Historic Floods in the Eastern Sierra Nevada

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Abstract. A preliminary flood history of the eastern Sierra Nevada was compiled from historic accounts, newspaper articles, and records of streamflow from five tributaries to the Owens River. In these streams, floods with an average frequency of recurrence of twenty-five to fifty years are about two to three times greater than the mean annual flood. Snowmelt floods are the principal hydrologic event each year with moderately high water for several weeks, although they rarely attain damaging levels. Midwinter rainfall is much less of a hazard on the eastern slope than on the western slope of the Sierra Nevada, but these rain-on-snow events still have potential for catastrophic flooding, as occurred in 1862. Summer thunderstorms have caused the greatest floods and damage in the eastern Sierra Nevada. Sudden releases of water from lakes have also caused localized damage. One-third to one-half of both the largest and smallest floods of the past 60 to 70 years have occurred since 1976, suggesting a recent tendency toward hydrologic extremes.

INTRODUCTION

Water has obviously played a critical, and commonly dominant, role in the history of the eastern Sierra Nevada. Conflicts and controversies about the relative scarcity of water in this region have been described in dozens of books and hundreds of articles. However, little attention has been given to the occasional periods of excessive water in the eastern Sierra Nevada. Overabundance of water in the form of floods has also influenced the region’s history. For example, the most violent “water war” in the Owens Valley seems not to have been over the Alabama Gates but rather between native tribes and early white settlers in desperate conditions during the floods of 1862. However, unlike persistent scarcity relative to demand, floods tend to be forgotten quickly, perhaps somewhat intentionally. This paper recalls some of the major floods of the past century, their causes and consequences.

The geographic area considered here is mainly the western half of the drainage basin of the Owens River. Tributaries in this catchment drain the eastern
slope of the Sierra Nevada from Olancha to Mammoth Lakes. Some additional information was obtained from the Mono Lake and Walker River basins. Most of the runoff-producing zone of the eastern Sierra Nevada lies between 2,000 and 3,500 m (6,500 to 12,000 ft), although elevations range from 1,100 to 4,420 m (3,600 to 14,495 ft). Streams in the mountain area tend to have very steep gradients (0.05 to 0.3 m per m) and little storage capacity in their channels. The portions of catchments in mountains also have relatively small subsurface storage capacity because bedrock is commonly exposed and soils and other unconsolidated deposits are thin. However, below the mountain front, the streams interchange water with the subsurface flow system of their alluvial fans [Lee, 1912; Kondolf, 1989]. Flood waves originating in the mountains also become attenuated downstream [McGlashan and Dean, 1913]. For example, during the period of coincident record (1927 to 1940) on Rock Creek, flood peaks decreased by 10 to 30 percent (average 20 percent) between the gauge at Little Round Valley (93 km²; 2,270 m [36 mi²; 7,450 ft]) and the gauge at Sherwin Hill (134 km², 1,500 m [52 mi²; 4,900 ft]).

The hydrology of the region is controlled by the accumulation of snow cover from November through April and snowmelt from April through July or August. Precipitation in summer and autumn is generally limited to infrequent, isolated convective showers. The eastern slope of the Sierra Nevada receives much less precipitation than the western slope [Rantz, 1969]. East-side basins also receive a higher proportion of precipitation as snowfall than the main river basins west of the crest because of the greater proportion of catchment area at higher elevations on the eastern slope.

This examination of the flood history of the eastern Sierra Nevada relied on both anecdotal information and systematic records of streamflow. A variety of books and articles on the general history on the Inyo-Mono area provided brief descriptions of some of the major flood events [e.g., Chalfant, 1933]. Newspapers beginning in the 1880s provided additional details of the impacts of floods on the inhabitants of the region. Uncited historical material was found in the Inyo Register, Inyo Independent, and/or Sierra Daily News.

