Evolution of the *Colorado Urban Hydrograph Procedure* (CUHP)

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History of Colorado Unit Hydrograph Procedure

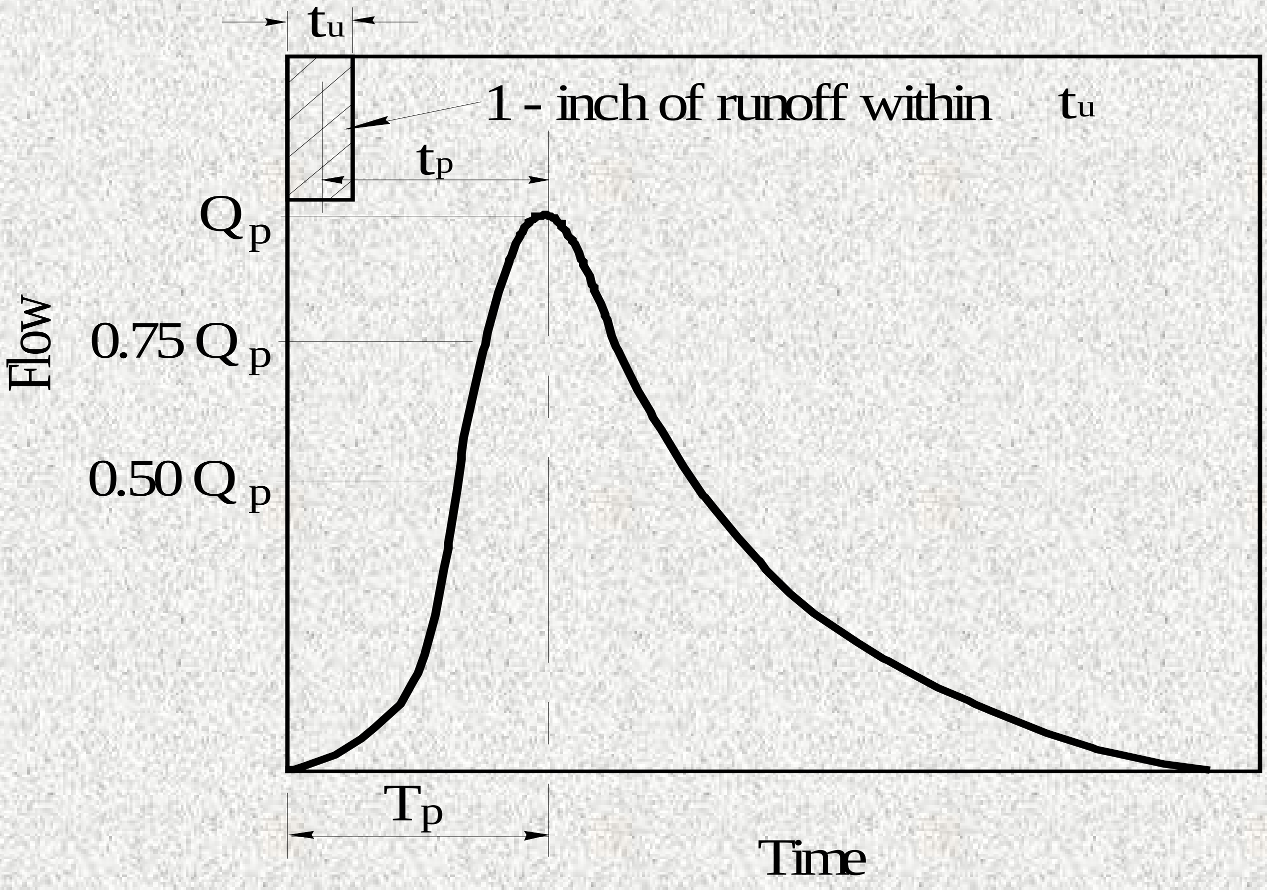
1969 - Wright Water Engineers developed the original hand calculating procedure published in the Urban Storm Drainage Criteria Manual.

1972 - First computer version written by Ben Urbonas & Stewart McGuire, URS/Ken R. White Co.
This was the first version of the one used today.

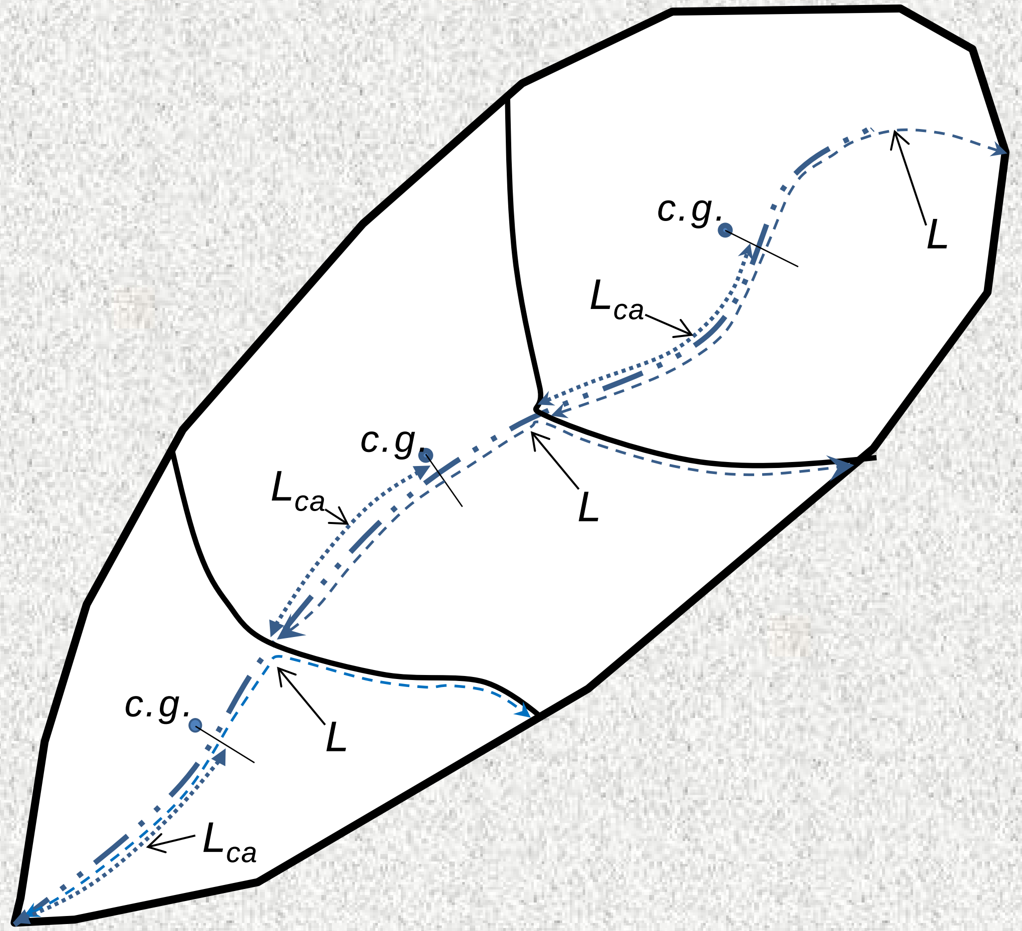
- Biggest challenge was to develop a numerical procedures to shape the unit hydrograph.)

