Module 14

Channel and Flood Protection

Plan Reviewer for Erosion and Sediment Control
14a. Channel Protection Criteria & the Energy Balance Method
Water Quantity Criteria Channel Protection
9VAC25-870-66. B

Channel Protection

<table>
<thead>
<tr>
<th>Natural</th>
<th>Man-made</th>
<th>Restored</th>
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<tbody>
<tr>
<td>EB</td>
<td>EB or 2-yr</td>
<td>EB or Design</td>
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</table>

----------TO LIMITS OF ANALYSIS----------

Channel Protection:
Concentrated stormwater flow shall be released into a stormwater conveyance system:

Photo: City of Charlottesville
Photo: Williamsburg Environmental Group
Photo: Elleanor G. Lawrence Park Fairfax County
Manmade stormwater conveyance system:

• Non-erosive capacity for 2-yr peak flow to Limits of Analysis OR

• Energy Balance (Natural Stormwater Conveyance)
Restored stormwater conveyance system:

- Development (density, scale, etc.) and peak flow rate consistent with the design parameters of the restored system to **the Limits of Analysis** analysis **OR**

- Energy Balance (Natural Stormwater Conveyance)

*Photo: City of Charlottesville*
Water Quantity Control Compliance

Limits of Analysis:

- Channel protection analysis carried to a point where:
  - Site’s *contributing DA* is < 1% of total watershed area or
  - Site’s *1-yr contributing peak flow rate* is < 1% of total watershed area (before implementation of any quantity BMPs)
Criteria for the Protection of Natural Channels

Protection of natural stream channels

- Restore them using natural channel design

- Protect them using the Energy Balance Method (1-yr event)

- Safe Harbor Provision
  (SWM Law § 62.1-44.15:28.10)
Stormwater Quantity
Channel Protection
9VAC25-870-66.A

Energy Balance

Post \( (Vol_{1-yr} \times \text{Peak } Q_{1-yr}) \leq \text{Pre } \left( Vol_{1-yr} \times \text{Peak } Q_{1-yr} \right) \text{(IF)} \)

\[
Q_{1\,\text{post}} \leq Q_{1\,\text{pre}} \left( \frac{PreVol_{1}}{Post\ Vol_{1}} \right) \text{(IF)}
\]

IF = Improvement Factor:

0.8 for sites > 1 acre or 0.9 for sites ≤ 1 acre
Energy Balance

Under no condition shall:

\[ Q_{1\;\text{post}} > Q_{1\;\text{pre}} \]

\[ Q_{1\;\text{post}} < Q_{1\;\text{forest}} \times \text{Forest Vol}_1/\text{Post Vol}_1 \]
Energy Balance

Goal: Establish “balance” exerted by pre- and post-developed stormwater discharge

\[(Q_{\text{peak pre}} \times \text{Vol}) \text{ with improvement factor}

\[(Q_{\text{peak}} \times \text{Vol})_{\text{pre}} \quad \text{and} \quad (Q_{\text{peak}} \times \text{Vol})_{\text{post}}\]
Why Energy Balance?

§ 62.1-44.15:28 A.11.
What is Energy Balance & Why use it?

Post-development runoff volume increases

Allowable discharge decreases

**Simple “balance”** offsets increase in volume and peak flow of developed condition hydrology
How Does Energy Balance encourage ESD?

\[ Q_{1 \text{post}} \leq Q_{1 \text{pre}} \left( \frac{\text{Pre Vol}_{1}}{\text{Post Vol}_{1}} \right) (IF) \]

- As Post Vol\(_1\) reduced
- Pre Vol\(_1\) to Post Vol\(_1\) ratio increases
- Allowable Q\(_{1 \text{post}}\) increases

*Decreases storage required for peak flow*
Increased Duration

Conventional SWM still releases Increased Runoff Volume
(Detained & released at slower rate, but for Longer Duration)

Post-Development, no BMPs

Post-Development, conventional SWM

Conventional SWM still releases Increased Runoff Volume

“2 year discharge”

