

CIVE 6361 Engineering Hydrology

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Probability Estimation Modeling

In addition to analysis of annual discharge frequencies, and pollutants probability estimation modeling is vital in rainfall analysis. The general purpose is to produce a rainfall patterns that shares the approximate statistics of observed extreme events for the purposes of design. These “artificial” storms are called design storms and are used extensively in hydrologic models to determine discharges and ultimately the sizes ant types of engineered structures.

Intensity-Duration-Frequency and Depth-Duration-Frequency

Typically in the USA, depth-duration-frequency values are obtained by a Table/Map look-up.

The NWS TP-40 document or HYDRO-35 documents are often used. In certain locales the required IDF/DDF chart is proscribed by the regulatory agency (City of Houston has a proscribed IDF). In the case of Texas, IDF curves have been reanalyzed for parts of the state. The document is displayed below and is located on the server.

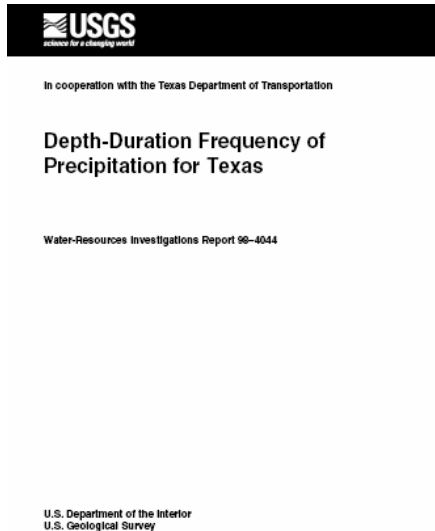


Figure 1

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Making your own IDF/DDF curves.

If data are available (such as in the Houston area) one can develop their own IDF curves from historical data. The general approach is outlined below. To prepare your own IDF curves, first one prepares the set of storms for analysis, ideally we need about 20 years of storms – multiple storms in a year can be used.

1. Bin the maximum storms in each year into different durations.

(Look-up “binning” in any advanced data analysis text; essentially you are tossing data into “bins” of prescribed width to create histograms, these histograms will become the DDF basis)

2. Prepare a Depth-Frequency curve for each duration period.

The set of curves is called the IDF (or DDF) chart.

*Simple Example*

As an example consider the following rainfall data for somewhere (a lot of the preprocessing is already done).

Typical data:

| Year | Annual Max. Intensity (mm/h) |         |         |          |
|------|------------------------------|---------|---------|----------|
|      | 30-min.                      | 60-min. | 90-min. | 120-min. |
| 1960 | 122.3                        | 100.3   | 81.1    | 55.3     |
| 1961 | 104.6                        | 82.9    | 64.5    | 39.7     |
| 1962 | 81                           | 60.8    | 41.5    | 16.5     |
| 1963 | 145.1                        | 123.7   | 104.7   | 81.7     |
| 1964 | 83                           | 61.5    | 40.7    | 16       |
| 1965 | 70.1                         | 51.1    | 30.1    | 11.3     |
| 1966 | 94.7                         | 71      | 51.7    | 26.7     |
| 1967 | 63.7                         | 41.5    | 21.8    | 10.1     |
| 1968 | 57.9                         | 35.7    | 17.1    | 9.7      |
| 1969 | 71.5                         | 50      | 31.3    | 15.9     |

Data are already binned into duration columns. That is the rainfall for 1960 was separated into all the 120-minute durations and the largest one chosen; then all the 90-min and its largest chosen, etc. The table entries are intensities, thus the depths have been divided by the durations to obtain length/time.

Next step is to get the relative frequencies, return periods, and interpolate as needed.

Each column is then put into rank order as in the earlier probability estimation discussion, and plotting positions assigned. The table is extended somewhat by interpolation, so I could get “whole-year” values of probability, a logical alternative would be to fit a probability distribution and find the “whole-year” value in the fashion previously described – in fact this approach (fit then extrapolate) is preferred.

