Runoff Generation

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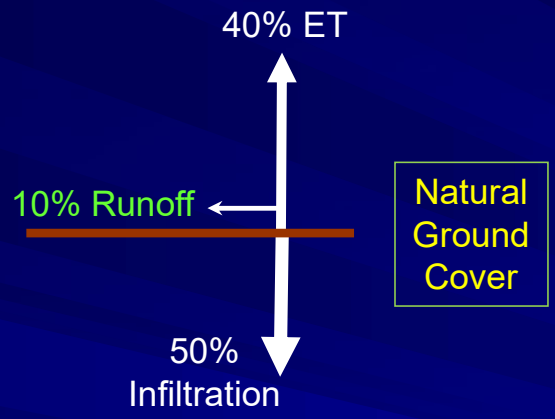
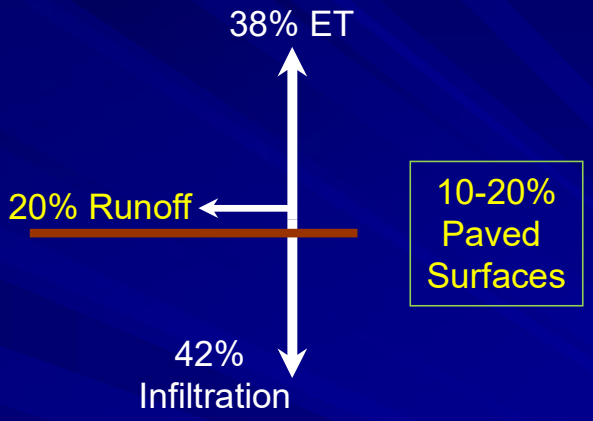
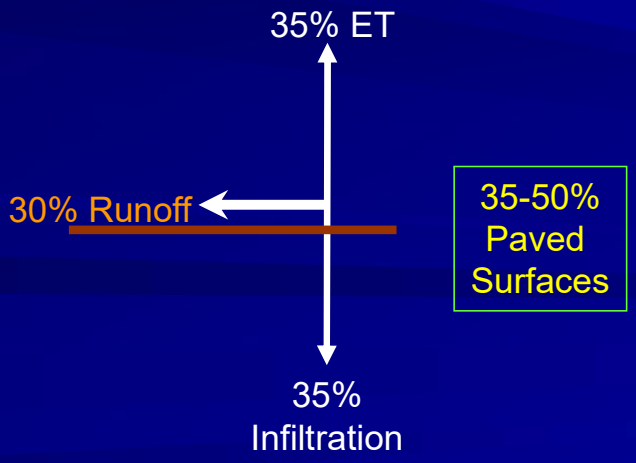
Runoff Generation

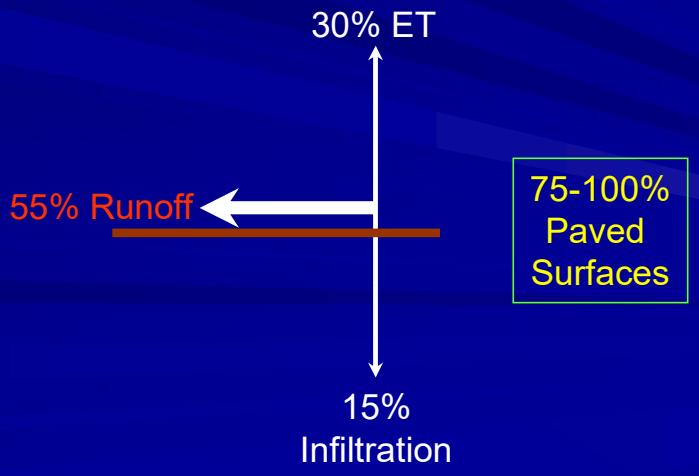
- Runoff is part of the hydrologic cycle
- Runoff generation is a function of:
  - Precipitation
  - Soil types
  - Land cover

Development Impacts on Hydrology









Runoff Volume Estimation

- Runoff generation is a function of a variety of factors, including:
  - Land use
  - Impervious surfaces
  - Soil types
  - Topography –
    - Basin slope
    - Depressional areas
  - Precipitation depth and event characteristics
- Runoff model must be capable of incorporating each of these factors into event-based runoff depths

Runoff Coefficients

Runoff coefficients (C values)

- Runoff coefficients reflect the proportion of rainfall that becomes runoff under specified conditions
- Tabular C values are used to size pipes using the Rational Formula:

$$Q = C \times i \times A$$

Where: C = estimate of runoff proportion for a design storm event (typically 10 yr)

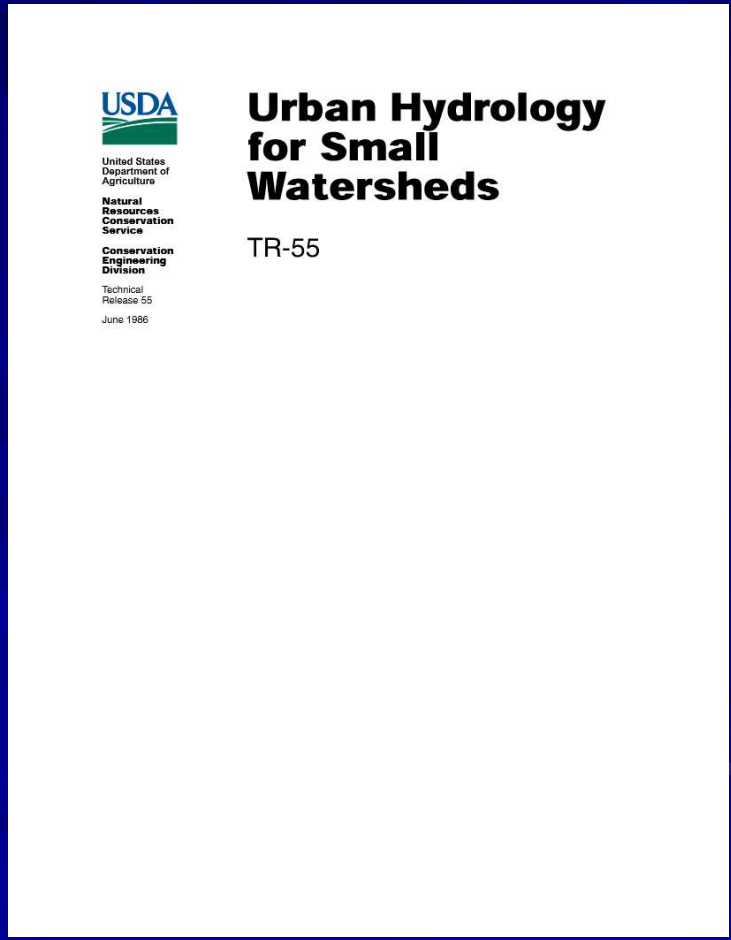
- Rational Formula runoff coefficients cannot be used for estimation of runoff volumes for non design storm conditions