“Low Impact Development” or Runoff Reduction Practices

Flow Rate

Increased Volume

Time

Increased Duration

= Pre-development

Post-Development, no BMPs

Post-Development, conventional SWM

14a. Channel Protection & Energy Balance | Pg. 9
Energy Balance

- **Post-Development Peak**
  - Post-urbanization (no SWM; 2 x Pre-urban Volume)
  - Pre-urbanization
  - Post-urbanization (Conventional SWM; 2 x Pre-urban Volume)
  - Energy Balance (2 x Pre-urban Volume)

- **Pre-Development 2-yr Peak**

- **Pre-Development 1-yr Peak**
How Does Energy Balance encourage ESD?

• RUNOFF REDUCTION

  – Decrease volume by

    ○ self-crediting site design

      – Less impervious cover

      – Minimizing impacts to native vegetation

      – Minimize impacts to native soils

    ○ utilizing structural and non-structural Runoff Reduction practices
### Energy Balance Terminology

\[
Q_{1\text{post}} \leq Q_{1\text{pre}} \left( \frac{\text{PreVol}_1}{\text{Post Vol}_1} \right) (IF)
\]

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<thead>
<tr>
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<th>Units</th>
<th>Term</th>
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<tbody>
<tr>
<td>NRCS TR-55</td>
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<tr>
<td>Runoff Depth</td>
<td>inches (in)</td>
<td>( Q )</td>
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<tr>
<td>Runoff Volume</td>
<td>cubic feet (ft(^3)) or acre feet (ac.ft.)</td>
<td>( V_r )</td>
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<tr>
<td>Storage Volume</td>
<td>cubic feet (ft(^3)) or acre feet (ac.ft.)</td>
<td>( V_s )</td>
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<tr>
<td>Peak Discharge</td>
<td>cubic feet per second (cfs)</td>
<td>( q_p )</td>
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**VRRM Treatment Volume Runoff Coefficients**

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<th>Term</th>
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<td>Unit-less Volumetric Runoff Coefficients</td>
<td>( R_v )</td>
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**VRRM Curve Number Adjustment**

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<td>Runoff Depth</td>
<td>( R_v )</td>
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**VSMP Regulations Channel Protection Criteria (4VAC50-60-56.B)**

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<th>Term</th>
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<tr>
<td>Peak Discharge</td>
<td>( Q )</td>
</tr>
<tr>
<td>Runoff Volume*</td>
<td>( R_v )</td>
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</table>

*Units of volume in the VSMP regulations Channel Protection Criteria can also be expressed in terms of watershed-inches or inches (consistent with Runoff Depth as expressed in the VRRM CN adjustment.*
How would you write this equation?

\[ Q_{1\,post} \leq Q_{1\,pre}\left(\frac{RV_{pre1}}{RV_{post1}}\right)(IF) \quad \text{(Regulation)} \]
Energy Balance: 9VAC25-870-66.A

How would you write this equation?

\[ Q_{1\text{post}} \leq Q_{1\text{pre}} \left( \frac{RV_{\text{pre}1}}{RV_{\text{post}1}} \right) (IF) \] (Regulation)

\[ Q_{1\text{post}} \leq Q_{1\text{pre}} \left( \frac{PreVol_{1}}{Post\ Vol_{1}} \right) (IF) \] (Simplified)
How would you write this equation?

\[ Q_{1 \text{post}} \leq Q_{1 \text{pre}} \left( \frac{RV_{\text{pre1}}}{RV_{\text{post1}}} \right) (IF) \]  
(Regulation)

\[ Q_{1 \text{post}} \leq Q_{1 \text{pre}} \left( \frac{PreVol_{1}}{Post Vol_{1}} \right) (IF) \]  
(Simplified)

\[ q_{1 \text{post}} \leq q_{1 \text{pre}} \left( \frac{Vr_{\text{pre1}}}{Vr_{\text{post1}}} \right) (IF) \]  
(TR-55)
14b. Energy Balance Design Example
1, 2, and 10-year volume (RV) measured in watershed inches

RV$_1$ = 1.28 inches
RV$_2$ = 1.76 inches
RV$_{10}$ = 3.30 inches
Where Does the Runoff Depth come From?

