DESIGN RAINFALL
Depth and Distribution

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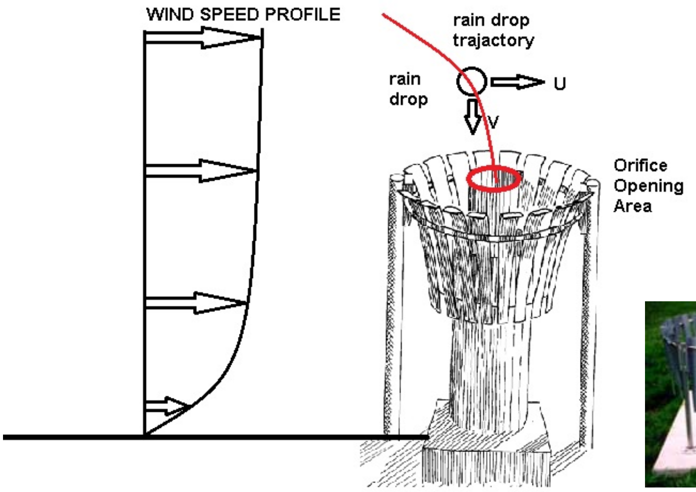
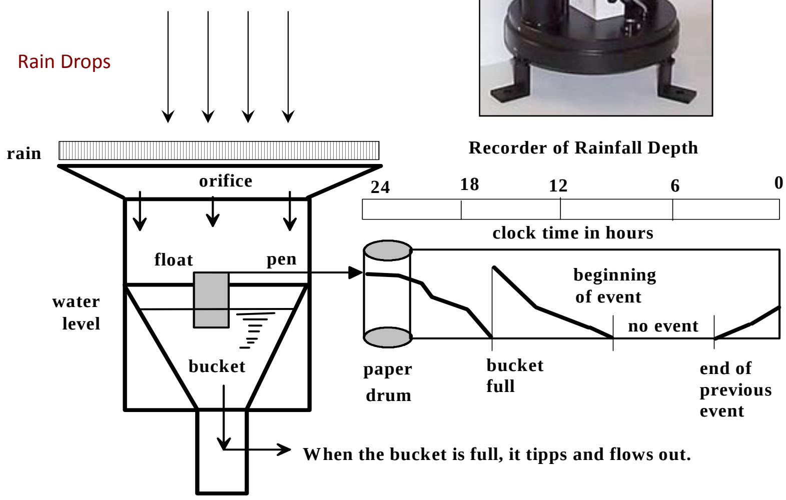
RAIN GAGE INSTALLATION – rain and wind gages

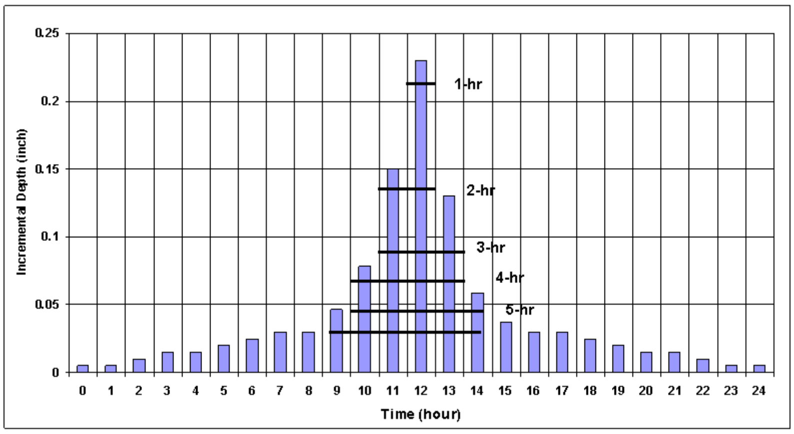
Set a shield around a rain gage to reduce (1) Wind speed effect and (2) Height effect



Tipping-bucket Rain Gage



Incremental volume: Rainfall-Depth Distribution



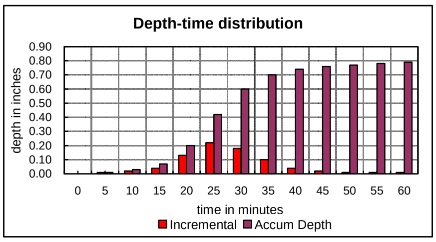
- Duration D
- Depth P
- Intensity I = P/D
- Distribution: Incremental curve VS cumulative (mass) curve
- Return Period: 2-, 5-, 10-, 25-, 50-, and 100-yr (extreme events)

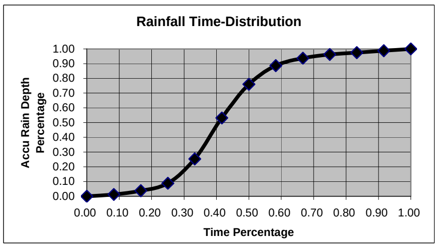
Cumulative Volume: Rainfall Depth Mass Curve

