Design of Swales in the Chesapeake Bay Watershed

Grass, Dry and Wet
Outline of Presentation

• How the three swale designs compare
• Designing more effective grass swales
• Dry swale design choices
• The special case for wet swales
• Adapting swale design in different regions of the Bay watershed
Swales

The local street right of way is the prime location to replace storm drain pipes with swales and filter, infiltrate, evapo-transpire or otherwise delay runoff to the stream, regardless of the underlying soil type.
Swale Applications

A ditch is not a swale
A grass swale is not a dry swale
A wet swale is actually a wetland
Let's compare our options
The differences between the four kind of swales are clearly evident in these cross-sections.
The type of swale you design has a major influence on its ability to reduce runoff and remove nutrients.

<table>
<thead>
<tr>
<th>Type of Swale</th>
<th>Runoff Reduction(^1)</th>
<th>TP EMC (^2) Reduction</th>
<th>TP Load Removed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Grass Swale, C&amp;D Soils</td>
<td>10%</td>
<td>15%</td>
<td>23%</td>
</tr>
<tr>
<td>Grass Swale, A&amp;B Soils</td>
<td>20%</td>
<td>15%</td>
<td>32%</td>
</tr>
<tr>
<td>Grass Swale, with CA (^3)</td>
<td>30%</td>
<td>15%</td>
<td>40%</td>
</tr>
<tr>
<td>Dry Swale, Level 1</td>
<td>40%</td>
<td>20%</td>
<td>52%</td>
</tr>
<tr>
<td>Dry Swale, Level 2</td>
<td>60%</td>
<td>40%</td>
<td>76%</td>
</tr>
<tr>
<td>Wet Swale, Level 1</td>
<td>0%</td>
<td>20%</td>
<td>20%</td>
</tr>
<tr>
<td>Wet Swale, Level 2</td>
<td>0%</td>
<td>40%</td>
<td>40%</td>
</tr>
</tbody>
</table>

\(^1\) annual runoff reduction as reported by CWP (2009)
\(^2\) change in event mean concentration (EMC) through the swale (CWP, 2009)
\(^3\) Only applied to C and D soils, CA = compost amended swale bottom
<table>
<thead>
<tr>
<th>Type of Swale</th>
<th>SWALE DEPTH To BR</th>
<th>DEPTH To WT</th>
<th>MIN HEAD</th>
<th>MAX SLOPE</th>
<th>SPACE (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Grass Channels</td>
<td>2</td>
<td>2 ft</td>
<td>2-3 ft</td>
<td>2 - 4%</td>
<td>5 - 15%</td>
</tr>
<tr>
<td>Dry Swales</td>
<td>2</td>
<td>2 ft</td>
<td>3-5 ft</td>
<td>4%</td>
<td>5 - 15%</td>
</tr>
<tr>
<td>Wet Swales</td>
<td>NA</td>
<td>0 ft</td>
<td>2 ft</td>
<td>2%</td>
<td>5 - 15%</td>
</tr>
</tbody>
</table>

These are general ranges only.

**BR** = Bedrock, vertical distance from bottom invert of swale and bedrock

**WT** = Seasonally High Water Table, vertical distance from bottom invert of swale and water table

**Minimum Head** = Vertical distance from inflow to practice and its bottom invert

**Max Slope** = maximum internal slope across the swale

**Space** = typical footprint of swale as percent of site area
Swales Work in Most Soil Conditions, (but they do have some design implications)

<table>
<thead>
<tr>
<th>Type of Swale</th>
<th>HSG A</th>
<th>HSG B</th>
<th>HSG C</th>
<th>HSG D</th>
</tr>
</thead>
<tbody>
<tr>
<td>Grass Swales</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Dry Swale</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Wet Swales</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
</tbody>
</table>

- X = Preferred Soil Group for Application
- X = Adequate, but requires an underdrain
- X = Adequate, but requires compost amendment on swale bottom
- X = Not recommended, unless these soils have very high water tables
All three swales design require a lot of surface area

• Individual swales can replace curb/gutter/storm drain for up to five acres contributing drainage area, for low density suburban development (max 25% IC)

• Shorter “headwater” swales can be used prior to drop inlets to storm drain pipes in denser developments

• Shift to green streets and linear bioretention at the most dense developments
Figure out three reasons why this otherwise fine swale is not providing much water quality benefit.
Grass Channels
Irreducible Concentrations through Grass Swales are High

<table>
<thead>
<tr>
<th>Outflow Concentration</th>
<th>(mg/L)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sediment</td>
<td>15 to 25</td>
</tr>
<tr>
<td>Total P</td>
<td>0.25 to 0.45</td>
</tr>
<tr>
<td>Total N</td>
<td>1.5 to 2.5</td>
</tr>
<tr>
<td>Fecal Coliform</td>
<td>Varies</td>
</tr>
</tbody>
</table>

Sources: Strecker et al 2004 and Caltrans 2005
Grass Channel Performance

Changes in pollutant concentration are not always great as they pass through grass channel.

