CE 374 K – Hydrology

Hydrologic Design

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Hydrologic Design

- Assess the impact of hydrologic events on designs
  - Design Scale – Range of design variables
  - Design Level – Magnitude of hydrologic event considered for the design
    - Return periods for various structures
      - 1 – 100 years (Minor structures) – Highway culverts & bridges, Farm structures, urban drainage, air fields, small dams (w/o LOL)
      - 100 – 1000 years (Intermediate structures) – Major levees, intermediate dams
      - 500 – 100,000 years (Major structures) – Large dams, intermediate & small dams (w LOL)
    - Probable Maximum Precipitation (PMP)
    - Probable Maximum Flood (PMF)

Tx-DOT Recommendations

Recommended Design Frequencies (years)						
	Design					Check Flood
Functional Classification and Structure Type	**2**	**5**	**10**	**25**	**50**	**100**
Freeways (main lanes):						
¨ culverts					X	X
¨ bridges					X	X
Principal arterials:						
¨ culverts			X	(X)	X	X
¨ small bridges			X	(X)	X	X
¨ major river crossings					(X)	X
Minor arterials and collectors (including frontage roads):						
¨ culverts		X	(X)	X		X
¨ small bridges			X	(X)	X	X
¨ major river crossings				X	(X)	X
Local roads and streets (off-system projects):						
¨ culverts	X	X	X			X
¨ small bridges	X	X	X			X
Storm drain systems on interstate and controlled access highways (main lanes):						
¨ inlets and drain pipe			X			X
¨ inlets for depressed roadways*					X	X
Storm drain systems on other highways and frontage:						
¨ inlets and drain pipe	X	(X)				X
¨ inlets for depressed roadways*				(X)	X	X

Extreme Events

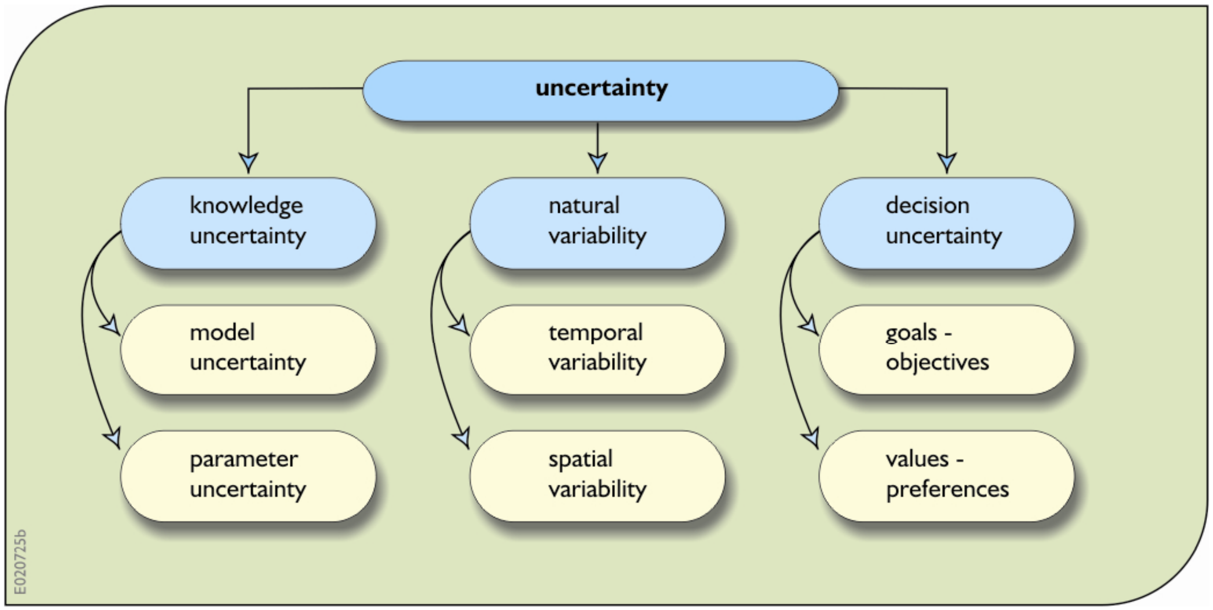
- Most extreme event from historic record sometimes used as design value.

