



CE 3372 WATER SYSTEMS DESIGN

LESSON 15: DRAINAGE HYDROLOGY – A REVIEW FALL 2020

OUTLINE

- Hydrology
 - Definitions and Motivation
 - Hydrographs
 - Design Storms

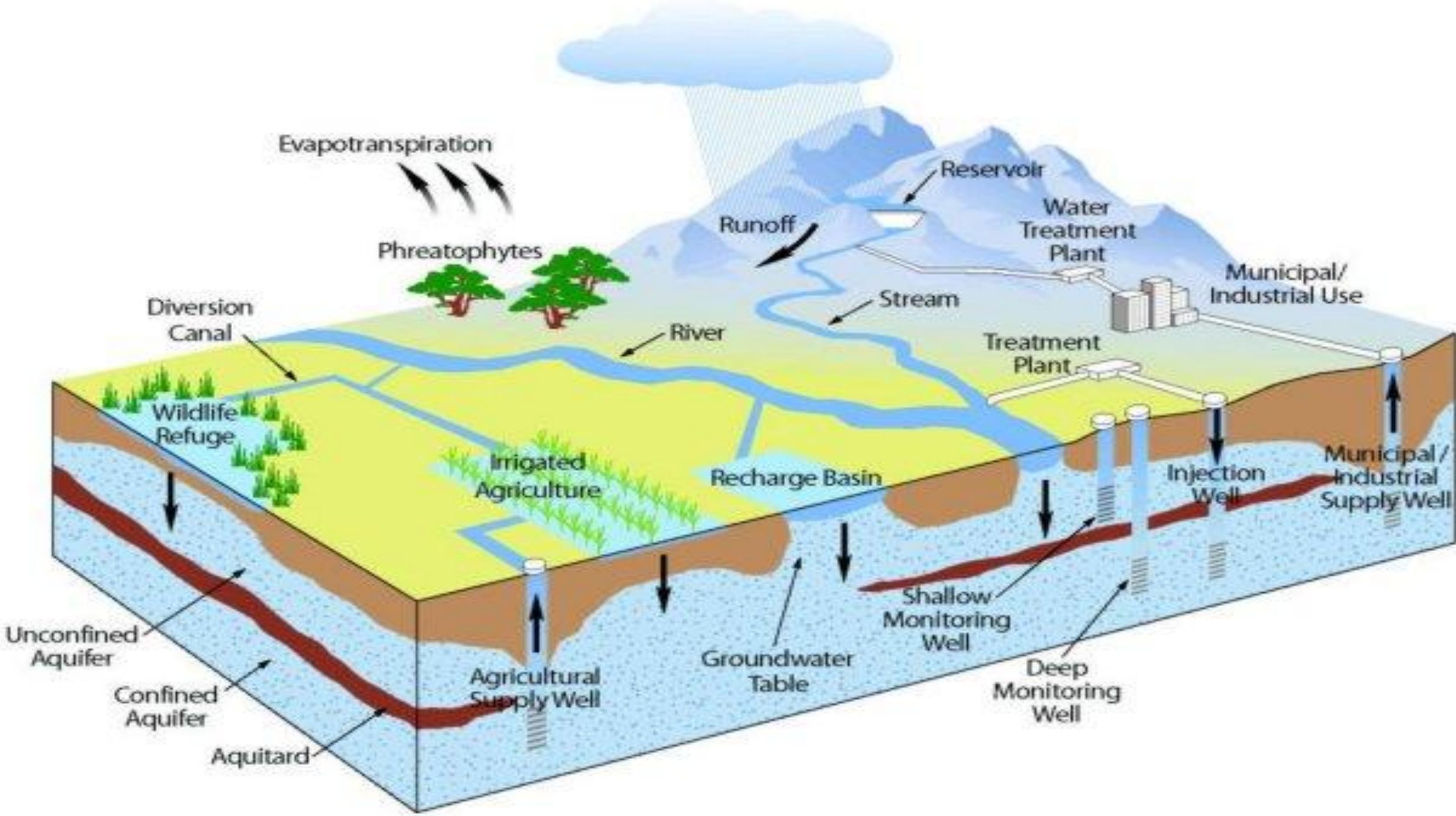


HYDROLOGY

- “The science dealing with the occurrence, circulation, distribution, and properties of the waters of the earth and it’s atmosphere”

-Dictionary.com



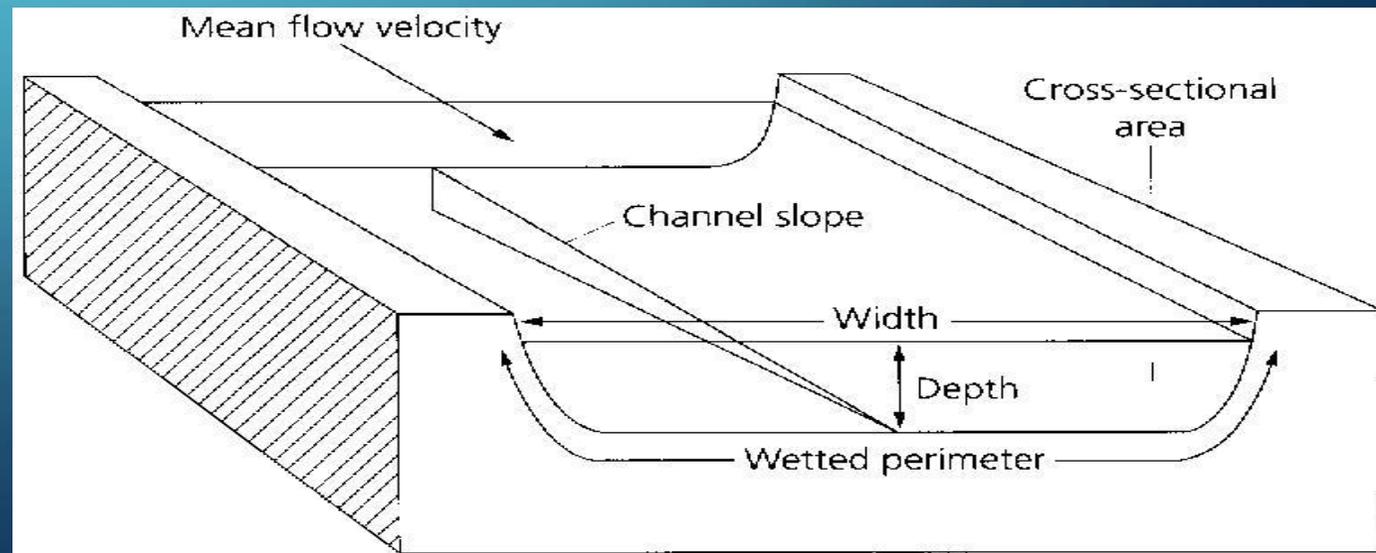






PEAK FLOW/DISCHARGE

- Discharge [L^3/T]- Volume of water through a given cross-sectional area at a period of time
- Peak flow corresponds to maximum water levels reached during a rainfall event
- Flood Timelapse



RAINFALL FREQUENCY

- Frequency

(Return Period) and probability (AEP) are related

- Frequency (years) = 100 / Probability (%)

Ex: 2-year = 100 / 50%

Exceedance Probability	Frequency
50%	2-Year
20%	5-Year
10%	10-Year*
4%	25-Year
2%	50 -Year*
1%	100-Year*
0.4%	250 -Year
0.2%	500-Year*