Systematic discharge records began in 1903 on five streams in the Owens Valley [McGlashan and Dean, 1913]. With growth of hydroelectric and water export operations, the system of stream gauges has greatly expanded so that today the eastern Sierra Nevada probably has the densest network of hydrometric stations of any mountain area in the world. However, flow records from only a few of these stations have been published semi-continuously. Examination of the frequency and magnitude of floods presented here was based largely on data from Convict, Rock, Pine, Big Pine, and Independence creeks, which have all been gauged since the 1920s.
THE OWENS RIVER

As the focus of water issues in the eastern Sierra Nevada, the Owens River is used here to introduce the flood history of the region. It has been gauged at several points since early in this century, but data from the Owens become less useful for flood interpretation after 1940 with completion of the Mono Craters Tunnel and Long Valley Dam. When the Los Angeles Aqueduct was being built, flood hazard was considered to be relatively low [City of Los Angeles, 1916: p. 111]: “As the Owens River is a stream that is fed by the melting snow in the mountains, rather than immediately by the rains, it is not subject to such violent floods as are characteristic of many other streams in the West.” However, floods have been sufficiently violent to have severely damaged the aqueduct within the Owens Valley on at least four occasions: January 1943, October 1945, December 1966, and August 1989. Although the Owens River is not subject to flash floods, as are desert rivers such as the Amargosa, it has had four peak flows exceeding twice the mean annual-flood measured at the gauge near Big Pine since 1906. This number of large-magnitude events, as an index of flood activity, equals the average for streams of the western slope of the Sierra Nevada [Kattelmann, et al., 1991].

In a catchment as large (1,100 km² [425 mi²] at Round Valley, 5,120 km² [1975 mi²] at Big Pine) and diverse (wet alpine to arid lowlands) as that of the Owens River, flood peaks are influenced by the relative timing of peaks in the tributary streams and spatial distribution of the runoff as well as the total volume of flow entering the river system. Therefore, the largest peak flows at one point on the river do not necessarily coincide with those elsewhere on the river. For example, the largest flood of record at the Round Valley and Pleasant Valley gauges, which occurred on December 12, 1937, was diluted to a relatively average event by the time it reached the gauges near Big Pine and Lone Pine. At the Big Pine gauge, the largest flood of each year was generated by winter rain storms in about 45 percent of the years of record, by snowmelt runoff about 30 percent of the time, and by summer thunderstorms in the other quarter of cases. The generation of floods by those and other causes is perhaps better examined on streams tributary to the Owens River that have more homogeneous catchments of less than 100 km² (39 mi²) in area. The remainder of this paper describes historic floods of the eastern Sierra Nevada categorized by primary cause.

SNOWMELT FLOODS

Because snow dominates the hydrology of the higher elevation portion of the Sierra Nevada, snowmelt is the most obvious mechanism of flood generation. The 0.5 to 1 m (1.5 to 3 ft) of snowpack water equivalence at maximum accumulation along the eastern slope represents a huge store of potential runoff. Each spring, melting of the winter’s snowcover produces a snowmelt flood in the area’s streams. High
discharges last for several weeks and result in 70 to 80 percent of the annual runoff within a three to four month-long period. Although snowmelt floods rarely produce the highest instantaneous discharges in the eastern Sierra Nevada, they may approach the peak flows generated by rain events and maintain such levels for several days to a couple of weeks. Before the tropical storms of 1978 to 1982, snowmelt runoff in 1969 had caused the greatest instantaneous discharges on record in several east-side streams. Production of snowmelt runoff from a catchment depends on the spatial distribution of both snow and energy available for melt. At the peak of accumulation, snowpack water equivalence is highly variable from high to low elevation and across different slopes and aspects [Elder, et al., 1991]. In addition, snowmelt at the highest elevations and in shaded locations may begin weeks later and melt more slowly than on low-elevation slopes exposed to sunlight. These differences in snow storage and energy input distribute the release of melt water to streams over time, particularly when snow disappears from south-facing slopes before the peak of melt rates on north-facing slopes. This lack of synchronization between contributions of snowmelt runoff from different parts of a basin tends to suppress peak streamflow during spring.

