MBFM hydromulch should be applied at a rate of 3600 pounds per acre.

2. **Mulching for seeding.** Straw mulch over newly seeded areas should be applied at a rate of 1 ½ tons per acre. This application provides some protection of the surface, while allowing some sunlight to penetrate and air to circulate thereby promoting seed germination. When compost is used as mulch over newly seeded areas, a minimum thickness of 1 inch should be spread evenly over flat surfaces. For compost used as mulch on slopes, see Compost Blankets in Section 7E-2. Hydromulch products applied with seeding (hydroseeding) are applied at the same rate as without seeding (see paragraph above).

The NPDES General Permit No. 2 requires that all disturbed areas where no construction activities are scheduled for a period of 21 calendar days or more, be stabilized within 14 days of the final construction activity. Mulching is one way to meet this requirement.

D. Maintenance

Inspect mulched areas for signs of thin or bare spots. Add mulch as required to maintain the thickness of the cover. Areas that show signs of erosion should be repaired, and may require additional protection with an erosion control blanket or other method.

E. Time of Year

Mulch applications for establishing vegetation should be done when weather and soil conditions are favorable. Mulch can be applied over bare frozen ground that has not been seeded to help prevent erosion until such time as vegetation can be established.

7E-6 Permanent Seeding

Source: Iowa NRCS, 2004.

BENEFITS

	L	M	H
Flow Control	■	■	□
Erosion Control	■	■	■
Sediment Control	■	■	□
Runoff Reduction	■	■	□
Flow Diversion	□	□	□

Description: Permanent seeding is a means of establishing permanent, perennial vegetative cover on disturbed areas. The purpose of permanent seeding is to prevent erosion, remove sediment from runoff, reduce the volume of runoff, and improve water quality.

Typical Uses: Permanent seeding is used to stabilize the ground after grading and land-disturbing activities have been completed, or whenever construction activities will be halted for a time period longer than temporary seeding can provide protection (i.e. one growing season).

Advantages:

- Relatively low cost.
- Most common method of providing permanent stabilization of disturbed ground.
- Highly effective as a stand alone measure in all but the most extreme situations (i.e. continuously flowing channels, steep slopes, high flows, etc.).
- Competes with undesirable vegetation noxious weeds.
- Vegetation absorbs water, reducing the volume of stormwater runoff.
- Vegetation filters out sediment and other pollutants, improving water quality.
- Provides an aesthetically pleasing, finished look to the site.

Limitations:

- Does not provide instant protection; requires sufficient time and moisture to establish.
- Difficult to establish in area subjected to concentrated flows.
- Seasonal limitations on planting may not coincide with construction schedule.

Longevity: Permanent.

SUDAS Specifications: Refer to Section 9010 (Seeding)

A. Description/uses

Permanent seeding consists of planting perennial vegetation on disturbed/denuded soil areas. Through seeding, a fibrous root system is established. This holds the soil in place and provides a canopy over the soil, protecting it from raindrop impact. The vegetation slows the velocity of the runoff, protecting the surface from sheet and rill erosion, while allowing suspended sediment to

B. Design considerations

Permanent seeding is the most commonly used method of providing permanent surface stabilization. It is an economical, long-term method of providing highly effective stabilization, and is aesthetically pleasing. However, in order to be effective, the designer must select the proper vegetation and recognize the practical limits of vegetation.

The following should be considered for all sites prior to permanent seeding:

1. **Site stabilization.** Steep slopes, which increase the erosion hazard, should be minimized. Vegetation alone is normally an effective method of stabilizing slopes that are 3:1 or flatter. For slopes steeper than 3:1, or for flatter slopes carrying runoff from upland areas, a rolled erosion control product may be required to provide slope stabilization until the vegetation is established.

In addition, slopes which are very steep (2:1 or greater) and areas which receive intermittent concentrated flows may require application of a turf reinforcement mat to provide permanent reinforcement to the vegetation.

2. **Sediment and water control devices.** Measures should be taken to divert sheet and concentrated flows away from areas that are to be seeded until the vegetation is established.

3. **Seeding methods.** There are four seeding methods to consider:
a. Broadcast seed spreader/cyclone seeder
b. Mechanical drill or cultipacker
c. Hydroseeder in which the seed is intermixed with mulch and water to creates a slurry
d. Pneumatic seeder in which the seed is intermixed with compost or a compost/soil blend

When hydroseeding and pneumatic seeding are utilized, the surface may be left with a more irregular surface, since these practices will fill small depressions and cover small bumps. These two types of seeding methods can be used in situations where slope and accessibility is a limiting factor and seedbed preparation is not possible, or where the application of seed, mulch and fertilizer (if necessary) in one operation is desirable.

Hand broadcasting seed may be utilized for small or inaccessible areas; however it is not recommended for larger areas because of the difficulty in achieving a uniform distribution.

4. **Seedbed preparation.** Proper seedbed preparation is essential for the seed to germinate and develop into a dense, healthy stand of vegetation.

a. **Subsoil preparation.** Newly graded areas may be severely compacted by the weight of heavy earth-moving and construction equipment. Disking or tilling reduces compaction in the uppermost layer of the soil, providing an adequate growing bed for the seed; however, the soil below this level may remain severely compacted. This compacted layer acts as an impermeable barrier, slowing or preventing the infiltration of water into the ground. Infiltration of precipitation reduces runoff, and recharges groundwater supplies. Techniques for reducing ground compaction, such as deep tillage, are described in the soil quality restoration guidelines in Chapter 2. While these techniques are not necessary for establishing permanent vegetation, they are an effective means of improving overall water quality, and the period prior to final stabilization is considered the ideal time to implement them.

b. **Topsoil.** In order to provide an adequate growing medium, a minimum of 6 inches of topsoil should be placed over the disturbed area prior to seeding. Deeper topsoil depths (8-12 inches or greater) are desirable as they increase the organic matter available for use by the plants, allow for

deeper root penetration and increase the moisture holding ability of the soil. These benefits will increase the drought tolerance and long-term health of the vegetation. Where sufficient topsoil is not available, composted material may be incorporated at the rate of 1 inch of compost for every 3 inches of deficient topsoil. This will increase the organic matter content of the soil, and provide an adequate growing medium for vegetation.

c. **Soil pH.** The soil pH should have a range of 5.5 to 7.5. Where soils are known to be highly acidic (pH 6.0 and lower), lime should be applied at the rate recommended by the soil-testing laboratory.

d. **Soil fertilization.** Soil fertilization is required for permanent seeding. Fertilizer rates specified in the SUDAS Specifications are recommended for most applications. Sites without sufficient topsoil or low organic matter may require higher fertilizer rates, or fertilizer with a higher nitrogen concentration.

5. **Seeding properties**
a. **General mixtures.** The SUDAS Specifications provide a number of seed mixes that are acceptable for most general applications. These mixes and a description of their intended usage are shown in Table 1.

Table 1: SUDAS seeding mixtures

Description	Typical Uses	Allowable Seeding Dates
Type 1 - Permanent Lawn Mixture	Used for residential and commercial turf sites. Fertilized; typically mowed	March 1 – May 31 August 10 – September 30
Type 2 - Permanent Cool-Season Mixture for Slopes and Ditches	Not typically mowed. Reaches maximum heights of 2-3 feet; low fertility requirements; grows in spring and fall; can go dormant in summer.	March 1 – May 31 August 10 – September 30
Type 3 – Permanent Warm-Season Slope and Ditch Mixture	Not typically mowed. Reaches heights of 5-6 feet; stays green throughout summer; responds well to being burned in spring; do not apply fertilizer.	March 1 – June 30
Type 4 – Temporary Erosion Control Mixture	Short-lived (6-8 months) mix for erosion control.	March 1 – September 30 (seeding dates vary by seasonal mix)
Wetland Seeding	Used in areas designated for wetland grass seeding.	April 1 – June 30 August 1 – August 31
Native Grass and Wildflower Seeding	Used in areas designated for native grass and wildflower seeding.	April 1 – June 30.

b. **Special mixtures.** Some sites require specifically designed or selected mixtures to address individual site characteristics. Site characteristics that require special consideration include very shady areas, detention ponds, wet areas, streambanks, severe slopes, and areas with poor soils.

6. **Weather.** When seeding, be aware of the weather. Do not seed when heavy rainfall is predicted, during windy weather or on wet/frozen ground (hydroseeding and pneumatic seeding may be an exception to seeding on wet/frozen ground).

7. **Matting.** A rolled erosion control product is recommended for slopes steeper than 3:1. RECPs may also be required for flatter slopes greater than 100 feet in length, to hold the seed in place and protect new vegetation from runoff until it becomes established. Refer to Section 7E-7 for additional information on RECPs.

8. **Mulching.** Mulching is recommended for most permanent seeding applications. Mulch aids in stabilizing the surface until vegetation is established. Mulch also helps retain soil moisture and maintains temperature conditions favorable to germination. Refer to Section 7E-5.

9. **Moisture.** If normal rainfall is insufficient to ensure vegetation establishment, mulching, matting, or controlled watering should be completed to keep seeded areas adequately moist.

C. Application

In order to achieve a dense, healthy stand of vegetation that will provide long-term surface stabilization, seed mixtures and fertilizer should be applied at the rates specified in the SUDAS Specifications.

D. Maintenance

Once the area is seeded, it should not be disturbed and should be protected from traffic. Newly seeded areas should be inspected weekly as part of the overall erosion control inspection, to ensure that grass is growing satisfactorily. Areas that have bare spots, or where erosion has occurred should be re-seeded.

E. Time of Year

The seed mixtures within the SUDAS Specifications should be placed within the dates specified, or as weather conditions allow.

7E-7 Temporary Rolled Erosion Control Products (RECP)

Source: North American Green – SC150.

BENEFITS

	L	M	H
Flow Control	■		
Erosion Control	■	■	■
Sediment Control			
Runoff Reduction			
Flow Diversion			

Description: Temporary rolled erosion control products (RECPs) consist of prefabricated blankets or netting which are formed from both natural and synthetic materials.

Typical Uses: Temporary rolled erosion control products (RECPs) are used as a temporary surface stabilizing measure and to aid in the establishment of vegetation. RECPs are typically used on steep slopes and in vegetated channels.

Advantages:

- Numerous manufacturers, each with a number of different products, allow for the selection of a product which meets the individual characteristics of each site.
- Stabilizes disturbed slope and protects surface from erosive forces of raindrop impact.
- Promotes growth of vegetation.
- Most products degrade over time, eliminating potential maintenance issue.

Limitations:

- With numerous products available, appropriate product selection can be difficult.
- Various products and manufacturers have different design and construction standards. Designer must rely on manufacturer's data.
- RECPs are temporary and do not provide permanent stabilization.
- Permanent stabilization and protection is dependent on the establishment of vegetation.

Longevity: Varies based upon product specified (3 months – 36 months)

SUDAS Specifications: Refer to Section 9040, 1.08, F, 2.08, and 3.12

A. Description/uses

Temporary rolled erosion control products (RECP) consist of netting or blanket materials that are used to stabilize disturbed surfaces and promote the establishment of vegetation. RECPs may also be used to stabilize the surface of channels until vegetation can be established, for low to moderate flow conditions.

They are manufactured from a wide variety of different materials including coconut fiber (coir), jute, nylon, polypropylene, PVC, straw, hay, or wood excelsior. These materials may be used individually, or in combination to form nets or blankets.

The products function by protecting the ground surface from the impact of raindrops and stabilize the surface until vegetation can be established. RECPs also promote the growth of vegetation by helping to keep seed in place, and by maintaining a consistent temperature and moisture content in the soil.

RECPs are not intended to provide long-term or permanent stabilization of slopes or channels. Their role is to protect the surface until the vegetation can establish itself and become the permanent stabilizing feature. In fact, most RECPs are either biodegradable or photodegradable and will decompose over a period of time.

B. Design considerations

RECPs are produced by a number of manufacturers, and are available in a wide variety of different configurations. Competing products from different manufacturers can have completely different material compositions and construction, but be intended to serve the same purpose. Given the wide variety of RECPs available, product selection and specification can be difficult. Fortunately, the Erosion Control Technology Council (ECTC) has developed a uniform product selection guide for RECPs. The ECTC is an organization representing suppliers and manufacturers of rolled erosion control products. A list of member organizations is available on their website (www.ectc.org).

Table 1 follows the guidelines of the ECTC and classifies products based upon longevity and product description. RECP longevity is divided into 4 categories ranging from 3 months to 3 years. RECPs are further classified by their general material properties and construction. These classifications include: mulch control nets, open weave textiles, and erosion control blankets.

Mulch control nets (MCN) are used in conjunction with loose mulches. The MCN is applied over the loose mulch to stabilize and hold it in place. MCNs are used as an intermediate application where loose mulch may not be stable, but an open weave textile or erosion control blanket is not necessary.

Open weave textiles (OWT) consist of natural or synthetic yarns that are woven into a 2-D matrix. OWT are similar to mulch control nets, but have higher strength and a more tightly woven construction, allowing them to provide erosion protection with or without the use of an underlying loose mulch layer.

While available, the use of mulch control nets and open weave textiles as rolled erosion control products is fairly uncommon. Erosion control blankets (ECB) are the most commonly used RECP. ECB are constructed of natural and synthetic materials that are glued, woven, or structurally bound with a netting or mesh. The most common of these products are made from straw, wood excelsior or coconut fiber attached to/between netting. A wide variety of erosion control blankets are available.

ECTC also established recommendations on the appropriate use/performance for each product classification. RECP selection and design should follow the product classification and recommendation shown in Table 1.

For slope applications, the designer should select a product from Table 1 that has the desired longevity and which is rated for the proposed slopes.

For channel applications, the channel lining should be analyzed for the 10-year storm in the permanent vegetated state (ignoring the RECP) as described in Section 7E-4 (Grass Channel). The
RECP should also be analyzed for shear stress. This analysis should be for the unvegetated state, representing the situation immediately after installation. Since it is considered a temporary measure, stabilizing the channel only until vegetation is established, the RECP does not need to be analyzed for a 10-year event as the vegetation does. Analyses of the RECP's shear strength for a 2-year event is adequate.

Proper installation of RECPs is critical. Prior to placing a RECP, the ground should be prepared and the area should be seeded and fertilized. It is imperative that seeding occur prior to placement of the RECP to ensure proper contact between seed and soil. Some manufacturers can embed the specified seed mixture into the product during the manufacturing process (if this process is used, follow the manufacturer's recommended installation specifications). After seeding, the appropriate RECP may be placed and anchored with stakes or staples. The manufacturer will provide specifications for the pattern and spacing of anchor stakes or staples, overlap between rolls (typically 6 inches), and any additional product requirements. It is important that the stakes or staples be properly installed to prevent "tenting" of the product as the vegetation begins to grow and push up on the matting. This can create an unsightly situation and the product can become entangled in mowing equipment.

At the tops of slopes and at the entrance to a channel, the leading edge of the RECP should be trenched into the ground, approximately 6 inches, anchored in place with stakes or staples, and backfilled. This prevents runoff from lifting the leading edge, and flowing between the ground and the RECP. Subsequent segments of RECPs should have their upstream edges trenched in, and the downstream edge should slightly overlap the next section to prevent water from flowing under the product.

Table 1: Typical rolled erosion control product properties and uses

Type	Product Description	Material Composition	Slope Applications	Channel Applications
			Max. Grade	Permissible Shear Stress [1,2]
ULTRA SHORT-TERM – Typical 3 month functional longevity				
1.A	Mulch Control Nets	A photodegradable synthetic mesh or woven biodegradable natural fiber netting	5:1 (H:V)	0.25 lbs/ft^2
1.B	Netless Rolled Erosion Control Blankets	Natural and/or polymer fibers mechanically interlocked and/or chemically adhered together to form a RECP	4:1 (H:V)	0.5 lbs/ft^2
1.C	Single-Net Erosion Control Blankets & Open Weave Textiles	Processed degradable natural and/or polymer fibers mechanically bound together by a single rapidly degrading, synthetic or natural fiber netting or an open weave textile of processed rapidly degrading natural or polymer yarns or twines woven into a continuous matrix.	3:1 (H:V)	1.5 lbs/ft^2
1.D	Double-Net Erosion Control Blankets	Processed degradable natural and/or polymer fibers mechanically bound together between two rapidly degrading, synthetic or natural fiber nettings.	2:1 (H:V)	1.75 lbs/ft^2
SHORT-TERM – Typical 12 month functional longevity				
2.A	Mulch Control Nets	A photodegradable synthetic mesh or woven biodegradable natural fiber netting	5:1 (H:V)	0.25 lbs/ft^2
2.B	Netless Rolled Erosion Control Blankets	Natural and/or polymer fibers mechanically interlocked and/or chemically adhered together to form a RECP	4:1 (H:V)	0.5 lbs/ft^2
2.C	Single-Net Erosion Control Blankets & Open Weave Textiles	An erosion control blanket composed of processed degradable natural or polymer fibers mechanically bound together by a single degradable synthetic or natural fiber netting to form a continuous matrix or an open weave textile composed of processed degradable natural or polymer yarns or twines woven into a continuous matrix.	3:1 (H:V)	1.5 lbs/ft^2
2.D	Double-Net Erosion Control Blankets	Processed degradable natural and/or polymer fibers mechanically bound together between two degradable synthetic or natural fiber nettings.	2:1 (H:V)	1.75 lbs/ft^2
EXTENDED-TERM – Typical 24 month functional longevity				
3.A	Mulch Control Nets	A slow degrading synthetic mesh or woven natural fiber netting	5:1 (H:V)	0.25 lbs/ft^2
3.B	Erosion Control Blankets & Open Weave Textiles	An erosion control blanket composed of processed slow degrading natural or polymer fibers mechanically bound together between two slow degrading synthetic or natural fiber nettings to form a continuous matrix or an open weave textile composed of processed slow degrading natural or polymer yarns or twines woven into a continuous matrix.	1.5:1 (H:V)	2.0 lbs/ft^2
LONG-TERM – Typical 36 month functional longevity				
4	Erosion Control Blankets & Open Weave Textiles	An erosion control blanket composed of processed slow degrading natural or polymer fibers mechanically bound together between two slow degrading synthetic or natural fiber nettings to form a continuous matrix or an open weave textile composed of processed slow degrading natural or polymer yarns or twines woven into a continuous matrix.	1:1 (H:V)	2.25 lbs/ft^2

[1] Refer to Section 7E-11 (Turf Reinforcement Mats) for additional information on determining shear stress in a channel
[2] Minimum shear stress RECP (unvegetated) can sustain without physical damage or excess erosion (0.5 in. soil loss during 30-minute flow event)

Source: Lancaster & Austin, 2004.

C. Application

Rolled erosion control products should be used on bare ground that is highly susceptible to erosion, such as slope and channels, and in locations where establishing vegetation may otherwise be difficult.

There are a wide variety of RECPs available. Table 1 shows the recommended applications for slopes and channels for each type of product. A manufacturer or supplier can provide further assistance in selecting an appropriate RECP. For channel applications, products that contain straw are not recommended due to the likelihood that the concentrated flow will dislodge the straw from the binding material, creating the potential for clogging problems downstream.

D. Maintenance

Once installed, there is little maintenance that needs to be done to RECPs. If the RECPs are vegetated, the vegetation should be watered as needed (refer to Section 7E-6). Until the vegetation is fully established, the surface should be inspected for signs of rill or gully erosion below the matting. Any signs of erosion, tearing of the product, or areas where the product is no longer anchored firmly to the ground should be repaired.

E. Time of year

Seeding and placement of RECPs should be completed well within the annual seeding window. While RECPs provide some stabilization of the channel or slope surface until the vegetation is established, the vegetation ultimately provides stabilization of the surface. The vegetation needs time to establish so it can resist flows from winter snowmelt and spring rains.

F. Design example

Due to difficulty establishing vegetation, and concerns with channel erosion, assume that a RECP is proposed for the design example from Section 7E-4 (Grass Channel).

Find the shear stress in the bare channel after the RECP has been installed. Determine if the RECP is sufficient to temporarily stabilize the channel, until the vegetation can become established.

The manufacturer states that the RECP can withstand a shear stress (without vegetation) of 2.0 lbs/ft^2. In addition, the manufacturer states that for depths between 0.5 feet and two feet, the Manning coefficient for the RECP varies from 0.05 to 0.018 respectively. The coefficient used for the analysis should be interpolated based upon the depth.

Assume a flow depth of 1.5 feet. Interpolating, the Manning coefficient is 0.029.

Trial 1 – Assume a depth of 1.5 feet. Interpolating, the Manning coefficient is 0.029.

> Area, A=13.5; Wetted Perimeter, P=15.4; Hydraulic Radius, R=0.88
> From Manning's Equation, Q=50 cfs. This is too high. Try a lower depth.

Trial 2 – Try 1.0 feet. n= 0.039.

> A=8.4; P=12.1; R=0.67; Q=19.5 cfs Too low. Try higher depth.

Trial 3 – Try 1.1 feet. n=.0372

A=8.1; P=12.1; R=0.67; Q=25.07 cfs. Say 24 cfs. OK

Find the shear stress on the bare RECP liner.

$$\tau_{max} = \gamma \times d \times S = 62.4 \times 1.1 \times 0.01 = 0.69 \ \ lbs/ft^2$$

0.69 lbs/ft^2 is less than the allowable value of 2.0 lbs/ft^2. The RECP liner should adequately protect the channel until vegetation is established.

7E-8 Sodding

Source: Welch, J.

BENEFITS

	L	M	H
Flow Control	■	■	□
Erosion Control	■	■	■
Sediment Control	■	■	□
Runoff Reduction	■	■	□
Flow Diversion	□	□	□

Description: A section of grass-covered surface soil held together by matted roots that is cut in pre-determined sections, transported and delivered directly to the job site ready to install.

Typical Uses: Sod is placed to prevent erosion and damage from sediment and water by stabilizing the soil surface and to improve the visual quality and utility of the area quickly. Sod is typically used in residential or commercial areas where prompt use or aesthetics are important such as building entrance zones or high activity areas. Sod is also used in areas of intermittent concentrated flow such as waterways and channels. Sod may also be utilized in critical areas such as storm drain inlets, steep slopes, and any area where conditions make seeding impractical or impossible.

Advantages:

- Provides immediate erosion and dust control.
- Provides finished landscape appearance at time of installation.
- Reduces likelihood of weed growth.
- Placement can occur any time soil moisture is adequate and ground is not frozen.
- Rapid stabilization of surfaces for traffic areas, channel linings, or critical areas.

Limitations:

- More costly when compared to seeding and mulching.
- Vegetation selection is limited (typically a cool-season bluegrass based mix).
- Time is necessary for root establishment.
- Watering is required to ensure establishment.

Longevity: Permanent.

SUDAS Specifications: Refer to Section 9020 (Sodding)

A. Description/uses

Sodding consists of transplanting turf-type vegetation to promptly stabilize areas that are subject to erosion. Sod may be field sod or commercial sod, a cultured product utilizing specific grass species. A sodded area provides one of the best methods for preventing soil particles from leaving the site, providing immediate protection against soil erosion from water and wind.

B. Design considerations

The following should be considered for all sites stabilized with sod.

1. **Fertilization.** Test soil to determine the exact requirements for lime and fertilizer. Soil tests should be conducted by the state soil testing lab or a reputable commercial laboratory. Information on soil testing and testing services is available from the Iowa State University Extension (http://www.extension.iastate.edu/).

2. **Site preparation.** In areas where topsoil has been stripped, a sodbed should be constructed by spreading a minimum of 6 inches of topsoil prior to sodding. Deeper topsoil depths (8-12 inches or greater) are desirable as they increase the organic matter available for use by the plants, allow for deeper root penetration and increase the moisture holding ability of the soil. These benefits will increase the drought tolerance and long-term health of the vegetation. Where sufficient topsoil is not available, composted material may be incorporated at the rate of 1 inch of compost for every 3 inches of deficient topsoil.

The top of the completed sodbed should contain a minimum soil organic matter content of 5%. In areas where topsoil has not been stripped, and the soil organic content is low, compost may be placed, as required, to increase the soil organic matter content.

The top 3 inches of the sodbed should be prepared by tilling, and the surface cleared of any trash, debris, roots, branches, and stones or clods larger than ¾ inch in diameter. Any low spots should be filled or leveled to avoid standing water. The fertilizer and any other soil amendments should be uniformly applied and incorporated into the top 1½ inches of the soil by tilling or disking. Complete soil preparation by rolling or cultipacking to firm the soil. Avoid using heavy equipment on the area, particularly when the soil is wet, as this may cause excessive compaction and make it difficult for the sod to take root.

Newly graded areas may be severely compacted by the weight of heavy earth moving and construction equipment. Disking or tilling reduces compaction in the uppermost layer of the soil, providing an adequate growing bed for the sod; however the soil below this level may remain severely compacted. This compacted layer acts as an impermeable barrier, slowing or preventing the infiltration of water into the ground. Infiltration of precipitation reduces runoff and recharges groundwater supplies. Techniques for reducing ground compaction, such as deep tillage, are described in the soil quality restoration guidelines in Chapter 2. While these techniques are not necessary for establishing sod, they are an effective means of improving overall water quality, and the period prior to final stabilization is considered the ideal time to implement them.

3. **Installation techniques**. Sod should be placed as soon as possible after the ground surface has been graded, to take advantage of the ground moisture, and installed within 36 hours of cutting. The soil should be slightly moist, but firm enough not to leave depressions if walked on. Install sod in a straight line at right angles to the direction of the slope, starting at the base of the area to be sodded and working uphill. Sodding operations should be planned so that sloped areas can be completely protected, from bottom to top, prior to halting operations for the day, or before

significant precipitation is expected. The angled ends caused by the automatic sod-cutting machine must be matched correctly.

Figure 1: Proper sod installation

Source: Kansas City APWA, 2003

Place the strips together tightly so that no open joints are left between strips or between the ends of strips. Lateral joints shall be staggered in a brickwork-type pattern to promote uniform growth and strength. Sod should not be overlapped or stretched, and all joints should be butted tightly to prevent voids. Sod should be laid perpendicular to the flow of water on slopes and in waterways. The edges of the sod at the top of the slopes should be slightly tucked under. A layer of soil should be compacted over the edge to conduct surface water over and onto the top of the sod. Fill any spaces between the joints and all sod edges with at least 2 inches of topsoil.

Care shall be taken to prevent voids or over-exposure of the roots, which would cause drying. As sodding of defined areas is completed, sod shall be rolled or tamped to provide firm contact between roots and soil. Seam openings between the mats are a sign the turf is shrinking and that the sod requires more water. Gaps between edges or ends of sod mats should be filled with topsoil and roll. If sod placement is delayed, it should be kept cool and moist. When placed on slopes steeper than 3:1, or in areas subject to concentrated flow, the sod should be anchored with pins, staples, or other approved methods at the ends and center, or every 3 to 4 feet for longer strips, to prevent movement. Sod should be kept moist until it is firmly rooted which typically takes a minimum of two weeks (see supplemental watering).

4. **Sod properties.** Sod should be of high quality, which the genetic origin is known, free of noxious weeds, disease, and insect problems consisting of a ¾ inch mat of vigorous turf. It should appear healthy and vigorous, and conform to the following specifications:

a. Sod should be live grass, machine cut at a uniform depth of 1/2 - 2 inches (excluding shoot growth and thatch).
b. Sod strips should be cut with smooth, clean edges and square ends to facilitate laying and fitting.
c. Sod should not be cut in excessively wet or dry weather.
d. Frozen sod should never be placed.
e. Sod should not be permitted to dry out.
f. Harvested sod pieces can vary from widths of 12 to 48 inches and lengths of two to 100 feet, but should be in sections strong enough to support their own weight and retain their size and shape when lifted by one end.
g. As noted in the installation considerations, harvest, delivery, and installation of sod should take place within a period of 36 hours.
h. Sod should be moistened after it is unrolled, which helps to maintain its viability, and stored in the shade if possible, during installation.

5. **Supplemental water.** After placement is complete, the sod should be irrigated to a depth sufficient that the underside of the sod mat and 4 inches of soil below sod is thoroughly wet. Irrigate at a rate that does not result in runoff. The moisture level can be checked by lifting a corner of a sod roll, and verifying that water is penetrating well into the subsoil. As a rule of thumb, watering should be scheduled as follows:

a. **First week.** The sod soil should be kept moist at all times. During dry spells, the sod should be watered daily, or as often as necessary to maintain moist soil. The sod should be watered during the heat of the day to prevent wilting.

b. **Second and subsequent weeks.** Water sod to maintain adequate moisture in the soil until the grass takes root. This can be determined by gently tugging on the sod. Resistance indicates that rooting has occurred.

c. **Summer installations (June – August).** Summer installations require high levels of attention to water application needs, as newly installed sod will dry out rapidly, suffering significant setback or total loss.

C. Application

The NPDES General Permit No. 2 requires that all disturbed areas, where no construction activities are scheduled for a period of 21 calendar days or more, be stabilized within 14 days of the final construction activity. Sodding is one way to meet this requirement.

D. Maintenance

The sodded area should be inspected daily for at least two weeks, or until the sod is established, to ensure that the moisture content is sufficient and that root establishment is proceeding. The sod should not be mowed regularly until it is well-established, and the roots have knitted down. The turf should never be mowed shorter than 2 ½ inches and no shorter than 3 inches during June, July, and August, in order to increase drought tolerance.

E. Time of year

Sod availability is seasonal, although it can be laid in nearly all weather conditions. Sod laid during the middle of the summer will require significantly more maintenance and watering. If the ground is frozen, sod cannot be cut and should not be laid; however, if it is available, unfrozen, dormant sod can be laid on unfrozen ground, provided there is not a significant layer of snow.

7E-9 Surface Roughening

Source: Clackamas County, 2000.

BENEFITS

	L	M	H
Flow Control	■		
Erosion Control	■		
Sediment Control			
Runoff Reduction	■		
Flow Diversion			

Description: Surface roughening is a temporary practice incorporated during grading, that reduces soil loss by reducing the flow velocity of runoff. Surface roughening may also be used as a method of reducing dust (See Section 7E-3).

Typical Uses: For slopes where additional grading is anticipated prior to permanent/temporary stabilization. To reduce runoff velocity, trap sediment, increase infiltration, and aid in the establishment of vegetative cover. Typically performed as an end-of-day practice.

Advantages:

- Simple and cost-effective.
- Immediate, short-term control.
- Reduces both wind and water erosion.

Limitations:

- Could increase soil compaction, requiring additional seedbed preparation.
- Not a stand-alone practice – it must be used in conjunction with other erosion and sediment control measures.

Longevity: Short-term, depends on precipitation.

SUDAS Specifications: Refer to Section 9040, 1.08, H and 3.11.

A. Description/uses

Disturbed, non-vegetated areas that are graded smooth and have compacted soil cause increased runoff and reduce the ability of vegetation to be re-established, resulting in erosion. Surface roughening abrades the soil surface with horizontal ridges and depressions across the disturbed area. The use of this practice helps lessen erosion and sediment transport during grading operations.

B. Design considerations

other erosion and sediment control practices. Surface roughening may be applied after grading activities ceased (temporarily), but will be resumed again within 21 days. Surface roughening might also be employed on an actively graded slope, prior to an impending storm, to provide some level of erosion protection.

Roughening methods include creating furrows across the slopes and tracking up and down the slope. The type of roughening depends on the steepness of the slope and the soil type.

1. **Directional tracking.** Tracking uses the depressions formed by the tracks from bulldozers and other construction vehicles. The vehicle is driven up and down the slope, leaving behind horizontal depressions in the soil. These depressions interrupt the runoff's flow, reducing its velocity and erosive capacity.

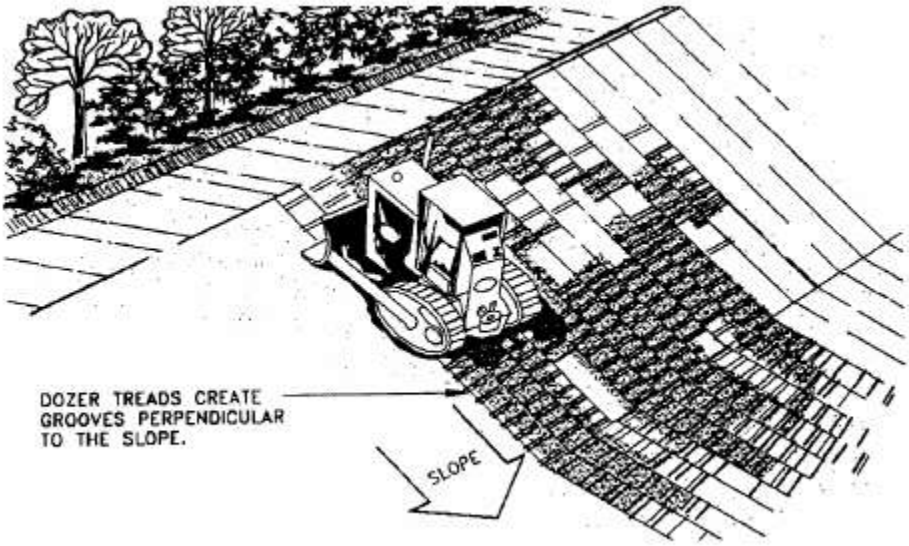
Directional tracking is the least effective, but likely most convenient, method of surface roughening. Directional tracking should only be performed on slopes that are 3:1 or flatter, as its use on steeper slopes may not prevent concentrated flow from developing. For slopes steeper than 3:1, grooving/furrowing should be used (see information below).

Directional tracking is ideally suited for sandy soils, as they do not compact as severely. Its use on clay-based soils should be limited, unless no other alternatives are available. As few passes of the machinery should be made as possible in order to limit compaction.

It is imperative that the equipment track perpendicular to the contour, creating groves that are parallel to the contour. Tracking along the contour will create vertical grooves and ridges for the runoff to follow, actually increasing the erosion potential.

2. **Grooving.** Grooving is a method of surface roughening that creates a series of ridges and depressions along the contour of the slope. Grooving may be accomplished with rippers, disks, spring harrows, chisel plows, or any equipment capable of operating safely on the slope. The grooves created should be no more than 15 inches apart and should not measure less than three inches in depth. Grooving is more effective erosion control practice than vehicle tracking and may be used with all soils types and all slopes.

Figure 1: Typical directional tracking on a bare slope



Source: US Army Corps of Engineers, 1997.

Regardless of the method used, after the disturbed area has been roughened it should be protected from vehicular traffic as it may greatly reduce the efficiency of the roughening and require the practice to be repeated. At no time should slopes be bladed or scraped to produce a smooth, hard surface.

C. Application

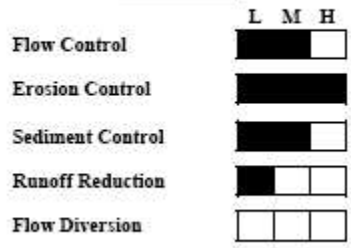
Surface roughening is a simple method of providing at least a minimal level of short-term erosion protection for slopes which are still under construction, but on which work is being halted for a short period of time. Surface roughening should be provided on all slopes at the end of the workday. It can also be done, in conjunction with mulching, after the fall seeding period has passed to stabilize a site and carry it through the winter months.

D. Maintenance

Surface roughening is a short-term practice that needs to be reapplied whenever the roughened surface is removed by re-grading or weather conditions. Typically, surface roughening on a slope will need to be reestablished after each rain event, regardless of intensity.

7E-10 Temporary Seeding

Source: Mississippi State University



Description: Temporary seeding is a means of growing a short-term (less than one-year) vegetative cover on disturbed areas that may be in danger of erosion. The purpose is to stabilize disturbed areas with existing or expected high rates of soil erosion by water or wind, reduce damage from sediment and runoff to downstream areas, and improve water quality.

Typical Uses: Temporary seeding may be used to stabilize rough-graded disturbed areas that will not have permanent stabilization or further work performed on them for a period of 21 days or more, and which require temporary stabilization for a period of less than one year.

Advantages:

- Relatively low cost.
- Competes with undesirable vegetation noxious weeds.
- Reduces flow velocity, thus reducing erosion potential.
- Traps suspended sediment.
- Improves construction site appearance.
- Reduces maintenance and clean out requirements associated with other erosion control structures (i.e. sediment basin cleanout frequency will be reduced if site is stable).
- Effective measure for dust control.

Limitations:

- Requires sufficient time and moisture to establish.
- Planted areas are susceptible to wind and water erosion until vegetation is established.
- Seasonal limitations on planting may not coincide with construction schedule.
- Method is only effective for one growing season.

Longevity: One growing season.

SUDAS Specifications: Refer to Section 9010 (Seeding).

A. Description/uses

Temporary seeding for construction site erosion control consists of planting appropriate rapidly growing vegetation on disturbed/denuded soil areas to reduce soil loss (erosion and sedimentation), decrease stormwater runoff volume, and lessen problems associated with mud and dust production from bare, unprotected soil surfaces. Through seeding, a fibrous root system is established. This holds the soil in place and provides a canopy over the soil, protecting it from raindrop impact. Typical applications for temporary seeding include stabilizing the denuded surface of excavations, slopes, diversions, dams, sediment basins, road embankments, and stockpiles.

The NPDES General Permit No. 2 requires that all disturbed areas where no construction activities are scheduled for a period of 21 calendar days or more, be stabilized within 14 days of the final construction activity. Temporary seeding is one way to meet this requirement.

B. Design considerations

The following should be considered for all sites that are to be stabilized with either temporary or permanent seeding.

1. **Site stabilization.** Minimize steep slopes, which increase the erosion hazard, and make seedbed preparation difficult. Concentrated flows should be diverted away from the seeding area.

2. **Sediment and water control devices.** Prior to seeding, necessary control practices such as dikes, swales/waterways, or sediment basins or diversions should be installed.

3. **Seeding methods.** There are four seeding methods to consider:
a. Broadcast seed spreader/cyclone seeder
b. Mechanical drill or cultipacker
c. Hydroseeder in which the seed is intermixed with mulch and water to creates a slurry.
d. Pneumatic seeder in which the seed is intermixed with compost or a compost/soil blend

When hydroseeding and pneumatic seeding are utilized, the surface may be left with a more irregular surface, since these practices will fill small depressions and cover small bumps. These two types of seeding methods can be used in situations where slope and accessibility is a limiting factor and seedbed preparation is not possible, or where the application of seed, mulch and fertilizer (if necessary) in one operation is desirable.

Hand broadcasting seed may be utilized for small or inaccessible areas; however, it is not recommended for larger areas because of the difficulty in achieving a uniform distribution.

4. **Seedbed preparation.** Seedbed preparation is essential for the vegetation's ability to germinate and grow. Seedbed preparations considerations include:

a. **Soil surface.** Topsoiling is not necessary for temporary seeding, though it may improve the chances of vegetation establishment. When the area is crusted or hardened, the soil surface shall be loosened by disking, raking, harrowing, or other acceptable means to a depth of approximately 2 inches. If the area has been recently loosened, no further roughening is required.

Soil compaction severely hinders seeding success rate and increases runoff rates. If the area has been compacted by heavy equipment, the surface to be seeded should be chisel plowed to a depth of 6 – 12 inches once heavy equipment has been removed from the area.

b. **Soil pH.** The soil pH should have a range of 5.5 to 7.5. Where soils are known to be highly acidic (pH 6.0 and lower), lime should be applied at the rate recommended by the soil-testing laboratory.

c. **Soil fertilization.** Fertilizer application is required for temporary seeding.

5. **Seed mixture.** Unless a specific seed mixture is required, the seed mixtures described in the SUDAS Specifications Section 9010 may be utilized. These are annual seed mixtures and are only intended to provide protection for one growing season (six to eight months). For applications requiring protection longer than one growing season, reseeding in the spring or dormant seeding in the fall may be required. Alternatively, areas which will not be disturbed for a period greater than can be protected by a temporary seed mixture, should have permanent seeding applied (refer to Section 7E-6)

Table 1: Temporary erosion control mixes

Seed Mixture	Allowable Seeding Dates
Spring Mix	March 1 – May 20
Summer Mix	May 21 – August 14
Fall Mix	August 15 – September 30

Source: SUDAS Specifications Section 9010.

6. **Weather.** When seeding, be aware of the weather. Do not seed when heavy rainfall is predicted, during windy weather or on wet/frozen ground (hydroseeding and pneumatic seeding may be an exception to seeding on wet/frozen ground).

7. **Matting.** A rolled erosion control product is recommended for slopes steeper than 3:1. RECPs may also be required for flatter slopes greater than 100 feet in length, to hold the seed in place and protect new vegetation from runoff until it becomes established. Refer to Section 7E-7 for additional information on RECPs.

8. **Mulching.** For temporary seeding, mulching is advised when seeding in the summer or during excessively hot or dry weather to maintain moisture levels; in the fall for winter cover; on slopes steeper than 3:1; and on adverse soils (shallow, rocky, or high in clay or sand). Mulching is not advised in concentrated flow situations. Refer to Section 7E-5.

9. **Moisture.** If normal rainfall is insufficient to ensure vegetation establishment, mulching, matting. or controlled watering should be completed to keep seeded areas adequately moist.

C. Application

In order to achieve the appropriate vegetation density, temporary seed mixtures and fertilizer should be applied at the rates specified in the SUDAS Specifications.

D. Maintenance

Once the area is seeded, it should not be disturbed and should be protected from traffic. Newly seeded areas should be inspected weekly as part of the overall erosion control inspection, to ensure that grass is growing satisfactorily. Areas that have bare spots or where erosion has occurred, should be re-seeded. Temporary seeding should be maintained until the area is again disturbed by construction, or permanent stabilization is achieved.

E. Time of year

The temporary seeding mixture used should be based upon the time of year as indicated in Table 1. The dates given are approximate and may be adjusted to account for annual weather patterns.

7E-11 Turf Reinforcement Mats (TRM)

Source: SI Geosolutions, Pyramat.

BENEFITS

	L	M	H
Flow Control	■		
Erosion Control	■	■	■
Sediment Control			
Runoff Reduction			
Flow Diversion			

Description: Turf reinforcement mats (TRMs) are composed of non-degradable synthetic fibers, filaments, nets, wire meshes, and/or other elements, processed into a permanent, three-dimensional matrix. TRMs are designed to impart immediate erosion protection, enhance vegetation establishment, and permanently reinforce vegetation during and after maturation.

Typical Uses: TRMs are typically used on steep slopes and in hydraulic applications such as high flow ditches and channels, stream banks, shorelines, and inlet/outlet structures. TRMs are used where erosive forces may exceed the limits of natural, unreinforced, vegetation, or in areas where limited vegetation establishment is anticipated.

Advantages:

- Can withstand high hydraulic shear stresses and velocities.
- Provides permanent, long-term reinforcement of vegetation. Does not degrade over time like RECPs.
- Ability to be vegetated creates a more aesthetically pleasing appearance than rip-rap, concrete, or other "hard armor" techniques.
- Can stabilize ground where vegetation is difficult to establish.
- Normally a less expensive alternative to "hard armor" techniques.

Limitations:

- Performance is dependant upon proper product selection and installation
- Can only withstand a limited amount of flow before hard armoring is required.

Longevity: Permanent.

SUDAS Specifications: Refer to Section 9040, 1.08, G, 2.09, and 3.13

A. Description/uses

Turf reinforcement mats (TRMs) are a three dimensional product, constructed of synthetic, nondegradable (though some products are a composite of degradable and non-degradable materials) materials. The non-degradable matting creates a permanent reinforcing system for vegetation. The resulting reinforced vegetation is able to withstand significantly greater erosive forces than normal vegetation.

Traditionally, hard-armor erosion control techniques, such as riprap and reinforced paving systems, have been employed to prevent soil erosion in highly erosive areas. Although these permanent measures can withstand substantial hydraulic forces, they are costly, and they do not provide the pollutant removal capabilities of vegetated systems.

TRMs enhance the natural ability of vegetation to permanently protect soil from erosion. In addition

to providing scour protection, TRMs are designed to encourage vegetative root and stem development. By protecting the soil from scouring forces and enhancing vegetative growth, TRMs can raise the threshold of natural vegetation to withstand higher hydraulic forces on slopes, in streambanks and channels, and at inlet/outlet structures.

TRMs, unlike temporary erosion control products, are designed to remain in place permanently to protect seeds and soils, improve germination, and reinforce established vegetation. Some TRMs incorporate natural, degradable fiber material to assist in the initial establishment of vegetation; however, the permanent reinforcement structure of TRMs is composed entirely of non-degradable materials.

In addition to providing permanent reinforcement of vegetation, TRMs also protect disturbed surfaces immediately after installation (prior to establishment of vegetation). This benefit is important for preventing soil loss and protecting newly seeded areas.

B. Design considerations

TRMs are produced by a number of manufacturers, and are available in a wide variety of configurations. The following steps should be considered when designing and specifying an appropriate TRM.

1. Hydraulic stresses:

TRMs in channels should be designed based upon the calculated shear stress. The shear stress imposed on the TRM in the channel should be evaluated under two conditions: temporary (unvegetated) and permanent (vegetated). The temporary condition represents the unvegetated conditions immediately after installation of the TRM. The permanent condition represents the long-term protection provided by the TRM in its fully vegetated state.

A TRM in a permanent vegetated state should be designed to withstand a 10-year storm event. In a fully vegetated channel, the TRM is located well below the top of the exposed vegetation. As a result, its has little impact on the level of shear created by the flow and its presence can be ignored. In doing this, the shear stress in the fully vegetated channel is determined in the same manner as described in Section 7E-4 (Grass Channel).

The TRM should also be analyzed for unvegetated state. Since this condition is temporary, the unvegetated TRM can be evaluated for a 2-year storm (rather than the 10-year). This analysis also follows the method described in Section 7E-4, but since there is no vegetation, the Manning coefficient is constant. The Manning coefficient of a TRM is normally provided in the manufacturer's literature.

Many TRM manufacturers have software available to aid in the calculation of shear stress. This software may be available through the manufacturer's website or local product representative. Once the anticipated shear stresses are known, a TRM can be selected. Most TRM manufacturers report the permissible shear stresses that their products can withstand in both the vegetated and unvegetated conditions. These values are typically determined from full-scale, third party hydraulic flume testing. Commonly accepted facilities for conducting these tests include the Texas Transportation Institute (TTI), Colorado State University, and Utah State University. The designer should select a product with a greater permissible shear stress than the actual calculated hydraulic shear stress of the system. Note: for TRMs containing degradable components, the

reported permissible values must represent only the permanent, synthetic portions of the TRM to satisfy the long-term design and performance requirements.

2. Non-hydraulic stresses:
In addition to the hydraulic stress (shear), consideration must also be given to non-hydraulic stresses. Examples of non-hydraulic stresses include heavy mowing equipment, occasional vehicular traffic, and heavy debris in the channel, or on a slope.

The materials that most TRMs are constructed from are not intended to withstand these nonhydraulic stresses. This type of loading can cause the material to tear, creating the potential for failure of the entire system.

For installations that will be exposed to these types of stresses, a high tensile strength material should be specified. These high tensile strength materials are commonly called high survivability or high performance TRMs. These high strength TRMs will provide long-term structural integrity, even when exposed to potentially damaging non-hydraulic stresses.

Table 1: TRM material requirements and acceptable applications

	Property[1]	Test Method	Type 1	Type 2	Type 3
Material	Thickness	ASTM D6525	0.25 in	0.25 in	0.25 in
	Tensile Strength[2]	ASTM D6818	125 lb/ft	1,500 lb/ft	3,000 lb/ft
	UV Resistance[3]	ASTM D4355	80% @ 500 hrs	80% @ 1,000 hrs	90% @ 3,000 hrs
Performance	Maximum Shear Stress (Channel Applications)	ASTM D4640	8 lb/ft^2	10 lb/ft^2	12 lb/ft^2
	Maximum Slope Gradient (Slope Applications)	N/A	1:1 (H:V) or flatter	1:1 (H:V) or flatter	1:1 (H:V) or greater

1. For TRMs containing degradable components, all values must be obtained on the non-degradable portion of the matting.
2. Minimum Average Roll Values, machine direction only. Tensile strength from ASTM D5035 may be substituted upon approval.
3. Tensile strength of structural components retained after exposure.
4. Minimum shear stress that fully-vegetated TRM can sustain without physical damage or excess erosion (0.5 in soil loss) during a 30 minute flow event in large scale testing. Acceptable large scale testing protocol includes ASTM D6460 or independent testing conducted by the Texas Transportation Institute, Colorado State University, Utah State University, or other approved testing facility.

C. Application
Turf reinforcement mats should be selected and used in locations where vegetation alone cannot withstand the anticipated flow velocities and shear stresses, and where hard armor (concrete and riprap) is not necessary or is visually unappealing, or where stormwater quality and sediment/pollutant removal is desirable.

D. Maintenance
Once installed, there is little maintenance that needs to be done to TRMs. If the TRM is to be vegetated, the vegetation should be watered as needed (refer to Section 7E-6). Until the vegetation is fully established, the ground surface should be inspected for signs of rill or gully erosion below the matting. Any signs of erosion, tearing of the matting, or areas where the matting is no longer anchored firmly to the ground should be repaired.

E. Design example
Assume a channel with a 4-foot bottom, 3:1 side slopes, and a slope of 3% is designed to carry 265 cfs. Lining the channel with a TRM is being proposed. Determine if a selected vegetated TRM, with Class C vegetation is adequate. Also analyze the TRM for the unvegetated condition

to ensure that it will provide sufficient protection until vegetation is established. The manufacturer of the TRMs provided the following information on the TRM's properties:

Permissible shear stress, vegetated – 8 lbs/ft2
Permissible shear stress, unvegetated – 4.55 lbs/ft2
Manning's n Coefficient – 0.026

Solution:

First determine the shear stress for the vegetated condition. Using Manning's equation, find the depth of flow. This can be done through a trial and error process, or by using various tables and charts.

Trial 1 – Assume a depth of 2 feet.

Area of Flow, $A = (b + Z \times d) \times d = (4 + 3 \times 2) \times 2 = 20 \text{ ft}^2$

Wetted Perimeter, $P = b + 2 \times \sqrt{d^2 + (Zd)^2} = 4 + 2 \times \sqrt{2^2 + (2 \times 3)^2} = 16.6 \text{ ft}$

Hydraulic Radius, $R = A/P = 20/16.6 = 1.2$

Manning coefficient (from Equation 1, Section 7E-4):

$$n = \frac{0.1.2^{1/6}}{19.97\left(\log\left(44.8 \times 0.66^{0.6} \times 1.2^{-0.4}\right) + \log\left(0.1.2^{1.4} \times .03^{0.4}\right)\right)} = 0.051$$

Solving Manning's yields: $Q = {}^{1.49}\!/_{n} AR^{2/3} S^{1/2} = \left({}^{1.49}\!/_{0.051}\right)(20)(1.2)^{2/3}(0.03)^{1/2} = 114 \text{ cfs}$

Since 114 cfs is less than the design value of 265 cfs, a larger depth should be assumed.

Trial 2 – Assume a depth of 3 feet.

Following the procedure for Trial 1 – A = 39; P=23; R=1.7; n=0.045; Q= 318 cfs. Q is too large.

Trial 3 – Assume a depth of 2.8 feet

A=34.7; P=21.7; R=1.6; n=.046; Q=266 – Say 265 cfs OK.

Now that the depth is known for the vegetated condition, the shear stress can be determined by Equation 2 from Section 7E-4.

$$\tau_{max} = \gamma \times d \times S = 62.4 \times 2.8 \times 0.03 = 5.2 \text{ lbs/ft}^2$$

Since the maximum shear stress of 5.2 lbs/ft2 is less than the capacity of the vegetated TRM (8.0 lbs/ft2), the design is acceptable.

Now analyze for the unvegetated condition to ensure that an adequate level of protection will be provided until the vegetation is established.

Following the same procedure as the previous example, the channel properties are calculated. Note that for the unvegetated condition, a constant Manning coefficient (in this case 0.026) can be assumed.

Assuming a depth of 2.1

A=21.6; P=17.3; R=1.25; Q=249. Q is too low. Select a larger depth.

Assuming a depth of 2.16

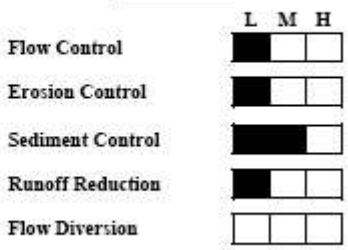
A=22.6; P=17.7; R=1.28; Q=265. Assume 266 cfs. OK

Calculate Shear stress on the unlined channel.

$$\tau_{max} = \gamma \times d \times S = 62.4 \times 2.16 \times 0.03 = 4.04 \text{ lbs/ft}^2$$

Since the maximum shear stress of 4.04 lbs/ft^2 is less than the capacity of the unvegetated TRM (4.55 lbs/ft^2), the design is acceptable.

7E-12 Vegetative Filter Strip



Description: A filter strip is a natural system that uses plants to treat stormwater runoff. The vegetated filter strip (VFS) serves as a perimeter buffer zone and a last defense between an area needing protection, such as a street or water body (stream, wetland, lake, etc.), and the adjacent property. Its primary purpose is to remove sediment and other pollutants from runoff water by filtration, deposition, infiltration, absorption, and vegetative uptake.

A VFS relies on the use of vegetation to slow runoff velocities and filter out sediment and other pollutants from construction site runoff. There can be a significant reduction in runoff volume for smaller flows that infiltrate pervious soils while contained within the filter strip. Sheet flow must be maintained across the entire filter strip for it to maintain its effectiveness.

Typical Uses: As a sediment control practice, a VFS installed specifically during construction is typically used to prevent sediment from moving into/onto adjacent property. It is intended to keep downstream areas free of sediment.

Advantages:

- Natural measure to remove coarse sediment.
- Reasonably low construction costs.
- Filter strips are a low-maintenance practice, but maintenance increases as sediment volumes increase.
- May be able to utilize existing vegetation as a treatment device.
- Provides an aesthetically pleasing appearance.

Limitations:

- Are not intended to treat concentrated flow.
- The disturbed area draining to the vegetated strip shall have slopes of 6 percent or less.
- Requires more land area than other sediment control practices.

Longevity: Permanent.

SUDAS Specifications: Refer to Section 9010 (Seeding) or 9020 (Sodding)

A. Description/uses

Vegetative Filter Strips (VFS) are densely vegetated strips of land (typically installed with sodforming grasses) with a uniform slope to maintain sheet flow, which are designed to treat runoff and remove pollutants through vegetative filtering and infiltration during the construction phase. A VFS is located along the length of the downslope edge of the entire disturbed area to treat the runoff.

A VFS relies on the use of vegetation to slow runoff velocities and filter out sediment and other pollutants from construction site runoff. There can be a significant reduction in runoff volume for smaller flows that infiltrate pervious soils while contained within the filter strip. To be effective, sheet flow must be maintained across the entire filter strip.

B. Design considerations

Because of the large area required to provide adequate treatment, filter strips are generally used to treat small drainage areas (less than five acres). However, larger sites which have significant undisturbed vegetation or sufficient area for construction of a VFS may be well suited for accommodating a vegetated filter strip.

The size of the filter strip depends on the drainage area and the filter strip slope. Flow must enter the filter strip as sheet flow and spread out over the width of the strip. It is desirable to keep flow depth across the strip below a ½ inch in order to maintain sheet flow.

A level spreader may be required at the upstream end of the strip to dissipate concentrated flows and ensure sheet flow across the strip. Level spreaders or filter berms should be constructed perpendicular to the slope every 100 feet for slopes less than 5% and every 50 feet for slopes greater than 5% to prevent concentrated flows from forming.

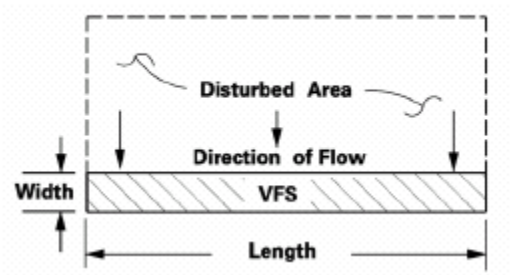
It should be noted that existing vegetation along a channel or drainage way can be used as a VFS. By simply protecting this vegetation during construction, an inexpensive VFS may be created.

C. Application

There are three different approaches to determining the size of a filter strip:

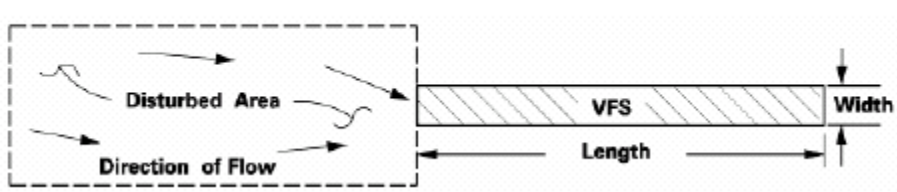
1. Adjacent to the disturbed ground, a VFS with a minimum width of 25 feet is adequate for treating runoff from disturbed areas up to 125 feet in width. For larger disturbed areas, the width of the VFS should be increased by 1 foot for every 5 feet beyond the 125-foot limit.

Figure 1: Vegetated filter strip adjacent to disturbed area



2. When the VFS is not completely adjacent to the site, it should be sized to be a minimum of one-half the area of the disturbed ground (i.e. Length X Width = ½ X Disturbed Area). The width of the VFS should be sized according to Manning's equation (refer to Chapter 2, to limit the flow depth to a 1/2-inch or less (a minimum of width of 25 feet should be provided).

Figure 2: Vegetated filter strip downstream of disturbed ground



3. The VFS may also be designed to provide a 20-minute travel time (contact time) for runoff. According to the EPA, this level of contact time with the vegetation is able to achieve 85% removal of Total Suspended Solids (TSS) (US-EPA, 1980).

D. Maintenance

Vegetated filter strips should be protected from vehicular traffic and construction equipment. The stand of vegetation should be maintained at a minimum height of 3 to 6 inches. Unwanted weeds, brush, and trees should be controlled.

Vegetated filter strips require regular inspection to ensure proper distribution of flows, examine for signs of rill formation, and check for and remove accumulated sediment.

7E-13 Check Dam

BENEFITS

	L	M	H
Flow Control	■	■	■
Erosion Control			
Sediment Control	■		
Runoff Reduction			
Flow Diversion			

Description: Check dams, sometimes called ditch checks, consist of a vertical barrier constructed across swales, ditches, and waterways. These structures are most commonly constructed of erosion stone, although silt fence and manufactured devices are also used. Straw bales were used at one time, however, due to their high rate of failure and low level of effectiveness, their use is severely limited.

Typical Uses: Check dams are used to control the velocity of concentrated runoff in ditches and swales, and to prevent gully erosion until the channel can be stabilized. The structures may also provide some sediment removal benefits, however this is not their primary function.

Advantages:

- Highly effective at reducing flow velocities in channels.
- Simple to construct.
- Low maintenance.

Limitations:

- Steep slopes require short spacing between check dams.
- Sediment removal practices are still required.
- Straw bales are ineffective and prone to failure.

Longevity: Stone Check Dams: One year. May be considered permanent.
Manufactured devices & silt fence: Six months.

SUDAS Specifications: Refer to Section 9040, 1.08, J, 2.11, and 3.15

A. Description/uses

A check dam is a small, temporary obstruction in a ditch or waterway used to prevent erosion by reducing the velocity of flow. A dam placed in the ditch or channel interrupts the flow of water, thereby reducing the velocity. Although some sedimentation may result behind the dam, check dams do not function as sediment trapping devices and should not be designed as such.

Check dams are most commonly constructed of loosely placed erosion stone or riprap, or from stonefilled gabions.

Silt fence, placed across a ditch or swale, is often used incorrectly under moderate or high flows as a check dam. Silt fence may be used as a check dam, however it should be limited to applications where the flow rate will be less than 1 cfs. See Section 7E-28 for additional information on using silt fence as a ditch check.

A variety of manufactured devices are also available for installation as ditch checks. One type of manufactured ditch check consists of a 9-10 inch tall, triangular-shaped structure constructed from sheets of perforated HDPE (High-Density Polyethylene Pipe). Another manufactured product is constructed from a length of triangular-shaped urethane foam. The foam is wrapped in a geotextile fabric for protection.

Gravel bag berms, formed from a pile of gravel-filled bags, may also be used to construct check dams. The bags may be constructed from a variety of porous fabrics, and are filled with clean, poorlygraded gravel. The purpose of the bag is to prevent individual gravel particles from being dislodged, and to allow the gravel barrier to be easily removed or relocated upon completion of the project.

Straw bales were commonly used in the past. However, field experience has shown that this technique is highly ineffective and prone to failures.

B. Design considerations

Regardless of the type of check dam installed, the concept for controlling the flow is the same. The check dam interferes with the flow in the channel, dissipating the energy of the flowing water, thereby reducing velocity and channel erosion.

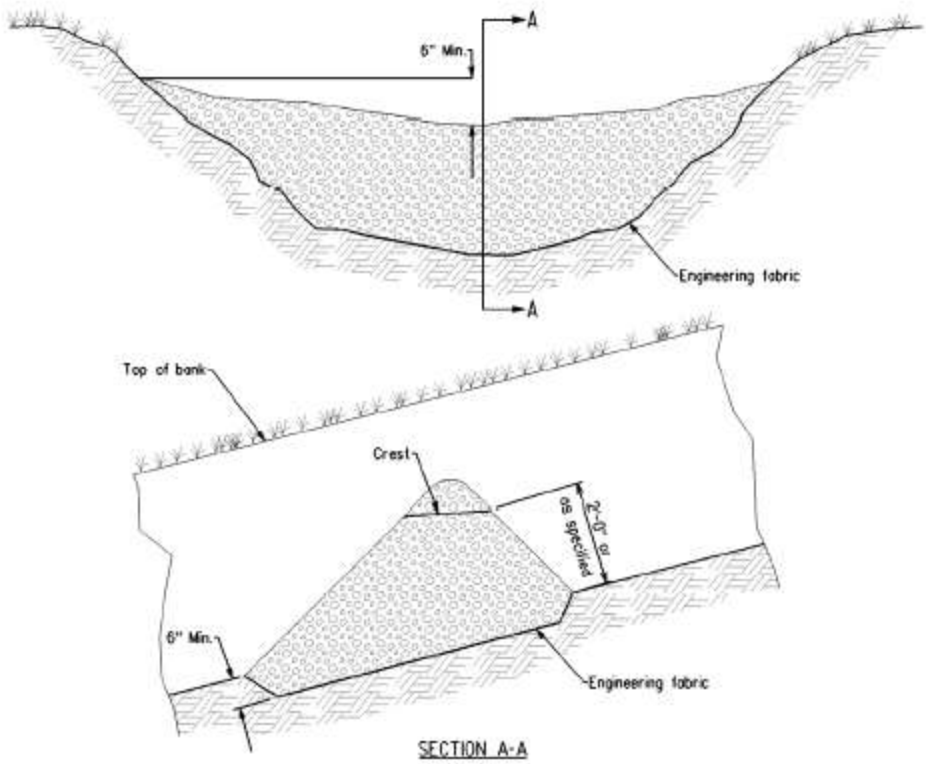
Check dams are not intended to control flows from large drainage areas. Typically, the maximum drainage area to a check dam should be limited to approximately 2 acres.

Check dams should be designed to pass the two-year storm without overtopping the roadway or side slopes of the channel. A weir equation can be used to determine the depth of flow over the structure if necessary.

1. **Stone check dams.** Stone check dams should be placed on top of a blanket of engineering fabric to prevent erosion of the underlying surface as water filters through the dam. A typical stone check dam is 2 feet high, with a 4-foot base and 2:1 side slopes. The crest of the check dam should be 6 inches lower than the sides to prevent flows from going around the dam, and eroding the sides of the channel. These dimensions are approximate, and may be modified based upon individual needs and for larger flows. However, heights much greater than 2 feet increase the potential for scour on the downstream side of the dam. For larger check dams, additional channel protection may be required on the downstream side.

The aggregate used should be large enough to prevent the flows from pushing individual stones downstream. A 6-inch erosion stone is normally sufficient.

Figure 1: Typical stone check dam



2. **Manufactured devices.** Triangular-shaped manufactured products should be designed and installed according to their manufacturer's recommendations. These products require anchoring to the ground to keep them in place and may require the installation of a blanket of engineering fabric below them.

3. **Gravel bag berms.** Gravel bag berms should be placed and spaced in the same manner as stone check dams. The berms should be placed on a layer of engineering fabric, and be limited to a height of 24 inches. The crest of the check dam should be 6 inches lower than the sides to prevent flows from going around the dam, and eroding the sides of the channel.

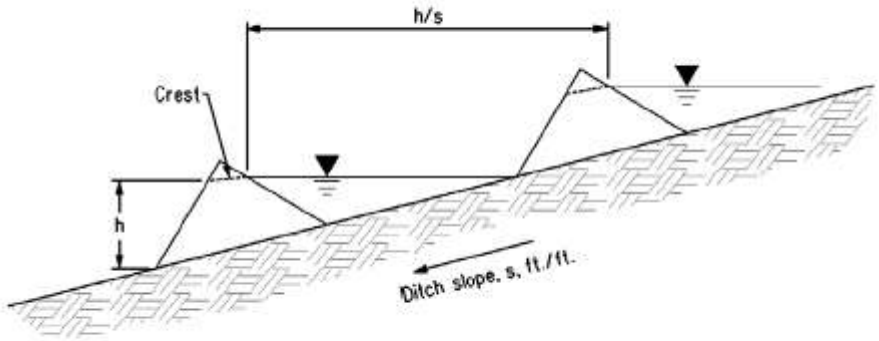
4. **Silt fence.** Silt fence may be used as a ditch check device for very low flow applications. See Section 7E-28 for additional information on this application.

C. Application

Achieving the proper spacing is the most important aspect of check dam design. The spacing between structures is dependent on the height of the check dam, and the grade of the waterway. In order to protect the channel between the check dams, the devices should be spaced such that the elevation of the toe of the upstream check dam is equal to the elevation of the crest of the downstream check dam. This allows the water between the check dams to pond, resulting in a greatly reduced flow velocity.

As a rule, check dams should not be spaced closer than 20 feet in order to allow for proper maintenance. If slopes and check dam height call for a spacing closer than 20 feet, a Rolled Erosion Control Product or Turf Reinforcement Mat should be considered as an alternative.

Figure 2: Typical check dam spacing



MANUFACTURED CHECK DAM
(Synthetic Permeable and Triangular Foam Check Dam)

D. Maintenance

Check dams should be inspected for damage every seven days and after any 1/2 inch or greater rainfall until final stabilization is achieved. Sediment should be removed when it reaches one-half of the original dam height. Upon final stabilization of the site, the check dams should be removed, including any stone that has been washed downstream, and any bare spots stabilized.

E. Time of year

Check dams function on a year-round basis.

F. Regional location

Check dams should be designed to account for the individual characteristics of each site.

7E-14 Diversion Structure

Source: Clackamas County, 2000.

BENEFITS

	L	M	H
Flow Control			
Erosion Control			
Sediment Control			
Runoff Reduction			
Flow Diversion			

Description: Consists of an excavated swale, berm, or combination of the two, constructed in such a manner as to direct water to a desired location.

Typical Uses: Diversion structures are used to intercept surface and shallow subsurface flows and divert this water away from disturbed areas, active gullies, and critically eroding areas. Diversion structures can also be constructed along slopes to reduce the slope length, intercepting and carrying runoff to a point stable outlet point or letdown structure.

Advantages:

- Reduces the volume of flow across disturbed areas, thereby reducing the potential for erosion.
- Breaks up concentration of water on long slopes.
- Maintaining a separation between clean water and sediment-laden water allows sediment basins and traps to function more efficiently.
- Easily constructed with equipment found on most construction sites.

Limitations:

- High flow velocities can cause erosion in the diversion structure.
- Diversion structures must be stabilized immediately after installation.

Longevity: One year.

SUDAS Specifications: Refer to Section 9040, 1.08, K and 3.17.

A. Description/uses

Diversion structures consist of swales or berms that are used to temporarily divert water around an area that is under construction or is being stabilized. Specific applications include perimeter control, diversion away from disturbed slopes, and diversion of sediment-laden water to treatment facilities.

As a perimeter control, temporary swales and/or berms may be constructed above a large disturbed area to divert upstream run-on around the site. This serves several purposes. First, the amount of runoff flowing over the disturbed area is reduced, thereby reducing the erosion potential. Secondly, clean water can be separated from the sediment-laden water and can be passed through or around the site. Sediment-laden water can be directed to a sediment trap or basin for treatment. Separating the upstream runoff from the sediment-laden water allows the designer to reduce the required size of the sediment removal structure, and allows the structure to work more efficiently.

Another specific use of a diversion structure is to keep upstream stormwater off of disturbed slopes or to safely carry it down the slope. This is accomplished by constructing a swale and/or berm at the top of the slope, and conveying it to a letdown structure or stable outlet. On long

slopes, they can be placed at regular intervals to trap and divert sheet flow before it concentrates and causes rill and gully erosion.

B. Design considerations

Diversion structures should be designed to carry peak flows from the 2-year, 24-hour storm. The maximum drainage area conveyed through a diversion structure should be 5 acres. The depth of the diversion should be based upon the design capacity, plus an additional 4 inches of freeboard. The minimum depth provided should be 18 inches. This may be provided solely by a berm or swale or may be developed with a combination of berm and swale. The shape of the diversion may be parabolic, trapezoidal, or V-shaped, with side slopes of 2:1 or flatter.

The minimum slope of the diversion structure should be sufficient to carry the design flow. The maximum slope of the diversion is limited by the permissible velocities of flows within the structure, as shown in the following table. Since any existing vegetation will likely be destroyed upon construction of the diversion structure, the bare surface situation should be considered for most applications.

Table 1: Diversion structure slopes by soil type

Soil Type	Permissible Velocity (fps)			
	Channel Vegetation			
	Bare	Poor	Fair	Good
Sand, silt, sandy loam, and silty, loam	1.5	1.5	2.0	3.0
Sandy clay, loam, and sandy clay, loam	2.0	2.5	3.0	4.0
Clay	2.5	3.0	4.0	5.0

Source: Smoot, 1999.

After construction of the diversion structure, it is important to stabilize the surface immediately with seed and mulch, sod, or other means.

C. Application

Diversion structures should be used around the perimeter of sites to prevent run-on of off-site flows over disturbed ground.

D. Maintenance

The channel should be inspected every seven days and after any 1/2 inch or greater rainfall. Any damage to the vegetated lining should be repaired. All debris should be removed and properly disposed of to provide adequate flow conveyance.

E. Time of year

When diversion structures are constructed during times when vegetation cannot be established to stabilize the surface, alternative stabilization methods such as sodding or matting may be required.

F. Regional location

As mentioned above, the allowable velocity within the diversion structure is based upon the soil characteristics of the site. Silty and sandy soils are more prone to erosion than clay soils. However, with the proper design and stabilization methods, diversion structures may be used in all appropriate locations.

7E-15 Level Spreader

Source: Umstead Coalition, 2005.

BENEFITS

	L	M	H
Flow Control	■	■	■
Erosion Control			
Sediment Control			
Runoff Reduction			
Flow Diversion	■	■	

Description: A level spreader is a low-cost method to convert small volumes of concentrated runoff into sheet flow and release it onto an area stabilized by existing vegetation.

Typical Uses: Level spreaders are commonly used at the outlet of a diversion structure or sediment removal structure to convert concentrated flow to uniform sheet flow prior to releasing the runoff onto stabilized downstream slopes. Level spreaders are also used to convey runoff from impervious surfaces, such as parking lots, onto vegetated areas or into detention basins.

Advantages:

- Widely used BMP due to ease of installation and availability of materials.
- Low cost and simple to construct.

Limitations:

- Flows from a level spreader should be limited to clean, diverted runoff, or runoff that has been passed through a sediment removal structure.
- The downstream slope must have existing vegetation and be capable of accepting sheet flow without incurring erosion.
- May require adjustment after freeze-thaw cycle due to heaving.

Longevity: One year.

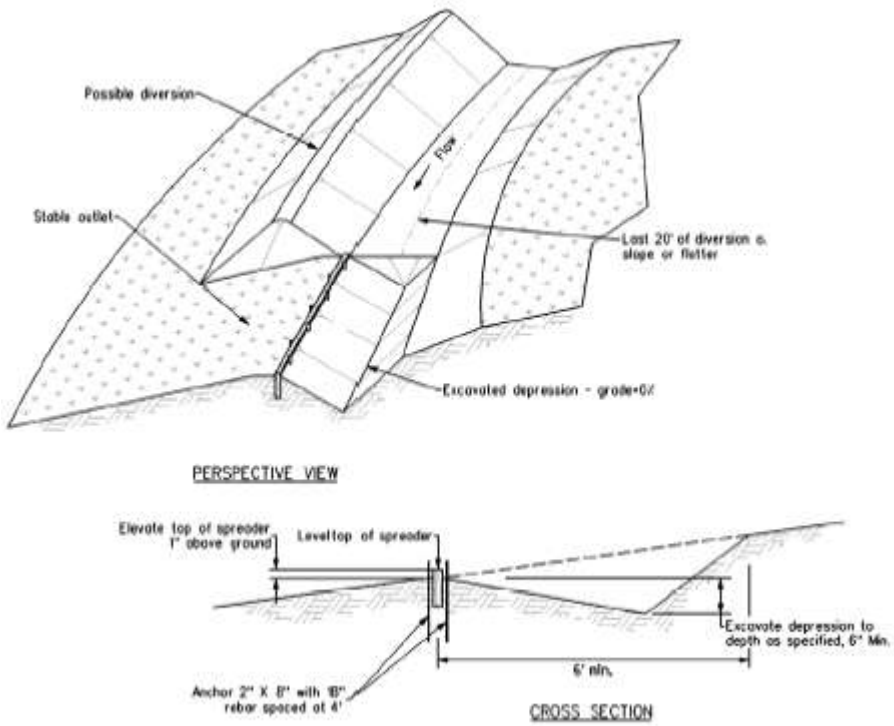
SUDAS Specifications: Refer to Section 9040, 1.08, L, 2.12, and 3.16.

A. Description/uses

A level spreader is a device used at the outlets of dikes and berms to convert the concentrated flows to sheet flow prior to discharging the flow onto a vegetated area downstream of the disturbed site.

A level spreader normally consists of a shallow excavation that serves as a stilling basin to allow runoff to pond up and dissipate its kinetic energy. An overflow weir is constructed to release the accumulated runoff. This weir is normally constructed from a 6x6 inch pressure-treated wooden timber placed at 0% grade to ensure uniform flow over the weir. For low flow applications, an earthen weir may also be constructed; however, special attention must be paid to ensure that the weir is level. If low points exist, concentrated flows will result and these could cause damage to the weir and the downstream slope.

Figure 1: Typical level spreader configuration



B. Design considerations

The grade of the last 20 feet of the diversion structure channel should be 1% or less to slow the velocity of the flow prior to draining into the depression. This will help reduce turbulence and erosion within the depression.

It is imperative that the receiving area downstream of the weir be stabilized sufficiently to receive the flows from the spreader without causing erosion. The receiving area must also be smooth to preserve the sheet flow and prevent the flow from concentrating. The slope of the receiving area should be less than 10%.

For level spreaders constructed from earthen embankments, a layer of erosion control matting should be placed on either side of the weir to provide additional stability to the surface.

C. Application

The length of the weir and depth of the depression required behind the weir are dependent on the anticipated flows over the weir. Select the length and depth of the spreader from Table 1 based upon the 10-year peak flow.

Table 1: Level spreader properties

Flow (cfs)	Min. Depth (ft)	Min. Length (ft)	Material
0-4	0.5	10	Stabilized Earth
5-10	0.5	10	6" x 6" Timber
10-20	0.6	20	6" x 6" Timber
20-30	0.7	30	6" x 6" Timber
30-40	0.8	40	6" x 6" Timber

D. Maintenance

The downstream slope should be inspected for signs of rilling. If rilling occurs, the length of the spreader may need to be increased, or additional stabilizing practices may need to be employed on the slope. If silt accumulates within the depression, it should be cleaned out when it loses one-third of its volume.

After a freeze-thaw cycle, the level spreader should be inspected to ensure that heaving has not occurred. Any displacement should be corrected to ensure that it is completely level.

E. Time of year

Level spreaders will function on a year-round basis.

F. Regional location

For soils that are highly sensitive to erosion, even when fully vegetated, the length of the spreader may need to be increased beyond that shown in the table.

7E-16 Rock Chutes and Flumes

BENEFITS

	L	M	H
Flow Control	■	■	□
Erosion Control	■	■	■
Sediment Control	□	□	□
Runoff Reduction	□	□	□
Flow Diversion	□	□	□

Description: Rock chutes are devices used to convey concentrated flows down an embankment or slope to a lower level without causing erosion.

Typical Uses: Commonly used as a permanent feature at the release point where runoff enters a ditch, stream, or lake. They are also used as a temporary measure to stabilize the inlet slope to a sediment trap or basin.

Advantages:

- Stabilizes slopes and areas where high flow volumes occur.
- Prevents further erosion at entrance to sediment removal devices, reducing the required cleanout frequency.

Limitations:

- May not be considered aesthetically pleasing for permanent installations.
- May be a relatively expensive measure for temporary structures.
- Requires careful construction practices.
- Difficult to maintain level, especially through freeze-thaw cycles.

Longevity: Permanent.

SUDAS Specifications: Refer to Section 9040, 2.19.

A. Description/uses

Rock chutes are devices used to stabilize the inlet slopes to sediment traps, sediment basins, rivers, ponds, lakes, and other drainage structures. The chutes consist of a rock-lined channel constructed on a steep slope.

Proper construction of the rock chute is imperative to its performance. The chute must be carefully notched into the ground to the thickness of the rock, to ensure positive drainage into the chute from the edges. If drainage into the chute from the edges is not provided, runoff will flow along the top of the chute, creating the potential for scouring under the chute.

After constructing the chute to the appropriate cross section, a layer of engineering fabric is usually placed to protect the underlying soils. Crushed stone of the size or weight specified is then placed over the fabric, creating a stable surface to transport large flows down steep grades.

B. Design considerations

The design of a rock chute is dependent on several factors including: the steepness of the slope; the shape of the channel; the volume and velocity of the water; the size of the riprap material; and the downstream tailwater.

In order to simplify the process of designing and sizing a rock chute, a spreadsheet has been developed by the Iowa division of the National Resource Conservation Service (NRCS). This spreadsheet is available on the internet and may be accessed from the following address: http://www.ia.nrcs.usda.gov/technical/design/program.html.

For permanent structures, an articulated or modular block system may also be considered. These products may be more aesthetically pleasing than a rock chute. Many can be vegetated to hide or mask the underlying armoring. Design information for these products is available from their respective manufacturers.

Installation of a turf reinforcement mat (TRM) might also be considered as an alternative to a rock chute (see Section 7E-11)

C. Application

Rock chutes should be considered at all locations where an elevation drop may create flow velocities that exceed the ability of the existing ground surface (bare or vegetated) to prevent erosion.

D. Maintenance

If designed and installed properly, maintenance of rock chutes is normally minimal. If the chute is left over a winter, it should be inspected in the spring to ensure that it is level. Any movement caused by freeze-thaw should be corrected.

7E-17 Rock Outlet Protection

Source: Mississippi State University

BENEFITS

	L	M	H
Flow Control	■	■	■
Erosion Control	■	■	■
Sediment Control			
Runoff Reduction			
Flow Diversion			

Description: Rock outlet protection is a common method of protecting a channel downstream of a storm sewer or culvert outlet from erosion. A layer of crushed stone placed on the bottom and sides of the channel protects the channel and dissipates the energy of the high velocity flow.

Typical Uses: Used at the outlet of storm sewer pipes, roadway and driveway culverts, and at any point concentrated runoff enters a channel.

Advantages:

- Widely used method of erosion protection.
- Materials are readily available in most areas.
- Effective at reducing scour when properly designed and installed.

Limitations:

- Commonly undersized.
- Not aesthetically pleasing.
- May not be adequate for flows from large pipes (>48 inches).

Longevity: Temporary or Permanent.

SUDAS Specifications: Refer to Section 9040, 1.08, V, 2.19, and 3.23

A. Description/uses

The most common method of protecting a channel at an outlet is to place a layer of crushed stone along the bottom and sides of the channel. The purpose of the stone is to protect the channel until the outlet flow loses sufficient velocity and energy, so that erosion will not occur in the downstream channel. Rock outlet protection is provided by constructing a blanket of crushed stone, to a specified depth at the outlet. The layer of the stone is constructed so that the top is flush with the invert elevation of the outlet pipe. The stone should be placed on a layer of engineering fabric to protect the underlying soil from the erosive action of the churning water.

For larger pipes, or for discharges from pipes with large head pressures, greater protection may be required. Additional protection can be provided by constructing a rock-lined plunge pool, stilling basin, or through the use of concrete energy dissipaters (see Chapter 2).

B. Design considerations

The following design information only applies to the design of rock protection at outlets. It does not apply to rock lining of channels or streams. In addition, the design of rock plunge pools or

stilling basins, and other types of energy dissipaters is not covered in this section. Refer to the Federal Highway Administration Hydraulic Engineering Circular No. 14 (HEC-14), "Hydraulic Design of Energy Dissipators for Culverts and Channels" for information on designing these structures.

The Iowa DOT Culvert Program (version 2.0) includes three methods of designing rock protection at the outlet of culverts. The methods include HEC-14 riprap basins, U.S. Army Corps of Engineers scour hole design and U.S. Bureau of Reclamation plunge basin design. This program is available online and can be obtained from the Iowa DOT's Office of Bridges and Structures.

The steps below describe the method of designing rock outlet protection:

1. **Tailwater depth.** The first step is to find the tailwater depth at the pipe outlet, corresponding to the appropriate design-year storm event for the outlet structure (see Chapter 2) for design criteria for various structures). Normally, the tailwater depth is found by determining the normal depth in the channel using Manning's equation (refer to Chapter 2). If downstream restrictions such as a culvert, dam or channel constriction exist, a more thorough analysis is required.

If the tailwater is less than half of the discharge flow depth (pipe diameter or box height if flowing full) it is classified as a *minimum tailwater condition.* If the tailwater is greater than or equal to half of the discharge flow depth, it is classified as a *maximum tailwater condition.* The tailwater condition will determine which figure (Figure 3 or 4) to use to find the necessary rock size and apron dimensions.

Pipes that outlet onto flat areas without a well-defined channel can be assumed to have a minimum tailwater condition.

If the tailwater condition cannot be easily determined for a channel, the apron should be designed for the maximum tailwater condition as a conservative approach.

2. **Stone size.** As the discharge flows over the crushed stone, the flow imposes shear stresses on the individual stones. Since the stones are only held in place by the force of gravity, they must have sufficient mass to prevent them from being dislodged by the force of the flowing water. For rock outlet protection design, the crushed stone material is selected based upon its average, or d_{50}, diameter. The d_{50} diameter represents the size at which half of the individual stones (by weight) are smaller than the specified diameter.

The d_{50} diameter is determined with Figure 3 or 4, for the appropriate tailwater condition. This value represents the minimum average diameter of stone necessary to resist the anticipated flows.

a. **Pipes flowing full.** The appropriate figure is entered along the x-axis at the design discharge. A vertical line is projected to the curve for the appropriate pipe diameter in the lower set of curves. From this point, a horizontal projection is made to the right, and the minimum d_{50} diameter is read.

b. **Partially full pipes and box culverts.** Using the depth of flow and velocity at the outlet, the intersection of d and v in the lower portion of the appropriate figure is found. From this point, a horizontal projection is made to the right, and the minimum d_{50} diameter is read.

Most crushed stone used for outlet protection is specified by weight, not by diameter. The following table lists the standard SUDAS and Iowa DOT revetment and erosion stone weights and corresponding d_{50} diameters. These gradations are also shown on Figures 3 and 4. Alternative gradations may be selected and specified if available from local aggregate suppliers.

Table 1: Standard revetment and erosion stone properties

Standard Classification	d_{50} Weight	Average d_{50} diameter[1]	Maximum Weight	Avg. max. diameter[1]
Class A Revetment Stone	125 lbs[2]	1.1[2] ft	400	1.7 ft
Class B Revetment Stone	275 lbs	1.5 ft	650	2.0 ft
Class D & E Revetment Stone	90 lbs	1.0 ft	250	1.4 ft
Erosion Stone	---	0.5 ft	---	.75 ft

[1]Diameters based upon an assumed specific gravity of 2.65.
[2]Approximate values for design purposes. Actual d_{50} value is not specified. (d_{75} = 75 lbs).

3. **Apron length.** A sufficient length of protection must be provided in order to reduce the velocity and energy of the flow to the level anticipated in the downstream channel. This length is dependent on the volume and velocity of the flow at the discharge point. It is also dependent on the tailwater condition of the downstream channel. The length, L_a, is found from Figure 3 or 4 for the appropriate tailwater condition.

