WRIR 00-4069

8/16/00

USGS
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Flood Hydrology for Dry Creek, Lake County, Northwestern Montana

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Abstract

Dry Creek is a small stream that drains about 8.74 square miles of rugged mountainous terrain upstream from Tabor Dam in the Mission Range near St. Ignatius, Montana. Because of uncertainty in plausible peak discharges and concerns regarding the ability of the Tabor Dam spillway to safely convey these discharges, the flood hydrology for Dry Creek was evaluated on the basis of three hydrologic and geologic methods. The first method involved determining an envelope line relating flood discharge to drainage area on the basis of regional historical data and calculating a 500-year flood for Dry Creek using a regression equation. The second method involved paleoflood methods to estimate the maximum plausible discharge for 35 sites in the study area. The third method involved rainfall-runoff modeling for the Dry Creek basin in conjunction with regional precipitation information to determine plausible peak discharges. All of these methods resulted in estimates of plausible peak discharges that are substantially less than those predicted by the more generally applied probable maximum flood technique.

INTRODUCTION

Dry Creek is a small stream that drains about 4.5 square miles of rugged mountainous terrain before entering St. Mary Lake in the Mission Range near St. Ignatius, Montana (fig. 1). St. Mary Lake was a natural lake impounded by glacial debris prior to the construction of Tabor Dam in 1930. Initial construction included an embankment across the outlet of Dry Creek, a second embankment across the low saddle of the existing glacial moraine at the downstream end of the lake, and a spillway. Subsequent construction in 1940 and 1952 raised both embankments about 20 feet and widened the spillway (Lockhart, 1993). The total drainage area upstream from the dam is about 8.74 square miles.

Because of concerns about the safety of Tabor Dam in the event of a large earthquake or flood, the Bureau of Reclamation evaluated the geologic stability of the embankments and foundation and the ability of Tabor Dam to safely pass the Probable Maximum Flood (PMF)--the flood that can be expected from the most severe combination of critical meteorologic and hydrologic conditions that are reasonably possible in a region (National Research Council, 1988). Although the geological investigation determined that the foundation was generally stable and that the embankments had relatively low potential for liquefaction, the calculated PMF would overtop the embankments and exceed the spillway capacity. The estimated costs to upgrade the spillway to PMF standards are about $2.5 million (Mike Brown, Safety of Dams Coordinator, Confederated Salish and Kootenai Tribes, oral commun., 1998).

Purpose and Scope

To help determine whether the PMF estimates for Dry Creek are reasonable in light of historical and geological evidence, the U.S. Geological Survey (USGS), in cooperation with the Confederated Salish and Kootenai Tribes, undertook a flood hydrology investigation of Dry Creek and other nearby basins on the west side of the Mission Range in Lake County, Montana. This report describes the results of that investigation. The investigation used three essentially independent methods to estimate extreme floods for Dry Creek. First, recorded flood-discharge data from 9 sites in the Mission Range study area (fig. 1) and 81 sites in western Montana were used to develop a regional envelope line relating flood discharge to drainage area, and a regional regression equation was used to calculate a 500-year flood magnitude for Dry Creek. Second, plausible maximum discharge was estimated for 35 sites in the Mission Range study area using paleoflood techniques. Third, rainfall-runoff modeling was used to estimate an extreme flood discharge for Dry Creek using a synthetic storm based on regional extreme precipitation in Montana. Results from the three independent methods were compared to two PMF estimates, one based on a thunderstorm and one based on a general storm.

Acknowledgments

Many individuals and landowners assisted with the study. Particular thanks are given to Mike R. Brown, Safety of Dams Coordinator for the Confederated Salish and Kootenai Tribes, who provided background

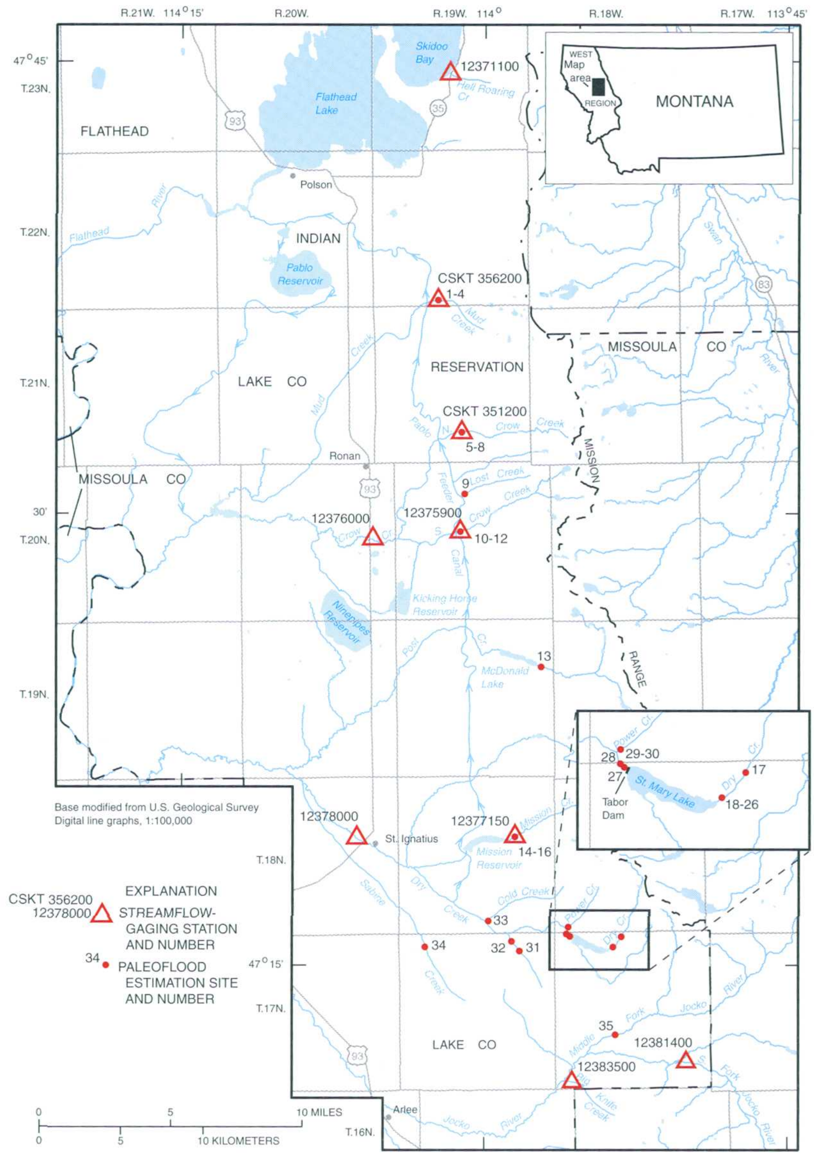


Figure 1. Location of streamflow-gaging stations and paleoflood estimation sites on streams draining the west side of the Mission Range, Montana.

