4.8 Open Channel Systems

Introduction

Vegetated open channels are designed to capture and treat the water quality design storm, and safely convey larger storm events. Examples of vegetated open channels include:

- Grass channel
- Dry swale
- Wet swale
- Two-stage ditch (may be used to provide detention for larger storm events)
- Regenerative stormwater conveyance

Open channel systems shall not be designed to provide stormwater detention except under extremely unusual conditions. Generally, open channel systems must be combined with a separate facility to meet these requirements.

Grass channels. (Figure 4.8-1a & Figure 4.8-2) can provide a modest amount of runoff filtering and volume attenuation within the stormwater conveyance system resulting in the delivery of less runoff and pollutants than a traditional system of curb and gutter, storm drain inlets, and pipes. The performance of grass channels will vary depending on the underlying soil permeability and channel slope. Grass channels, however, are not capable of providing the same stormwater functions as other LID BMPs, as they lack a significant storage volume. Their water quality credit can be boosted when compost amendments are added to the bottom of the channel (See Appendix C). Grass channels are a preferable alternative to both curb and gutter and storm drains as a stormwater conveyance system where development density, topography, and soils permit.

Dry swales. (Figure 4.8-1b & Figure 4.8-3) are essentially bioretention cells that are shallower, configured as linear channels, and covered with turf or other surface material (other than mulch and ornamental plants). The dry swale is a soil filter system that temporarily stores and then filters the desired design storm volume. Dry swales rely on a pre-mixed soil media filter below the channel that is similar to that used for bioretention. If soils are extremely permeable, runoff infiltrates into underlying soils. In most cases, however, the runoff treated by the soil media flows into an underdrain, which conveys treated runoff back to the conveyance system further downstream. The underdrain system consists of a perforated pipe within a gravel layer on the bottom of the swale, beneath the filter media. Dry swales may appear as simple grass channels with the same shape and turf cover, while others may have more elaborate landscaping. Swales can be planted with turf grass, tall meadow grasses, decorative herbaceous cover, or trees.

Wet swales. (Figure 4.8-1c & Figure 4.8-4) can provide a modest amount of runoff filtering within the conveyance. These linear wetland cells often intercept shallow groundwater to maintain a wetland plant community. The saturated soil and wetland vegetation provide an ideal environment for gravitational settling, biological uptake, and microbial activity. On-line or off-line cells are formed within the channel to create saturated soil or shallow standing water conditions (typically less than 6 inches deep).
Two Stage Ditches. (Figure 4.8-1d & Figure 4.8-5) are a modification of other open channel designs that provides some temporary detention for larger storm events. This option utilizes a modified cross section that includes a low flow conveyance channel to convey the “channel forming” (up to 2-year) event, and a bench with flattened side slopes to convey larger storm events. Originally used as an agricultural practice in the Midwestern United States, it mimics the geometry of a natural stream, thereby harnessing some aspects of natural fluvial functioning. This design option has the potential to provide greater detention for larger storm events, minimizes scour during large storms, increases bank stability, and can enhance nitrogen removal by providing a greater reactive surface for nutrient cycling. However, it requires a wider width than a trapezoidal or parabolic channel, and consequently cannot be applied on sites with a very narrow right of way. Additional information and design criteria can be found in Chapter 10 - Part 654 Stream Restoration Design, National Engineering Handbook (USDA, 2007).

Regenerative Stormwater Conveyance. (RSC) (Figure 4.8-1e & Figure 4.8-6) is a unique conveyance practice that can be used in locations where other conveyance practices are infeasible, or as a restoration practice for eroded or degraded outfalls and drainage channels. RSC utilizes a series of shallow aquatic pools, riffle weir grade controls, native vegetation and underlying sand and woodchip beds to treat, detain, and convey storm flow. It can be used in places where grades make traditional stormwater practices difficult to implement. RSC Systems combine features and treatment benefits of Swales, Infiltration, Filtering and Wetland practices. In addition, they are designed to convey flows associated with larger storm events in a non-erosive manner, which results in a reduction of channel erosion impacts commonly encountered at conventional stormwater outfalls and headwater stream channels.

Example from Coastal South Carolina: Crabtree Canal

The Two-Stage Ditch has primarily been applied in the Midwestern United States in agricultural applications. A recent project in Horry County, SC used this design to reconnect the floodplain of the Crabtree Canal to partially restore the Crabtree Swamp (Fuss et al., 2010). This demonstration project is supported by hydrologic modeling in the watershed conducted by Clemson University, which indicated that the two-stage design would decrease velocity and shear stress within the channel (Jayakaran et al., 2009).

The design options presented in this chapter expand application of this design to include channels designed to capture stormwater runoff from smaller drainage areas, in order to enhance pollutant removal in the upper reaches of the drainage system.
Figure 4.8-1. Open Channel Design Options

Figure 4.8-1a. Grassed Channel (Photo: CWP)

Figure 4.8-1b. Dry Swale (Photo: CWP)

Figure 4.8-1c. Wet Swale (Photo: CWP)

Figure 4.8-1d. Two-Stage Ditch (Photo: Ohio State University Extension)

Figure 4.8-1e. Regenerative Stormwater Conveyance (Photo: Biohabitats, Inc.)
## KEY CONSIDERATIONS: OPEN CHANNEL SYSTEMS

### DESIGN CRITERIA:
- Depending on the design option, can treat the design water quality storm by detaining this volume with check dams, or by conveying at low velocities and depth to promote filtering and infiltration.
- Design to convey larger storm events safely, and at non-erosive velocities.

### BENEFITS:
- Helps restore pre-development hydrology on development sites and reduces post-construction stormwater runoff rates, volumes and pollutant loads.
- Ideally suited to the coastal environment, where stormwater is conveyed primarily in open channels.

### LIMITATIONS:
- Difficult to apply in densely developed areas.
- With the exception of Regenerative Stormwater Conveyance Systems, cannot be used on steep slopes.