Unit Hydrograph

1. Defined as runoff hydrograph shape **from 1-inch of runoff** that occurs uniformly **over unit of time**
2. Tributary area shape and characteristics determine the hydrograph shape



Possible Catchment Shape



1968 CUHP

Basic Equations in the USDCM

$$t_p = C_t \left(L L_{ca} \right)^{0.3}$$

t_p = **time to peak** of the unit hydrograph from midpoint of unit rainfall in hours

L = **length along runoff flow path** to upstream limits of the catchment, in miles

L_{ca} = **length along runoff flow path** to a point adjacent **to the centroid of the catchment,** in miles

C_t = **coefficient <u>reflecting time to peak</u>**

$$q_p = \frac{640\, C_p}{t_p}$$

q_p = **unit peak rate of runoff**, in cfs per square mile

C_p = **coefficient <u>related to peak rate of runoff</u>**

<u>Guidance for selection of C_t and C_p coefficients was limited and required much user judgment. It was based on 1 to 3 runoff events in Harvard Gulch.</u>

History of Colorado Unit Hydrograph Procedure

1977 - UDFCD adopts mainframe version of CUHP

Program modified for UDFCD use by Gary Walkovitz, URS Company

Also, modified to permit (by Ben Urbonas**):**

a. Use of Horton's Equation for infiltration rates,

b. Vary infiltration rates by storm event,

c. Overriding of default unit hydrograph shape,

d. Generation output to file for interface with HEC FFA.

History of Colorado Unit Hydrograph Procedure

1979 - Major update and revision

Based on UDFCD/USGS rainfall/runoff data analysis

Calibrated to data for areas $\geq$ 90 and < 2000 acres

CUHP was calibrated and revised using rainfall/runoff data:

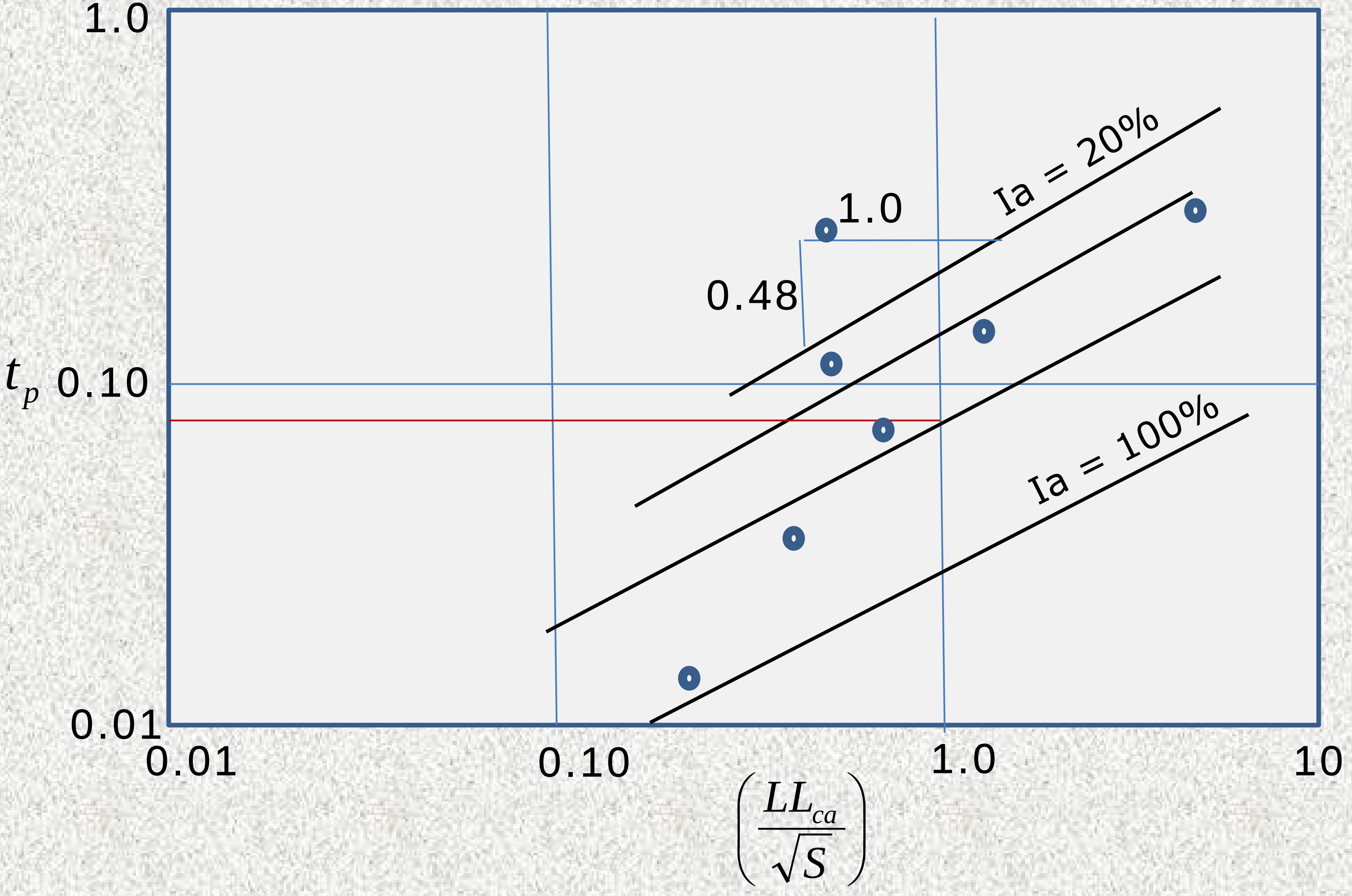
*** 8 different urban catchment conditions**

*** periods of data record ranged from 10 to 12 years**

1979 CUHP Revision Approach

- In 2969 UDFCD contracted with USGS to collect paired Rainfall Runoff Data at 29 urban catchments of various characteristics
- In 1978 began to analyze paired Rainfall/Runoff data
  - Test data for errors and integrity (started with 29 catchments)
    - Cross-plot runoff volume vs. rainfall volume
    - Discard catchments that showed clear errors (only 8 remained) (e.g., runoff volume greater than rainfall volume)
- Process data through HEC-1 to develop unit hydrograph for each storm
  - Find average unit hydrograph for each catchment
  - Take off values for unit peak runoff, time to peak, W50%, W75%
- Search for relationships between Catchment parameters and above values
- Seek to relate UH parameters to Catchment parameters

Finding the New C_t



1979 Version CUHP

Basic Equation that Changed

$$t_p = C_t \left(\frac{L\, L_{ca}}{\sqrt{S}} \right)^{0.48}$$

t_p = **time to peak** of the unit hydrograph from midpoint of unit rainfall, in hours

L = **length along runoff flow path** to upstream limits of the catchment, in miles

L_{ca} = **length along runoff flow path** to a point adjacent **to the centroid of the catchment,** in miles