The highest instantaneous discharges occur when several conditions coincide: solar radiation, wind speed, and humidity are all high; snow albedo and nighttime energy loss from the snowpack are low; and snow cover is almost continuous with some of it thin enough to allow radiation penetration to the ground [Kattelmann, 1991]. When snow accumulation continues into spring and melt is delayed, water is contributed from most of the elevation range of a catchment simultaneously under relatively high melt rates that result from increased sun angle in late spring. Such conditions produce the highest peak flows during snowmelt. These peaks average between 0.1 and 0.2 m$^3$s$^{-1}$km$^{-2}$ for east-side basins between 45 and 100 km$^2$ in area. These specific discharges during spring snowmelt are much lower than those for streams on the western slope (0.25 to 0.8 m$^3$s$^{-1}$km$^{-2}$) [Kattelmann, 1991] where elevations are lower and the snowpack energy balance is more positive. However, relative to the mean annual flood in each stream, snowmelt runoff produces more extreme events east of the crest than west of it. On the eastern slope, there have been at least three snowmelt floods greater than twice the mean annual flood over the period of record. On the west side, no peak discharge during the snowmelt season has exceeded this index of a large-magnitude event. This discrepancy appears to be related to the much larger floods produced on the western slope by mid-winter rain-on-snow events. In a decreasing ranking averaged across five east-side streams, snowmelt peak discharges were greatest in 1969, 1967, 1982, 1986, 1963, 1932, 1938, 1983, and 1980. These years generally corresponded with the years of greatest volume of snowmelt runoff. Cool, cloudy weather in June of 1969, 1980, and 1983 reduced flood peaks below what might have otherwise occurred.
During the snowmelt season, the volume of runoff may be a greater hazard to human activities and structures than the highest instantaneous water levels. For example, sustained high water undermined roadways along the Walker River and Big Pine Creek in the spring of 1983. The few reservoirs at high elevation on Bishop, Mammoth, Rush and Lee Vining creeks must spill water under exceptional runoff. Low-gradient channels in areas such as Bishop may be unable to convey enough water to avoid overbank flows during snowmelt runoff. Estimates of potential snowmelt runoff from snow surveys permit preparation for high-water weeks in advance. Channels can be cleaned out or even constructed, as in 1969 when the U.S. Army Corps of Engineers removed several bridges and dug a channel across State Route 168 in Bishop. Snowmelt runoff was more than 50 percent greater than the mean May-through-August volume in most east-side streams during 1969, 1938, 1983, 1986, 1980, 1982, 1967, and 1978 (in order of decreasing volume averaged for five streams). A positive aspect of above-average volumes has been the augmentation of Mono Lake when capabilities for diversion out of the Mono Lake/Owens River system have been exceeded.

The likelihood of occurrence of different volumes of snowmelt runoff can be estimated by fitting a probability distribution to historic runoff data. The statistical characterization of floods typically employs the concept of a recurrence interval, which is the average time between events of a given or larger magnitude. It means that over long periods of time floods of some size recur, on the average, with a certain frequency. Frequency analysis is usually applied to instantaneous peak discharges, but was also found to be useful here for May through August volumes. The Gumbel extreme-value distribution was used here instead of other possible distributions because of its wide applicability to a range of geophysical phenomena and its ease of calculation. This two-parameter distribution requires only the sample mean and standard deviation (SD) from a series of observed floods (more than 65 years for these streams). The Gumbel distribution is given by the equation:

\[ F(X < x) = \exp \left\{ -\exp \left[ -a \ (x - B) \right] \right\} \].

Its parameters can be estimated using the method of moments [Lowery and Nash, 1970]:

\[ a = 1.281 / SD \]
\[ B = \text{Mean} - 0.45 \ SD \]

where \( x \) is an annual flood peak and \( F(X < X) \) is the probability that \( x \) will be equalled or exceeded in any year. The recurrence interval equals \( 1 / [ F(X < x)] \). In practice, the above equation was inverted, and \( x \) was calculated for exceedence probabilities equivalent to recurrence intervals of 2.33, 5, 10, 25, and 50 years (where \( F(X < x) \) equals 0.43 [mean annual
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<table>
<thead>
<tr>
<th>Table 1. Estimated snowmelt runoff for selected recurrence intervals (RI).</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>RI</strong></td>
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<tr>
<td>-------</td>
</tr>
<tr>
<td>2.33</td>
</tr>
<tr>
<td>5</td>
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<tr>
<td>10</td>
</tr>
<tr>
<td>25</td>
</tr>
<tr>
<td>50</td>
</tr>
</tbody>
</table>

May through August streamflow (mm)

The equation

\[ x = \left( \ln \left( -\ln F(X < x) \right) \right) / -a + B \]

was used to generate Table 1. From this table, for the areas defined by their gaging stations, Convict Creek and Pine Creek produce substantially greater volumes of snowmelt runoff than the other streams under both average and extreme conditions. In these streams, an event of 25-year recurrence produces about twice the volume of the mean annual snowmelt flood.