RAINFALL EVENT Time-Distribution Analysis

Time interval 5.00 minutes
Time at beginning 5:30

Clock time t minutes	Rainfall Increment dP(t) inches	Cumualtive Rain Depth tP(t) inches	Normalized Time t/D	Normalized Rainfall Depth tP(t)/P
0.00	0.00	0.00	0.00	0.00
5.00	0.01	0.01	0.08	0.01
10.00	0.02	0.03	0.17	0.04
15.00	0.04	0.07	0.25	0.09
20.00	0.13	0.20	0.33	0.25
25.00	0.22	0.42	0.42	0.53
30.00	0.18	0.60	0.50	0.76
35.00	0.10	0.70	0.58	0.89
40.00	0.04	0.74	0.67	0.94
45.00	0.02	0.76	0.75	0.96
50.00	0.01	0.77	0.83	0.97
55.00	0.01	0.78	0.92	0.99
60.00	0.01	0.79	1.00	1.00



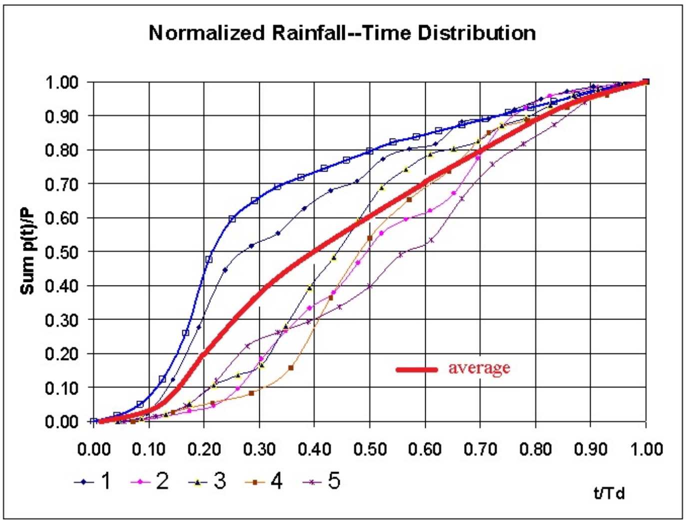


Observed Rainfall Distributions

Observed Rainfall at Stapleton Gage, Denver, Colorado

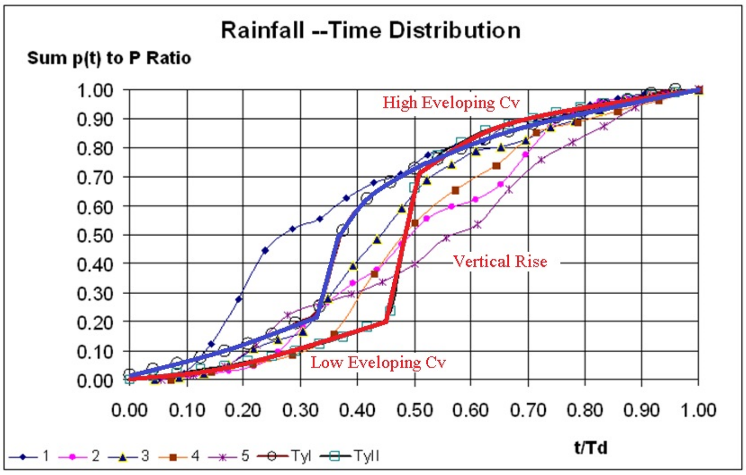
Time	3/20/1952	4/2/1957	9/28/1973	3/10/1977	8/24/1992
Hours	Incremental Rainfall Depth in inch				
1	0.00	0.00	0.00	0.00	0.00
2	0.03	0.01	0.01	0.03	0.03
3	0.14	0.02	0.02	0.03	0.06
4	0.21	0.03	0.04	0.03	0.15
5	0.23	0.03	0.07	0.08	0.20
6	0.10	0.10	0.04	0.22	0.08
7	0.05	0.17	0.04	0.19	0.06
8	0.10	0.16	0.15	0.12	0.09
9	0.07	0.13	0.15	0.09	0.12
10	0.04	0.09	0.12	0.12	0.18
11	0.09	0.17	0.14	0.04	0.09
12	0.04	0.17	0.13	0.04	0.24
13	0.02	0.08	0.07	0.04	0.20
14	0.09	0.05	0.06	0.04	0.12
15	0.01	0.10	0.02	0.00	0.11
16	0.04	0.20	0.03		0.13
17	0.04	0.19	0.06		0.10
18	0.03	0.10	0.03		0.02
19	0.02	0.07	0.05		0.00
20	0.01	0.02	0.04		
21	0.01	0.03	0.02		
22	0.00	0.02	0.02		
23		0.01	0.01		
24		0.00	0.00		