C_t = **coefficient <u>reflecting time to peak</u>**

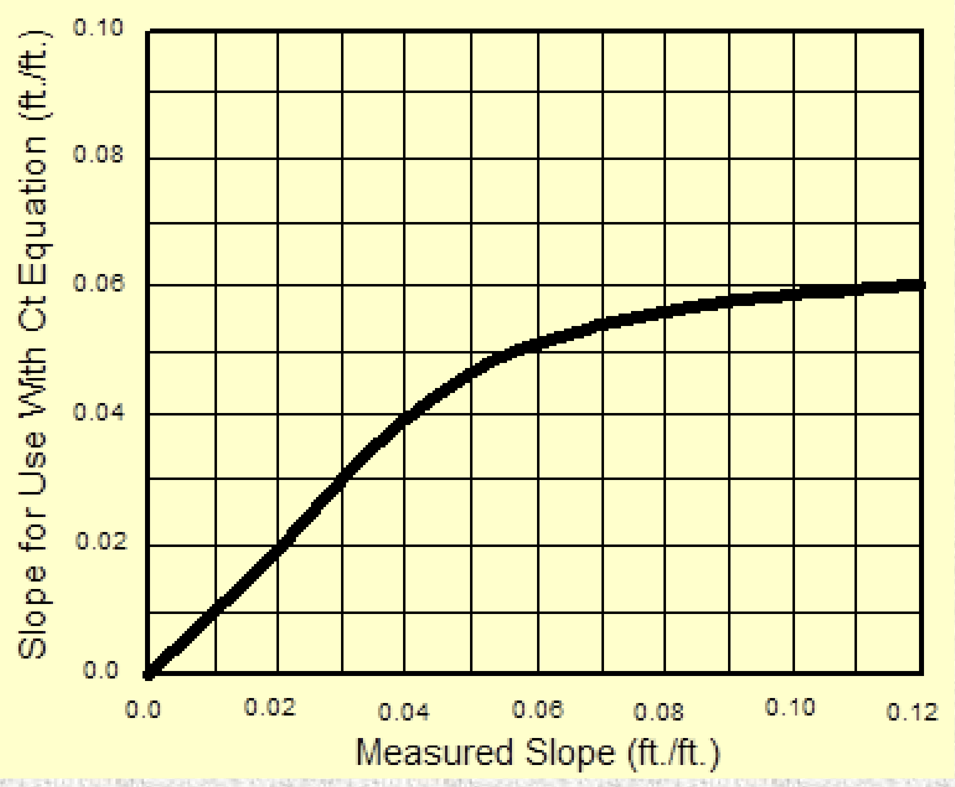
S = **weighted average slope of catchment** along flow path, in feet per foot

$\boldsymbol{q_p}$ equation was unchanged

The 1979 update for the first time provided quantitative guidance for selecting of C_t and C_p coefficients, relating them to imperviousness and area.

Waterway Slope is Now a Part of Updated CUHP

A need to **adjust steep slopes** was introduced



Weighted Waterway Slope

When the flow line slope varies along the drainageway, calculate a length-weighted:

1. Segment waterway into similar reaches
2. Correct the steep reach slopes using the correction coefficient in USDCM
3. Find weighted slope using the following equation:

$$S = \left(\frac{L_1 \cdot S_1^{\;0.24} + L_2 \cdot S_2^{\;0.24} + \cdots + L_n \cdot S_n^{\;0.24}}{L_1 + L_2 + \cdots + L_n} \right)^{4.17}$$

S = weighted catchment waterway slope in ft/ft

$S_1, S_2, \ldots S_n$ = slopes of individual reaches in ft/ft (after adjustments for steep slopes)

