Precipitation Depth-Duration-Frequency Characteristics for Lake Tahoe Basin
An Evaluation of NOAA14

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Executive Summary

1. The purpose of this study is to evaluate the precipitation depth-duration-frequency (ddf) curves published in NOAA14 by comparing these curves to those estimated from the NRCS SNOTEL data available in the Lake Tahoe Basin that was not used in the original NOAA14 analysis.
2. The available gage data limited the basin elevations and frequency curve durations where the NOAA14 estimates could be evaluated.
   2.1. The NOAA14 study encompassed a wide region of the southwestern U.S Precipitation gages from a number of different sources were used in estimating ddf curves. However, Only NOAA COOP gages were used that had a reasonable proximity to the Lake Tahoe Basin in the NOAA14 study. These gages were limited to either hourly or daily observations, and were located below elevation 7500 feet. NRCS SNOTEL gages in the study area were not considered to have sufficient record length at the time of the study.
   2.2. Analysis of the eight SNOTEL gages located within the basin provide much more information about precipitation variation in the basin than was available for the NOAA14 study.
   2.3. Significant concerns regarding the limitations of the data base used in NOAA14 results are that: 1) Only two daily gages (Glenbrook Creek and Tahoe City) were used that are located in the basin, 2) a significant extrapolation of the analysis results needs to be made for 60minute and 24hour duration ddf curve for elevations greater than 7500 feet and, 3) a significant extrapolation was needed to obtain ddf curves for durations less than 60 minutes given that there are no short duration gages in proximity to the basin.
   2.4. The SNOTEL data does provide some coverage to about the 9000 foot elevation, although the coverage is not uniform across the basin. Analysis of this data can be used to evaluate the extrapolation of NOAA14 results above 7500 feet for 24hour and 60 minute durations. Conclusions cannot be made regarding estimates above 9000 feet.
   2.5. An evaluation of the NOAA14 for ddf curves for durations less than 60 minutes cannot be made given the data available. However, application of NOAA14 estimates for durations less than 60 minutes requires a great of leap faith given the lack of data available. Then again, no other information is available to obtain these short duration estimates.
3. Gage measurement error for snow precipitation can potentially cause some significant bias towards under reporting.
   3.1. A frequency analysis of NOAA COOP gage record indicated that snow is a significant proportion of annual maximum daily precipitation for exceedance probabilities greater than 0.1 (10 year) event.
   3.2. The implications of the measurement error on estimating ddf curves is not entirely clear because it probably only affects the more frequent events. However, the potential exists that the measurement error will bias the mean annual maximum 24hr precipitation (generally less than the 10 year event) which is key to the use of PRISM to mapping the ddf curves in the NOAA14 methodology.
4. The NRCS SNOTEL data needed to be filtered to be useful in analyzing the available hourly data.
   4.1. The raw data can oscillates due to the variation in heating of the SNOTEL gage form diurnal variation in daily temperature. However, this variation does not occur during

the small range in diurnal variation during winter events. Consequently, winter storm rainfall is adequately reported by the SNOTEL gages

4.2. The temperature affects are significant during the summer, meaning that accurate estimates of summer precipitation could not be obtained. However, summer rainfall does not appear, based on analysis of NOAA gages, be a factor in estimating annual maximum daily or hourly precipitation statistics.

5. The analysis of the SNOTEL and NOAA gage data demonstrated that NOAA14 adequately estimates the 24hour and 60minute ddf curves. This conclusion is limited to elevations below 7500 feet and does not apply to durations less than 60 minutes (see 2).

5.1. Comparison of 60minute/24hour ratios demonstrated that period of record values estimated from SNOTEL and NOAA gage records agree well with those obtained from NOAA14 ddf curves.

5.2. A regional L-moment frequency analysis of the SNOTEL data resulted in estimated 24hour ddf curves that agree very closely with those obtained from NOAA14

6. An analysis was performed to identify the relationship between rainfall and precipitation frequency curves.

6.1. Rainfall frequency curves might be useful in applications to estimating design runoff from paved surfaces or where the analysis technique would be to simulate rainfall and add a base flow to account for the snowmelt contribution.