Runoff Estimation

- A runoff model must be selected for use in evaluating rainfall/runoff relationships for the methodology
  - Multiple models were evaluated
    - SCS Curve Number
    - ICPR
    - SWIM
- SCS Curve Number (CN) methodology was selected for this analysis
  - Common method used by most civil engineers and proprietary models
  - Model used to calculate annual runoff coefficients (C values) for meteorological sites throughout Florida

SCS Curve Number Methodology

- SCS Curve Number (CN) methodology
  - Outlined in NRCS document TR-55 titled "Urban Hydrology for Small Watersheds"
  - Common methodology used in many public and proprietary models
  - Curve numbers (CN Values) are empirically derived values used to predict runoff volume which vary as a function of soil type and land cover
  - Used to predict event specific runoff depths and volumes



SCS Method

- SCS method is based on Hydrologic Soil Groups (HSG)
  - Hydrologic Soil Groups (A,B,C & D) are determined by the minimum infiltration rate for bare soils after thorough wetting

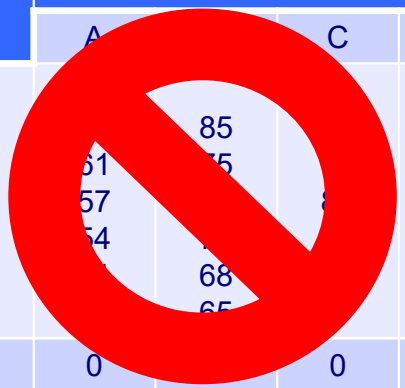
Hydrologic Soil Group (HSG)	Description	Soil Infiltration Rate	Runoff Potential
A	deep, well to excessively drained sands with a high rate of water transmission.	very high	very low
B	moderately deep to deep, moderately well to well drained soils with moderately fine to moderately coarse textures	high	low
C	soils with a layer that impedes downward movement of water and soils with moderately fine to fine structure	low	high
D	clay soils, soils with a permanent high water table, soils with a hardpan or clay layer at or near the surface	very low	very high

Typical Curve Numbers (TR-55)

Cover Type and Hydrologic Condition	Curve Number			
	A	B	C	D
Open space (lawns, parks, golf courses, cemeteries, etc.):				
Poor condition (grass cover < 50%)	68	79	86	89
Fair condition (grass cover 50% to 75%)	49	69	79	84
Good condition (grass cover > 75%)	39	61	74	80
Impervious areas:				
Paved parking lots, roofs, driveways, etc. (excl. ROW)	98	98	98	98
Streets and roads:				
Paved; curbs and storm sewer (excl. ROW)	98	98	98	98
Paved; open ditches (including right-of-way)	83	89	92	93
Gravel (including right-of-way)	76	85	89	91
Dirt (including right-of-way)	72	82	87	89
Pasture, grassland, or range:				
Poor condition	68	79	86	89
Fair condition	49	69	79	84
Good condition	39	61	74	80
Brush—brush-weed-grass mixture:				
Poor	48	67	77	83
Fair	35	56	70	77
Good	30	48	65	73
Woods:				
Poor	45	66	77	83
Fair	36	60	73	79
Good	30	55	70	77

Typical Curve Numbers (TR-55)

Cover Type and Hydrologic Condition	Imp. (%)	Curve Number			
		A		C	D
Residential					
Lot size: 1/8 acre or less ……	65		85		92
Lot size: 1/4 acre ……....	38	61	75		87
Lot size: 1/3 acre ……....	30	57			86
Lot size: 1/2 acre	25	54			85
Lot size: 1 acre	20		68		84
Lot size: 2 acre	12		65		82
Water/wetlands	0	0		0	0



- General curve numbers are available for residential and urban areas
  - General CN values reflect the runoff potential for the combined pervious and impervious areas
- The Methodology calculates runoff separately for pervious and impervious areas
- The Methodology evaluates loadings on an average annual basis
  - Therefore, water areas are assigned a CN and C-value of zero since precipitation and evaporation are approximately equal over an annual cycle
- Wetlands assigned a CN-value of 87

Hydrologic Conditions

- Each Hydrologic Soil Group has sub-sets for varying hydrologic conditions
- Defined as poor, fair, and good based on a combination of factors that affect infiltration and runoff
  - density and canopy of vegetative areas
  - amount of year-round cover
  - amount of grass or close-seeded legumes
  - percent of residue cover on the land surface (good ≥ 20%)
  - degree of surface roughness.
- Poor condition
  - Factors impair infiltration and tend to increase runoff
- Fair condition
  - Typical or average runoff conditions
- Good condition
  - Factors encourage average and better than average infiltration and tend to decrease runoff.

SCS Method of Calculating Runoff

- Estimation of runoff in the SCS Method is conducted using the following equations:
  - Soil storage is calculated using a weighted-average CN value based on land use and soil type

$$Soil\ Storage, \quad S = \left(\frac{1000}{CN} - 10\right)$$

  - Runoff is then calculated using the following equation: $Q = \frac{(P_i - 0.2S)^2}{(Pi + .8S)}$

