Semi-Arid Storm Hyetograph Properties in Wyoming

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ABSTRACT

Design storm patterns for use in predicting floods by simulating precipitation events in ungauged drainage basins in Wyoming are presented. The design patterns were developed from observed rainfall and are separated into two categories: thunderstorms (events less than 4 hr in duration) and general storms (events lasting 4 or more hr). Comparisons of predicted runoff using the new design storms and design storms recommended by the Soil Conservation Service (SCS) and the Bureau of Reclamation (BUREC) were made using the following models on a 0.83-mile^2 watershed: (a) HEC-1 (the Hydrologic Engineering Center); (b) HYMO (Problem-Oriented Computer Language for Hydrologic Modeling); (c) HYDRO (the SCS Triangular Hydrograph); and (d) the U.S. Geological Survey (USGS) distributed-routing digital rainfall-runoff models. The new design storms typically produce greater runoff peaks when simulating thunderstorm events, and, in most cases, smaller peaks when simulating runoff from general storms, than those predicted with the established procedures. Instructions describing the use and limitations of the new storm pattern construction method are included.

The design of hydraulic structures for use in ungauged drainage basins requires some estimate of flood flows and their frequency of occurrence. Because no historical streamflow data exist for these drainages, floods are generally estimated either by regional frequency analysis or, with the help of digital computers, by parametric rainfall-runoff event simulation.

Computer models dealing with rainfall-runoff event simulation are commonly used today by engineers and hydrologists. These models are used to predict flood hydrographs given an input rainfall volume, distributed over time in some manner, and certain geomorphic, soil, geologic, vegetative, or other basin parameters.

Studies exist in the literature that document the effects of time distribution of rainfall on runoff hydrographs. The reader is referred to works by Wei and Larson (1), Yen and Chow (2), and Shanholtz and Dickerson (3) as examples. Because this relationship between the time distribution of rainfall and hydrograph characteristics exists, the separate study of storm rainfall is essential for accurate flood prediction notwithstanding other variables that also influence the runoff process. In addition, methods of constructing design storms are available and in wide use, but they are general in nature and assume storms occur with the same temporal distribution across much of the country. Because of the drastic climatic differences between the areas encompassed by existing procedures, it was believed that the design curves of these methods are not likely to be representative of the actual time distribution of storms in semi-arid regions. It was therefore decided to develop a new design storm construction procedure applicable to semi-arid areas based on observed storm rainfall in Wyoming.

REVIEW OF PREVIOUS WORK

Relatively few precipitation studies conducted to date deal with the temporal distribution of rainfall in the manner used by hydrologists and engineers in parametric flood prediction.

The Soil Conservation Service (SCS) method (4) presents three temporal rainfall distribution curves for runoff prediction. The Type I and Type IA curves are used for studies in Alaska, Hawaii, and the coastal side of the Sierra Nevada and Cascade mountain ranges. The Type II curve is applied in the remaining part of the United States, Puerto Rico, and the Virgin Islands. These curves are based on generalized rainfall depth-duration curves obtained from published data of the U.S. Weather Bureau [National Oceanic and Atmospheric Administration (NOAA)]. All design storms developed using this method, regardless of duration, are based on the 24-hr volume for a given frequency and location.

The Bureau of Reclamation (BUREC) method (5) is developed in two parts, one for the United States east of the 105-degree meridian and the other for areas west of the 105-degree meridian. The procedure requires arranging hourly rainfall increments in a specified sequence depending on the duration and type of storm (thunderstorm or general storm). Maximum 6-hr point rainfall values are used in designing general storms, and maximum 1-hr point rainfall values are used in designing thunderstorms.

The U.S. Weather Bureau procedure (6) uses depth-duration-frequency (DDF) curves in design storm construction. In this method, rainfall intensities are obtained from the DDF curves for a given frequency and duration at a certain locality. These intensities are then rearranged arbitrarily to form a storm pattern.

Kerr et al. (7) present a method of hyetograph construction for Pennsylvania. Cumulative dimensionless rainfall versus time graphs used by the method are derived from historical rainfall data. The curves allow the user substantial flexibility because, rather than define a single storm sequence, they bracket a range of possible storm patterns. Selection of the time distribution of a design storm can be made by the user, providing the limits of the bracketing curves and the minimum and maximum intensities given are observed.

Huff (8) presents a procedure derived from heavy storms observed in Illinois. His distribution patterns are based on the time quartile in which the majority of rain occurs for a given storm. For each quartile storm type, frequency values are given so that the user knows the return period of his design storm.

A method described in Keifer and Chu (9) uses intensity-duration-frequency curves for hyetograph design at a given location. In general, the proposed storm pattern is fit to exponential growth and decay curves with the most intense part of the storm defined by a parameter termed the "advanceness ratio." This method was developed in Chicago for urban sewer design but can easily be used in other areas of the country where adequate rainfall records are available.

Frederick et al. (10) developed annual maximum precipitation events for different durations. The largest precipitation amounts for the selected durations that coincide with a given duration event are selected. The events are stratified according to magnitude, and ratios of shorter to longer duration precipitation totals are formed. Accumulated probabilities of this ratio are suggested as a tool to estimate precipitation increments necessary in the synthesis of precipitation mass curves. By analyzing the relative timing of the shorter duration event within the longer duration event, a characteristic time distribution can be developed.