From the intersection of discharge and pipe diameter, or for velocity and flow depth found in the previous step, a vertical line is projected to the appropriate discharge depth/pipe diameter in the upper set of curves. From this intersection, a horizontal line is projected to the left to determine the minimum length of rock protection required.

4. **Apron width.** For pipes that discharge into a well-defined channel, the width of the apron should extend to the top of the bank, or at least 1-foot above the maximum tailwater depth, whichever is less, along the entire length of the apron.

For outlets that discharge onto flat areas, the width of the apron at the upstream end of the culvert should be three times the diameter of the pipe, or equal to the width of the concrete pipe apron if one is provided. The width of the apron at the downstream end should be equal to the length of the apron, L_a, plus the diameter of the pipe, D.

5. **Apron depth.** The depth of the apron should be equal to one and one-half times the maximum stone diameter (See Table 1 for maximum diameter).

The channel downstream of the rock apron must be analyzed to ensure that existing or proposed channel liner is sufficient and that it will not be eroded under the anticipated flow depths. Methods for analyzing channel liners can be found in Section 7E-4 and Chapter 2.

Figure 1: Typical rock apron for outlet to a defined channel

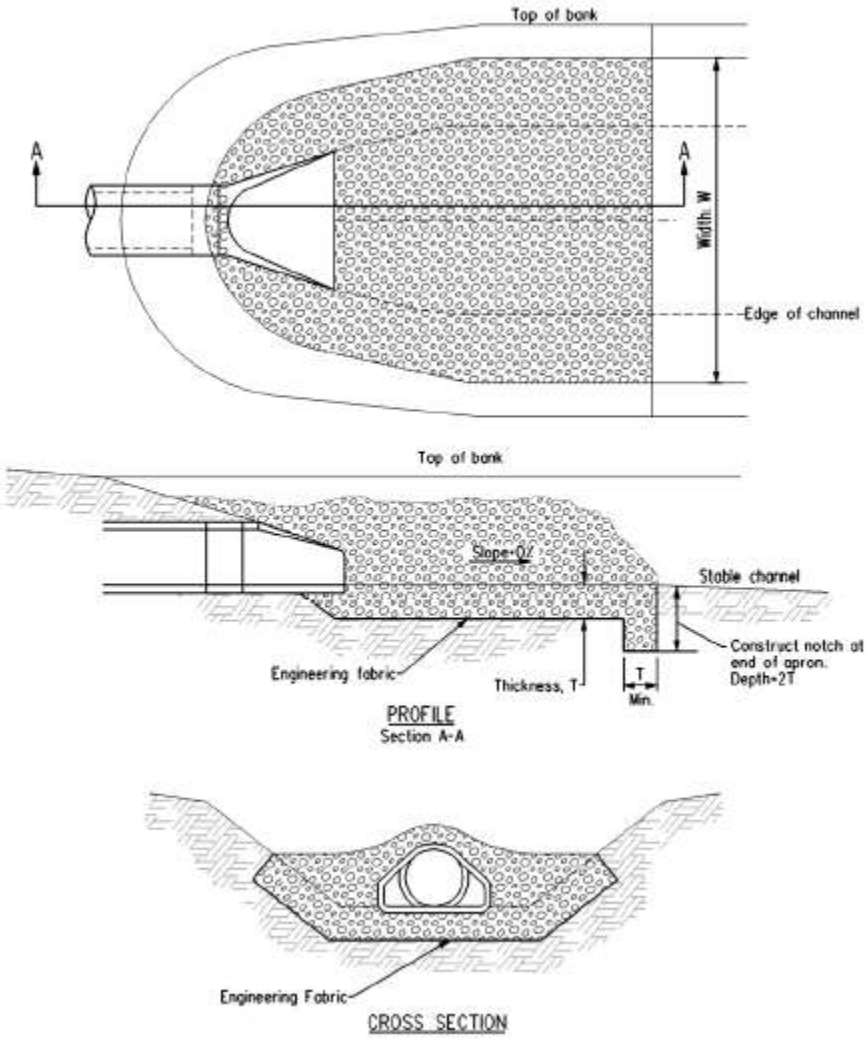
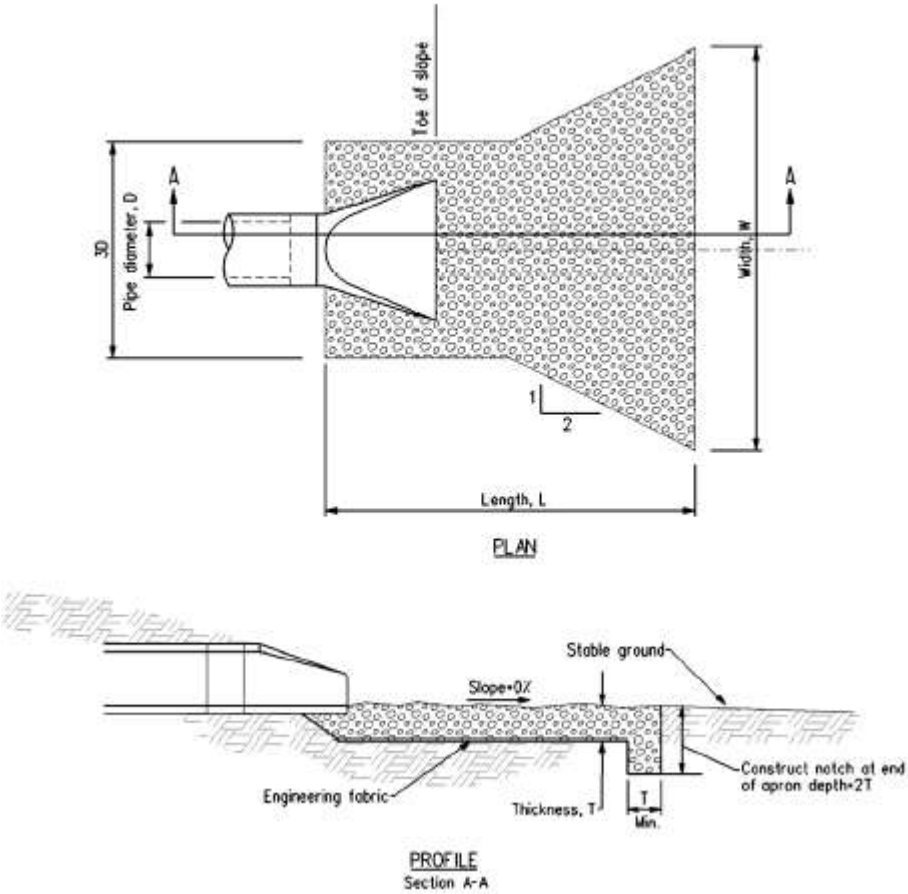

Top of bank
A
A
Width, W
Edge of channel
Top of bank
Slope=0/
Stable channel
Construct notch at end of apron. Depth=2T
Engineering fabric
Thickness, T
T
Min.
PROFILE
Section A-A
Engineering Fabric
CROSS SECTION

Figure 2: Typical rock apron for outlet to a flat area



C. Application

Outlet protection should be considered at all pipe and culvert outlets. Rock outlet protection is an easily constructed method of protection and is sufficient for many situations.

D. Maintenance

After installation, rock aprons should be inspected regularly. Special attention should be paid to the end of the apron, as it transitions to a natural channel. If scour or erosion is occurring at this junction, the apron should be extended, and additional stabilization methods may be required.

Figure 3: Design of outlet protection, minimum tailwater condition

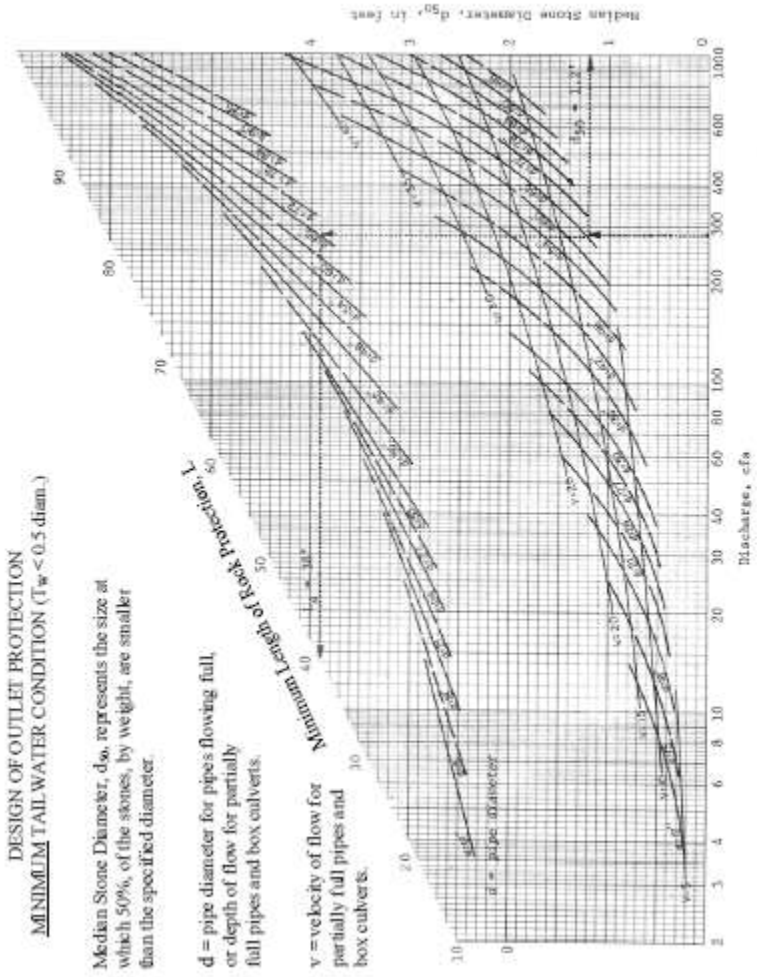
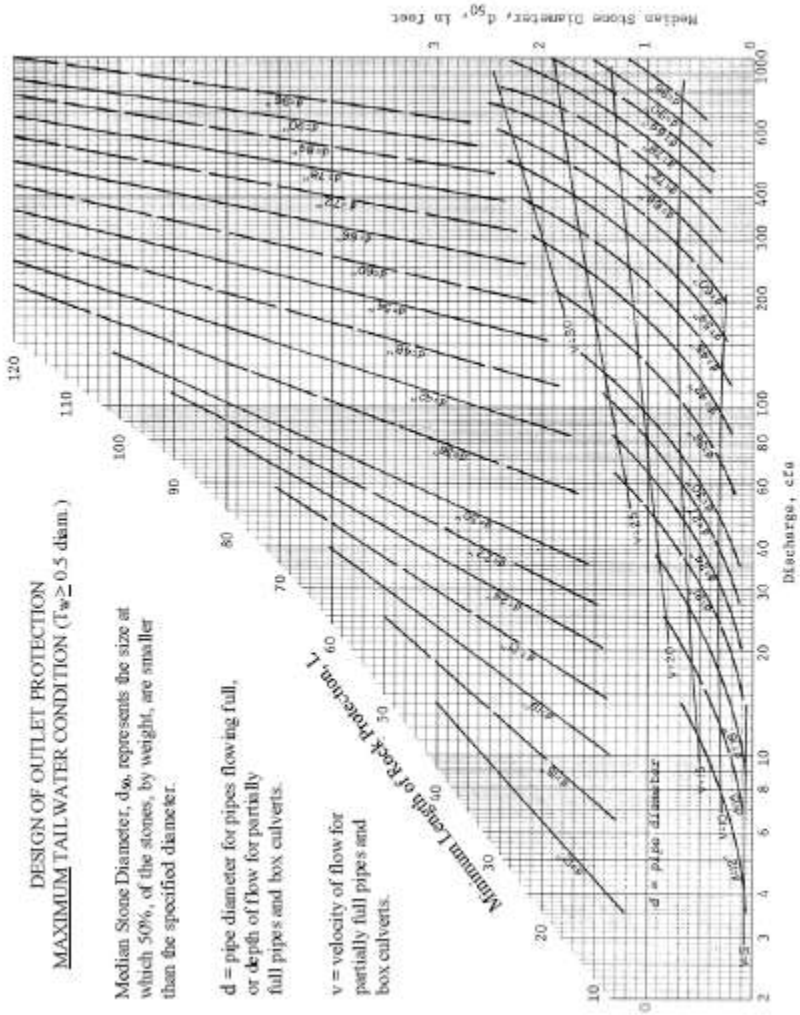


Figure 4: Design of outlet protection, maximum tailwater condition



Source: USDA NRCS, 2004.

7E-18 Flow Transition Mat

Source: ScourStop, 2006.

BENEFITS

	L	M	H
Flow Control	■		
Erosion Control	■	■	■
Sediment Control			
Runoff Reduction			
Flow Diversion			

Description: Transition mats are a synthetic alternative to using riprap.

Typical Uses: Used to dissipate energy and prevent scour at the transition from highly concentrate flow outlets to channel flow.

Advantages:

- Vegetated condition is more aesthetically pleasing than rip-rap.
- Installation can be mowed with conventional equipment.
- May be utilized as a temporary measure.
- May be more economical than other "hard-armor" methods.
- Installation does not require any heavy equipment.

Limitations:

- Continuous flow channels may not support vegetation.
- Not appropriate for high velocity discharges (>16 fps).

Longevity: Permanent.

SUDAS Specifications: Refer to Section 9040, 1.08, U, 2.14, and 3.19

A. Description/uses

A transition mat is a HDPE, UV stabilized, plastic sheet approximately 4 feet by 4 feet by 1/2 inch thick, comprised of multiple voids which allow vegetation to grow through, or small gravel and pebbles to accumulate and stabilize the area. The mat protects the area at pipe outlets from scour until the water spreading out in the channel diminishes the turbulent forces. The channel downstream of the outlet, where flow becomes uniform, must still be evaluated to ensure that the channel lining can withstand the anticipated shear stress.

B. Design considerations

Generally, vegetation alone and vegetated Turf Reinforcement Mats (TRM) (Section 7E-11) can carry significant storm water shear, but cannot withstand the turbulence and concentrated flow generated by a hard surface such as storm sewers, culverts, or parking lots. At these locations, additional measures are usually required to prevent scour. Transition mats are one option for protecting that critical area.

Transition mats can be installed in several different configurations to meet the particular site requirements.

Transition mats installed over sod are good applications for parking lot outlets or pipe outlets conveying storm water through residential developments. The installation can be mowed with standard equipment and unsightly rock riprap is avoided.

Installing sod and a Type 1 TRM under the transition mat adds a strong supporting element to the system. Vegetated TRMs already have proven shear force resistance of 12 pounds per feet. The sod eliminates the germination issue of a plain TRM installation, even though it adds a slight cost of material and labor, as well as potential short-term irrigation needs. Appropriate uses for a transition mat over a Type 1 TRM and sod would be 24-48 inch storm water pipes.

Transition mats may also be used without sod. A transition mat with a Type 1TRMs over bare soil might be used in situations where turfgrass is not desired, such as a rural area, or as a temporary installation. When used without sod, the flows should be slow and the area fairly flat to encourage sediment accumulation in the voids, where vegetation could also start. Pipe sizes should be limited to 24 inches.

Higher flow installations without sod can be accommodated using a higher class, Type 3 TRM over the bare soil. This type of installation may be applicable for temporary, pre-vegetation erosion control use (temporary meaning remove and reinstall when vegetation can be established), or as a permanent installation requiring substantial soil protection and vegetation growth over time. This installation could also be used in a streambed, where the mats would collect small gravel and sediment in the voids and appear naturally stabilized.

Installations with continuous low flows, such as irrigation over charge, should utilize a sub-surface drainage system directly downstream of the outlet to drain that low flow from the surface, thus allowing vegetation to properly establish. Of course, adequate slope is required for a sub-drain system. In some instances, marsh plants could be planted into a transition mat and TRM combination as another solution.

For installations where the slope of the discharge area or channel is greater than the outlet, but not a waterfall situation, transition mats should perform as specified. When the slope of the discharge area or channel is flatter than the outlet, and the grade break between the two exceeds 8%, the flow velocities and vector forces directed into the transition mat should be considered to determine if a flow transition mat is appropriate for the situation.

A temporary installation, for example the outlet of a temporary slope drain, can be readily achieved with a transition mat and TRM combination. Vegetation would generally not be necessary or desired, but scour protection would be quickly achieved, and the materials could be easily picked up and moved to another area on demand.

Transition mats do not dissipate energy by impact like rock outlet protection, but generally rely on the expansion area downstream to dissipate scour forces. The expansion area should be as wide and flat as possible. Channel side slopes that restrict expansion require protection with either a TRM or other means.

In addition to the potential scour area at the outlet, the channel downstream of the transition mat should be evaluated to ensure that it can carry the anticipated flows without eroding the streambank. Additional information on evaluating channel linings can be found in Section 7E-4, Grass Channel, and 7E-11, Turf Reinforcement Mats.

C. Application

Outlet protection should be designed to withstand the 10-year storm event. The following table lists the recommended dimensions for transition mat and TRM (if used) installations based upon pipe diameter.

Table 1: Flow Transition Mat Application

Pipe	Discharge[1]	Transition Mats		TRM
Diameter (inches)	cfs	Width (ft) x Length (ft)	Quantity	Width (ft) x Length (ft)
12"	8	4' x 4'	1	6' x 8'
24"	30	4' x 8'	2	11' x 12'
36"	75	8' x 12'	6	17' x 16'
48"	100	12' x 16'	12	23' x 20'

1. If the design discharge exceeds that for the diameter shown, alternative methods of outlet protection should be provided.

D. Maintenance

Transition mats are generally permanent installations, and maintenance should not be necessary. Utilized in a temporary installation, the transition mats and TRMs can be picked up and moved when appropriate.

7E-19 Temporary Slope Drain

Source: Mississippi State University

BENEFITS

	L	M	H
Flow Control			
Erosion Control			
Sediment Control			
Runoff Reduction			
Flow Diversion			

Description: Temporary slope drains consist of a pipe or tubing, installed from the top to the bottom of a disturbed slope. The drain transports concentrated runoff down the slope to a stabilized outlet, reducing the potential for erosion caused by runoff flowing over the disturbed slope.

Typical Uses: Used to transport concentrated runoff collected by a diversion structure, down a slope to a stable outlet or channel.

Advantages:

- Highly effective method for transporting runoff down a disturbed slope with minimal erosion.
- Easily constructed.
- Materials may be reused.

Limitations:

- Area around drain inlet must be carefully constructed to prevent water from flowing along the pipe, and breaching the diversion.
- The drain outlet must be discharged to a stable area, or outlet protection must be provided.

Longevity: Temporary, until vegetation is established.

SUDAS Specifications: Refer to Section 9040, 1.08, M, 2.13, and 3.18

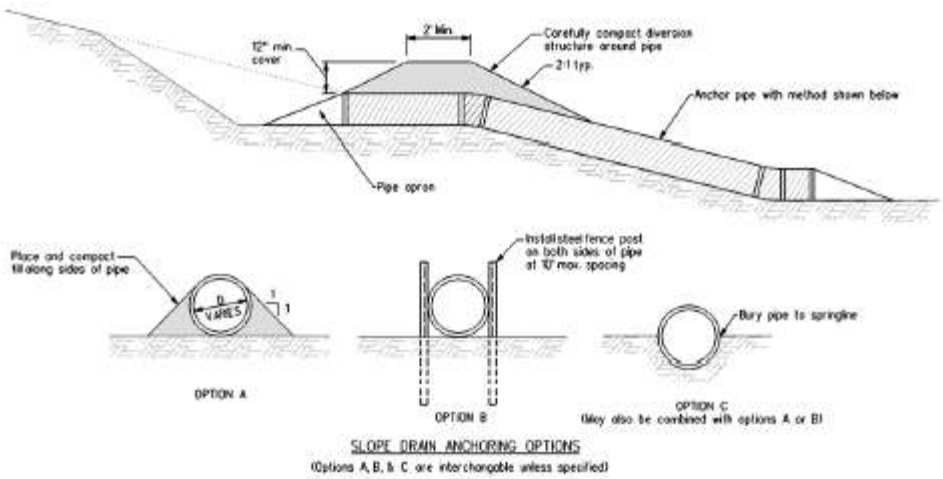
A. Description/uses

Temporary slope drains are constructed of flexible pipe or tubing, running from the top to the bottom of a disturbed slope. Slope drains provide a means of transporting collected runoff from the top of the slope to the bottom of the slope and prevent the erosive potential created by concentrated runoff flowing over the face of a disturbed slope.

Slope drains are commonly used in conjunction with diversion structures. A diversion structure at the top of the slope collects upland runoff and transports it to the desired outlet point. The slope drain provides an outlet for the diversion structure, safely carrying the collected runoff down the slope.

After grading, slopes are highly susceptible to erosion caused by sheet and concentrated flows from upland areas. Stabilizing the slope by seeding can be difficult as runoff over the slope may wash away seed and seedlings. Slope drains are used as a temporary measure to transport runoff down a slope, until the slope can be permanently stabilized. Eliminating flows over the face of a slope reduces erosion and provides newly planted seed an opportunity to establish itself without being washed away.

Figure 1: Temporary slope drain



B. Design considerations

Temporary slope drains should be sized to carry a two-year storm event. Table 1 provides a summary of recommended pipe diameters based upon the contributing drainage area.

Table 1: Slope drain diameters by drainage area

Maximum Drainage Area	Minimum Pipe Diameter
0.5 ac	8 in.
1.0 ac	10 in.
1.5 ac	12 in.
2.5 ac	15 in.
4 ac	18 in.
5 ac	21 in.
>5 ac	Special Design Required

Note: Values assumed a 2-year storm, 15 minute T_c, and a runoff coefficient of 0.5

Slope drains are normally installed in conjunction with diversion structures. The diversion structure should have a height or depth at the pipe inlet of at least 18 inches, or 6 inches greater than the pipe diameter, whichever is larger. The soil under and around the inlet of the pipe should have a low permeability, and be carefully compacted to ensure that seepage does not occur along the pipe-soil interface. The area around the inlet should be graded to ensure that flows are directed toward the pipe inlet.

The slope drain should have a minimum grade of 3%. A metal or flexible apron should be provided at the inlet of the pipe. If the area draining to the diversion and slope drain is disturbed, the slope drain should outlet to a sediment trap or sediment basin. If the upland area is undisturbed, the pipe outlet should bypass any sediment basins or traps, and drain to a stabilized area.
Unless the pipe drains to a stable outlet, protection such as rip-rap or a rolled erosion control product may be required at the outlet.

C. Application

Slope drains should be considered whenever a diversion structure is constructed on a disturbed slope steeper than 3%. When properly incorporated, diversion structures with slope drains provide a method to separate runoff from disturbed and stabilized areas, reducing the size requirements for sediment basins or traps.

D. Maintenance

The slope drain should be inspected for signs of leaking joints, pipe movement, erosion at the inlet and outlet, and seepage through the berm at the inlet.

E. Design example

Assume the runoff from 7.5 acres of bare ground is intercepted by a diversion structure and carried to the location of a proposed slope drain. Determine the required diameter of the slope drain.

Using the techniques described in Chapter 2, the following information is determined:

Time of Concentration, T_c = 15 minutes
Rainfall Intensity, I = 3.48 (Region 7)
Runoff Coefficient for bare ground, C = 0.5.

Using this information, the peak runoff is found to be 13.1 cfs by the Rational Method.

The minimum pipe diameter is found with the orifice equation (assume head to top of pipe).

$$Q = (0.6)(A)\sqrt{2gh}$$

Where:

Q	=	Runoff volume, cfs
A	=	Area of pipe opening
g	=	Acceleration of gravity, 32.2 ft/s^2
h	=	Head pressure (h=D/2 for head to top of pipe)

$$13.1 = (0.6)\left(\frac{\pi \times D^2}{4}\right)\sqrt{2 \times 32.2 \times \frac{D}{2}}$$, Solving for D yields a diameter of 1.9' or 23 inches.

Conclusion: Based upon the analysis, a 24-inch diameter pipe would be selected.

7E-20 Filter Berm

BENEFITS

	L	M	H
Flow Control	■		
Erosion Control			
Sediment Control	■		
Runoff Reduction			
Flow Diversion	■		

Description: A filter berm is a windrow-shaped (triangular) structure with a specified 'filter material' that normally is a blend of composted materials or other organic products, used to slow flow velocity, capture and degrade chemical pollutants, and trap sediment.

Typical Uses: Perimeter control, slope length reduction, flow diversion for small drainage areas, environmentally sensitive areas such as wetlands and waterways, at the edge of gravel parking lots, and general areas under construction.

Advantages:

- Less likely to obstruct wildlife movement and migration then other practices.
- Does not always need to be removed, thereby eliminating removal and disposal costs.
- Can be installed year-round in difficult soil conditions such as frozen or wet ground, on hard compacted soils, near pavements, and in wooded areas.

Limitations:

- Not suitable for areas of concentrated water flow or below culvert outlet aprons.
- Availability of suitable filter materials may be limited.
- Equipment operators may drive over berms, damaging the product.

Longevity: Six months.

SUDAS Specifications: Refer to Section 9040, 1.08, N, 2.01, and 3.05.

A. Description/uses

A filter berm typically consists of a three-dimensional matrix of biologically active stable composted organic material with various sized particles formed in a continuous windrow fashion (triangular) that slows and filters water to capture sediment and degrade pollutants. Its natural permeability allows water to seep through it while capturing sediment in its pore space and behind its mass, slowing water velocity and absorbing water pollutants, such as hydrocarbons, nutrients, and bacteria.

B. Design considerations

1. **Materials.** The key to achieving the proper balance between sediment removal and flow-through rate is using a filter material with the proper particle size. Filter material with a high percentage of fine particles will clog and create a barrier to flow. This will cause water to pond and the pressure may cause the installation to fail. Alternatively, filter material with particles that are too large will allow runoff to pass through the barrier with little or no resistance, eliminating the velocity reduction and sediment trapping benefits of the barrier. Refer to Section 9040 of the SUDAS Specifications for proper filter material size.

2. **General guidelines.** Filter berms should maintain a 2:1 base to height ratio to ensure berm stability, with a minimum berm size of 1 foot high by 2 feet wide.

3. **Slope control.** When installed on slopes, filter berms should be installed along the contour of the slope, perpendicular to sheet flow. The beginning and end of the installation should point slightly up the slope, creating a "J" shape at each end to contain runoff and prevent it from flowing around the ends of the berm. Allowable slope length for compost filter berms is dependent upon the grade of the slope as shown in Table 1. For slopes that receive runoff from above, a filter berm should be placed at the top of the slope to control the velocity of the flow running onto the slope, and to spread the runoff out into sheet flow. On steep or excessively long slopes a number of filter berms may be placed at regular intervals down the slope.

4. **Sediment control.** Filter berms remove sediment both by filtering, and by ponding water behind them. When used for sediment control, filter berms should be located to maximize the storage volume created behind the berm.

A common location to place filter berms for sediment control is at the toe of a slope. When used for this application, the berm should be located as far away from the toe of the slope as practical to ensure that a large storage volume is available for runoff and sediment.

C. Application

Compost filter berms should be spaced according to Table 1.

Table 1: Maximum filter berm spacing

Slope	Slope Length	Compost Berm Size Height x Width
0% - 2%	125'	1' x 2'
2% - 5%	75'	1' x 2'
5% - 10%	50'	1' x 2'

As mentioned previously, the material properties of the filter material are a significant factor in the performance of the berm. The wood chip product typically used as a filter material may not be readily available in all areas. This may limit the utilization of filter berms as an economical sediment control option in some areas.

D. Maintenance

Accumulated sediment should be removed, or a new berm installed, when it reaches approximately one-half of the berm height. If concentrated flows are bypassing or breaching the berm, it must be expanded, enlarged, or augmented with additional erosion and sediment control practices. Additional filter material should be added as required to maintain the dimensions of the berm. Any damage should be repaired immediately.

7E-21 Filter Sock

Source: Soil-Tek

BENEFITS

	L	M	H
Flow Control	■		
Erosion Control			
Sediment Control	■		
Runoff Reduction			
Flow Diversion	■		

Description: A filter sock is a tubular mesh sock filled with a specified 'filter material' that normally is a blend of composted materials or similar organic products, used to slow flow velocity, capture and degrade chemical pollutants, and trap sediment. They are most effective when designed to provide comprehensive water and sediment control throughout a construction site and if used in conjunction with erosion control practices.

Typical Uses: Perimeter control, inlet protection, slope length reduction, flow diversion for small drainage areas, environmentally sensitive areas such as wetlands and waterways, at the edge of gravel parking lots, and general areas under construction.

Advantages:

- Less likely to obstruct wildlife movement and migration then other practices.
- Does not always need to be removed, thereby eliminating removal and disposal costs.
- Can be installed year-round in difficult soil conditions such as frozen or wet ground, on hard compacted soils, near pavements, and in wooded areas, as long as stakes can be driven.
- Relatively low cost.

Limitations:

- Not suitable for areas of concentrated water flow, low points of concentrated runoff or below culvert outlet aprons.
- Availability of suitable sock filtering materials and equipment may be limited.
- Equipment operators may drive over socks, damaging the product.
- Often used improperly as the sole method of sediment control.
- Uneven ground may cause leakage under socks.

Longevity: Until sediment accumulates to one-half the height of the sock.

SUDAS Specifications: Refer to Section 9040, 1.08, O; 2.01 and 2.02; and 3.06.

A. Description/uses

A filter sock typically consists of a three-dimensional matrix of certified, composted organic material and/or other organic matter to create a filter medium. These various sized particles enclosed in a tubular mesh material slows and filters water to capture sediment and degrade pollutants. Its natural permeability allows water to seep through it while capturing sediment in its pore space and behind its mass, slowing water velocity, and absorbing water pollutants, such as hydrocarbons, nutrients, and bacteria.

The filter socks are typically constructed by filling a mesh tube with organic filter material, although other materials, such as crushed rock or gravel may be used. The sock is filled by blowing the material into the tube with a special pneumatic blower truck or similar device. Hand filling is not an acceptable means to fill the tube as the material is not compacted in the sock.

B. Design considerations

1. **Materials.** Several types of materials can be utilized for filter material in the sock. The key to achieving the proper balance between sediment removal and flow-through rate is using a material with the proper particle size. Filter material with a high percentage of fine particles will clog and create a barrier to flow. This will cause water to pond and the pressure could cause the installation to fail. Alternatively, filter materials with particles that are too large will allow flows to pass

through the barrier with little or no resistance, eliminating the velocity reduction and sediment trapping benefits of the barrier. Refer to Section 9040 of the SUDAS Specifications for proper filter material size.

Filter material normally consists of a wood chips or mulch that is screened to remove some of the fines and produce the desired gradation. Crushed stone or gravel is an ideal material to use when the sock will be used on a paved street for inlet protection, or other areas where the sock cannot be staked to hold it in place. The additional weight of the stone helps prevent the sock from moving. Socks can be filled with a fine compost material for applications where the sock is to be vegetated and remain as a permanent feature. This material should only be used in areas where ponding water is acceptable since it has a low flow-through rate, and will quickly plug with sediment.
The mesh sock used to contain the compost is designed to photo-degrade over time (approximately 18 months).

2. **General guidelines.** When installed on slopes, filter socks should be installed along the contour of the slope, perpendicular to flow, and staked at 10-foot intervals. The beginning and end of the installation should point slightly up the slope, creating a "J" shape at each end to contain runoff and prevent it from flowing around the ends of the sock. Individual section of filter sock should be limited to 200-foot lengths. This limits the impact if a failure occurs, and prevents large volumes of water from accumulating and flowing to one end of the installation, which may cause undermining or damage to the sock.

Once installed, additional loose compost (or soil from the site) should be placed at the bottom of the sock, along the leading edge, filling the seam between the ground surface and the sock.

3. **Slope control.** Filter socks can be installed at regular intervals on long slopes to reduce the effective slope length, and limit the velocity of runoff flowing down the slope. The design layout of filter socks will help prevent concentrated flows from developing, which can cause rill and gully erosion. As a secondary benefit, filter socks installed on slopes can remove suspended sediment from runoff that results from any erosion that has occurred. Allowable slope length for filter socks is dependent upon the size of the sock and the grade of the slope as shown in Table 1. For slopes that receive runoff from above, a sock should be placed at the top of the slope to control the velocity of the flow running onto the slope, and to spread the runoff out into sheet flow. On steep or excessively long slopes a number of socks may be placed at regular intervals down the slope.

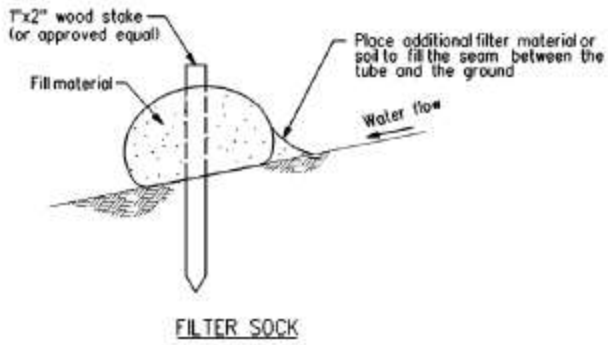
4. **Sediment control.** Filter socks remove sediment both by filtering, and by ponding water behind them. When used for sediment control, filter socks should be located to maximize the storage volume created behind the sock.

A common location to place filter socks for sediment control is at the toe of a slope. When used for this application, the sock should be located as far away from the toe of the slope as practical to ensure that a large storage volume is available for runoff and sediment.

5. **Inlet Protection.** Filter socks may also be used to provide inlet protection. The drainage area to a filter sock around an intake should not exceed 1/4 acre for every 100 feet of sock unless used in conjunction with other erosion and sediment control practices. Filter socks used for inlet protection should be staked at regular intervals, not exceeding 6 to 8 feet, to prevent movement of the sock. For protection of curb inlets in pavement, the length of sock recommended above is not practical. Using short sections of filter socks, such as those for curb intakes in pavement, should

be done with caution. Because the length of filter sock is short, it is only able to filter a small volume of runoff. This increases the chances that significant ponding will occur, possibly dislodging the sock, or that the flows will simply bypass or overtop the sock, eliminating any treatment potential. For additional information on inlet protection, refer to Section 7E-25

Figure 1: Typical filter sock installation



C. Application

Filter socks, placed on slopes, should be spaced according to Table 1.

Table 1: Maximum filter sock spacing

	Sock Diameter			
Slope	8"	12"	18"	24"
2%	85	100'	100'	100'
5%	50'	75'	100'	100'
10%	40'	50'	85'	100'
5:1	35'	40'	55'	60'
4:1	30'	40'	50'	50'
3:1	30'	35'	40'	40'

As mentioned previously, the material properties of the filter are a significant factor in the performance of the sock. The wood chip product typically used as a filter material may not be readily available in all areas. This may limit the utilization of filter socks as an economical sediment control option in some areas.

D. Maintenance

Accumulated sediment should be removed, or a new sock installed, when it reaches approximately one-half of the sock diameter. If sheet flows are bypassing or breaching the sock during design storm events, it must be repaired immediately and better secured, expanded, enlarged or augmented with additional erosion and sediment control practices.

7E-22 Wattle

Source: Clackamas County, 2000

BENEFITS

	L	M	H
Flow Control	■		
Erosion Control			
Sediment Control	■		
Runoff Reduction			
Flow Diversion	■		

Description: Wattles are a sediment and stormwater velocity control device. They are tubes of straw, rice straw, or coconut husk encased in ultraviolet (UV) degradable plastic netting or 100% biodegradable burlap material. Wattles help stabilize slopes by breaking up the length, and by slowing and spreading overland water flow.

Typical Uses: Wattles may be suitable along the toe, top, face, and at grade breaks of exposed and erodible slopes to shorten slope length and spread runoff as sheet flow; at the end of a downward slope where it transitions to a steeper slope; along sidewalks and curbs to prevent sediment from washing into gutters; around storm drains and drop inlets; down-slope of exposed soil areas; and around temporary material spoil and stockpiles, such as topsoil and for streambank (sensitive area) protection.

Advantages:

- Lightweight, easy to stake, and may be installed quickly.
- Removal is not necessary, as wattles are typically left in place permanently to biodegrade and/or photo-degrade.
- Wattles come in a variety of diameters and lengths.

Limitations:

- They are difficult to move once saturated.
- Wattles are temporary, lasting only one or two seasons.
- If not properly staked and trenched in, wattles can be transported by high flows.
- Wattles have a very limited sediment capture zone.
- Wattles should not be used on slopes subject to creep or slumping.

Longevity: Varies, 3-6 months or until sediment accumulates to one-half the height of the wattle.

SUDAS Specifications: Refer to Section 9040, 1.08, I, 2.10, and 3.14.

A. Description/uses

Wattles are formed by filling tubular netting with fibrous organic material such as straw, rice straw, or coconut fiber inside of a mesh sock. Alternatively, a wattle may be constructed by tightly rolling a straw/coconut erosion control blanket to form a multi-layer roll.

The completed wattle consists of a long, flexible tube that may be installed along the contours of slopes or at the base of slopes to help reduce soil erosion and retain sediment. Wattles can be highly effective when they are used in combination with other surface soil erosion/re-vegetation practices, such as surface roughening, straw mulching, erosion control blankets and hydraulic mulching. When wattles are placed at the toe and on the face of slopes, they intercept runoff, reduce its flow velocity, release the runoff as sheet flow, and provide removal of sediment from the runoff. By interrupting the length of a slope, wattles can also reduce erosion.

B. Design considerations

Wattles should be used to intercept and control sheet flow and should not be used for situations with concentrated flows greater than 1/2 cfs.

Installation of wattles begins by constructing a shallow trench, 2 to 4 inches deep, and shaped to accept the wattle, along the contour of the slope. All debris (rocks and clods) that would prevent

close contact between the wattle and soil should be removed. The wattle is placed in the trench, and excavated material from the trench is packed tightly along the base of the wattle, on the uphill side.

The wattle should be secured with 1-inch by 1-inch wooden stakes. The stakes should be placed at a 4-foot spacing and driven in perpendicular to the slope through the center of the wattle leaving less than 2 inches of stake exposed above the wattle. The terminating ends of each wattle installation should be turned uphill a minimum of 6 inches to prevent runoff from flowing around the ends of the wattle.

When practical, the wattles may be left in place. Over time, they will break down, decay, and eventually disappear completely. When wattles are removed, any trenches, depressions, or other ground disturbances caused by the removal of the wattle should be backfilled and repaired with the excess sediment captured by the wattle, prior to spreading the straw or other final erosion control protection.

1. **Flat ground application.** Install along sidewalks and behind curbs, fitting tightly against the concrete before backfilling, then backfill the wattle to create a trench.

2. **Storm drain inlet protection.** Wattles placed along the back of curb should be offset, as required to go around structures such as curb intakes that project behind the back of curb. At these locations, the wattle should be placed behind the structure (not over it) and shaped to direct water around either side of the structure to prevent ponding. At area intake locations, a shallow trench should be constructed 1 to 2 feet away from the edge of the intake. The wattle should be placed in the trench and firmly staked in place.

3. **Slope application.**
a. Wattles should be installed on the contour.
b. Wattles should be installed from the bottom of the slope up.

4. **Materials.** Wattles can be made from straw, rice straw, coconut husk, or other approved material. The netting consists of biodegradable burlap or high-density polyethylene and ethyl vinyl acetate containing ultraviolet inhibitors.

Straw should be Certified Weed Free Forage, by a manufacturer whose principle business is wattle manufacturing. Coir (coconut fiber) can be in bristle and mattress form, and should be obtained from freshwater cured coconut husk.

C. Application

Wattles are available in a variety of diameters ranging from 9 inches to 20 inches. The most common sizes are 9 and 12-inch wattles. The allowable spacing for these diameters is given in Table 1

Table 1: Recommended wattle spacing by slope

Slope	Spacing Intervals (ft)	
	9" Diameter	12" Diameter
<4:1	20	40
2:1 to 4:1	15	30
2:1 or greater	10	20

For soft, loamy soils, the spacing interval should be decreased. For hard, rocky soils, the spacing interval shown in Table 1 may be increased.

For highly erosive soils, and for slopes 2:1 or greater, an additional row of wooden stakes should be provided on the downhill side of the wattle.

D. Maintenance

Repair or replace split, torn, unraveling or slumping wattles.

If the wattle is used as a sediment capture device, or as an erosion control device to maintain sheet flows, sediment that accumulates in the wattle must be periodically removed when accumulation reaches one-half the designated sediment storage depth, usually one-half the distance between the top of the fiber roll and the adjacent ground in order to maintain effectiveness.

If wattles are used for reduction of slope length, sediment removal should not be required as long as the system continues to control the grade. Additional sediment control practices are required to be used in conjunction with this type of application.

7E-23 Flocculents

Source: Applied Polymer Systems, 2006.

BENEFITS

	L	M	H
Flow Control			
Erosion Control			
Sediment Control	■	■	■
Runoff Reduction			
Flow Diversion			

Description: Flocculents are natural materials or a class of chemicals that cause colloidal particles (clay) to coagulate. The coagulated particles group together to form flocs that will settle out of detained stormwater.

Typical Uses: Used in conjunction with sediment basins and sediment traps to remove suspended clay and fine silt particles from stormwater runoff prior to discharge.

Advantages:

- Ability to remove fine particles that would not settle out otherwise.
- Increases the percentage of fines removed during the detention period.
- May be used to remove suspended particles during dewatering operations.

Limitations:

- Requires specific dosing of the appropriate flocculent to achieve proper sedimentation.
- Flocculent must be thoroughly mixed with the stormwater.
- Flocculated particles must still be allowed to settle which takes time.
- Some flocculents are considered chemical pollutants. When these are used, the discharge must be carefully monitored to ensure that flocculent is adequately removed by settling.
- Flocculated material must be removed upon completion of the project for basins that are to be converted into permanent structures.

Longevity: Only effective on the runoff volume they are applied to. No long-term benefits.

SUDAS Specifications: Typically, flocculents are only used in special circumstances and therefore have not been included in SUDAS Specifications.

A. Description/uses

Even with the proper sediment controls in place, suspended clay and loess particles are difficult to remove. Water ponded for days, or even weeks, can remain murky due to the suspension of these fine particles. Flocculents aid in removing these fine particles and may be a desirable treatment method for locations with clay or loess soils that are upstream of lakes, ponds, or other sensitive waterways.

B. Design considerations

Fine soil particles, such as loess and clay particles, are difficult to remove with conventional settling techniques (basins, traps, etc.). The colloidal particles contain a negative electrostatic surface.

Particles with like charges repel each other, preventing them from sticking together and settling out. This allows these small particles to remain in suspension indefinitely.

Coagulants are a class of chemicals that may be added to turbid stormwater to aid in the removal of suspended colloidal particles. Negatively-charged soil particles are attracted to the positively-charged coagulant particles. These particles stick together and form a larger, neutrally-charged particle called a floc. Since the colloidal particle forms a neutrally-charged floc, it no longer

repels other particles, and can combine with other floc particles. The process of combining flocs into larger flocs that can be settled out of suspension is called flocculation. While the class of chemicals that ultimately cause the process of flocculation are technically called coagulants, the term flocculents has been adopted and is more widely used within the industry.

One flocculent that has been commonly used for stormwater applications is Polyacrylamide (PAM). Two versions of PAM are available, cationic and anionic. Only anionic PAM should be used, as cationic PAM is considered highly toxic. Anionic PAM has been used for many years in the water and wastewater industry and is considered safe for humans and aquatic life when used at the recommended rates.

Chitosan is another flocculent that is derived from the exoskeletons of crustaceans. It is generally considered safe for use in stormwater and water bodies.

A variety of other flocculent materials are available. Since trace amounts of flocculent will undoubtedly be discharged, the product used should be non-toxic and safe for both human and aquatic life and should not create Biochemical Oxygen Demand (BOD) problems in the downstream discharge waters.

Selection of an appropriate flocculent is highly dependent on the soil particle type and concentration. Analysis of a sample of the contaminated water is usually required to select the proper product and application rate. Manufacturers of these products will normally assist in this process.

C. Application

Several different methods of delivery are available for the application of flocculents to stormwater runoff. The most basic involves a solid form of the flocculent, either in block or pellet form, that is placed in a wire basket or mesh screen within the runoff as it flows into the sediment basin. The flowing water slowly dissolves the material, releasing flocculent into the basin.

More advanced methods involve equipment that will inject a liquid form of the flocculent into the runoff stream or storm sewer pipe at the desired rate.

Portable equipment that treats and filters the runoff is also available. Contaminated runoff is pumped from a sediment basin, treated with a flocculent, and then passed through sand filters to remove the suspended solids. The treated water may then be discharged.

Regardless of the flocculent material or method used, the material should never be added directly to the sediment basin or any standing water, unless adequate agitation is provided. The flocculent product should be introduced well in advance of the sediment control structure to allow for adequate mixing before the runoff arrives in the structure.

Adequate facilities need to be provided to allow for the settlement of the flocculated particles.

Normally, a properly designed sediment basin is sufficient for this application. The accumulated material should be removed and properly disposed.

D. Maintenance

Sediment should be removed on a routine basis to ensure a volume to receive the sediment. Timing will be based on having ample storage volume to accommodate anticipated runoff. Retention time and sediment storage volume are critical.

E. Time of year

The effectiveness of the flocculent can be affected by temperature. The manufacturer should account for this when providing specific product and dosing rate recommendations.

7E-24 Flotation Silt Curtain

BENEFITS

	L	M	H
Flow Control			
Erosion Control			
Sediment Control	■	■	
Runoff Reduction			
Flow Diversion			

Description: A flotation silt curtain (also called a turbidity curtain) consists of a geosynthetic fabric that is suspended vertically in a body of water. The top of the curtain is attached to floats, and the bottom is weighted.

Typical Uses: Flotation silt curtains are used when construction occurs in a water body or along a stream bank or shoreline. Flotation silt curtains prevent sediment, which is stirred up during construction, from migrating out of the work area and into the rest of the water body.

Advantages:

- Allows for containment of sediment-laden water within a water body.
- Protects contained water from turbulence, allowing particles to fall out of suspension.

Limitations:

- Limited to use only in areas where other erosion and sediment control practices cannot be used.
- Cannot stop the flow of a significant amount of water.
- Must not be used to filter entire stream flow.
- Difficult to remove fine silt and clay particles.

Longevity: One construction season (do not leave in place during winter).

SUDAS Specifications: Typically, flotation silt curtains are only used in special circumstances and therefore have not been included in SUDAS Specifications.

A. Description/uses

A flotation silt curtain, also called a turbidity curtain, consists of a heavy geosynthetic fabric that is suspended vertically in a water body, with floats at the top, and weights at the bottom. The purpose of the curtain is to act as a divider, preventing sediment laden-water from migrating to the rest of the water body.

Flotation silt curtains are commonly used when construction is required near or within a water body, where other erosion and sediment control practices cannot be used. This may include dredging operations, stream bank improvements, bridge pier construction, etc.

B. Design considerations

For ponds or other relatively still water bodies, which do not have significant inflow into the containment area, the flotation silt curtain consists of a relatively impermeable membrane that provides a barrier between clean water and sediment-laden water. The barrier creates a containment basin, in which sediment is trapped and allowed to fall out of suspension. Runoff into this type of curtain should be minimized, as the available volume is limited.

For situations that have moving water, such as lakes or streams, a provision must be made to allow water to flow through the curtain. This is normally accomplished by constructing part of the curtain from heavy filter fabric. The filter fabric allows water to pass through the curtain, maintaining equilibrium, but retaining sediment particles. While these curtains are designed to allow for some water movement, they do not have high flow-through rates, and should not be installed across a channel. When used in a stream, channel, or other body of moving water, the flotation silt curtains must be placed parallel to the direction of flow.

Unless the water body is subject to wind or wave actions, the curtain should extend the entire depth of the water, and rest on the bottom. The weighted bottom of the curtain needs to maintain contact with the bottom of the water body in order to keep sediment from flowing under the curtain. In order to do this, enough slack must be provided to allow the curtain to rise and fall as the depth of the water varies, without breaking contact with the bottom of the water body.

In situations where there is significant wind or wave action, the weighted end of the curtain should not extend to the bottom of the water body. Wind/wave action on the flotation system can cause movement of the lower end of the curtain, causing it to rub against the bottom, stirring up additional sediment. In these situations, a minimum 1-foot gap should be provided between the lower end of the curtain and the bottom of the water body. In addition, it is not practical to extend the curtain deeper than 10 or 12 feet. Deeper installations can be affected by the moving water, stressing the material, and causing the bottom of the curtain to be pushed around, billowing up toward the surface.

When determining the required length of the flotation silt curtain, an additional 10-20% should be included over the straight-line measurements. This allows for easier installation and reduces stresses caused by high winds and wave action.

Once the curtain has been positioned within the water body, the top is held in place by connecting it to anchors that are installed at regular intervals. The ends of the curtain (both upper and lower) should be extended to the shoreline, and anchored to a stable object, such as a tree.

C. Application

Flotation silt curtains are divided into three types, Type I, Type II, and Type III, based upon the flow conditions within the water body. The information provided here applies to minimal and moderate flow conditions, where the velocity of flow is 5 feet per second or less. For situations where the flow is greater than this, additional investigation is required, and a qualified manufacturer should be consulted.
The three types of silt curtains are differentiated by the strength and flow through rate of the fabric, and the strength of the connecting materials used:

1. Type I curtains are considered light-duty and are intended for areas where there is no current, and where the area is protected from wind and wave action.

2. Type II curtains can be used in areas with moderate running current (up to 3.5 fps), or where wind and water currents can affect the curtain.

3. Type III curtains are used in areas with considerable current (up to 5 fps), or where the curtain is subject to more severe wind and wave action.

D. Maintenance

A decision must be made on how to handle the accumulated sediment. Unless the accumulation is significant, consideration should be given to leaving this sediment in place. The process of removing the sediment can re-suspend the particles. Regardless of whether or not the accumulated sediment is removed, suspended sediment should always be allowed to settle for a minimum of 24 hours prior to removal of the silt curtain.

Once they are suspended in the water, clay and silt particles are difficult to remove by settling methods alone. For waters contaminated with clay or fine silts, the addition of a flocculent to the containment area may be considered prior to removal of the silt curtain. Care must be taken when selecting a flocculent as some are detrimental to water bodies and should not be used. See Section 7E-22 for additional information on flocculents.

E. Time of year

Sediment curtains should not be left in place during winter months, as ice can cause the curtain to rip or be torn from its shoreline supports.

7E-25 Inlet Protection

Source: Soil-Tek

BENEFITS

	L	M	H
Flow Control			
Erosion Control			
Sediment Control	■		
Runoff Reduction			
Flow Diversion			

Description: Inlet protection devices consist of a variety of manufactured sediment barriers and products, which are used to filter runoff before it enters the storm sewer system.

Typical Uses: Inlet protection is considered the last line of protection against releasing sediment into the stormwater system or a water body. Inlet protection should be considered around all stormwater intakes and culverts that accept runoff from disturbed areas.

Advantages:

- Provide one last opportunity to remove suspended particles from stormwater runoff.
- Areas requiring protection are easy to identify during both planning and construction.

Limitations:

- Available practices are not effective at removing fine particles.
- May be used improperly as the sole method of erosion and sediment control.
- Require high level of maintenance.
- Limited to treating runoff from areas of 1 acre or less.

Longevity: Varies by product. Until sediment accumulates and clean out is required.

SUDAS Specifications: Refer to Section 9040, 1.08, T, 2.17, and 3.22.

A. Description/uses

Inlet protection can be provided by a variety of methods. A number of new manufactured products are currently available which claim to adequately filter runoff before it enters the storm sewer intake.

The effectiveness of these products has yet to be determined.

The traditional method of providing inlet protection is to construct a filter at the opening. The filter is constructed from wire mesh or a steel plate, filter fabric, and crushed stone.

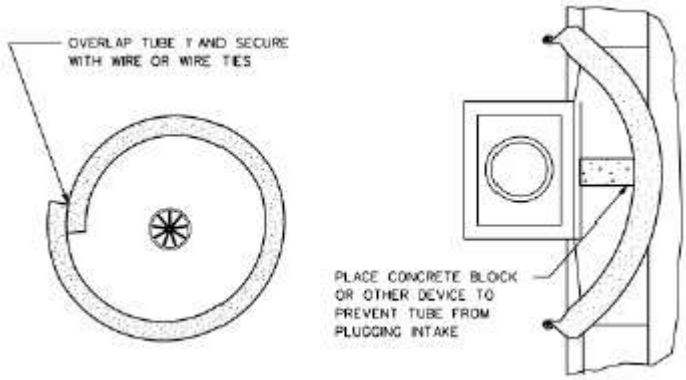
B. Design considerations

Most inlet protection devices rely on filtering techniques or on ponding small volumes of water to remove suspended particles. In general, the only way to remove fine particles from suspension is to detain the runoff for an extended period of time. Because inlet protection devices do not have the ability to pond and store large volumes of water, they are generally considered ineffective at removing fine particles from suspension in runoff. However, they are the last line of protection against releasing sediment-laden runoff into a stormwater system or water body. In addition, they may provide some benefit by trapping a portion of the larger suspended particles.

Because of their relative inefficiency compared to other techniques, inlet protection devices should not be used on a project as the sole method of sediment removal.

The traditional method for providing inlet protection was to construct a filter at the opening. The filter was constructed from wire mesh, filter fabric, and crushed stone. Runoff flowing to the intake would percolate through the stone and filter fabric before entering the intake. This stone medium slowed the flow of water and filtered larger sediment particles from the water. Today, these methods have been replaced with alternative techniques and materials.

Figure 1: Filter tubes used for inlet protection



Silt fence, placed around the perimeter of an area intake, can also serve as an inlet protection device. Silt fence used around an intake should be reinforced with 6x6-inch welded wire fabric, placed on the inside of the silt fence and securely attached to the posts. Silt fence should not be placed where concentrated flows are expected.

Filter socks may be used around the perimeter of an area intake, or in locations where silt fence cannot be installed, such as paved areas. Refer to Section 7E-21 for additional information on using filter socks around intakes.

A variety of manufactured products including storm intake filter socks, synthetic filter tubes for open throat curb intakes, intake inserts, pop-up filters for area intakes, and many others. These products should be used and installed according to the manufacturer's recommendations.

Using any inlet protection device that restricts the flow into the intake should be avoided for intakes that are on-grade. Because of the flow restriction, a majority of the flow to an on-grade intake will be bypassed to the downstream intake. This creates the potential for flooding problems downstream. To limit the potential for flooding, the drainage area to a protected inlet should be limited to 1 acre. For drainage areas larger than 1 acre, temporary sediment traps, flow diversion, or other methods should be considered.

As mentioned previously, there are a number of manufactured devices that are intended for use as inlet protection. These products should be used according to the manufacturer's recommendations.

C. Application

Inlet protection devices should be considered for inlets that are to receive runoff from small disturbed areas (less than 1 acre). These devices are used as a last line of defense against releasing sediment into the storm sewer or a water body.

D. Maintenance

Inlet protection devices are easily plugged, and may require a high level of maintenance. The devices should be cleaned out or replaced when standing water is still evident 48 hours after a rain event.

7E-26 Sediment Basin

BENEFITS

	L	M	H
Flow Control	■	■	■
Erosion Control			
Sediment Control	■	■	■
Runoff Reduction	■		
Flow Diversion			

Description: Sediment basins, like sediment traps, are temporary structures that are used to detain sediment-laden runoff long enough to allow a majority of sediment to settle out. Sediment basins are larger than sediment traps, serving drainage areas between 5 and 100 acres.

Sediment basins use a release structure to control the discharge, and normally have an emergency spillway to release the flow from larger storms. If properly planned, the basins may also serve as permanent stormwater management facilities, such as detention basins or permanent sediment removal structures.

Typical Uses: Used below disturbed areas where the contributing drainage area is greater than 5 acres. Basins require significant space and the appropriate topography for construction.

Advantages:

- Can greatly improve the quality of runoff being released from a site by removing suspended sediment on a large-scale basis.
- May be designed as a permanent structure to provide future detention, or for long-term water quality enhancement.

Limitations:

- Large in both area and volume.
- Use is somewhat dependent on the topography of the land.
- Must be carefully designed to account for large storm events.
- Not to be located within live streams.
- May require protective fencing.

Longevity: 18 months. May be converted to a permanent feature.

SUDAS Specifications: Refer to Section 9040, 1.08, P, 2.15, and 3.20.

A. Description/uses

Sediment basins, like sediment traps, are temporary structures used to detain runoff so sediment will settle before it is released. Sediment basins are much larger than sediment traps, serving drainage areas up to 100 acres. If properly planned and designed, sediment basins can be converted to permanent stormwater management facilities upon completion of construction.

B. Design considerations

Adequate storage volume is critical to the performance of the basin. Sediment basins that are undersized will perform at much lower removal efficiency rates. Sediment basin volumes and dimensions should be sized according to the criteria in Section 7D-1.

A sediment basin consists of several components for releasing flows: a principal spillway, a dewatering device, and an emergency spillway. The principal spillway is a structure which passes a given design storm. It also contains a de-watering device that slowly releases the water contained in the temporary dry storage. An emergency spillway may also be provided to safely pass storms larger than the design storm.

1. **Principal spillway.** The principal spillway consists of a vertical riser pipe connected at the base to a horizontal outlet pipe. The outlet pipe carries water through the embankment and discharges beyond the downstream toe of the embankment.

The first step in designing a principal spillway is to set the overflow elevation of the riser pipe. The top of the riser should be set at an elevation corresponding to a storage volume of 3,600 cubic feet per acre of disturbed ground. When an emergency spillway is provided, this elevation should be a minimum of 1 foot below the crest of the emergency spillway. If no emergency spillway is used, the top of the riser should be set at least 3 feet below the top of the embankment. The next step is to determine the size of the riser and outlet pipes required. These pipes are sized to carry the peak inflow, Q_p, for the design storm. If an emergency spillway will be included, the principal spillway should be designed to handle the peak inflow for a 2-year, 24-hour storm, without exceeding the elevation of the emergency spillway. If an emergency spillway is not included, the principal spillway must be designed to pass the 25-year storm, with at least 2 feet of clearance between the high-water elevation and the top of the embankment. Peak inflow flow rates should be determined according to the methods described in Chapter 2. The peak rate should account for the lack of vegetation and high runoff potential that is likely to occur during construction.

The riser size can be determined using the following equations. The flow through the riser should be checked for both weir and orifice flow. The equation, which yields the lowest flow for a given head, is the controlling situation.

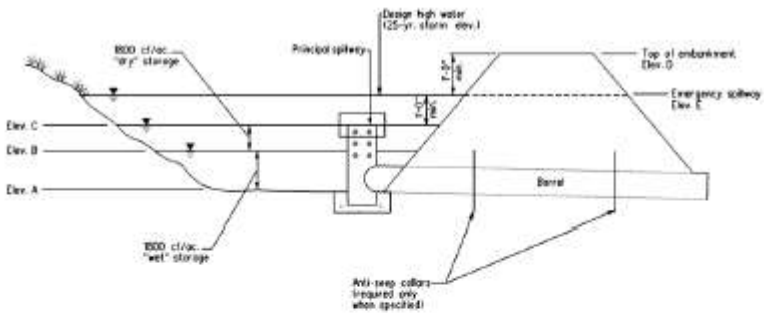
Weir Flow	Orifice Flow	
$Q = 10.5 \times d \times h^{\frac{3}{2}}$	$Q = 0.6 \times A \times \sqrt{2gh}$	**Equations 1 and 2**

Where:

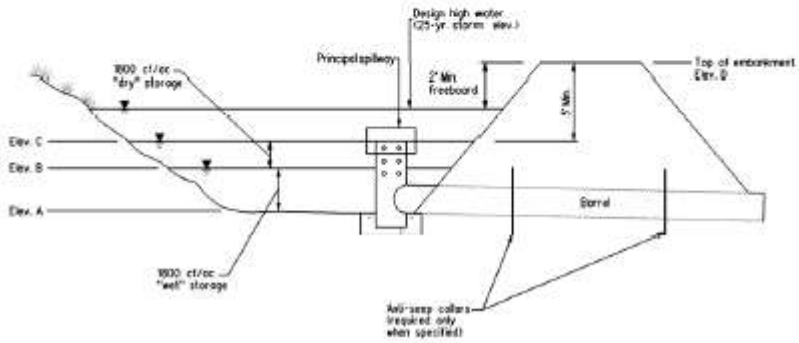
Q	=	Inlet capacity of riser, cfs
d	=	Riser diameter, ft
h	=	Allowable head above top of riser, ft
A	=	Open area of the orifice, ft^2
g	=	Acceleration of gravity, (32.2 ft/s^2)

The allowable head is measured from the top of the riser to the crest of the emergency spillway or to the crest of the embankment if no emergency spillway is provided.

Figure 1: Typical sediment basin configuration



Sediment basin with emergency spillway



Sediment basin without an emergency spillway

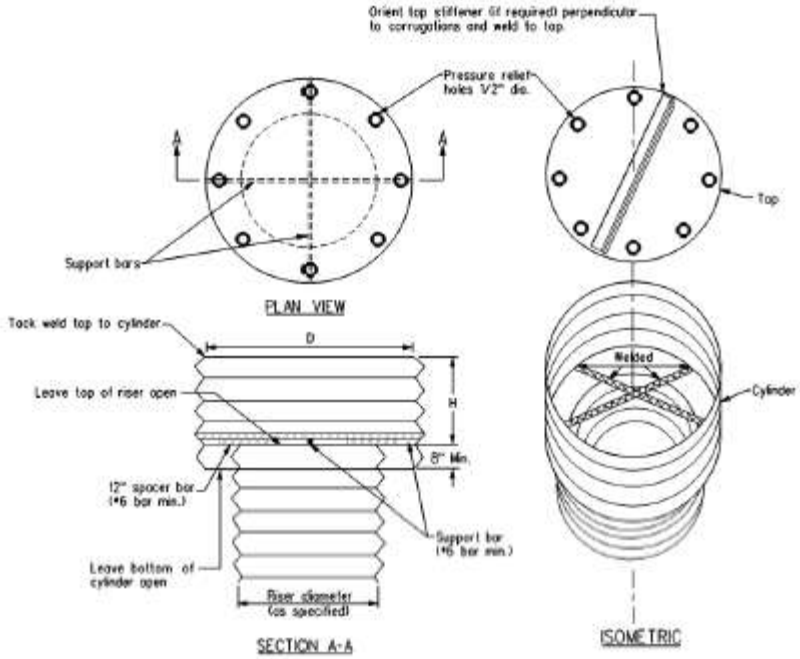
2. **Outlet barrel.** The size of the outlet barrel is a function of its length and the total head acting on the barrel. This head is the difference in elevation of the centerline of the outlet of the barrel and maximum elevation of the water (design high water). The size of the outlet barrel can be determined using Chapter 2 for culvert design.

3. **Anti-vortex device.** An anti-vortex device should be installed on top of the riser section to improve flow characteristics of water into the principal spillway, and prevent floating debris from blocking the spillway.

There are numerous ways to provide protection for concrete pipe including various hoods, grates, and rebar configurations that are part of the project-specific design, and will frequently be part of a permanent structure.

The design information provided in the following detail and table are for corrugated metal riser pipes.

Figure 2: Example anti-vortex device



Source: Adapted from Roberts, 1995 (FHWA).

Table 1: Design information for anti-vortex and trash rack device

Riser Diam. in.	Cylinder		Height in.	Minimum Size Support Bar	Minimum Top	
	Diameter in.	Thickness gage			Thickness	Stiffener
12	18	16	6	#6 rebar or 1½ x $^{3}/_{16}$ angle	16 ga. (F&C)	---
15	21	16	7	" "	" "	---
18	27	16	8	" "	" "	---
21	30	16	11	" "	16 ga. (C), 14 ga. (F)	---
24	36	16	13	" "	" "	---
27	42	16	15	" "	" "	---
36	54	16	17	#8 rebar	14 ga. (C), 12 ga. (F)	---
42	60	16	19	" "	" "	---
48	72	16	21	1 ¼" pipe or 1¼ x 1¼ x ¼ angle	14 ga. (C), 10 ga. (F)	---
54	78	16	25	" "	" "	---
60	90	14	29	1 ½" pipe or 1½ x 1½ x ¼ angle	12 ga. (C), 8 ga. (F)	---
66	96	14	33	2" pipe or 2 x 2 x ¼ angle	" "	2 x 2 x ¼ angle
72	102	14	36	" "	" "	2½ x 2½ x ¼ angle
78	114	14	39	2 ½" pipe or 2 x 2 x ¼ angle	" "	" "
84	120	12	42	" "	" "	2½ x 2½ x $^{3}/_{16}$ angle

Note 1: The criterion for sizing the cylinder is that the area between the inside of the cylinder and the outside of the riser is equal to or greater than the area inside the riser. Therefore, the above table is invalid for use with concrete pipe risers.

Note 2: Corrugation for 12"-36" pipe measures $2^{2}/_{3}$" x ½"; for 42"-84" the corrugation measures 5"x1" or 3"x1".

Note 3: C = Corrugated; F = Flat.

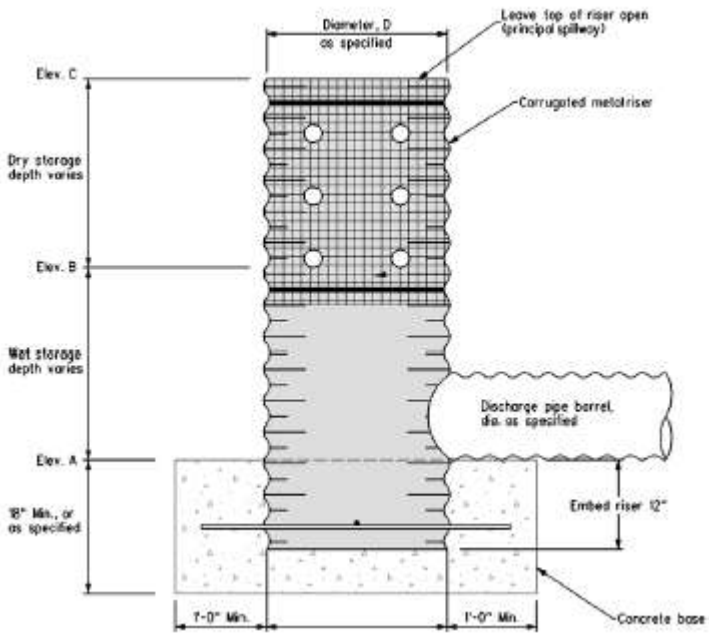
Source: Roberts, 1995 (FHWA)

The riser pipe needs to be firmly attached to a base that has sufficient weight to prevent flotation of the riser. The weight of the base should be designed to be at least 1.25 times greater that the buoyant forces acting on the riser at the design high water elevation.

A base typically consists of a poured concrete footing with embedded anchors to attach to the riser pipe to anchor it in place.

4. **Dewatering device.** The purpose of the dewatering device is to release the impounded runoff in the dry storage volume of the basin over an extended period of time. This slow dewatering process detains the heavily sediment-laden runoff in the basin for an extended time, allowing sediment to settle out. The dewatering device should be designed to drawdown the runoff in the basin from the crest of the riser to the wet pool elevation over a period of at least 6 hours.

Figure 4: Theoretical discharge orifice for design of perforated risers



the desired draw-down of the dry storage volume. Riser pipes with customized perforations to meet individual project requirements can be easily fabricated from a section of corrugated metal pipe. The contractor or supplier can drill holes of the size, quantity, and configuration specified on the plans. The lower row of perforations should be located at the permanent pool elevation (top of the wet storage volume). The upper row should be located a minimum of 3 inches from the top of the pipe (principal spillway elevation).

Dewatering device design begins by determining the average flow rate for a 6-hour drawdown time. Once the average discharge is known, the number and size of perforations required can be determined. To calculate the area of the perforations, a single rectangular orifice that extends from the wet pool elevation to the proposed elevation of the top row of holes (a minimum of 3 inches below the principal spillway) is assumed.

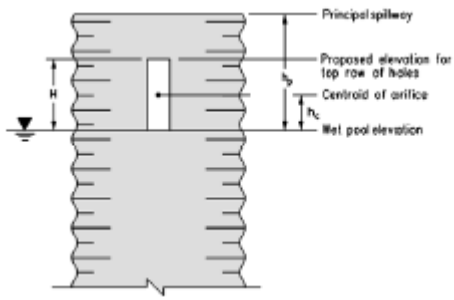
Next, the average head acting on the rectangular orifice as the basin is dewatered is determined. This average head is approximated by the following equation:

$$h_a = \frac{(h_p - h_c)}{2}$$ **Equation 3**

Where:

h_a	=	Average head during dewatering
h_p	=	Maximum head (between the wet pool and principal spillway)
h_c	=	Distance between the wet pool elevation and the centroid of the orifice, ft

Figure 5: Theoretical discharge orifice for design of perforated risers



Once the average head is known, the area of the rectangular orifice is sized according to Equation 4 to provide the average flow rate for the 6-hour drawdown. Providing evenly spaced perforations that have a combined open area equal to that of the calculated rectangular orifice, will provide the desired discharge rate for a 6-hour drawdown.

$$A = \frac{Q_a}{0.6 \times (2g \times h_a)^{1/2}}$$ **Equation 4**

Where:

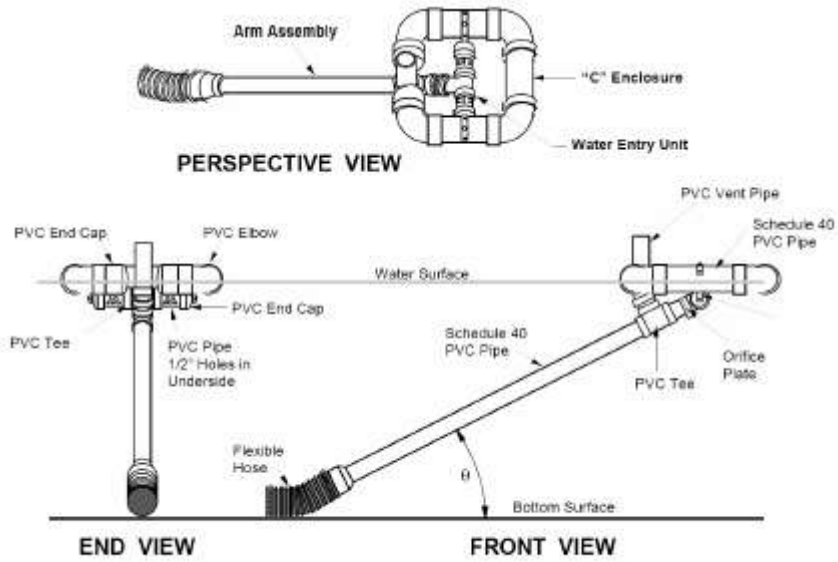
A	=	Total area of the orifices, sf
h_a	=	Average head acting on the orifice (Equation 3)
Q_a	=	Average flow rate required for 6-hour drawdown, cfs Q=S/21,600 sec. (6 hour drawdown only)
S	=	Dry storage volume required, cf

The number and diameter of the holes is variable. The diameter selected should be a minimum of 1 inch to minimize clogging, and should be a multiple of 1/4 of an inch. The perforation configuration should consist of a minimum of three horizontal rows and two vertical columns of evenly spaced perforations. Selecting a combination of hole diameter and number of holes is a trial and error process. Once the configuration is determined, the required information should be specified on the plans.

An alternative to the traditional riser is to provide a skimmer device that floats on the surface of the water in the basin. The skimmer is made of a straight section of PVC pipe equipped with a float and attached with a flexible coupling to an outlet at the base of the riser. Because the skimmer floats, it rises and falls with the level of the water in the basin and drains only the cleanest top layer of runoff. Sediment removal rates from basins equipped with skimmers have been shown to be significantly more effective than with a perforated riser or orifice.

Skimming devices are normally proprietary. Discharge information should be obtained from the manufacturer.

Figure 6: Example skimmer for drawdown of wet storage



Source: Penn State University.

5. **Emergency spillway.** An emergency spillway acts as an overflow device for a sediment basin by safely passing the large, less frequent storms through the basin without damage to the embankment. It also acts in case of an emergency such as excessive sedimentation or damage to the riser that prevents flow through the principal spillway. The emergency spillway should consist of an open channel constructed adjacent to the embankment over undisturbed material, not fill. This channel should be stabilized with matting, seeding, or sodding.

Where conditions will not allow the construction of an emergency spillway on undisturbed material, the spillway may be constructed on top of the embankment and protected with nonerodible material such as erosion stone.

An evaluation of site and downstream conditions must be made to determine the feasibility of, and justification for, the incorporation of an emergency spillway. In some cases, the site topography does not allow a spillway to be constructed in undisturbed material, and the temporary nature of the facility may not warrant the cost of disturbing more acreage to construct and armor an emergency spillway. The principal spillway should then be sized to convey a 25-year storm event, providing 2 feet of freeboard between the design high water elevation and the top of the embankment. If the facility is designed to be permanent, the added expense of constructing and armoring an emergency spillway may be justified.

When an emergency spillway is required, it should be designed to safely pass the 25-year design storm with a minimum of one-foot clearance between the high water elevation and the top of the basin embankment. Since the principal spillway is only designed to carry the 2-year event, the emergency spillway must carry the remainder of the 25-year event.

$$Q_e = Q_{25} - Q_p \qquad \textbf{Equation 5}$$

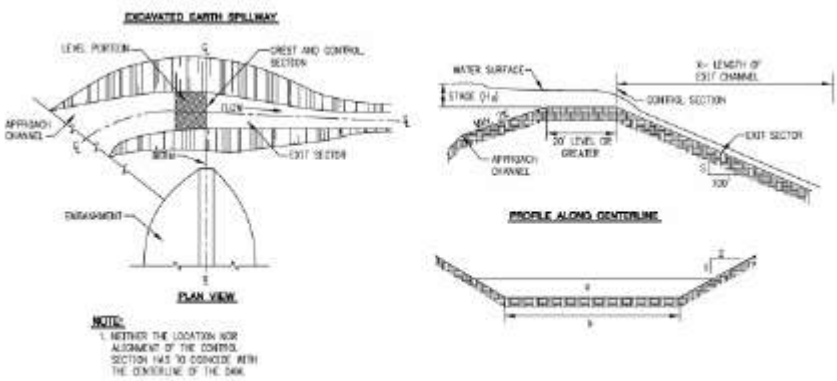
Where:

Q_e	=	Required emergency spillway capacity, cfs
Q_{25}	=	25-year, 24 hour peak flow, cfs
Q_p	=	Principal spillway capacity at high water elevation, cfs

Based upon the flow requirements, Table 1 can be used to determine the minimum width of the emergency spillway (b), the minimum slope of the exit channel (S), and the minimum length of the exist channel (X).

A control section at least 20 feet in length should be provided in order to determine the hydraulic characteristics of the spillway, according to Table 1. The control section should be a level portion of the spillway channel at the highest elevation in the channel. If the length and slope of the exit channel indicated in Table 1 cannot be provided, alternative methods of evaluating the spillway must be conducted.

Figure 7: Typical sediment basin emergency spillway



Source: Roberts, 1995.

Table 1: Design data for earthen emergency spillways

Stage (H_p) in feet	Spillway Variables	Bottom Width (b) in feet																
		8	10	12	14	16	18	20	22	24	26	28	30	32	34	36	38	40
0.5	Q	6	7	8	10	11	13	14	15	17	18	20	21	22	24	25	27	28
	V	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7
	S	3.9	3.9	3.9	3.8	3.8	3.8	3.8	3.8	3.8	3.8	3.8	3.8	3.8	3.8	3.8	3.8	3.8
	X	32	33	33	33	33	33	33	33	33	33	33	33	33	33	33	33	33
0.6	Q	8	10	12	14	16	18	20	22	24	26	28	30	32	34	35	37	39
	V	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
	S	3.7	3.7	3.7	3.7	3.6	3.7	3.6	3.6	3.6	3.6	3.6	3.6	3.6	3.6	3.6	3.6	3.6
	X	36	36	36	36	36	36	37	37	37	37	37	37	37	37	37	37	37
0.7	Q	11	13	16	18	2	23	25	28	30	33	35	38	41	43	44	46	48
	V	3.2	3.2	3.3	3.3	3.3	3.3	3.3	3.3	3.3	3.3	3.3	3.3	3.3	3.3	3.3	3.3	3.3
	S	3.5	3.5	3.4	3.4	3.4	3.4	3.4	3.4	3.4	3.4	3.4	3.4	3.4	3.4	3.4	3.4	3.4
	X	39	40	40	40	41	41	41	41	41	41	41	41	41	41	41	41	4
0.8	Q	13	16	19	22	26	29	32	35	38	42	45	46	48	51	54	57	60
	V	3.5	3.5	3.5	3.6	3.6	3.6	3.6	3.6	3.6	3.6	3.6	3.6	3.6	3.6	3.6	3.6	3.6
	S	3.3	3.3	3.3	3.2	3.2	3.2	3.2	3.2	3.2	3.2	3.2	3.2	3.2	3.2	3.2	3.2	3.2
	X	44	44	44	44	45	45	45	45	45	45	45	45	45	45	45	45	45
0.9	Q	17	20	24	28	32	35	39	43	47	51	53	57	60	61	68	71	75
	V	3.7	3.8	3.8	3.8	3.8	3.8	3.8	3.8	3.8	3.8	3.8	3.8	3.8	3.8	3.8	3.8	3.8
	S	3.2	3.1	3.1	3.1	3.1	3.1	3.1	3.1	3.1	3.1	3.1	3.1	3.1	3.1	3.1	3.1	3.1
	X	47	47	48	48	48	48	48	48	48	48	49	49	49	49	49	49	49
1.0	Q	20	24	29	33	38	42	47	51	56	61	63	68	72	77	81	86	90
	V	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4
	S	3.1	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
	X	51	51	51	51	52	52	52	52	52	52	52	52	52	52	52	52	52
1.1	Q	23	28	34	39	44	49	54	60	65	70	74	79	84	89	95	100	105
	V	4.2	4.2	4.2	4.3	4.3	4.3	4.3	4.3	4.3	4.3	4.3	4.3	4.3	4.3	4.3	4.3	4.3
	S	2.9	2.9	2.9	2.9	2.9	2.9	2.9	2.9	2.9	2.8	2.8	2.8	2.8	2.8	2.8	2.8	2.8
	X	55	55	55	55	55	55	55	56	56	56	56	56	56	56	56	56	56
1.2	Q	28	33	40	45	51	58	64	69	76	80	86	92	98	104	110	116	122
	V	4.4	4.4	4.4	4.4	4.4	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5
	S	2.9	2.9	2.8	2.8	2.8	2.8	2.8	2.8	2.8	2.8	2.8	2.8	2.8	2.8	2.8	2.8	2.8
	X	58	58	59	59	59	59	59	59	60	60	60	60	60	60	60	60	60
1.3	Q	32	38	46	53	58	65	73	80	86	91	99	106	112	119	125	133	140
	V	4.5	4.6	4.6	4.6	4.6	4.6	4.7	4.7	4.7	4.7	4.7	4.7	4.7	4.7	4.7	4.7	4.7
	S	2.8	2.8	2.8	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7
	X	62	62	62	63	63	63	63	63	63	63	63	64	64	64	64	64	64
1.4	Q	37	44	51	59	66	74	82	90	96	103	111	119	127	134	142	150	158
	V	4.5	4.8	4.8	4.8	4.8	4.8	4.8	4.8	4.8	4.9	4.9	4.9	4.9	4.9	4.9	4.9	4.9
	S	2.8	2.7	2.7	2.7	2.7	2.7	2.7	2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.6
	X	65	66	66	66	66	67	67	67	67	67	67	68	68	68	68	68	69
1.5	Q	41	50	58	66	75	85	92	101	108	116	125	133	142	150	160	169	178
	V	4.8	4.9	4.9	5	5	5	5	5	5	5	5	5	5	5	5.1	5.1	5.1
	S	2.7	2.7	2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.5	2.5	2.5
	X	69	69	70	70	71	71	71	71	71	71	71	72	72	72	72	72	72
1.6	Q	46	56	65	75	84	94	104	112	122	132	142	149	158	168	178	187	197
	V	5	5.1	5.1	5.1	5.1	5.2	5.2	5.2	5.2	5.2	5.2	5.2	5.2	5.2	5.2	5.2	5.2
	S	2.6	2.6	2.6	2.6	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5
	X	72	74	74	75	75	76	76	76	76	76	76	76	76	76	76	76	76
1.7	Q	52	62	72	83	94	105	115	126	135	145	156	167	175	187	196	206	217
	V	5.2	5.2	5.2	5.3	5.3	5.3	5.3	5.4	5.4	5.4	5.4	5.4	5.4	5.4	5.4	5.4	5.4
	S	2.6	2.6	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5
	X	76	78	79	80	80	80	80	80	80	80	80	80	80	80	80	80	80
1.8	Q	58	69	81	93	104	116	127	138	150	160	171	182	194	204	214	226	233
	V	5.3	5.4	5.4	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.6	5.6	5.6	5.6	5.6	5.6
	S	2.5	2.5	2.5	2.5	2.4	2.4	2.4	2.4	2.4	2.4	2.4	2.4	2.4	2.4	2.4	2.4	2.4
	X	80	82	83	84	84	84	84	84	84	84	84	84	84	84	84	84	84
1.9	Q	64	76	88	102	114	127	140	152	164	175	188	201	213	225	235	246	260
	V	5.5	5.5	5.5	5.6	5.6	5.6	5.7	5.7	5.7	5.7	5.7	5.7	5.7	5.7	5.7	5.7	5.7
	S	2.5	2.5	2.5	2.4	2.4	2.4	2.4	2.4	2.4	2.4	2.4	2.4	2.4	2.4	2.4	2.4	2.4
	X	84	85	86	87	88	88	88	88	88	88	88	88	88	88	88	88	88
2.0	Q	71	83	97	111	125	138	153	164	178	193	204	218	232	245	256	269	283
	V	5.6	5.7	5.7	5.7	5.8	5.8	5.8	5.8	5.8	5.8	5.8	5.9	5.9	5.9	5.9	5.9	5.9
	S	2.5	2.4	2.4	2.4	2.4	2.4	2.4	2.4	2.3	2.3	2.3	2.3	2.3	2.3	2.3	2.3	2.3
	X	88	90	91	91	91	91	91	92	92	92	92	92	92	92	92	92	92

Data to the right of the heavy vertical lines should be used with caution, as the resulting sections will be either poorly proportioned, or have velocities in excess of 6 feet per second

Q=Spillway Capacity, cfs
V=Velocity, fps
S=Maximum downstream embankment slope, %
X=Minimum length of the exit channel, ft

Source: Roberts, 1995.

In addition to checking the capacity of the spillway, the discharge velocity should also be considered. The allowable velocity for vegetated channels or channels lined with a turf reinforcement mat should be carefully analyzed. See Section 7E-4 and 7E-11 for information on permissible velocities. For non-erodible linings such as concrete or rip-rap, design velocities may be increased.

6. **Anti-seep collars.** Anti-seep collars help prevent water from flowing along the interface between the outlet barrel and the embankment. This movement of water can, over time, destabilize the embankment, causing it to wash out or burst.

Anti-seep collars are not normally required for sediment basins. However, when the height of the embankment exceeds 10 feet, or the embankment material has a low silt-clay content, anti-seep collars should be used. Anti-seep collars should be used on all structures that may be converted to permanent features.

The first step in designing anti-seep collars is to determine the length of the barrel within the saturated zone. The length of the saturated zone is determined with the following:

$$L_s = Y(Z+4)\left(1+\frac{S}{0.25-S}\right) \quad \text{Equation 6}$$

Where:

L_s	=	Length of the barrel within saturated zone, ft
Y	=	Depth of water at principal spillway crest, ft
Z		Slope of upstream face of embankment, Z ft H: 1 ft V.
S	=	Slope of the barrel in ft per ft

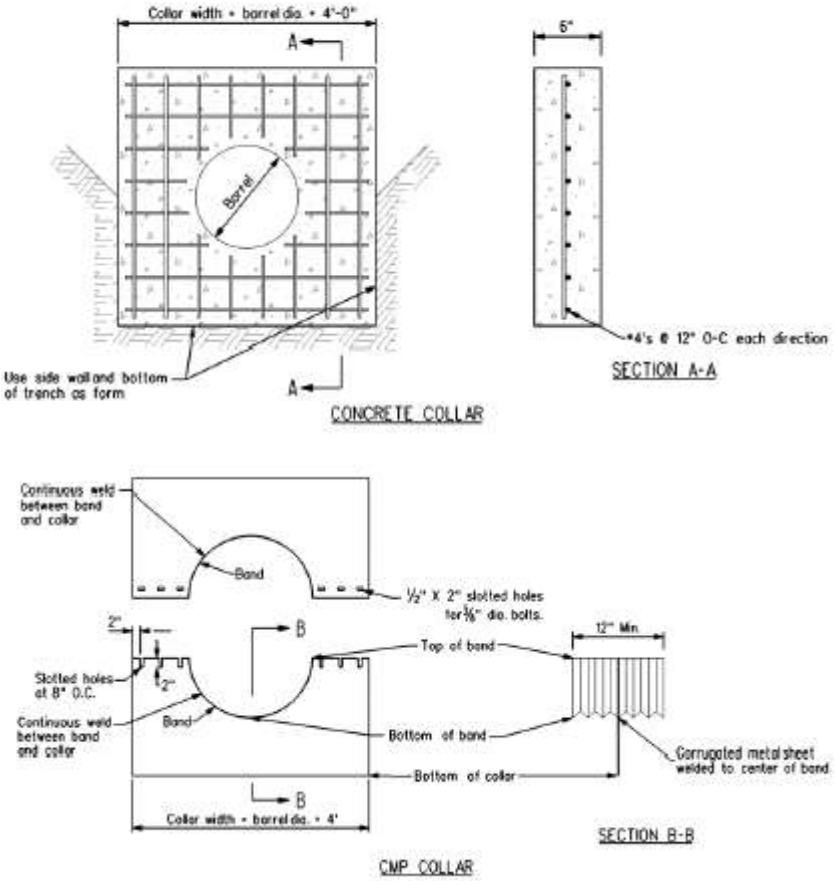
An increase in the seepage length along the barrel of 10% should be provided. Determine the length required to achieve this by multiplying L_s by 10% ($0.10L_s$). This increase in length represents the total collar projection. This can be provided for by one or multiple collars.