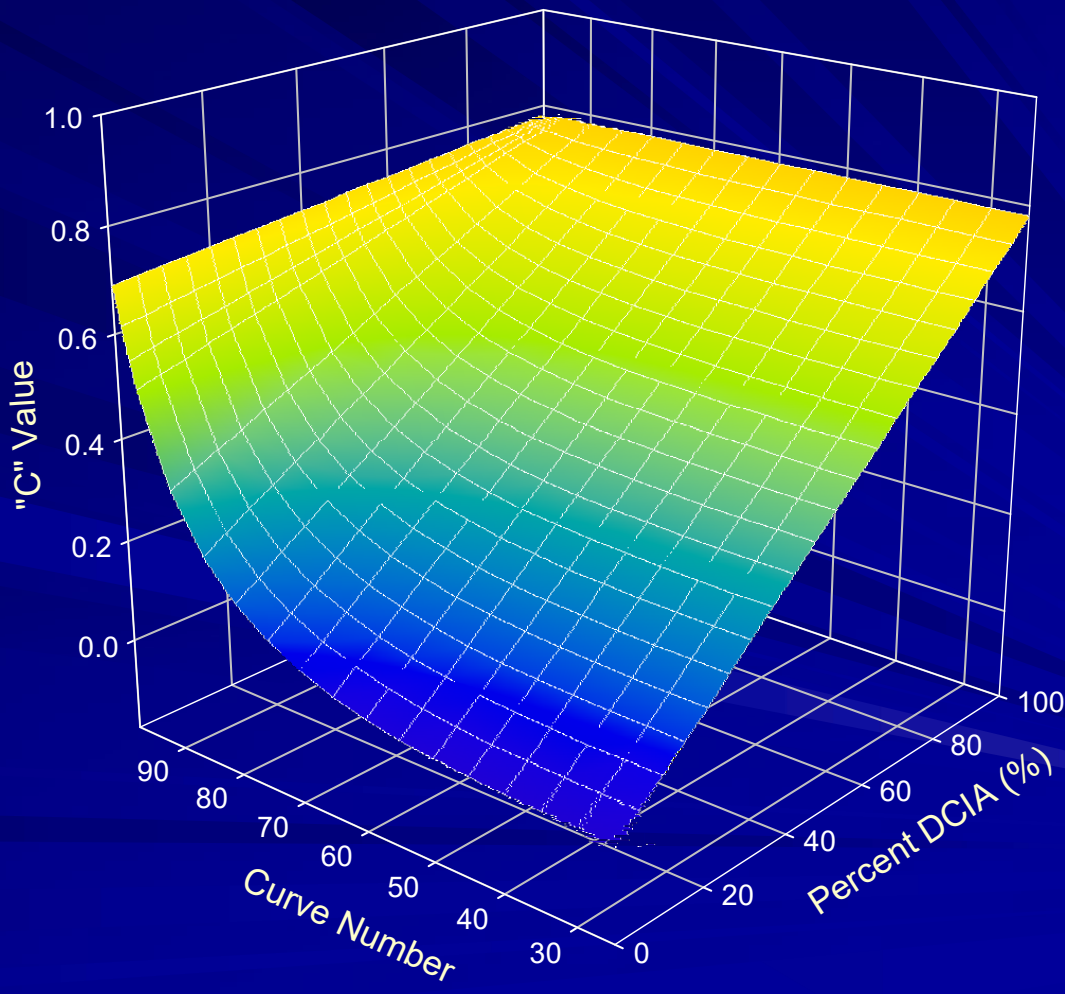
- However, the SCS Method can be subject to large errors due to averaging CN values
- To reduce this error, the SCS method was modified to calculate separate runoff volumes for the DCIA and non-DCIA areas

Relationship Between Curve Number, Percent DCIA, and C Value

- Linear relationship between C Value and DCIA

- Exponential relationship between C Value and CN value

- Implies that averaging CN values is statistically invalid and leads to over-estimation of runoff volume



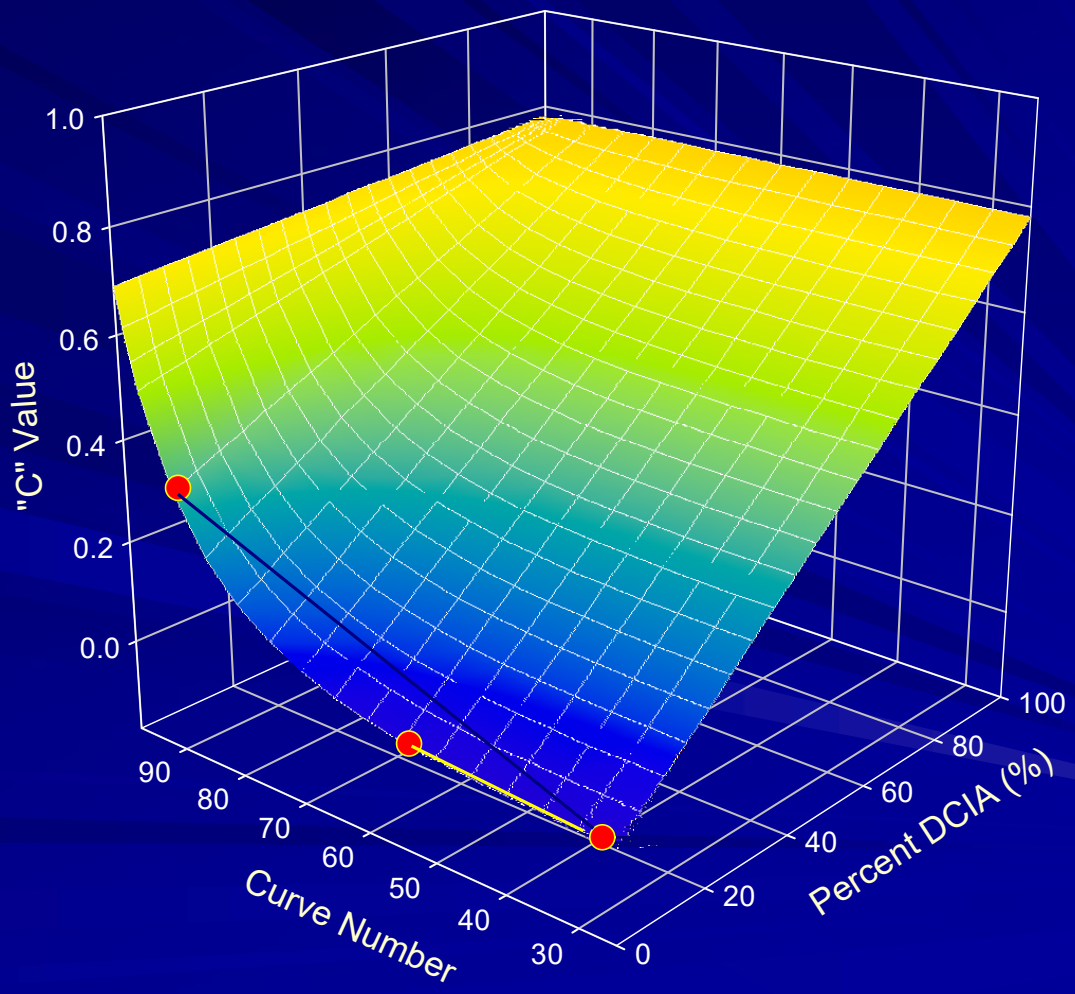
Impacts of Averaging Curve Numbers

- At low CN values the impact of averaging CN values is small

- Impact becomes much greater when averaging high CN values

Parameter	Area 1	Area 2	Combined Area
CN Value	40	60	50
Modeled C Value	0.016	0.048	0.029
Mean C value		0.032	+10%
CN Value	40	90	65
Modeled C Value	0.016	0.252	0.061
Mean C value		0.134	+120%

- Eliminating DCIA reduces the impact of averaging CN values



Directly Connected Impervious Areas (DCIA)

- Definition of DCIA varies depending on the type of analysis
  - Flood routing – Major events
    - DCIA includes all impervious areas from which runoff discharges directly into the drainage system
    - Also considered to be DCIA if runoff discharges as a concentrated shallow flow over pervious areas and then into the drainage system
      - Ex. – Shallow roadside swales
    - Often generously estimated to provide safety factor for design
  - Annual runoff estimation – Common daily events
    - DCIA includes all impervious areas from which runoff discharges directly into the drainage system during small events
    - Does not include swales
    - Generally, results in a lower DCIA value than used for flood routing