### STORMWATER MANAGEMENT PRACTICE PERFORMANCE:

#### Runoff Reduction Credit Approach
(applies to Shellfish Bed, SMS4, and infiltration credit approaches)
- Grass Channel: 10% - 20% credit for design volume
- Dry Swale: 60% credit for storage volume
- Wet Swale: 0% credit
- RSC: 100% credit for storage volume

#### Coastal Zone Credit
- Grass Channel: 10% - 20% credit for design volume
- Dry Swale, Wet Swale, and RSC: 100% credit for storage volume of practice

#### Statewide Water Quality Requirement Credit Approach
- Grass Channel, Dry Swale, and RSC: Runoff Reduction credit applies to infiltration requirement.
- Wet Swale: At least ½” of runoff must be stored and released over 24 hours

### Annual Pollutant Removal

<table>
<thead>
<tr>
<th>Pollutant</th>
<th>Removal</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Suspended Solids</td>
<td>40% - 45%</td>
</tr>
<tr>
<td>Total Phosphorus2</td>
<td>20% - 40%</td>
</tr>
<tr>
<td>Total Nitrogen3</td>
<td>20% - 35%</td>
</tr>
<tr>
<td>Metals</td>
<td>30%</td>
</tr>
<tr>
<td>Pathogens4</td>
<td>N/A</td>
</tr>
</tbody>
</table>

1 expected annual pollutant load removal
2 range, with best removal for the wet or dry swales
3 range with best removal for grassed channels
4 No data available, but expected poor pollutant removal.

### SITE APPLICABILITY:
- Rural Use
- Suburban Use
- Construction Cost: Low-Medium
- Maintenance: Medium
- Area Required: Medium
- Construction Cost: Low-Medium
Figure 4.8-2. Grass Channel Typical Plan and Section
Figure 4.8-3. Dry Swale Typical Plan and Section
Chapter 4

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Figure 4.8-4. Wet Swale

Figure 4.8-5. Two-Stage Ditch

Figure 4.8-6. Regenerative Stormwater Conveyance
Open Channel Feasibility Criteria

Open channel systems are primarily applicable for land uses such as roads, highways, and residential development. Some key feasibility issues for open channels include the following:

Contributing Drainage Area. The maximum contributing drainage area to most open channels should be 2.5 acres, and preferably less. When open channels treat and convey runoff from drainage areas greater than 2.5 acres, the velocity and flow depth through the channel often becomes too great to treat runoff or prevent erosion in the channel. The design criteria for maximum channel velocity and depth are applied along the entire length (See Open Channel Design Criteria). Two-stage ditches and RSCs do not have the same restrictions, and generally are feasible for larger drainage areas.

Available Space. Open channel footprints can fit into relatively narrow corridors between utilities, roads, parking areas, or other site constraints. Dry Swales should be approximately 3% to 10% of the size of the contributing drainage area, depending on the amount of impervious cover. Wet swale footprints usually cover about 5% to 15% of their contributing drainage area. Grass channels can be incorporated into linear development applications (e.g., roadways) by utilizing the footprint typically required for an open section drainage feature. The footprint required will likely be greater than that of a typical conveyance channel. However, the benefit of the storage volume may reduce the footprint requirements for stormwater management elsewhere on the development site.

Site Topography. Grass channels and wet swales should be used on sites with longitudinal slopes of less than 4%. Check dams can be used to reduce the effective slope of the channel and lengthen the contact time to enhance filtering and/or infiltration. Longitudinal slopes of less than 2% are ideal and may eliminate the need for check dams. However, channels designed with longitudinal slopes of less than 1% should be monitored carefully during construction to ensure a continuous grade, in order to avoid flat areas with pockets of standing water. RSC practices are typically used for slopes less than 10%, but can be used on slopes up to 30% if proper cascade structures are used.

For dry swales, check dams will be necessary regardless of the longitudinal slope to create the necessary ponding volume.

Land Uses. Open channels can be used in residential, commercial, or institutional development settings.

When open channels are used for both conveyance and water quality treatment, they should be applied in linear configurations parallel to the contributing impervious cover, such as roads and small parking areas. The linear nature of open channels makes them well-suited to treat highway or low- and medium-density residential road runoff if there is adequate right-of-way width and distance between driveways. Typical applications of open channels include the following, as long as drainage area limitations and design criteria can be met:

- Within a roadway right-of-way
- Along the margins of small parking lots
- Oriented from the roof (downspout discharge) to the street
- Disconnecting small impervious areas
Used to treat the managed turf areas of sports fields, golf courses, and other turf-intensive land uses, or to treat drainage areas with both impervious and managed turf cover (such as residential streets and yards).

Open channels are not recommended when residential density exceeds 4 dwelling units per acre, due to a lack of available land and the frequency of driveway crossings along the channel.

Open channels can also provide pretreatment for other stormwater treatment practices.

**Available Hydraulic Head.** A minimum amount of hydraulic head is needed to implement open channels in order to ensure positive drainage and conveyance through the channel. The hydraulic head for wet swales and grass channels is measured as the elevation difference between the channel inflow and outflow point. The hydraulic head for dry swales is measured as the elevation difference between the inflow point and the storm drain invert. Dry swales typically require 3 to 5 feet of hydraulic head since they have both a filter bed and underdrain.

**Hydraulic Capacity.** Open channels are typically designed as on-line practices which must be designed with enough capacity to convey runoff from the 2-year and 10-year design storms at non-erosive velocities. This means that the swale’s surface dimensions are more often determined by the need to pass the 10-year storm events, which can be a constraint in the siting of open channels within existing rights-of-way (e.g., constrained by sidewalks).

**Depth to Water Table.** Designers should ensure that the bottom of dry swales and grass channels is at least 0.5 feet above the seasonally high groundwater table, to ensure that groundwater does not intersect the filter bed, since this could lead to groundwater contamination or practice failure. It is permissible for wet swales to intersect the water table. For RSC, the water table should not inundate pools or reduce available storage.

**Soils.** Soil conditions do not constrain the use of open channels, although they do dictate some design considerations:

- Dry swales in soils with infiltration rates of less than 0.3 inches per hour will need an underdrain. Designers must verify site-specific soil permeability at the proposed location using the methods for on-site soil investigation presented in Appendix B, in order to eliminate the requirements for a dry swale underdrain. Designers should always decrease the measured infiltration rate by a factor of 2 during design, to approximate long term infiltration rates.

- Grass channels situated on low-permeability soils may incorporate compost amendments in order to improve performance (see Appendix C).