reports, hand tools and equipment, letters of authorization for access to streams in the study area, and general support for the project. Thanks also are given to Dave R. Johnson and Stephen R. Holnbeck (USGS), who assisted with field work and helped the authors interpret and review the data, and to J.E. O'Connor (USGS), whose thorough review of the report resulted in many improvements.

FLOOD HYDROLOGY

Information about past floods in the study area, both from streamflow-gaging station records and geologic evidence, together with information about rare storms and the rainfall-runoff process, can increase understanding of the magnitude of extreme floods in the study area. The following sections describe (1) flood history of the study area and use of an envelope line and a regional regression equation to estimate large floods for Dry Creek, (2) paleoflood methods for determination of plausible floods and application to the study area, (3) rainfall-runoff modeling of an extreme, synthetic storm on the Dry Creek basin above St. Mary Lake, and (4) comparisons of these results with PMF estimates for Dry Creek.

Flood History

Dry Creek drains the western side of

the southern part of the rugged Mission Range in northwestern Montana. The core of the Mission Range was deeply gouged by Pleistocene glaciers, and headwater streams, such as Dry Creek upstream from St. Mary Lake, are very steep with alternating sections of bedrock cataracts and alluvial, bouldery V-shaped channels. Away from the core of the Mission Range, stream slopes decrease, and the gravelly channels are flanked by levees of debris-flow deposits and isolated terrace remnants.

Mean annual precipitation in the study area ranges from about 15 inches in the valley floor to about 60 inches at the Mission Range crest (Parrett, 1997). Most precipitation falls as snow, and most runoff peaks result from snowmelt in conjunction with spring rainstorms.

Large storms in the Mission Range typically originate in the Pacific Ocean and arrive from the west. Large storms that arise in the Gulf of Mexico and produce large floods in some mountainous areas of Montana do not significantly affect the west side of the Mission Range. For example, the large 1964 storm that came from the Gulf and caused extreme flooding along both sides of the Continental Divide in Montana caused relatively minor flooding on Mission Range streams (Boner and Stermitz, 1967).

Nine streamflow-gaging stations that have at least 10 years of peak-discharge data are located on streams that drain the west side of the Mission Range. The stations, drainage areas, number of years of record, and maximum annual-peak discharges are shown in table 1. Although the peak-discharge records are relatively short (10 to 26 years) and mostly recent, two peaks shown on table 1 are for the flood of 1908, one of the largest regional floods in western Montana in the last 100 years (Merritt, 1990).

The log-Pearson probability distribution was fit to the peak-discharge record at each station in table 1 as described by the Interagency Advisory Committee on Water Data (1982). The fitted log-Pearson probability distribution can be used to calculate peak discharge for any specified exceedance probability. The reciprocal of exceedance probability, commonly referred to as recurrence interval, represents the average time, in years, between exceedances of a given flood magnitude and may be used to characterize extreme floods on a probabilistic basis. For example, a flood magnitude having an exceedance probability of 0.002 is an extreme flood that is exceeded, on average, once in 500 years. The peak discharge having a 500-year recurrence interval, commonly referred to as the 500-year flood, was calculated for each of the nine stations in the Mission Range study area (table 1). Because the log-Pearson probability distribution may yield unreliable estimates of flood magnitude when the record length is significantly shorter than the recurrence interval, the calculated 500-year floods for the Mission Range study area were compared with those for a larger regional data set.

The Mission Range study area lies in the West Region, a portion of western Montana having common flood-

Table 1. **Streamflow-gaging stations and flood data for streams draining the west side of the Mission Range, Montana**

Station number	Station name	Drainage area (square miles)	Years of record	Period of record	Maximum peak discharge (cubic feet per second)	Peak discharge having 500-year recurrence interval (cubic feet per second)
12371100	Hell Roaring Creek near Polson	6.22	26	1917-32,1948, 1959-67,1980, 1982-97	160	280
CSKT 356200	Mud Creek above Pablo Feeder Canal	2.34	13	1982-97	90	120
CSKT 351200	North Crow Creek at campground	10.6	16	1983-98	685	1,200
12375900	South Crow Creek near Ronan	7.57	16	1983-98	312	600
12376000	Crow Creek near Ronan	46.1	10	1907-17	[1]1,400	1,200
12377150	Mission Creek above reservoir, near St. Ignatius	12.4	16	1983-98	706	880
12378000	Mission Creek near St. Ignatius	74.8	11	1907-17	[1]1,700	1,100
12381400	South Fork Jocko River near Arlee	56.0	16	1983-98	1,220	1,700
12383500	Big Knife Creek near Arlee	6.88	17	1982-98	100	130

[1]Maximum peak discharge occurred in 1908 and is believed to be the largest in past 100 years.

frequency characteristics defined by Omang (1992). Omang (1992) applied the log-Pearson probability distribution to 81 stations in the West Region having a total of 1,710 station-years of record and calculated peak discharges having recurrence intervals up to 500 years. To indicate the range of maximum flood experience in the West Region compared to that in the Mission Range study area, the maximum known flood at each of the 9 stations in the study area and at each of the 81 stations used by Omang (1992) was plotted on a log-log basis relating discharge to drainage area, and an envelope line encompassing the plotted data was hand-drawn (fig. 2). Maximum recorded floods in the Mission Range study area plotted well within the range of maximum floods in the West Region and well below the envelope line.