6.2. Rainfall frequency curves could be reasonably defined for daily precipitation, but not so for the 60 minute duration. It might be possible to use NOAA14 ddf relationships in concert with derive daily rainfall estimates to obtain 60 minute rainfall frequency curves.

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References:

Bogdanova, E.G., Ilyin, B. M., and Dragomilva, I.V., 2002. Application of a comprehencisve bias-correction model to precipitation measured at Russian North Pole drifting stations, *Jour. of Hydrometeorology*, **V**(3), p700-713.

Goldman, D. M., and Baldwin, T., 2005. Derivation of Watershed Modeling Parameters for use in a Drainage Design Manual for Lake Tahoe Basin, California-Nevada. Cold Regions Research and Engineering Laboratory, US Army Corps of Engineers, Hanover, NH, prepared in cooperation with, Sacramento District, US Army Corps of Engineers and the Lake Tahoe Storm Water Quality Improvement Committee, Lake Tahoe California-Nevada.

Greenlee, Dan, 2004. Personal Communication regarding precipitation measurement error for Lake Tahoe NRCS SNOTEL gages, dan.greenlee@nv.usda.gov, May.

Hosking, J.R.M., and, Wallis, J.R., 1997. Regional Frequency Analysis, An Approach Based on L-Moments, Cambridge University Press, New York, 224p.

NCDC, 2006. Climate data, including NOAA Cooperative Precipitation Data, National Climatic Data Center Web-Site,
http://www.ncdc.noaa.gov/oa/climate/stationlocator.html

NRCS, 2006. SNOTEL data, National Resource Conservation Service Web-Site,
http://www.wcc.nrcs.usda.gov/snotel/California/california.html

NWS, 2006. NOAA Atlas 14, Precipitation Frequency Atlas of the United States, Volume 1, Semiarid Southwest (Arizona, Southeast California, Nevada, New Mexico and Utah), National Weather Service, Hydrometeorological Design Studies Center
http://hdsc.nws.noaa.gov/hdsc/pfds/index.html

Smith, J.A., 1992. Handbook of Hydrology, ed. Maidment, D.R., Chapter 3: “Precipitation”, McGraw-Hill.

Taylor, G.H., C. Daly and W.P. Gibson, 1993: Development of an Isohyetal Analysis for Oregon Using the PRISM Model, *The State Climatologist*, National Climatic Data Center, NOAA, Asheville, NC.

1. Introduction

The purpose of this report is to evaluate the applicability of the NOAA14 (NWS, 2006) precipitation depth-duration-frequency (ddf) curves to the Lake Tahoe Basin. The ddf curves play an important role in tradition drainage design problems; and, may be important in applications of best management practices intended to meet water quality objectives

The development of the NOAA14 curves was done without considering the available SNOTEL precipitation data (NRCS, 2006) in the basin Part of the reason for not using this data was the limited period of record available at the time when NOAA14 was being developed; and partly, because there was some concern about data quality. However, since this time, the SNOTEL gage record available has become significant. Furthermore, a preliminary investigation indicated that the data was valuable.

The comparison is limited by the data available described in section 2. The available limits the analysis to comparison of the 24 hour and 60 minute frequency curve durations and to elevations below 9000 feet. Comparisons for shorter duration precipitation or greater evaluations cannot be performed because of the lack of the data.

This limited data requires a significant amount of faith in applying NOAA14 in the Lake Tahoe Region. As is discussed in section 2, **no** short duration (less than 60minute) gages are located in the Lake Tahoe Basin or at any elevation that would verify the NOAA14 the ratio of 60minute to shorter duration precipitation used to compute depth-duration frequency curves. Furthermore, the location of the vast majority of gages used in the NOAA14 study lie below 7,500 feet. Computation of frequency curves for greater elevations depends greatly on faith in the extrapolation of the PRISM (Taylor, 1993) regression relationships. The analyses performed in this study cannot evaluate this extrapolation of regression relationships for the 60minute to short duration ratios. **Those performing drainage design analysis in the Lake Tahoe Basin should be cognizant of the limitation that available data has on the accuracy of NOAA14 or other depth-duration-frequency relationships developed for the Lake Tahoe basin because of this lack of gage data**.