Choose a collar size that is at least 4 feet larger than the barrel diameter (2 feet in all directions). Calculate the collar projection by subtracting the pipe diameter from the collar size. Then determine the number of collars required by dividing the seepage length increase ($0.10L_s$) by the collar projection. To reduce the number of collars required, the collar size can be increased. Alternatively, providing more collars can decrease the collar size.

Collars should be placed at a maximum spacing of 14 times the minimum projection above the pipe, and a minimum spacing of 5 times the minimum projection. All collars should be located within the saturated zone. If spacing will not allow this, at least one collar should be located within the saturated zone.

Alternative methods of controlling seepage, such as a filter diaphragm may also be acceptable. A filter diaphragm consists of a layer of porous material running perpendicular to the outlet barrel which intercepts and controls water movement and fines migration within the embankment.

Figure 8: Anti-seep collars



Source: Adapted from Virginia DCR, 1999.

7. **Safety fence.** Depending on the depth, location, and local ordinances, a safety fence and appropriate signing may be required around the sediment basin.

8. **Additional considerations.** Sediment basins which are more than 10 feet high, or which have storage capacities in excess of 10 acre-feet may require review and approval from the Iowa DNR per IAC 567-71.3. A vast majority of temporary sediment basins will not fall under these regulations. Basins that are intended to become permanent features are more likely to require this review.

C. Application

Sediment basin volumes and dimensions should be sized according to the criteria in Section 7D-1. Sediment basins are normally required for disturbed drainage areas of 10 acres or greater.

D. Maintenance

Maintenance and cleanout frequencies for sediment basins depend greatly on the amount of precipitation and sediment load arriving at the basin. During inspections, the embankment should be reviewed for signs of seepage, settlement, or slumping. These problems should be repaired immediately. Sediment should be removed from the basin when it accumulates to one-half of the wet storage volume.

During sediment cleanout, trash should be removed from the basin, and the dewatering device and riser pipe should be checked and cleared of any accumulated debris.

E. Design example

Assume a construction site has 12 acres of disturbed ground which drains to a common location. In addition, 8 acres of off-site area drains through the construction site. Due to site restrictions, the 8 acres of off-site drainage cannot be routed around the site. Design a temporary sediment basin, with and emergency spillway, to handle and treat the runoff from the 20 acre site.

Solution:
1. **Basin volume.** The Iowa DNR NPDES General Permit No. 2 requires a minimum storage volume of 3,600 cubic feet of storage per acre drained.

Therefore: 20 acres x 3600 cf = 72,000 cf.
According to Section 7D-1, D, 3, this volume should be split equally between wet and dry storage (36,000 cf each).

For the remaining calculations, assume that a basin has been sized and laid out to provide the following elevations:

Elevation A (Bottom of Basin) = 100
Elevation B (Wet Storage) = 103.0
Elevation C (Dry Storage) 105.0
Elevation D (Invert of emergency spillway) = 106.5
Elevation E (Top of embankment) = 108.5

2. **Size the principal spillway (riser**). From TR-55, using the methods described in Chapter 2, assume the peak inflow from the 2-year, 24-hour storm is 41 cfs.

In order to determine the required diameter of the principal spillway, the available head elevation above the spillway must be determined. From the elevation information provided above, the principal spillway is at elevation 105.0, and the invert of the emergency spillway is at elevation 106.5. Based upon this, the allowable head is 1.5 feet (106.5-105.0).

The diameter of principal spillway (riser) is found by trial and error process, with the weir and orifice equations:

Try a 24 inch diameter riser: (d=2 ft, A=3.14 ft^2)

Weir Flow	Orifice Flow
$Q = 10.5 \times d \times h^{\frac{3}{2}}$	$Q = 0.6 \times A \times \sqrt{2gh}$
$Q = 10.5 \times 2 \times 1.5^{\frac{3}{2}} = 39\,\text{cfs}$	$Q = 0.6 \times 3.14 \times \sqrt{2 \times 32.2 \times 1.5} = 19\,\text{cfs}$

The lower flow rate (orifice) controls at 19 cfs. The design flow rate was 41 cfs; therefore, the proposed 24 inch riser is too small. Try a larger diameter.

Try a 36" diameter riser. (d=3', A=7.1 ft^2)

Weir Flow	Orifice Flow
$Q = 10.5 \times 3 \times 1.5^{\frac{3}{2}} = 58\,\text{cfs}$	$Q = 0.6 \times 7.1 \times \sqrt{2 \times 32.2 \times 1.5} = 42\,\text{cfs}$

The lower flow rate (orifice) controls at 42 cfs. This is greater than the design flow. Select a 36" diameter riser pipe for the principal spillway.

3. **Size the dewatering orifice.** To dewater 36,000 cubic feet, the average discharge, Q_a, is found as follows:

$$Q_a = \frac{36{,}000}{6 \times 60 \times 60} = 1.7 \text{ cfs.}$$

Next, determine the average head acting on the perforations during dewatering. Assume a rectangular orifice extends from the lowest set of perforations at the wet storage elevation (103.0), up to the upper row of perforations, 3 inches below the principal spillway (105.0-0.25 = 104.75). Based upon this, the maximum head, h_p, is 2 feet (105-103) and the distance to the centroid of the orifice is 0.875 feet [(104.75-103)/2].

From Equation 3, the average head acting on the openings is:

$$h_a = \frac{(h_p - h_c)}{2} = \frac{(2 - .875)}{2} = .56 \text{ feet.}$$

Once the average head and average discharge are known, the total orifice area can be calculated from Equation 4:

$$A = \frac{Q_a}{0.6 \times (2g \times h_a)^{1/2}} = \frac{1.7}{0.6 \times (2 \times 32.2 \times 0.56)^{1/2}} = 0.47 \text{ sf}$$

Several perforation configurations could provide this area. One feasible selection would be to provide 18, 2-1/4 inch holes in three rows (6 holes per row).

4. **Size the emergency spillway.** Since this basin will have an emergency spillway, the principal spillway (riser) was only designed only to carry the 2-year storm. Larger storms, which exceed the capacity of the principal spillway, will be carried by the emergency spillway. The emergency spillway will be designed to carry the 25-year storm event.

From TR-55, using the methods described in Chapter 2, assume the inflow from the 25-year storm is 99 cfs.

During high flow events, both the principal spillway and the emergency spillway will be bypassing flow from the basin. From step 2, the capacity of the principal spillway is 42 cfs. Therefore, from Equation 5, the required capacity of the emergency spillway is as follows:

$$Q_e = Q_{25} - Q_p = 99 - 42 = 57 \text{ cfs.}$$

The capacity of the emergency spillway must be at least 57 cfs. From the assumptions above, the difference in elevation between the invert of the emergency spillway, and the top of the embankment is 2 feet. Since a minimum of 1 foot must be provided between the design high-water elevation and the top of the embankment, 1-foot of head is available for discharge across the spillway.

From Table 1, find the discharge (Q) that equals or exceeds the design value of 57 cfs. From the

table, for 1-foot of head, move horizontally to the discharge value of 61 cfs. Moving vertically in the table, the corresponding width for a discharge of 61 cfs is 26 feet.

5. **Design example summary:**

Basin Volume: 72,000 cubic feet (split equally between wet and dry storage)
Principal Spillway diameter: 36 inches
Dewatering Device: 18, 2-1/4 inch holes in 3 rows (6 holes per row).
Emergency Spillway width: 26 feet.

7E-27 Sediment Trap

Source: Mississippi State University

BENEFITS

	L	M	H
Flow Control	■	■	■
Erosion Control			
Sediment Control	■	■	■
Runoff Reduction	■		
Flow Diversion			

Description: A sediment trap is a temporary structure that is used to detain sediment-laden runoff from small drainage areas (less than 5 acres) long enough to allow sediment to settle out. These devices are constructed by excavating a temporary pond to a pre-determined shape and volume. A stone weir or spillway most commonly controls flow from the structure.

Typical Uses: Used to remove suspended soil particles prior to releasing runoff from a construction site. Normally located at the lowest point of a construction site.

Advantages:

- One of the most useful and cost-effective measures for treating sediment-laden runoff.
- Helps control overall stormwater runoff for small storms, thus protecting streams and rivers.
- Relatively easy and cost-effective to construct.

Limitations:

- May be large and require a substantial amount of site area.
- Sediment traps may need to be eliminated prior to final stabilization on high-density sites because the occupied area is planned for development. This may make it difficult to keep the sediment trap functioning during the entire construction phase.
- Sediment traps are fairly ineffective at removing fine silts or clay particles.
- Not designed to treat runoff during intense rainfall events, which can re-suspend sediment within the trap.

Longevity: 18 months.

SUDAS Specifications: Refer to Section 9040, 1.08, Q, 2.16, and 3.21.

A. Description/uses

Sediment traps are temporary sediment control structures or ponds, having a simple outlet structure stabilized with engineering fabric and rip-rap. They are typically installed in a drainage way or other point of discharge downstream from a disturbed area.

Sediment traps are one of the most reliable measures for treating sediment-laden runoff from small construction sites and may be considered the primary method of sediment removal for many sites.

Sediment traps are highly effective at treating runoff from disturbed sites up to 5 acres. For larger sites, multiple traps are recommended. For disturbed areas greater than 10 acres, a sediment basin may be required (see Section 7E-26).

B. Design considerations

Sediment trap volumes and dimensions should be sized according to the criteria in Section 7D-1. A storage volume of 3,600 cf should be provided for every acre of disturbed ground. This storage volume should be divided equally between wet storage and dry storage.

Sediment traps should be constructed at a low point, or at the point where concentrated flows leave the site. The location should be reviewed to ensure that the trap can be easily accessed for cleanout and maintenance, and that a failure of the sediment trap will not cause a loss of life or property. Sediment traps are often constructed in ditches or swales by excavating a small area to create a depression.

Construction phasing must be considered when locating sediment traps. As construction progresses, the sediment trap may need to be removed in order to complete the proposed improvements. Select a location which will allow the sediment trap to remain in service as long as possible. If construction phasing does not allow a sediment trap to remain in service until final stabilization, the trap may need to be relocated.

The outlet for a sediment trap normally consists of a stone embankment, through which the runoff flows. The embankment slows the rate and velocity of the runoff, creating a temporary pond, which allows sediment to settle out. Equations for calculating the flow through a porous medium, which would allow for exact sizing of the outlet, are available. However, these equations require that the porosity of the stone be known. In addition, an adjustment would need to be made to account for clogging of the voids over time. These criteria are difficult to determine, therefore, it is recommended that the width of the embankment be based upon the drainage area as indicated in the following table:

Table 1: Embankment widths for sediment traps

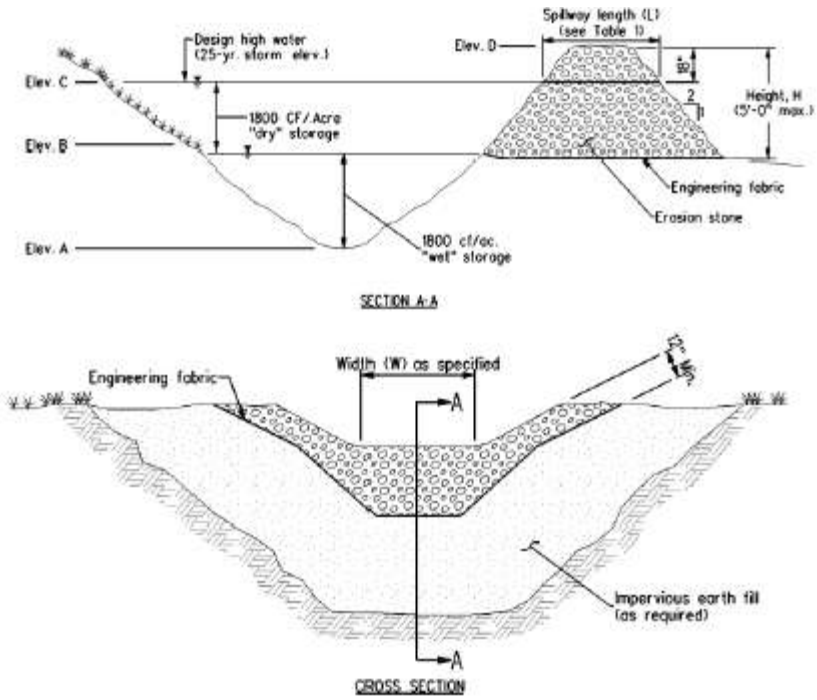
Contributing Drainage Area	Embankment Width
1 ac	4 ft
2 ac	6 ft
3 ac	8 ft
4 ac	10 ft
5 ac	12 ft

Source: Roberts, 1995 (FHWA).

The stone embankment should be located at the low point of the basin. The bottom of the stone embankment should equal the elevation of the top of the wet storage portion of the trap. The stone embankment serves two purposes. The porous nature of the crushed stone allows water to seep through the embankment, providing a means to dewater the dry storage volume of the trap after each rainfall event. The top of the embankment serves as an overflow spillway to control the outlet of flows during large storm events.

Construction of the stone embankment should begin by placing a layer of engineering fabric down to protect the underlying soils and help prevent them from being washed away. Next, erosion stone, or a similarly-sized material, is placed over the filter fabric to create an embankment of the height and width required.

Figure 1: Typical sediment trap with a stone outlet



Source: Adapted from Roberts, 1995 (FHWA).

C. Application

Sediment traps, in conjunction with other erosion control features, should be considered whenever more than 2 acres are disturbed. If more than 5 acres are disturbed, a sediment basin should be considered. If less than 2 acres are disturbed, sediment laden runoff may be controlled by other means such as silt fence or filtering products.

Sediment trap volumes and dimensions should be sized according to the criteria in Section 7D-1. 3,600 cf of storage should be provided for every acre of disturbed ground. This storage volume should be divided equally between wet storage and dry storage.

D. Maintenance

Sediment traps must be cleaned out as sediment accumulates within the trap. It is recommended to clean out the trap when it has lost one-half of the wet storage volume. Upon completion of the project, the trap area should be backfilled and stabilized. Alternatively, the trap may be converted to a permanent sediment basin or detention basin.

7E-28 Silt Fence

BENEFITS

	L	M	H
Flow Control	■		
Erosion Control			
Sediment Control	■	■	
Runoff Reduction			
Flow Diversion	■	■	

Description: Silt fence is a temporary sediment barrier of geotextile fabric that is anchored into the ground and supported by posts on the downstream side of the fabric. Silt fences temporarily impound runoff and retain sediment onsite. They are most effective when designed to provide comprehensive water and sediment control throughout a construction site and if used in conjunction with erosion control practices.

Typical Uses: Used to control sheet flow runoff from disturbed land. May also be used to create a sediment trap for removal of suspended particles from low volume concentrated flows.

Advantages:

- Widely used BMP due to ease of installation and availability of materials.
- Relatively low cost.

Limitations:

- Ineffective against high flows.
- Must be removed after final stabilization.

Longevity: Until sediment accumulates to one-half the height of the fence.

SUDAS Specifications: Refer to Section 9040, 1.08, R, 2.05, and 3.07.

A. Description/uses

Silt fence is a temporary barrier used to remove sediment from runoff. The fence works by intercepting sheet flow from slopes, causing the runoff to pond behind the fence, thereby promoting deposition of sediment on the uphill side of the fence.

Silt fence consists of a geotextile fabric that is trenched or sliced into the ground. The bottom of the fence is anchored into the ground by compacting the disturbed soil along both sides of the trench or slice. The top of the fence is attached to steel posts for support, creating a barrier to the flow of contaminated stormwater runoff.

Silt fence is one of the most commonly used sediment control practices. As such, it is often used improperly, or installed incorrectly. It should be placed at regular intervals on slopes to impound water. Silt fence can also be used in ditches and swales to create a small sediment containment system or ditch check. However, use as a ditch check should be limited to minor ditches and swales due to the potential for blow-out or undermining of the silt fence by high flows.

A common misconception among many designers is that the silt fence actually “filters” suspended particles from runoff. The effectiveness of silt fence is primarily derived from its ability to pond water behind the fence. This ponding action allows suspended particles to settle

out on the uphill side of the fence. Particles are not removed by filtering the runoff through the fabric.

B. Design considerations

1. **Overland flow:**

a. **General guidelines.** Silt fence for sediment and slope control should be installed along the contour of the slope (i.e. the entire length should be at the same elevation). At each end of the silt fence a 20-foot segment should be turned uphill ("J"-hook) to prevent ponded water from flowing around the ends of the silt fence. Individual sections of silt fence should be limited to 200-foot lengths. This limits the impact if a failure occurs, and prevents large volumes of water from accumulating and flowing to one end of the installation, which may cause damage to the fence.

b. **Sediment control.** When used for sediment control, silt fence should be located to maximize the storage volume created behind the fence. Larger storage volumes increase the sediment removal efficiency of the silt fence, and decrease the required replacement/clean-out intervals.

A common location to place silt fence for sediment control is at the toe of a slope. When used for this application, the silt fence should be located as far away from the toe of the slope as practical to ensure that a large storage volume is available for runoff and sediment.

c. **Slope control.** Silt fence can be installed on a slope to reduce the effective slope length and limit the velocity of runoff flowing down the slope. Silt fence also helps prevent concentrated flows from developing, which can cause rill and gully erosion. As a secondary benefit, silt fence installed on slopes can remove suspended sediment from runoff that results from any erosion that has occurred. For slopes that receive runoff from above, a silt fence should be placed at the top of the slope to control the velocity of the flow running onto the slope, and to spread the runoff out into sheet flow.

d. **Perimeter control.** Silt fence is commonly used as a perimeter control along streets or adjacent to water bodies to prevent polluted water from leaving the site. When a diversion or perimeter control silt fence is installed in the direction of a slope, a 20-foot length of fence should be turned in, across the slope, at regular intervals (100 feet) to create a "J"-hook. These "J"-hooks act as check dams, controlling the velocity of the diverted runoff as it travels along the fence.

2. **Concentrated flow.** For concentrated flows in swales or ditches, the silt fence is installed at right angles to the flow of water with the end posts turned uphill to prevent water from flowing around the edges. The 2-year discharge in the ditch should be checked to ensure that it does not exceed 1 cfs . For ditch or swale applications greater than 1 cfs, alternative methods of sediment removal and velocity control within the ditch, such as rock or manufactured ditch checks and sediment traps, are required.

3. **Diversion.** Silt fence can also be utilized as a synthetic diversion structure to redirect clean water around a site and intercept sediment-laden runoff and transport it to a sediment removal practice.

C. Application

For sediment control applications, the maximum contributing area should not exceed ¼ acre per 100 feet of fence. If the contributing area exceeds this value, additional silt fence should be installed to break up the runoff into multiple storage areas.

When used as a velocity control measure for sheet flow on long slopes of disturbed ground, silt fence should be placed at the spacing interval stated in the table below:

Table 1: Silt fence spacing on slopes

Table 1: Silt fence spacing on slopes

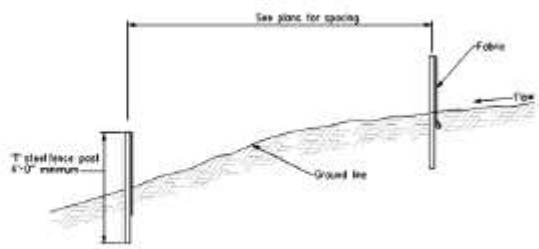
Slope	Placement Interval (ft)
<10:1 (10%)	100
5:1 (20%)	60
4:1 (25%)	50
3:1 (33%)	40

When silt fence is used under concentrated flow, as a ditch check to intercept soil and debris from water flowing through ditches or swales, the following spacing guidelines should be used:

Figure 1: Typical ditch check spacing

Table 2: Ditch check spacing

Ditch Grade, %	Spacing, (ft)
1-2	150
2-4	75
4-6	40
>6	25



D. Maintenance

When accumulated sediment reaches approximately one-half of the fence height, new silt fence should be installed, leaving the existing fence in place, and locating the new silt fence a sufficient distance away from it to provide area for sediment accumulation. When site conditions require that the silt fence be cleaned out, rather than replaced, extreme care must be taken to ensure that the silt fence is not damaged. Removed sediment should be spread out and stabilized. Any areas of damaged silt fence should be replaced immediately.

Upon project completion, fence fabric, posts, and accumulated sediment should be removed. Any areas disturbed by the removal of the silt fence or sediment should be stabilized.

E. Time of year

Silt fences are effective on a year-round basis. Installation may not be possible when there is frost in the ground due to the requirement to trench or slice the fence below the ground surface.

7E-29 Stabilized Construction Exit

BENEFITS

	L	M	H
Flow Control			
Erosion Control			
Sediment Control	■		
Runoff Reduction			
Flow Diversion			

Description: A stabilized construction exit is a temporary, stabilized layer of large aggregate that is located at any point where traffic leaves a construction site and enters a public road or other paved areas. Effectiveness depends on length, depth of rock, frequency of use, and maintenance of temporary rock exit.

Typical Uses: Used where construction vehicles exit a construction site onto a public street. The purpose of the rock exit is to prevent mud from being tracked out onto the roadway, where it can cause plugging of storm sewers and fugitive dust problems.

Advantages:

- Low cost and easily installed.
- Helps prevent tracking of mud onto public streets, reducing fugitive dust and clogged storm sewers.
- Provides stable exit/entrance for construction traffic.

Limitations:

- Rock must be replaced once the voids become plugged with mud.
- May not remove all soil from vehicles, especially on muddy sites.
- Rock and sediment must be disposed of upon completion.

Longevity: Varies, based upon site conditions and volume of traffic.

SUDAS Specifications: Refer to Section 9040, 1.08, S, 2.20, and 3.24.

A. Description/uses

A stabilized construction exit consists of a pad of large aggregate, often underlaid with engineering fabric. Rock exits should be located at any point where traffic will be leaving a construction site and entering a public roadway. The stabilized construction exit reduces the amount of sediment (dust, mud, etc.) tracked offsite by construction equipment, especially if a wash-rack is incorporated for removing caked sediment.

B. Design considerations

The exit from a construction site is a significant source for offsite sediment deposition. Exit and parking areas are continuously disturbed, leaving no opportunity for vegetation stabilization. During wet weather, these areas often become muddy, and construction vehicles track this mud off of the site and deposit it onto the public roadway where it clogs storm sewers and creates fugitive dust problems.

A stabilized construction exit can reduce the amount of sediment that is tracked into the street by construction traffic. A rock exit stabilizes the access to the site, and helps remove mud and clay from vehicle tires before they leave the site. A stabilized construction exit should be constructed on every construction site, prior to the mobilization of construction equipment.

1. **Location.** A stabilized construction exit should be located at every point where construction traffic leaves a construction site. Vehicles leaving the site should travel over the entire length of the rock exit.

When possible, the exit should be located on level ground, at a location with appropriate sight distance. Construction vehicles should be prohibited from leaving the site at locations other than the stabilized construction exit. Fence should be constructed if necessary. If additional access to the site is required, additional rock exits should be constructed

2. **Site preparation.** The area of the exit should be excavated to the proposed thickness of the stone, stripping any topsoil, vegetation, and soft soils as necessary to provide a stable subgrade. When soft soil conditions exist, or when earthmoving or other heavy equipment will use the exit, a subgrade stabilization fabric should be placed over the entire length and width of the exit prior to placing the rock.

3. **Drainage.** Slopes should not exceed 15% and should be carefully graded to drain transversely to prevent runoff from the exit from flowing into the street. All surface water flowing off of the construction exit should be directed to a sediment removal device (sediment basin or trap, silt fence, filter sock, etc.).

4. **Tire washing or "wash-rack."** A properly constructed rock exit should not be relied upon to remove all the mud from construction traffic. In some cases, the action of tires moving over a gravel pad may not adequately clean tires. If conditions on the site are such that the majority of the mud is not removed by the vehicles traveling over the rock, then the tires of the vehicles should be washed before entering the public road. Manual washing of the tires should be provided, or automated wash racks should be installed. Wash water must be carried away from the exit to a sediment removal device (sediment basin or trap, silt fence, filter tube, etc.). Allsediment shall be prevented from entering storm drains, ditches, or watercourses.

C. Application

1. **Length.** Minimum of 50 feet with an exception for single family residential lots which should be 30 feet. For sites that will be utilizing the exit to haul a large volume of earth, the length of the entrance should be increased.

2. **Width.** Minimum of 20 feet wide. Busy entrances will need the capability of handling a lane of traffic each way, typically 30 feet wide. Flare the entrance where it meets the existing road to provide a turning radius.

3. **Geotextile.** If soft soil conditions exist, or when earthmoving or other heavy equipment will utilize the exit, a layer of subgrade stabilization fabric should be placed over the prepared subgrade prior to placement of the rock to minimize migration of stone into the underlying soil by heavy vehicle loads. The barrier created by the fabric also aids in removal of the stone upon completion of the project, or as required for maintenance.

4. **Stone.** The rock for the exit should consist of a nominal 2 to 3 inch clean crushed stone or recycled concrete. A 6 to 12-inch thick layer of stone, depending on anticipated traffic, should be placed over the entire length and width of the construction exit. Rock with smaller aggregate does not adequately remove mud and clay from vehicles, and may be picked up by vehicle tires and carried out into the street.

D. Maintenance

Construction exits should be inspected daily to ensure that mud and dirt are not being tracked onto roadways. All sediment deposited on paved roadways should be removed, not washed into the stormwater system or into waterways, at the end of each workday.

Rock exits may require that additional stone be placed if the existing material becomes buried or if the subgrade is soft or becomes saturated.

Upon completion of the project the rock exit, engineering fabric and any accumulated sediment should be removed and disposed of.

APPENDIX B – STORMWATER BMP DESIGN STANDARDS INDEX

SECTION	DESCRIPTION
2E-2	Infiltration Trenches
2E-3	Infiltration Basins

2E-4	Bioretention Systems
2E-5	Soil Quality Restoration
2E-6	Native Landscaping
2F-1	Sand Filter
2G-2	Dry Detention
2G-3	Wet Detention
2H-1	Stormwater Wetlands
2I-2	Grass Swales
2I-3	Dry and Wet Swales
2I-4	Vegetated Filter Strips

2E-2 Infiltration Trenches

Source: California Stormwater Manual

Pollutant Removal Low = <30% Medium = 30-65% High = 65-100%			
	Low	Med	High
Suspended Solids			■
Nitrogen		■	■
Phosphorous		■	
Metals			■
Bacteriological			■
Hydrocarbons		■	

Description: An infiltration trench is a long, narrow, rock-filled trench with no outlet that receives stormwater runoff. Runoff is stored in the void space between the stone aggregate and infiltrates through the bottom and into the soil matrix. Infiltration trenches can range from 3-12 feet deep, are backfilled with stone aggregate, and are lined with filter fabric. Underground trenches receive runoff through pipes or channels, whereas surface trenches collect sheet flow from the drainage area. Trenches should be designed to drain completely within 6-48 hours. Infiltration trenches perform well for removal of fine sediment and associated pollutants. Pre-treatment using buffer strips, swales, or detention basins is important for limiting amounts of coarse sediment entering the trench, which can clog and render the trench ineffective.
Typical uses: Residential subdivisions, high-density residential, ultra-urban areas, and parking lots.
Advantages:

- Appropriate for small sites with porous soils
- Infiltration trenches reduce runoff volume and filter pollutants
- Provide stream baseflow and recharge groundwater.
- As an underground BMP, trenches are unobtrusive and have little impact on site aesthetics

Limitations:

- Use should be restricted to small drainage areas – generally less than 5 acres
- Suitable for NRCS HSG-A/B soils; limited application in HSG-C soils; not recommended in HSG-D soils. Do not use with soil infiltration rates < 0.5 inches/hour
- Seasonal high water table should be 4 feet below bottom of trench
- Susceptible to clogging by sediment – use upstream BMPs for sediment removal
- Restricted in karst areas
- Placement under paved surfaces or in industrial or commercial settings not recommended

Maintenance requirements:

- Remove sediment accumulation to ensure proper functioning
- Inspect for clogging – install an integrated observation well/peizometer to check water level
- Remove sediment from pre-treatment areas

Description

By diverting runoff into the soil, an infiltration trench not only treats the water quality volume, but also helps to preserve the natural water balance on a site and can recharge groundwater and preserve baseflow. Due to this fact, infiltration systems are limited to areas with highly porous soils where the water table and/or bedrock are located well below the bottom of the trench. In addition, infiltration trenches must be carefully sited to avoid the potential of groundwater contamination.

Infiltration trenches are not intended to trap sediment. Due to their high potential for failure, these facilities must only be considered for sites where upstream sediment control can be ensured.

Pretreatment using buffer strips, swales, or detention basins is important for limiting amounts of coarse sediment from entering the trench because it can clog the trench and render it ineffective. An example infiltration trench system is shown in Figure 1.

Stormwater management suitability

Infiltration trenches are designed primarily for reduction in stormwater runoff volume, but when integrated with other BMPs, they can achieve significant water quality improvement. Runoff volume control can be achieved for the water quality volume for smaller storm events up to the limits of the local infiltration capacity of the local soils. The runoff volume gradually infiltrates through the bottom and sides of the trench and into the subsoil, eventually reaching the water table. By diverting runoff into the soil, an infiltration trench not only treats the water quality volume, but also helps to preserve the natural water balance on a site, recharge groundwater, and preserve baseflow.

An infiltration trench may also be designed to capture and infiltrate the entire channel protection volume, CPv, in either an off-line or on-line configuration. For larger sites, or where only the WQv is diverted to the trench, another structural control must be used to provide CPv extended detention. Infiltration trenches must be used in conjunction with another best management practice to provide overbank and extreme flood protection, if required.

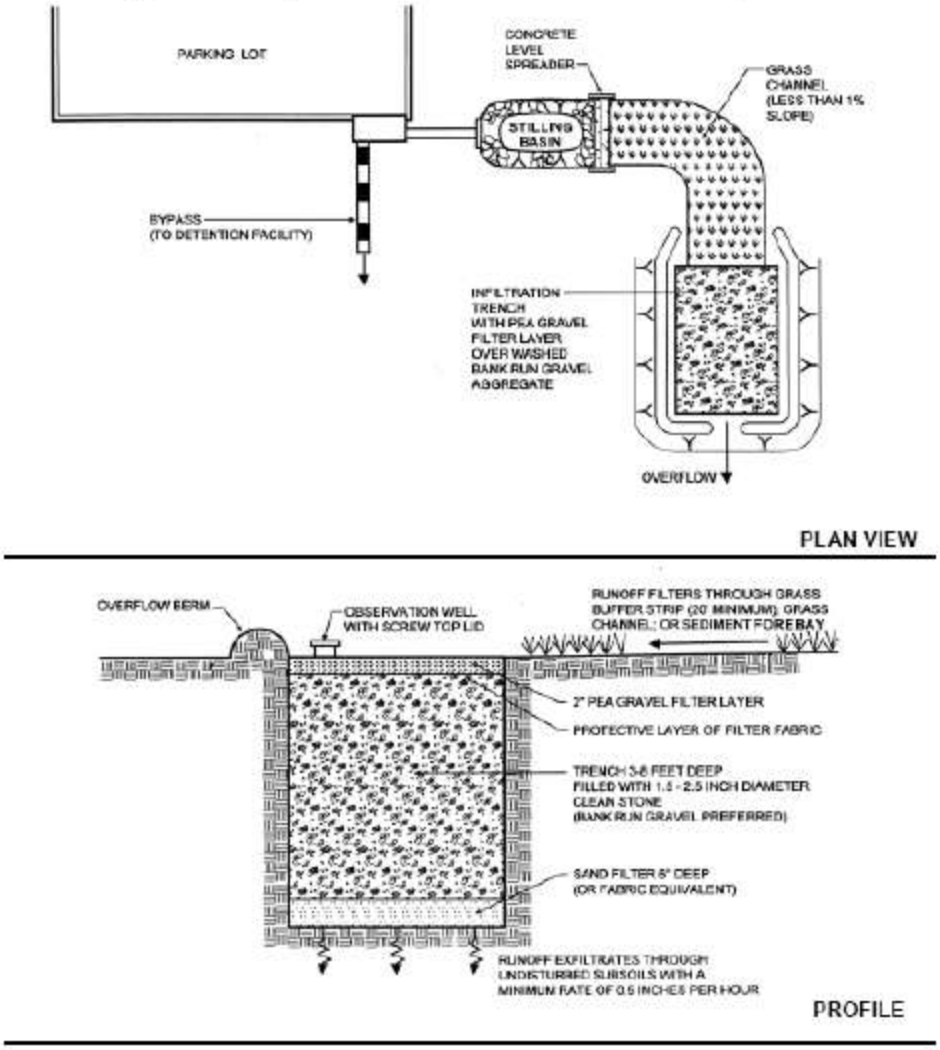
Pollutant removal capabilities

Infiltration trenches can remove a wide variety of pollutants from stormwater through sorption (the action of soaking up or attracting substances), precipitation, filtering, and bacterial and chemical degradation. Pre-treatment areas up-gradient of the infiltration site are provided to remove a larger portion of the TSS and overall sediment load. Examples of some pre-treatment areas include grit chambers, water quality inlets, sediment traps, swales, and vegetated filter strips (SEWRPC 1991; Harrington 1989).

When used with pre-treatment areas, infiltration trenches can remove up to 80 percent of sediments, metals, coliform bacteria, and organic matter; and up to 60 percent of phosphorus and nitrogen (Schueler 1992). Biochemical oxygen demand (BOD) removal is estimated to be between 70 to 80 percent. Lower removal rates for nitrate, chlorides, and soluble metals should be expected. Undersized or poorly-designed infiltration trenches can reduce TSS removal performance. An infiltration trench is presumed to be able to remove 80% of the TSS load in typical urban postdevelopment runoff when sized, designed, constructed, and maintained in accordance with the recommended specifications. In a situation where a removal rate is not deemed sufficient, additional controls may be put in place at the given site in a series or “treatment train” approach. For additional information on monitoring BMP performance, see ASCE/EPA *“*Urban Stormwater BMP Performance Monitoring: A Guidance Manual for Meeting the National Stormwater BMP Database Requirements.”

Using washed aggregate and adding organic matter and loam to the subsoil may improve pollutant removal efficiencies. The addition of organic material and loam to the trench subsoil will enhance metals and nutrient removal through adsorption.

Figure 1: Example of an off-line infiltration trench configuration



Source: Center for Watershed Protection

Application and feasibility

Infiltration trenches are generally suited for medium- to high-density residential, commercial, and institutional developments where the subsoil is sufficiently permeable to provide a reasonable infiltration rate and the water table is low enough to prevent groundwater contamination. They re applicable primarily for impervious areas where there are not high levels of fine particulates (clay/silt soils) in the runoff, and should only be considered for sites where the sediment load is relatively low.

Infiltration trenches can be used either to capture sheet flow from a drainage area or to function as an off-line device. Due to the relatively narrow shape, infiltration trenches can be adapted to many different types of sites and can be utilized in retrofit situations. Unlike some other structural stormwater controls, they can easily fit into the margin, perimeter, or other unused areas of developed sites. Infiltration trenches capture and treat small amounts of runoff but do not control peak hydraulic

flows. Infiltration trenches should be used in conjunction with another best management practice to provide both water quality control and peak flow control (Harrington 1989). Peak flow control is usually achieved with a slow release of the stormwater management volume through an orifice in the storage facility. As a result, the water quality volume will equal the stormwater detention area below the orifice, and must infiltrate to exit.

The applicability of infiltration trenches depends on native soils, slope, depth to water tables, depth to bedrock, size of drainage area, and proximity to wells, surface waters, and foundations. Trenches are generally suitable to sites with gentle slopes, permeable soils, deep bedrock, and deep groundwater. Excessive slope of the drainage area, fine-particle soil types, and proximate location of the water table and bedrock may prevent the use of infiltration trenches.

1. **General feasibility.**

    a. Suitable for Residential Subdivision Usage – yes

    b. Suitable for High Density/Ultra Urban Areas – yes

    c. Regional Stormwater Control – no

2. **Physical feasibility – physical constraints at project site.**

    a. **Drainage area.** 5 acres maximum

    b. **Space required.** Will vary depending on the depth of the facility.

    c. **Site slope.** No more than 6% (for pre-construction facility footprint).

    d. **Minimum head.** Elevation difference needed at a site from the inflow to the outflow: 1 foot.

    e. **Minimum depth to water table.** Four feet recommended between the bottom of the infiltration trench and the elevation of the seasonally high water table.

    f. **Soils.** Infiltration rate greater than 0.5 in/hr required (typically HSG-A and B soils).

    g. **Other constraints/considerations.** Aquifer protection: no hotspot runoff allowed; meet setback requirements in design criteria.

Planning and design criteria

1. **Evaluation of the site.** Per the general criteria listed in 2E-1.

2. **Slope and drainage area.** The drainage area slope determines the velocity of the runoff and influences the amount of pollutants entrained in the runoff. Infiltration trenches work best when the up-gradient drainage area slope is less than 5 percent (Schueler, 1987). The down-gradient slope should be no greater than 15 percent to minimize slope failure and seepage. The slope of the surrounding area should be such that the runoff is evenly distributed as sheet flow as it enters the trench. Runoff can be captured by depressing the trench surface or by placing a berm at the down-gradient side of the trench. In general, infiltration trenches are suitable for drainage areas up to 5 acres. Supplemental BMPs should always be carefully considered. The drainage area

must be fully developed and stabilized with vegetation before constructing an infiltration trench. High sediment loads from unstabilized areas will quickly clog the infiltration trench.

3. **Depth to water table and bedrock.** Land availability, the depth to bedrock, and the depth to the water table will determine whether the infiltration trench is located underground or at grade. Feasible sites should have a minimum of 4 feet to bedrock in order to reduce excavation costs. There should also be at least 4 feet below the trench to the water table to prevent potential groundwater problems.

4. **Minimum setbacks.** Stormwater easements may be necessary to accommodate setbacks. Recommended setbacks are as follows:

   a. Property line: 10 feet

   b. Building foundation: 25 feet

   c. Private well: 100 feet

   d. Public water supply well: 1,000 feet

   e. Septic system tank/leach field: 100 feet

   f. Surface waters: 100 feet

5. **Location and siting:**
   a. Infiltration trenches can be used to capture sheet flow or function as an off-line device. They are suitable for medium- to high-density residential areas. Because of their narrow shape, they can be added to many different sites and retrofit situations. They easily fit into the margin, perimeter, or other unused areas of developed sites. Infiltration trenches are not suitable for sites that use or store chemicals or hazardous materials, unless diversion structures prevent hazards from entering the trench. The potential for spills can be minimized by aggressive pollution prevention measures. Many municipalities and industries have developed comprehensive spill prevention control and countermeasure plans. These plans should be modified to include the infiltration trench and the contributing drainage area. When used in an off-line configuration, the WQv is diverted to the infiltration trench through the use of a flow splitter. Stormwater flows greater than the WQv are diverted to other controls or downstream, using a diversion structure or flow splitter.

   b. To reduce the potential for costly maintenance and/or system reconstruction, it is strongly recommended that the trench be located in an open or lawn area, with the top of the structure as close to the ground surface as possible. Infiltration trenches should not be located beneath paved surfaces, such as parking lots.

   c. The underlying soils must meet the soils screening criteria with an infiltration rate, *f*, of 0.5 in/hr or greater, as initially determined from NRCS soil textural classification; and subsequently confirmed by field geotechnical tests. The minimum geotechnical testing is one test hole per 5,000 square feet, with a minimum of two borings per facility (taken within the proposed limits of the facility). Infiltration trenches cannot be used in fill soils.

   d. Infiltration trenches should have a contributing drainage area of 5 acres or less.

e. Infiltration trenches are designed for intermittent flow and must be allowed to drain and allow re-aeration of the surrounding soil between rainfall events. They must not be used on sites with a continuous flow from groundwater, sump pumps, or other sources. Trenches should be designed to drain completely within 6 to 72 hours. A shorter drain time of 48 hours is often used as a factor of safety in the design. A minimum drainage time of 6 hours will ensure satisfactory pollutant removal. The maximum drainage time is dependent on the precipitation zone. In Iowa, the average time between storm events is approximately 72 hours. Therefore, the trench should be designed to drain completely within a maximum of 72 hours.

f. The site assessment approach for stormwater infiltration sites is very similar to the site assessment used for the design of onsite wastewater treatment systems. In a soil/water infiltration system (SWIS) for septic tank effluent, the same concerns are considered as with seasonal high groundwater, depth to water table, and soil permeability. The typical loading rates for septic tank effluent in B soils would be on the order of 0.5-1.0 gal/day/ft^2 of infiltration surface. These are long-term loading rates and are based on the assumption that a bio-mat will eventually form at the soil/water interface.

6. **Cold weather considerations.** Climate can limit infiltration trench use. Winter sanding can clog an infiltration trench, and winter salting can increase the potential for chloride contamination of groundwater. Additionally, the trench surface may freeze, thereby preventing the runoff from entering the trench and allowing the untreated runoff to enter surface water. However, recent studies indicate that if properly designed and maintained, infiltration trenches can operate effectively in colder climates. By keeping the trench surface free of compacted snow and ice, and by ensuring that part of the trench is constructed below the frost line, the performance of the infiltration trench during cold weather will be greatly improved.

Physical specifications, geometry, and volume

1. A well-designed infiltration trench consists of:

   a. Excavated shouldow trench backfilled with sand, coarse stone, and pea gravel; and lined with a filter fabric.

   b. Appropriate pre-treatment measures.

   c. One or more observation wells to show how quickly the trench dewaters or to determine if the device is clogged.

   d. A plan view and profile schematic for the design of an off-line infiltration trench is shown in Figure 1. A schematic for an on-line infiltration facility is shown in Figure 2.

2. Physical specifications of an infiltration trench include:

   a. The required trench storage volume is equal to the WQv. For smaller sites, an infiltration trench can be designed with a larger storage volume to include the Cpv.
   b. A trench must be designed to fully dewater the entire WQv within 24 to 48 hours after a rainfall event. The slowest infiltration rate obtained from tests performed at the site should be used in the design calculations.

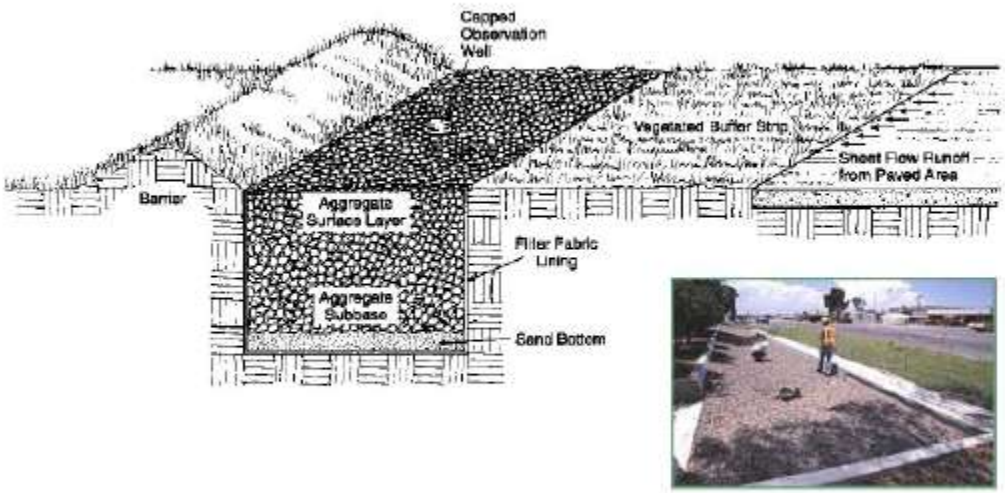
c. Trench depths should be between 3 and 8 feet, to provide for easier maintenance. The width of a trench is usually less than 25 feet.

d. Broader, shouldow trenches reduce the risk of clogging by spreading the flow over a larger area for infiltration.

e. The surface area required is calculated based on the trench depth, soil infiltration rate, aggregate void space, and fill time (assume a fill time of 2 hours for most designs).

f. The bottom slope of a trench should be flat across its length and width to evenly distribute flows, encourage uniform infiltration through the bottom, and reduce the risk of clogging.

Figure 2: Example of an on-line infiltration trench configuration



Source: Georgia Stormwater Manual, 2000

3. Components of an infiltration trench (See Figure 3):
   a. **Aggregate.** The basic infiltration trench uses stone aggregate in the top of the trench to promote filtration. The stone aggregate is normally 1 to 3 inches in diameter, which provides a void space of ~35 percent (SEWRPC 1991; Harrington 1989; Schueler 1987). The stone aggregate should be washed to remove dirt and fines before placement in the trench. The aggregate should be non-crushed limestone or a river-run washed stone (often referred to as septic rock). A 4 to 6 inch layer of clean, washed, ASTM C33 medium aggregate concrete sand is placed on the bottom of the trench to encourage drainage and prevent soil compaction when the stone aggregate is added. The design can be modified by substituting pea gravel for stone aggregate in the top foot of the trench. The pea gravel should be #8 to 3/8-inch. The pea gravel improves sediment filtering and maximizes the pollutant removal in the top of the trench. When the modified trenches become clogged, they can generally be restored to full performance by removing and replacing only the pea gravel layer, without replacing the lower stone aggregate layers. Infiltration trenches can also be modified by adding a layer of organic material (peat) or loam to the trench subsoil. This modification appears to enhance the removal of metals and nutrients through adsorption.

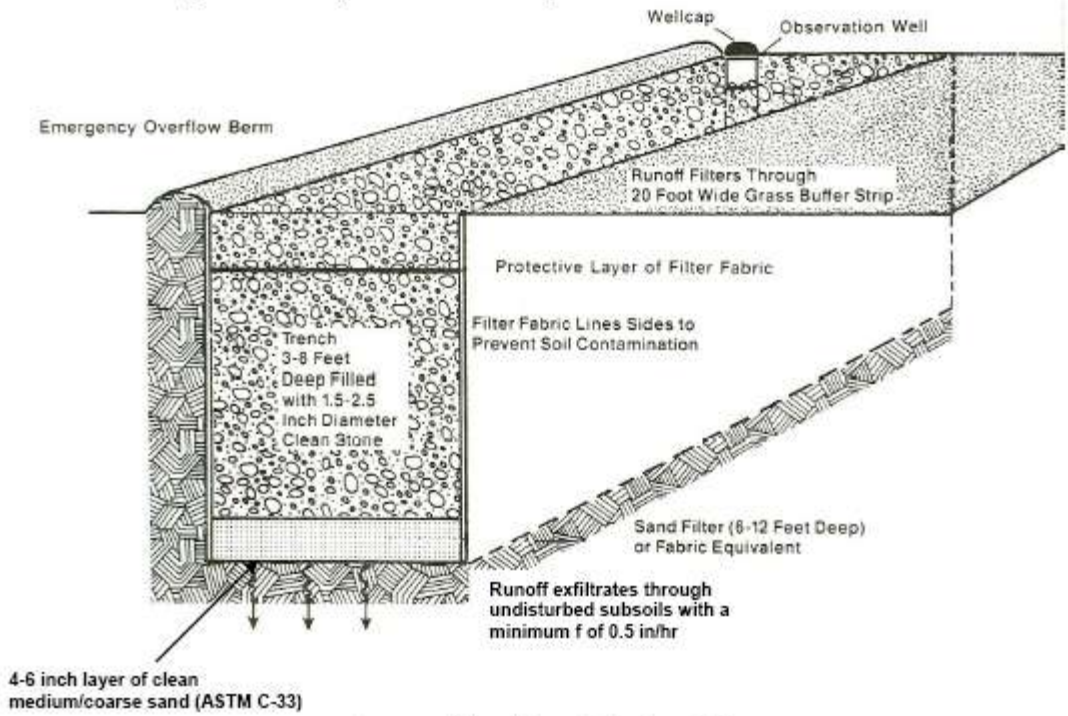
b. **Sheet flow.** The trench surface may consist of stone or vegetation with inlets to evenly distribute the runoff entering the trench (SEWRPC 1991; Harrington 1989). A level spreader can be installed to create sheet flow (Harrington 1989).

c. **Filter fabric.** The sides and bottom of the infiltration trench should be lined with filter fabric. The fabric should be placed around the walls and bottom of the trench, and 1 foot below the trench surface. The filter fabric should overlap each side of the trench in order to cover the top of the stone aggregate layer. The filter fabric prevents sediment in the runoff and soil particles from the sides of the trench from clogging the aggregate. Filter fabric placed 1 foot below the trench surface will maximize pollutant removal within the top layer of the trench and decrease the pollutant loading to the trench bottom, reducing the required frequency of maintenance.

d. **Observation well.** (See example schematics). An observation well allows monitoring of drainage. The observation well can be 4- to 6-inch diameter PVC pipe with a lockable cap. The well can either be 6 inches above-ground or flush with the ground, depending on the trench surface. It is anchored to a footplate at the bottom of the trench, and should be located near the longitudinal center of the infiltration trench. A visible floating marker should be provided to indicate the water level. The pipe should have a plastic collar with ribs to prevent rotation when removing the cap. The screw-top lid should be a cleanout with a locking mechanism or special bolt to discourage vandalism. The depth to the invert should be marked on the lid.

e. **Filter strip.** A vegetated buffer strip, 20-25 feet wide, is established adjacent to the infiltration trench to capture large sediment particles in the runoff. The buffer strip is installed immediately after trench construction using sod instead of hydroseeding (Schueler 1987). The buffer strip should be graded with a slope between 0.5 and 15 percent so that runoff enters the trench as sheet flow.

Figure 3: Components and configuration of an infiltration trench



Source: Adapted from Schueler, 1987

Design of infiltration trenches

The design of an infiltration trench is based on the textural class and nominal infiltration rate of the soils underlying the trench such that a feasible design is possible. The design of an infiltration trench is also based on the maximum allowable depth of the trench (d_{max}- ft). The maximum allowable depth should meet the following criteria:

$d_{max} = (fT_s/n)/12$ **Equation 1**

where:
f = final infiltration rate of the trench area (in/hr)
T_s = maximum allowable storage time (hr)
n = porosity, volume voids/total volume (Vv/Vt) of the aggregate reservoir.

A nominal value for n of 0.32-0.35 is typical. This can be adjusted based on specific measurement for the aggregate specified. The maximum allowable storage time should be no greater than 72 hours. The maximum allowable depth for a site may also be limited by the depth to the water table.

The infiltration trench is sized to accept the design volume that enters the trench (V_W) plus the volume of rain that falls on the surface of the trench (PA_t) minus the exfiltration volume (fTA_t) out of the bottom of the trench. Based on NRCS hydrograph analysis, the effective filling time for most infiltration trenches (T) will generally be less than two hours. The volume of water that must be stored in the trench (V) is defined as:

$V = V_W + (P/12)(A_t) - (f/12)TA_t$ **Equation 2**
where:

V_W = water quality volume (WQv) or total runoff volume to be infiltrated (ft^3)
P = design rainfall event (in)
A_t = trench surface area (ft^2)
f = infiltration rate (in/hr)
T = fill time (hr)

For most design storm events, the volume of water due to rainfall on the surface area of the trench (PA_t) is small when compared to the design volume (V_W) of the trench, and may be ignored with little loss in accuracy to the final design. The volume of rainfall and runoff entering the trench can be defined in terms of trench geometry. The gross volume of the trench (V_t) is equal to the ratio of the volume of water that must be stored (V_w) to the porosity (*n*) of the stone reservoir in the trench; V_t is also equal to the product of the depth (d_t-ft) and the surface area (A_t-ft^2):

$V_t = V/n = d_t \times A_t \times n$ **Equation 3**

Combining equations 2e-2.1 and 2E-2.2 provides the following expression:
$d_t \times A_t \times n = V_W + (P/12)(A_t) - (f/12)TA_t$

Assuming the volume of water falling directly onto the trench area is negligible, then:

$d_t \times A_t \times n = V_W - (f/12)TA_t$ **Equation 4**

Because both dimensions, A_t and d_t, of the trench are unknown, the equation may be rearranged to determine the area of the trench (A_t) if the value of d_t is determined, based on either the location of the water table, or the maximum allowable depth of the trench (d_{max}):

$A_t = V_W / (nd_t + fT/12)$ **Equation 5**

Design procedures

Design plans should include a geotechnical evaluation that determines the feasibility of using an infiltration trench at the site (See Section 2E-1).

1. **Step 1**. Compute runoff control volumes. Calculate the WQv, CPv, Qp, and the 100-year Qf. See Part 2C for calculations.

2. **Step 2.** Determine if the development site and conditions are appropriate for the use of an infiltration trench. Confirm any local design criteria and check with local agencies to determine if there are any additional restrictions and/or surface water or watershed requirements that may apply. Consider any special site-specific design conditions, including:
   - Soil:
     - Soil type (USDA classifications)
     - Percent clay
     - Permeability
     - Assessment procedures
   - Depth to water table
   - Slope
   - Drainage area

3. **Step 3.** Compute the peak discharge rate for the water quality volume event. The peak rate of discharge for water quality design is needed for sizing of the off-line diversion structure and piping.

   a. Using WQv (or total volume to be infiltrated), compute CN.

   b. Compute time of concentration using WINTR-55 method

   c. Determine appropriate unit peak discharge from time of concentration.

   d. Compute Qwq from unit peak discharge, drainage area, and WQv.

3. **Step 4.** Size the flow diversion structure, if needed. A flow regulator (or flow splitter diversion structure) should be supplied to divert the WQv to the infiltration trench. Size low-flow orifice, weir, or other device to pass the Qwq.

4. **Step 5.** Size the infiltration trench:

   a. Determine the trench volume by assuming the WQv will fill the void space based on the computed porosity of the stone aggregate backfill (normally about 35%).

   b. A site-specific trench depth is calculated based on the soil infiltration rate, aggregate void space, and the trench storage time as described above (Harrington 1989). Compute the maximum allowable trench depth (d_{max}) from Equation 1. Select the trench design depth (d_t) based on the depth that is the required depth above the seasonal groundwater table, or a depth less than or equal to d_{max}, whichever results in the smaller depth. Trench depths are usually between 3-12 feet (SEWRPC 1991; Harrington 1989). However, a depth of 8 feet is most commonly used (Schueler 1987).

   c. Compute the trench surface area (A_t) for the particular soil type using Equation 4:

      $A_t = WQv / (n d_t + fT/12)$

      where:
      A_t = trench surface area, ft^2
      WQv = water quality volume (or total volume to be infiltrated), ft^3
      f = infiltration rate, in/hr
      T = drain time (maximum time to dewater the entire WQv), hours

   d. A minimum drainage time of 6 hours should be provided to ensure satisfactory pollutant removal in the infiltration trench (Schueler 1987). Although trenches are designed to provide temporary storage of stormwater, the trench should drain prior to the next storm event. For Iowa, the mean time between storm events is about 72 hours. Using a shorter drain time of 48 hours would provide a more conservative design.

   e. In the event that the sidewalls of the trench must be sloped for stability during construction, the surface dimensions of the trench should be based on the following equation:

      $A_t = (L - Zd_t)(W - Zd_t)$ **Equation 6**

Where L and W are the top length and width, and Z:1 is the trench side-slope ratio. The design procedure would begin by selecting a top width (W) that is greater than $2 \times Zd_t$ for a specified slope (Z). The side slope ratio value will depend on the soil type and the depth of the trench. The top length (L) may then be determined as:

$$L = Zd_t + At / (W - Zd_t) \qquad \textbf{Equation 7}$$

6. **Step 6**. Determine pre-treatment volume and design pre-treatment measures. Size pre-treatment facility to treat 25% of the water quality protection volume for off-line configurations.

7. **Step 7.** Design spillway(s): Adequate stormwater outfalls should be provided for the overflow exceeding the capacity of the trench, ensuring non-erosive velocities on the downslope.

Inspection and maintenance requirements

Infiltration trenches, as with all BMPs, must have routine inspection and maintenance designed into the life performance of the facility. The principal maintenance objectives are to prevent clogging and groundwater contamination. Maintenance and inspection plans should be identified prior to establishment. Infiltration trenches and any pre-treatment BMPs should be inspected after large storm events to remove any accumulated debris or material. A more thorough inspection of the trench should be conducted annually. A summary of inspection and maintenance activities is provided in Table 1.

A record should be maintained of the dewatering time of an infiltration trench to determine if maintenance is needed. (Ponded water lasting more than 24 hours usually indicates that the trench is clogged). When vegetated buffer strips are used, they should be inspected for erosion or other damage after each major storm event. Trees and other large vegetation adjacent to the trench should also be removed to prevent damage to the trench.

Maintenance responsibility for an infiltration trench should be assigned to a responsible jurisdiction or authority through a legally binding and enforceable maintenance agreement completed as a condition of the site plan approval.

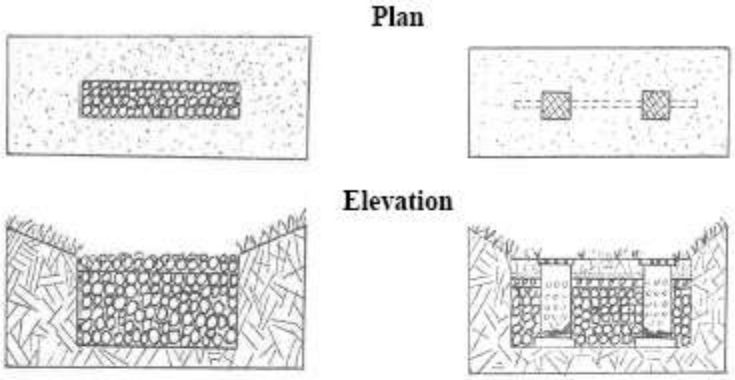
Table 1: Typical maintenance activities for infiltration trenches

Activity	Schedule
• Ensure the contributing drainage area, facility, and inlets are clear of debris. • Ensure that the contributing area is stabilized. • Remove sediment and oil/grease from pre-treatment devices, as well as overflow structures. • Mow grass filter strips as necessary. Remove grass clippings.	Monthly
• Check observation wells following three days of dry weather. Failure to percolate within this time period indicates clogging. • Inspect pre-treatment devices and diversion structures for sediment buildup and structural damage. • Remove trees that start to grow in the vicinity of the trench.	Semi-annual
• Replace pea gravel/topsoil and top surface filter fabric (when clogged).	As needed
• Perform total rehabilitation of the trench to maintain design storage capacity. • Excavate trench walls to expose clean soil.	Upon failure

Source: US EPA, 1999

Example schematics

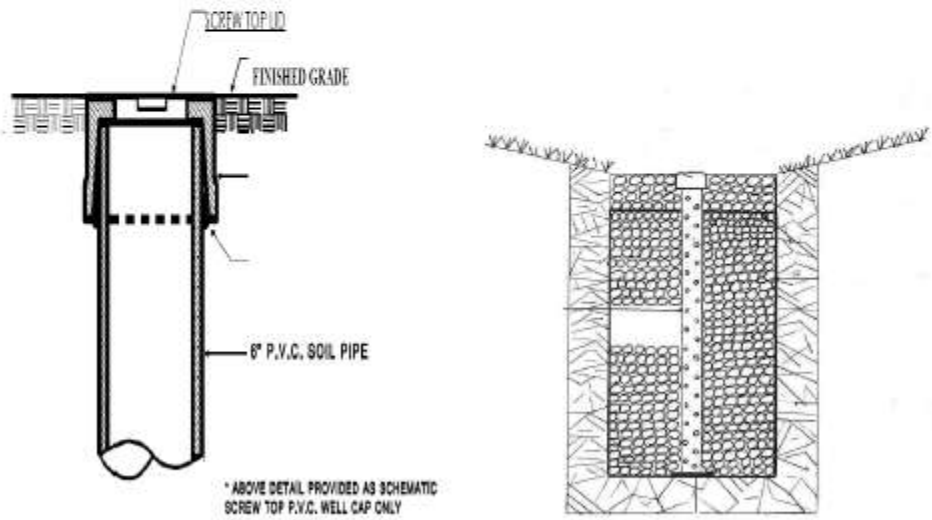
Figure 4: Types of infiltration trenches



(a) Trench with a stone surface (b) Trench with a vegetated surface and inlets

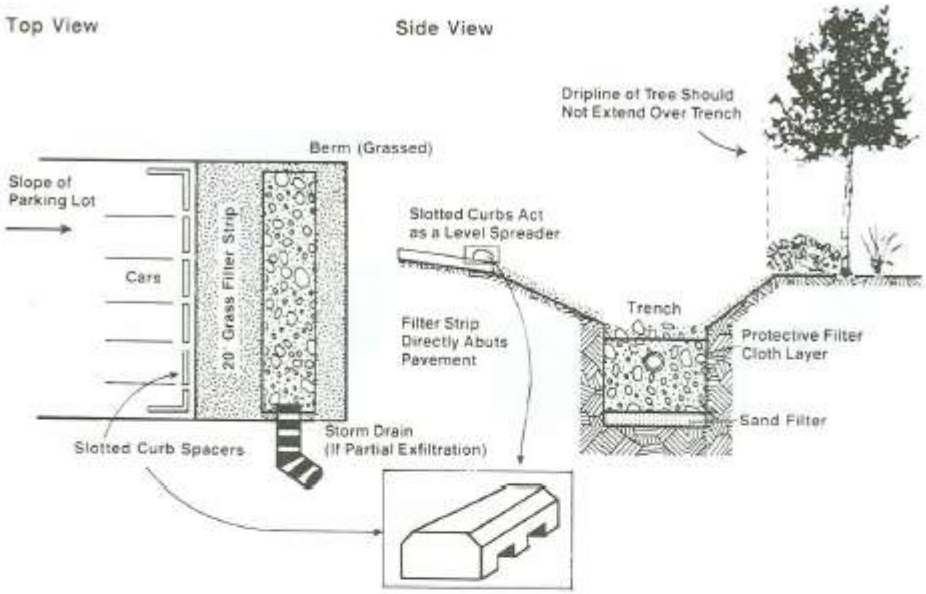
Source: Schueler, 1987

Figure 5: Example observation well and access lid



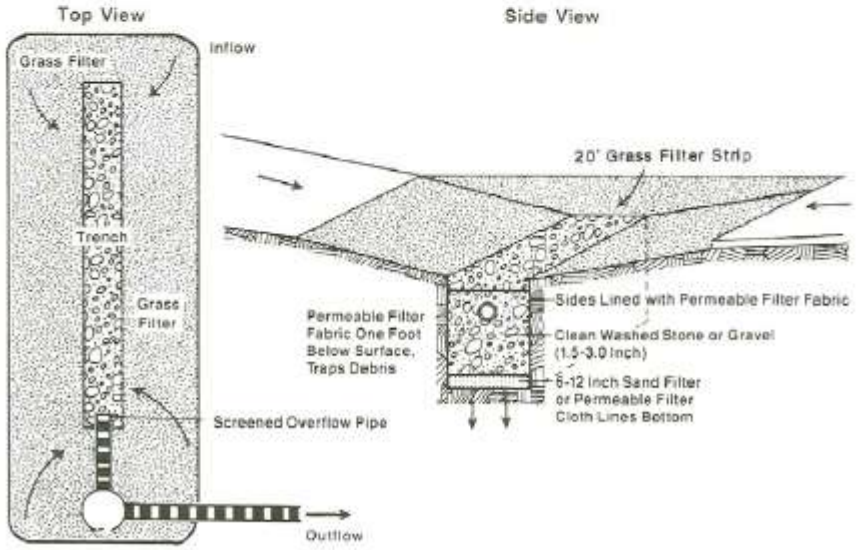
Source: Adapted from Maryland WRA

Figure 6: Commercial trench design – parking lot



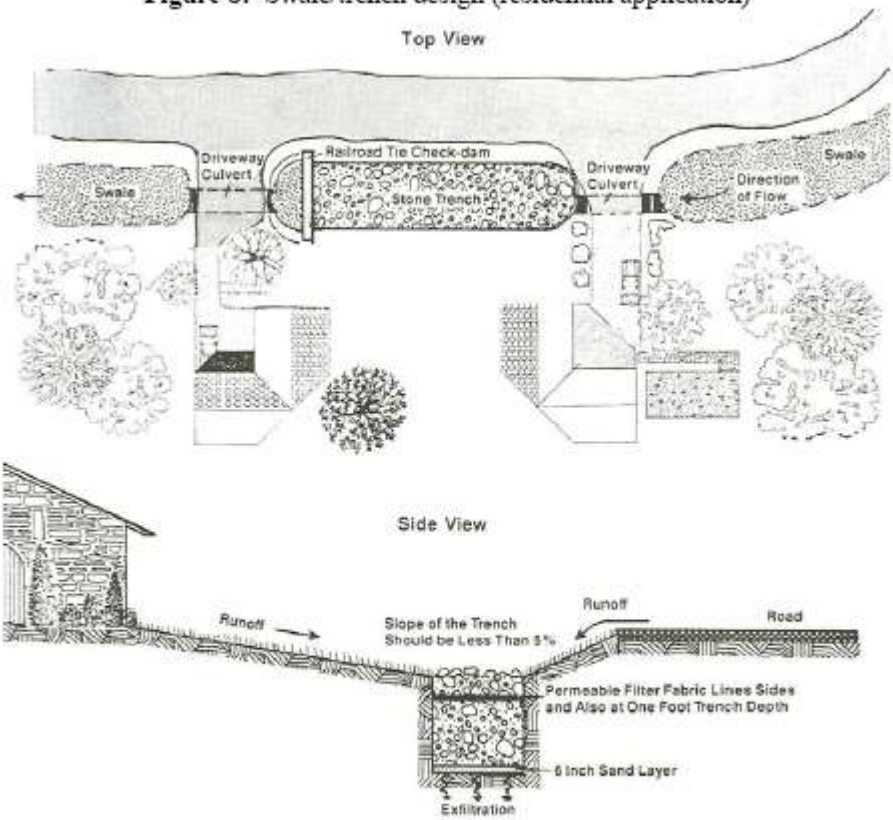
Source: MWCOG, 1987

Figure 7: Median strip design – multiple lane street/highway



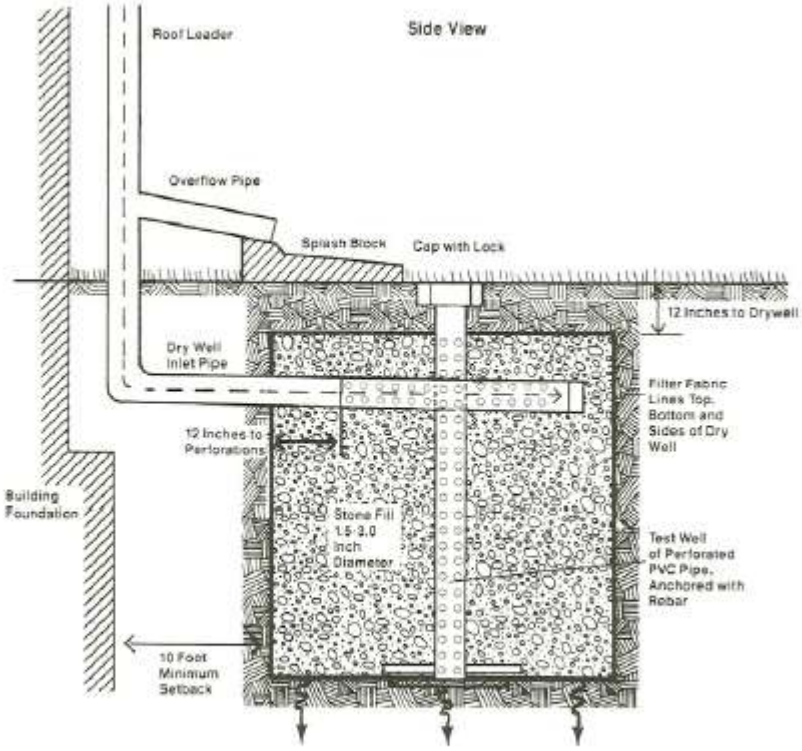
Source: MWCOG, 1987

Figure 8: Swale/trench design (residential application)



Source: MWCOG, 1987

Figure 9: Infiltration: dry well design



Source: MWCOG, 1987

Design example

Infiltration Trench

Figure 10: Infiltration design example site plan

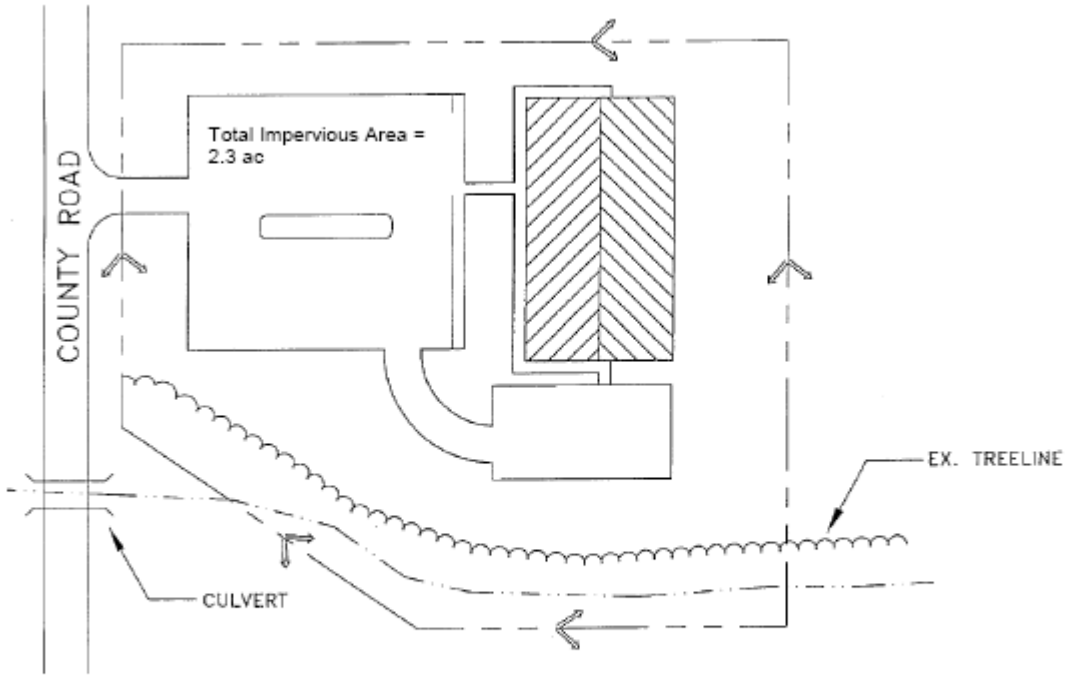


Table 2: Bucketsville, IA Community Center; Marshould County, IA

Base Site Data	Hydrologic Data		
Total site drainage area (A) = 4 ac		Pre-	Post-
Impervious area = 2.3 ac; I = 2.2/4 = 57.5%	CN	68	84
Soils: HSG B (loam)	t_c	0.32	0.18

This example is focused on the design of an infiltration trench to meet the water quality treatment requirements for the site. CPv and Qp are not addressed in this example, other than determination for preliminary storage volume and peak discharge requirements. The CPv and Qp requirements will be handled by another set of downstream BMPs. Infiltration trenches provide water quality treatment (WQv) and recharge volume (Rev). Flows in excess of the WQv will be bypassed. The bypassed flow will be conveyed downstream and combined with other off-site flows in a conventional detention basin for Qp control.

1. **Step 1.** Compute runoff control volumes from unified sizing criteria.

   a. Compute WQv:
      a. Rv = 0.05 + (57.5)(0.009) = 0.57
      b. WQv = (1.25 in)(Rv)(A)/12
         = (1.25)(0.57)(4.0)(1-ft/12-in)(43,560-ft^2/ac)
         = **10,345 ft^3 = 0.237 ac-ft**

   b. Compute stream channel protection volume, (CPv):
      1) Use WINTR-55 to compute the pre- and post-development peak runoff rates for the 1-year, 24-hour duration storm.

Condition	CN	Q_1	Q_1	Q_{25}	Q_{100}
		inches	cfs	cfs	cfs
Pre-developed	68	0.5	0.6	6.0	9.0
Post-developed	84	1.9	5.5	17.0	22.0

2) Use WINTR-55 to compute channel protection storage volume:
   a) q_u = 600 csm/in
   b) qo/qi = 0.04
   c) Vs/Vr = 0.683-1.43(qo/qi)+1.64(qo/qi)^2 -0.804(qo/qi)^3
   d) Vs = CPv and Vr = volume of runoff in inches
   e) Vs/Vr = 0.64
   f) Vs = CPv = 0.64(1.9 in)(1/12)(4 ac) = 0.405 ac-ft = **17,656 ft^3**
   g) CPv of 17,756 ft^3 to be released over 24 hours:
   h) 17,656 ft^3/(24 hr x 3600 sec/hr) = 0.2 cfs (average release rate for CPv)

c. Determine overbank protection flood protection volume (Q_{p25}).
   1) Use WINTR-55 for analysis of Q_5 to Q_{100} runoff volume in inches and respective peak rates.

   2) For a Q_{in} of 17 cfs and an allowable Q_{out} of 6 cfs, the Vs necessary for 25-year control is 0.52 ac-ft or 22,677 ft^3 under a developed CN of 84.

d. Compute WQv peak discharge (Q_{wq}) from Section 2C-6 and Modified NRCS WINTR55 procedure.
   a. WQv = **10,345 ft^3 = 0.237 ac-ft**
   b. CN = 1000/[10+5P+10Q_a-10(Q_a ^{2} + 1.25Q_aP)$^{0.5}$]
   P = rainfall depth for water quality storm – 1.25 inches
   Q_a = runoff volume, inches (equal to P x Rv) = (1.25)(0.57) = 0.712 in
   c. CN = 1000/[10 + 5(1.25 in) + 10(0.71 in) – 10[(0.71 in)^2 + 1.25(0.71 in)(1.25 in)]$^{0.5}$ CN = 93.8 Use CN = 94
   d. Use t_c = 0.18 hour

e. Compute Q_{WQ} using WINTR55 using modified CN and t_c:
   1) WINTR55 results for *modified* CN = 94 and tc = 0.18 hr:
   For 1.25-inch rainfall, q_u = 622.89 csm/in
   2) Q_{WQ} = 3.89 cfsec

f. Compute 1-year, 2-year, and 10-year peak discharge using conventional WINTR55 procedure:
   1) For 57.5% impervious, B soils, CN=98 for impervious and CN=64 for open space
   2) CN = 84
   3) Use t_c = 0.18 hr
   4) WINTR55 results (runoff and peak discharge summary):

Design storm event	Runoff volume (inches)	Peak discharge, Q (cfs)	Unit discharge, q_u (csm/in)
1-year	1.018	5.57	891.69
2-year	2.187	11.94	1910.82
10-year	2.897	15.7	2511.58
25-year	4.095	21.9	3504.19
50-year	4.754	25.25	4040.43
100-year	5.706	30.04	4806.93

2. **Step 2.** Determine if the development site and conditions are appropriate for using an infiltration trench. Site specific data:
   - Soil: loam
   - Infiltration rate: 0.8 in/hr
   - Ground elevation at BMP: 1020
   - Seasonally high water table: 1008
   - Stream invert: 1006
   - Soil slopes: 1.2%

3. **Step 3.** Confirm design criteria and applicability.

Infiltration Feasibility	
Criteria	**Status**
Infiltration rate (*f*) greater than or equal to 0.5 in/hr.	Infiltration rate is 0.8 in/hr. OK.
Soils have a clay content of less than 20% and a silt/clay content of less than 40%.	Loam soil at this site meets both criteria.
Infiltration cannot be located on slopes greater than 6% or in fill soils.	Slope is 1.2%; not fill soils. OK.
Hotspot runoff should not be infiltrated.	Not a hotspot land use. OK.
Infiltration is prohibited in karst topography.	Not in karst. OK.
The bottom of the infiltration facility must be separated by at least 4 feet vertically from the seasonally high water table.	Elevation of seasonally high water table: 1008 feet. Elevation of BMP location: 1020 feet. The difference is 12 feet. The trench can be up to 8 feet deep. OK.
Infiltration facilities must be located 100 feet horizontally from any water supply well.	No water supply wells nearby. OK.
Maximum contributing area generally less than 5 acres. (Optional)	4 acres. OK.
Setback 25 feet down-gradient from structures.	50 feet straight-line distance between the parking lot and the tree line. OK if the trench is 25 feet wide or narrower.

4. **Step 4.** Size the infiltration trench.

   a. Use Equation 4.
      1) $A_t = WQv / (nd_t + fT/12)$
      2) A_t – area of trench, ft^2
      3) WQv = volume to be stored/infiltrated, ft^3
         n = porosity
         F = infiltration rate, in/hr
         T = fill time

d_t = depth of trench, ft

4) Assume that:
   N = 0.34
   F = 0.8 in/hr
   Ts = maximum storage time = 72 hours
   d_{max} = (fTs / *n*)/12 = [(0.8)(72.0)/0.34]/12 = 14.2 ft

   However, maximum depth for this site will be 8 ft due to water table

b. A_t = (10,345-ft^3/[(0.34)(8 ft) + (0.8)(2.0)/12] = **3,635 ft**

c. For a width, W, of 25 feet, determine the length, L:
   L ft = 3,635 ft/25 ft = 145 ft

Assume that 1/3 of the runoff from the site drains to Point A and 2/3 drains to Point B. Use an Lshaped trench in the corner of the site (see Figure 11 for a site plan view). The surface area of the trench is proportional to the amount of runoff it drains (e.g., the portion draining from Point A is half as large as the portion draining Point B).

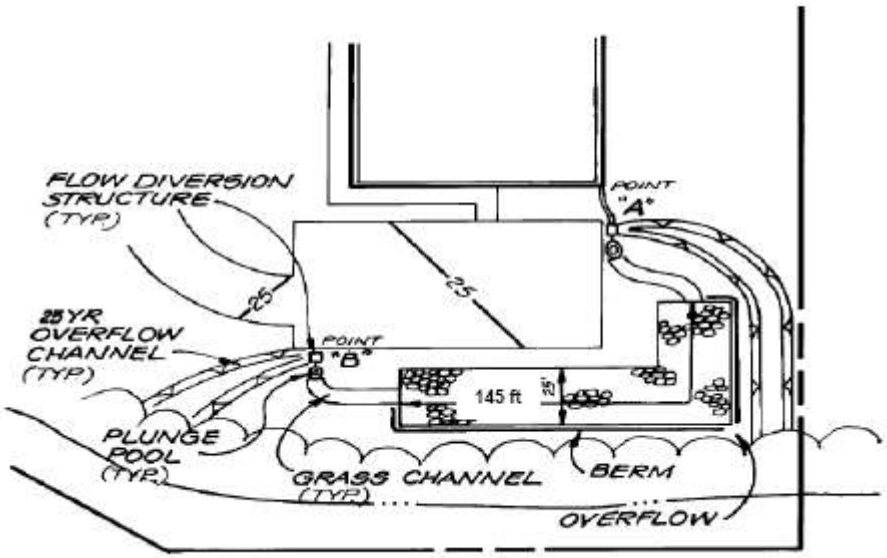
5. **Step 5.** Size the flow diversion structures.

   a. Since two entrances are used, two flow diversions are needed. For the entire site:
      $Q_{25\text{-year}}$ = 21.9 cfs

   b. Peak flow for WQv = 3.89 cfs (step 3).

   c. For the first diversion (Point A):
      1) Assume peak flow equals 1/3 of the value for the entire site. Thus, $Q_{25\text{-year}}$ = 21.9/3 = 7.3 cfs. Peak flow for WQv = 3.89/3 = 1.3 cfs.
      2) Size the low-flow orifice to pass 1.3 cfs with 1.5 feet of head using the orifice equation.
         Q=CA(2gh) ½ ; 1.3 cfs = 0.6A(2 × 32.2 fps^2 × 1.5 ft) ½
         A= 0.22 ft^2; d = 0.53-ft; use 8-inch pipe with 8-inch gate valve
      3) Size the 25-year overflow weir crest at 1022.5 feet.
         Use a concrete weir to pass the 25-year flow (7.3-1.3 = 6 cfs). Assume 1 foot of head to pass this event. Size using the weir equation.
         Q = $CLH_{1.5}$
         L= Q/($CH_{1.5}$)
         L = 6 cfs/ $(3.1)(1)_{1.5}$ = 1.93 ft; use 2 feet (see Figure 12)

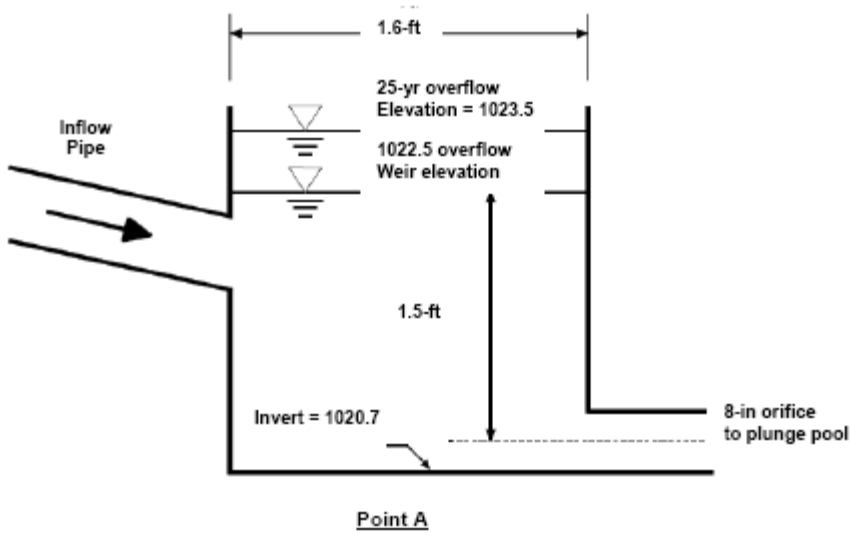
Figure 11: Infiltration trench site plan

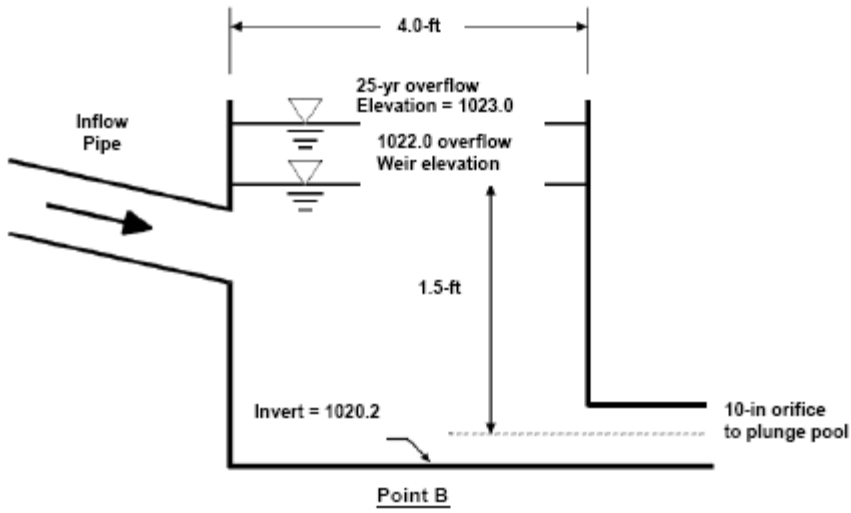


d. Size the second diversion (Point B) using the same techniques.
   1) Peak flow equals 2/3 of the value for the entire site. Thus: $Q_{25\text{-year}}$ = 21.9*0.67 = 14.7 cfs
      Peak flow for WQv = 3.89*0.67 = 2.6 cfs
   2) Size the low-flow orifice to pass 2.6 cfs with 1.5 ft of head using the orifice equation.
      Q=CA(2gh) ½ ; 2.6 cfs = 0.6A(2 × 32.2 fps^2 × 1.5') ½
      A=0.44-ft^2; d = 0.75 ft; use 10-inch pipe with 10-inch gate valve

e. Size the 25-year overflow weir crest at 22 feet. Use a concrete weir to pass the 25-year flow (14.7 –2.6 = 12.1 cfs). Assume 1 foot of head to pass this event. Size using the weir equation.
   1) Q = $CLH^{1.5}$; L= Q/($CH^{1.5}$)
   2) L = 12.1 cfs/ $(3.1)(1)^{1.5}$ = 3.9 ft; use 4 ft (see Figure 12)

Figure 12: Weir elevation sizing





6. **Step 6.** Size pre-treatment volume and design pre-treatment measures. As a rule of thumb, size pre-treatment to treat 25% of the WQv. Therefore, treat 10,345 ft^3 x 0.25 = 2,586 ft^3. For pretreatment, use a pea-gravel filter with a geotextile filter fabric, a plunge pool, and a grass channel.

   a. **Pea gravel filter.** The pea gravel filter layer covers the entire trench with 2 inches of material (see Figure 11). Assuming a porosity of 0.32, the water quality treatment volume in the pea gravel filter layer is: $WQv_{(filter)}$ = (0.32)(2 in)(1/12)(3635 ft^2) = 194-ft^3.

   b. **Plunge pools.** Use a 5-ft x 10-ft plunge pool at Point A and a 10-ft x 10-ft plunge pool at Point B with average depths of 2 feet. $WQv_{(pool)}$ = (10 ft)(10 ft + 5 ft)(2 ft) = 300 ft^3

c. **Grass channel.** The WQv for the grass channel needs to treat the remaining volume (2,586-194-300)ft^3 = 2092- ft^3

Use the procedure in Section 2I to design the grass channels:

a. The channel at Point A should treat 1/3 of 2092 ft^3 or 698 ft^3.

b. Assume a trapezoidal channel with a 4-foot channel bottom, 3:1 side slope, and a Manning's n of 0.15. Use a 1% longitudinal slope.

c. Use a peak discharge of 1.3 cfs (Peak flow for 1/3 of the WQv).

d. Compute velocity: V=0.5 fps.

e. To retain the 1/3 of WQv (3,448 ft^3) for 10-minutes, the length would be 300 feet. Since the swale only needs to treat 25% of the WQv minus the treatment provided by the plunge pool and the gravel layer, or 698 ft^3 , the length is pro-rated to reflect this reduction.

