Predicting Heavy Rainfall Events in California: A Symposium to Share Weather Pattern Knowledge

Presented by
Sierra College Science Center
and
Floodplain Management Association

at
Sierra College
Rocklin, California

June 25, 1994

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PURPOSE: There is an emerging body of knowledge regarding weather patterns responsible for producing heavy rainfall events in California. Greater aware of and further development of this knowledge can provide advance warning of these events to operators of dams and reservoirs used for flood control, to offices of emergency services, to disaster relief organizations, and to the citizens of California.

This symposium is intended to bring together knowledgeable people to:

(1) share their research and experience regarding weather patterns which cause heavy rainfall events in California,
(2) increase the dissemination of this knowledge, and
(3) advance the science of identifying and recognizing these weather patterns.

SPONSORS: Sierra College Science Center
5000 Rocklin, CA 95677
Phone: (916) 781-0475
Fax: (916) 781-0455

Floodplain Management Association
4145 Maybell Way
Palo Alto, CA 94306
Phone: (415) 493-7198
Fax: (415) 493-6950

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Charles Dailey
Sierra College Science Center
5000 Rocklin Road
Rocklin, CA 95677

Development of Design Storm Procedures for San Joaquin County

J. J. DeVries, Boyle Engineering Corporation, Sacramento, CA
T. V. Hromadka, Boyle Engineering Corporation, Newport Beach, CA

Introduction

Designers of storm water management systems are faced with the problem of determining discharges for system components that are related to some measure of economic efficiency (i.e., damage to property or interference with human activity), or more importantly, a measure of the potential danger to human life. When danger to life can be managed through warning systems and other methods, economic efficiency becomes the major factor that must be considered. To do this in the most accurate fashion requires very detailed analysis of the damages associated with specific flooding levels and the frequency of occurance of the floods. For major projects a very detailed analysis may be feasible, but for most small and moderate size projects, the engineers conducting the design have neither the information or the resources to conduct such a detailed investigation. Agencies (such as a city or county flood control agency) therefore usually require the selection of a particular frequency of the event for which the structure or system is to be designed. Minor structures such as culverts on secondary roads may be designed for floods with a return frequency of 10 to 25 years, while bridges on major thoroughfares are usually designed to carry the 100-yr flood.

The design of a flood management system is based on a flood discharge of a specific frequency. Where stream discharge records are available, these can be used to develop a flood flow frequency relationship. The problem that most hydraulic engineers and hydrologists face is that stream flow records are rarely available at the required locations. To overcome this problem designers use hydrologic models with rainfall of the desired return period T (or frequency, which is 1/T) as a means of computing a flood of a specific return period. There is a major problem associated with this, since runoff is a function of ***effective*** rainfall, or the total rainfall minus losses. The losses are a function of antecedent rainfall and have their own frequency distribution. However, most hydrologic analyses are based on the assumption that the calculated flood flow frequency is the same as the frequency of the rainfall used for the computation of the discharge.

To incorporate a factor of safety into the process a low value for the loss rate is usually chosen so that the discharge may be over-predicted in most cases. For return periods that are greater than 50 to 100 years, the most intense period of rainfall that produces the peak runoff discharge often occurs after a period of more moderate rainfall. This sequence tends to produce low loss rates during the highest rainfall periods so that the effective rainfall during this period is the largest. Thus, a rainfall event with a 25-yr return period may produce a flood with a 5-year return period or possibly a flood with a 40-year return period. However, in most cases it can be expected that a rainfall with a 100-yr return period will produce a flood of approximately the same frequency.

Presented at **Predicting Heavy Rainfall Events in California: A Symposium to Share Weather Pattern Knowledge**, C. Dailey, ed., Sierra College, Rocklin, CA 95677, June 25, 1994.

A design storm must provide the following (Viessman *et al.* 1989): storm duration, point rainfall depth, areal depth adjustment, storm intensity, time distribution, and areal distribution pattern. These parameters are developed from historical records of rainfall in the region to which the storms are to be simulated. The analysis becomes a process of evaluating observed rainfall at appropriate rainfall stations and computing the frequencies of occurance associated with rainfalls of specific durations.

