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Review of the Gladstone, Colorado Rainfall Observation, October 5, 1911

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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).

Southwestern Colorado received relatively large amounts of rainfall during this October event. Most of the precipitation produced 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, Colorado and New Mexico with a single large rainfall total reported in southeastern Utah. Exceptions to the widespread rainfall observation amounts in the two to four inch range were a few relatively low rainfall storm totals, e.g. Eureka, Colorado, and the very large rainfall daily total reported at Gladstone, Colorado on October 5.

Many investigators have reviewed the reliability of the Gladstone observation. Loren Crow, Certified Consulting Meteorologist, concluded that the rainfall amount is "WAY OUT THERE" after completing a review of other high elevation rainfall reports in Colorado (August, 1992). Site-specific Probable Maximum Precipitation (PMP) studies for drainage basins in northwestern Colorado have considered this storm event. The conclusion reached in these studies was that, although widespread moderate-heavy rains occurred in the region, the validity of the maximum precipitation value of 8.2 inches reported at Gladstone, elevation 10,400 feet, is subject to continued question (Tomlinson and Solak, 1994; Tomlinson and Solak, 1996). The majority of the Extreme Precipitation Task Committee associated with the Colorado Climate Center Extreme Storm Precipitation Study concluded that 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 (McKee and Doesken, 1997). John Pruess in his Masters

thesis at Colorado State University investigated the rainfall reports and flood evidence in southwestern Colorado associated with the 1911 storm. He concluded that while it is impossible to absolutely verify the accuracy of a measurement made in 1911, historical and hydrologic information suggest that the reported rainfall from Gladstone could be overestimated (Pruess, 1996).

Information from each of these investigations has been consolidated and is presented in this paper. Additionally, rainfall/runoff modeling for Cement Creek has been completed for several scenarios; using the rainfall isohyetal pattern and mass curve previously published, using the rainfall isohyetal pattern and mass curve from a new analysis using the AWA software package SPAS (Storm Precipitation Analysis System) and the 8.05 inches rainfall reported at Gladstone, using the rainfall isohyetal pattern and mass curve from SPAS with a value of 0.81 inches for Gladstone, and using the rainfall isohyetal pattern and mass curve from SPAS without observations from Gladstone and Eureka. The computed flows in Cement Creek at Silverton have been compared subjectively with reports related to the actual flooding and quantitatively with the paleoflood results from John Pruess's thesis.

Significant Meteorological Features

Between October 4-6, 1911, a dissipating tropical storm moved northward from the tip of Baja California and through southeastern Arizona and then, after combining with an extra-tropical low pressure system, moved northeastward through central Colorado and into central Iowa (Hanson and Schwarz, 1981). Figure 1 shows the surface weather maps for October 3-6, 1911 and Figure 2 consolidates the tropical storm track with significant weather features for the storm for the period October 4-6.

Eastern Pacific hurricane tracks for the early 1900's are not available in the hurricane archives, unlike Atlantic hurricane tracks that are available back into the 1800's (weather.unisys.com/hurricane). However, from the 1300 GMT surface maps, the track of the tropical storm can be estimated. The tropical storm tracked northward over the

Baja peninsula and the Gulf of California into western Arizona during the daytime and evening hours of October 4th, joining with the extratropical low pressure system that had been moving southeastward over southern Nevada during the same period. The air mass in the warm sector of the low pressure center was very warm and moist. As the extratropical low pressure center accelerated to the northeast, its atmospheric dynamics combined with the remnant tropical storm moisture and topographic features in Arizona, Colorado and New Mexico to produce extreme rainfall. Although no upper air data are available, it is suspected that the low pressure center was associated with a 500mb trough. The rapid acceleration to the northeast indicates that the storm followed a strong jet stream orientated from the southwest to the northeast. Southeast winds over southwestern Colorado during the morning of October 4 gave way to strong southerly winds following the warm front passage and ahead of the cold front passage on the 5th (Hansen and Schwarz, 1981). This scenario is consistent with the relatively large rainfall amount reported at Monticello, Utah (4.42 inches) with minor topographic features as well as the reports of strong south winds interacting with the south facing slopes of the mountains in Colorado (Weaver, 1968). Dewpoints temperatures adjusted to sea level in the warm sectors were reported as high 71 degrees F (Hansen and Schwarz, 1981). Maximum persisting 12-hour 1000 mb dewpoint temperatures for the region are around 70 degrees F for the first part of October (Climate Atlas of the U.S., 1968).

Between 1300 GMT (6:00am Mountain Standard Time) on October 4th and 1300 GMT on October 6th the storm moved roughly 2000 miles in 48 hours. The average speed during this period was 42 mph (Pruess, 1996). Loren Crow estimated the movement of the tropical storm and extratropical low pressure system at 15 mph between 1300 GMT on October 3rd and 4th, 33 mph between 1300 GMT on October 4th and 5th, and 46 mph between 1300 GMT on October 5th and 6th (Crow, 1992).

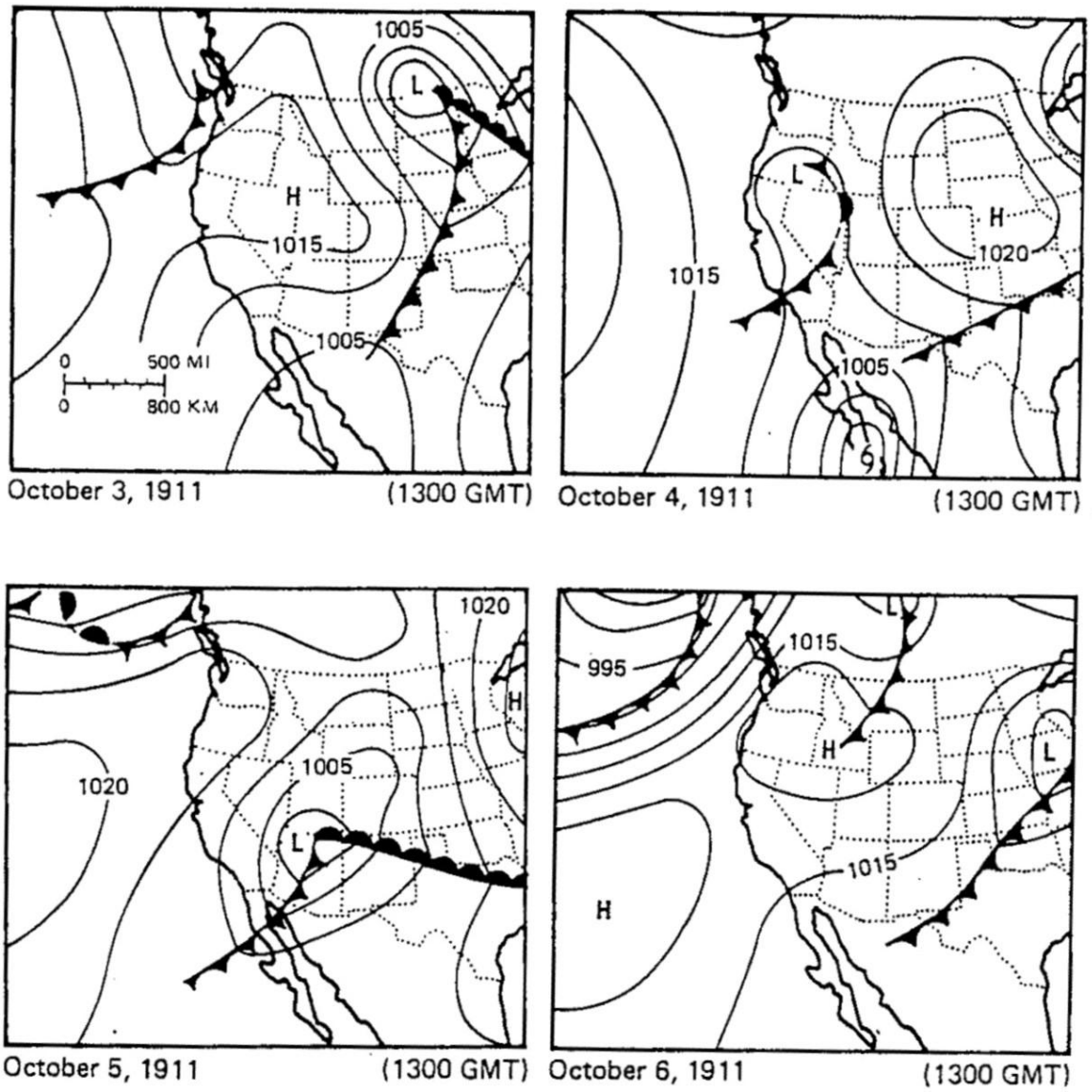


Figure 1 Surface weather maps for October 3-6, 1911 (Hansen and Schwarz, figure 2.20, 1981)

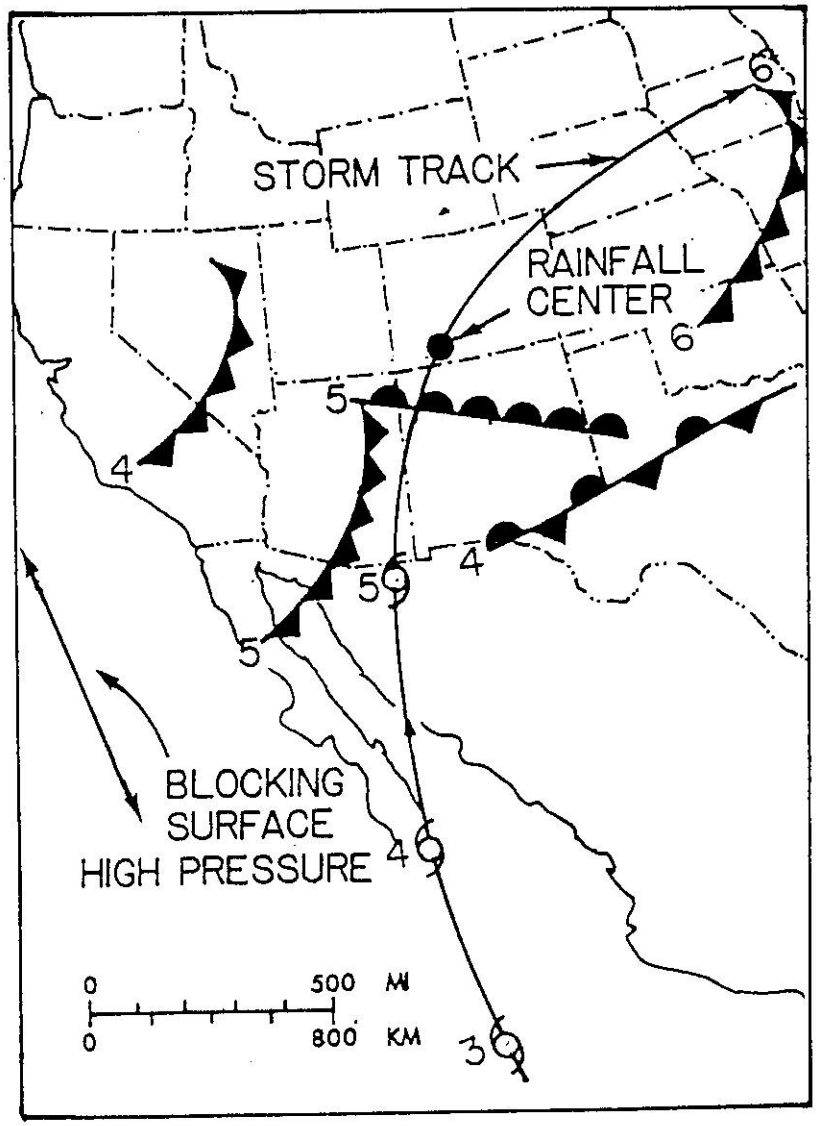


Figure 2 Storm track and significant weather features for the storm of October 4-6, 1911 (Hansen and Schwarz, figure 2.19, 1981)

The average daily speeds have been confirmed using the 1300 GMT daily maps for October 3-6. Using these speeds, estimated positions have been computed for October 4th and 5th at 0100 GMT (6:00pm MST). Additionally, the time that the low pressure center would have moved over Gladstone has been estimate to be about 2:00pm on October 5th. Figure 3 shows the estimated storm locations and speeds. The green line is the straight line between locations at 1300 GMT October 4-6 and the black curved line is the estimated track of the tropical storm and the low pressure center. The storm track differs slightly from the track shown in Figure 1 because of positioning uncertainty.