Therefore, adjust the length: L = (300 ft) (698 ft^3/3448 ft^3) = 60.7 feet. **Use 60 feet.** Size the channel at Point B in a similar manner for the 2/3 of WQv.

2E-3 Infiltration Basins

BENEFITS Low = <30% Medium = 30-65% High = 65-100%			
	Low	Med	High
Suspended Solids			■
Nitrogen		■	■
Phosphorous		■	■
Metals			■
Bacteriological			■
Hydrocarbons			■

Description: Infiltration basins are dry ponds constructed to allow infiltration to occur simultaneously with other treatment processes. Infiltration basins are often designed as off-line or end-of-pipe BMPs to capture a defined volume of stormwater runoff volume and transform the water into groundwater flow through infiltration. Pollutants are also removed through filtration and adsorption as the water percolates through the underlying soils. A key feature of an infiltration basin is vegetation, which increases the infiltration capacity of the basin. Dense vegetation also impedes soil erosion and scouring of the basin floor. It is generally characterized as an open impoundment dedicated to infiltration, greater than 15 feet wide, with a flat earthen floor.

Typical uses: Residential watersheds

Advantages:

- Can be effective for removing fine sediment, trace metals, nutrients, and bacteria
- Principle benefit is groundwater recharge and preservation of the natural water balance of the development site
- Can be useful for controlling the WQv and often can provide for the channel protection volume (CPv)
- Reduce flooding
- Reduce thermal impacts to streams

Disadvantages/limitations:

- Not appropriate for treating significant loads of sediment and other pollutants due to potential for clogging of the basin infiltration surface
- Potentially high failure rate due to improper siting, design, and lack of maintenance – especially if pre-treatment is not included in the overall design
- Maintenance of effective upstream pre-treatment, a sediment forebay, and vegetation in the basin infiltration area will prolong infiltration performance and increase the interval between cleaning
- Not recommended in karst areas, industrial parks, high-density or heavy industrial areas, chemical or pesticide storage areas, or fueling stations

Maintenance requirements:

- Remove sediment accumulation from basin and pre-treatment areas
- Mow and remove litter and debris

A. Description

Infiltration basins are dry ponds constructed to allow infiltration to occur simultaneously with other treatment processes. An infiltration basin can be used for both stormwater quality and quantity controls. The storage basin is designed with a large surface area and the design water depth is kept shouldow (≤ 1 foot). The influent point(s) to the basin are configured with energy dissipation and/or a level spreader to efficiently distribute the flow into the basin. Infiltration basins are detention ponds constructed to allow infiltration to occur simultaneously with other treatment processes. Figure 1 provides a typical detail for a conventional infiltration basin. Figure 2 illustrates a combined infiltration/detention basin. The operating

characteristics of infiltration basins are essentially the same as for dry detention, with a few significant exceptions:

1. Infiltration basins also remove dissolved solids in the volume of infiltrated water, whereas dry detention basins do not.

2. The settling velocities of the particles are increased by a value equal to the infiltration rate in the basin. The impact would be more important for the clay-sized particles than for silt, sand, and small or large aggregates.

3. Infiltration practices differ from typical dry basins because they have the ability to meet the groundwater recharge requirements (see Part 2B), and therefore provide an additional element of control or performance.

B. Stormwater management suitability

Infiltration basins are designed primarily for reduction in stormwater runoff volume, but also have high removal capability for fine particulates, metals, and bacteria. Runoff volume control can be achieved for the WQv for smaller storm events, up to the limits of the local infiltration capacity of the local soils. The runoff volume gradually infiltrates through the bottom and sides of the trench and into the subsoil, eventually reaching the water table. By diverting runoff into the soil, an infiltration trench not only treats the water quality volume, but also helps to preserve the natural water balance on a site, recharge groundwater, and preserve base flow.

An infiltration basin can also be designed to capture and infiltrate the entire channel protection volume in either an off-line or online configuration. For larger sites, or if only the WQv is diverted to the basin, another structural control must be used to provide CPv extended detention. Since infiltration basins are similar in form to traditional dry detention basins, additional control for peak discharge reduction (overbank flooding-Q_p) can be provided by adding additional depth for detention storage and including a suitably-sized outlet structure.

C. Pollutant removal capabilities

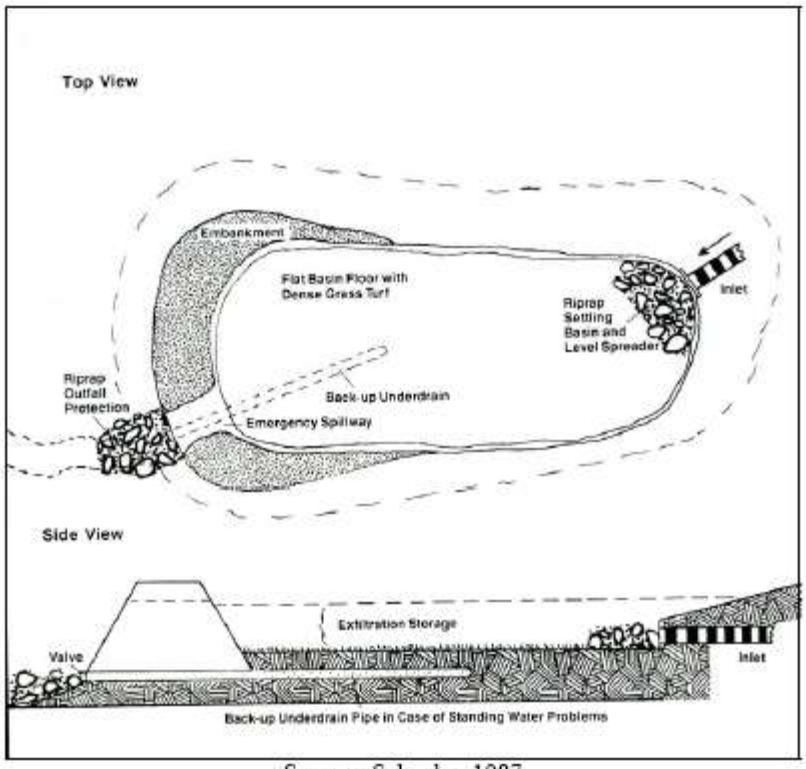
Infiltration basins are effective in removing both soluble and fine particulate pollutants in urban runoff. Coarse-grained particulates should be removed with preliminary upstream BMPs. While the pollutant removal capability of infiltration basins can be highly variable, the removal is achieved by diverting the run off through the floor of the basin and into the soil. Table 1 provides estimates of removal rates for infiltration basins sized to capture the WQv.

Table 1: Pollutant removal rates for infiltration basins

Pollutant	Removal rate %
Sediment	90%
Total P	60-70%
Total N	55-60%
Metals	85-90%
Bacteria	90%

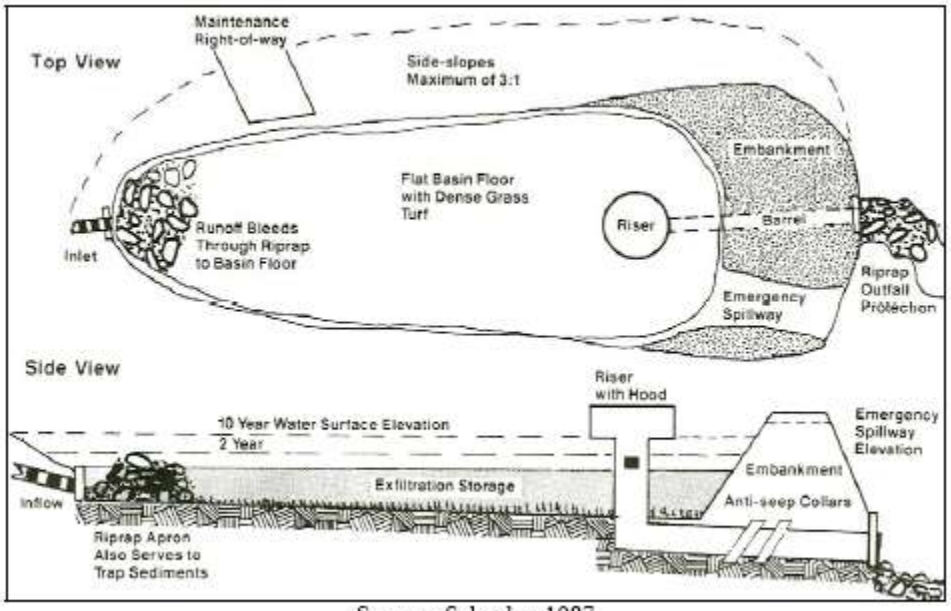
Source: U.S. EPA, 1983; Stahre and Urbonas, 1990; ASCE, 2001

Figure 1: Infiltration basin schematic



Source: Schueler, 1987

Figure 2: Combined infiltration and detention basin configuration



Source: Schueler, 1987

D. Application and feasibility

The infiltration basin uses an open area or shouldow depression for storage. These basins may or may not have a permanent pool. The success of infiltration basins depends on locating the basins above highly-pervious soils and properly constructing the basins to maintain the permeability of the basin floor infiltration area.

1. **Soils.** Soils are the key evaluation factor, and are initially based on an investigation of the NRCS hydrologic soils groups (HSG) at the site (see Section 2E-1). Note that more detailed geotechnical tests are usually required for infiltration feasibility, and during design to confirm permeability and other factors. Infiltration basins must be built in soils with high infiltration rates.

    a. Infiltration basins are not a feasible option on sites with HSG-D soils, or any soil with clay content greater than 30%. Silt loams and sandy clay loams (HSG-C soils) provide marginal infiltration rates, and would not be suitable for infiltration basin application in most circumstances. Soils with a combined silt/clay percentage of over 40% by weight will likely experience frost-heave and should be avoided for infiltration basin application. A site located over fill soils that form an unstable subgrade should also be avoided.

    b. If the soils at the site pass the initial screening discussed above, an additional series of soil cores are collected to a depth of at least 5 feet below the proposed elevation of the basin bottom. Since soil conditions can vary substantially over a short distance, a minimum of 6 to 8 soil borings may be required across the site to predict future infiltration performance. The soil cores are examined for evidence of impermeable soil layers that can impede infiltration. The presence of impermeable layers may not preclude the use of a basin as long it penetrates the layers completely. Alternately, if impervious layers are present, soils can be removed and replaced with more permeable materials that penetrate to a pervious layer.

c. At least three in-hole conductivity tests should be performed using USBR 7300-89 or Bouwer-Rice procedures (the latter if groundwater is encountered within the boring); two tests at different locations within the proposed basin, and the third down-gradient by no more than approximately 40-50 feet. The tests should measure permeability in the side slopes and the basin subgrade within a depth of 12-15 feet of the basin floor invert. The minimum acceptable hydraulic conductivity as measured in any of the three required test holes is 0.5 in/hr. If any test hole shows less than the minimum value, the site should be disqualified from further consideration.

d. The results of a study of disturbed and compacted urban soils (i.e. heavy equipment) compared to undisturbed sites by the NRCS National Soil Mechanics Center show that as soil bulk density increases to 1.65 g/cm^3, infiltration rates of the soil decrease rapidly. When the bulk density increases above 1.65 g/cm^3 infiltration rates decline slowly, approaching zero. The measured infiltration rates for disturbed soils with high bulk densities were significantly lower than expected (OCSCD et al., 2001). For infiltration basin design, soil borings taken throughout the proposed site should indicate soil bulk densities in the basin bottom of $\leq$1.45 g/cm^3, and measured permeability rates of $\geq$ 0.5 inches/hr.

2. **Slope.** Infiltration basins are not feasible if the slope of the contributing watershed is greater than 20%. Within the basin itself, a slope of less than 5% is preferable.

3. **Water table.** The bottom of the infiltration facility should be separated by at least 4 feet vertically from the seasonally high water table or bedrock layer, as documented by on-site soil testing.

4. **Drainage area.** The contributing drainage area to an individual infiltration basin practice designed solely for water quality control can range from 5-25 acres. A maximum of 10 acres is recommended for full conventional infiltration basins when all of the site criteria have been met satisfactorily and good pre-treatment is provided. For combination infiltration/detention basins, a drainage area up to 50 acres is typical. The volume to be infiltrated is determined from the WQv and/or Cpv, and the remaining volume for peak discharge control is established above the maximum depth established for infiltration. The storage volume for peak discharge control is discharged through a separate outlet structure. If the drainage area is more than 50% impervious, the space required for infiltration may be become too large to accommodate on the site.

5. **Head.** Head is the elevation difference needed at a site (from the inflow to the outflow) to allow for gravity operation within the practice. A minimum head of 1 foot, and a maximum of 3 feet is recommended. Additional head may be required if additional storage volume for peak discharge control for Qp is provided.

6. **Separation distances.** Infiltration basins should be located a minimum of 100 feet horizontally from any water supply well. Infiltration practices should not be placed in locations that cause water problems to downgrade properties. Infiltration facilities should be setback 25 feet downgradient from structures.

E. Planning and design criteria

1. **Pre-treatment.** A minimum of 25% of the WQv is recommended to be pre-treated prior to entry into the infiltration basin. If the infiltration rate for the underlying soils is greater than 2 in/hr,

50% of the WQv should be pre-treated prior to entry into the infiltration facility. Exit velocities from pre-treatment should be non-erosive (< 10 ft/sec) during the 2-year design storm. Infiltration systems can be designed using redundant methods (treatment train approach) to protect the long term integrity of the infiltration rate. The following pre-treatment techniques can be used to provide protection against premature clogging and failure:

- Grass swale or grass filter strip
- Sedimentation basin, sediment forebay, stilling basin, sump pit, or other acceptable measures
- Bottom sand layer

2. **Surface area of basin floor.** The rate and quantity of ex-filtration is enhanced by increasing the surface area of the basin floor, especially as the soil infiltration rate approaches the minimum rate of 0.5 in/hr. Therefore, large and relatively shouldow (< 3 ft) basins are preferable to basins that are small and deep. Additional surface area for the basin floor can also help compensate for diminished infiltration capacity from long-term surface clogging.

3. **Reducing influent water velocity.** Inlet conveyance channels to the basin are stabilized to prevent incoming runoff velocities from reaching erosive conditions and scouring the basin floor. Providing riprap at the inlet channels and pipe outfalls will provide effective control. The riprap will also serve to spread the incoming flow more uniformly over the surface of the basin floor to provide improved infiltration. The best approach is to avoid a riprap pilot channel, and instead terminate the riprap in the form of a wider structure to serve as a level spreader (Figure 1). A 20-foot filter strip combined with a riprap level spreader will provide effective sheet flow onto the basin floor.

4. **Basin slopes.** The floor of the basin is graded to have a slope close to zero. The goal in infiltration basin design is to achieve a uniform ponding depth across the entire surface of the basin. If the basin is sloped towards the outlet structure riser, or if low spots are created, the runoff volume will concentrate in small portions of the basin and reduce the infiltration effectiveness. The low spots will tend to remain under water a longer period of time, due to the limited soil infiltration capacity. Over a longer period of time, these low spots may eventually become clogged with excess sediment. The basin side slopes should be ≤ 3:1 to enhance vegetative stabilization. The shouldower side slopes facilitate mowing, access, and improved public safety.

5. **Establishing vegetation.** A dense turf of water-tolerant grass is established on the floor and side slopes of the infiltration basin immediately after construction. The turf promotes better pollutant removal because:
   - Root penetration and thatch formation in the turf maintains and may improve the original infiltration capacity of the basin floor
   - The turf grows through the accumulated sediment and pollutant deposited in the basin, preventing re-suspension during larger storm events
   - The turf assimilates soluble nutrients for growth. Plant nutrients can be effectively removed from the system if the clippings are removed during/after mowing operations
   - A dense growth of turf will prevent soil erosion and scouring of the basin floor that could reduce the overall efficiency of the basin. Ground covers such a tall fescues and Bermuda grass are generally used for this purpose.

   A dense and vigorous vegetative cover is established over the contributing pervious drainage areas before runoff is accepted into the facility. Infiltration basin sites should not serve as a sediment control device during the site construction phase. In addition, the erosion and

sediment control plan for the site must clearly indicate how sediment will be prevented from entering the infiltration site. Do not construct infiltration practices until all of the contributing drainage area has been completely stabilized.

6. **Basin buffer.** A vegetative screen around the basin to restrict direct view from adjacent properties may improve the aesthetics of the site and public acceptance of the facility. Regular mowing will prevent establishment of woody vegetation growth from the buffer area onto the basin bottom.

7. **Maximum drain time.** The depth of ex-filtration storage within the basin is adjusted to ensure it completely drains within 72 hours after the maximum design ex-filtration event. A drain time of 48 hours can be used for a more conservative design. Complete drainage is needed to maintain aerobic conditions in the unsaturated zone under the basin, to support bacteria that aid in organic pollutant removal. It is also important to completely empty the basin before the next storm. For example, the average time between storms events in Iowa in the warmer season (June to September) is 96 hours.

8. **Sediment forebays.** The long-term performance of an infiltration basin can be enhanced if sediment forebays are constructed near the inlet(s) to trap incoming sediment loads. The forebays also serve to reduce the influent velocity and provide uniform dispersal of flow into the basin area.

9. **Winter operation.** When the soil freezes, infiltration will likely cease. While some nominal infiltration may occur under partially frozen conditions, the basin will not likely treat rain or snowmelt during the winter. In this case, a bypass at the inlet can be provided for the winter season; or an accessory low-level outlet can be provided and opened to allow direct drainage of snowmelt or winter runoff.

10. **Safety.** Fencing around the basin area can be included in the final site plan if public access to the area is not desired. If the area around the basin has a recreational use, a safety shelf around the perimeter of the basin can be included for times when the basin is flooded and the design depth will exceed 3 feet. Steep slopes should be avoided ($\leq$ 3:1), and signs should warn against deep water or any health risks. An auxiliary spillway is provided to safely bypass or move high flows through the basin and protect against structural failure.

F. General design

1. Water quality volume (WQv) is determined as described in Sections 2B-1 and 2C-6.

2. Basin should be sized so the entire water quality volume is infiltrated within 48-72 hours.

3. Vegetation establishment on the basin floor may help reduce the clogging rate.

4. The truncated hydrograph method described later in this section can be used as an alternative analytical procedure if the infiltration basin is used to control peak discharge.

5. If runoff is delivered by a storm drain pipe or along the main conveyance system, the infiltration practice should be designed as an off-line practice (see Figure 4).

6. Adequate stormwater outfalls should be provided for the overflow associated with the 10-year design storm event (non-erosive velocities on the downslope).

7. A minimum of 25% of the WQv must be pre-treated prior to entry to an infiltration facility. If the "*f*" for the underlying soils is greater than 2 in/hr, 50% of the WQv should be pre-treated prior to entry into an infiltration facility. This can be provided by a sedimentation basin, sediment forebay, stilling basin, sump pit, or other acceptable measures. Exit velocities from pre-treatment should be non-erosive during the 2-year design storm.

8. The construction sequence and specifications for each infiltration practice should be followed, as outlined in the SUDAS specifications. The longevity of infiltration practices is strongly influenced by the care taken during construction.

9. Groundwater separation should be at least 4 feet from the basin invert to the measured ground water elevation.

10. Location away from buildings, slopes, and highway pavement (greater than 25 feet) and wells and bridge structures (greater than 100 feet).

11. Sites constructed of fill, having a base flow or a slope greater than 15%, should not be considered.

12. Ensure that adequate head is available to operate flow splitter structures (to allow the basin to be off-line) without ponding in the splitter structure or creating backwater upstream of the splitter.

13. A conveyance system should be included in the design of all infiltration basins in order to ensure that excess flow is discharged at non-erosive velocities. The overland flow path of surface runoff exceeding the capacity of the infiltration system is evaluated to preclude erosive concentrated flow. If computed flow velocities do not exceed the non-erosive threshold, overflow may be accommodated by natural topography or grass swales (see Part 2I). Adequate stormwater outfalls should be provided for the overflow associated with the 10-year design storm event (non-erosive velocities on the downslope).

14. If runoff is delivered by a storm drain pipe or along the main conveyance system, the infiltration practice should be designed as an off-line practice (see Figure 4 for an example of an off-line infiltration basin).

G. Physical specifications, geometry, and volume

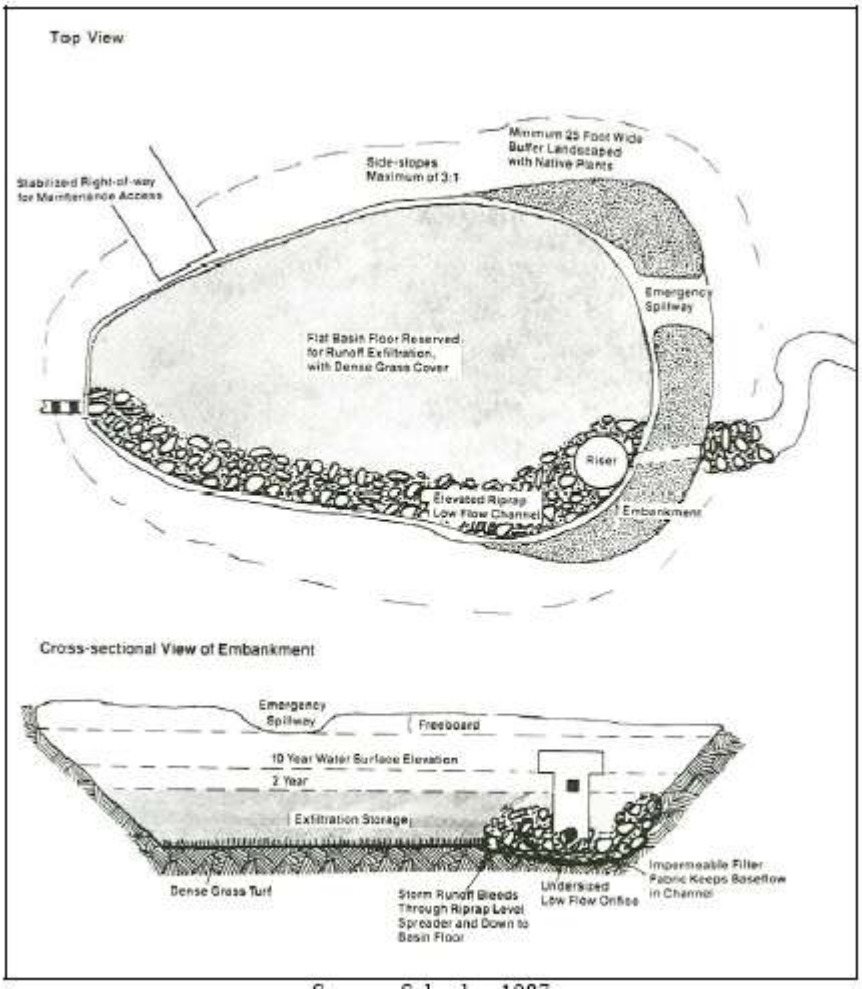
1. Configuration of a conventional infiltration basin for water quality (WQv) treatment and a combination infiltration/detention basin for quality and quantity control are shown in Figures 1 and 2, respectively.

2. For the design of larger infiltration basins, the routing of small baseflows and larger storm runoff volume can be problematic while still providing effective ex-filtration capacity for the small and moderate size storms. A design variant called a side-by-side infiltration basin (Figure 3) contains a riprap pilot channel along one margin of the basin, and extends all the way to the outlet structure riser. The pilot channel is elevated several feet above the basin floor. Baseflow is confined to the pilot channel (use an impermeable geotextile liner), and travels directly to an under-sized low-flow orifice at the base of the riser, and then discharges from the basin. Storm flow pulses are also directed though the pilot channel. Once the incoming storm flow reaches a given depth, it overflows the liner in the pilot channel and is conveyed down across the basin

floor. The invert of the low-flow orifice is set from a dead storage zone down to the basin floor, thus storing the equivalent of the first flush runoff volume, and/or the WQv.

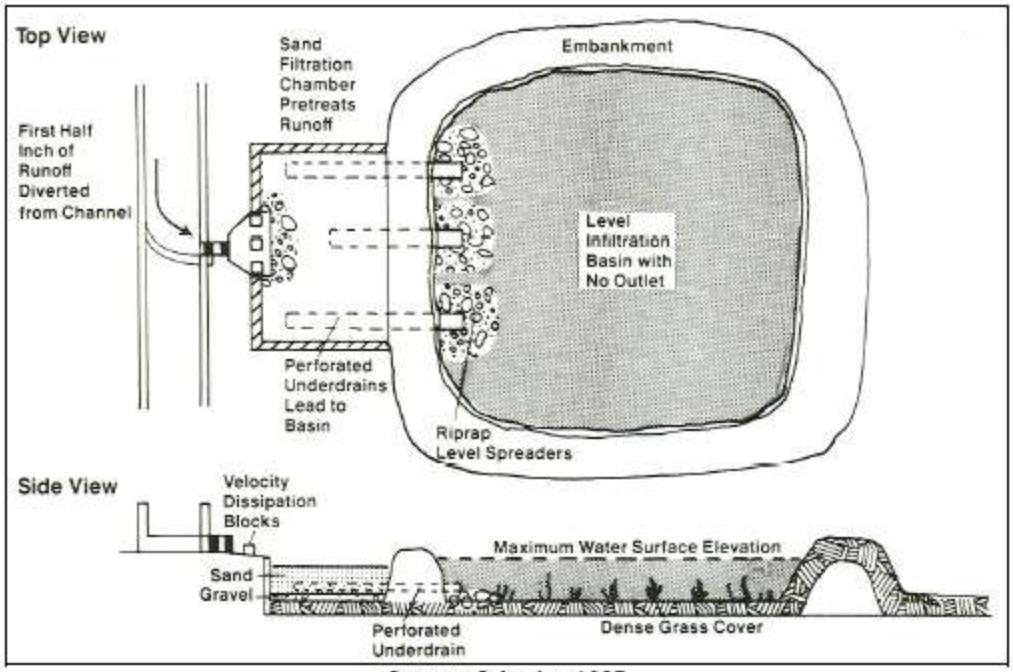
3. The off-line design variant (Figure 4) is used to divert and ex-filtrate the first flush runoff volume of larger storms (> 1.25 inch) and the WQv design storm (≤ 1.25 inch) from a storm sewer or open surface channel. These may be useful for development situations where ex-filtration cannot be achieved at a downstream stormwater detention basin due to soil limitations. The design utilizes a combination of an off-line sand filter and infiltration basin to treat the WQv or first flush volume. A weir is placed across a natural or man-made channel diverting runoff into an offline sand filter. After passing through the filter, runoff is collected by subdrains leading to a level vegetated infiltration basin. This design is recommended for sites which produce high sediment loads.

Figure 3: Side-by-side infiltration basin configuration



Source: Schueler, 1987

Figure 4: Side-by-side infiltration basin configuration



Source: Schueler, 1987

H. Design of infiltration basins

There are two general types of situations where infiltration basins may be used: First is the determination of the dimensions of an infiltration basin required to provide storage and treatment of the WQv or design peak discharge (Qp). Second, site conditions may dictate the layout and capacity of the infiltration basin, and in this case, the level of control provided by such a layout might only provide partial treatment of the WQv. In the latter case, control may not be sufficient, and additional control, possibly using other acceptable BMPs, may be required. However, both cases are suitable for use when considering incorporating groundwater recharge into future development. The following procedure can be used for designing infiltration basins to meet the WQv, and the overbank flood protection (Qp) volume requirements. These methods are based on the methodology described in the Maryland Stormwater Design Manual (2000). The design procedures are based on either intercepting the WQv from the area contributing runoff, or using the truncated hydrograph method for control of the runoff from an area for either the CPv or Qp. The design equations may be defined for either case of stormwater quality or quantity control because the volume of water (V_B) stored in the individual infiltration practice may be determined from the methods described earlier.

An alternative sizing criteria is the use of the maximized capture volume method (ASCE/WEF, 1998) described in Section 2C-2.

The design of an infiltration basin is based on the same soil textural properties and maximum allowable depth as the infiltration trench such that a feasible design is possible. However, because the infiltration basin uses an open area or shouldow depression for storage, the maximum allowable depth (d_{max}) should meet the following criteria:

$d_{max} = f \times T_p$ **Equation 1**

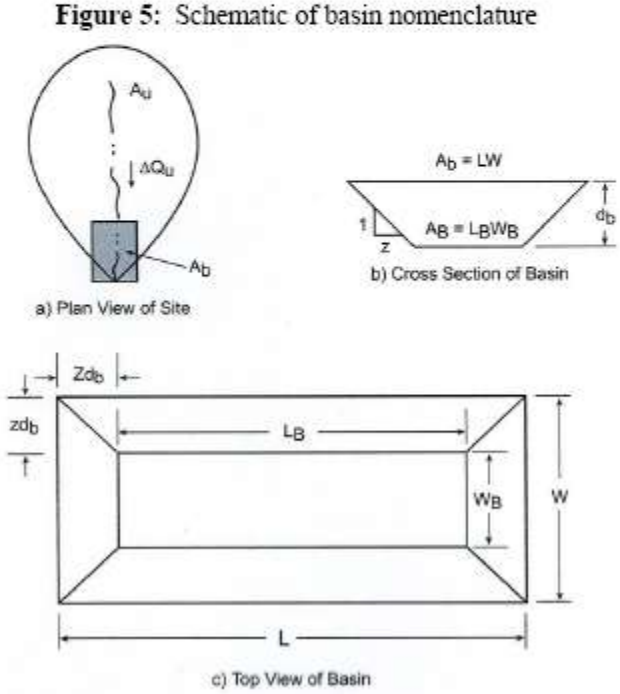
where:
f is the final infiltration rate of the trench area (in/hr)
T_p is the maximum allowable ponding time (hr)

Values of d_{max} for selected types and minimum infiltration rates and drain times of 48 hours and 72 hours are given in Table 2.

Table 2: Soil types, infiltration rates and maximum storage depth for infiltration basins

Soil texture type	Minimum infiltration rate	NRCS HSG	Maximum depth of storage d_{max} (in)	
	f (in/hr)		48 hours	72 hours
Sand	8.27	A	397	595
Loamy sand	2.41	A	116	174
Sandy loam	1.02	B	49	73
Loam	0.52	B	25	37

Figure 5: Schematic of basin nomenclature



The following design calculations assume infiltration only through the basin bottom area. Neglecting the likely infiltration through the sides of the basin will provide some additional design factor of safety.

Three design elements must be considered when sizing an infiltration basin:

- Required storage volume
- Maximum basin depth
- Basin volume

An infiltration basin is sized to accept the design volume that enters the basin (V_r), plus the volume of rain that falls on the surface of the basin (PA_B), minus the ex-filtration volume (fTA_B)

out of the bottom of the basin. The design volume in most cases will be the WQv determined for the drainage area (A_u). Based on NRCS hydrograph analysis, the effective filling time for most infiltration basins will generally be less than 2 hours. Therefore use T = 2 hours. The volume of water that must be stored in the basin (V_B) is defined as:

$V_B = V_r + (PA_B)/12 - fTA_B$ **Equation 2**

Or

$V_B = WQv + (PA_B)/12 - fTA_B$

where:
P is the design rainfall event (in)
A_B is the basin surface area (ft^2)
WQv (ft^3)

For most design storm events, the volume of water due to rainfall on the surface area of the basin (PA_B) is small when compared to the design volume (Vr or WQv) of the basin, and may be ignored with little loss in accuracy to the final design. Likewise, the term fTA_B represents the volume of water infiltrated through the basin bottom during the time inflow exceeds the outflow (fill time). For a fill time of 2 hours, this volume may be so small in relation to the runoff volume that it can be ignored without introducing significant error.

The volume of rainfall and runoff entering the basin can be defined in terms of basin geometry. The geometry of a basin will generally be in the shape of an excavated trapezoid with a specified side slope (See Figure 5). The average end-area equation (Equation 3) is used to estimate the storage volume of the infiltration basin. The volume of a trapezoidal shaped basin may be approximated by:

$V = [(A_B + A_b) \times d_b] / 2 = [(LW + L_bW_b)d_b] / 2$ **Equation 3**

where:
A_b = water surface area at the design depth (ft^2)
A_B = the bottom surface area (ft^2)
d_b = design depth (ft)
L = basin top length
W = basin top width
$L_B = L-2Zd_b$ = bottom length
$W_B = W-2Zd_b$ = bottom width
Z = side slope ratio (W:H)

Calculating Equations 2 and 3 provides the following expression for the required bottom area of the basin (A_b):

$A_B = (2V_B - A_td_b) / (d_b - 2P + 2fT)$ **Equation 4**

If a rectangular shape is used, the bottom length and width of the basin may be defined in terms of the top length and width as:

$L_B = L - 2Zd_b$

$W_B = W - 2Zd_b$

where:
Z is the specified side slope ratio (i.e., Z: 1)

Substituting the above relationships for L_B and W_B into Equation 4 provides an equation for the basin top length:

$$L = [V_B + Zd_b (W - 2Zd_b)] / W (d_b - P) - Zd_b{}^2 \qquad \textbf{Equation 5}$$

The solution of Equation 5 will be based on assuming an initial basin top width or a width set by the constraints of the site. The solution will iterative until the desired L/W ratio is achieved.

I. Procedures for infiltration basin design

1. **Step 1.** Determine the volume of water for storage using the methods for WQv, Cpv, or Qp, summarized in Sections 2B-1 and 2C-6.

2. **Step 2.** Compute the maximum allowable basin depth (d_{max}) from the feasibility equation, $d_{max} = fT_p$. Select the basin design depth (d_b) based on the depth that is the required depth above the seasonal groundwater table (4-foot minimum), or a depth less than or equal to d_{max}, whichever results in the smaller depth.

3. **Step 3.** Compute the basin surface area dimensions for the site soil type using Equation 25. A long, narrow basin generally improves infiltration, and may influence the selection of a length-towidth ratio. A side slope steepness must be selected. An initial length or width of the basin is set, and the equation solved for the remaining dimension. If a rectangular shape is used, the basin top length (L_t) and width (W_t) must be greater than $2Zd_b$ for a feasible solution. If L_t and W_t are not greater than $2Zd_b$, the bottom dimensions would be less than or equal to zero. In this case, the basin depth (d_b) is increased for a feasible solution.)

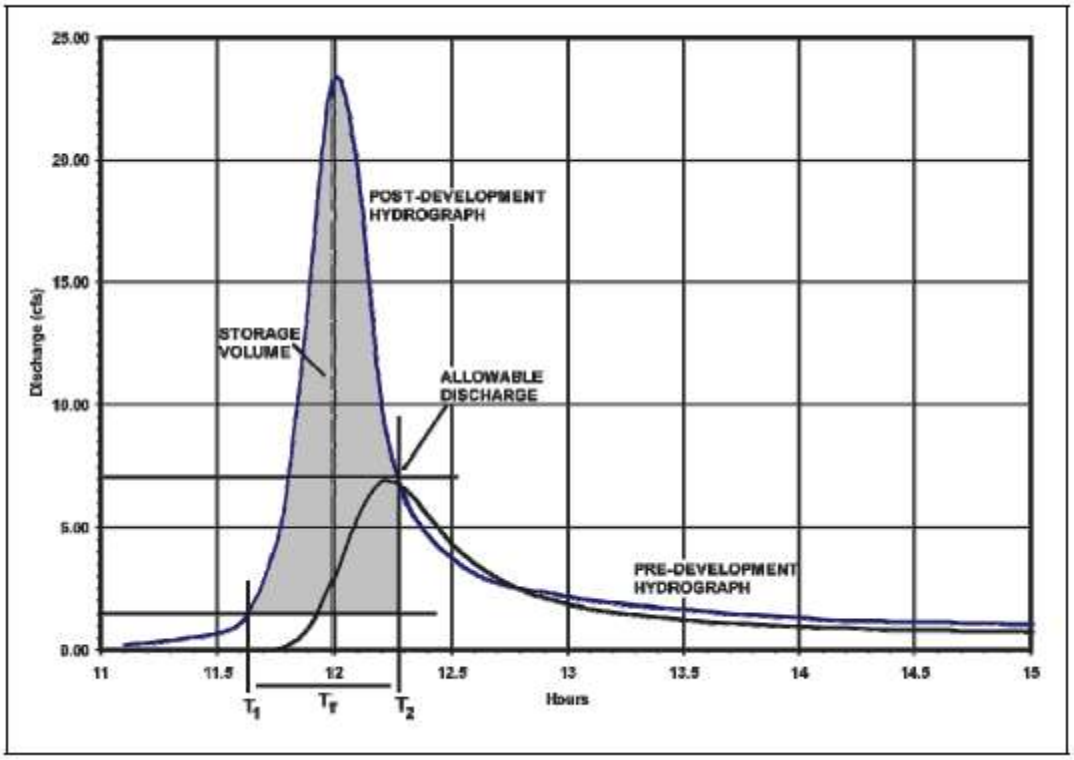
4. **The truncated hydrograph method for stormwater quantity management.** For local overbank flooding control (Qp), the peak discharge for the post-developed hydrograph for a selected return period(s) should not exceed the peak discharge from the pre-developed hydrograph after development for stream channel erosion control and/or flood control purposes. In previous stormwater quantity management infiltration design methods, the difference between the pre-development and post-development runoff volumes was stored in the proposed infiltration structure. In most cases, this volume of runoff occurs prior to the actual hydrograph peak (see Figure 5), and therefore actual peak discharge control is not provided. Therefore, when considering an infiltration basin for peak discharge or stormwater quantity control, the truncated hydrograph method is used to determine the necessary infiltration storage volumes.

   The pre-development and post-development peak discharges are computed using NRCS WINTR-55 or WINTR-20 methodology. The time (T_2) at which the allowable discharge occurs on the receding limb of the post-development hydrograph, as shown in Figure 5, is determined from the NRCS methods. The volume of runoff under the post-development hydrograph and to the left of the allowable discharge at T_2 is the design storage volume (V).

   The computed infiltration storage volume, V, may be adjusted to account for the volume of water which ex-filtrates from the infiltration structure during the period of time required to fill the structure. The ex-filtration volume (V_e) is the product of the minimum soil infiltration rate (ft/hr), the filling time (hr), and the surface area of the infiltration practice. The filling time (T_f) of the

infiltration practice may be determined directly from the post-development hydrograph, as shown in Figure 5. T_f is the difference between T_2, where the allowable discharge occurs on the recession limb, and the time, T_1, where the discharge value on the rising of the hydrograph is equal to the minimum infiltration discharge. The times T_1 and T_2 can be determined from the TR-20 output file after the WINTR-55 program scenario is run. The minimum discharge is equal to the minimum soil infiltration rate (expressed as ft/sec) times the surface area (ft^2) of the infiltration practice.

Figure 5: Truncated hydrograph method



J. Maintenance

Infiltration basins are relatively high-maintenance BMPs. Infiltration basins fail for one or more of the following reasons:

- • Premature clogging with sediment
- • A design infiltration rate greater than the actual infiltration rate
- • The basin site was used for construction site erosion control (sediment trap or basin)
- • Soil was compacted during construction
- • The upland soils or the basin sides were not stabilized with vegetation, and excessive sediment was delivered to the basin

Consideration should be given to placing the basin into operation only after 90% of the upland development site has been built out and stabilized with vegetation. The other option is to strictly enforce construction site erosion controls during the development build-out process. If the basin was designed as an off-line structure, bypass the structure as excessive sediment loads are being transported from the drainage areas during development.

The stormwater management plan includes maintenance, inspection, access, and enforcement of the operating requirements for the structure. The key elements of the plan are as follows:

1. An operation and maintenance plan should be prepared prior to placing the basin into operation.

2. Following construction, inspect the basin monthly, as well as after every major storm to ensure the basin is draining within the maximum drain time limit.

3. Inspect annually or semi-annually for settling, cracking, erosion, leakage, tree growth on the embankments, condition of the inlet and outlet channels, sediment accumulation in the basin bottom, and the condition of the grass turf.

4. If the basin has a sediment forebay, determine the degree of sediment accumulation and schedule a clean-out if necessary.

5. The basin should be mowed at least twice a year to prevent woody growth, stimulate grass growth, and enhance nutrient removal.

6. Do not mow when the ground is wet to avoid compaction of the bottom soils.

7. Remove trash and debris at least twice a year, or more often as necessary.

8. If the soils were marginal for infiltration and the basin is prone to extended ponding, periodic tilling of the basin bottom and re-seeding might be necessary. Till and re-vegetate in the early fall.

9. Over time, an infiltration basin will accumulate sediment, and the overall infiltration rate will diminish. Deep tilling, regrading, and replanting will help to restore the original infiltration performance. When the basin is thoroughly dry, remove the top cracked layer of sediment, and till and re-seed the remaining soil. Basins can be designed with a 6-12 inch layer of sand on the bottom or a filter fabric to facilitate removal.

10. If the sediment is accumulating faster than the growth of the turfgrass, the pre-treatment system needs to be re-evaluated. Maintenance of the pre-treatment system (sediment forebay, filter strip, grass) must occur on a regular basis to prevent heavy sediment build-up in the basin. The operating life of the pre-treatment system or inlet/bypass structure will likely be shorter than the infiltration basin, and will require occasional structural repair or equipment replacement.

K. Design example

Infiltration Basin

An infiltration basin is proposed for a development site northwest of Sioux City, IA. The site soil conditions have been investigated and found to be appropriate for an infiltration basin. The preliminary NRCS soil survey indicated HSG-B soils, which was confirmed with a series of soil borings to verify soil texture gradation, depth to groundwater, and soil bulk densities. The redevelopment condition is undeveloped, and current land use is pasture and some wooded area. The total drainage area is 6 acres. The development is a residential subdivision with ½-acre parcels. The estimated impervious area after development will be 28%.

- Soils – 80% loam and 20% sandy loam (HSG-B)
- Nominal infiltration rate from soil survey analysis – 0.8 in/hr

- Depth to seasonal high groundwater – 12 feet
- Soil cores indicate a uniform loam/sandy loam to a depth of 15 feet
- Average of four in-situ soil permeability tests with a double ring infiltrometer indicating an average final infiltration rate of 0.96 in/hr. Initial infiltration rates averaged 2.3 in/hr.

Determine the bottom dimensions of an infiltration basin given the following design criteria:

- Design for drain time 72 hours
- Maximum ponding depth will be 24 inches for the WQv
- Design storm for WQv is 1.25 inches
- Additional storage volume will be provided in the infiltration/detention basin for CPv (Calculations not included in this design example)
- The pre-development T_c was determined to be 0.42 hour
- The post-development T_c is estimated to be 0.2 hour at full build-out
- The goal for the L/W ratio for the basin is a minimum of 3:1

1. **Determine WQv:**
   Rv = 0.05 + 0.009 (28%) = 0.302.

   WQv = Rv x P = (0.302)(1.25 inches) = 0.38 inches

   WQv = (0.38 inches/12) x (43560 ft^2/acre)(6 acre) = 8276 ft^3

2. **Determine Rev - percent volume method:**

$$Rev = \frac{[(S)(Rv)(A)]}{12}$$

   where:
   Rv = 0.302
   A = site area in acres
   S = soil-specific recharge factor (from HSG) = 0.34 (Table 4, Section B for HSG-B soils)

   Rev = (0.34)(0.302)(6 ac)/12 = 0.051 ac-ft = 2236 ft^3 (Considered part of the WQv)

   For this site, the goal is to infiltrate the entire WQv so the Rev requirement will be met.

3. **Compute the maximum allowable depth, d_{max} (Equation 1):**

   $d_{max} = f \times T_p$

   d_{max} = 0.96 inches/hr x 72-hr = 69.12 inches = 5.76-ft

4. **Determine the required storage volume for the basin, V_B (Equation 4).** Assume a trapezoidal basin with 3:1 side slopes. For this design, the design depth, d_b = 2 ft (24 inches), the desired basin L/W ratio is 3:1, and the desired basin top width (W) is 40 feet.

5. **Desired design depth of 2 feet is less than d_{max}, or 5.7 feet.**

6. **Calculate storage volume required – Equation 2:**
   $V_B = WQv + (PA_B)/12 - fTA_B$

$= 8{,}276\ ft^3 + [(1.25\ in)(W)(L)/12] - [(0.96 in/hr)(2\ hr)/12)(W)(L)]$
$= 8{,}276\ ft^3 + [(1.25)(40\ ft)(L\ ft)]/12 - [(0.96\ in/hr)(2\ hr)/12(40\ ft)(L\ ft)]$
$= 8{,}276\ ft^3 + 4.17(L)ft^3 - 6.4\ (L)\ ft^3 = 8{,}276\ ft^3 - (2.23\ ft^2)(L\ ft)$

7. **Determine the length dimension for the basin using a W = 40 ft, Z = 3, and D_b = 2 feet:**

$V_B = [(LW + L_B W_B)/2] \times d_b$

From Step 6 above:

$V_B = 8{,}276\ ft^3 - (2.23\ ft^2)\ (L\ ft) = [(L\ ft)(40\ ft) + (40'\text{-}12')(L' - 12')]/2 \times 2\ ft$

$8{,}276\ ft^3 - (2.23\ ft^2)\ (L\ ft) = [(40\ ft)(L\ ft) + (28\ ft)(L\ ft) - 336\ ft^2)/2\ ] \times 2\ ft$

$8{,}276\ ft^3 - (2.23\ ft^2)\ (L\ ft) = (68\ ft^2)(L\ ft) - 336\ ft^3$

$(70.23\ ft^2)(L\ ft) = 8612\ ft^3$

L = 122.6-ft ≈ **123 ft** (L/W = 3.07)

8. **Total area of basin, A_b = 123 ft x 40 ft = 4,920 ft^2**

9. **$A_B = L_B \times W_B$ = 111 ft x 28 ft = 3,108 ft^2**

10. **Check drain time for *f* = 0.96 in/hr and ponding depth of 24 in:**

$T_p = d_b/f$ = 24 inches/0.96 in/hr = 25 hrs

2E-4 Bioretention Systems

BENEFITS Low = <30% Medium = 30-65% High = 65-100%	Low	Med	High
Suspended Solids			■
Nitrogen		■	
Phosphorous		■	■
Metals		■	■
Bacteriological		■	■
Hydrocarbons		■	

Description: Bioretention and rain garden systems incorporate shouldow landscaped stormwater basins (depressions) with an engineered soil subgrade. Stormwater runoff collected in the upper layer of the system is filtered through the surface vegetation, mulch layer, pervious soil layer, and then stored temporarily in a stone aggregate base layer. The WQv is drained from the aggregate base by infiltration into the underlying soils and/or to an outlet through a perforated pipe subdrain. The piped outlet can discharge into a downstream earthen channel, detention structure, or storm sewer system. Systems can operate either off-line or online. They are designed with a combination of plants that may include grasses, flowering perennials, shrubs, or trees. Integrated upstream treatment is provided by a perimeter grass filter strip or grass swale for initial capture of sediment.

Typical uses:

- Manages runoff from residential, commercial, and institutional sites.
- Drainage area size typically up to 5 acres; for larger impervious area, 2-3 acres maximum is recommended; larger areas can be divided into smaller sub-areas with individual bioretention areas distributed throughout the site.
- Concave landscaped areas such as parking lot islands, road medians, and street rights-of-way.

Advantages/benefits:

- Reduce runoff rate and volume from impervious areas; provide opportunity for filtration and infiltration processes. Good for highly-impervious areas, such as parking lots.
- Removes fine sediments, heavy metals, nutrients, bacteria, and organics. Reduces thermal pollution from runoff across pavement surfaces.
- Flexible design options for varying site conditions; subdrain system allows use on sites with higher seasonal water table levels. Good retrofit opportunities.
- Flexible landscaping options can provide an aesthetic feature.

Disadvantages/limitations:

- Not appropriate for steep slopes (> 15%).
- High sediment loads can cause premature failure; upstream practice is needed.
- Concentrated flows may need special consideration in design.

Maintenance requirements:

- Routine landscape maintenance - weeding and annual removal of undesirable vegetation.
- Removal of dead plant debris (mowing, pruning, or burning)
- Maintenance of sediment in grassed area.

Description

Bioretention areas (also referred to as bioretention filters or rain gardens) are structural stormwater controls that capture and temporarily store the water quality volume using soils and vegetation in shouldow basins or landscaped areas to remove pollutants from stormwater runoff.

Bioretention areas use vegetation and engineered soils as a treatment area to accept runoff from impervious surfaces. Stormwater flows into the bioretention area, ponds on the surface, and gradually

infiltrates into the engineered soil layer. Example applications of bioretention and rain gardens are illustrated in Figure 1. The components of the bioretention system are illustrated in Figures 2 and 3. Bioretention systems are intended to replicate the stable hydrologic functions of a native ecosystem. Bioretention functions as a soil and plant-based filtration system for stormwater runoff, and removes pollutants through a variety of physical, chemical, and biological processes in the upper engineered soil layer and the underlying native soils. The design can impact the processes and their function. Some of the major processes that occur through bioretention include: interception, infiltration, settling, evapo-transportation, filtration, absorption, thermal attenuation, and biological degradation/decomposition.

The filtered runoff can be allowed to either infiltrate into the underlying soils or be temporarily stored in the aggregate subdrain system and discharged at a controlled rate to the storm sewer system or a downstream open channel. Runoff can be controlled closer to where it is generated by the uniform distribution of bioretention areas to break up the area in manageable sub-watersheds. Higher flow events (> Q_2), and runoff volume that exceed the infiltration capacity of these systems can be returned to the conveyance system or safely bypassed.

Vegetative systems in bioretention areas enhance infiltration and provide a significant evapotranspiration component. Native species provide resistance to moisture changes, insects, and disease; and provide uptake of runoff water and pollutants. Deep-rooted native plants (grasses and forbs) are recommended to maintain high organic matter content in the soil matrix, provide high infiltration rates, and provide uptake of runoff water. The mulch layer and organic matter component of the soil matrix provide filtration and a place for beneficial microbial activity. Aerobic conditions are necessary to maintain microbial activity for processing pollutants.

There are many ways to incorporate bioretention systems into new construction projects or to retrofit existing urban areas. Bioretention can be used in residential yards (rain gardens), as interior or perimeter structures in parking lots, for rooftop drainage at residential and commercial building sites, along highway and road drainage swales, within larger landscaped pervious areas, and as landscaped islands in impervious or high-density environments.

A complementary upstream practice is provided to reduce the sediment loading to the bioretention area. Systems are often built with grass filter strips around the bioretention area. These filter strips remove particulates and reduce runoff velocity. Filter strips also prevent crusting of pore spaces with fines and reduce maintenance. A freeboard storage area (temporary ponding) creates temporary storage for runoff prior to infiltration, evaporation, and uptake.

Each component of the bioretention system is important. The engineered soil layer provides filtration and holds water and nutrients for the plants, enhances biological activity, encourages root growth, and provides storage of stormwater through the voids within the soil particles. The plant material evapotranspires stormwater, creates pathways for infiltration through the plant roots, improves soil structure, improves aesthetics, and reinforces long-term performance of subsurface infiltration. Native plant material is recommended because of its deep root structure and ability to improve soil quality. The mulch layer acts as a filter for pollutants in runoff, protects underlying soil from drying and eroding, and provides an environment for microorganisms to degrade organic pollutants. It also provides a medium for biological growth, decomposition of organic material, and adsorption and bonding of heavy metals.

Mosquitoes are not a problem because bioretention areas and rain gardens do not retain standing water long enough for mosquito reproduction (four to 10 days). Properly designed bioretention and rain garden systems will infiltrate standing water with 4 to 12 hours.

Figure 1: Example bioretention applications

(a) Rain garden for single family residence

(b) Bioretention in landscaped parking lot median

(c) Newly planted bioretention area after storm

(d) New bioretention area after construction

Source: Georgia Stormwater Manual

Table 1: Bioretention design components

Pre-treatment area	Grass buffer strip or vegetated swales are commonly used pre-treatment devices. Required where a significant volume of debris or suspended material is anticipated such as parking lots and commercial areas.
Ponding area	Provides for surface storage of the storm runoff before it filters through the soil bed. Also provides for some evaporation of ponded water and settling of sediments in the runoff. Typically limited to a depth of 6-9 inches. Additional freeboard depth should be provided for online systems to allow surcharge above overflow outlet during larger storm runoff events (> Q_2).
Organic mulch layer	The organic mulch layer protects the soil bed from erosion, retains moisture in the plant root zone, provides a medium for biological growth and decomposition of organic matter, and provides some filtration of larger sediment particles. Three to four inches of good quality coarse shredded hardwood mulch are recommended.
Planting soil bed (engineered soil matrix)	The planting soil bed provides water and nutrients to support plant life in the bioretention system. Stormwater filters through the planting soil bed and pollutants are removed through filtration, plant uptake, adsorption, and bacteriological decomposition. • Total depth = 4.5 to 5.5 feet; planting soil depth = 18-30 inches • Soil mixtures include: medium sand (50-60%), topsoil (sandy/clay loam) (20-25%), leaf compost (20-25%). Provides organic matter content and facilitates good plant root systems; and a permeable substrata w/~ 25% porosity. • Strive for organic matter content of 10%. • Maximum clay content of mixture ≤ 5%.
Stone aggregate sub-base layer	The aggregate layer at the bottom of the structure provides additional temporary storage capacity for the captured runoff after filtration. • An open-graded, clean, durable aggregate of 1-2 inches diameter will provide a porosity of 35-40%. • Depth of the aggregate layer can be varied to provide more storage volume • A nominal depth of 12-inches is typically provided.
Plant materials	Native species.
Inlet and outlet controls	Non-erosive flow velocities (≤ 0.5 fps).
Maintenance	Routine landscape maintenance (removal of dead plant debris); plant replacement as needed; mowing and/or burning.
Hydrologic design	Unified sizing criteria; system is sized to retain the WQv, recharge volume is minimum infiltration goal; runoff flows in excess of the Qp for the WQv design storm are usually bypassed; check capability to provide some peak flow attenuation for larger runoff events up to the Q_5.

Stormwater management suitability

Bioretention areas are designed primarily for stormwater quality, i.e. the removal of pollutants. Bioretention can provide limited runoff quantity control, particularly for smaller storm events. These facilities may sometimes be used to partially or completely meet channel protection requirements on smaller sites. However, bioretention areas will typically need to be used in conjunction with another structural control to provide channel protection as well as overbank flood protection. It is important to ensure that a bioretention area safely bypasses higher flows.

1. **Water quality (WQv).** Bioretention is an excellent stormwater treatment practice due to the variety of pollutant removal mechanisms. Each of the components of the bioretention area is designed to perform a specific function (see Figure 4).
   a. The grass filter strip (or grass channel) reduces incoming runoff velocity and filters particulates from the runoff.

   b. The ponding area provides for temporary storage of stormwater runoff prior to its evaporation, infiltration, or uptake and provides additional settling capacity.

   c. The organic or mulch layer provides filtration, as well as an environment conducive to the growth of microorganisms that degrade hydrocarbons and organic material.

   d. The planting soil in the bioretention facility acts as a filtration system, and clay in the soil provides adsorption sites for hydrocarbons, heavy metals, nutrients, and other pollutants.

   e. Both woody and herbaceous plants in the ponding area provide vegetative uptake of runoff and pollutants, and also serve to stabilize the surrounding soils.

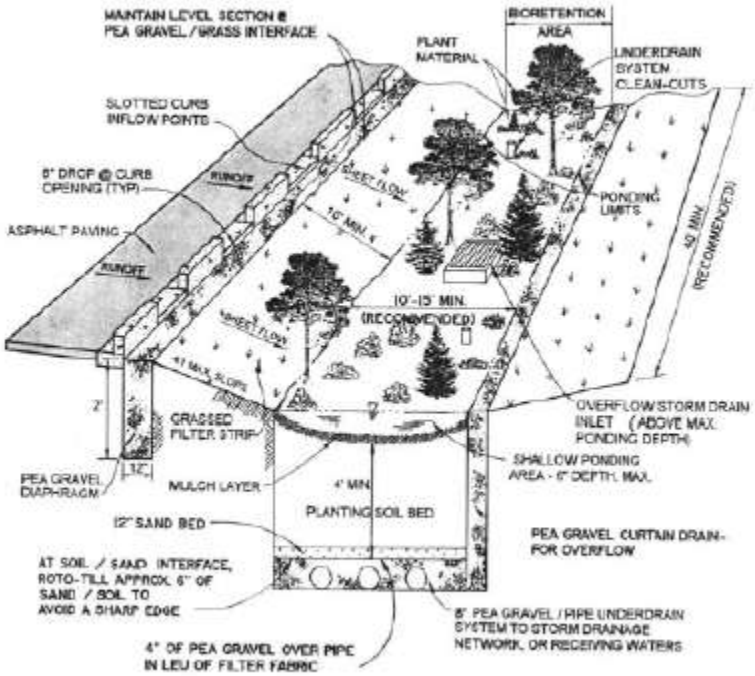
   f. Finally, a sand bed provides for positive drainage and aerobic conditions in the planting soil, and provides a final polishing treatment media.

2. **Channel protection (CPv).** For smaller sites, a bioretention area may be designed to capture the entire channel protection volume in either an off-line or online configuration. Given that a bioretention facility is typically designed to completely drain over 48 hours, the requirement of extended detention of the 1-year, 24-hour storm runoff volume will be met. For larger sites, where only the WQv is diverted to the bioretention facility, another structural control must be used to provide CPv extended detention.

3. **Overbank flood protection.** Another structural control must be used in conjunction with a bioretention area to reduce the post-development peak flow of storms greater than the 5-year storm (Qp) to pre-development levels (detention).

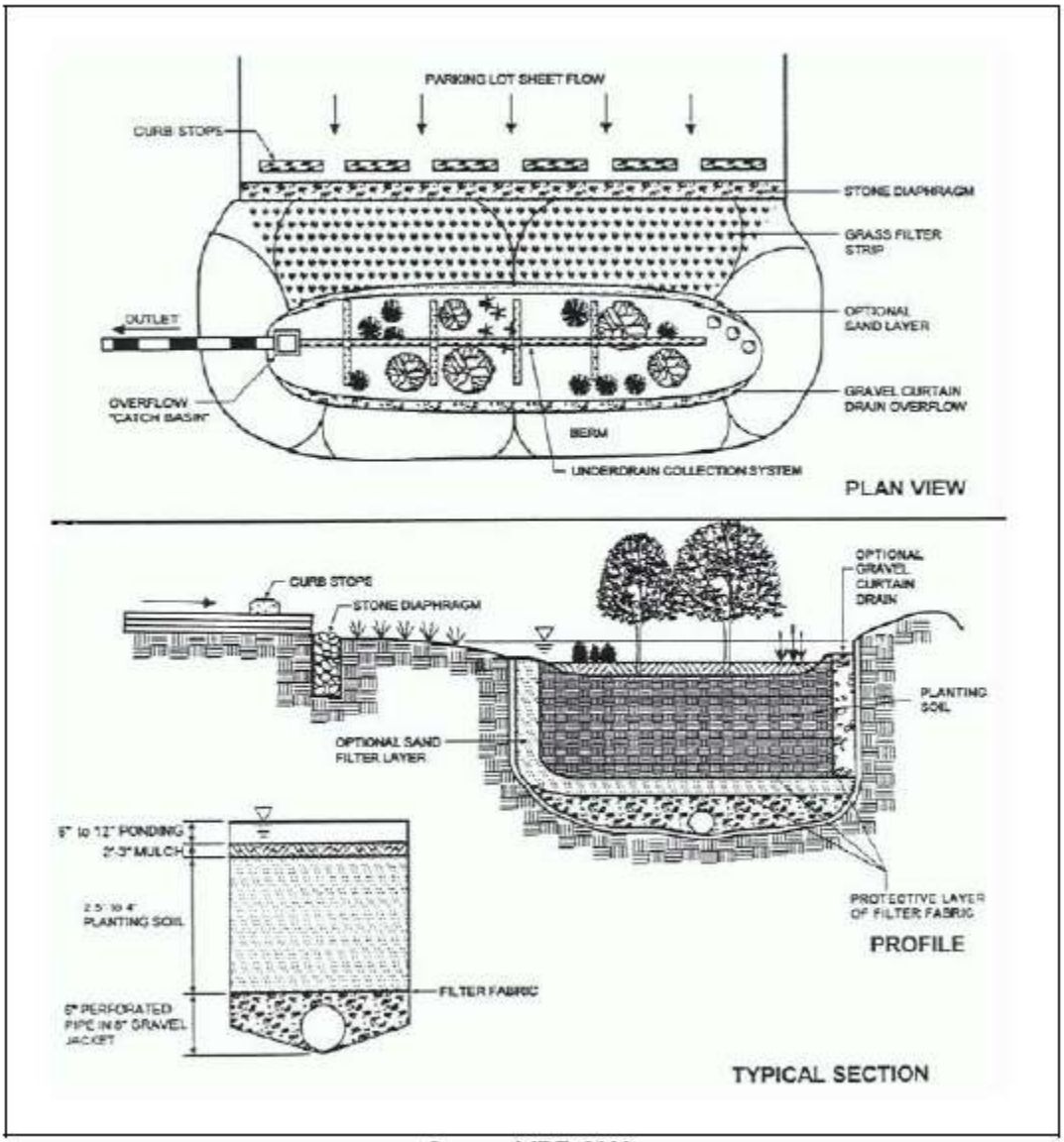
4. **Extreme flood protection.** Bioretention areas must provide flow diversion and/or be designed to safely pass extreme storm flows and protect the ponding area, mulch layer, and vegetation.

Figure 2: Bioretention system components



Source: Claytor and Schueler, 1996

Figure 3: Bioretention system



Source: MDE, 2000

Pollutant removal capabilities

In landscaped and residential areas, the major pollutants of concern are fertilizers such as nitrogen and phosphorus. The following design pollutant removal rates are conservative average pollutant reduction percentages for design purposes, derived from sampling data, modeling, and professional judgment. In a situation where a removal rate is not deemed sufficient, additional controls may be put in place at the given site in a series or treatment train approach. For additional information on monitoring BMP performance, see ASCE/EPA "Urban Stormwater BMP Performance Monitoring: A Guidance Manual for Meeting the National Stormwater BMP Database Requirements."

Table 2: Pollutant removal efficiency of bioretention areas

Parameter	Removal Efficiency (%)
Total suspended solids	80
Total phosphorous	65-85
Total nitrogen	50
Pathogens	70-100
Heavy metals	45-95

Source: US EPA

More information on pollutant removal capabilities for bioretention BMPs can be found in the National Pollutant Removal Performance Database (www.cwp.org), the National Stormwater Best Management Practices Database (www.bmpdatabase.org), and the ASCE/EPA database.

The University of Maryland Engineering Department, completed an evaluation "Optimization of Bioretention," of the effectiveness of pollutant removal. The experiment yielded valuable data on pollutant removal efficiency rates and processes for bioretention. This manual incorporates those findings into the design criteria. The following table summarizes the efficiency removal rates for various pollutants.

Table 3: Cumulative percent removal by depth

Laboratory/Field Summary (%)								
Depth	Cu	Pb	Zn	P	TKN	NH_4	NO_3	TN
1 ft	90	93	87	0	37	54	-97	-29
2 ft	93	99	98	73	60	86	-194	0
3 ft	93	99	99	81	68	79	23	43

Source: Davis, A.P. et al, University of Maryland, 1998

Application and feasibility

Bioretention systems are suitable for a wide variety of development options, including commercial, high-density urban, and single-family residential areas. They can be used for new construction and also to retrofit urban landscapes. Their capacity to be used as a landscaped feature allows them to fit into many types of urban design. Bioretention facilities are ideally suited to many ultra-urban areas, such as landscaped parking lot islands and along streets and boulevards. Ultra- rban areas are densely-developed urban areas in which little pervious surface exists. While they consume a fairly large amount of space (approximately 5-10 percent of the area that drains to them), they can fit into existing parking lot islands or other landscaped areas. They can also treat runoff from intensively managed areas that have the potential for pollutants, such as golf courses. Figure 4 includes some example site configurations.

The following criteria should be evaluated to ensure the suitability of a bioretention area for meeting stormwater management objectives on a site or development:

1. **General feasibility:**
   - Suitable for residential subdivision usage – yes
   - Suitable for high-density/ultra urban areas – yes
   - Regional stormwater control – no

2. **Physical feasibility – physical constraints at project site:**

- Drainage area: 5 acres maximum; 0.5 to 2 acres are preferred
- Space required: Approximately 5-8% of the tributary impervious area is required; minimum 200 ft^2 area for small sites (10 feet x 20 feet)
- Site slope: No more than 6% slope
- Minimum head: Elevation difference needed at a site from the inflow to the outflow: 5 feet
- Minimum depth to water table: A separation distance of 2 feet is recommended between the bottom of the bioretention facility and the elevation of the seasonally high water table.
- Soils: No restrictions; engineered media required. For rain garden applications where no subdrain is provided, HSG D soils should be avoided, or the system may experience longer periods of standing water.

Planning and design criteria

1. **Initial considerations:**
   a. Determine the purpose of the bioretention system – what are the site requirements for water quality and quantity control?

   b. What design storm is required to meet the stormwater management criteria?

   c. Can bioretention be used for water quality and quantity control?

   d. Can the bioretention facility be used independently of other BMPs, or will it be installed along with other practices?

2. **Location and siting:**

   a. Bioretention areas should have a maximum contributing drainage area of 5 acres; 0.5 to 2 acres are preferred. Multiple bioretention areas can be used for larger areas.

   b. Bioretention areas can either be used to capture sheet flow from a drainage area or function as an off-line device. Online designs should be limited to a maximum drainage area of 0.5 acres.

   c. When used in an off-line configuration, the WQv is diverted to the bioretention area through the use of a flow splitter. Stormwater flows greater than the WQv are diverted to other controls or downstream. (See Part 2D for more discussion of off-line systems and design guidance for diversion structures and flow splitters).

   d. Bioretention systems are designed for intermittent flow and must be allowed to drain and reaerate between rainfall events. They should not be used on sites with a continuous flow from groundwater, sump pumps, or other sources.

   e. Bioretention area locations should be integrated into the site planning process, and aesthetic considerations should be taken into account in their siting and design. Elevations must be carefully worked out to ensure that the desired runoff flow enters the facility with no more than the maximum design depth.

   f. Available room for installation including setback requirements.

3. **General design.** A well-designed bioretention area consists of:
   a. Grass filter strip (or grass channel) between the contributing drainage area and the ponding area.

b. Ponding area containing vegetation with a planting soil bed.

c. Organic/mulch layer.

d. Gravel and perforated pipe subdrain system to collect runoff that has filtered through the soil layers (bioretention areas can optionally be designed to infiltrate into the soil – see description of infiltration trenches for infiltration criteria).

e. A bioretention area design will also include some of the following:
   1) Optional sand filter layer to spread flow, filter runoff, and aid in aeration and drainage of the planting soil.
   2) Stone diaphragm at the beginning of the grass filter strip to reduce runoff velocities and spread flow into the grass filter.
   3) Inflow diversion or an overflow structure consisting of one of five main methods:
      a. Use a flow diversion structure.
      b. For curbed pavements use an inlet deflector (see Figure 6).
      c. Use a slotted curb and design the parking lot grades to divert the WQv into the facility. Bypass additional runoff to a downstream catch basin inlet. Requires temporary ponding in the parking lot.
      d. Use a short deflector weir (maximum height 6 inches) designed to divert the maximum water quality peak flow into the bioretention area.
      e. An in-system overflow consisting of an overflow catch basin inlet and/or a pea gravel curtain drain overflow. (See Figure 2 for an overview of the various components of a bioretention area). Figure 3 provides a plan view and profile schematic of an online bioretention area. An example of an off-line facility is shown in Figure 5.

4. General planning criteria:

a. Facilities can be placed close to the source of runoff generation.

b. The site permits the dispersion of flows and bioretention facilities to be distributed uniformly. Distributed placement of bioretention areas across a development site results in smaller, more manageable subdrainage areas and therefore helps to control runoff closer to its source.

c. Potential bioretention facilities should be applied where subdrainage areas are limited to less than 1-2 acres, and preferably less than 1 acre.

d. Stormwater management site integration is a feasible alternative to end-of-pipe BMP design.

e. Availability of suitable site conditions (groundwater elevation and depth to bedrock).

f. Bioretention areas can either be used to capture sheet flow from a drainage area or function as an off-line device. Online systems take all the runoff water from an impervious surface. Online designs should be limited to a maximum drainage area of 0.5 acres. Multiple bioretention systems are preferred when managing larger impervious surfaced areas.

g. When used in an off-line configuration, the WQv is diverted to the bioretention area through the use of a flow splitter, diversion structure, and/or overflow outlet. Stormwater flows greater than the WQv are diverted to other controls or downstream (see Section 2F-1 for more discussion of off-line systems and design guidance for diversion structures and flow splitters).

h. Bioretention systems are designed for intermittent flow and must be allowed to drain and reaerate between rainfall events. They should not be used on sites with a continuous flow from groundwater, sump pumps, or other sources.

i. Bioretention area locations should be integrated into the site planning process, and aesthetic considerations should be taken into account in their siting and design. Elevations must be carefully worked out to ensure that the desired runoff flow enters the facility with no more than the maximum design depth.

j. Generally, commercial or residential drainage areas exceeding 1-3 acres in size will discharge flows greater than the 5 cfs for a 10-year storm event. When flows exceed this level, the designer should evaluate the potential for erosion to stabilized areas. Typically, flows greater than 5 cfs for the 10-year storm event will require pipe enclosure across developed lots. By using drainage dispersion techniques, retaining existing contours, concentrated quantities of flow can often be reduced below these thresholds, eliminating or reducing the need for a pipe conveyance system. This may be accomplished by dispersing larger drainage areas to multiple bioretention facilities.

Physical specifications and geometry

1. Recommended minimum dimensions of a bioretention area are 10 feet wide by 20 feet long. All designs except small residential applications should maintain a length to width ratio of at least 2:1.

2. The planting soil filter bed is sized using a Darcy's Law equation with a filter bed drain time of 48 hours and a coefficient of permeability (k) of 0.5 ft/day.

3. The maximum recommended ponding depth of the bioretention areas is 6 inches.

4. The planting soil bed must be at least 4 feet deep. Planting soils should be sandy loam, loamy sand, or loam texture with a clay content ranging from 10-25%. The soil must have an infiltration rate of at least 0.5 inches per hour and a pH between 5.5 and 6.5. In addition, the planting soil should have a 1.5 to 3% organic content and a maximum 500 ppm concentration of soluble salts.

5. For online configurations, a grass filter strip with a pea gravel diaphragm is typically utilized (see Figure 5) as the pre-treatment measure. The required length of the filter strip depends on the drainage area, imperviousness, and the filter strip slope. Design guidance on filter strips for pretreatment can be found in Part 2I.

6. For off-line applications, a grass channel with a pea gravel diaphragm flow spreader is used for pre-treatment. The length of the grass channel depends on the drainage area, land use, and channel slope. The minimum grassed channel length should be 20 feet. Design guidance on grass channels for pre-treatment can be found in Part 2I.

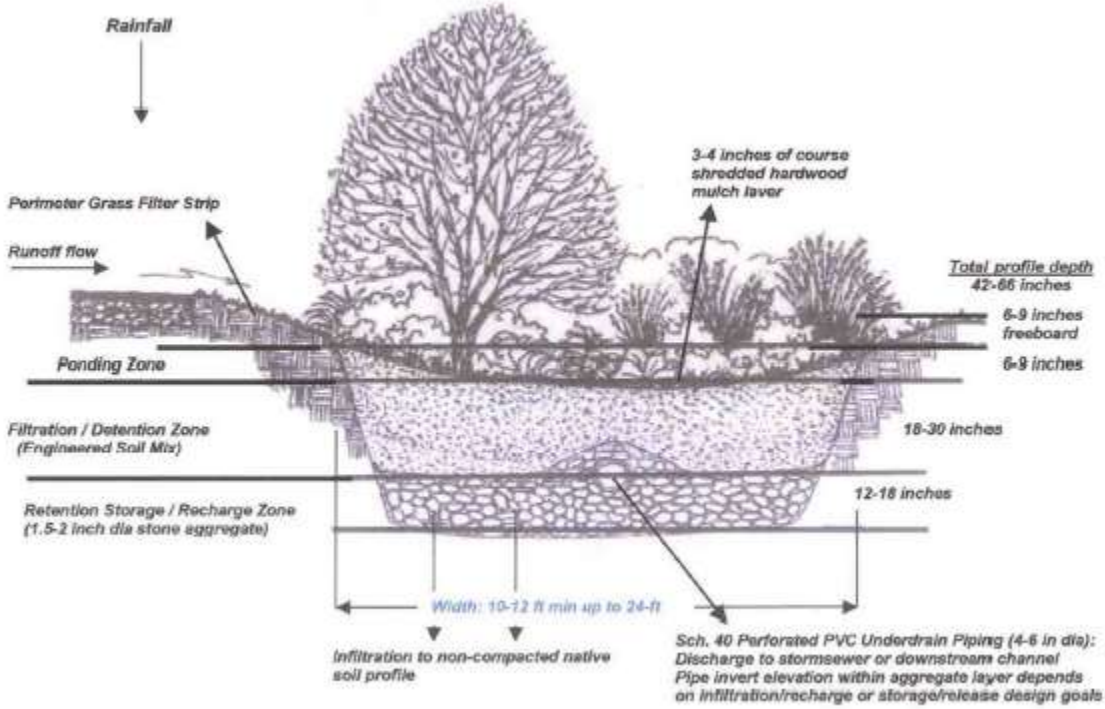
7. The mulch layer should consist of 2-4 inches of commercially-available fine shredded hardwood mulch or shredded hardwood chips.

8. The sand bed should be 12-18 inches thick. Sand should be clean and have less than 15% silt or clay content.

9. Pea gravel for the diaphragm and curtain, where used, should be ASTM D 448 size No. 6 (1/8" to ¼").

10. The subdrain collection system is equipped with a 6-inch perforated PVC pipe (AASHTO M 252) in a 12-inch gravel layer. The pipe should have 3/8-inch perforations, spaced at 6-inch centers, with a minimum of 4 holes per row. The pipe is spaced at a maximum of 10 feet on center and a minimum grade of 0.5% must be maintained. A permeable filter fabric is placed between the gravel layer and the planting soil bed.

Figure 4: Bioretention system components



Structures

1. **Pre-treatment inlets.** Adequate pre-treatment and inlet protection for bioretention systems is provided when all of the following are provided:
   - Grass filter strip below a level spreader, or grass channel
   - Pea gravel diaphragm
   - Organic or mulch layer

2. **Outlet structures.** An outlet pipe is provided from the subdrain system to the facility discharge. Due to the slow rate of filtration, outlet protection is generally unnecessary.

3. **Emergency spillway.** An overflow structure and non-erosive overflow channel are provided to safely pass flows that exceed the storage capacity from the bioretention area to a stabilized downstream area or watercourse. If the system is located off-line, the overflow should be set above the shouldow ponding limit. The high-flow overflow system within the structure typically consists of a yard drain catch basin, though any number of conventional systems could be used.

The throat of the catch basin inlet is normally placed 6 inches above the mulch layer at the elevation of the shouldow ponding area.

Design procedures

1. **Step 1**. Compute runoff control volumes from the unified stormwater sizing criteria (See Part 2B).

    a. Calculate the WQv and Rev.

    b. Compute the CPv.

    c. Compute Qp or downstream stormsewer conveyance capacity (i.e. ≤ 5-yr peak discharge rate, Qp_5).

    d. Compute Qf.

    e. Determine total DA to be served by the bioretention BMPs; maximum DA less than 5 acres; divide larger DAs into smaller sub-areas of 1-2 acres if possible.

    f. Determine the actual amount of impervious area for the total DA and/or sub-areas.

2. **Step 2**. Determine if the development site and conditions are appropriate for the use of a bioretention area. Consider the application and feasibility and location and siting criteria.

3. **Step 3**. Confirm local design criteria and applicability.

    a. Consider any special site-specific design conditions/criteria.

    b. Check with local officials and other agencies to determine if there are any additional restrictions and/or surface water or watershed requirements that may apply.

4. **Step 4.** Compute WQv peak discharge (Qwq).

    a. WQv (ft^3) = Rv x P x DA x 43,560 ft^2/acre x 1 ft/12 in
        1) P is design rainfall depth in inches (i.e. 1.25 inches)
        2) DA is drainage area in acres
        3) Rv = runoff coefficient for the DA served by the BMP
        4) Rv = 0.05 + (0.009)(I), where I = impervious area in %

    b. The peak rate of discharge for water quality design storm (Qwq) is needed for sizing of offline diversion structures. (See Section 2C-6).
        1) Using WQv (or total volume to be captured), compute CN.
        2) Compute time of concentration using TR-55 method.
        3) Determine appropriate unit peak discharge from time of concentration.
        4) Compute Qwq from unit peak discharge, drainage area, and WQv.
        5) An alternate method is to determine the Qwp using the Rational method; use the design rainfall depth and a 2-hour duration to provide a design rainfall intensity for use in the rational method equation (i.e. Q cfsec = C x I x A); use the Rv calculated above for the "C" runoff coefficient.

5. **Step 5**. Size flow diversion structure, if needed.

   a. A flow regulator (or flow splitter diversion structure) should be supplied to divert the WQv to the bioretention area.

   b. Size low flow orifice, weir, or other device to pass Qwq.

6. **Step 6**. Determine size of bioretention ponding/filter area.
   A. The required planting soil filter bed area is computed using the following equation (based on Darcy's Law):

$$A_f = \frac{WQv \times df}{[k \times (hf + df) \times (tf]}$$

   where:
   A_f = surface area of ponding area (ft^2)
   WQv = water quality volume (or total volume to be captured)
   df = filter bed depth (1.5 feet minimum)
   k = coefficient of permeability of filter media (ft/day) (use 1 in/hr for a sandy loam for the engineered soil mix; if using a natural soil profile, use 0.5 ft/day for silt-loam)
   hf = average height of water above filter bed (ft) - (typically 3-4.5 inches, which is half of the 6-9 inch ponding depth)
   tf = design filter bed drain time (days); (2 days is recommended maximum)

   B. Check value of Af determined from above equation – should be in the range of 10-15% of the total impervious drainage area.

7. **Step 7**. Set design elevations and dimensions of facility; see physical specifications and geometry.

8. **Step 8.** Design conveyances to facility (off-line systems). See the example figures to determine the type of conveyances needed for the site.

9. **Step 9.** Design pre-treatment. Provide pre-treatment with a grass filter strip (online configuration) or grass channel (off-line), and stone diaphragm. Nominal width of perimeter grass filter strips should be 10-foot minimum, if possible.

10. **Step 10**. Size subdrain system. See physical specifications and geometry. Hydraulic capacity of the subdrain piping must be sufficient to convey the expected discharge from the soil filter layer: Avg Flow Rate, Q (cfsec) = inches/hour x total area of filter x 1 ft/12 in x 1 hr/3600 sec.

11. **Step 11**. Design emergency overflow. An overflow must be provided to bypass and/or convey larger flows to the downstream drainage system or stabilized watercourse. Non-erosive velocities (<10 fps) need to be ensured at the outlet point.

12. **Step 12.** Prepare vegetation and landscaping plan. A landscaping plan for the bioretention area should be prepared to indicate what type of vegetation is to be used (species, etc) and procedures for establishing vegetation.

Inspection and maintenance requirements

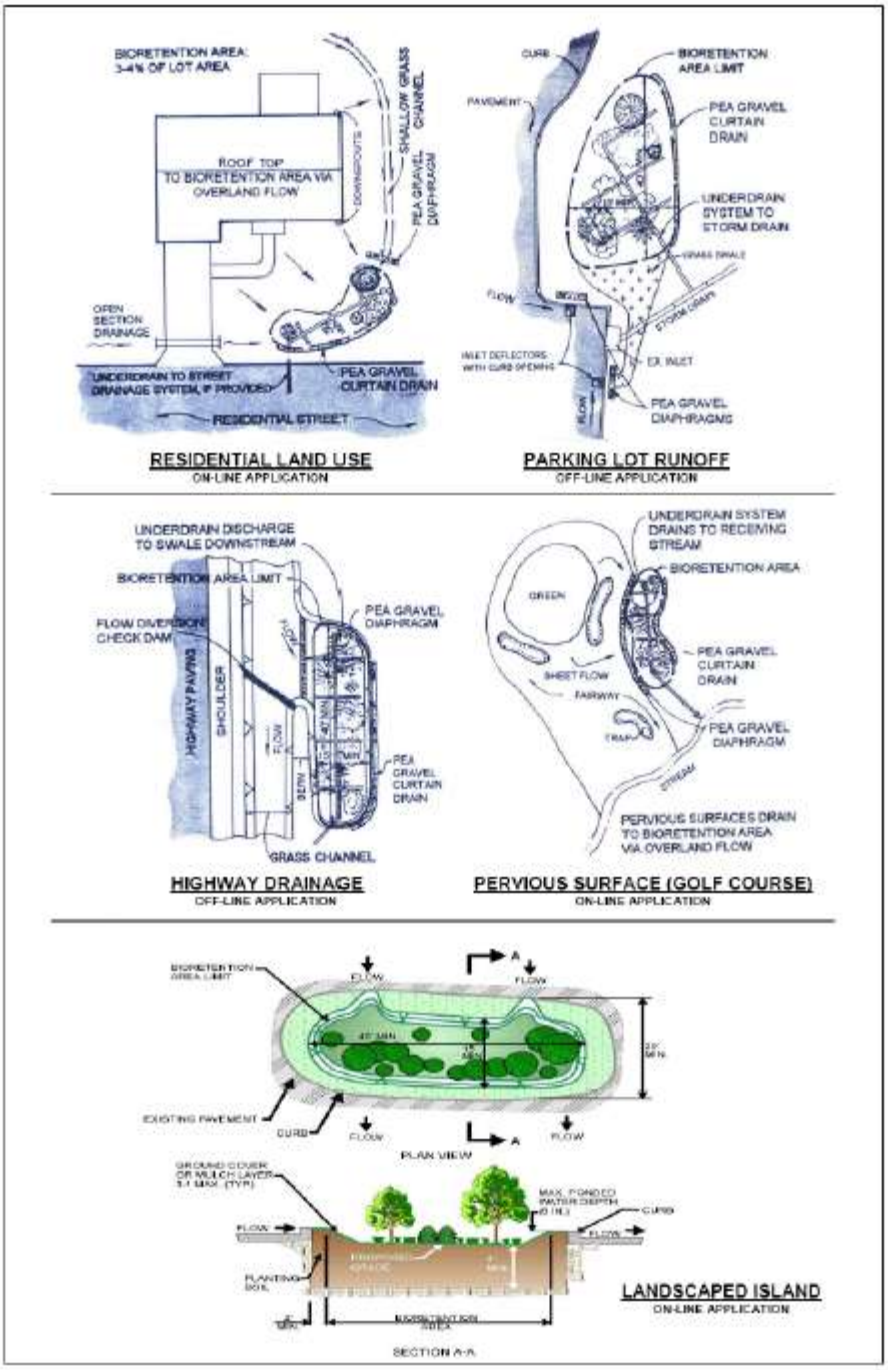
Adequate access must be provided for all bioretention facilities for inspection, maintenance, and landscaping upkeep, including appropriate equipment and vehicles.

