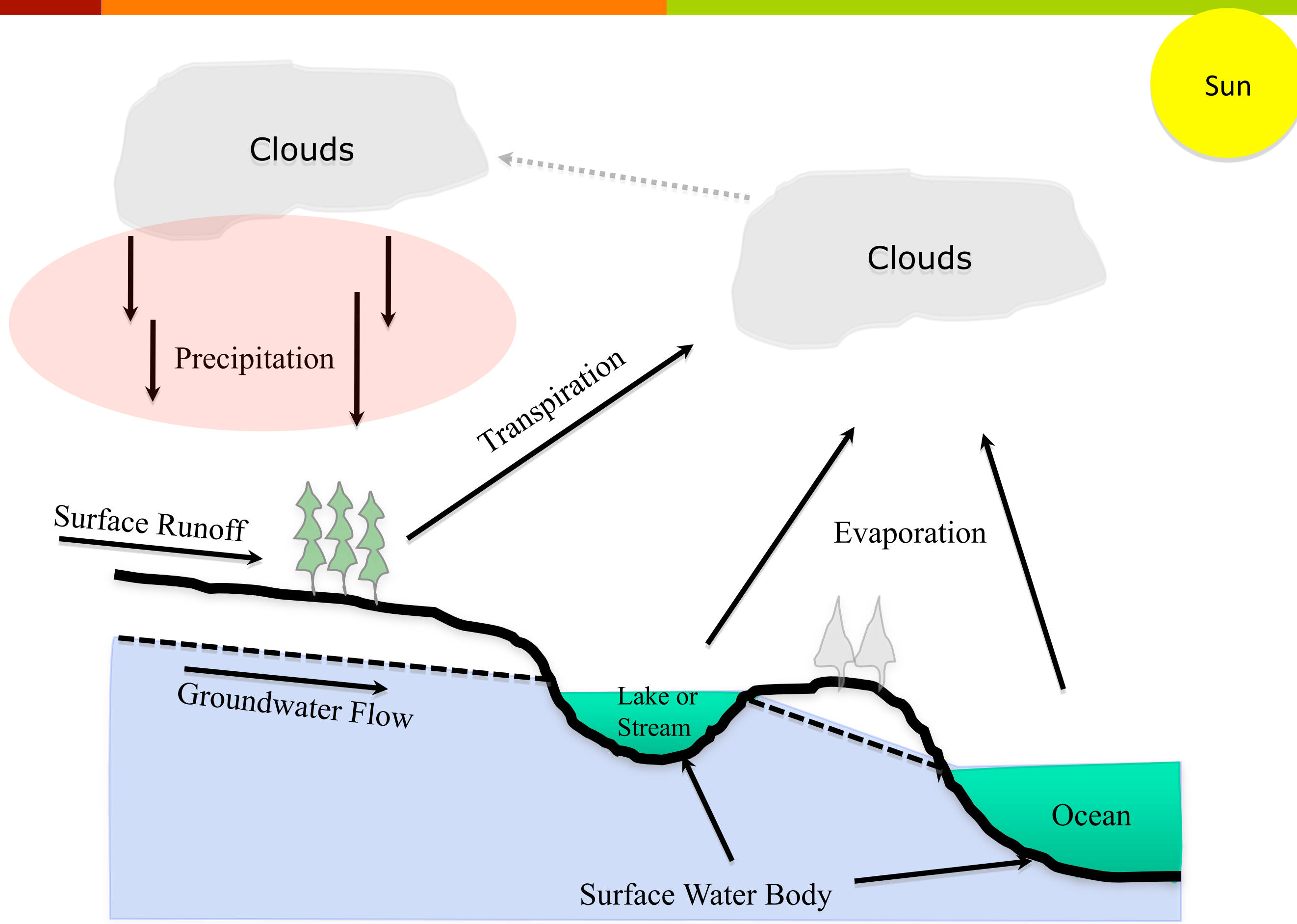
CE 3354 ENGINEERING HYDROLOGY

LECTURE 8: POINT PRECIPITATION; DESIGN STORMS

OUTLINE

- Precipitation
- Intensity-Duration-Frequency
  - NOAA Atlas 14
  - EBDLKUP-2015
- Design Storms
  - SCS Precip. Distributions
  - TxHYETO-2015

PRECIPITATION



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

PRECIPITATION VARIABLES

- Unlike flood frequency the rainfall probabilities are expressed as a combination of frequency (same idea as AEP), depth, and duration.

- The inclusion of depth and duration reflects that different “storms” can produce the same total depth, but deliver that depth over much different times

Consider a slow gentle rain for a long time versus a fast hard rain very rapidly

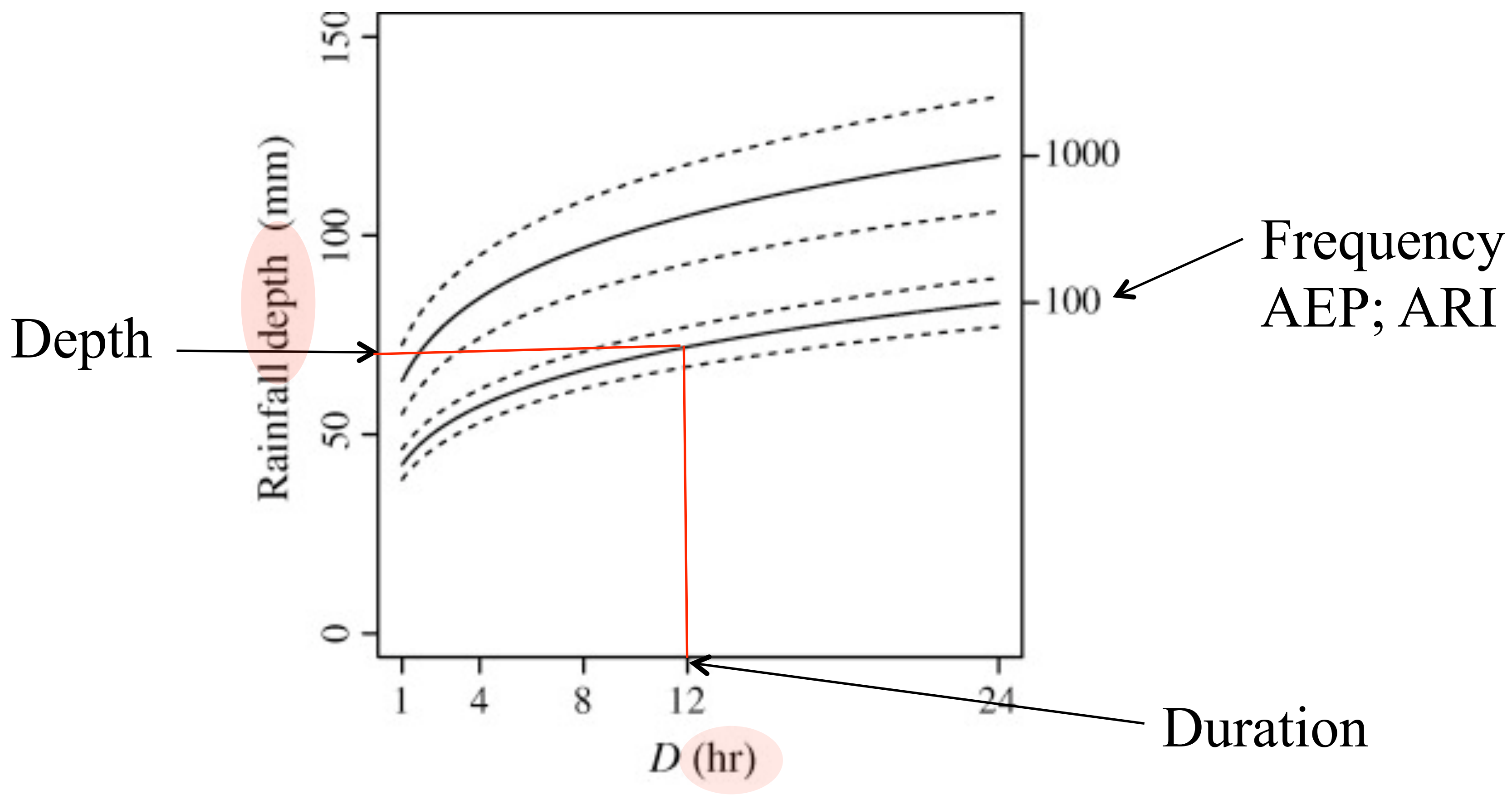
DEPTH-DURATION-FREQUENCY

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



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.