An analysis was performed that used both the SNOTEL gages and NOAA cooperative gages (NCDC,2006) to develop ddf frequency curve relationships for comparison with those obtained in NOAA14 for the 24hour and 60 minute durations. Sections 3 and 4 respectively compare the relationship between 24hour and 60minute ratios and the ddf curves obtained using the SNOTEL and NOAA gage data with that published in NOAA14.

Finally, section 5 provides an analysis of rainfall-frequencies in the Lake Tahoe Basin. NOAA14 provides precipitation ddf curves which includes both snow and rain. Converting precipitation information to design runoff requires some assumptions regarding the coincident occurrence of storm temperature to compute design flows. A rainfall frequency curve would perhaps provide more direct information for developing design flows, particularly for paved areas such as in highway drainage design. Section 6 provides the base empirical gage frequency curves used in the L-moment frequency analysis of section 4.

2. Data Base

2.1.Introduction

The purpose of this section is to describes both the gage data basin available for the Lake Tahoe Basin and the implications of the quality of this data for estimating depth-duration-frequency (ddf) curves. In section 2.2, the potential limitations of the NOAA14 analysis for application to the Lake Tahoe Basin given the gage data available is discussed . Section 2.3 describes the gage data base used in this study that includes the SNOTEL gages not used in the NOAA14 analysis. Section 2.4 assesses the impact of snow precipitation gage measurement error on the estimation of precipitation ddf curves. Besides the general problem of gage measurement error, filtering of the SNOTEL data was required to obtain hourly estimates because of the effects of diurnal temperature variation on gage measurements as is discussed in Section 2.5.

2.2. NOAA14 gage data base

The NOAA14 study used two daily/hourly gages on the outskirts of the basin (Truckee RS and Mt. Rose Christmas Tree) and two daily gage within the basin (Tahoe City and Glenbrook) (see Table 2.1). Note that although hourly data is available for Mt. Rose Christmas Tree it was not used in NOAA14, possibly because of quality control issues. Figure 2.1 shows that the location of N-minute gages (gages capable of recording precipitation at less than 60 minute intervals) do not exist near the basin.

The available gages do not provide information on hourly precipitation within the basin. No gages exist at elevations for providing data greater than 7500 feet ; or, N-minute interval data for estimating ddf curves relevant to the basin. The NOAA14 analysis relies on a linear extrapolation of mean annual precipitations estimates using the PRISM regression methodology (see Taylor, 1993 and NWS, 2006) to obtain ddf curves for duration of 60 minutes or greater. Estimated N-minute ddf curves are based on the ratios found from the few stations available in the study (see Table 2.2).

Consequently, the limited gage data base causes the following concerns regarding the NOAA14 application to the Lake Tahoe Basin:

- Only one gage was available within the basin to obtain 24 hour ddf estimates and 60 no hourly gages were available;
- A significant extrapolation of the PRISM regression analysis was needed to obtain results for elevations greater than 7500 feet. NRCS SNOTEL gages do cover elevations up to almost 9000 feet, although the coverage is not uniform. Consequently, the analysis performed in this report using the NRCS SNOTEL gages can at best make an evaluation up to about the 9000 foot elevation.
- There is almost no evidence to suggest that ratios shown in Table 2.2 for estimating N-minute ddf curves is relevant to the meteorologic condition within the basin.

Perhaps most disturbing is the extrapolation of the N-minute ratios because the N-minute ddf curves are critical to small scale drainage design. Since PRISM recognizes that elevation is the primary explanatory variable for mapping precipitation variation, there is not much reason to assume that the N-minute/60minute ratios shown in Table 2.2 are valid for Lake Tahoe. Having said that, there is no other information available to obtain estimates. At the very least, the NOAA14 web site needs to be clear about the limitations of the analysis. A caveat for these estimates perhaps should be reported along with the ddf estimates.

This report can only address the first concerns listed where the analysis of the available SNOTEL gages can be used to verify the NOAA14 results for the 24hour and 60minute ddf curves given the data available up to about the 9000 foot elevation..