**WINTER RAIN FLOODS**

Warm storms in winter have not produced the same degree of flooding in the high-elevation catchments of the eastern Sierra Nevada that such storms have caused on the western slope. Rain-on-snow events east of the crest have relatively low rainfall intensity because of the rain-shadow effect. Also, much smaller proportions of each catchment on the eastern slope are below typical rain-snow transition altitudes (1,500 to 2,300 m [5,000 to 6,000 ft]) compared to their west-side counterparts. Nevertheless, winter rain storms have caused substantial flooding in the Owens Valley and in the northern basins of the Walker, Carson, and Truckee rivers. The greatest flood during the historical period of the eastern Sierra Nevada was described by early settlers in 1861 and 1862. Rain and snow alternated on the floor of the Owens Valley with some precipitation every day from late December 1861 through mid-February 1862. The Owens River was estimated to be one-fourth to one-half mile (400 to 800 m) wide and Owens Lake rose 3 to 4 m (10 to 13 ft) during that winter. People were killed by flood waters in Bodie Creek, and the inundation of the Owens Valley led to violent conflicts over food between Indians and white ranchers [Chalfant, 1933; DeDecker, 1966]. Other floods of the late 19th century included December 1867 to January 1868 when more than 400 mm (16 in) of rain was measured in Bishop and January 1890 when bridges and railroad tracks were washed out and Main Street in Bishop was described as a lake.
The Owens Valley suffered two floods in January 1914. The first event left water in Bishop streets “several feet deep” (Figure 1) and almost every house in Bishop was damaged [Inyo Independent, 1914]. One week later, a more intense storm hit the area, but it caused the worst damage in Big Pine where roads were deeply eroded, water mains broken, and bridges washed away. Although the Owens River carried record amounts of water during the December 1937 storm that caused extensive damage on the western slope, Owens Valley roads and towns escaped without serious problems. The eastern Sierra Nevada had high water but suffered relatively little damage during other famous floods of rivers tributary to the Central Valley: February 1938, January 1943, November 1950, January 1952, December 1955, February 1963, December 1964, December 1966, January 1969, January 1980, April 1982, and February 1986. Most of these storms had relatively high freezing levels but still deposited only a few tens of millimeters of rainfall in the lowest elevation portions of the east-side mountain catchments. Streamflow at least doubled in response to most of these storms and may have had enhanced erosive power because of snow and ice creating narrower than normal channels [Erman, et al., 1988]. However, winter streamflow peaks in the five streams studied were almost always less than 3 m$^3$s$^{-1}$, hardly a flood. Such peak flows were only an annual maximum in a few cases by default when snowmelt runoff was quite small. Based on the period of record, a winter storm with potential for overbank flows has occurred in about one of four years, on the average. These events were not ranked regionally because of their different effects in different streams. Farther north in the

Figure 1. High water in Bishop, January 25, 1914. Photo courtesy of County of Inyo, Eastern California Museum.
Walker River drainage, the greatest floods of record in 6 streams were caused by the rain-on-snow events of December 1955 and February 1963. The worst damage in the past few decades from winter floods in the southern basins of the eastern Sierra Nevada probably occurred in November and December 1950 when almost 1 km (0.6 mi) of U.S. Highway 395 was washed out in the Walker River canyon and other roads were damaged in Pine Creek canyon and Round Valley. The storm of December 1966 caused extensive damage to roads all along the eastern slope as well as to the Los Angeles Aqueduct near Lone Pine [Waananen, 1971]. The storm of April 11 to 13, 1982 was unusually warm (rain above 3,000 m [10,000 ft]) and late in the season. Most of the damage from this rain-on-snow event occurred at relatively high elevations: Mammoth Lakes, Rock Creek, and Aspen Springs. A more limited event of this nature occurred in early March 1991.