- Wet swales work best on the more impermeable Hydrologic Soil Group (HSG) C or D soils, or in areas where the groundwater is very close to the surface.

- In fill soil locations, geotechnical investigations are recommended to determine if the use of an impermeable liner and underdrain are necessary for open channel designs.

**Utilities.** Approval from the applicable utility company or agency is required if utility lines will run below or through open channel areas. Typically, utilities can cross linear channels if they are specially protected (e.g., double-casing). Water and sewer lines generally need to be placed under adjacent road pavements to enable the use of open channels.
Avoidance of Irrigation or Baseflow. Open channels should be located so as to avoid inputs of springs, irrigation systems, chlorinated wash-water, or other continuous dry weather flows.

Setbacks. Open channels should be set back at least 10 feet down-gradient from building foundations and property lines, 50 feet from septic system fields and 150 feet from public or private drinking water wells. The 10-foot building setback may be relaxed if an impermeable building liner is installed.

Pollutant Hotspot Land Uses. Open channels may not be an appropriate stormwater management practice for certain pollutant-generating sites. In areas where higher pollutant loading is likely (i.e. oils and greases from fueling stations or vehicle storage areas, sediment from un-stabilized pervious areas, or other pollutants from industrial processes), appropriate pretreatment, such as an oil-water separator or filtering device must be provided. These pretreatment facilities should be monitored and maintained frequently to avoid negative impacts to the channel and subsequent water bodies.

On sites with existing contaminated soils, infiltration is not allowed. In these conditions, dry and wet swales must include an impermeable liner.

Feasibility in Coastal South Carolina. Open channels are ideally suited to the coastal environment, since open channel drainage is often the norm due to the flat topography. Depending on underlying soil and other characteristics, however, a specific open channel option may be the most appropriate. For example, the wet swale design option is most suited to areas with elevated groundwater tables, while dry swales and grassed channels are best suited for sandy soils of the coastal plain.

Economic Considerations. While most open channel designs provide relatively small water quality credits when compared with other stormwater practices, they nevertheless provide greater quality benefits than traditional conveyance designs, such as curb and gutter.

Open Channel Conveyance Criteria

The bottom width and slope of a grass channel should be designed such that the velocity of flow from the design storm provides a minimum hydraulic residence time (the time for runoff to travel the full length of the channel) of 9 minutes for the peak flows from the water quality volume storm event. Check dams may be used to reduce the flow velocity and achieve the needed hydraulic residence time. Check dams should be spaced based on channel slope and ponding requirements, consistent with the criteria in Open Channel Design Criteria.

Open channels should also convey the 2- and 10-year storms at non-erosive velocities (generally less than 6 fps) for the soil and vegetative cover provided. The final designed channel shall provide 1 foot minimum freeboard above the designated water surface profile of the channel. The analysis should evaluate the flow profile through the channel at normal depth, as well as the flow depth over top of the check dams.

The RSC system is typically designed to convey larger storm events, up to and including the 100-year storm event.
Open Channel Pretreatment Criteria

Pretreatment is required for open channels to dissipate energy, trap sediments and slow down the runoff velocity. The selection of a pretreatment method depends on whether the channel will experience sheet flow or concentrated flow. Several options are as follows:

- **Check Dams** (channel flow): These energy dissipation devices are acceptable as pretreatment on small open channels with drainage areas of less than 1 acre. The most common form is the use of wooden or stone check dams. The pretreatment volume stored should be 10% of the design volume.

- **Tree Check Dams** (channel flow; Figure 4.8-7): These are street tree mounds that are placed within the bottom of grass channels up to an elevation of 9 to 12 inches above the channel invert. These check dams are similar to traditional check dams, except that the dam is created with a tree mound. Stormwater that is ponded behind the check dam percolate through the excavated soil below the tree’s roots. Flows above the elevation of the check dam are conveyed over an armored downstream slope to reduce erosion potential.

![Figure 4.8-7. Tree Check Dam (Source: Cappiella, 2009)](image-url)
Grass Filter Strip (sheet flow): Grass filter strips extend from the edge of the pavement to the bottom of the open channel at a slope of 5:1 or flatter. Alternatively, provide a combined 5 feet of grass filter strip at a maximum 5% (20:1) cross slope and 3:1 or flatter side slopes on the open channel.

Gravel or Stone Diaphragm (sheet flow): The gravel diaphragm is located at the edge of the pavement or the edge of the roadway shoulder and extends the length of the channel to pre-treat lateral runoff. This requires a 2- to 4-inch elevation drop from a hard-edged surface into a gravel or stone diaphragm. The stone must be sized according to the expected rate of discharge.

Gravel or Stone Flow Spreaders (concentrated flow). The gravel flow spreader is located at curb cuts, downspouts, or other concentrated inflow points, and should have a 2- to 4-inch elevation drop from a hard-edged surface into a gravel or stone diaphragm. The gravel should extend the entire width of the opening and create a level stone weir at the bottom or treatment elevation of the channel.

Initial Sediment Forebay (channel flow). This grassed cell is located at the upper end of the open channel segment with a 2:1 length to width ratio and a storage volume equivalent to at least 15% of the total design storm volume. The pretreatment volume stored must be 10% of the design volume.

Open Channel Design Criteria

Channel Geometry. Design guidance regarding the geometry and layout of open channels is provided below:

- Generally, open channels should be aligned adjacent to and the same length as the contributing drainage area identified for treatment.
- Open channels should be designed with a trapezoidal or parabolic cross section. A parabolic shape is preferred for aesthetic, maintenance and hydraulic reasons.
- The bottom width of the channel should be between 4 to 8 feet wide to ensure that an adequate surface area exists along the bottom of the swale for filtering. If a channel will be wider than 8 feet, the designer should incorporate benches, check dams, level spreaders or multi-level cross sections to prevent braiding and erosion along the channel bottom.
- Open channel side slopes should be no steeper than 3H:1V for ease of mowing and routine maintenance. Flatter slopes are encouraged, where adequate space is available, to enhance pretreatment of sheet flows entering the channel.
- In the two-stage ditch option, the benches above the elevation of the 2-year storm event should have between a 0% and 3% side slope. In addition, the width of each bench should, at a minimum, be equal to the top width of the lower conveyance channel.
- RSC has several specific geometry requirements, which are outlined in RSC Sizing below.
Check dams. Check dams may be used for pretreatment, to break up slopes, and to increase the hydraulic residence time in the channel. Design requirements for check dams are as follows:

- Check dams should be spaced based on the channel slope, as needed to increase residence time, provide design storm storage volume, or any additional volume attenuation requirements. In typical spacing, the ponded water elevation at a downhill check dam should match the toe elevation of the upstream check dam. More frequent spacing may be desirable in dry swales to increase the ponding volume.

