

Review of the Gladstone, Colorado, Rainfall Observation, October 5, 1911, and its Impact on Site-Specific Probable Maximum Precipitation (PMP) Values

Ed Tomlinson, PhD
Applied Weather Associates, LLC
Monument, Co

Tye Parzybok
Metstat, Inc
Windsor, Co

Introduction

The October 4-6, 1911, rainstorm over the southwestern US produced large rainfall amounts and significant flooding. The eight inch daily rainfall total reported on October 5 is an extreme amount for the Gladstone elevation of 10,400 feet. The reliability of the reported rainfall observation has been questioned by many investigators but, lacking definitive evidence that the observation was unreliable, it remained in the data base.

Applied Weather Associates (AWA) conducted several site-specific Probable Maximum Precipitation (PMP) studies for basins in western Colorado where the Gladstone observation had a dominate impact. However, lacking evidence that the Gladstone observation was erroneous, it was used in the studies. AWA became aware of a thesis produced at Colorado State University (CSU) that investigated paleoflood flood evidence in the Cement Creek drainage basin where Gladstone is located. The thesis concluded that a relatively large but not catastrophic flood had occurred in the drainage basin.

A hydrologic run-off modeling effort was initiated to simulate the flood that would have been produced in the Cement Creek basin had the reported daily rainfall of eight inches occurred. The results of the modeling effort and comparison with the computed flows based on the paleoflood evidence showed a factor of 16 difference. Considering potential errors associated with both the paleoflood flow estimations and the run-off modeling, an order of magnitude difference remained.

Based on this analysis and comparison, it was recommended that the Gladstone observation be considered erroneous and a recommendation was made that the observation not be used in future hydrologic studies. The Colorado State Engineer Office has concurred with the recommendation. The impact of removing the Gladstone observation from the rainfall data base is approximately a 35% decrease in site-specific PMP values for western Colorado. This impact would also apply to regions of southeastern Utah, northern New Mexico and northern Arizona.

The Storm

The October 4-6, 1911, rainstorm over the southwestern US produced large rainfall amounts and significant flooding. A mid-latitude low pressure center and associated cold and warm fronts combined with moisture from an eastern Pacific Ocean tropical storm to produce this extreme rainfall event (Hansen and Schwarz, 1981). Between October 4-6, 1911, the dissipating tropical storm moved northward from the tip of Baja California over western Arizona

and then, after combining with an extra-tropical low pressure system, tracked northeastward through central Colorado to central Iowa.

Southwestern Colorado received relatively large amounts of rainfall during this October event. Most of the precipitation fell as rain instead of the snowfall usually expected with October storms at high elevations (Crow, 1992). Two to four inches of rain were observed at many locations, several at high elevations, in Arizona, Utah, Colorado and New Mexico. Exceptions to the widespread rainfall observation amounts in the two to four inch range were a few relatively low rainfall storm totals, and the very large rainfall daily total reported at Gladstone, Colorado on October 5, 1911.

Rainfall Observations

Rainfall began over the Four Corners region during the afternoon and evening hours of October 4th. After the two systems merged during the night, the low pressure center accelerated to the northeast, producing continuous rainfall both north and south of the storm track. Southwestern Colorado was under strong southerly surface wind flow during this time with a warm front moving northward, spreading rainfall ahead of the front. The rainfall was enhanced over the southern slopes of the southwestern Colorado mountains with rainshadow effects north of mountain ridges (Hansen and Schwarz, 1981).