Rainfall Data

Records for twenty-one rainfall gages with lengths of record from 5 to 101 years were found for San Joaquin County. An additional seven gages located adjacent to the county were also used. Most of the twenty-eight gages had daily rainfall data. Five of the gages had rainfall data for short durations, down to 5 minutes. These were used to define a relationship between the 24-hour rainfall values and shorter rainfall durations.

Based on the work of Goodridge for the California Department of Water Resources (DWR 1981, Goodridge 1990) and for other agencies (Goodridge 1991, 1992), it has been shown that for many locations in California there is a high degree of correlation between the average maximum 24-hr rainfall at a station and the mean annual precipitation at that station. The data from the rainfall records are shown in Table 1, and a plot of the relationship between the average maximum 24-hr rainfall and the M.A.P. is shown in Figure 2. Figure 3 shows a similar relationship for adjacent counties. It should be noted that the daily rainfall is recorded at a specific time each day by the observer. The factor used to correct this value so that it corresponds to the rainfall that can be expected to occur within a given period of 24 hours is 1.14.

Goodridge has performed extensive statistical analyses on rainfall throughout the state of California (Goodridge 1990). His work indicates that an appropriate frequency distribution for rainfall is the Pearson Type 3 distribution. To fit data to this distribution requires the mean, the standard deviation, and the skew. With samples of small size (all rainfall records are small samples) the skew cannot be reliably determined from the sample statistics, and regional skew values are used. Goodridge has determined that the regional skew for the Central Valley region is 0.11. This value was used in the analyses for San Joaquin County described here.

The rainfall of a particular frequency and duration can be determined by using frequency factors with the following relationship (Chow 1964).

$$x = \bar{x} + Ks \qquad (1)$$

where x is the value of the parameter, $\bar{x}$ is the mean, s is the standard deviation, and K is the frequency factor. For the Pearson Type 3 distribution, K is a function of the skew and recurrence interval. Frequency factors for commonly-used return intervals are given in Table 2.

Table 1 - San Joaquin County Rainfall Data

SAN JOAQUIN COUNTY GAGES

Station	Sta. No.	MAP in.	Max Day in.	Avg Max Day in.	Length of Record yr	Lat.	Long.	Elev. ft
Linden FS	B00495302	19.13	2.72	1.42	5	38.022	-121.082	89
Linn Ranch	B00496000	21.02	2.16	1.60	5	38.133	-121.102	120
Clements	B00181300	17.46	3.65	1.70	36	38.204	-121.098	120
Elliot	B00276000	17.48	2.75	1.56	38	38.236	-121.194	92
Lockford	B00501000	16.96	2.86	1.61	53	38.165	-121.148	106
Lodi	B00503200	17.08	3.76	1.67	101	38.116	-121.289	40
Manteca	B00530300	11.57	2.35	1.24	12	37.800	-121.200	40
Ripon	B00744780	13.09	1.91	1.17	27	37.743	-121.128	65
Stockton AP	B00855800	13.31	2.33	1.42	15	37.900	-121.250	22
Stockton FS4	B00856000	14.47	3.20	1.41	96	38.000	-121.317	12
Tracy 2 SSE	B00899900	9.05	2.28	1.11	41	37.709	-121.410	107
Youngstown	B00985900	16.50	2.83	1.51	34	38.177	-121.241	65
Castle Rock	B80158300	10.13	2.85	1.21	37	37.634	-121.505	515
Kerlinger	B80450800	8.75	2.59	1.09	35	37.670	-121.430	172
Lone Tree Cyn	B80507400	8.09	2.22	1.05	17	37.611	-121.380	420
Bensons Ferry	B90068200	15.51	2.48	1.41	10	38.250	-121.433	17
Mandeville Island	B90529600	11.32	4.00	1.48	9	38.033	-121.567	10
Stockton Dsp Plt	B90855400	9.55	2.97	1.57	39	37.936	-121.328	11
Tracy Carbona	B90899900	9.55	2.49	1.08	56	37.696	-121.414	137
Tracy Pumping Plt	B90900100	11.96	2.80	1.34	32	37.796	-121.581	61
Lockford	B00501000	16.96	2.83	1.51	53	38.165	-121.148	106