Non-DCIA Area Calculations

- Non-Directly Connected Impervious Areas (non-DCIA):
  - Includes pervious areas + impervious areas which are not considered to be DCIA
- Non-DCIA Curve Number (non-DCIA CN Value):

$$\text{Non-DCIA CN Value} = \frac{(\text{Area}_{\text{perv.}}) \times (\text{CN}_{\text{perv.}}) + (\text{Area}_{\text{non-DCIA}}) \times 98}{(\text{Area}_{\text{perv.}}) + (\text{Area}_{\text{non-DCIA}})}$$

- The Non-DCIA CN Value is then used to calculate the soil storage:

$$Soil\ Storage,\ S = \left(\frac{1000}{nDCIA\ CN} - 10 \right)$$

Calculation of Runoff Volumes

Separate calculations are conducted for the DCIA and non-DCIA areas

- Using an overall CN value for the area would lead to significant errors in estimating runoff

1. Runoff from non-DCIA areas is calculated by:

$$Q_{nDCIA_i} = \frac{(P_i - 0.2S)^2}{(P_i + 0.8S)}$$

CN = curve number for pervious area
Imp. = percent impervious area
DCIA = percent directly connected impervious area
non-DCIA CN = curve number for non-DCIA area
P_i = rainfall depth for event (i)
R_{nDCIAi} = rainfall excess for non-DCIA for event **(i)**

2. Runoff from DCIA is calculated as:

$$Q_{DCIAi} = (P_i - 0.1)$$

When P_i is less than 0.1, Q_{DCIAi} is equal to zero

Curve Number Adjustments

CN values were adjusted based on Antecedent Moisture Condition (AMC

Antecedent Moisture Condition (AMC)	Total Antecedent 5-Day Rainfall (inches)	
	Dormant Season (October – February)	Growing Season (March – September)
I – Dry Conditions	< 0.5	< 1.4
II – Normal	0.5 – 1.1	1.4 – 2.1
III – Wet Conditions	> 1.1	> 2.1

Typical CN adjustments for varying AMC conditions

CN for Condition II	Corresponding CN for Condition	
	I	III
100	100	100
90	78	98
80	63	94
70	51	87
60	40	79
50	31	70
40	23	60
30	15	50

Hydrologic Modeling

- Continuous simulation of runoff from a hypothetical 1-acre site using SCS curve number methodology and historical rainfall data set for 45 rainfall sites with hourly data
  - Data ranged from 13 – 64 years per site, but most contained 30+ years of data per site (mean of 4,685 events/site)
- Runoff modeled for all rain events at each site
  - Mean of 4,685 rain events/site
  - DCIA percentages from 0-100 in 5-unit intervals
  - Non-DCIA curve numbers from 25-95 in 5-unit intervals
  - 350 combinations per rainfall site x 45 sites = 15,750 model runs
- Total generated runoff depth compared with rainfall depth for each site to calculate the mean annual runoff coefficient (ROC):

$$\text{Mean Annual Runoff Coefficient (ROC)} = \frac{\text{Total Runoff Depth Over Simulation Period}}{\text{Total Rainfall Depth Over Simulation Period}}$$

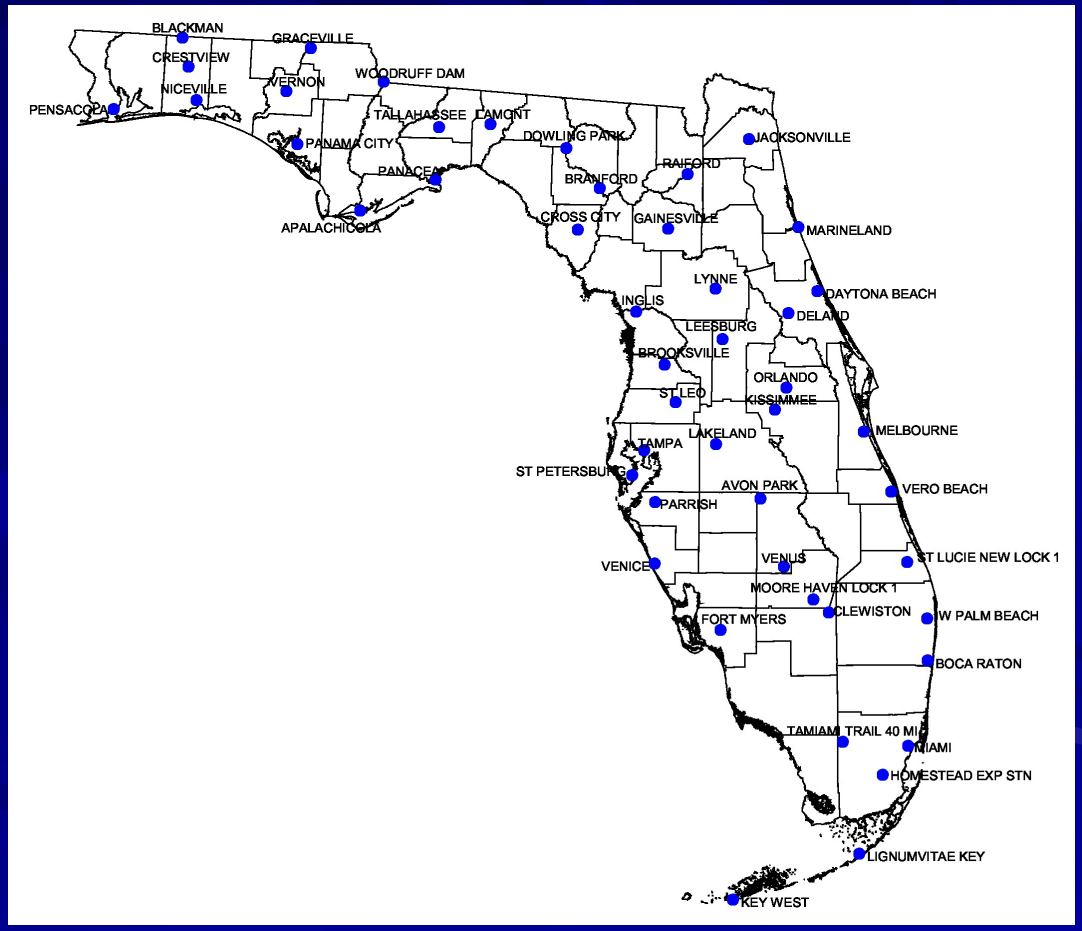
Meteorological Sites Included in Runoff Modeling