SUMMER AND AUTUMN FLOODS

When subtropical air masses move into the Sierra Nevada in summer and early autumn, sufficient moisture is available to generate extreme rainfall. Under thunderstorm conditions in the Great Basin, intense rainfall is generally limited to small, isolated areas of a few square kilometers in extent and short durations [Butler, et al., 1966]. Along the eastern slope of the Sierra Nevada, peak flows in summer can be generated by both short, high-intensity cloudbursts and intermittent showers over several hours to a couple of days. Widespread summer flooding had been rare in the eastern Sierra Nevada until the 1970s, when serious floods occurred in many of the region’s streams from 1972 to 1985.

The first account found of flood damage during summer was the destruction of the Silver Spout mine on Kearsarge Peak by a cloudburst flood in the early 1900s [DeDecker, 1966]. Flash floods and debris flows in October 1945 damaged roads and the Los Angeles Aqueduct in several places. Lee Vining and the Tioga Pass road suffered from flash floods in late July of 1952 and 1955. Runoff from thunderstorms in late July 1956 raised Crowley Lake to capacity, halting diversion of water from the Mono Basin. A cloudburst flood in June 1963 closed the mine and mill in Pine Creek canyon.

The recent sequence of regional flooding in late summer began on September 5, 1972. The next event, September 11, 1976, generated high flows primarily in the southern streams. In early September 1978, a tropical storm caused widespread damage to roads and bridges and resulted in several deaths among backcountry hikers. The greatest recorded floods in several east-side streams occurred in late September 1982 when 150 to 200 mm (6 to 8 in) of rain fell in two days. Flooding would have been worse if the snow level had not lowered during the storm. Some 38 homes were damaged on the Big Pine Indian Reservation, and more than 40 homes were damaged elsewhere. Bridges were washed out...
on the Glacier Lodge/Big Pine Creek road and Pine Creek road. The Inyo County Public Works Department estimated the flooding caused more than seven million dollars of damage throughout the county. Additional floods occurred on August 10, 1983; July 19, 1984; August 18, 1984; and July 20, 1985. The most recent summer flood occurred in August 1989 when Olancha Creek deposited sediment and debris on roads, and in homes and the aqueduct. This same storm caused extensive damage in Benton, Hammil Valley, and Chalfant Valley. Based on the flood record of the past two decades, serious summer floods appear to recur somewhere in the Owens Valley at a frequency of about every two years, on the average. The frequency in any individual stream is much less, i.e., about one in five years.

OUTBURST FLOODS

Major floods in the eastern Sierra Nevada have been caused or augmented by mechanisms other than snowmelt or rainfall. These floods are generated by the sudden release of water from storage. The failure of natural or man-made dams is the most obvious cause of such floods. Although this type of flood is of limited areal extent, it may produce flood peaks several times higher than those caused by any other process. Because such floods are generated at a point, generally in the absence of other inputs to streamflow, the flood wave is rapidly attenuated downstream.

The occurrence of outburst floods in east-side streams may be illustrated by a few documented examples from Bishop Creek. In June of 1909, a flow-equalizing dam of the Nevada-California Power Company at Bishop Park failed under excessive releases from Lake Sabrina. The flood wave damaged Hydroelectric Plant No. 4 and bridges downstream. In March 1952, a snow avalanche briefly dammed Bishop Creek until the snow failed, releasing a small flood. Avalanche dams probably form and fail rather frequently in the High Sierra but are rarely observed. The second-largest flow recorded in Bishop Creek occurred during the September 1978 flood when a log-and-debris jam impounding some of the flood waters suddenly broke free. Failure of the North Lake dam during the storm of September 26, 1982 caused the largest flood measured in Bishop Creek. Fortunately, the 8,000 m$^3$ (300,000 ft$^3$) of water behind the dam was released rather slowly by gradual erosion of the dam over a few minutes rather than in a catastrophic failure. The flood wave was greatly attenuated by the time it reached Bishop three hours later. However, the flood virtually destroyed Hydroelectric Plant No. 4.