METHODOLOGY

Accumulation of Rainfall Data

The study of time distribution of rainfall requires historic data recorded as continuously as possible. Because continuously recorded rainfall data were not available in the quantities needed for this study, discrete data were used. Hourly measurements from NOAA publications (1948-1979) (11) provided the data base for the study of general storms whereas the 5-min incremental precipitation data available in Rankl and Barker (12) were used in thunderstorm analysis. The precipitation stations used from both sources are described in Table 1.

The definition of a storm had to be established before usable information could be obtained from the data. In this paper, the criteria used for defining a storm are as follows:

1. General storm--preceded and followed by at least 2 hr of zero rainfall, at least 4 hr in duration, and at least 0.5 in. in volume.
2. Thunderstorm--preceded and followed by at least 1 hr of zero rainfall, at least 20 minutes and at most 4 hr in duration, and at least 0.5 in. in volume.

These criteria are arbitrary but consistent with similar criteria recommended by Huff (8), Ward (13), and Croft and Marston (14). Minimum duration requirements were used to ensure that the time distribution of any storm was described by at least four data points. A total of 531 general storms and 72 thunderstorms were examined.

The period of record represented by the data at most stations covers the years 1969-1979, though the lack of definable storms at some stations required data from as early as 1948. Because the development of design storms inherently assumes future rainfall events will occur with the same distribution as past events, the use of data from stations with variable periods of record is acceptable, assuming consistency of past records.

Description of Study Areas

The state of Wyoming was divided into its major surface water drainage basins for this study. This was done to determine if differences in storm rain-

TABLE 1 Precipitation Stations Providing Data for Study

Reference Number	Location Name or Number	Major Drainage Basin	Source	Recording Interval
1	Casper WSO AP	North Platte	NOAA[a]	1-Hour
2	Cheyenne WSFO AP	North Platte	NOAA	1-Hour
3	Douglas Aviation	North Platte	NOAA	1-Hour
4	Encampment	North Platte	NOAA	1-Hour
5	Jelm	North Platte	NOAA	1-Hour
6	Laramie 2 WSW	North Platte	NOAA	1-Hour
7	Medicine Bow	North Platte	NOAA	1-Hour
8	Oregon Trail Crossing	North Platte	NOAA	1-Hour
9	Pathfinder Dam	North Platte	NOAA	1-Hour
10	Phillips	North Platte	NOAA	1-Hour
11	Pine Bluffs	North Platte	NOAA	1-Hour
12	Rawlins FAA AP	North Platte	NOAA	1-Hour
13	Saratoga 4 N	North Platte	NOAA	1-Hour
14	Seminoe Dam	North Platte	NOAA	1-Hour
15	Shirley Basin Station	North Platte	NOAA	1-Hour
16	Torrington 1 S	North Platte	NOAA	1-Hour
17	Wheatland 4 N	North Platte	NOAA	1-Hour
18	Buffalo	Powder	NOAA	1-Hour
19	Douglas 17 NE	Powder	NOAA	1-Hour
20	Dull Center	Powder	NOAA	1-Hour
21	Gillette 18 SW	Powder	NOAA	1-Hour
22	Hat Creek 14 N	Powder	NOAA	1-Hour
23	Lance Creek	Powder	NOAA	1-Hour
24	Moorcroft	Powder	NOAA	1-Hour
25	Mule Creek	Powder	NOAA	1-Hour
26	Newcastle	Powder	NOAA	1-Hour
27	Osage	Powder	NOAA	1-Hour
28	Pine Tree 9 NE	Powder	NOAA	1-Hour
29	Powder River	Powder	NOAA	1-Hour

TABLE 1 (continued)

Reference Number	Location Name or Number	Major Drainage Basin	Source	Recording Interval
30	Recluse	Powder	NOAA	1-Hour
31	Sheridan WSO AP	Powder	NOAA	1-Hour
32	Story	Powder	NOAA	1-Hour
33	Boysen Dam	Big Horn	NOAA	1-Hour
34	Lander WSO AP	Big Horn	NOAA	1-Hour
35	Meteetse 1 ESE	Big Horn	NOAA	1-Hour
36	Powell Field Station	Big Horn	NOAA	1-Hour
37	Riverton	Big Horn	NOAA	1-Hour
38	Tensleep 4 NE	Big Horn	NOAA	1-Hour
39	Thermopolis	Big Horn	NOAA	1-Hour
40	Thermopolis 25 WNW	Big Horn	NOAA	1-Hour
41	Worland	Big Horn	NOAA	1-Hour
42	Big Piney	Green	NOAA	1-Hour
43	Mountain View	Green	NOAA	1-Hour
44	Mud Springs	Green	NOAA	1-Hour
45	Rock Springs FAA AP	Green	NOAA	1-Hour
46	Lake Yellowstone	Yellowstone	NOAA	1-Hour
47	Jackson	Snake	NOAA	1-Hour
48	Moran 5 WNW	Snake	NOAA	1-Hour
49	Evanston 1 E	Bear	NOAA	1-Hour
50	06631150	North Platte	USGS[b]	5-Minutes
51	06634910	North Platte	USGS	5-Minutes
52	06634950	North Platte	USGS	5-Minutes
53	06644840	North Platte	USGS	5-Minutes
54	06648720	North Platte	USGS	5-Minutes
55	06648780	North Platte	USGS	5-Minutes
56	06312910	Powder	USGS	5-Minutes
57	06312920	Powder	USGS	5-Minutes
58	06313050	Powder	USGS	5-Minutes
59	06313180	Powder	USGS	5-Minutes
60	06316480	Powder	USGS	5-Minutes
61	06382200	Powder	USGS	5-Minutes
62	06233360	Big Horn	USGS	5-Minutes
63	06238760	Big Horn	USGS	5-Minutes
64	06238780	Big Horn	USGS	5-Minutes
65	06256670	Big Horn	USGS	5-Minutes
66	06267260	Big Horn	USGS	5-Minutes
67	06267270	Big Horn	USGS	5-Minutes
68	06274190	Big Horn	USGS	5-Minutes