The calculated 500-year flood discharges for stations in the Mission Range study area (table 1) and those calculated by Omang (1992) also were plotted on a log-log basis relating discharge to drainage area (fig. 3). The calculated 500-year floods in the Mission Range study area were well within the range of calculated 500-year floods for the West Region. The envelope line encompassing maximum recorded floods in the West Region (fig. 2) is also shown on figure 3 for comparison of maximum recorded floods with calculated 500-year floods. The relatively good agreement between recorded maximum and calculated 500-year floods in the Mission Range study area with those in the West Region indicate that extreme flood experience is similar in the two areas and that methods for estimation of large floods in the West Region are applicable in the Mission Range study area. Accordingly, a regression equation using drainage area and mean annual precipitation as explanatory variables developed by Omang (1992) was used to calculate a 500-year flood magnitude of 490 cubic feet per second for Dry Creek at Tabor Dam (drainage area = 8.74 square miles). The standard error of prediction for the regression equation, 55 percent (Omang, 1992), was used to calculate an upper bound for the estimated 500-year flood for Dry Creek as 490 cubic feet per second plus 55 percent of 490 cubic feet per second, or 760 cubic feet per second. Both values of calculated 500-year flood are plotted on figure 3.

Although figures 2 and 3 provide reasonable information about the magnitude of large floods on Dry Creek based on regional flood experience, the information is not sufficient to estimate the magnitude of large floods necessary for assessing dam safety. Two independent methods for estimating flood magnitudes for dam safety are based on paleoflood estimation methods and rainfall-runoff modeling using regionalized extreme-storm depths.

Paleoflood Methods

Paleoflood hydrology is the study of floods that occurred prior to the collection of systematic flood records or direct measurements (Costa, 1986). Such prehistoric floods are evidenced by geologic and botanical features in and adjacent to the stream channels. In mountainous areas of the western United States where glaciation has extensively reworked channel deposits, paleoflood evidence pertinent to modern climatic regimes generally is limited to about the last 10,000 years. Paleoflood evidence in mountainous areas generally consists of bouldery bar deposits, gravel deposits on flanking terraces, and, on a shorter time scale, scars on trees in the flood plain. This kind of evidence serves to identify the maximum height or stage of floodwater from large-magnitude floods at a site. Although some paleoflood studies have identified a series of past flood stages, commonly the only identifiable stage is that for the largest flood. An identifiable deposit or mark associated with a paleoflood is termed a paleostage indicator (Jarrett, 1991).

The absence of flood evidence can also provide useful information on past large-magnitude flood stages. The altitude of a streamside land surface that shows no evidence of paleoflood deposition or erosion can be considered a maximum limit for the stage of past floods (Levish and others, 1994, and Ostenaa and others, 1996, 1997).

Once a paleostage indicator or maximum limit for flood stage has been identified, discharge can be calculated by application of various hydraulic engineering methods, such as slope-area calculations, critical-depth calculations, normal-depth calculations, or step-backwater analyses (Barnes and Davidian, 1978). Slope-area calculations and step-backwater analyses are based on the principle of the conservation of kinetic and potential energy through a stream reach and require measurement of cross-sectional flow areas at several locations in the reach. Critical-depth and normal-depth calculations provide at-site estimates of discharge and require measurement of cross-sectional flow area at a single location. Thus, an implicit assumption for application of all hydraulic methods is that channel geometry has not significantly changed since the paleoflood. This assumption limits strict application of paleoflood methods to stream channels, such as those in mountainous settings, whose dimensions are largely controlled by bedrock outcrops.

Although the slope-area and step-backwater methods require more channel-geometry data than the critical-depth and normal-depth methods, their use may be unwarranted for many paleoflood applications where stages, cross-sectional areas, and knowledge about channel friction losses during paleoflood conditions

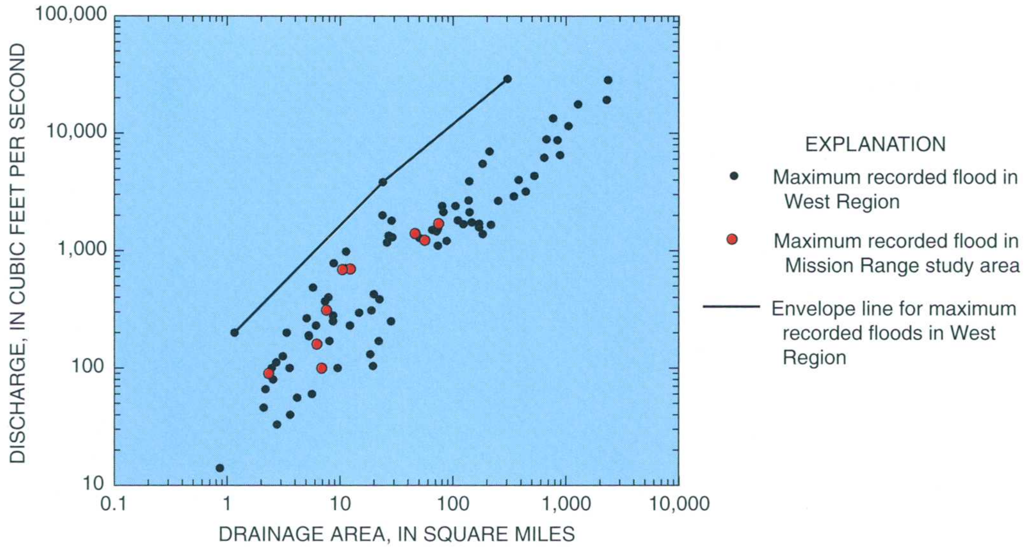


Figure 2. Maximum recorded floods in the study area and in the West Region, Montana.