TSS, metals and nitrogen show some decline in concentration.

Phosphorus and fecal coliform levels often do not drop (in some cases, increase).

In nearly all cases, the bulk of pollutant removal occurs by infiltration rather than filtering.

Infiltration is seldom guaranteed in grass swales due to short residence times and compacted soils.
Grass is not much of a filter, pollutant concentrations through grass swales do not decline much

<table>
<thead>
<tr>
<th></th>
<th>(mg/L)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Outflow Concentration</strong></td>
<td><strong>(mg/L)</strong></td>
</tr>
<tr>
<td>Sediment</td>
<td>15 to 25</td>
</tr>
<tr>
<td>Total P</td>
<td>0.25 to 0.45</td>
</tr>
<tr>
<td>Total N</td>
<td>1.5 to 2.5</td>
</tr>
<tr>
<td>Fecal Coliform</td>
<td>Often Increases</td>
</tr>
</tbody>
</table>

Sources: Strecker et al 2004 and Caltrans 2005
Field studies indicate that most grass swales did not achieve their hydraulic residence time. Application on slopes greater than 2% is problematic w/o cells or checkdams. Grass height/mowing regime does not appear to influence removal capability. Removal drops sharply when vegetative cover in bioswale >80%.

Bottom Line: We need more engineering in grass swales to improve their hydrologic function.
Grass Channels started out as a stormwater credit in MD but are now an ESD practice.
MD ESD Sizing for Grass Channels

The maximum flow velocity for the ESDv shall be less than or equal to 1.0 fps.

\[ P_E = 10'' \times \frac{A_f}{DA} \]  
(Equation 5.3)
MDE Grass Channels Design Criteria

- OK for A, B & C Soils
- For roads not parking lots
- Swale length = road length
- Max slope of 4%
- Max ESD flow depth of 4 inches
- Check dams or infiltration berms
- Swale bottom at least 2% of CDA
- Max CDA of 1 acre

* CDA = contributing impervious drainage area
Maximum flow velocity of 1 foot per second during a one inch rainfall event.....this one doesn’t cut it
Grass channels should never be used for parking lot runoff, use dry swale or bioretention instead
CSN Design Guidelines for Grass Channel

1. Explicitly prohibit for parking Lots
2. Minimum bottom width of 4 feet
3. One foot of restored soil along channel bottom required for C and D soils and mass graded B soils
4. No more than 3% slope in any 50 foot segment (low check dams)
5. May need initial biodegradable geo-fabric
6. Be non-erosive for 10 year storm
Dry Swale
Why the Dry Swale was Invented -- To Prevent This
What you don't see is really impressive: dry swale.
Dry Swale Runoff Reduction

- Excellent research in recent years
- Significant reduce runoff volume (mean 40%)
- May be as high as 80% with greater ET and less efficient underdrain collection
<table>
<thead>
<tr>
<th>Virginia Dry Swale Design Guidance</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Level 1 Design (RR:40; TP:20; TN:25)</strong></td>
</tr>
<tr>
<td>TV= (Rv)(A)</td>
</tr>
<tr>
<td>Swale slopes from &lt;0.5% or &gt;2.0%</td>
</tr>
<tr>
<td>Soil infiltration rates less than 0.5 in</td>
</tr>
<tr>
<td>Swale served by underdrain</td>
</tr>
<tr>
<td>On-line design</td>
</tr>
<tr>
<td>Media depth less than 18 inches</td>
</tr>
<tr>
<td>Turf cover</td>
</tr>
</tbody>
</table>

All Designs: acceptable media mix tested for phosphorus index
MD ESD Sizing For Small Dry Swales (bioswales)

- OK for all soil types
- Follow standard swale criteria
- Surface area 2% of CDA

\[ P_E = 15'' \times \frac{A_f}{DA} \]  
(Equation 5.2)
Design Choices for Dry Swales

Note: many of the design choices are similar to those made for bioretention (e.g., sizing, soil testing, filter depth, media recipe, etc.)
Design Choices
Driveway Elements

• Innovative ways to connect dry swale cells
• Use them to create upstream storage cells
• Some cells can be expanded into street bioretention or expanded tree pits
Design Choices
Steep Slopes

- Terracing is the best to break up steep slopes (5%).
- Stone or concrete weirs become a major design element to prevent erosion from major events.
Design Choices
Curb Edges

• Use gutters without curbs to preserve road edge and maximize sideslope flows into the swale
Design Choices
Vegetation Management

• Most dry swales can have a turf cover, but opportunities for creative landscaping exist to enhance performance
Design Choices
Roadway Shoulders

• The road right of way is optimal place for dry swales
• Resistance from road engineers and utilities to water
• Major barrier to overcome
Design Choices
Construction Sequencing

- Roads (and their drainage) are usually the first thing that is constructed at a site.
- The swale system will be exposed throughout the construction phase.
- Use the swale as an erosion control practice until the site is stabilized and then convert to swale.
Design innovations for dry swales

• Lose the filter fabric (choker stone is enough)
• Select the most appropriate grass species for expected swale conditions
• Erosion control fabric for steeper grades
• Add check dams to promote trapping and storage
• Shallow media at least 18 to 36 inches deep and large inefficient under drains
Wet Swale
Wet Swales

- Mostly for C and D Soils
- Non-residential applications
- Useful in flat terrain with high water table
Wet Swale Sizing in MD

Wet swales shall be designed to store at least 75% of the ESDv.