[a]NOAA (11)
[b]Rankl and Barker (12)

fall characteristics exist between basins. Figure 1 shows the state of Wyoming divided into these major drainages along with the precipitation stations used in this study. It should be noted that the precipitation data base (Figure 1) is not well distributed across the state and that most of the precipitation stations are located in valley areas. Data for the thunderstorm analysis are mainly concentrated in the center of the state.

Analysis of Storm Parameters

Determining if differences in storm rainfall characteristics exist between basins requires statistical analysis of certain storm parameters. Definitions of parameters used in describing storm rainfall follow:

1. Storm duration--the amount of elapsed time, in hours, from the beginning to the end of a storm.
2. Storm volume--the total amount of rainfall measured during a storm, in inches.
3. Rain intensity--the average rainfall rate during a storm, in inches per hour, calculated by dividing a storm's volume by its duration.
4. Percent time to peak intensity--the amount of time, expressed as a percent of total storm duration, from the beginning of a storm to the period of most intense rainfall.
5. Pattern index--the area beneath a dimensionless cumulative rainfall versus time curve, expressed as a decimal or as a percent.

Pattern index and percent time to peak intensity were the parameters used for determining whether differences in the time distribution of rainfall exist between basins. This determination was made by using a one-way analysis of variance (ANOVA) technique for samples of unequal size. The procedure, described in Miller and Freund (15), tests for differences in the population means for the populations

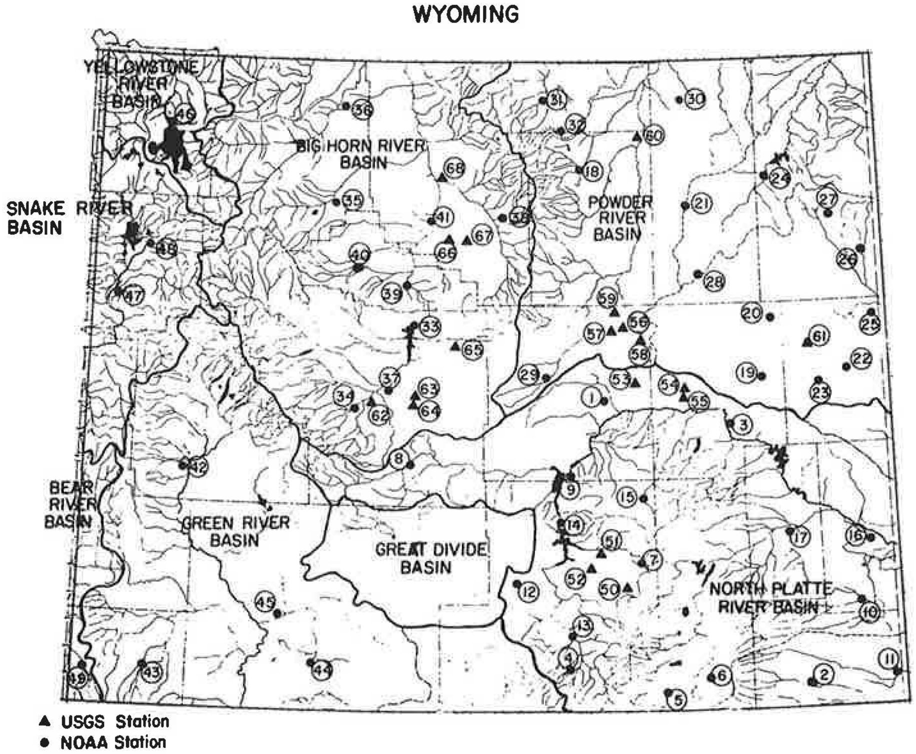

FIGURE 1 Map of Wyoming indicating the major surface water drainages. Station numbers refer to Table 1.

from which the samples were taken. Such tests indicate whether significant differences in parameter values exist between all the major drainages. If differences existed, the state would have to be divided accordingly before design storms could be constructed. If no differences existed, the state as a whole could be analyzed with the resulting design storms applicable statewide. The other parameters were used for describing the rainfall characteristics of each major drainage and for the state as a whole.

Construction of Design Curves

All the observed dimensionless mass rainfall curves are superimposed on one graph to create a family of probable storm patterns. Such an approach to design storm development is described in Kerr et al. (7). The most attractive feature of this method is its flexibility, which allows the user a choice of three given design hyetographs, as well as the freedom to construct a hyetograph, within limits. Such flexibility is desirable when, for example, a person is designing a structure based on peak flow-rate in one instance and on runoff volume in another. The use of several curves can allow maximization of either peak discharge or runoff volume for a given storm volume. A single design curve does not have this ability.