Plot the dimensionless mass curves for observed rainfall distributions



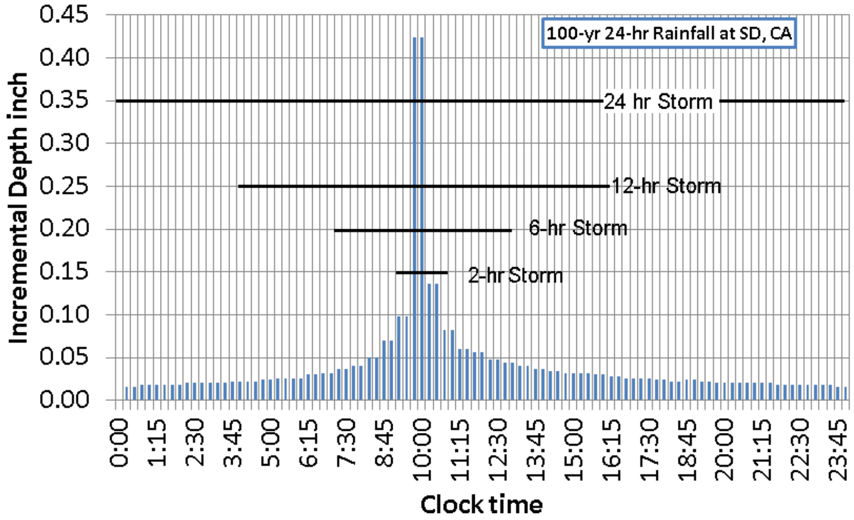
How to convert the observed into the design curves?

Observed and Design Rainfall Curves
How were SCS Type I and II curves developed?



Non-dimensional time/duration
Non-dimensional accumulated rainfall depth/total.

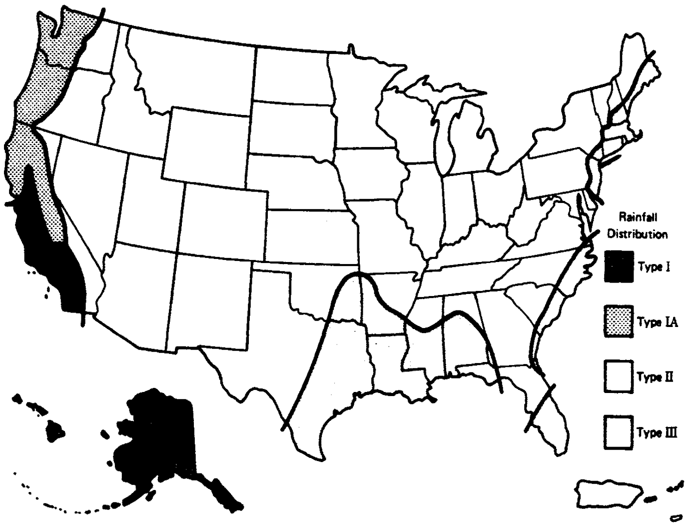
100-yr SCS 24-hr Ty-I: Incremental Depth-time Distribution



SCS 24-hr Rainfall Mass Curves

Time	Type I	Type II	Type IIA	Type IA	6-hr
hours		p(t)/P24			p(t)/P6
0.000	0.000	0.000	0.000	0.000	0.000
1.000	0.017	0.011			0.080
2.000	0.035	0.022	0.010	0.050	0.050
3.000	0.055	0.035			0.705
4.000	0.076	0.046	0.030	0.075	0.835
5.000	0.099	0.063	0.060	0.016	0.160
6.000	0.125	0.080	0.700	0.220	1.000
7.000	0.156	0.098	0.780	0.275	
8.000	0.194	0.123	0.820	0.450	
9.000	0.254	0.147	0.840	0.525	
10.000	0.515	0.181			
11.000	0.624	0.235	0.865	0.625	
12.000	0.682	0.663	0.890	0.675	
13.000	0.727	0.772	0.905	0.710	
14.000	0.762	0.820	0.915	0.740	
15.000	0.797	0.860			
16.000	0.830	0.880	0.940	0.800	
17.000	0.857	0.902			
18.000	0.882	0.921			
19.000	0.905	0.937			
20.000	0.926	0.952	0.980	0.910	
21.000	0.946	0.965			
22.000	0.965	0.978			
23.000	0.985	0.990			
24.000	1.000	1.000	1.000	1.000	