$L_1, L_2, \ldots L_n$ = lengths of corresponding reaches

1979 Version CUHP

Basic Time to Peak Equations

$$T_p = 60\, t_p + 0.5\, t_u$$

T_p = **time from beginning of unit rainfall** to peak of hydrograph, in minutes

t_u = **unit rainfall duration**, in minutes

$$C_p = P \cdot C_t \cdot A^{0.15}$$

C_p = unit hydrograph **peaking coefficient**

C_t = **time to peak coefficient**

P = **peaking parameter**

A = **catchment area** in square miles

1979 Version CUHP

Basic Equations that Did Not Change

Unit Peak Runoff and Peak Runoff

$$q_p = \frac{640\, C_p}{t_p}$$

q_p = unit **peak rate of runoff**, in cfs per square mile

C_p = **coefficient related to peak rate of runoff**

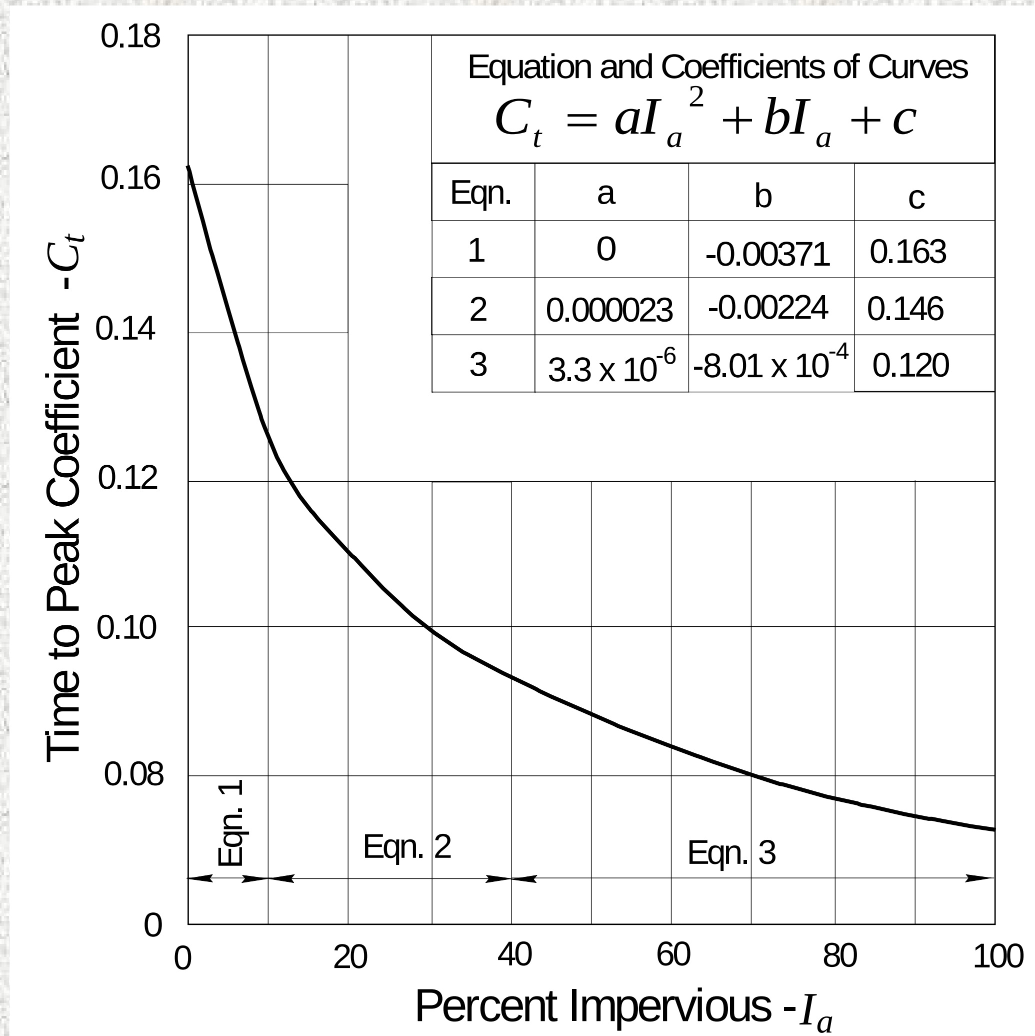
$$Q_p = q_p\, A$$

Q_p = **peak of the unit hydrograph,** in cfs

A = **area of catchment**, in square miles

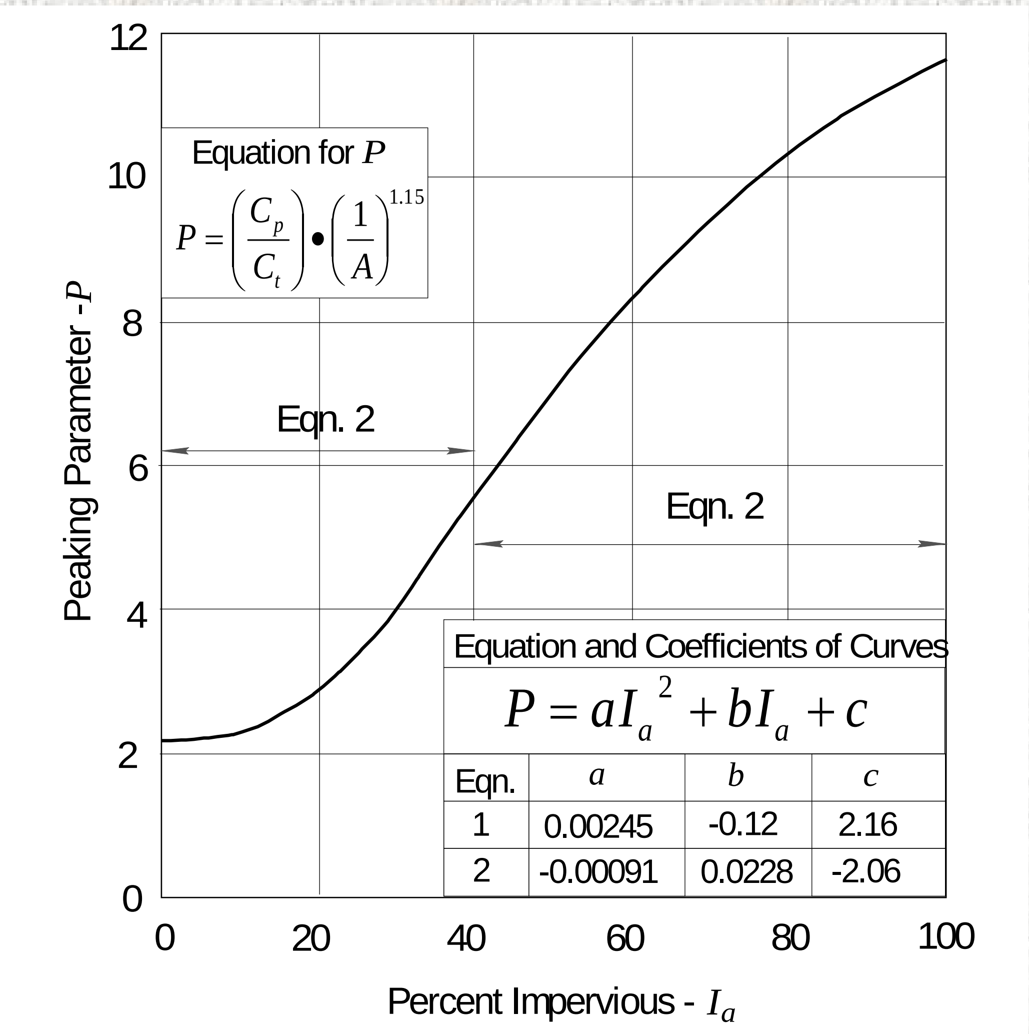
Unit Hydrograph

New Calibrated C_t Coefficient



Unit Hydrograph

New Calibrated C_p Coefficient



Eqn.	a	b	c
1	0.00245	-0.12	2.16
2	-0.00091	0.0228	-2.06

$$C_p = PC_tA^{0.15}$$

P = peaking parameter from Figure

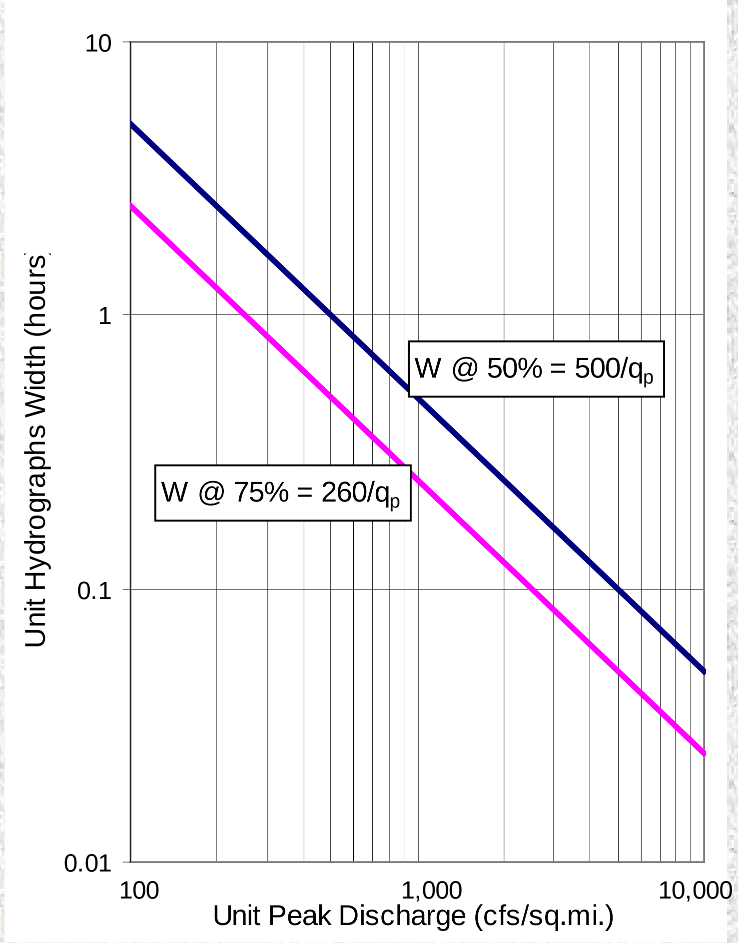
C_t = coefficient

A = catchment area, in square miles

Unit Hydrograph

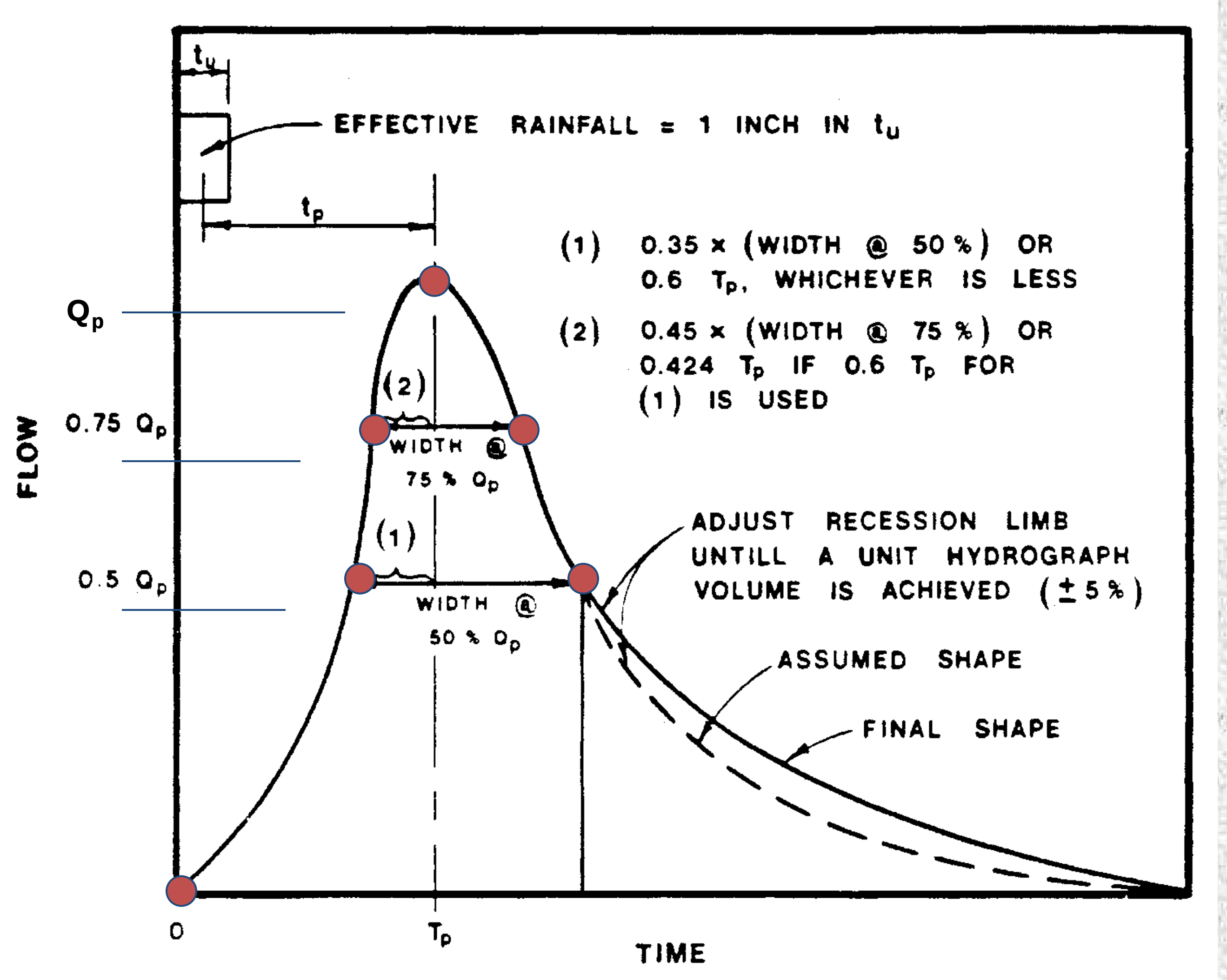
Calibrated UH widths at 50 & 75% of Q_p

Did not Change

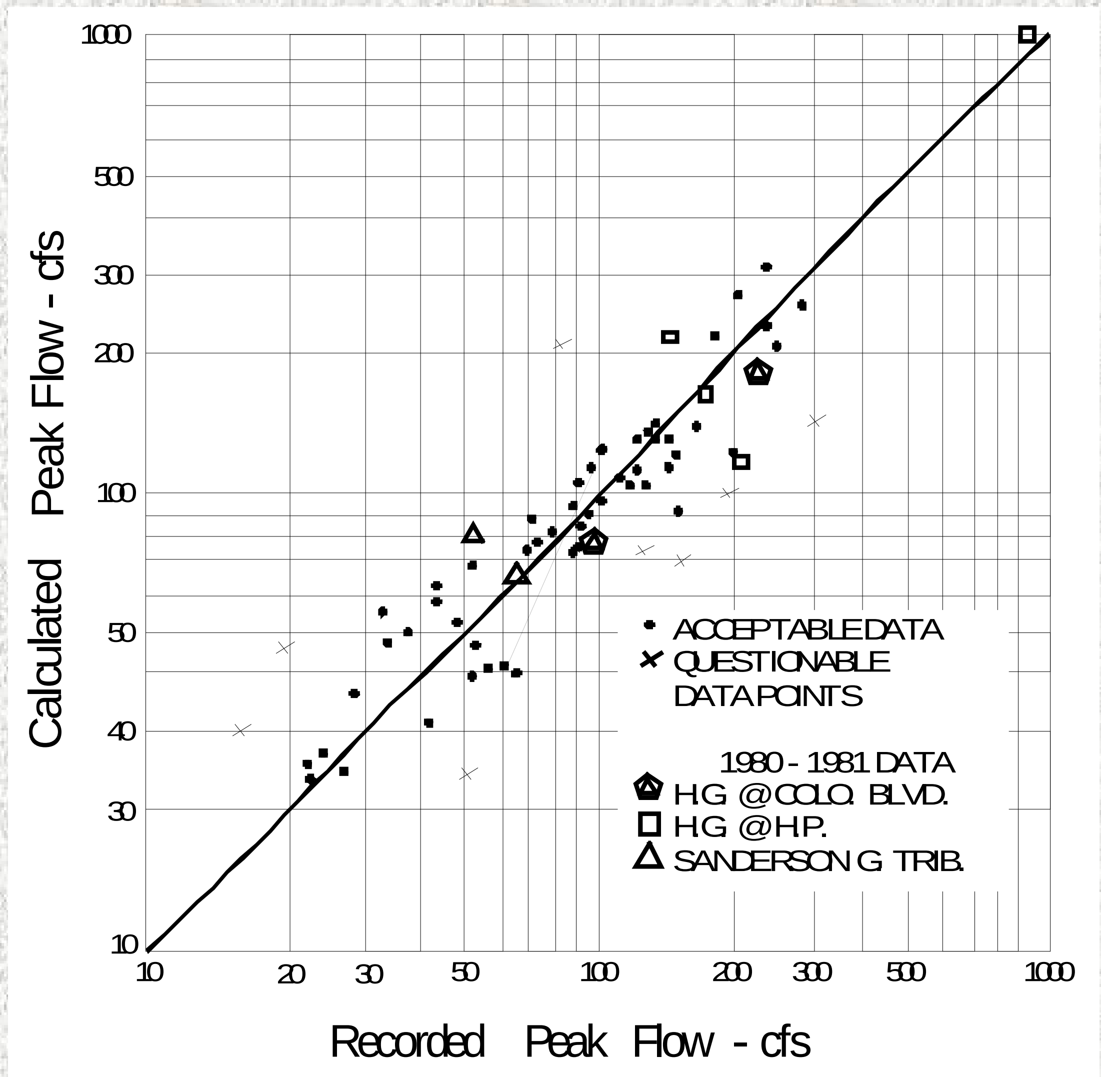


Unit Hydrograph

Points that define UH shape and shaping it.