Station (Outside county)	Sta. No.	MAP in.	Max Day in.	Avg Max Day in.	Length of Record yr	Lat.	Long.	Elev. ft
Modesto	B00573800	11.83	2.72	1.36	100	37.647	-121.001	91
Modesto	B00574100	11.92	2.80	1.32	49	37.643	-121.067	92
Modesto 6SW	B00573635	12.08	2.28	1.36	19	37.625	-121.008	91
Turlock	B00907300	11.67	2.24	1.38	95	37.491	-120.850	115
Eugene Stuart	B00290900	14.94	2.49	1.56	43	37.921	-120.857	175
Antioch PP	B80023200	12.41	1.54	1.35	89	37.984	-121.728	60
Oakdale	B00630600	15.51	2.02	1.56	10	37.769	-120.848	155

Table 2 - Frequency Factors for Pearson Type 3 Distribution for Skew = 1.1

Return Period (yr)	Frequency Factor
2	-0.180
5	0.745
10	1.341
25	2.066
50	2.585
100	3.087
200	3.575

Development of Mean Annual Precipitation Map

Application of this method requires the determination of the mean annual precipitation for the calculation of the average maximum daily rainfall. Figure 1 shows a map of San Joaquin County with contours of equal annual rainfall. This map was developed using the rain gage data in Table 1 plus data available from rainfall maps for adjacent counties (Sacramento County 1993, Goodridge 1991, 1992). The general rainfall contour pattern was initially developed by interpolating contours from the measured data at the rainfall stations. There were some anomalies, where stations quite close together had significantly different measured rainfall amounts. It was recognized that the catch of a rain gage is quite sensitive to gage location and exposure. The position of the contours were therefore adjusted to give smooth contours based on the gages with in the county as well as with published rainfall contour maps from adjacent counties.

Storm Duration

Durations Less than 24 Hours--Rainfalls of durations of less than 24 hours were correlated with the 24-hr values (the average maximum rainfall for a given duration vs. the average maximum 24-hr rainfall). This relationship is log-linear, so that the points can be fitted to a straight line when they are plotted on log-log graph paper. The relationship is given by the equation

$$P_T = (P24_j)\left(\frac{T}{1440}\right)^{0.401} \qquad (2)$$

where T is the duration of the rainfall in minutes, P_T is the precipitation in the interval in inches, and the exponent 0.401 is the slope of the line on the log-log plot.