- The maximum desired check dam height is 12 inches (for maintenance purposes). However, for some sites, a maximum of 18 inches can be allowed, with additional design elements to ensure the stability of the check dam and the adjacent and underlying soils. The average ponding depth throughout the channel should be 12 inches.

- Armoring may be needed at the downstream toe of the check dam to prevent erosion.

- Check dams must be firmly anchored into the side-slopes to prevent outflanking; check dams must also be anchored into the channel bottom so as to prevent hydrostatic head from pushing out the underlying soils.

- Check dams must be designed with a center weir sized to pass the channel design storm peak flow (15-year storm event for man-made channels).

- For grass channels, each check dam should have a weep hole or similar drainage feature so it can dewater after storms. This is not appropriate for dry swales

- Check dams should be composed of wood, concrete, stone, compacted soil, or other non-erodible material, or should be configured with elevated driveway culverts.

- Individual channel segments formed by check dams or driveways should generally be at least 25 to 40 feet in length.

Check dams for grass channels should be spaced to reduce the effective slope to less than 2%, as indicated in Table 4.8-1.
Table 4.8-1. Typical Check Dam (CD) Spacing to Achieve Effective Channel Slope

<table>
<thead>
<tr>
<th>Channel Longitudinal Slope</th>
<th>Spacing¹ of 12-inch High (max.) Check Dams³,⁴ to Create an Effective Slope of 2%</th>
<th>Spacing¹ of 12-inch High (max.) Check Dams³,⁴ to Create an Effective Slope of 0 to 1%</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.5%</td>
<td>–</td>
<td>200 ft. to –</td>
</tr>
<tr>
<td>1.0%</td>
<td>–</td>
<td>100 ft. to –</td>
</tr>
<tr>
<td>1.5%</td>
<td>–</td>
<td>67 ft. to 200 ft.</td>
</tr>
<tr>
<td>2.0%</td>
<td>–</td>
<td>50 ft. to 100 ft.</td>
</tr>
<tr>
<td>2.5%</td>
<td>200 ft.</td>
<td>40 ft. to 67 ft.</td>
</tr>
<tr>
<td>3.0%</td>
<td>100 ft.</td>
<td>33 ft. to 50 ft.</td>
</tr>
<tr>
<td>3.5%</td>
<td>67 ft.</td>
<td>30 ft. to 40 ft.</td>
</tr>
<tr>
<td>4.0%</td>
<td>50 ft.</td>
<td>25 ft. to 33 ft.</td>
</tr>
<tr>
<td>4.5%²</td>
<td>40 ft.</td>
<td>20 ft. to 30 ft.</td>
</tr>
<tr>
<td>5.0%²</td>
<td>40 ft.</td>
<td>20 ft. to 30 ft.</td>
</tr>
</tbody>
</table>

Notes:
¹ The spacing dimension is half of the above distances if a 6-inch check dam is used.
² Open channels with slopes greater than 4% require special design considerations, such as drop structures to accommodate greater than 12-inch high check dams (and therefore a flatter effective slope), in order to ensure non-erosive flows.
³ All check dams require a stone energy dissipater at the downstream toe.
⁴ Check dams require weep holes at the channel invert. Swales with slopes less than 2% will require multiple weep holes (at least 3) in each check dam.

Ponding Depth. Check dams should be used in dry swales to create ponding cells along the length of the channel. The maximum ponding depth in a dry swale should not exceed 18 inches. It may be necessary or desirable to space check dams more frequently than is shown in Table 4.8-1 in order to increase the ponding depth.

Dry Swale Filter Media. Dry swales require replacement of native soils with a prepared soil media. The soil media provides adequate drainage, supports plant growth, and facilitates pollutant removal within the dry swale. At least 18 inches of soil media should be added above the choker stone layer to create an acceptable filter. The recipe for the soil media is identical to that used for bioretention and is provided in Section 4.2 Bioretention. The soil media should be obtained from an approved vendor to create a consistent, homogeneous fill media. One acceptable design adaptation is to use 100% sand for the first 18 inches of the filter and add a combination of topsoil and leaf compost for the top 4 inches, where turf cover will be maintained.

Dry Swale Underdrain. Some dry swale designs will not use an underdrain (where soil infiltration rates meet minimum standards (see Open Channel Feasibility Criteria). When underdrains are necessary, they should have a minimum diameter of 4 to 6 inches and be encased in a 12-inch deep gravel bed. Two layers of stone should be used. A choker stone layer, consisting of #8 or #78 stone at least 3 inches deep, should be installed immediately below the filter media. Below the choker stone layer, the main underdrain layer should be at least 12 inches deep and composed of 1-inch double washed stone. The underdrain pipe should be set at least 4 inches above the bottom of the stone layer.
**Impermeable Liner:** This material should be used only for appropriate fill applications where deemed necessary by a geotechnical investigation. Use a thirty mil (minimum) PVC Geomembrane liner covered by 8 to 12 oz./sq. yd. non-woven geotextile.

**Dry Swale Observation Well.** A dry swale should include observation wells with cleanout pipes along the length of the swale, if the contributing drainage area exceeds 1 acre. The wells should be tied into any T’s or Y’s in the underdrain system, and should extend upwards to be flush with surface, with a vented cap.

**Grass Channel Material Specifications.** The basic material specifications for grass channels are outlined in Table 4.8-2.