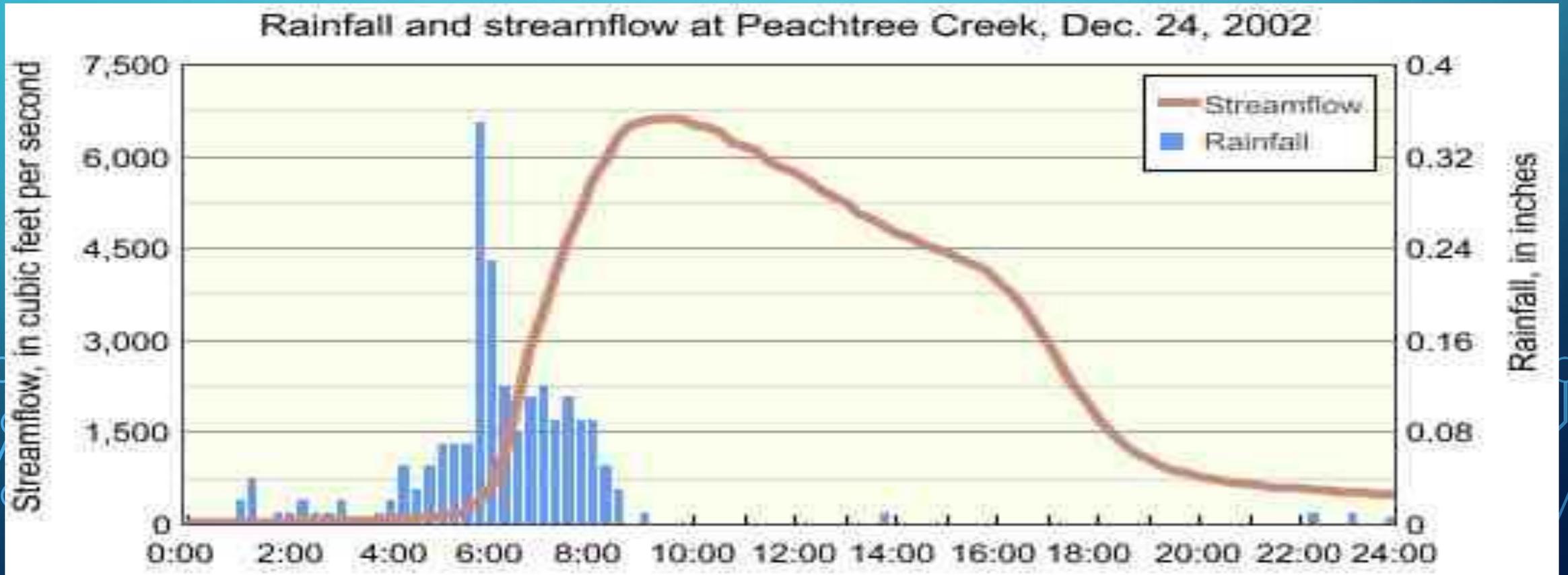
* For flood insurance purposes



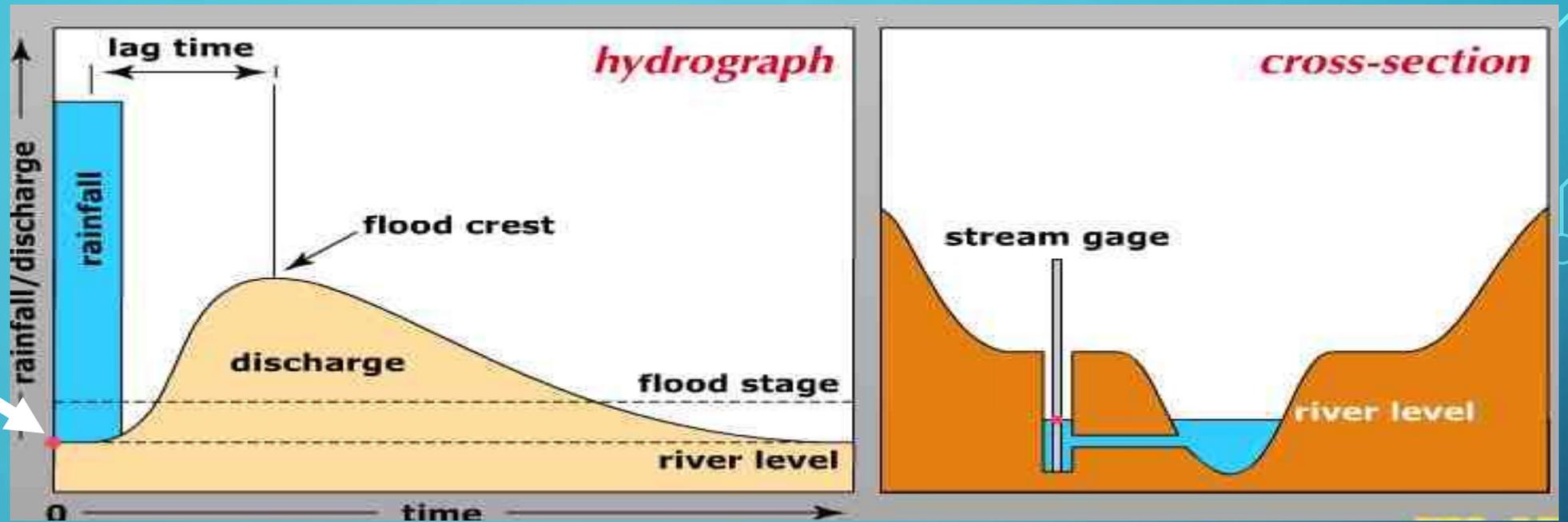
HYDROGRAPHS

HYDROGRAPH

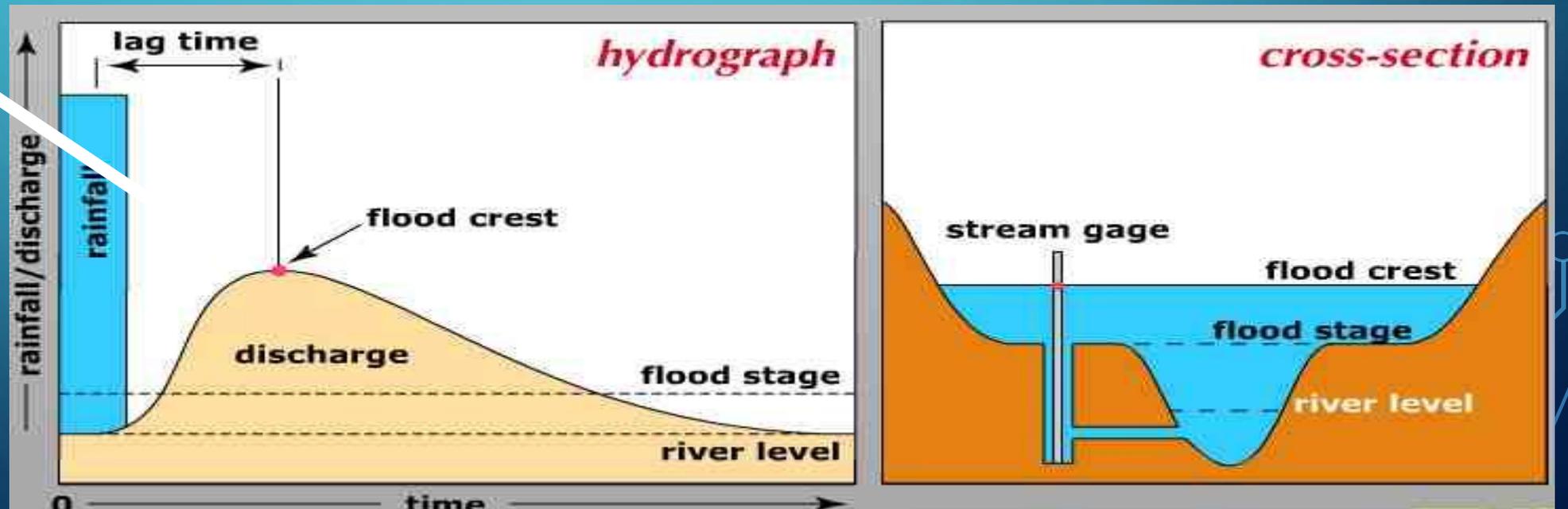
- Graph – Flow vs. Time



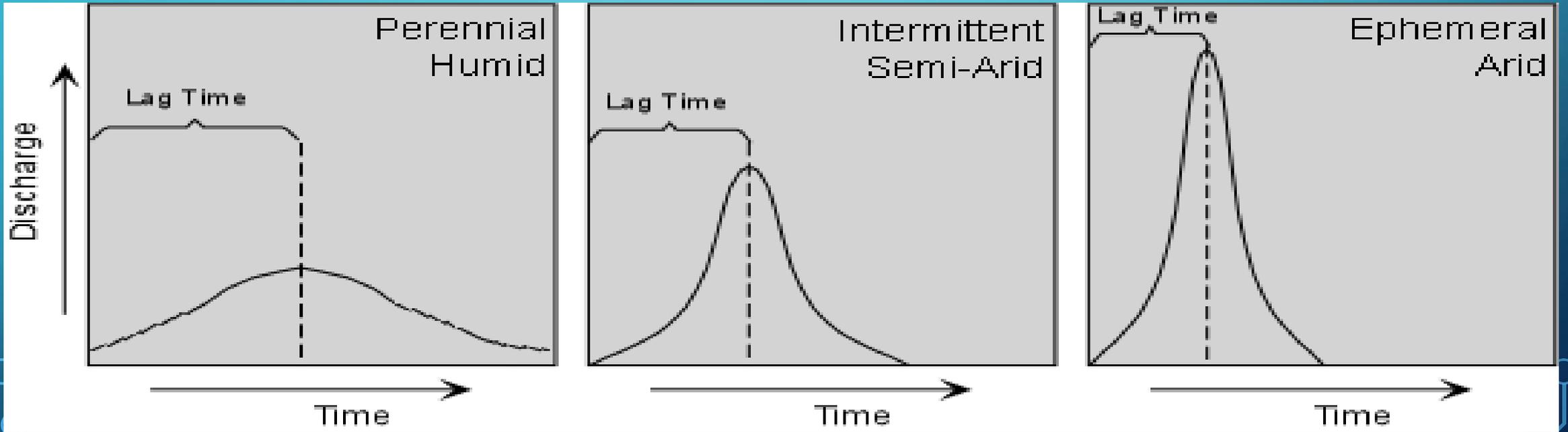
Before
Rain



After
Rain &
water
moves
to streams



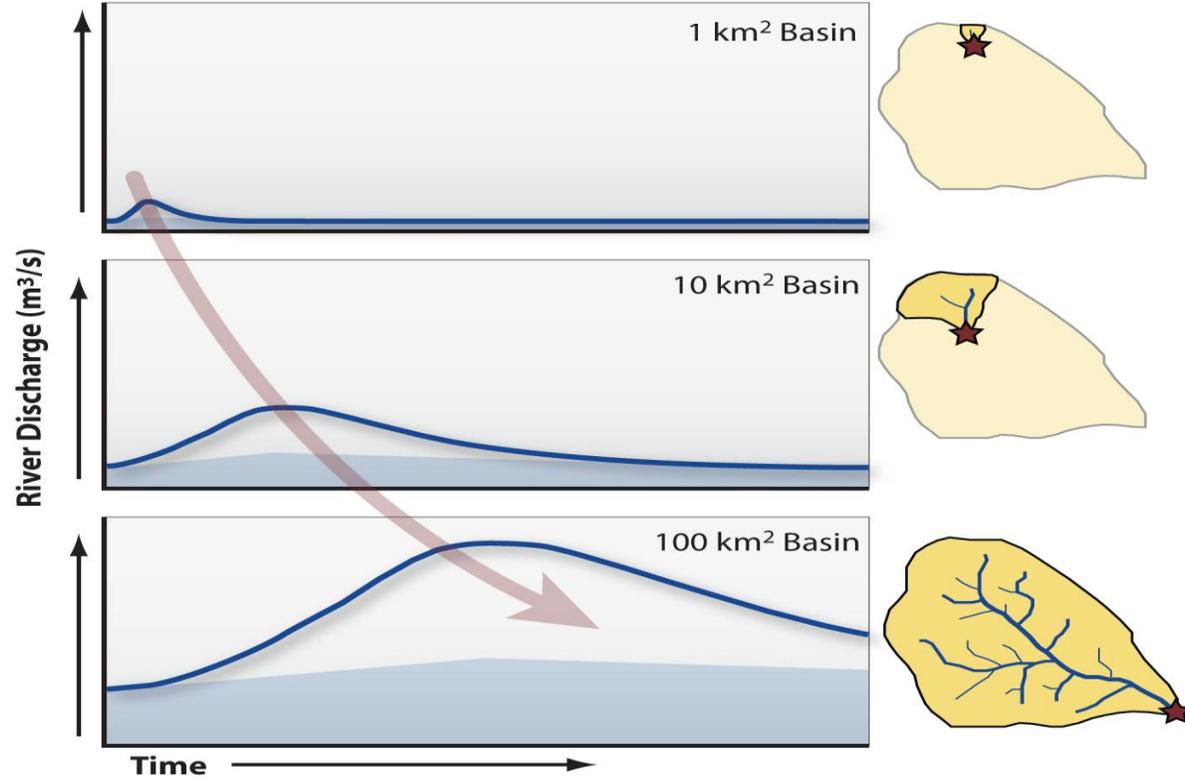
HYDROGRAPHS



Permeable

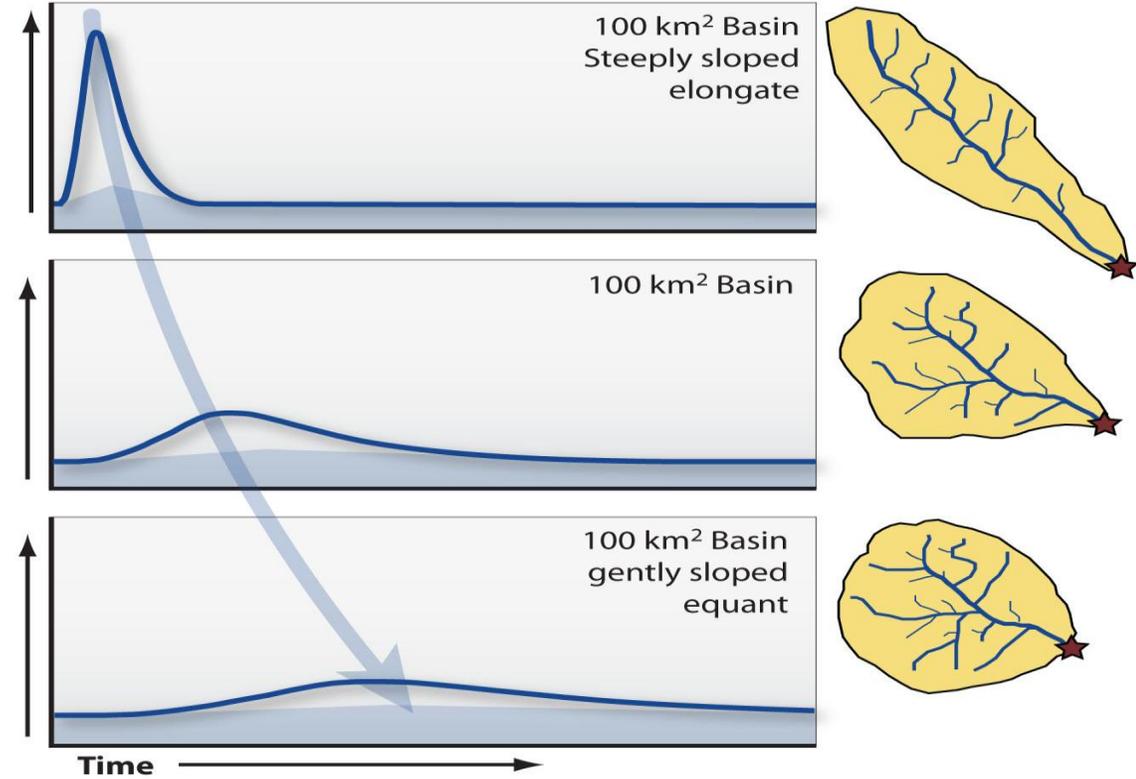
Low infiltration

Effects Of Basin **Scale** On The Hydrograph:



River discharge increases with basin area. Rivers rise and fall more slowly in large basins than in small basins.

Effects Of Basin **Slope** and **Shape** On The Hydrograph:



Hydrographs are more peaked and floods more abrupt in narrow, steep basins than in equant, gently sloping basins.

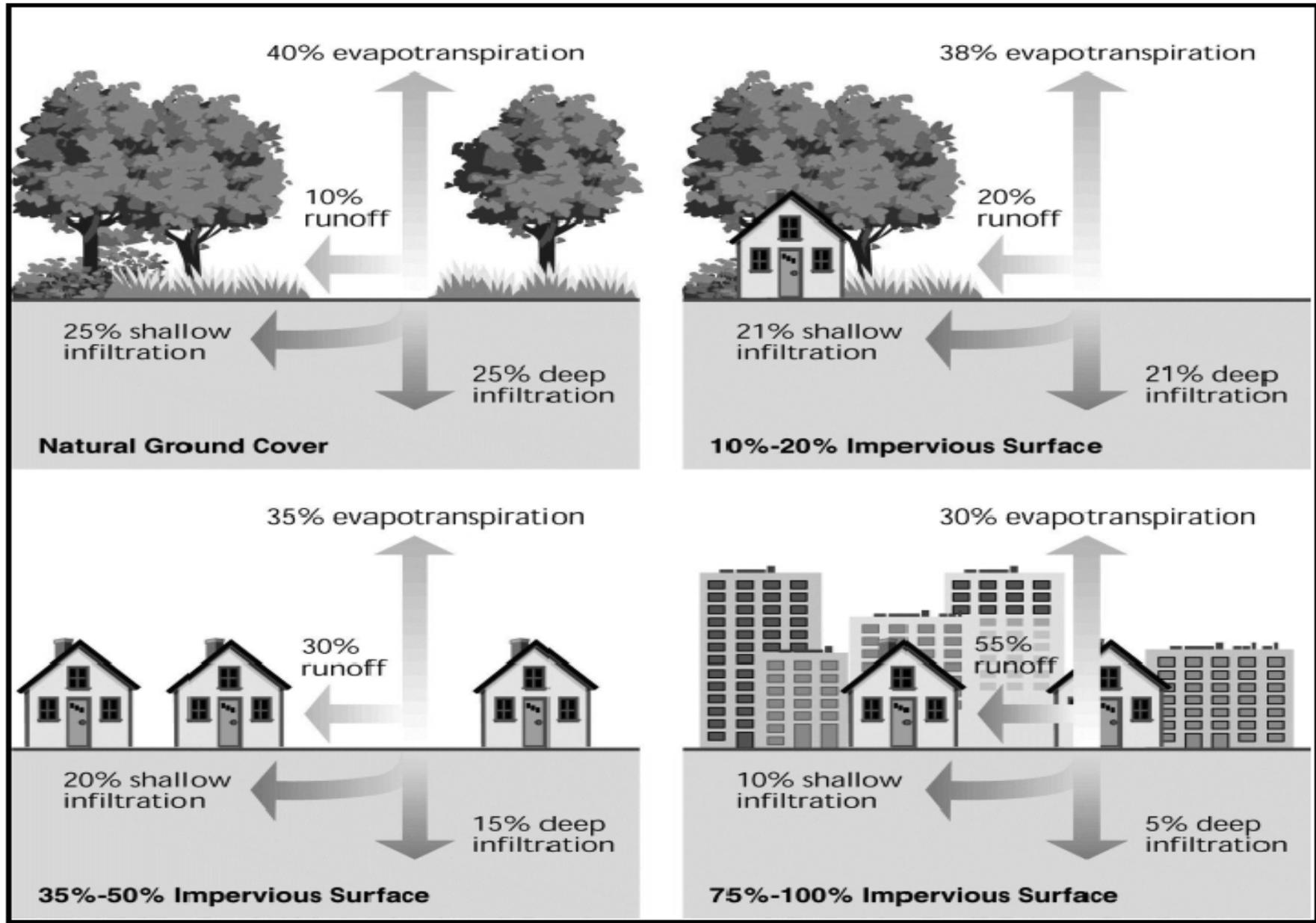


Figure 1.2: Relationship Between Impervious Cover and Surface Runoff

Source: Federal Interagency SRWG, 2000



DESIGN INTENSITIES

PRECIPITATION

- Intensity-Duration-Frequency
 - NOAA Atlas 14
 - ~~EBDLKUP-2015 (Being replaced by a TAMU-TTI product)~~
- Design Storms
 - SCS Precip. Distributions
 - ~~TxHYETO-2015 (Being replaced by a TAMU-TTI product)~~

PRECIPITATION VARIABLES

There are four variables of engineering interest:

1. Intensity: how hard it rains
2. Duration: how long it rains at any given intensity
3. Frequency: how often it rains at any given intensity and duration
4. Spatial Distribution: the equivalent uniform rainfall depth over an area

DEPTH-DURATION-FREQUENCY

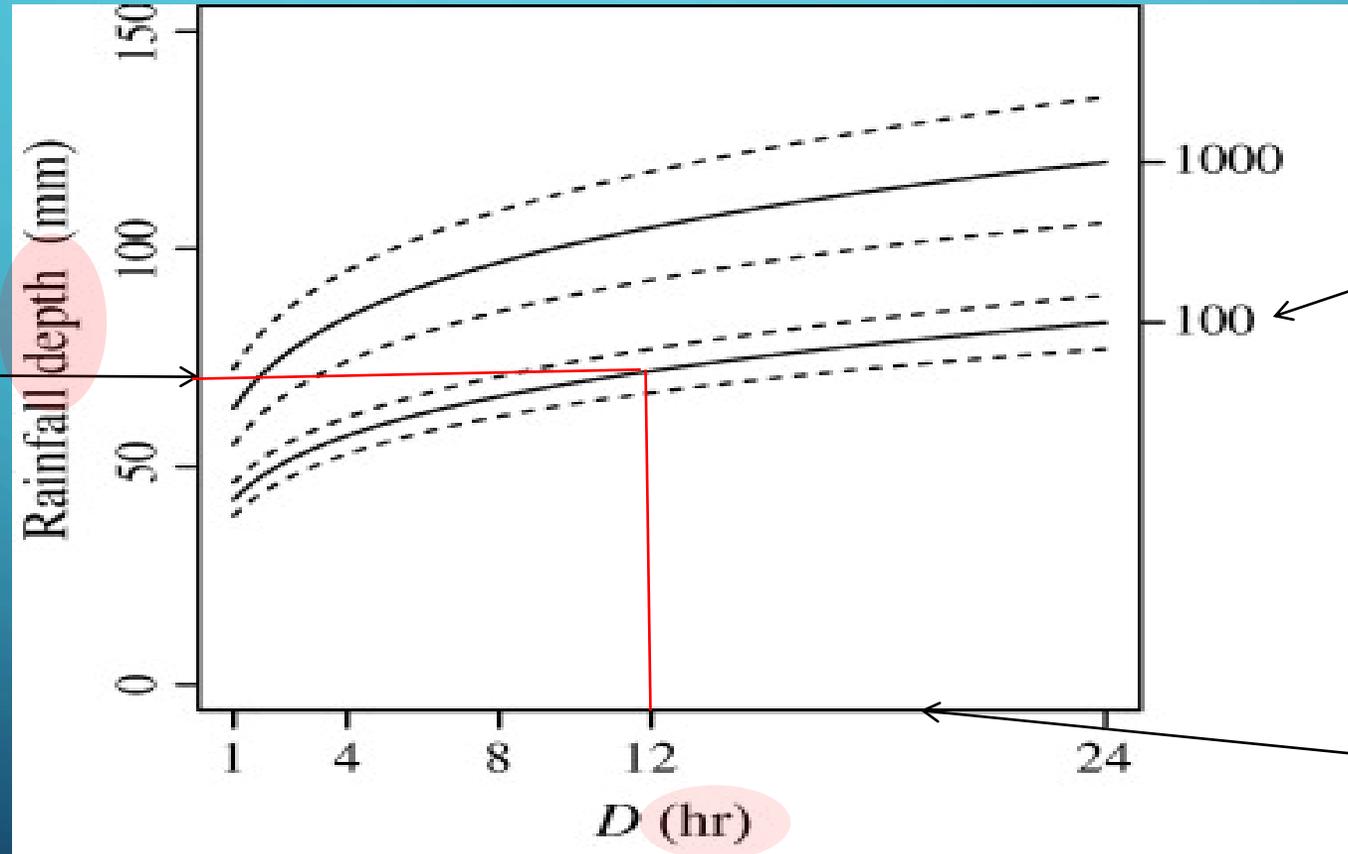
- Depth of rainfall is the accumulated depth (in a gage) over some time interval.
- Duration is that time interval.
- Frequency is the probability (like AEP) of observing the depth over the given duration.

DEPTH-DURATION-FREQUENCY

- DDF curve

e.g. 12 hour, 100-year (AEP=1%), depth is 70 millimeters

Depth



Frequency
AEP; ARI

Duration

INTENSITY

- An alternate to DDF is to present the magnitude as an intensity (a rate).
- Intensity is the ratio of an accumulated depth to some averaging time, usually the duration.

$$i_{avg} = \frac{D}{T_C}$$

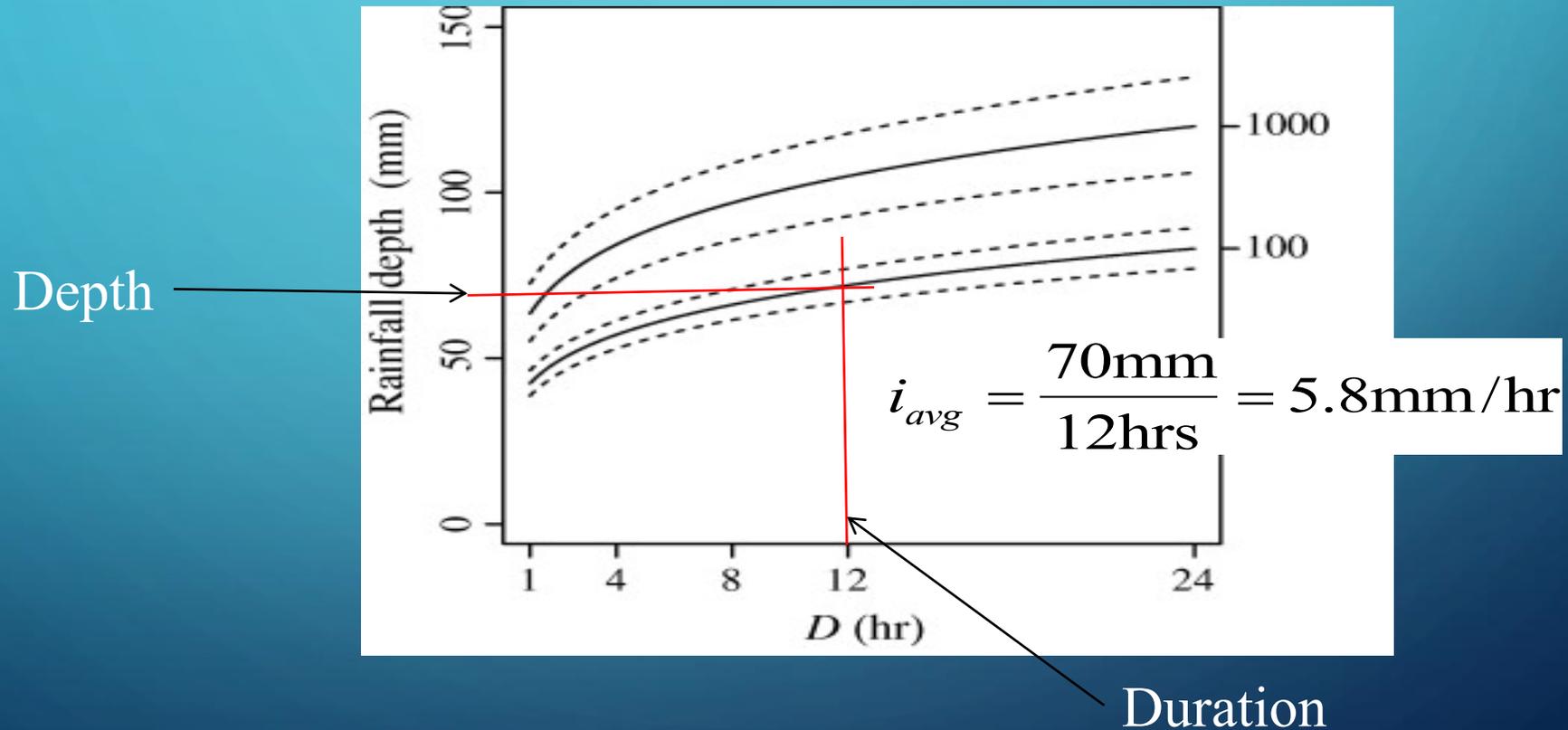
Intensity is NOT the instantaneous rainfall rate

INTENSITY-DEPTH RELATIONSHIP

- Intensity (average rate) from depth

e.g. 12 hour, 100-year (AEP=1%), depth is 70 mm

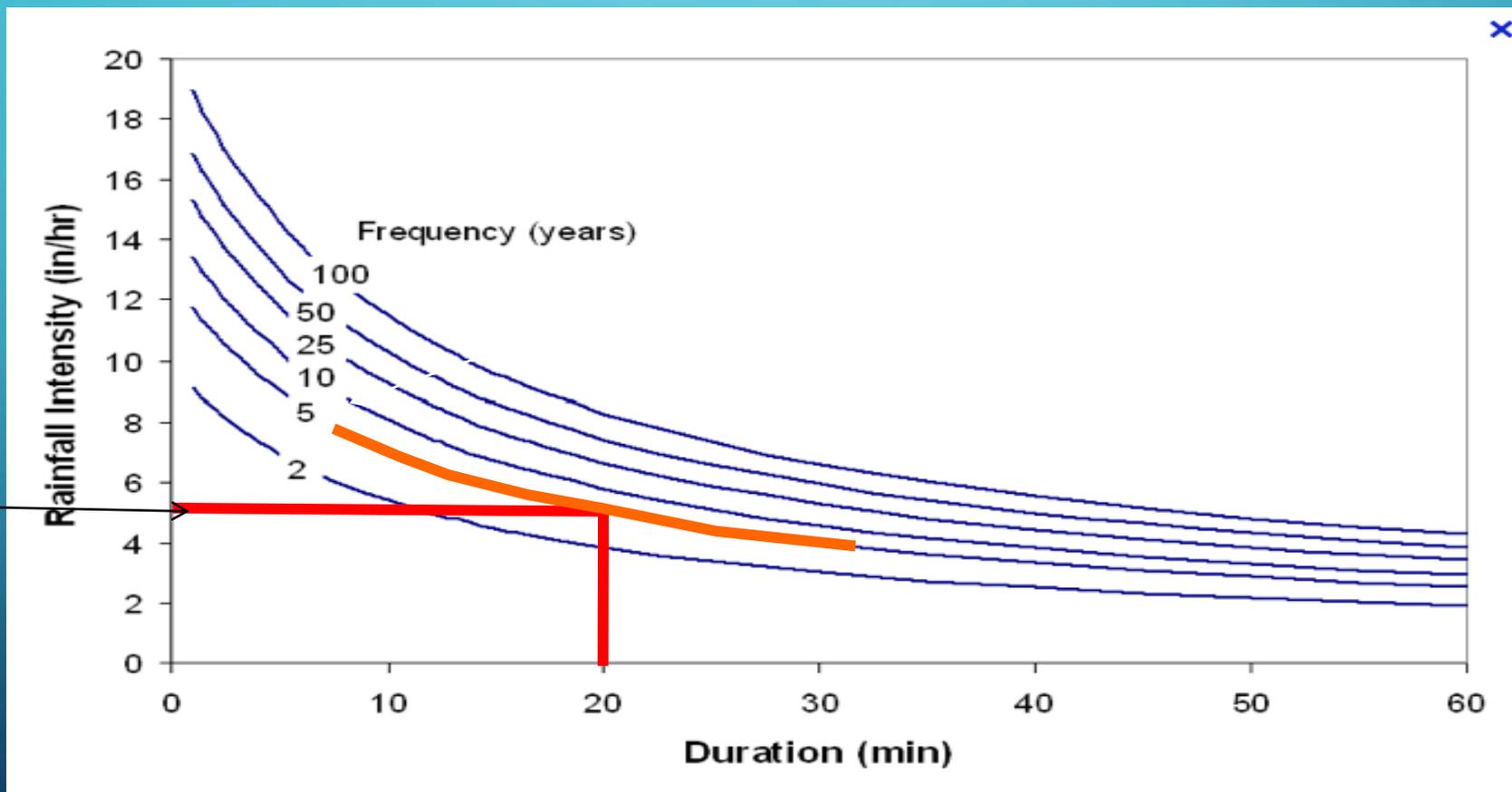
average intensity is $70\text{mm}/12\text{hr} = 5.8 \text{ mm/hr}$