Table 2.1: SNOTEL and NOAA gages

Gage	ID	Elev	Latitude	Longitude	Period of Record
NOAA Cooperative					
[3]Mt. Rose Christmas Tree (H/D)[5]	265441	7235	39.34222	119.8636	010CT1971-01OCT2000
[3]Truckee RS (H/D)	049043	6020	39.3311	120.8192	01JAN1948 - 01JAN2001
Daggett Pass	262119	7334	[1]38 59	119 53	01JAN1988 - 01JAN2001
[3]Glenbrook Creek	263205	6350	[1]39 05	119 56	01JAN1948 - 01JAN2001
[4]Tahoe City	048758	6240	39.167	120.1330	01JAN1931 - 01JAN1999
Meyers Inspection	045572	6345	[1]38 51	120 01	01JAN1955 - 01JAN1969
NRCS SNOTEL					
Big Meadow	19K08S	8249	39.45503	119.942217	01JAN1983 - 01JAN2005
CSSLAB	20K31S	6855	39.3256	120.368067	01JAN1983 - 01JAN2005
Independence Camp	20k03S	6456	39.40167	120.21823	01JAN1980 - 01JAN2005
Independence Ck.	20K04S	7003	39.4528	120.292683	01JAN1978 - 01JAN2005
Mt. Rose Ski	19K07S	8801	39.31573	119.894733	01JAN1980 - 01JAN2005
[4]Echo Peak (H/D)	20L06	7670	38.84903	120.0785	01JAN1980 - 01JAN2005
[4]Fallen Leaf (H/D)	20L10	6236	38.93405	120.0545667	01JAN1979 - 01JAN2005
[4]Hagan's Meadow(H/D)	19L03	7776	38.85185	119.9374167	01JAN1978 - 01JAN2005
[4]Heavenly Valley (H/D)	19L24	8582	38.92433	119.9164667	01JAN1978 - 01JAN2005
[4]Marlette Lake (H/D)	19K04S	7880	39.16395	119.8967167	01JAN1978 - 01JAN2005
[4]Rubicon #2 (H/D)	20L02	7689	38.9992	120.1303167	01JAN1980 - 01JAN2005
[4]Squaw Valley G.C. (H/D)	20K30	8029	39.18998	120.26475	01JAN1980 - 01JAN2005
[4]Tahoe City Cross (H/D)	20K27S	6797	39.17162	120.1536167	01JAN1980 - 01JAN2005
[4]Ward Creek #3 (H/D)	20K25S	6655	39.13562	120.2176333	01JAN1978 - 01JAN2005

[1]Degrees and minutes, [2] NOAA14 gages, [3]Hourly and Daily data available for gage [5](H/D)
[4]Gages within the Lake Tahoe Basin

Table 2.2: Ratio between NOAA14 60 min and shorter duration precipitation depths (reproduced from Table 4.1.3, NWS, 2006)

	5-min	10-min	15-min	30-min
NOAA Atlas 14 Volume 1	**0.318**	**0.484**	**0.600**	**0.808**
NOAA Atlas 2	*0.29*	*0.45*	*0.57*	*0.79*
Arkell and Richards, 1986	*0.34*	*0.52*	*0.62*	*0.82*

Figure 4.1.5. Regional groupings for n-minute data for NOAA Atlas 14 Volume 1.

