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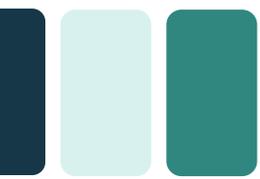


Stormwater Management Plan Review Course



Module 5

Stormwater Quantity Requirements



5a. Stormwater Quantity Requirements - Overview



The Evolution of MS-19

The regulatory Drivers:

- The Erosion & Sediment Control (ESC) Regulations
- Stormwater Management (SWM) Regulations (Part IIC)
- SWM Law
- SWM Regulations (Part IIB)



ESC Regulations: Minimum Standard 19

9VAC25-840-40.19.

Concentrated stormwater runoff leaving a development site shall be discharged directly into an adequate natural or man-made receiving channel, pipe or storm sewer system.

Adequacy of all channels and pipes shall be verified in the following manner



SWM Regulations (Part IIC): Minimum Standard 19 (reduction)

9VAC25-870-97. Stream channel erosion.

The VSMP authority shall require compliance with subdivision 19 of 9VAC25-840-40 of the ESC Regulations.

VSMP authority may determine that some watersheds require enhanced criteria :

1-year Extended Detention (ED)

Channel Protection 'safe harbor'

§ 62.1-44.15:28.10 require that VSMPs

- Where TMDL or exceptional waters require more stringent control the following shall satisfy any regulatory requirements for natural channel capacity:
 - (i) 48 hour ED of the WQv (0.5");
 - (ii) 24-hour ED of the 1-yr storm runoff; and
 - (iii) proportional reduction of the 1.5, 2, and 10-yr storms peak flow rate using forested condition energy balance.



SWM Regulations (Part IIB): Quantity Control

Meet the new boss . . .

. . . Same as the old boss?

9VAC25-870-66. Water quantity.

Channel Protection.

Channel protection and flood protection minimum standards are established pursuant to the requirements of subdivision 7 of § 62.1-44.15:28 of the Code of Virginia.



SWM Regulations (Part IIB): Quantity Control

9VAC25-870-66. Water quantity.

Channel Protection.

Compliance with the minimum standards set out in this section shall be deemed to satisfy the requirements of subdivision 19 of 9VAC25-840-40 (Minimum standards; Virginia Erosion and Sediment Control Regulations).



Primary Regulatory Driver: SWM Law

§ 62.1-44.15:28 A.10

Require that VSMPs:

- **Replicate**, as nearly as practicable, existing predevelopment runoff characteristics and site hydrology, or
- **Improve upon** contributing share of predevelopment stream channel erosion or localized flooding

Circle Back to ESC Law & Regulations

§ 62.1-44.15:52. ESC Law.

- After July 1, 2014, flow rate capacity requirements
 - **SWM Water Quantity Requirements**
(§ 62.1-44.15:24 et seq.) and attendant regulations (9VAC25-870-66)
 - Unless grandfathering provisions apply



5b. Channel Protection Criteria & the Energy Balance Method

9VAC25-870-66. Water quantity.

Channel Protection:

Concentrated stormwater flow shall be released in to a stormwater conveyance system:



System Capacity

"Manmade stormwater conveyance system"
means a pipe, ditch, vegetated swale, or other stormwater conveyance system constructed by man except for restored stormwater conveyance systems



System Capacity

Manmade stormwater conveyance system:

- Non-erosive capacity for **2-yr peak** flow to **Limits of Analysis** **OR**
- Energy Balance (Natural Stormwater Conveyance)



System Capacity

"Restored stormwater conveyance system"
means a stormwater conveyance system that has been designed and constructed using natural channel design concepts. Includes the main channel and the flood-prone area adjacent to the main channel.



Photo: Williamsburg Environmental Group

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

System Capacity

***"Natural stormwater conveyance system"** means the main channel of a natural stream and the flood-prone area adjacent to the main channel.*



Photo: Ellanor C. Lawrence Park Fairfax, County



Criteria for the Protection of Natural Channels

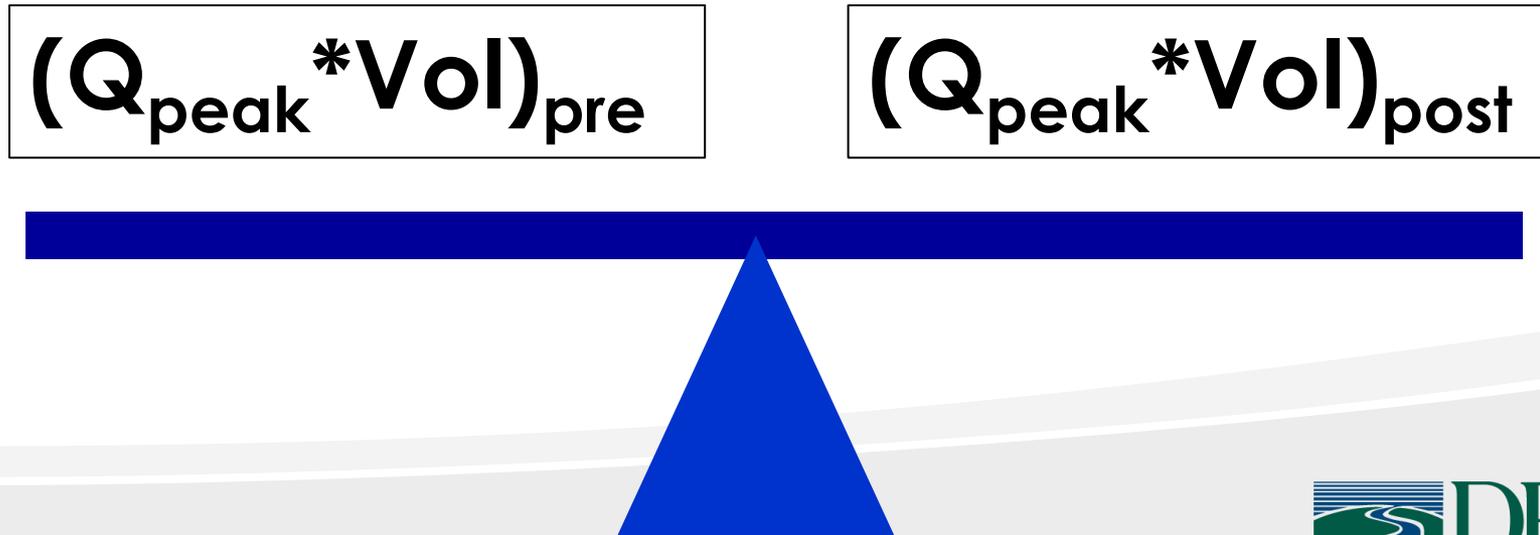
Protection of natural stream channels

- Restore them using natural channel design
- Protect them using the Energy Balance Method (1-yr event)
- Safe Harbor Provision (from SWM Law § 62.1-44.15:28.10)

Energy Balance

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

$(Q_{\text{peak}_{\text{pre}}} * \text{Vol})$ with improvement factor



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

Stormwater Quantity Channel Protection

9VAC25-870-66.A

Energy Balance

Post ($\text{Vol}_{1\text{-yr}} * \text{Peak } Q_{1\text{-yr}}$) \leq **Pre** ($\text{Vol}_{1\text{-yr}} * \text{Peak } Q_{1\text{-yr}}$)

$$Q_{1\text{post}} \leq Q_{1\text{pre}} \left(\frac{\text{Pre Vol}_1}{\text{Post Vol}_1} \right) (IF)$$