Figure 2 is a set of design curves. All of the storms used in the development of this set of curves are nondimensionalized and plotted on one graph of percent rainfall versus percent time. The bold vertical lines at each 10 percent time increment represent the range of all storm data used. In the center of the plot is the mean curve. The curve is fit through the points representing the average cumulative percent rainfall at each 10 percent time increment. It should be noted that the mean curve does not describe the average observed storm;

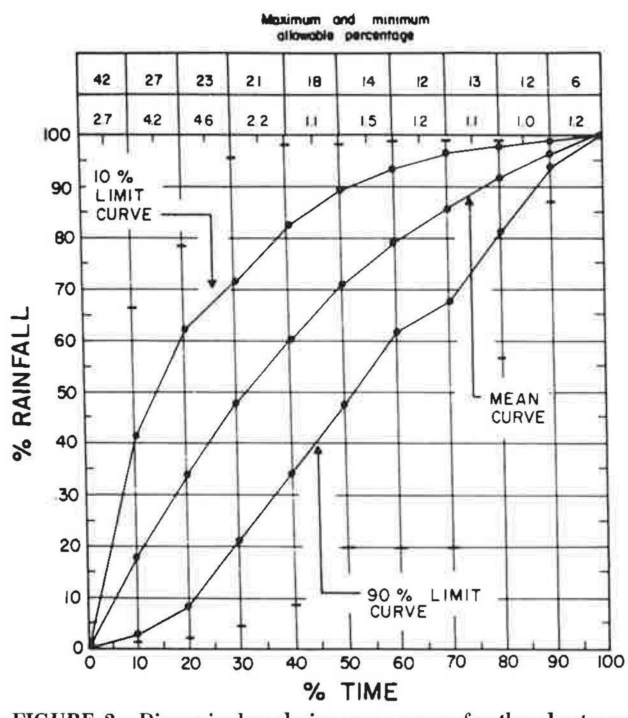

FIGURE 2 Dimensionless design mass curves for thunderstorms in Wyoming.

rather, it shows average accumulated rainfall with time based on all storms used.

Also drawn on the plot are 10- and 90-percent limit curves. The 10-percent limit curve represents, at a given percentage of storm duration, that value above which 10 percent of the storms had accumulated more precipitation. Similarly, 10 percent of the storms had each accumulated less than the value described by the 90 percent limit line at a given percentage of storm duration. It is incorrect to assume that 10 percent of the storms were totally above the 10 percent limit line or totally below the 90 percent limit line. The use of 10 percent as the cutoff when defining the upper and lower limit lines is arbitrary but reasonable. Using a smaller cutoff percentage resulting in a broader set of enveloping limit curves would be too general to accurately predict probable storm patterns. A larger cutoff value would result in a narrower envelope and a loss in flexibility of the method.

Under the assumption that future rainfall events will have the same time distribution as past events, these limit curves are the boundaries of a region of probable storm sequences. The user of the curves has the freedom to use either limit curve or the mean curve when choosing a design storm. The user may choose his own storm sequence as long as it is between the limit curves at all times and adheres to the maximum and minimum percentage guidelines in the first line of Figure 2. These percentage guidelines are constructed in a manner similar to the limit curves in that for each 10 percent time interval they represent intensities exceeded by only 10 percent of the storms (minimum percentage of storm volume for that 10 percent increment of time) as well as intensities exceeded by more than 90 percent of the storms (minimum percentage of storm volume for that 10 percent increment of time). In using these percentage guidelines, the designer cannot create a storm with a percentage greater than the value defined by the maximum or less than that defined by the minimum for the appropriate 10 percent time increment of storm duration.

Designing storms in this manner makes the utmost use of historical rainfall patterns while allowing the user flexibility in choosing the time distribution that will provide the critical peak discharge or runoff volume for his purpose.

Comparison of Storm Design Methods

The creation of new storm patterns for use in a particular region is logically accompanied by a comparison of the results of using the new method with results obtained using established design storm techniques. Such a comparison will prove the need for the new region-specific design curves if the existing general methods do not produce similar runoff characteristics when applied to a given event.

The different storm designs are compared by inputting them to four different rainfall-runoff simulation models and examining the runoff hydrographs produced. Thunderstorm and general storm runoff are simulated with each model. For each model and storm type, the infiltration parameters are held constant so that any differences noted in outflow hydrograph characteristics can be attributed to differences in the input hyetographs. The models used are described in Table 2. In addition to the design storm construction method presented in this paper, techniques given by SCS (4) and BUREC (5) are used for comparison. These last two methods have been described in the review of previous work.

DESIGN STORM RESULTS

Statistical Analysis

Examination of the linear regression and ANOVA tests performed on the rainfall data leads to the following conclusions:

1. A difference in the time distribution of thunderstorm rainfall compared to general storm rainfall exists for the entire state of Wyoming.
2. The time distribution of both thunderstorms and general storms is not dependent on the drainage basin in which the storms occur. However, the data in Figure 1 indicate that the data base used was not well distributed across the state.
3. No relationship exists between time distribution characteristics and duration of general storms or thunderstorms.

Inferred by Conclusions 1 and 2 is the need for only one set of general storm design curves and one set of thunderstorm design curves for use statewide. Conclusion 3 infers that design storms of varying duration, that is 1-, 2-, or 3-hr thunderstorms or 6-, 12-, or 24-hr general storms, can all be handled with the same set of design curves. Table 3 lists the results of selected important linear regression and ANOVA tests used in drawing these conclusions. The rest of the statistical analysis results can be found in Tyrrell (22).

Probably the most outstanding characteristic of the storms analyzed is their individual diversity.