Only a few stations reported rainfall totals greater than four inches. Each of these stations was either along or south of the storm track and had a river or creek valley to the south where limited moisture advection could occur, e.g. Silverton and Cumbres, Colorado. The following stations reported rainfall totals greater than 3.4 inches:

Table 1. Stations reporting rainfall totals more than 3.4 inches during October 4-6, 1911

Name	Location	Rainfall	Elevation
Gladstone, CO	37.9N, 107.7W	8.15"	10,800 ft
Harveys Ranch, NM	35.8N, 105.5W	5.07"	9,400 ft
Cumbres, CO	37.0N, 106.5W	4.83"	10,000 ft
Alamos Ranch, NM	35.9N, 106.4W	4.59"	8,600 ft
Monticello, UT	37.9N, 109.3W	4.42"	7,000 ft
Silverton, CO	37.8N, 107.7W	4.23"	9,300 ft
Olathe, CO	38.6N, 108.0W	3.98"	5,400 ft
Uncompahgre, CO	38.4N, 108.2W*	3.98"	6,200 ft
Pagosa Springs, CO	37.3N, 107.0W	3.81"	7,400 ft
Wagon Wheel, CO	37.8N, 106.8W*	3.61"	8,800 ft
Terminal Dam, CO	37.6N, 107.8W	3.52"	8,400 ft
Durango, CO	37.4N, 107.9W	3.41"	6,500 ft

*coordinates do not match name location

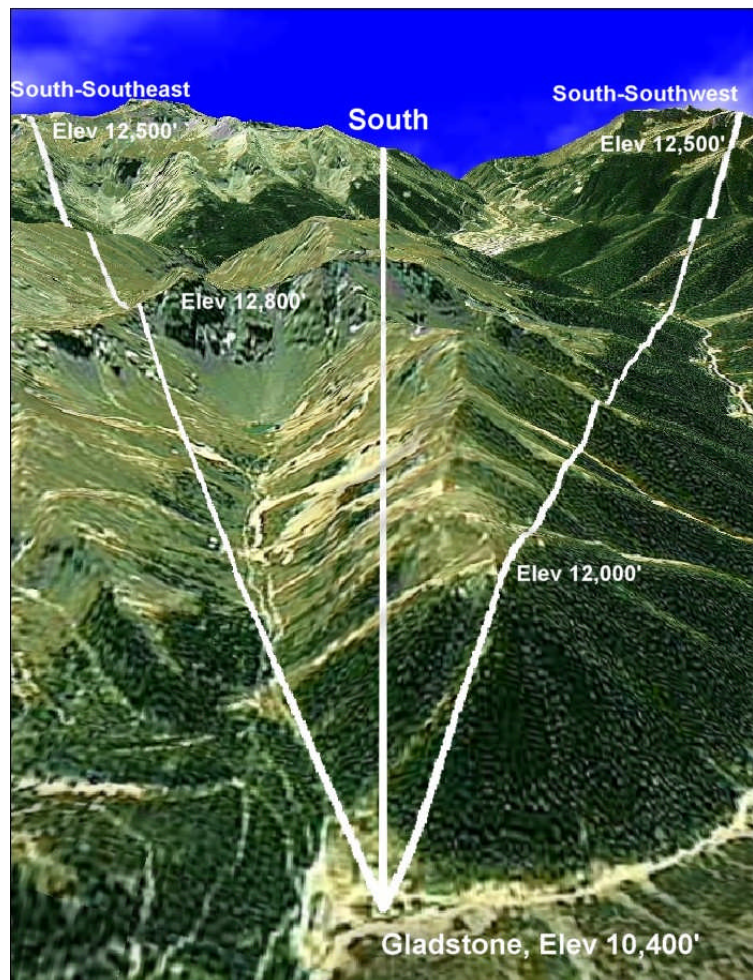
Topography

Precipitation was heaviest on the steep upslope areas of the San Juan mountains that were open to the strong, moist southerly flow and had low upwind barriers (Hansen and Schwarz, 1981). Gladstone was the only location in Colorado that reported over eight inches of rainfall while Silverton was one of two Colorado locations that reported over four inches of total rainfall.

Since southerly winds were associated with the rainfall, upwind moisture barriers to the south, river and creek valleys oriented south to north, and steep downwind slopes immediately to the south of these locations were identified. In particular, the reported rainfall total at the Gladstone location was evaluated for consistency with expected topographic effects. In general, rainfall enhancement is expected immediately upwind and over upslope regions without significant upwind moisture barriers; decreased rainfall is anticipated downwind of significant upwind moisture barriers; and lower rainfall totals are expected immediately downwind of steep downslope regions.