1979 Calibrated CUHP
Recorded vs. Calculated Peak Flows

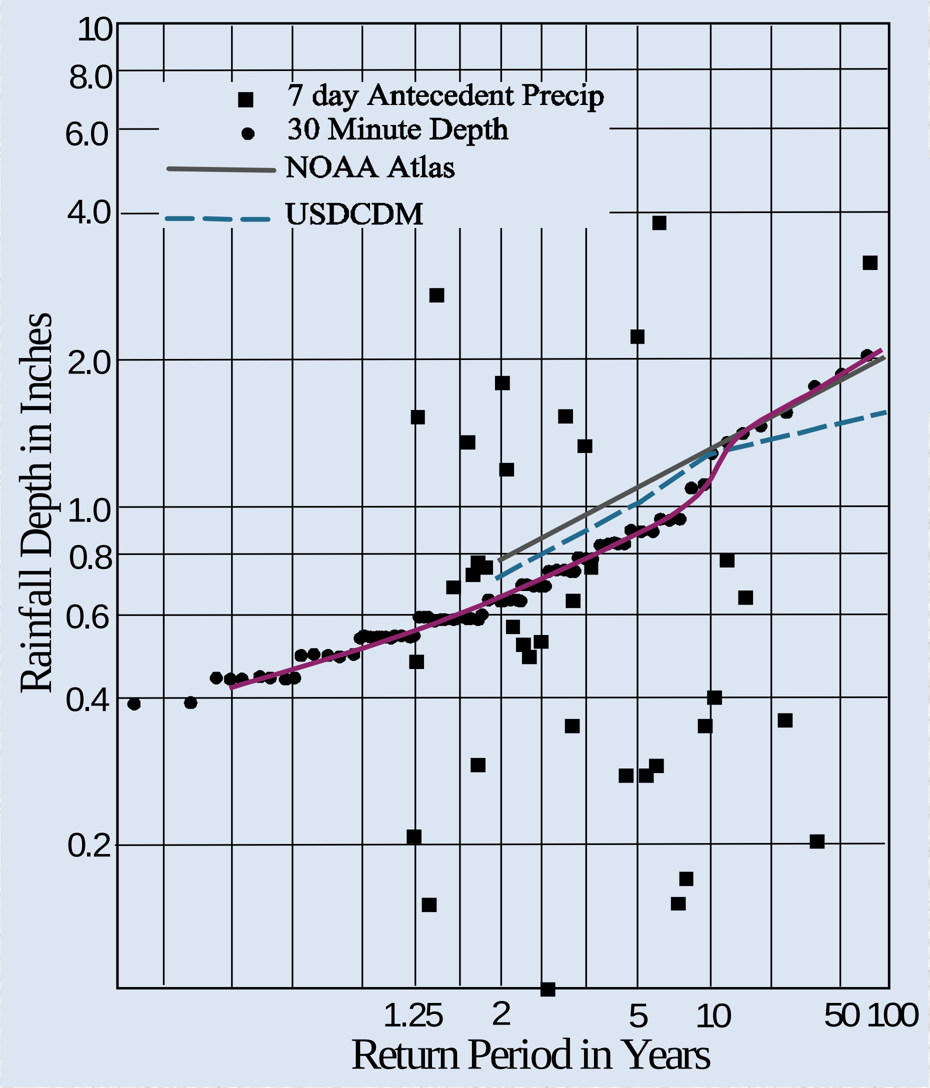


Now that we have a calibrated Unit Hydrograph, let's

CALIBRATE DESIGN STORMS

Goal: Match peak/volume return period of design storm to that of storm hydrograph.

1979 Comparison of 30 minute Depths
73 years of Data, NOAA Atlas, UDFCD Manual



Note: Practically no patter relating rainfall to antecedent precipitation

Original Pre-1979 Design Storm Procedure

1. User picked off 5-minute through 2-hour rainfall depths from isopluvial maps in USDCM
2. Plot a depth-duration curve
3. Segregated the values into 5-minute depths
4. Rearrange the 5-minute incremental depths into a “logical” temporal arrangement by placing the highest depth increment at 30 or 35 minutes from start of storm (depending on return period).

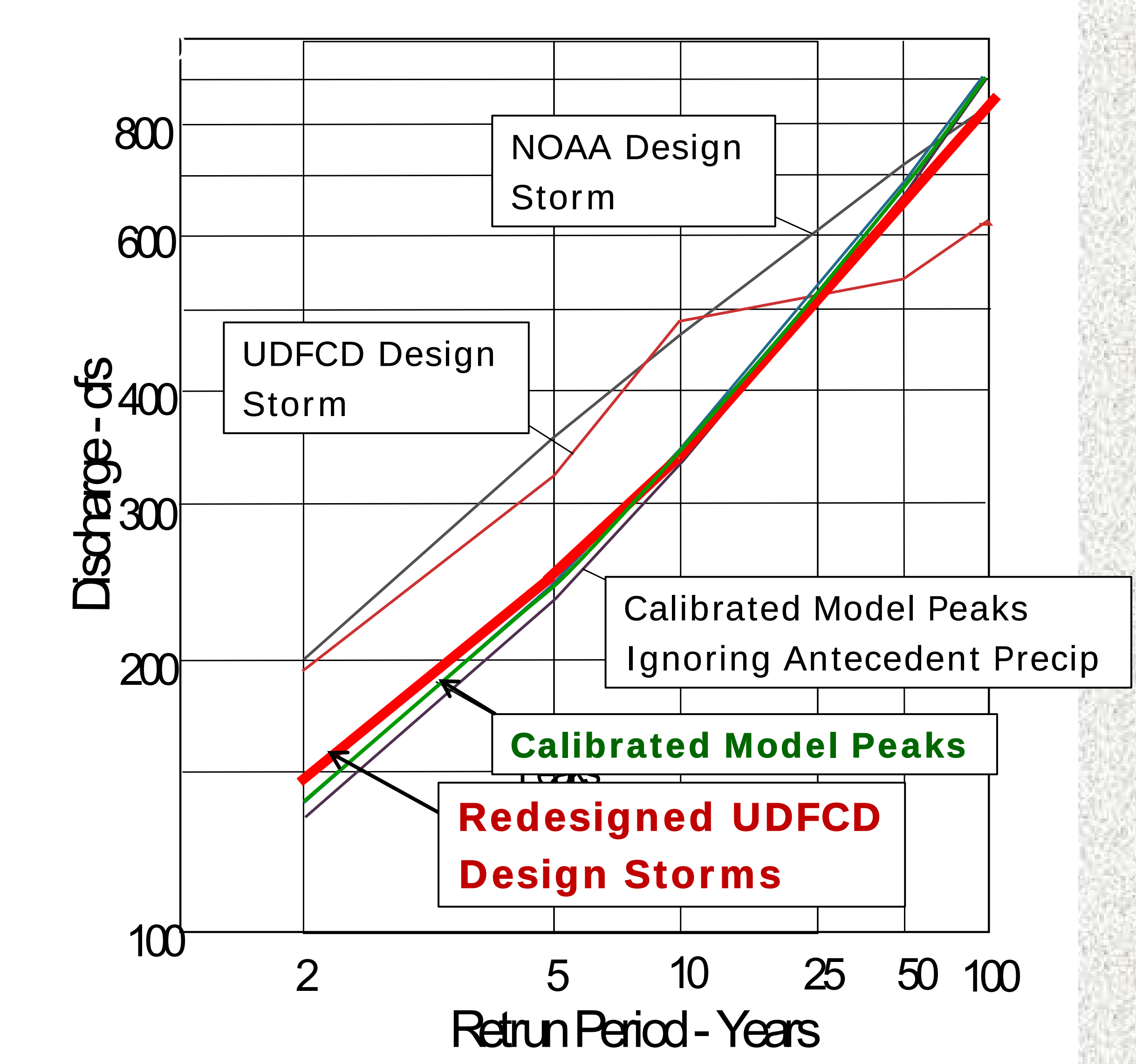
UDFCD Design Storm Analysis for 1979 Update

1. **Calibrated CUHP model using recorded simultaneous rainfall/runoff data for a variety of land uses using the catchments used in developing updated CUHP**
2. **Used the calibrated CUHP to process three larges storms with 5-minute data for each of the 73 years of historical rainfall data**
3. **Picked off the largest 73 runoff peaks and volumes**
4. **Performed Log-Pearson Type III frequency analysis**
5. **Results became the basis for comparing peaks and volumes between existing and new design storms**