Figure 3 Approximate Storm Track and Speed, October 4-6, 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).

Storm rainfall totals of two inches or more were produced at locations in eastern Arizona, southwestern Colorado and northern New Mexico. Figure 4 shows the region where generally 2 inches to 4 inches of rain was observed and the region where generally 1 inch to 2 inches of rain fell. There were individual stations within each region with slightly more or less rainfall. Stations in Region A are generally exposed to southerly wind flows whereas stations in Region B generally have significant moisture barriers (above 12,000 feet) to the south. Most stations are affected by the surrounding topography.

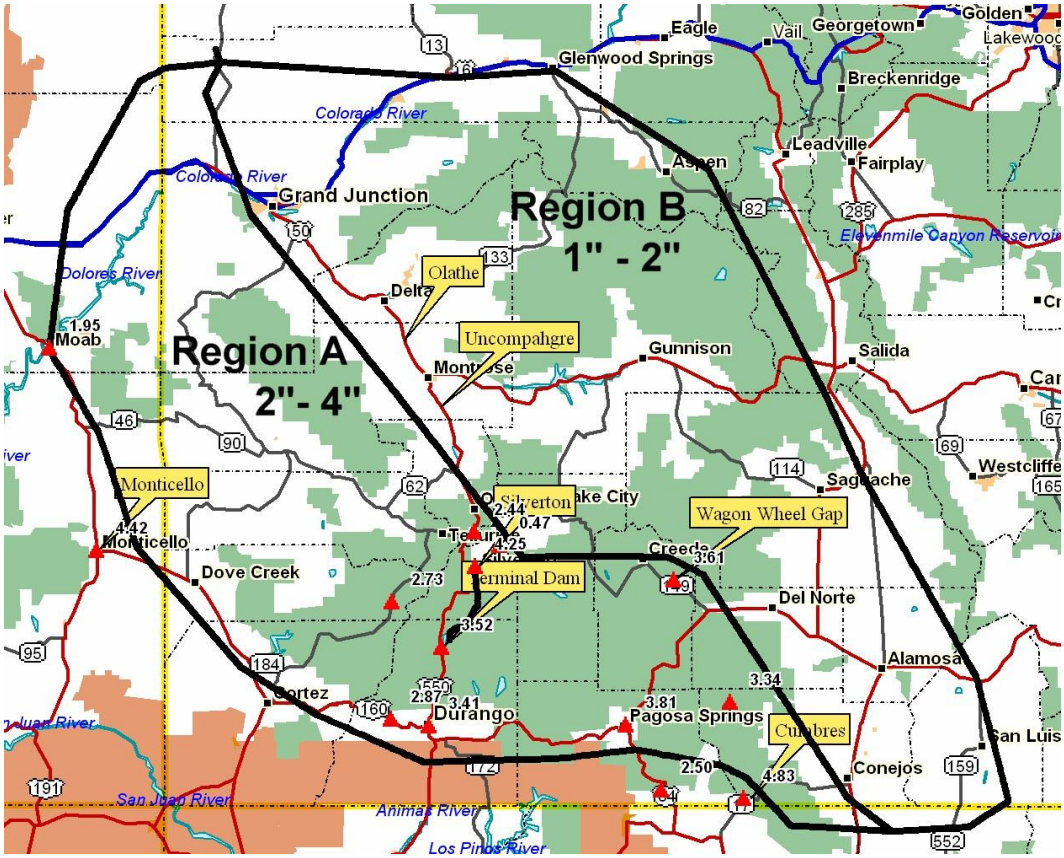


Figure 4 Locations with the largest reported rainfall totals and generalized regions of rainfall amounts

The rain start/stop times at various hourly locations are shown in the mass curve presented in Figure 5. It is clear that the storm system moved up from the south, hit Alamos Ranch, NM first then hit Silverton and Monticello, UT at about the same time. Then a few hours later hit Wagon Wheel, and then finally Montrose. This progression of rainfall is what would expect from the storm track shown in Figure 3. All of the hourly data for this storm were extracted from Bureau of Reclamation documents received from the Colorado Climate Center.

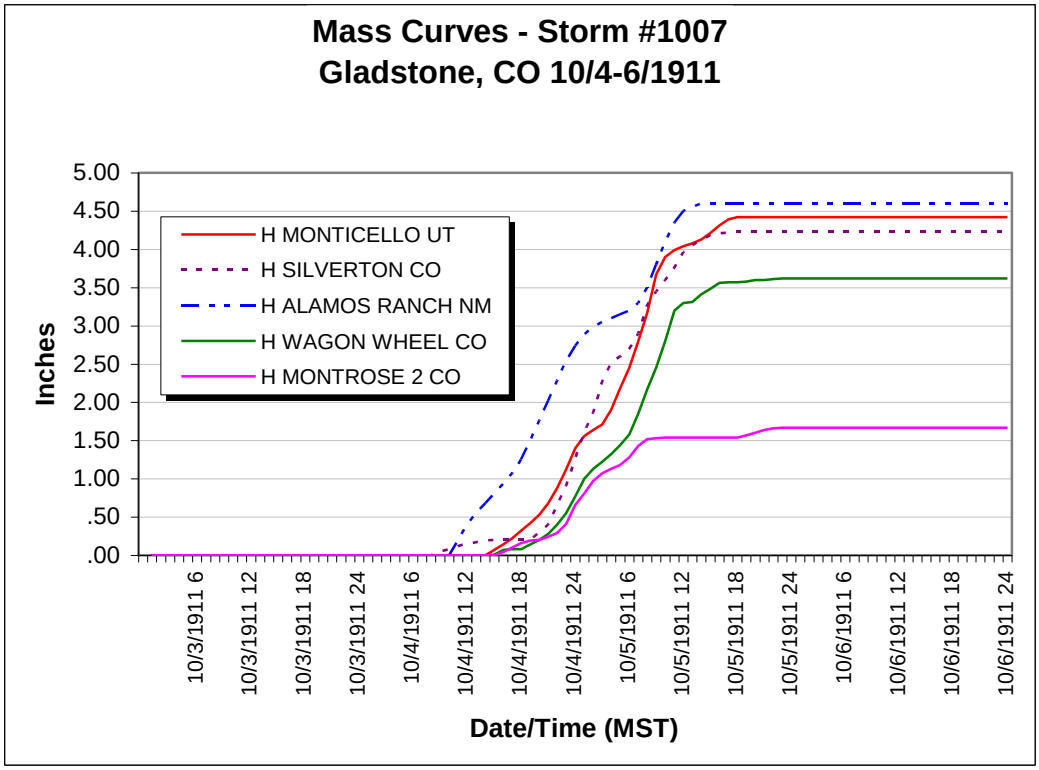


Figure 5. Mass curves for various rainfall observation locations

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
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

Rainfall Reports from Gladstone and Eureka

Rainfall reports from Silverton, Gladstone, and Eureka from 1910 through 1912 were reviewed. The monthly values are shown in Figure 6. and the accumulated rainfall totals for the period January 1910 through January 1911 are shown in Figure 7. Figure 6. shows that Gladstone generally reported more rainfall than Eureka (27 months vs 4 months) but October was the only month that show an extremely large difference. Figure 7. shows that Gladstone rainfall totals for 1910 through 1911 were consistently larger than Eureka rainfall totals with Silverton reporting rainfall totals between the two.

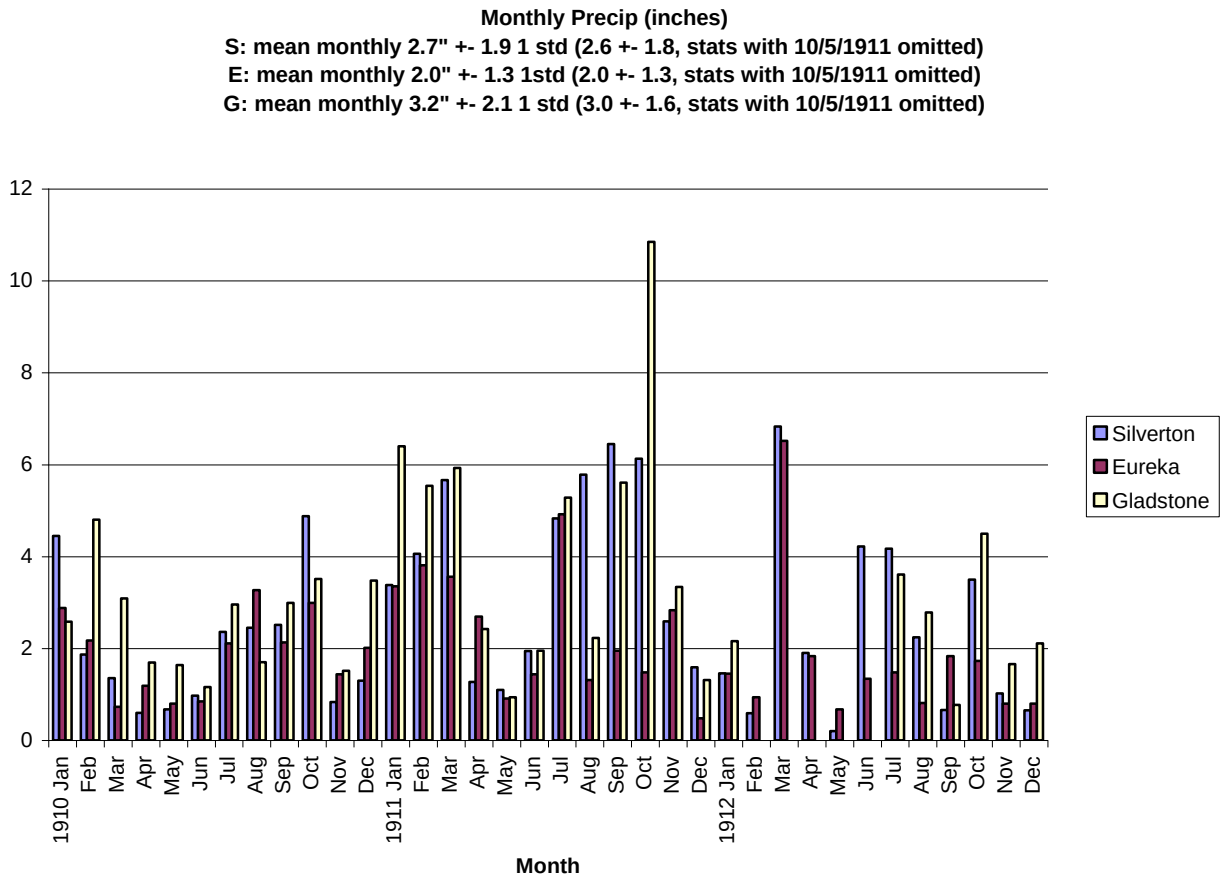


Figure 6. Monthly precipitation for Silverton, Eureka and Gladstone for 1910 through 1912. Monthly reports from Gladstone are missing from February through June 1912.