Figure 1 provides a three-dimensional view of the terrain along with inflow vectors for the south-southeast, south and south-southwest directions. While the terrain south (upwind) of Gladstone is fairly consistent with elevations between 12,000 feet and 13,000 feet, the terrain south of Silverton contains the Animas River valley, oriented roughly south to north. The Animas River valley has limited horizontal width but provides a path for atmospheric moisture to move northward to Silverton without a significant moisture barrier. Although there is a major topographic barrier between Silverton and Gladstone, a limited amount of atmospheric moisture that reaches Silverton could continue over Cement Creek to Gladstone. Additionally, Gladstone is at the foot of steep downslopes under southerly flow conditions, putting Gladstone's location in a rainshadow region.

Figure 1 Three-dimensional view of the terrain south of Gladstone. Inflow vectors for the south-southeast, south and south-southwest directions are shown.



Reported Flooding

John Pruess, a Masters degree student at CSU, included in his thesis extensive discussions related to newspaper accounts that reported on the October 1911 flooding as well as discussions based on historic photographs (Pruess, 1996). The newspaper accounts often had conflicting reports and contained subjective descriptions of the flooding.

Railway tracks and bridges were washed out. In particular, bridges on the road to Gladstone were washed out and the road to Eureka was damaged. However, it was expected that few repairs on both of these roads would open the roads in a short time (Silverton Standard, Saturday, October 7, 1911). These bridges were constructed of wood timbers and spanned streams very near the bankfull level. The fact that the bridges could be replaced or repaired in just a few days indicates that the flows were not much greater than bankfull and/or the destruction may not have been total (Pruess, 1996).

Photographs taken in 1912 show Cement Creek in Silverton and near Gladstone. One of these photos shows a locomotive moving upstream along Cement Creek toward Gladstone in 1912. Evidence of an extreme flood in 1911 is not visible in the photograph. If substantial out-of-bank flooding had occurred, flood evidence, such as erosional or depositional features should be noticeable in the 1912 photos. The existence of established willows that encroached upon the channel and a small bar deposit that does not represent significant overbank flooding is evidence that the flood of 1911 was not extreme. Another 1912 photograph of Cement Creek flowing through Silverton shows slackwater deposits, woody debris on the tops of in-channel flood bars and depositional surfaces beyond the present channel. However, the evidence in the photograph does not indicate that any substantial out-of-bank flooding occurred in 1911 (Pruess, 1996).

Pruess arrived at two definite conclusions based on the historical information:

- 1) A significant rainstorm caused unusually high flow in Cement Creek resulting in local damage.
- 2) The flow was not an extreme flood.

Rainfall Analyses

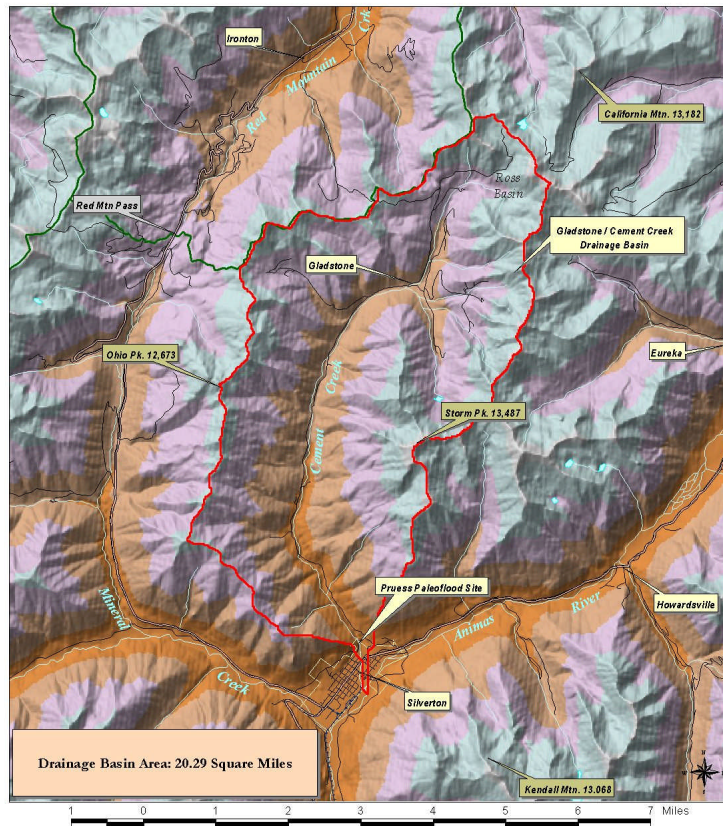
The results from the paleoflood investigation provide new information related to the October 1911 rainfall over the Cement Creek drainage basin. This information was not available to the Extreme Precipitation Task Committee in October 1996 when they made the statement "The committee acknowledged that the Gladstone storm of October 1911 (Storm #40) was an extreme event for that region, but the majority of the committee believed the specific local rainfall report at Gladstone was most likely in error although the magnitude of the error is not known and cannot be inferred easily from other information".