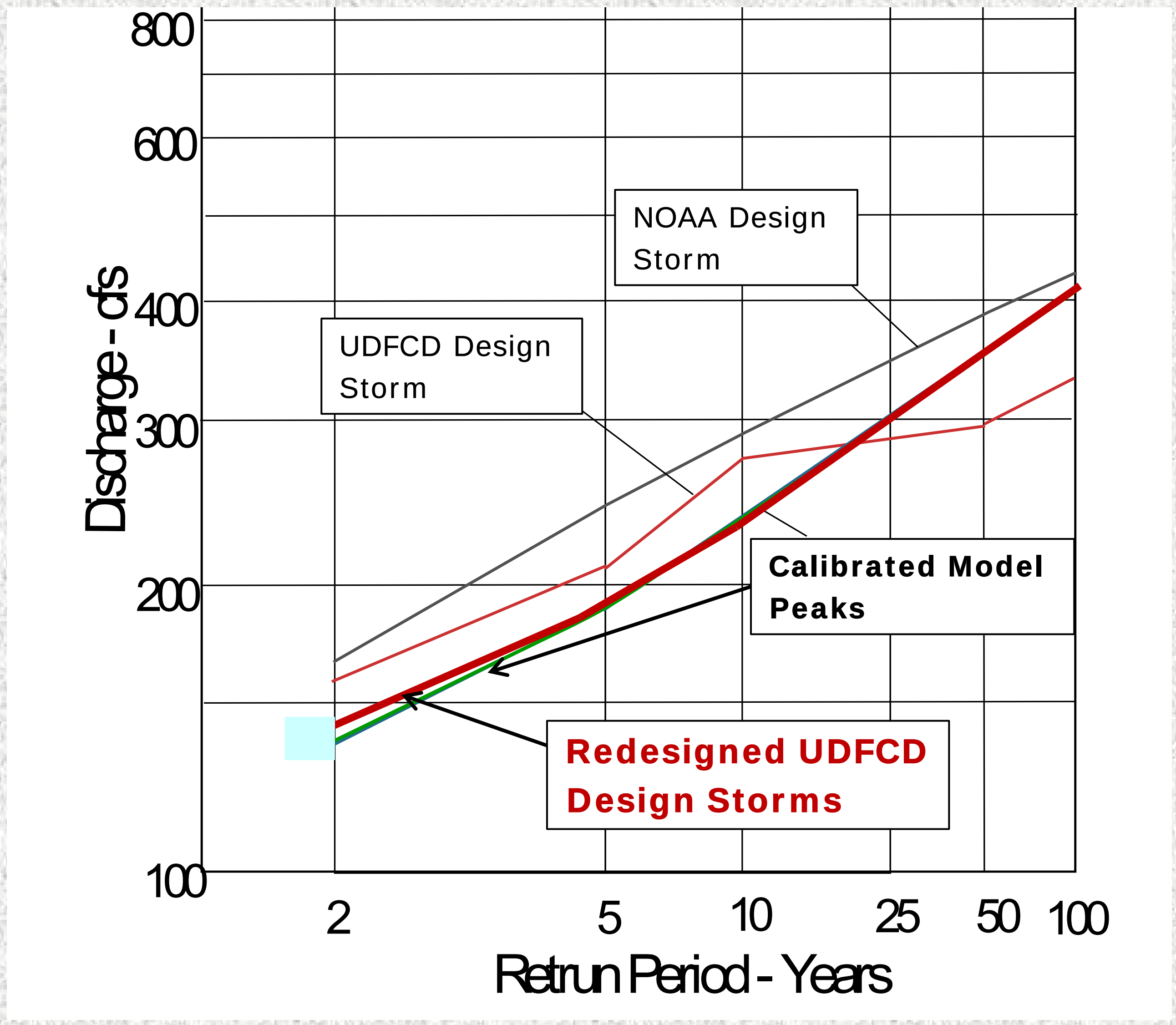
Post 1979
UDFCD Design Storms

1. **Developed using 73 years of rainfall to model runoff peaks using calibrated unit hydrograph model**
2. **<u>2-hour duration</u> <u>front-loaded</u> <u>design storm pattern</u> was selected after studying 73 years of storm patterns**
   - <u>3- and 6-hour</u> duration storms were also developed for use with <u>large catchments</u>
3. **<u>Design storm distributions</u> were <u>adjusted</u> to <u>produce</u> <u>runoff peaks</u> that best <u>match runoff peaks at all return periods</u>**

Redesigned Design Storm Peaks vs. Runoff Peak Statistics (250 ac & 40% Imp.)



Redesigned Design Storm Peaks vs. Runoff Peak Statistics (90 ac & 97% Imp.)



History of Colorado Unit Hydrograph Procedure

1984 - Program converted to run of PCs by Young S. Yoon and Niem-Sheng Hsu, Boyle Engineering Corporation to:

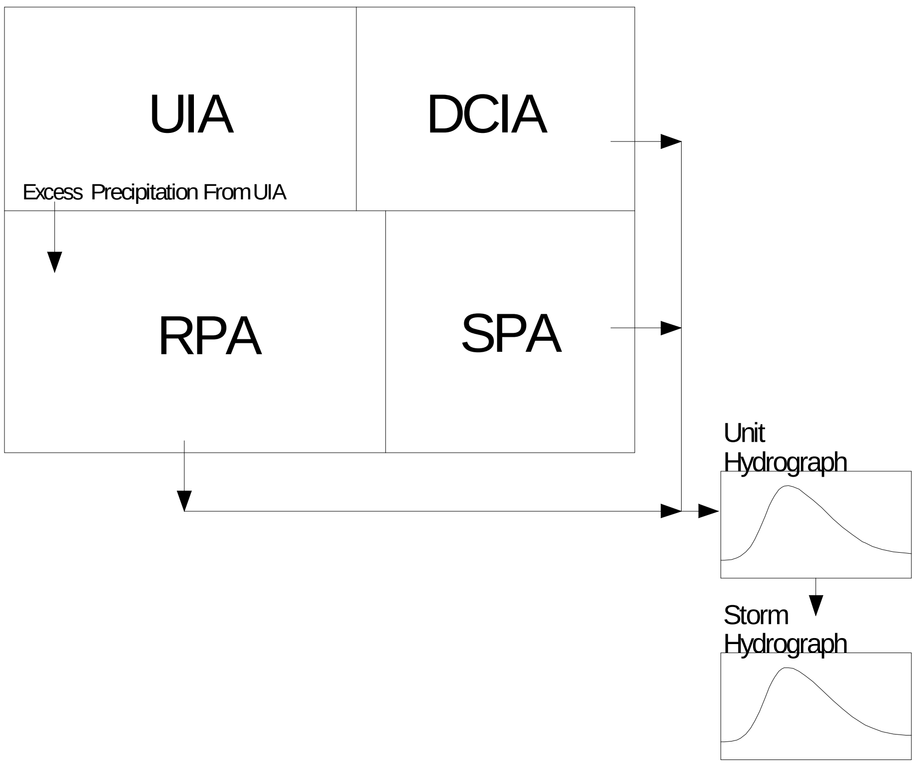
- Write storm hydrograph file for use with UDSWM2-PC,
- Permit an estimate of hydrographs for small drainage areas using time of concentration to compare results of Rational Method.

History of Colorado Unit Hydrograph Procedure

2005 - Excel user interface developed by John-Michael O'Brien, UDFCD intern and John O'Brien, Wright Water Engineers to execute the C-language version of the software and to interface with EPA SWMM 5.0 software.

This included the "Converter" to translate older versions of CUHP and UDSWM input to run under the rewritten CUHP and EPA's SWMM 5.0.

2005 Model Conceptual Relationships for Directly Connected Imperviousness



Runoff Areas:

DCIA = directly (hydraulically) connected impervious

UIA = unconnected impervious

RPA = receiving pervious

SPA = separate pervious

CUHP Runoff Calculations

CUHP calculates excess precipitation for each unit time step (e.g., 5-minute steps)

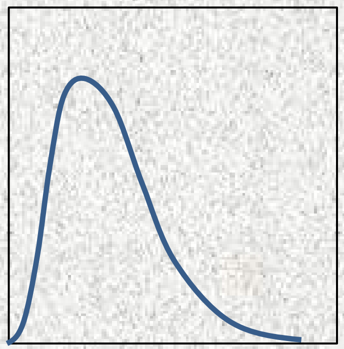
1. First calculated runoff from impervious areas
2. Splits by connected/unconnected ratios
3. Adds connected impervious portion to total runoff
4. Transfers unconnected runoff to the receiving pervious area and adds runoff depth to rainfall depth. Calculates runoff form receiving pervious area.
   Adds to total runoff
5. Calculates runoff from separate pervious area and adds to total runoff