Hourly Rainfall Sites Used for Runoff Modeling

- 45 sites total

- Runoff modeling conducted for each rain event at each site over available period of record

- 350 combinations of DCIA and non-DCIA per rainfall site x 45 sites = 15,750 model runs

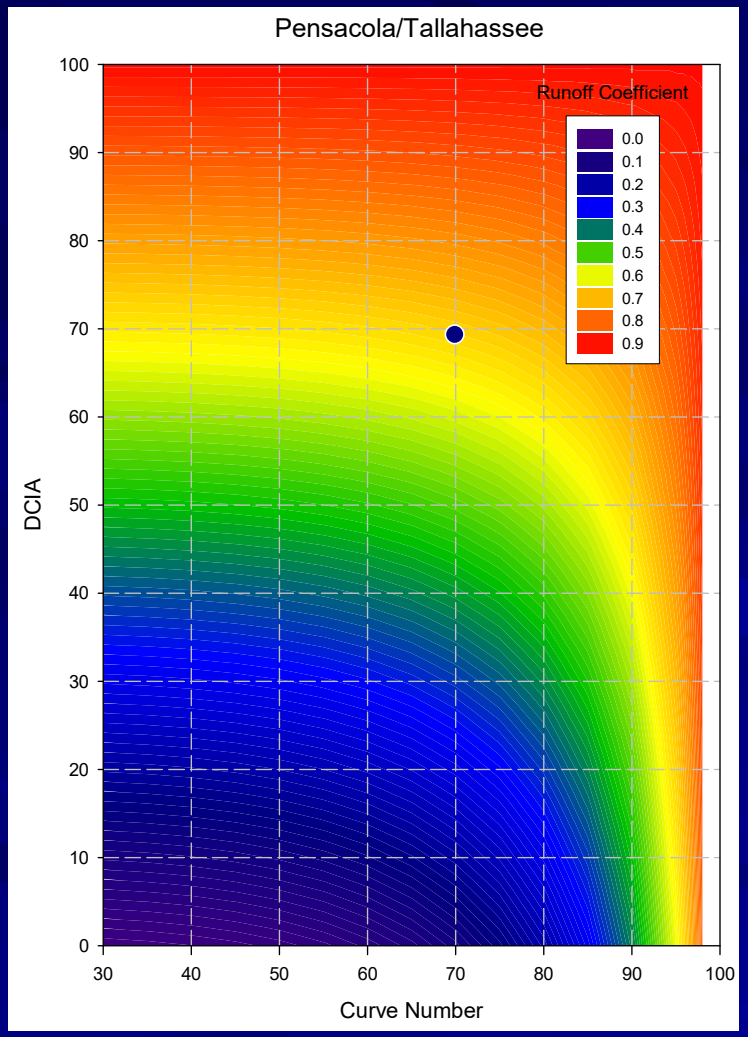


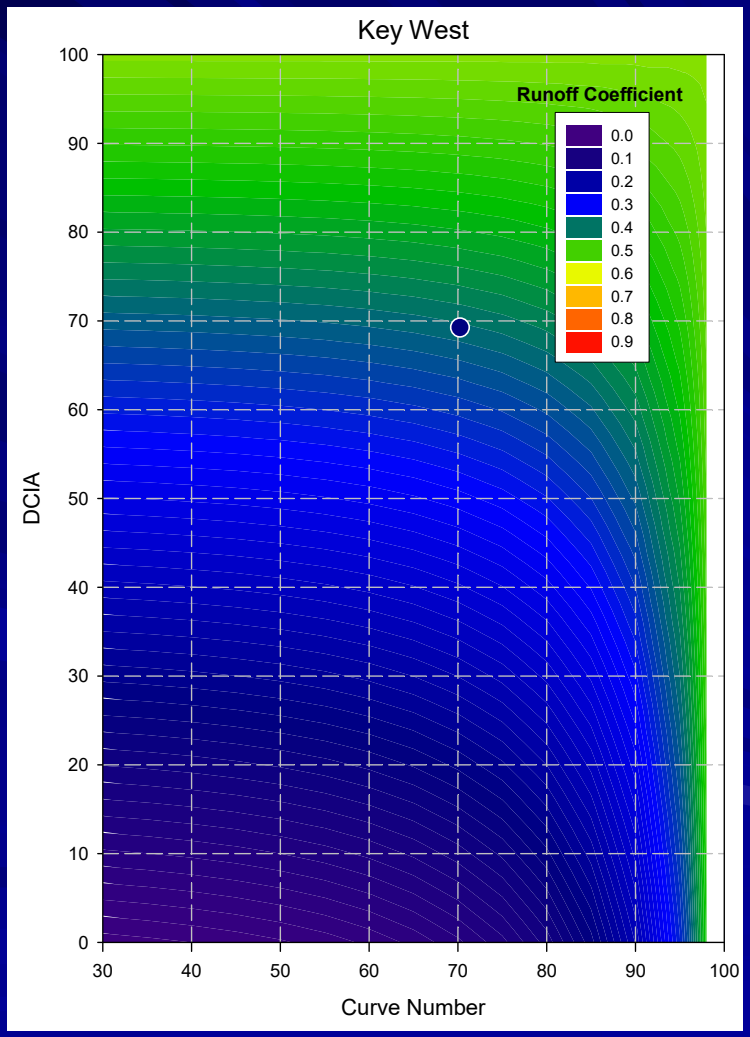
Modeled ROC Values for Various Combinations of CN and DCIA