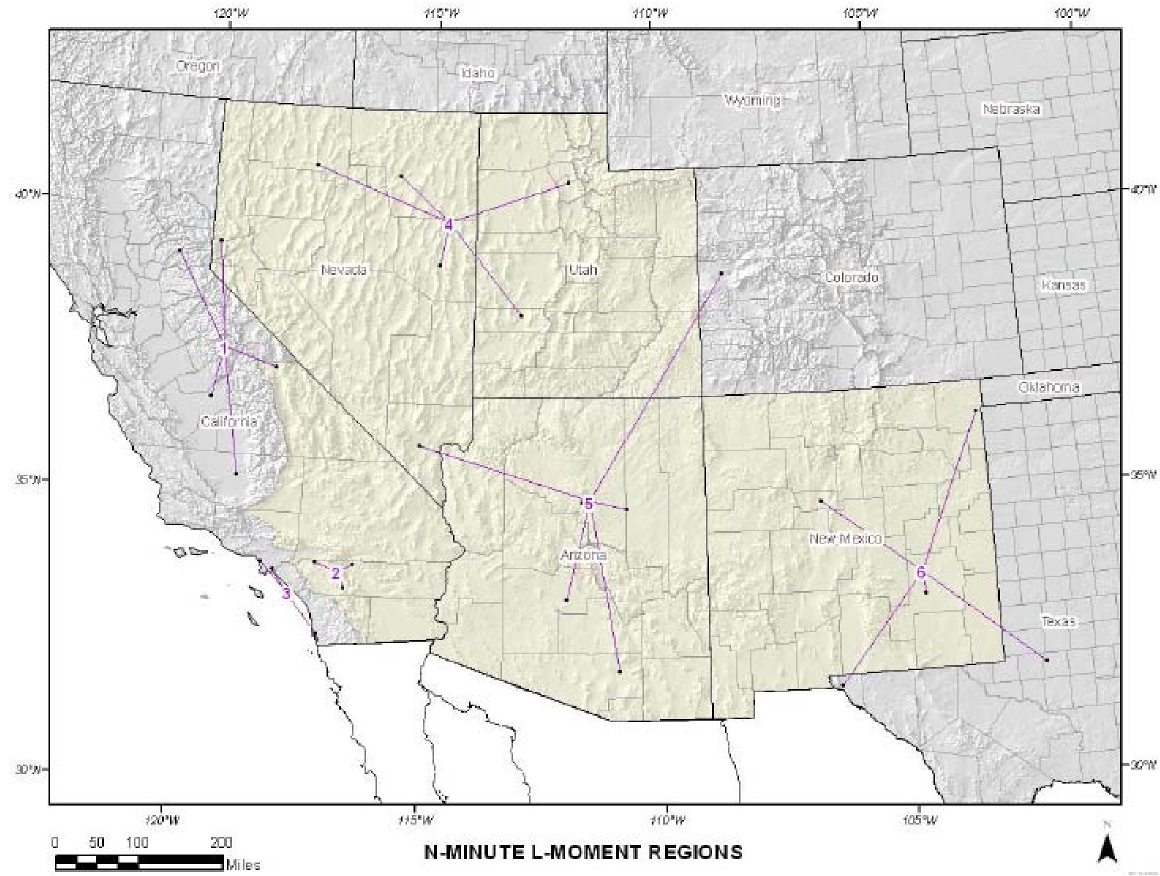

Figure 2.1: Location of NOAA14 short duration (less than hourly) recording gage

2.3. Gage Description

The precipitation gages used in this evaluation of NOAA14 (see Table 2.1) are either within the Lake Tahoe Basin our located in close proximity to the basin boundary. The NOAA cooperative gages (NCDC, 2006) either had daily and hourly or daily data available. The NRCS SNOTEL (NRCS, 2006) data is irregular interval, allowing the derivation of hourly or daily interval data.

The unfortunate aspect of the SNOTEL data is that for much of the available record is only daily data. However, starting in 1993 3hr-6hr intervals were recorded. It was not until the afternoon of January 1, 1997 (the major new years day storm in Lake Tahoe) was hourly data recorded.

The lack of hourly data available from the SNOTEL gages was a major disappointment since one important goal of the study was to compare 60minute/24hr annual maximum ratios obtained from gages and those provided in NOAA14. The NOAA cooperative gages provided a longer record of information on these ratios than the SNOTEL data.

2.4. Gage measurement error

The purpose of this section is to acknowledge that the snow precipitation measurement error can introduce some significant bias in estimates of Lake Tahoe Basin ddf curves. Snow precipitation is a dominant factor in precipitation events within the Lake Tahoe. . As Smith (1992) points out, the measurement error for snow is greater than that of rain. Consequently, quantifying the rain versus snow ratio in a precipitation event as a function of storm exceedance probability is important to understanding the potential bias introduced by gage measurement error.

Figure 2.2 displays the runoff, temperature and measures precipitation at the Fallen Leaf Lake gage for the 01Jan1997 storm, the flow event of record in the Lake Tahoe Basin. This storm had a high percentage of rainfall, even at relatively high elevations (above 8000 feet). Examination of the temperature record indicates that air temperature persisted above freezing for the first one and half days of the event. The conclusion that might be made from this single event is that very large events have high energy and are relatively warm compared to frequently observe events. Consequently, the measurement error for large infrequent storms would be relatively small because the major part of the event is dominated by rain.