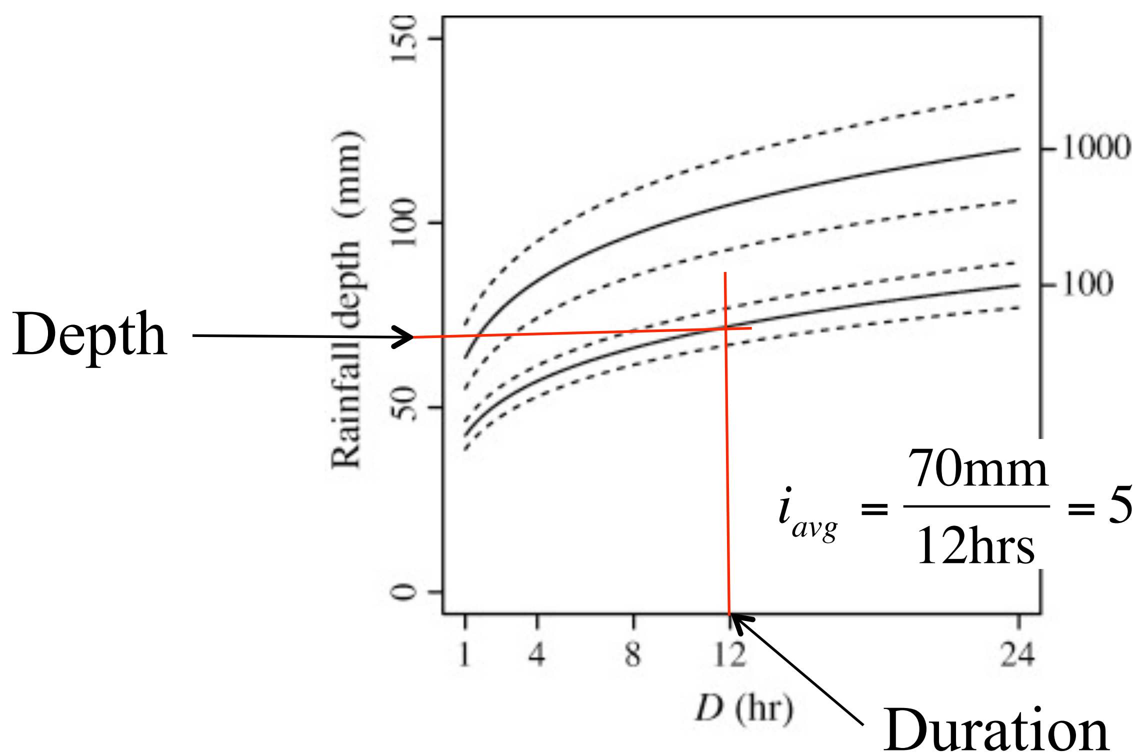
$$i_{avg} = \frac{D}{T_C}$$

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 70mm/12hr = 5.8 mm/hr

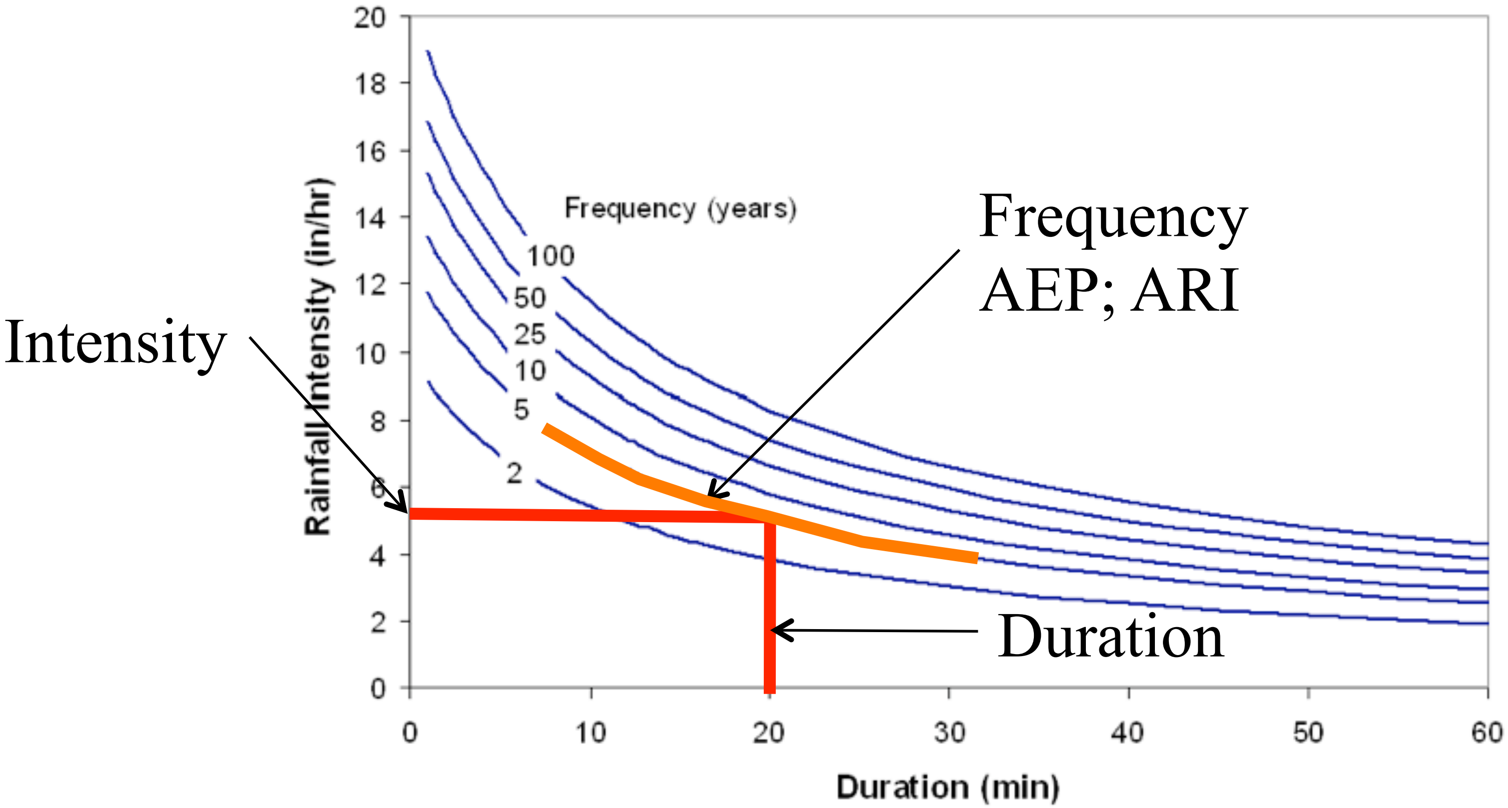


$$i_{avg} = \frac{70\text{mm}}{12\text{hrs}} = 5.8\text{mm/hr}$$

INTENSITY-DURATION-FREQUENCY

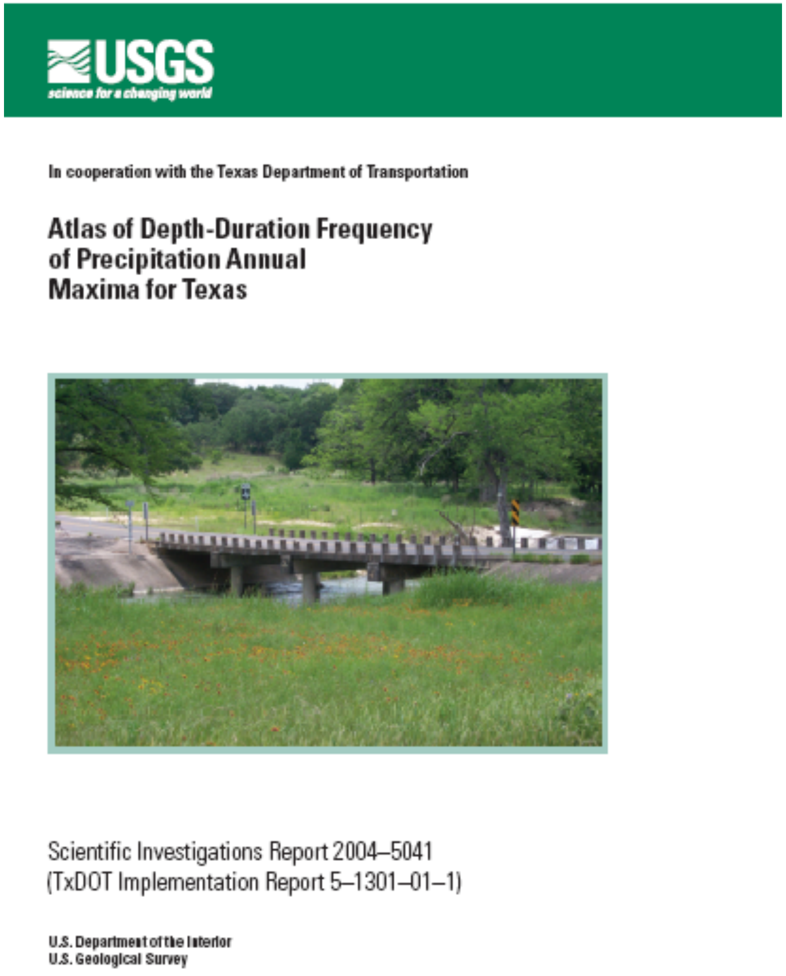
- IDF curves

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



HOW TO CONSTRUCT A DDF CURVE

- DDF curves for a location can be constructed from maps of depth for a given duration and AEP.
- Such maps are available from:
  - NWS TP40 (online)
  - NWS HY35 (online)
  - NOAA Atlas 14 (online)
  - Texas DDF Atlas (online)



USGS
science for a changing world

In cooperation with the Texas Department of Transportation

Atlas of Depth-Duration Frequency of Precipitation Annual Maxima for Texas

Scientific Investigations Report 2004–5041
(TxDOT Implementation Report 5–1301–01–1)

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

IDF Data Sources

Harris County
3 hour, 5-year (AEP=20%) depth = 3.6 inches

Location

ARI (AEP = 1/5 = 20%)