Table 4: Typical maintenance activities for bioretention areas

Activity	Schedule
• Pruning and weeding to maintain appearance • Mulch replacement when erosion is evident • Remove trash and debris	As needed
• Inspect inflow points for clogging (off-line systems). Remove any sediment. • Inspect filter strip/grass channel for erosion or gullying. Re-seed or sod as necessary. • Trees and shrubs should be inspected to evaluate their health and remove any dead or severely diseased vegetation.	Semi-annually
• The planting soils should be tested for pH to establish acidic levels. If the pH is below 5.2, lime should be applied. If the soil pH is above 7.5, then gypsum can be applied to reduce the pH.	Annually
• Replace mulch over the entire area • Replace pea gravel diaphragm when necessary	2 to 3 years

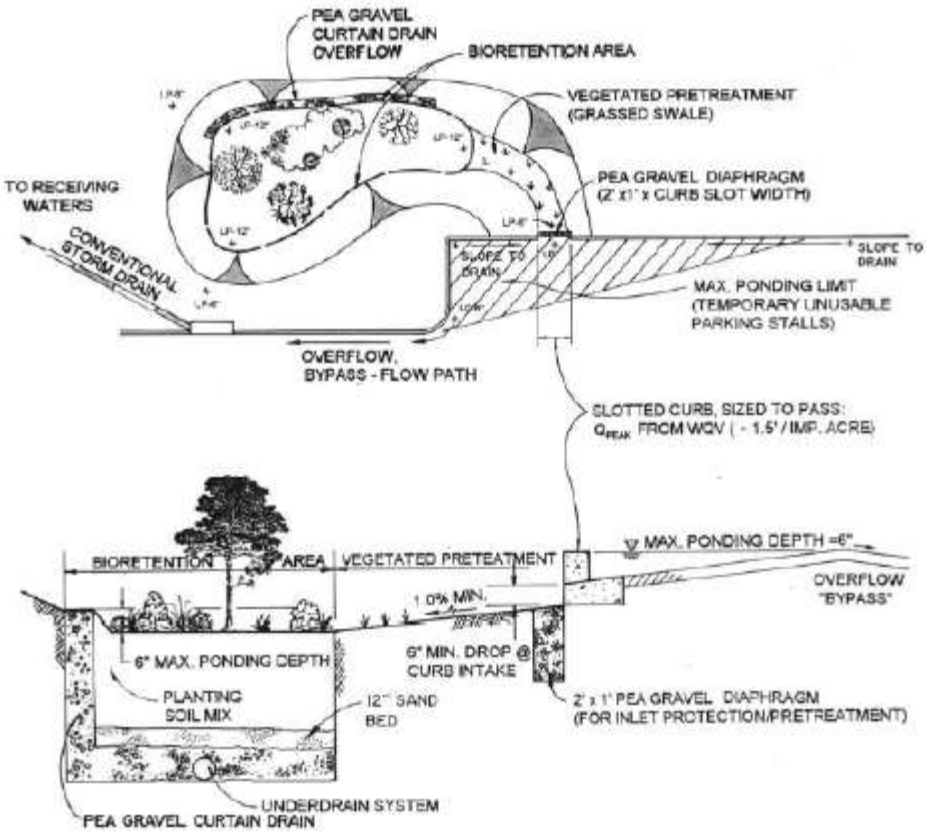
Source: EPA, 1999; Georgia SW Manual

Figure 5: Bioretention area applications



Source: Claytor and Schueler, 1996

Figure 6: Bioretention with slotted curb-cut diversion



Source: Prince George's County, MD, 2000

Design example

Bioretention System

Figure 7: Bucketsville, IA recreation center, Marshould County, IA

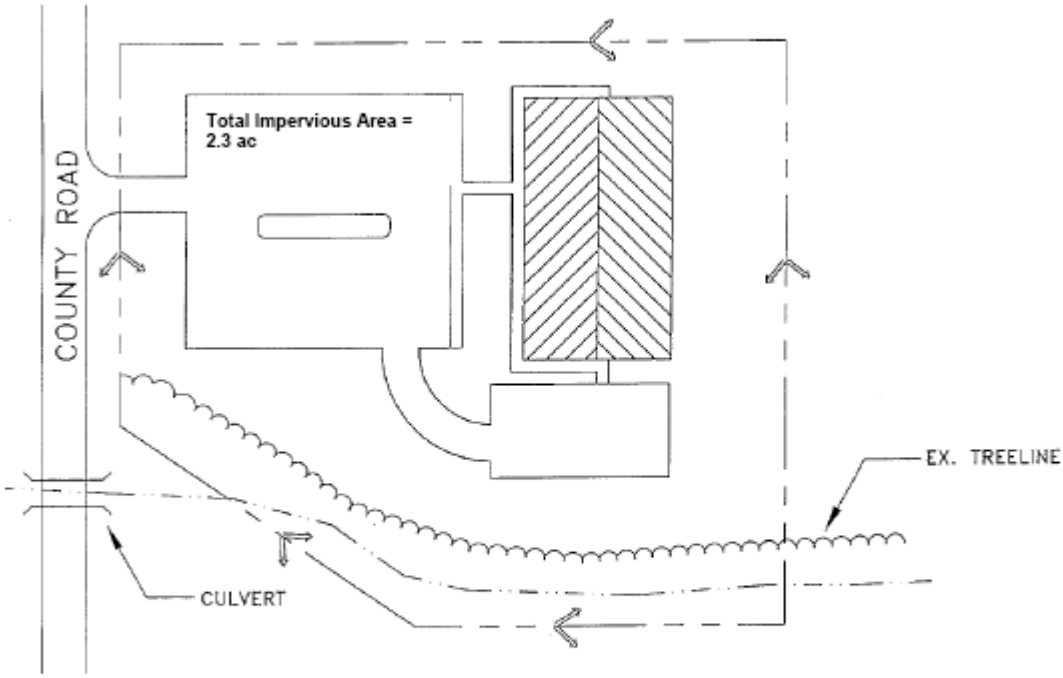


Table 5: Site data

Base Site Data	Hydrologic Data		
Total site drainage area (A) = 4 ac		Pre-	Post-
Impervious area = 2.3 ac; I = 2.2/4.0 = 57.5%	CN	68	84
Soils: HSG B (loam)	t_c	0.32	0.18

This example is focused on the design of a bioretention system to meet the water quality treatment requirements for the site. CPv and Qp are not addressed in this example other than determination for preliminary storage volume and peak discharge requirements. The CPv and Qp requirements will be handled by another set of downstream BMPs. Infiltration trenches provide water quality treatment (WQv) and recharge volume (Rev). Flows in excess of the WQv will be bypassed. The bypassed flow ill be conveyed downstream and combined with other off-site flows in a conventional detention basin for Qp control.

1. **Step 1.** Compute runoff control volumes from unified sizing criteria.
   a. **Compute WQv:**
      Rv = 0.05 + (42.6)(0.009) = 0.43
      Runoff, Q_a = (1.25 in)(0.43) = 0.54 inches
      WQv = (1.25 in)(Rv)(A)/12
      = (1.25)(0.43)(6)(1 ft/12 in)(43,560 ft^2/ac)
      = 11,706 ft^3 = 0.269 ac-ft

   b. **Compute the channel protection volume (CPv):**
      1) CPv is provided by 24-hour extended detention of the 1-year, 24-hour duration rainfall event. Use WINTR-55 method to (Section 2C-5) to determine the pre- and postdevelopment peak discharges for the 1-year, 5-year, 10-year, 25-year, and 100-year

24- hour return period events. Summary of WINTR-55 data and results are provided in Table 5.

Condition	CN	$Q_{1\text{-yr}}$		$Q_{5\text{-yr}}$	$Q_{10\text{-yr}}$	$Q_{25\text{-yr}}$	$Q_{100\text{-yr}}$
		inches	cfs	cfs	cfs	cfs	cfs
Pre-developed	57	0.038	0.08	3.31	5.27	8.29	13.41
Post-developed	75	0.581	4.11	13.33	16.98	22.02	29.78

2) Procedure for determining the CPv using WINTR-55 methods is discussed in Sections 2B-1 and 2C-6; using results in Table 5 summary for 1-year post-developed condition:

q_u 754 csm/in
T(extended detention time) = 24 hrs for CPv

Knowing qu and T, find qo/qi for the Type 2 Rainfall using Figure 1 in Section 2C-6:

From Figure 1 (plot of qo/qi vs. qu): qo/qi = 0.025

For a Type 11 rainfall distribution,

$Vs/Vr = 0.683 – 1.43(qo/qi) + 1.64 (qo/qi)^2 – 0.804 (q0/qi)^3$ **Equation 4**

Where Vs is the channel protection storage (CPv, and Vr equals the volume of runoff in inches.

Vs/Vr = 0.648

Therefore, Vs = CPv = (0.648)(0.581 inches)(1/12)(6 acres) = 0.188 ac-ft = **8,200 ft^3**

c. **Compute the overbank flood protection volume (Q_{p10}).** For this site, assume the postdevelopment peak for the Q_5 through Q_{25} must be controlled to the pre-development levels. For example, the post-development Q_{10} of 17 cfs must be attenuated to the pre-development Q_{10} of 5.27 cfs.

q_i = 17 cfs q_o = 5.27 cfs q_o / q_i = 0.31

$Vs/Vr = 0.683 – 1.43(qo/qi) + 1.64 (qo/qi)^2 – 0.804 (qo/qi)^3$

Vs/Vr = 0.374

For 10-year control for a developed CN of 75, where the P10 is 4.7 inches and the 10-year runoff (Qa) is 2.205 inches:

Vs = Q_{p10} = (0.374)(2.205)(1/12)(6 acres) = **0.412 ac-ft = 17,961 ft^3**

(Note: The Qp_{25} would be computed in the same manner.)

Also note the procedure used above for calculating Vs/Vr is for preliminary storage calculations. At final design, a full reservoir routing will be completed to confirm the level of control with the outlet structure and final basin elevation/storage configuration. WINTR-55 can be used for completing a reservoir routing. The storage basin is considered a “reach” in the TR-20 routing procedure, and an initial primary spillway can be sized in this manner. WINTR-55 uses the storage-indication method for the pond routing.

d. **Determine the safe conveyance of the 100-yr design storm.** At final design, determine that the discharge conveyance channel is adequate to convey the 100-year event and discharge to the adjacent receiving stream channel, or provide additional storage in the detention structure used for CPv and Qpv.

2. **Step 2.** Determine if the development site and conditions are appropriate for use of bioretention area. Site specific data: Existing ground elevation at the facility location is 926 feet, mean sea level. Soil boring observations reveal that the seasonally high water table is at 913 feet and underlying soil is loam (ML). Adjacent creek invert is at 912 feet.

3. **Step 3.** Confirm local design criteria and applicability. There are no additional local criteria that must be met for this design.

4. **Step 4.** Compute WQv peak discharge (Qwq). The procedure for determining the Qwq is covered in Section 2C-6. Since this structure will operate as an online facility, a flow diversion structure will not be used and the Qwq is not needed.

5. **Step 5.** Size flow diversion structure, if needed. Bioretention areas can be either online or offline. Online facilities are generally sized to receive, but not necessarily treat, the 25-year event. Off-line facilities are designed to receive a more or less exact flow rate through a weir, channel, manhole, flow splitter, etc. This facility is situated to receive direct runoff from grass areas and parking lot curb openings and piping for the 25-year event (22 cfs), and no special flow diversion structure is incorporated.

6. **Step 6.** Determine size of bioretention ponding/filter area.

   $A_f = (WQv)\ (d_f)/[\ (k)\ (h_f + d_f)\ (t_f)]$

   where:
   A_f = surface area of filter bed (ft^2)
   d_f = filter bed depth (ft); 4 ft used in this design includes 18 inches of aggregate base, plus 30 inches of engineered media (sand + compost + loam topsoil)
   k = coefficient of permeability of filter media (ft/day) (Use 0.5 ft/day)
   h_f = average height of water above filter bed (ft); ½ of the design ponding depth. A ponding depth of 9 inches is used for this design.
   t_f = design filter bed drain time (days) (48 hours is recommended)

   $A_f = (11{,}706\ ft^3)(4\ ft)\ /\ [(0.5\ ft/day)(4.5\ in/12 + 4\ ft)(2\ days)$

   A_f = **10,703 ft^2**

7. **Step 7.** Set design elevations and dimensions of facility. Assume a roughly 2:1 rectangular shape. Given a filter area requirement of 10,703 ft^2. If the L=2W, then L=146 ft and W will be 74 ft for a total area of LW (146 x 74) or 10,804 ft^2. See Figure 8. A more linear configuration is accomplished by setting the width equal to 30 ft and providing an overall length of 356 ft. The total area can also be divided into multiple cells, such as three cells at 30 ft wide and 120 ft long.

   Set top of facility at 924 feet, with the berm at 926 feet. The facility is 4 feet deep, which will provide 7 feet of separation distance (unsaturated zone) above the seasonally high water table. See Figure 9 for a typical section of the facility.

8. **Step 8.** Design conveyance to facility (off-line systems). This facility is not designed as an offline system.

9. **Step 9.** Design pre-treatment. Provide pre-treatment with a grass filter strip to convey sheet flow from the pavement area and contributing pervious areas. A minimum filter strip width of 15 ft is provided.

10. **Step 10.** Size subdrain area. Base subdrain design on 10% of the A_f or 1,070 ft^2. Use 6-inch perforated plastic pipes surrounded by a 3-foot-wide gravel bed, 8-feet on center. The subdrain piping is set up off the bottom of the aggregate bed distance equal to the expected Rev volume.The subdrains are connected to a header pipe to convey the underflow to a downstream final conveyance. See Figures 8 and 9. (1070 ft^2)/3 ft per foot of subdrain = 356 ft, say 360 feet of perforated subdrain. For the three-cell configuration above, each cell would have 120 feet of perforated subdrain along its entire length.

11. **Step 11.** Design emergency overflow. The parking area, curb, and gutter are sized to convey the 25-year event to the facility. Should filtering rates become reduced due to facility age or poor maintenance, an overflow weir is provided to pass the 25-year event. Size this weir with 6 inches of head, using the weir equation:

    $Q = CLH^{3/2}$
    where:
    C = 2.65 (smooth crested grass weir)
    Q = 22 cfs
    H = 6 inches

    Solve for L: $L = Q / [(C) (H^{3/2})]$ or $(22.0 \text{ cfs}) / [(2.65) (.5)^{1.5}] = 23.5\text{-ft}$ (Use 24 ft)

    Outlet protection in the form of riprap or a plunge pool/stilling basin should be provided to ensure non-erosive velocities. See Figures 8 and 9.

12. **Step 12.** Prepare vegetation and landscaping plan. Choose plants based on factors such as whether native or not, resistance to drought and inundation, cost, aesthetics, maintenance, etc. Select species locations (i.e., on center planting distances) so species will not “shade out” one another. Do not plant trees and shrubs with extensive root systems near pipe work.

Figure 8: Site plan for bioretention facility

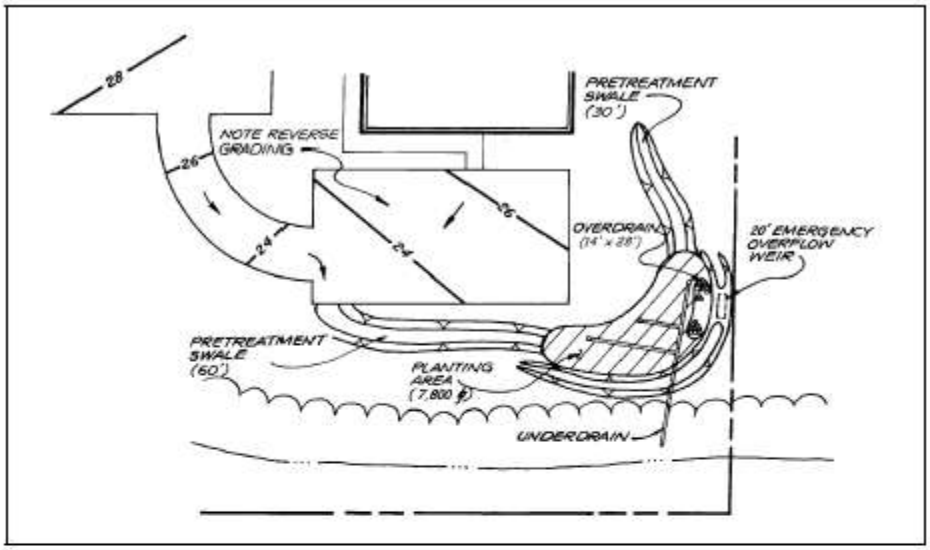


Figure 9: Profile of bioretention area

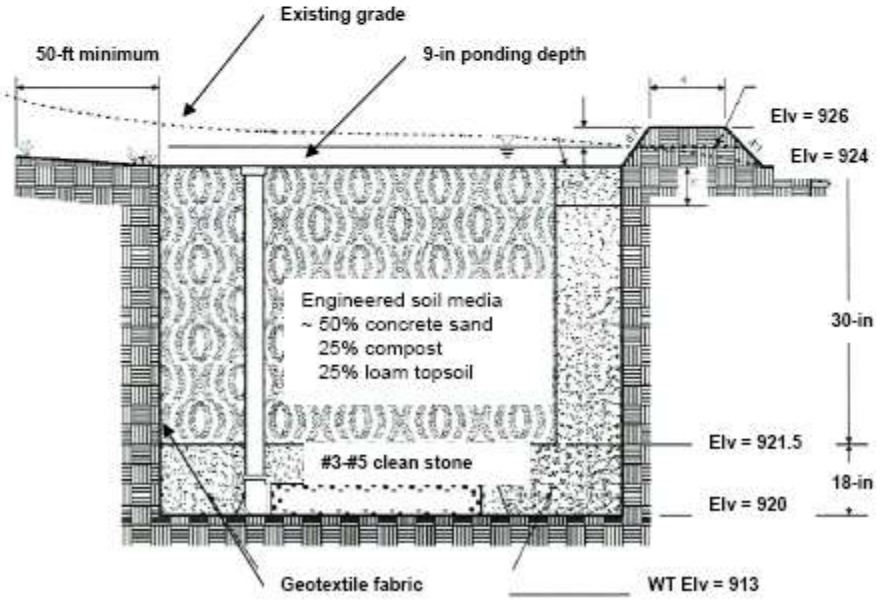


Table 5: WINTR-55 site data description and analysis results

--- Identification Data ---

User: SEJ Date: 12/28/2006
Project: Bucketsville Recreation Center Units: English
SubTitle: **Predeveloped** Area Units: Acres
State: Iowa
County: Marshould
Filename: C:\Documents and Settings\Stephen\Application Data\WinTR-55\Bioretention _pre.w55

--- Sub-Area Data ---

Name	Description	Reach	Area(ac)	RCN	Tc
DA-1	Outlet	6	57	.328	

Total area: 6 (ac)

------ Storm Data -------

Rainfall Depth by Rainfall Return Period

0.3-Yr (in)	1-Yr (in)	2-Yr (in)	5-Yr (in)	10-Yr (in)	25-Yr (in)	100-Yr (in)
1.25*	2.38	3.2	4.1	4.7	5.5	6.7

* 1.25 inches is the WQv design storm depth

Storm Data Source: User-provided custom storm data (Section 2C-2) Bulletin 71, Table 2.
Rainfall Distribution Type: Type II
Dimensionless Unit Hydrograph: <standard>

-------Sub-Area Land Use and Curve Number Details------

Sub-Area Identifier	Land Use	Hydrologic Soil Group	Sub-Area Area (ac)	Curve Number
DA-1	Meadow -cont. grass (non grazed)	B	4	58
	Woods (good)	B	2	55
	Total Area / Weighted Curve Number		6	**57**

------Sub-Area Time of Concentration Details-------

Sub-Area Identifier/	Flow Length (ft)	Slope (ft/ft)	Mannings's n	End Area (sq ft)	Wetted Perimeter (ft)	Travel Velocity (ft/sec)	Time (hr)
DA-1							
SHEET	100	0.0150	0.240				0.267
SHOULDOW	500	0.0200	0.050				0.061
				Time of Concentration			**0.328**

Pre-development runoff and peak discharge from TR-20 summary in WINTR-55

Storm	P	Runoff, Qa	Peak Discharge, Qp	Unit peak discharge, q_u	Total Runoff Volume
	inches	inches	ft^3/sec	csm	ft^3
1-yr	2.38	0.038	0.08	9.01	828
2-yr	3.2	0.038	1.05	112.17	828
5-yr	4.1	0.661	3.31	353.05	14,396
10-yr	4.7	0.948	5.27	561.84	20,647
25-yr	5.5	1.38	8.29	883.98	30,056
100-yr	6.7	2.12	13.41	1430.17	46,174

--- Identification Data ---

User: SEJ Date: 12/28/2006
Project: Bucketsville Recreation Center Units: English
SubTitle: **Post-developed** Area Units: Acres
State: Iowa
County: Marshould
Filename: C:\Documents and Settings\Stephen\Application Data\WinTR-55\Bioretention _post.w55

----- Sub-Area Data -----

Name	Description	Reach	Area(ac)	RCN	Tc
DA-1		Outlet	6	75	.228

Total area: 6 (ac)

------- Storm Data --------

Rainfall Depth by Rainfall Return Period

0.3-Yr (in)	1-Yr (in)	2-Yr (in)	5-Yr (in)	10-Yr (in)	25-Yr (in)	100-Yr (in)
1.25	2.38	3.2	4.1	4.7	5.5	6.7

Storm Data Source: User-provided custom storm data (Section 2C-2) Bulletin 71, Table 2.
Rainfall Distribution Type: Type II
Dimensionless Unit Hydrograph: <standard>

----------Sub-Area Land Use and Curve Number Details--------

Sub-Area Identifier	Land Use	Hydrologic Soil Group	Sub-Area Area (ac)	Curve Number
DA-1				
	Open space; grass cover > 75% (good)	B	1.44	61
	Paved parking lots, roofs, driveways	B	2.56	98
	Woods (good)	B	2.00	55
	Total Area / Weighted Curve Number		6.00	75

--------Sub-Area Time of Concentration Details-------

Sub-Area Identifier/	Flow Length (ft)	Slope (ft/ft)	Mannings's n	End Area (sq ft)	Wetted Perimeter (ft)	Velocity (ft/sec)	Travel Time (hr)
DA-1							
SHEET	50	0.0150	0.240				0.153
SHOULDOW	600	0.0200	0.050				0.073
CHANNEL	50					7.250	0.002
				Time of Concentration			**0.228**

Post-development runoff and peak discharge from TR-20 summary in WINTR55

Storm	P	Runoff, Qa	Peak Discharge, Qi	Peak discharge Qi	Unit peak discharge, q_u	Total Runoff Volume
	inches	inches	ft^3/sec	csm	csm/in	ft^3
1-yr	2.38	0.581	4.11	437.81	754	12,654
2-yr	3.2	1.092	8.21	875.10	801	23,784
5-yr	4.1	1.739	13.33	1421.37	817	37,875
10-yr	4.7	2.205	16.98	1810.27	821	48,025
25-yr	5.5	2.858	22.02	2347.89	821	62,290
100-yr	6.7	3.883	29.78	3174.9	818	84,572

2E-5 Soil Quality Restoration

BENEFITS Low = <30% Medium = 30-65% High = 65-100%			
	Low	Med	High
Suspended Solids	■	■	■
Nitrogen	■	■	■
Phosphorous	■	■	■
Metals	■	■	■
Bacteriological	■	■	■
Hydrocarbons	■	■	■

Description: Healthy soils have tremendous capacity for infiltrating and storing water. Healthy soils also have active microbial life that will breakdown and utilize many pollutants moving in urban non-point runoff. Soil quality restoration helps urban landscapes absorb, infiltrate and purify runoff. Directing stormwater flows onto landscapes with good soil quality reduces the volume of runoff that is generated. Soil quality restoration involves a combination of steps. Reducing compaction, increasing pore space, improving organic matter content, and re-establishment of soil dwelling populations (microbes, worms, insects, etc) are the main components of soil quality restoration. Soil quality restoration is most beneficial to soils that have been altered and compacted through recent land-disturbing activities on construction sites, but almost any urban landscape can benefit from soil quality restoration techniques.

Typical uses:

- Included in the final grading and stabilization of construction sites.
- Incorporated into lawn care management practices on established landscapes.

Advantages/benefits:

- Reduces stormwater runoff volume.
- Protects water quality by infiltrating and processing pollutants moving in stormwater runoff.
- Reduces the need for irrigation by increasing water holding capacity and water availability.
- Usually reduces the need for fertilizers and pesticides.

Disadvantages/limitations:

- Access to soil restoration services may be limited.
- Access to compost may be limited.
- May increase landscaping costs initially.

Maintenance requirements:

- After restoration practices, the key need is to maintain and increase organic matter content.
- Annual applications of compost amendments is recommended (but not required).
- Do not remove lawn clippings; leave to decompose and maintain organic matter content.
- Minimize pesticide use to maintain healthy populations of earthworms, soil dwelling insects, and soil microbes.
- Native landscaping will maintain and enhance soil quality restoration over time.

A. Description

Soil quality is best maintained by minimizing land-disturbing activities. Design new developments to fit the existing topography to the greatest extent possible. Use a “building envelope” to confine grading activities, construction traffic, stockpiling of materials, and other construction activities within a cordoned-off area.

Where land-disturbing activities can't be avoided, perform soil quality restoration as part of the final landscaping. Soil quality restoration generally must be on a lot-by-lot basis in residential developments. Residential development featuring single-family dwellings typically provides 50% to 70% green space, making the soil profile a potential water management and water storage resource. Typically, urban soil gets compacted and altered during construction. Even though urban green space is covered with vegetation, they may actually have post-development curve numbers of up to 90. Consequently, urban green space is typically "hydrologically dysfunction," meaning these landscapes can not absorb and infiltrate water.

On commercial or other ultra-urban development (i.e., lake shore development, condo or townhouse complexes with limited green space), try to maintain 20% to 30% green space. Locate this green space strategically so that impervious surface runoff can be directed to it in a sheet flow, if possible. With 20% green space and good soil quality to a depth of 1.5 feet, the WQv of runoff generated from an 80% impervious development can be infiltrated and stored. If 30% green space can be maintained, the WQv from the 70% impervious surface can be managed by good soil quality to a depth of 1 foot. Good soil quality is defined as having at least 40% pore space, at least 5% organic matter content, and a healthy population of soil microbes and other species of soil dwellers.

If only 10% of a development site can be maintained as green space, install bioretention cells to manage the WQv from the 90% impervious surface.

B. Stormwater management suitability

Soil quality restoration is applicable on all developable sites. Reducing compaction, increasing soil permeability, and improving the soils quality by increasing organic content will enhance and maintain infiltration and healthy vegetation. This non-structural practice will improve water quality and will improve infiltration. Some reduction in runoff volume will be achieved through increased infiltration.

C. Pollutant removal capabilities

Good soil quality will generally provide for the capture of most of the major pollutants of concern, and would be comparable to a bioretention cell for pollutant removal. Hydrocarbons, bacteria, phosphorous, sediment, metals, etc, are generally captured in the top part of the profile when runoff is infiltrated. A healthy microbial population will break down and utilize many of the pollutants. A pollutant such as nitrogen moving in solution could move past the root zone of turf landscapes with high percolation rates. Incorporating strategic native landscaping along with soil quality restoration is recommended for increased evapotranspiration and more nutrient uptake.

D. Application and feasibility

Some component of soil quality restoration is applicable to almost all Iowa soils. Conditions such as extended periods of high water table could render soil quality restoration not feasible. However, such sites would typically not be developed.

The model to be emulated with soil quality restoration (and other infiltration-based stormwater management practices) is the quality of soil that developed under the native prairie ecosystems that existed across Iowa before European settlement. Most of the prairie soils of Iowa originally had at least 45% pore space, and a minimum of 8-10% organic matter content. Altered and compacted soils have higher bulk density and lower porosity. When soils are compacted the area available for water storage in the soil profile is reduced.

A healthy soil profile with 45% pore space should typically be able to infiltrate anywhere from 0.6 inches to 2 inches of water per hour into the soil profile. The water-holding capacity of most prairie soils should be around 0.2 inches of water per inch of soil profile. Therefore, a soil with 45% porosity should be able to store at least 2.4 inches of rainfall in the first foot of soil profile. This amount of storage capacity is approximately 160% of the water quality volume that SUDAS recommends we design our stormwater management systems to treat for water quality protection.

Pore space volume and size of pores will typically decrease as you move down in a soil profile, but most upland soils will still maintain the ability to store anywhere from 0.15 to 0.2 inches of water per inch of soil profile. Therefore, a healthy 3-foot soil profile has the potential capacity to store 5.4 to 7.2 inches of rain. The intensity of rainfall and the infiltration rates of a soil would determine how much rain can actually be infiltrated and stored before runoff is generated. The potential infiltration and storage capacity of healthy soils makes an infiltration-based and groundwater driven hydrology seem quite feasible, which was the case back when the prairies and other native ecosystems were intact. If we can mimic this type of a hydrology for 90% or more of rainfall events in Iowa, the potential for water quality enhancement and stabilization of stream flows seems quite feasible, as well.

The 8-10% organic matter content of the prairie soils added to the feasibility of historic landscapes being able to absorb and infiltrate most rainfall events. Today, Iowa soils typically have 2-4% organic matter content, and often less on altered construction sites where topsoil has been stripped and exported off-site. Consequently, modern soils have probably lost 60-80% of their ability to absorb, infiltrate, and store rainfall. Therefore, our modern landscapes initiate runoff sooner and shed more total runoff. Consequently, we have a flashier hydrology and more runoff events that transport pollutants to surface waters. Infiltrated rain on the historic landscape moved slowly through the soil matrix to emerge down-gradient as cool, clean groundwater discharge that fed and maintained stable, clean flows in streams and rivers, and clean, stable levels of water in lakes and wetlands. The goal of soil quality restoration (and the other infiltration-based stormwater management practices) is to make our modern urban landscapes mimic the hydrologic functionality of our historic landscapes, at least for the water quality volume (1.25 inches of rain or less).

E. Planning and design criteria

A soil management plan (SMP) should be created for each new development. Soil management plans are needed to treat landscapes as mass grading is completed and infrastructure is installed. A second SMP will usually be needed for individual lots unless land-disturbing activity and traffic are confined within a building envelope.

Soil management plans will typically involve a seven-step process:

- Determine soil conditions (pre- and post-construction).
- Identify areas where soils and vegetation will not be disturbed.
- Determine areas where topsoil will be stripped and stockpiled.
- Determine tillage needs to address compaction.
- Determine the porosity and organic matter content needed to manage the WQv.
- Quantify compost amendments needs and specify methods of amending.
- Specify methods for establishing vegetative cover (i.e. sodding, seeding rates).
- Specify erosion control components needed until vegetation is well established.

First and foremost, existing soil quality should be protected. By minimizing land-disturbing activities, soil profiles are left intact and compaction does not occur. Compaction, which increases bulk density and reduces pore space, is a primary culprit in the creation of hydrologically dysfunctional landscapes. Never compact, place fill, or perform deep till under the drip line of trees to be saved.

Stripping and removing topsoil is another key aspect of post-construction soil quality problems. Topsoil contains the organic matter that is the key to soils being able to absorb water. High organic matter gives soils the ability to absorb water like a sponge. Low organic matter content means soils will be able to absorb less rainfall before runoff is generated. Topsoil should be stripped, stockpiled and returned as part of final grading. Topsoil will typically need to be amended with compost to achieve the desired organic matter content of 5-10%.

Healthy topsoil also harbors microbes that breakdown many of the pollutants transported by stormwater runoff. Replacing topsoil in post-construction and supplementing it with compost to achieve a healthy population of soil microbes is a necessary component of soil quality restoration. If topsoil is not available, compost can be substituted at the rate of 1 inch of compost for 3 inches of topsoil (see compost blanket standards in Chapter 7).

Where land-disturbing activities can not be avoided, deep tillage should be performed as part of the final grading. Tillage should be done to a depth specified in the soil management plan. Tillage should be specified to ensure that landscapes have at least enough porosity to absorb the WQv. Generally, the depth of tillage needed will relate to the amount of green space on a site. Rules of thumb for tillage depth are:

- 70% green space: 6-inch depth of tillage
- 50% green space: 8-inch depth of tillage
- 30% green space: 12-inch depth of tillage
- 20% green space: 18-inch depth of tillage

If compost-amended topsoil will be spread after tillage, depth of tillage may be reduced by the amount of topsoil to be placed; but compacted soils should always be tilled to a minimum depth of 4 inches before the addition of topsoil. Apply at least 1 inch of coarse compost (3/4” to 1 inch) and incorporate with deep tillage to help prevent re-consolidation of tilled soil. Do not re-compact the site while top dressing or placing a compost blanket. Use low ground-contact pressure equipment for the spreading of topsoil and/or compost.

Perform deep tillage when soil moisture conditions are optimum. Optimum conditions are when soil moisture content is ~ 40%. Do not use rotary tillage, as this breaks down soil structure, kills worms, and creates small pore spaces that can re-consolidate. Use ripping tillage tools for deep tillage. Apply compost as specified in the soil management plan to achieve at least 5% organic matter content. Applying some compost before deep tillage is a good way to get some organic matter into the soil profile, but earthworms will move organic matter down into the profile with time. Apply at least a 2-inch compost blanket in conjunction with seeding to provide rapid germination and establishment of vegetative cover. A 2-inch compost blanket will provide erosion control until the site is stabilized by vegetation and will typically achieve at least 5% organic matter content.

Incorporate strategic use of native landscaping and direct impervious surface runoff toward areas with restored soil quality and native landscaping.

F. Design procedures

1. Review grading, landscaping, and soil management plans to ensure soil quality restoration is included as needed.

2. Determine existing soil conditions (bulk density, moisture content, organic matter content).

3. Determine depth and type of tillage needed to achieve 40% minimum pore space to the specified depth.

4. Calculate amount of compost amendment needed

G. Inspection and maintenance requirements

Monitor the site after rainfall events to ensure no erosion is occurring. Monitor weekly and after rains of 0.5 inches until vegetation is well established.

Long-term maintenance involves maintaining organic matter content. Do not remove lawn clippings. Leave clippings on the yard to decompose and recycle nutrients and organic matter. Annual applications of ¼ to ½ inches of compost will maintain or increase organic matter.

If earthworms are not present, inoculate the green space with worms in conjunction with a compost application.

H. Design example

1. **Calculating pore space/available storage in tilled soil profiles.** These calculations assume impervious surfaces will have a runoff coefficient of 1, or 100% runoff onto green space.

   a. Example 1:
   1) 30% impervious and 70% green space (6-inch depth of tillage)
   2) One acre = 43,560 sq ft. x 70% green space = 30,492 sq ft of green space
   3) Available storage: 30,492 sq ft x 0.5 ft (6-inch) depth of tillage x 0.4 (40% pore space) = 6,098 cu ft of pore space in 6 inches of tilled soil profile
   4) Required pore space for WQv: (4,538 cu ft – same for all examples). 27,152 gals/ac/1 inch of rain. 27,152 x 1.25 inch (WQv) = 33,940 gals x 0.1337 cu ft per gal = 4,538 cu ft of pore space needed vs. 6,098 cu ft of available pore space.

   b. Example 2:
   1) 50% impervious and 50% green space (8” depth of tillage)
   2) One acre = 43,560 sq ft. x 50% green space = 21,780 sq ft of green space
   3) Available storage: 21,780 sq ft x 0.67 ft (8 in) depth of tillage x 0.4 (40% pore space) = 5,837 cu ft of pore space in 8 inches of tilled soil profile.
   4) Required pore space for WQv: 4,538 cu ft needed vs. 5,837 cu ft of available pore space.

   c. Example 3:
   1) 70% impervious and 30% green space (12-in depth of tillage)
   2) One acre = 43,560 sq ft. x 30% green space = 13, 068 sq ft of green space
   3) Available storage: 13,068 sq ft x 1 ft (12-in) depth of tillage x 0.4 (40% pore space) = 5,227 cu ft of pore space in 12 inches of tilled soil profile.
   4) Required pore space for WQv: 4,538 cu ft needed vs. 5,227 cu ft of available pore space.

   d. Example 4:
   1) 80% impervious and 20% green space (18-in depth of tillage)
   2) One acre = 43,560 sq ft x 20% green space = 8,712 cu ft of green space
   3) Available storage: 8,712 sq ft x 1.5 ft depth of tillage x 40% pore space = 13,068 cu ft of storage in pore space in 1.5 foot of tilled soil profile.
   4) Required pore space for WQv: 4,538 cu ft needed vs. 5,227 cu ft of available pore space.

2. **Equation for calculating compost application rates.** To achieve a target soil organic matter content, the following equation can be used to calculate compost application rates**:**

$$CR = Dx \frac{[SBD(SOM\% - FOM\%)]}{[SBD(SOM\% - FOM\%) - CBD(COM\% - FOM\%)}$$

where:
CR = Compost application rate (inches)
D = Depth of incorporation (inches)
SBD = Soil bulk density (lb/cubic yard dry weight)
SOM% = Initial soil organic matter (%)
FOM% = Final target soil organic matter (%)
CBD = Compost bulk density (lb/cubic yard dry weight)
COM% = Compost organic matter (%)

Source: Technical Memo for Puget Sound Stormwater BMP Manual
http://www.psat.wa.gov/Programs/LID/PSAT_TechMemo3.pdf

An additional method to achieve a desired organic matter content of about 10% would be to add 1 part compost to 2 parts topsoil (or 25-35% compost amendment by volume). To achieve 5% organic matter content, add 1 part compost to 5 parts topsoil (or about 15-20% compost amendment by volume). These simplified methods assume compost will have an organic matter content of 40-60%.

An Excel compost amendment rate spreadsheet is available for download at http://www.soilsforsalmon.org/resources.htm.

2E-6 Native Landscaping

BENEFITS Low = <30% Medium = 30-65% High = 65-100%			
	Low	Med	High
Suspended Solids	■	■	■
Nitrogen	■	■	■
Phosphorous	■	■	■
Metals	■	■	■
Bacteriological	■	■	■
Hydrocarbons	■	■	■

Description: Native plants are those that grew naturally in Iowa before European settlement, and therefore are well-adapted to this environment. The tallgrass prairie ecosystem developed in Iowa over 10,000 years ago. It was an extremely diverse habitat that consisted of grasses, forbs (flowering plants), insects, and other animals. It adapted to survive conditions that ranged from hot and dry to moist and boggy in any given year; in addition to severe winters, frequent high winds, grazing by buffalo, and routine fire. The response to this ever-changing environment was the development of deep, fibrous root systems commonly reaching 6-12 inches deep. These root systems led to the development of Iowa's fertile soils, and can still contribute significantly to soil quality enhancement. Carefully chosen native plants can be used in a wide variety of infiltration and filtration practices to increase water quality. Landscaping with native plants provides color and habitat, and is an important component for engineered practices to capture and treat the water quality volume and the first flush of runoff from larger storms.

Typical uses:

- Used in conjunction with engineered water management practices.
- Used for runoff management from residential, commercial, and institutional sites.
- Used in rain gardens, bioretention areas, vegetated swales, and basins.

Advantages/benefits:

- Reduces runoff rate and volume from impervious areas in infiltration practices.
- Removes sediment and pollutants to improve water quality.
- Plants are beautiful, hardy, drought-resistant, and low-maintenance.
- Provides aesthetic value and habitat for beneficial insects and animals.
- Reduces the need for inputs from fertilizers, pesticides, water, and mowing.

Disadvantages/limitations:

- Maintenance techniques are not as widely-known as for turf grass.
- Establishment takes longer than turf grass, especially with seeded areas.

Maintenance requirements:

- Annual removal of vegetation growth through burning, or mowing and baling/raking.
- Plantings need to be watered and weeded regularly during establishment.
- Maintenance goes down after establishment (2-3 years).

A. Description

Landscaping with native plants is a simple way to obtain multiple benefits while mimicking the native ecosystems of the tallgrass prairie, oak savannas, woodlands, and wetlands. Native species are lowmaintenance once established because they are adapted to Iowa temperatures, wind, and rainfall patterns. Properly-designed native landscaping can improve the value of the site, improve aesthetics, support wildlife, increase soil and water quality, and absorb noise.

Through plant uptake, plants can bind nutrients and other pollutants, and remove water through evapotranspiration. Pathways for rainfall infiltration will be created through root development, which

also contributes to a healthy soil structure. Each year, a part of the deep root mass of native plant dies off and decomposes. This annual organic matter deposition helps build soil organic carbon, which in turn helps the soil absorb more water. Soil microbes help bind together particles of sand, silt, and clay, along with organic matter, creating a more granular soil structure, which increases porosity and water holding capacity. An additional benefit of the deep root system is seen when native plants also resist local pests and disease. Natives do not get as stressed as typical non-native species during droughts or other severe environmental conditions common in Iowa.

Native species bloom at a variety of times throughout the growing season and attract butterflies and birds often not seen in non-native landscapes. Native plants attract this variety of beneficial birds, butterflies, insects, and other wildlife by providing diverse habitats and food sources. Conversely, closely-mowed lawns are of little benefit to most wildlife.

B. Stormwater management suitability

Native plants are used in many areas that are designed to infiltrate and temporarily store the water quality volume (WQv).

C. Pollutant removal capabilities

Native plants do not require fertilizers or pesticides, and will eliminate their use when replacing sod lawns. Typically, lawns also require significant amounts of watering to survive, which often results in additional runoff of water and pollutants. Weekly emissions from lawn mowing equipment used on typical sod lawns also contribute to air pollution. Native plants remove carbon from the air and sequester it in the soil. Sequestered atmospheric carbon increases soil organic matter, which increases the soil's ability to absorb water. Deeply-rooted native plants increase the soil's capacity to store water and reduce water runoff.

D. Application and feasibility

Native landscaping plants can be used in most of the infiltration and filtration practices. They can also be used as a landscape amenity. Application and feasibility are dependent on the type of application. Various native plants were adapted to dry, mesic, or wet landscapes. Consider your landscape or type of practice and choose plant species that will work best.

1. **Dry soils.** Dry soils are typically found in well-drained, exposed areas. They are more common on south-facing slopes where it is warmest and driest during the summer.

2. **Mesic soils.** Mesic refers to areas that are well-drained, yet moist like a typical vegetable garden. Mesic sites are not overly wet or dry.

3. **Wet soils.** Wet sites often occur low on the landscape and have a high water table. Lists of recommended species and those to avoid are available on the Iowa Native Lands website (http://www.prrcd.org/inl/recommended_plants.htm). Additional guidance is provided in the SUDAS Landscaping Specification (Section 9010).

E. Planning and design criteria

Native prairie plantings can be established from seed or plugs (young, rooted plants). Plugs are better than seed in smaller projects in residential areas because they are easier to establish and maintain. Natives can be incorporated into an existing garden bed, or a new bed can be made by removing sod and loosening the soil. Try to avoid putting native plants in soils that have been fertilized, as this often results in overly tall growth far beyond typical for that species.

In residential settings, it is usually best to use shorter native plants to create an aesthetically-pleasing landscape. This means avoiding species that grow more than 4 feet tall, such as big blue stem, Indian grass, compass plant, and cup plant. Native plants can be designed into any sunny landscape, but rarely do well in deep shade. Woodland species can tolerate shade but often do not have deep root systems.

Native plants can be intermingled in more formal beds and borders, or incorporated as a more natural informal prairie garden. Turf borders should be left to define the area or provide a path through the planting.

Strategically-placed native species plantings can function similarly to engineered infiltration- and filtration-based practices. Choose plants based on site considerations for light, moisture, and soil. Vary plant structure, height, bloom succession, and flower color for seasonal appeal and butterfly habitat. After planting, a shredded-wood mulch layer helps establish natives by retaining moisture and discouraging weeds, but may float if water pools. A few small rocks can help overcome this problem during the establishment phase.

F. Design procedures

Design procedures generally involve matching plant or seed mix selection to the soils, moisture regimes, and aspect of a site. Plant height, color scheme, and shade or open sun tolerance all come into play in plant selection for a site. A number of native nurseries have pre-selected mixes for various conditions; care should be taken with those mixes to ensure the species are appropriate for the site and don't get overly tall. Native seed supplies often provide information on preferences of various species if you want to create your own blend. Species lists for plant suitable for Iowa native landscaping are online at: http://www.prrcd.org/inl/recommended_plants.htm. See the SUDAS Seeding Specification (9010) for more information.

Always plant mowed turf borders or low-growing native turf around native landscaping in an urban setting to provide a border and kept appearance. In plantings such as bio-retention areas, consider a border planting of shorter prairie grasses, such as prairie dropseed, just inside the turf border. Border plantings increase social acceptance of native landscaping sites. Design the planting to accommodate fire management whenever possible.

Develop all mixtures based on pure live seed. Exclude or keep aggressive grasses like switchgrass or other cultivars to a minimum, or eliminate entirely. If the site is within one mile of an existing native prairie (not a reconstructed prairie), local ecotypes are recommended.

1. **Using live plants.** On small urban plantings, it is usually best to buy live plants. Plants should be spaced 12-18 inches apart. Live plantings will establish more quickly than seed, and provide an aesthetically-pleasing site, usually in the first year.

2. **Seeding recommendations.** When seeding a mix of native plants, plan on it taking about three years to get good establishment (ground cover). Native plants spend the first year or two developing deep root systems before putting much energy into above-ground growth. Therefore, a

good maintenance plan is essential to keep the site mowed and/or weeded, to protect plants from weedy competition, and avoid unsightly-looking areas that can turn public opinion against native landscaping.

3. **Native turf.** A new alternative showing promise for certain settings is the use of a native turf mix. A native turf features a blend of low-growing native grasses that would provide more a lawn-like appearance, while providing deep, fibrous root systems that will help build and maintain soil quality. Mowing on native turf plantings could be eliminated, and the height of the vegetation would stay in the 8 to 18-inch range. Or, mowing could be done on a limited basis (once a month or less). It should be noted that native grasses are warm-season grasses, which means they respond to the increased sunlight as days grow longer and hotter. Therefore, native turf will not break dormancy and green up as early in the growing season as cool season sod lawns. However, they will be green and growing during the long, hot days of summer when nonnative cool season turf often goes dormant in response to the hot, dry conditions. Native turf will not need fertilization or watering after the root systems are established. A way to irrigate should be provided the first, and possibly the second, year to ensure good establishment; but after root development has been achieved, no more irrigation will be necessary.

G. Inspection and maintenance requirements

Native prairie plantings require less maintenance than turf grass and non-native gardens, but still need routine weeding and watering until established. Fertilizer is not recommended for prairie plantings, as it can stimulate excessive growth and cause plants to flop over. Dead vegetation should be removed in the fall or spring. Delaying this step until spring will allow winter landscape interest and provide seed and cover for over-wintering birds. Remove dead vegetation by burning, mowing, raking, and/or baling the residue.

2F-1 Sand Filter

BENEFITS Low = <30% Medium = 30-65% High = 65-100%			
	Low	Med	High
Suspended Solids			■
Nitrogen	■		
Phosphorous		■	
Metals		■	
Bacteriological		■	
Hydrocarbons		■	

Description: A sand filter is a multi-chamber structure designed to treat stormwater runoff through filtration, using a sediment forebay and a sand bed as its primary filter media. In some cases, a third chamber may be used to collect filtered runoff. Typically, an underdrain is used to return the filtered runoff to the conveyance system.

Typical uses: High-density/ultra-urban location where available land is restricted, such as a receiving area for runoff from an impervious site.

Advantages/benefits:

- Stormwater filters have their greatest applicability for small development sites – drainage areas of up to 5 surface acres.
- Good for highly impervious areas.
- Good retrofit capability.
- Good for areas with extremely limited space.
- Can provide runoff quality control, especially for smaller storms; generally provide reliable rates of pollutant removal through careful design and regular maintenance.
- No restrictions on soils at installation site if filtered runoff is returned to the conveyance system.

Disadvantages/limitations:

- High maintenance burden.
- Not recommended for areas with high sediment content in stormwater or areas receiving significant clay/silt runoff.
- Relatively costly.
- Possible odor problems.
- Porous soil required at site, if filtered runoff is to be exfiltrated back into the soil.
- Not recommended for residential developments due to higher maintenance burden.

Maintenance requirements:

- Inspect for clogging – rake first inch of sand.
- Remove sediment from forebay/chamber.
- Replace sand filter media as needed.

A. Description

Sand filters are structural stormwater controls that capture and temporarily store stormwater runoff and pass it through a filter bed of sand. Most sand filter systems consist of two or three chambered structures. The first chamber is a sediment forebay or sedimentation chamber, which removes floatables and heavy sediments. The second is the main filtration chamber, which removes additional pollutants by filtering the runoff through a sand bed. A third chamber is sometimes utilized to collect the filtered runoff. The filtered runoff is typically returned to the conveyance system by an

underdrain, though it can also be partially or fully exfiltrated into the surrounding soil in areas with porous soils. Because they have few site constraints besides head requirements, sand filters can be used on development sites where the use of other structural controls may be precluded. However, sand filter systems can be relatively expensive to construct and install.

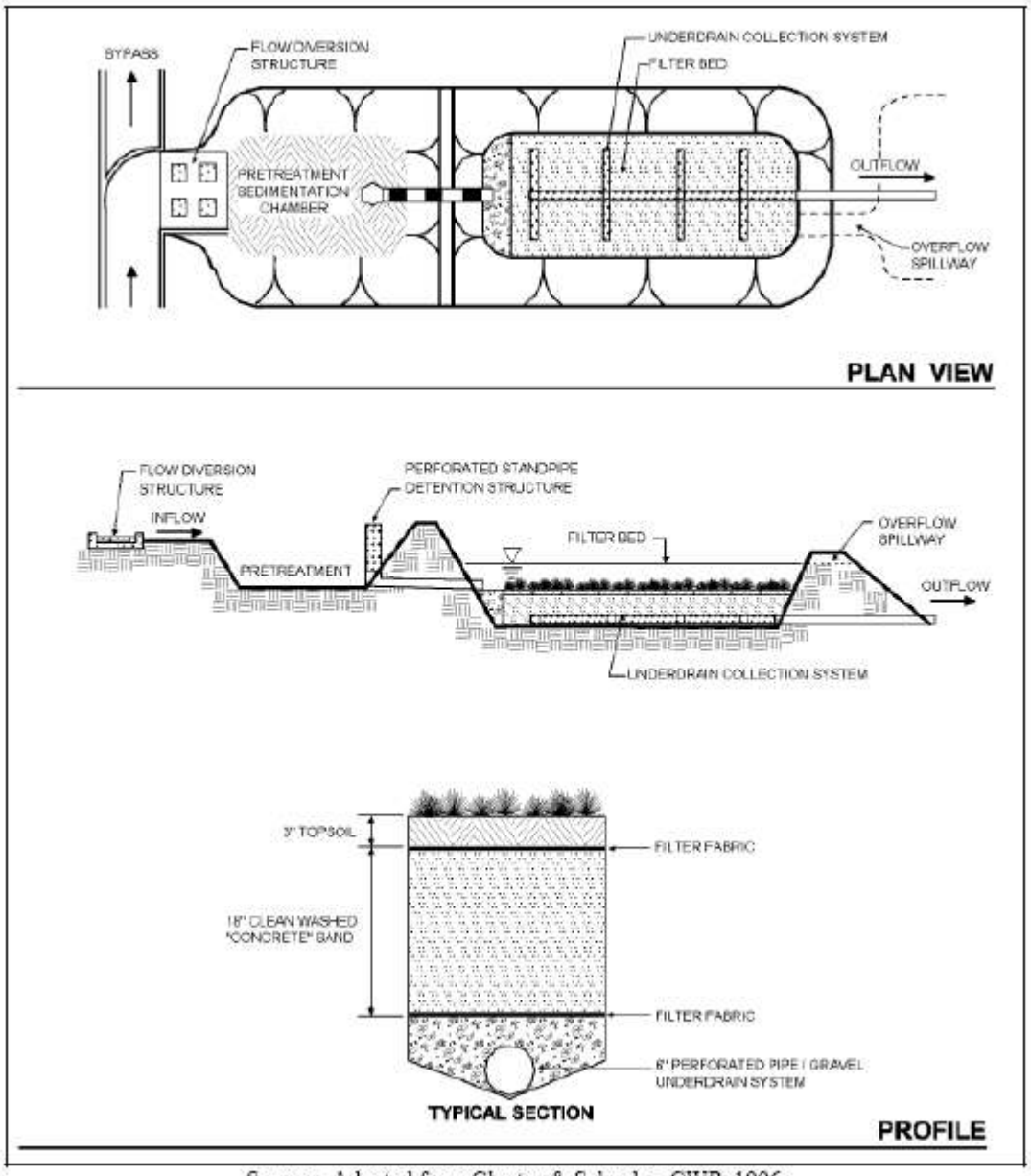
There are three sand filter system design variants: the surface sand filter, perimeter sand filter, and underground sand filter. Descriptions of these filter systems are provided below:

1. **Surface sand filter.** The surface sand filter is a ground-level open-air surface structure that consists of a pre-treatment sediment forebay and a filter bed chamber (Figures 1 and 2). This system is typically used to treat drainage areas 2-10 acres in size and is typically located off-line. Surface sand filters can be designed as an excavation with earthen embankments or as a concrete or block structure. A flow splitter is used to divert the first flush of runoff into an off-line sedimentation chamber. The chamber may be either wet or dry, and is used for pre-treatment. Coarse sediments drop out as the runoff velocities are reduced. Runoff is then distributed into the second chamber, which consists of 18-24-inch deep sand filter bed and temporary runoff storage above the bed. Pollutants are trapped or strained out at the surface of the filter bed. The filter bed surface may have optional sand or grass cover. A series of perforated pipes located in a gravel bed collect the runoff passing through the filter bed, and return it into the stream or channel at a downstream point. If underlying soils are permeable, and groundwater contamination unlikely, the bottom of the filter bed may have no lining, and all or part of the filtered runoff may be allowed to exfiltrate into the soil.

2. **Perimeter sand filter.** The perimeter sand filter is an enclosed filter system typically constructed just below grade in a vault along the edge of an impervious area such as a parking lot (Figure 3). First developed by Shaver and Baldwin (1991), the system consists of two parallel trench-like chambers installed along the perimeter of a parking lot. This system is usually used to treat drainage areas up to 2 acres in size, and consists of a sedimentation chamber and a sand bed filter. Runoff flows into the first chamber through a series of inlet grates located along the top of the control. The first trench provides pre-treatment through sedimentation in a shallow permanent pool of water before the runoff spills into the second trench, which consists of an 18-inch deep sand layer. During a storm event, runoff is temporarily detained above the normal pool and sand layer. When both chambers fill up to capacity, excess parking lot runoff is routed to a bypass drop inlet. The remaining runoff is filtered through the sand, collected by underdrain piping, and delivered to a protected outflow point.

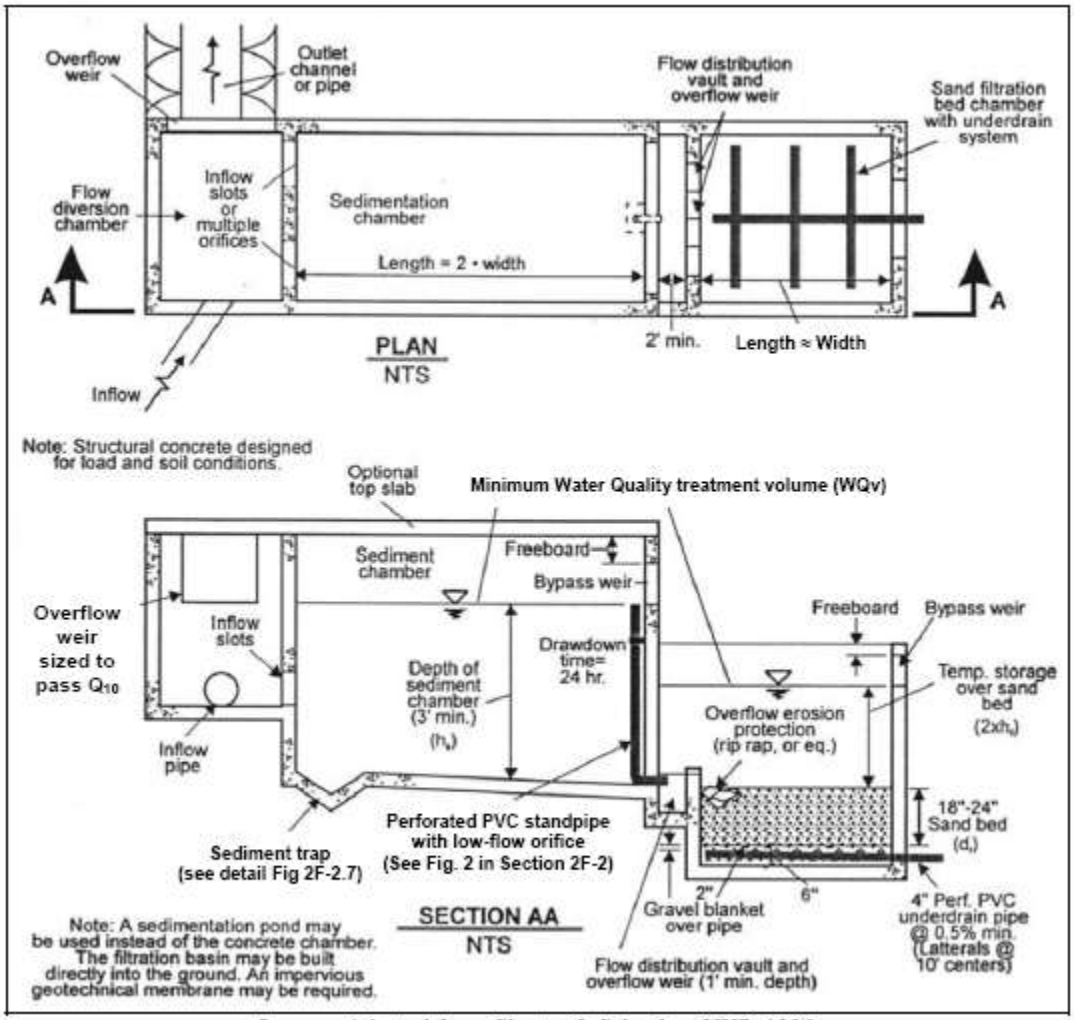
3. **Underground sand filter.** The underground sand filter is intended primarily for extremely space-limited and high-density areas. In this design, the sand filter is placed in a three-chamber underground vault (either on-line or off-line) accessible by manholes or grate openings (Figure 4). The initial chamber, a sedimentation (pre-treatment) chamber, temporarily stores runoff and utilizes a wet pool to capture sediment. The sedimentation chamber is connected to the sand filter chamber by a submerged wall that protects the filter bed from oil and debris. The filter bed is 18-24 inches deep and may have a protective screen of gravel or permeable geotextile to limit clogging. During a storm, the water quality volume (WQv) is temporarily stored in both the first and second chambers. Flows in excess of the filter's capacity are diverted through an overflow weir. The sand filter chamber also includes an underdrain system with inspection and cleanout wells. Perforated drain piping under the sand filter bed extends into a third chamber that collects filtered runoff.

Figure 1: Surface sand filter (earthen structure)



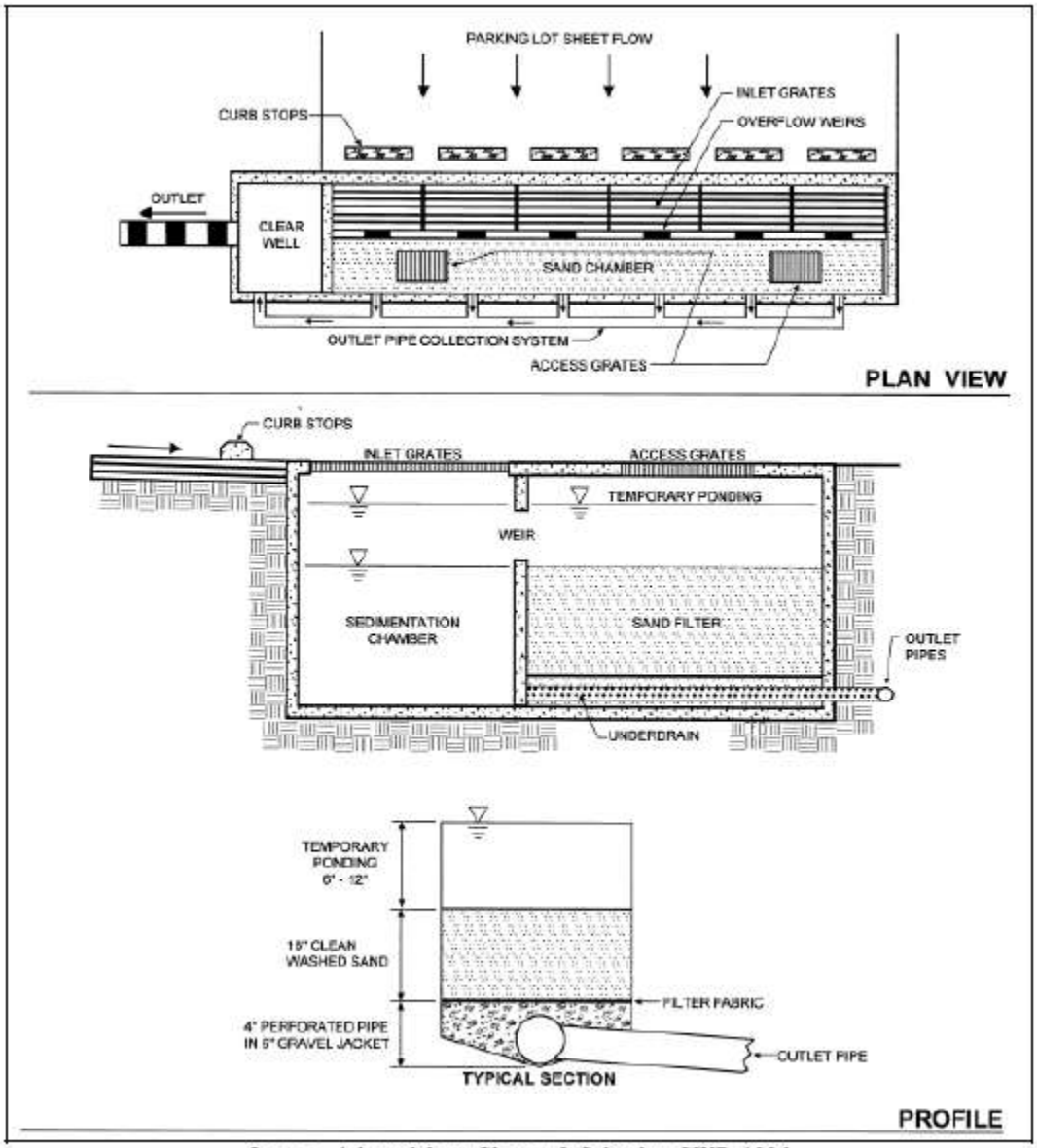
Source: Adapted from Claytor & Schueler, CWP, 1996

Figure 2: Surface sand filter (concrete structure)



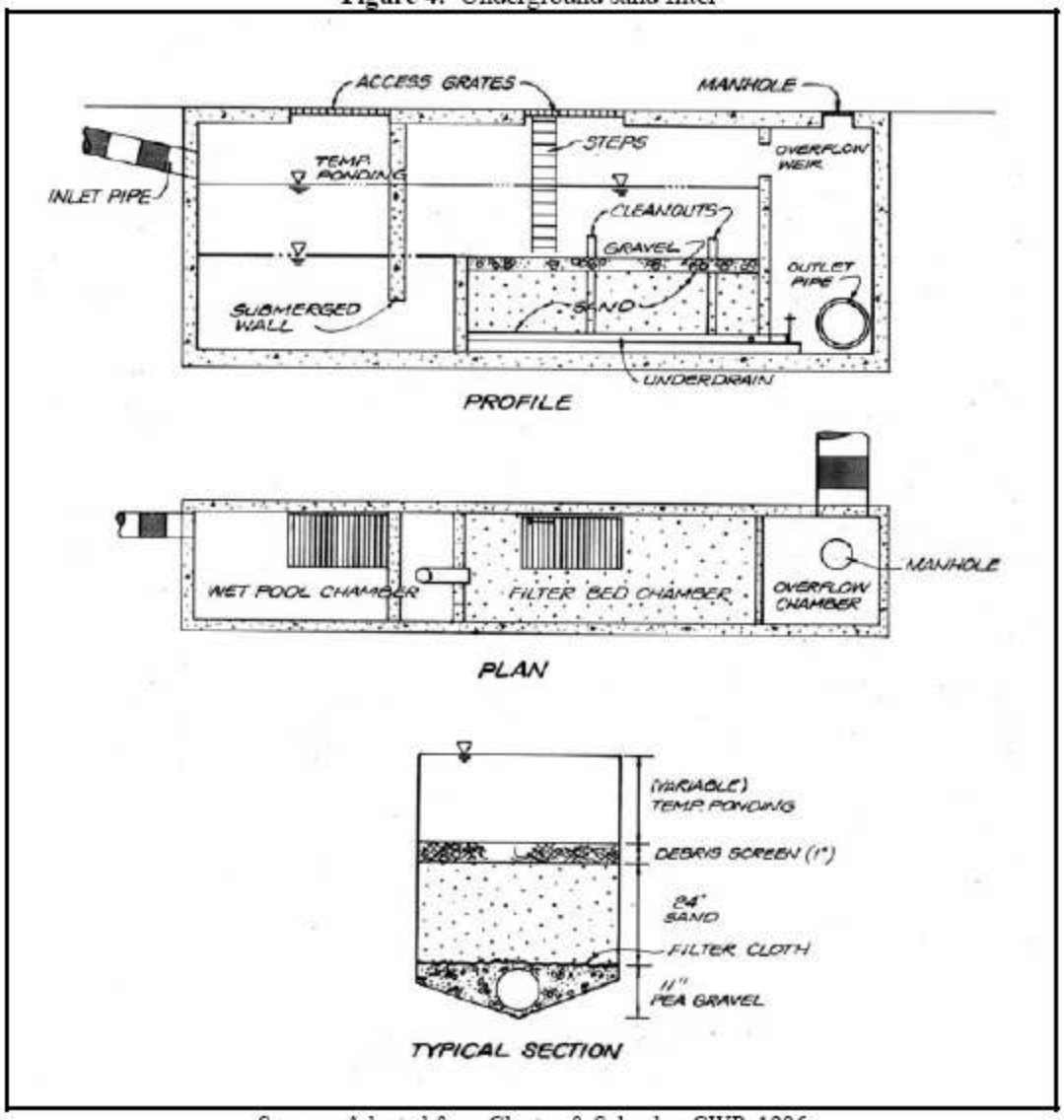
Source: Adapted from Claytor & Schueler, CWP, 1996

Figure 3: Perimeter sand filter



Source: Adapted from Claytor & Schueler, CWP, 1996

Figure 4: Underground sand filter



Source: Adapted from Claytor & Schueler, CWP, 1996

Figure 5: Surface sand filter

Figure 6: Perimeter sand filter

B. Stormwater management suitability

Sand filter systems are designed primarily as off-line systems for stormwater quality (i.e., the removal of stormwater pollutants) and will typically need to be used in conjunction with another structural control to provide downstream channel protection, overbank flood protection, and extreme flood protection, if required. However, under certain circumstances, filters can provide limited runoff quantity control, particularly for smaller storm events.

1. **Water quality.** In sand filter systems, stormwater pollutants are removed through a combination of gravitational settling, filtration, and adsorption. The filtration process effectively removes suspended solids and particulates, biochemical oxygen demand (BOD), fecal coliform bacteria, and other pollutants. Surface sand filters with a grass cover have additional opportunities for bacterial decomposition, as well as vegetation uptake of pollutants, particularly nutrients. See Pollutant Removal Capabilities for planning and design purposes.

2. **Channel protection.** For smaller sites, a sand filter may be designed to capture the entire channel protection volume, CPv, in either an off-line or on-line configuration. Given that a sand filter system is typically designed to completely drain over 40 hours, the requirement of extended detention of the 1-year, 24-hour storm runoff volume will be met. For larger sites or where only the WQv is diverted to the sand filter facility, another structural control must be used to provide Cpv extended detention.

3. **Overbank flood protection.** Another structural control must be used in conjunction with a sand filter system to reduce the post-development peak flow of the 25-year storm (Qp) to redevelopment levels (detention).

4. **Extreme flood protection.** Sand filter facilities must provide flow diversion and/or be designed to safely pass extreme storm flows and protect the filter bed and facility.

C. Pollutant removal capabilities

The following design pollutant removal rates are conservative average pollutant reduction percentages for design purposes derived from sampling data, modeling, and professional judgment. In a situation where a removal rate is not deemed sufficient, additional controls may be put in place at the given site in a series or treatment train approach.

- Total suspended solids – 80%
- Total phosphorous – 50%
- Total nitrogen – 25%
- Fecal coliform – 40%
- Heavy metals – 50%

D. Application and feasibility

1. **General feasibility.**
   a. Suitable for Residential Subdivision Usage – no

   b. Suitable for High Density/Ultra Urban Areas – yes

c. Regional Stormwater Control – no

2. **Physical feasibility – physical constraints at project site.**
   a. **Drainage area.** 10 acres maximum for surface sand filter; 2 acres maximum for perimeter sand filter.

   b. **Space required.** Function of available head at site.

   c. **Site slope.** No more than 6% slope across filter location.

   d. **Minimum head.** Elevation difference needed at a site from the inflow to the outflow: 5 feet for surface sand filters; 2-3 feet for perimeter sand filters.

   e. **Minimum depth to water table.** For a surface sand filter with exfiltration (earthen structure), 2 feet are required between the bottom of the sand filter and the elevation of the seasonally high water table.

   f. **Soils.** No restrictions; Group A soils generally required to allow exfiltration (for surface sand filter earthen structure).

   g. **Other constraints/considerations.** Aquifer protection: do not allow exfiltration of filtered hotspot runoff into groundwater.

E. Planning and design criteria

The following criteria are to be considered minimum standards for the design of a sand filter facility:

1. **Application and site feasibility criteria.** Sand filter systems are well-suited for highly impervious areas where land available for structural controls is limited. Sand filters should primarily be considered for new construction or retrofit opportunities for commercial, industrial, and institutional areas where the sediment load is relatively low, such as parking lots, parking ramps, driveways, loading docks, gas stations, garages, airport runways/taxiways, and storage yards. Sand filters may also be feasible and appropriate in some multi-family or higher density residential developments.

2. **Initial selection criteria.**

   a. Is the filter appropriate for the type of development being considered?

   b. Do site conditions such as space consumption, available head, cost, or maintenance consideration favor the use of the proposed design?

   c. How effective is the stormwater filter design in removing the key pollutants of concern?

The following physical constraints should be evaluated to ensure the suitability of a sand filter facility for meeting stormwater management objectives on a site or development:

3. **Location and siting.**
   a. Surface sand filters should have a contributing drainage area of 10 acres or less. The maximum drainage area for a perimeter sand filter is 2 acres.

b. **Minimum head.** Elevation difference needed at a site from the inflow to the outflow: 5 feet for surface sand filters; 2-3 feet for perimeter sand filters.

c. **Minimum depth to water table.** For a surface sand filter with exfiltration (earthen structure), 2 feet are required between the bottom of the sand filter and the elevation of the seasonally high water table.

d. **Soils.** No restrictions; HSG A soils generally required to allow exfiltration (for surface sand filter earthen structure)

e. **Pre-treatment**. Any disturbed areas within the sand filter facility drainage area should be identified and stabilized. Sites with less than 50% imperviousness or high clay/silt sediment loads must not use a sand filter without adequate pre-treatment due to potential clogging and failure of the filter bed. Filtration controls should only be constructed after the construction site is stabilized.

f. Hydraulic loading.

1) **Quantity**. Surface sand filters are generally used in an off-line configuration where water is diverted to the filter facility through the use of a flow diversion structure and flow splitter. Likewise, flow greater than the capacity of the surface sand filter is diverted to other controls or downstream using a flow diversion structure or flow splitter.

2) **Flow pattern.** Sand filter systems are designed for intermittent flow and must be allowed to drain and re-aerate between rainfall events. They should not be used on sites with a continuous flow from groundwater, sump pumps, or other sources.

g. Perimeter sand filters are typically sited along the edge, or perimeter, of an impervious area such as a parking lot.

F. Flow regulation

1. Since sand filters are designed to provide treatment for the WQv only, they should be located offline from the primary conveyance/detention system.

2. Sand filters should be located where they can intercept as much of the site impervious area as possible and where discharge to the primary conveyance system is feasible.

3. Off-line designs are recommended for sand filter systems to avoid mixing with larger storm events which are likely to re-suspend settled solids within the sedimentation chamber, scour the filter bed, or otherwise compromise the pollutant removal effectiveness of these facilities.

4. The design objective is to capture and divert the WQv to the sand filter and bypass larger storms to the downstream storm drainage system or receiving water. WQv is computed based on the methods identified in Parts 2B and 2C.

5. In most Iowa jurisdictions, the enclosed conveyance systems are sized for the 5-10 year storm event. Open channel systems may be sized for larger events. A flow diversion structure must be able to accommodate these larger flows as well as the water quality storm.

6. Two methods for diverting the WQv include computing a peak discharge (Qp) for the water quality storm (See Section 2C-7), and

a. Using an isolation/diversion structure upstream and within the drainage network as shown in Figure 7.

b. Incorporating the isolation/diversion structure within the treatment practice itself as shown in Figure 6.

7. The preferred method for accomplishing a diversion is within the treatment practice itself, where the overflow (or bypass) weir elevation is set equal to the design WQv elevation within the adjacent practice. This method ensures larger inflows will overflow the bypass weir, thus minimizing mixing within the BMP. It is also a more reliable capture technique than reliance on computed Qp to size the diversion structure.

8. It is still necessary to compute the Qp to size the intake slots or openings. The openings directing runoff to the treatment practice should be slightly oversized to ensure that the entire WQv is treated.

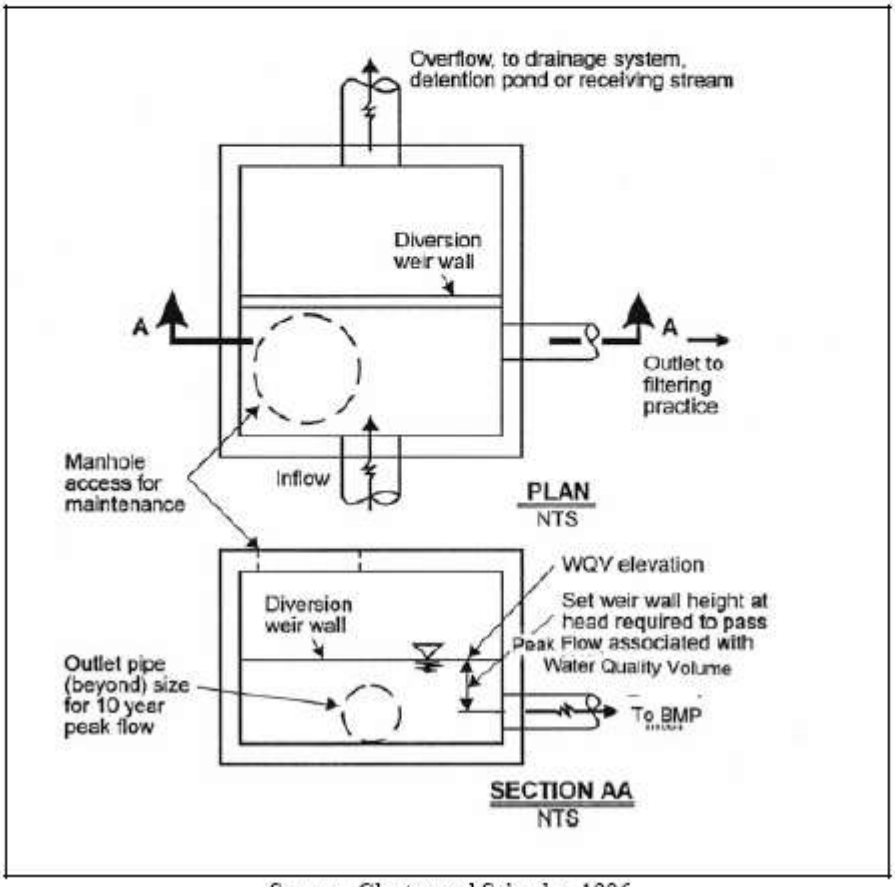
9. In many cases, however, it is not possible to maintain the necessary geometry and elevations to locate the isolation/diversion structure within the treatment practice itself. An alternative technique for isolation/diversion within the drainage network is described in Table 1.

Table 1: Design procedures for diversion of WQv within the drainage network

STEPS	CALCULATION
1	Peak discharge (Qp) for WQv is computed based on the methods presented in Parts 2B and 2C.
2	Qp for the bypass storm is computed (most jurisdictions use the 10-year frequency storm). Use the Rational Formula or NRCS WinTR-55.
3	Size diversion slots/openings or pipe utilizing the orifice equation: $Q = CA(2gh)^{0.5}$
4	Size overflow weir for bypass storm using the weir equation: $Q = CLh^{3/2}$ Size the outfall pipe, if provided, using the orifice equation (to check inlet condition flow capacity) and Manning's equation to check friction losses.

Source: Claytor and Schuler, 1996

Figure 7: Isolation/diversion structure



Source: Claytor and Schueler, 1996

2G-2 Dry Detention

Source: Georgia Stormwater Manual, 2002

Pollutant Removal Low = <30% Medium = 30-65% High = 65-100%			
	Low	Med	High
Suspended Solids	■	■	
Nitrogen	■		
Phosphorous	■	■	
Metals		■	
Bacteriological	■		
Hydrocarbons	■		

Description: A dry detention or extended dry detention basin is a surface storage basin or facility designed to provide water quantity control through detention and/or extended detention of stormwater runoff.

Typical uses: Residential subdivision, high-density residential, ultra-urban areas, and parking lots. Also used for regional detention facilities.

Advantages:

- Applicable for drainage areas up to 75 acres.
- Typically less costly than stormwater (wet) ponds for equivalent flood storage, as less excavation is required.
- Used in conjunction with water quality structural control.
- Recreational and other open space opportunities between storm runoff events.

Limitations:

- Controls for stormwater quantity only – not intended to provide water quality treatment.

Maintenance requirements:

- Remove sediment accumulation to ensure proper functioning.
- Inspect for clogging – install an integrated observation well/peizometer to check water level.
- Remove sediment from pre-treatment areas.

A. Description

Dry detention and dry extended detention (ED) basins are surface facilities intended to provide for the temporary storage of stormwater runoff to reduce downstream water quantity impacts. These facilities temporarily detain stormwater runoff, releasing the flow over a period of time. They are designed to completely drain following a storm event and are normally dry between rain events.

Dry detention basins are intended to provide overbank flood protection (peak flow reduction of the 5-year (Qp_5) through 25-year storm (Qp_{25}), and can be designed to control the extreme flood (100-year, Qf) storm event.

Dry ED basins provide downstream channel protection through extended detention of the channel protection volume (CPv), and can also provide Qp_{25} and Qf control. Both dry detention and dry ED basins provide limited pollutant removal benefits, and are not intended for water quality treatment. Detention-only facilities must be used in a treatment train approach with other structural controls that provide treatment of the WQv. Compatible multi-objective use of dry detention facilities is strongly encouraged.

B. Design criteria and physical specifications

1. Location:

a. Dry detention and dry ED basins are to be located downstream of other structural stormwater controls providing treatment of the water quality volume.

b. The maximum contributing drainage area to be served by a single dry detention or dry ED basin is 75 acres.

2. General design:

a. Dry detention basins are sized to temporarily store the volume of runoff required to provide overbank flood (Qp_5-Qp_{25}) protection (i.e., reduce the post-development peak flow of the 25-year storm event to the pre-development rate), and control the 100-year storm (Qf) if required.

b. Dry ED basins are sized to provide extended detention of the channel protection volume over24 hours and can also provide additional storage volume for normal detention (peak flow reduction) of Qp_{25} and Qf.

c. Routing calculations must be used to demonstrate that the storage volume is adequate. See Section 2C-11 for procedures on the design of detention storage.

d. Storage volumes greater than 100 acre-feet are subject to the requirements of the Iowa dams and impoundment regulations (IAC 567-Chapters 70-73) and Iowa DNR Technical Bulletin No. 16 (December 1990).

e. Vegetated embankments should be less than 20 feet in height and have side slopes no steeper than 3:1 (horizontal to vertical), although 4:1 is preferred. Riprap-protected embankments should be no steeper than 3:1. Geotechnical slope stability analysis is recommended forembankments greater than 10 feet in height and is mandatory for embankment slopes steeper than those given above. All embankments must be designed to State of Iowa guidelines for dam safety Iowa DNR Tech Bulletin #16.

f. The maximum depth of the basin should not exceed 10 feet.

g. Areas above the normal high water elevations of the detention facility should be sloped toward the basin to allow drainage and to prevent standing water. Careful finish grading is required to avoid creation of upland surface depressions that may retain runoff. The bottom area of storage facilities should be graded toward the outlet to prevent standing water conditions.

h. A low-flow or pilot channel across the facility bottom from the inlet to the outlet (often constructed with riprap) is recommended to convey low flows and prevent standing water conditions.

i. Adequate maintenance access must be provided for all dry detention and dry ED basins.

3. Inlet and outlet structures:

a. Inflow channels are to be stabilized with flared riprap aprons, or the equivalent. A sediment forebay sized to 0.1 inches per impervious acre of contributing drainage should be provided for dry detention and dry ED basins that are in a treatment train with off-line water quality treatment structural controls.

b. For a dry detention basin, the outlet structure is sized for control of the Qp5 through Qp25 (based upon hydrologic routing calculations) and can consist of a weir, orifice, outlet pipe, combination outlet, or other acceptable control structure. Small outlets that will be subject to clogging or are difficult to maintain are not acceptable.

c. For a dry ED basin, a low-flow orifice capable of releasing the channel protection volume over 24 hours must be provided. The channel protection orifice should have a minimum diameter of 3 inches and should be adequately protected from clogging by an acceptable external trash rack. The orifice diameter may be reduced to 1 inch if internal orifice protection is used (e.g., an over-perforated vertical stand pipe with 0.5-inch orifices or slots that are protected by wire cloth and a stone filtering jacket). Adjustable gate valves can also be used to achieve this equivalent diameter. See Section 2C-13 for more information on the design of outlet works.

d. Seepage control or anti-seep collars should be provided for all outlet pipes.

e. Riprap, plunge pools or pads, or other energy dissipators are to be placed at the end of the outlet to prevent scouring and erosion. If the basin discharges to a channel with dry weather flow, care should be taken to minimize tree clearing along the downstream channel, and to reestablish a forested riparian zone in the shortest possible distance. See Section 2N-2 for more guidance on energy dissipation design.

f. A secondary (emergency) spillway is to be included in the stormwater pond design to safely pass the extreme flood flow. The spillway prevents pond water levels from overtopping the embankment and causing structural damage. The secondary spillway must be designed to Iowa DNR standards, and must be located so that downstream structures will not be impacted by spillway discharges.

g. A minimum of 1 foot of freeboard must be provided, measured from the top of the water surface elevation for the extreme flood, to the lowest point of the dam embankment not counting the secondary spillway.

h. For structures without a secondary spillway, the top of dam (embankment) elevation should be 2 feet higher than the peak flood elevation expected during the freeboard design flood.