As part of the storm analysis phase for several site-specific PMP studies for basins in western Colorado, AWA performed additional storm rainfall analyses of the October 1911 storm and contracted Flow Technologies to model the runoff in Cement Creek for several different rainfall analyses. The intended use of the results from the rainfall/runoff modeling was to compare the computed rainfall/runoff modeled discharges with the maximum runoff determined from the paleoflood investigation.

A Geographic Information System (GIS) Digital Elevation Model (DEM) was constructed and used to compute the drainage area for the Cement Creek basin. The DEM is presented in Figure 2. The area of the drainage basin was computed to be 20.29 square miles.

Gladstone / Cement Creek Drainage Basin Map
Silverton Mining District, Colorado

Figure 2 Cement Creek
Drainage Basin Map



Four rainfall analyses were used in the rainfall/runoff modeling. The first case used a previously analyzed isohyetal pattern (Pruess, 1996) while the other three cases used isohyetal patterns developed using the AWA Storm Precipitation Analysis System (SPAS) software package. The four cases are as follows:

- 1) Adopted isohyetal pattern based on the Bureau of Reclamation isohyetal analysis (Pruess, 1996), referred to as Gladstone “Previous”.
- 2) SPAS isohyetal pattern using the Gladstone observation of 8.05” on October 5 as entered on the October 1911 observation form, referred to as Gladstone “High”.
- 3) SPAS isohyetal pattern using a rainfall value of 0.81 for Gladstone on October 5, referred to as Gladstone “Low”*.
- 4) SPAS isohyetal pattern without either the Gladstone or Eureka observations, referred to as w/o Gladstone & Eureka.

* Both Pruess and Crow suggested that the Gladstone observation could have been off by an order of magnitude. Based on this suggestion, the third case used a value of 0.81” for Gladstone on October 5.

Paleoflood Investigation

John Pruess and Dr. Bob Jarrett from the USGS Denver office collected detailed paleoflood data for several locations in the region from Gladstone down Cement Creek towards Silverton, and Eureka down the Animas River towards Durango. One of those sites is on Cement Creek, 0.4 kilometers upstream of the Greene Street bridge in Silverton. This location is very close to where Cement Creek enters the Animas River (Pruess, 1996).

Paleoflood evidence at the site included a within-channel bar located near the right bank and a well-defined mineral stain on the left bedrock wall of the channel. The bar is interpreted as the largest flood deposit emplaced since at least the closing of the railroad line in the 1920s. However, during a reconnaissance of upstream reaches of Cement Creek, no evidence of flows larger than that represented within the surveyed reach was observed. Therefore, the in-channel bar is believed to represent the largest flow to have occurred at this study site (Pruess, 1996).

Pruess computed the preferred water-surface elevation at this site using the cross section in Figure 3 and a step-backwater analysis. The computed preferred discharge is 424 cubic feet per second (cfs).