Applicable Areas for SCS 24-hr Curves



Time	P(t)/P1				
	2-yr	5-yr	10-yr	50-yr	100-yr
minutes	percent	percent	percent	percent	percent
0.00	0.00	0.00	0.00	0.00	0.00
5.00	2.00	2.00	2.00	1.30	1.00
10.00	4.00	3.70	3.70	3.50	3.00
15.00	8.40	8.70	8.70	5.00	4.60
20.00	16.00	15.30	15.00	8.00	8.00
25.00	25.00	25.00	25.00	15.00	14.00
30.00	14.00	13.00	12.00	25.00	25.00
35.00	6.30	5.80	5.60	12.00	14.00
40.00	5.00	4.40	4.30	8.00	8.00
45.00	3.00	3.60	3.80	5.00	6.20
50.00	3.00	3.60	3.20	5.00	5.00
55.00	3.00	3.00	3.20	3.20	4.00
60.00	3.00	3.00	3.20	3.20	4.00
65.00	3.00	3.00	3.20	3.20	4.00
70.00	2.00	3.00	3.20	2.40	2.00
75.00	2.00	2.50	3.20	2.40	2.00
80.00	2.00	2.20	2.50	1.80	1.20
85.00	2.00	2.20	1.90	1.80	1.20
90.00	2.00	2.20	1.90	1.40	1.20
95.00	2.00	2.20	1.90	1.40	1.20
100.00	2.00	1.50	1.90	1.40	1.20
105.00	2.00	1.50	1.90	1.40	1.20
110.00	2.00	1.50	1.90	1.40	1.20
115.00	1.40	1.50	1.70	1.40	1.20
120.00	1.40	1.50	1.30	1.40	1.20

Denver's 2-hr Design Rainfall Curves

(a) Design Rainfall Curve is formed by the y-axis as % to the index rainfall depth and the x-axis as % to the index duration.

(b) Index rainfall depth = one-hr depth for the selected return period: 2, 5, 10, 50, and 100 year.

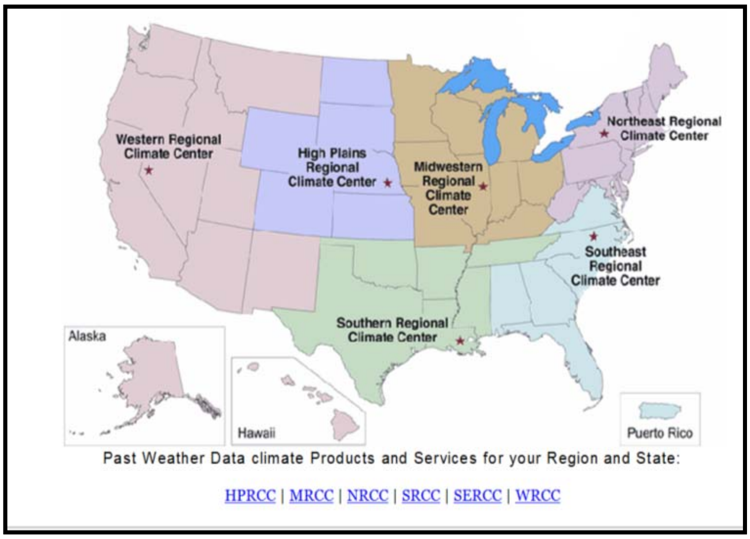
(c) Index rainfall duration = 2 hr.

National Design Rainfall Curves:
SCS 6-. 12-, and 24-hr curves
Type 24I, and 24IA
Type 24II and 24IIA

Software : CUHP2005, Rain Curve and Rain Zone

National Climate Center for Rainfall Data

http://www.ncdc.noaa.gov/oa/climate/climatedata.html#surface



National Climate Center for Rainfall Data

http://www.ncdc.noaa.gov/oa/climate/climatedata.html#surface

Surface Data

- **Graphs & Maps**
  Weather Charts, Climate Maps of the US, Paleoclimate Data
- **Radar**
  National & Regional Radar Mosaics, NEXRAD Level II and III data, Additional Radar Resources
- **1-Minute/5-Minute**
  ASOS 1-Minute & 5-Minute Data
- **Hourly**
  US Climate Reference Network, Local Climatological Data, Surface Weather Observations, Hourly & 15 minute Precipitation Data
- **Daily**
  Cooperative, NWS, Local Climatological Data, World War II Era, more
- **Monthly**
  Climate at a Glance, Cooperative, Local Climatological Data, more
- **Modeled**
  Temperature Anomalies, NOMADS, Climate Models

NOAA Point Rainfall Atlas for the USA

A. Durations to I day and return periods to 100 years
NOAA Technical Memorandum NWS HYDRO-35 (1977) "5 to 60-minute Precipitation-Frequency for Eastern and Central United States"
Technical Paper 40 covering 48 states (1961) recommended for 37 contiguous states east of the 105th meridian for durations of 2 to 24 hours.
Technical Paper 42. Puerto Rico and Virgin Islands (1961)
Technical Paper 43. Hawaii (1962)
Technical Paper 47. Alaska (1963) NOAA Atlas

B. Precipitation Atlas 2 for the 11 Western United States (1973)
Vol. 1- Montana, Vol. 11- Wyoming, Vol. III- Colorado, Vol. IV- New Mexico, Vol. V- Idaho
Vol. VI- Utah, Vol. VII- Nevada, Vol. VIII- Arizona, Vol. IX- Washington, Vol. X- Oregon
Vol. XI- California

C. Durations from 2 to 10 days and return periods to 100 years
Technical Paper 49. 48 contiguous states (1964)
Technical Paper 51. Hawaii (1965)
Technical Paper 52. Alaska (1965)
Technical Paper 53. Puerto Rico and Virgin Islands (1965)