<table>
<thead>
<tr>
<th>Table 4.8-2. Grass Channel Materials Specifications</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Component</strong></td>
</tr>
<tr>
<td>Grass</td>
</tr>
</tbody>
</table>
| Check Dams | ♦ Check dams should be constructed of a non-erosive material such as wood, gabions, riprap, or concrete. All check dams should be underlain with filter fabric conforming to local design standards.  
♦ Wood used for check dams should consist of pressure treated logs or timbers, or water-resistant tree species such as cedar, hemlock, swamp oak or locust.  
♦ Computation of check dam dimensions is necessary, based on the surface area and depth used in the design computations. |
| Diaphragm | Pea gravel used to construct pretreatment diaphragms should consist of washed, open-graded, course aggregate between 3 and 10 mm in diameter and must conform to local design standards. |
| Erosion Control Fabric | Where flow velocities dictate, biodegradable erosion control netting or mats that are durable enough to last at least two growing seasons must be used. |

**Dry Swale Material Specifications.** Dry swale material specifications are identical to those for bioretention, and can be found in Table 4.2-3 Bioretention Material Specifications.

**RSC Material Specifications.** RSC has several design elements that are unique to this practice. The practice includes riffle and pool segments, underlain with a sand/wood chip bed, and with a top dressing of compost and plant material. Table 4.8-3 outlines the materials needed for this practice.
### Table 4.8-3. Regenerative Stormwater Conveyance System Material Specifications

<table>
<thead>
<tr>
<th>Material</th>
<th>Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Footer Boulders</td>
<td>Should have a natural appearance and be equivalent in size to Class 3 Rip Rap (average diameter 26.4 inches)</td>
</tr>
<tr>
<td>Cobble</td>
<td>Should have a natural appearance and a minimum diameter of 6”</td>
</tr>
<tr>
<td>Sand/Woodchip Bed</td>
<td>♦ The sand component of the sand/wood chip bed should meet the AASHTO-M-6 or ASTM-C-33, 0.02 inches to 0.04 inches in size. Sand shall be a</td>
</tr>
<tr>
<td></td>
<td>silica-based coarse aggregate. Substitutions such as Diabase and Graystone (AASHTO) #10 are not acceptable. No calcium carbonate or dolomite-</td>
</tr>
<tr>
<td></td>
<td>ic sand substitutions are acceptable. No “rock dust” can be used for sand. Locally-approved pulverized glass may be substituted if the local</td>
</tr>
<tr>
<td></td>
<td>authority undertakes testing to verify compliance with the particle size specification. No art glass shall be used for a pulverized glass</td>
</tr>
<tr>
<td></td>
<td>material. ♦ For woodchips, use aged, shredded hardwood chips/mulch. The woodchips should be added to the sand mix, approximately 20 percent by</td>
</tr>
<tr>
<td></td>
<td>volume, to increase the organic content and promote plant growth and sustainability.</td>
</tr>
<tr>
<td>Choker Stone</td>
<td>The choker stone layer between the sand bed and the bank run gravel should be clean, washed #8 or #78 stone.</td>
</tr>
<tr>
<td>Bank Run Gravel</td>
<td>The bank run gravel layer that is placed beneath and above the sand bed/choker stone layers should be constructed using clean, washed #5 or</td>
</tr>
<tr>
<td></td>
<td># 57 coarse aggregate.</td>
</tr>
<tr>
<td>Compost</td>
<td>The compost used as a top dressing over the RSC System should consist of a 100% organic compost, with a pH of between 6.0 and 7.0, a moisture</td>
</tr>
<tr>
<td></td>
<td>content of between 30 and 55%, and a particle size of 0.25 inches or less. (See Appendix C for compost specifications)</td>
</tr>
<tr>
<td>Wood Chips</td>
<td>The wood chips used within the sand bed should consist of double-shredded or double-ground hardwood mulch that is free of dyes, chromated</td>
</tr>
<tr>
<td></td>
<td>copper arsenate and other preservatives.</td>
</tr>
<tr>
<td>Plant Materials</td>
<td>Plants should be native species, appropriate to the planting/wetness zone where they are located.</td>
</tr>
</tbody>
</table>
**Wet Swale Design Issues.** The following criteria apply to the design of wet swales:

- The average normal pool depth (dry weather) throughout the swale should be 6 inches or less.
- The maximum temporary ponding depth in any single Wet Swale cell should not exceed 18 inches at the most downstream point (e.g., at a check dam or driveway culvert).
- Check dams should be spaced as needed to maintain the effective longitudinal slope.
- Individual Wet Swale segments formed by check dams or driveways should generally be at least 25 to 40 feet in length.
- Wet Swale side slopes should be no steeper than 4H:1V to enable wetland plant growth. Flatter slopes are encouraged where adequate space is available, to enhance pretreatment of sheet flows entering the channel. Under no circumstances are side slopes to be steeper than 3H:1V.

**Grass Channel Enhancement Using Compost Soil Amendments.** Soil compost amendments serve to increase the runoff reduction capability of a grass channel. The following design criteria apply when compost amendments are used:

- The compost-amended strip should extend over the length and width of the channel bottom, and the compost should be incorporated to a depth as outlined in Appendix C.
- The amended area will need to be rapidly stabilized with perennial grass species.
- For grass channels on steep slopes, it may be necessary to install a protective biodegradable geotextile fabric to protect the compost-amended soils. Care must be taken to consider the erosive characteristics of the amended soils when selecting an appropriate geotextile.

**Grass Channel Sizing.** Unlike other stormwater practices, grass channels are designed based on a peak rate of flow. Designers must demonstrate channel conveyance and treatment capacity in accordance with the following guidelines:

- Hydraulic capacity should be verified using Manning’s Equation or an accepted equivalent method, such as erodibility factors and vegetal retardance.
  - The flow depth for the peak flow generated by the water quality volume should be maintained at 4 inches or less.
  - Manning’s “n” value for grass channels should be 0.2 for flow depths up to 4 inches, decreasing to 0.03 at a depth of 12 inches and above (Haan et. al, 1994).
  - Peak flow rates for the 2-year and 10-year frequency storms should be non-erosive, in accordance with Table 4.8-5 below (see *Open Channel Landscaping Criteria*), or subject to a site-specific analysis of the channel lining material and vegetation; and the 10-year peak flow rate should be contained within the channel banks (with a minimum of 6 inches of freeboard).
- Calculations for peak flow depth and velocity should reflect any increase in flow along the length of the channel, as appropriate. If a single flow is used, the flow at the outlet should be used.
The hydraulic residence time (the time for runoff to travel the full length of the channel) should be a minimum of 9 minutes for the peak flows from the water quality volume or design storm (Mar et al., 1982; Barrett et al., 1998; Washington State Department of Ecology, 2005). If flow enters the channel at several locations, a 9 minute minimum hydraulic residence time should be demonstrated for each entry point, using Equations 4.8-1 – 4.8-5 below.