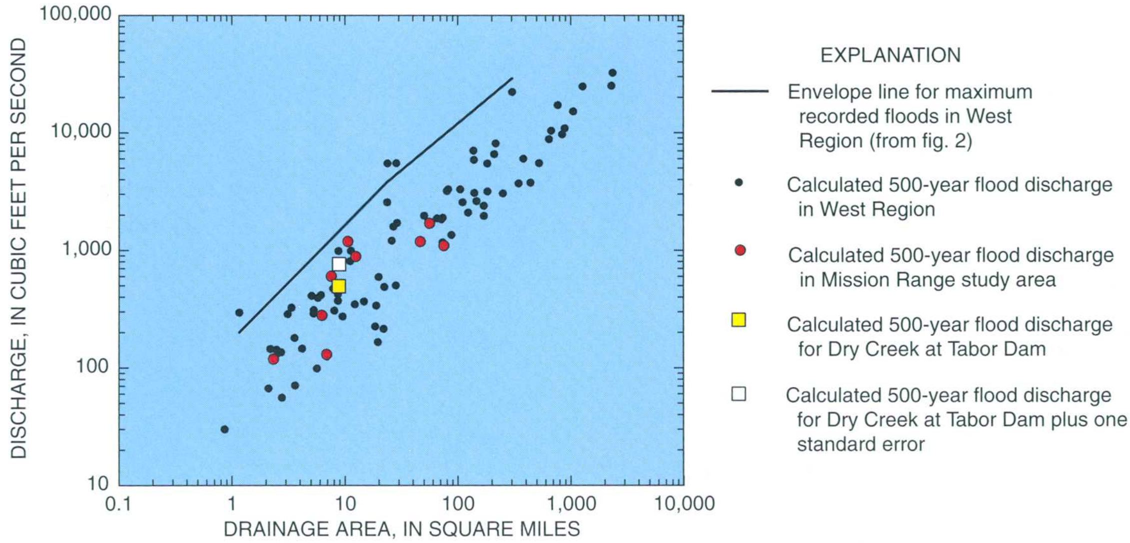


Figure 3. Estimated 500-year floods in the study area and the West Region, Montana.

are very imprecise, at best. The critical-depth method, which is based on the assumption that critical flow occurs at the cross section, is the only method that does not require an estimate of channel friction loss (Manning's roughness coefficient). Because super-critical flow conditions are very unlikely for extended reaches in natural streams (Jarrett, 1984), critical flow generally represents the maximum discharge for a given stage. In addition, because flow conditions that approach critical flow are likely only for very steep natural channels, the critical-depth method is particularly well suited for paleoflood estimation on steep mountain streams. Under these conditions, estimates from the critical-depth method are most likely to overpredict peak discharge. Thus, all paleoflood discharge estimates for this study were based on the critical-depth method. The equation for calculation of critical discharge (discharge at critical depth) in an irregular channel (Henderson, 1969, p. 51) is the following:

$$Q = (g\,A^3/T)^{0.5} \qquad (1)$$

where Q is the discharge, in cubic feet per second,
g is the acceleration of gravity (32.2 feet per second squared),
A is the cross-sectional area of flow, in square feet, and
T is the top width of flow, in feet.

In the study area, no evidence of paleoflood erosion or deposition was found at most sites. Large, ancient mid-channel flood bars were found at three sites (table 2), Mission Creek above Mission Reservoir (sites 14 and 15) and Dry Creek above St. Mary Lake (site 18). Because of uncertainty about channel geometry at the time the ancient bars were formed, the discharge at the time of bar formation could not be estimated. Nevertheless, the altitude of these bars represent maximum limits for flood stage since bar formation, and maximum flood discharge was estimated at these sites by calculating the discharge that would significantly overtop the bars. Because flood depth on a bar greater than about 1 foot was considered likely to severely erode soil surfaces and deposit additional sand or gravel bars, significant overtopping was considered to be a depth of 1 foot. Although no bars were age dated, the period since formation was assumed to be at least several hundred years, on the basis of the large fir and cedar trees growing on the well-developed soil profile on the bar surfaces.

At other estimation sites, the maximum limits for flood stage were the tops of adjacent stream banks where no evidence of previous flood erosion or deposition was found. Flood stages greater than about 1 foot above the banks were considered likely to leave evidence of erosion and deposition. Consequently, the limit of paleoflood discharge was estimated at these sites by making critical-depth calculations for stages corresponding to the tops of banks, plus 1 foot.

The paleoflood discharge estimation sites are shown on figure 1, and the resulting limits on paleoflood discharge are tabulated in table 2. Table 2 indicates the values of the variables used in the critical-depth calculations and, for some sites, the estimated age of the bank surfaces used as the maximum limits of flood stage. At some sites, the ages of the bank surfaces were estimated on the basis of estimated ages of large trees or surface soils. These estimated ages, although highly approximate at best, provide some gross indication of the frequency of large overtopping floods. At one site on Dry Creek (site 17), the age of the bank surface could be determined fairly reliably because of the presence of undisturbed ash deposits. Based on previous age dating of ash deposits in northwestern Montana (Carrara, 1989), the ash deposit on the Dry Creek site was identified as the late Quaternary Mazama ash from about 6,800-6,900 years before present. Thus, the frequency of overtopping at this Dry Creek site is less than once every 6,800-6,900 years, indicating that floods larger than the overtopping flood are extremely rare. One other site, Post Creek above McDonald Lake (site 13), had undisturbed, fine-grained soil on the bank surface that also might be Mazama ash.

Because Dry Creek was the particular stream of interest for this study,

Late Quaternary Mazama ash about 4 inches below the surface found on the right bank of Dry Creek

Table 2. Paleoflood estimation sites for streams draining west side of Mission Range, Montana