Pr[most extreme event of last N years will be exceeded once in next n years]

$$P(N,n) = \frac{n}{N+n}$$

What is: P[largest flood of last N years will be exceeded in N years] ?

Uncertainty & Risk



- Risk
  - Structure may fail if event exceeds T – Year design magnitude
  - i.e., Pr[event occurs at least once in *n* years]
  - Natural inherent risk of failure

$$R = 1 - [1 - P(X \geq x_T)]^n = 1 - \left[1 - \frac{1}{T}\right]^n \qquad P(X \geq x_T) = \frac{1}{T}$$

Intensity-Duration-Frequency Estimates

- Design flows established from:
  - Rainfall intensities for storms of particular duration and return period

- Rainfall intensities can be found in:
  - TP-40 (U.S. Weather Bureau Technical Paper No. 40)
    - Durations: 30 minutes to 24 hours
    - Recurrence intervals: 2 to 100 years
  - HYDRO–35 (1977)
    - Durations: 5 to 60 minutes
    - Recurrence intervals: 2 to 100 years
  - Asquith (1998*)
    - Durations: 15 minutes to 7 days
    - Recurrence intervals: 2 to 500 years

Asquith, W.H., *Depth-Duration Frequency of Precipitation for Texas* WRI 98-4044, U.S. Geological Survey, Austin, Texas 1998

Example

- Find the 25-year 30-minute design rainfall depth for OK City
  - Get values of 15- and 60-minute rainfall for 2- and 100-year return periods

$$P_{2-\text{yr},15-\text{min}} = 1.02\,in.$$
$$P_{100-\text{yr},15-\text{min}} = 1.86\,in.$$
$$P_{2-\text{yr},60-\text{min}} = 1.85\,in.$$
$$P_{100-\text{yr},60-\text{min}} = 3.80\,in.$$

Example

Return Period, T years	a	b
5	0.674	0.278
10	0.496	0.449
25	0.293	0.669
50	0.146	0.835

$$P_{2-\text{yr},30-\text{min}} = 0.51 P_{2-\text{yr},15-\text{min}} + 0.49 P_{2-\text{yr},60-\text{min}}$$

$$P_{2-\text{yr},30-\text{min}} = 0.51(1.02) + 0.49(1.85) = 1.43\,in.$$

$$P_{100-\text{yr},30-\text{min}} = 0.51 P_{100-\text{yr},15-\text{min}} + 0.49 P_{100-\text{yr},60-\text{min}}$$

$$P_{100-\text{yr},30-\text{min}} = 0.51(1.86) + 0.49(3.80) = 2.81\,in.$$

$$P_{25-\text{yr},30-\text{min}} = aP_{2-\text{yr},30-\text{min}} + bP_{100-\text{yr},30-\text{min}}$$

$$P_{25-\text{yr},30-\text{min}} = 0.293(1.43) + 0.669(2.81) = 2.30\,in.$$

Intensity – Duration – Frequency Curves

- Hydrologic design – What rainfall event should we use?
- Use relationship between:
  - Intensity i (depth per unit time, e.g., in./hr.)
  - Duration T_d, and
  - Frequency (return period)
  - Coefficients: c, e, f

$$i = \frac{c}{(T_d)^e + f}$$

Houston (10-year)

$$i = \frac{c}{(T_d)^e + f} = \frac{97.4}{(20)^{0.77} + 4.8} = 6.56\, in.$$

Los Angeles (10-year)