Modeled ROC values for Miami – 64 years from 1942 - 2005

NDCIA CN	Percent DCIA																				
	0	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90	95	100
30	0.008	0.048	0.088	0.128	0.168	0.208	0.248	0.288	0.328	0.368	0.408	0.448	0.488	0.528	0.568	0.608	0.648	0.688	0.728	0.768	0.808
35	0.012	0.052	0.092	0.132	0.171	0.211	0.251	0.291	0.331	0.370	0.410	0.450	0.490	0.529	0.569	0.609	0.649	0.689	0.728	0.768	0.808
40	0.018	0.057	0.097	0.136	0.176	0.215	0.255	0.294	0.334	0.373	0.413	0.452	0.492	0.531	0.571	0.611	0.650	0.690	0.729	0.769	0.808
45	0.025	0.064	0.103	0.142	0.182	0.221	0.260	0.299	0.338	0.377	0.417	0.456	0.495	0.534	0.573	0.612	0.651	0.691	0.730	0.769	0.808
50	0.034	0.072	0.111	0.150	0.189	0.227	0.266	0.305	0.343	0.382	0.421	0.460	0.498	0.537	0.576	0.614	0.653	0.692	0.731	0.769	0.808
55	0.044	0.082	0.121	0.159	0.197	0.235	0.273	0.312	0.350	0.388	0.426	0.464	0.502	0.541	0.579	0.617	0.655	0.693	0.732	0.770	0.808
60	0.057	0.095	0.132	0.170	0.207	0.245	0.282	0.320	0.357	0.395	0.433	0.470	0.508	0.545	0.583	0.620	0.658	0.695	0.733	0.770	0.808
65	0.073	0.110	0.147	0.183	0.220	0.257	0.294	0.330	0.367	0.404	0.441	0.477	0.514	0.551	0.588	0.624	0.661	0.698	0.735	0.771	0.808
70	0.093	0.129	0.165	0.201	0.236	0.272	0.308	0.344	0.379	0.415	0.451	0.486	0.522	0.558	0.594	0.629	0.665	0.701	0.737	0.772	0.808
75	0.120	0.155	0.189	0.223	0.258	0.292	0.327	0.361	0.395	0.430	0.464	0.498	0.533	0.567	0.602	0.636	0.670	0.705	0.739	0.774	0.808
80	0.157	0.189	0.222	0.254	0.287	0.319	0.352	0.385	0.417	0.450	0.482	0.515	0.547	0.580	0.613	0.645	0.678	0.710	0.743	0.775	0.808
85	0.209	0.239	0.269	0.299	0.329	0.359	0.389	0.419	0.449	0.479	0.509	0.538	0.568	0.598	0.628	0.658	0.688	0.718	0.748	0.778	0.808
90	0.292	0.318	0.343	0.369	0.395	0.421	0.447	0.472	0.498	0.524	0.550	0.576	0.602	0.627	0.653	0.679	0.705	0.731	0.756	0.782	0.808
95	0.445	0.464	0.482	0.500	0.518	0.536	0.554	0.572	0.590	0.609	0.627	0.645	0.663	0.681	0.699	0.717	0.736	0.754	0.772	0.790	0.808
98	0.614	0.624	0.633	0.643	0.653	0.662	0.672	0.682	0.692	0.701	0.711	0.721	0.730	0.740	0.750	0.760	0.769	0.779	0.789	0.798	0.808

Annual ROC Values as a Function of DCIA and non-DCIA Curve Number

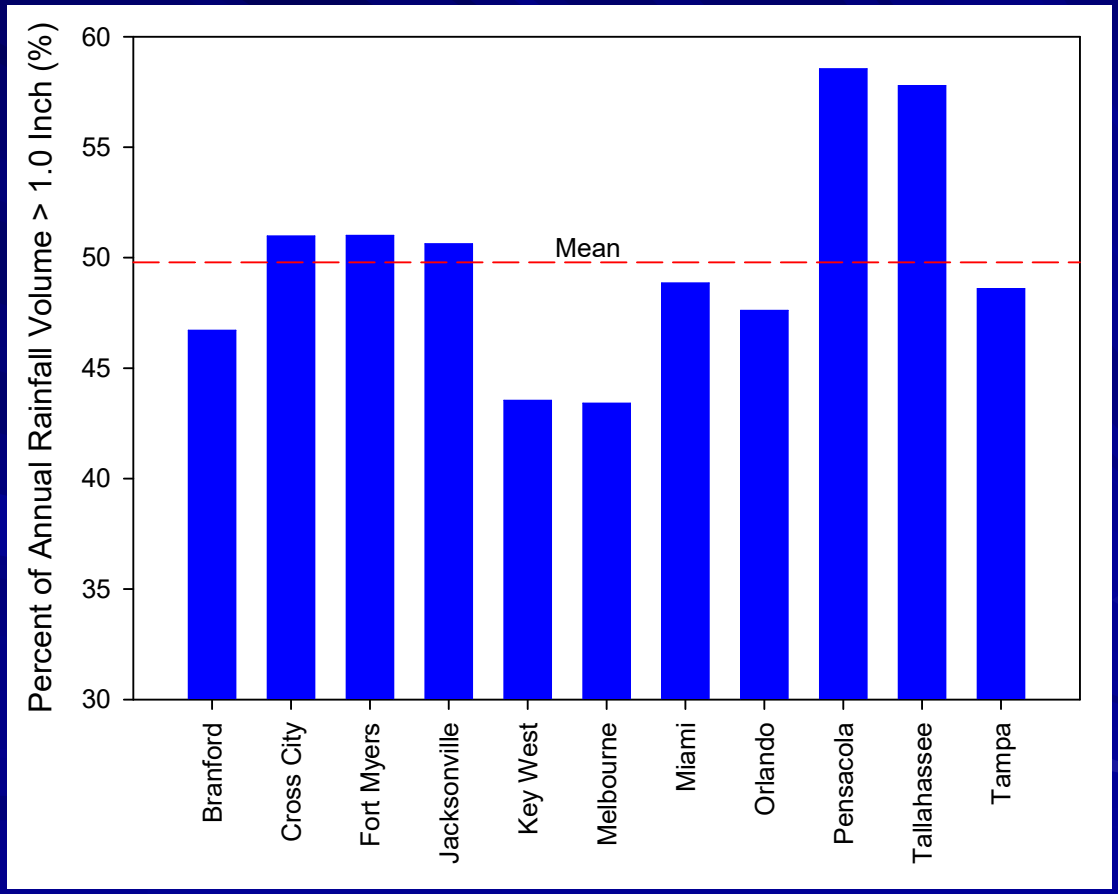




Impacts of Rainfall Characteristics on Runoff Generation

- Key West and Melbourne have a large percentage of small events and a lower percentage of large rain events
  - Results in less annual runoff volume

Pensacola and Tallahassee have a low percentage of small events and a higher percentage of large events
  - Results in more annual runoff volume