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| Rel.Freq | T     | Annual Max. Intensity (mm/h) |        |        |       |
|----------|-------|------------------------------|--------|--------|-------|
|          |       | 30                           | 60     | 90     | 120   |
| 0.09     | 11.00 | 145.10                       | 123.70 | 104.70 | 81.70 |
| 0.11     | 10.00 | 140.95                       | 119.45 | 100.41 | 76.90 |
| 0.18     | 5.50  | 122.30                       | 100.30 | 81.10  | 55.30 |
| 0.21     | 5.00  | 117.47                       | 95.55  | 76.57  | 51.05 |
| 0.27     | 3.67  | 104.60                       | 82.90  | 64.50  | 39.70 |
| 0.34     | 3.00  | 97.40                        | 74.25  | 55.19  | 30.25 |
| 0.36     | 2.75  | 94.70                        | 71.00  | 51.70  | 26.70 |
| 0.40     | 2.50  | 89.38                        | 66.68  | 47.06  | 22.06 |
| 0.45     | 2.20  | 83.00                        | 61.50  | 41.50  | 16.50 |
| 0.50     | 2.00  | 81.91                        | 61.12  | 41.06  | 16.23 |
| 0.55     | 1.83  | 81.00                        | 60.80  | 40.70  | 16.00 |
| 0.57     | 1.75  | 77.98                        | 57.71  | 37.71  | 15.97 |
| 0.64     | 1.57  | 71.50                        | 51.10  | 31.30  | 15.90 |
| 0.67     | 1.50  | 70.99                        | 50.70  | 30.86  | 14.23 |
| 0.73     | 1.38  | 70.10                        | 50.00  | 30.10  | 11.30 |
| 0.80     | 1.25  | 64.86                        | 43.05  | 23.31  | 10.32 |
| 0.82     | 1.22  | 63.70                        | 41.50  | 21.80  | 10.10 |
| 0.83     | 1.20  | 62.65                        | 40.45  | 20.95  | 10.03 |
| 0.91     | 1.10  | 57.90                        | 35.70  | 17.10  | 9.70  |

Shaded rows are interpolated. Observe that the data are ranked and assigned plotting probabilities. Finally plot curves of interest

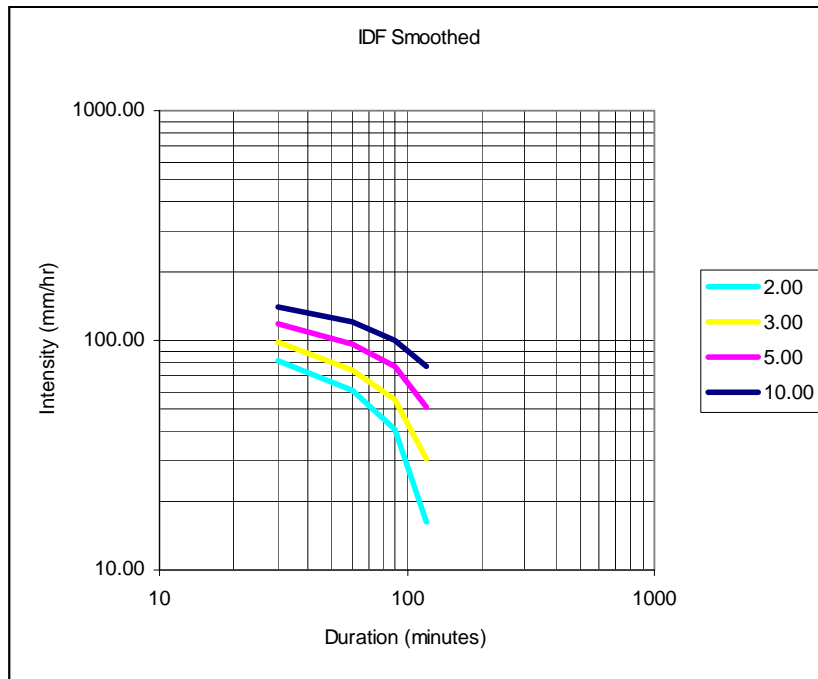


Figure 2. IDF Chart

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Curves represent different return intervals (probabilities). You should be able to create crude curves quickly if the data set is small enough. In the example, no attempt to fit a distribution was done, but in practice the Extreme Value Type -1 is almost always used to extrapolate beyond the range in the actual data.

Probable Maximum Precipitation

The most current definition of PMP is as follows: "Theoretically, the greatest depth of precipitation for a given duration that is physically possible over a given size storm area at a particular geographical location at a certain time of the year." This definition comes from the National Weather Service Hydrometeorological Report 55A (HMR 55A).

PMP methods are used in dam safety calculations and similar types of projects where failure will cause loss of life (the actual wording is "probable loss of life" but the meaning is failure will kill). The general procedure to construct PMP values (you will need to read NWS methods if you really want to calculate your own) is:

1. Study major storms in the region to determine maximal areal rainfall and area reduction factors.
2. Transpose the storms to the location of interest.
3. Adjust rainfall for each study storm by ratio of maximum atmospheric moisture at the location to the moisture in the storm (non-trivial step)
4. Produce envelope curves of resulting rainfall values for different durations (i.e. a PMP-DDF is being constructed). The storm area is part of the result, so you will have a DDF for 1 sq.mi. storms, 2 sq.mi. storms etc.