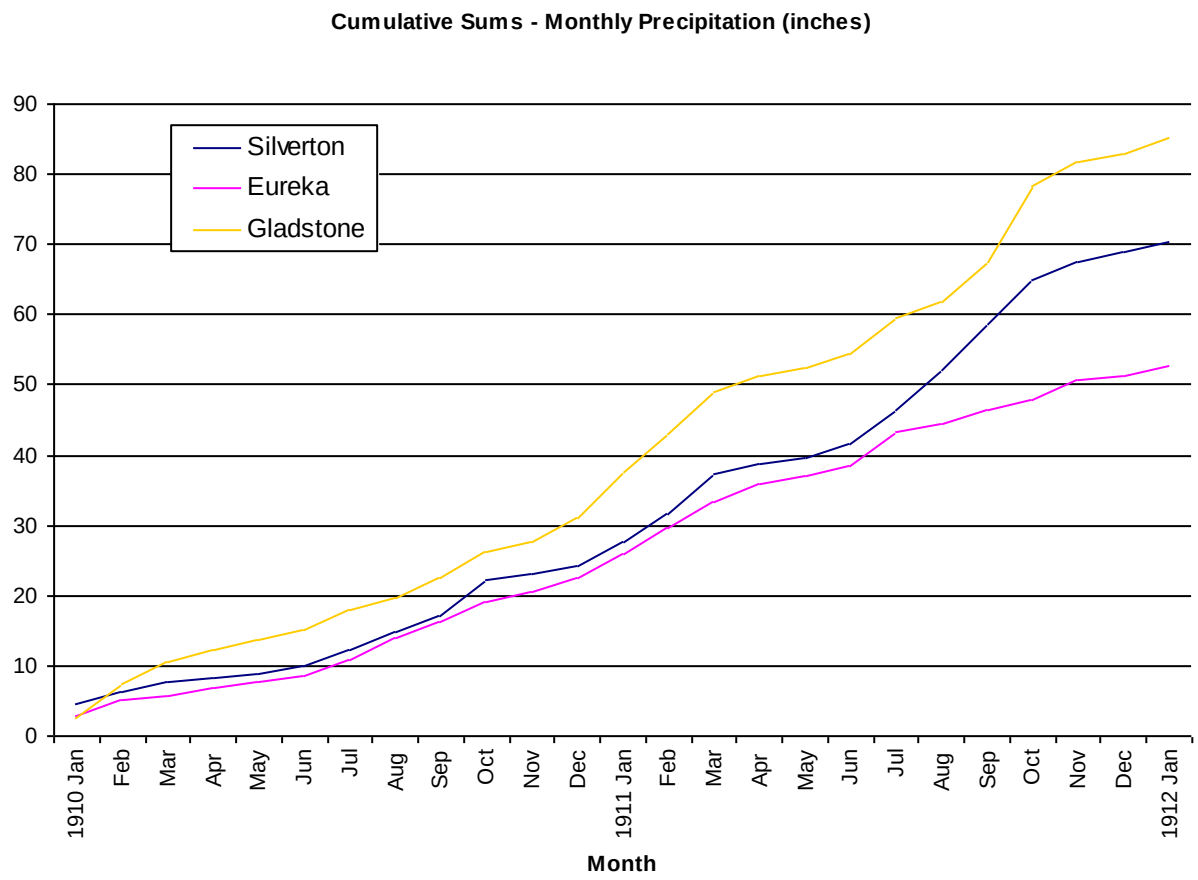


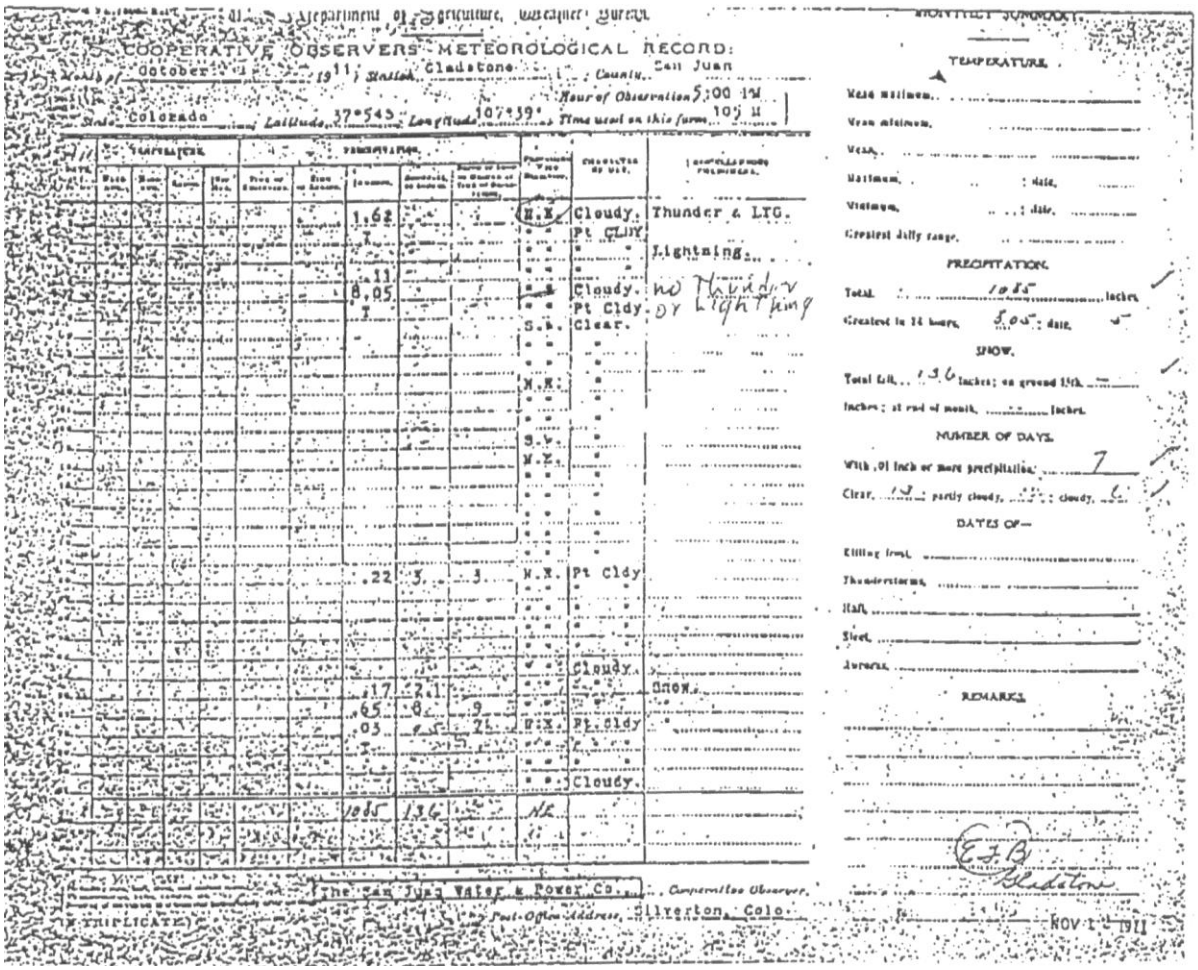
Figure 7. Cumulative rainfall totals for Silverton, Eureka and Gladstone for the period January 1910 through January 1912.

Copies of the observation forms from Gladstone and Eureka for October, 1911 are shown in Figures 8 and 9. Both forms are initialed by someone with the initials E.F.B. and stamped with the date Nov 12, 1911. Possibly this person prepared the forms for The San Juan Water and Power Co. for both Gladstone and Eureka using information provided by the observers at each location. Other monthly observation forms for 1910 through 1912 for Silverton, Eureka and Gladstone have the same initials. All of the forms where typed and appeared to be diligently filled out. Traces were even entered. It appears unlikely that this person made the observations at both locations each day since although the locations are less than 5 miles apart, the distance along the roadway is almost 15 miles. Figure 10 shows the roadway distance between Gladstone and Eureka.

The Gladstone observation form has rainfall values typed in for each day in October, 1911. The value of 8.05 is clearly legible for day 5. On the right side of the form is a space where the monthly total precipitation and the greatest in 24 hours are entered. Hand written in this space is a value of 5.05 with the date 5. Each of these values is clearly legible. This value of 5.05 is in disagreement with the 8.05 entered for the 5th day of the month. It is not known which of these values is valid or if either is valid. Historically the 8.05" value has been used but the 5.05" value is equally legible, both reported for day 5 of the month.

Under the column titled "Prevailing Wind Direction", the Gladstone form has N.E. entered on day 1 with " " entered for day 2 through day 6. Under the same column on the Eureka observation form Calm. is entered for day 1 with " entered for day 2 through day 4. Day 5 has S entered with Calm for the next eight days. Storm discussions consistently refer to strong south winds on October 5 and attribute some of the large rainfall totals to the interaction of the strong moist south winds with the south facing slopes of the San Juan Mountains (Hansen and Schwarz, 1981). The south wind direction was observed at Eureka but was not reported at Gladstone. From the synoptic situation, a daily prevailing wind direction of south should have been reported for all locations ahead of the approaching low pressure center. Certainly a change in prevailing wind direction should have been noted between day 4 and day 5 and/or day 5 and day 6.. If the moisture

that fed the rainfall event at Gladstone was advected northward and eastward over Cement Creek (the only path that does not transit high mountain moisture barrier of 12,000 ft to 13,000 ft) (Crow, 1992), the reported wind direction should have been west or southwest, exactly opposite from the reported prevailing wind direction. The N.E. wind direction reported is not consistent with the expected direction.


COOPERATIVE OBSERVERS' METEOROLOGICAL RECORD:

Month of October 1911; State Colorado; Station Gladstone; County San Juan; Latitude 37°54.5; Longitude 107°39'; Hour of Observation 5:00 PM; Time used on this form 10½ H

Date	Wind Direction	Cloudiness	Remarks
	N.E.	Cloudy. Pt Cldy	Thunder & LTG. Lightning.
		Cloudy. Pt Cldy.	no Thunder or Lightning
	S.E.	Clear.	
	N.E.		
	S.E.		
	N.E.		
	N.E.	Pt Cldy	
		Cloudy.	
			Snow.
	N.E.	Pt. Cldy	
		Cloudy.	
	NE		

TEMPERATURE. Mean maximum. Mean minimum. Mean. Maximum. : date. Minimum. : date. Greatest daily range.

PRECIPITATION. Total 10.85 inches. Greatest in 24 hours 5.05 : date.

SNOW. Total fall 13.6 inches; on ground 15th. inches; at end of month. inches.

NUMBER OF DAYS. With .01 inch or more precipitation 7. Clear 13 ; partly cloudy ; cloudy 6.

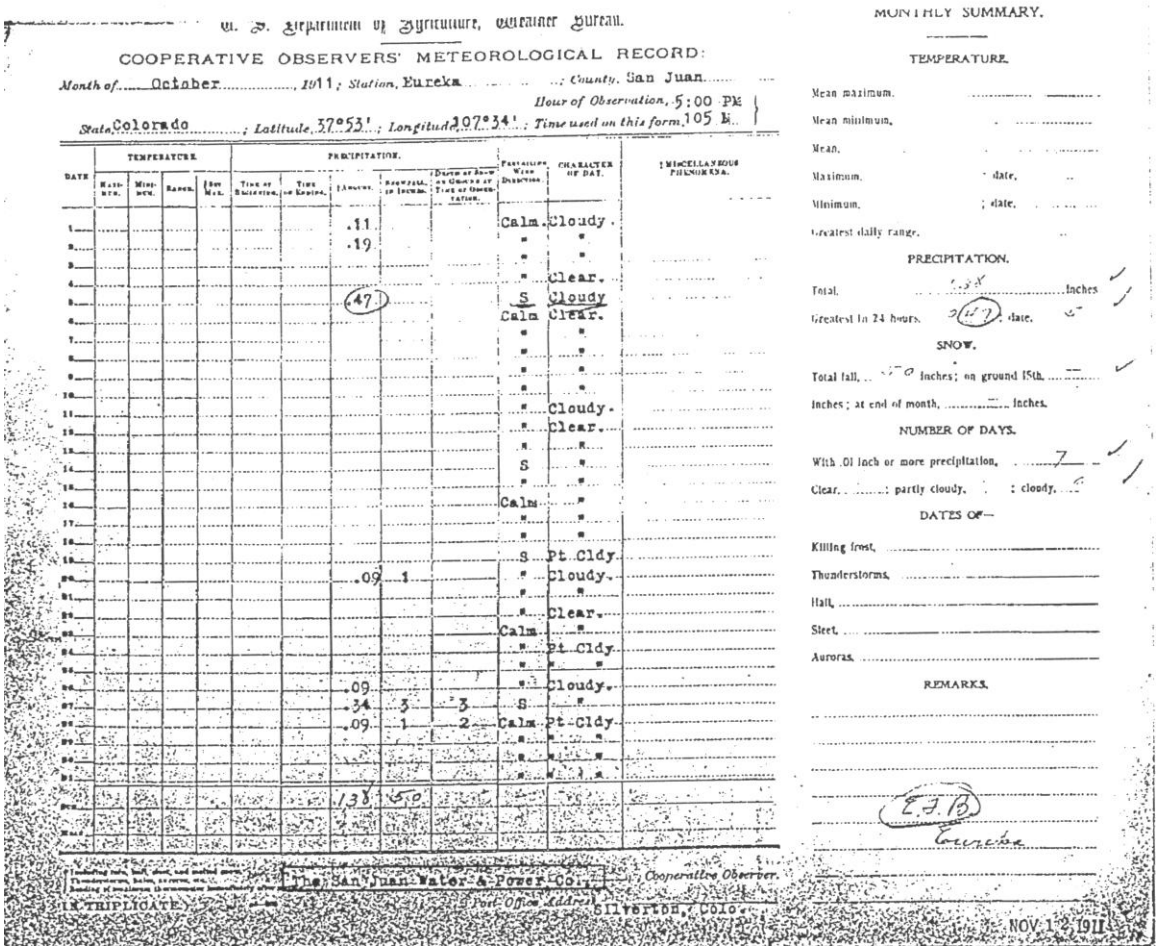
DATES OF— Killing frost. Thunderstorms. Hail. Sleet. Aurora.