Site number (fig. 1)	Stream	Drainage area (square miles)	Flow area (A) (square feet)	Flow width (T) (feet)	Limit of paleoflood discharge (Q) (cubic feet per second)	Estimated age of bank surface (years)
1	Mud Creek above Pablo Feeder Canal	2.34	124	35	1,300	--
2	Mud Creek above Pablo Feeder Canal	2.34	72	23	720	200
3	Mud Creek above Pablo Feeder Canal	2.34	142	31	1,700	>500
4	Mud Creek above Pablo Feeder Canal	2.34	176	35	2,200	--
5	North Crow Creek above Pablo Feeder Canal	10.6	315	85	3,400	--
6	North Crow Creek above Pablo Feeder Canal	10.6	430	127	4,500	>500
7	North Crow Creek above Pablo Feeder Canal	10.6	290	83	3,100	--
8	North Crow Creek above Pablo Feeder Canal	10.6	685	215	6,900	--
9	Lost Creek above Pablo Feeder Canal	2.77	176	35	2,200	--
10	South Crow Creek above Pablo Feeder Canal	7.53	105	30	1,100	<100
11	South Crow Creek above Pablo Feeder Canal	7.53	280	50	3,800	--
12	South Crow Creek above Pablo Feeder Canal	7.53	268	72	2,900	--
13	Post Creek above McDonald Lake	16.4	324	144	2,700	[1]6,800-6,900
14	Mission Creek above Mission Reservoir	12.3	194	53	2,100	200
15	Mission Creek above Mission Reservoir	12.3	237	61	[2]2,800	--
16	Mission Creek above Mission Reservoir	12.3	490	83	6,800	--
17	Dry Creek above St. Mary Lake	3.95	174	88	1,400	[1]6,800-6,900
18	Dry Creek above St. Mary Lake	4.54	314	41	[3]4,900	--
19	Dry Creek above St. Mary Lake	4.54	173	41	2,000	--
20	Dry Creek above St. Mary Lake	4.54	190	50	2,100	--
21	Dry Creek above St. Mary Lake	4.54	204	36	2,800	--
22	Dry Creek above St. Mary Lake	4.54	173	74	1,500	100
23	Dry Creek above St. Mary Lake	4.54	164	31	2,100	100
24	Dry Creek above St. Mary Lake	4.54	330	66	4,200	--
25	Dry Creek above St. Mary Lake	4.54	150	25	2,100	--
26	Dry Creek above St. Mary Lake	4.54	380	81	4,700	--
27	Dry Creek below St. Mary Lake	8.74	180	45	2,000	--
28	Dry Creek below St. Mary Lake	8.74	204	60	2,100	--
29	Power Creek near mouth	1.31	47	24	370	--
30	Power Creek near mouth	1.31	41	28	280	--
31	Unnamed Dry Creek tributary above unnamed reservoir	2.16	40	65	180	--
32	Unnamed Dry Creek tributary below unnamed reservoir	2.85	21	21	120	--
33	Cold Creek near mouth	4.07	21	14	150	100
34	Sabine Creek near St. Ignatius	1.73	100	100	570	--
35	Middle Fork Jocko River near Arlee	25.7	380	90	4,400	--

[1]Age estimated from possible late Quaternary Mazama ash sample.
[2]Includes overbank flow estimated at 130 cubic feet per second.
[3]Large discharge estimate may reflect channel degradation.

several estimates of the limits of paleoflood discharge were made above St. Mary Lake, and two estimates were made below St. Mary Lake. The estimates below St. Mary Lake were just downstream from Tabor Dam, where the drainage area for Dry Creek was the same as for Dry Creek at Tabor Dam. Multiple estimates were made at several other streams as well. The multiple estimates sometimes varied widely, largely due to the variable channel geometry at sites where maximum limits of flood stage could be identified. For example, the estimated overtopping flood discharge might be relatively small for banks that were only a foot or two above the present water surface. Conversely, the estimated overtopping flood discharge might be relatively large where the bank surface was a terrace several feet above the present water surface. The estimated ages of the bank surfaces also varied widely; but surfaces that were higher, relative to the present water surface, tended to have larger trees and thicker, well-formed, undisturbed soils than bank surfaces that were lower.

The stream cross section for the Dry Creek site (site 17) having undisturbed Mazama ash on the bank surface is shown in figure 4. The limit of paleoflood discharge for site 17--1,400 cubic feet per second--is considered to be the best single estimate for the study area because the maximum limit of flood stage was readily identifiable and reliably age dated, and the bedrock-controlled channel geometry was considered to be stable over time.

Rainfall-Runoff Modeling

Rainfall-runoff modeling based on precipitation events with large recurrence intervals offers an independent means for estimating low-frequency flood magnitude. A recent report by Parrett (1997) described methods for estimating rainfall depths for 2-, 6-, or 24-hour duration rainstorms having recurrence intervals up to 5,000 years. The method is based on application of the Generalized Extreme Value (GEV) probability distribution to pooled dimensionless rainfall-depth data for three regions in Montana. Within each region, the estimated equivalent record length of the pooled data ranged from 660 to 4,900 years. Equivalent record length is significantly shorter than total station years of pooled data because of the effects of interstation correlation. At-site storm rainfall depths for various nonexceedance probabilities (quantiles) are calculated from the dimensionless data as follows:

$$Q_i(F) = \mu_i q(F) \qquad (2)$$

where

$Q_i(F)$ is the quantile of nonexceedance probability F at site i,

μ_i is the mean storm rainfall depth at site i, and

$q(F)$ is the dimensionless regional quantile of non-exceedance probability F.