INTENSITY-DURATION-FREQUENCY

- IDF curves

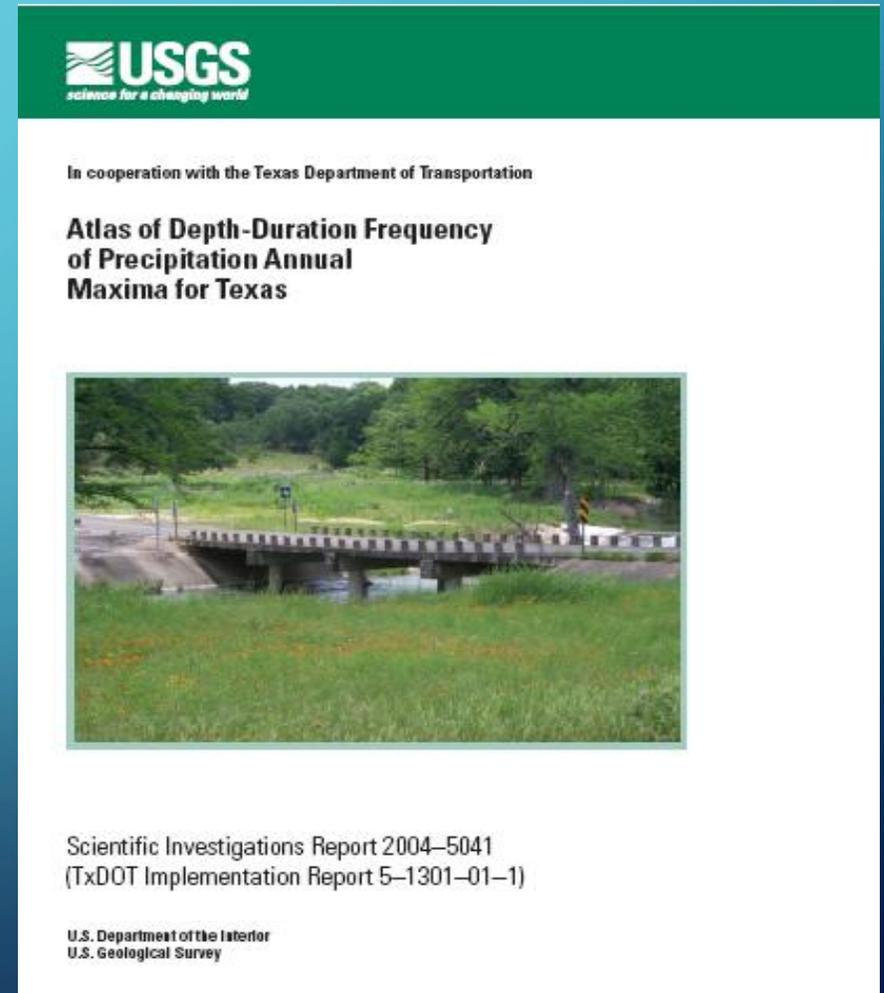
e.g. 20 min, 5-year (AEP=20%), intensity is 5.5 in/hr



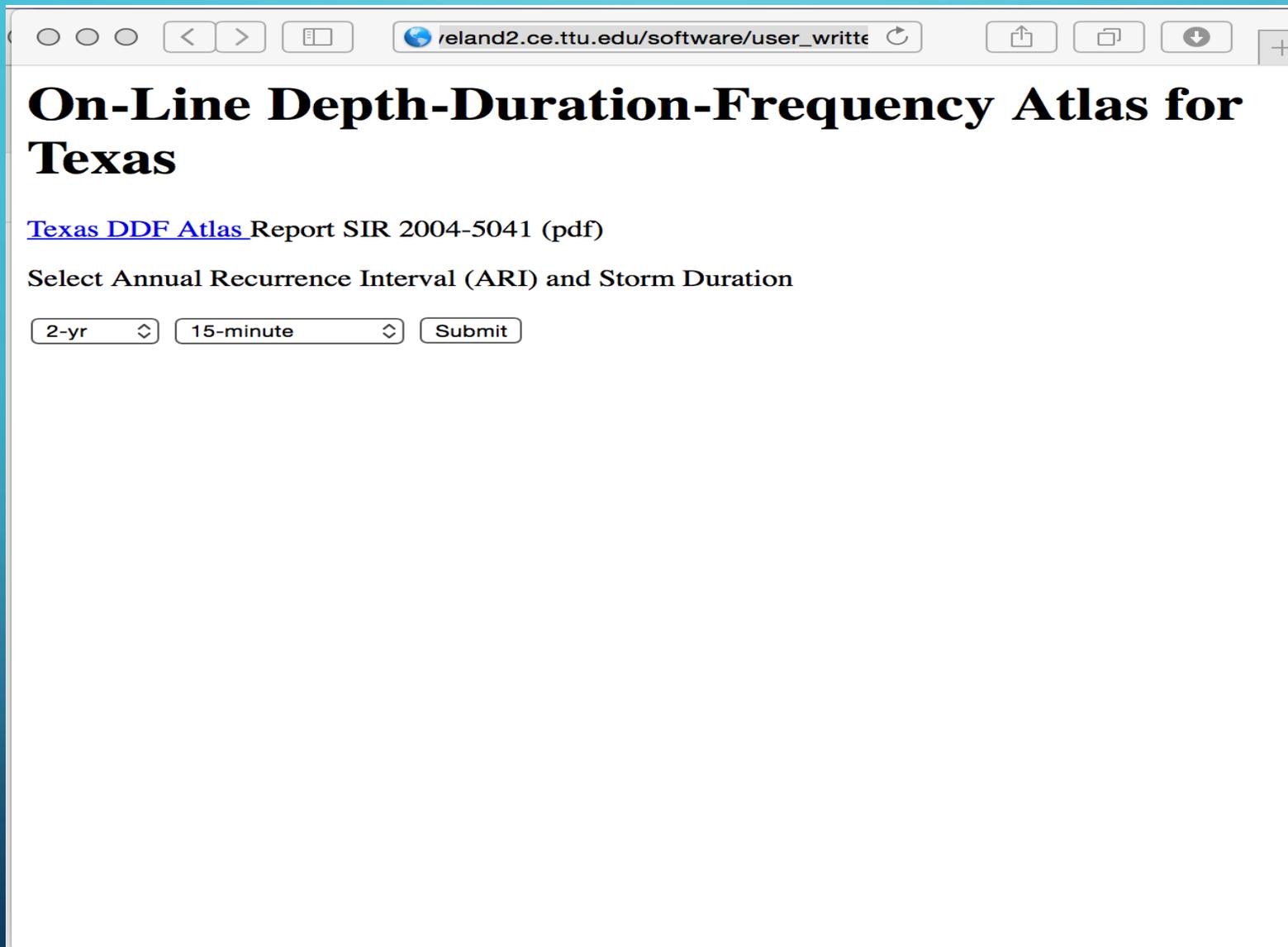
Intensity

ESTIMATING DEPTH AND INTENSITY

- DDF can be constructed from maps of depth for a given duration and AEP.
- Such maps are available from:
 - NWS TP40 (online) << Deprecated
 - NWS HY35 (online) << Deprecated
 - NOAA Atlas 14 (online)
 - Texas DDF Atlas (online) << Deprecated
- Other tools include:
 - EBDLKUP-2015 << Deprecated

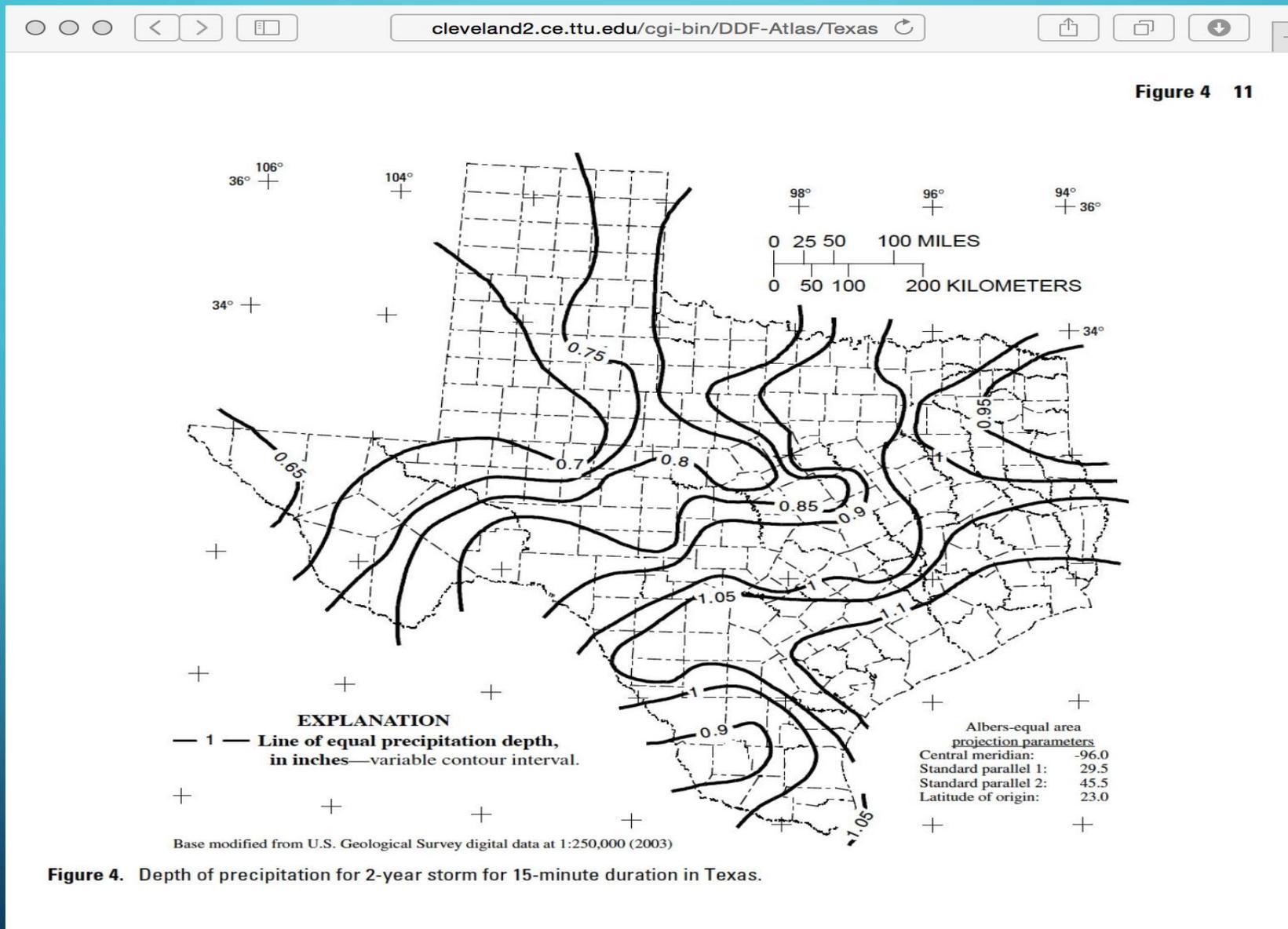


DDF MAPS (DIRECT ACCESS)



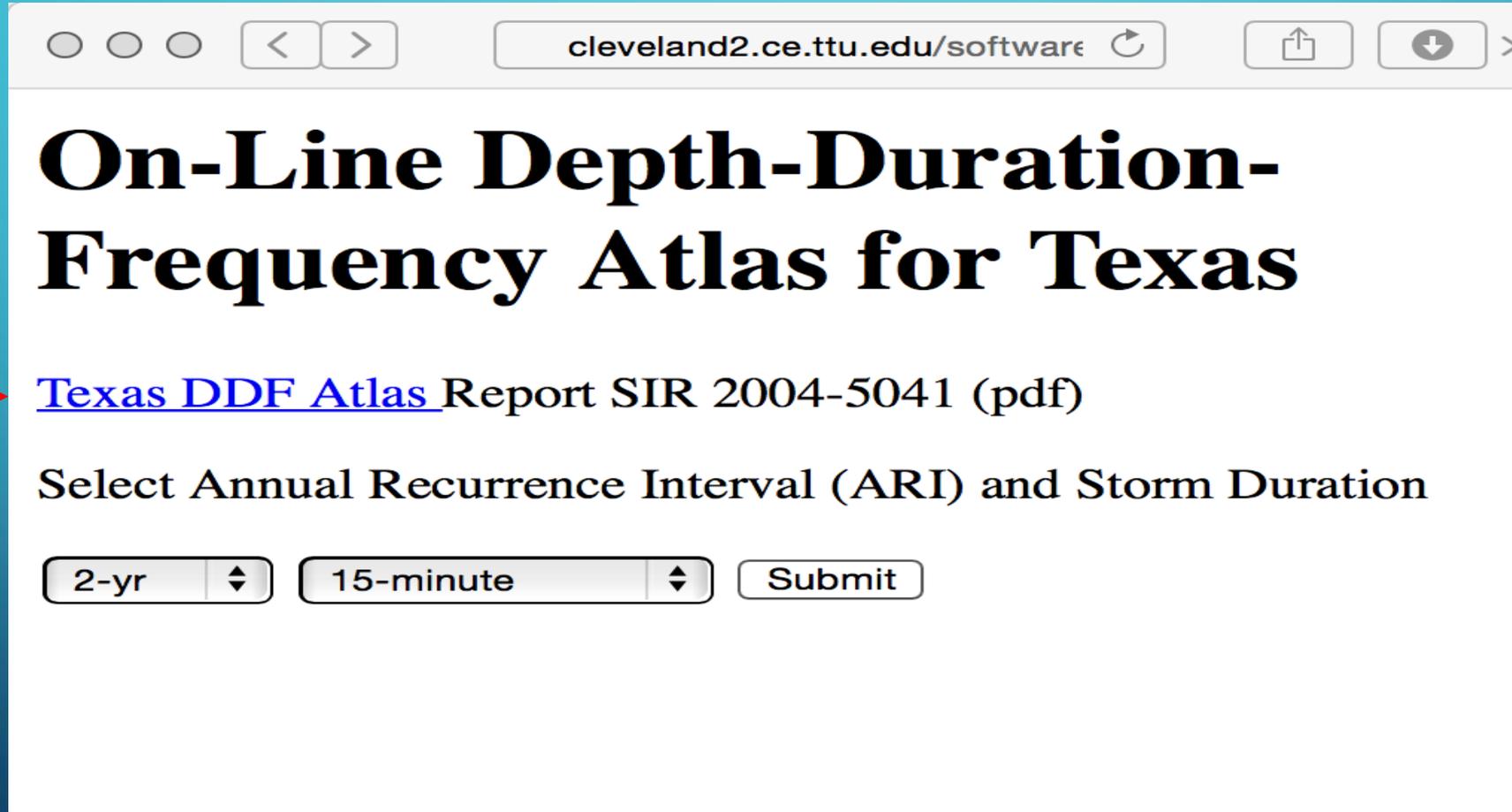
The screenshot shows a web browser window with the address bar containing the URL `reland2.ce.ttu.edu/software/user_writte`. The main heading of the page is **On-Line Depth-Duration-Frequency Atlas for Texas**. Below the heading, there is a link for [Texas DDF Atlas Report SIR 2004-5041 \(pdf\)](#). The page prompts the user to "Select Annual Recurrence Interval (ARI) and Storm Duration". There are two dropdown menus: the first is set to "2-yr" and the second is set to "15-minute". A "Submit" button is located to the right of the second dropdown menu.

DDF MAPS (DIRECT ACCESS)



DDF MAPS (DIRECT ACCESS)

- The interface also has a link to the original document



The screenshot shows a web browser window with the address bar containing 'cleveland2.ce.ttu.edu/software'. The main heading is 'On-Line Depth-Duration-Frequency Atlas for Texas'. Below the heading, there is a blue underlined link 'Texas DDF Atlas Report SIR 2004-5041 (pdf)' which is highlighted by a red arrow. Underneath the link, the text reads 'Select Annual Recurrence Interval (ARI) and Storm Duration'. At the bottom, there are two dropdown menus: the first is set to '2-yr' and the second is set to '15-minute'. To the right of these dropdowns is a 'Submit' button.

NOAA ATLAS 14

- ~~A tool for use outside Texas is NOAA Atlas 14~~

- ~~Texas is one of a few states not yet in the Atlas~~

- The Atlas is an on-line tool that returns tables of depths for given geographic locations
- The on-line tool is called the Precipitation Frequency Data Server

<http://hdsc.nws.noaa.gov/hdsc/pfds/>

NOAA ATLAS 14

hdsc.nws.noaa.gov/hdsc/pfds/

NOAA's National Weather Service
Hydrometeorological Design Studies Center
Precipitation Frequency Data Server (PFDS)

Home Site Map News Organization Search NWS All NOAA Go

State:

General Info
Homepage
Current Projects
FAQ
Glossary

Precipitation Frequency (PF)
PF Data Server

- PF in GIS Format
- PF Maps
- Temporal Distr.
- Time Series Data
- PFDS Perform.

PF Documents

Probable Maximum Precipitation (PMP)
PMP Documents

Miscellaneous
Publications
AEP Storm Analysis
Record Precipitation

Contact Us
Inquiries
List-server

USA.gov
U.S. Department of Commerce
National Oceanic and Atmospheric Administration

Precipitation Frequency Data Server (PFDS)

The Precipitation Frequency Data Server (PFDS) is a point-and-click interface developed to deliver NOAA Atlas 14 precipitation frequency estimates and associated information. Upon clicking a state on the map

NOAA ATLAS 14

hdsc.nws.noaa.gov/hdsc/pfds/pfds_map_cont.html?bkmrk=ok

PF Data Server Home - HDSC/OHD/NWS/NOAA

NOAA ATLAS 14 POINT PRECIPITATION FREQUENCY ESTIMATES: OK

DATA DESCRIPTION

Data type: precipitation depth Units: english Time series type: annual maximum

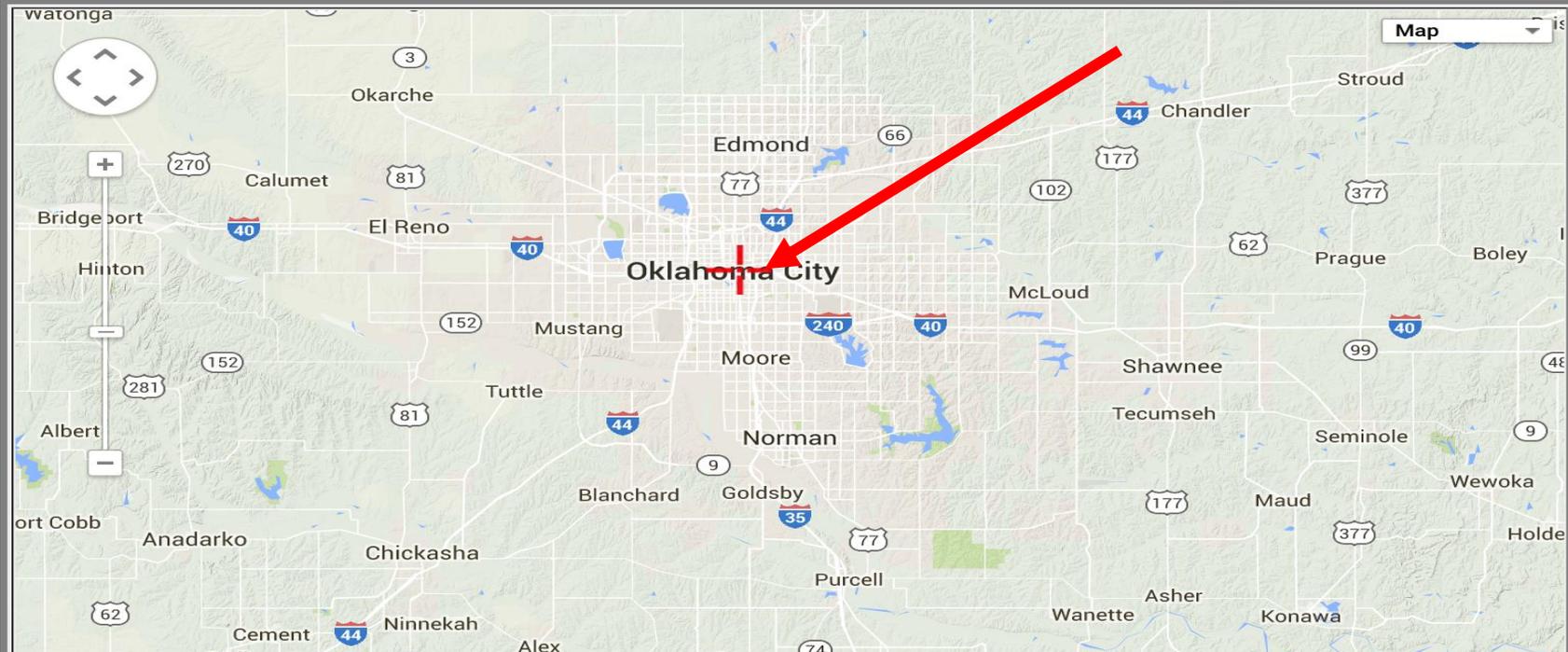
SELECT LOCATION

1. Manually:

a) Enter location (decimal degrees, use "-" for S and W): latitude: longitude: submit

b) Select station (click here for a list of stations used in frequency analysis for OK): select station