REMARKS

E.J.B. Gladstone

The San Juan Water & Power Co. Cooperative Observer. Post-Office Address, Silverton, Colo. NOV 1 1911

Figure 8. Monthly observation form for Gladstone, Colorado for October, 1911



U. S. Department of Agriculture, Weather Bureau.

COOPERATIVE OBSERVERS' METEOROLOGICAL RECORD:

Month of October, 1911; Station, Eureka; County, San Juan

Hour of Observation, 5:00 PM

State Colorado; Latitude 37°53'; Longitude 107°34'; Time used on this form 105 B

DATE	Temperature: Maximum	Temperature: Minimum	Temperature: Range	Temperature: Mean	Precipitation: Time of Beginning	Precipitation: Time of Ending	Precipitation: Amount	Precipitation: Snowfall or Snow	Precipitation: Depth of Snow on Ground at Time of Observation	Prevailing Wind Direction	Character of Day	Miscellaneous Phenomena
1							.11			Calm	Cloudy	
2							.19			"	"	
3										"	"	
4										"	Clear	
5							(.47)			S	Cloudy	
6										Calm	Clear	
7										"	"	
8										"	"	
9										"	"	
10										"	"	
11										"	Cloudy	
12										"	Clear	
13										"	"	
14										S	"	
15										"	"	
16										Calm	"	
17										"	"	
18										"	"	
19										S	Pt Cldy	
20							.09	1		"	Cloudy	
21										"	"	
22										"	Clear	
23										Calm	"	
24										"	Pt Cldy	
25										"	"	
26							.09			"	Cloudy	
27							.34	3	3	S	"	
28							.09	1	2	Calm	Pt Cldy	
29										"	"	
30										"	"	
31										"	"	
Sum							1.33	5.0				
Mean												

Thunderstorms, hail, sleet, and auroras, etc.: The San Juan Water & Power Co., Cooperative Observer.

Reading of maximum thermometer [illegible]

Post Office address: Silverton, Colo.

SIX TRIPLICATE

NOV 1 2 1911

MONTHLY SUMMARY.

TEMPERATURE.

Mean maximum.

Mean minimum.

Mean.

Maximum. date.

Minimum. ; date.

Greatest daily range.

PRECIPITATION.

Total. 1.38 inches

Greatest in 24 hours. 3 (.47) date.

SNOW.

Total fall, 5.0 inches; on ground 15th. —

inches; at end of month, — inches.

NUMBER OF DAYS.

With .01 inch or more precipitation, 7

Clear, : partly cloudy, : cloudy, 6

DATES OF—

Killing frost,

Thunderstorms,

Hail,

Sleet,

Auroras,

REMARKS.

E.J.B.

Eureka

Figure 9. Monthly observation form for Eureka, Colorado for October, 1911

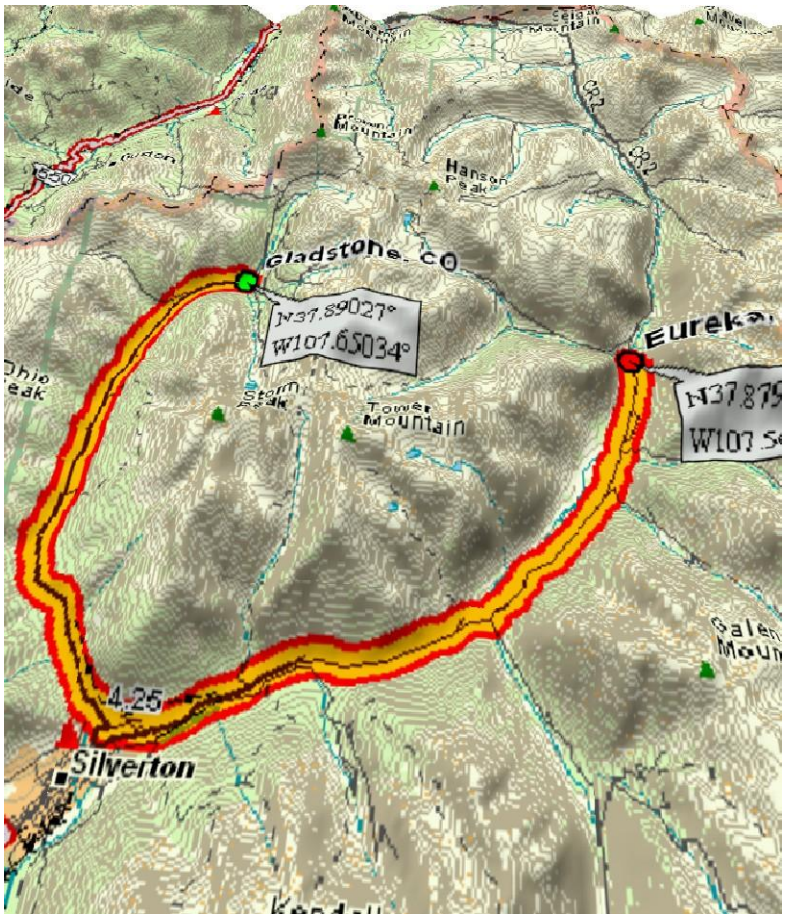


Figure 10. Route from Gladstone to Eureka via the roadway, the distance is approximately 15 miles

Topography

Precipitation was heaviest on the steep upslope areas of the San Juan mountains that were open to the strong, moist, southerly flow that had low upwind barriers nearby (Hansen and Schwarz, 1981). Gladstone was the only location in Colorado that reported over 5 inches of rainfall while Silverton was one of two Colorado locations that reported over four inches of total rainfall. Figures 8 - 10 provide maps of the terrain surrounding and south of Gladstone, Eureka and Silverton. Since southerly winds were associated with the rainfall, upwind moisture barriers to the south, river and creek valleys that are oriented south to north, and steep downwind slopes immediately to the south of these locations have been identified. In particular, the reported rainfall totals at these three locations are 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 potentially significantly lower rainfall totals are expected immediately downwind of steep downslope regions.

Figures 11 – 13 show terrain profiles directly south of the three locations. Each profile shows relatively high terrain upwind under southerly wind flow conditions. Additionally, the profiles show steep downslope conditions immediately upwind of Gladstone and Eureka. Figures 14 – 16 provide three-dimensional views of the terrain along with inflow vectors for the south-southeast, south and south-southwest directions. While the terrain upwind of Gladstone and Eureka 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. Figures 17 shows a photo taken from a half mile north-northeast of Gladstone looking to the south-southwest and Figure 18 shows a photo taken from Gladstone looking to the south. Figure 19 shows the Animas River valley profile south of Silverton. 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 and between Silverton and Eureka, a limited amount of

atmospheric moisture that reaches Silverton could continue over Cement Creek and the Animas River to Gladstone and Eureka. Additionally, both locations are at the foot of steep downslopes under southerly flow conditions, putting both locations in a rainshadow region.

From these topographic considerations, Silverton should have received more rainfall than either Gladstone or Eureka under the southerly wind flow conditions of October 4-5, 1911, because of more limited lower atmospheric moisture availability and the rainshadow locations of Gladstone and Eureka, but the amount of difference is difficult to quantify. Certainly the amount reported at Gladstone (almost twice that at Silverton) would not be expected. Similarly, the amount reported at Eureka (only one tenth that at Silverton) appears to be potentially low. Loren Crow in his discussion of the Gladstone rainfall observation stated that the troubling aspect of the observation is that Gladstone is in an almost closed basin. The basin is accessible below 12,000 feet only over a very narrow span of direction to the south and south-southwest. The minimal rainfall at Eureka illustrates the effect of shielding by the mountains (Crow, 1992).

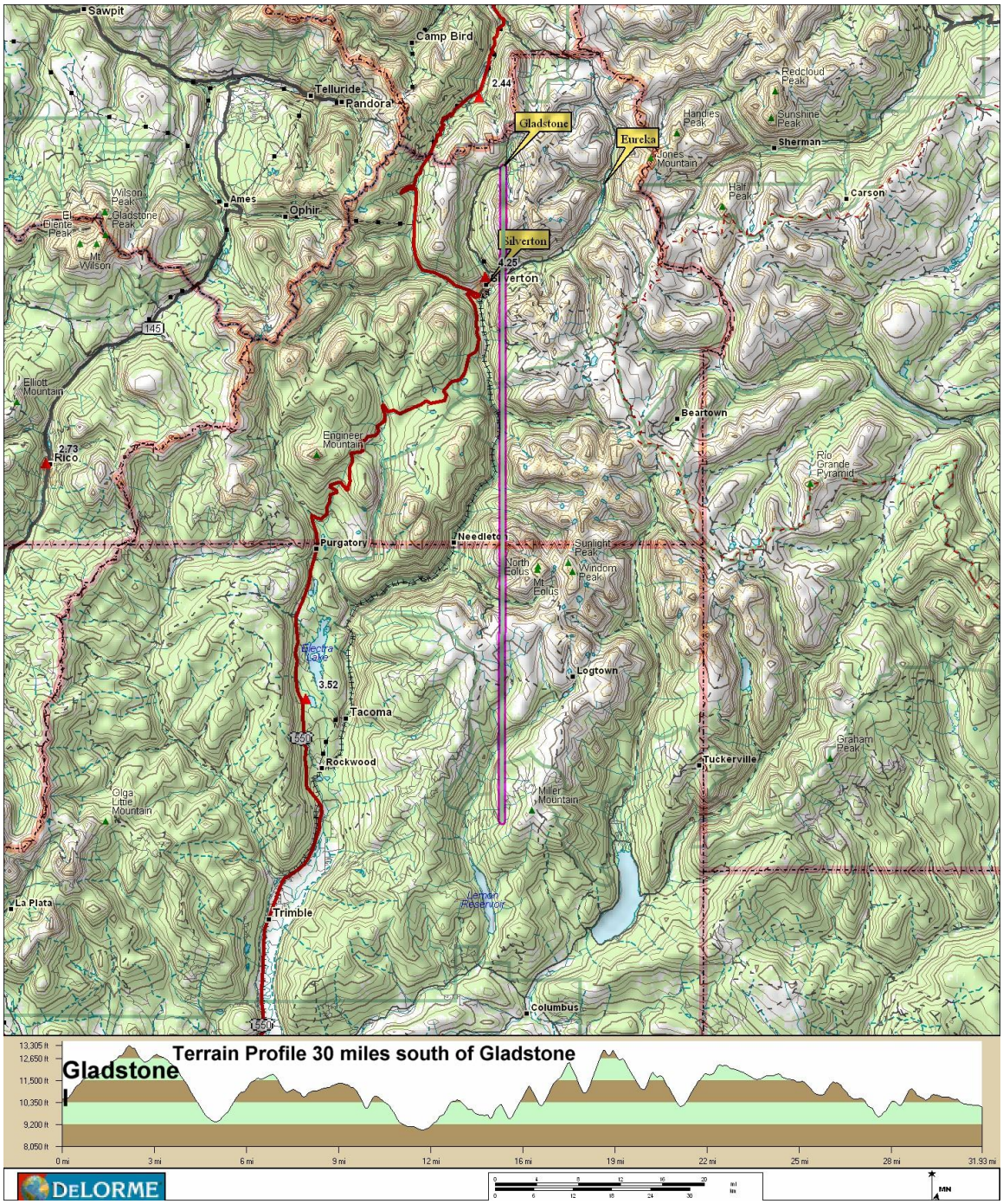


Figure 11. Map Showing Topography Surrounding Gladstone and the Terrain Profile to the South of Gladstone