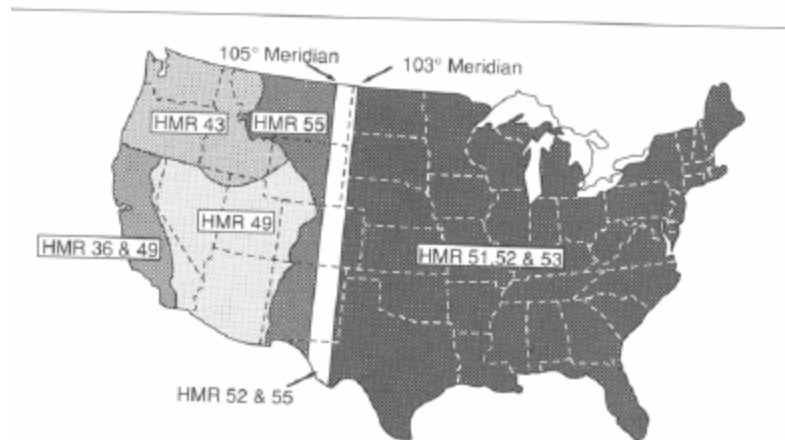
A quick check of the results should produce point values smaller than (Linsley and others, 1982)

$$depth_{\max}(\text{inches}) = 16.4 * [\text{duration}(\text{hrs})]^{0.48}$$

In Texas use of PMP for dams is by statute (specified in the law). The construction of PMP values from data is extremely complicated and most engineers (myself included) would use tabulated values for their area.

The tabulations are found in various NWS reports, a few of which are on my server. The map below lists the different report numbers to use in different regions. Notice the continental divide region is treated entirely separately from the rest of the nation (significant orographic influences on precipitation type and depths)

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Rainfall Time Distributions

Time-depth data is called a hyetograph. The cumulative hyetograph (is also a hyetograph) is called a rainfall-time distribution pattern. It is a distribution if, indeed, it represents a statistical representation of actual data, otherwise it is just one realization of an infinite number of possible patterns.

Design Hyetographs:

Analyze actual data – this approach works if you have data.

Select a synthetic method (typically based on total depth IDF-type data).

DDF Balanced storm method

A balanced storm is a storm that produces a depth independent of the duration of the storm. The general procedure is to use IDF data to generate storm depths for different intervals.

The elapsed time is broken into small intervals; the smallest should be on the IDF curve.

The storm is “allowed” to proceed such that accumulated depth is consistent with the IDF curve.

*Example*

As an example consider the above data for a 5-year storm.

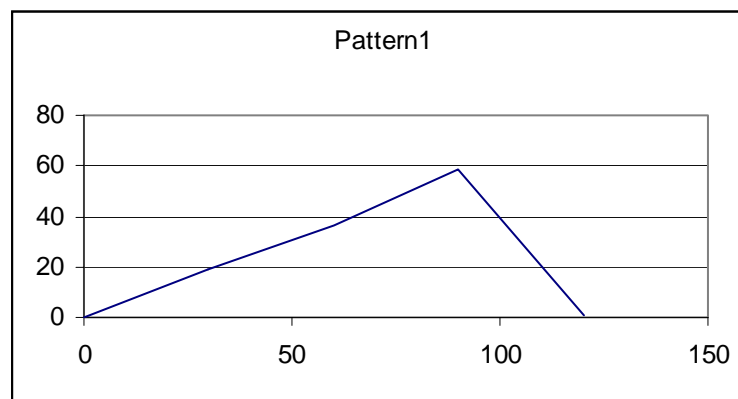
Put into balanced storm context

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| Time | AccTime | Rates  | Acc.Depth | Inc.Depth | Pattern1 |
|------|---------|--------|-----------|-----------|----------|
| 0    |         |        |           |           | 0        |
| 30   | 0.5     | 117.47 | 58.73636  | 58.73636  | 19.3     |
| 60   | 1       | 95.55  | 95.55455  | 36.81818  | 36.81    |
| 90   | 1.5     | 76.57  | 114.8591  | 19.30455  | 58.7     |
| 120  | 2       | 58.00  | 116       | 1.140909  | 1.14     |

Shaded area is “adjusted” upward to prevent negative increments (actual number is 51.05 in the rate column).