IF = Improvement Factor:

(0.8 for sites > 1 acre or 0.9 for sites \leq 1 acre)

Stormwater Quantity Channel Protection

9VAC25-870-66.A

Energy Balance

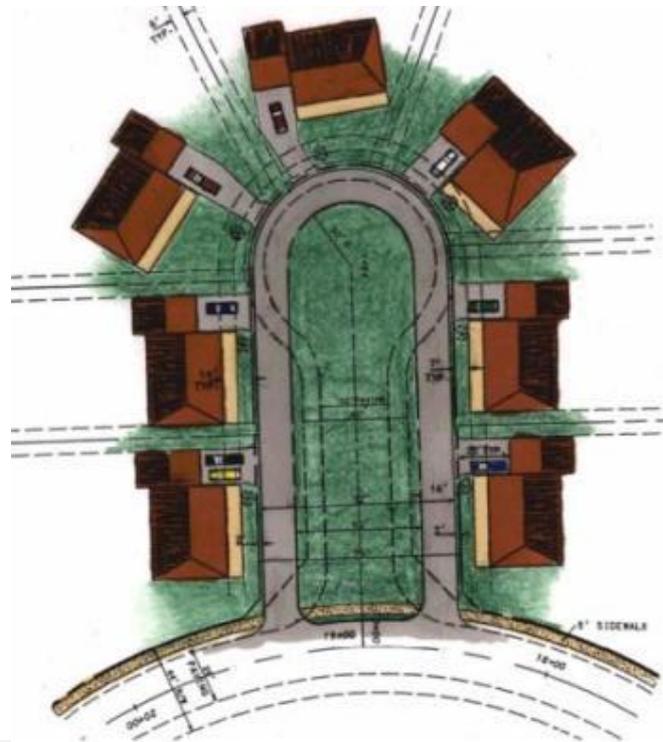
Under no condition shall:

$$Q_{1 \text{ post}} > Q_{1 \text{ pre}}$$

$$Q_{1 \text{ post}} < Q_{1 \text{ forest}} * \text{Forest Vol}_1 / \text{Post Vol}_1$$

Why Energy Balance?

§ 62.1-44.15:28 A.11.

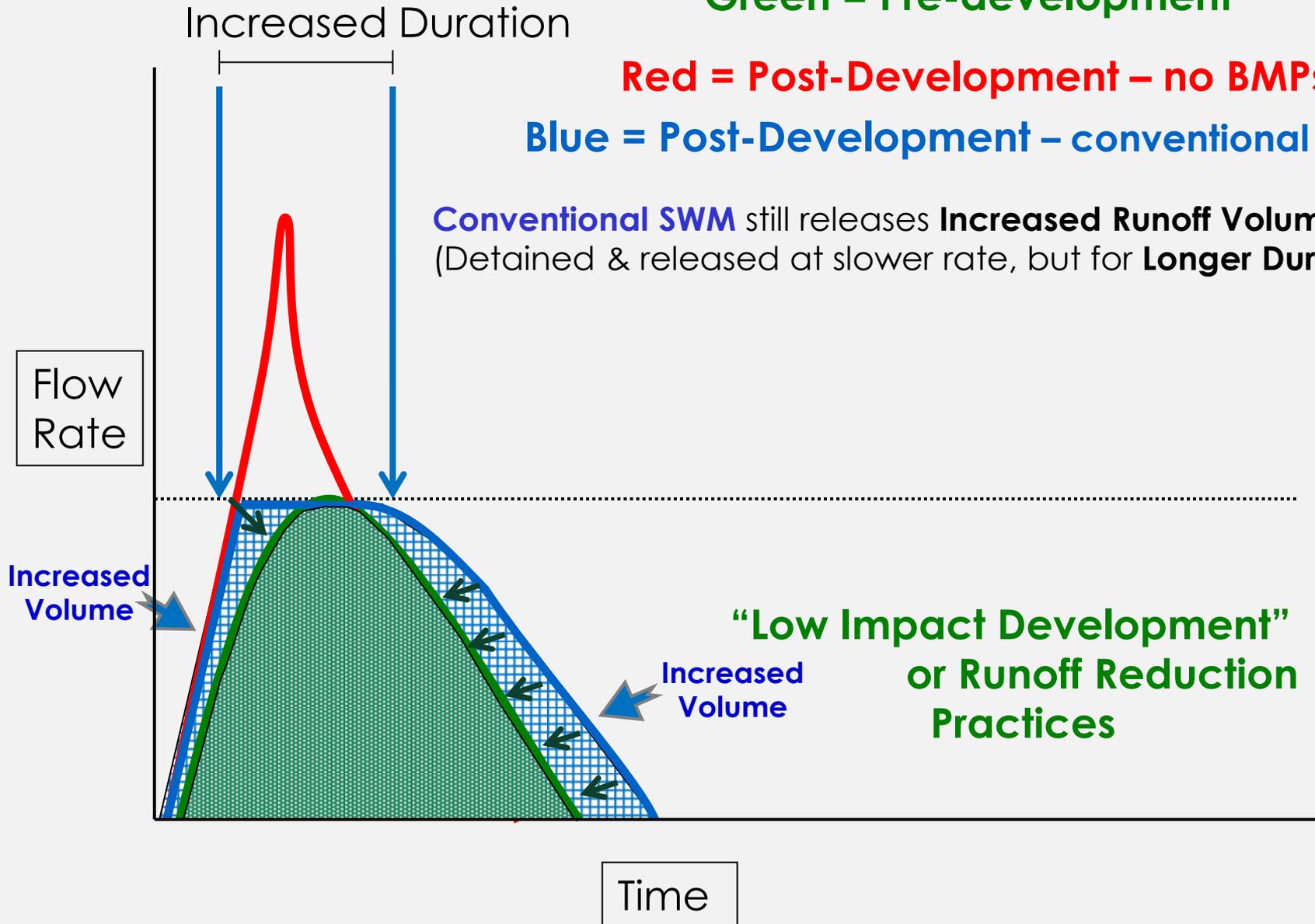


Green = Pre-development

Red = Post-Development – no BMPs

Blue = Post-Development – conventional SWM

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



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**

How Does Energy Balance encourage ESD?

- VRRM Spreadsheet calculates volume reduction with **double credit**:
 - Reduced Vol_{post1} → Energy Balance
 - Reduced Curve Number (CN) → Q_{1post}

How Does Energy Balance encourage ESD?

$$Q_{1post} \leq Q_{1pre} \left(\frac{PreVol_1}{PostVol_1} \right) (IF)$$

- As $PostVol_1$ reduced
- $PreVol_1$ to $PostVol_1$ ratio increases
- Allowable Q_{1post} increases



***Decreases storage required for peak flow**



Improvement Factor (*IF*)

§ 62.1-44.15:28

- requires stormwater regulations to *improve upon contributing share of existing predevelopment runoff characteristics and site hydrology*
- At minimum, pre-developed discharge will be reduced using factor of 0.8 or 0.9

Energy Balance Terminology

$$Q_{1post} \leq Q_{1pre} \left(\frac{PreVol_1}{PostVol_1} \right) (IF)$$

Description	Units	Term
NRCS TR-55		
Runoff Depth	inches (in)	Q
Runoff Volume	cubic feet (ft ³) or acre feet (ac.ft.)	V _r
Storage Volume	cubic feet (ft ³) or acre feet (ac.ft.)	V _s
Peak Discharge	cubic feet per second (cfs)	q _p
VRRM Treatment Volume Runoff Coefficients		
Unit-less Volumetric Runoff Coefficients		R _v
VRRM Curve Number Adjustment		
Runoff Depth	inches	RV
VSMP Regulations Channel Protection Criteria (4VAC50-60-66.B)		
Peak Discharge	cubic feet per second (cfs)	Q
Runoff Volume*	cubic feet (ft ³) or acre feet (ac.ft.)*	RV
<p>*Units of volume in the VSMP regulations Channel Protection Criteria can also be expressed in terms of <i>watershed-inches</i> or inches (consistent with Runoff Depth as expressed in the VRRM CN adjustment).</p>		



Energy Balance: 9VAC25-870-66.A

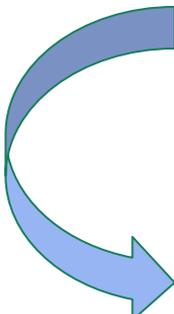
How would you write this equation?