Duration = 3 hour

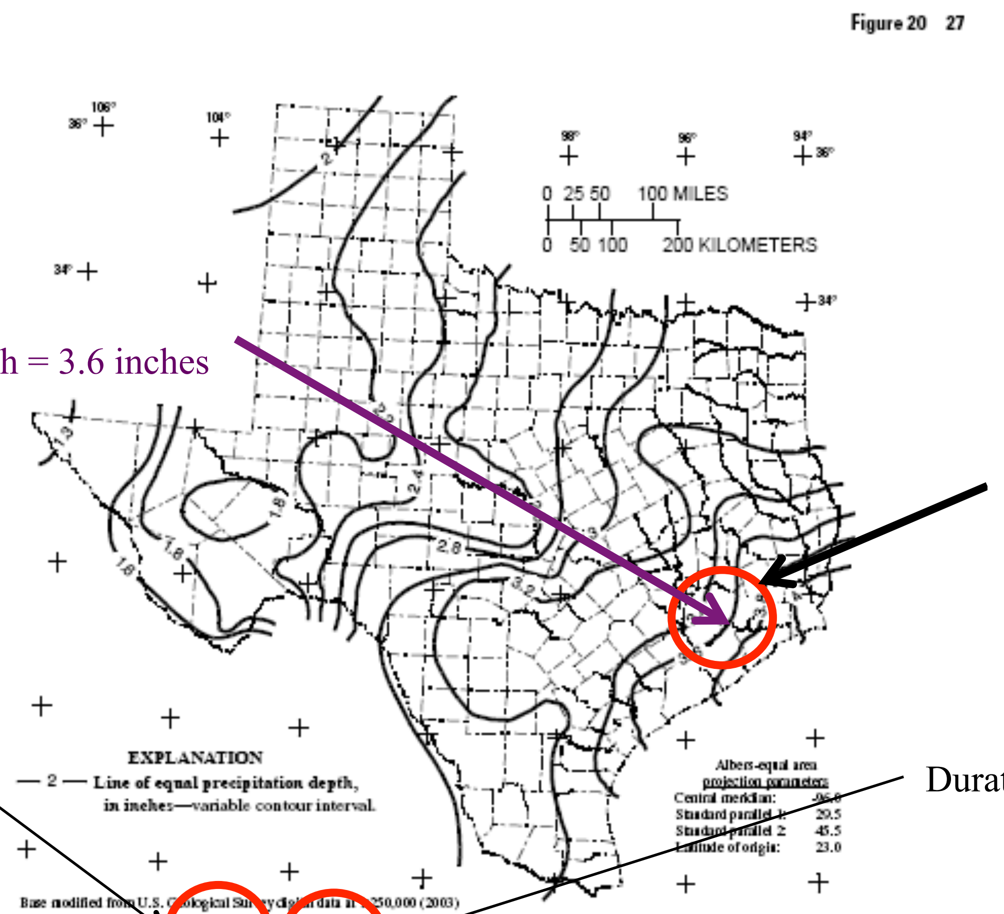


Figure 20. Depth of precipitation for 5-year storm for 3-hour duration in Texas.

HOW TO CONSTRUCT A IDF

1. Select the AEP of interest.
2. Locate the maps for that AEP – in the DDF Atlas, each duration for a given AEP is on a separate map.
3. From each map, write the duration and depth into a table for the location of interest.
4. A plot of depth versus duration for these tabulated values is a Depth-Duration curve for the particular AEP.
5. Divide the Depth by the Duration, the result is depth per duration – an intensity
6. Repeat as needed for different AEP to construct a family of IDF curves.

EXAMPLE: IDF FOR HARRIS COUNTY

- Construct the IDF Curve for the 50%-chance storm for Harris County using the DDF Atlas.
  - Step 1: Select the AEP (50%; 2-year storm)
  - Step 2: Locate maps for 2-year storm (Figures 4-15 in the DDF Atlas)
  - Step 3: From each map write the duration and depth into a table. (Next two slides illustrate finding this information)
  - Step 4: Divide the depths by the duration to obtain average rate (intensity)

EXAMPLE: IDF FOR HARRIS COUNTY

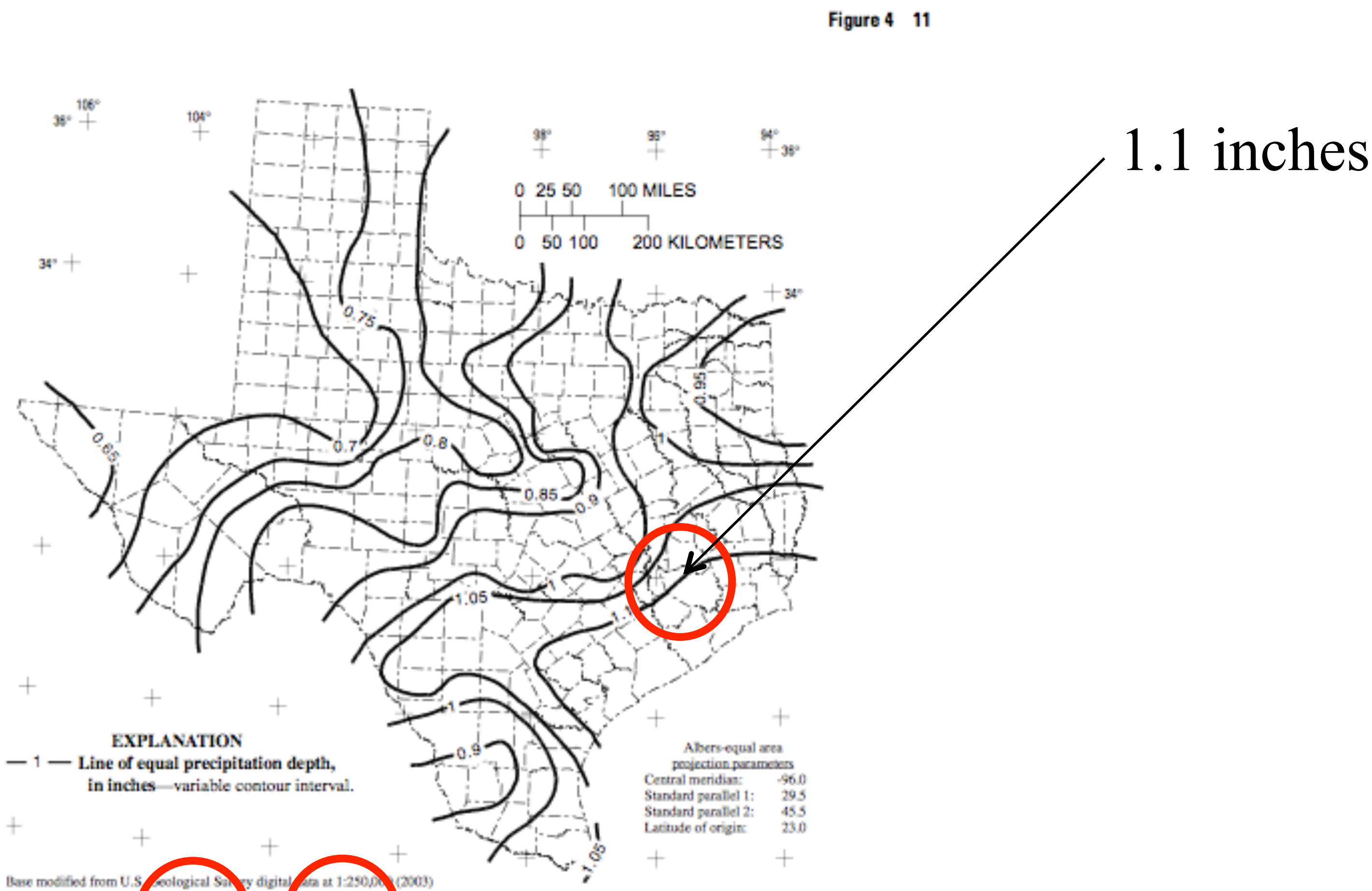
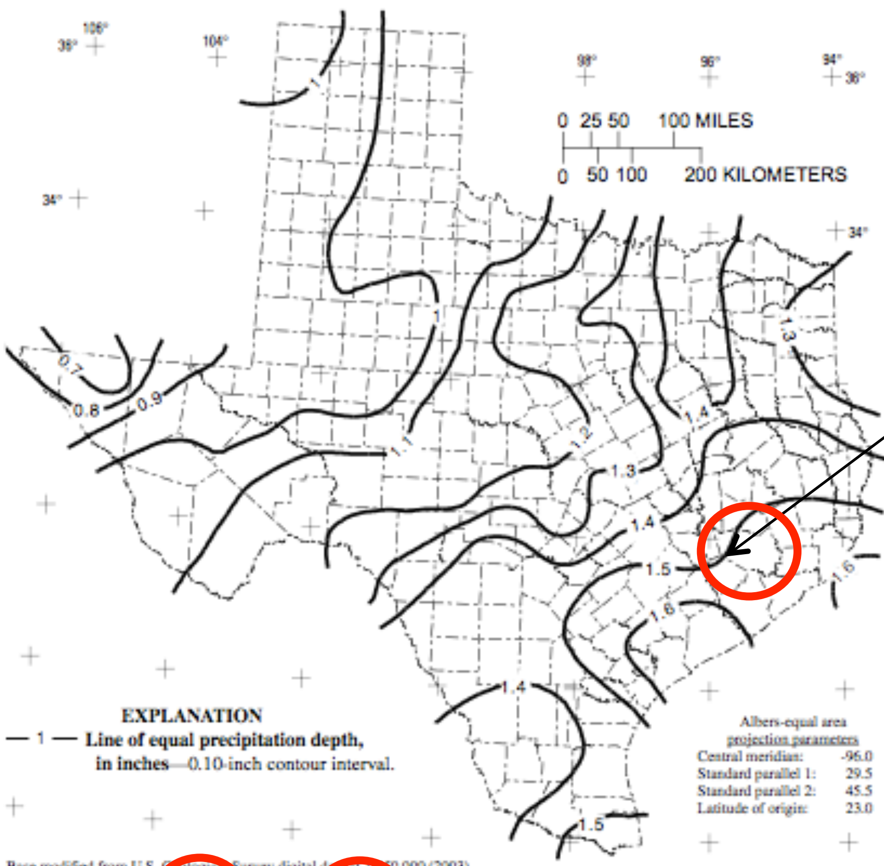


Figure 4. Depth of precipitation for 2-year storm for 15-minute duration in Texas.