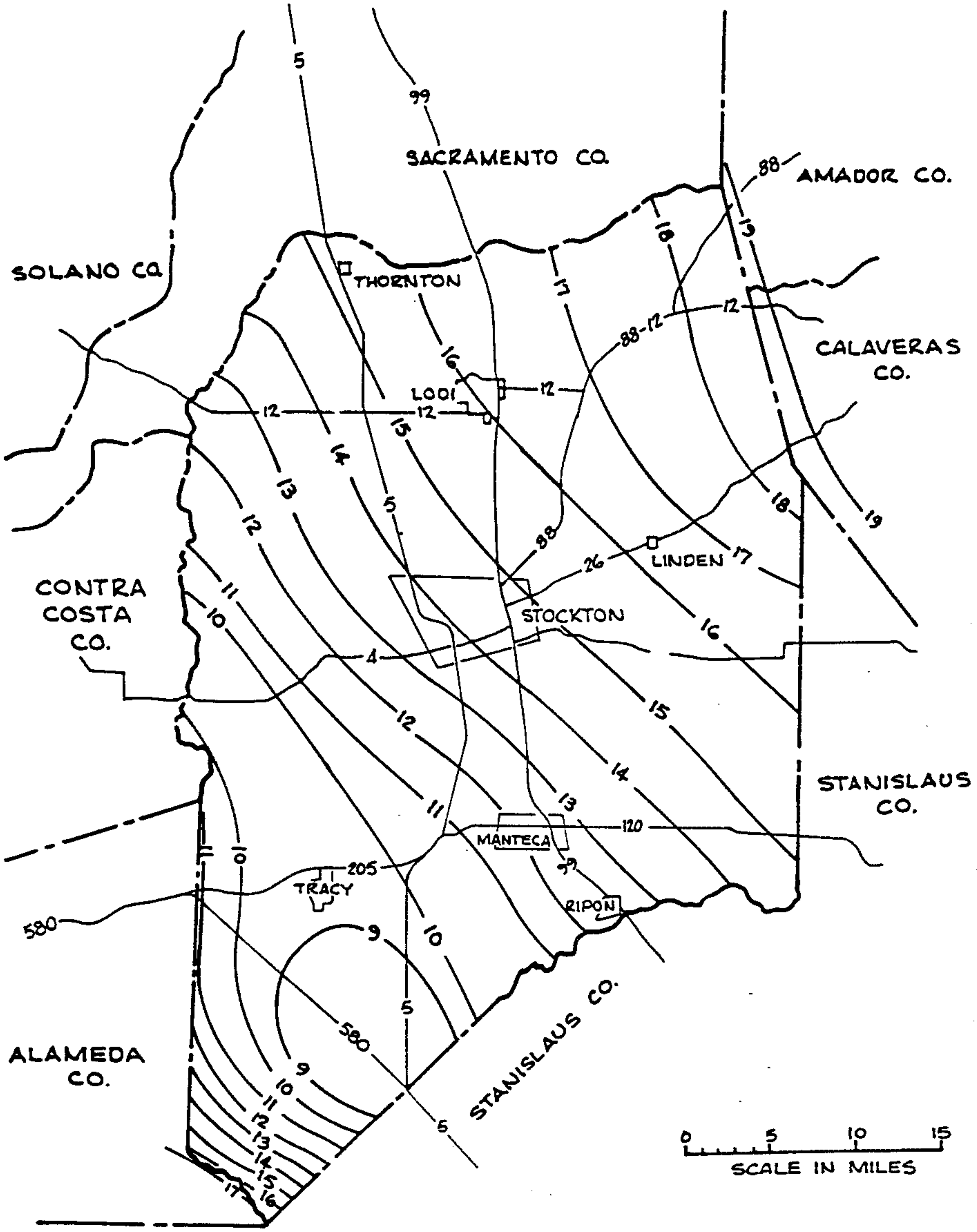


Figure 1. Mean Annual Precipitation for San Joaquin County

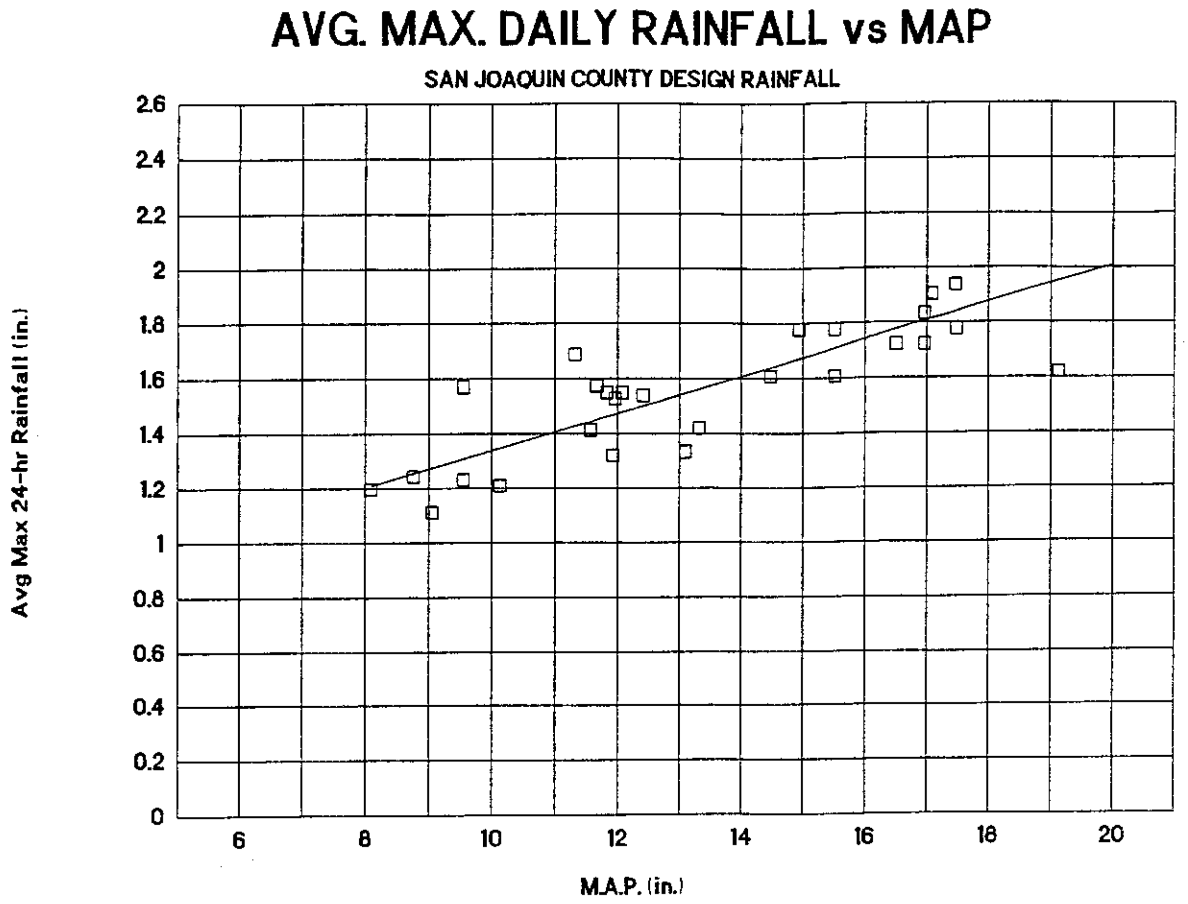


Figure 2. Average Daily Maximum Rain vs MAP -- San Joaquin County

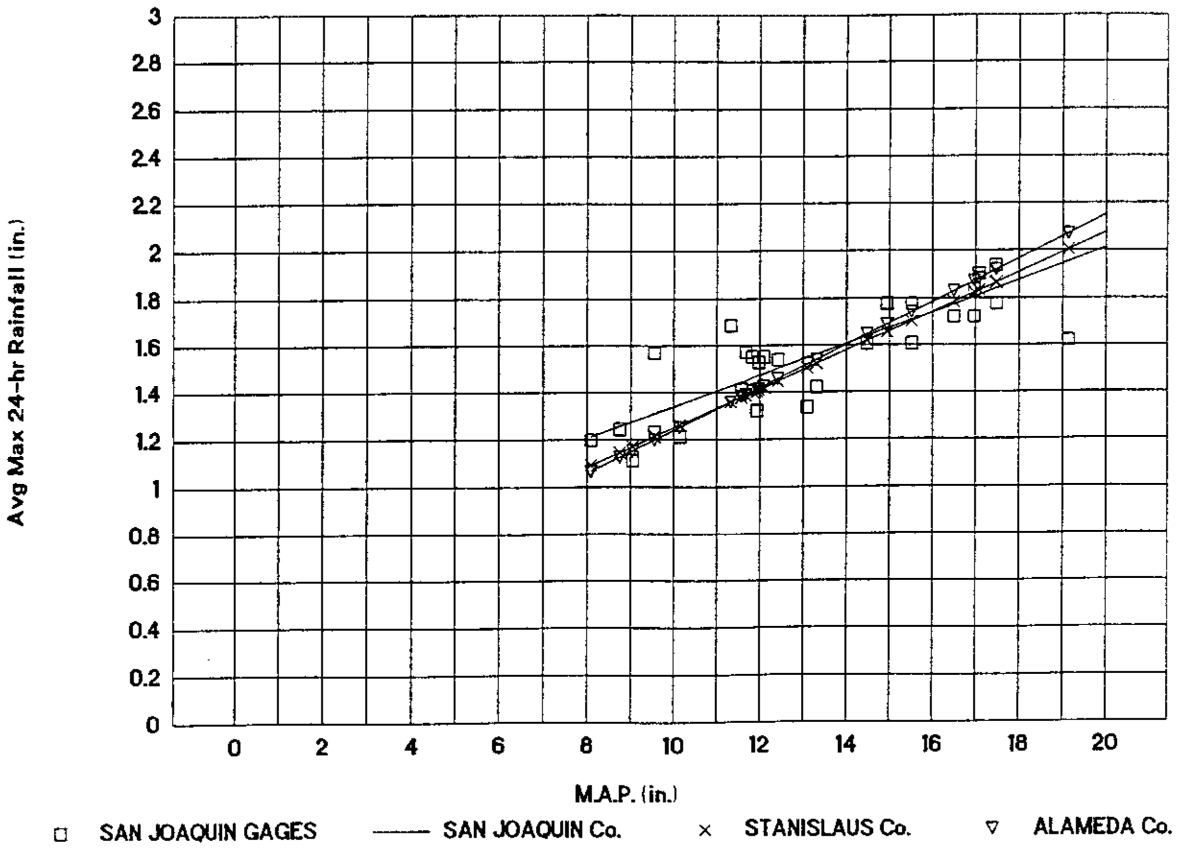


Figure 3. Average Daily Maximum Rain vs MAP -- San Joaquin and Adjacent Counties

Actual individual storms have durations of varying length. For design purposes hydrologists usually use storms of six hours and twenty-four hours as representative of storm durations that are appropriate for design of storm water management systems. The rainfall intensity varies within these periods so that a distribution of rainfall within the period must be developed. This is done by constructing a design storm from the design rainfall for the various durations from 5 minutes, 10 minutes, 15 minutes, 30 minutes, 1 hour, etc. up to the total storm period of 6 or 24 hours.

Point Rainfall Depth and Areal Depth Adjustment