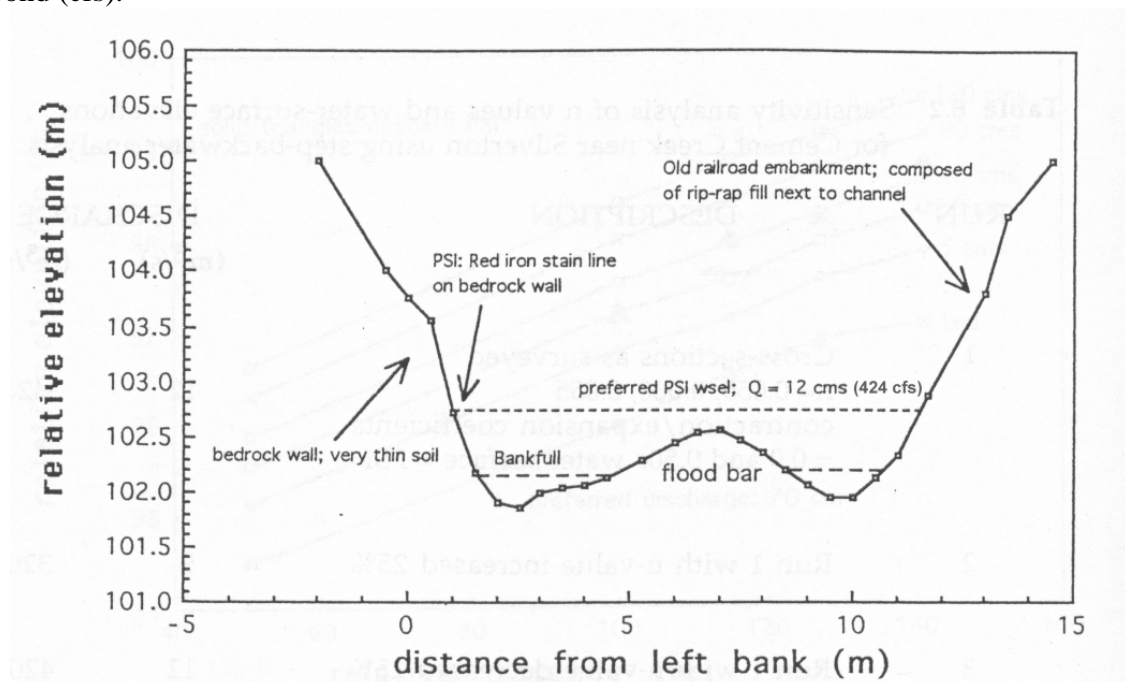


Figure 3 Preferred Water-Surface Elevation for the Cement Creek Paleoflood Site (Pruess, 1996)

Runoff Modeling for the Cement Creek Drainage Basin

Rainfall/runoff (RF/RO) modeling was performed for the four different storm rainfall scenarios. At the time of the Gladstone storm occurrence, Cement Creek had been heavily clear-cut for mining operations which included cutting and burning large areas of the basin. Hydrologic characteristics were very different in the clear-cut areas. To account for the hydrology of the clear-cut areas, Cement Creek basin was subdivided into two basins - these are named "Native" and "Clear-cut". Native Basin includes the drainage area above timberline, and

the forested area that has not been disturbed. It was assumed that about one-half of the basin was forested and one-half of that was clear-cut; i.e., 25% of the total drainage area.

Cement Creek RF/RO modeling was performed via the US Army Corps of Engineers HEC-1 hydrologic model with application of the SCS Curve Number method. Detailed data for other loss methods that require infiltration data were not available for this study, but curve numbers are generic and can be selected using basic knowledge of hydrologic characteristics for a basin, standard charts, and experience and judgment of the analyst.

Based on available information, Cement Creek soils are of SCS hydrologic soil group (HSG) B and C. Due to the variation, an average curve number of 65 for B and C soils in forested conditions was used for native conditions.