2. Use map:



Map

a) Select location
(move crosshair or double click)

b) Click on station icon
(show stations on map)

LOCATION INFORMATION:
Name: Oklahoma City, Oklahoma, US*
Latitude: 35.4689°
Longitude: -97.5079°
Elevation: 1214 ft*

USA.gov

AMS-based precipitation frequency estimates with 90% confidence intervals (in inches)¹

Duration	Annual exceedance probability (1/years)								
	1/2	1/5	1/10	1/25	1/50	1/100	1/200	1/500	1/1000
5-min	0.457 (0.359-0.589)	0.596 (0.467-0.770)	0.706 (0.549-0.915)	0.857 (0.645-1.14)	0.976 (0.718-1.31)	1.10 (0.780-1.51)	1.23 (0.834-1.72)	1.40 (0.915-2.00)	1.53 (0.976-2.21)
10-min	0.669 (0.526-0.863)	0.873 (0.683-1.13)	1.03 (0.804-1.34)	1.25 (0.945-1.67)	1.43 (1.05-1.92)	1.61 (1.14-2.21)	1.79 (1.22-2.51)	2.05 (1.34-2.93)	2.25 (1.43-3.24)
15-min	0.816 (0.641-1.05)	1.06 (0.833-1.38)	1.26 (0.981-1.63)	1.53 (1.15-2.04)	1.74 (1.28-2.35)	1.96 (1.39-2.69)	2.19 (1.49-3.06)	2.50 (1.63-3.57)	2.74 (1.74-3.95)
30-min	1.19 (0.937-1.54)	1.56 (1.22-2.02)	1.86 (1.45-2.41)	2.26 (1.70-3.01)	2.58 (1.89-3.47)	2.90 (2.06-3.98)	3.24 (2.21-4.54)	3.71 (2.42-5.29)	4.07 (2.58-5.87)
60-min	1.57 (1.24-2.03)	2.08 (1.62-2.68)	2.48 (1.93-3.21)	3.05 (2.30-4.07)	3.50 (2.58-4.72)	3.98 (2.82-5.46)	4.47 (3.05-6.27)	5.16 (3.38-7.39)	5.71 (3.63-8.23)
2-hr	1.95 (1.55-2.49)	2.59 (2.05-3.30)	3.10 (2.44-3.97)	3.83 (2.93-5.08)	4.43 (3.29-5.92)	5.05 (3.63-6.88)	5.70 (3.93-7.94)	6.62 (4.38-9.41)	7.35 (4.72-10.5)
3-hr	2.18 (1.74-2.76)	2.89 (2.30-3.67)	3.48 (2.76-4.43)	4.33 (3.34-5.72)	5.03 (3.77-6.70)	5.77 (4.17-7.84)	6.56 (4.55-9.10)	7.67 (5.11-10.9)	8.56 (5.53-12.2)
6-hr	2.59 (2.09-3.24)	3.41 (2.75-4.27)	4.11 (3.29-5.17)	5.15 (4.03-6.76)	6.02 (4.58-7.97)	6.96 (5.10-9.39)	7.97 (5.60-11.0)	9.42 (6.35-13.3)	10.6 (6.91-15.0)
12-hr	3.02 (2.47-3.73)	3.92 (3.20-4.85)	4.71 (3.82-5.86)	5.91 (4.68-7.71)	6.93 (5.34-9.11)	8.05 (5.97-10.8)	9.27 (6.58-12.7)	11.0 (7.51-15.5)	12.5 (8.22-17.5)
24-hr	3.47 (2.87-4.23)	4.47 (3.69-5.47)	5.36 (4.40-6.58)	6.72 (5.39-8.68)	7.88 (6.14-10.3)	9.16 (6.88-12.2)	10.6 (7.58-14.4)	12.6 (8.67-17.5)	14.3 (9.49-19.9)
2-day	3.94 (3.30-4.75)	5.10 (4.26-6.16)	6.12 (5.08-7.42)	7.65 (6.20-9.75)	8.95 (7.05-11.5)	10.4 (7.87-13.6)	11.9 (8.65-16.1)	14.2 (9.85-19.5)	16.0 (10.8-22.2)
3-day	4.29 (3.62-5.13)	5.52 (4.64-6.62)	6.60 (5.51-7.94)	8.21 (6.69-10.4)	9.56 (7.58-12.2)	11.0 (8.42-14.4)	12.6 (9.23-16.9)	14.9 (10.5-20.5)	16.8 (11.4-23.3)
4-day	4.58 (3.88-5.45)	5.88 (4.96-7.01)	7.00 (5.87-8.38)	8.65 (7.08-10.9)	10.0 (7.99-12.7)	11.5 (8.84-15.0)	13.2 (9.64-17.6)	15.5 (10.9-21.2)	17.4 (11.8-23.9)
7-day	5.32 (4.56-6.27)	6.80 (5.81-8.04)	8.03 (6.81-9.52)	9.78 (8.04-12.1)	11.2 (8.98-14.0)	12.7 (9.81-16.3)	14.3 (10.6-18.9)	16.6 (11.7-22.5)	18.4 (12.6-25.2)
10-day	5.97 (5.15-6.99)	7.57 (6.50-8.89)	8.86 (7.56-10.4)	10.7 (8.80-13.1)	12.1 (9.74-15.0)	13.6 (10.5-17.3)	15.2 (11.2-19.9)	17.4 (12.3-23.4)	19.1 (13.2-26.0)
20-day	7.77 (6.78-8.98)	9.59 (8.34-11.1)	11.0 (9.50-12.8)	12.9 (10.7-15.5)	14.4 (11.7-17.6)	15.9 (12.4-19.9)	17.4 (13.0-22.5)	19.4 (13.9-25.9)	21.0 (14.7-28.5)
30-day	9.23 (8.12-10.6)	11.3 (9.87-13.0)	12.8 (11.2-14.8)	14.9 (12.5-17.7)	16.4 (13.4-19.9)	18.0 (14.2-22.4)	19.5 (14.7-25.1)	21.6 (15.6-28.6)	23.2 (16.3-31.3)
45-day	11.1 (9.79-12.6)	13.5 (11.9-15.4)	15.3 (13.4-17.5)	17.6 (14.9-20.8)	19.4 (15.9-23.3)	21.1 (16.7-26.1)	22.8 (17.2-29.0)	25.0 (18.1-32.9)	26.6 (18.8-35.7)
60-day	12.6 (11.2-14.2)	15.4 (13.7-17.5)	17.5 (15.5-20.0)	20.2 (17.1-23.7)	22.2 (18.3-26.5)	24.1 (19.2-29.6)	26.0 (19.7-32.9)	28.3 (20.6-37.1)	30.1 (21.3-40.2)

¹ Precipitation frequency (PF) estimates in this table are based on frequency analysis of annual maxima series (AMS). Numbers in parenthesis are PF estimates at lower and upper bounds of the 90% confidence interval. The probability that precipitation frequency estimates (for a given duration and annual

EBDLKUP-2015

- EBDLKUP-2015 is a spreadsheet tool for Texas that produces intensity estimates by county for user supplied averaging times

$$I_{AEP;COUNTY} = \frac{B}{(T_c + D)^E} \quad (1)$$

where I is the intensity in inches per hour, T_c is the time of concentration in minutes, B is a scaling value, D is an offset, and E is an exponent.

- The intensity estimates are based on the depths in the DDF Atlas
- Suitable for Texas Only

DEPRECATED SHOULD NOT USE

USE NOAA ATLAS 14

DEPTH, INTENSITY, AND DURATION

- Conversion from Depth-Duration to Intensity-Duration is obtained by the ratio of depth to duration

$$i_{avg} = \frac{D}{T_C}$$

- Conversion from Intensity-Duration to Depth-Duration is obtained by multiplication

$$D = i_{avg} * T_C$$



DESIGN HYETOGRAPHS

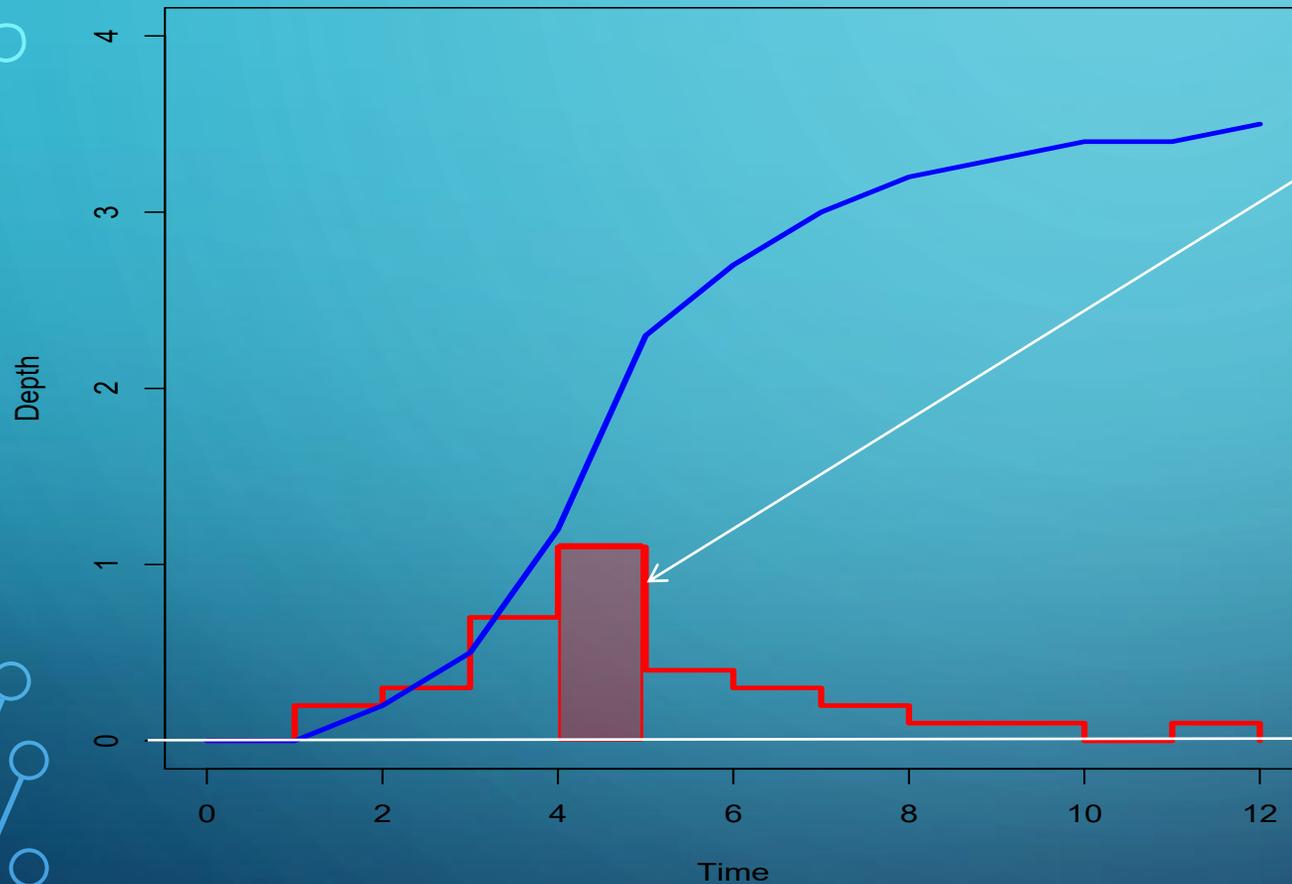
HYETOGRAPHS

- The IDF approach only estimates average rate (over an averaging time)
- When time behavior of a storm is important then we have to generate hyetographs (time series of rainfall)
- Design storms are statistical models of such temporal behavior and are used in hydrologic models when hydrographs need to be generated

RAINFALL DISTRIBUTIONS

- Rainfall distributions represent temporal patterns of a storm.
- A rainfall distribution is also called a hyetograph.
- Rainfall distributions are used when we need to estimate an entire hydrograph.

RAINFALL DISTRIBUTIONS



- Each “block” represents the amount of rainfall for the time interval
- The diagram is called “incremental” rainfall
- The running sum of the blocks is the cumulative distribution

RAINFALL DISTRIBUTIONS

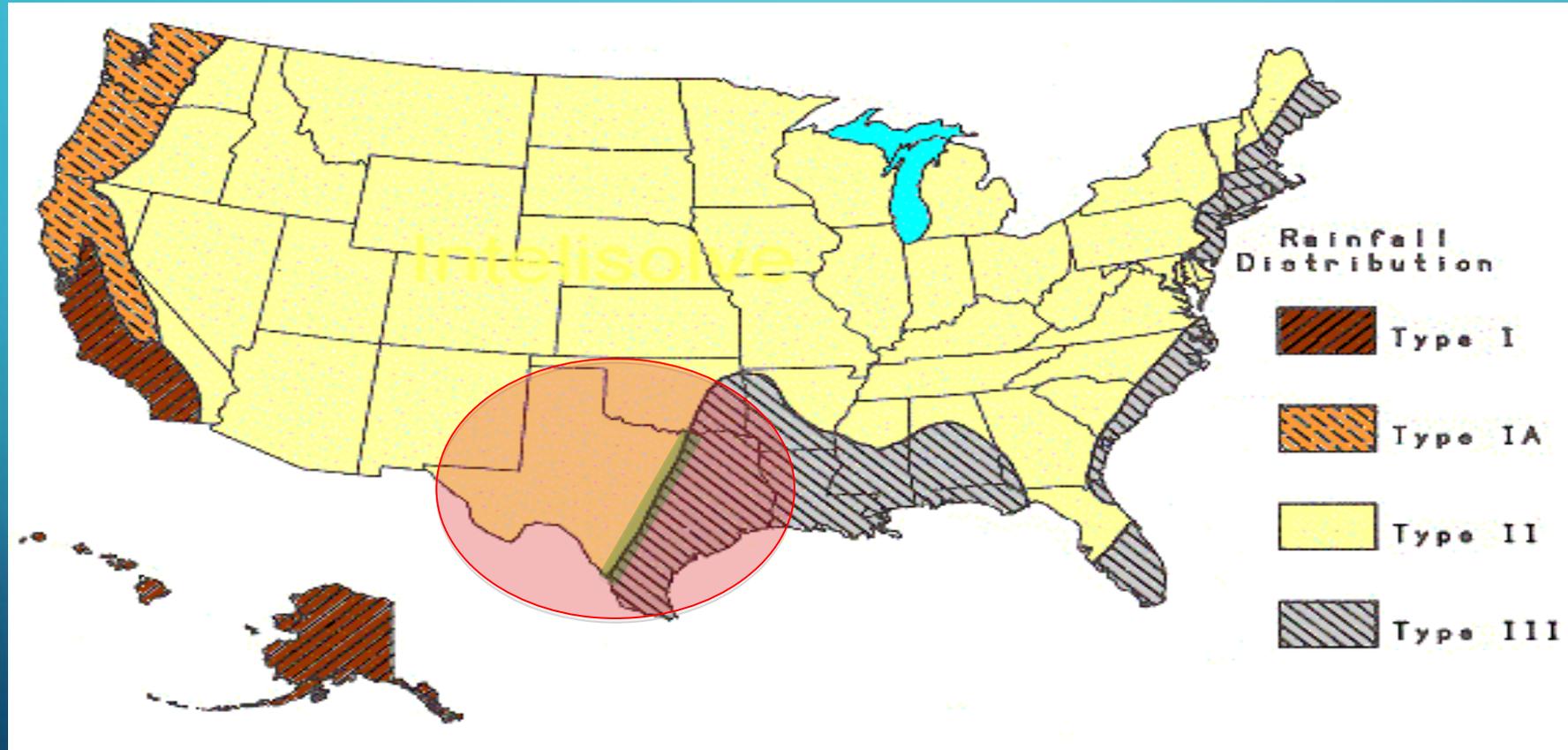
- Distributions are created from historical storms and analyzed to generate statistical models of rainfall – these models are called design storms.
- Design storm distributions are typically dimensionless hyetographs
 - NRCS Type Storms (24 hour, 6 hour)
 - Empirical Texas Hyetographs (TxHYETO-2015)

SCS RAINFALL TYPE CURVES

- SCS(1973) analyzed DDF curves to develop dimensionless rainfall temporal patterns called type curves for four different regions in the US.
- SCS type curves are in the form of percentage mass (cumulative) curves based on 24-hr rainfall of the desired frequency.
- Intended for use with the SCS Curve Number runoff generation model!

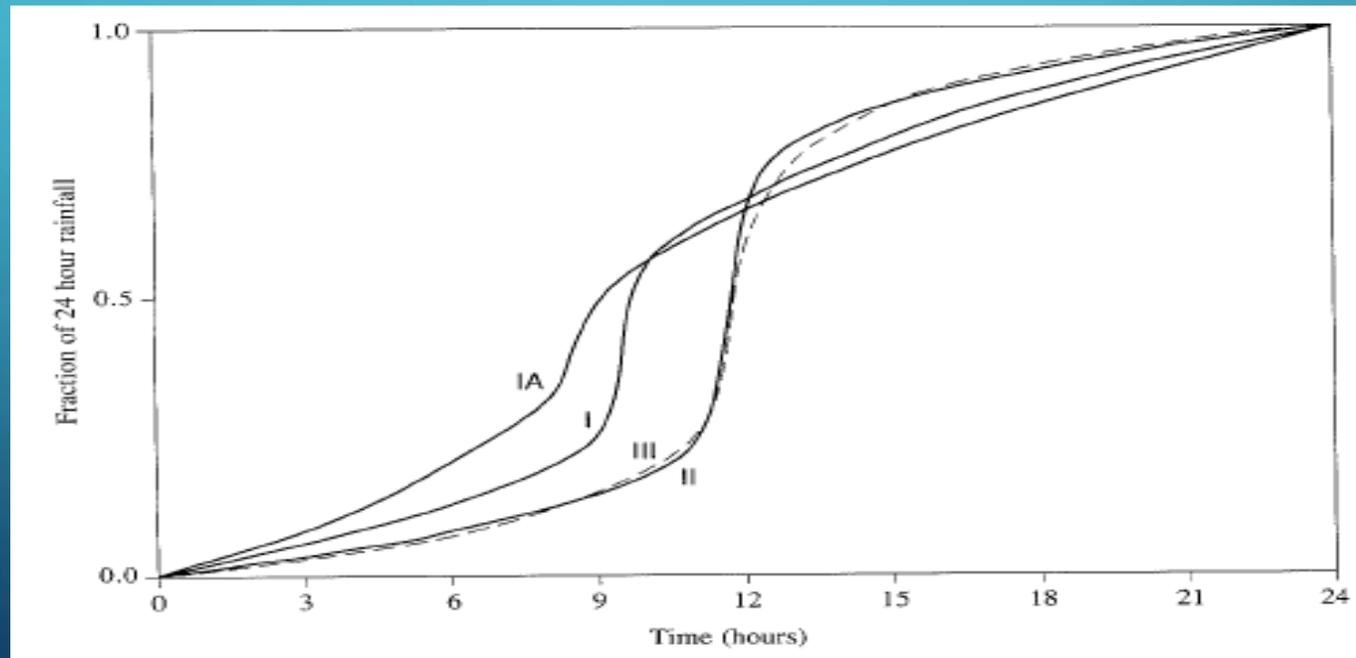
SCS RAINFALL TYPE CURVES

- Location selects the Type Curve



SCS RAINFALL TYPE CURVES

- The 24-hour precipitation depth of desired frequency is specified (DDF Atlas), the SCS type curve is rescaled (multiplied by the known number) to get the time distribution.