TABLE 2 Description of Digital Computer Models Used in Design Storm Comparisons

Model	Citation	Method of Estimating Infiltration	Method of Constructing Outflow Hydrograph
SCS Triangular Hydrograph	Design of Small Dams (5)	Uses a "minimum infiltration rate" and runoff curve number based on soil type.	Relates incremental excess precipitation to incremental runoff with a hydrograph that is triangular in shape.
HEC-1	U.S. Army Corps of Engineers (16)	Uses an exponentially decaying function that depends on rainfall intensity and antecedent losses.	Derives outflow hydrograph from either (1) unitgraph input by either, or (2) Clark (17) synthetic unitgraph.
HYMO	Williams and Hann (18). U.S. Department of Agriculture.	Similar to SCS method above; uses curve number and minimum infiltration rate.	Uses dimensionless unitgraph (described by exponential expressions relating flowrate to time) and a "dimensionless shape parameter."
USGS	David R. Dawdy, John C. Shaake, Jr., and William M. Alley (19). U.S. Geological Survey.	Uses the Philip (20) variation of the Green-Ampt (21) equation. Method includes soil-moisture accounting between storms.	Performs finite difference solution of kinematic wave equation for each channel and overland flow segment in drainage basin.

TABLE 3 Results of Selected Statistical Analysis of Rainfall Characteristics

Linear Regression:

Dependent Variable	vs	Independent VAriable	Correlation Coefficient (R)	Conclusion
Pattern Index for all storms.		Duration of all storms.	.167	No significant relationship.
[a]Duration of all general storms-North Platte drainage.		Percent time to Peak Intensity-general storms-North Platte drainage.	.055	No significant relationship.
[a]Duration of all thunderstorms-North Platte drainage.		Percent time to Peak Intensity-thunderstorms-North Platte drainage.	.170	No significant relationship.

Analysis of Variance:

Null Hypothesis (H_0)	F Statistic Data	$F_{.05}$	$F_{.10}$	Conclusion
Pattern Index values for general storms are equal for all five major drainages.	1.22	2.44	1.99	Do not reject H_0; conclude no difference in Pattern Index due to drainage basin location.
Pattern Index values for thunderstorms are equal for three major drainages.	.79	3.14	2.38	Do not reject H_0; conclude no difference in Pattern Index due to drainage basin location.
[a]Pattern Index values are equal for thunderstorms and general storms-North Platte River drainage.	24.65	3.91	2.74	Reject H_0; conclude some difference in Pattern Index due to type of storm.

[a]Results from the North Platte drainage data analysis are presented as an example. Results from the other basins are similar.

This same finding is corroborated in the paper by Kerr et al. (7) for storms in Pennsylvania. It is precisely because of this diversity that the use of an enveloping set of curves is preferred to the use of a single storm pattern when attempting to predict runoff.

Presentation and Use of Design Curves

Figures 2 and 3 show the design curves for thunderstorms and general storms, respectively, constructed according to the procedures previously outlined.

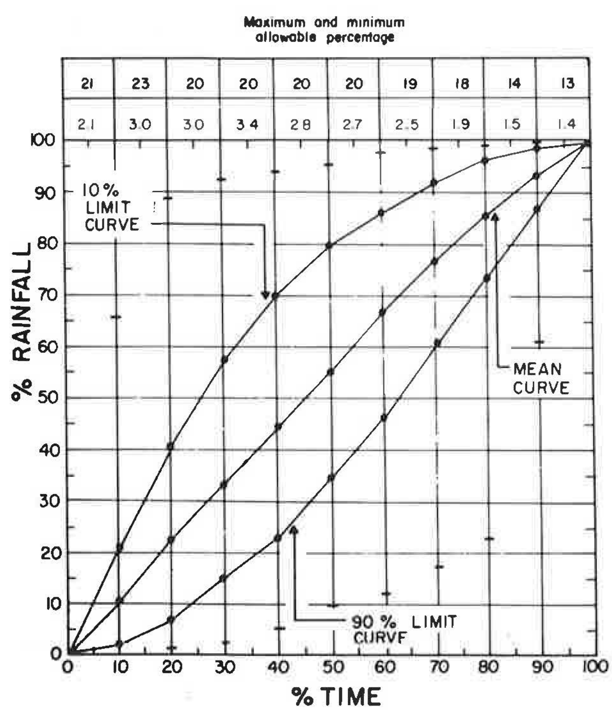

FIGURE 3 Dimensionless design mass curves for general storms in Wyoming.

Figure 2 is to be used when the duration of the design storm of interest is less than 4 hr. Figure 3 is to be used for events 4 hr long or longer.

Following is a list of steps involved in using the design curves:

1. Select the storm type to be simulated at a certain location; for example, the 10-yr, 6-hr event in Buffalo, Wyoming. Consult some source of rainfall frequency data, such as the Rainfall Frequency Atlas by Miller et al. (23), to find the volume of rain expected for this event.
2. Select the appropriate set of design curves. For the preceding example, the general storm curves (Figure 3) are applicable because the duration is longer than 4 hr.
3. Select one curve from the plot, either the 10- or 90-percent limit curve, the mean curve, or some nonstandard curve. When choosing a nonstandard curve, the user must remember to stay on or between the limit curves at all times. Also, the steepness (intensity) of a curve in any 10 percent time interval is dictated by the maximum and minimum allowable percentages shown at the top of the design curves. A nonstandard curve must not include more than the maximum percentage of storm volume indicated (maximum intensity), nor less than the minimum percentage of storm volume indicated (minimum intensity), in any given 10 percent interval of storm time. Examples of nonstandard time distributions are given in succeeding sections of this paper.
4. Using the curve from Step 3, select the percent rainfall values that correspond to the percent time values.
5. Organize the data obtained in Step 4 into the form required by whatever model is being used; that is, rainfall either as actual depth or a percent of storm volume, sequences either cumulative or incremental.
6. Run the model with infiltration and geomorphic soil, geologic, vegetative, or other basin parameters as required.