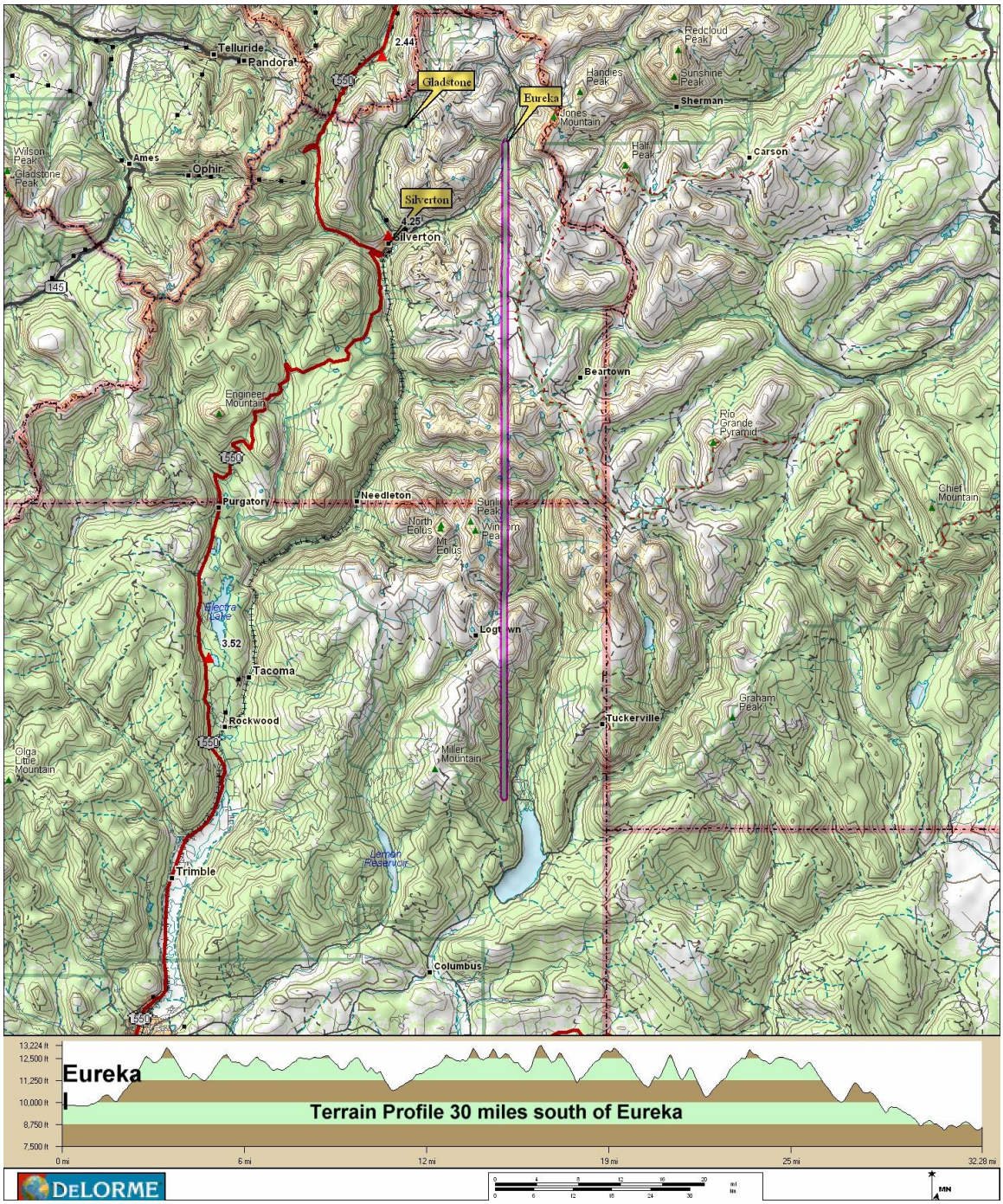


Figure 12. Map Showing Topography Surrounding Eureka and the Terrain Profile to the South of Eureka

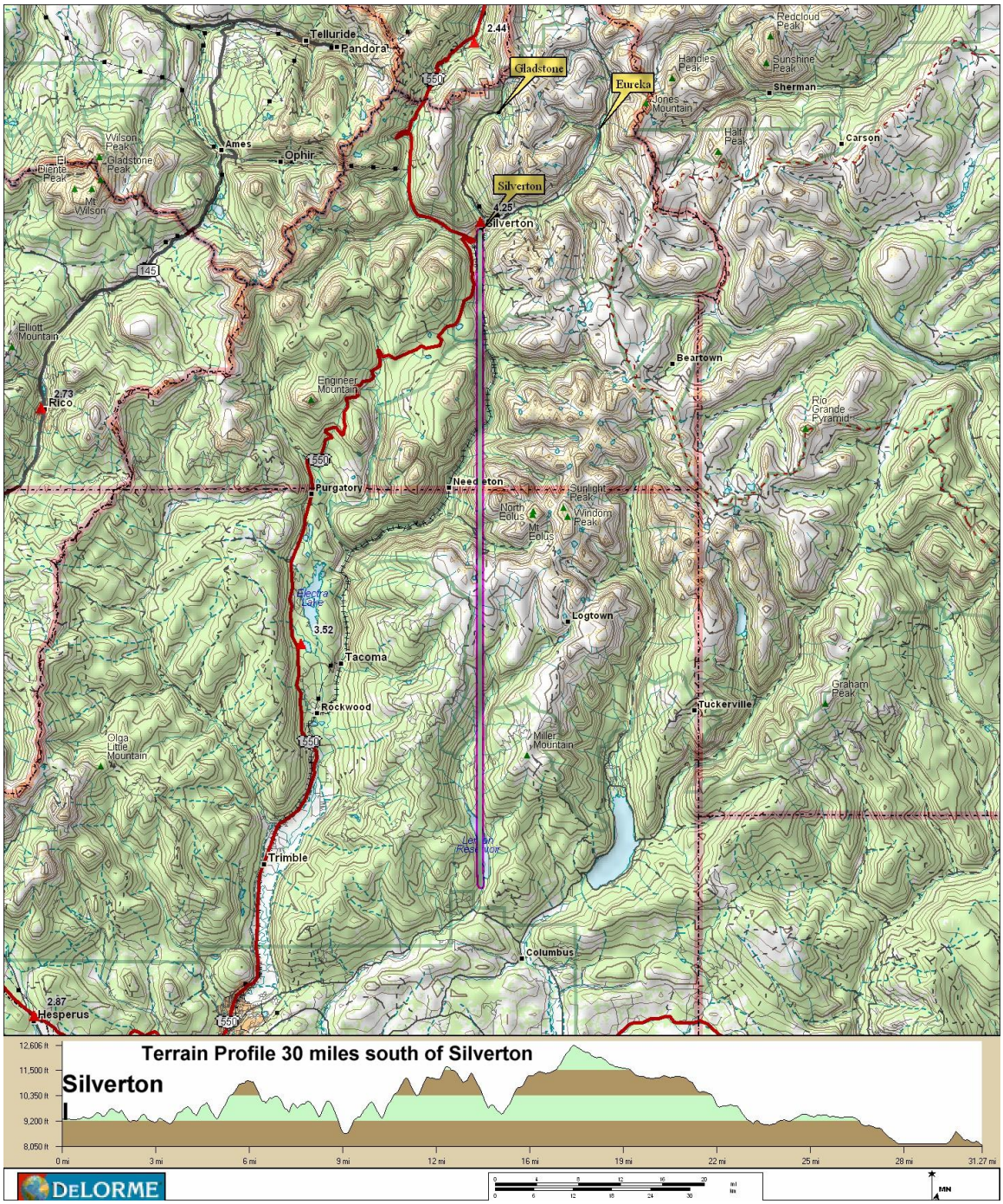


Figure 13. Map Showing Topography Surrounding Silverton and the Terrain Profile to the South of Silverton

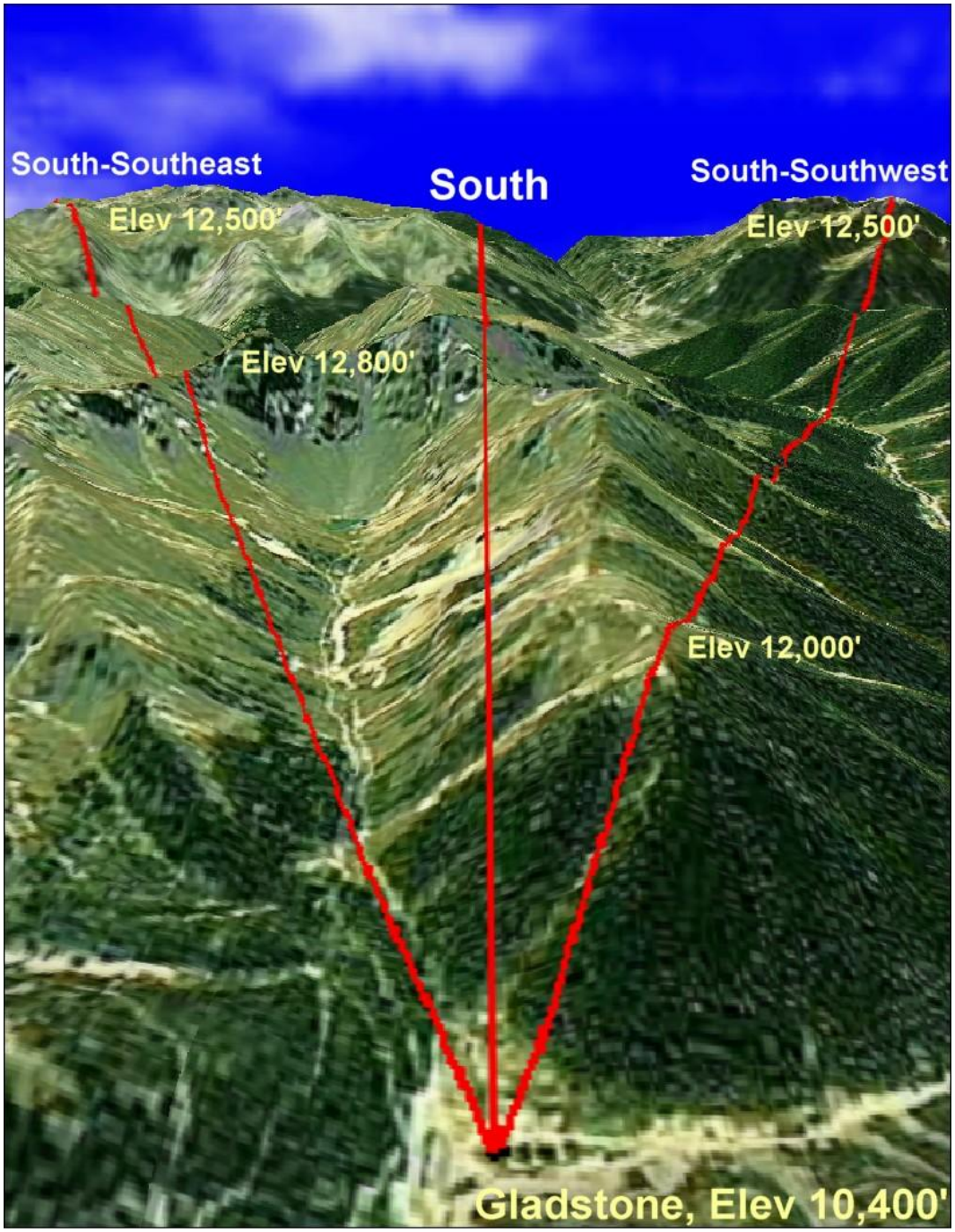


Figure 14. Three-dimensional View of the Terrain South of Gladstone with Inflow Vectors for the South-Southeast, South and South-Southwest Directions