The rainfall data are from point measurements at a rain gage and require adjustment for the size of the area to which it is to be applied. Depth-area reduction curves similar to those used by the National Weather Service (Hershfield 1961) are provided in the San Joaquin County Hydrology Manual. For areas less than ten square miles this adjustment is usually neglected.

Storm Intensity and Time Distribution

When applied to a watershed using a rainfall-runoff model the rainfall must be distributed in time. This is done by tabulating rainfall amounts for a storm of given return interval for the specified durations (5-min, 10-min, 15-min, 30-min, 1-hr, 2-hr, 3-hr, 6-hr, 12-hr, and 24-hr). The appropriate time interval is selected and the incremental rainfall in each time period is determined. This gives a table of rainfall amounts for a constant time interval, from the greatest amount in the interval to the smallest. This rainfall now must be distributed in time to produce an actual storm pattern. For the San Joaquin County Hydrology Manual this design storm is arranged to position the rainfall with the maximum intensity two-thirds of the way through the storm period. This will give a more conservative rainfall pattern for the analysis of detention storage than a symmetrically shaped storm pattern.

A typical design storm for San Joaquin County is shown in Figure 4. This storm represents a 100-yr, 3-hr design storm for the Stockton area where the MAP = 15 in. The Average Maximum Daily Rain = 1.69 in., and $P24_{100}$ = 3.53 in. The 1-hour, 100-yr rainfall is 0.98 in., while the 10-minute, 100-yr rainfall is 0.48 in.

Data Format

The precipitation data are provided in the hydrology manual in the form of tables of Intensity-Duration-Frequency for specified return periods (2-yr, 5-yr, 10-yr, 25-yr, 50-yr, and 100-yr) for Mean Annual Precipitation (MAP) values from 9 inches to 19 inches. This range of values spans the total variation of rainfall within the county (Table 3). No elevation adjustment factor was provided because the effect of elevation is included in the MAP value. It is only in the very north-eastern and south-western parts of San Joaquin County that any significant elevation effects are seen. Graphs giving intensity-duration-frequency data are also provided.