It is recommended that the user run several simulations with different hyetographs to determine the critical runoff volume or peak discharge. The suite of design curves used probably will include both limit curves, the mean curve, and several curves chosen arbitrarily by the user.

A parameter not included in this study is the areal distribution of rainfall. Therefore, the user of the method presented here is obliged to reduce point rainfall values when working with large drainage basins. Methods of reducing point rainfall with increasing drainage basin area are presented in Design of Small Dams (5) and in the Rainfall Frequency Atlas (23). These reductions are necessary because of the tendency of point rainfall values to overestimate actual areal precipitation on large areas.

Because this new design method depicts "probable" events, rather than extreme events (i.e., ultrahigh-intensity bursts or long periods of very intense rain), it should not be used when designing for runoff due to "probable maximum" rainfall. Existing methods for probable maximum design (5) should be consulted for those cases.

RESULTS OF DESIGN STORM COMPARISONS

General Information

The purpose of this section is to compare the use of differing design storms in parametric flood prediction. Computer models used are HEC-1 (Hydrologic Engineering Center), HYMO (Problem-Oriented Computer Language for Hydrologic Modeling), HYDRO (SCS Triangular Hydrograph method), and USGS (U.S. Geological Survey-distributed routing model). The reader is referred to Table 2 for descriptions and references for these models. Design storms recommended by BUREC (5) and SCS (4) are used in the comparison.

The procedure followed in the comparison was to input differing design storms to a model, while leaving all geomorphic, soil, geologic, vegetative, infiltration, and other basin parameters unchanged, and examine differences in the simulated outflow hydrograph peak and volume. Variations thus found are attributable only to variations in the input hyetograph.

Some problems were encountered in the use of existing design storms. For example, the SCS method, rather than using a rainfall volume based on a certain duration for a given frequency, uses the 24-hr amount for designing storms of all durations. This practice results in slightly different storm volumes than those for varying durations found in Miller et al. (23) publication. Despite this anomaly, the SCS hyetograph was used without a volume correction. Thus, a valid method-by-method comparison is ensured. The BUREC method also involves an odd twist basing its storm volumes on fractions and multiples of the 6-hr value for a given frequency. Modern practice has corrected this deficiency by allowing the use of volumes expected for various durations, not a manipulation of the 6-hr amount, while retaining the recommended time sequence. The BUREC method also typically calls for basing designs on runoff from a 3-hr thunderstorm and an 18-hr general storm. Because there exists no 18-hr duration precipitation data, no storms of this length were used in comparison. Also, a 2-hr thunderstorm was deemed most representative of short duration events (thus, the 3-hr event was not used).

Storms selected for the comparisons were 2, 6, and 24 hr in duration. The 2-hr event is considered a thunderstorm; the other two are general storms. A small drainage (0.83 $mile^2$) in the Powder River Basin was the test basin used for the simulations. Storm volumes (6) for the durations listed earlier (with a 10-yr return period) at this location are: 2-hr = 1.60 in.; 6-hr = 2.00 in.; and 24-hr = 2.75 in. Runoff model parameters used with each model for comparison can be found in Tyrrell (22).

Design Hyetographs

Figures 4 and 5 show the dimensionless design hyetographs used for the thunderstorm and general storms as cumulative rainfall amounts. The WYO distribution sequences (mean, 10- and 90-percent limit) can be found in the curves shown in Figures 2 and 3. Those WYO storms designated A and B correspond to nonstandard curves arbitrarily selected by the authors using Figures 2 and 3. The data in Table 4 indicate the cumulative values for each design hyetograph for the 10-yr, 2-hr thunderstorm.

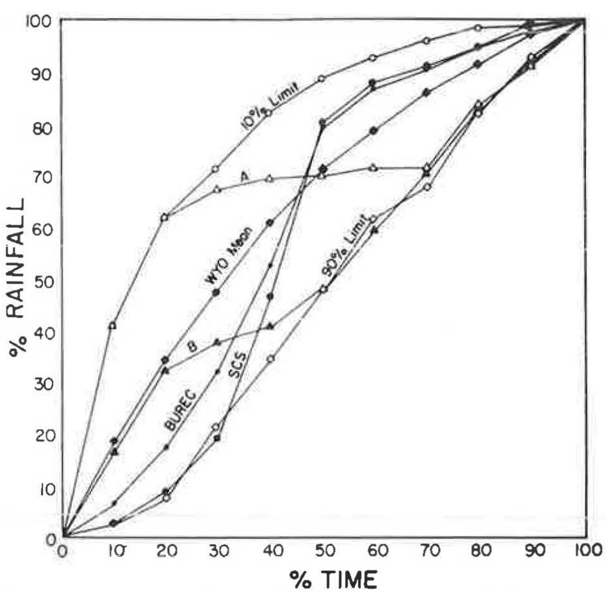

FIGURE 4 Dimensionless design mass curves (thunderstorms) for comparative purposes.