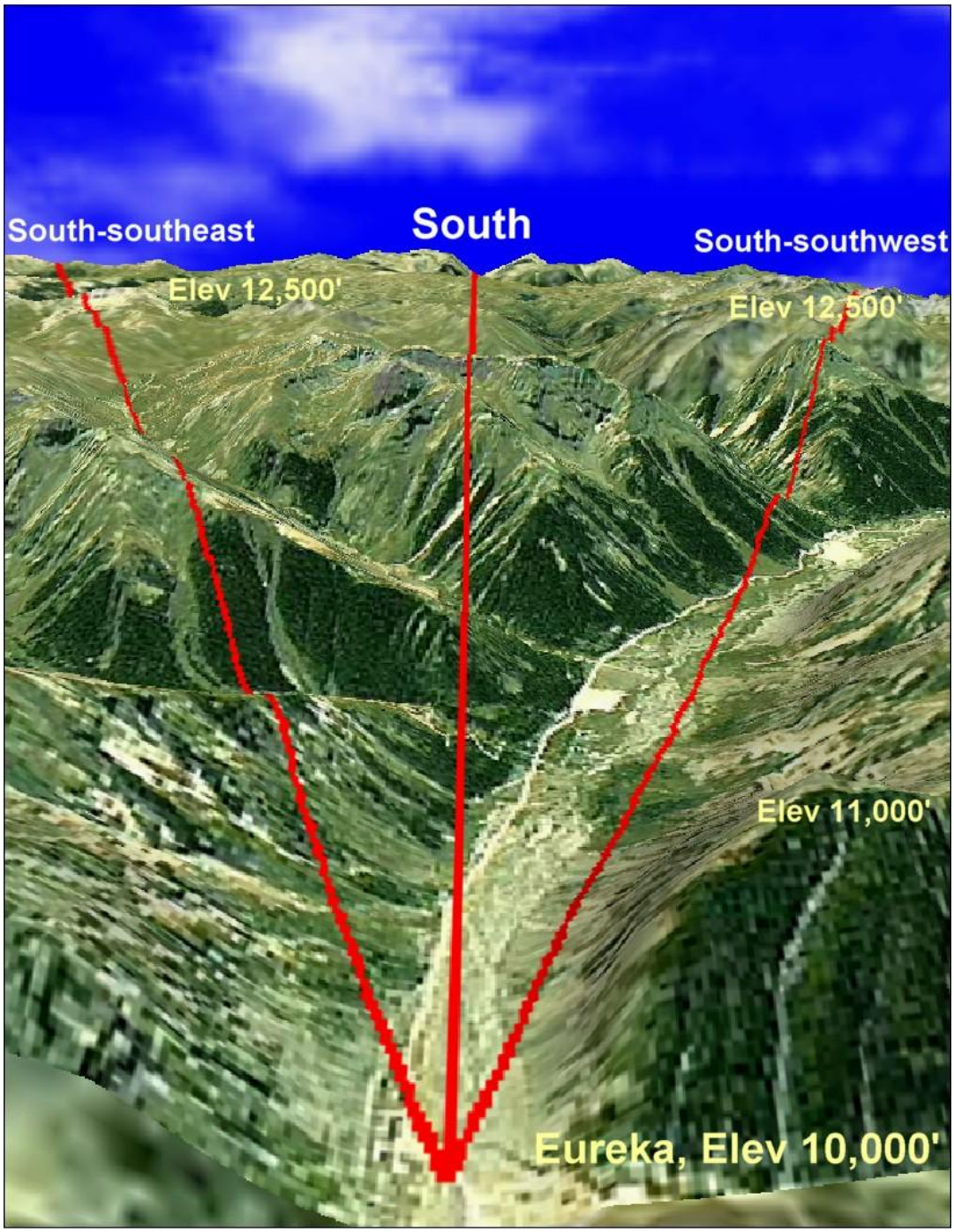


Figure 15. Three-dimensional View of the Terrain South of Eureka with Inflow Vectors for the South-Southeast, South and South-Southwest Directions

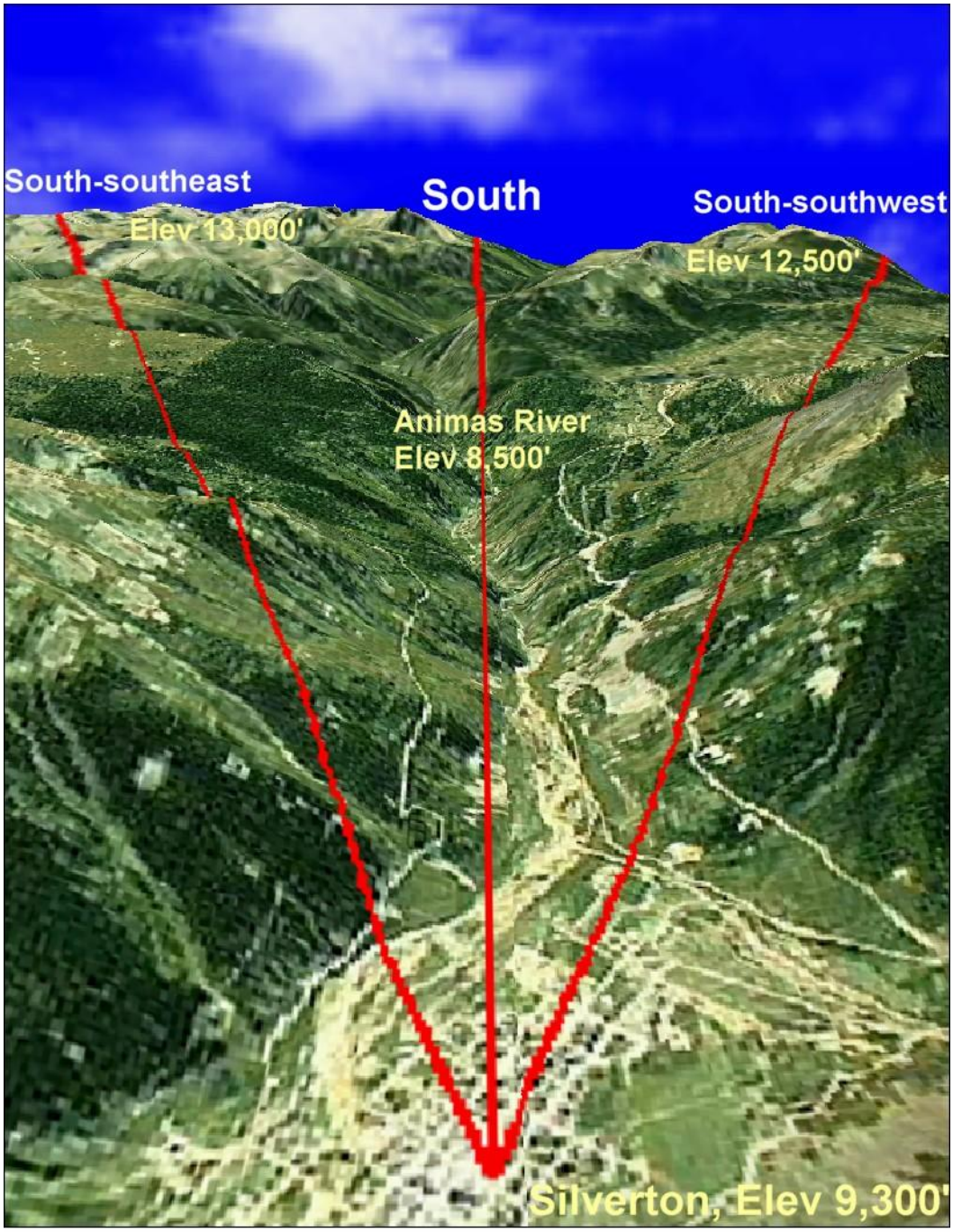


Figure 16. Three-dimensional View of the Terrain South of Silverton with Inflow Vectors for the South-Southeast, South and South-Southwest Directions

Figures 17. Photo taken from 0.5 miles north-northeast of Gladstone looking south-southwest, September, 2003.

Figure 18. Photo taken from Gladstone looking to the south, September, 2003. Storm Peak, elevation 13,380', is on the right two miles away.

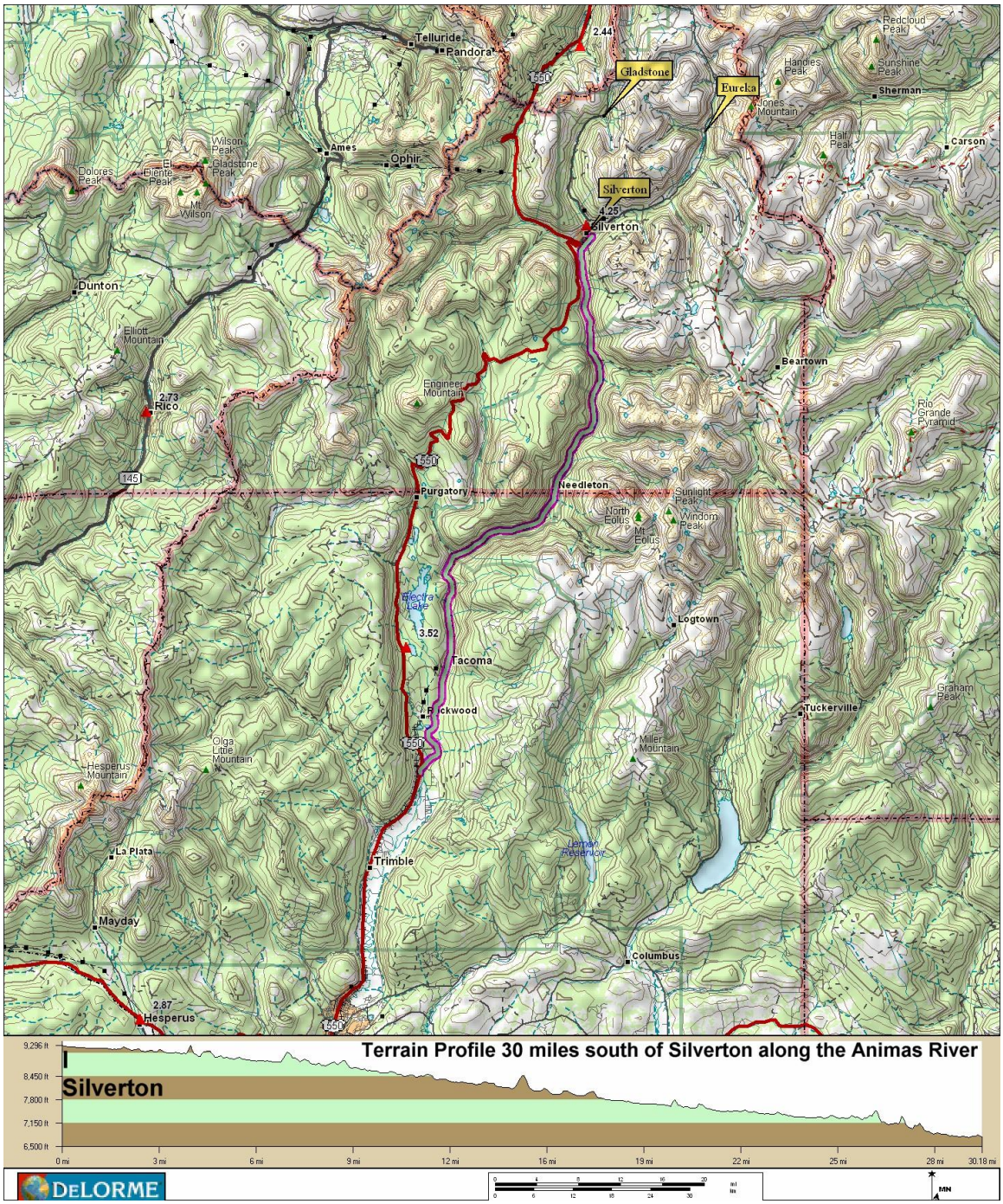


Figure 19. Map Showing Topography Surrounding Silverton and the Profile of the Animas River Valley South of Silverton

Reported Flooding

Pruess included in his thesis extensive discussions related to newspaper accounts related to 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. Figure 18 shows a picture taken in September 2003 of what is believed to be a similar bridge over Cement Creek below Gladstone. The fact that the bridges could be replaced or repaired in just a few days indicate that the flows were not much greater than bankfull and/or the destruction may not have been total (Pruess, 1996).

Figure 20. Bridge over Cement Creek below Gladstone, September 2003.

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 (Figure 21). Evidence for the occurrence 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 (Figure 22). 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

Figure 21 Cement Creek near Gladstone, 1912 (Sundance Publishing, Ltd.)

Figure 22. Cement Creek at Silverton, 1912 (Sundance Publishing, Ltd.)

Paleoflood Investigation

Jarrett and Pruess collected detailed paleoflood data for several locations in the region from Gladstone 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). The location is shown on the map in Figure 24.

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 23 and a step-backwater analysis. The computed preferred discharge is 424 cubic feet per second (cfs).