CUHP Produces Storm Runoff Hydrograph

Steps to generate runoff hydrograph

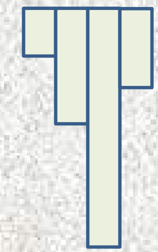
1. Develop Unit Hydrograph based on:
   - Catchment area, shape, slope, imperviousness
2. Convert design rainfall into runoff for each time increment based on:
   - Imperviousness, soil/groundcover type, connected/unconnected character of catchment
3. Multiply unit hydrograph by runoff at each time increment of runoff
4. Sum all the resultant mini storm hydrographs to obtain design hydrograph

Convolution of Unit Hydrograph, Runoff Hyetograph into Storm Hydrograph



Unit Hydrograph

X



Hyetograph

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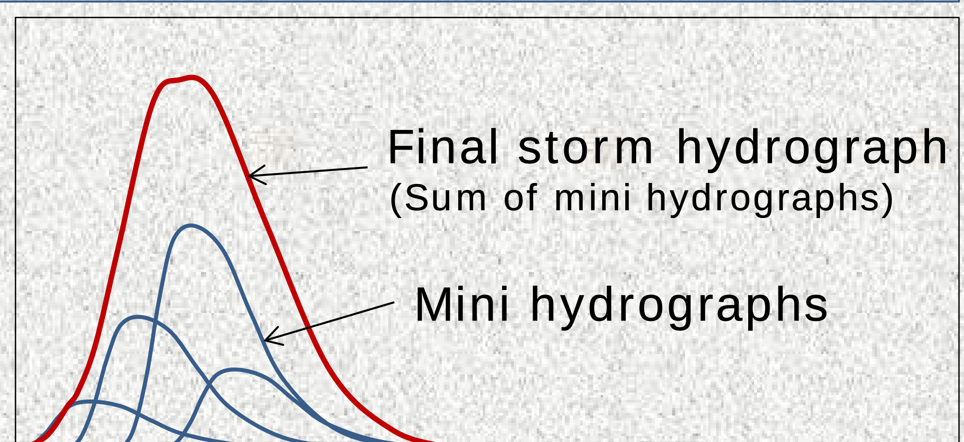

Finding the Storm Hydrograph:
Cross-multiply excess precipitation at each time step by ordinates of the Unit Hydrograph

Time min.	Unit Graph cfs	Excess Rainfall Depth In Inch																					Hydrograph cfs
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
		0.04	**0.09**	**0.31**	**0.15**	**0.06**	**0.05**	**0.03**	**0.03**	**0.03**	**0.03**	**0.03**	**0.03**	**0.03**	**0.02**	**0.01**	**0.01**	**0.01**	**0.01**	**0.01**	**0.01**	**0.01**	**0.01**	
5	**115**	4.6																						4.6
10	**345**	13.8	10.4																					24.2
15	**520**	20.8	31.1	35.7																				87.6
20	**463**	18.5	46.8	107.0	17.3																			189.6
25	**350**	14.0	41.7	161.2	51.8	6.9																		275.6
30	**260**	10.4	31.5	143.5	78.0	20.7	5.8																	289.9
35	**210**	8.4	23.4	108.5	69.5	31.2	17.3	3.5																261.8
40	**168**	6.7	18.9	80.6	52.5	27.8	26.0	10.4	3.5															226.4
45	**138**	5.5	15.1	65.1	39.0	21.0	23.2	15.6	10.4	3.5														198.4
50	**110**	4.4	12.4	52.1	31.5	15.6	17.5	13.9	15.6	10.4	3.5													176.9
55	**88**	3.5	9.9	42.8	25.2	12.6	13.0	10.5	13.9	15.6	10.4	3.5												160.9
60	**70**	2.8	7.9	34.1	20.7	10.1	10.5	7.8	10.5	13.9	15.6	10.4	3.5											147.8
65	**55**	2.2	6.3	27.3	16.5	8.3	8.4	6.3	7.8	10.5	13.9	15.6	10.4	3.5										137.0
70	**40**	1.6	5.0	21.7	13.2	6.6	6.9	5.0	6.3	7.8	10.5	13.9	15.6	10.4	2.3									126.8
75	**30**	1.2	3.6	17.1	10.5	5.3	5.5	4.1	5.0	6.3	7.8	10.5	13.9	15.6	6.9	1.2								114.5
80	**20**	0.8	2.7	12.4	8.3	4.2	4.4	3.3	4.1	SA	6.3	7.8	10.5	13.9	10.4	3.5	1.2							93.8
85	**15**	0.6	1.8	9.3	6.0	3.3	3.5	2.6	3.3	4.1	5.0	6.3	7.8	10.5	9.3	5.2	3.5	1.2						83.3
90	**8**	0.3	1.4	6.2	4.5	2.4	2.8	2.1	2.6	3.3	4.1	5.0	6.3	7.8	7.0	4.6	5.2	3.5	1.2					70.3
95	**2**	0.1	0.7	4.7	3.0	1.8	2.0	1.7	2.1	2.6	3.3	4.1	5.0	6.3	5.2	3.5	4.6	5.2	3.5	1.2				60.6
100	**0**	0.0	0.2	2.5	2.3	1.2	1.5	1.2	1.7	2.1	2.6	3.3	4.1	5.0	4.2	2.6	3.5	4.6	5.2	3.5	1.2			52.5
105			0.0	0.6	1.2	0.9	1.0	0.9	1.2	1.7	2.1	2.6	3.3	4.1	3.4	2.1	2.6	3.5	4.6	5.2	3.5	1.2		45.7
110				0.0	0.3	0.5	0.8	0.6	0.9	1.2	1.7	2.1	2.6	3.3	2.8	1.7	2.1	2.6	3.5	4.6	5.2	3.5	1.2	41.2
115					0.0	0.1	0.4	0.5	0.6	0.9	1.2	1.7	2.1	2.6	22.0	1.4	1.7	2.1	2.6	3.5	4.6	5.2	3.5	56.7
120						0.0	0.1	0.2	0.5	0.6	0.9	1.2	1.7	2.1	1.8	1.1	1.4	1.7	2.1	2.6	3.5	4.6	5.2	31.3
125							0.1	0.1	0.2	0.5	0.6	0.9	1.2	1.7	1.4	0.9	1.1	1.4	1.7	2.1	2.6	3.5	4.6	24.6
130								0.0	0.1	0.2	0.5	0.6	0.9	1.2	1.1	0.7	0.9	1.1	1.7	1.7	2.1	2.6	3.5	18.9
135									0.0	0.1	0.2	0.5	0.6	0.9	0.8	0.6	0.7	0.9	1.1	1.4	1.7	2.1	2.6	14.2
140										0.0	0.1	0.2	0.5	0.6	0.6	0.4	0.6	0.7	0.9	1.1	1.4	1.7	2.1	10.9
145											0.0	0.1	2.0	0.5	0.4	0.3	0.4	0.6	0.7	0.9	1.1	1.4	1.7	10.1
150												0.0	0.1	0.2	0.3	0.2	0.3	0.4	0.6	0.7	0.9	1.1	1.4	6.2
155													0.0	0.1	0.2	0.2	0.2	0.3	0.4	0.6	0.7	0.9	1.1	4.7
160														0.0	0.0	0.1	0.2	0.2	0.3	0.4	0.6	0.7	0.9	3.4
165															0.0	0.0	0.1	0.2	0.2	0.3	0.4	0.6	0.7	2.5
170																0.0	0.0	0.1	0.2	0.2	0.3	0.4	0.6	1.8
175																	0.0	0.0	0.1	0.2	0.2	0.3	0.4	1.2
180																		0.0	0.0	0.1	0.2	0.2	0.3	0.8
185																			0.0	0.0	0.1	0.2	0.2	0.5
190																				0.0	0.0	0.1	0.2	0.3
195																					0.0	0.0	0.1	0.1
200																						0.0	0.0	0.0

QUESTIONS?

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