$$i = \frac{c}{(T_d)^e + f} = \frac{20.3}{(20)^{0.63} + 2.06} = 2.34\, in.$$

Intensity – Duration – Frequency Curves

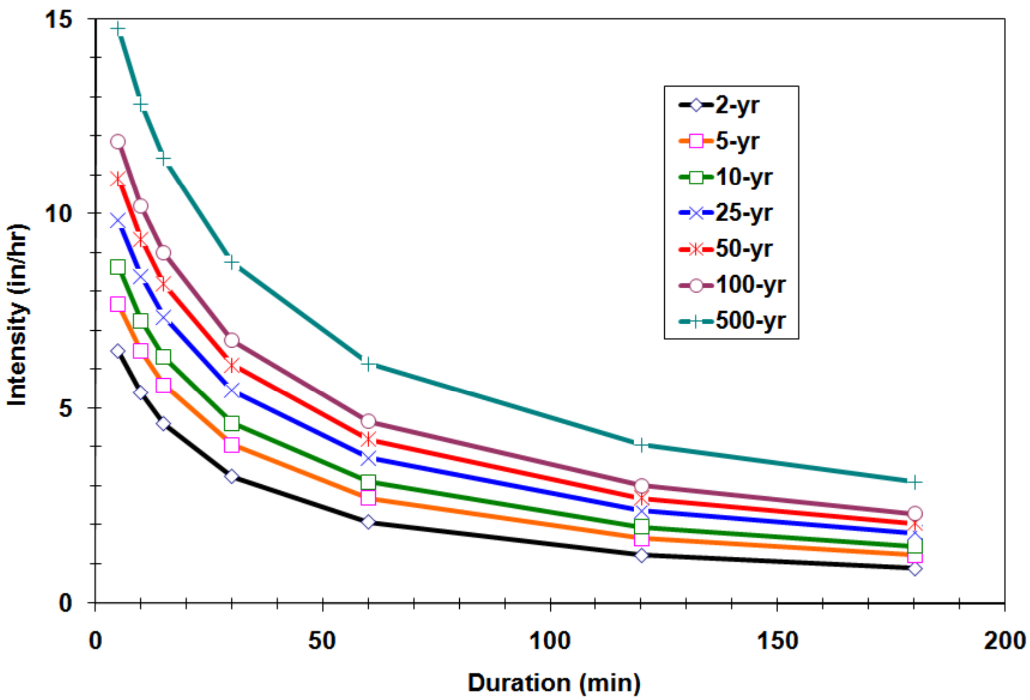
- Book method

$$i = \frac{c}{(T_d)^e + f}$$

- City of Austin method

$$i = \frac{a}{(T_d + b)^c}$$

Storm Frequency	a	b	c
2-year	106.29	16.81	0.9076
5-year	99.75	16.74	0.8327
10-year	96.84	15.88	0.7952
25-year	111.07	17.23	0.7815
50-year	119.51	17.32	0.7705
100-year	129.03	17.83	0.7625
500-year	160.57	19.64	0.7449



Example: IDF Curves

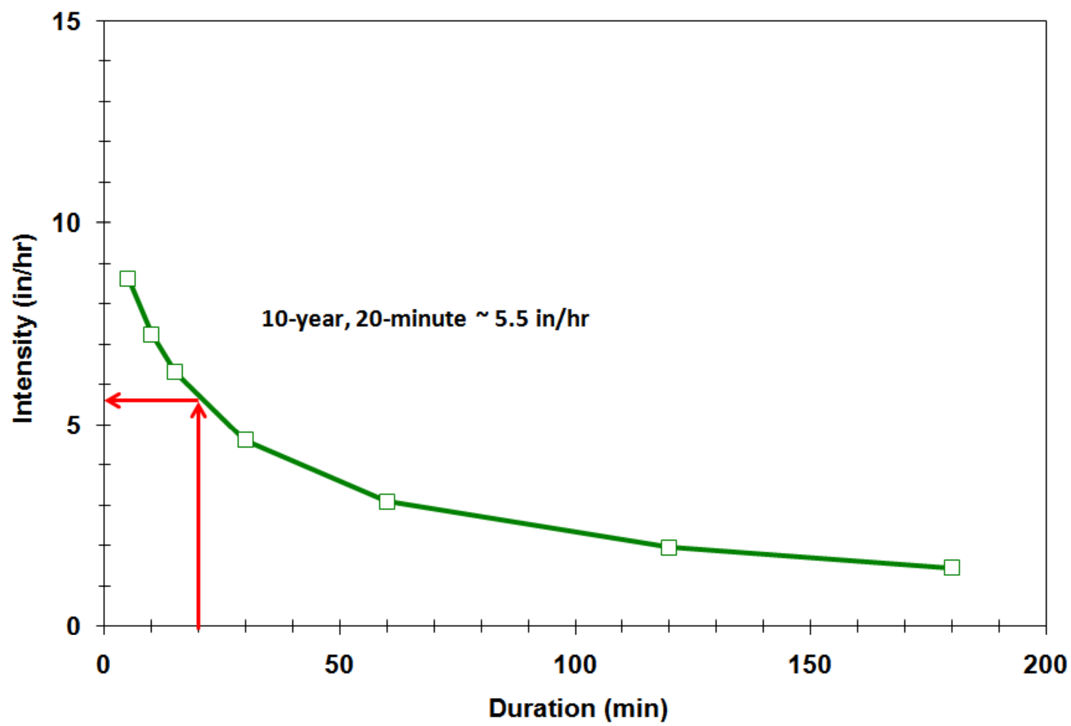
- Determine the 10-year, 20-minute design rainfall intensity for Austin, Texas