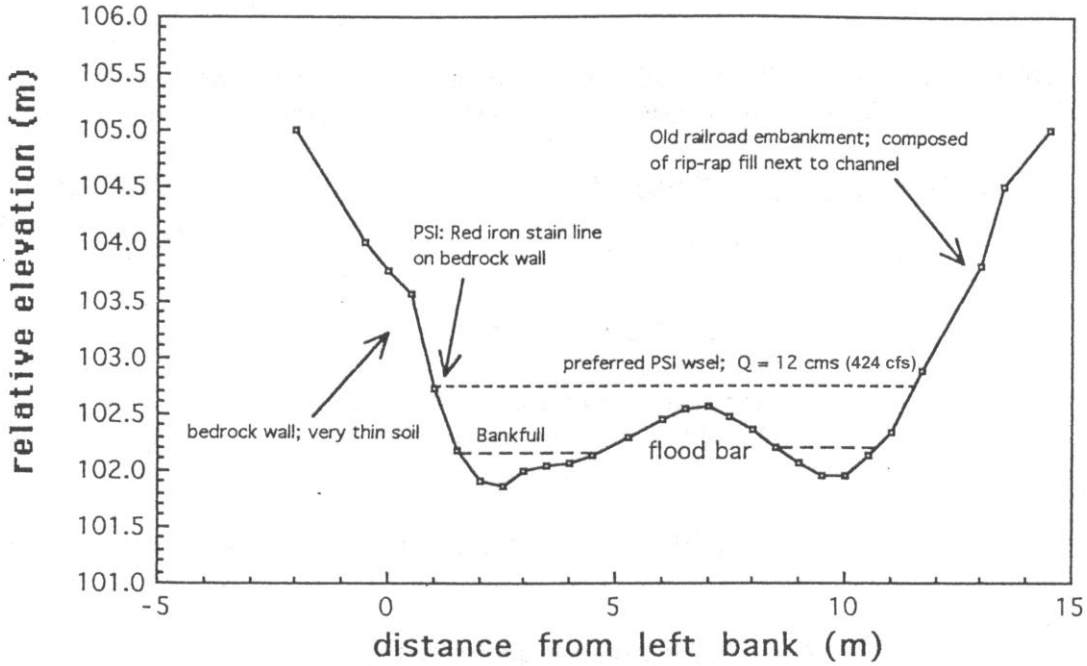


Figure 23. Preferred Water-Surface Elevation for the Cement Creek Paleoflood Site (Pruess, 1996)

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, Applied Weather Associates 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 24. The area of the drainage basin was computed to be 20.29 square miles.

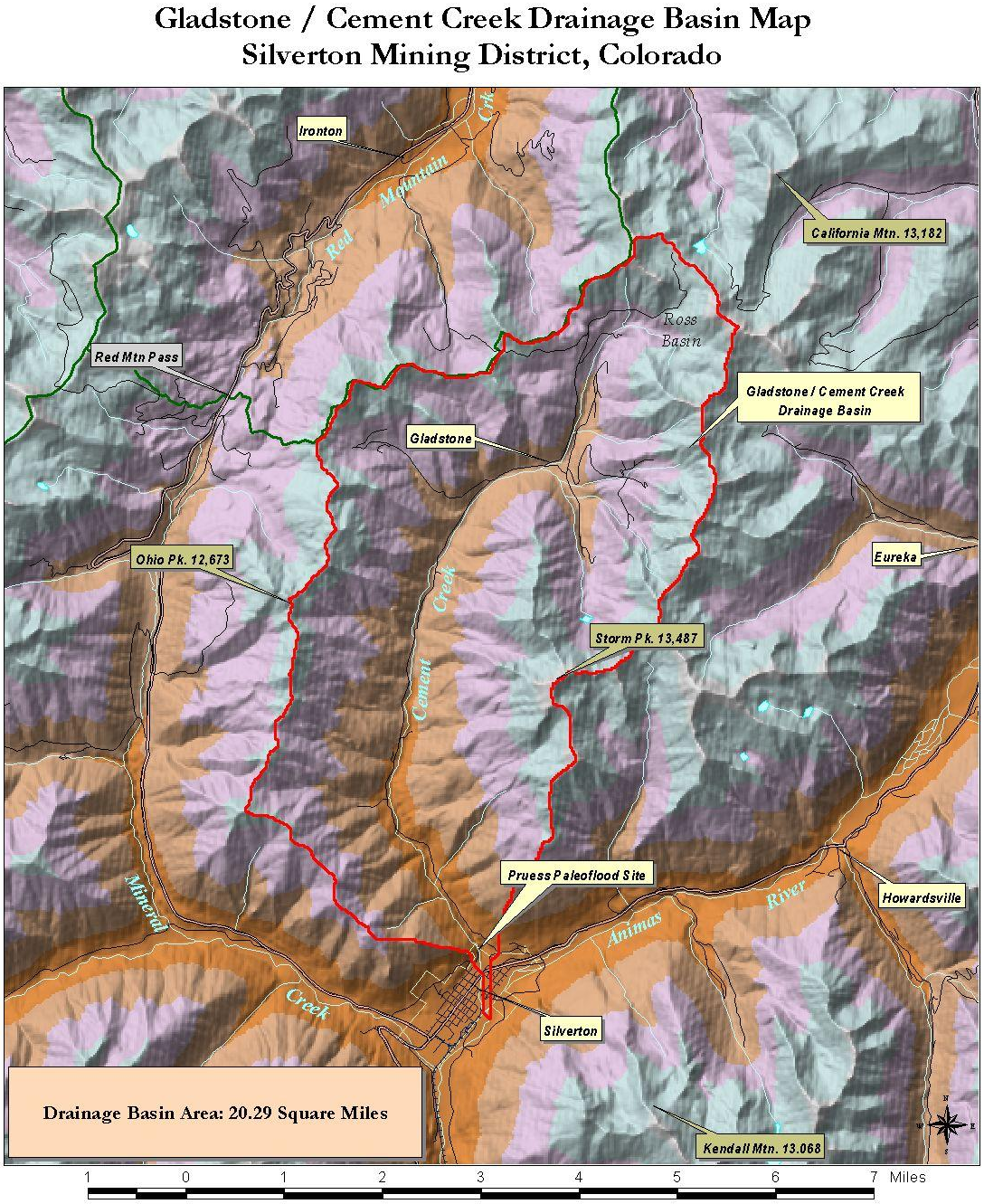


Figure 24. Cement Creek Drainage Basin Map

Four rainfall analyses were used in the rainfall/runoff modeling. Each used the mass curves presented in Figure 5. for timing of the rainfall. The first case used a previously analyzed isohyetal pattern while the other three cases used the AWA Storm Precipitation Analysis System (SPAS) isohyetal patterns. 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 is entered on the observation form (Figure 8), 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.

The isohyetal patterns for each of the four cases are presented in Figures 25-28.

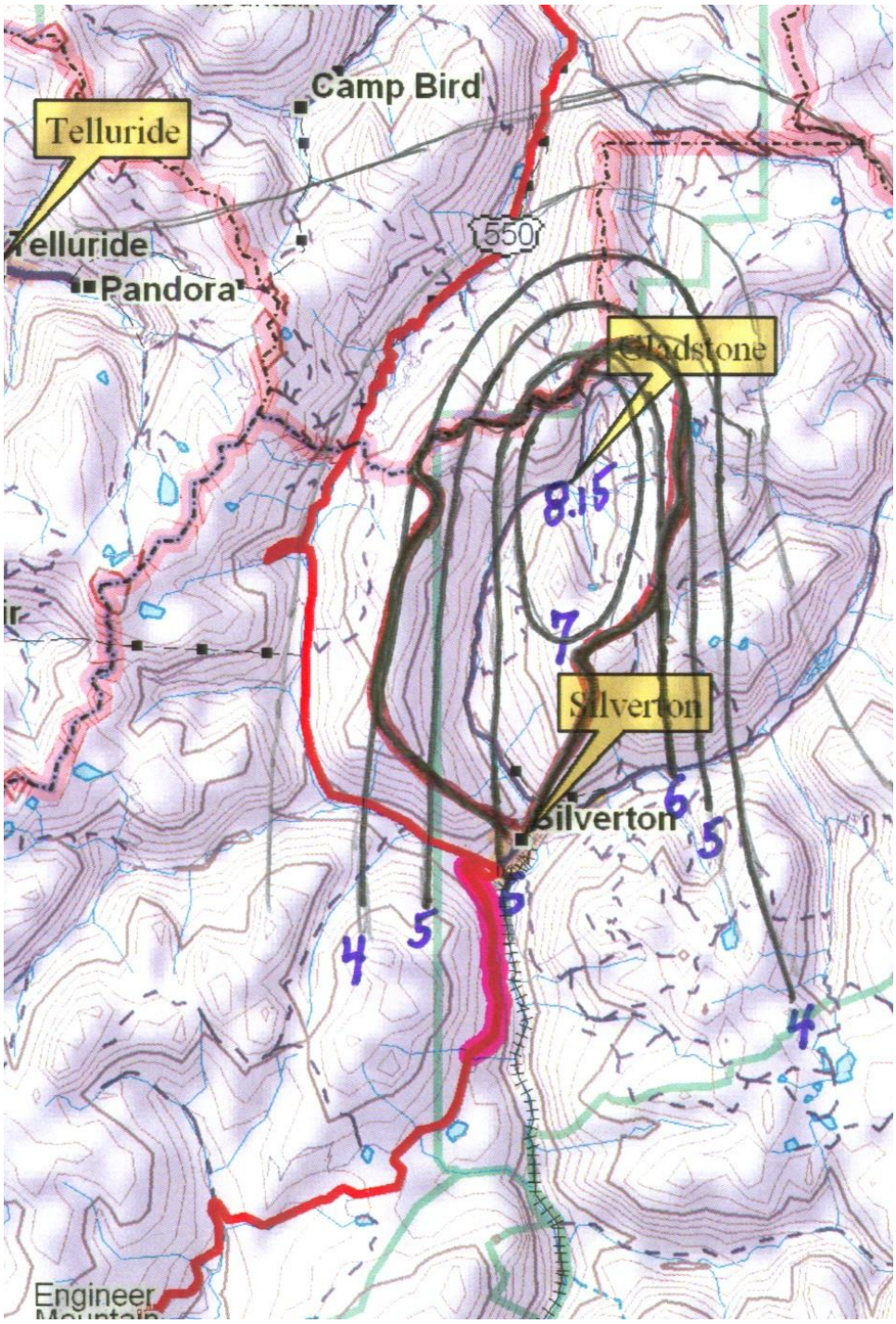


Figure 25. Adopted isohyetal pattern based on the Bureau of Reclamation isohyetal analysis (Pruess, 1996) , referred to as Gladstone "Previous"

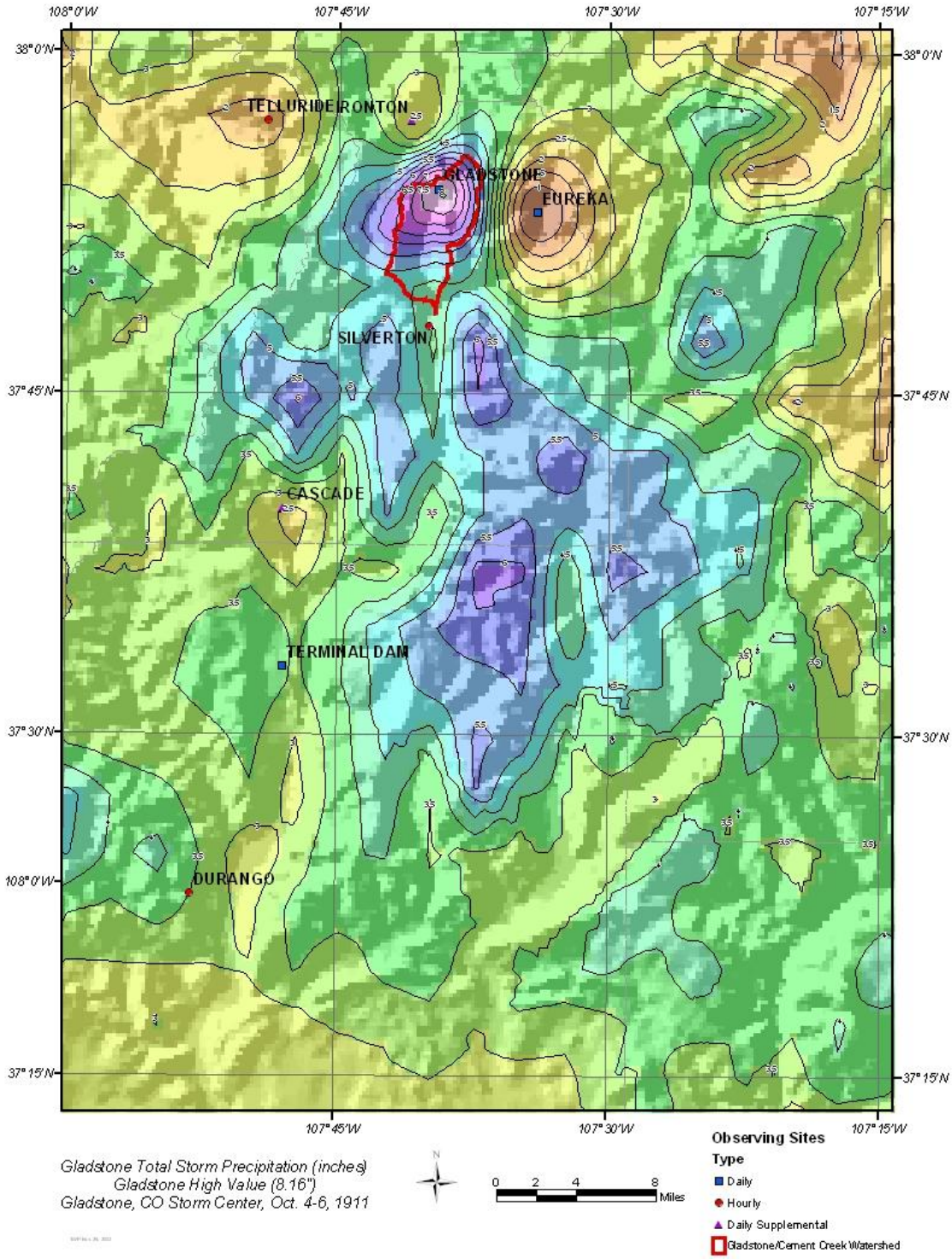


Figure 26. SPAS isohyetal pattern using the Gladstone observation of 8.05" on October 5, referred to as Gladstone "High"