C. Inspection and maintenance requirements

Table 1: Typical maintenance activities for dry detention/dry ED basins

Activity	Schedule
• Remove debris from basin surface to minimize outlet clogging and improve aesthetics. • Inspect installed low-flow orifices in ED basins for clogging	Annually and following significant storm events
• Remove sediment buildup • Repair and re-vegetate eroded areas • Perform structural repairs to inlet and outlets	As needed, based on inspection
• Mow to limit unwanted vegetation	Routine

Source: Denver Urban Storm Drainage Manual, 1999

D. Example schematics

Figure 1: Schematic of dry detention basin

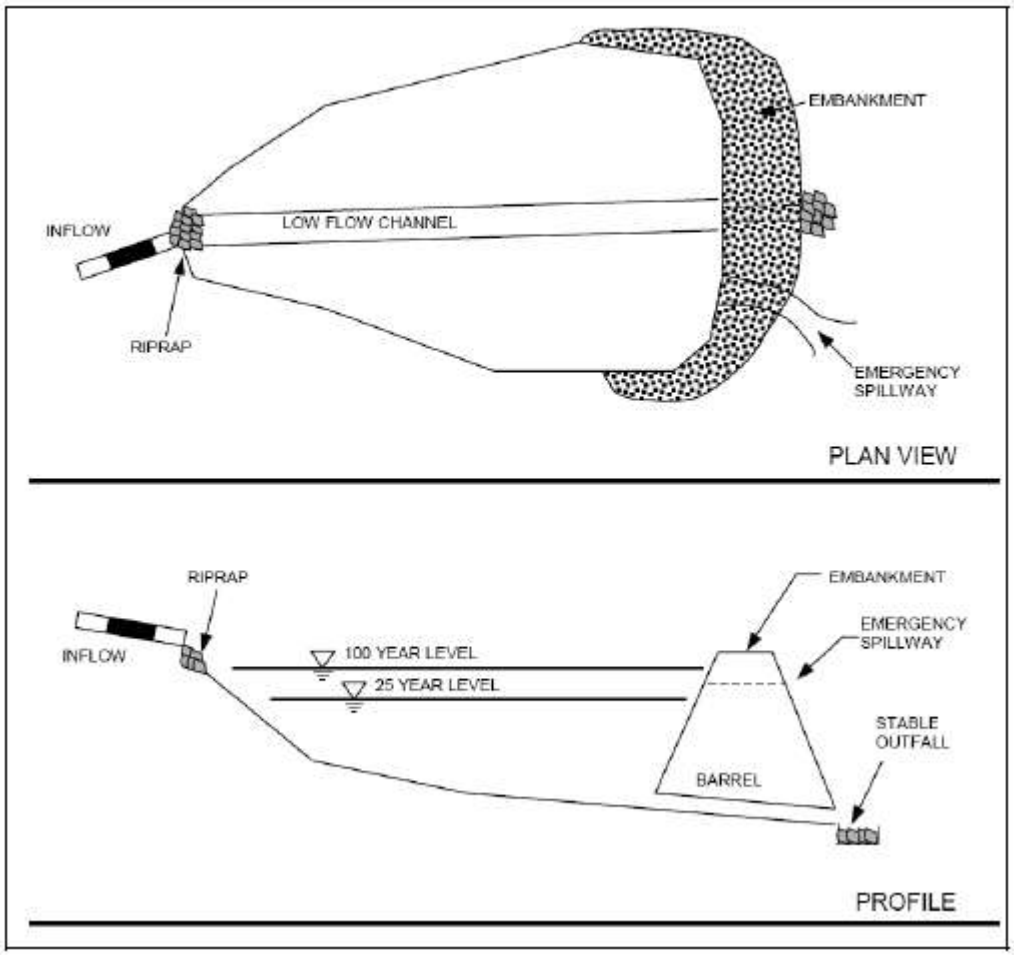
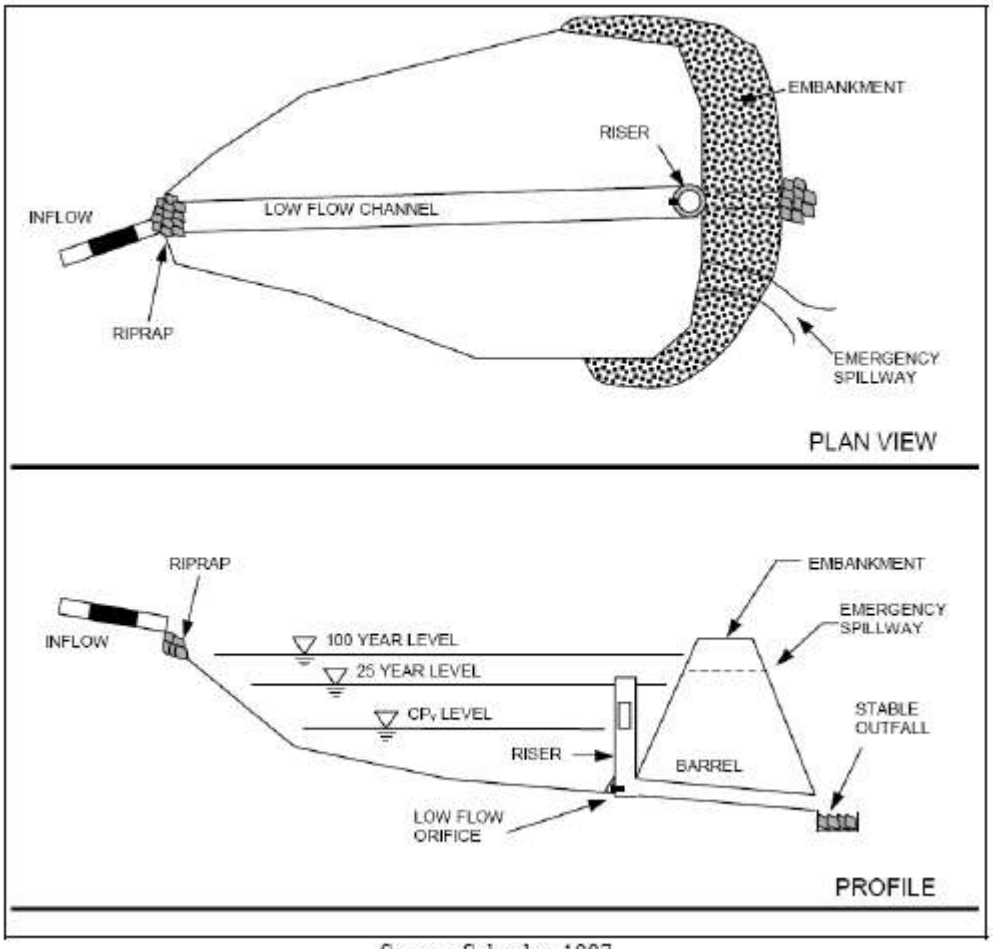
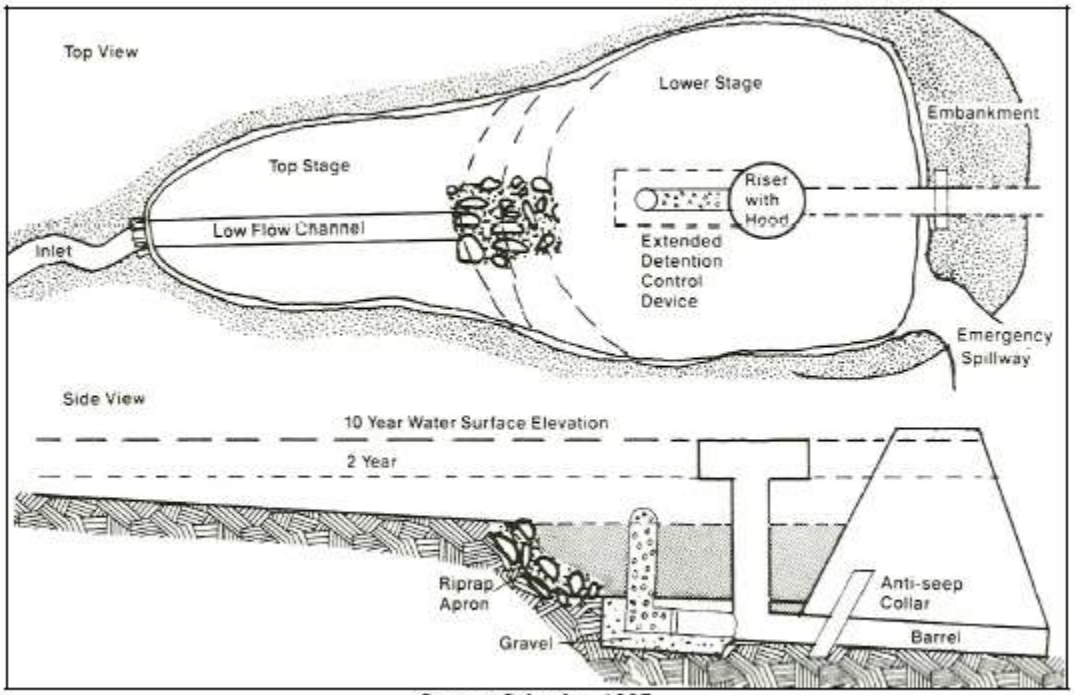


Figure 2a: Schematic of extended dry detention basin (Example 1)



Source: Schueler, 1987

Figure 2b: Schematic of extended dry detention basin (Example 2)



Source: Schueler, 1987

2G-3 Wet Detention

Source: Georgia Stormwater Manual, 2001

Pollutant Removal Low = <30% Medium = 30-65% High = 65-100%			
	Low	Med	High
Suspended Solids		■	■
Nitrogen		■	
Phosphorous		■	
Metals		■	
Bacteriological			■
Hydrocarbons		■	

Description: A wet detention basin is a constructed stormwater detention basin that has a permanent pool of water. Runoff from each rain event is detained and treated in the pool primarily through settling and biological uptake mechanisms. Wet ponds are among the most widely used stormwater practices.

Typical uses: Residential subdivision, low-density commercial; not recommended for high-density residential, ultra-urban areas.

Advantages:

- Moderate to high removal of urban pollutants. The permanent wet pool can provide significant water quality improvement across a relatively broad spectrum of constituents, including dissolved nutrients.
- High community acceptance. Wet basins can provide substantial aesthetic/recreational value and wildlife and wetlands habitat. Ponds are often viewed as a public amenity when integrated into a park setting.
- Widespread application with sufficient capture volume can provide additional control of channel erosion and enlargement.

Limitations:

- Minimum contributing drainage area of 25 acres; 10 acres for a micro-pool ED pond. Need for base flow or supplemental water if water level is to be maintained.
- Mosquito and midge breeding is likely to occur in ponds.
- Cannot be placed on steep unstable slopes.
- Potential for thermal impacts in downstream reach from warmer discharge.
- Depending on volume and embankment height, pond designs may require approval from the Iowa Department of Natural Resources (Re: Iowa Technical Bulletin 16).

Maintenance requirements:

- Monitor sediment accumulation and remove periodically.
- Remove debris from inlet and outlet structures.
- Maintain side slopes and shoreline vegetation.

A. Description

Stormwater ponds (also referred to as wet ponds, retention ponds, or wet extended duration [ED]ponds) are constructed stormwater retention basins that have a permanent pool of water throughout the year. They can be created by excavating an already existing natural depression, or through the construction of embankments.

In a stormwater pond, runoff from each rain event is detained and treated in the pool through gravitational settling and biological uptake until it is displaced by runoff from the next storm. The permanent pool also serves to protect deposited sediments from re-suspension. Above the permanent

pool level, additional temporary storage (live storage) is provided for runoff quantity control. The upper stages of a stormwater pond are designed to provide extended detention of the 2-year storm for downstream channel protection, as well as normal detention of larger storm events (25-year and, optionally, the 100-year storm event). A general schematic of a wet detention basin is shown in Figure 1.

Stormwater ponds are among the most cost-effective and widely-used stormwater practices. A welldesigned and landscaped pond can be an aesthetic feature on a development site when planned and located properly.

There are several different variants of stormwater pond design, the most common of which include the wet pond, the wet extended detention pond, and the micro-pool extended detention pond. In addition, multiple stormwater ponds can be placed in series or parallel to increase performance or meet site design constraints. Below are descriptions of each design variant:

1. **Wet pond.** A wet pond is a stormwater basin constructed with a permanent (dead storage) pool of water equal to the water quality volume. Stormwater runoff displaces the water already present in the pool. Temporary storage (live storage) can be provided above the permanent pool elevation for larger flows.

2. **Wet extended detention (ED) pond.** A wet extended detention pond is a wet pond where the water quality volume is split evenly between the permanent pool and extended detention (ED) storage provided above the permanent pool. During storm events, water is detained above the permanent pool and released over 24 hours. This design has similar pollutant removal to a traditional wet pond, but consumes less space.

3. **Micro-pool extended detention (ED) pond.** The micro-pool extended detention pond is a variation of the wet ED pond where only a small “micro-pool” is maintained at the outlet to the pond. The outlet structure is sized to detain the water quality volume for 24 hours. The micropool prevents re-suspension of previously-settled sediments, and also prevents clogging of the low flow orifice.

4. **Multiple pond systems.** Multiple pond systems consist of constructed facilities that provide water quality and quantity volume storage in two or more cells. The additional cells can create longer pollutant removal pathways and improved downstream protection.

Figure 2 shows a number of examples of stormwater pond variants. Figures 6 through 8 provide plan view and profile schematics for the design of a wet pond, wet extended detention pond, micro-pool extended detention pond, and multiple pond system.

B. Stormwater management suitability

Stormwater ponds are designed to control both stormwater quantity and quality. Thus, a stormwater pond can be used to address all of the unified stormwater sizing criteria for a given drainage area.

1. **Water quality.** Ponds treat incoming stormwater runoff by physical, biological, and chemical processes. The primary removal mechanism is gravitational settling of particulates, organic matter, metals, bacteria, and organics as stormwater runoff resides in the pond. Another mechanism for pollutant removal is uptake by algae and wetland plants in the permanent pool,

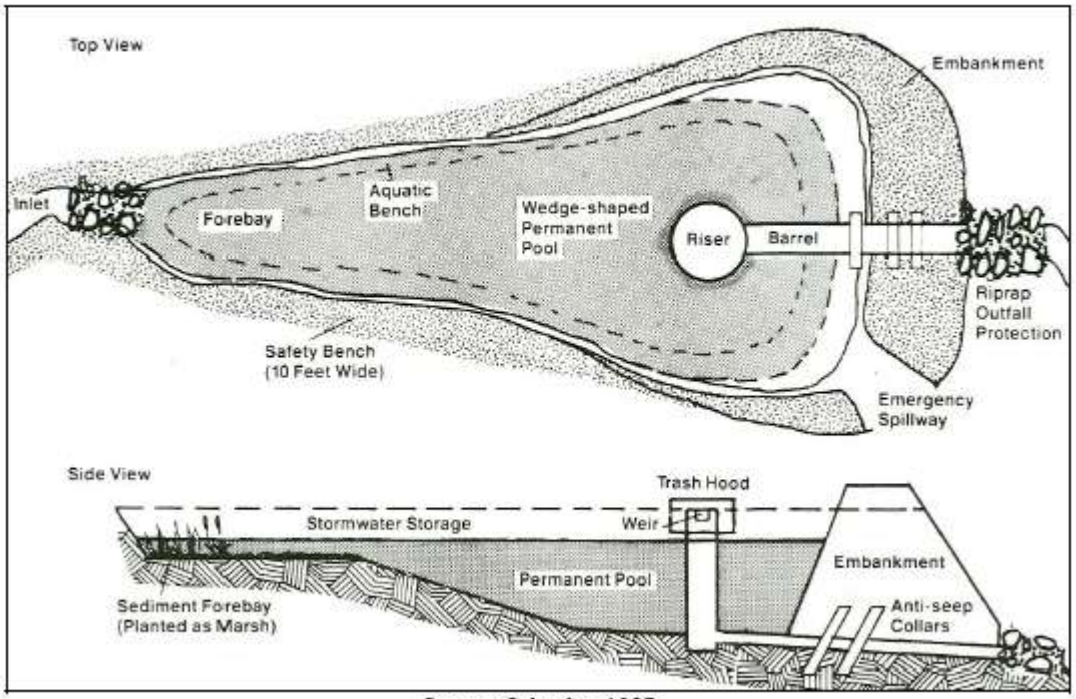
particularly of nutrients. Volatilization and chemical activity also work to break down and eliminate a number of other stormwater contaminants, such as hydrocarbons.

2. **Channel protection.** A portion of the storage volume above the permanent pool in a stormwater pond can be used to provide control of the channel protection volume (Cpv). This is accomplished by releasing the 1-year, 24-hour storm runoff volume over a 24-hour period (extended detention).

3. **Overbank flood protection.** A stormwater pond can also provide storage above the permanent pool to reduce the post-development peak flows of the 5-yr (Qp5) through the 25-year storm (Qp25) to pre-development levels (detention).

4. **Extreme flood protection.** In situations where it is required, stormwater ponds can also be used to provide detention to control the 100-year storm peak flow (Qf). Where this is not required, the pond structure is designed to safely pass extreme storm flows.

Figure 1: Schematic of wet detention basin (wet pond)



Source: Schueler, 1987

Figure 2: Examples of design variants of wet detention basins

Source: Georgia Stormwater Manual, 2001

C. Pollutant removal capabilities

All of the stormwater pond design variants are presumed to be able to remove 80% of the total suspended solids load in typical urban post-development runoff when sized, designed, constructed, and maintained in accordance with the recommended specifications. Undersized or poorly-designed ponds can reduce TSS removal performance.

The following design pollutant removal rates are conservative average pollutant reduction percentages for design purposes derived from sampling data, modeling, and professional judgment. In a situation where a removal rate is not deemed sufficient, additional controls may be put in place at the given site in a series or treatment train approach.

- Total suspended solids – 85%
- Total phosphorus – 50%
- Total nitrogen – 30%
- Fecal coliform – 70% (if no resident waterfowl population present)
- Heavy metals – 50%
-

For additional information and data on pollutant removal capabilities for stormwater ponds, see the National Pollutant Removal Performance Database (2nd Edition) available at www.cwp.org and the National Stormwater Best Management Practices (BMP) Database at www.bmpdatabase.org.

D. Application and feasibility

Stormwater ponds are generally applicable to most types of new development and redevelopment, and can be used in both residential and nonresidential areas. Ponds can also be used in retrofit situations. The following criteria should be evaluated to ensure the suitability of a stormwater pond for meeting stormwater management objectives on a site or development.

1. **General feasibility**
   - Suitable for residential subdivision usage: yes
   - Suitable for high-density/ultra-urban areas: land requirements may preclude use
   - Regional stormwater control: yes

2. **Physical feasibility - physical constraints at project site**

   a. **Drainage area.** A minimum of 25 acres is needed for wet pond and wet ED pond to maintain a permanent pool; 10 acres minimum for micro-pool ED pond. A smaller drainage area may be acceptable with an adequate water balance and anti-clogging device. In these cases, a water balance may be performed (see subsection 2C-10 for details).

   b. **Space required.** Approximately 2-3% of the tributary drainage area.

   c. **Site slope.** There should be more than 15% slope across the pond site.

   d. **Minimum head.** Elevation difference needed at a site from the inflow to the outflow: 6-8 feet.

   e. **Minimum depth to water table.** If used on a site with an underlying water supply aquifer or when treating a hotspot, a separation distance of 2 feet is required between the bottom of the pond and the elevation of the seasonally high water table.

   f. **Soils.** Underlying soils of hydrologic Group C or D should be adequate to maintain a permanent pool. Most Group A soils and some Group B soils will require a pond liner. Evaluation of soils should be based upon an actual subsurface analysis and permeability tests.

   g. **Topography.** A stormwater pond should be sited such that the topography allows for maximum runoff storage at minimum excavation or construction costs. Pond siting should also take into account the location and use of other site features such as buffers and undisturbed natural areas, and should attempt to aesthetically fit the facility into the landscape. Bedrock close to the surface may prevent excavation.

   h. Minimum setback requirements for stormwater pond facilities (when not specified by local ordinance or criteria):
   - From a property line: 10 feet
   - From a private well: 100 feet; if well is down-gradient from a hotspot land use, then the minimum setback is 250 feet
   - From a septic system tank/leach field: 50 feet
   - All utilities should be located outside of the pond/basin site

3. **Other constraints/considerations:**

   a. Consideration should be given to the thermal influence of stormwater pond outflows on downstream coldwater fisheries habitat.

b. Stormwater ponds cannot be located within a stream or any other navigable waters of the U.S., including wetlands, without obtaining a Section 404 permit under the Clean Water Act, and any other applicable state permit.

E. Design approach

Two alternative approaches are used to establish design criteria for water quality purposes in wet detention ponds. The first approach is based on solids-settling, and assumes that all pollutant removal within the pond occurs primarily due to sedimentation. The second approach treats the wet pond as a lake with controlled levels of eutrophication to account for the biological, physical, and chemical processes that are principal mechanisms for nutrient removal (Hartigan, 1989 and Walker, 1987). Both approaches relate the pollutant removal efficiencies to hydraulic residence time.

The design approach is selected on the basis of the water quality control efforts (TSS vs. nutrient) reduction, as well as site and economic constraints. The controlled eutrophication approach requires longer residence times and larger storage volumes compared to those of the solids-settling approach. However, if the chief concern is to control nutrient levels in waters such as lakes and reservoirs, it is then advantageous to use the controlled eutrophication approach. If the major goal is the removal of a broad spectrum of pollutants, especially those adsorbed onto suspended matter, it may be preferable to base the design criteria on the sedimentation models. Currently, the most common pond water quality practice designs for runoff pollution control rely heavily on the sedimentation process.

1. **Design variations.** Two basic design variations can be used to satisfy particular site-specific conditions or requirements. These are:

   a. A wet pond with a permanent pool of water with a volume (V_B) equal to some fraction or multiple of the mean storm runoff volume (V_R). The runoff displaces a portion of the pool volume, is treated during the dry period, and in turn is displaced by the next storm. A schematic of this wet pond design is illustrated in Figure 6.

   b. A multipurpose, multi-stage wet pond designed to provide stormwater management (peak attenuation, etc.) in addition to water quality enhancement.

2. **Design parameters.** The primary removal mechanism for pollutants in wet ponds is by settling of the solid materials. Thus, wet ponds should be designed to maximize sedimentation within the permanent pool. The permanent pool of water is equal to some fraction or multiple of the runoff volume (V_B/V_R). The runoff displaces a portion of the pool volume, is treated during the dry period, and in turn is displaced by the next storm. Schueler and Helfrich (1988) summarized typical design criteria for this approach in Table 1. General hydrologic and hydraulic suggestions for onsite (drainage area 20-100 acres) and regional (drainage area 100-300 acres) wet pond water quality practices for treatment of nutrients and a broader spectrum of pollutants are given in Table 2. Some important design parameters are discussed below:

   a. **Pool volume.** The volume of the permanent pool in relation to the drainage area or runoff volume is the most critical parameter in the sizing of the wet pond and its ability to remove pollutants. Various design criteria or rules of thumb are expressed in terms of the VB/VR ratio, where VB is the volume of the permanent pool and VR is the volume of runoff for an average storm. The starting point for selecting a design is to size the pool for a hydraulic detention time, which is a simple calculation to make, and then check the pollutant removal with the procedures detailed above. The value of detention time T (in years) is given by

dividing the permanent pool volume VB by the product of the total number of runoff events per year, n, namely:

$$T = VB/nVR$$

Field studies indicate that an optimum removal of approximately 50% nutrients occurs at T values of 2-3 weeks for pools with mean depths of 3-6 feet (Hartigan et al., 1989). In the eastern U.S., this optimum range for T values corresponds to VB/VR ratios of 4-6. Ponds with values of T greater than 2-3 weeks have a greater risk of thermal stratification and anaerobic bottom waters, resulting in an increased risk of significant export of nutrients from bottom sediments.

The design criteria for the permanent pool storage volume can be quantified in terms of the average hydraulic retention time, T, the ratio VB/VR, or minimum total suspended sediment removal rate. For example, the State of Florida (Florida DER, 1988) requires an average hydraulic retention time of 14 days, equivalent to VB/VR of 4. The UDFCD's BMP criteria manual in the Denver, Colorado, area (UDFCD, 1992) specifies that the permanent pool storage volume should be 1.0-1.5 times the water quality capture volume, which is equivalent to VB/VR on the order of 1.5-2.5.

Another approach is to require detention of a specified runoff volume as surcharge above the permanent pool. Storage in the surcharge zone is released during a specified period through an outlet structure. The surcharge detention requirement is intended to reduce shortcircuiting and enhance settling of total suspended sediments. Settling-solids analysis shows that retention ponds sized for nutrient removal with a minimum detention time, T, of 2 weeks and a minimum VB/VR of 4 achieve total suspended sediment removal rates of 80 to 90%. Addition of an extended detention zone above the permanent pool is unlikely to produce measurable increases in the removal of total suspended sediments. Still, a surcharge extended detention volume is recommended whenever the VB/VR, is less than 2.5. Whenever one is used or required, it is suggested that the maximized event-based volume with a 12-hour drain time be used.

In cases where relatively permeable soils (HSG A and B) are encountered, the risk of drawdown may be minimized by installing a 6-inch clay liner at the bottom of the pond.

b. **Pool depth.** The depth of the permanent pool is an important design parameter since it affects solids-settling. Mean depth of the pool is obtained by dividing the storage volume by the pool surface area. The pool should be shallow enough to ensure aerobic conditions and avoid thermal stratification, yet be deep enough to minimize algal blooms or re-suspension of previously-deposited materials by major storms or wind-generated disturbances. Prevention of thermal stratification will minimize short-circuiting and maintain aerobic bottom waters, thus maximizing pollutant uptake and minimizing the potential release of nutrients to the overlying waters. An average depth of 3-6 feet is sufficient to maintain the environment within the pool. A 10-foot wide and 1-foot deep bench is needed around the perimeter of the pool to promote aquatic vegetation and to reduce the potential safety hazard to the public. Shallow depth near the inlet structure is desirable to concentrate sediment deposition in a smaller and more easily-accessible area. The effluent riser should be located in a deeper area to facilitate withdrawal of cooler bottom water for the mitigation of downstream thermal impacts, if any.

The minimum depth of the open water area should be greater than the depth of sunlight penetration to prevent emergent plant growth in this area, on the order of 6-8 feet. A mean depth of approximately 3-10 feet should produce a pond with sufficient surface area to promote algae photosynthesis, and should maintain an acceptable environment within the permanent pool for the average hydraulic retention times recommended above, although separate analyses should be performed for each locale. If the pond has more than 2 acres of water surface, mean depths of 6.5 feet will protect it against wind-generated re-suspension of sediments. The mean depths of the more effective retention ponds monitored by the NURP study typically fall within this range. A water depth of approximately 6 feet over the major portion of the pond will also increase winter survival of fish (Schueler, 1987).

A maximum depth of 10-13 feet should reduce the risk of thermal stratification (Schueler, 1987). Readily-visible stormwater management facilities receive more and better maintenance than those in less visible, more remote locations. Readily-visible facilities can also be inspected faster and more easily by maintenance and mosquito-control personnel. If maintained at the recommended 3-6 foot depth, the permanent pool can serve as aquatic habitat.

c. **Minimum surface area of permanent pool.** Minimum surface area will be contingent upon local topography, minimum depth, and solids-settling guidelines. For on-site wet pond water quality basins, the typical minimum pool surface area is 0.25 acres.

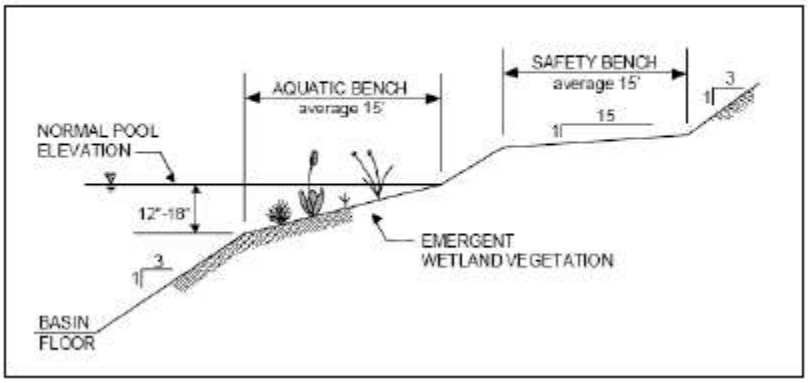
d. **Minimum drainage area and pond volume.** The minimum drainage area for an onsite wet pond water-quality structure should be large enough to sustain the wet pond during the summer periods. The drainage area should permit sufficient base flow, to prevent excessive retention times or severe drawdowns of the permanent pool during dry seasons. Unless regional experience is available for determining the minimum drainage area required in a particular location, it is recommended that a water balance calculation be performed using local runoff, evapotranspiration, ex-filtration, and base flow data to ensure that the base flow is adequate to keep the pond full during the dry season. Base flow will, of course, vary considerable from watershed to watershed in a region. However, a regionalized analysis would be helpful. Monthly and annual evaporation and precipitation data is available State of Iowa State climatology bureau (http://www.agriculture.state.ia.us/climatology.htm) or from the Department of Agronomy at Iowa State University http://mesonet.agron.iastate.edu/index.phtml).

The maximum tributary catchment area should be set to reduce the exposure of upstream channels to erosive stormwater flows, reduce effects on perennial streams and wetlands, and reduce public safety hazards associated with dam height. Again, regional experience will be useful in providing guidelines. For example, some stormwater master plans have restricted the maximum tributary catchments to 100-300 acres, depending on the amount of imperviousness in the watershed, with highly-impervious catchments restricted to the lower end of this range, and vice versa. As a rule of thumb, a minimum drainage area of 20 acres is required to sustain the desired dry weather inflow. In general, 4 acres of contributing drainage area are needed for each acre-foot of storage. As indicated earlier, however, a local analysis is needed.

e. **Side slopes.** Side slopes along the shoreline of the retention pond should be 4:1 or flatter to facilitate maintenance (such as mowing) and reduce public risk of slipping and falling into the water. In addition, a littoral zone (portion less than 15 feet deep, which is home to most of the aquatic plant life) should be established around the perimeter of the permanent pool to

promote the growth of emergent vegetation along the shoreline and deter individuals from wading (see Figure 3). The emergent vegetation around the perimeter serves several other functions: it reduces erosion, enhances the removal of dissolved nutrients in urban stormwater discharges, may reduce the formation of floating algal mats, and provides habitat for aquatic life and wetland wildlife. This bench for emergent wetland vegetation should be at least l0 feet wide with a water depth of 0.5-1.5 feet. The total area of the aquatic bench should be 25-50% of the permanent pool's water surface area. Local agricultural agencies or commercial nurseries should be consulted about guidelines for using wetland vegetation within shallow sections of the permanent pool.

Figure 3: Typical stormwater pond geometry criteria



2. **Pond configuration.** Length to width ratio of the pond should be as large as possible to simulate conditions found in plug flow reaction kinetics. Under the ideal plug flow conditions, a “plug” or “pulse” of runoff enters the basin and moves as a plug through the pond without mixing. Relatively large length-to-width ratios can help reduce short-circuiting, enhance sedimentation, and help prevent vertical stratification within the permanent pool. Griffin et al. (ASCE, 1985) showed that the dead storage for length-to-width ratios less than 2:1 was in the range of 27%, and for length-to-width ratios greater than 2:1, was in the range of 17%. A minimum length-to-width ratio of 2:1 is therefore recommended for the permanent pool. The permanent pool should expand gradually from the basin inlet and contract gradually toward the outlet, maximizing the travel time from the inlet to the outlet. Baffles or islands within the pool can increase the flow path length and reduce short-circuiting.

   To reduce the frequency of major cleanout activities within the pool area, a sediment forebay with a hardened bottom should be constructed near the inlet to trap coarse sediment particles. As with detention basins, a frequently-used value for the forebay storage capacity is approximately 10% of the permanent pool storage. Access for mechanized equipment should be provided to facilitate removal of sediment. The forebay can be separated from the remainder of the permanent pool by one of several means: a lateral sill with wetland vegetation, two ponds in series, differential pool depth, rock-filled gabions, a retaining wall, or a horizontal rock filter placed laterally across the permanent pool.

3. **Pretreatment/inlets:**

   a. Each pond should have a sediment forebay or equivalent upstream pre-treatment. A sediment forebay is designed to remove incoming sediment from the stormwater flow prior to dispersal in a larger permanent pool. The forebay should consist of a separate cell, formed by an

acceptable barrier. A forebay is to be provided at each inlet, unless the inlet provides less than 10% of the total design storm inflow to the pond. In some design configurations, the pre-treatment volume may be located within the permanent pool.

b. The forebay is sized to contain 0.1 inches per impervious acre of contributing drainage, and should be 4-6 feet deep. The pre-treatment storage volume is part of the total WQv requirement, and may be subtracted from WQv for permanent pool sizing.

c. A fixed vertical sediment depth marker is installed in the forebay to measure sediment deposition over time. The bottom of the forebay may be hardened (e.g., using concrete, paver blocks, etc.) to make sediment removal easier.

d. Inflow channels are to be stabilized with flared riprap aprons, or an equivalent. Inlet pipes to the pond can be partially-submerged. Exit velocities from the forebay must be non-erosive.

4. Outlets:

a. An outlet for a wet detention basin typically consists of a riser with a hood or trash rack to prevent clogging, and an adequate anti-vortex device for basins serving large drainage areas. Some typical outlet structures and details are provided in Section 2C-13. Anti- seep collars should be installed along outlet conduits passing through or under the dam embankment. If the pond is a part of a larger peak-shaving extended detention basin, the outlet should be designed for the desired flood control performance. Section 2C-13 provides more guidance on outlet design, especially for low flow. Typically, the riser structure should be sized to drain the permanent pool within 48 hours so sediments may be removed mechanically when necessary. The drain pipe should be controlled by a locking gate valve at the outlet.

b. A number of outlets at varying depths in the riser provide internal flow control for routing of the water quality, channel protection, and overbank flood protection runoff volumes. The number of orifices can vary and is usually a function of the pond design. For example, a wet pond riser configuration is typically comprised of a channel protection outlet (usually an orifice) and overbank flood protection outlet (often a slot or weir). The channel protection orifice is sized to release the channel protection storage volume over a 24- hour period (12-hour extended detention may be warranted in some coldwater streams). Since the water quality volume is fully contained in the permanent pool, no orifice sizing is necessary for this volume. As runoff from a water quality event enters the wet pond, it simply displaces that same volume through the channel protection orifice. Thus an off-line wet pond providing only water quality treatment can use a simple overflow weir as the outlet structure.

In the case of a wet ED pond or micro-pool ED pond, there is generally a need for an additional outlet (usually an orifice) that is sized to pass the extended detention water quality volume that is surcharged on top of the permanent pool. Flow will first pass through this orifice, which is sized to release the water quality ED volume in 24 hours. The preferred design is a reverse slope pipe attached to the riser, with its inlet submerged 1 foot below the elevation of the permanent pool to prevent floatables from clogging the pipe, and to avoid discharging warmer water at the surface of the pond. The next outlet is sized for the release of the channel protection storage volume. The outlet (often an orifice) invert is located at the maximum elevation associated with the extended detention water quality volume, and is sized to release the channel protection storage volume over a 24-hour period (12-hour extended detention may be warranted in some coldwater streams).

Alternative hydraulic control methods to an orifice can be used, and include the use of a broad-crested rectangular, V-notch, proportional weir, or an outlet pipe protected by a hood that extends at least 12 inches below the normal pool.

c. The water quality outlet (if design is for a wet ED or micro-pool ED pond) and channel protection outlet should be fitted with adjustable gate valves or other mechanism that can be used to adjust detention time.

d. Higher flows (overbank and extreme flood protection) flows pass through openings or slots protected by trash racks further up on the riser.

e. After entering the riser, flow is conveyed through the barrel and is discharged downstream. Anti-seep collars should be installed on the outlet barrel to reduce the potential for pipe failure.

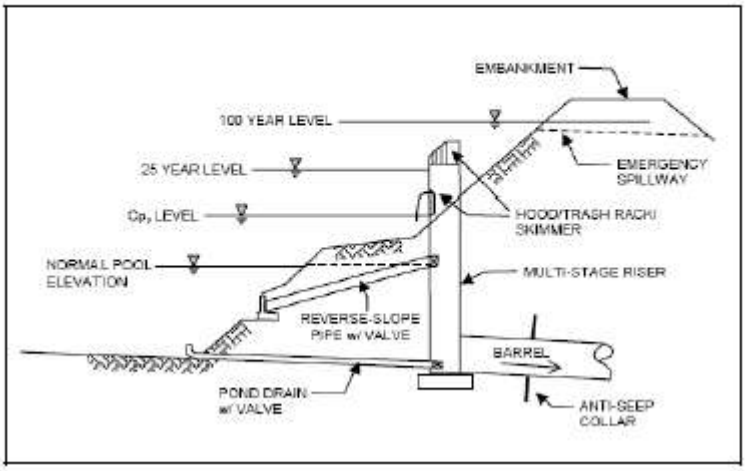
f. Riprap, plunge pools or pads, or other energy dissipators are to be placed at the outlet of the barrel to prevent scouring and erosion. If a pond daylights to a channel with dry weather flow, care should be taken to minimize tree clearing along the downstream channel, and to reestablish a forested riparian zone in the shortest possible distance. Additional guidance on energy dissipation design is included in Section 2N-2.

g. Each pond must have a bottom drain pipe with an adjustable valve that can completely or partially drain the pond within 24 hours.

h. The pond drain should be sized one pipe size greater than the calculated design diameter. The drain valve is typically a hand wheel-activated knife or gate valve. Valve controls shall be located inside of the riser at a point where they will not normally be inundated and can be operated in a safe manner.

See the design procedures Sections 2C-11 and 2C-13 for additional information and specifications on pond routing and outlet works.

Figure 4: Typical multiple outlet structure for wet detention basin



5. Secondary (emergency) spillway:

a. An emergency spillway is to be included in the stormwater pond design to safely pass the extreme flood flow. The spillway prevents pond water levels from overtopping the embankment and causing structural damage. The emergency spillway must be located so that downstream structures will not be impacted by spillway discharges.

b. A minimum of 1 foot of freeboard must be provided, measured from the top of the water surface elevation for the extreme flood to the lowest point of the dam embankment, not counting the emergency spillway.

6. Maintenance access:

a. A maintenance right-of-way or easement must be provided to a pond from a public or private road. Maintenance access should be at least 12 feet wide, having a maximum slope of no more than 15%, and be appropriately stabilized to withstand maintenance equipment and vehicles.

b. The maintenance access must extend to the forebay, safety bench, riser, and outlet and, to the extent feasible, be designed to allow vehicles to turn around.

c. Access to the riser is to be provided by lockable manhole covers and manhole steps within easy reach of valves and other controls.

7. Safety features:

a. All embankments and spillways must be designed to State of Iowa guidelines for dam safety (see Iowa DNR at http://www.iowadnr.com/water/floodplain/damsafety.html), and Iowa Technical Bulletin #16.

b. Fencing of ponds is not generally desirable, but may be required by the local review authority. A preferred method is to manage the contours of the pond through the inclusion of a safety bench (see above) to eliminate drop-offs and reduce the potential for accidental drowning. In addition, the safety bench may be landscaped to deter access to the pool.

c. The principal spillway opening should not permit access by small children, and end walls above pipe outfalls greater than 48 inches in diameter should be fenced to prevent access. Warning signs should be posted near the pond to prohibit swimming and fishing in the facility.

8. Landscaping:

a. Aquatic vegetation can play an important role in pollutant removal in a stormwater pond. In addition, vegetation can enhance the appearance of the pond, stabilize side slopes, serve as wildlife habitat, and temporarily conceal unsightly trash and debris. Therefore, wetland plants should be encouraged in a pond design along the aquatic bench (fringe wetlands), safety bench and side slopes (ED ponds), and within shallow areas of the pool itself. The best elevations for establishing wetland plants, either through transplantation or volunteer colonization, are within 6 inches (plus or minus) of the normal pool elevation. Additional information on establishing wetland vegetation and appropriate wetland species for Iowa can be found in the SUDAS Specifications Section 9010.

b. Woody vegetation may not be planted on the embankment, or allowed to grow within 15 feet of the toe of the embankment and 25 feet from the principal spillway structure.

c. A pond buffer should be provided that extends 25 feet outward from the maximum water surface elevation of the pond. The pond buffer should be contiguous with other buffer areas that are required by existing regulations (e.g., stream buffers) or that are part of the overall stormwater management concept plan. No structures should be located within the buffer, and an additional setback to permanent structures may be provided.

Table 1: Hydrologic and hydraulic design criteria for standard extended detention wet pond systems

Permanent Pool Storage	
Design criteria	Treat WQv and/or first flush of runoff
Storage volume	1.25 watershed inch Rv* watershed area
Water surface elevation	Established by invert of extended detention pipe
Pipe sizing (pool drain)	Drain pool volume within 24 hours
Extended Detention Storage	
Design criteria	Provide minimum 24-hour detention for 1-year, 24-hour rainfall event runoff
Storage volume	CPv (See Section 2C-6)
Water surface elevation	Upper limit set at beginning of 2-year or 5-year design storm storage
Pipe sizing – allowable release rate (Q_R)	Q_R = CPv – ft^3/24-hr/3600
Two-Year Storm Event Peak Discharge Control Storage	
Design criteria	Maintain 2-year pre-development peak discharge for 2-year design; can be replaced with 5-year pre-development discharge IAW local jurisdiction policy.
Storage volume	Obtained from WINTR-55 short cut method of full calculation with WINTR20, HEC-HMS or other methods.
Water surface elevation	Upper limit: bottom of 100-year storage Lower limit: top of extended detention storage
Safety Storm/Secondary Spillway	
Design criteria	Safety storm: design event depends on hazard classification Secondary (emergency) spillway: must pass the safety storm
Storage volume	Safety storm: obtained from WINTR-55 or WINTR20 (NRCS, 2005) Secondary spillway: obtained from NRCS spillway charts (NRCS, 1982)

* The Modified Rational method should not be used for storage calculations.

Source: Schueler and Helfrich, 1988

Table 2: Recommended criteria for wet pond design for nutrient removal*

Design Parameter	Recommended Criteria	
	On-site wet pond	*Regional*
Storage volume (permanent pool)	T = 2 weeks or more V_B/V_R > 4 or higher V_B = 2*WQv	Same as onsite wet pond
Mean depth (permanent pool)	3 to 6 ft	Same as onsite wet pond
Surface area (permanent pool)	> 0.25 acres	3 to 5 acres or more
Drainage area	Minimum of 20-25 acres	100-300 acres, depending on impervious cover
Side slopes	5:1 to 10:1 (H:V)	
Length/width ratio	2:1 or greater	
Soils at site	HSG B, C, or D Compaction may be required on A and B soils	
T = average hydraulic residence time * Projected nutrient removal (P = 65%, Solids 85-90%)		

Source: Hartigan et al, 1989

F. Design procedures

1. **Step 1.** Compute runoff control volumes from the unified stormwater sizing criteria. Calculate the WQv, Cpv, Qp, and the Qf. (See Sections 2B-1 and 2C-6). The The ASCE-WEF Maximized Water Quality Volume procedure is recommended for determining the WQv for the basin, using a drawdown time of 48-hours (see Section 2C-6).

2. **Step 2.** Determine if the development site and conditions are appropriate for the use of a stormwater pond. Consider application and feasibility criteria and any location and siting issues.

3. **Step 3.** Confirm local design criteria and applicability. Consider any special site-specific design conditions/criteria (additional site-specific design criteria and issues). Check with local officials and other agencies to determine if there are any additional restrictions and/or surface water or watershed requirements that may apply.

4. **Step 4.** Determine pretreatment volume. A sediment forebay is provided at each inlet, unless the inlet provides less than 10% of the total design storm inflow to the pond. The forebay should be sized to contain 0.1 inches per impervious acre of contributing drainage, and should be 4-6 feet deep. The forebay storage volume counts toward the total WQv requirement, and may be subtracted from the WQv for subsequent calculations.

5. **Step 5.** Determine permanent pool volume (and water quality ED volume).

    a. **Wet pond.** Size permanent pool volume to 1.5 to 2.0* WQv.

    b. **Wet ED pond.** Size permanent pool volume to 1.0 WQv. Size extended detention volume to 0.5 WQv.

    c. **Micro-pool ED pond.** Size permanent pool volume to 25-30% of WQv. Size extended detention volume to remainder of WQv.

6. **Step 6.** Determine pond location and preliminary geometry. Conduct pond grading and determine storage available for permanent pool (and water quality extended detention if wet ED pond or micro-pool ED pond). This step involves initially grading the pond (establishing contours) and determining the elevation-storage relationship for the pond.

    a. Include safety and aquatic benches.

    b. Set WQv permanent pool elevation (and WQv-ED elevation for wet ED and micro-pool ED pond) based on volumes calculated earlier.

7. **Step 7.** Compute extended detention orifice release rate(s) and size(s), and establish Cpv elevation:

    a. **Wet pond.** The Cpv elevation is determined from the stage-storage relationship, and the orifice is then sized to release the channel protection storage volume over a 24-hour period (12-hour extended detention may be warranted in some coldwater streams). The channel protection orifice should have a minimum diameter of 3 inches, and should be adequately protected from clogging by an acceptable external trash rack. A reverse slope pipe attached to the riser, with its inlet submerged 1 foot below the elevation of the permanent pool, is a recommended design. The orifice diameter may be reduced to 1 inch if internal orifice protection is used (i.e., an over-perforated vertical stand pipe with ½-inch orifices or slots that are protected by wire cloth and a stone filtering jacket). Adjustable gate valves can also be used to achieve this equivalent diameter.

    b. **Wet ED pond and micro-pool ED pond.** Based on the elevations established in Step 6 for the extended detention portion of the water quality volume, the water quality orifice is sized to release this extended detention volume in 24 hours. The water quality orifice should have a minimum diameter of 3 inches, and should be adequately protected from clogging by an acceptable external trash rack. A reverse slope pipe attached to the riser, with its inlet submerged 1 foot below the elevation of the permanent pool, is a recommended design. Adjustable gate valves can also be used to achieve this equivalent diameter. The Cpv elevation is then determined from the stage-storage relationship. The invert of the channel protection orifice is located at the water quality extended detention elevation, and the orifice is sized to release the channel protection storage volume over a 24-hour period (12-hour extended detention may be warranted in some coldwater streams).

8. **Step 8.** Calculate Qp_{25} (25-year storm) release rate and water surface elevation.

    a. Set up a stage-storage-discharge relationship for the control structure for the extended detention orifice(s) and the 25-year storm.

    b. Complete a final design pond routing using the Modified Puls or Storage-Indication method to check water surface elevation and discharge rate for the Q_5 through Q_{25} storm events.

9. **Step 9.** Design embankment(s) and spillway(s).

    a. Size emergency spillway, calculate 100-year water surface elevation, set top of embankment elevation, and analyze safe passage of the extreme food volume (Qf).

b. At final design, provide safe passage for the 100-year event.

10. **Step 10.** Investigate potential pond hazard classification. The design and construction of stormwater management ponds are required to follow the Iowa dam safety guidelines and Iowa DNR Technical Bulletin #16.

11. **Step 11.** Design inlets, sediment forebay(s), outlet structures, maintenance access, and safety features. See Sections 2C-12 and 2C-13 for additional details.

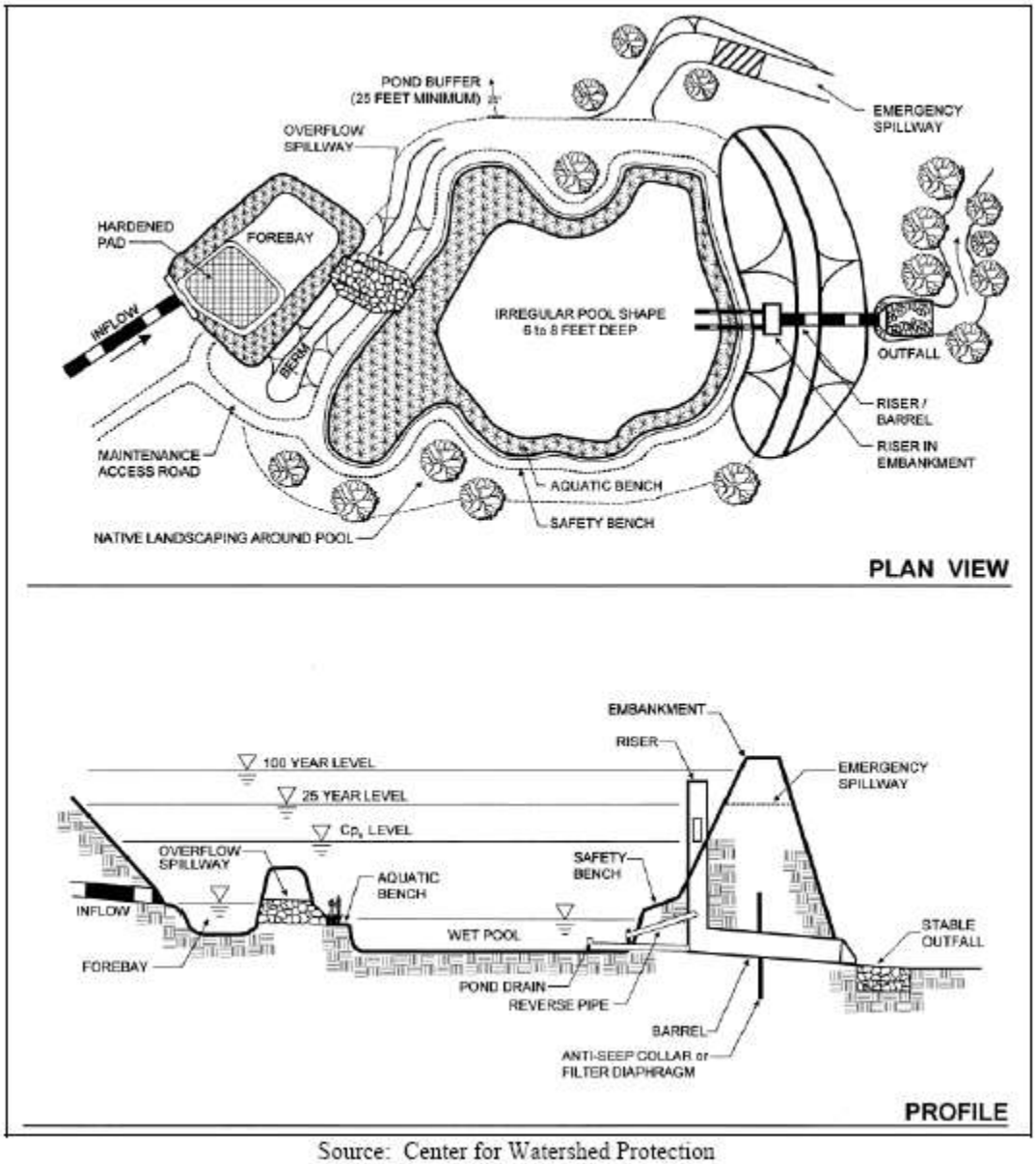
12. **Step 12.** Prepare vegetation and landscaping plan. A landscaping plan for a stormwater pond and its buffer should be prepared to indicate how aquatic and terrestrial areas will be stabilized and established with vegetation.

G. Inspection and maintenance requirements

Table 3: Typical maintenance activities for ponds

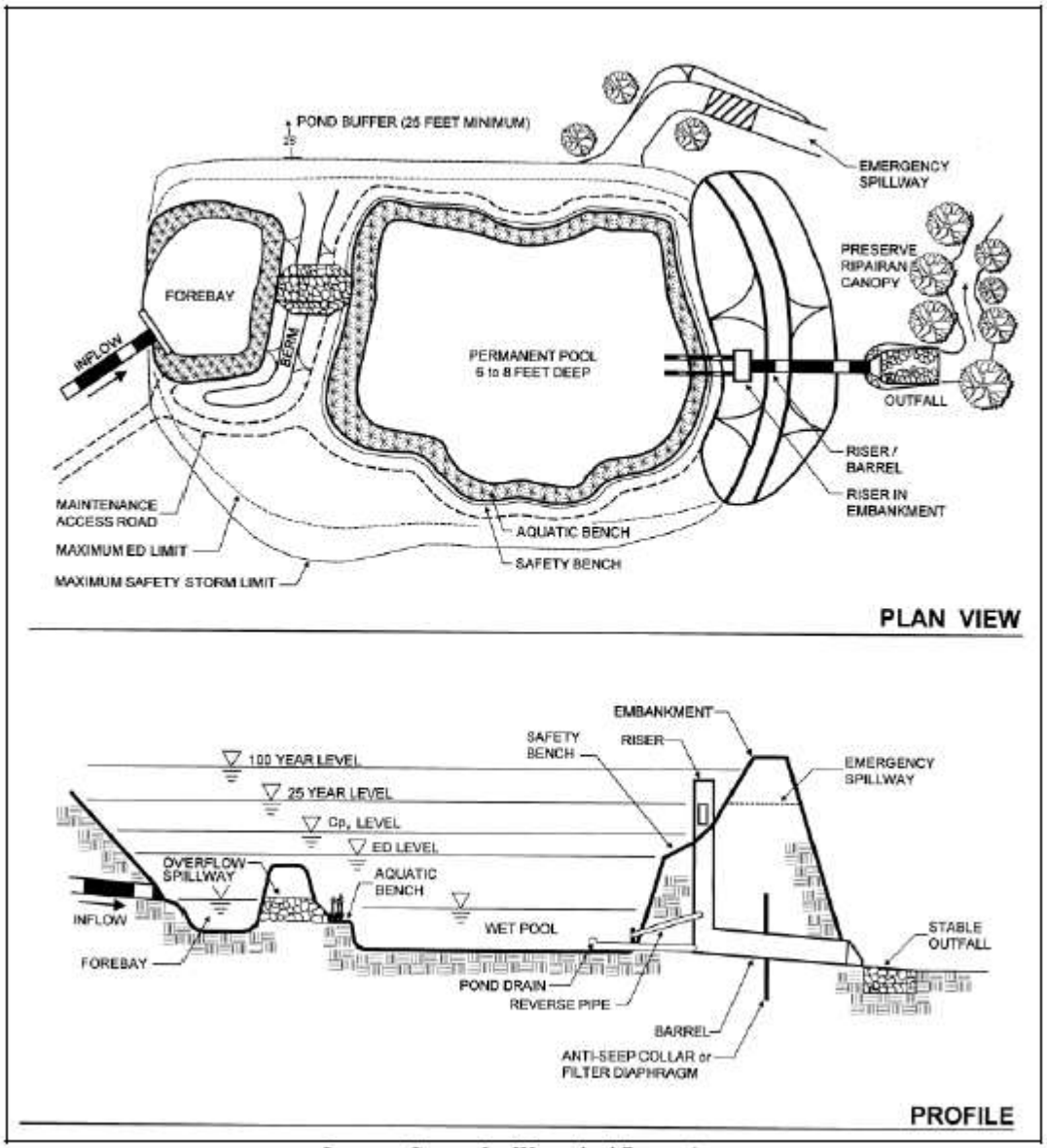
Activity	Schedule
• Clean and remove debris from inlet and outlet structures. • Mow side slopes.	Monthly
• If wetland components are included, inspect for invasive vegetation.	Semi-annual inspection
• Inspect for damage, paying particular attention to the control structure. • Check for signs of eutrophic conditions. • Note signs of hydrocarbon build-up, and remove appropriately. • Monitor for sediment accumulation in the facility and forebay. • Examine to ensure that inlet and outlet devices are free of debris and operational. • Check all control gates, valves or other mechanical devices.	Annual inspection
• Repair undercut or eroded areas.	As needed
• Perform wetland plant management and harvesting.	Annually (if needed)
• Remove sediment from the forebay.	5-7 years, or after 50% of the total forebay capacity has been lost
• Monitor sediment accumulations, and remove sediment when the pool volume has become reduced significantly, or the pond becomes eutrophic.	10-20 years, or after 25% of the permanent pool volume has been lost

Figure 5: Example schematic of wet detention basin (wet pond)



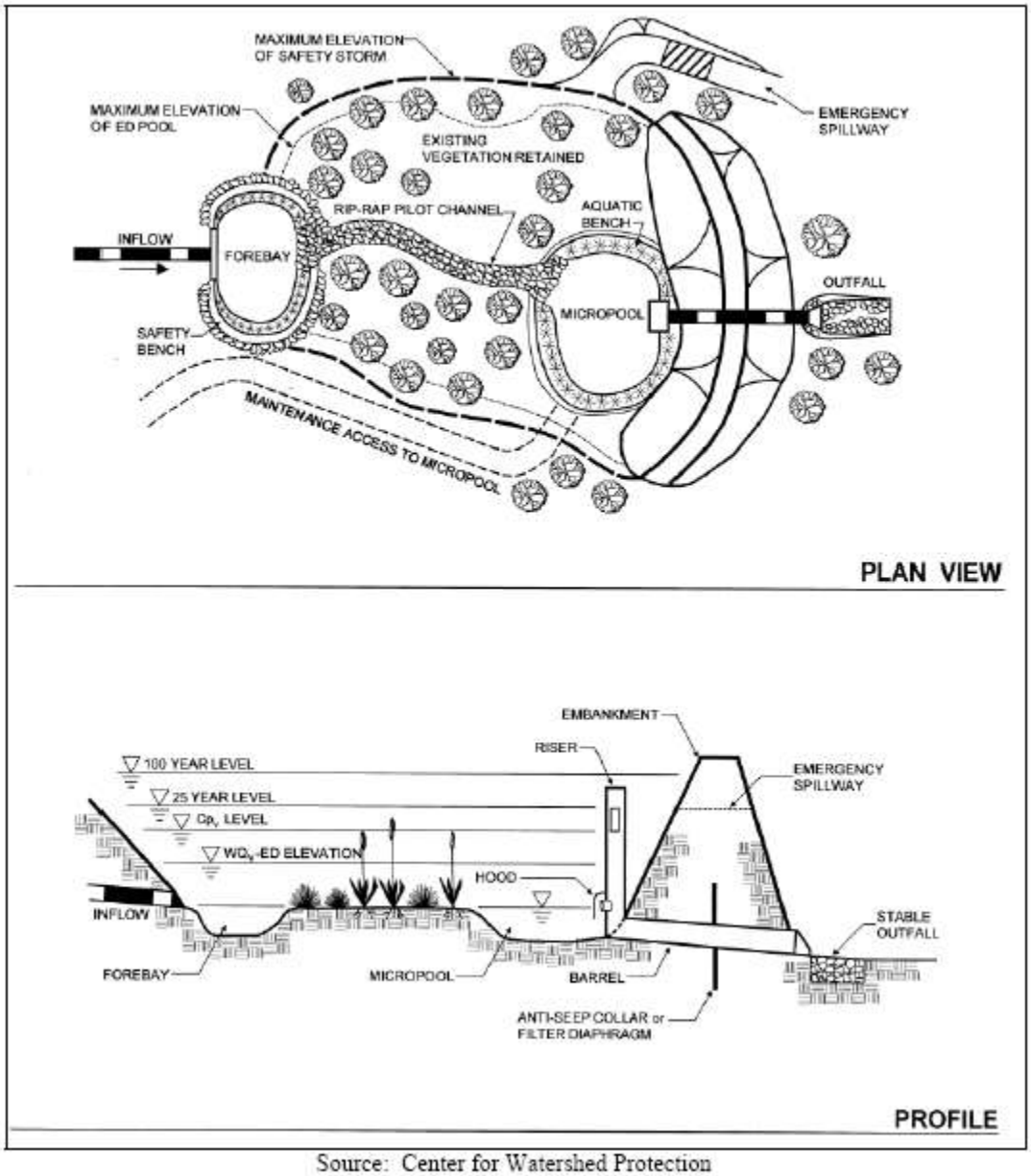
Source: Center for Watershed Protection

Figure 6: Example schematic of wet extended detention basin (ED wet pond)



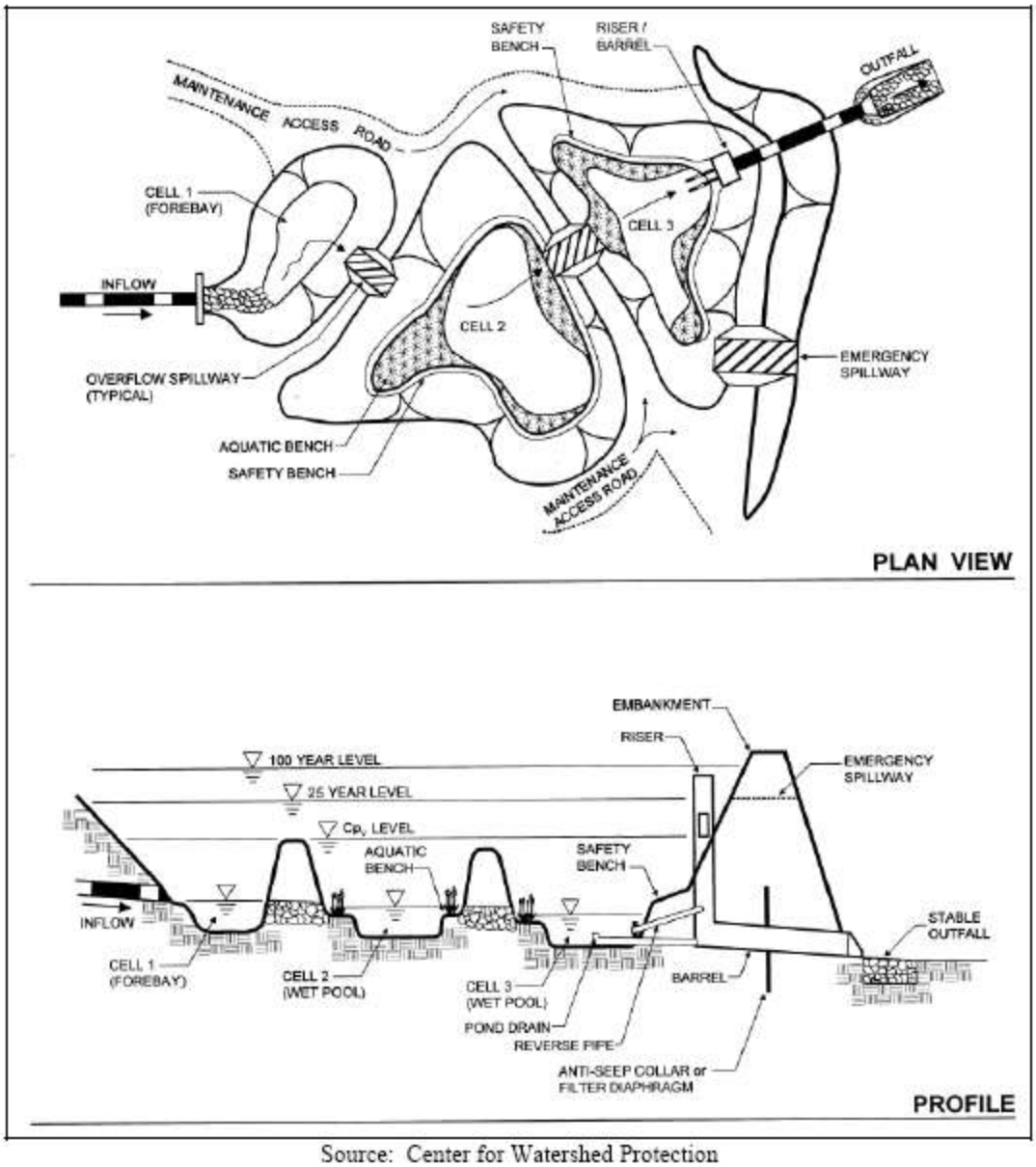
Source: Center for Watershed Protection

Figure 7: Example schematic of micro-pool extended detention pond



Source: Center for Watershed Protection

Figure 8: Example schematic of multiple pond system



Source: Center for Watershed Protection

2H-1 Stormwater Wetlands

BENEFITS Low = <30% Medium = 30-65% High = 65-100%	Low	Med	High
Suspended Solids			■
Nitrogen		■	
Phosphorous	■	■	
Metals		■	■
Bacteriological		■	■
Hydrocarbons			■

Description: Stormwater wetlands are constructed wetland systems explicitly designed to incorporate the functions of natural wetlands to aid in pollutant removal from stormwater. Constructed wetlands can also provide for quantity control of stormwater by providing a significant volume of temporary water storage above the permanent pool elevation. As stormwater runoff flows through the wetland, pollutant removal is achieved by settling and biological uptake within the practice. Wetlands are among the most effective stormwater practices in terms of pollutant removal, and also offer aesthetic value. A sediment forebay is provided for removal of course sediments that could degrade performance.

Typical uses:

- Larger residential developments and medium-density suburban commercial areas. Not suited for high-density/ultra urban areas due to space constraints.

Advantages/benefits:

- Very good removal of suspended and particulate pollutants.
- Biological uptake of nutrients by wetland plants.
- Reduction of peak flows and flood attenuation.
- Enhancement of vegetation diversity and wildlife habitat in urban areas.
- Relatively low maintenance costs

Disadvantages/limitations:

- Needs continuous baseflow for viable wetland vegetation – a critical design factor for smaller areas (<20 acres).
- Usually some release of nutrients in the fall and winter months.
- May act as a heat sink with discharge of warmer water to downstream reaches.
- May attract year-round population of wild geese if natural buffers not included in the wetland design.
- Relatively higher land requirements and construction costs than most other BMPs.

Maintenance requirements:

- Replacement of wetland vegetation to maintain at least 50% surface area coverage.
- Remove invasive vegetation.
- Monitor sediment accumulation and remove periodically.

A. Description

Stormwater wetlands are constructed wetland systems explicitly designed to incorporate the natural functions of wetlands to aid in pollutant removal from stormwater. Constructed wetlands can also provide for quantity control of stormwater by providing a significant volume of temporary water storage above the permanent pool elevation. As stormwater runoff flows through the wetland, pollutant removal is achieved by settling and biological uptake within the practice. A sediment forebay is provided for removal of course sediments that could degrade performance. Stormwater wetlands are designed specifically for the purpose of treating stormwater runoff, and typically have less bio-diversity than natural wetlands both in terms of plant and animal life. However, as with

natural wetlands, stormwater wetlands require a continuous base flow or a high water table to support aquatic vegetation.

There are several design variations of the stormwater wetland, each design differing in the relative amounts of shallow and deep water, and dry storage above the wetland. These include the shallow wetland, the extended detention shallow wetland, pond/wetland system and pocket wetland. Below are descriptions of each design variant:

1. **Shallow wetland.** In the shallow wetland design, most of the water quality treatment volume is in the relatively shallow high marsh or low marsh depths. The only deep portions of the shallow wetland design are the forebay at the inlet to the wetland, and the micro-pool at the outlet. One disadvantage of this design is that since the pool is very shallow, a relatively large amount of land is typically needed to store the water quality volume. (See Figure 2).

2. **Extended detention shallow wetland.** The extended detention (ED) shallow wetland design is the same as the shallow wetland; however, part of the water quality treatment volume is provided as extended detention above the surface of the marsh and released over a period of 24 hours. This design can treat a greater volume of stormwater in a smaller space than the shallow wetland design. In the extended detention wetland option, plants that can tolerate both wet and dry periods need to be specified in the ED zone. (See Figure 3).

3. **Pond/wetland systems.** The pond/wetland system has two separate cells: a wet pond and a shallow marsh. The wet pond traps sediments and reduces runoff velocities prior to entry into the wetland, where stormwater flows receive additional treatment. Less land is required for a pond/wetland system than for the shallow wetland or the ED shallow wetland systems. (See Figure 4).

4. **Pocket wetland.** A pocket wetland is intended for smaller drainage areas of 2-10 acres and typically requires excavation down to the water table for a reliable water source to support the wetland system. (See Figure 5).

B. Stormwater management suitability

Similar to stormwater detention systems (wet ponds), stormwater wetlands are designed to control both stormwater quantity and quality. Thus, a stormwater wetland can be used to address all of the unified stormwater sizing criteria for a given drainage area.

1. **Water quality.** Pollutants are removed from stormwater runoff in a wetland through uptake by wetland vegetation and algae, vegetative filtering, and through gravitational settling in the slowmoving marsh flow. Other pollutant removal mechanisms are also at work in a stormwater wetland, including chemical and biological decomposition, and volatilization.

2. **Channel protection.** The storage volume above the permanent pool/water surface level in a stormwater wetland is used to provide control of the channel protection volume (Cpv). This is accomplished by releasing the 1-year, 24-hour storm runoff volume over 24 hours (extended detention). It is best to do this with minimum vertical water level fluctuation, as extreme fluctuation may stress vegetation.

3. **Overbank flood protection:** A stormwater wetland can also provide storage above the permanent pool/water surface level to reduce the post-development peak flow of the 10-year storm (Qp) to pre-development levels (detention). If a wetland facility is not used for overbank

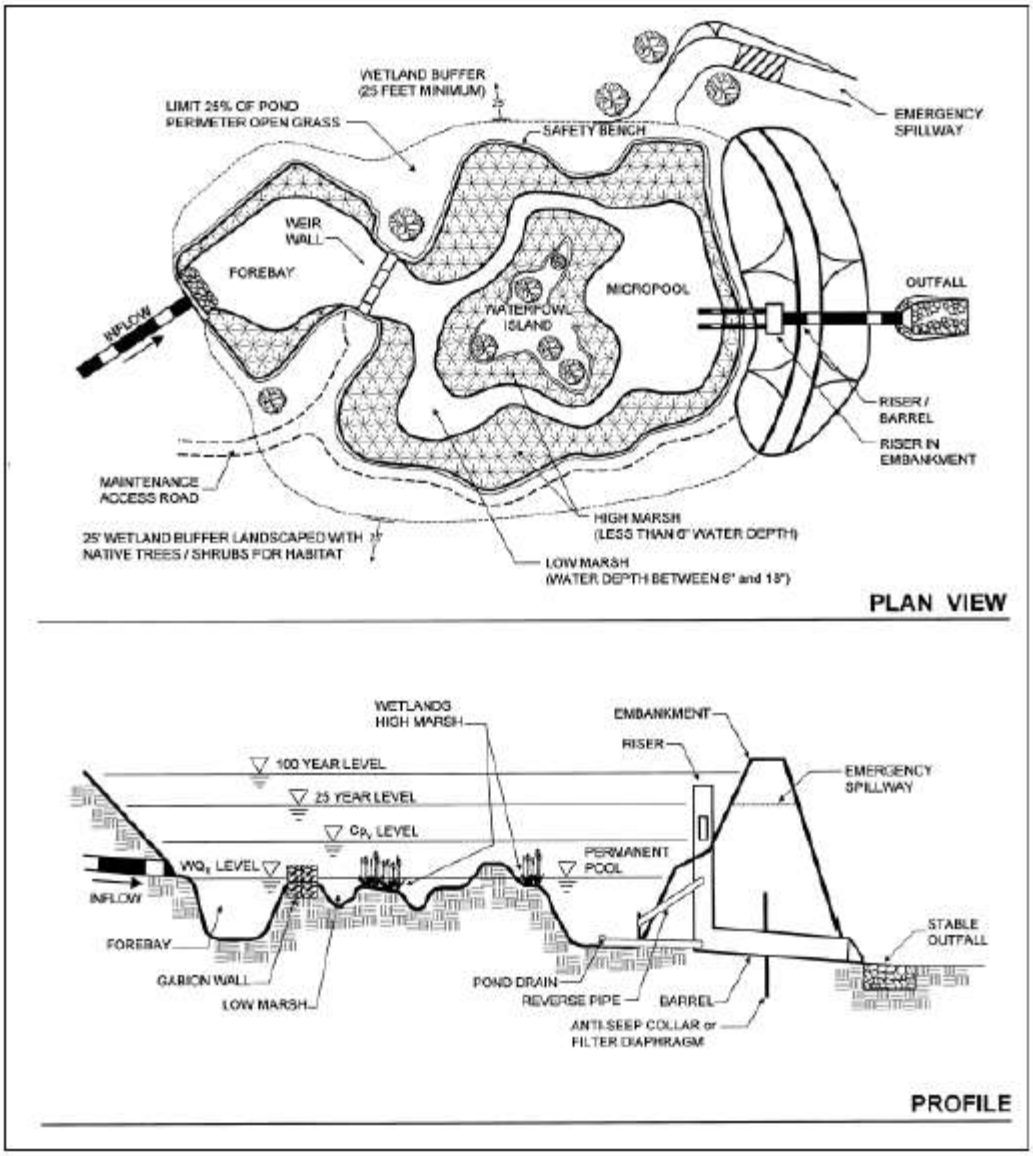
flood protection, it should be designed as an off-line system to pass higher flows around rather than through the wetland system.

4. **Extreme flood protection:** In situations where it is required, stormwater wetlands can also be used to provide detention to control the 100-year storm peak flow (Qf). Where Qf peak control is not required, a stormwater wetland must be designed to safely pass extreme storm flows.

Figure 1: Stormwater wetland examples

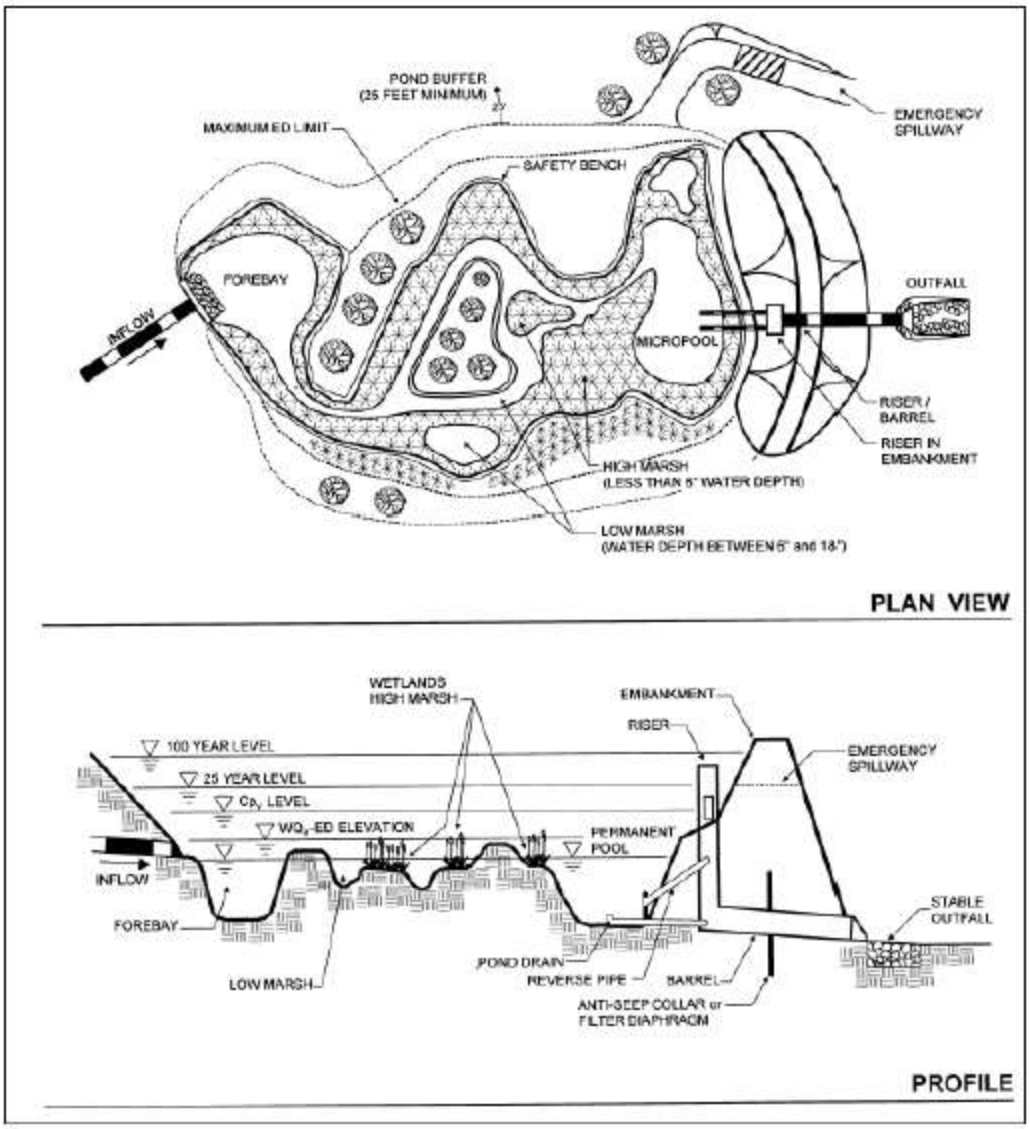
Source: Georgia Stormwater Manual, 2002

Figure 2: Shallow wetland schematic



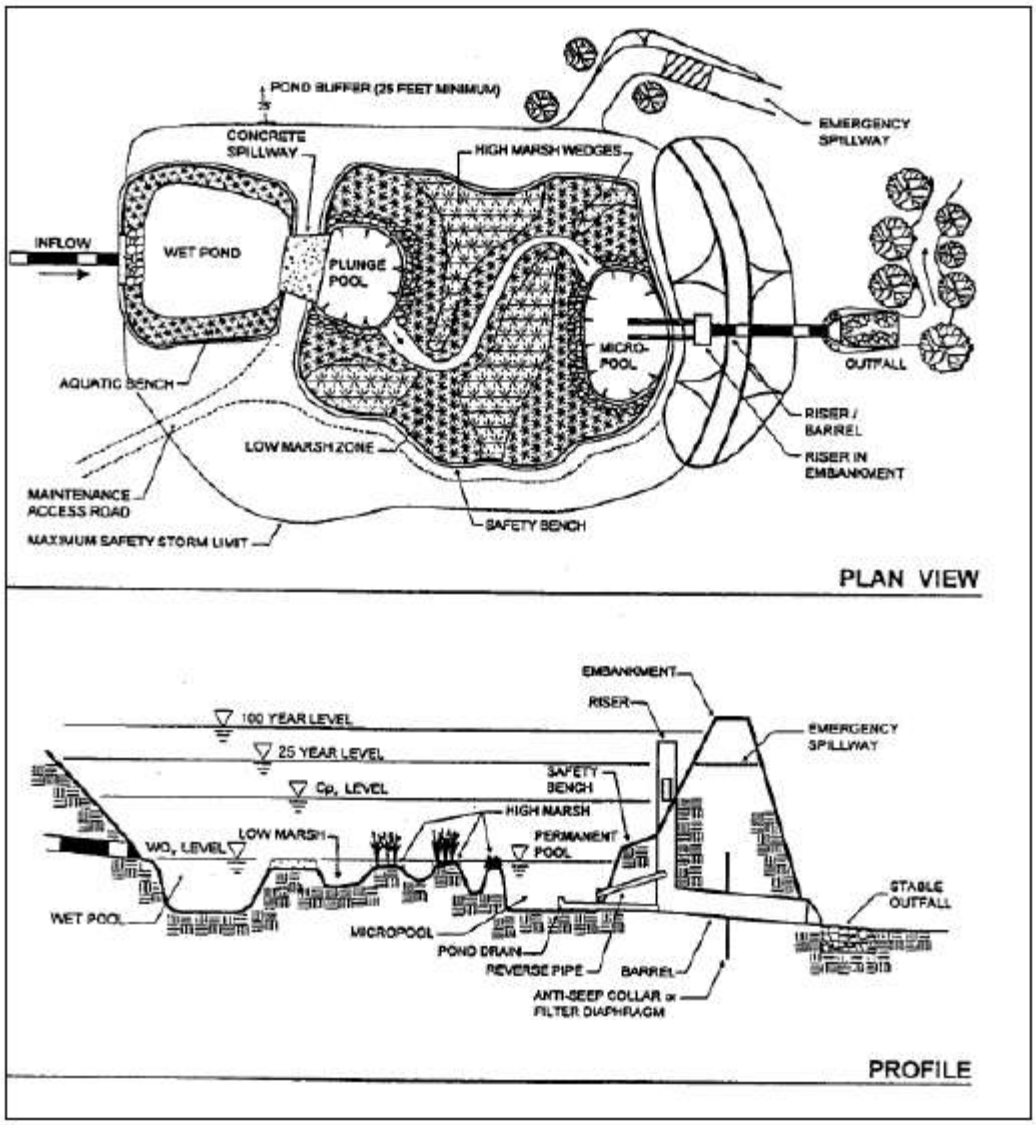
Source: Center for Watershed Protection

Figure 3: Extended detention shallow wetland schematic



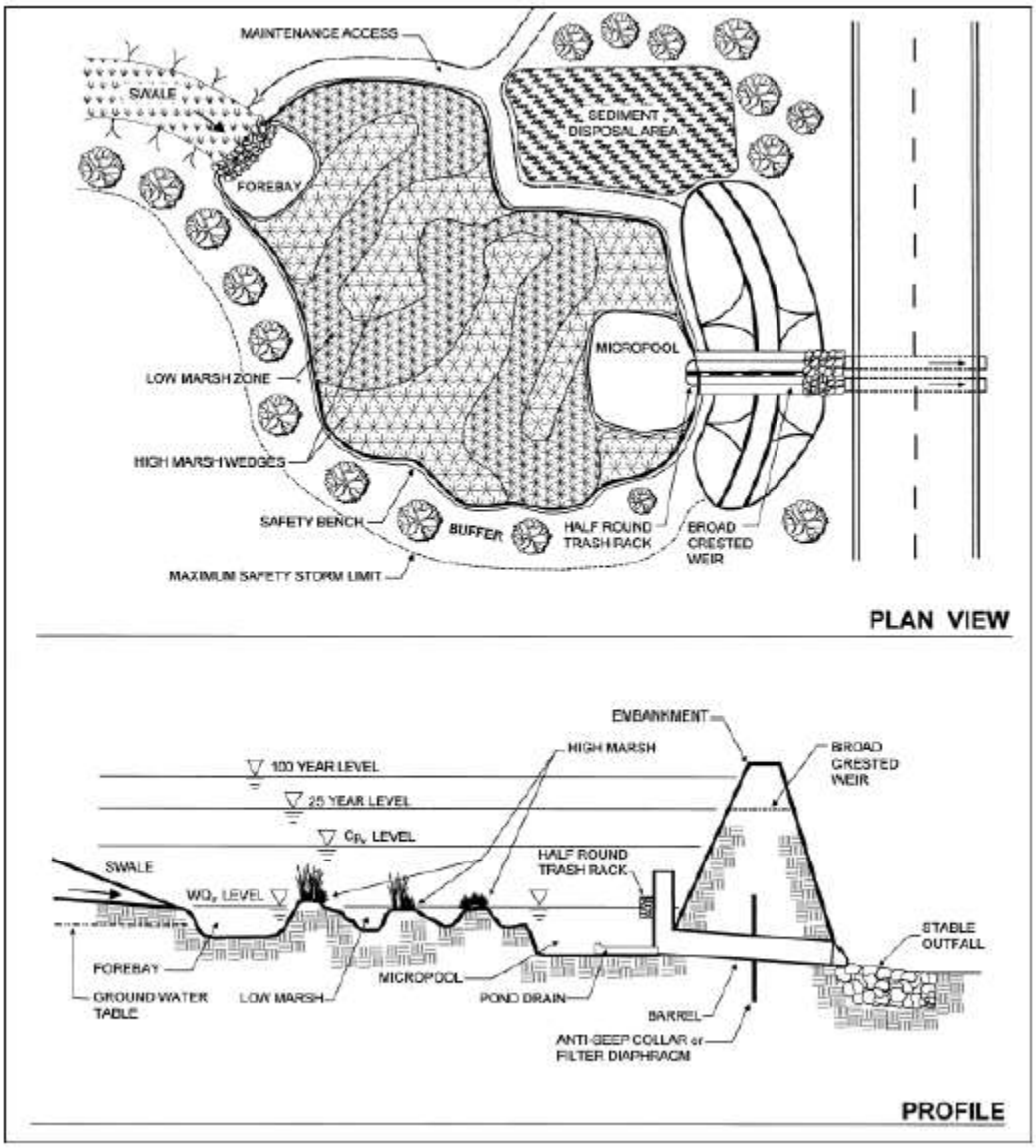
Source: Center for Watershed Protection

Figure 4: Pond/wetland system schematic



Source: Center for Watershed Protection

Figure 5: Pocket wetland system schematic



Source: Center for Watershed Protection

C. Pollutant removal capabilities

Conventional stormwater wetlands have a high pollutant removal capability, generally comparable to wet ponds. All of the stormwater wetland design variants are presumed to be able to remove 80% of the TSS load in typical urban post-development runoff when sized, designed, constructed, and maintained in accordance with the recommended specifications. Phosphorous and nitrogen removal will be more variable. Under-sized or poorly-designed wetland facilities can reduce TSS removal performance. The following design pollutant removal rates are conservative average pollutant reduction percentages for design purposes derived from previous published sampling data, modeling,and professional judgment. In a situation where a removal rate is not deemed sufficient, additional controls may be put in place at the given site in a series or treatment train approach.

- Total suspended solids – 80%
- Total phosphorus – 40%
- Total nitrogen – 30%
- Fecal coliform – 70% (if no resident waterfowl population present)
- Heavy metals – 50%

Overall performance is greatest during the growing season and lowest during the winter months (Strecker, et al, 1990). For additional information and data on pollutant removal capabilities for stormwater wetlands, see the National Pollutant Removal Performance Database (2nd Edition) available at www.cwp.org and the National Stormwater Best Management Practices Database at www.bmpdatabase.org.