Storm Frequency	a	b	c
2-year	106.29	16.81	0.9076
5-year	99.75	16.74	0.8327
10-year	96.84	15.88	0.7952
25-year	111.07	17.23	0.7815
50-year	119.51	17.32	0.7705
100-year	129.03	17.83	0.7625
500-year	160.57	19.64	0.7449

$$i = \frac{a}{(T_d + b)^c}$$

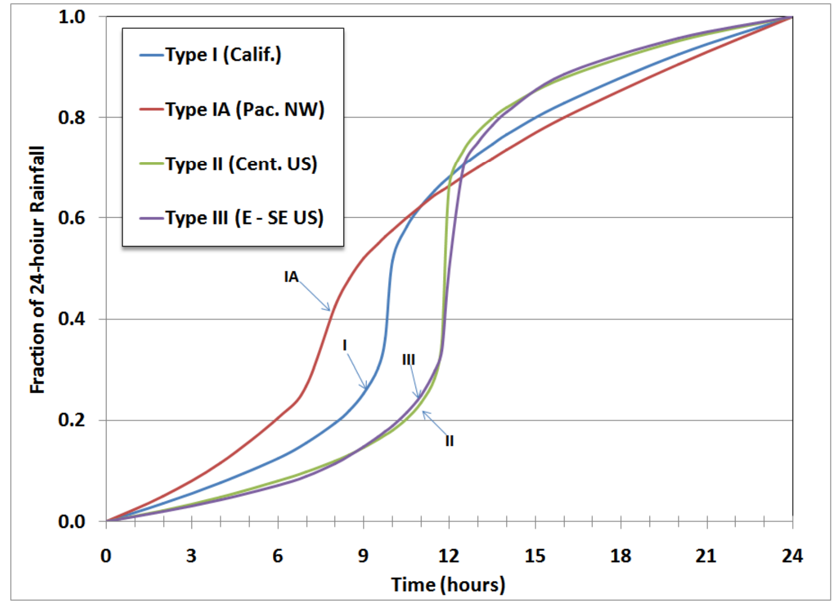
$$= \frac{96.84}{(20 + 15.88)^{0.7952}}$$