Resulting pattern

The pattern is boring because there is not a lot of data in the example, fitting to an EV-1 can improve the appearance of the storm pattern (note it is OK to fit to a distribution because we are synthesizing a storm anyway – it does not increase the “knowledge” of the actual behavior).

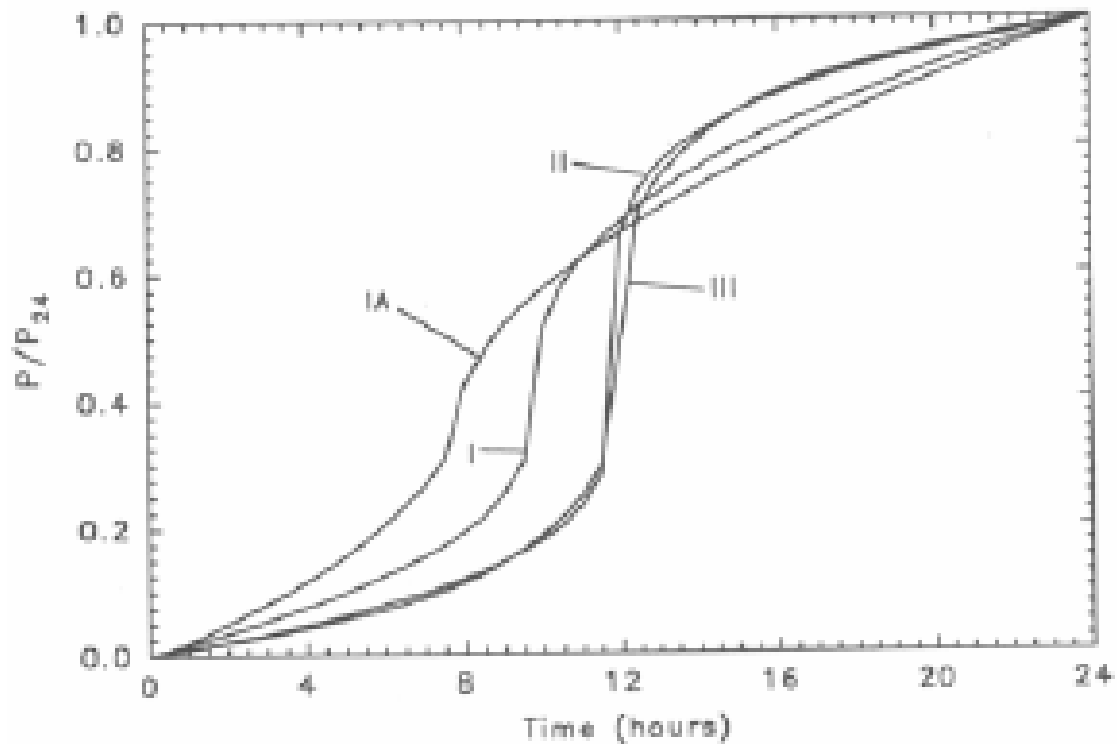
SCS Method

The SCS patterns are based on a TABULATION of different storm “types”. Types I, II, III, and IV. To the best of my knowledge the SCS never published a functional relationship between the tabulation and time (hours).

Most of the storms fit a three-parameter exponential-type function pretty well. (Use SOLVER to get the parameters).

For storms less than 24 hours, the storm is centered at 12-hours and the tabulations are used. The method is described in the National Engineering Handbook (you were asked to find this in an earlier exercise).

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The SCS Patterns do not fit Texas data very well, and Texas storms were recently studied by several Texas researchers. The report is USGS SIR 2004-5075.