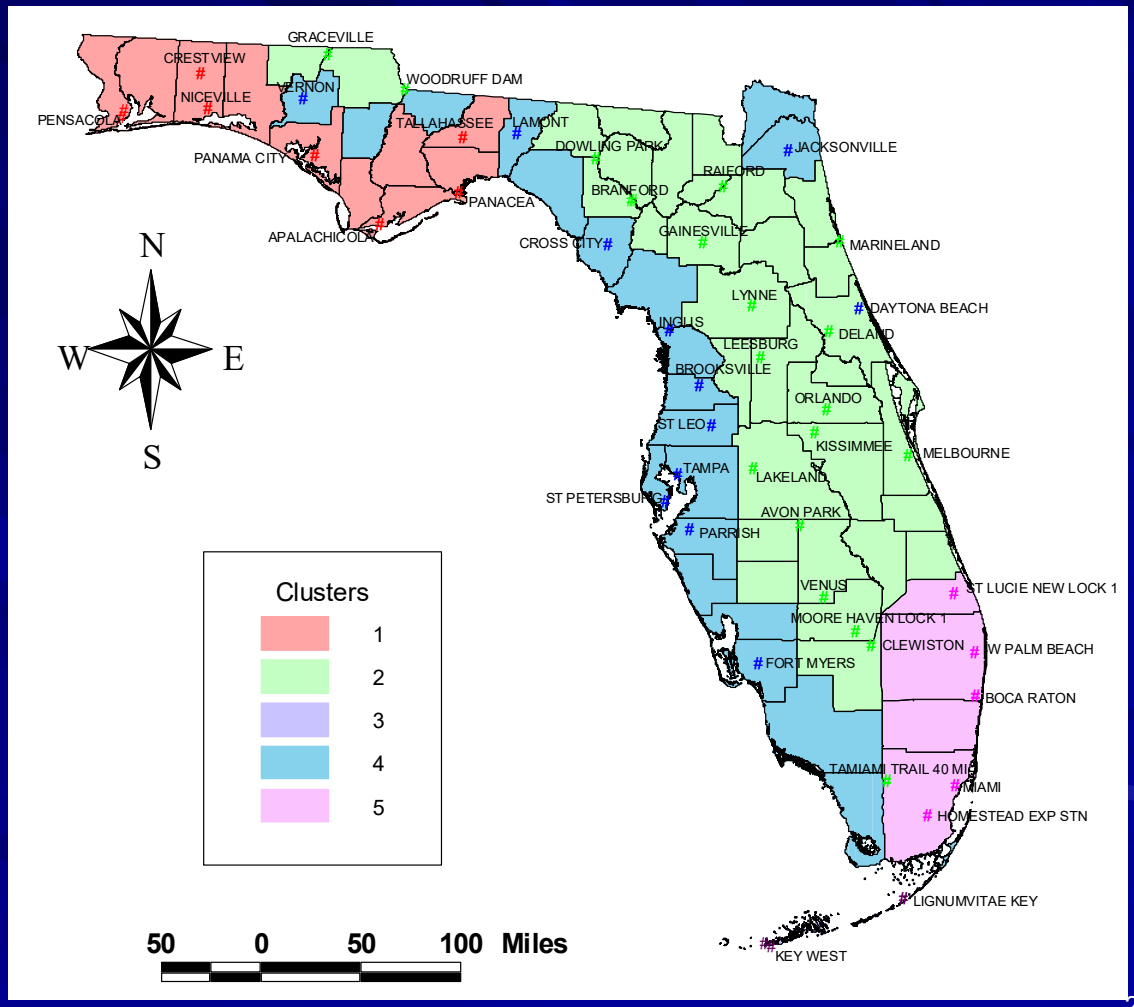


Similar Meteorological Zones

- Cluster analysis used to identify areas with similar annual rainfall/runoff relationships (ROC values)

- Analysis identified 5 significantly different areas

- Differences due to rainfall distribution rather than annual rainfall depth



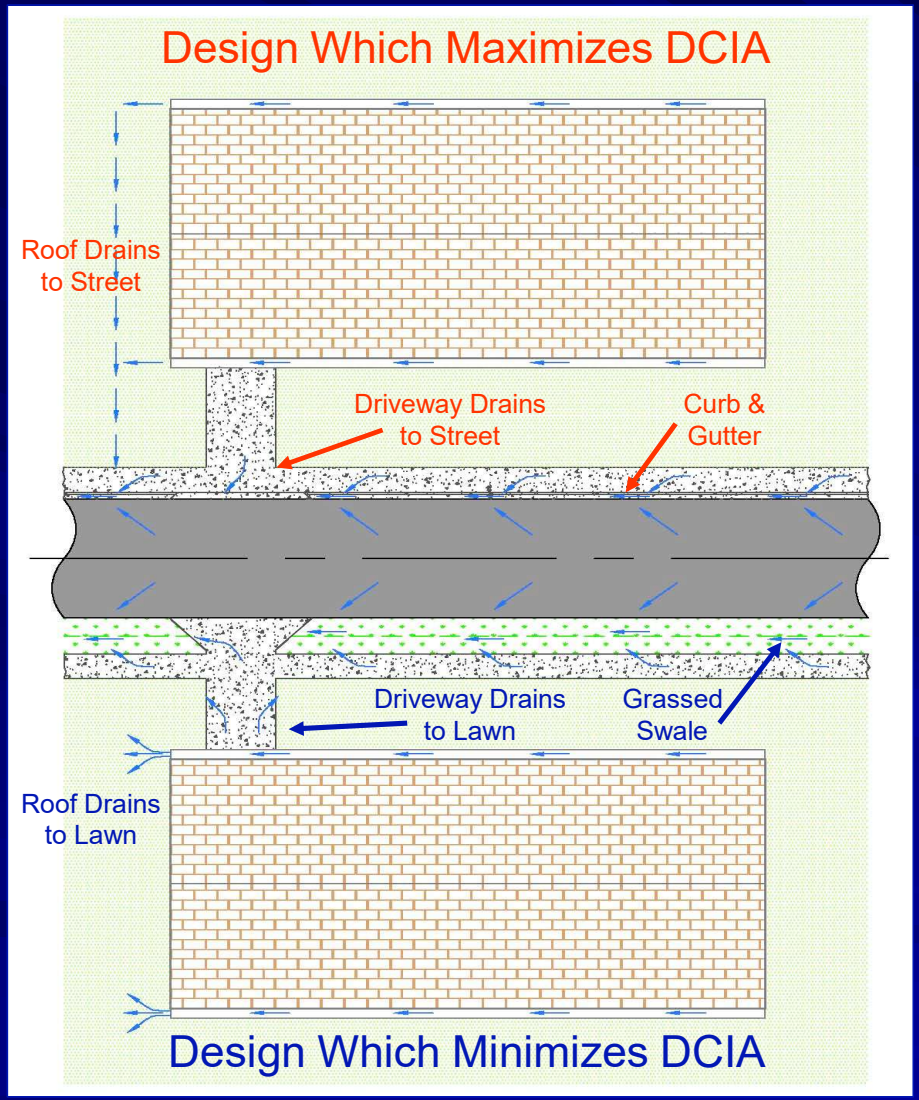
Runoff Calculation Data

- ROC values for the 5 meteorological zones are provided in Appendix C of Harper and Baker (2007)