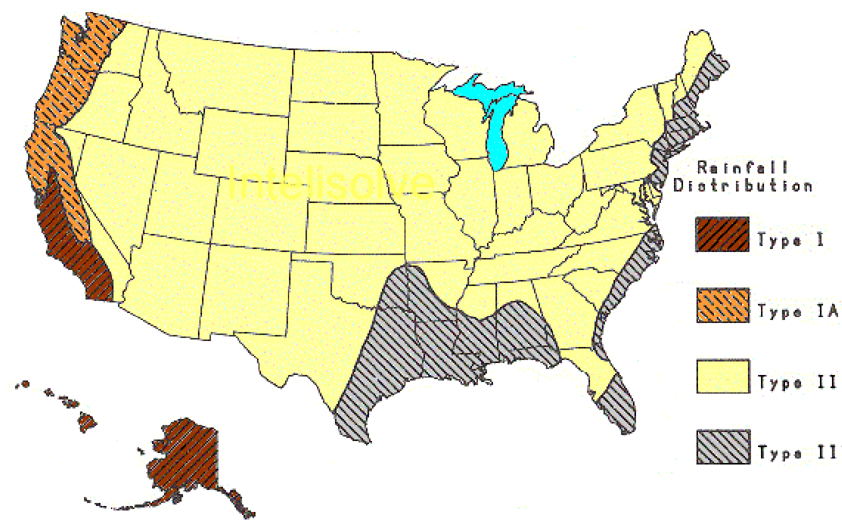
$$= 5.62\, in/hr$$



Design Hyetographs

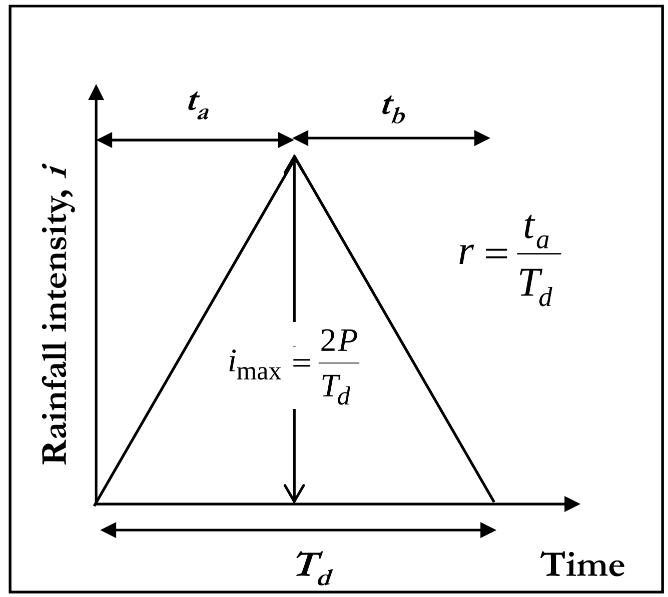
- Distribute rainfall over time (get hyetograph)
  - Historic storms
    - Use measured storm(s) that occurred and caused damage
  - IDF synthetic patterns
    - hyetograph developed from IDF curves
  - SCS synthetic patterns
    - SCS obtained rainfall patterns using generalized IDF values
    - Divided the US into zones





Triangular Hyetograph Method

- Requires precipitation depth P and duration T_d
- Time before peak = t_a
- Recession time = t_r
- Storm advancement coefficient = r
- Once the triangle is constructed, intensities at regular intervals can be determined for input to rainfall-runoff calculations.



Example – Triangular Hyetograph

- Find: Triangular hyetograph for a 5-year return period storm of duration 15 minutes with *r* = 0.38.

$$P_{2,15} = 0.88\,in$$

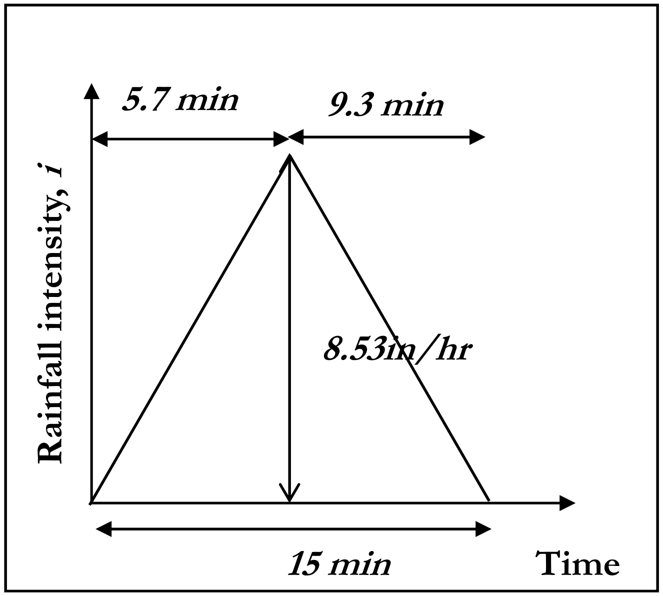
$$P_{100,15} = 1.70\,in$$

Return Period, T years	a	b
5	0.674	0.278
10	0.496	0.449
25	0.293	0.669
50	0.146	0.835

$$P_{5-\mathrm{yr}} = a_{5\mathrm{yr}} P_{2\mathrm{yr},15\mathrm{min}} + b_{5\mathrm{yr}} P_{100\mathrm{yr},15\mathrm{min}}$$
$$= 0.674(0.88) + 0.278(1.70)$$
$$= 1.07\,in.$$