Example: IDF for Harris County

12 Atlas of Depth-Duration Frequency of Precipitation Annual Maxima for Texas



1.5 inches

Figure 5. Depth of precipitation for 2-year storm for 30-minute duration in Texas.

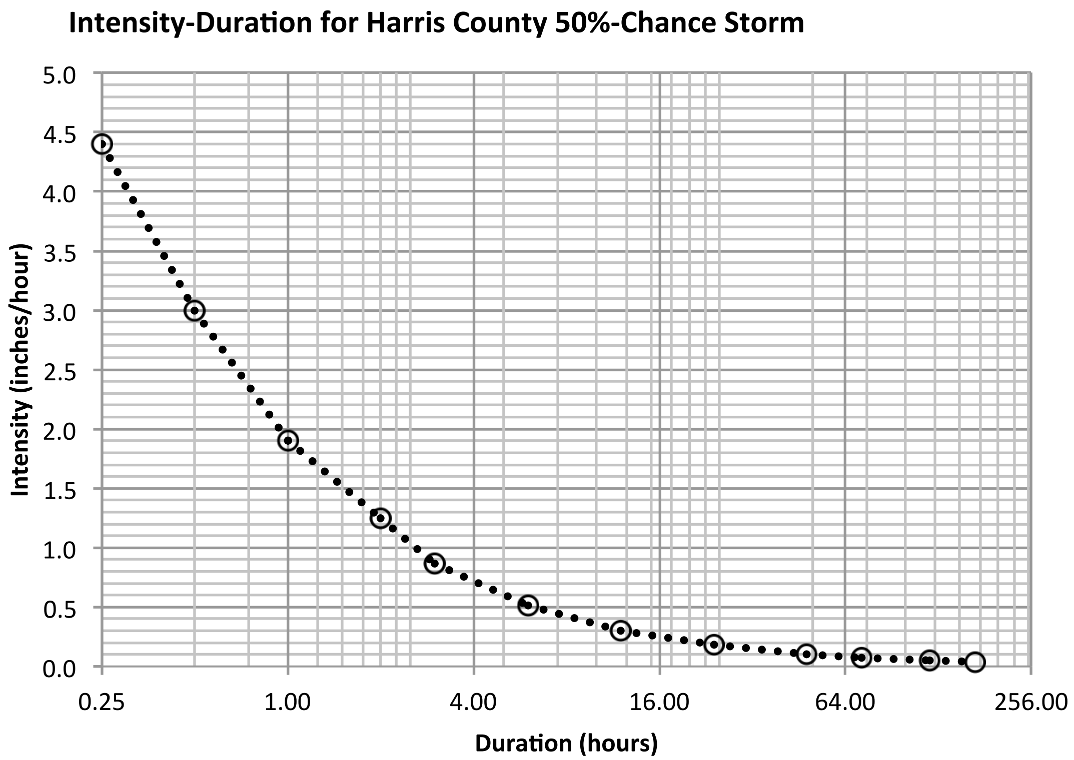
DDF FOR HARRIS COUNTY

- Construct the DDF Curve for the 50%-chance storm for Harris County using the DDF Atlas.
  - Step 3: From each map write the duration and depth into a table.
  - Step 4: Divide the depths by the duration to obtain average rate (intensity)

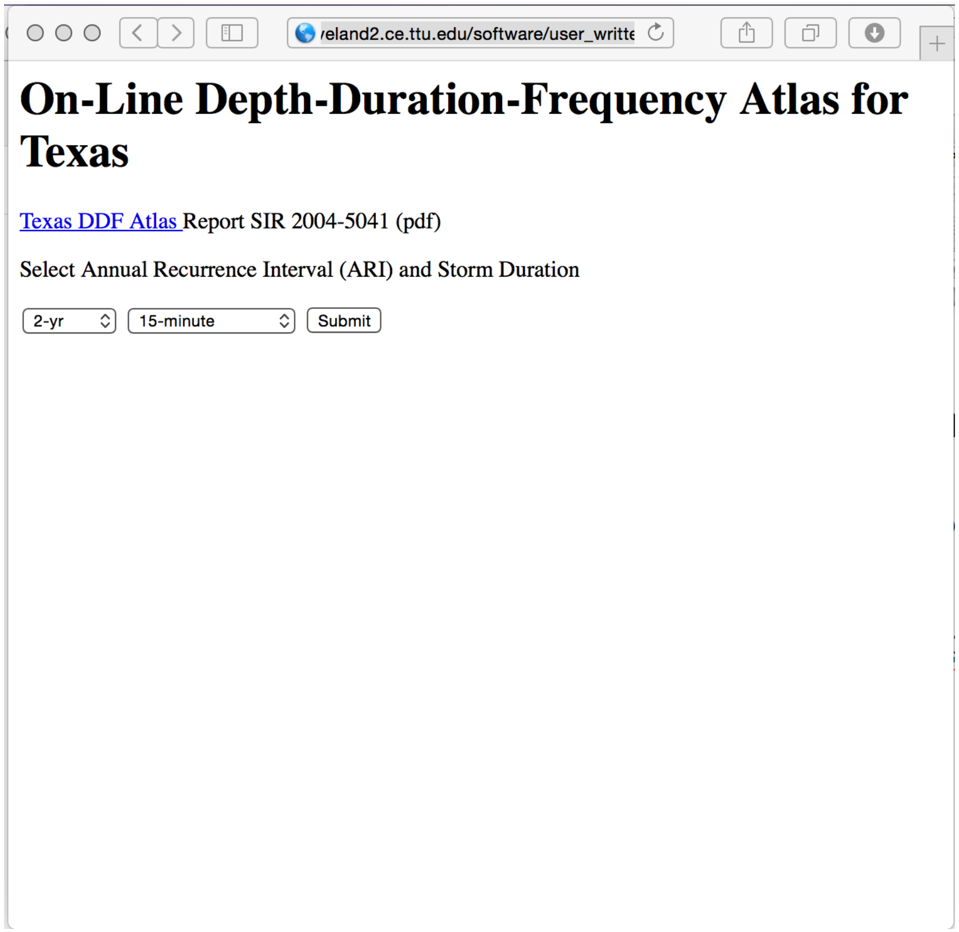
	A	B	C
1	Duration (hours)	Depth (inches)	Intensity (inches/hour)
2	0.25	1.10	4.40
3	0.50	1.50	3.00
4	1.00	1.90	1.90
5	2.00	2.50	1.25
6	3.00	2.60	0.87
7	6.00	3.10	0.52
8	12.00	3.60	0.30
9	24.00	4.40	0.18
10	48.00	5.0	0.10
11	72.00	5.5	0.08
12	120.00	6.0	0.05
13	168.00	6.5	0.04

IDF FOR HARRIS COUNTY

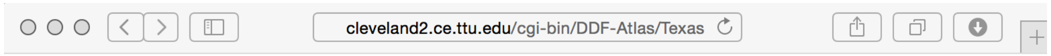
- Step 5: A plot of intensity versus duration for these tabulated values is an Intensity-Duration curve for the particular AEP.



DDF MAPS (DIRECT ACCESS)



DDF MAPS (DIRECT ACCESS)



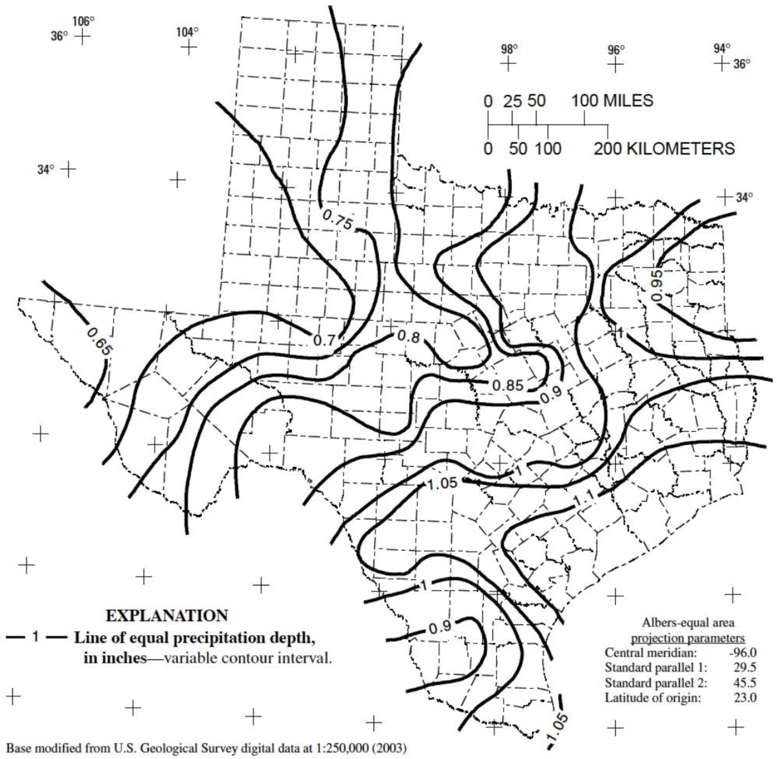
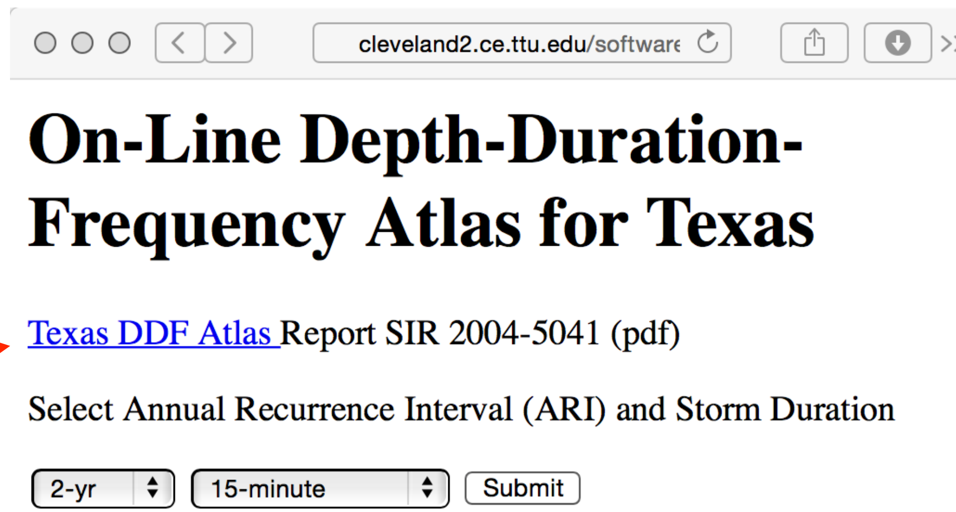