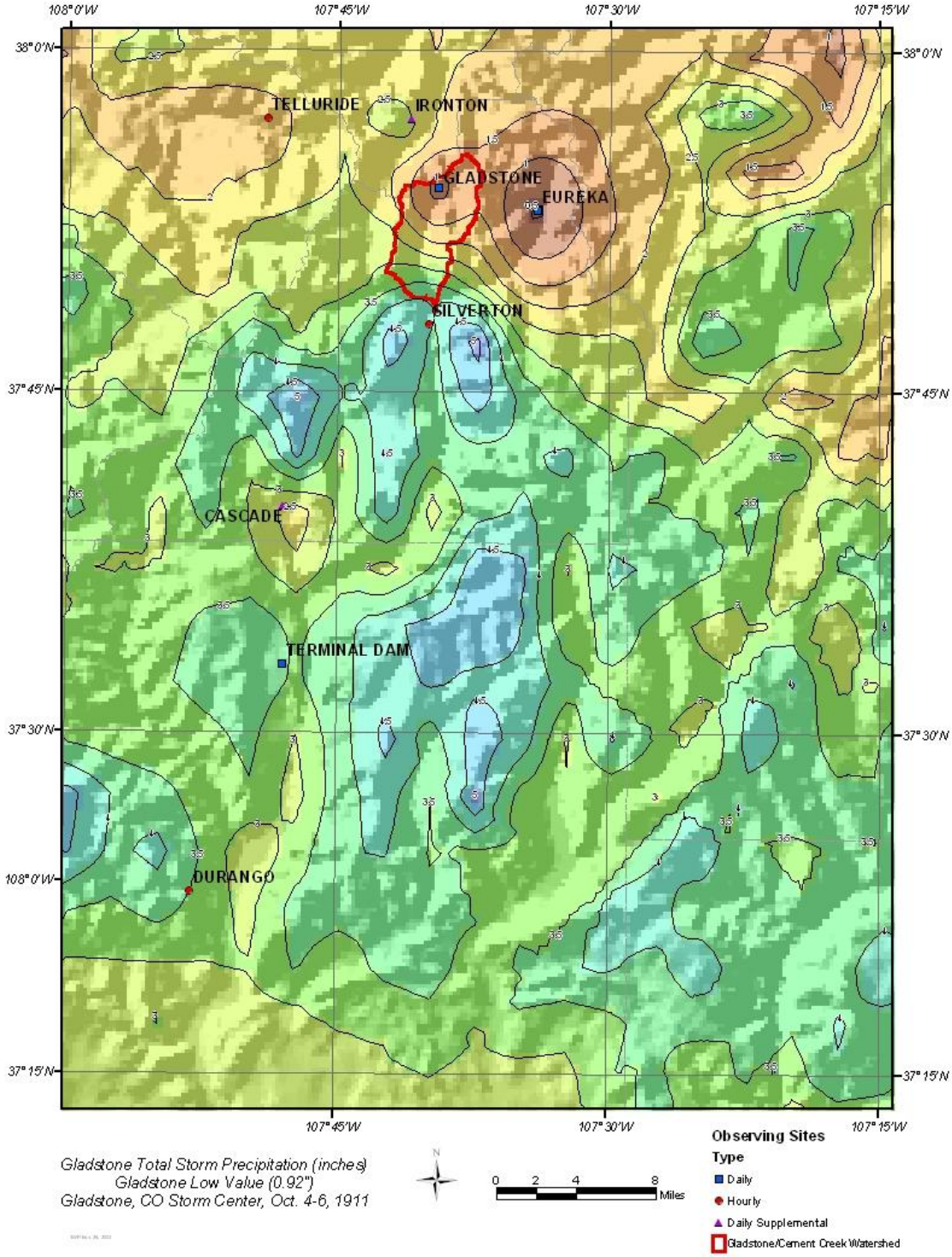


Figure 27. SPAS isohyetal pattern using a rainfall value of 0.81 for Gladstone on October 5, referred to as Gladstone "Low"

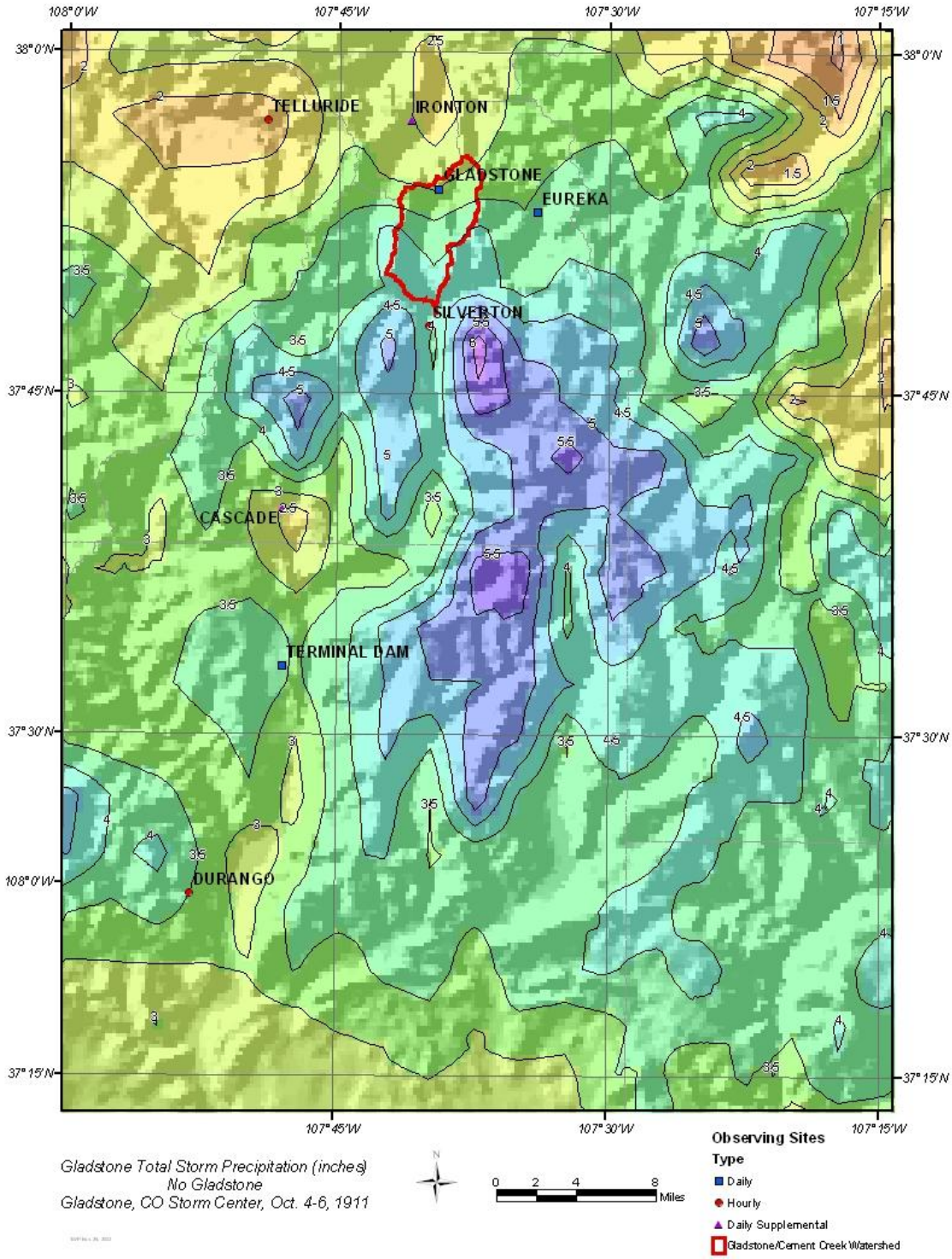


Figure 28. SPAS isohyetal pattern without either the Gladstone or Eureka observations, referred to as w/o Gladstone & Eureka

Runoff Modeling for the Cement Creek Drainage Basin

A rainfall/runoff (RF/RO) modeling study was performed for four different storm scenarios on Cement Creek near Silverton, Colorado for the purpose of providing additional information to help evaluate the validity of the 1911 Gladstone Storm reported rainfall amounts. The four storm scenarios are presented in the Rainfall Analysis section of this paper on p.35.

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. Being that Cement Creek drainage area is 20.19 mi^2, the drainage area for Native and Clear-cut Basins are 15.19 and 5.05 mi^2, respectively.

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 by 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 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 Jr., Arthur G., US Department of the Interior, Bureau of Reclamation, Denver Office, 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 a topographic map, average rainfall computed from storm isohyetals clipped to the basin boundary and rainfall distribution determined from historic meteorological data. Those values were provided by Applied Weather Associates. Based on historic accounts of the storms it was reported that 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, it was felt that the Cement Creek HEC-1 model was reasonable for evaluating the three 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 timing of the rainfall was based on Bureau of Reclamation mass curves obtained from the Colorado Climate Center (see Figure 5.). The first two cases, previous Bureau of Reclamation isohyetal analysis and a new SPAS isohyetal analysis, used the reported values of 8.05" at Gladstone for October 5. The computed average rainfall values over the Cement Creek drainage basin were almost identical, 6.14" and 6.25". The runoff modeling produced approximately 7,000 cfs for both cases. The third case used the same rainfall data except a value of 0.81" was used for Gladstone for October 5. The computed average rainfall value over the Cement Creek drainage basin was 1.94". The runoff modeling produced 1,300 cfs for this case. A fourth case was analyzed. The same rainfall data was used except no rainfall values were entered for either Gladstone or Eureka. The computed average rainfall value over the Cement Creek drainage basin was 3.68". The runoff modeling for this case produced approximately 3,500 cfs.

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 an order of magnitude 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 Gladstone or Eureka observations, the modeled runoff was significantly 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, more than an order of magnitude difference between the runoff modeling using the high Gladstone observation value and the paleoflood runoff value indicates a significant discrepancy. Although the runoff modeling results using the lower rainfall value at Gladstone does not agree with the paleoflood analysis, considering the errors associated with each computation and considering that the runoff modeling value is higher than the paleoflood value, the two analyses can be considered to be in general agreement. Using the rainfall analysis that excluded Gladstone and Eureka, the runoff modeled discharge is considerably larger than the paleoflood value. Since the basin average rainfall for this case was about 3.5 inches (a value consistent with the general rainfall observations of two to four inches in the region), the analysis suggest that indeed the Gladstone and Eureka drainage basins are in rainshadow regions of the high mountains to the south. Using a rainfall value for Gladstone on the order of that reported at Eureka provides a computed runoff more consistent with the paleoflood results and more consistent with the reported smaller flood along Cement Creek and the Animas River above Silverton compared with the significant flood along the Animas River below Silverton (Pruess, 1996).

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 is 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.

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