D. Probable maximum precipitation
Hydrometeorological Report 33. States east of the 105th meridian (1956)
Hydrometeorological Report 36. California (1961)
Hydrometeorological Report 39. Hawaii (1963)
Hydrometeorological Report 43. Northwest States (1966)
Hydrometeorological Report No. 49 Colorado and Great Basin Drainage
Hydrometeorological Report No. 51 East of the 105th Meridian
Technical Paper 38. States west of the 105th meridian (1960)

Point Rainfall Statistics for Colorado

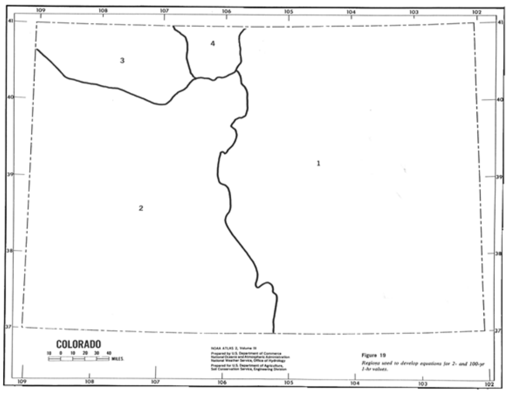
HYDROLOGIC ZONES IN THE STATE OF COLORADO

Identify the hydrologic zone for your project site: Zone 1, 2, 3 or 4.

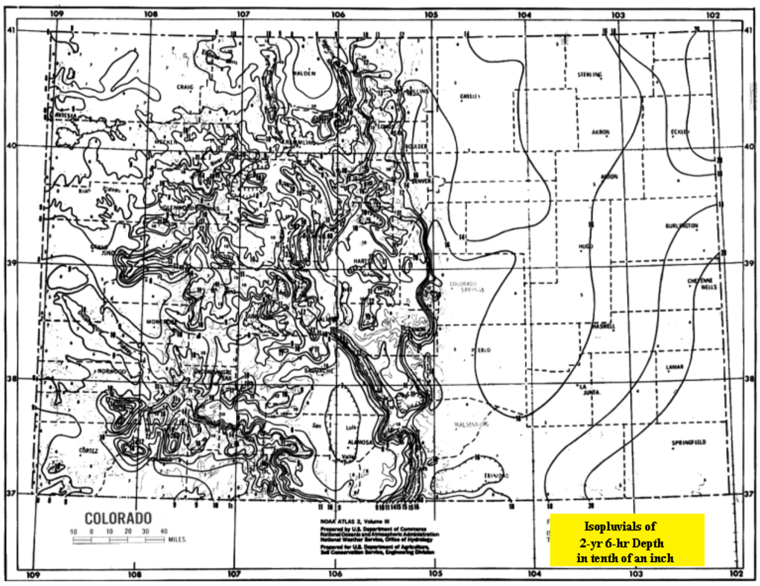
Geographic Regions in the State of Colorado

Zone 1: South Platte, Republican, Arkansas, and Cimarron River Basins
Zone 2: San Juan, Upper Rio Grande, Upper Colorado, and Gunnison River Basins, and Green River Basin below Confluence with the Yampa River
Zone 3: Yampa and Green River Basins above confluence of Green and Yampa Rivers
Zone 4: North Platte River Basins

Definition of these four zones is below:



Sample from Rainfall Atlas VOl-III for Colorado



Point Rainfall Statistics for Denver

Rainfall Zone Rainfall Curve

IDF TABLE FOR ZONE 1 IN THE STATE OF COLORADO

Zone 1: South Platte, Republican, Arkansas, and Cimarron River Basins

The elevation at the center of the watershed in hundreds of feet = 55.00 (input)

(Example: enter 55.0 for an elevation of 5500 feet.)

1. Precipitation-Duration-Frequency Table

Return Period	Rainfall Depth in inches for Various Durations								
	5-min	*10-min*	*15-min*	*30-min*	*1-hr*	*2-hr*	*3-hr*	*6-hr*	*24-hr*
(1)	*(2)*	*(3)*	*(4)*	*(5)*	*(6)*	*(7)*	*(8)*	*(9)*	*(10)*
	output	*output*	*output*	*output*	*input*	*output*	*output*	*input*	*input*
2-yr	0.32	0.50	0.63	0.87	1.11	1.29	1.43	1.65	2.17
5-yr	0.43	0.67	0.85	1.18	1.49	1.72	1.88	2.15	2.65
10-yr	0.50	0.77	0.97	1.35	1.71	1.96	2.15	2.45	3.11
25-yr	0.58	0.90	1.15	1.59	2.01	2.30	2.51	2.85	3.69
50-yr	0.67	1.04	1.32	1.82	2.31	2.62	2.85	3.21	4.21
100-yr	0.76	1.19	1.50	2.08	2.64	2.93	3.16	3.51	4.59

Notes: 1. Read Volume III for 6-hr and 24-hr rainfall depths

2. Based on 2- and 100-yr one-hr rainfall depths, the design chart to you right shall be used for dertermining 5-, 10-, 25-, and 50-yr one-hour rainfall depths.