Zone 1 - Panhandle

NDCIA	Percent DCIA																				
CN	0	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90	95	100
30	0.006	0.048	0.090	0.132	0.175	0.217	0.259	0.301	0.343	0.386	0.428	0.470	0.512	0.554	0.596	0.639	0.681	0.723	0.765	0.807	0.849
35	0.009	0.051	0.093	0.135	0.177	0.219	0.261	0.303	0.345	0.387	0.429	0.471	0.513	0.555	0.597	0.639	0.681	0.723	0.765	0.807	0.849
40	0.014	0.056	0.098	0.139	0.181	0.223	0.265	0.307	0.348	0.390	0.432	0.474	0.515	0.557	0.599	0.641	0.682	0.724	0.766	0.808	0.849
45	0.020	0.062	0.103	0.145	0.186	0.228	0.269	0.311	0.352	0.394	0.435	0.476	0.518	0.559	0.601	0.642	0.684	0.725	0.767	0.808	0.849
50	0.029	0.070	0.111	0.152	0.193	0.234	0.275	0.316	0.357	0.398	0.439	0.480	0.521	0.562	0.603	0.644	0.685	0.726	0.767	0.808	0.849
55	0.039	0.079	0.120	0.161	0.201	0.242	0.282	0.323	0.363	0.404	0.444	0.485	0.525	0.566	0.606	0.647	0.687	0.728	0.768	0.809	0.849
60	0.052	0.092	0.132	0.172	0.212	0.252	0.291	0.331	0.371	0.411	0.451	0.491	0.531	0.570	0.610	0.650	0.690	0.730	0.770	0.810	0.849
65	0.069	0.108	0.147	0.186	0.225	0.264	0.303	0.342	0.381	0.420	0.459	0.498	0.537	0.576	0.615	0.654	0.693	0.732	0.771	0.810	0.849
70	0.092	0.130	0.167	0.205	0.243	0.281	0.319	0.357	0.395	0.433	0.471	0.508	0.546	0.584	0.622	0.660	0.698	0.736	0.774	0.812	0.849
75	0.121	0.158	0.194	0.230	0.267	0.303	0.340	0.376	0.412	0.449	0.485	0.522	0.558	0.595	0.631	0.667	0.704	0.740	0.777	0.813	0.849
80	0.162	0.196	0.230	0.265	0.299	0.334	0.368	0.402	0.437	0.471	0.506	0.540	0.574	0.609	0.643	0.678	0.712	0.746	0.781	0.815	0.849
85	0.220	0.252	0.283	0.315	0.346	0.378	0.409	0.441	0.472	0.503	0.535	0.566	0.598	0.629	0.661	0.692	0.724	0.755	0.787	0.818	0.849
90	0.312	0.339	0.366	0.393	0.419	0.446	0.473	0.500	0.527	0.554	0.581	0.608	0.634	0.661	0.688	0.715	0.742	0.769	0.796	0.823	0.849
95	0.478	0.496	0.515	0.533	0.552	0.571	0.589	0.608	0.626	0.645	0.664	0.682	0.701	0.719	0.738	0.757	0.775	0.794	0.812	0.831	0.849
98	0.656	0.666	0.676	0.685	0.695	0.705	0.714	0.724	0.734	0.743	0.753	0.763	0.772	0.782	0.792	0.801	0.811	0.821	0.830	0.840	0.849

- Required input data include:
  - Rainfall meteorological zone based on rainfall zone map
  - Annual rainfall depth from isopleth maps
  - Basin DCIA
  - Non-DCIA curve number
- BMPFast conducts iterations for uneven values of DCIA and CN
  - Calculates annual runoff coefficient (ROC value) and annual runoff volume



Impacts of Disconnecting DCIA on Annual C Values

Parameter	Standard Design	Disconnect DCIA
% Imp.	40	40
DCIA (%)	20	0
Hydrologic Soil Group (HSG)	D	D
Pervious CN	80	80
Non-DCIA CN	84.5	87.2
ROC Value		
-Zone 1	0.341	0.261 (-23%)
-Zone 2	0.286	0.196 (-31%)
-Zone 3	0.297	0.210 (-29%)
-Zone 4	0.306	0.219 (-28%)
-Zone 5	0.325	0.245 (-25%)

- Designs which minimize DCIA can reduce generated runoff volume and required treatment system size

Example Calculations

1. Land Use (100 ac site.): 90 acres of single-family residential
   5 acres of stormwater management systems
   5 acres of preserved wetlands

2. Ground Cover/Soil Types

   A. Residential areas will be covered with lawns in good condition
   B. Soil types in HSG D

3. Impervious/DCIA Areas

   A. Residential areas will be 25% impervious, 75% of which will be DCIA

   Impervious Area = 25% of developed site = 90 ac x 0.25 = 22.50 acres

   DCIA Area = 22.50 acres x 0.75 = 16.88 acres

   DCIA Percentage = (16.88 ac/90.0 ac) x 100 = 18.75% of developed area

Example Calculations – con't.

4. Calculate composite non-DCIA curve number from TR-55:

Curve number for lawns in good condition in HSG D = 80

Areas of lawns = 90 acres total – 22.50 ac impervious area = 67.50 acres pervious area

Impervious area which is not DCIA = 22.50 ac – 16.88 ac = 5.62 ac

Assume a curve number of 98 for impervious areas

$$\text{Non-DCIA curve number} = \frac{67.50\ ac\ (80) + 5.62\ ac\ (98)}{67.50\ ac + 5.62\ ac} = 81.4$$

Example Calculations – con't.

5. Calculate annual runoff volume for developed area

The proposed developed area for the project is 90 ac. Estimation of runoff volumes is not included for the 5-acre stormwater management area since runoff generated in these areas is incorporated into the performance efficiency estimates for the stormwater system.

a. **Pensacola (Zone 1) Project**: The model calculates the annual runoff coefficient based on the meteorological zone and the hydrologic characteristics.

Pensacola = Zone 1, DCIA = 18.75%, and non-DCIA CN = 81.4

Annual C value = 0.304

The annual rainfall for Pensacola = 65.5 inches (From Isopleth Map)

Annual generated runoff volume = 90 ac x 65.5 in/yr x 1 ft/12 in x 0.304 = **149.3 ac-ft/yr**

Example Calculations – cont.

5. Calculate annual runoff volume for developed area – cont.

b. Key West (Zone 3) Project: The model calculates the annual runoff coefficient based on the meteorological zone and the hydrologic characteristics.

Key West = Zone 3, DCIA = 18.75%, and non-DCIA CN = 81.4

Annual C value = 0.266

Annual rainfall for Key West = 40.0 inches (From Isopleth Map)

Annual generated runoff volume = 90 ac x 40.0 in/yr x 1 ft/12 in x 0.266 = **79.8 ac-ft/yr**

Summary

- Like rainfall, runoff in Florida is highly variable
  - Impervious area
    - Direct relationship between runoff and impervious percentage
  - Non-DCIA CN value
    - Exponential relationship between CN value and runoff
  - Characteristics of rain events
- New Stormwater Rule and BMPFast Model use the 2007 Report methodology for calculating runoff volumes

Runoff Generation

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BMPFast

ERD
Water Quality Engineering

FLORIDA DEPARTMENT OF ENVIRONMENTAL PROTECTION

University of Central Florida