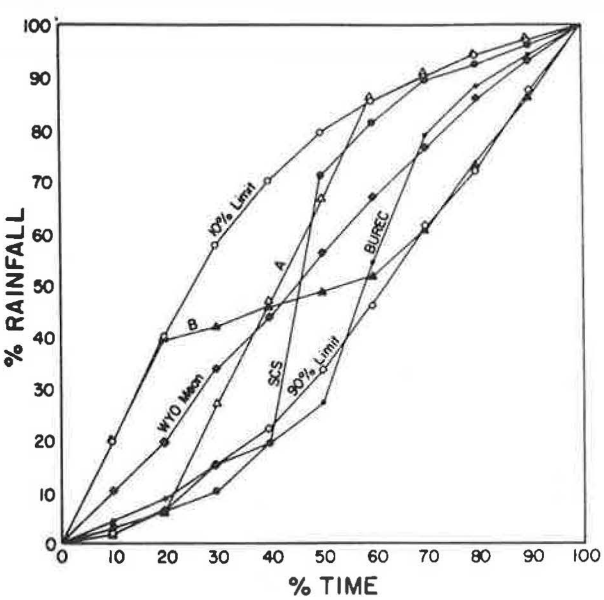

FIGURE 5 Dimensionless design mass curves (general storms) for comparative purposes.

TABLE 4 Comparative Hyetographs for 10 Year, 2-Hour Thunderstorm Cumulative Rainfall (inches)

Time, Minutes	[a]SCS Type II	BUREC	WYO: Mean	10% Limit	90% Limit	A	B
0	----	----	----	----	----	----	----
15	.06	.14	.35	.75	.06	.75	.35
30	.15	.36	.66	1.10	.24	1.02	.58
45	.45	.65	.91	1.30	.50	1.09	.64
60	1.17	1.26	1.14	1.44	.75	1.12	.75
75	1.30	1.39	1.30	1.50	1.01	1.15	1.01
90	1.37	1.49	1.42	1.55	1.25	1.25	1.25
105	1.43	1.55	1.52	1.58	1.44	1.44	1.44
120	1.47	1.60	1.60	1.60	1.60	1.60	1.60

[a]Based on 10 year, 24-hour volume (2.75")

Tables 5, 6, and 7 present the results of the runoff model runs for the 2-, 6-, and 24-hr events, respectively. Generally, results from HEC-1, HYMO, and HYDRO simulations indicate that for longer events, the WYO curves produce less runoff (peak and volume) than the other methods, while for shorter events, the WYO curves produce greater runoff. Results from USGS model runs differed from the other models' results by predicting, for all three storm durations, smaller runoff peaks and volumes due to the WYO design curves when compared with established procedures. Because of these results, it is suggested that current methods, in general, may lead to consistent over-design of hydraulic structures, at least when long duration (general storms) events are stated as part of the design criteria. Also, the ability of any one of the group of WYO curves to produce greater runoff than the others is dependent on the model used.

DISCUSSION OF RESULTS

The most significant difference between the WYO design storm methodology and those developed by SCS and BUREC is the use of totally dimensionless curves. By nondimensionalizing the time axis, the average intensities of designed storms are decreased as the storm durations are increased. For example, if two general storms of the same volume but differing durations, for example, 6 and 12 hr, were distributed over time according to the mean curve of Figure 3, the 12-hr storm would have one-half the intensity of the 6-hr event at any point along the curve. This explains why the WYO curves tend to produce smaller runoff peaks than the other methods for long events and larger peaks for short events. Such a change in intensity with duration may appear inappropriate at first, but analysis of 100 runoff-producing storms recorded by Rankl and Barker (12) indicates that,

TABLE 5 Runoff Characteristics for 10 Year, 2-Hour Thunderstorm

	MODEL:							
	HYDRO		HYMO		HEC-1		USGS	
Design Storm	Peak (cfs)	Vol. (in.)	Peak (cfs)	Vol. (in.)	Peak (cfs)	Vol. (in.)	Peak (cfs)	Vol. (in.)
SCS Type II	47.8	.098	11.7	.036	38	.39	41.1	.162
BUREC	65.3	.137	17.3	.053	36	.38	40.2	.162
WYO-Mean	61.7	.139	12.9	.040	28	.31	16.0	.094
10% Limit	61.8	.123	19.9	.061	42	.45	33.2	.146
90% Limit	76.1	.135	30.7	.100	29	.32	20.6	.107
-A	62.2	.125	17.2	.064	34	.42	22.2	.138
-B	76.1	.135	30.7	.100	27	.32	19.2	.103

TABLE 6 Runoff Characteristics for 10 Year, 6-Hour General Storm

	MODEL:							
	HYDRO		HYMO		HEC-1		USGS	
Design Storm	Peak (cfs)	Vol. (in.)	Peak (cfs)	Vol. (in.)	Peak (cfs)	Vol. (in.)	Peak (cfs)	Vol. (in.)
SCS Type II	85.3	.175	42.7	.143	36	.38	47.1	.184
BUREC	81.6	.251	37.6	.205	20	.23	19.4	.116
WYO-Mean	52.8	.275	18.9	.094	2	.03	6.7	.065
10% Limit	50.5	.208	26.9	.103	11	.14	8.5	.075
90% Limit	83.6	.287	54.8	.261	10	.12	12.4	.085
-A	89.1	.221	49.4	.164	18	.22	16.7	.101
-B	83.6	.226	55.8	.261	10	.16	10.5	.082