2. Rainfall Intensity-Duration-Frequency Table

Return Period	Rainfall Depth in inches for Various Durations								
	5-min	*10-min*	*15-min*	*30-min*	*1-hr*	*2-hr*	*3-hr*	*6-hr*	*24-hr*
(1)	*(2)*	*(3)*	*(4)*	*(5)*	*(6)*	*(7)*	*(8)*	*(9)*	*(10)*
	output	*output*	*output*	*output*	*output*	*output*	*output*	*output*	*output*
2-yr	3.85	2.99	2.53	1.75	1.11	0.65	0.48	0.28	0.09
5-yr	5.19	4.02	3.40	2.35	1.49	0.86	0.63	0.36	0.11
10-yr	5.95	4.62	3.90	2.70	1.71	0.98	0.72	0.41	0.13
25-yr	6.99	5.43	4.58	3.18	2.01	1.15	0.84	0.48	0.15
50-yr	8.04	6.24	5.27	3.65	2.31	1.31	0.95	0.54	0.18
100-yr	9.17	7.12	6.01	4.16	2.64	1.47	1.05	0.59	0.19

Colorado Empirical Rainfall Formulas for Point Depth

			1-	Hr			2-	hr	3-	hr
Zone	a	b	c	d	e	f	m	n	r	q
1	0.218	0.709		1.897	0.439	-0.008	0.342	0.658	0.597	0.403
2	-0.011	0.942		0.494	0.755		0.341	0.659	0.569	0.431
3	0.019	0.711	0.001	0.338	0.670	0.001	0.250	0.750	0.467	0.533
4	0.028	0.890		0.671	0.757	-0.003	0.250	0.750	0.467	0.533

Table 6.2 Coefficients for Precipitation Formulas Developed for Colorado

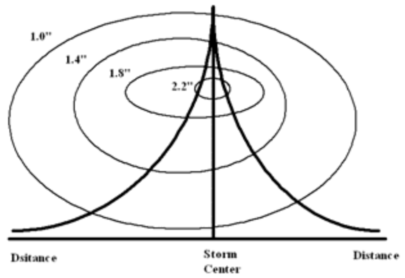
2-year 1-hr
$$P_2^{\,1} = a + b\left(\frac{P_2^{\,6} \times P_2^{\,6}}{P_2^{\,24}}\right) + cZ \qquad (6.1)$$

100-year 1-hr
$$P_2^{\,1} = d + e\left(\frac{P_{100}^{\,6} \times P_{100}^{\,6}}{P_{100}^{\,24}}\right) + fZ \qquad (6.2)$$

2-hr(?)
$$P^2 = mP^6 + nP^1 \text{ for a specified frequency} \qquad (6.3)$$

3-hr(?)
$$P^3 = rP^6 + qP^1 \text{ for a specified frequency} \qquad (6.4)$$

For Large Watersheds
Point Rainfall Depth =➔ Area Rainfall Depth
using the Depth-Area-Reduction Factors (DARF)

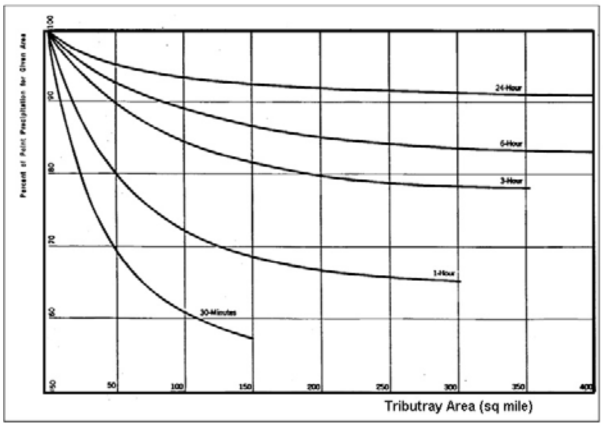


1. Plot Equal-Depth Contours
2. Highest (Pt) Depth at Storm Center
3. Calculate area-averaged depth for a selected area
4. DARF= avg Depth/Pt Depth for the selected area

This analysis is duration dependent.

Precip Depth inch	Incremental Covering Area sq miles	Incremental Rainfall Volume inch-sq mi	Total Covering Area sq mi	Total Rainfall Volume inch-sq mi	Area Average Depth inch	Rainfall DARF
2.20	1.00	2.20	1.00	2.20	2.20	1.00
1.80	8.00	14.40	9.00	16.60	1.84	0.92
1.40	15.00	21.00	24.00	37.60	1.57	0.78
1.00	20.00	20.00	44.00	57.60	1.31	0.65

Recommended DARF for the USA



Watershed Area= 100 sq miles
Rainfall Duration= 6 hr
Ponit Rainfall P6= 3 inches
DARF= 0.88
Area Rainfall Depth = 3*0.88= 2.64 inch

Use 2.64 inch for 6-hr rainfall depth on the area of 100 sq mile to predict the flow at the watershed outlet.