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

Energy Balance: 9VAC25-870-66.A

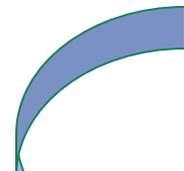
How would you write this equation?

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


$$Q_{1post} \leq Q_{1pre} \left(\frac{PreVol_1}{PostVol_1} \right) (IF) \quad (\text{Simplified})$$

Energy Balance: 9VAC25-870-66.A

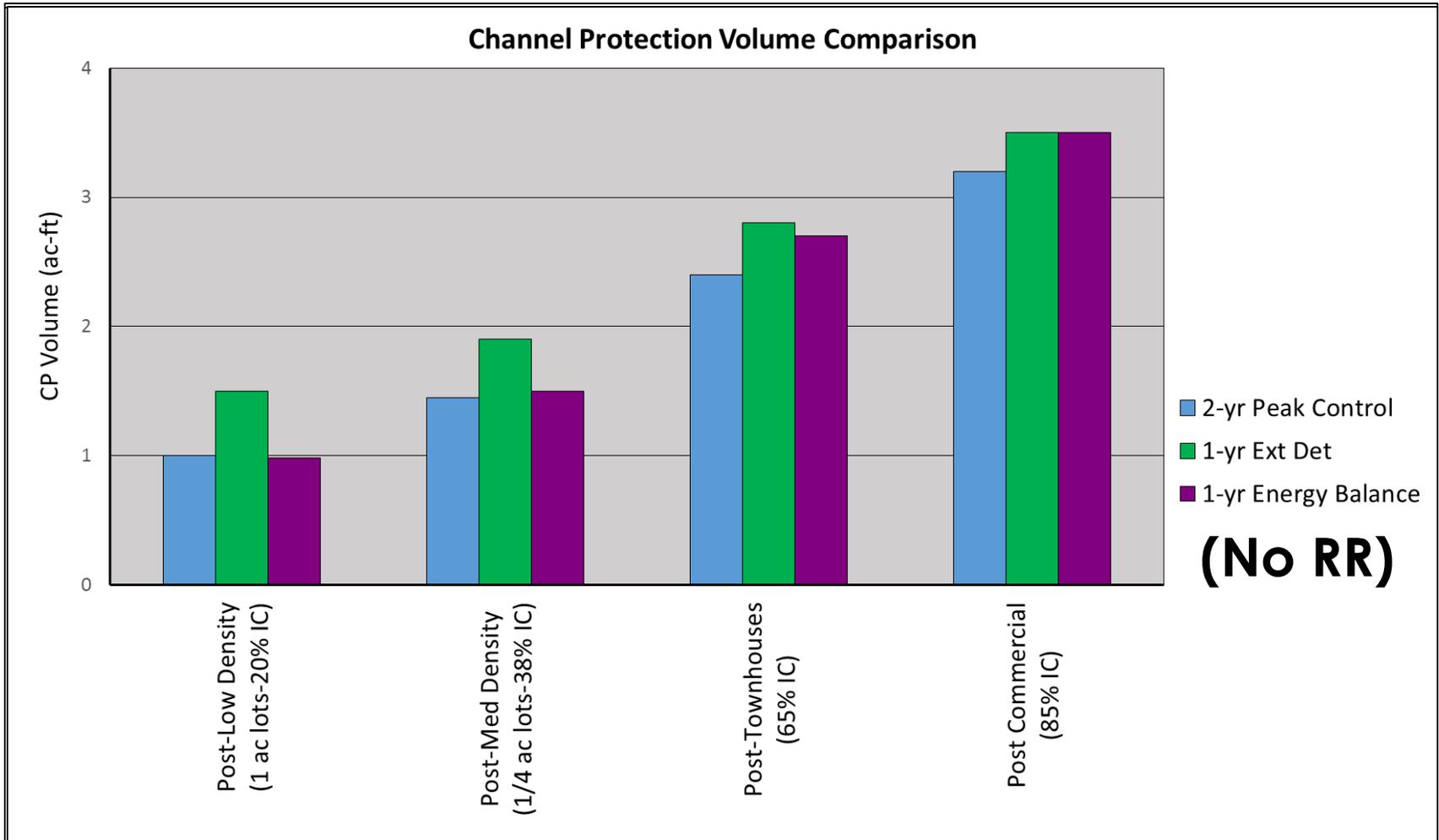
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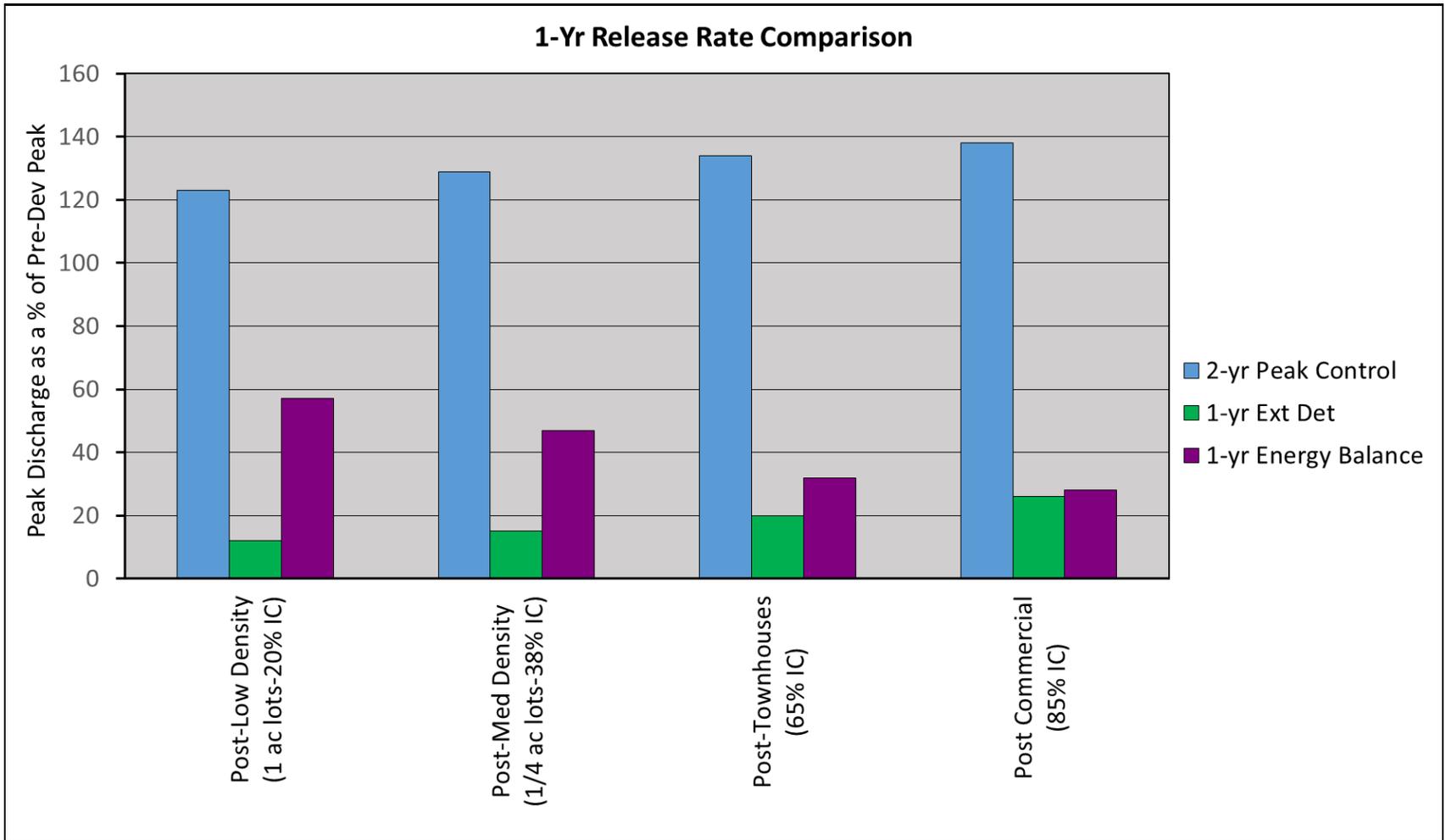