Curves on this sheet are for the case \( I_a = 0.2S \), so that

\[
Q = \frac{(P-0.2S)^2}{P + 0.8S}
\]

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<th>60</th>
<th>55</th>
<th>50</th>
<th>45</th>
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\[ Q_{1-yr} = 1.28'' \]
\[ P_{1-yr} = 2.79'' \]
### Table 2-1 Runoff depth for selected CN’s and rainfall amounts

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</table>

CN = 83

1-inch rain is equivalent to approximately 1.28 inches on P<sub>1-yr</sub> = 2.79" for CN = 83.
Energy Balance Design Example: Option 2 [with RR]

Project Graphic Courtesy of Geosyntec
### Channel & Flood Protection Tab

<table>
<thead>
<tr>
<th>Event (years)</th>
<th>Drainage Area A</th>
<th>Drainage Area B</th>
<th>Drainage Area C</th>
<th>Drainage Area D</th>
<th>Drainage Area E</th>
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<tbody>
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<td>0.00”</td>
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<td>2-year storm</td>
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<td>10-year storm</td>
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**Volume Reduction** = 23,065 ft³

1, 2, and 10-year volume (RV) reduction:

- RV₁ = 1.28” → 0.96”
- CN₁ = 83 → 77
- RV₂ = 1.76” → 1.44”
- CN₂ = 83 → 78
- RV₁₀ = 3.30” → 2.98”
- CN₁₀ = 83 → 80
Curve Number Adjustment: Hydrograph Modification

Runoff Depth Equations (TR-55):

Eq. 2-1: \[ Q = \frac{(P - I_a)^2}{(P - I_a) + S} \]

Eq. 2-2: \[ I_a = 0.2S \]

Eq. 2-4: \[ S = \left(1000 \frac{1000}{CN}\right) - 10 \]

Where:

- \( Q \) = runoff depth (in)
- \( P \) = precipitation depth (in)
- \( S \) = potential maximum retention after runoff begins
- \( I_a \) = initial abstraction, volume that must be filled before runoff begins
Step 1: 2.8" rainfall

Step 2: Original CN = 83

Step 3: 1.28" runoff

Step 4: Adjust For Retention (0.96")

Step 5: Adjusted CN ~ 77

Curves on this sheet are for the case $I_a = 0.2S$, so that

$$Q = \frac{(P-0.2S)^2}{P + 0.8S}$$
### Channel & Flood Protection Tab

1, 2, and 10-year storm rainfall depths

**Volume Reduction** = 23,065 ft³

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<th>Target Rainfall Event (in)</th>
<th>1-year storm</th>
<th>2-year storm</th>
<th>10-year storm</th>
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<tr>
<td>C</td>
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<table>
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<th>Drainage Area (acres)</th>
<th>Runoff Reduction Volume (cf)</th>
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</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Drainage Area</th>
<th>Drainage Area (acres)</th>
<th>Runoff Reduction Volume (cf)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>19.80</td>
<td>23,065</td>
</tr>
<tr>
<td>B</td>
<td>0.00</td>
<td>0</td>
</tr>
<tr>
<td>C</td>
<td>0.00</td>
<td>0</td>
</tr>
<tr>
<td>D</td>
<td>0.00</td>
<td>0</td>
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</table>

**1, 2, and 10-year volume (RV) reduction** =

- \(RV_1 = 1.28'' \rightarrow 0.96''\)
- \(CN_1 = 83 \rightarrow 77\)
- \(RV_2 = 1.76'' \rightarrow 1.44''\)
- \(CN_2 = 83 \rightarrow 78\)
- \(RV_{10} = 3.30'' \rightarrow 2.98''\)
- \(CN_{10} = 83 \rightarrow 80\)
# Energy Balance Design Example