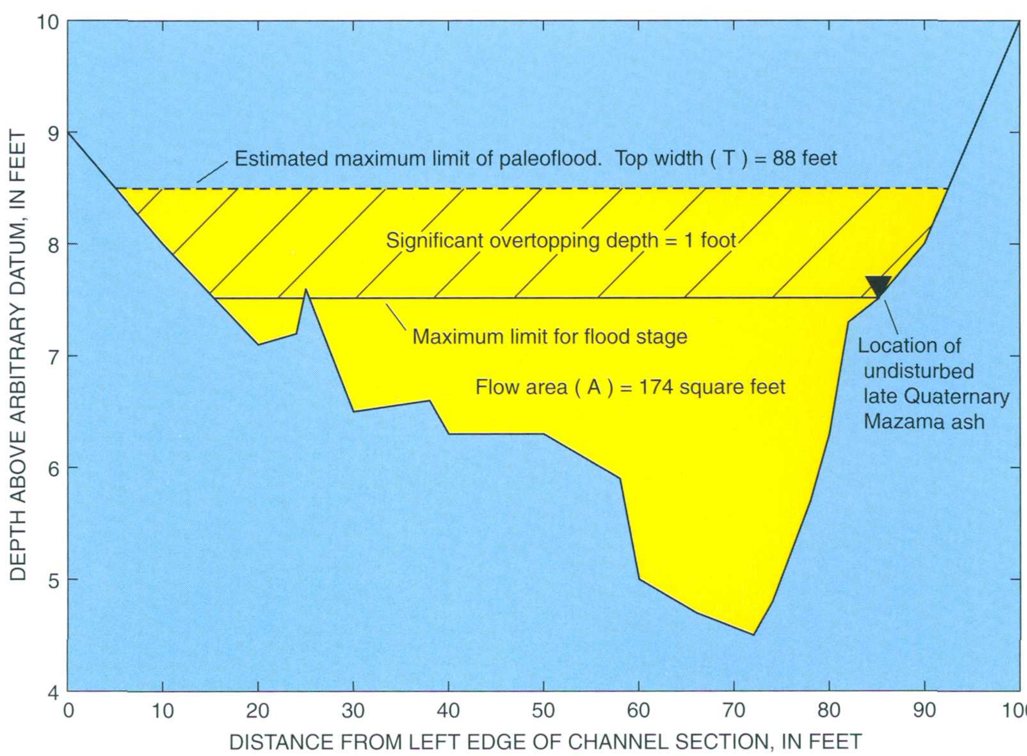


Figure 4. Channel geometry of Dry Creek above St. Mary Lake at paleoflood estimation site 17, Montana.

The dimensionless regional quantiles are calculated from the GEV distribution as follows:

$$q(F) = \xi + \alpha(\{1-(-\log F)^{\kappa}\}/\kappa), \quad (3)$$

where

ξ, α, and κ are GEV distribution parameters that vary by region and by storm duration.

Equation 3 was used to calculate dimensionless storm rainfall depths for two 2-hour duration storms in the region that includes the Mission Range study area. One depth was calculated for a recurrence interval of 500 years (non-exceedance probability = 0.998) so that the rainfall-runoff model could be calibrated to match the upper bound of 500-year flood discharge for Dry Creek at Tabor Dam determined from the regional regression equation (760 cubic feet per second) developed by Omang (1992). The second depth was calculated for a recurrence interval of 5,000 years (non-exceedance probability = 0.9998), the largest recurrence interval for which the method for storm-rainfall-depth estimation is considered to provide reliable results (Parrett, 1997). The 2-hour duration storm, rather than the 6- or 24-hour duration storm, was used for rainfall-runoff modeling because the 2-hour duration was considered to be more applicable to a small drainage basin (Parrett, 1997) such as Dry Creek at Tabor Dam than the longer duration storms. The resultant 2-hour duration dimensionless rainfall depths for a 500-year and a 5,000-year recurrence interval storm were 3.54 and 5.47, respectively.

Storm rainfall depth expressed in inches is calculated from equation 2 by multiplying dimensionless storm rainfall depth by the mean value of annual maximum 2-hour storm rainfall depth for the selected site. Mean annual maximum storm rainfall depth, in turn, is calculated from regression equations using latitude, longitude, and mean annual precipitation (Parrett, 1997). Values of mean annual maximum 2-hour storm rainfall depth were calculated for five locations evenly distributed within the Dry Creek basin above Tabor Dam and averaged to produce a basin-mean estimate of 0.584 inches.

Finally, the basin-mean storm rainfall depths for Dry Creek at Tabor Dam for a 500-year and a 5,000-year recurrence interval were calculated from equation 2 as:

$$Q_i(0.998) = \mu_i q(0.998),$$

$$Q_i(0.998) = 0.54(3.54),$$

$$Q_i(0.998) = 2.07 \text{ inches},$$

and

$$Q_i(0.9998) = \mu_i q(0.9998),$$

$$Q_i(0.9998) = 0.584(5.47)$$

$$Q_i(0.9998) = 3.19 \text{ inches}$$

A design hyetograph for each 2-hour rainstorm was developed using methods that are based on a probabilistic assessment of storm data in Montana (Parrett, 1998). Each design hyetograph was developed for a total period of storm activity of 4 hours to account for rainfall that typically occurs before and after a period of intense precipitation (Parrett, 1998, p.7, 29). The hyetographs were based on median or typical temporal distribution patterns for large storms described by Parrett (1998), and the calculated at-site rainfall depths for 5-minute time increments were adjusted to provide basin-mean values for the 8.74 square mile basin above Tabor Dam. Figure 5 shows the resultant design hyetographs for the 500-year and 5,000-year recurrence intervals for the Dry Creek basin above Tabor Dam. Total rainfall depths for the 4-hour periods

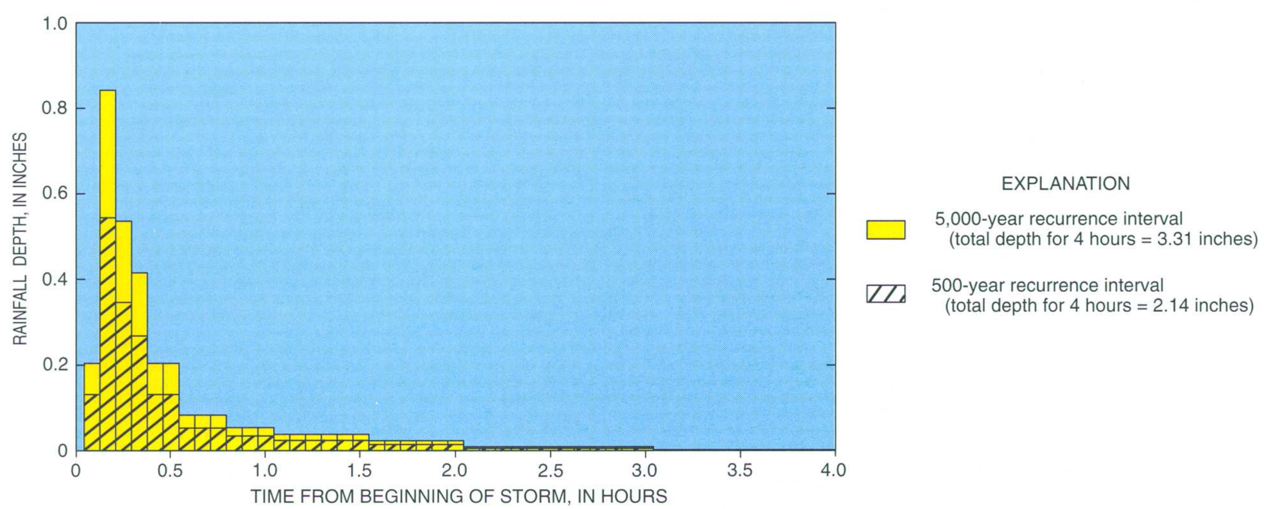


Figure 5. Storm hyetographs for the area of Dry Creek basin above Tabor Dam, Montana.

of storm activity for the 500-year and 5,000-year recurrence intervals were 2.14 and 3.31 inches, respectively.