Do we need a new DARF for your project site ?
Can we derive the local DARF?

BASICS: Rainfall Population based on one-hr depths from 1948 to 1977 recorded at San Diego, CA

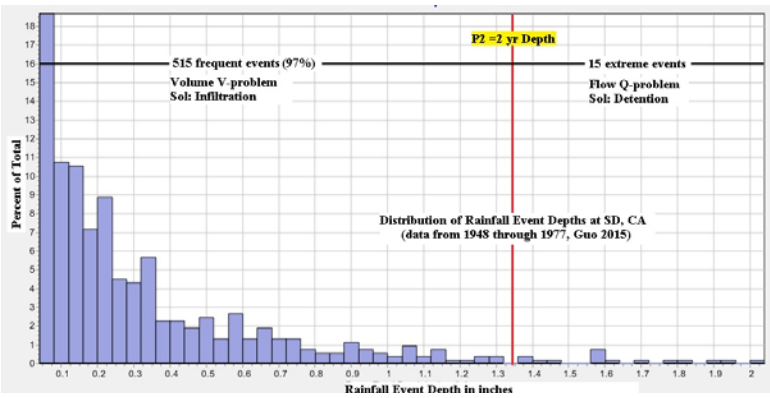
Facts:

1. Only 15 events out of 30 years >2 yr event (i.e. 3%)
2. 97% of events<2 yr event

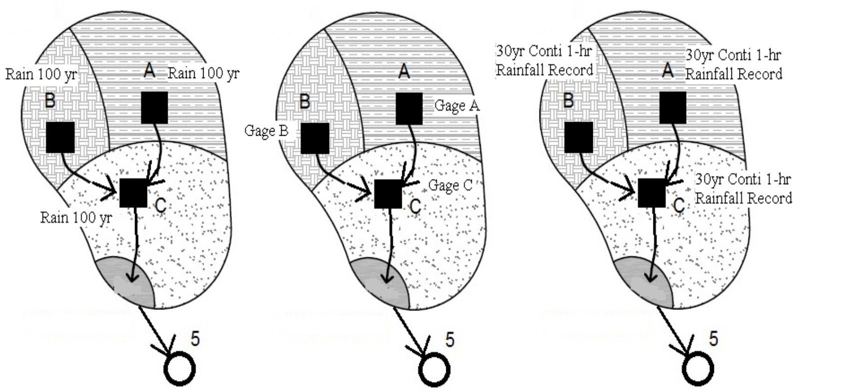
Two stormwater PROBLEMS from urbanization:

Q-problem (peak flow reduction for extreme events)

V-problem (runoff volume reduction for frequent events)



Types of Rainfall Input to SWMM

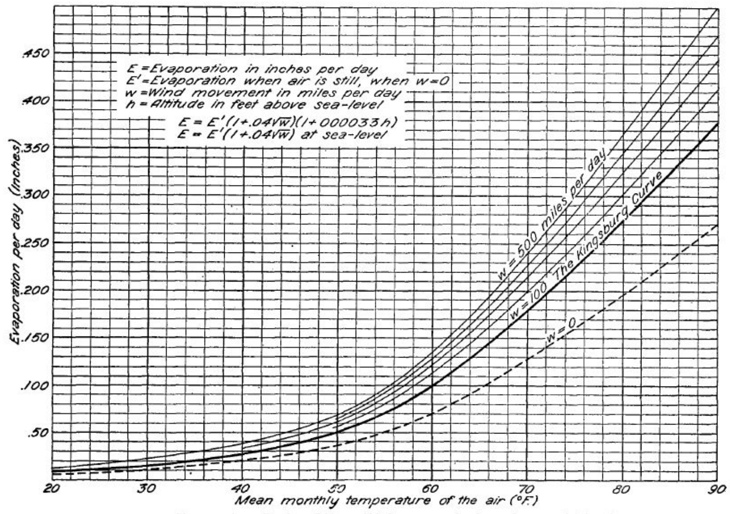


Single Design Event
Single Rainfall Depth
Time Distribution only

Single Observed Event
Several Rain Gages
Spatial and Time Distribution

Continuous Simulation for 30 to 50 years
One-hr or 15-min Incremental Rainfall Depths
Spatial Distribution only

Evaporation Rates for Detention Basin



http://www.wrcc.dri.edu/htmlfiles/westevap.final.html for states in the USA

Evaporation, Temp, Snow for US States

http://www.wrcc.dri.edu/htmlfiles/westevap.final.html

Standard daily pan evaporation is measured using the four-foot diameter Class A evaporation pan.. A "0.00" total indicates no measurement is taken. Stations marked with an asterisk (*) have estimated totals computed from meteorological measurements using a form of the Penman equation. Click on a State: Arizona, California, Colorado, Hawaii & Pacific Islands, Idaho, Montana, Nevada, New Mexico, Oregon, Utah, Washington,