The bottom width of the grass channel is therefore sized to maintain the appropriate flow geometry as follows:

**Equation 4.8-1: Manning’s Equation**

\[
V = \frac{1.49}{n} \times R^{2/3} \times S^{1/2}
\]

where:

- \( V \) = flow velocity (ft/s)
- \( n \) = roughness coefficient (0.2, or as appropriate)
- \( R \) = hydraulic radius = \( D \) = flow depth (ft)

(Note: \( D \) approximates hydraulic radius for shallow flows)

- \( S \) = channel slope (ft/ft)

**Equation 4.8-2: Continuity Equation**

\[
Q = V \times (W \times D)
\]

where:

- \( Q \) = design storm peak flow rate (cfs)
- \( V \) = design storm flow velocity (ft/s)
- \( W \) = channel width (ft)
- \( D \) = flow depth (ft)

(Note: channel width \((W)\) x depth \((D)\) approximates the cross sectional flow area for shallow flows.)

Combining Equations 4.8-1 and 4.8-2, and re-writing them provides a solution for the minimum width:

**Equation 4.8-3: Minimum Width**

\[
W = \frac{n \times Q}{1.49 \times D^{3/2} \times S^{3/2}}
\]
Solving Equation 4.8-2 for the corresponding velocity provides:

**Equation 4.8-4: Corresponding Velocity**

\[ V = \frac{Q}{W \times D} \]

The width, slope, or Manning’s “n” value can be adjusted to provide an appropriate channel design for the site conditions. However, if a higher density of grass is used to increase the Manning’s “n” value and decrease the resulting channel width, it is important to provide material specifications and construction oversight to ensure that denser vegetation is actually established. Equation 4.8-5 can then be used to ensure adequate hydraulic residence time.

**Equation 4.8-5: Grass Channel Length for Hydraulic Residence Time of 9 minutes (540 seconds)**

\[ L = 540 \times V \]

where:

- \( L \) = minimum swale length (ft)
- \( V \) = flow velocity (ft/sec.)

The storage volume (\( S_v \)) provided by the grass channel is equal to the total runoff from the design storm, and is used to size the channel (conveyed at a depth of 4 inches or less).

*In the LID Compliance Calculator spreadsheet, the \( S_v \) for grass channels in A/B soils or with compost-amended channel bottom is given a 20% runoff reduction credit; the \( S_v \) for grass channels in C/D soils is given a 10% runoff reduction credit. Storage credits for projects in the Coastal Zone are the same as the runoff reduction credits.*

**Dry Swale Sizing.** Dry swales are typically sized to capture the water quality volume, and are sized exactly as bioretention areas, with check dams providing the necessary ponding volume.

**Wet Swale Sizing.** While there are no specific state requirements for the size of the permanent pool, pollutant removal can be improved by storing the equivalent of at least ½ inch of runoff in the permanent pool. For the water quality volume to be treated fully, the wet swale must also provide temporary storage of ½ inch of runoff from the site. Within ½ mile from receiving water bodies, the requirement is ½ inch of runoff from the site, or 1 inch of runoff from built-upon areas, whichever is greater. This temporary storage should not exceed a depth of 12 inches above the permanent pool elevation, and must be stored and released over 24 hours.

For water quality calculation purposes, the storage volume, \( S_v \), for a wet swale is equal to the temporary storage volume (The \( S_v \) does not include the permanent pool or the 2-year and 10-year detention volumes.).

*In the LID Compliance Calculator spreadsheet, wet swales are not assigned any runoff reduction credit. For projects in the Coastal Zone, the \( S_v \) for wet swales is given a 100% credit toward the storage requirement. For the statewide water quality requirements, wet swales are credited as a pond with permanent pool, and at least ½ inch of runoff must be stored and released over 24 hours.*
RSC Sizing. RSC design is described in detail by Anne Arundel County (2011). The following description provides an overview of this process, but designers should consult Anne Arundel County (2011) or the latest design variation for RSC for additional design guidelines. The Anne Arundel County guidance can be found at: http://www.aacounty.org/DPW/Watershed/StepPoolStorm-Conveyance.cfm.

RSC design is an iterative process in which the channel is sized to convey the 100-year storm event, using manning’s equation for parabolic channels. Some key sizing considerations include the following:

1. One control structure and pool (riffle-pool) combination is needed for each foot of elevation difference along the channel.
2. The length of each grade control structure or pool is determined by Equation 4.8-6.

\[
L_{pool} = \frac{L_{riffle}}{(\text{Elevation Change}) \times 2}
\]

Note that in areas with steep slopes (10% or greater) the length of the pool or riffle may be small (<10'). In these locations, cascades may be needed as a part of the system design.

3. The minimum width of grade control structures should be 8 ft and the width should be equal to 10 times the channel depth (Figure 4.8-8).
4. The depth of flow in the riffle sections should be less than 4 inches.
5. Cobbles in the riffle section should be sized so that the velocity of the 100-year storm is non-erosive (Table 4.8-4).

Figure 4.8-8. Typical Width and Depth of Riffle Sections (Source: Anne Arundel County, 2011).
Table 4.8-4. Maximum Allowable Velocity

<table>
<thead>
<tr>
<th>Cobble size (in)</th>
<th>Allowable velocity (ft/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>5.8</td>
</tr>
<tr>
<td>5</td>
<td>6.4</td>
</tr>
<tr>
<td>6</td>
<td>6.9</td>
</tr>
<tr>
<td>7</td>
<td>7.4</td>
</tr>
<tr>
<td>8</td>
<td>7.9</td>
</tr>
<tr>
<td>9</td>
<td>8.4</td>
</tr>
<tr>
<td>10</td>
<td>8.8</td>
</tr>
<tr>
<td>11</td>
<td>9.2</td>
</tr>
<tr>
<td>12</td>
<td>9.6</td>
</tr>
<tr>
<td>15</td>
<td>10.4</td>
</tr>
</tbody>
</table>

6. Pools should be between 1.5 and 3 feet deep, and equal to the width of the riffle sections.

7. The RSC system is underlain with a sand bed with a 1.5 foot depth and a width between 4 and 14 feet.

8. The downstream edge of the riffle should incorporate a series of boulders in a parabolic shape.

9. Place a cobble apron below the riffle section to allow for a stable transition between the riffle section and the downstream pools when the pools are dry. The cobble apron should be approximately 5 feet wide and 3 feet long.