A PE value equivalent to the volume captured and treated shall be applied to the contributing drainage area.

Assume about 8 to 12 inches
## Level 1 and 2 Design Criteria for Wet Swales in VIRGINIA

<table>
<thead>
<tr>
<th>Level 1 Design (RR:0; TP:20; TN:25)</th>
<th>Level 2 Design (RR:0; TP:40; TN:35)</th>
</tr>
</thead>
<tbody>
<tr>
<td>( T_v = \frac{[(1 \text{ inch})(R_v)(A)]}{12} )</td>
<td>( T_v = \frac{[(1.25 \text{ inch})(R_v)(A)]}{12} )</td>
</tr>
<tr>
<td>Swale slopes less than 2% (^1)</td>
<td>Swale slopes less than 1% (^1)</td>
</tr>
<tr>
<td>On-line design</td>
<td>Off-line swale cells</td>
</tr>
<tr>
<td>No planting</td>
<td>Wetland planting within swale cells</td>
</tr>
<tr>
<td>Turf cover in buffer</td>
<td>Trees within swale cells</td>
</tr>
</tbody>
</table>

\(^1\) Wet Swales are generally recommended only for flat coastal plain conditions with a high water table. A linear wetland is always preferred to a wet swale.
CSN Wet Swale Design Criteria

1. Average dry weather ponding depth no more than 6 inches
2. Max. dry weather ponding of 18 inches
3. Multiple cell system, at least every 50 ft
4. Wetland planting plan (emergent or forested)
5. Have hydraulic capacity for 10 year storm
<table>
<thead>
<tr>
<th>Practice</th>
<th>Spec No.</th>
<th>Karst Terrain</th>
<th>Coastal Plain</th>
<th>Trout Waters</th>
<th>Ultra-Urban</th>
<th>Hotspots</th>
</tr>
</thead>
<tbody>
<tr>
<td>Grass Channels</td>
<td>3</td>
<td>Accepted</td>
<td>Restricted</td>
<td>Accepted</td>
<td>Restricted</td>
<td>Restricted</td>
</tr>
<tr>
<td>Dry Swales</td>
<td>11</td>
<td>Preferred</td>
<td>Preferred</td>
<td>Preferred</td>
<td>Restricted</td>
<td>Restricted</td>
</tr>
<tr>
<td>Wet Swales</td>
<td>13A</td>
<td>Prohibited</td>
<td>Preferred</td>
<td>Accepted</td>
<td>Restricted</td>
<td>Restricted</td>
</tr>
</tbody>
</table>

**KEY**

- **Preferred Practice:** widely feasible and recommended
- **Accepted Practice:** can work depending on site conditions
- **Restricted Practice:** extremely limited feasibility
- **Prohibited Practice:** do not use due to environmental risk
Shallow Dry Swale Design in Coastal Plain

- PREFFERED Practice
- Minimum depth of filter bed can be relaxed to 18 inches if head is problematic
- Minimum depth to water table below bed can be reduced to a foot if equipped with under drain
- Shift to wet swale or linear wetland if water table is within 2.5 feet of surface
- Minimum under drain slope of 0.5% and tied into ditch system
Wet Swale Design in Coastal Plain

- PREFERRED practice
- Useful in areas of high water table
- Series of on-line or off-line cells in the ditch system
- Design for saturated soils not standing water
- Consider incorporating sand or compost to improve swale soils
- Not recommended for residential areas due to mosquitoes
- Plant with wet-footed species (sedges, wet meadow mix)
- Weep holes at check dams
Grass Channel Design in Coastal Plain

- DISCOURAGED practice
- Poor nitrogen and bacteria removal
- Dry swales, wet swales or linear wetlands preferred
- Grass channels may be suitable if soils are in HSG A, and water table is 12 inches below surface
- A minimum slope of 0.5% must be maintained to ensure positive drainage
- May want to include off-line cells to increase storage
Dry Swale Design for Karst

• Try to locate them on predevelopment flow path
• Bottom invert should be at least two ft above bedrock
• Filter bed media can be less than 18 inches
• Lateral set back from roads
• Can often dispense with underdrain
• Tie it into an adequate channel or discharge to karst swale protection area
Grass Channel Design for Karst

- Incorporate soil compost amendments along bottom to improve treatment
- Check dams are discouraged since they pond too much water. Spreaders that are flush with ground surface can spread flows evenly.
- The minimum depth to the bedrock layer can be 18 inches.
- The grass channel may have off-line cells and should be tied into an adequate discharge point.