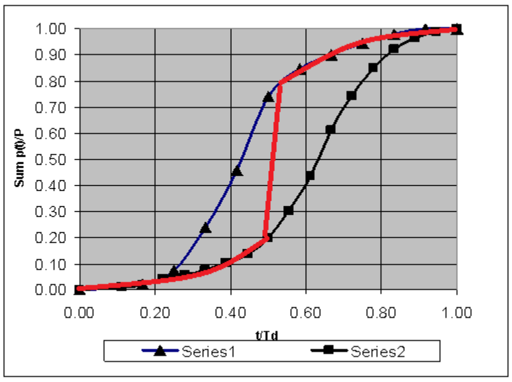
EVAPORATION MONTHLY RATE IN INCHES FOR STATE OF CALIFORNIA
http://www.wrcc.dri.edu/htmlfiles/westevap.final.html

Location	Period of	Monthly Evaporation Rate in inches												Annual
California	Record	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	Rate
ANTIOCH PUMP PLANT 3	1955-2005	1.17	1.99	4.25	6.27	8.96	10.84	11.60	10.06	7.77	4.91	2.07	1.22	71.11
AUBURN DAM PROJECT	1972-1984	1.42	1.89	3.13	4.89	7.73	10.08	11.66	10.70	8.08	5.00	1.97	1.36	67.91
AVENAL 9 SSE	1955-1961	1.80	2.90	6.20	9.39	12.96	16.73	18.67	16.37	12.61	8.05	3.89	2.44	112.01
BACKUS RANCH	1948-1963	2.85	3.86	6.77	9.80	12.69	15.93	16.92	15.95	12.19	8.01	4.25	2.98	112.20
BEAUMONT PUMPING PLANT	1948-1975	2.90	3.29	4.08	5.03	6.40	8.15	10.64	9.97	7.90	5.87	3.22	2.90	70.35
BEAUMONT 1 E	1948-2001	3.10	3.73	4.99	5.23	7.60	9.31	10.97	10.66	8.85	6.53	5.16	3.95	80.08
BERRYESSA LAKE	1957-1970	1.53	2.15	3.79	5.82	8.90	11.00	13.22	12.06	8.67	5.72	2.48	1.66	77.00
BOCA	1948-2005	0.00	0.00	0.00	0.00	6.83	8.52	10.01	9.09	6.48	4.32	0.00	0.00	45.25
BRANNAN ISLAND	1968-1977	1.15	1.74	4.36	7.03	10.49	12.39	13.51	12.02	9.03	4.80	1.83	1.08	79.43
CACHUMA LAKE	1952-2005	2.44	3.53	4.41	6.01	7.55	8.56	9.50	8.98	7.00	5.42	3.49	2.79	69.68
CAMP PARDEE	1948-2005	0.72	1.12	2.32	4.18	7.04	9.43	11.17	9.50	6.51	3.77	1.40	0.72	57.88
CHICO EXPERIMENT STN	1906-2005	1.26	2.13	3.82	5.63	8.28	10.11	11.48	9.71	7.36	4.46	2.09	1.30	67.63
CHULA VISTA	1948-2005	2.81	3.45	5.03	6.06	6.76	6.96	7.63	7.48	6.21	5.02	3.58	2.78	63.77
COW CREEK	1948-1961	3.21	5.62	9.78	13.98	17.25	21.37	21.89	20.17	15.36	10.71	4.91	3.85	148.10
DAVIS 1 WSW	1917-2005	1.49	2.34	4.54	7.13	10.19	12.17	12.77	11.28	9.08	6.35	2.89	1.45	81.68
DEATH VALLEY	1961-2005	3.93	5.38	9.10	13.00	16.76	19.11	20.98	18.86	13.95	9.78	5.54	3.75	140.14
DUTTONS LANDING	1955-1977	1.42	2.09	3.87	5.70	7.74	9.34	9.34	8.27	6.75	4.65	2.25	1.46	62.88
FALL RIVER MILLS INTAKE	1948-2005	0.00	0.00	2.47	5.80	7.54	9.48	12.14	10.57	7.59	3.78	1.14	0.00	60.51

Homework – Derive a Design Rainfall Curve from two events

Time	20-Jun	23-Nov
t	Dp(t)	Dp(t)
hour	inch	inch
0.00	0.00	0.00
2.00	0.10	0.10
3.00	0.25	0.15
4.00	0.75	0.20
5.00	1.00	0.20
6.00	1.30	0.20
7.00	0.50	0.30
8.00	0.25	0.40
9.00	0.20	0.70
10.00	0.15	1.20
11.00	0.10	1.50
12.00	0.00	2.00
13.00		1.50
14.00		1.20
15.00		0.80
16.00		0.50
17.00		0.30
18.00		0.10

Inadequate data is a common challenge in hydrologic designs. Can you derive a conservative rainfall distribution using the two cases observed.



Q AND A :
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