$$i_{\max} = \frac{2P}{T_d} = \frac{2*1.07}{0.25} = 8.56\,in/hr$$

$$t_a = rT_d = 0.38*0.25 = 0.095\,hr = 5.7\,\mathrm{min}$$



Alternating Block Hyetograph Method

- Using I-D-F curves to find rainfall intensities for Δt, $2\Delta t$, $3\Delta t$, etc. increments of time
- Organize intensities around the center of the storm
- Different methods can be used to arrange the intensities
  - Alternating block method
  - Chicago method
  - Balanced method
- Area under the hyetograph equal to the design storm depth, P

Alternating Block Method

- Develop design hyetograph from IDF curve
  - Precipitation depth in n time intervals Δt
  - Select return period
  - Read i from IDF curve for each duration $D = \Delta t, 2\Delta t, 3\Delta t, \ldots$
  - Find P = intensity * duration= $i * D$
  - Find incremental precipitation ΔP from differences
  - Reorder increments
    - Maximum incremental precipitation at center
    - Remaining arranged in descending order alternately right and left

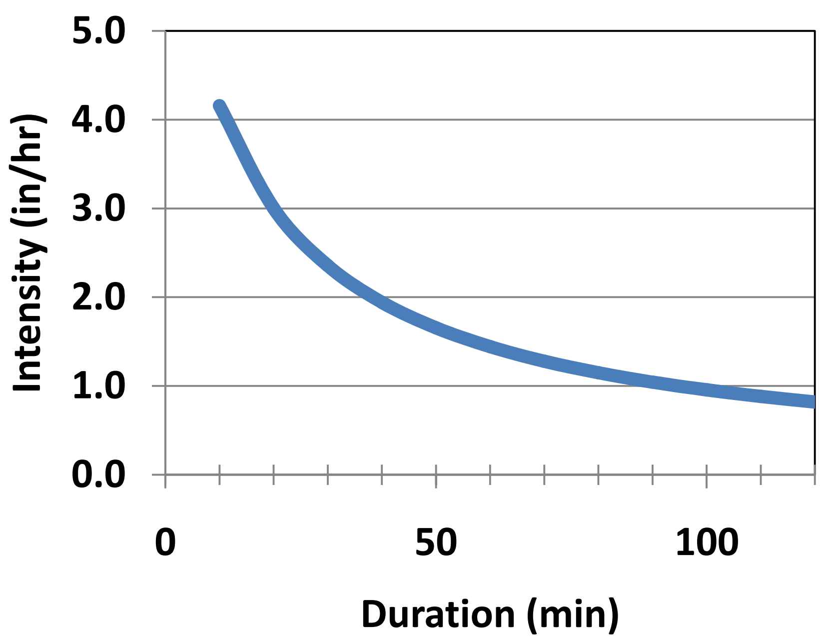
Example: Alternating Block Method

Find: Design precipitation hyetograph for a 2-hour storm (in 10 minute increments) in Denver with a 10-year return period 10-minute

$$i = \frac{c}{(T_d)^e + f} = \frac{96.6}{(T_d)^{0.97} + 13.90}$$

$i =$ design rainfall intensity
$T_d =$ Duration of storm
$c, e, f =$ coefficients