D. Application and feasibility

Stormwater wetlands are generally applicable to most types of new development and redevelopment, and can be used in both residential and non-residential areas. However, due to the large land requirements, wetlands may not be practical in higher-density areas. The following criteria should be evaluated to ensure the suitability of a stormwater wetland for meeting stormwater management objectives on a site or development.

1. General feasibility:

- Suitable for residential subdivision usage – yes (some concern for insect control)
- Suitable for high-density/ultra-urban areas – land requirements may preclude use
- Regional stormwater control – yes

2. **Physical feasibility – physical constraints at project site:**

- **Drainage area.** A minimum of 25 acres and a positive water balance is needed to maintain wetland conditions; 5 acres for pocket wetland.
- **Space required.** Approximately 3-5% of the tributary drainage area.
- **Site slope.** There should be no more than 8% slope across the wetland site.
- **Minimum head.** Elevation difference needed at a site from the inflow to the outflow: 3-5 feet; 2-3 feet for pocket wetland.
- **Minimum depth to water table.** If used on a site with an underlying water supply aquifer or when treating a hotspot, a separation distance of 2 feet is recommended between the bottom of the wetland and the elevation of the seasonally high water table; pocket wetland is typically below water table.
- **Soils.** Permeable soils are not well-suited for a constructed stormwater wetland without a high water table. Underlying soils of hydrologic group C or D should be adequate to maintain wetland conditions. Most HSG A soils and some B soils will require a liner. Evaluation of soils should be based upon an actual subsurface analysis and permeability tests.

2I-2 Grass Swales

Grass swale (VA DCR, 1999)

BENEFITS Low = <30% Medium = 30-65% High = 65-100%			
	Low	Med	High
Suspended Solids		■	
Nitrogen	■	■	
Phosphorous	■	■	
Metals		■	■
Bacteriological	■		
Hydrocarbons	*	*	*

* Insufficient Data

Description: Grass swales are designed to convey stormwater runoff at a non-erosive velocity, as well as enhance its water quality through infiltration, sedimentation, and filtration. Check dams can be used within the swale to slow the flow rate, promote infiltration, and create small, temporary ponding areas. The vegetation covering the side slopes and channel bottom provide a filtration surface as the runoff is slowly conveyed to a downstream discharge location. The vegetation also serves to reduce flow velocities.

Typical uses:

- Manages runoff from residential sites, parking areas, and along perimeter of paved roadways.
- Located in a drainage easement at the rear of side of residential parcels.
- Used as a pre-treatment conveyance for other water quality BMPs.
- Road shoulder rights-of-way; used adjacent to paved roadways in place of curb and gutter, or used as a conveyance channel on the back side of curb-cut openings.

Advantages/benefits:

- Mitigates runoff from impervious surfaces; removes sediment and pollutants to improve water quality
- Reduce runoff rate and volume in highly impervious areas; reduced runoff velocity.
- Provides for groundwater recharge if design and site soils provide sufficient infiltration.
- Good option for small area retrofits for residential or institutional areas of low to moderate density; linear configuration works well with highway or residential street applications.

Disadvantages/limitations:

- Cannot alone achieve 80% goal reduction of TSS.
- Sediment and pollutant removal sensitive to proper design of slope and maintaining sufficient vegetation density; possible re-suspension of sediment.
- Limited to small areas (< 5 acres); cannot be used on steep slopes (> 6%).
- Higher maintenance than curb and gutter systems.

Maintenance requirements:

- Needs routine landscape maintenance; maintain grass height of approximately 4-6 inches.
- Inspect annually for erosion problems; remove accumulated trash and debris.
- Remove sediment from forebay and channel (if necessary).

A. Description

Grass swales, also called biofilters, are typically designed to provide nominal treatment of runoff as well as meet runoff velocity targets for the water quality design storm. Grass swales are well-suited to a number of applications and land uses, including treating runoff from roads and highways and pervious surfaces.

Grass swales differ from the enhanced dry swale design in that they do not have an engineered filter media to enhance pollutant removal capabilities, and therefore have a lower pollutant removal rate than a dry or wet (enhanced) swale. Grass swales can partially infiltrate runoff from small storm events in areas with pervious soils. When properly incorporated into an overall site design, grass swales can reduce impervious cover, accent the natural landscape, and provide aesthetic benefits.

When designing a grass swale, the two primary considerations are channel capacity and minimization of erosion. Runoff velocity should not exceed 1 fps during the peak discharge associated with the water quality design rainfall event, and the total length of a grass swale should provide at least five minutes of residence time. To enhance water quality treatment, grass swales must have broader bottoms, lower slopes, and denser vegetation than most drainage channels. Additional treatment can be provided by placing check dams across the channel, below pipe inflows and at various other points along the channel.

B. Stormwater management suitability

Grass swales can provide effective control under light to moderate runoff conditions, but their ability to control large storms is limited. Therefore, they are most applicable in low- to moderately-sloped areas, or along highway medians as an alternative to ditches or curb and gutter drainage (Boutiette and Duerring, 1994). Their performance diminishes sharply in highly urbanized settings, and they are generally not effective enough to receive construction stage runoff where high sediment loads can overwhelm the system (Schueler et al., 1992). Grass swales are often used as a pre-treatment measure for other downstream BMPs, particularly infiltration devices (Driscoll and Mangarella, 1990). Grass swales are typically shallow, vegetated, man-made conveyance channels designed such that the bottom elevation is above the water table to facilitate the infiltration of runoff to the soil. The vegetation covering the side slopes and channel bottom provide a filtration surface as the runoff is collected and slowly conveyed to a downstream discharge location. Swales provide additional treatment of the stormwater runoff as water moves through a subsoil matrix and infiltrates into the underlying soils. The vegetation also serves to reduce flow velocities. Swales can be either dry or wet; dry swales are more desirable where standing water is not wanted, such as residential areas; wet swales can be used where standing water does not create a nuisance and where the groundwater is close enough to the surface to maintain a shallow permanent pool between storm events. An advantage of wet swales is the ability to include wetland vegetation to assist in pollutant removal (U.S. EPA 1999b).

C. Pollutant removal capabilities

Pollutants are removed in swales by the filtering action of grass, deposition in low velocity areas, or by infiltration into the subsoil. The primary pollutant removal mechanism is through sedimentation of suspended materials. Therefore, TSS and adsorbed metals are most effectively removed through a grass swale. Removal efficiencies reported in the literature vary, but generally fall into the low to medium range, with some swale systems recording no water quality effects at all. Table 1 presents pollutant removal efficiencies for swale lengths of 200 feet and 100 feet. Although research results varied, these data clearly indicate greater pollutant removal at longer swale lengths. In general, thecurrent literature reports that a well-designed, well-maintained swale system can be expected to remove 70% of TSS, 30% for total phosphorus (TP), 25% for total nitrogen (TN), and 50 to 90% for trace metals (Barret et al., 1993 and GKY and Associates, Inc., 1991). The nitrogen removals may be fairly optimistic, given that studies conducted by Yousef et al. (1985) and others produced negative nitrogen removal in many cases. It is theorized that the outwelling of nitrogen from grass clippings and other organic materials from the swale produced these results.

Seasonal differences in swale performance can be important. In temperate climates, fall and winter temperatures force vegetation into dormancy, thereby reducing uptake of runoff pollutants, and removing an important mechanism for flow reduction. Decomposition in the fall and the absence of grass cover in the winter can often produce an outwelling of nutrients, and exposes the swale to erosion during high flows, increasing sediment loads downstream. Pollutant removal efficiencies for many constituents can be markedly different during the growing and dormant periods (Driscoll and Mangarella, 1990).

Table 1: Swale pollutant removal efficiencies

Pollutant removal efficiencies (%)								
Design	**Solids**	**Nutrients**		**Metals**			**Other**	
	TSS	TN	TP	Zn	Pb	Cu	FOG	COD**
200-ft swale	83	25*	29	63	67	46	75	25
100-ft swale	60	*	45	16	15	2	49	25
* Some swales (100-ft systems) show negligible or negative removal for TN ** Limited data								

Sources: Barret et al., 1993; Schueler et al, 1991; Yu,1993; and Yousef et al., 1985

The following design pollutant removal rates are conservative average pollutant reduction percentages for design purposes derived from sampling data, modeling and professional judgment.

- Total suspended solids: 50%
- Total phosphorus: 25%
- Total nitrogen: 20%
- Fecal coliform: insufficient data
- Heavy metals: 30%

D. Application and feasibility

The grass swale consists of a broad, mildly-sloped open channel designed to maintain a minimum residence time of 10 minutes for the water quality storm (Figure 1). Grass swales have traditionally been utilized only for stormwater conveyance purposes. However, the design provides capacity to convey a larger storm (usually the 10-year frequency storm); as well as protection against erosion for smaller, more frequent storms (usually the 2-year event). Water quality treatment in standard grass swales is provided by managing the slope and vegetation in the channel to slow the velocity to ~1 fps for the water quality design storm (≤ 1.25 inches). The design for a grass swale is flow-rate based.

E. Grass swales for pre-treatment

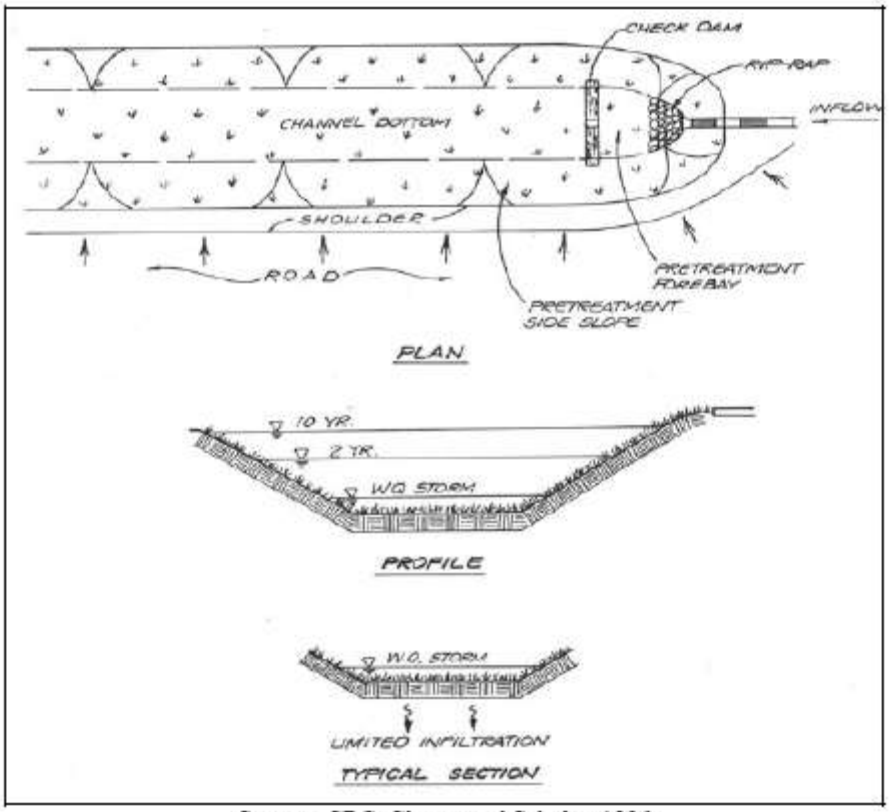
A number of other structural controls, including bioretention areas and infiltration trenches, may utilize a grass swale as a pre-treatment measure. The length of the grass swale depends on the drainage area, land use, and channel slope. Table 2 provides sizing guidance for grass swales for a 1-acre drainage area. The minimum length of a grass swale should be 20 feet.

Table 2: Grass swale sizing guidance

Parameter	Upstream imperviousness					
	≤ 33%		34-66 %		≥ 67%	
Slope (max = 4%)	< 2%	>2%	<2%	>2%	<2%	>2%
Grass swale minimum length (feet)*	25	40	30	45	35	50
*assumes 2-foot wide bottom width						

Source: CRC, Claytor and Schuler, 1996

Figure 1: Configuration of grass swale



Source: CRC, Claytor and Schuler, 1996

F. Check dams

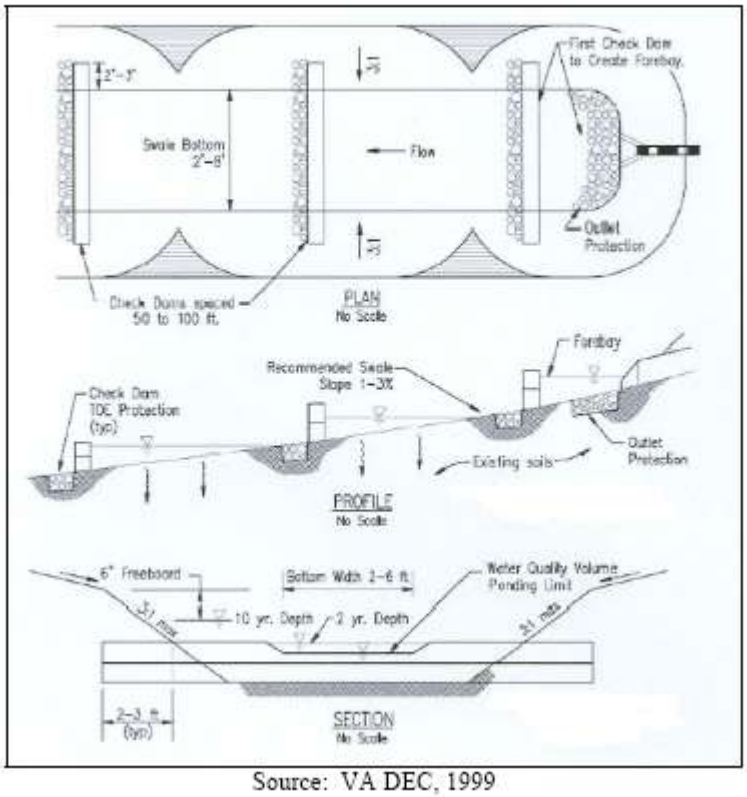
Check dams are used in swales for two reasons: to increase pollutant removal efficiency and/or to compensate for steep longitudinal slope. The dams should be installed perpendicular to the direction of flow and anchored into the slope of the channel. The side slopes of the check dams should be between 5:1 and 10:1 to facilitate mowing operations. The berm height should not exceed 2 feet, and water detained behind the berm should infiltrate into the soils within 24 hours (Colorado Department of Transportation, 1992). Figure 2 shows an example of check dams erected at regular intervals to maintain a shallower, uniform slope (VA DEC, 1999). With this configuration, energy-dissipating and flow-spreading riprap is often used across check dams and for a short distance downstream at the toe of the drops. Check dams should be spaced so that the toe of the upstream dam is at the same elevation as the top of the downstream dam. Check dams can be constructed using earth, riprap, gabions, railroad ties, or pressure-treated wood logs. Figure 3 provides typical check dam configurations for a riprap and a half-round corrugated metal pipe check dam (VA DEC, 1999). For best performance, check dams should have a level upper surface rather than the uneven surface of a

riprap check dam. Earthen check dams are not recommended, due to erosion potential and high maintenance effort.

Figure 2: Grass swale with check dams (berms)

Source: VA DEC, 1999

Figure 3: Typical swale with check dam configuration



Source: VA DEC, 1999

G. Channel design criteria

The design approach consists of three criteria for sizing grass swales for stormwater quality treatment, while also accommodating larger storms:

- The channel is initially designed, based on the treatment principles of small storm hydrology for the water quality storm (see Section 2C-7).
- The channel design is then checked against the larger 2-year storm to ensure a non-erosive condition.
- Finally, the capacity for conveyance of the 10-year frequency storm is checked and a minimum freeboard is applied.

The design procedure is a rate-based sizing criteria which uses Manning's equation to compute velocities and depths, based on specified channel geometry and slope. Figure 4 illustrates the design components of the grass swale. The specific design considerations are presented below, and a summary is provided in Table 3.

1. **General design criteria.**
   a. Grass swales should generally be used to treat small drainage areas of less than 5 acres. If the practices are used on larger drainage areas, the flows and volumes through the channel become too large to allow for filtering and infiltration of runoff.
   b. Grass swales should be designed on relatively flat slopes of less than 4%, channel slopes between 1-2% are recommended.
   c. Grass swales can be used on most soils with some restrictions on the most impermeable soils. Grass swales should not be used on soils with infiltration rates less than 0.3 inches per hour if infiltration of small runoff flows is intended.
   d. A grass swale should accommodate the peak flow for the water quality design storm – Qwq (see Section 2C-7).
   e. Runoff velocities must be non-erosive. For the Qwq, the velocity should be ≤ 1 fps. The full-channel design velocity will typically govern.
   f. A minimum five-minute residence time is recommended for the water quality peak flow. Residence time may be increased by reducing the slope of the channel, increasing the wetted perimeter, or planting a denser grass (raising the Manning's n).
   g. The depth from the bottom of the channel to the groundwater should be at least 2 feet to prevent a moist swale bottom or contamination of the groundwater.
   h. Check dams within the channel will maximize retention time (Figure 2).
   i. Select a grass that can withstand relatively high-velocity flows at the entrances, and both wet and dry periods. See SUDAS specifications for a list of appropriate grasses for use in Iowa.

2. **Shape.** The channel should be trapezoidal or parabolic in shape. The trapezoidal cross section is the easiest to construct and a more efficient hydraulic configuration. However, since channels tend to become parabolic in shape over time, a channel originally designed as a trapezoidal section should also be checked against parabolic sizing equations as a long-term functional assessment. The criteria presented in this section assume a trapezoidal cross section. Note that the same design principles will govern parabolic cross sections, except for the cross sectional geometry.

3. **Bottom width.** For a trapezoidal cross section, size the bottom width between 2 and 8 feet. The 2-foot minimum allows for construction considerations and ensures a minimum filtering surface for water quality treatment. The 8-foot maximum prevents shallow flows from concentrating and potentially eroding channels, thereby maximizing the filtering by vegetation. Widths up to 12 feet may be used if separated by a dividing berm or structure to avoid braiding. The bottom width is a

dependent variable in the calculation of velocity based on Manning's equation. If a larger channel is needed, the use of a compound coss section is recommended.

4. **Manning's n value.** The roughness coefficient, n, varies with the type of vegetative cover and flow depth. At very shallow depths, where the vegetation height is equal to or greater than the flow depth, the n value should be approximately 0.15. This value is appropriate for flow depths up to 4 inches. For higher flow rates and flow depths, the n value decreases to a minimum of 0.03 for grass swales at a depth of approximately 12 inches. The n value must be adjusted for varying flow depths between 4 and 12 inches (see Figure 5 for variable n values with varying depths).

5. **Side slopes.** The side slopes should be flat as possible to aid in providing pre-treatment for lateral incoming flows and to maximize the channel filtering surface. Steeper side slopes are likely to have potential for erosion from incoming lateral flows. A maximum slope of 3:1 is recommended (33%); a 4:1 slope is preferred where space permits.

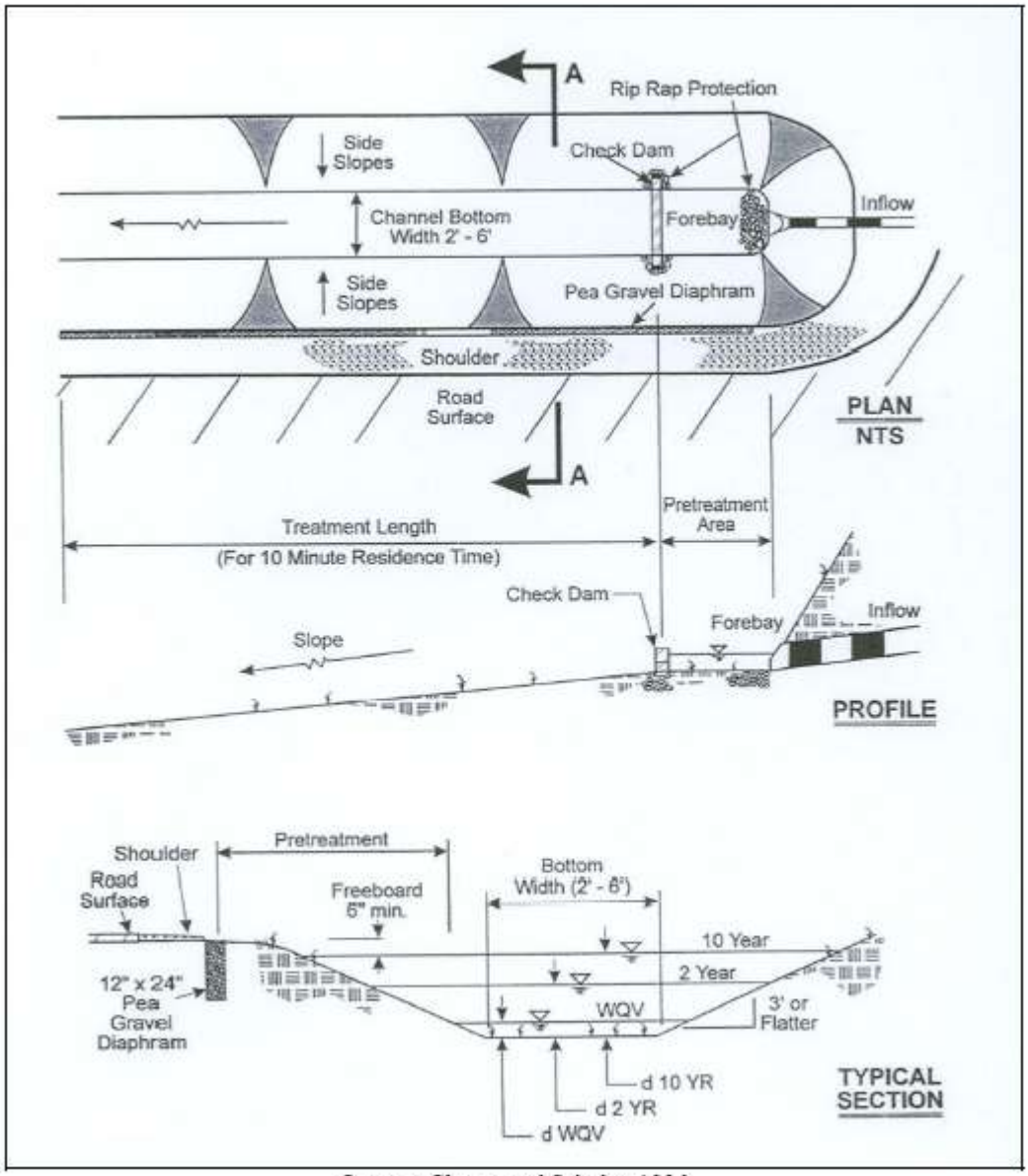
6. **Channel longitudinal slope.** The slope of the channel should be steep enough to ensure uniform flow and that which can be constructed using conventional construction equipment without ponding, but not steeper than 4%. A minimum slope of 1% is recommended.

7. **Flow depth.** Maximum depth of flow no greater than one-third of the vegetation height for infrequently mowed swales, or no greater than one-half of the vegetation height for regularly mowed swales, up to a maximum of 4 inches. The maximum flow depth for water quality treatment should be approximately the same as the height of the grass. Since most channels will be mowed relatively infrequently, the vegetation may reach heights of 6 inches or more. However, since higher grass will likely flatten during higher flows, a maximum flow depth of 4 inches is recommended for water quality design. The flow depth for the 2-year and 10-year storms will depend on the flow rate and channel geometry.

8. **Flow velocity.** The maximum flow velocity for water quality treatment should be sufficiently low to provide adequate residence time within the channel. A maximum flow velocity of 1 fps for water quality treatment is required. The maximum flow velocity for the 2-year storm should be non-erosive (a rate of 4-5 fps is generally recommended). The permissible velocities of several grass species are listed in Table 4. Velocity values are purely guidelines and may not always be representative of field conditions. The 10-year permissible velocity may be somewhat higher due to the low frequency of occurrence. A permissible maximum rate of approximately 7 fps for this event is recommended.

9. **Length of channel**. Generally grass swale length (for conveyance) is a function of site drainage constraints and a required length is not necessary. However, for water quality treatment, a minimum residence time of 10 minutes should be reached to facilitate filtering. The minimum length required for water quality treatment grass swales is equal to the velocity, in feet per second, multiplied by the minimum residence time of 600 seconds.

Figure 4: Configuration and design components of a grass swale for water quality treatment



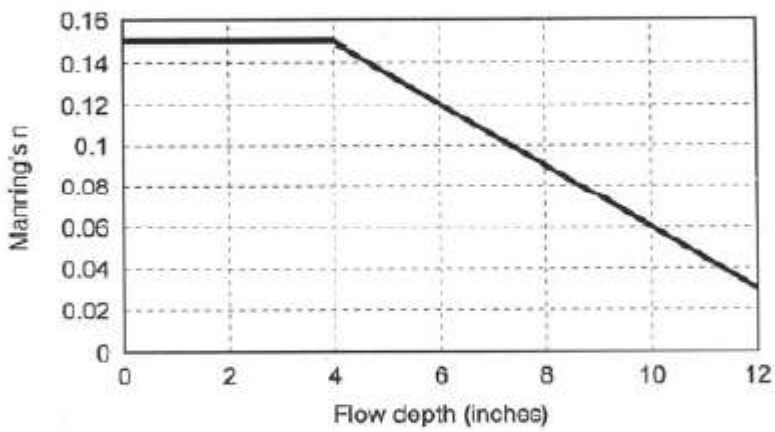
Source: Claytor and Schuler, 1996

Table 3: Design criteria for trapezoidal grass swales for water quality treatment

Parameter	Design Criteria
Bottom width	2-ft minimum, 6-ft maximum*
Side slopes	3:1 or flatter
Channel longitudinal slope	1% minimum; 4% maximum
Flow depth	4 inches for water quality treatment
Manning's n value	0.15 for water quality treatment (depth < 4 inches); varies from 0.15-0.03 for depths of 4-12 inches; 0.03 minimum for depths > 12 inches (see Figure 5)
Flow velocity	1 fps for water quality treatment; 4-5 fps for 2-yr storm; 7 fps for 10-yr storm
Length	Length necessary for 10-minute residence time
* Widths up to 12 feet are allowable when using a division structure to avoid meandering concentrated flows	

Source: Adapted from Claytor and Schuler, 1996

Figure 5: Variable Manning's n with flow depth



Source: Claytor and Schuler

Table 4: Selecting maximum permissible swale velocities for stability

		Maximum Velocity (fps)	
Cover Type	Slope (%)	Erosion-resistant soils	Easily-eroded soils
Kentucky blue grass; Tall fescue	0-5	6	5
Kentucky blue grass; Rye grasses	5-10	5	4
Grass – legume	0-5	5	4
Mixture	5-10	4	4
Red fescue	0-5	3	2.5

Source: Temple et al, 1987

H. Design procedure

The following steps are recommended for completing a grass swale design:

- Determine design flow rate to the system (Qwq)
- Determine the slope of the system
- Select a swale shape
- Determine required channel width
- Calculate the cross sectional area of flow

- Calculate the velocity of channel flow
- Calculate swale length
- Select swale location based on the design parameters
- Select a vegetation cover for the swale
- Check for swale stability

1. **Step 1: Determine design flow rate.**

    a. Determine the WQv using a design storm depth of 1.25 inches, or use the 90% rule to select rainfall depth for the water quality storm (refer to Parts 2B and 2C).

    b. Compute the peak rate of discharge (Qwq) for the water quality storm, based on the procedures identified in Section 2C-7. Note: This calculation can be done using WINTR-55 after a custom CN is computed using the water quality design storm depth (1.25 inches).

    c. The design storm is subject to local regulations, and thus may vary on a local basis.

    d. Unless runoff from larger events is designed to bypass the swale, consideration must be given to the control of channel erosion and destruction of vegetation. A stability analysis for larger flows (up to the 100-yr, 24-hour) must be performed. Runoff quantity and design flows can be estimated using a variety of mathematical, graphical, and computerized techniques.

    e. Use the Qwq to size the channel, maintaining design criteria parameters noted in Table 3.

    f. Determine the velocity (fps) for the Qwq and n=0.15 for channel widths of 2 feet, 4 feet, and 6 feet, or use computer model which solves Manning's equation or other open channel flow equations.

    g. Compute 2-year and 10-year frequency storm event peak discharges using NRCS WINTR-55.

    h. Check 2-year velocity for erosive potential (adjust geometry if necessary, and re-evaluate WQv design parameters).

    i. Check 10-year depth and velocity for capacity (adjust geometry if necessary, and re-evaluate WQV and 2-year design parameters).

    j. Provide minimum freeboard above 10-year stormwater surface elevation (6 inches minimum, recommended).

2. **Step 2: Determine the slope of the system.** (See Table 3). The slope of the swale will be somewhat dependent on where the swale is placed, but should be between the stated criteria of 1-4%. An optimum slope of 1.5-2% is desired. With slopes less than 2%, the use of under drainage may be required. If the slope is between 4-6%, vertical drops of 6-12 inches will be required using check dams/berms at 50- to 100-foot intervals. Energy dissipating and flow spreading riprap will be needed across check dams and for a short distance downstream of the toe drops. If the slope is greater than 6%, the grade will need to be traversed to reduce the slope of any segment to below 4% preferably, or to below 6% with check dams.

3. **Step 3: Select a swale shape.** Normally, swales are designed and constructed in a trapezoidal shape, although alternative designs can be parabolic, rectangular, or triangular. Trapezoidal cross

sections would be preferred because of relatively wider vegetative areas and ease of maintenance. This also avoids the sharp corners present in v-shaped and rectangular swales, and offer better stability than the vertical walls of rectangular swales. A parabolic shape is best for erosion control, but is hard to construct. Trapezoidal shapes tend to become parabolic over time, due to the growth of vegetation and settlement of solids (Horner, 1988). Unless space is a problem, the design process should begin assuming a trapezoidal shape. The remainder of the design process assumes that a trapezoidal shape has been selected. A minimum side slope of 3:1 or flatter should be used; a side slope of 4:1, or even 5:1, would be preferred. The wider the wetted area of the swale, the slower the flow.

4. **Step 4: Determine required channel width.** Estimates for channel width for the selected shape can be obtained by applying Manning's equation (Equation 2). Figure 6 presents channel geometry and equations for a trapezoidal swale, the most frequently-used shape. A Manning's n value of 0.15-0.2 is recommended for routine swales that will be mowed with some regularity. For swales that are infrequently mowed, a Manning's n value of 0.24 is recommended. A higher n value can be selected if it is known that vegetation will be very dense. Figure 7 provides a range of n values.

   a. Continuity Equation.

   $Q = V \times A$ **Equation 1**

   where V = the mean velocity (fps) and A = the flow cross sectional area normal to the direction of the flow (ft^2).

   The cross sectional area is the product of the channel width and the depth of flow in the channel. The depth of flow in the channel for a uniform discharge is the normal depth. At normal depth the slope of the invert (channel bottom), the slope of the HGL, and the slope of the EGL are equal and parallel to each other. Normal depth for a given discharge can be determined using the Manning equation. Velocities for grass swales are calculated with Manning's equation, but the characteristic dimension now becomes the hydraulic radius.

   b. Manning's Equation.

   $V = (1.49/n)\, R^{2/3} S^{1/2}$ **Equation 2**

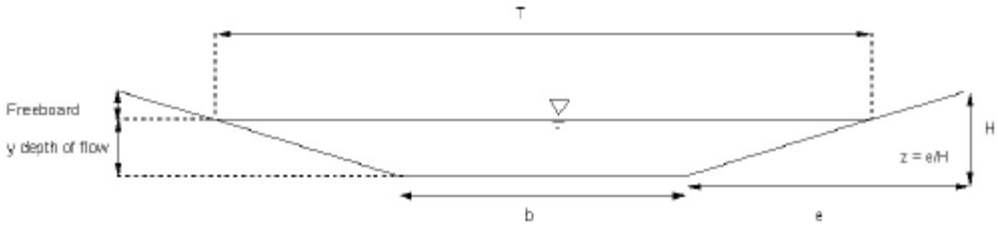
   where V = the mean velocity (fps), R = the hydraulic radius (ft), S = the slope of the energy line (channel invert), and n = the coefficient of roughness.

   Further, hydraulic radius, R, of the swale is defined as:

   $R = A/P$

   where A = cross sectional area of swale (ft^2), and P = wetted perimeter of swale (ft).

Figure 6: Channel and flow geometry for a trapezoid swale



c. Side slope.

$Z = e / H$ **Equation 3**

d. Cross sectional area.

$A = by + zy^2$ **Equation 4**

e. Top width.

$T = b + 2Hz$ **Equation 5**

f. Wetted perimeter.

$P = b + 2y\,[1+z^2]^{0.5}$ **Equation 6**

g. Hydraulic radius.
$R = A/P = (by + by2)/\,[b + 2y\,[1+z^2]^{0.5}]$ **Equation 7**

h. Swale depth.

$H = y + \text{freeboard}$ **Equation 8**

where y = flow depth, b = bottom width, and e = side width of trapezoidal channel.

Manning's n values are not constant, but vary widely with depth of flow as shown in Figure 5. Vegetated channels are grouped into retardance classes A through E shown in Table 5. In each these retardance classes, Manning's n is shown as a function of product of velocity V in fps and hydraulic radius R in ft. Using these curves, Ree (1949) developed nomographs for solving Manning's equation for each retardance class. An example is shown in Figure 8 for Retardance class C. Nomographs for other retardance classes are given in Haan et al. (1994).

i. Manning's equation (Equation 2) can be solved for flow by combining with the continuity equation (Equation 1).

j. The bottom width of the trapezoid cannot be solved directly so the solution is iterative. However, the calculations can be solved fairly quickly using a spreadsheet with iterative capabilities and the ability to vary only certain variables.

k. Typically, flow depth, y, is set at 3-4 inches maximum (Table 3). Flow depth can also be estimated by subtracting 2 inches from the expected grass height, if the grass type and the height it will be maintained is known. Values lower than 3-4 inches can be used, but doingso

will increase the computed width (T or b) of the swale. Flow depth is subject to a stability check as described below.

l. The computed bottom swale width should be between 2-8-feet. Relatively wide swales (those wider than 8 feet are more susceptible to flow channelization and are less likely to have uniform sheet flow across the swale bottom for the entire swale length. A practical minimum swale width for trapezoidal swales should also be established for ease of maintenance, e.g., to facilitate swale mowing with standard lawn mowers. Therefore, if b for a trapezoid swale is greater than 8 feet, investigate either (a) the probability for channelization given flow spreader device(s) to be used and swale maintenance practices, or (b) methods by which the design flow (Q) can be reduced. Since length may be used to compensate for width reduction (and vice versa) so that the area is maintained, the swale width can be arbitrarily set to 8 feet to continue with the analysis. If b<2 feet, set b=2 feet and continue. Narrower widths can be used if space is very constrained.

5. **Step 5: Calculate cross sectional area of flow.** Compute the cross-sectional area (A) for the design flow, using Equation 4.

6. **Step 6: Calculate the velocity of the channel flow.**
   a. Using the continuity equation (Equation 1), the channel flow velocity can be calculated. The channel flow velocity should be less than 1 fps to prevent grasses from being flattened, which reduces filtration. A velocity lower than this maximum value is recommended to achieve the 10-minute hydraulic residence time criterion, particularly in shorter swales (at V=1 fps, a 600-foot swale is needed for a 10-minute hydraulic residence time and a 300-foot swale for a 5-minute residence time).

   b. If the value V suggests that a longer swale will be needed than space permits, investigate how the design flow Q can be reduced; or increase flow depth (y) and/or swale bottom width (b) up to the maximum allowable values and repeat the analysis.

7. **Step 7: Calculate swale length.**
   a. Compute the swale length (L) using the following equation:

   $L = Vt_r\,(60\ \text{sec/min})$ **Equation 10**

   where: t_r = Hydraulic residence time (in minutes).

   b. Use t_r = 10 minutes for this calculation. Swale length may be a matter of local regulation, however length is directly related to achieving the goal of a 10-minute hydraulic residence time. This criterion has been shown to be the optimum value for good removal of particulates, oil, and grease. Performance data from research has indicated that shorter residence times cause a reduction in pollutant removal rates. Longer times may be required if expected pollutant removal efficiency for solids is to exceed 80%.

8. **Step 8: Select swale location.** Options for swale locations may be limited, or may be decided through processes outside the control of the designer. If this is the case, swale geometry should be maximized by the designer, using the above equations, and given the area to be utilized. If the location has not yet been chosen, it is advantageous to compute the required swale dimensions and then select a location where the calculated width and length will fit. If locations available cannot accommodate a linear swale, a wide-radius curved path can be used to gain length. Sharp

bends should be avoided to reduce erosion potential. Regardless of when and how site selection is performed, consideration should be given to the following site criteria:

a. **Soil type.** Soil characteristics in the swale bottom should be conducive to grass growth. Soils that contain large amounts of clay cause relatively low permeability and result in standing water, which may cause grass to die. Compacted soils will need to be tilled before seeding or planting. If topsoil is required to facilitate grass seeding and growth, use 6 inches of the following recommended topsoil mix: 50-80% sandy loam, 10-20% clay, and 10-20% composted organic matter (leaf compost).

b. **Slope.** The natural slope of the potential location will determine the nature and amount of regrading, or if additional measures to reduce erosion and/or increase pollutant removal are required. Biofilters should be graded carefully to attain uniform longitudinal and lateral slopes, and to eliminate high and low spots. If needed, grade control checks should be provided to maintain the computed longitudinal slope and limit maximum flow velocity.

c. **Natural vegetation.** The presence and composition of existing vegetation can provide valuable information on soil and hydrology. If wetland vegetation is present, inundated conditions may exist at the site. The presence of larger plants, trees and shrubs may provide additional stabilization along the swale slopes, but also may shade any grass cover established. Most grasses grow best in full sunlight, and prolonged shading should be avoided. It is preferable that vegetation species be native to the region of application, where establishment and survival have been demonstrated.

9. **Step 9: Select vegetative cover.** A dense planting of grass provides the filtering mechanism responsible for water quality treatment in swales. In addition, grass has the ability to grow through thin deposits of sediment and sand, stabilizing the deposited sediment and preventing it from being re-suspended in runoff waters. Few other herbaceous plant species provide the same density and surface per unit area. Grass is by far the most effective choice of plant material in swales, however not all grass species provide optimum vegetative cover for use in swale systems. Dense turf grasses are best for vegetative cover. Table 6 is provided as an example of the variations in grass species. See the SUDAS specifications for information on the recommended or optimum turf grass species most suitable to the area, based on suitability in terms of cold tolerance, heat tolerance, mowing height adaptation, drought tolerance, and maintenance cost and effort.

   The type of grass cover can be selected at any earlier stage in the design process. Often if grass cover is known, optimum height can be established and flow depths can be set accordingly. In areas of poor drainage, wetlands species can be planted for increased vegetative cover. Use wetland species that are finely divided and relatively resilient, like grass. Use of invasive species should be avoided to eliminate proliferation in the swale and downstream.

10. **Step 10: Check swale stability.** The stability check is performed for the combination of highest expected flow and least vegetation coverage and height.

    a. Compute 2-year and 10-year frequency storm event peak discharges using NRCS WINTR-55.

    b. Check 2-year velocity for erosive potential (adjust geometry if necessary, and re-evaluate WQv design parameters).

c. Check 10-year depth and velocity for capacity (adjust geometry if necessary, and re-evaluate WQv and 2-year design parameters).

d. Provide minimum freeboard above 10-year stormwater surface elevation (6 inches minimum, recommended).

e. Stability is normally checked for flow rate (Q) for the 100-yr, 24-hour storm unless runoff from larger such events will bypass the swale. Q can be determined using the same methods mentioned for the initial design storm computation.

f. The maximum velocity, V_{max} (fps), that is permissible for the vegetation type, slope, and soil conditions should be obtained. Table 4 provides maximum velocity data for a variety of vegetative covers and slopes.

g. The estimated degree of retardance for different grass coverage (good or fair) should be obtained for the selected vegetation height. Estimation should be based on coverage and height that will first receive flow, or whenever coverage and height are at their lowest. Table 5 provides qualitative degrees of retardance for coverage and grass height.

Table 5: Guide for selecting degree of flow retardance

Average height of grass (inches)	Degree of vegetation coverage	
	Good	Fair
>25	A (very high)	B (high)
11-24	B (high)	C (moderate)
6-10	C (moderate)	D (low)
2-6	D (low)	D (low)
<2	E (very low)	E (very low)

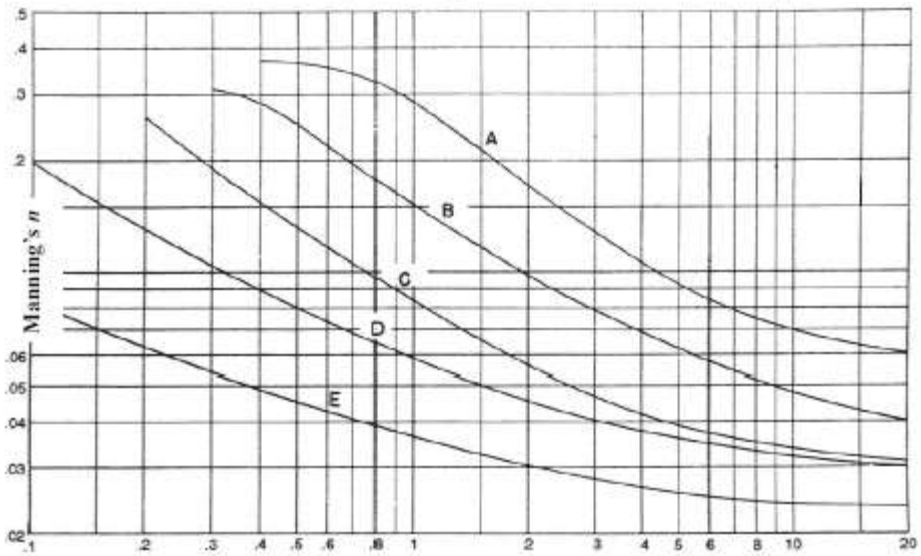
Source: NRCS, 1954

Table 6: Manning roughness coefficients, n, for typical grasses for well-maintained straight channels without shrubbery or trees

Grass Type (1)	Depth of Flow	
	0.7-1.5 feet (2)	> 3.0 feet (3)
Bermuda grass, buffalo grass, Kentucky bluegrass		
a. Mowed to 2 inches	0.035	0.030
b. Length 4-6 inches	0.040	0.030
Good stand; any grass		
a. Length of 12 inches	0.070	0.035
b. Length of 24 inches	0.100	0.035
Fair stand; any grass		
a. Length of 12 inches	0.060	0.035
b. Length of 24 inches	0.070	0.035

Source: Chow, 1959

Figure 7: Relation between Manning's n roughness coefficient VR* and degree of retardance**



*VR: product of velocity and hydraulic radius
**Degree of flow retardance due to vegetation: A-very high, B-high, C-moderate, D-low, E-very low

Source: Haan et al., 1994

h. Select a trial Manning's n value for poor vegetation cover and low height. A good initial choice is n=0.04. Using the alpha code assigned for the degree of retardance and the chosen n value, consult the graph in Figure 7 to obtain a first approximation for VR (velocity times hydraulic radius, ft^2/sec).

i. Compute the hydraulic radius, using the V_{max} determined for vegetation type and slope, by applying the following equation:

$$R = VR/V_{max}$$ **Equation 11**

For precision, the VR value obtained from the graph, in units of ft^2/s, should be converted to metric units by multiplying by a factor of 0.09290 to obtain VR in m^2/s. From Manning's equation (metric):

$$V = 1.0/n\ R^{2/3}S^{1/2}$$, then

$$VR = (R^{1.67}S^{0.5})/n$$ **Equation 12**

Once the actual VR is determined, compare this value with the first approximation for VR obtained through Figure 2I-2.7. If they do not agree within 5%, adjust Manning's n value and repeat the process until acceptable agreement is reached. If n<0.033 is needed to get agreement, set n = 0.033, solve VR again using Manning's equation above, and proceed. The actual velocity for the final design conditions should be computed using the following equation:

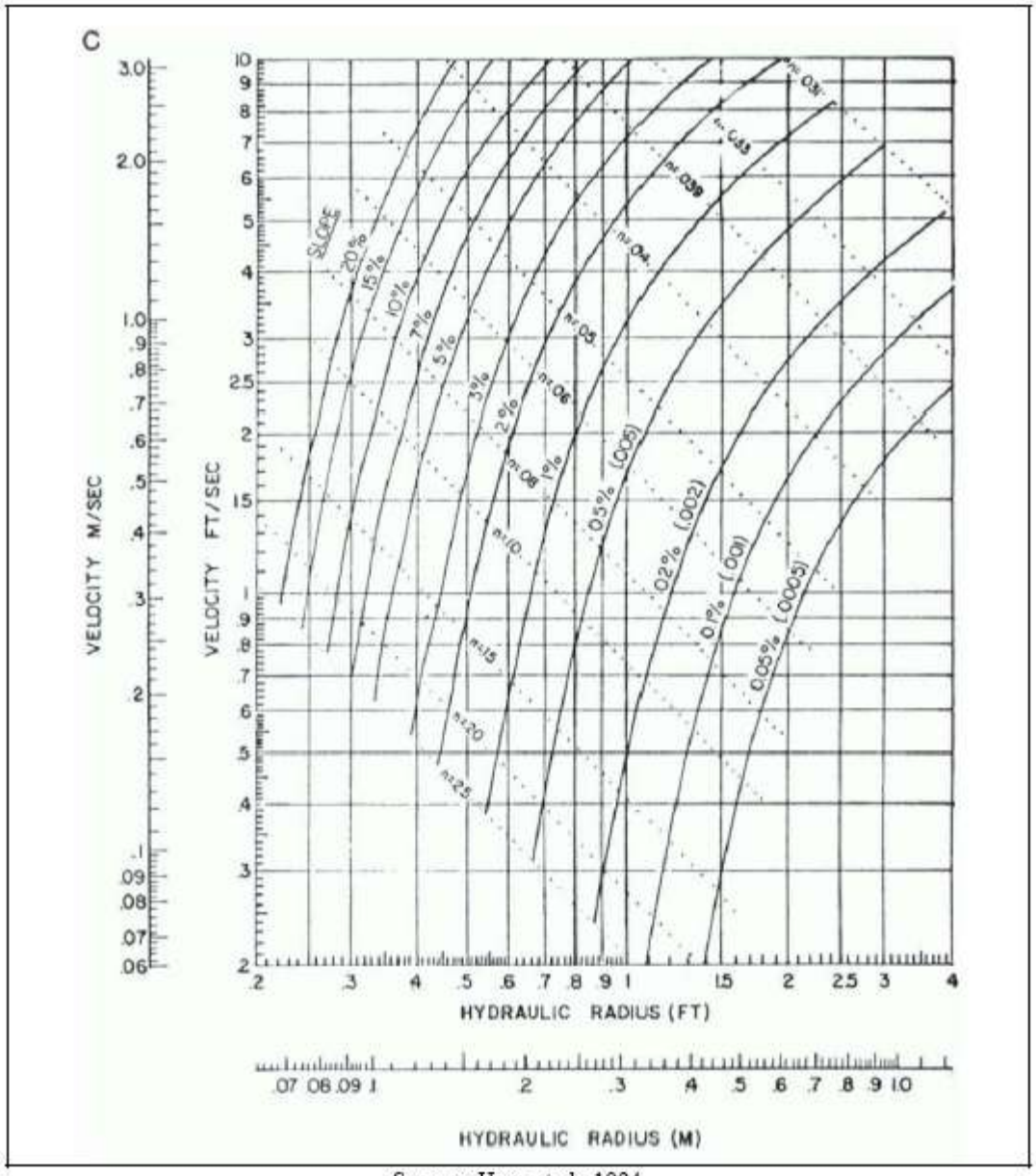
$$V = VR/R$$ **Equation 13**

The actual velocity V should be less than or equal to the maximum value obtained from Table 4. The area required for stability is computed using the continuity equation (Equation 1). The area value obtained in this procedure should be compared with the area value obtained in the design flow analysis. If less area is required for stability than is provided for design flow, the design is acceptable. If more area is required for stability, use the area value obtained in the stability analysis to recalculate channel dimensions and recalculate the depth of flow, solving Equation 4 for y.

This stability flow depth, if needed, should be compared to the depth used in the design flow. The larger of the two values should be used, plus 12 inches (6 inches minimum) of freeboard, to obtain the channel depth (Equation 8).

A final check for capacity should be performed based on the stability check and the maximum vegetation height and cover to ensure that capacity is adequate if the largest expected event coincides with the greatest retardance. Use Manning's equation with Manning's n value used for design flow and the calculated channel dimension (including freeboard) to compute the flow capacity of the channel. If the flow capacity is less than the flow rate of the stability check, increase the channel cross sectional area as needed for this conveyance, and specify the new channel dimensions. Horner (1988) advocated using a parabolic shape for design even if a design for a trapezoidal shape is initially used in construction. A check using the parabolic shape may give an indication of performance at some later date. If there is insufficient space for the grass swale as designed, possibilities include dividing the flow among several swales, installing detention to control release rate upstream, increasing longitudinal slope, increasing side slopes, increasing vegetation height and design depth of flow (design should ensure vegetation remains standing during design flow), and reducing developed surface area to reduce runoff coefficient value and gain space for use of the grass swale.

Figure 8: Solution to Manning's equation for retardance class C



Source: Haan et al., 1994

I. Inspection and maintenance requirements

Table 7: Typical maintenance activities for grass swales

Activity	Schedule
Mow grass to maintain a height of 3-6 inches.	As needed (frequently/seasonally)
Remove sediment buildup in the bottom of the grass swale once it has accumulated to 25% of the original design volume.	As needed (infrequently)
Inspect grass along side slopes for erosion and formation of rills or gullies and correct.	Annually (semi-annually the first year)
Remove trash and debris accumulated in the channel.	
Based on inspection, plant an alternative grass species if the original grass cover has not been successfully established.	

Source: Claytor and Schuler, 1996

Table 8: Example criteria for turf grass cover

High ↑	Cold Tolerance	Heat Tolerance	Mowing Height	Drought Tolerance	Maintenance
	Kentucky bluegrass Red fescue		Tall fescue		
		Tall fescue	Red fescue Kentucky bluegrass Perennial ryegrass		
		Kentucky bluegrass Perennial ryegrass		Tall fescue Red fescue	Kentucky bluegrass Perennial ryegrass
	Tall fescue				
		Red fescue		Kentucky bluegrass Perennial ryegrass	Tall fescue
↓ *Low*					

Source: Adapted from Young et al., 1996

J. Design example

Trapezoidal Grass Swale

1. **Basic data.** Small commercial lot 300 feet deep x 145 feet wide located in Des Moines, IA.

   a. Drainage area (A) = 1 acre

   b. Impervious percentage (I) = 70%

   c. Rv = 0.05 + (0.009)* (I) = 0.68

2. **Water quality peak flow.** (See Section 2C-7 for details).

   a. Compute the water quality volume in inches:

   WQv = 1.2 (0.05 + 0.009 * 70) = 0.82 inches

   b. Compute modified CN for 1.25-inch rainfall (P=1.25 inches)

CN = 1000/[10+5P+10Q-10(Q2+1.25*Q*P)½]

= 1000/[10+5*1.25+10*0.82-10(0.822+1.25*0.82*1.25)½]

= 96.49 (Use CN = 96)

c. For CN = 96 and an estimated time of concentration (t_c) of 8 minutes (0.13 hours), compute the Qwq for a 1.25-inch storm.

Compute Qwq using NRCS WINTR-55:

Qwq = 1.24 cfs

d. Compute Q_2 and Q_{10} using CN=87 for this site (70% impervious urban commercial site with B soils) and t_c = 0.13 hr: WINTR-55 results:

Q_2 = 2.42 cfs Q_{10} = 4.14 cfs Q_{100} = 7.17 cfs

3. **Use Qwq to size the channel.** The maximum flow depth for water quality treatment should be approximately the same height of the grass. A maximum flow depth of 4 inches is allowed for water quality design. A maximum flow velocity of 1 fps for water quality treatment is required. For Manning's n, use 0.15 for medium grass, 0.25 for dense grass. Longitudinal slope is 2%. Grass will need to be maintained at a 6-inch height. Trapezoidal channel with side slope of 4:1 (z = 4.0). Tall fescue will be used as the grass type.

a. Input variables:

n = 0.15
S = 0.02 ft/ft
D = 4/12 = 0.33 ft

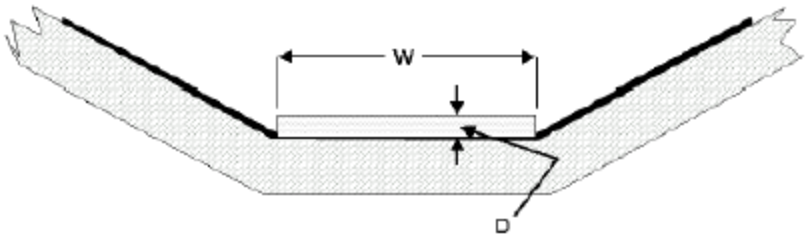
b. Then:

Qwq = Q = V x A = [1.49/n $D^{2/3}$ $S^{1/2}$] x DW

where:
Q = peak flow (cfs)
V = velocity (fpsec)
A = flow area (ft2) = WD
W = channel bottom width (ft)
D = flow depth (ft)
S = slope (ft/ft)

Note: D approximates hydraulic radius for shallow flows.

Figure 9: Using Qwq to size a channel



c. Then for a known n, Q, D, and S minimum width can be calculated.

$(nQ)/(1.49\ D^{5/3}\ S^{1/2}) = W = (0.15*1.24)/(1.49*0.33^{5/3}*0.02^{1/2}) = 5.6$ feet min. (use 6 feet)

$V = Q/(WD) = 1.24\ ft^3/sec/(6\text{-ft} * 4/12\text{-ft}) = 0.62$ fps (okay: < 1 fps)

Note: WD approximates flow area for shallow flows.

Minimum length for 5-minute residence time, L = V * (5*60) = 186 feet (~372 feet for t = 10 minutes).

d. Depending on the site geometry; the width, slope, or density of grass (Manning's n value) might be adjusted to slow the velocity and shorten the channel in the next design iteration. For example, using an 8-foot bottom width* of flow and a Manning's n of 0.25, solve for new depth and length.

$Q = VA = 1.49/n\ D^{5/3}\ S^{1/2}\ W$

$D = [(Q * n)/(1.49 * S^{1/2} * W)]^{3/5}$
$= [(1.24 * 0.25)/(1.49 * 0.02^{1/2} * 8.0)]^{3/5} = 0.36$ ft (okay: < 4 inches)

$V = Q/WD = 1.24/(8.0 * 0.36) = 0.43$ fps

L = 0.43 fps * 5 min * 60 sec/min = 129 feet

For a velocity of 0.62 fps, a channel bottom width of 6 feet, flow depth of 4 inches, and Q = 1.24 cfs

A = 1.24 ft3/sec / 0.62 fps = 2 ft^2

4. Check for stability and capacity at the computed dimensions.

a. $Q_{10} = 4.14$ cfs and $Q_{100} = 7.17$ cfs. From design flow, width of channel bottom is 6 feet. Base the check on a grass height of 6 inches and with fair coverage. From Table 5, the degree of retardance is category D. The soils are HSG B soils and will be erosion-resistant. The maximum velocity (V_{max}) is 6 fps (1.80 m/sec) from Table 4. Select a trial Manning's n value of 0.04, which corresponds to a VR value (velocity x hydraulic radius) of 3 ft^2/sec using Figure 7. Convert the VR value to metric units:

$VR_{metric} = VR_{english}$ x 0.0929 = 3 ft^2/sec x 0.0929 = 0.28 m^2/sec

b. Calculate the hydraulic radius, R, using Equation 12:

$R = 0.28\ m^2/sec\ /\ 1.80\ m/sec = 0.15\ m\ (0.47\ feet)$

c. Using the computed hydraulic radius, calculate the actual VR using Equation 12:

$VR = (0.15\ m)^{1.67} \times (0.02)^{0.5} / 0.04 = 0.16\ m^2/sec\ (1.68\ ft^2/sec)$

The estimated VR value, 3 ft^2/sec, is not within 5% of the computed VR value, 1.68 ft^2/sec. Using a new Manning's n value of 0.036, from Figure 5, the new estimated VR is 6 ft^2/sec (0.56 m^2/sec). The recalculated R from Equation 10 is 0.31 m (0.98 feet) and the recalculated VR from Equation 12 is 0.55 m^2/sec (5.92 ft^2/sec). The new value is within 5% of the estimated value of 0.56 m^2/sec, so proceed with stability check.

d. The actual velocity for the new design is recomputed using Equation 13:

$V = 0.56\ m^2/sec\ /\ 0.31\ m = 1.80\ m/sec\ (5.91\ fps)$

The actual velocity is less than the estimated maximum velocity of 6 fps from Table 5, and the stability check can proceed.

e. Calculate the X-section area to test stability using the continuity equation:

$A = Q_{100} / V = (7.17\ ft^3/sec) / (5.91\ fps) = 1.21\ ft^2$

The stability area of 1.21 ft^2 is less than the original calculated flow area of 2 ft^2, so can proceed to the capacity check. If the stability area was larger, then would need to select a new trial size and flow depth and recalculate the X-section area of flow until this condition is met.

f. The channel dimensions, including freeboard, are used to compute the flow capacity of the channel. The greater of the two flow depths from the design flow or stability check should be used. In this example, the stability check flow depth of 0.98 feet is greater than the design flow depth of 0.33 feet (4 inches). Using Equation 8:

$H = y + freeboard = 0.98\ ft + 1\ ft = 1.98\ ft$

g. Using Manning's equation, the Manning's n value selected in the design flow (0.15) and the channel dimensions, recompute the flow capacity for the channel. Using Equation 4, and using H for Y:

$A = by + zy^2 = (6.0\text{-}ft)(1.98\ ft) + (4)(1.98\ ft)^2 = 27.56\ ft^2$

Substituting Equation 6 into Equation 7 (using H for y):
$R = A/P = 27.56ft^2 / [6\ ft + (2)(1.98\ ft)(1+4^2)^{0.5}] = 1.54\ ft$

Using Equations 1 and 2 (n = 0.15, S = 0.02):

$Q = (27.56\ ft^2) \times (1.49)(1.54\ ft)^{0.667} \times (0.02)^{0.5} / 0.15 = 51.64\ ft^3/sec$

The flow capacity of 51.6 ft^3/sec for the swale is greater than the stability check flow rate of 7.17 ft^3/sec for the 100-yr storm, provided in the example site data

2I-3 Dry and Wet Swales

Source: Georgia Stormwater Manual

BENEFITS Low = <30% Medium = 30-65% High = 65-100%	Low	Med	High
Suspended Solids			■
Nitrogen	■	■	
Phosphorous	■		
Metals			■
Bacteriological	*	*	*
Hydrocarbons	*	*	*

* Insufficient Data

Description: Dry swales (also called bio-swales) are a type of open vegetated channel used to treat and attenuate the WQv of stormwater runoff. The swale also serves as a conveyance to move excess stormwater to a downstream discharge point. In dry swales, the entire WQv is temporarily retained in a pool or series of pools created by permanent check dams. The holding time provides an opportunity for sedimentation of particulates and facilitates infiltration of runoff. The wet swale is a vegetated channel designed to retain water or marshy conditions that support wetland vegetation. A high water table or poorly-drained soil is necessary to retain water.

Typical uses:

- Manage runoff from residential sites, parking areas, and along perimeter of paved roadways.
- Located in a drainage easement at the rear of side of residential parcels.
- Road shoulder rights-of-way; used adjacent to paved roadways in place of curb and gutter, or used as a conveyance channel on the back side of curb-cut openings.

Advantages/benefits:

- Mitigate runoff from impervious surfaces.
- Remove sediment and pollutants to improve water quality.
- Reduce runoff rate and volume in highly impervious areas; reduce runoff velocity.
- Provide for groundwater recharge if design and site soils provide sufficient infiltration.
- Good option for small area retrofits – replacing existing drainage ditches.
- Good retrofit opportunities for residential or institutional areas of low to moderate density.
- Linear configuration works well with highway or residential street applications.

Disadvantages/limitations:

- Sediment/pollutant removal sensitive to proper design of slope and maintaining sufficient vegetation density.
- Limited to small areas (<5 acres); cannot be used on steep slopes (>6%).
- Higher maintenance than curb and gutter systems.
- Possible re-suspension of sediment.

Maintenance requirements:

- Need routine landscape maintenance; maintain grass height of approximately 4-6 inches.
- Inspect annually for erosion problems; remove accumulated trash and debris.
- Remove sediment from forebay and channel (if necessary).

A. Description

Dry and wet swales (also referred to as vegetated open channels, water quality swales, or enhanced swales) are conveyance channels engineered to capture and treat the water quality volume for a drainage area. They differ from a normal drainage channel or swale through the incorporation of specific features that enhance stormwater pollutant removal effectiveness. Dry and wet swales are designed with limited longitudinal slopes to force the flow to be slow and shallow, thus allowing for

particulates to settle and limiting the effects of erosion. Berms and/or check dams installed perpendicular to the flow path promote settling and infiltration. Brief descriptions of these two designs are listed below (Claytor and Schuler, 1996):

1. **Dry swale.** The dry swale consists of an open channel capable of temporarily storing the water quality treatment volume, and a filtering medium consisting of a soil bed with an underdrain system. The dry swale uses volume-based sizing criteria. The dry swale is designed to drain down between storm events within approximately one day. The water quality treatment mechanisms are similar to bioretention practices, except that the pollutant uptake is likely to be more limited since only a grass cover crop is available for nutrient uptake. Dry swales are sized to allow the entire WQv to be filtered or infiltrated through the bottom of the swale. Because they are dry most of the time, they are often the preferred option in residential settings. Figure 3 illustrates the configuration and design components of the dry swale.

Figure 1: Dry swale

Source: Georgia Stormwater Manual, 2001

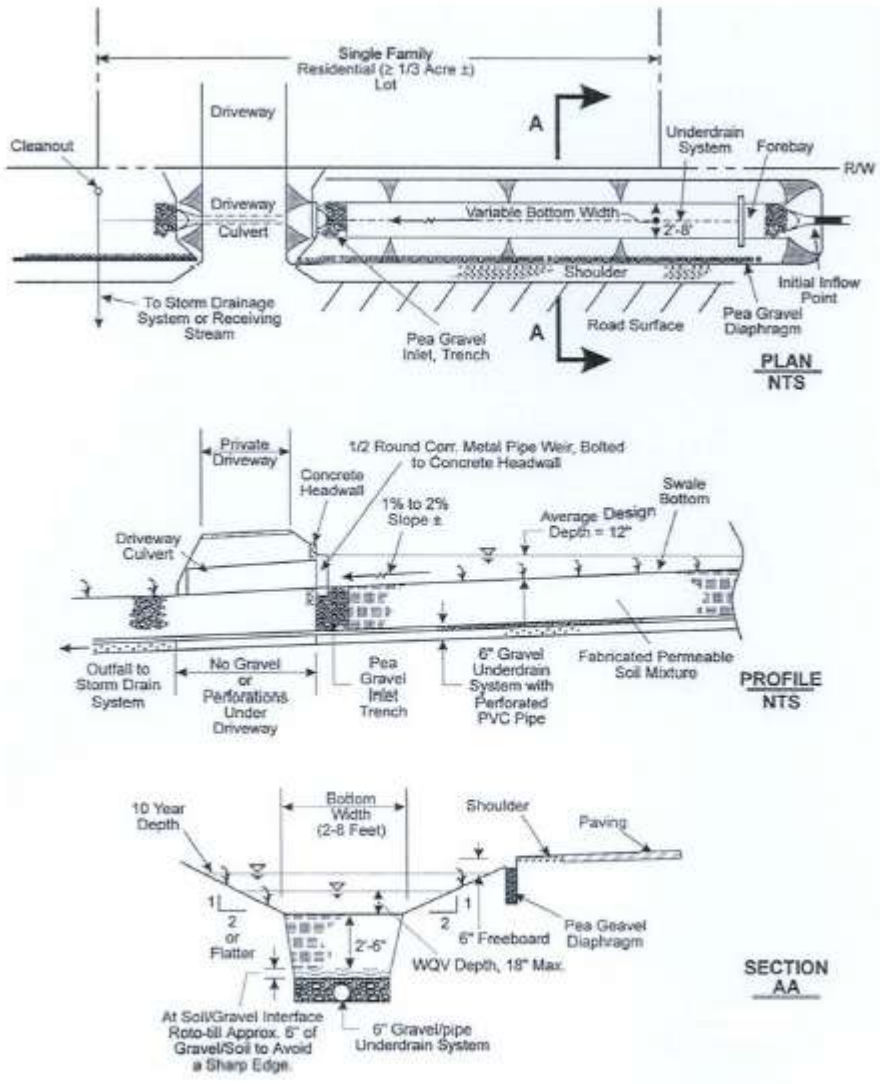
2. **Wet swale (wetland channel).** The wet swale also consists of a broad open channel capable of temporarily storing the WQv (also a volume-based sizing criteria), but does not have an underlying filtering bed. The wet swale is constructed directly within existing soils and may or may not intercept the water table. Like the dry swale, the WQv within the wet swale should be stored for approximately 24 hours. The wet swale has water quality treatment mechanisms similar to stormwater wetlands, which rely primarily on settling of suspended solids, adsorption, and uptake of pollutants by vegetative root systems. Figure 4 illustrates the configuration and design components of the wet swale.

Figure 2: Wet swale

Source: Georgia Stormwater Manual, 2001

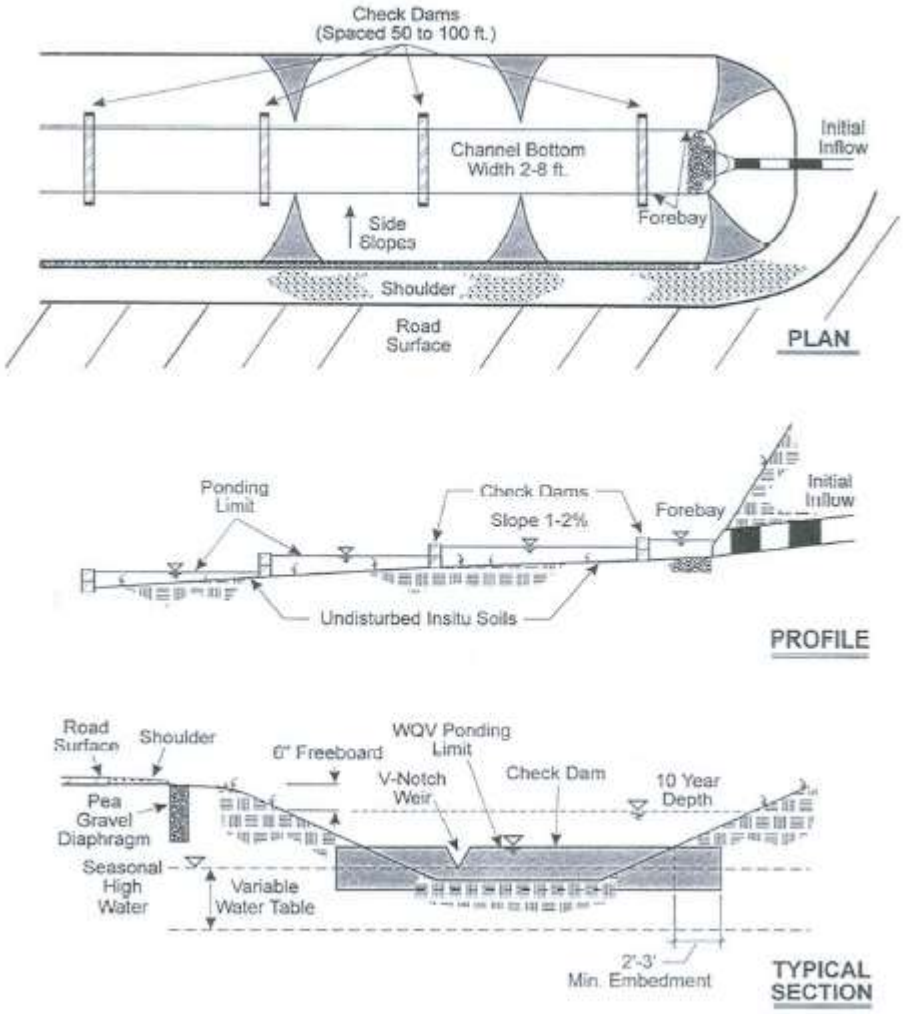
Dry and wet swales are not to be confused with a filter strip or grass swale, which are limited application structural controls, and not considered acceptable for meeting the TSS removal performance goal when used alone. Ordinary grass swales are not engineered to provide the same treatment capability as a well-designed dry swale with filter media. Filter strips are designed to accommodate overland flow rather than channelized flow, and can be used as stormwater credits to help reduce the total water quality treatment volume for a site. Both of these practices may be used for pre-treatment or included in a treatment train approach where redundant treatment is provided. For a further discussion of these limited application structural controls, see Sections 2I-2 and 2I-4.

Figure 3: Configuration and design components of a dry swale BMP



Source: Claytor and Schuler, 1996

Figure 4: Configuration and design components of a wet swale BMP



Source: Claytor and Schuler, 1996

B. Stormwater management suitability

Dry and wet swale systems are designed primarily for stormwater quality and have only a limited ability to provide channel protection or to convey higher flows to other controls.

1. **Water quality.** Dry swale systems rely primarily on filtration through an engineered media to provide removal of stormwater contaminants. Wet swales achieve pollutant removal both from sediment accumulation and biological removal. Section 2I-1 provides median pollutant removal efficiencies that can be used for planning and design purposes.

2. **Channel protection.** Generally only the WQv is treated by a dry or wet swale, and another structural control must be used to provide Cpv extended detention. However, for some smaller sites, a swale may be designed to capture and detain the full Cpv.

3. **Overbank flood protection.** Enhanced swales must provide flow diversion and/or be designed to safely pass overbank flood flows. Another structural control must be used in conjunction with an enhanced swale system to reduce the post-development peak flow of the 25-year storm (Qp25) to pre-development levels (detention).

4. **Extreme flood protection.** Enhanced swales must provide flow diversion and/or be designed to safely pass extreme storm flows. Another structural control must be used in conjunction with an enhanced swale system to reduce the post-development peak flow of the 100-year storm (Qf) if necessary.

C. Pollutant removal capabilities

Both the dry and wet enhanced swale are presumed to be able to remove 80% of the total suspended solids load in typical urban post-development runoff when sized, designed, constructed, and maintained in accordance with the recommended specifications. Undersized or poorly-designed swales can reduce TSS removal performance. The following design pollutant removal rates are conservative average pollutant reduction percentages for design purposes derived from sampling data, modeling, and professional judgment. In a situation where a removal rate is not deemed sufficient, additional controls may be put in place at the given site in a series or treatment train approach.

- Total suspended solids – 80%
- Total phosphorus – dry swale 50%, wet swale 25%
- Total nitrogen – dry swale 50%, wet swale 40%
- Fecal coliform – insufficient data
- Heavy metals – dry swale 40%, wet swale 20%

For additional information and data on pollutant removal capabilities for enhanced dry and wet swales, see the National Pollutant Removal Performance Database (2nd Edition) available at www.cwp.org and the International Stormwater Best Management Practices (BMP) Database at www.bmpdatabase.org.

D. Application and feasibility

Dry and wet swales can be used in a variety of development types; however, they are primarily applicable to residential and institutional areas of low to moderate density where the impervious cover in the contributing drainage area is relatively small, and along roads and highways. Dry swales are mainly used in moderate- to large-lot residential developments, small impervious areas (parking lots and rooftops), and along rural highways. Wet swales tend to be used for highway runoff applications, small parking areas, and in commercial developments as part of a landscaped area.

Because of their relatively large land requirements, enhanced swales are generally not used in higherdensity areas. In addition, wet swales may not be desirable for some residential applications, due to the presence of standing and stagnant water, which may create nuisance odor or mosquito problems.

The topography and soils of a site will determine the applicability of the use of one of the two swale designs. Overall, the topography should allow for the design of a swale with sufficient slope and cross sectional area to maintain non-erosive velocities. The following criteria should be evaluated to ensure the suitability of a stormwater pond for meeting stormwater management objectives on a site or development.

1. **General feasibility.**

   a. Suitable for residential subdivision usage – yes

   b. Suitable for high-density/ultra urban areas – no

   c. Regional stormwater control – no

2. **Physical feasibility – physical constraints at project site.**

   a. **Drainage area.** 5 acres maximum

   b. **Space required.** Approximately 10-20% of the tributary impervious area

   c. **Site slope.** Typically no more than 4% channel slope

   d. **Minimum head.** Elevation difference needed at a site from the inflow to the outflow: 3-5 feet for dry swale; 1 foot for wet swale

   e. **Minimum depth to water table.** 2 feet required between the bottom of a dry swale and the elevation of the seasonally high water table if an aquifer or treating a hotspot; wet swale is below water table or placed in poorly drained soils.

   f. **Soils.** Engineered media for dry swale

   g. The WQv for high-density residential, commercial, and industrial land uses will most likely be too great to be accommodated with most swale designs. However, swales may be appropriate for pre-treatment in association with other practices for these higher-density land uses, or may be acceptable solutions for watershed retrofit projects.

3. **Other constraints/considerations.** Aquifer protection: exfiltration should not be allowed for hotspots.

E. Planning and design criteria

The following criteria are considered minimum criteria for the design of dry and wet swale system.

1. **Location and siting.**

   a. A dry or wet swale should be sited such that the topography allows for the design of a channel with sufficiently mild slope (unless small drop structures are used) and cross sectional area to maintain non-erosive velocities.

   b. Dry and wet swale systems should have a contributing drainage area of 5 acres or less.

   c. Swale siting should also take into account the location and use of other site features, such as buffers and undisturbed natural areas, and should attempt to aesthetically fit the facility into the landscape.

d. A wet swale can be used where the water table is at or near the soil surface, or where there is a sufficient water balance in poorly drained soils to support a wetland plant community.

2. General design.

a. Both dry and wet swales are designed to treat the WQv through a volume-based design and to safely pass larger storm flows. Flow enters the channel through a pre-treatment forebay. Runoff can also enter along the sides of the channel as sheet flow through the use of a pea gravel flow spreader trench along the top of the bank.

b. **Dry swale.** A dry swale system consists of an open conveyance channel with a filter bed of permeable soil overlaying a perforated pipe underdrain system. Flow passes into and is detained in the main portion of the channel, where it is filtered through the soil bed. Runoff is collected and conveyed by a perforated pipe and gravel underdrain system to the outlet. Figure 3 provides a plan view and profile schematic for the design of a dry swale system.

c. **Wet swale.** A wet swale or wetland channel consists of an open conveyance channel which has been excavated to the water table or to poorly drained soils. Check dams are used to create multiple wetland cells, which act as miniature shallow marshes. Figure 4 provides a plan view and profile schematic for the design of a wet swale system.

3. Physical specifications and geometry.

a. Channel slopes between 1-2% are recommended unless topography necessitates a steeper slope, in which case 6- to 12-inch drop structures can be placed to limit the energy slope to within the recommended 1-2% range. Energy dissipation will be required below the drops. Spacing between the drops should not be closer than 50 feet. Depth of the WQv at the downstream end should not exceed 18 inches.

b. Dry and wet swales should have a bottom width of 2-8 feet to ensure adequate filtration. Wider channels can be designed but should contain berms, walls, or a multi-level cross section to prevent channel braiding or uncontrolled sub-channel formation.

c. Dry and wet swales are parabolic or trapezoidal in cross section, and are typically designed with moderate side slopes no greater than 2:1 for ease of maintenance and side inflow by sheet flow (4:1 or flatter recommended).

d. Dry and wet swales should maintain a maximum WQv ponding depth of 18 inches at the end point of the channel. A 12-inch average depth should be maintained.

e. The peak velocity for the 2-year storm must be nonerosive for the soil and vegetative cover provided.

f. If the system is on-line, channels should be sized to convey runoff from the overbank flood event (Qp25) safely with a minimum of 6 inches of freeboard and without damage to adjacent property.

4. Dry swale.

a. Dry swale channels are sized to store and infiltrate the entire WQv with less than 18 inches of ponding, and allow for full filtering through the permeable soil layer. The maximum ponding time is 48 hours, though a 24-hour ponding time is more desirable.

b. The bed of the dry swale consists of a permeable soil layer of at least 30 inches in depth, above a 4-inch diameter perforated PVC pipe (AASHTO M 252) longitudinal underdrain in a 6-inch gravel layer. The soil media should have an infiltration rate of at least 1 foot per day (1.5 feet per day maximum) and contain a high level of organic material to facilitate pollutant removal. A permeable filter fabric is placed between the gravel layer and the overlying soil.

c. The channel and underdrain excavation should be limited to the width and depth specified in the design. The bottom of the excavated trench shall not be loaded in a way that causes soil compaction, and scarified prior to placement of gravel and permeable soil. The sides of the channel shall be trimmed of all large roots. The sidewalls shall be uniform with no voids and scarified prior to backfilling.

5. Wet swale.

a. Wet swale channels are sized to retain the entire WQv with less than 18 inches of ponding at the maximum depth point.

b. For wet swales, the WQv volume is still retained for 24 hours, but ponding may continue indefinitely depending on the depth and elevation to the water table.

c. Check dams can be used to achieve multiple wetland cells. V-notch weirs in the check dams can be utilized to direct low-flow volumes.

6. Pre-treatment inlets.

a. Inlets to dry and wet swales must be provided with energy dissipators such as riprap or rock-lines stilling basins.

b. Pre-treatment of runoff in both a dry and wet swale system is typically provided by a sediment forebay located at the inlet. The pre-treatment volume should be equal to 0.1 inches per impervious acre. This storage is typically obtained by providing check dams at pipe inlets and/or driveway crossings.

c. Dry and wet swale systems that receive direct concentrated runoff have a 6-inch drop to a pea gravel diaphragm flow spreader at the upstream end of the control.

d. A pea gravel diaphragm and gentle side slope is provided along the top of channels to provide pre-treatment for lateral sheet flows.

7. Outlet structures.

a. **Dry swale.** The underdrain system should discharge to the storm drainage infrastructure or a stable outfall.

b. **Wet swale.** Outlet protection must be used at any discharge point from a wet swale to prevent scour and downstream erosion.

8. **Emergency spillway/overflow.** Dry and wet swales must be adequately designed to safely pass flows that exceed the design storm flows.

9. **Maintenance access.** Adequate access is to be provided for all dry and wet swale systems for inspection and maintenance.

10. **Safety features.** Ponding depths should be limited to a maximum of 18 inches.

11. **Landscaping.** Landscape design should specify proper grass species and wetland plants based on specific site, soils, and hydric conditions present along the channel. Below is some specific guidance for dry and wet swales:

    a. **Dry swale.** Information on appropriate turf grass species for Iowa can be found in the SUDAS Specifications Manual Section 9010.

    b. Wet swale.
    1 Emergent vegetation should be planted or wetland soils may be spread on the swale bottom for seed stock.
    2 Information on establishing wetland vegetation and appropriate wetland species for Iowa can be found in the SUDAS Specifications Manual, Section 9010.
    3) Where wet swales do not intercept the groundwater table, a water balance calculation should be performed to ensure an adequate water budget to support the specified wetland species. See Section 2C-10 for guidance on water balance calculations.

12. Additional site-specific design criteria and issues.

    a. Physiographic factors (local terrain design constraints).
    1 Low relief: reduced need for use of check dams.
    2 High relief: often infeasible if slopes are greater than 4%.
    3 Karst: no exfiltration of hotspot runoff from dry swales; use impermeable liner.

    b. **Soils.** No additional criteria.

    c. **Special downstream watershed considerations.** Aquifer protection: no exfiltration of hotspot runoff from dry swales; use impermeable liner.

Table 1: Summary design criteria for dry and wet swale systems

Parameter	Swale Design Criteria
Pre-treatment volume	0.05-0.10 inches per impervious acre at initial inflow point
Preferred shape	Trapezoidal or parabolic
Bottom width	2-foot minimum, 8-foot maximum widths; up to 16-foot width if a dividing berm is installed to reduce concentrated flow channels.
Side slopes	2:1 maximum; 4:1 is optimum
Longitudinal slope	1-2% without check dams. On greater slopes, check dams added to achieve ponding of the WQv.
Sizing criteria	Length, width, depth, and slope needed to provide surface storage for WQv. Outlet structures sized to release WQv over 24 hours.
Hydraulic residence time	Minimum: 5 minutes; Optimum: 10-minutes
Average flow velocity	0.9 fps
Length	Minimum: 100 feet; Optimum: 200 feet
Underlying soil bed	Equal to swale width *Dry swale*: Moderately-permeable soils (USC ML, SM, or SC); soil mix 30 inches deep with gravel/pipe underdrain. *Wet swale*: Undisturbed soils, no underdrain system
Depth and capacity	Surface storage of WQv with a maximum depth of 18-inches for water quality treatment (12-inch average depth); safely convey 2-yr storm peak discharge with non-erosive velocity (4-5 fps); adequate conveyance capacity for the 10-yr storm peak discharge with 6 inches of freeboard.

Source: Adapted from Claytor and Schuler, 1996

F. Design procedure

1. **Step 1.** Compute runoff control volumes from the unified stormwater sizing criteria. Calculate the WQv, Cpv, Qp, and the Qf. (See Part 2B).

2. **Step 2**. Determine if the development site and conditions are appropriate for the use of a dry or wet swale system. Consider the application and site feasibility criteria, location, and siting guidelines.

3. **Step 3.** Confirm local design criteria and applicability. a. Consider any special site-specific design conditions/criteria from Section 2D-1. b. Check with local officials and other agencies to determine if there are any additional restrictions and/or surface water or watershed requirements that may apply.

4. **Step 4.** Determine pre-treatment volume.
   a. The forebay should be sized to contain 0.1 inches per impervious acre of contributing drainage.

   b. The forebay storage volume counts toward the total WQv requirement, and should be subtracted from the WQv for subsequent calculations.

5. **Step 5.** Determine swale dimensions.

   a. Size bottom width, depth, length, and slope necessary to store WQv with less than 18 inches of ponding at the downstream end.

   b. Slope cannot exceed 4% (1-2% recommended).

c. Bottom width should range from 2-8 feet.

d. Ensure that side slopes are no greater than 2:1 (4:1 recommended).

6. **Step 6.** Compute the number of check dams (or similar structures) required to detain WQv.

7. **Step 7.** Calculate draw-down time.

   a. **Dry swale.** Planting soil should pass a maximum rate of 1.5 feet in 24 hours, and must completely filter WQv within 48 hours.

   b. **Wet swale.** Must hold the WQv.

8. **Step 8.** Check 2-year and 25-year velocity erosion potential and freeboard.

   a. Use NRCS WINTR55 to compute estimates of the peak flow rates for the 2-yr through 100-yr storm events.

   b. Check for erosive velocities and modify design as appropriate.

   c. Provide a minimum of 6 inches freeboard for the 10-year discharge.

   d. Check stability for larger storm events and overland flow pathways for the larger storms.

9. **Step 9.** Design low-flow orifice at downstream headwalls and check dams. Design orifice to pass WQv in 6 hours, using orifice equation.

10. **Step 10.** Design inlets, sediment forebay(s), and underdrain system (dry swale).

11. **Step 11**. Prepare vegetation and landscaping plan. A landscaping plan for a dry or wet swale should be prepared to indicate how the dry or wet swale system will be stabilized and established with vegetation.

G. Design example

Dry swale

1. **Site description.** Bucketsville, IA Recreation Center (Story County, IA).

   a. Site area = total drainage area (A) = 3.4 acres

   b. Total impervious area (building, parking, and driveway) = 1.9 acres I = 56%

   c. Soils: HSG – C

   d. Pre-development: meadow in good condition

Table 2: Data for Story County example

Rainfall Data for Story County Example
(24-hr duration)

Return period	Rainfall, P (inches)
0.3-yr (WQ event)	1.25
1-yr	2.38
2-yr	2.91
5-yr	3.64
10-yr	4.27
25-yr	5.15
100-yr	6.61

	Hydrologic Data	
	Pre	Post
CN	71	87
t_c	0.34	0.22

WINTR55 Storm Summary – Pre-development				
Storm	P (inches	Runoff Q_a (inches	Q_p, Peak Discharge, cfs	Total Runoff Volume (ft^3)
1	2.38	0.38	1.27	4,690
2	2.91	0.71	2.34	8,763
5	3.64	1.15	4.05	14,193
10	4.27	1.58	5.70	19,500
25	5.15	2.22	8.18	27,399
100	6.61	3.39	12.57	41,839
WINTR55 Storm Summary – Post-development				
Storm	P (inches	Runoff Q_a (inches	Q_p, Peak Discharge, cfs	Total Runoff Volume (ft^3)
WQ storm	1.25	0.79	3.7	*9,750*
1	2.38	1.20	5.32	14,810
2	2.91	1.65	7.27	20,364
5	3.64	2.29	10.04	28,263
10	4.27	2.87	12.46	35,422
25	5.15	3.70	15.85	45,665
100	6.61	5.09	21.48	62,870

This example focuses on the design of a dry swale (with media) to meet the water quality treatment requirements of the site. Channel protection and overbank flood control is not addressed in this example other than quantification of preliminary storage volume and peak discharge requirements. In general, the primary function of dry swales is to provide water quality treatment and groundwater recharge, and not large storm attenuation. Flows in excess of the WQv are typically routed to bypass the facility. Where quantity control is required, the bypassed flows can be routed to conventional detention basins (or some other facility such as underground storage vaults).