$$Q_{1post} \leq Q_{1pre} \left(\frac{PreVol_1}{PostVol_1} \right) (IF) \quad (\text{Simplified})$$

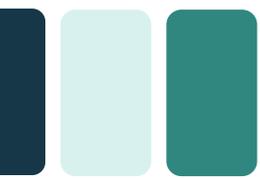

$$q_{1post} \leq q_{1pre} \left(\frac{Vr_{pre1}}{Vr_{post1}} \right) (IF) \quad (\text{TR-55})$$

Comparison of Volume Requirements 2-yr Peak, 1-yr ED, & 1-yr EB



Comparison of Peak Discharge: 2-yr Peak, 1-yr ED, & 1-yr EB vs 1-yr Pre

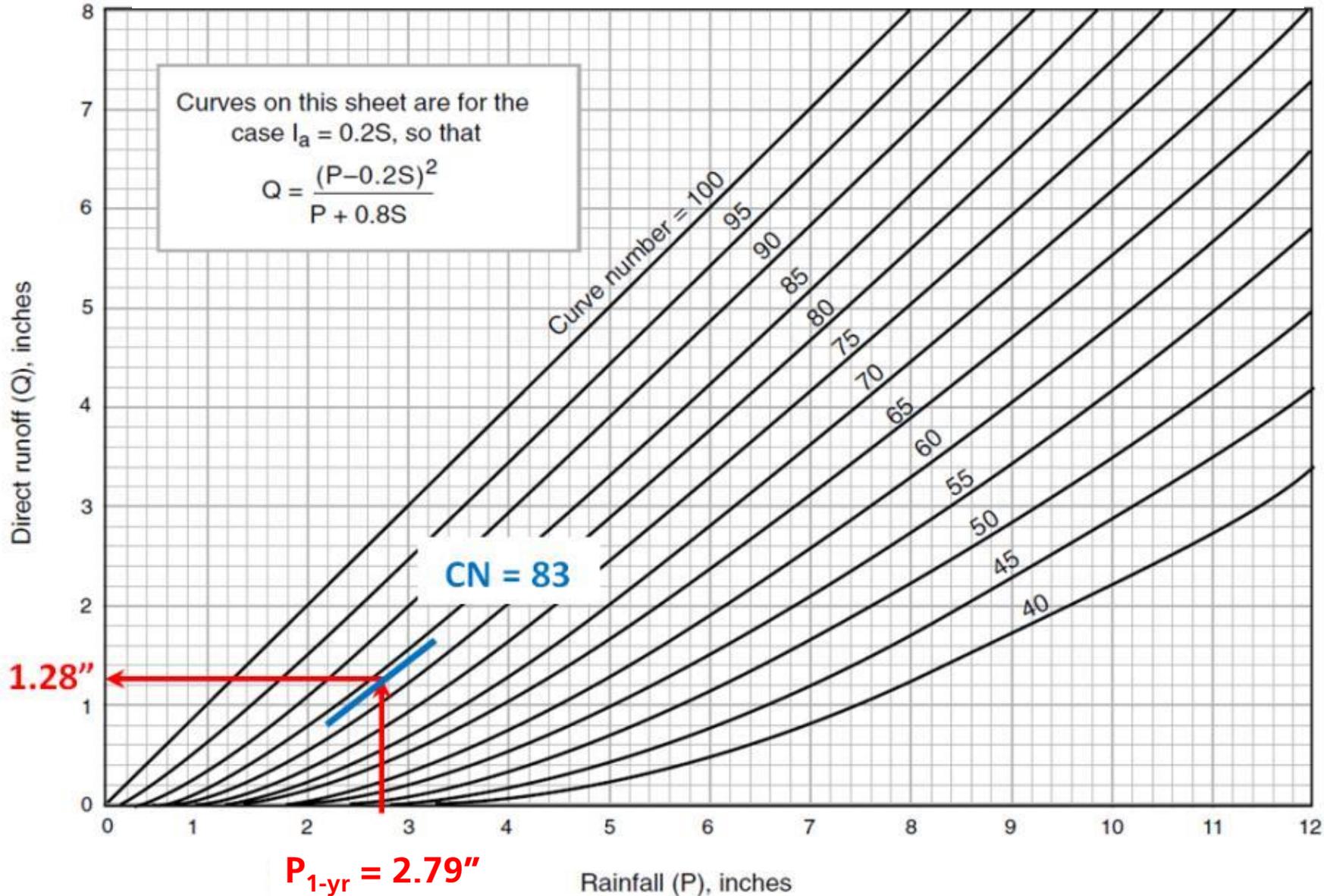




5c. Energy Balance Design Example

Figure 2-1

Where Does the Runoff Depth come From?



Where Does the Runoff Depth come From?