TABLE 7 Runoff Characteristics for 10 Year, 24-Hour General Storm

Design Storm	HYDRO Peak (cfs)	HYDRO Vol. (in.)	HYMO Peak (cfs)	HYMO Vol. (in.)	HEC-1 Peak (cfs)	HEC-1 Vol. (in.)	USGS Peak (cfs)	USGS Vol. (in.)
SCS Type II	138.6	.346	57.9	.285	30	.34	43.1	.189
BUREC	95.5	.268	45.9	.221	14	.16	14.4	.103
WYO-Mean	0	0	0	0	0	0	1.49	.043
10% Limit	24.3	.107	14.7	.091	0	0	2.22	.051
90% Limit	8.0	.085	6.5	.074	0	0	2.88	.056
-A	50.9	.384	36.6	.319	0	0	5.18	.069
-B	8.1	.075	6.1	.063	0	0	2.82	.056

although there is not a good linear relationship (R = 53 percent), the peak intensity of a storm appears to decrease with increasing storm length, as shown in Figure 6. It appears reasonable, therefore, for the WYO storm design techniques to make long storms generally less intense than short storms.

Lower rainfall intensity, as obtained from the different WYO curves, is the reason zero runoff is predicted in some instances for the 24-hr event. For example, referring to Table 7, no runoff is produced using the WYO mean curve with the HYDRO and HYMO models. Notice that, for general storms, the WYO mean curve is almost a 45-degree line indicating an almost constant intensity storm. For the 14-hr event, this constant intensity (0.11 in./hr) is less than the minimum infiltration loss of 0.15 in./hr. Thus, no runoff occurs. Similarly, the HEC-1 model produces zero runoff in several instances. Because shorter storms do produce runoff, according to HEC-1, the reason for zero predicted runoff in the longer storms obviously also involves low rainfall intensity and associated infiltration losses.

It is interesting to note that choosing a WYO curve for producing peak discharge or volume depends on the computer model to be used. For instance, referring to Table 5, the WYO 90 percent limit curve produces more runoff (peak and volume) than the 10 percent limit curve when HYDRO and HYMO are used. When HEC-1 is used, the 10 percent limit curve yields the greatest runoff peak and volume. The user of these curves is, therefore, warned not to assume that a peak-producing hyetograph for one model will perform similarly with a different simulation scheme. The user should always test several curves for their peak-producing ability when changing models, or when changing storm durations with the same model.

SUMMARY AND CONCLUSIONS

Summary

Parametric flood prediction on ungauged basins in Wyoming requires the use of temporal storm patterns that realistically represent anticipated local rainfall events. Because methods of hyetograph construction currently in use are very general in application, this requirement is not met. Therefore, a design storm methodology based on analysis of time distribution characteristics of 603 observed storms in Wyoming is presented. The WYO method of storm design uses not one but several mass rainfall curves, allowing flexibility of use and maximization of runoff from a given storm volume.

Comparisons were made between the WYO method and design storms recommended by SCS and BUREC using HEC-1, HYMO, HYDRO, and USGS distributed routing rainfall-runoff models.

Conclusions

1. The time distribution of both thunderstorms and general storms in Wyoming is not dependent on the drainage basin in which the storms occur.
2. The most outstanding characteristic of the storms analyzed is their individual diversity. No relationship exists between time distribution characteristics and duration of general storms or thunderstorms. However, a difference in the time distribution of thunderstorm rainfall, compared to general storm rainfall, exists.
3. One set of thunderstorm design curves and one set of general storm design curves can be used to

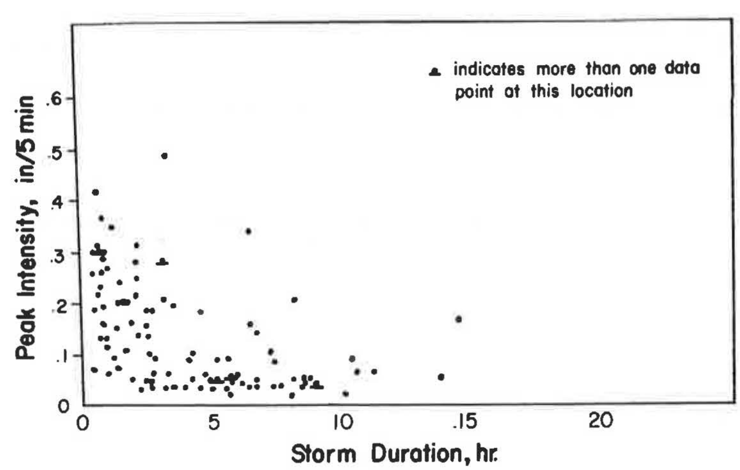

FIGURE 6 Variation in peak intensity with storm duration.

create design hyetographs for the entire state of Wyoming.

4. The WYO design storm methodology should not be used to design for probable maximum type events because the most intense rainfall values have been neglected by the definition of 10- and 90-percent limit curves.

5. Simulation of runoff peak and volume using WYO design curves is sensitive to storm duration and choice of runoff model.

6. WYO curves typically predict greater runoff peaks than SCS or BUREC synthetic hyetographs for short duration events, and less runoff, in most cases, for long duration events, according to HEC-1, HYMO, and HYDRO model results.

7. WYO curves consistently produce less runoff than SCS or BUREC synthetic hyetographs when the USGS distributed routing model is used.

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