RAINFALL DISTRIBUTIONS

	A	B	C	D	E	F
1	SCS 24-hour Rainfall Distribution (from Chow, Maidment, Mays, 1988 pg. 461)					
2	Pt/P24					
3	Hour t	t/24	Type - I	Type-IA	Type-II	Type-III
4	0	0	0	0	0	0
5	2	0.083	0.035	0.05	0.022	0.02
6	4	0.167	0.076	0.116	0.048	0.043
7	6	0.25	0.125	0.206	0.08	0.072
8	7	0.292	0.156	0.268	0.098	0.089
9	8	0.333	0.194	0.425	0.12	0.115
10	8.5	0.354	0.219	0.48	0.133	0.13
11	9	0.375	0.254	0.52	0.147	0.148
12	9.5	0.396	0.303	0.55	0.163	0.167
13	9.75	0.406	0.362	0.564	0.172	0.178
14	10	0.417	0.515	0.577	0.181	0.189
15	10.5	0.438	0.583	0.601	0.204	0.216
16	11	0.459	0.624	0.624	0.235	0.25
17	11.5	0.479	0.654	0.645	0.283	0.298
18	11.75	0.489	0.669	0.655	0.357	0.339
19	12	0.5	0.682	0.664	0.663	0.5
20	12.5	0.521	0.706	0.683	0.735	0.702
21	13.6	0.542	0.727	0.701	0.772	0.751
22	13.5	0.563	0.748	0.719	0.799	0.785
23	14	0.583	0.767	0.736	0.82	0.811
24	16	0.667	0.83	0.8	0.88	0.886
25	20	0.833	0.926	0.906	0.952	0.957
26	24	1	1	1	1	1

RAINFALL DISTRIBUTIONS

	A	B	C	D	E	F
1	SCS 6-hour Rainfall Distribution (from Chow, Maidment, Mays, 1988 pg. 461)					
2	Hour t	t/6	Pt/P6			
3	0	0	0			
4	0.6	0.1	0.04			
5	1.2	0.2	0.1			
6	1.5	0.25	0.14			
7	1.8	0.3	0.19			
8	2.1	0.35	0.31			
9	2.28	0.38	0.44			
10	2.4	0.4	0.53			
11	2.52	0.42	0.6			
12	2.64	0.44	0.63			
13	2.76	0.46	0.66			
14	3	0.5	0.7			
15	3.3	0.55	0.75			
16	3.6	0.6	0.79			
17	3.9	0.65	0.83			
18	4.2	0.7	0.86			
19	4.5	0.75	0.89			
20	4.8	0.8	0.91			
21	5.4	0.9	0.96			
22	6	1	1			
23						
24						

SCS RAINFALL TYPE CURVES

Using the Type Curves

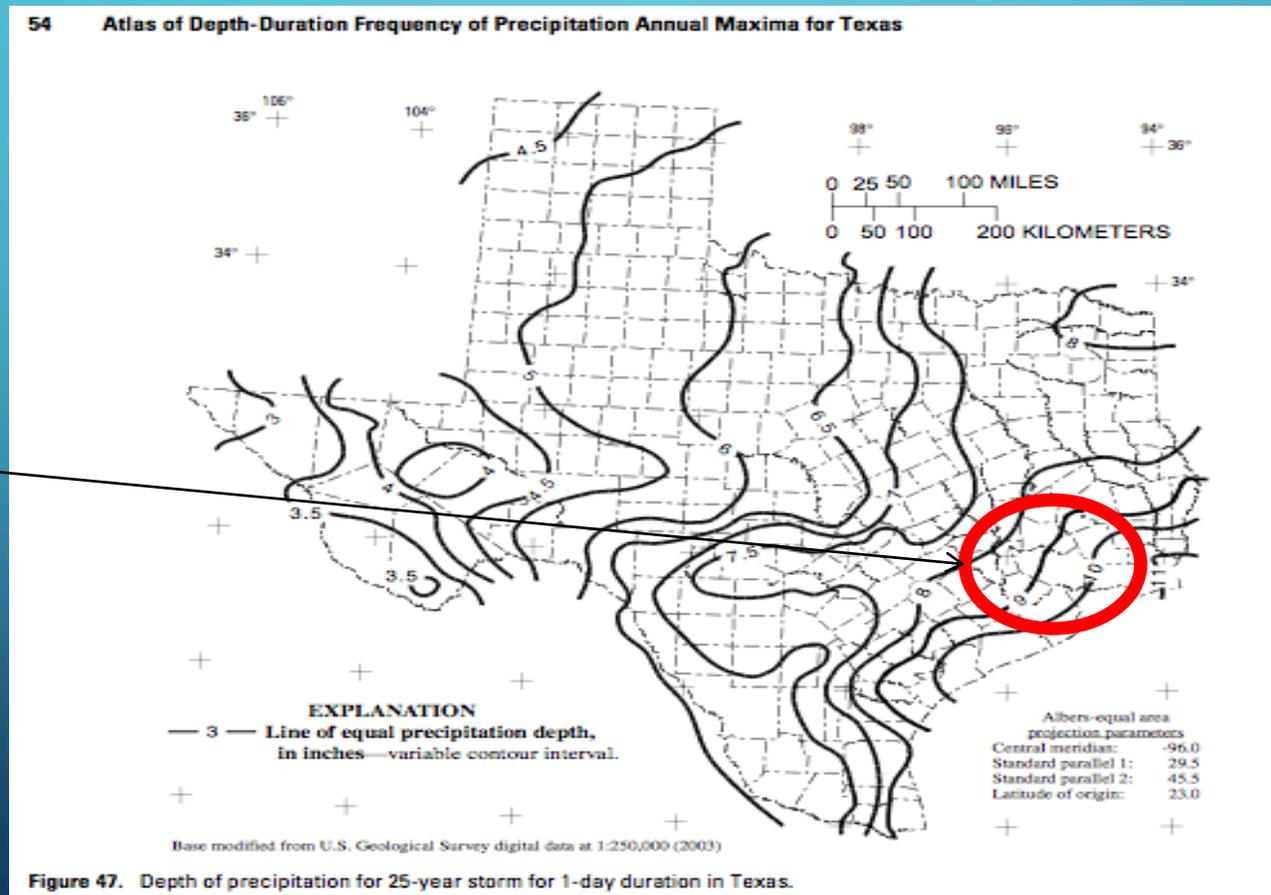
1. Use DDF Atlas, TP-40, etc. to set total depth, P for the 24 hour storm (or 6 hour storm)
2. Pick appropriate SCS type curve (location).
3. Multiply (rescale) the type curve with P to get the design mass curve.
4. Get the incremental precipitation from the rescaled mass curve to develop the design hyetograph.

EXAMPLE: SCS DESIGN STORM

- Generate a design hyetograph for a 25-year, 24-hour duration SCS Type-III storm in Harris County using a one-hour time increments
 1. Look up 24-hour, 25-year depth for Harris County in the DDF Atlas.
 2. Cumulative fraction - interpolate SCS table
 3. Cumulative rainfall = product of cumulative fraction * total 24-hour rainfall (10.01 in)
 4. Incremental rainfall = difference between current and preceding cumulative rainfall
 5. Plot results of incremental

EXAMPLE: GENERATE SCS DESIGN STORM

- Look up 24-hour, 25-year depth for Harris County in the DDF Atlas.



P ~ 10 inches

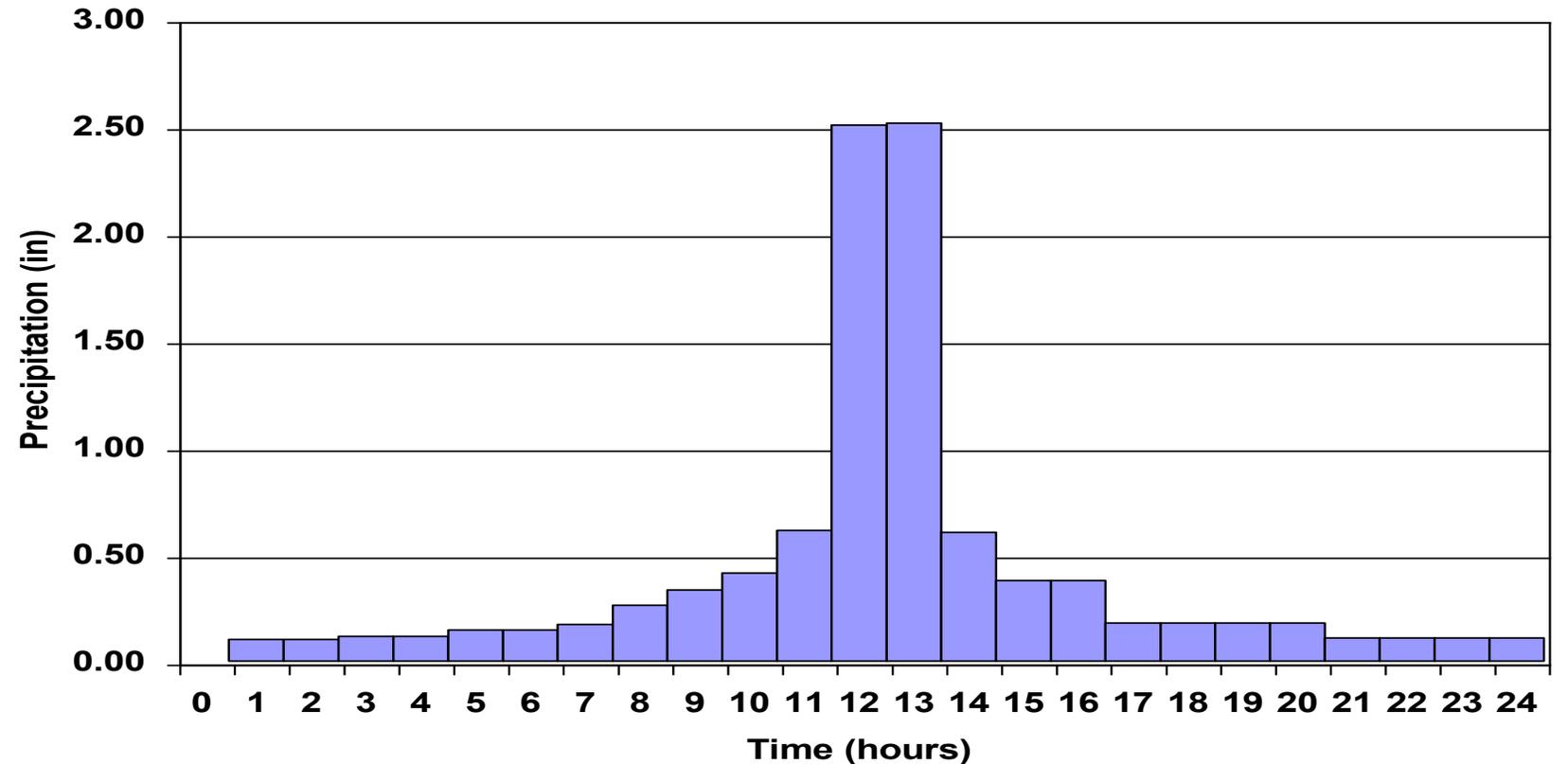
EXAMPLE: SCS DESIGN STORM

SCS Tabulation

DDF Atlas

$$p(t) = \frac{P_t}{P_{24}} \square P$$

Time	Cumulative Fraction	Cumulative Precipitation	Incremental Precipitation
(hours)	Pt/P24	Pt (in)	(in)
0	0.000	0.00	0.00
1	0.010	0.10	0.10
2	0.020	0.20	0.10
3	0.032	0.32	0.12
4	0.043	0.43	0.12
5	0.058	0.58	0.15
6	0.072	0.72	0.15
7	0.089	0.89	0.17
8	0.115	1.15	0.26
9	0.148	1.48	0.33
10	0.189	1.89	0.41
11	0.250	2.50	0.61
12	0.500	5.01	2.50
13	0.751	7.52	2.51
14	0.811	8.12	0.60
15	0.849	8.49	0.38
16	0.886	8.87	0.38
17	0.904	9.05	0.18
18	0.922	9.22	0.18
19	0.939	9.40	0.18
20	0.957	9.58	0.18
21	0.968	9.69	0.11
22	0.979	9.79	0.11
23	0.989	9.90	0.11
24	1.000	10.00	0.11



TEXAS EMPIRICAL HYETOGRAPHS

- Alternative to SCS Type Curves is the Texas Empirical Hyetographs
 - Based on Texas data.
 - Reflects “front loading” observed in many real storms.
 - Rescales time and depth.



In cooperation with the Texas Department of Transportation

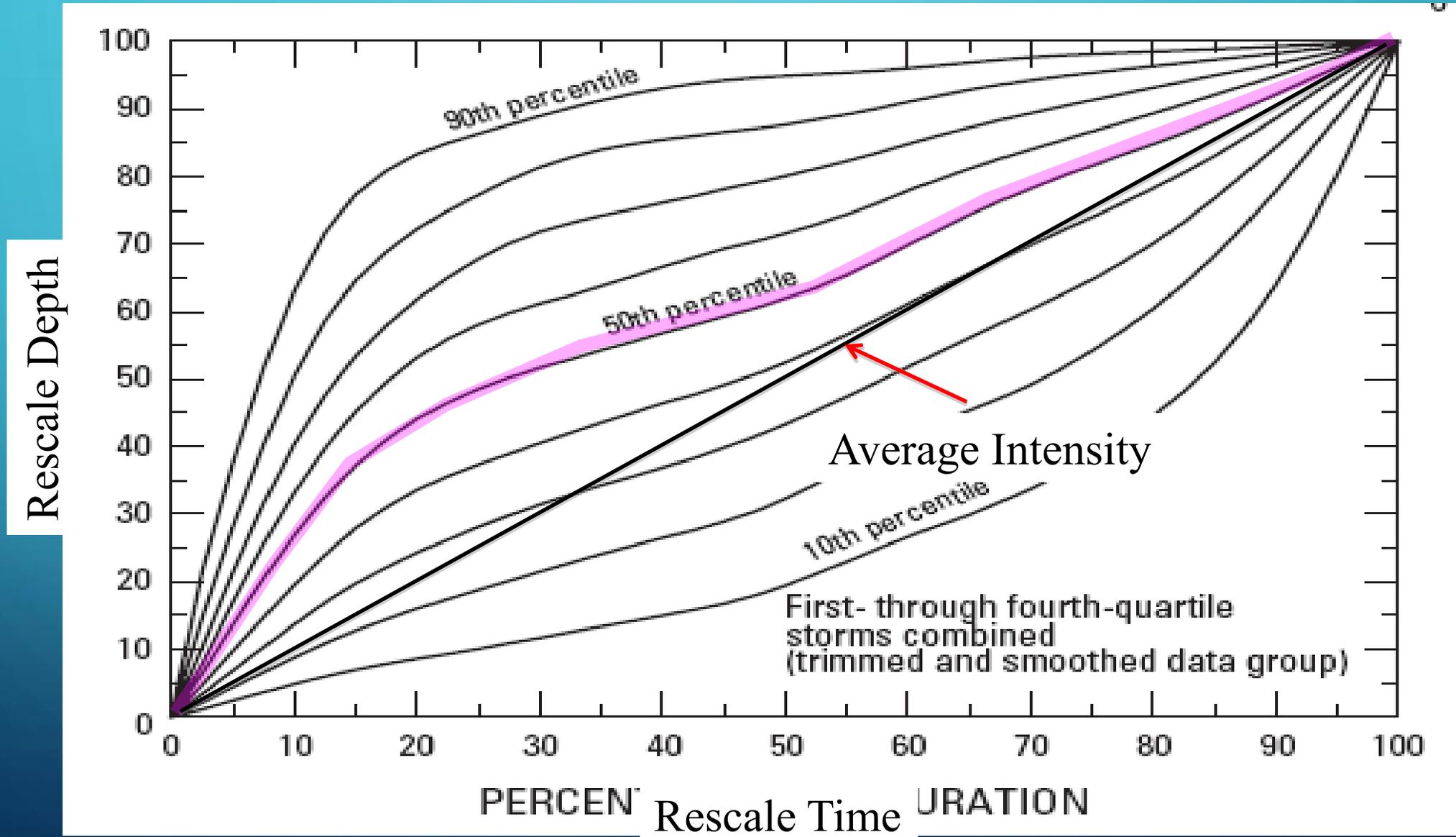
Empirical, Dimensionless, Cumulative-Rainfall Hyetographs Developed From 1959–86 Storm Data for Selected Small Watersheds in Texas



Scientific Investigations Report 2004–5075
(TxDOT Research Report 0–4194–3)

U.S. Department of the Interior
U.S. Geological Survey

TEXAS EMPIRICAL HYETOGRAPHS



TEXAS EMPIRICAL HYETOGRAPHS

- Use the 50th percentile curve (median storm).
 1. Multiply the time axis by the storm duration.
 2. Multiply the depth axis by the storm depth.
 3. Result is a design storm for given duration and AEP.