Figure 4. Depth of precipitation for 2-year storm for 15-minute duration in Texas.

DDF MAPS (DIRECT ACCESS)

- The interface also has a link to the original document

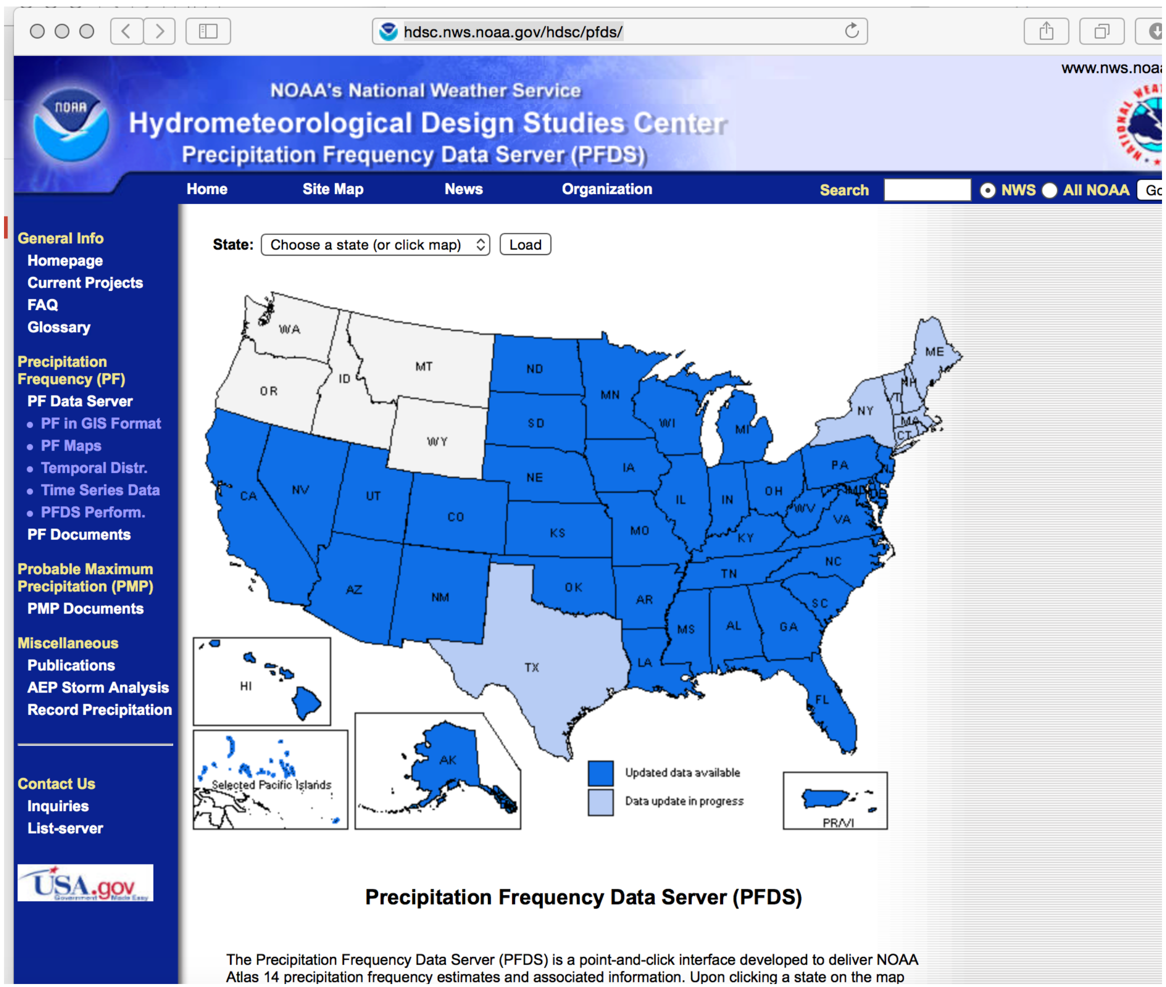


NOAA ATLAS 14

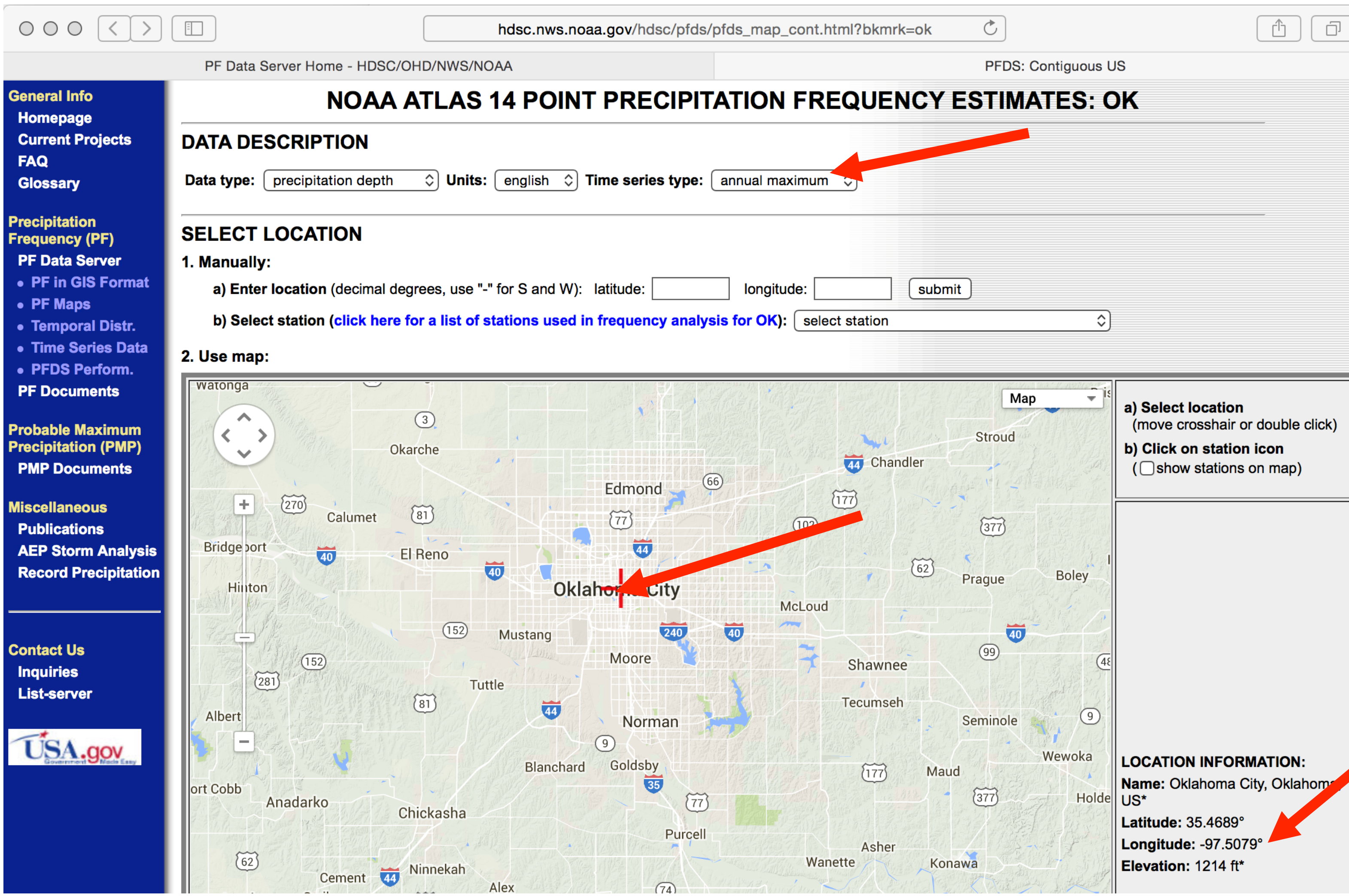
- A tool for use outside Texas is NOAA Atlas 14
  - Texas is one of a few states not yet in the Atlas
- The Atlas is an on-line tool that returns tables of depths for given geographic locations
- The on-line tool is called the Precipitation Frequency Data Server

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

NOAA ATLAS 14



NOAA ATLAS 14



NOAA ATLAS 14

PF Data Server Home - HDSC/OHD/NWS/NOAA | PFDS: Contiguous US

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!