Hydrologic parameters were developed in the Clear-cut basin to account for clear-cutting. Clear-cutting operations on Cement Creek would result in compacted and possibly hydrophobic soils (due to burning). Such soils exhibit hydrologic characteristics similar to an impervious surface; thus, a high curve number of 90 was assumed for conservativeness.

An important component of the unit hydrograph is lag time. Lag time was estimated using methodology and relationships contained in the Bureau of Reclamation Flood Hydrology Manual (Cudworth, 1989) as a function of basin geometry (length, length to centroid, slope, and Manning's n value).

Other input parameters include drainage area, average basin rainfall, rainfall distribution, and antecedent moisture. Drainage area was obtained from the GIS DEM (Figure 3), average rainfall computed from storm isohyets clipped to the basin boundary and rainfall distribution determined from historic meteorological data. Based on historic accounts, there was considerable rain preceding the Gladstone storm and the ground was saturated; thus, antecedent moisture was assumed to be 0.5 inch for Native Basin, and 0.1 in for Clear-cut Basin.

As a form of calibration, or "reality check," modeling results were compared to a FEMA floodplain study performed for Silverton, Colorado which included frequency flood data for Cement Creek. The Cement Creek HEC-1 model used for the Gladstone storm was applied using the National Weather Service 100-yr/24-hr rainfall value and was within 10 percent agreement with the FEMA 100-yr discharge (1,640 cfs (FEMA) vs. 1,840 cfs (Cement Ck HEC-1 model)). Thus, that the Cement Creek HEC-1 model is reasonable for evaluating the four storm scenarios.

Cement Creek was initially modeled as a native basin in order to calibrate the model with the above FEMA study, and then modified to include the clear-cut sub basin.

Cement Creek/Gladstone Storm Rainfall/Runoff Modeling Results

STORM SCENARIO	BASIN AVE RAINFALL (in)	PEAK DISCHARGE (cfs)
Gladstone "Previous"	6.14	6,920
Gladstone "High"	6.25	7,080
Gladstone "Low"	1.94	1,300
w/o Gladstone & Eureka	3.68	3,450

Conclusions

The rainfall observation for Gladstone, Colorado, for October 5, 1911 has been suspected to be erroneous for many years by various investigators who have studied the October 4-6, 1911 storm. It is inconsistent with other high elevation rainfall observations in the Colorado Rocky Mountains during October and is much higher than any other rainfall total reported for the 1911 storm (Crow, 1992).

Rainfall/runoff modeling has been completed for four separate rainfall analyses for the Cement Creek drainage basin. The runoff modeling for the four cases were compared to the paleoflood maximum runoff value of 424 cfs. For the first two cases that included the 8.05" observation, the modeled runoff was more than a factor of 16 larger than the paleoflood maximum runoff value. For the third case that included a 0.81" value for the Gladstone observation, the modeled runoff of 1,300 cfs, still three times greater than the paleoflood maximum runoff value. For the fourth case without either of the Gladstone or Eureka observations, the modeled runoff was slightly less than an order of magnitude higher than the paleoflood maximum runoff.

It is recognized that both the runoff modeling and the paleoflood maximum runoff computations have some error associated with assumptions and approximations. Possible errors associated with the runoff modeling and the paleoflood estimates may be about +/- 25% for each analysis. However, the more than 1,600% difference between the runoff modeling using the high Gladstone observation value and the paleoflood runoff value indicates a significant discrepancy. The Gladstone observation form for October, 1911, did not reflect a change in the prevailing wind direction to south on October 5th as was reported at Eureka and would be expected from the synoptic discussions. If the wind direction is considered to not be reliable, possibly so should the reported rainfall, especially since two different values are reported for October 5th.

The paleoflood analysis provided a detailed and comprehensive study for not only the Cement Creek site but for several other sites along and adjacent to the Animas River. For all sites, the paleoflood results were in general agreement with the reported flood magnitude. Had the Cement Creek basin experienced a flood of the magnitude computed using the 8.05" rainfall observation for Gladstone on October 5, 1911, paleoflood stage indicators (PSIs) representative of the larger flood (approximately 7,000 cfs) would have been produced and identified during the paleoflood investigation. The absence of PSIs associated with a 7,000 cfs flood indicates that a flood of that magnitude has not occurred in the basin.