The total $S_v$ in the RSC system (available for water quality treatment) is determined by Equation 4.8-7.

**Equation 4.8-7. Storage in RSC Systems**

\[ S_v = V_{pool} + V_{sandbed} \]

where:

- $V_{pool}$ = Volume in pools
- $V_{sandbed}$ = Volume in the sand bed (use 25% porosity)

*In the LID Compliance Calculator spreadsheet, the $S_v$ for RSCs is given a 100% runoff reduction credit and, for projects in the Coastal Zone, a 100% credit toward the storage requirement.*
Open Channel Landscaping Criteria

All open channels must be stabilized to prevent erosion or transport of sediment to receiving practices or drainage systems. Several types of grasses appropriate for dry open channels (grass channels and dry swales) are listed in Table 4.8-5. Designers should choose plant species that can withstand both wet and dry periods and relatively high velocity flows for planting within the channel. Designers should ensure that selected grass species are suited to the specific conditions on the site, including flow rate, slope, and aesthetic considerations. For more information on stabilization seeding, see the Charleston County Stabilization Specifications.

### Table 4.8-5. Recommended vegetation for open channels.

<table>
<thead>
<tr>
<th>Common Name</th>
<th>Botanical Name</th>
</tr>
</thead>
<tbody>
<tr>
<td>Common Bermudagrass</td>
<td>Cynodon dactylon</td>
</tr>
<tr>
<td>Common Carpetgrass</td>
<td>Axonopus affinis</td>
</tr>
<tr>
<td>Bahiagrass</td>
<td>Paspalum notatum</td>
</tr>
<tr>
<td>Coastal Panicgrass</td>
<td>Panicum amarum</td>
</tr>
<tr>
<td>Weeping Lovegrass</td>
<td>Eragrostis curvula</td>
</tr>
<tr>
<td>White Clover</td>
<td>Trifolium repens</td>
</tr>
<tr>
<td>Indianagrass</td>
<td>Sorghastrum nutans</td>
</tr>
<tr>
<td>Virginia Wildrye</td>
<td>Elymus virginicus</td>
</tr>
<tr>
<td>Crimson Clover</td>
<td>Trifolium incarnatum</td>
</tr>
<tr>
<td>Bowntop Millet</td>
<td>Panicum ramosum</td>
</tr>
<tr>
<td>Sweet Sorghum</td>
<td>Sorghum bicolor</td>
</tr>
<tr>
<td>Perennial Ryegrass</td>
<td>Lolium perenne</td>
</tr>
</tbody>
</table>

_Wet swales should be planted with grass and wetland plant species that can withstand both wet and dry periods as well as relatively high velocity flows within the channel. For a list of wetland plant species suitable for use in wet swales, refer to the wetland planting guidance and plant lists provided in Section 4.12 Stormwater Wetlands._

The Landscape design should specify proper grass species based on specific site, soils, and hydric conditions present along the channel.

Open channels should be seeded at such a density to achieve a 90% vegetated cover after the second growing season. Taller and denser grasses are preferable, although the species is less important than good stabilization and dense vegetative cover.

Grass channels should be seeded and not sodded. Seeding establishes deeper roots and sod may have muck soil that is not conducive to infiltration. Grass channels should be protected by a biodegradable erosion control fabric to provide immediate stabilization of the channel bed and banks.
**Open Channel Construction Sequence**

**Design Notes.** Channel invert and tops of banks should be shown in plan and profile views. A cross sectional view of each configuration should be shown for proposed channels. Completed limits of grading should be shown for proposed channels. For proposed channels, the transition at the entrance and outfall is to be clearly shown on plan and profile views.

**Open Channel Installation.** The following is a typical construction sequence to properly install open channels, although steps may be modified to reflect different site conditions or design variations. Grass channels should be installed at a time of year that is best to establish turf cover without irrigation. For more specific information on the installation of wet swales, designers should consult the construction criteria outlined in Section 4.12 Stormwater Wetlands.

**Step 1:** Protection during Site Construction. Ideally, open channels should remain outside the limit of disturbance during construction to prevent soil compaction by heavy equipment. However, this is seldom practical, given that the channels are a key part of the drainage system at most sites. In these cases, temporary erosion and sediment controls such as dikes, silt fences, and other erosion control measures should be integrated into the swale design throughout the construction sequence. Specifically, barriers should be installed at key check dam locations, and erosion control fabric should be used to protect the channel. For dry swale designs, excavation should be no deeper than 2 feet above the proposed invert of the bottom of the planned underdrain until the site is stabilized and construction of the BMP begins. Dry Swales that lack underdrains (and rely on filtration) must be fully protected by silt fence or construction fencing to prevent compaction by heavy equipment during construction.

**Step 2:** Installation should only begin after the entire contributing drainage area has been stabilized with vegetation. Any accumulation of sediments that does occur within the channel must be removed during the final stages of grading to achieve the design cross-section. Erosion and sediment controls for construction of the channel should be installed as specified in the erosion and sediment control plan. Stormwater flows must not be permitted into the channel until the bottom and side slopes are fully stabilized.

**Step 3:** Grade the grass channel to the final dimensions shown on the plan. Excavators or backhoes should work from the sides to grade and excavate the open channels to the appropriate design dimensions. Excavating equipment should have scoops with adequate reach so they do not have to sit inside the footprint of the open channel area. If constructing a dry swale, the bottom of the swale should be ripped, roto-tilled or otherwise scarified to promote greater infiltration.