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

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

using same duration!

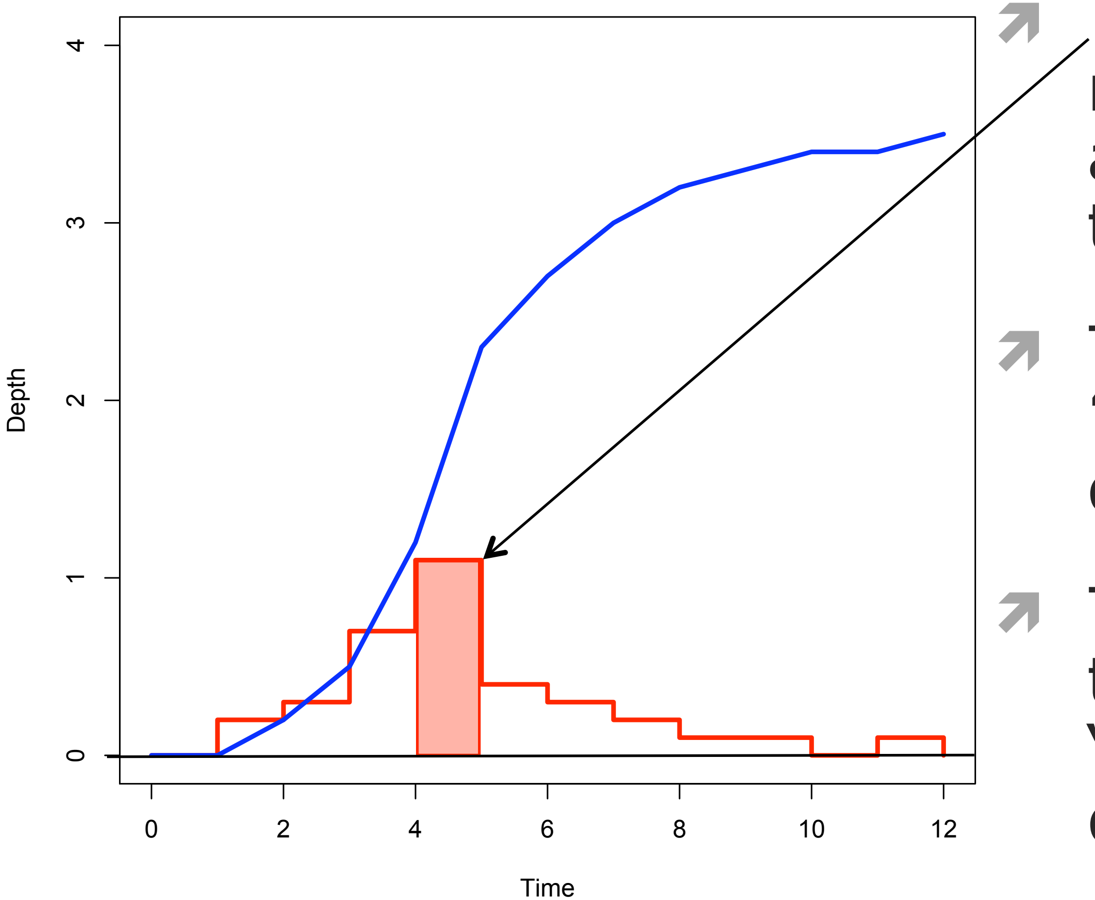
DESIGN STORMS

- 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 block diagram is "incremental" rainfall distribution
- The running sum of the blocks is the "cumulative" rainfall distribution

RAINFALL DISTRIBUTIONS

- Distributions are created from historical storms and analyzed to generate statistical models of rainfall – these models are called design storms.

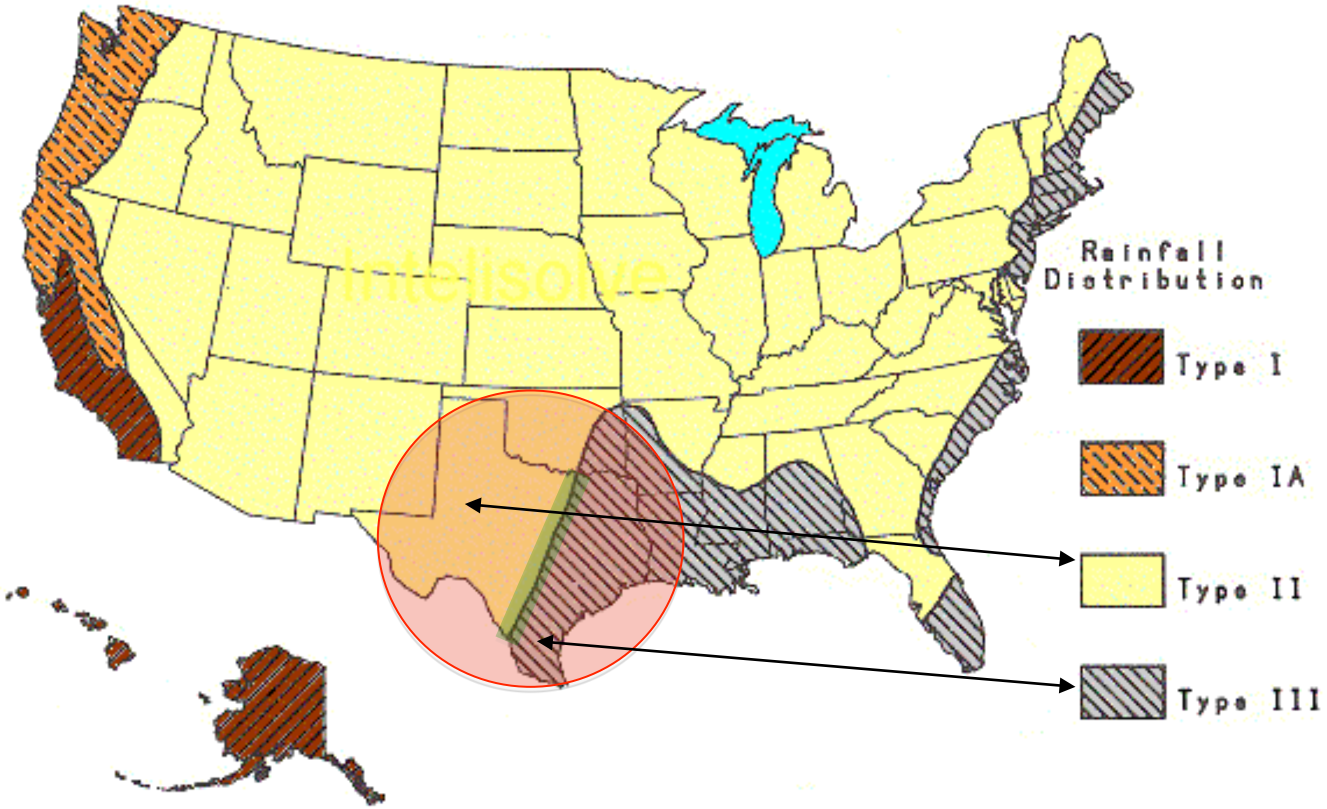
- Design storm distributions are typically dimensionless hyetographs
  - NRCS Type Storms (24 hour, 6 hour)
    CMM (pg. 461)
  - Huff Quartile Hyetographs
    - Empirical Texas Hyetographs (TxHYETO-2015)

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!