To determine the flood peaks resulting from the storm hyetographs in figure 5, the HEC-1 rainfall/runoff model (U.S. Army Corps of Engineers, 1990) was used. This model uses one of several unit-hydrograph and infiltration-loss methods to develop a discharge hydrograph resulting from a basin-averaged rainfall input. For this analysis, the Clark unit hydrograph and the runoff Curve Number method (U.S. Army Corps of Engineers, 1990) for estimating infiltration losses were used to determine the discharge hydrographs for the Dry Creek basin above Tabor Dam.

Application of the Clark unit hydrograph requires estimates of basin time of concentration, tc, and storage coefficient, R. These values were estimated from regression equations developed for large storms in Montana (Holnbeck and Parrett, 1996) and found to be 1.2 hours and 5.7 hours, respectively. The runoff Curve Number was used as the calibration variable and was varied until the peak discharge from the model for the 500-year storm hyetograph matched the upper bound of 500-year peak discharge determined from the regional regression equation (760 cubic feet per second). The resultant runoff Curve Number of 85 is representative of a mountainous, partly forested basin having relatively low infiltration in western Montana.

The HEC-1 model with the selected values for tc, R, and runoff Curve Number was considered to be calibrated for use in modeling large-storm runoff from Dry Creek and was then used to calculate the discharge peak from the 5,000-year storm hyetograph. The resultant peak discharge from the 5,000-year storm hyetograph was 1,340 cubic feet per second. The HEC-1 model calculates runoff from the storm only and does not include stream baseflow preceding the storm. As discussed by Parrett (1998), the most likely time for a large storm to occur in the Mission Range study area is in May or June, when streamflow is already high from snowmelt runoff. For this analysis, the baseflow was presumed to be about bankfull discharge, or about 120 cubic feet per second, at the time of the 5,000-year storm. Thus, the total estimated 5,000-year peak discharge for Dry Creek basin above Tabor Dam is 1,460 cubic feet per second.

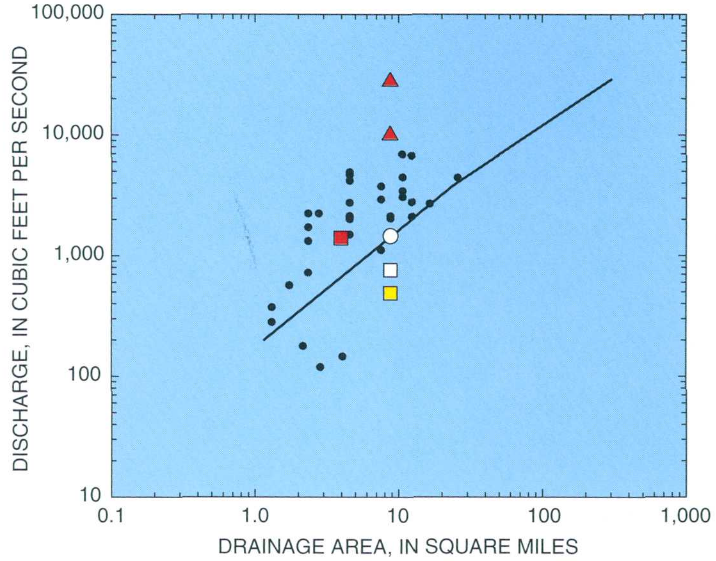
Comparison of Extreme Flood Estimates

The results from the three methods for evaluating extreme floods on Dry Creek are summarized on figure 6. The envelope line for maximum recorded floods in the West Region, two estimates of 500-year flood discharge for Dry Creek at Tabor Dam based on a regional regression equation, the estimated 5,000-year flood discharge determined for Dry Creek at Tabor Dam by rainfall-runoff modeling, and the 35 estimates of maximum limit of paleoflood discharge in the Mission Range study area are plotted on figure 6. The estimated limit of paleoflood discharge for Dry Creek at the site having the undisturbed late Quaternary Mazama ash is highlighted on figure 6, because it was considered to be the best estimate based on paleoflood methods. The best estimate for extreme flood discharge based on paleoflood methods (1,400 cubic feet per second) is remarkably close to the estimated 5,000-year flood discharge from rainfall-runoff modeling (1,460 cubic feet per second), but the drainage area for the paleoflood estimate (3.95 square miles) is less than half that for the rainfall-runoff estimate (8.74 square miles). Expressed in terms of unit discharge (discharge divided by drainage area), the best paleoflood estimate for Dry Creek (354 cubic feet per second per square mile) is larger than the 5,000-year unit discharge from rainfall-runoff modeling (167 cubic feet per second per square mile). Given that the paleoflood estimate represents a limit on extreme flooding since the time of Mazama ash deposition (about 6,800-6,900 years before present), the larger paleoflood unit discharge is not unexpected.

Figure 6 also includes two estimates of PMF for Dry Creek basin above Tabor Dam provided by the Bureau of Reclamation (Kamstra, 1998). One estimate (27,900 cubic feet per second) is based on the assumption that a thunderstorm provides the Probable Maximum Precipitation (PMP) over the basin, and the other estimate (10,000 cubic feet per second) is based on the assumption that the PMP results from an areally larger, but less intense, general storm. The depth for the thunderstorm PMP was 10.6 inches over a 6-hour duration, and the depth for the general storm PMP was 28.0 inches over a 72-hour duration. As shown on figure 6, both PMF estimates plot well above the extreme flood magnitudes estimated for Dry Creek using the three independent methods for this study.