## One-Year Storm Hydrology Summary: 19.8 acres

<table>
<thead>
<tr>
<th></th>
<th>Pre-Developed</th>
<th>Post-Developed no RR</th>
<th>Post-Developed with RR</th>
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<tbody>
<tr>
<td>Runoff Curve Number</td>
<td>71</td>
<td>83</td>
<td>77</td>
</tr>
<tr>
<td>Runoff Volume (RV)</td>
<td>0.62 in</td>
<td>1.28 in</td>
<td>0.96 in</td>
</tr>
<tr>
<td>Runoff Volume</td>
<td>1.02 ac-ft.</td>
<td>2.11 ac-ft.</td>
<td>1.58 ac-ft.</td>
</tr>
<tr>
<td>Peak Discharge ($q_1$)</td>
<td>9 cfs</td>
<td>39 cfs</td>
<td>27 cfs</td>
</tr>
<tr>
<td>Post Developed EB Allowed Peak Discharge (cfs)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Storage Volume Reqd., (ac-ft)</td>
<td></td>
<td></td>
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Energy Balance Design Example

- Compute the Energy Balance (EB) Allowed Peak Discharge (with and without RR):

\[
q_{1post} \leq q_{1pre} \left( \frac{Vr_{pre1}}{Vr_{post1}} \right) (IF)
\]

**without RR**

\[
q_{1post} \leq 9 \text{ cfs} \left( \frac{0.62''}{1.28''} \right)(0.8)
\]

\[
q_{1post} \leq 3.5 \text{ cfs}
\]

**with RR**

\[
q_{1post} \leq 9 \text{ cfs} \left( \frac{0.62''}{0.96''} \right)(0.8)
\]

\[
q_{1post} \leq 4.7 \text{ cfs}
\]
### Energy Balance Design Example

**One-Year Storm Hydrology Summary: 19.8 acres**

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<td>3.5 cfs*</td>
<td>4.7 cfs*</td>
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1. Increase in allowable discharge!
2. Energy Balance discharge not required to be less than ratio reduction for Forested condition
### Energy Balance Design Example

#### One-Year Storm Hydrology Summary: 19.8 acres

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<td><strong>4.7 cfs</strong></td>
</tr>
<tr>
<td>Storage Volume Reqd. (ac-ft)</td>
<td>1.16 ac-ft.*</td>
<td>0.76 ac-ft.*</td>
<td></td>
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37% Reduction in required 1-yr Channel Protection Storage Volume
14c. Flood Protection
Water Quantity Criteria Flood Protection
9VAC25-870-66. C

**No Flooding:**

Demonstrate:
- No 10-yr flooding pre
- No 10-yr flooding post (detention/improvements)

---TO LIMITS OF ANALYSIS---

**Local Flooding:**

Must eliminate flooding by:
- On-site detention
- System improvements
- Combination

---TO LIMITS OF ANALYSIS---

OR

- Detention of 10-year peak flow to less than existing

---NO LIMITS OF ANALYSIS (POST)---
Water Quantity Control Compliance

Limits of Analysis:

• Downstream capacity analysis carried to a point where:
  
  – Site’s *contribution DA* is < 1% of total watershed area or
  
  – Site’s *10-yr contributing peak flow rate* is < 1% of total watershed area (before implementation of any quantity detention)

  – Storm water conveyance system enters mapped floodplain/flood-prone area
14d. Sheet Flow
Sheet Flow


D. Increased volumes of sheet flow resulting from pervious or disconnected impervious areas, or from physical spreading of concentrated flow through level spreaders, must be identified and evaluated for potential impacts on down-gradient properties or resources.
Sheet Flow
9VAC25-870-66. D

- **volumes of sheet flow** must be identified and evaluated

- **volumes of sheet flow creating impacts** must be diverted to stormwater management facility or conveyance system
Questions?