**Step 4:** *(for Dry Swales)* If constructing a dry swale, place an acceptable filter fabric on the underground (excavated) sides of the dry swale with a minimum 6 inch overlap. Place the stone needed for storage layer over the filter bed. Perforate the underdrain pipe and check its slope. Add the remaining stone jacket, and then pack #57 stone to 3 inches above the top of the underdrain, and then add 3 inches of pea gravel as a filter layer. Add the soil media in 12-inch lifts until the desired top elevation of the dry swale is achieved. Water thoroughly and add additional media as needed where settlement has occurred.
Step 4: *(Optional, for grass channels)* Add soil amendments as needed. Till the bottom of the grass channel to a depth of 1 foot and incorporate compost amendments according to Appendix C.

Step 5: Install check dams, driveway culverts, and internal pretreatment features as shown on the plan. Fill material used to construct check dams should be placed in 8 to 12-inch lifts and compacted to prevent settlement. The top of each check dam should be constructed level at the design elevation.

Step 6: Hydro-seed the bottom and banks of the open channel, and peg in erosion control fabric or blanket where needed. After initial planting, a biodegradable erosion control fabric should be used, conforming to the South Carolina BMP Handbook (SDHEC, 2005).

Step 7: Plant landscaping materials as shown in the landscaping plan, and water them weekly during the first 2 months. The construction contract should include a care and replacement warranty to ensure that vegetation is properly established and survives during the first growing season following construction.

Step 8: Conduct the final construction inspection and develop a punchlist for facility acceptance.

**Open Channel Construction Inspection.** Inspections during construction are recommended to ensure that the open channel is built in accordance with these specifications.

Some common pitfalls can be avoided by careful construction supervision that focuses on the following key aspects of dry swale installation:

- Make sure the desired coverage of turf or erosion control fabric has been achieved following construction, both on the channel beds and their contributing side-slopes.
- Inspect check dams and pretreatment structures to make sure they are at correct elevations, are properly installed, and are working effectively.
- For dry swale designs:
  - Check the filter media to confirm that it meets specifications and is installed to the correct depth.
  - Check elevations such as the invert of the underdrain, inverts for the inflow and outflow points, and the ponding depth provided between the surface of the filter bed and the overflow structure.
  - Ensure that caps are placed on the upstream (but not the downstream) ends of the underdrains.
- Check that outfall protection/energy dissipation measures at concentrated inflow and outflow points are stable.

The real test of an open channel occurs after its first big storm. The post-storm inspection should focus on whether the desired sheet flow, shallow concentrated flows, or fully concentrated flows assumed in the plan actually occur in the field. Minor adjustments are normally needed as part of this post-storm inspection (e.g., spot reseeding, gully repair, added armoring at inlets, or realignment of outfalls and check dams). Also, inspectors should check that dry swale practices drain completely within the minimum 6-hour drawdown period.
Open Channel Maintenance Criteria

Maintenance is a crucial element that ensures the long-term performance of open channels. Once established, grass channels have minimal maintenance needs outside of the spring cleanup, regular mowing, repair of check dams, and other measures to maintain the hydraulic efficiency of the channel and a dense, healthy grass cover. Dry swale designs may require regular pruning and management of trees and shrubs. The surface of dry swale filter beds can become clogged with fine sediment over time, but this can be alleviated through core aeration or deep tilling of the filter bed. Additional effort may be needed to repair check dams, stabilize inlet points, and remove deposited sediment from pretreatment cells.

Table 4.8-6. Suggested Maintenance Activities and Schedule for Open Channels

<table>
<thead>
<tr>
<th>Maintenance Activity</th>
<th>Schedule</th>
</tr>
</thead>
<tbody>
<tr>
<td>♦ Mow grass channels and dry swales during the growing season to maintain grass</td>
<td>As needed</td>
</tr>
<tr>
<td>heights in the 4” to 6” range, but no greater than 1/3 of the grass height during</td>
<td></td>
</tr>
<tr>
<td>any one mowing.</td>
<td></td>
</tr>
<tr>
<td>♦ Ensure that the contributing drainage area, inlets, and facility surface are</td>
<td>Quarterly</td>
</tr>
<tr>
<td>clear of debris.</td>
<td></td>
</tr>
<tr>
<td>♦ Ensure that the contributing drainage area is stabilized. Perform spot-re-seeding</td>
<td></td>
</tr>
<tr>
<td>if/where needed.</td>
<td></td>
</tr>
<tr>
<td>♦ Remove accumulated sediment and oil/grease from inlets, pretreatment devices,</td>
<td></td>
</tr>
<tr>
<td>flow diversion structures, and overflow structures.</td>
<td></td>
</tr>
<tr>
<td>♦ Repair undercut and eroded areas at inflow and outflow structures.</td>
<td></td>
</tr>
<tr>
<td>♦ Add reinforcement planting to maintain 90% turf cover. Reseed any dead spots in</td>
<td>Annual</td>
</tr>
<tr>
<td>vegetation.</td>
<td>inspection</td>
</tr>
<tr>
<td>♦ Remove any accumulated sand or sediment deposits behind check dams.</td>
<td></td>
</tr>
<tr>
<td>♦ Inspect upstream and downstream of check dams for evidence of undercutting or</td>
<td></td>
</tr>
<tr>
<td>erosion, and remove trash or blockages at weepholes.</td>
<td></td>
</tr>
<tr>
<td>♦ Examine channel bottom for evidence of erosion, braiding, excessive ponding or</td>
<td></td>
</tr>
<tr>
<td>dead grass.</td>
<td></td>
</tr>
<tr>
<td>♦ Check inflow points for clogging and remove any sediment.</td>
<td></td>
</tr>
<tr>
<td>♦ Inspect side slopes and grass filter strips for evidence of any rill or gully</td>
<td></td>
</tr>
<tr>
<td>erosion and repair.</td>
<td></td>
</tr>
<tr>
<td>♦ Look for any bare soil or sediment sources in the contributing drainage area and</td>
<td></td>
</tr>
<tr>
<td>stabilize immediately.</td>
<td></td>
</tr>
</tbody>
</table>

An example maintenance checklist for the different types of open channels is included in Appendix F.
Open Channel Systems References and Additional Resources


12. USDA. 1954. Handbook of Channel of Design for Soil and Water Conservation. Stillwater Outdoor Hydraulic Laboratory and the Oklahoma Agricultural Experiment Station. SCS-TP-61, Washington, DC.