Figure 3

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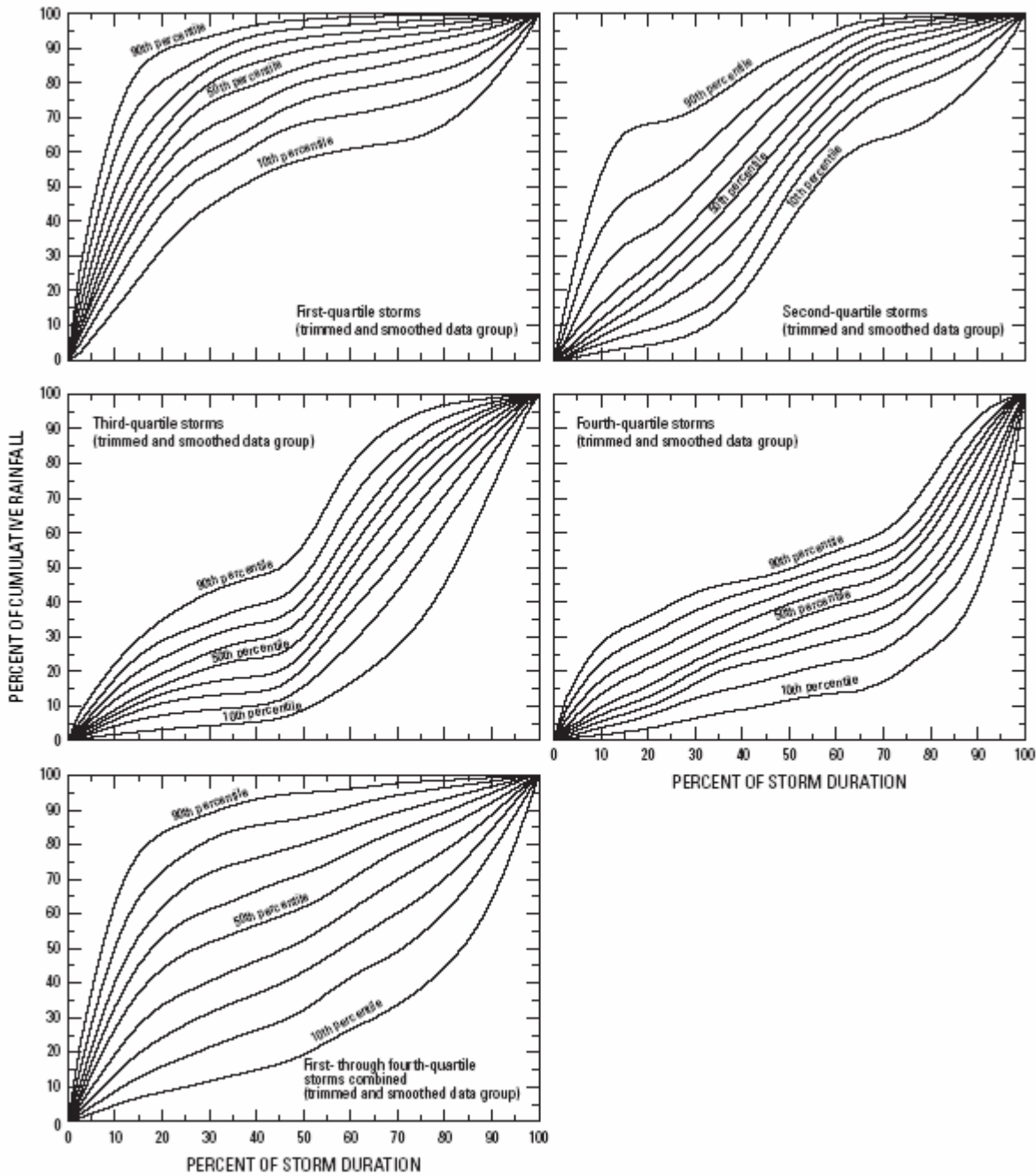


Figure 11. 10th- to 90th-percentile dimensionless hyetograph curves for a storm duration of 0 to 72 hours and a rainfall total of 1 inch or more.

These curves are based on actual Texas rainfalls and indicate that for most storms nearly all the rainfall occurs in the first half of the storm. (Read the report for more details as well as the SCS storms).

Chicago Hyetograph



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The Chicago hyetograph is a function that preserves total depth of the storm and distributed the storm relative to its peak based on analyst supplied parameters. The analyst must study storms in the area of interest to select the unknown parameters. The method is fairly straightforward to apply.

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References

Asquith, W.H., 1998. Depth-Duration Frequency Analysis of Precipitation for Texas. U.S. Geological Survey, WRIR 98-4044. U.S. Geological Survey, Branch of Information Services, Box 25286, Denver CO 80225-0286.

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Haan, C.T., Barfield, B.J., Hayes, J.C., 1994. Design Hydrology and Sedimentology for Small Catchments. Academic Press, San Diego, 588p.

Wurbs and James, 2002. Water Resources Engineering. Prentice-Hall, New Jersey. Chapter 7.

Williams-Sether, T. Asquith, W.H., Thompson, D.B., Cleveland, T.G., and Fang, X. Empirical, Dimensionless, Cumulative-Rainfall Hyetographs Developed From 1959–86 Storm Data for Selected Small Watersheds in Texas. U.S. Geological Survey, SIR 2004-5075.