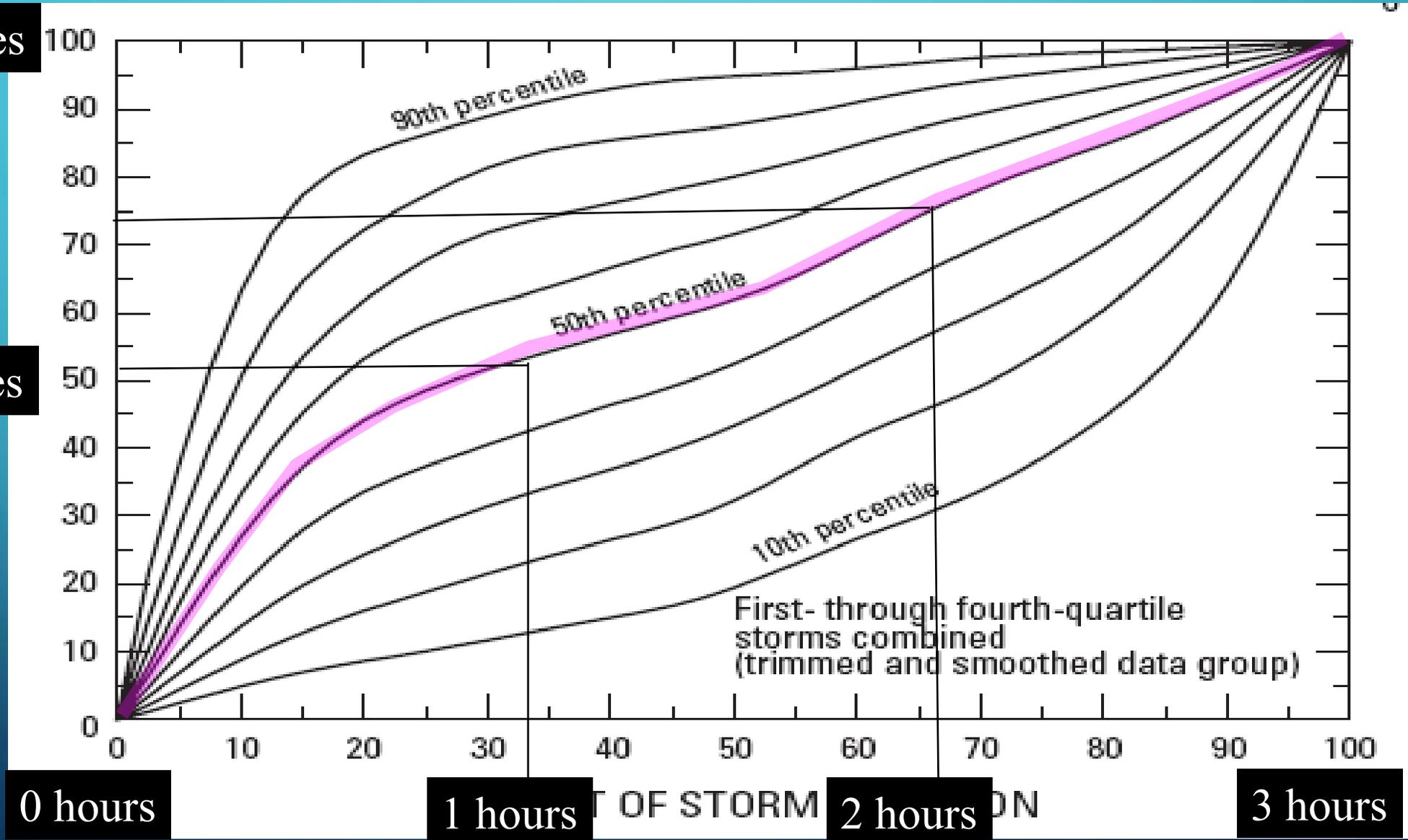
EXAMPLE: TEXAS EMPIRICAL HYETOGRAPHS

- Construct a design storm for the 3-hour, 2-year rainfall in Harris County using the Texas Empirical Hyetograph
 1. Obtain the depth from the DDF Atlas
 2. Rescale the depth and time using the Texas Empirical Hyetograph

EXAMPLE: TEXAS EMPIRICAL HYETOGRAPHS

2.6 inches

1.3 inches



0 hours

1 hours

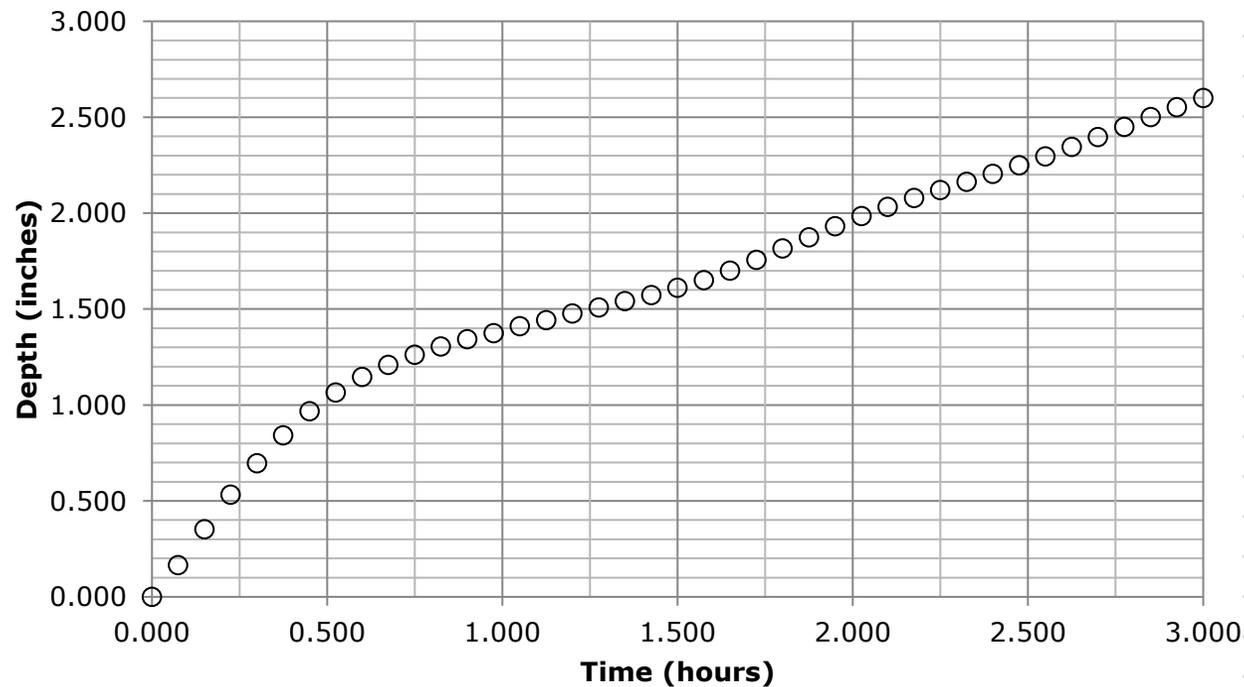
2 hours

3 hours

DURATION OF STORM (MIN)

EXAMPLE: TEXAS EMPIRICAL HYETOGRAPHS

- Probably easier to use the tabulation
- SIR-2004-5075



Duration =>	3	Depth=>	2.6
Fraction Time	Elapsed Time	Fraction Depth	Cumulative Depth
0.000	0.000	0.000	0.000
0.025	0.075	0.064	0.166
0.050	0.150	0.136	0.353
0.075	0.225	0.205	0.533
0.100	0.300	0.268	0.698
0.125	0.375	0.324	0.843
0.150	0.450	0.372	0.967
0.175	0.525	0.410	1.066
0.200	0.600	0.441	1.147
0.225	0.675	0.466	1.210
0.250	0.750	0.485	1.262
0.275	0.825	0.502	1.306
0.300	0.900	0.517	1.344
0.325	0.975	0.529	1.375
0.350	1.050	0.543	1.411
0.375	1.125	0.555	1.443
0.400	1.200	0.568	1.477
0.425	1.275	0.580	1.509
0.450	1.350	0.593	1.542
0.475	1.425	0.605	1.573
0.500	1.500	0.620	1.611

TXHYETO-2015

- Texas Empirical Hyetograph tool that approximates the hyetographs using a function fit.
- User supplies:
 - Depth
 - Duration
 - Desired Time Steps (increments)
- Tool returns a time series of cumulative depth every increment (intended for copy-paste into HEC-HMS)

HYDROLOGIC ANALYSIS

- **Runoff models:**
 - Rational Method
 - HCFCD Discharge-Area Curves (1960s)
 - TxDOT and USGS Regression Equations
 - SCS CN MODEL
- **Infiltration models**
 - GREEN-AMPT
 - HORTON

HYDROLOGIC ANALYSIS

- Unit hydrograph models
 - Clark Unit Hydrograph
 - Soil Conservation Service (SCS) Unit Hydrograph Method
 - Johnson & Sayre Curves and Generalized Regression Equations
 - Gamma uh (Asquith)

Table 3.1 Applications of the Recommended Hydrologic Methods

Method	Rational Method	SCS Method	Modified Rational	Snyder's Unit Hydrograph	USGS / TXDOT Equations	ISWM Water Quality Volume Calculation
Water Quality Protection Volume (WQ_v)						✓
Streambank Protection Volume (SP_v)		✓		✓		
Flood Mitigation Discharge (Q_f)		✓		✓	✓	
Storage Facilities		✓	✓	✓		
Outlet Structures		✓		✓		
Gutter Flow and Inlets	✓					
Storm Drain Pipes	✓	✓		✓		
Culverts	✓	✓		✓	✓	
Bridges		✓		✓		
Small Ditches	✓	✓		✓		
Open Channels		✓		✓	✓	
Energy Dissipation		✓		✓		

Table 3.2 Constraints on Using Recommended Hydrologic Methods

Method	Size Limitations ¹	Comments
Rational	0 – 100 acres	Method can be used for estimating peak flows and the design of small site or subdivision storm sewer systems.
Modified Rational ²	0 – 200 acres	Method can be used for estimating runoff volumes for storage design.
Unit Hydrograph (SCS) ³	Any Size	Method can be used for estimating peak flows and hydrographs for all design applications.
Unit Hydrograph (Snyder's) ⁴	1 acre and larger	Method can be used for estimating peak flows and hydrographs for all design applications.
TXDOT Regression Equations	10 to 100 mi ²	Method can be used for estimating peak flows for rural design applications.
USGS Regression Equations	3 – 40 mi ²	Method can be used for estimating peak flows for urban design applications.
iSWM Water Quality Protection Volume Calculation	Limits set for each Structural Control	Method can be used for calculating the Water Quality Protection Volume (WQ _v).

¹ Size limitation refers to the drainage basin for the stormwater management facility (e.g., culvert, inlet).

² Where the Modified Rational Method is used for conceptualizing, the engineer is cautioned that the method could underestimate the storage volume.

³ This refers to SCS routing methodology included in many readily available programs (such as HEC-HMS or HEC-1) that utilize this methodology.

⁴ This refers to the Snyder's methodology included in many readily available programs (such as HEC-HMS or HEC-1) that utilize this methodology.

A decorative graphic on the left side of the page, consisting of white lines and circles on a blue background, resembling a circuit board or data network.

PEAK DISCHARGE

RATIONAL METHOD

- $Q_p = CiA$

where

Q_p = peak runoff [L^3/T]

C = a dimensionless coefficient

i = rainfall intensity [L/T]

A = drainage area [L^2]

RATIONAL METHOD - C

TABLE 7-10 Runoff Coefficients for the Rational Method

Description of Area	Range of Runoff Coefficients	Recommended Value*
Business		
Downtown	0.70–0.95	0.85
Neighborhood	0.50–0.70	0.60
Residential		
Single-family	0.30–0.50	0.40
Multiunits, detached	0.40–0.60	0.50
Multiunits, attached	0.60–0.75	0.70
Residential (suburban)	0.25–0.40	0.35
Apartment	0.50–0.70	0.60
Industrial		
Light	0.50–0.80	0.65
Heavy	0.60–0.90	0.75
Parks, cemeteries	0.10–0.25	0.20
Playgrounds	0.20–0.35	0.30
Railroad yard	0.20–0.35	0.30
Unimproved	0.10–0.30	0.20

It is often desirable to develop a composite runoff coefficient based on the percentage of different types of surface in the drainage area. This procedure often is applied to typical "sample" block as a guide to selection of reasonable values of the coefficient for an entire area. Coefficients with respect to surface type currently in use are listed below.

RATIONAL METHOD - I

$$Q_p = CiA$$

- Rainfall intensity (I) = total amount of rain (rainfall depth) falling over a given time of concentration $[L/T]$

$$I = \frac{P_d}{t_c}$$

$$i = \frac{b}{(t_c + d)^e}$$

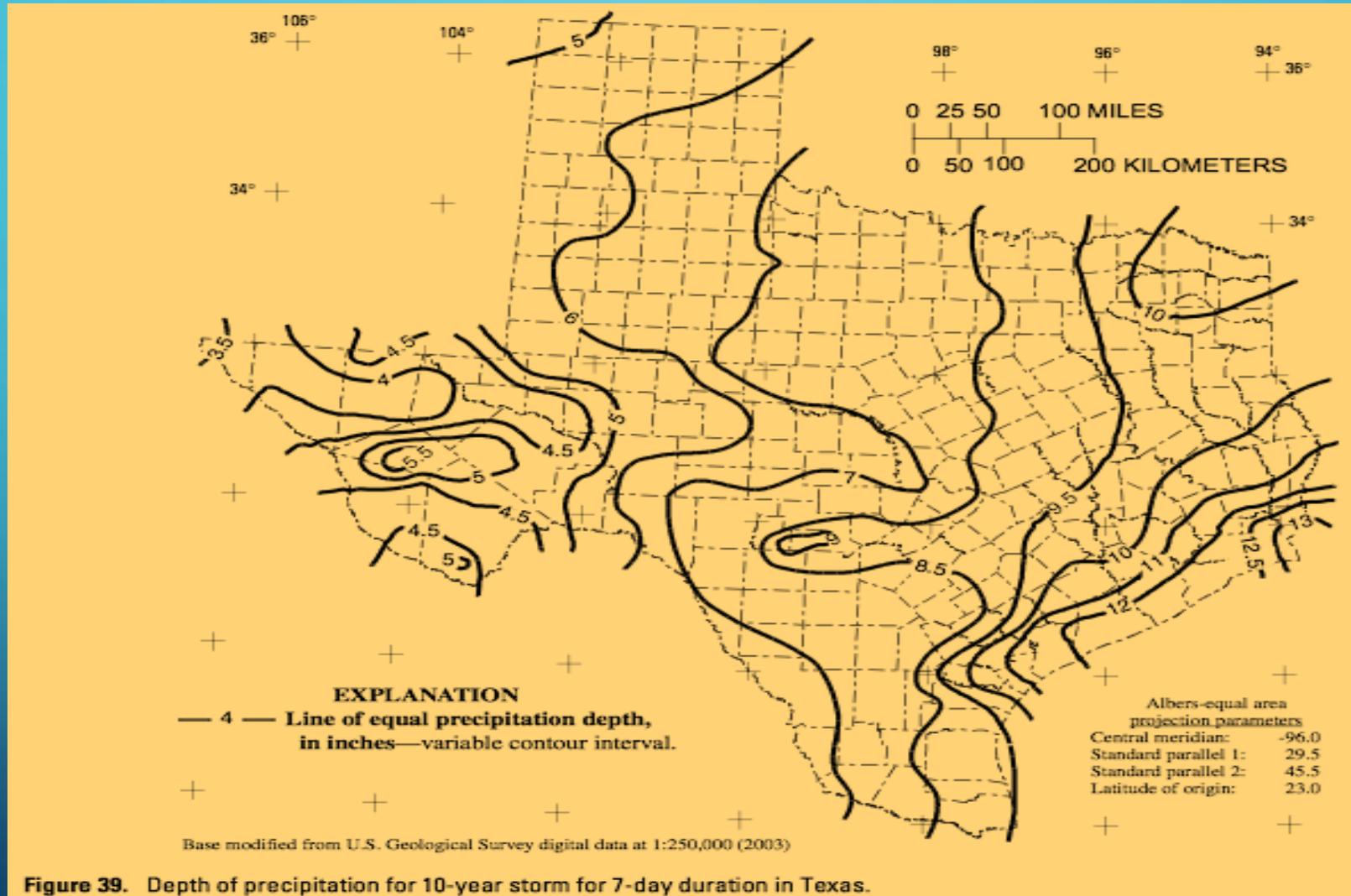
RATIONAL METHOD - I

$$I = \frac{P_d}{t_c}$$

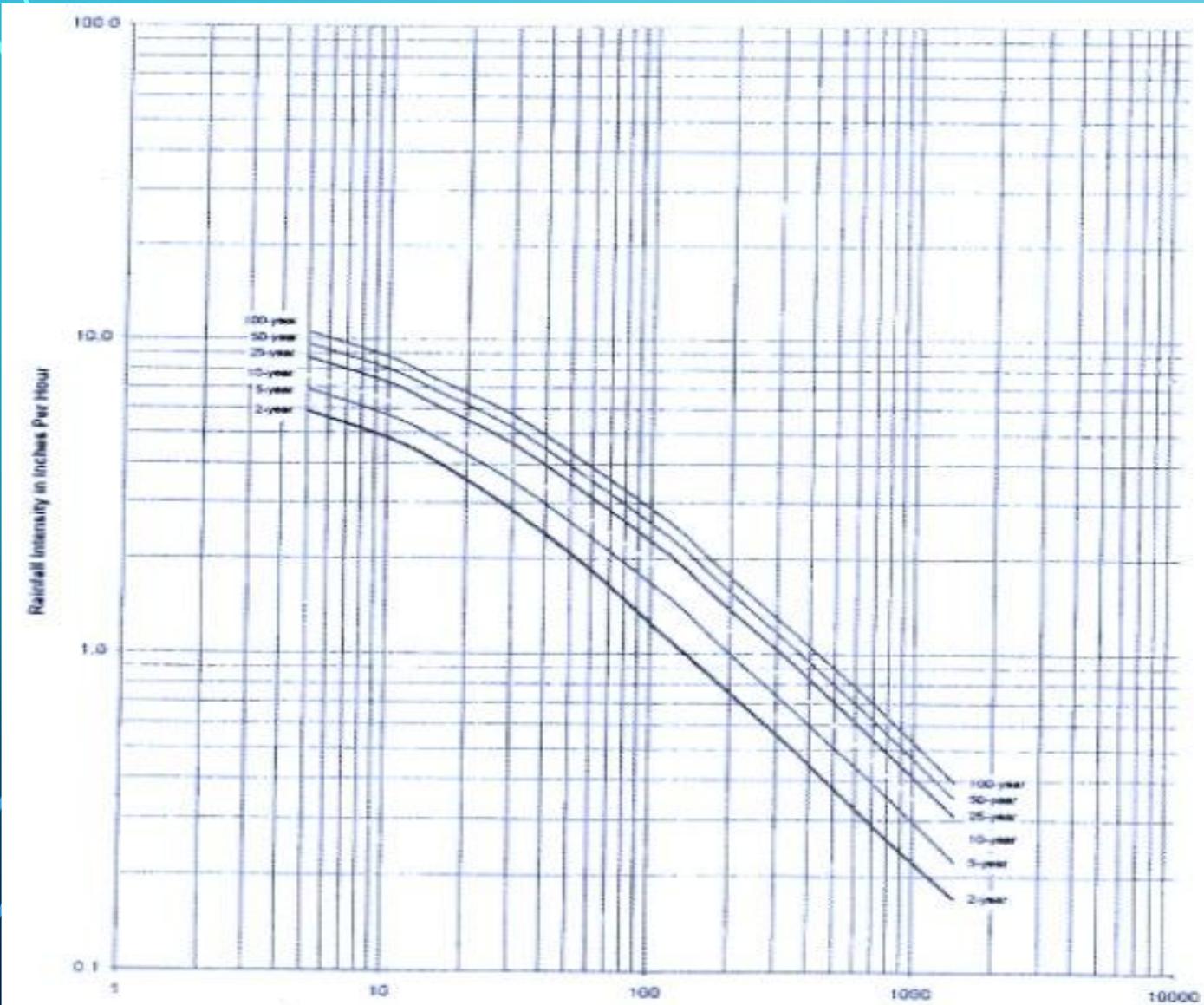
P_d = depth of rainfall (in. or mm) for AEP
design storm of duration

t_c = drainage area time of concentration (hr.)

DEPTH-DURATION FREQUENCY



IDF CURVES



$$i = \frac{b}{(t_c + d)^e}$$

RATIONAL METHOD - I

$$i = \frac{b}{(t_c + d)^e}$$

Table 2: IDF parameters for Lubbock County.

Parameter	Return Interval (years)					
	2	5	10	25	50	100
e	0.830	0.821	0.813	0.816	0.808	0.810
b	47	60	69	82	88	101
d	10.0	10.1	10.1	10.1	10.1	10.0

TIME OF CONCENTRATION (T_c)

- Time required (after start of rainfall event) for most distant point in watershed to begin contributing runoff to the watershed outlet
- Typical is 10min to 300min; most jurisdictions restrict the small end to 10 (or 5 minutes)

$$t_c = t_{ov} + t_{ch}$$

$$t_c = t_{sh} + t_{sc} + t_{ch}$$

KERBY-KIRPICH METHOD

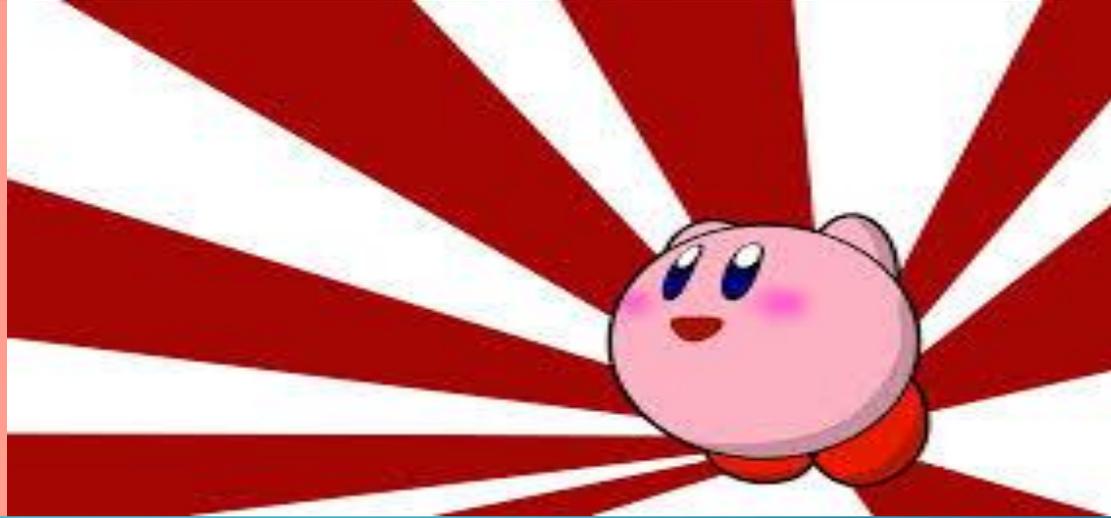
$$t_c = t_{ov} + t_{ch}$$

Equation 4-13.