Table 3: WINTR-55 current data description

User: SEJ Date: 12/10/2006
Project: Bucketsville Rec Center Units: English
SubTitle: Dry Swale **(pre-development)** Area Units: Acres
State: Iowa County: Story
Filename: C:\Documents and Settings\Stephen\Application Data\WinTR-55\Dry Swale_pre.w55

--- Sub-Area Data ---

Name	Description	Reach	Area(ac)	RCN	Tc
DA-1		Outlet	3.4	71	.341
		Total area: 3.40 (ac)			

-----Storm Data------

Rainfall Depth by Rainfall Return Period

0.3-yr (in)	1-Yr (in)	2-Yr (in)	5-Yr (in)	10-Yr (in)	25-Yr (in)	100-Yr (in)
1.25	2.38	2.91	3.64	4.27	5.15	6.61

Storm Data Source: User-provided custom storm data (MRA – Bulletin 71)
Rainfall Distribution Type: Type II
Dimensionless Unit Hydrograph: <standard>

-------Sub-Area Land Use and Curve Number Details------

Sub-Area Identifier	Land Use	Hydrologic Soil Group	Sub-Area Area (ac)	Curve Number
DA-1	Meadow -cont. grass (non grazed)	C	3.4	71
	Total Area / Weighted Curve Number		3.4	71

-------Sub-Area Time of Concentration Details--------

Sub-Area Identifier/	Flow Length (ft)	Slope (ft/ft)	Mannings's n	End Area (sq ft)	Wetted Perimeter (ft)	Velocity (ft/sec)	Travel Time (hr)
DA-1							
SHEET	100	0.0150	0.240				0.280
SHALLOW	500	0.0200	0.050				0.061
						Time of Concentration	**.341**

------Hydrograph Peak/Peak Time Table------

Sub-Area or Reach Identifier	Peak Flow and Peak Time (hr) by Rainfall Return Period 1-Yr (cfs) (hr)	2-Yr (cfs) (hr)	5-Yr (cfs) (hr)	10-Yr (cfs) (hr)	25-Yr (cfs) (hr)	100-Yr (cfs) (hr)
SUBAREAS						
DA-1	1.27	2.34	4.05	5.70	8.18	12.57
	12.13	12.13	12.12	12.11	12.10	12.10
OUTLET	1.27	2.34	4.05	5.70	8.18	12.57

--- Identification Data ---

User: SEJ Date: 12/10/2006
Project: Bucketsville Rec Center Units: English
SubTitle: Dry Swale **(post-development)** Area Units: Acres
State: Iowa County: Story
Filename: C:\Documents and Settings\Stephen\Application Data\WinTR-55\Dry Swale_post.w55

--- Sub-Area Data ---

Name	Description	Reach	Area (ac)	RCN	Tc
DA-1		Outlet	3.4	87	0 .222

Total area: 3.40 (ac)

------Sub-Area Land Use and Curve Number Details-------

Sub-Area Identifier	Land Use	Hydrologic Soil Group	Sub-Area Area (ac)	Curve Number
DA-1	Open space; grass cover > 75% (good)	C	1.5	74
	Paved parking lots, roofs, driveways	C	1.9	98
	Total Area / Weighted Curve Number		3.4	87
			===	==

-------Sub-Area Time of Concentration Details------

Sub-Area Identifier/	Flow Length (ft)	Slope (ft/ft)	Mannings's n	End Area (sq ft)	Wetted Perimeter (ft)	Velocity (ft/sec)	Travel Time (hr)
DA-1							
SHEET	50	0.0150	0.240				0.161
SHALLOW	600	0.0200	2.91				0.058
CHANNEL	50	0.0200	0.024	4.50	10.30	4.630	0.003
						Time of Concentration	**.222**

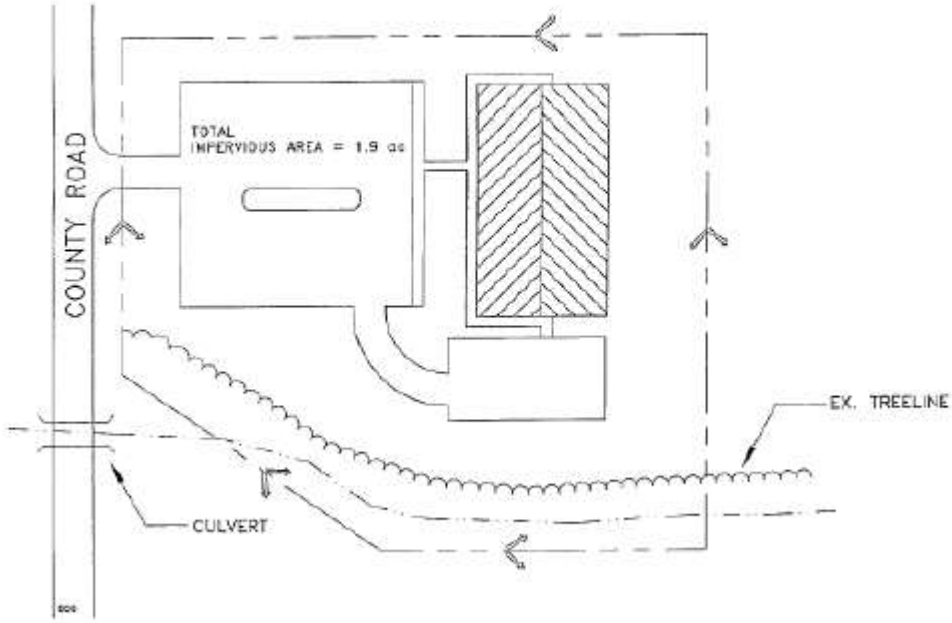
---------Hydrograph Peak/Peak Time Table--------

Sub-Area or Reach Identifier	Peak Flow and Peak Time (hr) by Rainfall Return Period						
	0.3-Yr (cfs)	1-Yr (cfs)	2-Yr (cfs)	5-Yr (cfs)	10-Yr (cfs)	25-Yr (cfs)	100-Yr (cfs)
	(hr)	(hr)	(hr)	(hr)	(hr)	(hr)	
SUBAREAS							
DA-1	1.55	5.32	7.27	10.04	12.46	15.85	21.48
	12.05	12.03	12.02	12.02	12.02	12.02	12.02
REACHES							
OUTLET	**1.55**	**5.32**	**7.27**	**10.04**	**12.46**	**15.85**	**21.48**

WINTR20 summary data for the 1-yr post-development scenario (From WINTR55 analysis)

Area or Reach Identifier	Drainage Area (sq mi)	Rain Gage ID or Location	*STORM 1-Yr* Runoff Amount (in)	Elevation (ft)	Peak Flow Time (hr)	Peak Flow Rate (cfs)	Peak Flow Rate (csm)
DA-1		0.005		1.200		12.03	5.32 1002.36

Figure 5: Site plan for dry swale design example



2. **Compute water quality volume (WQv) and WQv peak discharge (Q_{wq}).**

   a. Rv = 0.05 +(0.009)(56) = 0.55

   b. P = 1.25 inches (WQv design storm)

   c. WQv = 0.55 x 1.25 inches = 0.69 inches (Q)

   d. WQv = 0.69 inches x 3.4 acres x 1/12 x 43,560 ft^2/ac = 8,516 ft^3

3. **Compute Qwq.**

   a. Compute modified CN for 1.25-inch rainfall (P=1.25) (see Section 2C-6):

   $CN = 1000/[10+5P+10Q-10(Q^2+1.25QP)^{0.5}$

   $= 1000/[10+(5)(1.25)+(10)(0.69) -10((0.74)^2+(1.25)(0.69)(1.25))^{0.5}]$

   = 96.15 (Use CN = 96)

   b. For CN = 94 and an estimated time of concentration (tc) of 13 minutes (0.22 hours) compute the Q_{wq} for the 1.25-inch storm. Results from WINTR55 are:

   Qwq = 3.7 ft^3/sec

4. **Compute channel protection volume (CPv).** The criteria for stream channel protection, (Part 2B), is 24-hour extended detention for the 1-year, 24-hour event. The Cpv is calculated here even though it will be provided downstream of the dry swale. The methodology for calculating the CPv is summarized in Section 2C-6. The WINTR-55 analysis performed above for the pre/post development scenarios provides data for this analysis.

a. For the post-development scenario, CN = 87 and t_c = 0.22 hour, the peak discharge, q_p, for the 1-year storm event is 5.32 cfs, or 1002.36 csm (See WINTR-55 result summary).

$q_p = q_u A_m Q F$

b. The unit peak rate, q_u, is 835.3 csm/in (1002.26 csm/1.2 inches).

c. Using q_u and extended detention time, T, of 24 hours, find q_o/q_i for a Type II rainfall distribution. (See Section 2C-6).

$q_o/q_i = 0.03$

d. For Type II rainfall distribution:

$V_s/V_r = 0.683 - 1.43(qo/qi) + 1.64\,(qo/qi)^2 - 0.804\,(qo/qi)^3$ **Equation 1**

$V_s/V_r = 0.64$

CPv = $V_s = (V_s/V_r)V_r = (V_s/V_r)(Q_a)(A)/12$

Note: $V_r = Q_a$ (runoff in inches for developed 1-year storm from WINTR-55 analysis)

CPv = (0.64)(1.2 in)(3.4 ac)/12 = 0.218 ac-ft = 9,479 ft3

5. **Determine overbank flood protection volume (Q25).** For this site, the p ost-developed Q25(15.85 cfs) must be controlled to the pre-development rate for the 5-year storm, Q5-pre (4.05 cfs)

From WINTR55 analysis:
-------STORM 25-Yr-----
Area or Drainage Rain Gage Runoff ---------- Peak Flow --------
Reach Area ID or Amount Elevation Time Rate Rate
Identifier (sq mi) Location (in) (ft) (hr) (cfs) (csm)

DA-1 0.005 3.697 12.02 15.85 2985.75

q_u = 807.6 csm/in qo = 4.05 cfs qi = 15.85 cfs qo/qi = 0.26

From Section 2C-6 and a Type II rainfall distribution:

$V_s/V_r = 0.405$

V_s = (0.405)(3.697 in)(3.40 ac)/12 = 0.424 ac-ft = 18,480 ft^3

Note: The channel protection volume (CPv) and the detention storage for larger storm peak flow control will be provided by separate downstream detention storage for this site; no additional design details will be provided in this example.

6. **Determine if the development site and conditions are appropriate for the use of dry swale system.** Existing ground elevation at the facility location is 984 feet, mean sea level. Soil boring observations reveal that the seasonally high water table is at 976 feet, and underlying soils are silt loams (ML). Adjacent creek invert is at 972 feet.

7. **Confirm local design criteria and applicability.** There is a local requirement that the 25-year storm is contained within the top of banks of all channels, including the dry swale BMP controls. No additional local criteria are applicable.

8. **Determine pretreatment volume.** For this site, we will use two dry swale systems (DS-1 and DS-2) indicated in Figure 6. Provide two shallow forebays at the head of the swales equal to 0.05 inches per impervious acre of drainage (each). Note: total recommended pre-treatment requirement is 0.1 inches per impervious acre. For this site, the impervious area is 1.9 acres.

   (0.05 in) (1 ft/12 in) (43,560 ft^2/ac)(1.9 ac) = 345 ft^3

   Use a 2-foot deep pea gravel drain at the head of the swale to provide erosion protection, and to act as a level spreader to distribute the inflow. Any side flow at this site will be minimal, and will enter the swales as sheet flow.

9. **Determine swale dimensions.** Required: bottom width, depth, length, and slope necessary to store WQv with less than 18 inches of ponding. Use a trapezoidal channel with a measured maximum WQv depth of 18 inches. A shallow concrete wall configured with a low-flow orifice, with an integral trash rack will provide outlet flow control (see Figure 6 for location). A schematic of the outlet is illustrated in Figure 7.

   The total swale length of 1500 feet will be divided into two branches, as shown in Figure 6.

   Dry swale #1: 1000 feet
   Dry swale #2: 500 feet

   The outlet structure will be set at the existing invert minus 3 feet at (984 – 3 = 981 feet). The existing upstream invert for dry swale #1 is 992 (length of 1000 feet), and the existing invert for dry swale #1 is 988 (length of 500 feet).

   Slope of dry swale #1: (992 - 981)/1000 feet = 0.011 = 1.1%
   Slope of dry swale #2: (988 - 981)/500 feet = 0.014 = 1.4%

   Minimum slope is 1% (OK)

   For a trapezoidal cross section with a bottom width of 6 feet, a WQv average depth of 9 inches, 3:1 side slopes, compute the cross-sectional area:

   Area = (6 ft)(0.75 ft) + (0.75 ft)(2.25 ft) = 6.2 ft^2 (See Figure 8)

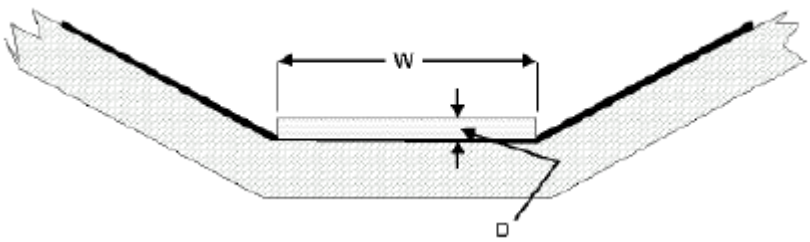
   Calculate volume provided:

   Swale volume = (6.2 ft^2)(1500 ft) = 9300 ft^3 [9.300 ft^3 > WQv of 8,516 ft^3] (OK)

10. **Determine the number of check dams to be installed along the length of the swale to detain WQv (See Figure 9).** For dry swale #1, 1000 feet @ 1/1% slope and maximum depth of 18 inches, set check dams at spacing of 1.5 ft/0.011 = 136 ft; place at 135 ft ---- > 8 required. For dry swale #2, 500 feet @1.4% slope and maximum depth at 18 inches, set check dams at spacing of 1.5 ft/0.014 = 107 ft; place at 107-ft ----> 5 required.

11. **Determine the drain-down time.** To ensure the swales will drain down within the 24-hour criteria, the planting media will need to pass a maximum rate of 1.5 ft (18 in) in 24 hours (k = 1.5 ft/day). Provide a 6-inch perforated subdrain pipe and gravel system below the soil bed (see Figure 8).

12. **Check 2-year and 25-year flow for velocity erosion potential and freeboard.** Plan to provide 6 inches of freeboard above the 25-year discharge water level. The 25-year peak discharge is 15.9 cfs; assume 70% (11.13 cfs) is routed through swale #1 and 30% (4.77 cfs) through swale #2.



From Manning's equation and trapezoidal channel: (for swale #1)
$Q = VA = 1.49/n\ D^{5/3}\ S^{1/2}\ W$

Use n = 0.08 for swale surface condition (See Section 2I-2):

$D = [(Q * n)/(1.49 * S^{1/2} * W)]^{3/5}$
$= [(11.13\ cfs) * 0.08)/(1.49 * (0.011)^{1/2} * (6\ ft)]^{3/5} = 0.97$ ft (depth @ q_{p25})

V = Q/WD = 11.13 cfs/(6 ft * 0.97 ft) = 1.91 fps

Add 0.5 feet of freeboard above the top of the check dams, and add 25-year flow depth to determine the total swale depth:

1.5 ft (berm) + 0.5 ft (freeboard) + 0.97 ft (25-year flow depth) = 2.97 ft (total depth of swale)

Use 3 feet total depth.

Determine required 25-year overflow weir length:

$Q = CLH^{3/2}$ C = 3.1 Q_{25} = 15.9 cfs H = 0.97 ft + 0.5 ft = 1.47 ft

$L = (15.0\ cfs)/[(3.1)(1.47)^{1.5}]$ = 2.88 ft (use 3 feet).

13. **Design low-flow orifice at downstream headwall and checkdam (See Figure 7).** Design orifice to pass 8,516 cfs (WQv) in 6 hours:

$(8416\ ft^3)/(6\ hr)(3600\ sec/hr) = 0.39\ cfs = 4\ cfs$

Use orifice equation: $Q = CA(2gh)^{1/2}$

Assume H = 1.5 ft (18 inches)

$A = (0.4\ cfs)/[(0.6)((2)(32.2\ ft/sec^2)(1.5\ ft)^{0.5})] = 0.068\ ft^2$

$Diameter = [(0.068\ ft^2)/0.785]^{0.5} = 0.29\ ft = 3.5$ inches; use 4-inch orifice.

Provide a 3-inch V-notch slot in each check dam.

14. **Design inlets, sediment forebay, and subdrain piping.** Use minimum 4-inch Schedule 40 PVC perforated pipe (see Figure 9).

15. **Prepare vegetation, seeding, and landscaping plan.**

Figure 6: Site plan for dry swales

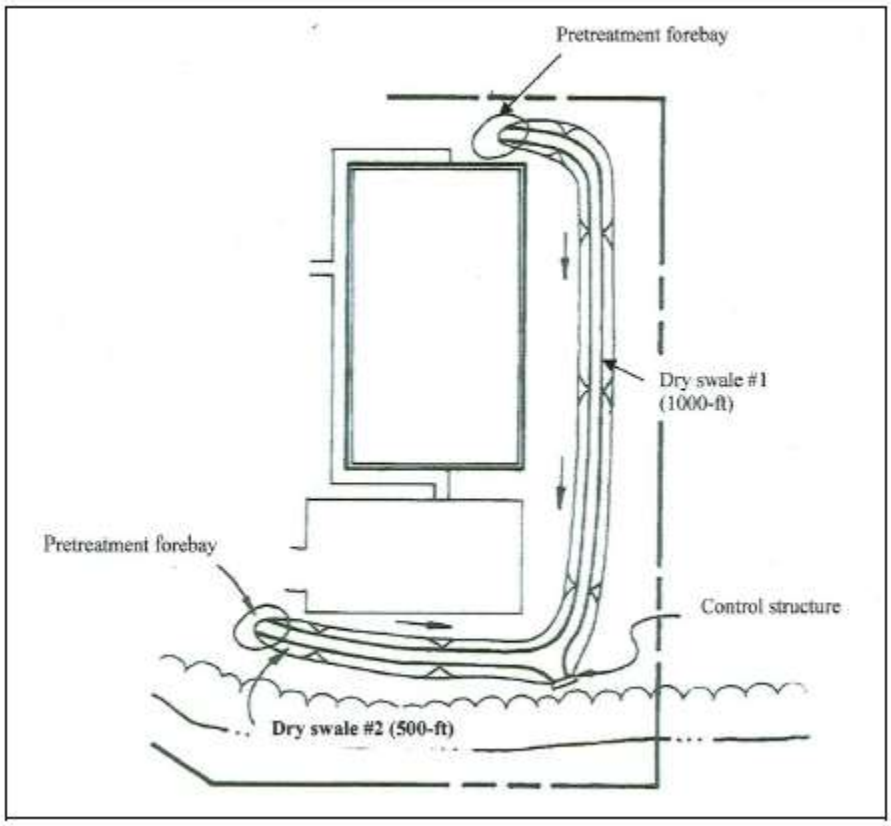


Figure 7: Control structure at swale outlet

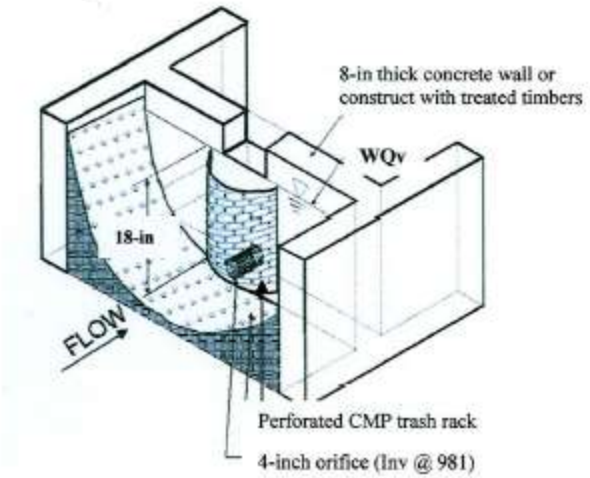
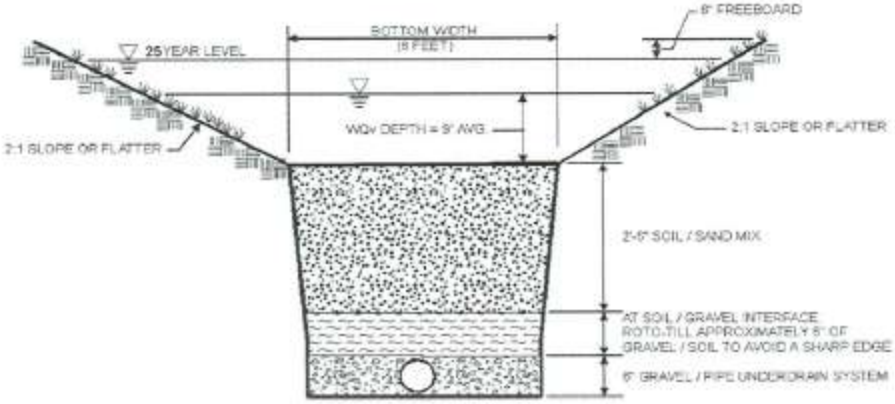
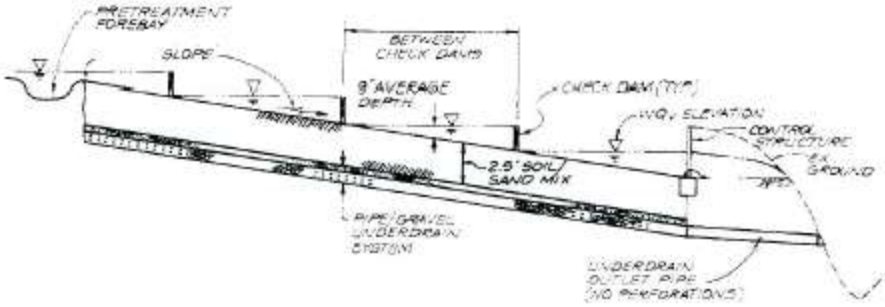


Figure 8: Trapezoidal dry swale section



Source: Adapted from Claytor and Schuler

Figure 9: Dry swale #1 profile



Source: Adapted from Claytor and Schuler

2I-4 Vegetated Filter Strips

Source: UDFCD, 1999

BENEFITS Low <30% Medium=30-65% High=65-100%			
	Low	Med	High
Suspended Solids			■
Nitrogen	■	■	
Phosphorous	■		
Metals			■
Bacteriological	*	*	*
Hydrocarbons	*	*	*

* Insufficient data

Description: Vegetated filter strips (VFS) are zones of vegetation through which sediment and pollutant-laden flow are directed before being discharged to a concentrated flow channel. They may closely resemble many natural ecological communities such as grassy meadows or riparian forests. Dense vegetative cover facilitates sediment attenuation and pollutant removal. VFS provide little treatment for concentrated flows. Grading and level spreaders are often used to create a uniformly sloping area to distribute the runoff evenly across the filter strip.

Typical uses:

- Manage runoff from residential sites, parking areas, and along perimeter of paved roadways.
- Located in a drainage easement at the rear of side of residential parcels.
- Road shoulder rights-of-way; used adjacent to paved roadways in place of curb and gutter, or used as a conveyance channel on the back-side of curb-cut openings.

Advantages/benefits:

- Mitigates runoff from impervious surfaces.
- Remove sediment and pollutants to improve water quality.
- Reduce runoff rate and volume in highly impervious areas; reduce runoff velocity.
- Provide for groundwater recharge if design and site soils provide sufficient infiltration.
- Good retrofit opportunities for residential or institutional areas of low to moderate density.
- Linear configuration works well with highway or residential street applications.

Disadvantages/limitations:

- Sediment and pollutant removal sensitive to proper design of slope and maintaining sufficient vegetation density.
- Limited to small areas (<5 acres); cannot be used on steep slopes (>6%).
- Possible re-suspension of sediment.

Maintenance requirements:

- Needs routine landscape maintenance; maintain grass height of approximately 2-4 inches.
- Inspect annually for erosion problems; seed or sod bare areas.

A. Description

Vegetated filter strips (VFS) are uniformly-graded and densely-vegetated sections of land engineered and designed to treat runoff and remove pollutants through vegetative filtering and infiltration. The primary purpose of a VFS is either to enhance the quality of stormwater runoff on small sites in a treatment system approach, or as a pre-treatment device for another BMP. The dense vegetative cover facilitates conventional pollutant removal through

detention, filtration by vegetation, sediment deposition, and infiltration and adsorption in the soil (Yu and Kaighn, 1992). VFS can also be used as a pre-treatment BMP in conjunction with a primary BMP. This reduces the sediment and particulate pollutant load reaching the primary BMP, which in turn reduces the BMP maintenance costs and enhances its pollutant removal capabilities. Filter strips are located adjacent to impervious areas and can be used in residential and commercial areas and along highways and roads. Because their effectiveness depends on having an evenly-distributed sheet flow over their surface, the size of the contributing area and the associated volume of runoff have to be limited. Flow can be directly accepted from a parking lot, roadway, or building roof, provided the flow is distributed uniformly over the strip. They are ideal components of the outer zone of a stream buffer, or as pre-treatment for another structural stormwater control. Filter strips can serve as a buffer between incompatible land uses, landscaped to be aesthetically pleasing, and provide groundwater recharge in areas with pervious soils.

VFS are generally grouped into three categories:

- • **Constructed filter strips.** Constructed filter strips are filter strips that are constructed and maintained to allow for overland sheet flow through the vegetation, primarily grass-like plants with density approaching that of tall lawn grass.
- • **Natural vegetative strips.** Natural vegetative strips are any natural vegetative area through which sediment-laden flow is directed, including riparian vegetation around drainage channels. Flow is typically not broad overland sheet flow, but occurs in small concentrated flow channels or flow zones. Vegetation can range from grass-like plants to brush or trees with ground litter.
- • **Riparian vegetative buffer strips.** Riparian vegetative buffer strips are strips of vegetation that grow along stream and concentrated flow channels. The vegetation may be constructed or natural. To be effective, the VFS will normally be located on the contour perpendicular to the general direction of flow.

Filter strips are often used as a stormwater site design credit when used in conjunction with other structural practices. Filter strips rely on the use of vegetation to slow runoff velocities and filter out sediment and other pollutants from urban stormwater. There can also be a significant reduction in runoff volume for smaller flows that infiltrate pervious soils while contained within the filter strip. To be effective, sheet flow must be maintained across the entire filter strip. Once runoff flow concentrates, it effectively short-circuits the filter strip and reduces the water quality performance. Therefore, a flow spreader must normally be included in the filter strip design.

There are two different filter strip designs:

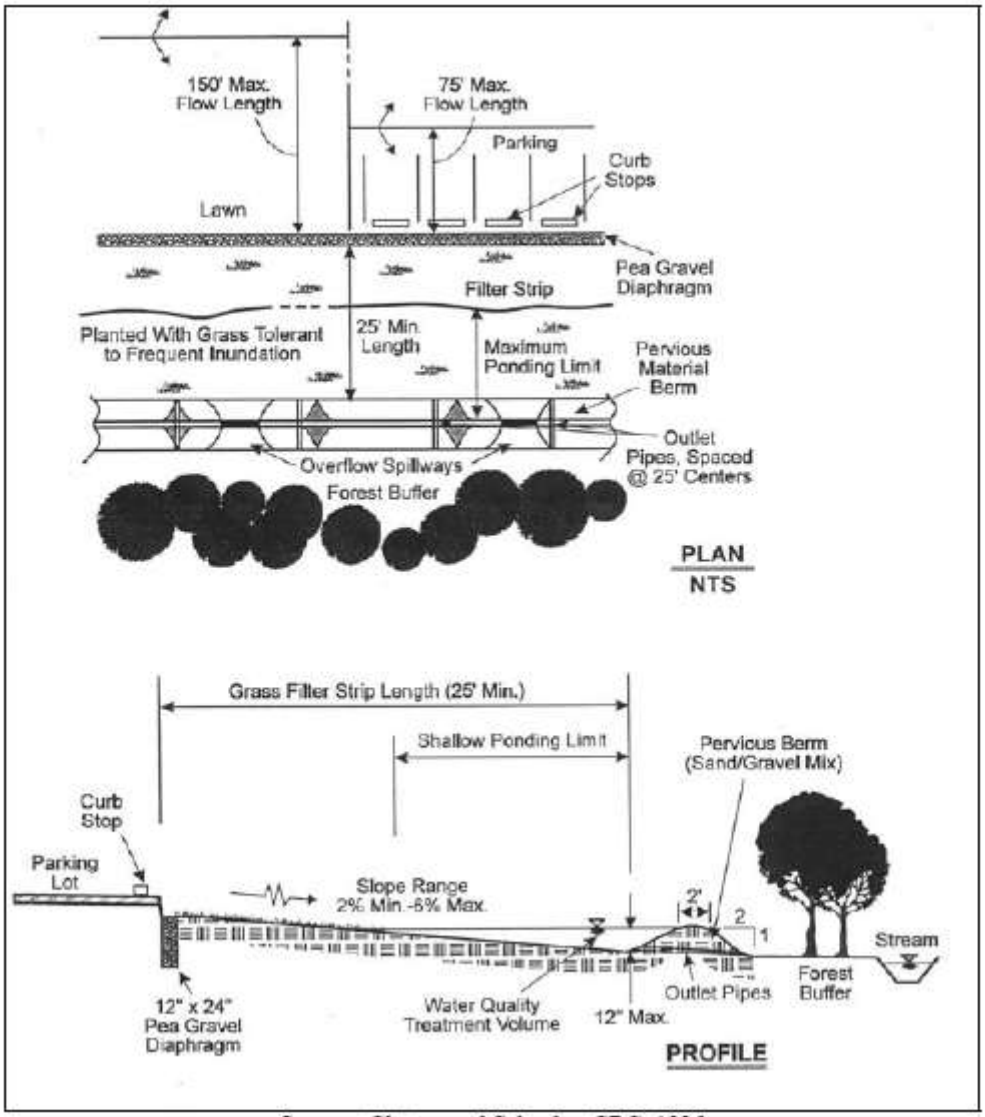
1. A filter strip design that includes a permeable berm at the bottom (Figure 1). The presence of the berm increases the contact time with the runoff, thus reducing the overall width of the filter strip required to treat stormwater runoff.

2. A simple filter strip (See Figure 2).

Filter strips are typically an on-line practice, so they must be designed to withstand the full range of storm events without eroding. The design approach for filter strips involves site design techniques to maintain prescribed maximum sheet flow distances, as well as checking to ensure adequate temporary storage for the WQv for a 24-hour period. Filter strips are also designed using volume-based sizing criteria.

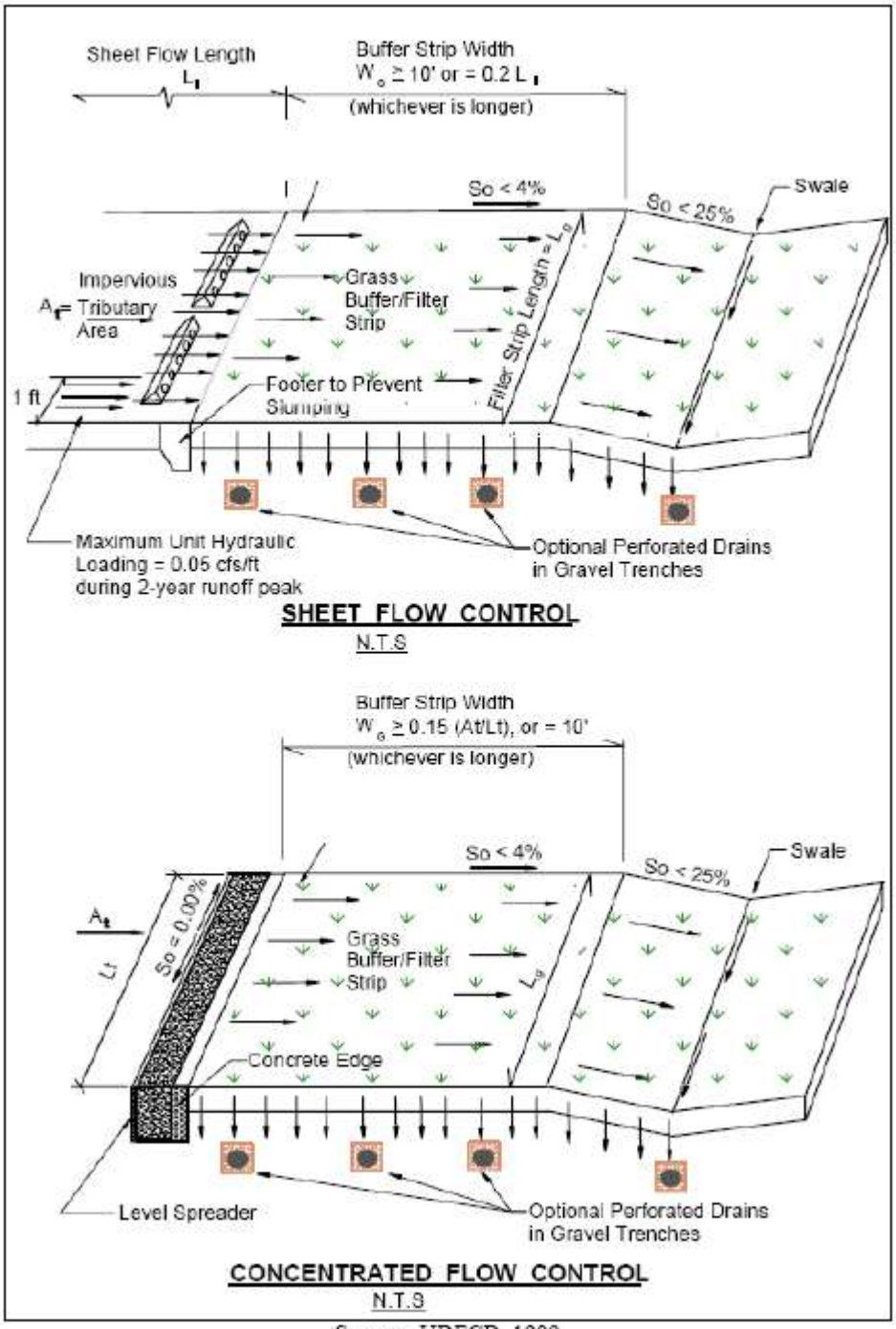
Therefore, the use of filter strips to treat stormwater runoff is primarily a function of limiting the flow path to the filter. One of the main abuses of the past has been draining too much area through the filter strip. In most cases the sheet flow distance limitations will be the controlling factor. Figures 1 and 2 illustrate the primary design components of the two filter strip design variants.

Figure 1: Vegetated filter strip (with berm)



Source: Claytor and Schueler, CRC, 1996

Figure 2: Grass buffer filter strip (without berm)



Source: UDFCD, 1999

B. Pollutant removal capabilities

Filter strips provide only marginal pollutant removal and require that follow-up structural BMPs be provided. Pollutant removal from filter strips is highly variable and depends primarily on density of vegetation and contact time for filtration and infiltration. These in turn depend on soil and vegetation type, slope, and presence of sheet flow. The following design

pollutant removal rates are conservative average pollutant reduction percentages for design purposes derived from sampling data, modeling, and professional judgment.

- Total suspended solids – 50%
- Total phosphorus – 20%
- Total nitrogen – 20%
- Fecal coliform – insufficient data
- Heavy metals – 40%

C. Design criteria

1. General criteria.

a. Filter strips should be used to treat small drainage areas. Flow must enter the filter strip as sheet flow spread out over the width (long dimension normal to flow) of the strip, generally no deeper than 1-2 inches. As a rule, flow concentrates within a maximum of 75 feet for impervious surfaces, and 150 feet for pervious surfaces (Claytor and Schueler, 1996). For longer flow paths, special provisions must be made to ensure design flows spread evenly across the filter strip.

b. Filter strips should be integrated within site designs.

c. Filter strips should be constructed outside the natural stream buffer area whenever possible to maintain a more natural buffer along the streambank.

d. Filter strips should be designed for slopes between 2-6%. Greater slopes than this would encourage the formation of concentrated flow. Flatter slopes would encourage standing water.

e. Filter strips should not be used on soils that cannot sustain a dense grass cover with high retardance. Designers should choose a grass that can withstand relatively high-velocity flows at the entrances, and both wet and dry periods. See SUDAS Specifications Manual Section 9010 for a list of appropriate grasses for use in Iowa.

f. The filter strip should be at least 15 feet long to provide filtration and contact time for water quality treatment. Twenty-five feet is preferred (where available), though length will normally be dictated by design method.

g. Both the top and toe of the slope should be as flat as possible to encourage sheet flow and prevent erosion.

h. An effective flow spreader is to use a pea gravel diaphragm (a small trench running along the top of the filter strip) at the top of the slope (ASTM D 448 size no. 6, 1/8-3/8-inch). The pea gravel diaphragm serves two purposes. First, it acts as a pre-treatment device, settling out sediment particles before they reach the practice. Second it acts as a level spreader, maintaining sheet flow as runoff flows over the filter strip. Other types of flow spreaders include a concrete sill, curb stops, or curb and gutter with saw-teeth cut into it.

i. Ensure that flows in excess of design flow move across or around the strip without damaging it. Often a bypass channel or overflow spillway with protected channel section is designed to handle higher flows.

j. Pedestrian traffic across the filter strip should be limited by providing a designated walkway.

k. Maximum discharge loading per foot of filter strip width (perpendicular to flow path) is found using Manning's equation:

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

Equation 1

where:
q = discharge per foot of width of filter strip (ft^3/sec-ft)
Y = allowable depth of flow (inches)
S = slope of filter strip (%)
n = Manning's roughness coefficient

Use 0.15 for medium grass, 0.25 for dense grass, and 0.35 for very dense grass. (See Table 1).

l. The minimum width of a filter strip is:

$$W_{f\text{-}MIN} = Q/q$$

Equation 2

where: $W_{f\text{-}MIN}$ = minimum filter strip width perpendicular to flow (feet)

2. Filter strip without berm.

a. Size filter strip (parallel to flow path) for a contact time of 5 minutes minimum.

b. Equation for filter length is based on the SCS TR55 travel time equation (SCS, 1986):

$$L_f = \frac{(T_t)^{1.25} (P_{2\text{-}24})^{0.625} (S)^{0.5}}{3.34n}$$

Equation 3

where:
L_f = length of filter strip parallel to flow path (ft)
T_t = travel time through filter strip (minutes)
$P_{2\text{-}24}$ = 2-yr, 24-hr rainfall depth (inches)
S = slope of filter strip (%)
n = Manning's roughness coefficient

Use 0.15 for medium grass, 0.25 for dense grass, and 0.35 for very dense grass. (See Table 1).

3. **Filter strip with berm.**

   a. Size outlet pipes to ensure that the water detained by the berm drains within 24 hours.

   b. Specify grasses resistant to frequent inundation within the shallow ponding limit.

   c. Berm material should be of sand, gravel and sandy loam to encourage grass cover (Sand: ASTM C-33 fine aggregate concrete sand 0.02-inch to 0.04-inch; Gravel: 1/2-inch to 1-inch: use IA DOT #3-coarse PCC aggregate or IA DOT #29-porous backfill).

   d. Size filter strip to contain the WQv within the wedge of water backed up behind the berm.

   e. Maximum berm height is 12 inches.

4. **Filter strips for pre-treatment.**

   a. A number of other structural controls, including bioretention areas and infiltration trenches, may utilize a filter strip as a pre-treatment measure. The required length of the filter strip depends on the drainage area, imperviousness, and the filter strip slope. Table 1 provides sizing guidance for bioretention filter strips for pre-treatment.

Table 1: Pre-treatment filter strip sizing guidance

Parameter	Impervious Areas				Pervious Areas (i.e. Lawns)			
Maximum inflow approach length (feet)	35		75		75		100	
Filter strip slope (maximum = 6%)	<2%	>2%	<2%	>2%	<2%	>2%	<2%	>2%
Filter strip minimum length (feet)	10	15	20	25	10	12	15	18

Source: Claytor and Schueler, 1996

D. Inspection and maintenance requirements

Filter strips require similar maintenance to other vegetative practices. Maintenance is very important for filter strips, particularly in terms of ensuring that flow does not short-circuit the practice.

Table 2: Typical maintenance activities for vegetated filter strips

Activity	Schedule
Mow grass to maintain a 2-4 inch height.	Regularly (as required seasonally)
Inspect pea gravel diaphragm for clogging and remove accumulated sediment.	Annual inspection (semi-annual first year)
Inspect vegetation for rill and gully erosion. Seed or sod bare areas.	
Inspect to ensure that grass has established. If not, replace with alternate species.	

Source: Claytor and Schueler, CRC, 1996

E. Design example

Filter strip

1. **Basic site data.** Small commercial parcel located in Ankeny, IA

    a. Parcel size: 240 feet deep x 200 feet wide

    b. Drainage area (A) = 1.1 acres

    c. Soils – HSG-B

    d. Roof and paved parking: 28,800-ft^2 (0.66 acres)

    e. Impervious percentage (I) = 60%

    f. Slope = 3.6%, Manning's n = 0.25

    g. Design for allowable flow depth of 1 inch

Figure 3: Data for Polk County example

Rainfall Data for Polk County Example
(24-hr duration)

Return period	Rainfall, P (inches)
0.3-yr (WQ event)	1.25
1-yr	2.38
2-yr	3.2
5-yr	4.1
10-yr	4.7
25-yr	5.5
100-yr	6.7

2. **Calculate maximum discharge loading per foot of filter strip width.** Use Equation 1:

    $q = (0.00236/0.25) \times (1.0)^{5/3} \times (3.6)^{0.5} = 0.018$ ft^3/sec-ft

3. **Compute WQv and WQv peak flow (Q_{wq}).**

    a. Compute water quality volume in inches:
        1. P = 1.25 inches

2. Rv = 0.05 + 0.009(60) = 0.59
3. WQv = P x Rv = 1.25 inches x 0.59 = 0.74 inches

b. Compute modified CN for 1.25-inch rainfall (P=1.25). (See Section 2C-7).
$CN = 1000/[10+5P+10Q-10(Q^2+1.25QP)^{0.5}$
$= 1000/[10+(5)(1.25)+(10)(0.74) -10((0.74)^2+(1.25)(0.74)(1.25))^{0.5}]$
= 94.36 (Use CN = 94)

c. For CN = 94 and an estimated time of concentration (tc) of 8 minutes (0.13 hours) compute the Q_{wq} for the 1.25-inch storm. Results from WINTR55 are:

Qwq = 1.21 ft^3/sec

d. For standard CN based on actual impervious and pervious area on B soils: CN=83. Compute Q_{p-2} and Q_{p-10} for developed condition. Results from WINTR55 are:

Q_{p-2} = 2.73 cfs Q_{p-10} = 4.9 cfs

4. **Compute minimum filter width.** Use Equation 2:

W_{f-MIN} = Q/q = 1.21 ft^3/sec / 0.018ft^3/sec-ft = 67 feet

Since the width of the parcel is 200 feet, the actual width of the filter strip can depend on site grading and the flow path configuration to the filter strip in sheet flow through a pea gravel level spreader.

5. **Filter without a berm.**

a. 2-yr, 24-hr storm for Polk County = 3.2 inches

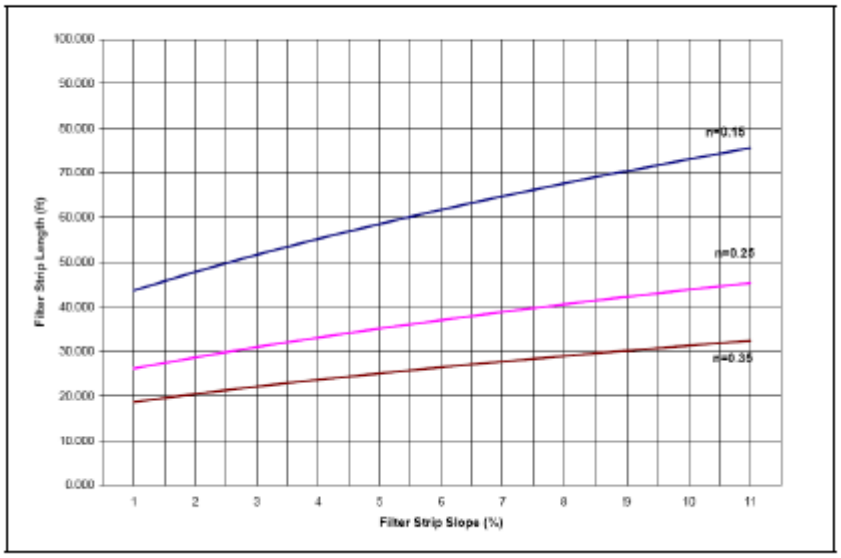
b. Use 5-minute travel contact time

c. Use Equation 3:

$L_f = (5)^{1.25} \times (3.2)^{0.625} \times (3.6)^{0.5} / (3.34 * 0.25)$ = 35 feet

Note: Reducing the filter strip slope to 2% and planting a denser grass (raising the Manning n to 0.35) would reduce the filter strip length to 22 feet. Sensitivity to slope and Manning's n changes are illustrated for this example in Figure 4

Figure 4: Example problem sensitivity of filter strip length to slope and Manning's n



6. **Filter with berm.**

   a. Pervious berm height is 8 inches

   b. Compute WQv in cubic feet: (Use WQv result in Step 3.a)

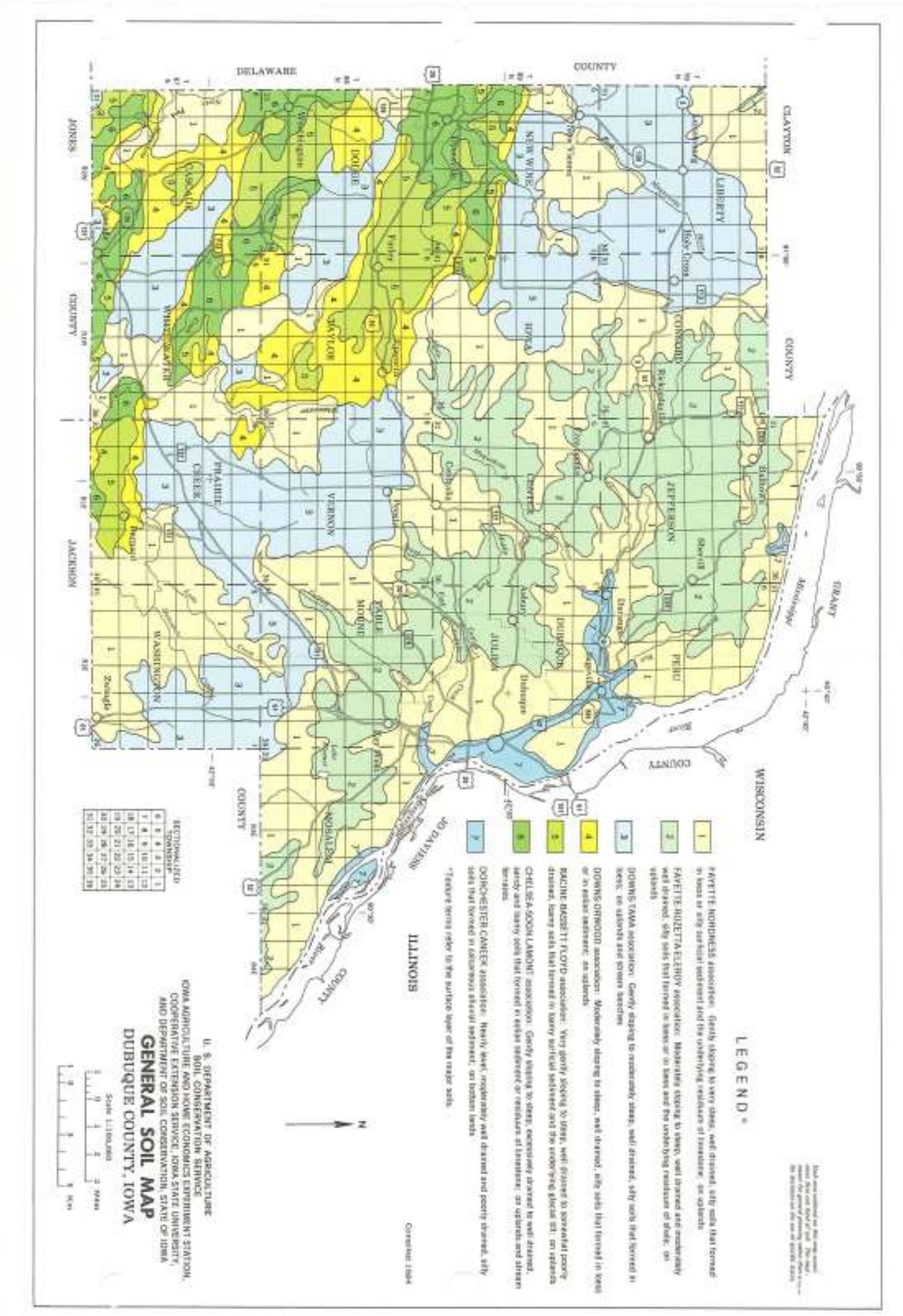
      WQv = 0.74 inches x 1.1 acres x 1/12 ft/inch x 43,460 ft^2/acre = 2,955 ft^3

   c. For a berm height of 8 inches, the volume of the wedge of water captured by the filter strip is:

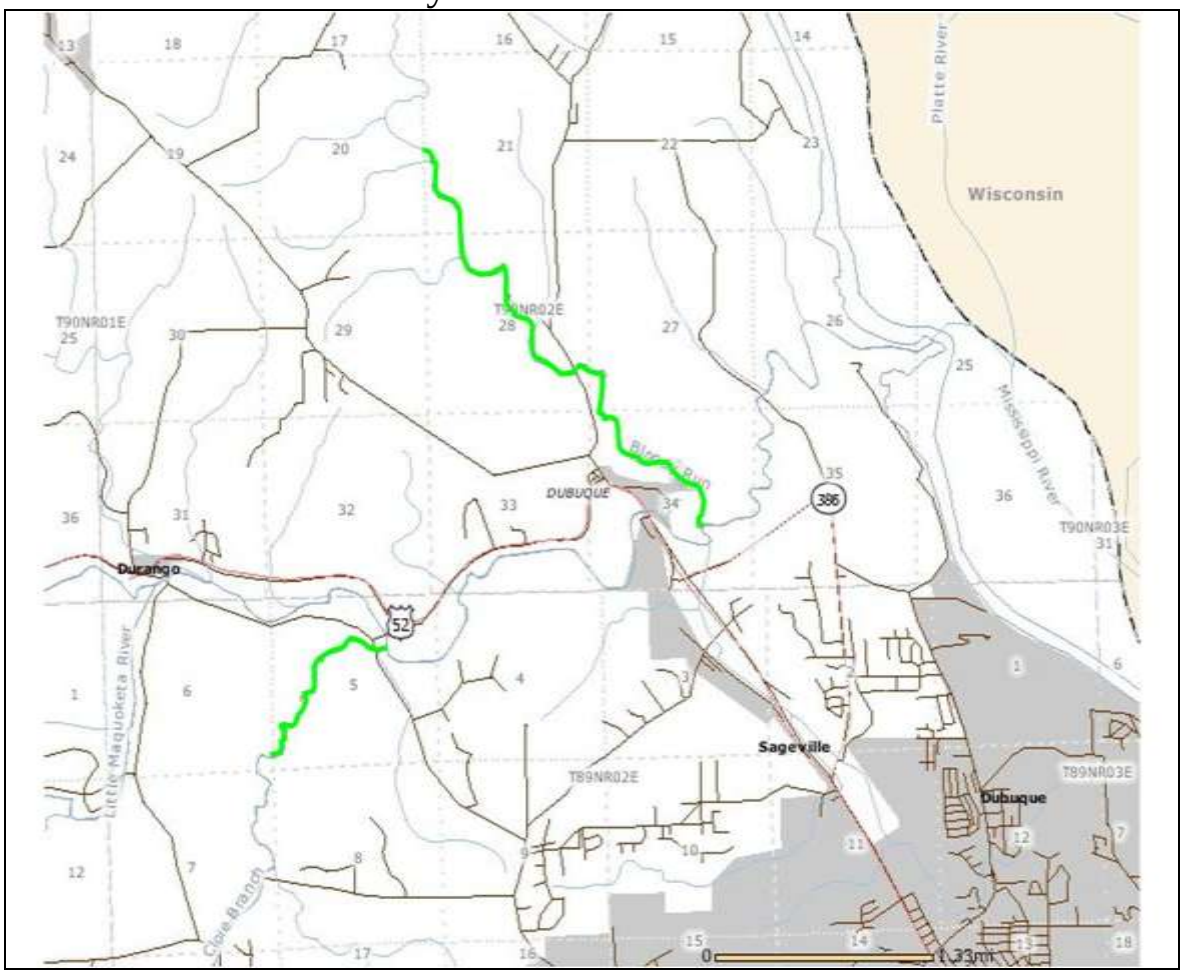
      Volume = Wf x Lf x ½ x 0.67 ft = 0.335WfLf = 2,955 ft3

   d. For a maximum width of the filter of 200 feet, the length of the filter would then be 44 feet.

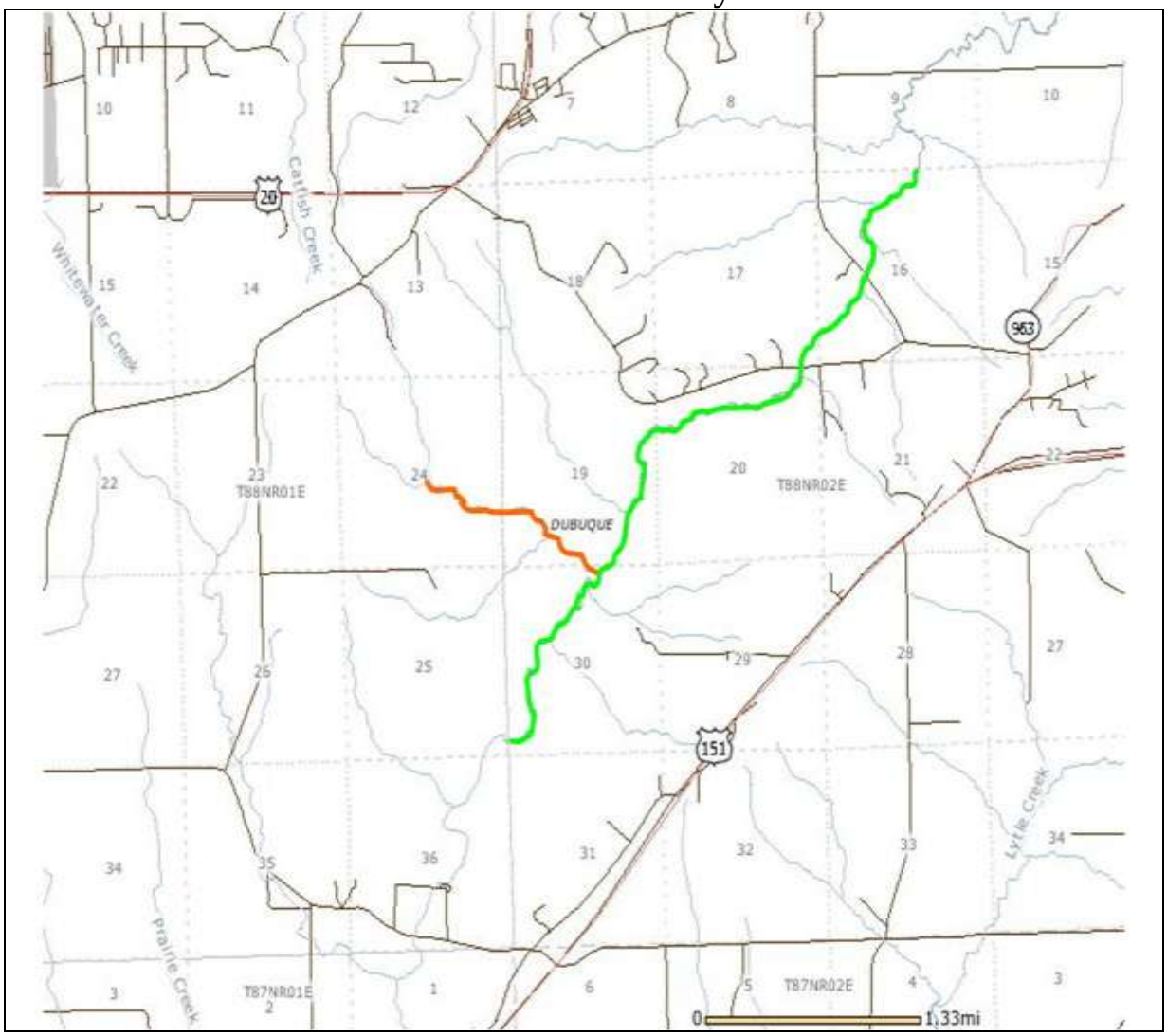
   e. For a 1-foot berm height, the length of the filter would be 30 feet.


DELAWARE
COUNTY
CLAYTON
JONES
COUNTY
JACKSON
WISCONSIN
GRANT
ILLINOIS
LEGEND
GENERAL SOIL MAP
DUBUQUE COUNTY, IOWA

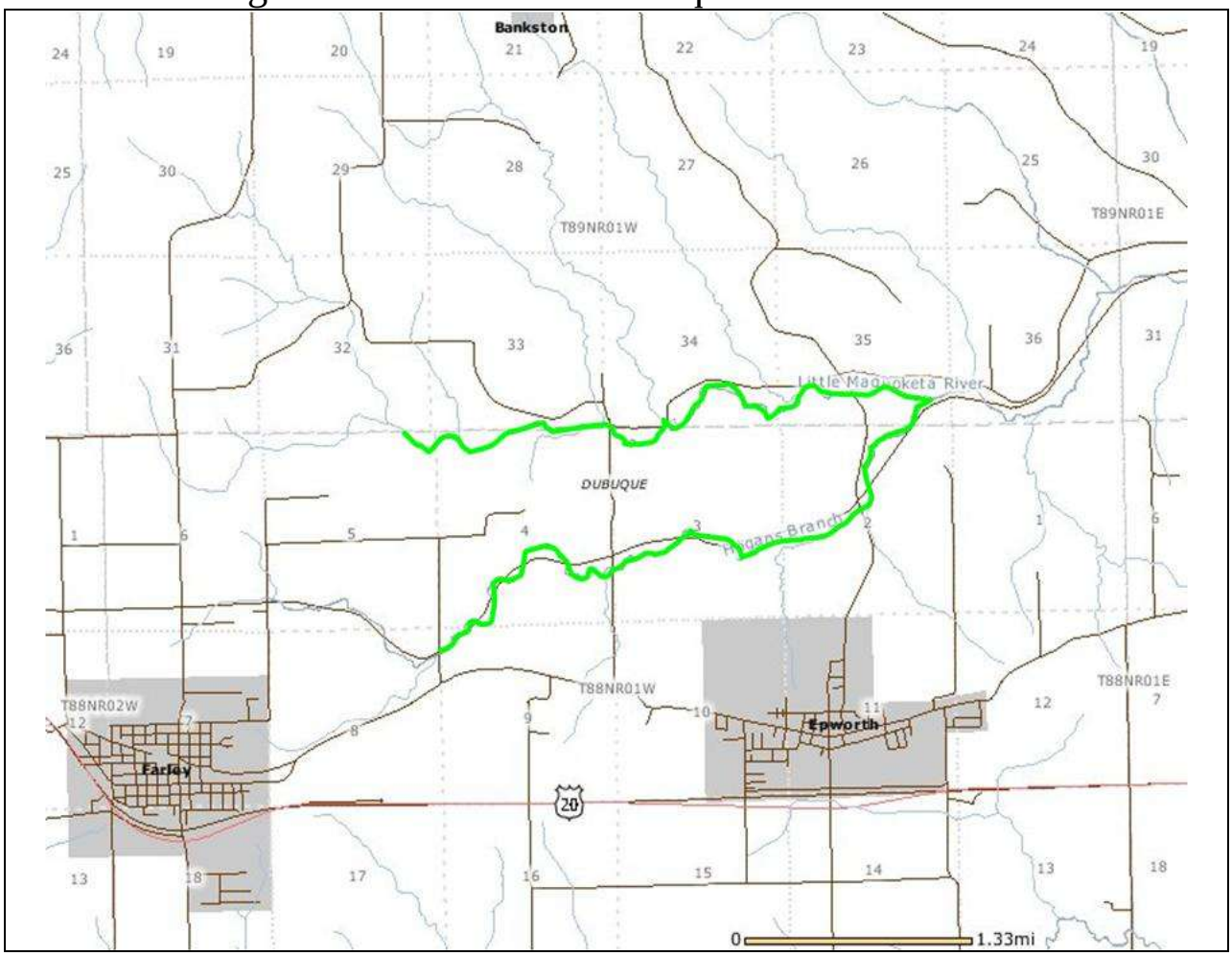
Bloody Run and Cloie Branch



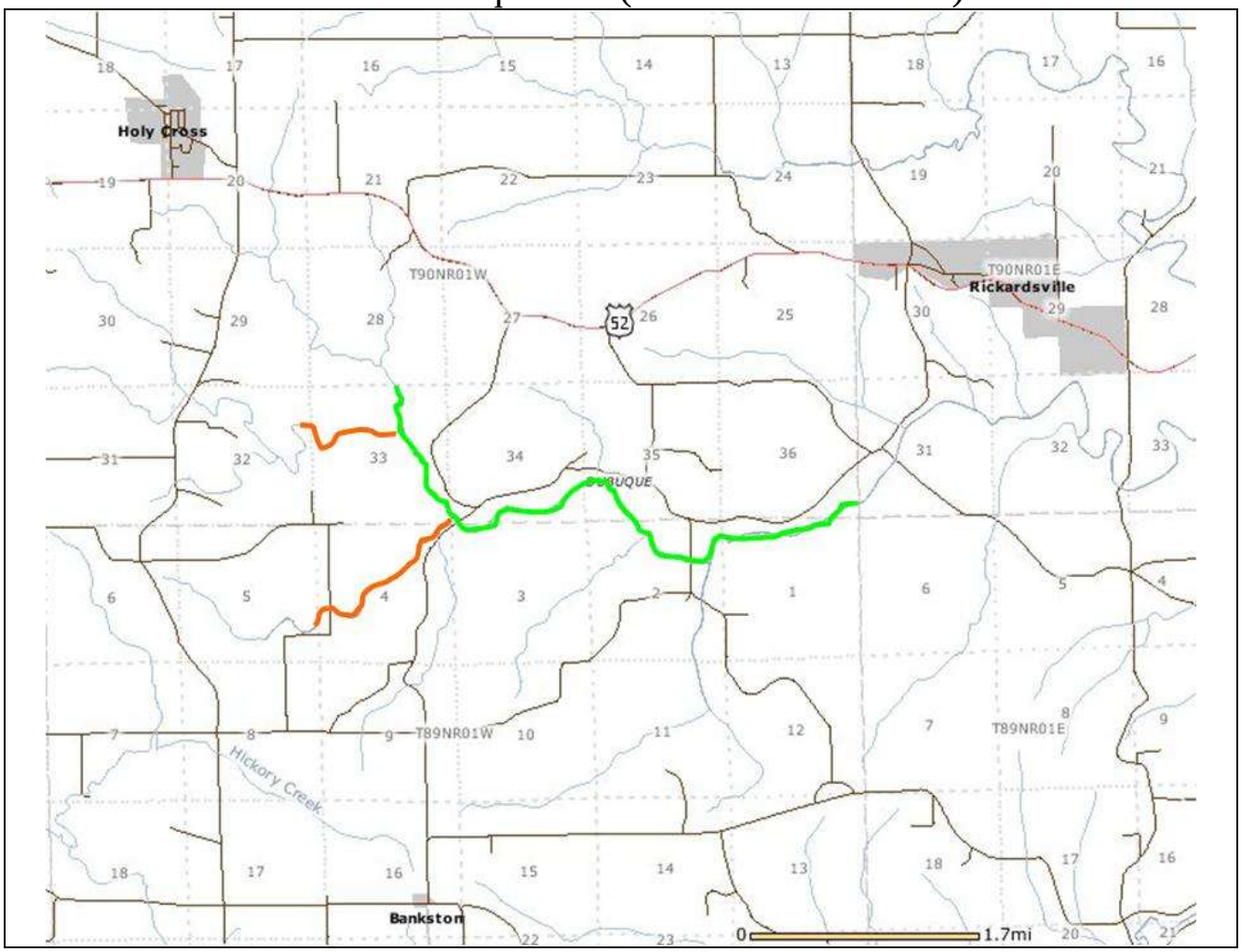
Catfish Creek and Monastery Creek



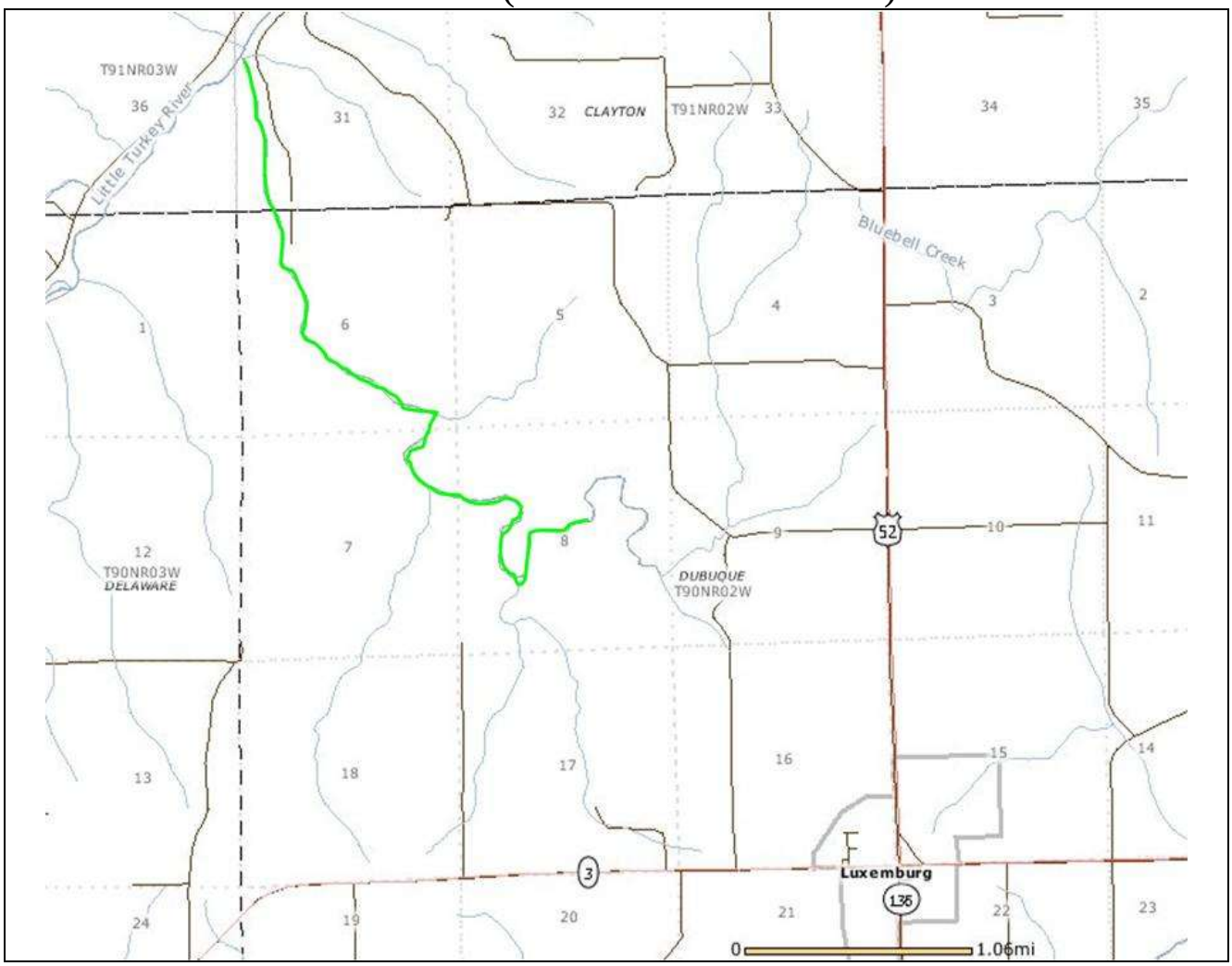
Hogans Branch and Little Maquoketa River



Middle Flork Little Maquoketa (aka Bankston Creek)



Point Hollow Creek (aka White Pine Hollow)



Plan & Permit Applicability Matrix

Post-Construction Stormwater Management[2]	Construction Site Erosion Control[1]: Yes	Construction Site Erosion Control[1]: No
Yes	Both Permits Required - Use Flowcharts A & B	Post-Construction Required - Use Flowchart B
No	Construction Site Erosion Control Permit Required - Use Flowchart A	No Permit Required

[1] Applicability per 1.3.A.1

Answer "Yes" if any of the following apply:

- Land disturbance of 4,000 square feet or more.
- Land disturbance on a slope more than 6%.
- Land disturbance involving excavation and/or filling more than 200 cubic yards of material.
- Land disturbance of more than 100 lineal feet of road ditch, grass waterway, or other area where surface drainage flows in open channels.
- New public or private roads or access drives longer than 150 feet.
- Development that requires land division.
- Land disturbance less than 4,000 square feet that has a high risk of soil erosion or water pollution, as determined by local ordinance administration.
- Land disturbance of any size within any of the following areas:
  - Within the watershed of a cold water stream
  - Within 300 feet of the ordinary high-water mark of any navigable water or 1,000 feet of a lake or pond.
  - Within the 100 year floodplain
  - Within 75 feet of a shoreland wetland or inland wetland

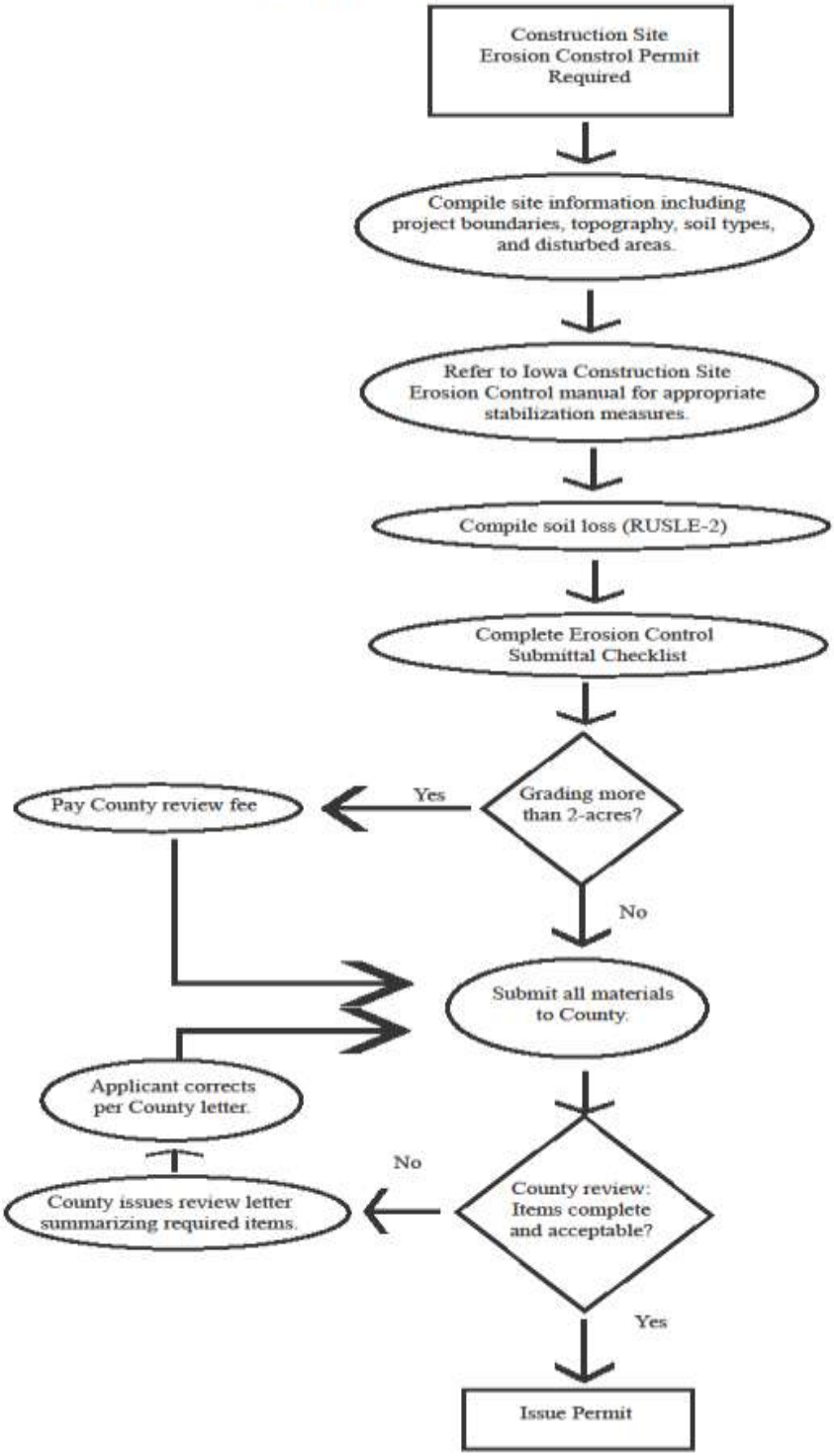
[2] Applicability per 1.3.B.1

Answer "Yes" if any of the following apply:

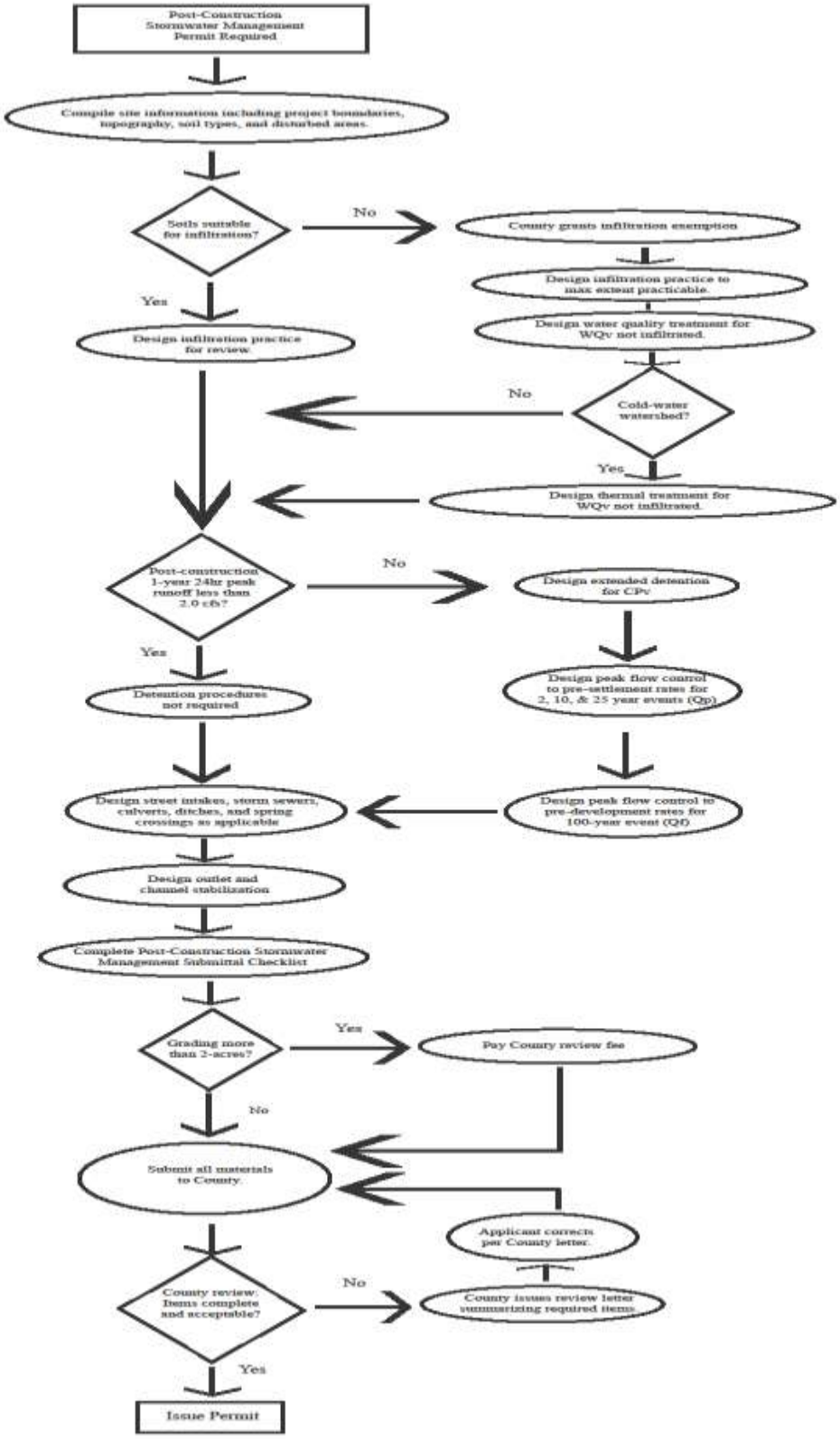
- New development and redevelopment site with 1-acre or more of land disturbing area.
- Development requiring a subdivision plat.
- Commercial or industrial development that requires a certified survey map.
- Any new development or redevelopment, regardless of size, with a Standard Industrial Classification (SIC) code that falls under the NPDES Industrial Stormwater Permit program or a hotspot land use.

Note: Provided flowcharts and checklists are intended only as a guide for the applicant. Comprehensive applicability, requirements, and practices are found in Chapter 1 section 1.3 of the Dubuque County Erosion Sediment Control and Stormwater Management Manual.

Flow Chart A


Construction Site Erosion Constrol Permit Required
Compile site information including project boundaries, topography, soil types, and disturbed areas.
Refer to Iowa Construction Site Erosion Control manual for appropriate stabilization measures.
Compile soil loss (RUSLE-2)
Complete Erosion Control Submittal Checklist
Grading more than 2-acres?
Yes
Pay County review fee
No
Submit all materials to County.
Applicant corrects per County letter.
County review: Items complete and acceptable?
No
County issues review letter summarizing required items.
Yes
Issue Permit

Flow Chart B


Post-Construction Stormwater Management Permit Required
Compile site information including project boundaries, topography, soil types, and disturbed areas.
Soils suitable for infiltration?
No
County grants infiltration exemption
Design infiltration practice to max extent practicable.
Design water quality treatment for WQv not infiltrated.
Cold-water watershed?
No
Yes
Design thermal treatment for WQv not infiltrated.
Yes
Design infiltration practice for review.
Post-construction 1-year 24hr peak runoff less than 2.0 cfs?
No
Design extended detention for CPv
Design peak flow control to pre-settlement rates for 2, 10, & 25 year events (Qp)
Yes
Detention procedures not required
Design peak flow control to pre-development rates for 100-year event (Qf)
Design street intakes, storm sewers, culverts, ditches, and spring crossings as applicable
Design outlet and channel stabilization
Complete Post-Construction Stormwater Management Submittal Checklist
Grading more than 2-acres?
Yes
Pay County review fee
No
Submit all materials to County.
Applicant corrects per County letter.
County review: Items complete and acceptable?
No
County issues review letter summarizing required items.
Yes
Issue Permit

Dubuque County Erosion Control Plan Submittal Checklist

Site Description including the following items:

Attached	N/A	
☐	☐	The nature of the construction activity
☐	☐	Major soil-disturbing activities
☐	☐	An estimate of the total area of the project site and the total disturbed area
☐	☐	Watershed size for each drainage area
☐	☐	A summary of available information describing the existing soil and soil properties
☐	☐	The name of the receiving waters and ultimate receiving waters of runoff from the site.
☐	☐	Anticipated sequence of major construction activities
☐	☐	The order for implementation of the control measures.
☐	☐	Temporary and permanent stabilization control measures used.
☐	☐	Maintenance procedures required to keep the controls functioning in an effective manner.
☐	☐	Practices for preventing hazardous materials that are stored on the site from contaminating stormwater.
☐	☐	Possibility for non-stormwater related discharges from the site
☐	☐	Method to limit the off-site tracking of sediment by vehicles

A site map (or maps) including the following items:

Attached	N/A	
☐	☐	Limits of soil-disturbing activities
☐	☐	Drawing of site to show the location of property lines
☐	☐	A plan note stating that areas not subject to construction activity for 21 days or more must have stabilizing measures initiated within 14 days after construction activity has ceased
☐	☐	A plan note stating that any waste materials from the site must be properly disposed of.
☐	☐	For disturbed drainage areas smaller than 10 acres, a sediment basin or sediment control along the sideslope and downslope boundaries of the construction area is required. For sites with 10 acres or more of disturbed drainage areas that drain to a common location, a sediment basin providing 3600 cf of storage per acre drained is required where attainable

Other supporting materials:

Attached	N/A	
☐	☐	Computations to show that 5.0 ton/Ac/yr soil loss standard is being met.
☐	☐	A signed affidavit stating that the project will not exceed the allowable soil loss limits
☐	☐	List additional state or local regulations that apply to the project.
☐	☐	List any applicable procedures or requirements specified on plans approved by state or local officials.
☐	☐	Fee to cover the cost for reviewing the erosion control plans and for performing two site visits
☐	☐	Sample inspection form
☐	☐	A certification statement by responsible parties

Explanation for items marked N/A

_____

_____

_____

Dubuque County Stormwater Management Plan Submittal Checklist

Project Report Narrative including the following items:

Attached	N/A	
☐	☐	A cover sheet
☐	☐	The nature of the construction activity, an estimate of the total area of the project site, and the total anticipated impervious area.
☐	☐	Watershed size for each drainage area
☐	☐	Describe pre-settlement/pre-development land use, topography, drainage patterns natural and manmade features
☐	☐	Describe post-developed land use and proposed grading
☐	☐	Describe contributing off-site drainage patterns, land use, and stormwater conveyance.
☐	☐	Discussion of site soils and their suitability for infiltration
☐	☐	Describe the features to control runoff rate, pollutants in stormwater, and infiltration
☐	☐	Indicate what permits have been applied for and received
☐	☐	Pre-settlement and pre-development runoff analysis
☐	☐	Post-Development runoff analysis
☐	☐	Rate control structure and conveyance system analysis
☐	☐	Water Quality Volume and infiltration analysis
☐	☐	Wet detention (retention) basin analysis
☐	☐	Extended detention basin analysis
☐	☐	Thermal impact analysis

A site map (or maps) including the following items:

Attached	N/A	
☐	☐	Show the proposed development, including street layout, topography, building location, etc.
☐	☐	Location of floodway, floodplains, and wetlands.
☐	☐	Soil map or geotechnical information
☐	☐	Location and elevations of Jurisdictional benchmarks
☐	☐	Proposed property lines (if known)
☐	☐	Existing drainage facilities and structures
☐	☐	Proposed drainage facilities and structures
☐	☐	Cross sections and profiles of road ditches
☐	☐	Proposed outfall point(s)
☐	☐	The 100-year elevation in management facilities and overland flow provisions
☐	☐	Critical minimum lowest opening elevation of buildings

Supporting Computations

Attached	N/A	
☐	☐	Runoff coefficients and curve numbers for each sub-watershed
☐	☐	Total impervious area (ft^2 and % of total drainage area)
☐	☐	Times of concentration for each sub-watershed
☐	☐	Storm sewer design summaries
☐	☐	Peak runoff calculations
☐	☐	Detention basin design (including extended detention & peak flow reduction)
☐	☐	Water Quality Volume calculations
☐	☐	Infiltration basin design calculations
☐	☐	Open channel flow calculations
☐	☐	Culvert design calculations or nomographs.
☐	☐	Erosion protection design.

Explanation for items marked N/A

_____

_____

_____

Sources:

"Dane County Erosion Control and Stormwater Management Manual." January 2, 2007. Dane County Land and Water Resources Department.

"Iowa Stormwater Manual." February 19, 2007. The Center for Transportation Research and Education at Iowa State University.

"Iowa Statewide Urban Design and Specifications." October 16, 2007. SUDAS Program (A program of the Center for Transportation Research and Education at Iowa State University).