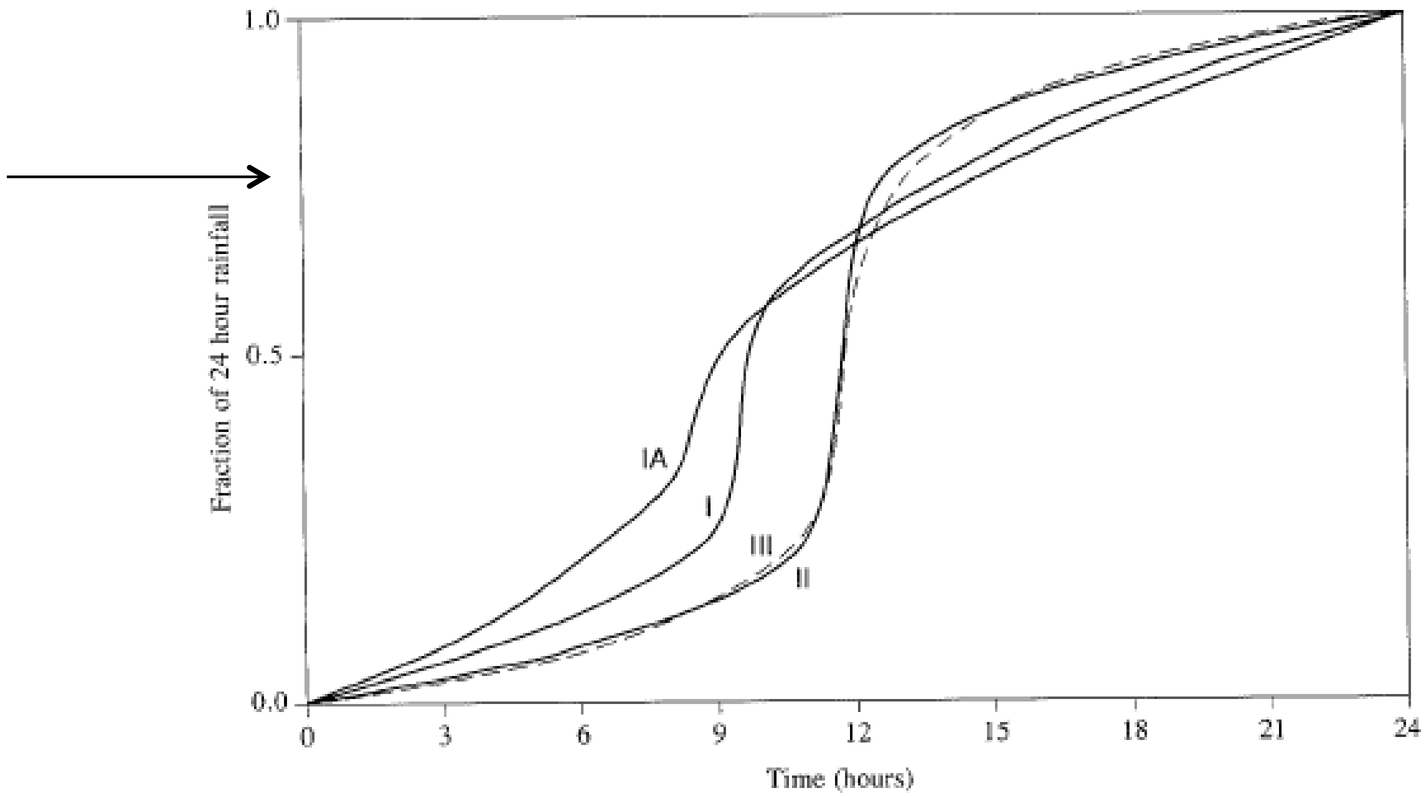
SCS RAINFALL TYPE CURVES

- 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 to get the 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

SCS 6-hour Rainfall Distribution (from Chow, Maidment, Mays, 1988 pg. 461)

Hour t	t/6	Pt/P6
0	0	0
0.6	0.1	0.04
1.2	0.2	0.1
1.5	0.25	0.14
1.8	0.3	0.19
2.1	0.35	0.31
2.28	0.38	0.44
2.4	0.4	0.53
2.52	0.42	0.6
2.64	0.44	0.63
2.76	0.46	0.66
3	0.5	0.7
3.3	0.55	0.75
3.6	0.6	0.79
3.9	0.65	0.83
4.2	0.7	0.86
4.5	0.75	0.89
4.8	0.8	0.91
5.4	0.9	0.96
6	1	1

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.

HARRIS CO. 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

GENERATE SCS DESIGN STORM

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

54 Atlas of Depth-Duration Frequency of Precipitation Annual Maxima for Texas

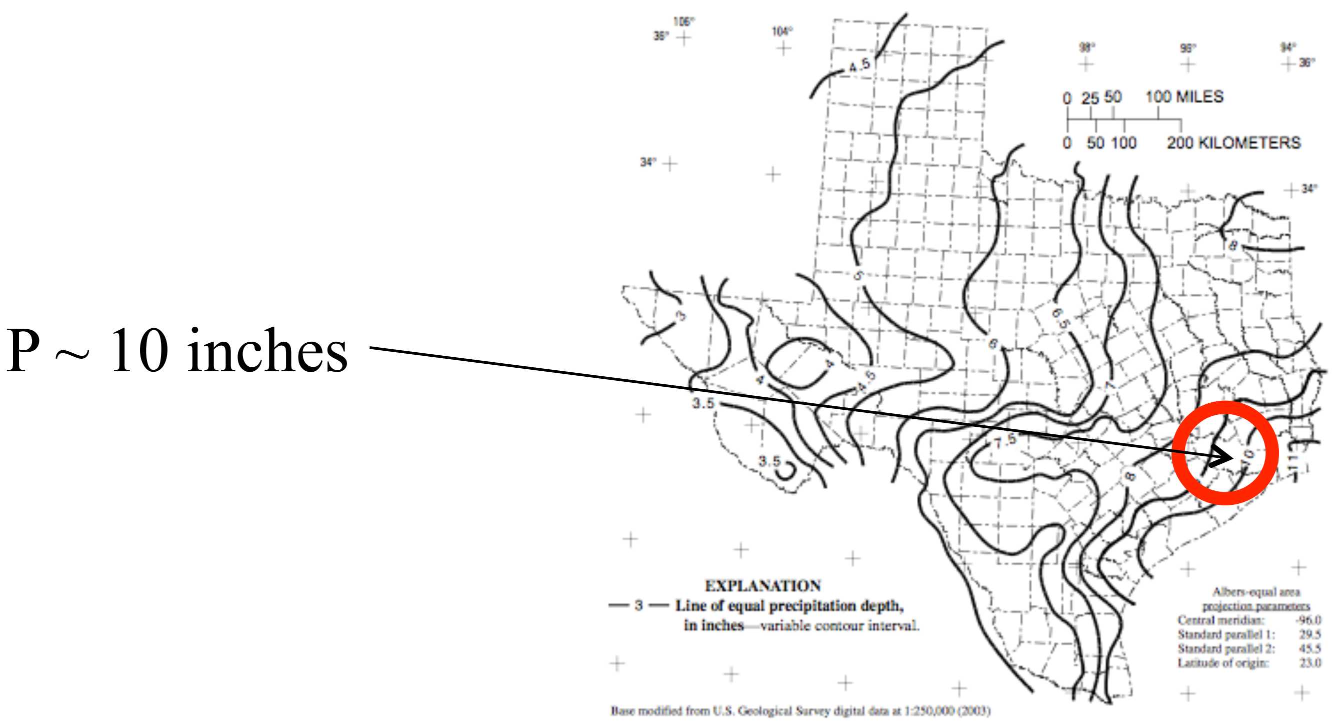
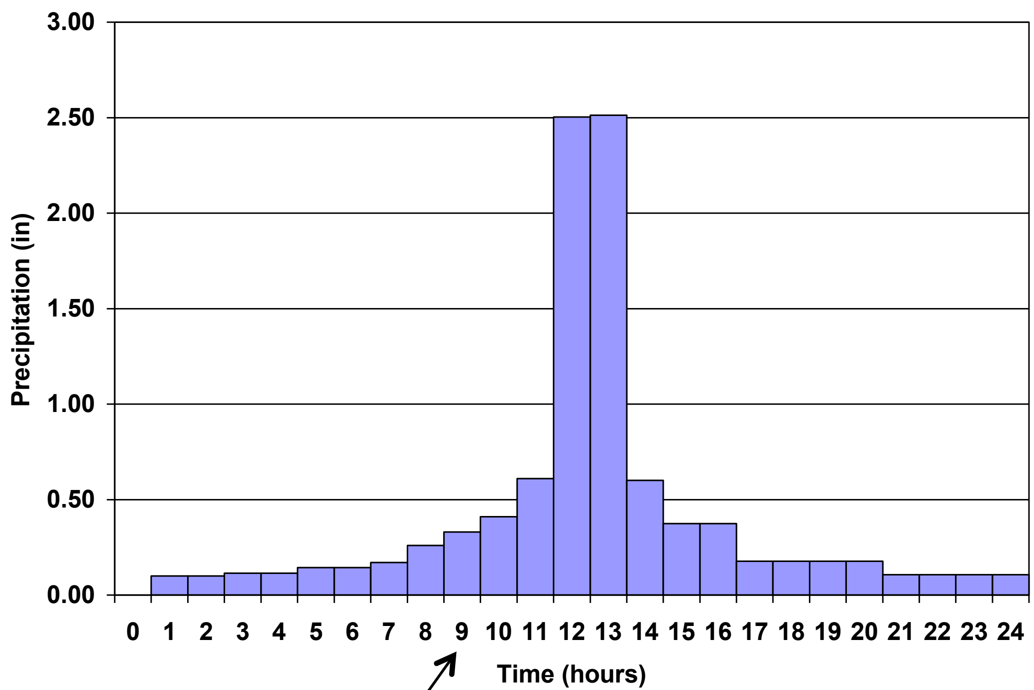


Figure 47. Depth of precipitation for 25-year storm for 1-day duration in Texas.

EXAMPLE: SCS DESIGN STORM

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	[illegible]	2.50
13	0.751	[illegible]	2.51
14	0.811	8.12	[illegible]
15	0.849	8.49	[illegible]
16	0.886	8.87	[illegible]
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



SCS Tabulation

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

DDF Atlas

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.