Where:

t_{ov} = overland flow time

t_{ch} = channel flow time



- Applicable to watersheds
 - area: 0.25 sq. mi. to 150 sq. mi.
 - main channel slopes: 0.002 to 0.02 (ft/ft)
 - main channel lengths: 1 to 50 miles

(Roussel et al. 2005)



$$t_c = t_{ov} + t_{ch}$$

$$t_{ov} = K(L \times N)^{0.467} S^{-0.235}$$

Equation 4-14.

Where:

t_{ov} = overland flow time of concentration, in minutes

K = a units conversion coefficient, in which $K = 0.828$ for traditional units and $K = 1.44$ for SI units

L = the overland-flow length, in feet or meters as dictated by K

N = a dimensionless retardance coefficient

S = the dimensionless slope of terrain conveying the overland flow

Table 4-5: Kerby Equation Retardance Coefficient Values

Generalized terrain description	Dimensionless retardance coefficient (N)
Pavement	0.02
Smooth, bare, packed soil	0.10
Poor grass, cultivated row crops, or moderately rough packed surfaces	0.20
Pasture, average grass	0.40
Deciduous forest	0.60
Dense grass, coniferous forest, or deciduous forest with deep litter	0.80

$$t_c = t_{ov} + t_{ch}$$



$$t_{ch} = KL^{0.770} S^{-0.385}$$

Equation 4-15.

Where:

t_{ch} = the time of concentration, in minutes

K = a units conversion coefficient, in which $K = 0.0078$ for traditional units and $K = 0.0195$ for SI units

L = the channel flow length, in feet or meters as dictated by K

S = the dimensionless main-channel slope

NRCS METHOD



$$t_c = t_{sh} + t_{sc} + t_{ch}$$

Equation 4-16.

Where:

t_{sh} = sheet flow travel time

t_{sc} = shallow concentrated flow travel time

t_{ch} = channel flow travel time

- Applicable for:

- small watersheds
- majority overland flow

(so timing of the peak flow is not significantly affected by the contribution flow routed through underground storm drain systems.)



$$t_c = t_{sh} + t_{sc} + t_{ch}$$

$$t_{sh} = \frac{0.007(n_{ol}L_{sh})^{0.8}}{(P_2)^{0.5}S_{sh}^{0.4}}$$

Equation 4-17.

Where:

t_{sh} = sheet flow travel time (hr.)

n_{ol} = overland flow roughness coefficient (provided in Table 4-6)

L_{sh} = sheet flow length (ft) (300 ft. maximum)

P_2 = 2-year, 24-h rainfall depth (in.) (provided in the TxDOT 5-1301-01-1)

S_{sh} = sheet flow slope (ft/ft)



$$t_c = t_{sh} + t_{sc} + t_{ch}$$

$$t_{sc} = \frac{L_{sc}}{3600KS_{sc}^{0.5}}$$

Equation 4-18.

Where:

t_{sc} = shallow concentrated flow time (hr.)

L_{sc} = shallow concentrated flow length (ft)

$K = 16.13$ for unpaved surface, 20.32 for paved surface

S_{sc} = shallow concentrated flow slope (ft/ft)



$$t_c = t_{sh} + t_{sc} + t_{ch}$$

$$t_{ch} = L_{ch} / \left(3600 \frac{1.49}{n} R^{\frac{2}{3}} S_{ch}^{\frac{1}{2}} \right)$$

Equation 4-19.

Where:

t_{ch} = channel flow time (hr.)

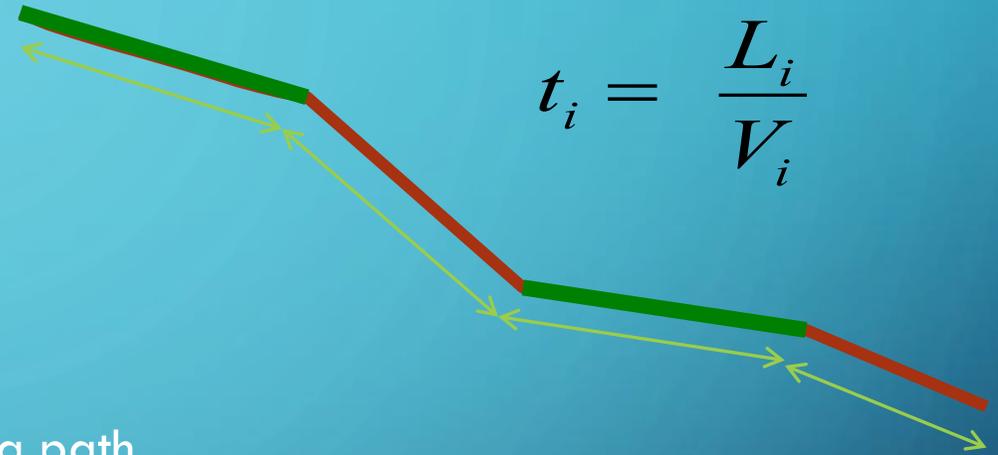
L_{ch} = channel flow length (ft)

S_{ch} = channel flow slope (ft/ft)

n = Manning's roughness coefficient

NRCS UPLAND METHOD

- Specify flow path
- Determine cover on flow path
- Determine slope(s) along path
 - Partition into different cover types and slopes along path
- Apply velocity model on each part
add times for entire path



UPLAND METHOD VELOCITY CHART

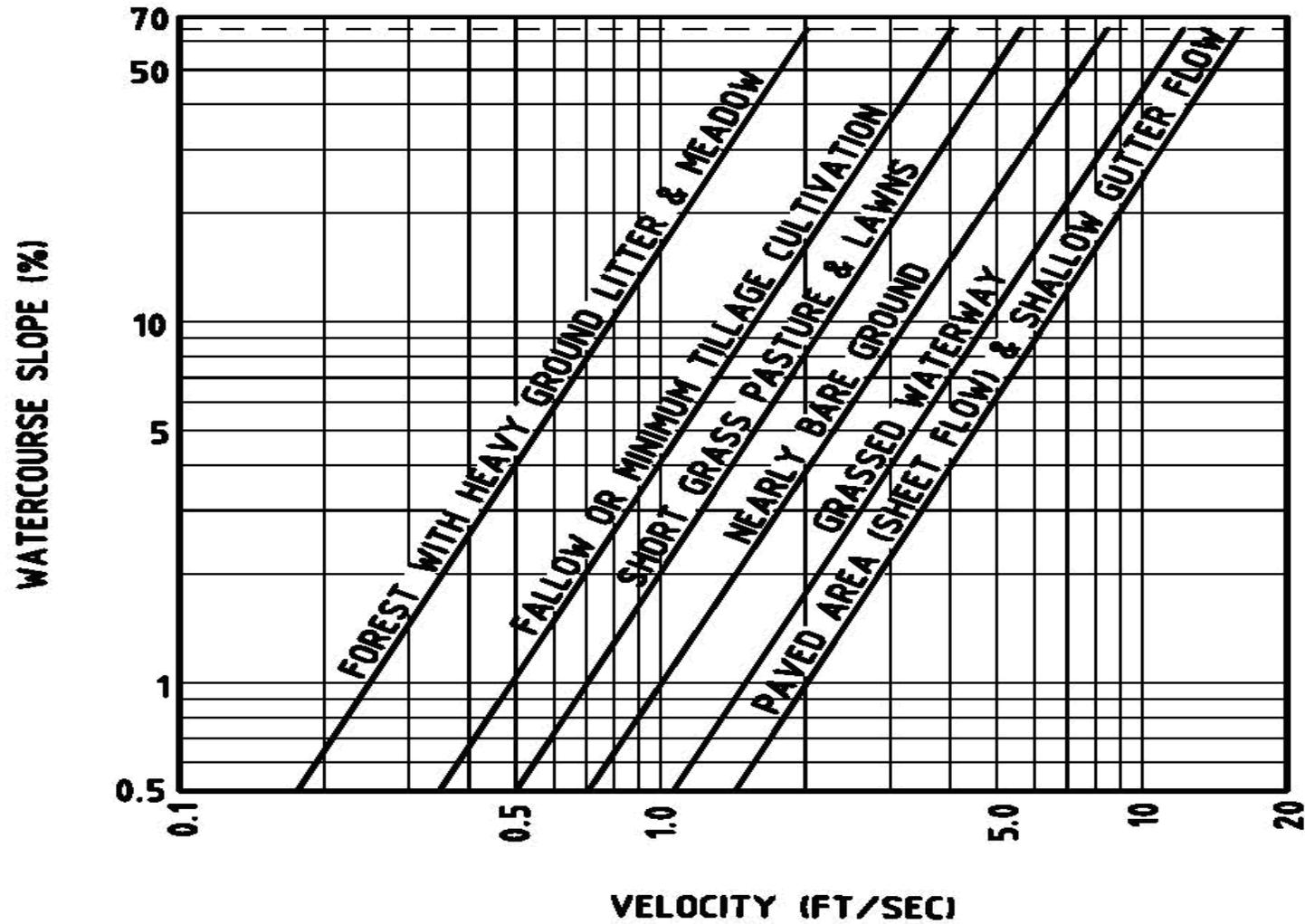
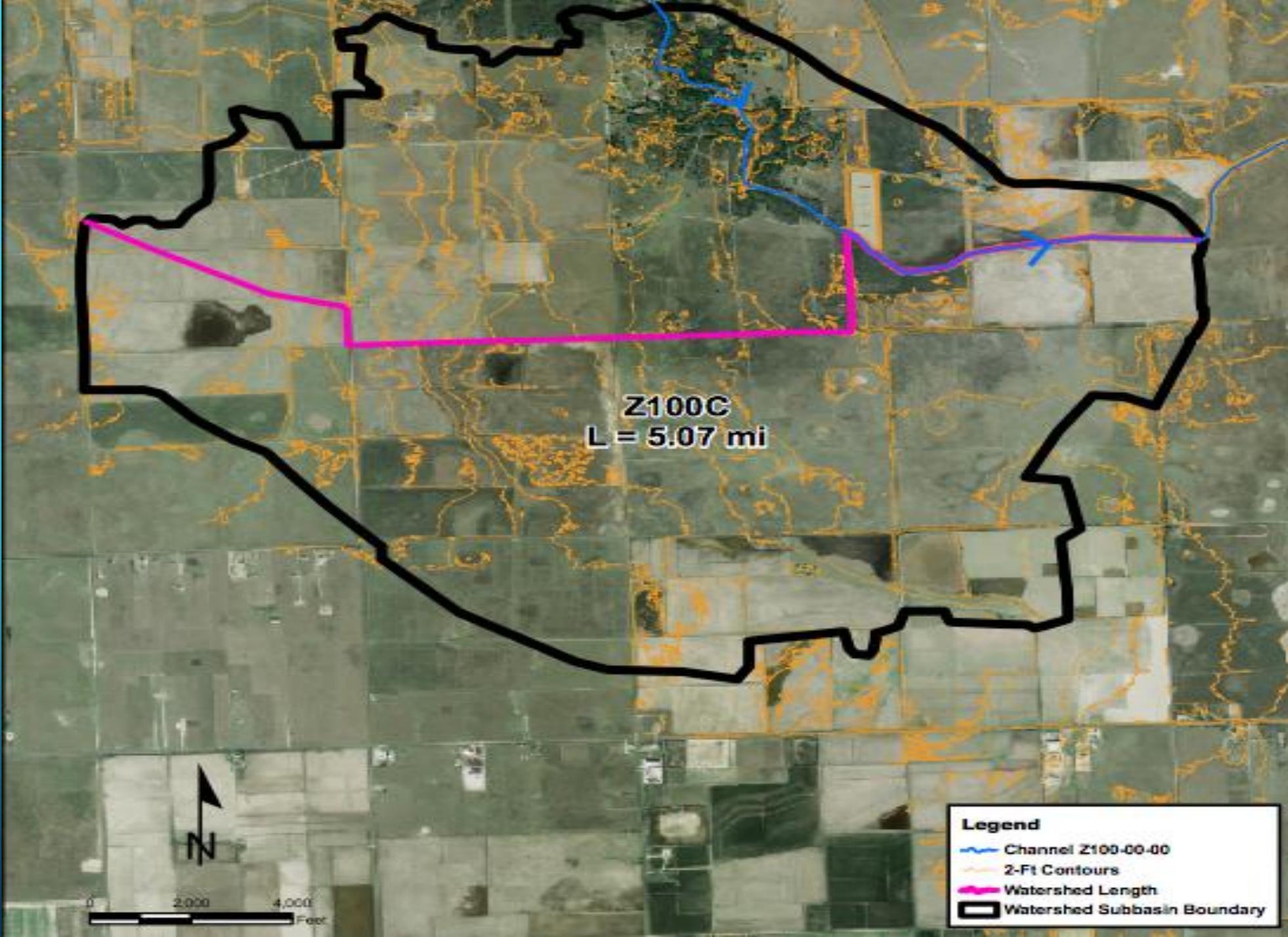
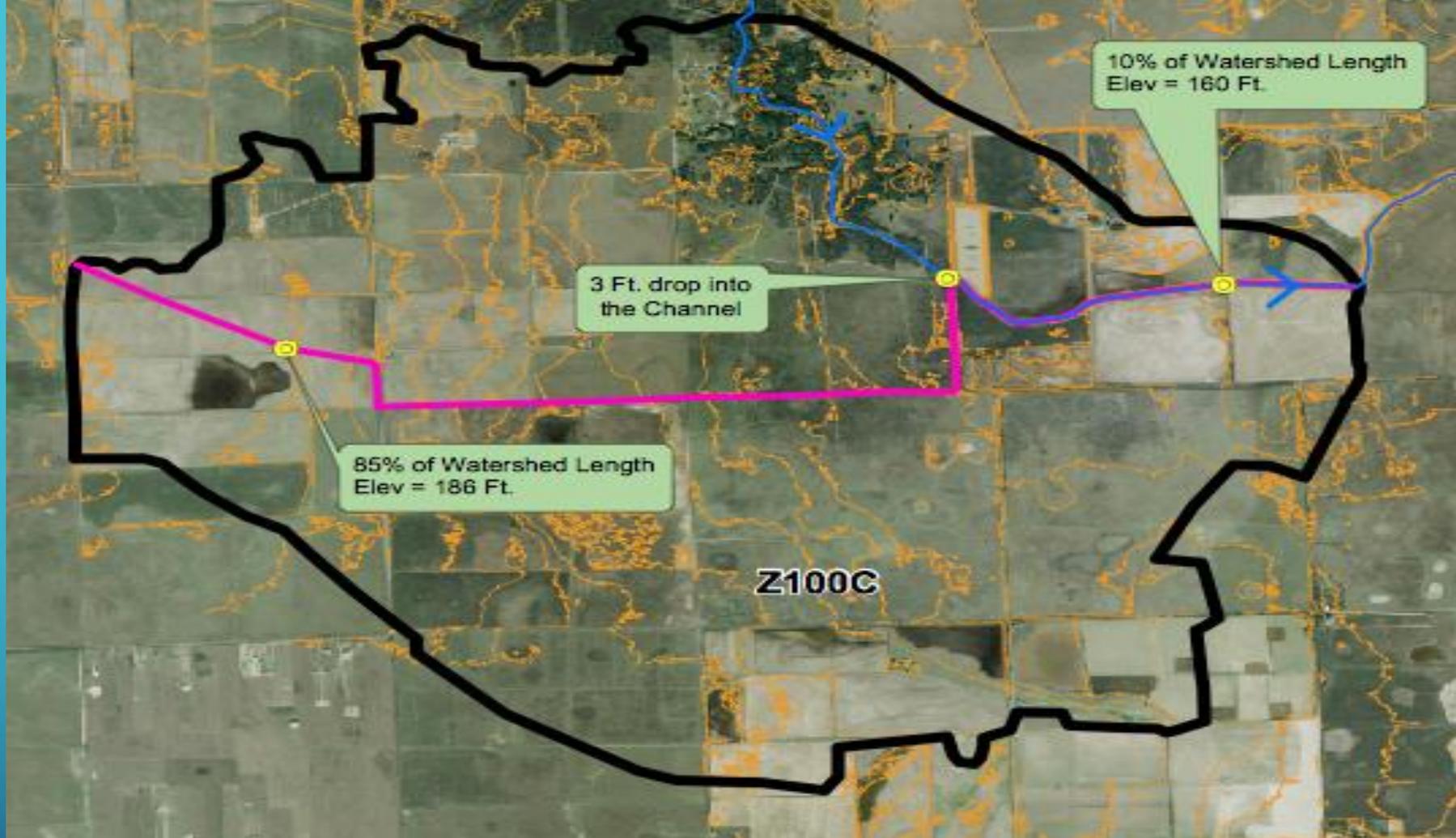


Figure 5-4. Velocities for Upland Method of Estimating Time of Concentration--English
(Adapted from the National Engineering Handbook Volume 4)

WATERSHED LENGTH



WATERSHED SLOPE



Z100C Channel Slope Calculation

Z100C Watershed Length = 26,770 ft (5.07 mi)
75% of Watershed Length = 20,077 ft (3.80 mi)

Elevation at 10% of Watershed Length = 186 ft
Elevation at 85% of Watershed Length = 160 ft

Slope = $\frac{186 \text{ ft} - (160 \text{ ft} + 3 \text{ ft drop into channel})}{3.80 \text{ mi}}$

Slope = 6.05 ft/mi



Legend

- Channel Z100-00-00
- 2-Ft Contours
- Watershed Length
- Watershed Subbasin Boundary

RATIONAL METHOD

$$Q_p = CiA$$

- Find t_c to calculate intensity
- Plug and chug

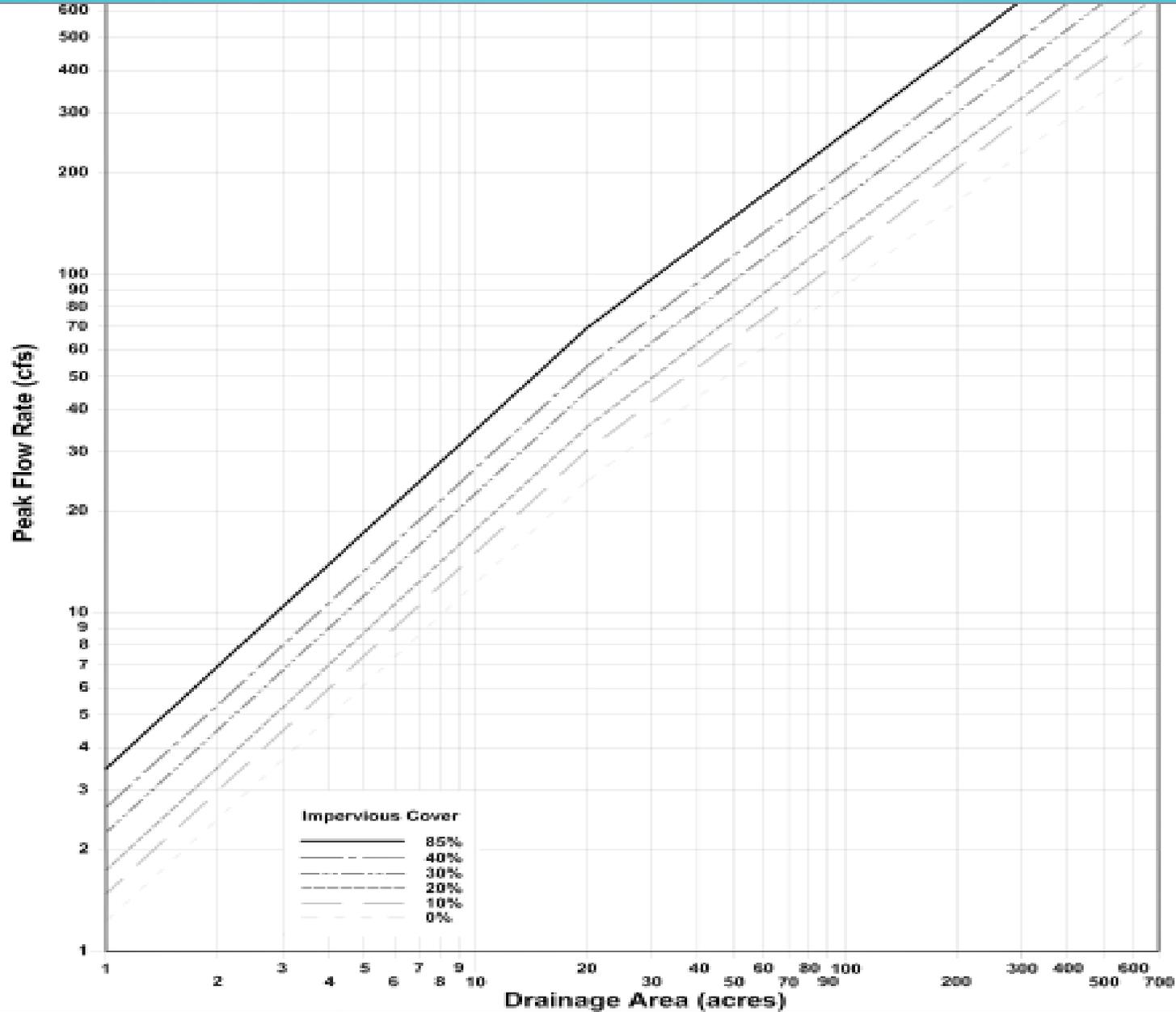
$$t_c = t_{ov} + t_{ch}$$

$$t_c = t_{sh} + t_{sc} + t_{ch}$$

$$I = \frac{P_d}{t_c}$$

$$i = \frac{b}{(t_c + d)^e}$$

HCFCD SITE RUNOFF CURVES



**POLICY,
CRITERIA, &
PROCEDURE
MANUAL**

SITE RUNOFF CURVES FOR 10% EXCEEDANCE PROBABILITY (10-YEAR FREQUENCY) STORM

DATE: 12/21/2010

EXHIBIT 3-1

A decorative graphic on the left side of the slide, consisting of a network of white lines and circles on a blue gradient background. The lines are vertical and horizontal, with some branching out, resembling a circuit board or a data network. The circles are small and white, connected to the lines.