Runoff depth for curve number of— **CN = 83**

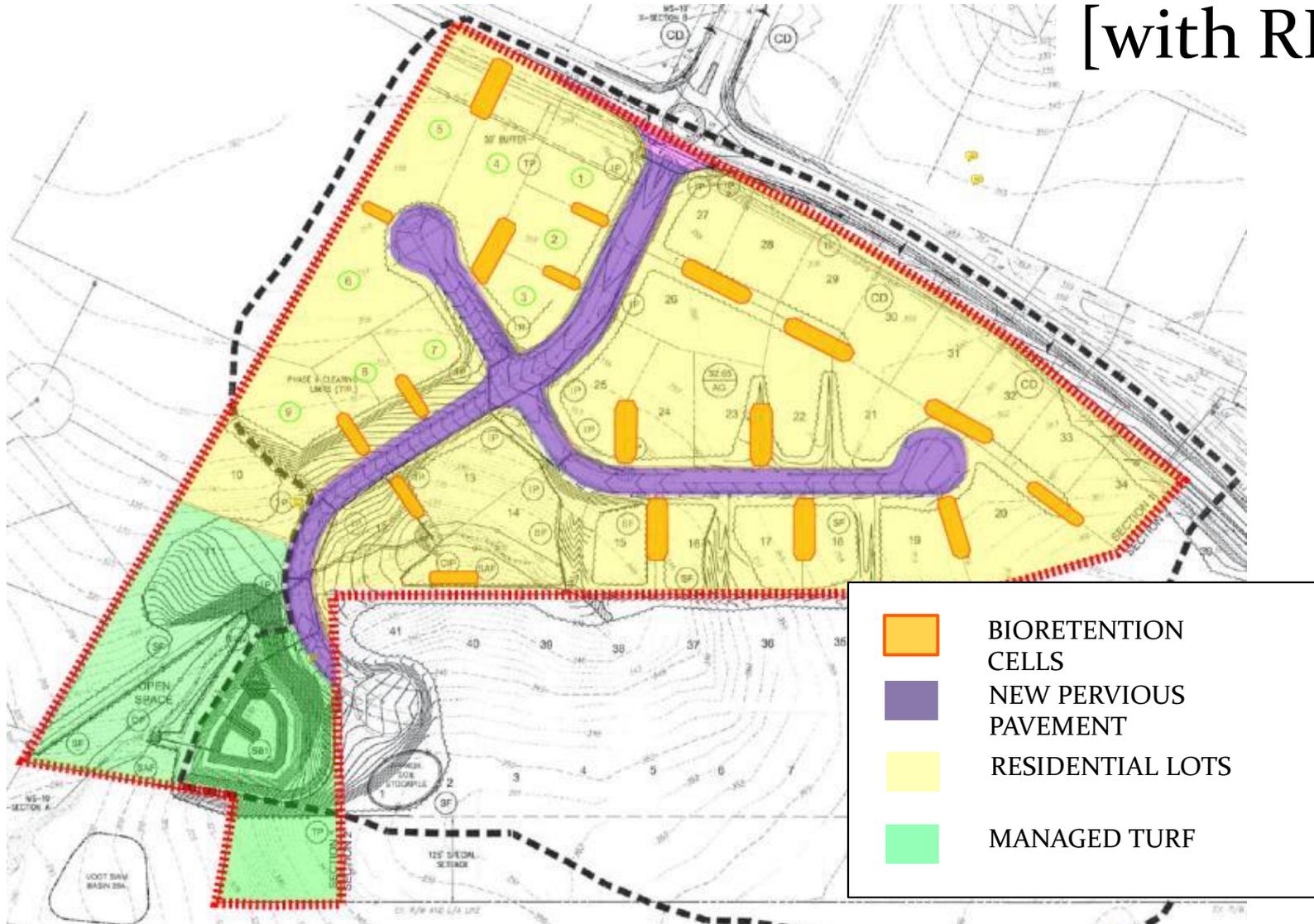
Rainfall	Runoff depth for curve number of— CN = 83												
	40	45	50	55	60	65	70	75	80	85	90	95	98
	inches												
1.0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.08	0.17	0.32	0.56	0.79
1.2	.00	.00	.00	.00	.00	.00	.03	.07	.15	.27	.46	.74	.99
1.4	.00	.00	.00	.00	.00	.02	.06	.13	.24	.39	.61	.92	1.18
1.6	.00	.00	.00	.00	.01	.05	.11	.20	.34	.52	.76	1.11	1.38
1.8	.00	.00	.00	.00	.03	.09	.17	.29	.44	.65	.93	1.29	1.58
2.0	.00	.00	.00	.02	.06	.14	.24	.38	.56	.80	1.09	1.48	1.77
2.5	.00	.00	.02	.08	.17	.30	.46	.65	.89	1.18	1.53	1.96	2.27
3.0	.00	.02	.09	.19	.33	.51	.71	.96	1.25	1.59	1.98	2.45	2.77
3.5	.02	.08	.20	.35	.53	.75	1.01	1.30	1.6	1.98	2.45	2.94	3.27
4.0	.06	.18	.33	.53	.76	1.03	1.33	1.67	2.04	2.46	2.92	3.43	3.77
4.5	.14	.30	.50	.74	1.02	1.33	1.67	2.05	2.46	2.91	3.40	3.92	4.26
5.0	.24	.44	.69	.98	1.30	1.65	2.04	2.45	2.89	3.37	3.88	4.42	4.76
6.0	.50	.80	1.14	1.52	1.92	2.35	2.81	3.28	3.78	4.30	4.85	5.41	5.76
7.0	.84	1.24	1.68	2.12	2.60	3.10	3.62	4.15	4.69	5.25	5.82	6.41	6.76
8.0	1.25	1.74	2.25	2.78	3.33	3.89	4.46	5.04	5.63	6.21	6.81	7.40	7.76
9.0	1.71	2.29	2.88	3.49	4.10	4.72	5.33	5.95	6.57	7.18	7.79	8.40	8.76
10.0	2.23	2.89	3.56	4.23	4.90	5.56	6.22	6.88	7.52	8.16	8.78	9.40	9.76
11.0	2.78	3.52	4.26	5.00	5.72	6.43	7.13	7.81	8.48	9.13	9.77	10.39	10.76
12.0	3.38	4.19	5.00	5.79	6.56	7.32	8.05	8.76	9.45	10.11	10.76	11.39	11.76
13.0	4.00	4.89	5.76	6.61	7.42	8.21	8.98	9.71	10.42	11.10	11.76	12.39	12.76
14.0	4.65	5.62	6.55	7.44	8.30	9.12	9.91	10.67	11.39	12.08	12.75	13.39	13.76
15.0	5.33	6.36	7.35	8.29	9.19	10.04	10.85	11.63	12.37	13.07	13.74	14.39	14.76

**P_{1-yr} =
2.79"**

1.28"

L/ Interpolate the values shown to obtain runoff depths for CN's or rainfall amounts not shown.

Energy Balance Design Example: Option 2 [with RR]



Channel & Flood Protection Tab

	A	B	C	D	E	F	G	H
1				1-year storm	2-year storm	10-year storm		
2	Target Rainfall Event (in)			2.79	3.38	5.14		
3								
4	Drainage Area A							
5	Drainage Area (acres)		19.80					
6	Runoff Reduction Volume (cf)		23,065					
7								
8	Drainage Area B							
9	Drainage Area (acres)		0.00					
10	Runoff Reduction Volume (cf)		0					
11								
12	Drainage Area C							
13	Drainage Area (acres)		0.00					
14	Runoff Reduction Volume (cf)		0					
15								
16	Drainage Area D							
17	Drainage Area (acres)		0.00					
18	Runoff Reduction Volume (cf)		0					
19								
20	Drainage Area E							
21	Drainage Area (acres)		0.00					
22	Runoff Reduction Volume (cf)		0					
23								
24								
25	Based on the use of Runoff Reduction practices in the selected drainage areas, the spreadsheet calculates an adjusted $RV_{Developed}$ and adjusted Curve Number.							
26								
27	Drainage Area A			A soils	B Soils	C Soils	D Soils	
28	Forest/Open Space – undisturbed, protected forest/open space or reforested land	Area (acres)	0.00	0.00	0.40	0.00		
29		CN	30	55	70	77		
30	Managed Turf – disturbed, graded for yards or other turf to be mowed/managed	Area (acres)	0.00	0.00	12.13	0.00		
31		CN	39	61	74	80		
32	Impervious Cover	Area (acres)	0.00	0.00	7.27	0.00		
33		CN	98	98	98	98		
34							Weighted CN	
35							83	2.05
36				1-year storm	2-year storm	10-year storm		
37	$RV_{Developed}$ (in) with no Runoff Reduction			1.28	1.76	3.30		
38	$RV_{Developed}$ (in) with Runoff Reduction			0.96	1.44	2.98		
39	Adjusted CN			77	78	80		
40								