SUMMARY

Three methods of hydrological and geological analysis to evaluate the magnitude of extreme floods in the Dry Creek basin of northwestern Montana provided mutually consistent estimates of plausible peak discharges. The first method used limited recorded flood data from within the Mission Range study area together with more extensive flood data from a larger region in western Montana. Maximum recorded discharges in the study area were within the range of maximum recorded discharges in the West Region and well below an envelope curve encompassing all



EXPLANATION

- Envelope line for maximum recorded floods in West Region (from fig. 2)
- Maximum limit of paleoflood discharge in Mission Range study area
- Maximum limit of paleoflood discharge for Dry Creek above St. Mary Lake (site 17)
- Calculated 500-year flood discharge for Dry Creek at Tabor Dam (from fig. 3)
- Calculated 500-year flood discharge for Dry Creek at Tabor Dam plus one standard error (from fig. 3)
- Estimated 5,000-year flood discharge for Dry Creek based on rainfall-runoff modeling
- Estimates for probable maximum flood (PMF) for Dry Creek (Kamstra, 1998)

Figure 6. Summary of maximum recorded and estimated flood discharges in the study area and the West Region, Montana.

maximum recorded discharges in the West Region. Calculated 500-year flood discharges for stations in the study area also were comparable to those for stations in the West Region. A regression equation developed for use in the West Region was used to calculate the 500-year flood (490 cubic feet per second) and an upper bound value for the 500-year flood (760 cubic feet per second) for Dry Creek above Tabor Dam.

The second method used paleoflood techniques to estimate maximum limits of paleoflood stage at 35 sites in the Mission Range study area. The critical-depth method was used to estimate discharge for the maximum limits for paleoflood stage. The single best estimate for the limit of paleoflood discharge (1,400 cubic feet per second) was for a site on Dry Creek above St. Mary Lake where the maximum limit of flood stage was readily identifiable and reliably age-dated, based on the presence of undisturbed Mazama ash, at about 6,800-6,900 years before present.

The third method used regional extreme precipitation data for Montana to develop a synthetic storm for the Dry Creek basin having a 5,000-year recurrence interval. The synthetic storm was used in a rainfall-runoff model to estimate a 5,000-year flood discharge for Dry Creek at Tabor Dam (1,460 cubic feet per second). Results from all three methods were significantly smaller than two previously estimated values of PMF (10,000 and 27,900 cubic feet per second).

REFERENCES

Barnes, H.H., Jr., and Davidian, Jacob, 1978, Indirect methods, *in* Hershey, R.W., ed., Hydrometry--Principles and practices: New York, Wiley, p. 149-204.

Boner, F.C., and Stermitz, Frank, 1967, Floods of June 1964 in northwestern Montana: U.S. Geological Survey Water-Supply Paper 1840-B, 242 p.

Carrara, P.E., 1989, Late Quaternary glacial and vegetative history of the Glacier National Park region, Montana: U.S. Geological Survey Bulletin 1902, 64 p.

Costa, J.E., 1986, A history of paleoflood hydrology in the United States: EOS, Transactions of the American Geophysical Union, v. 67, no. 17, p. 428-430.

Henderson, F.H., 1969, Open channel flow: New York, MacMillan Company, 108 p.

Holnbeck, S.R., and Parrett, Charles, 1996, Procedures for estimating unit hydrographs for large floods at ungaged sites in Montana: U.S. Geological Survey Water-Supply Paper 2420, 60 p.

Interagency Advisory Committee on Water Data, 1982, Guidelines for determining flood flow frequency--Bulletin 17B of the Hydrology Subcommittee: U.S. Geological Survey, Office of Water Data Coordination, 183 p.

Jarrett, R.D., 1984, Hydraulics of high-gradient streams: Journal of Hydraulic Engineering, v. 110, no. 11, Nov. 1984, p. 1519-1539.

Jarrett, R.D., 1991, Paleohydrology and its value in analyzing floods and droughts: U.S. Geological Water-Supply Paper 2375, p. 105-116.

Kamstra, L.A., 1998, Tabor Dam Montana, probable maximum flood study: Bureau of Reclamation, various paging.

Levish, D.R., Ostenaa, D.A., and O'Connell, D.R.H., 1994, A non-inundation approach to paleoflood hydrology for the event-based assessment of extreme flood hazards, *in* Association of State Dam Safety Officials, 11th Annual Conference Proceedings, Lexington, Kentucky, p. 69-82.

Lockhart, A.C., 1993, Geologic report for deficiency verification analysis, Tabor Dam, Flathead Agency irrigation division, Montana: Bureau of Reclamation, various paging.

Merritt, L.A., 1990, Montana floods and droughts, *in* National Water Summary 1988-89: U.S. Geological Survey Water-Supply Paper 2375, p. 369-376.

National Research Council, 1988, Estimating probabilities of extreme floods, methods and recommended research: Committee on Techniques for Estimating Probabilities of Extreme Floods, Water Science and Technology Board, National Research Council, National Academy Press, 141 p.

Omang, R.J., 1992, Analysis of the magnitude and frequency of floods and the peak-flow gaging network in Montana: U.S. Geological Survey Water-Resources Investigations Report 92-4048, 70 p.

Ostenaa, D.A., Levish, D.R., and O'Connell, D.R.H., 1996, Paleoflood study for Bradbury Dam, Cachuma Project, California: Seismotectonic Report 96-3, Bureau of Reclamation, various paging.

Ostenaa, D.A., Levish, D.R., O'Connell, D.R.H., and Cohen, E.A., 1997, Paleoflood study for Causey and Pineview Dams, Weber Basin and Ogden River Projects, Utah: Seismotectonic Report 96-6, Bureau of Reclamation, various paging.

Parrett, Charles, 1997, Regional analysis of annual precipitation maxima in Montana: U.S. Geological Survey Water-Resources Investigations Report 97-4004, 51 p.

Parrett, Charles, 1998, Characteristics of extreme storms in Montana and methods for constructing synthetic storm hyetographs: U.S. Geological Survey Water-Resources Investigations Report 98-4100, 55 p.

U.S. Army Corps of Engineers, 1990, HEC-1 flood hydrograph package, user's manual: Davis, California, Hydrologic Engineering Center, 283 p.

Looking west at St. Mary Lake and Tabor Dam from Dry Creek above St. Mary Lake.

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