REGRESSION EQUATIONS

TEXAS REGRESSION EQ.

- Regression equations are used to transfer flood characteristics from **gauged to ungauged** sites
 - Done by using watershed and climatic characteristics as explanatory or predictor variables
- Reliable > 10 sq. mi. drainage area
- Only for non-urbanized watersheds

$$Q_T = P^c S^d \times 10^{[e\Omega + a + bA^{\lambda}]}$$

- Other states have their **OWN** (Different) equations!

TEXAS REGRESSION EQ.

$$Q_T = P^c S^d \times 10^{[e\Omega + a + bA^\lambda]}$$

Equation 4-12.

Where:

Q_T = peak discharge of recurrence interval T years (cfs)

P = mean annual precipitation in inches from Figure 4-6

S = dimensionless main channel slope

Ω = OmegaEM from Figure 4-5

A = contributing drainage area (mi²)

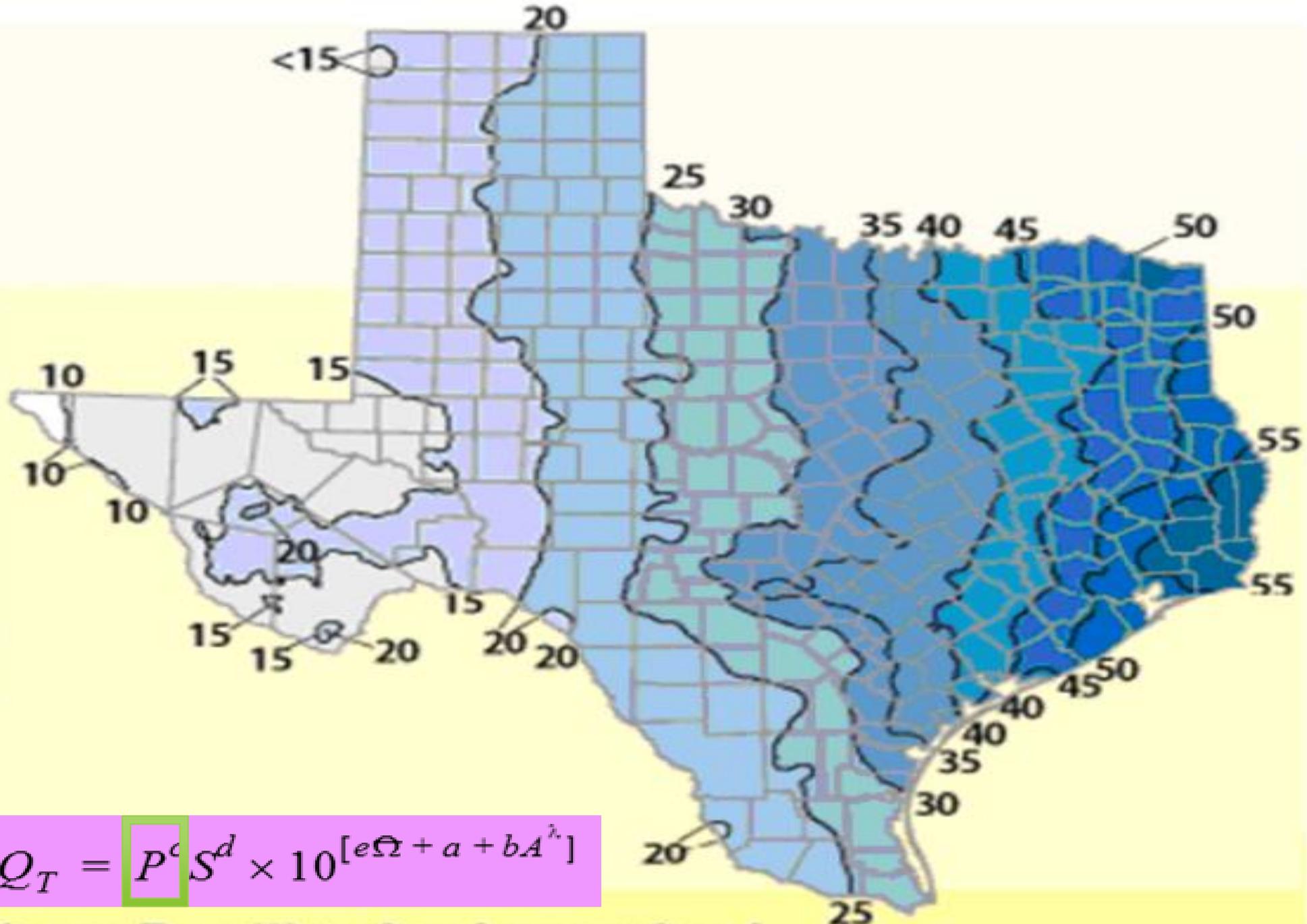
λ = a power determined by iterative PRESS-minimization for the recurrence interval

a, b, c, d, e = regression coefficients specific for the recurrence interval

$$Q_T = P^c S^d \times 10^{[e\Omega + a + bA^k]}$$

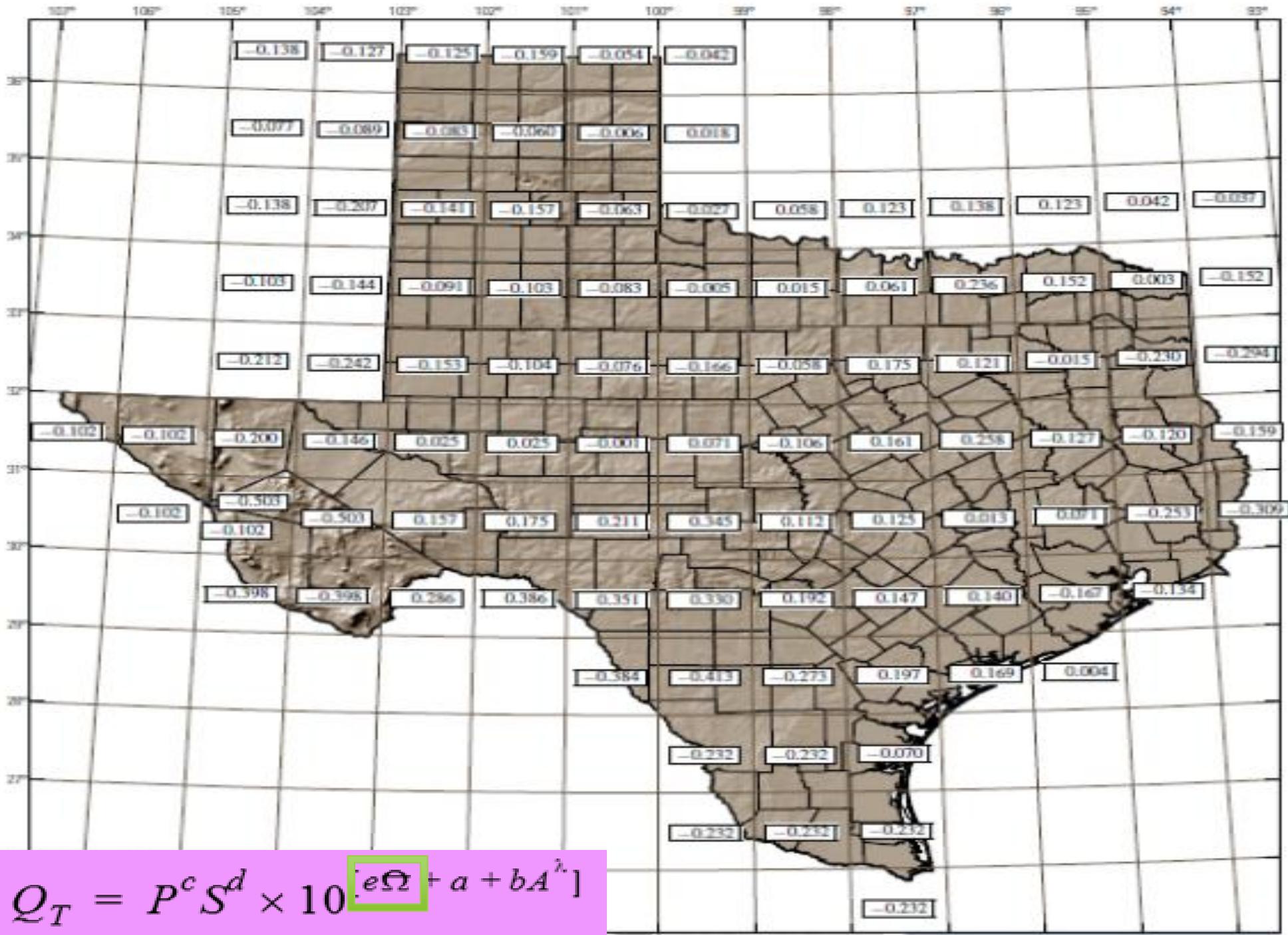
Table 4-4: Regression Equations

Regression Equations	RSE	Adj. R-squared	AIC statistic	PRESS statistic
$Q_2 = P^{1.398} S^{0.270} \times 10^{[0.776\Omega + 50.98 - 50.30A^{-0.0058}]}$	0.29	0.84	273	64.6
$Q_5 = P^{1.308} S^{0.372} \times 10^{[0.885\Omega + 16.62 - 15.32A^{-0.0215}]}$	0.26	0.88	122	49.1
$Q_{10} = P^{1.203} S^{0.403} \times 10^{[0.918\Omega + 13.62 - 11.97A^{-0.0289}]}$	0.25	0.89	86.5	46.6
$Q_{25} = P^{1.140} S^{0.446} \times 10^{[0.945\Omega + 11.79 - 9.819A^{-0.0374}]}$	0.26	0.89	140	49.5
$Q_{50} = P^{1.105} S^{0.476} \times 10^{[0.961\Omega + 11.17 - 8.997A^{-0.0424}]}$	0.28	0.87	220	55.6
$Q_{100} = P^{1.071} S^{0.507} \times 10^{[0.969\Omega + 10.82 - 8.448A^{-0.0467}]}$	0.30	0.86	320	64.8



$$Q_T = P^c S^d \times 10^{[e\Omega + a + bA^\lambda]}$$

Source: Texas Water Development Board.



$$Q_T = P^c S^d \times 10^{[e\Omega + a + bA^\lambda]}$$

VALUE OF REGRESSION EQUATIONS

- The regression equations are not really intended for hydraulic structure design – but:
 - They are useful to check that other methods are about the correct magnitude

NRCS CURVE NUMBER

- One step up from Rational in complexity is the CN method
- CN model is built-in to SWMM
 - Rational Method is not built-in, but a hack is presented later in the course.

INFILTRATION MODELS

- One step up from Curve Number is an infiltration model.
 - Green-Ampt is quite commonly used.
 - GA model is built-in to SWMM
 - Hortonian Infiltration is also used.
 - Horton is built-in to SWMM

EXAMPLE OF USING RATIONAL EQUATION

- Estimate the peak discharge from a 200 acre, undeveloped, sandy-loam drainage area with 3-5% slope in Bexar County.
- The desired AEP is 0.5 (50%).
- The time of concentration is 60 minutes.

REQUIRED INFORMATION

- Depth for 60-minute, 50% Chance storm in Bexar County, Texas.
- T_c for a 200 acre parcel

Given

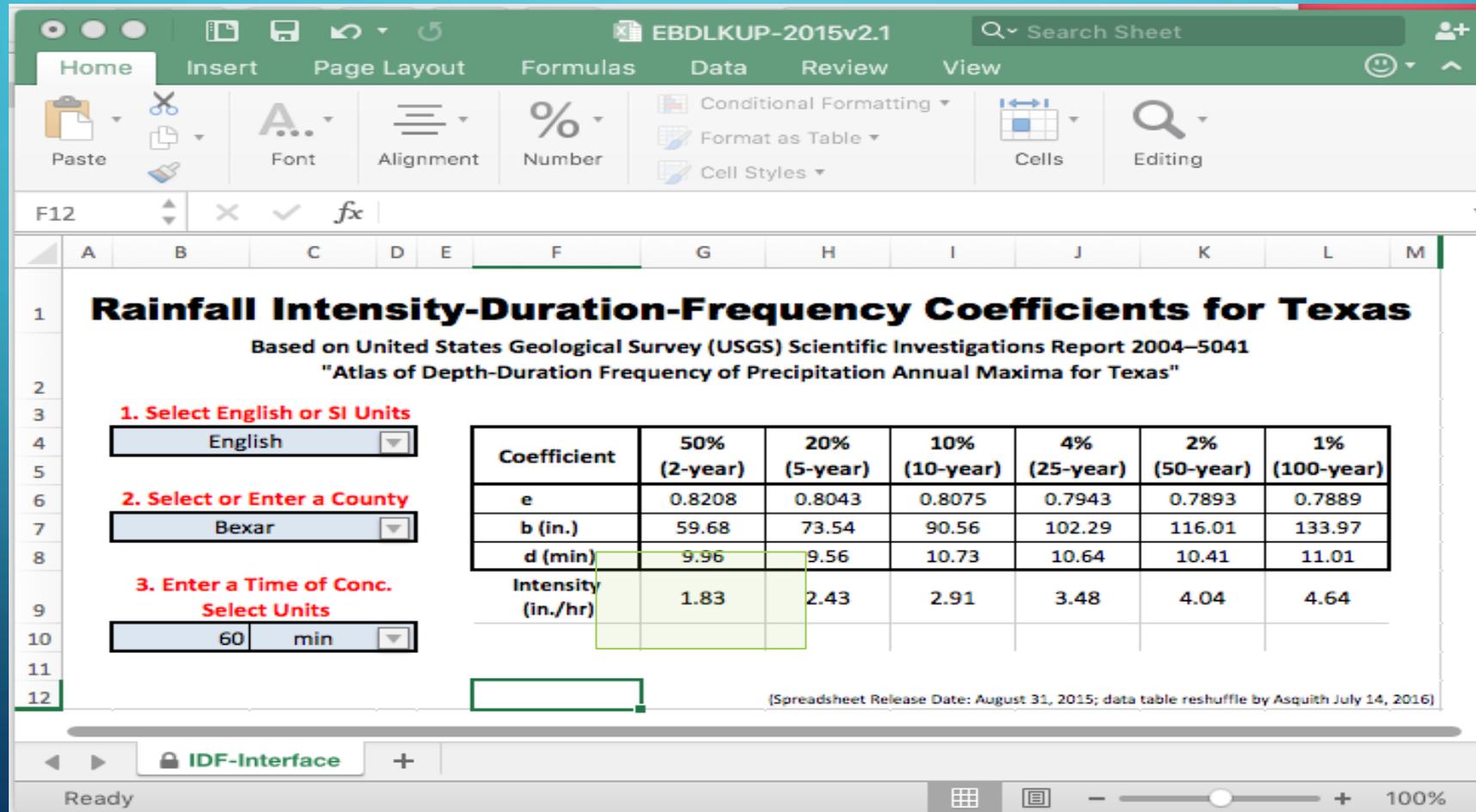
– if not would need a map and apply:

- Kerby-Kirpich; NRCS Upland; or NRCS Velocity

- Runoff coefficient for the parcel

DEPTH FOR 60-MINUTE, 50% CHANCE STORM IN BEXAR COUNTY, TEXAS.

- DDF Atlas or ~~EBDLKUP-2015~~ NOAA Atlas 14



Rainfall Intensity-Duration-Frequency Coefficients for Texas
Based on United States Geological Survey (USGS) Scientific Investigations Report 2004-5041
"Atlas of Depth-Duration Frequency of Precipitation Annual Maxima for Texas"

1. Select English or SI Units
English

2. Select or Enter a County
Bexar

3. Enter a Time of Conc.
Select Units
60 min

Coefficient	50% (2-year)	20% (5-year)	10% (10-year)	4% (25-year)	2% (50-year)	1% (100-year)
e	0.8208	0.8043	0.8075	0.7943	0.7893	0.7889
b (in.)	59.68	73.54	90.56	102.29	116.01	133.97
d (min)	9.96	9.56	10.73	10.64	10.41	11.01
Intensity (in./hr)	1.83	2.43	2.91	3.48	4.04	4.64

(Spreadsheet Release Date: August 31, 2015; data table reshuffle by Asquith July 14, 2016)

INTENSITY TO BE APPLIED

- $T_c = 60$ minutes
- $D = 1.83$ inches
- Intensity = 1.83 inches/hour

RUNOFF COEFFICIENT

- Look up in Table

- $C=0.25$

Table 4-10: Runoff Coefficients for Urban Watersheds

Type of drainage area	Runoff coefficient
Business:	
Downtown areas	0.70-0.95
Neighborhood areas	0.30-0.70
Residential:	
Single-family areas	0.30-0.50
Multi-units, detached	0.40-0.60
Multi-units, attached	0.60-0.75
Suburban	0.35-0.40
Apartment dwelling areas	0.30-0.70
Industrial:	
Light areas	0.30-0.80
Heavy areas	0.60-0.90
Parks, cemeteries	0.10-0.25
Playgrounds	0.30-0.40
Railroad yards	0.30-0.40
Unimproved areas:	
Sand or sandy loam soil, 0-3%	0.15-0.20
Sand or sandy loam soil, 3-5%	0.20-0.25
Black or loessial soil, 0-3%	0.18-0.25

COMPUTE Q_p

- Apply equation:

- $Q_p = C i A$

$$= (0.25)(1.83 \text{ in/hr})(200 \text{ acres})$$

$$= 91.5 \text{ cfs}$$

- Pay attention to units, in SI the equation has a unit conversion constant!

PRACTICAL CONSIDERATIONS

- The designer will need to consider topography and flow paths to
 - Estimate T_c using some defensible method
- Use locally relevant depth-duration-frequency tools
 - EBDLKUP, DDF Atlas for Texas
 - NOAA for elsewhere
- Use meaningful runoff coefficients
- Be sure applying appropriately

NEXT TIME

- Inlets

- Inlets to capture the runoff from a sub-catchment
- Hydraulics consideration for:
 - Curb-on-grade
 - Curb-in-sag
 - Drop inlets