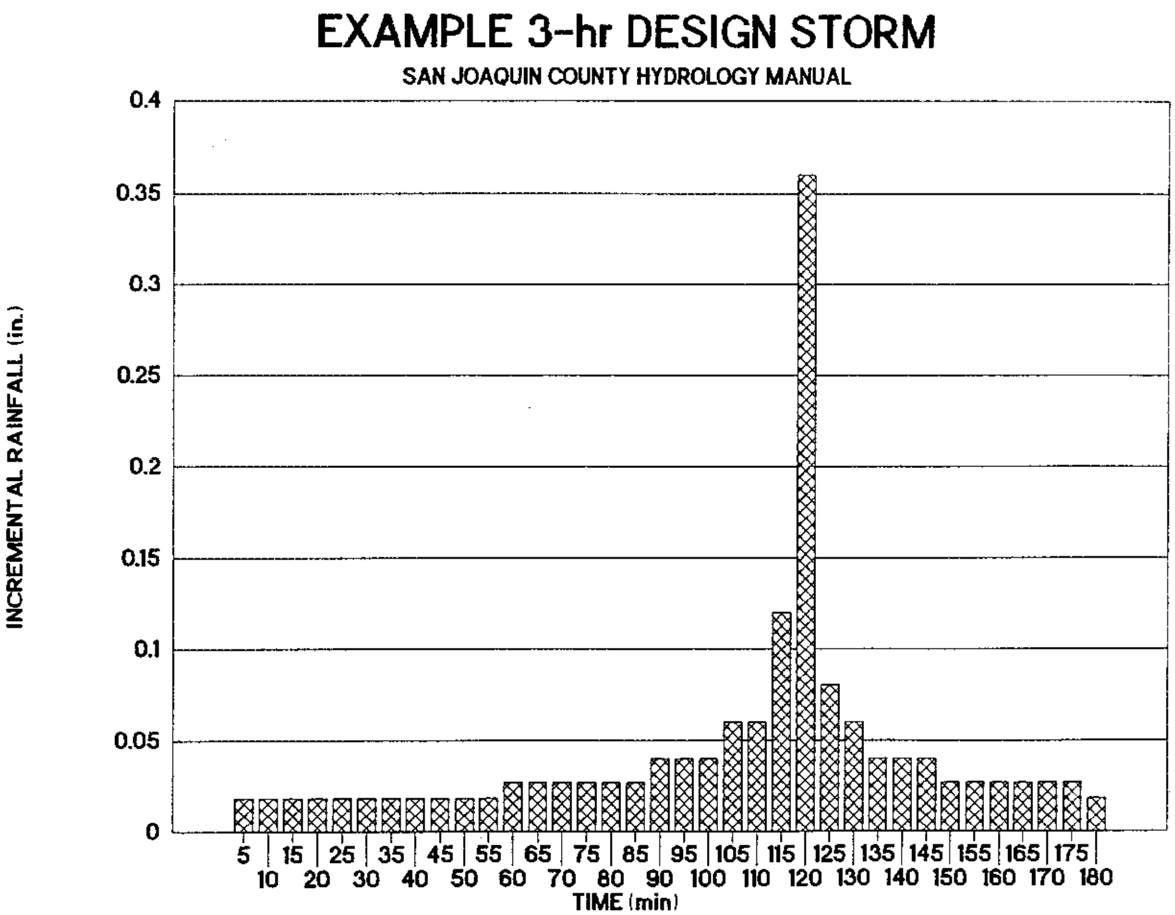


Figure 4. Typical Design Storm for San Joaquin County

Summary

A design storm procedure for the San Joaquin County Hydrology Manual was developed to provide the data for storm duration, point rainfall depth, areal depth adjustment, storm intensity, and time distribution pattern. These data were developed from historical records of rainfall in the San Joaquin County region. Records for twenty-one rainfall gages with lengths of record from 5 to 101 years within the county and seven gages located adjacent to the county were were used. Five of the gages had short duration rainfall data.

Rainfall for specified frequency and duration is calculated from the average maximum daily rainfall, which in turn is determined from the mean annual precipitation. The data are arranged into a pattern to form a design storm which is used with a computer model of the rainfall-runoff process.

Acknowledgements

The encouragement and support of John Pulver and Mike Callahan of San Joaquin County is greatly appreciated. Jim Goodridge provided the basic rainfall station data used in this study. The people of the State of California owe Jim a great debt for his efforts in collecting, analyzing, and disseminating rainfall data for hydrologic and climatological applications in California.

References

Chow, V. T. 1964. "Statistical and Probability Analysis of Hydrologic Data." in *Handbook of Applied Hydrology.* McGraw-Hill, New York.

DWR. 1981. *Rainfall Depth-Duration-Frequency for California*, California Department of Water Resources, Sacramento.

Goodridge, J. 1990. "Precipitation Analysis." in *Proceedings of a Workshop on County Hydrology Manuals.* J. J. DeVries, ed., Lighthouse Publications, Mission Viejo, CA.

Goodridge, J. 1991. "Stanislaus County Design Rainfall." J. Goodridge Consulting Engineer, Chico.

Goodridge, J. 1992. "Alameda County Design Rainfall." J. Goodridge Consulting Engineer, Chico.