USGS
science for a changing world

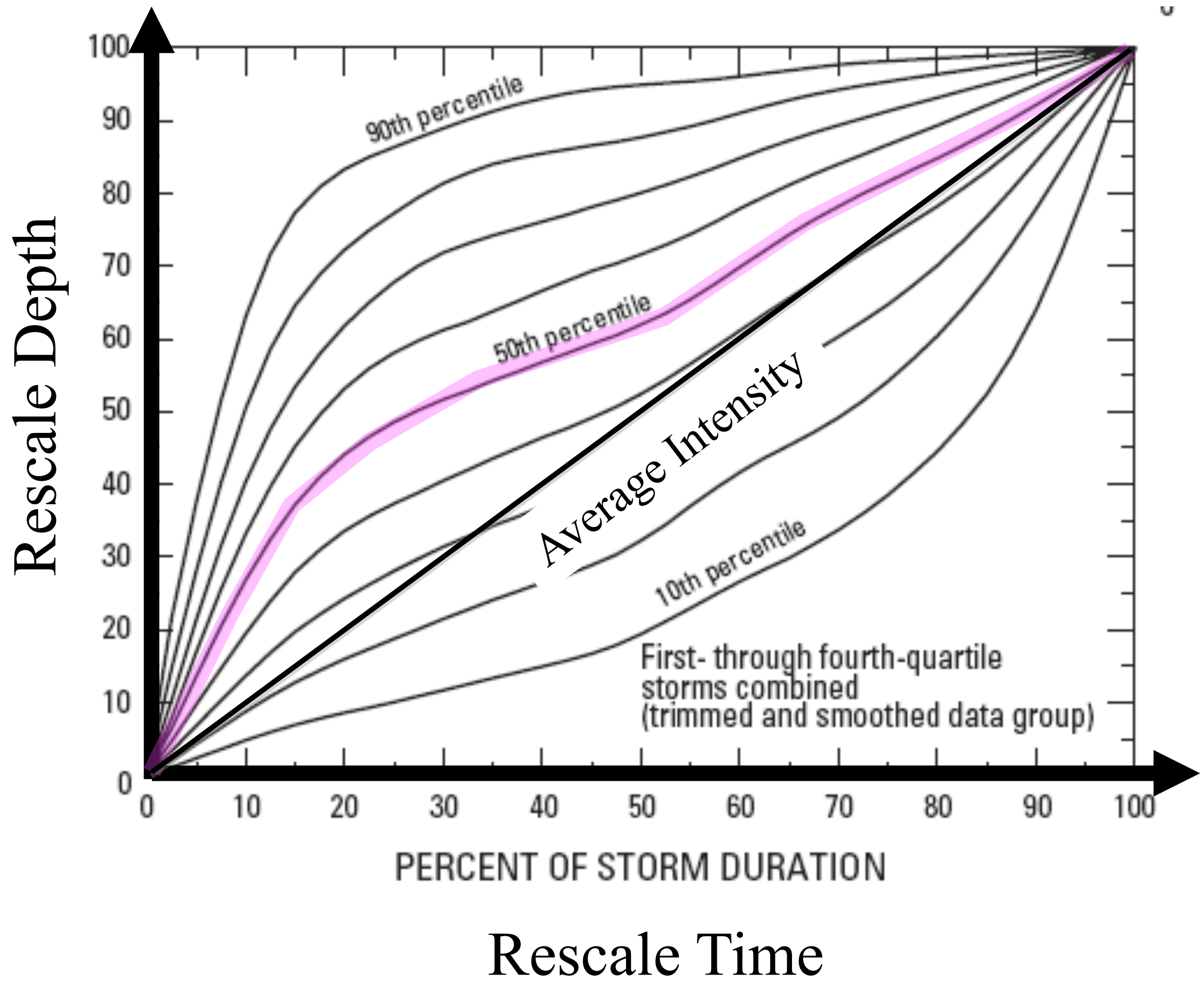
In cooperation with the Texas Department of Transportation

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



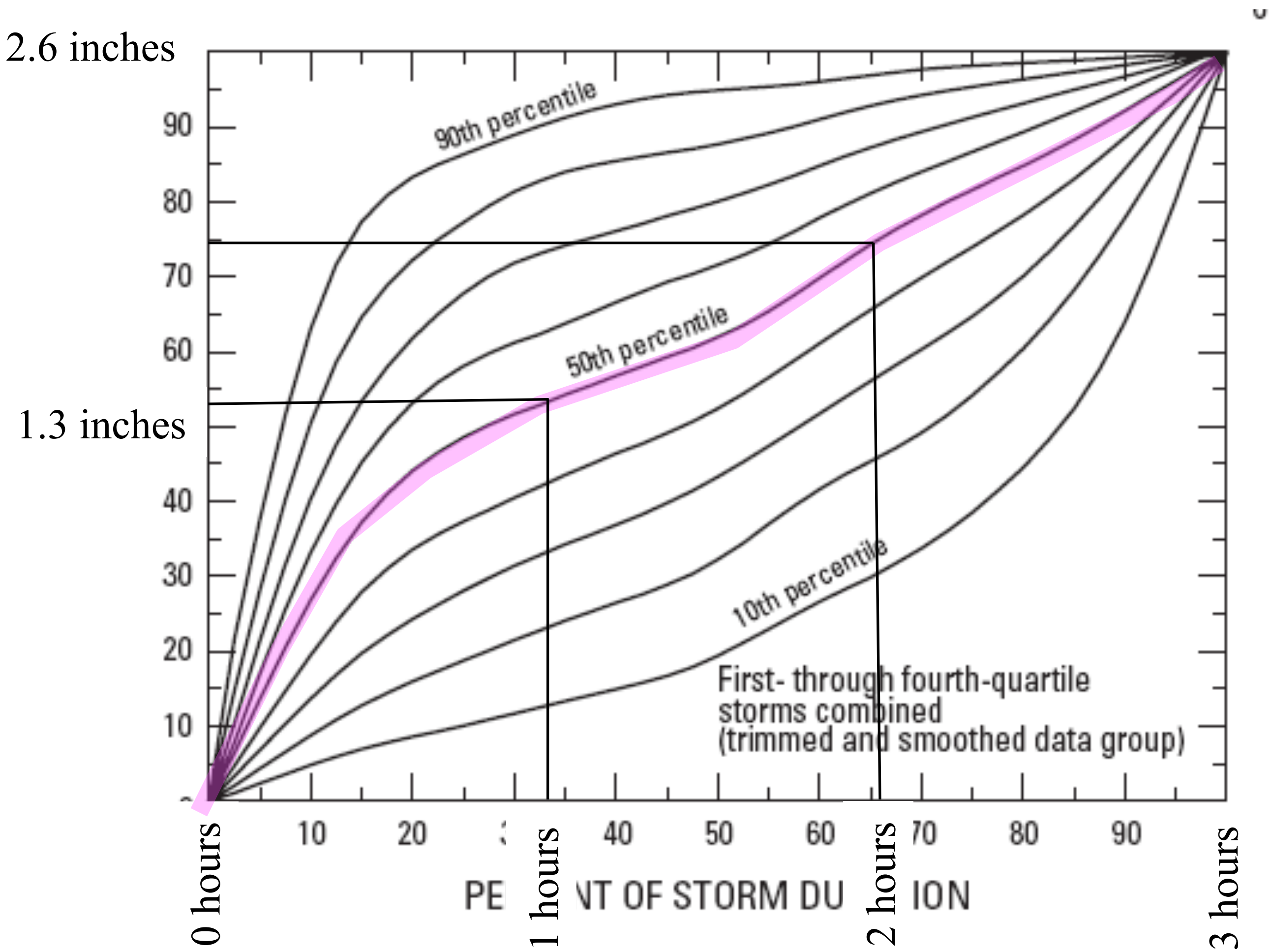
Texas Empirical Hyetographs

- 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.

TEXAS EMPIRICAL HYETOGRAPHS

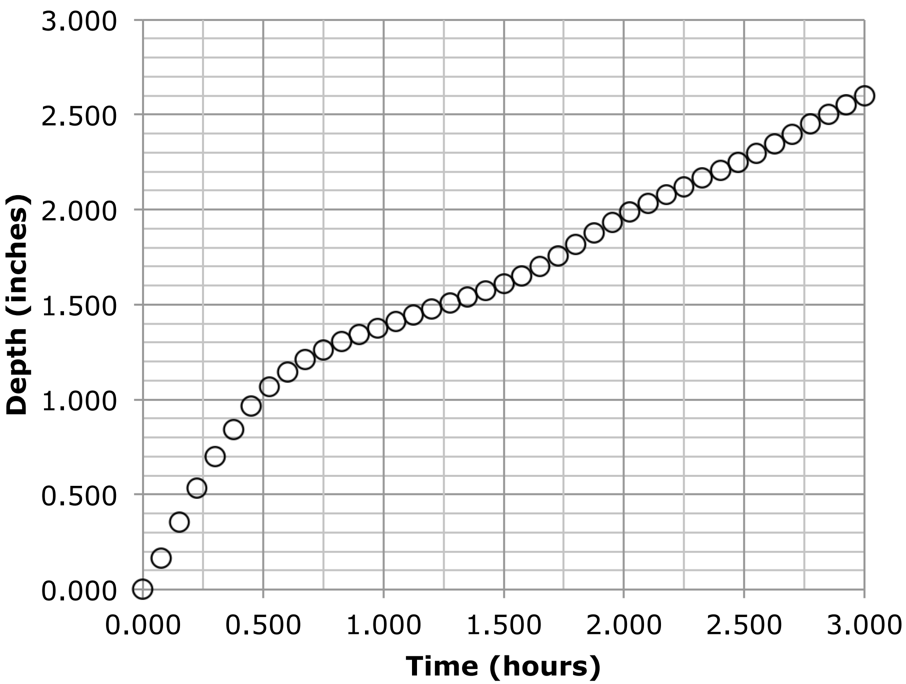
- Construct a design storm for the 3-hour, 2-year rainfall in Harris County using the Texas Empirical Hyetograph
  1. Obtain the depth from the DDF Atlas
  2. Rescale the depth and time using the Texas Empirical Hyetograph

EXAMPLE: TEXAS EMPIRICAL HYETOGRAPHS



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)

NEXT TIME

- The Rational Equation for Estimating Peak Discharges (for small drainage areas)
- Introduction to HEC-HMS
  - Set up a simple, constant intensity rainfall model
  - Approximate the rational method in HEC-HMS