Recommendation

Based on this analysis, it was recommended that the Gladstone observation of 8.05 inches on October 5, 1911 be considered in error and not be used in future rainfall analyses. The Colorado State Engineer Office has concurred with this recommendation (Colorado SEO, 2004).

Impact on Site-Specific PMP Studies

Several site-specific PMP studies were impacted by the elimination of the Gladstone observation. For each of these studies, the next highest rainfall observation for the October 1911 storm was used. That was for Cumbres, Colorado, elevation 10,000 feet, where 4.83 inches of rainfall was observed. The three site-specific PMP studies had an average reduction in PMP values of 32% for durations up to 24 hours and 38% for durations up to 72 hours.

Although HMR-49 does not list the storms used in the development of PMP values for western Colorado, the Gladstone rainfall observation was available and should have been included in the development of the generalized PMP values. It is not known what effect the elimination of the Gladstone observation would have had on the HMR-49 PMP values but without the Gladstone rainfall observation, the generalized PMP values would probably have been significantly lower as is the case for the site-specific PMP values for western Colorado.

References

- American Meteorological Society, 1996: *Glossary of Weather and Climate*, Boston, Ma., 272 pp.
- Colorado State Engineer Office (SEO), written communication, September 23, 2004.
- Crow, Loren W., 1992: Letter to Mr. William H. Haggard C.C.M., August 13, 1992.
- Cudworth Jr., A. G., 1989: Bureau of Reclamation Flood Hydrology Manual, US Department of the Interior, Bureau of Reclamation, Denver, CO.
- Hansen, E.M., F.K. Schwarz, and J.T Reidel, 1977: Probable Maximum Precipitation Estimates. Colorado River and Great Basin Drainages. *Hydrometeorological Report No. 49*, NWS, NOAA, U.S. Department of Commerce, Silver Spring, Md, 161 pp.
- Hansen, E.M., and F.K. Schwarz, 1981: Meteorology of Important Rainstorms in the Colorado River and Great Basin Drainages, *Hydrometeorological Report No.50*, NWS, NOAA, U.S. Department of Commerce, Silver Spring, Md., 167 pp.
- Jarrett, R.D.: Flood elevation limits in the Rocky Mountains. *Proceedings, ASCE 1993 National Conference on Hydraulic Engineering and International Symposium on Engineering Hydrology. San Francisco, 180-185.*
- McKee, T.B., and N.J. Doesken, 1997: Colorado Extreme Storm Precipitation Study. Colorado State University Climatology Report 97-1, Fort Collins, Co., 107 pp.
- Miller, J.F., R.H. Fredrick, and R.J. Tracey, 1973: *NOAA Atlas 2, Precipitation-Frequency Atlas of the Western United States*. U.S. Department of Commerce, National Oceanic and Atmospheric Administration, National Weather Service, Silver Spring, Md.
- Pruess, Jonathan William, 1996: *Paleoflood Reconstructions within the Animas River Basin Upstream from Durango, Colorado*, Masters Thesis, Colorado State University, Fort Collins, Colorado.
- Pruess, Jonathan, Ellen E. Wohl, and Robert D. Jarrett, 1998: Methodology and Implications of Maximum Paleodischarge Estimates for Mountain Channels, Upper Animas River Basin, Colorado, U.S.A., *Arctic and Alpine Research*, Vol. 30, No.1, p. 40 – 50.
- Storm Studies – Pertinent Data Sheets, and Isohyetal Map, U.S. Department of Interior, Bureau of Reclamation, Denver, Co.
- Tomlinson, Edward M., and Mark Solak, 1996: *Site-Specific Probable Maximum Precipitation (PMP) Study of the Elkhead Drainage Basin*, North American Weather Consultants, Salt Lake City, Utah.