Lake water can also enter stream channels suddenly by displacement from avalanches. Impact of a large avalanche on to the ice cover of a lake can force substantial volumes of water into the outlet channel. These avalanche-induced floods are the only means of generating high flow immediately downstream of lakes with stable outlets, which otherwise attenuate floods. After the avalanche cycle of April 1982, the ice cover of
3.3—HISTORIC FLOODS IN THE EASTERN SIERRA NEVADA

### Table 2

<table>
<thead>
<tr>
<th>RI</th>
<th>Convict</th>
<th>Rock</th>
<th>Pine</th>
<th>Big Pine</th>
<th>Independence</th>
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<td>7.5</td>
<td>8.6</td>
<td>13.9</td>
<td>12.4</td>
<td>4.2</td>
</tr>
</tbody>
</table>

Table 2. Estimated peak discharges for selected recurrence intervals (RI).

A couple of the Virginia Lakes was piled to several meters depth on the shore near the lake outlet. Evidence of lake displacement by avalanches in February 1986 was also noted in the Bishop Creek and Rock Creek basins by Williams and Clow [1990].

**FREQUENCY OF PEAK STREAMFLOW**

The magnitude of peak discharges corresponding to different recurrence intervals can be estimated by fitting a frequency distribution to the observed series of annual floods. These floods were generated by a mixture of causes described above. Although separation of the set of floods by type should improve the fit of the distribution, this distinction is rarely made in practice [Woo and Waylen, 1984], and the separation by cause is not yet complete for the streams of the eastern Sierra Nevada. Our frequency analyses used the Gumbel distribution described above and the set of annual floods through 1990 for five streams (Table 2).

Similar analyses were done by the Geological Survey with data through 1964 [Butler, et al., 1966] and 1975 [Waananen and Crippen, 1977]. The new data used here includes several of the largest ten floods for the period of record. The addition of several extreme values in a short part of the total record length has altered the shape of the distributions. Butler et al. [1966] reported ratios of floods at different recurrence intervals to the mean annual flood (recurrence interval of 2.33 years) and noted that the ratios for the Sierra Nevada increase with duration of the recurrence interval much more slowly than in other parts of the Great Basin. Twenty-five years of additional data shows that these ratios increase at an even slower rate than originally thought. For example, the latest data set shows that floods of a fifty-year recurrence interval are only about 2.4 times greater than the mean annual flood, on the average. Similarly, the occurrence of several “five- to ten-year floods” in the past decade has lowered the expected magnitude of floods of longer recurrence interval compared to the study of Waananen and Crippen [1977].
TRENDS IN THE FLOOD SERIES

Although the period of record of measured streamflow in principal tributaries to the Owens River is too short (less than 70 years) to suggest any definite trends over time, a cluster of comparatively-extreme events is present in recent years. Five of the largest eight to eleven snowmelt floods (in terms of volume) since the 1920s occurred from 1978 to 1986 (Figure 2). Five of the smallest thirteen or fourteen snowmelt floods have occurred from 1987 to 1991. Instantaneous peak flows have a similar distribution. For example, in Rock Creek, four of the ten largest annual
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floods and three of the six smallest annual floods occurred during the 1980s. These events support theories of some climatologists that extreme events are becoming more common in North America (because of an observed shift in hemispheric flow patterns).

SUMMARY

Flooding in streams of the eastern Sierra Nevada are produced by a variety of mechanisms. Snowmelt floods on the eastern slope have much smaller volumes and consistently lower peak flows than their west-side counterparts. East-side snowmelt floods with a 25-year recurrence interval produce about twice as much runoff from May through August as the mean annual flood. Midwinter rain-on-snow events have generated only minor peak flows in east-side streams south of Conway Summit but still constitute a hazard to roadways near stream channels. Thunderstorms in summer and early autumn have caused the greatest floods and damage in the eastern Sierra Nevada and are relatively common occurrences. Large outbursts from impoundments have been rare in this century, but can be devastating close to their source. Floods of long recurrence interval are only two to three times greater than the mean annual flood in streams of the eastern Sierra Nevada. A disproportionately number of the greatest and smallest floods of record have occurred in the past two decades.

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