Haan, C. T. 1977. *Statistical Methods in Hydrology*. Iowa State University Press, Ames.

Hershfield, D. M. 1961. *Rainfall Frequency Atlas of the United States for Durations from 30 Minutes to 24 Hours and Return Periods from 1 to 100 Years.* Technical Paper 40, U. S. Dept. of Commerce, Weather Bureau, Washington, D. C.

Sacramento County. 1993. "Hydrology Manual." Department of Public Works, Sacramento.

Table 3. Typical Data Table From San Joaquin County Hydrology Manual

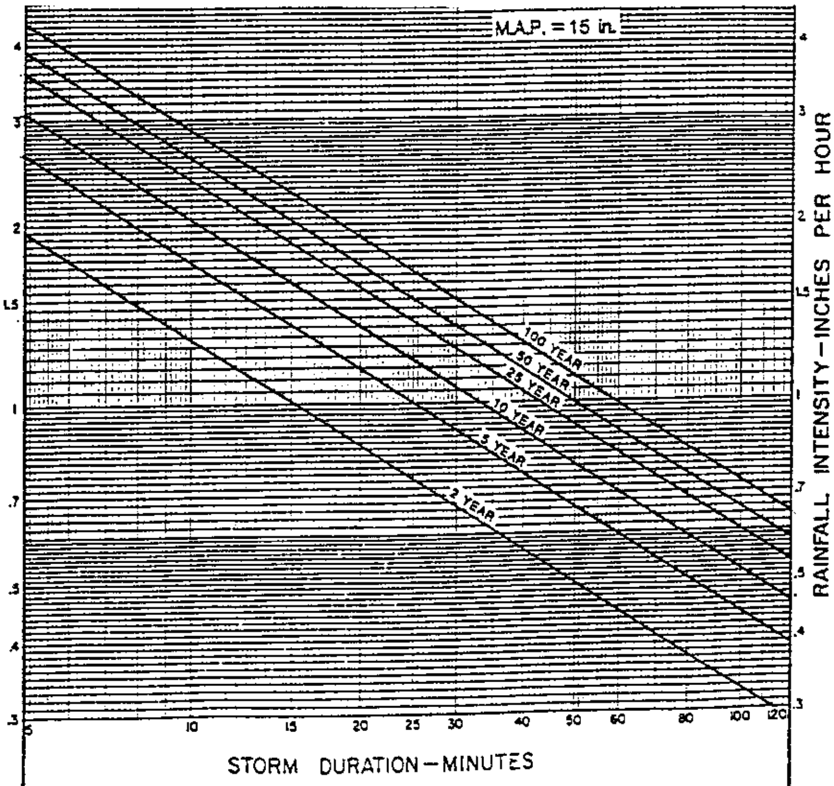
DEPTH-DURATION-FREQUENCY

Skew = 1.1
Cv = 0.354

MAP	Freq. (yr)	K	5-min	10-min	1-hr	2-hr	6-hr	24-hr	PAVG24
15	2	-0.180	0.16	0.21	0.44	0.58	0.90	1.57	1.675
15	5	0.745	0.22	0.29	0.59	0.78	1.21	2.12	1.675
15	10	1.341	0.26	0.34	0.69	0.91	1.42	2.47	1.675
15	25	2.066	0.30	0.40	0.81	1.07	1.66	2.90	1.675
15	50	2.420	0.32	0.42	0.87	1.15	1.78	3.11	1.675
15	100	3.087	0.36	0.48	0.98	1.30	2.01	3.51	1.675

INTENSITY-DURATION-FREQUENCY

MAP	Freq. (yr)	K	5-min	10-min	1-hr	2-hr	6-hr	24-hr
15	2		1.947	1.285	0.439	0.290	0.150	0.065
15	5		2.628	1.735	0.593	0.391	0.202	0.088
15	10		3.067	2.024	0.692	0.456	0.236	0.103
15	25		3.600	2.376	0.812	0.536	0.277	0.121
15	50		3.861	2.548	0.871	0.575	0.297	0.130
15	100		4.352	2.872	0.981	0.648	0.335	0.146



BOYLE

INTENSITY - DURATION CURVES
MEAN ANNUAL PRECIPITATION = 15 in.