1, 2, and 10-year storm rainfall depths

Volume Reduction = 23,065 ft³

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

$RV_1 = 1.12'' \rightarrow 0.96''$
 $CN_1 = 83 \rightarrow 77$
 $RV_2 = 1.54'' \rightarrow 1.44''$
 $CN_2 = 83 \rightarrow 78$
 $RV_{10} = 2.98'' \rightarrow 2.98''$
 $CN_{10} = 83 \rightarrow 80$



Curve Number Adjustment

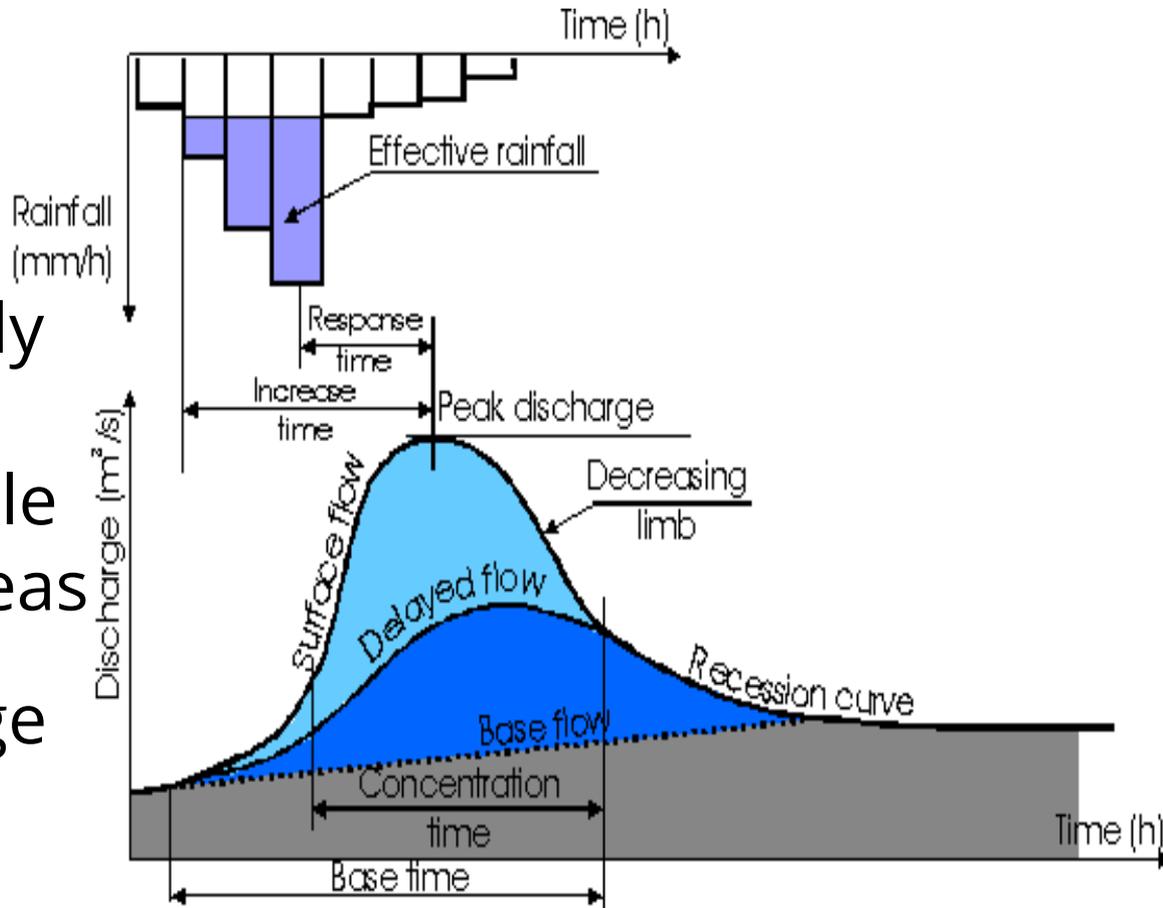
Challenge:

- Provide quantity “credit” for distributed retention practices
- Avoid Complex routing/modeling of multiple practices, yet simulate single event modeling
- Allow designers to target volume as primary metric (quantity and quality)

Hydrograph Modification

Simplifying Assumptions:

- Retention uniformly distributed if considering multiple features or sub-areas
- Negligible discharge from under-drains (if any)



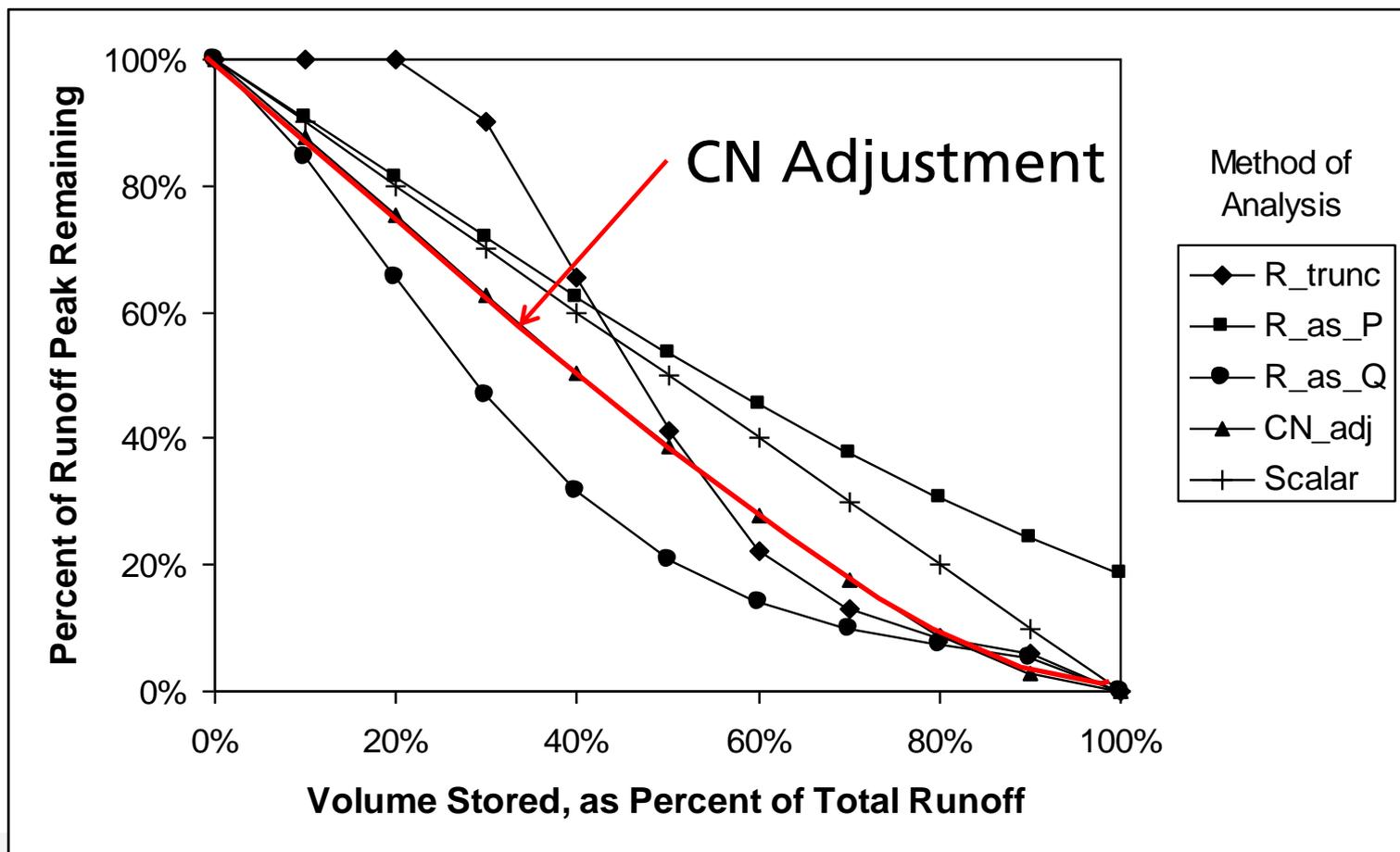


Hydrograph Modification

Methods Considered:

1. Hydrograph Truncation
2. Hydrograph Scalar Multiplication
3. Precipitation Adjustment
4. Runoff Adjustment
5. Curve Number Adjustment

5 Methods Considered; Curve Number Adjustment Selected



Excerpted from work by Paul R. Koch, Ph.D., P.E.

Does It Really Work?

Reported Reductions in Runoff Volume:

Losses Due to Exfiltration, Evapotranspiration
and Post Storm Delivery

- Sampling of reductions reported
by research:

CT: 99%	PA: 80%
UK: 58%	Aus: 73%
FL: 98%	WA: 96%
NC: 30 to 65%	MD: 46 to 54%



Does It Really Work?



Photo: Conservation Design Forum

- Extended Filtration of Bioretention systems mimic pre-developed hydrologic response (an undeveloped watershed)
- Permeable Pavement systems equipped with underdrains demonstrate significant RR
 - Extended discharge that can be considered negligible in comparison to surface runoff from other areas of site

Curve Number Adjustment: Hydrograph Modification

Runoff Depth Equations (TR-55):

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

$$\text{Eq. 2-2: } I_a = 0.2 S$$

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

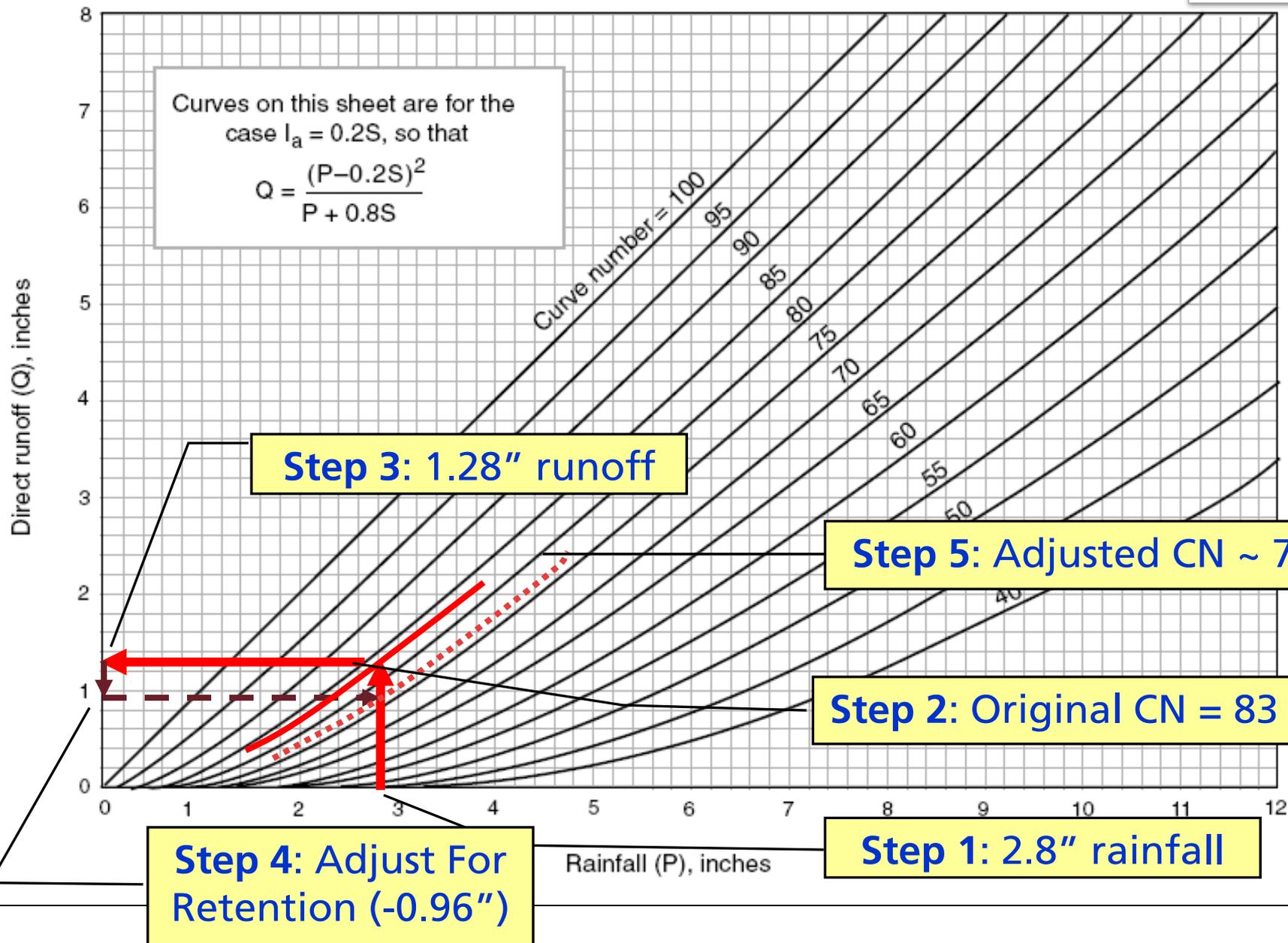
Where:

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



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1, 2, and 10-year storm rainfall depths

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$RV_1 = 1.12'' \rightarrow 0.96''$
 $CN_1 = 83 \rightarrow 77$

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 $CN_2 = 83 \rightarrow 78$

$RV_{10} = 2.98'' \rightarrow 2.98''$
 $CN_{10} = 83 \rightarrow 80$



Energy Balance Design Example

One-Year Storm Hydrology Summary: 19.8 acres

	Pre-Developed	Post-Developed no RR	Post-Developed with RR
Runoff Curve Number	71	83	77
Runoff Volume (RV)	0.62 in	1.28 in	0.96 in
Runoff Volume	1.02 ac-ft.	2.11 ac-ft.	1.58 ac-ft.
Peak Discharge (q_1)	9 cfs	39 cfs	27 cfs
Post Developed EB Allowed Peak Discharge (cfs)			
Storage Volume Req'd., (ac-ft)			