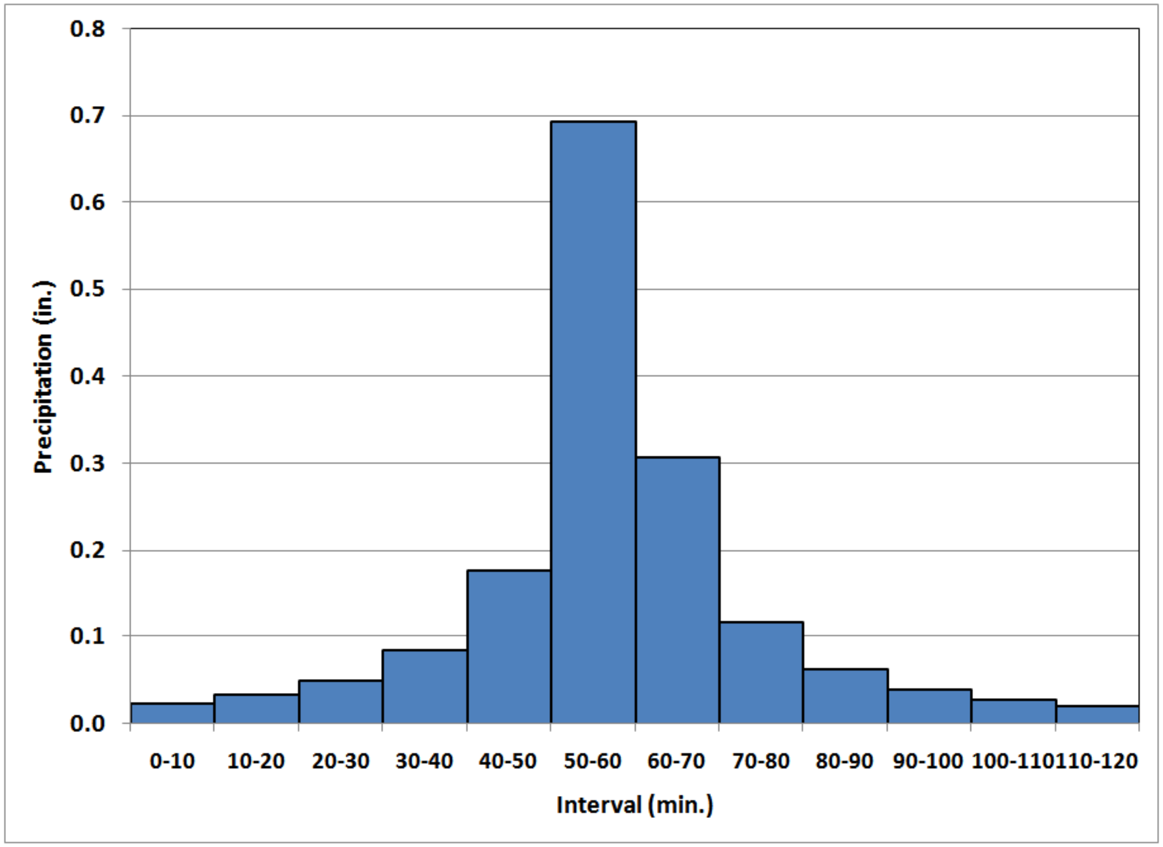
Duration (min)	Intensity (in/hr)
10	4.158
20	3.002
30	2.357
40	1.943
50	1.655
60	1.443
70	1.279
80	1.149
90	1.044
100	0.956
110	0.883
120	0.82



Example: Alternating Block Method

Duration (min)	Intensity (in/hr)	Cumulative Depth (in)	Incremental Depth (in)
10	4.158	0.693	0.693
20	3.002	1.001	0.308
30	2.357	1.179	0.178
40	1.943	1.295	0.117
50	1.655	1.379	0.084
60	1.443	1.443	0.064
70	1.279	1.492	0.049
80	1.149	1.532	0.040
90	1.044	1.566	0.034
100	0.956	1.593	0.027
110	0.883	1.619	0.026
120	0.82	1.640	0.021

No.	Time (min)	Precip. (in)	No.
1	0-10	0.024	11
2	10-20	0.033	9
3	20-30	0.050	7
4	30-40	0.084	5
5	40-50	0.178	3
6	50-60	0.693	1
7	60-70	0.308	2
8	70-80	0.117	4
9	80-90	0.063	6
19	90-100	0.040	8
11	100-110	0.028	10
12	110-120	0.021	12



Flood Frequencies for Projects

- Tx-DOT Recommendation
  - For all drainage facilities - evaluate the impact of the 100-year flood event
  - In some cases, evaluate a flood event larger than the 100-year flood to ensure the safety of the structure and downstream development.
  - Bridge foundations - 500-year flood analysis is required for checking scour failure
  - If a catastrophic failure can release a flood wave that would result in loss of life, disruption of essential services, or excessive economic damage, the design should be evaluated in terms of a probable maximum flood (PMF)