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

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

$$q_{1post} \leq 4.7 \text{ cfs}$$

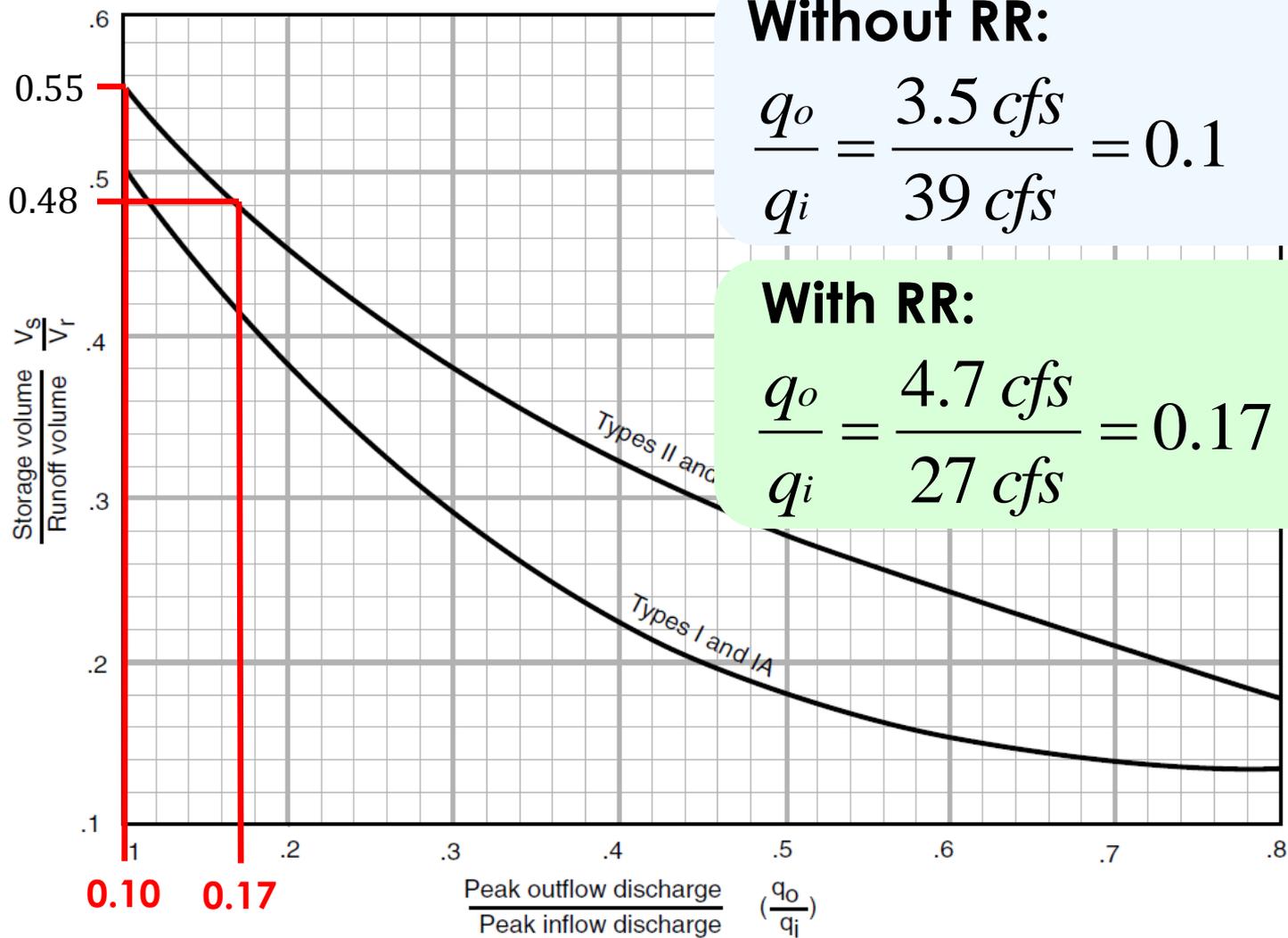
Energy Balance Design Example

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Runoff Curve Number	71	83	77
Runoff Volume (RV)	0.62 in	1.28 in	0.96 in
Runoff Volume	1.02 ac-ft.	2.11 ac-ft.	1.58 ac-ft.
Peak Discharge (q_1)	9 cfs	39 cfs	27 cfs
Post Developed EB Allowed Peak Discharge (cfs)		3.5 cfs*	4.7 cfs*

1. Increase in allowable discharge!
2. Energy Balance discharge not required to be less than ratio reduction for Forested condition

Figure 6-1 Approximate detention basin routing for rainfall types I, IA, II, and III



Without RR:

$$\frac{q_o}{q_i} = \frac{3.5 \text{ cfs}}{39 \text{ cfs}} = 0.1 \quad \frac{V_s}{V_r} = 0.55$$

With RR:

$$\frac{q_o}{q_i} = \frac{4.7 \text{ cfs}}{27 \text{ cfs}} = 0.17 \quad \frac{V_s}{V_r} = 0.48$$

Energy Balance Design Example

- Compute the Storage Volume required (V_s) to achieve the allowable peak outflow:

without RR

$$\frac{q_o}{q_i} = \frac{3.5 \text{ cfs}}{39 \text{ cfs}} = 0.1$$

$$\frac{V_s}{V_r} = \frac{V_s}{2.11 \text{ ac-ft}} = 0.55$$

Storage Required (V_s)
= 1.16 ac-ft

with RR

$$\frac{q_o}{q_i} = \frac{4.7 \text{ cfs}}{27 \text{ cfs}} = 0.17$$

$$\frac{V_s}{V_r} = \frac{V_s}{1.58 \text{ ac-ft}} = 0.48$$

Storage Required (V_s)
= 0.76 ac-ft

Energy Balance Design Example

One-Year Storm Hydrology Summary: 19.8 acres

	Pre-Developed	Post-Developed no RR	Post-Developed with RR
Runoff Curve Number	71	83	77
Runoff Volume (RV)	0.62 in	1.28 in	0.96 in
Runoff Volume	1.02 ac-ft.	2.11 ac-ft.	1.58 ac-ft.
Peak Discharge (q_1)	9 cfs	39 cfs	27 cfs
Post Developed EB Allowed Peak Discharge (cfs)		3.5 cfs	4.7 cfs
Storage Volume Req'd. (ac-ft)		1.16 ac-ft.*	0.76 ac-ft.*

37% Reduction in required 1-yr Channel Protection Storage Volume



VRRM Compliance Spreadsheet Limitations

- Spreadsheet uses different Land Cover terminology than NRCS Methods
- Not single-event routing model
- Reflects *annual* volume & *annual* pollutant load reduction
- VRRM spreadsheet does not reflect over-sized practices
- CN Adjustment based on annual credit
 - Predicated on required practice sizing

VRRM Compliance Spreadsheet Limitations

- Multiple treatment trains difficult to compute?
 - Aggregated practices
(e.g. several lots of simple impervious disconnection)
 - Do **not** all flow to same type of downstream practice
 - Must be aggregated on separate DA tabs based on common downstream practice

VRRM Compliance Spreadsheet Limitations

- Multiple treatment trains difficult to compute?
 - Spreadsheet **cannot** track aggregated volumes from separate DA tabs going to single downstream practice
 - Designer **must** independently track volume



5d. Flood Protection

Water Quantity Criteria Flood Protection

9VAC25-870-66. localized flooding:

Local Flooding:

Demonstrate:

- * No 10-yr flooding now
- * No 10-yr flooding after development
 - * to Limits of Analysis

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
- * Limits of Analysis (post)
not required



5e. Limits of Analysis

Water Quantity Control Compliance

Limits of Analysis:

- Downstream capacity analysis carried to a point where:
 - Site's **contributing 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)





Sheet Flow

9VAC25-870-66. Water quantity.

- 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?