This conclusion is perhaps born out by a frequency analysis of both annual maximum daily rainfall and precipitation for the Tahoe City gage shown in Figure 2.3 (see section 5 for the derivation of this curve). As can be seen, the curves separate significantly for storm events with exceedance probabilities greater than 0.1 (the 10 year events). Although the period of record is limited, it may not be unreasonable to assume that measurement error affects the precipitation depth estimated for event more frequent than 0.1

Bodganova et al. (2002) identifies the factors that might affect precipitation gage measurements of snowfall measurements:

- aerodynamic error – the affect of wind on direct capture of falling snow;

- false precipitation – the blowing of drifted snow from the ground surface into the gage;
- trace precipitation – precipitation recorded as 0.0 because depth was smaller than smallest gage measurement gradation;
- gage interior influence – joint effect of wetting, evaporation and condensation within the gage interior.

The actual bias measured by these researchers for gages in the North Pole is probably not relevant to the Lake Tahoe Basin gages, but the cause and effects are relevant.

More specific experience on measurement error for the SNOTEL gage network is reported by Greenlee (2004):

> *1. During storms with strong winds the snow simply blows over the top of the gage and it just simply doesn't fall in and therefore is not "counted".*
>
> *2. At some of the higher sites, especially, the prec gages can cap over with snow. I've been into some of our sites in the middle of winter and seen up to 2-3 feet of snow sitting on top of the prec gage. Obviously this won't be measured at the site until things warm up and the cap of snow melts down into the gage. At a couple of our more wind prone sites, prec typically measures much less water than what the* **[snow]** *pillows do for a given storm.*

Note: [ ] added for clarity

The under prediction of precipitation due to the occurrence of snow necessarily adds some bias to both the at-gage ddf analysis and the mapping of these results using PRISM. The impact of the bias on the at-site curves is not easy to discern since the largest event in the period of record are not affected, perhaps as greatly, being rainfall dominated. However, the mean depths used to estimate the ddf curves are probably influenced by the snow measurement error. This error in had some potential for having an important influence on mapping NOAA14 ddf curves since PRISM is used to map the mean. NOAA14 uses the PRISM estimated mean at any location together with a dimensionless ddf curve to compute ddf relationship at the location (see section 4.4).

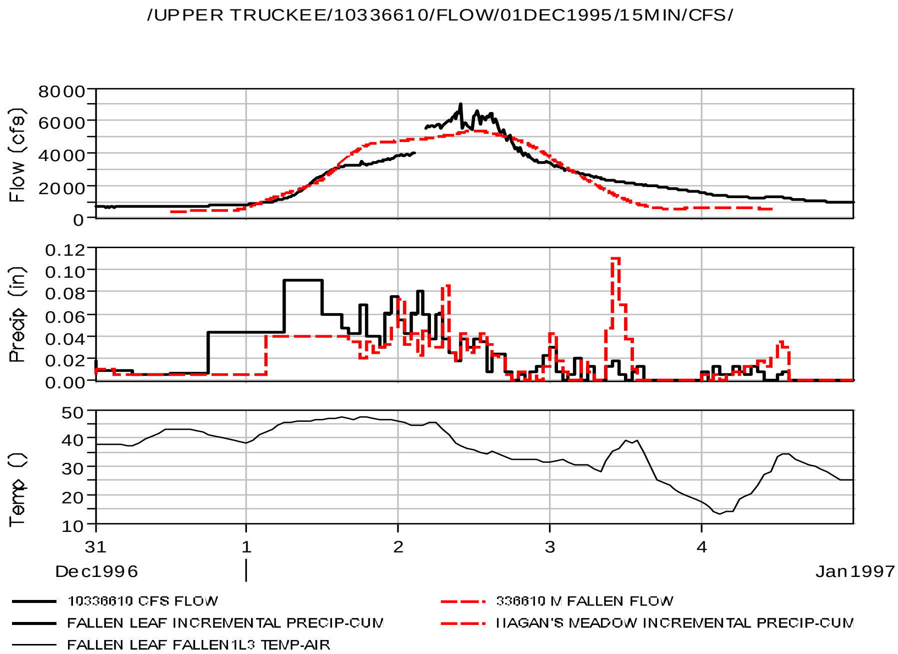

Figure 2.2: The 01 January 1997 event at Fallen Leaf Lake USGS stream gage
(see Goldman et al., 2005)

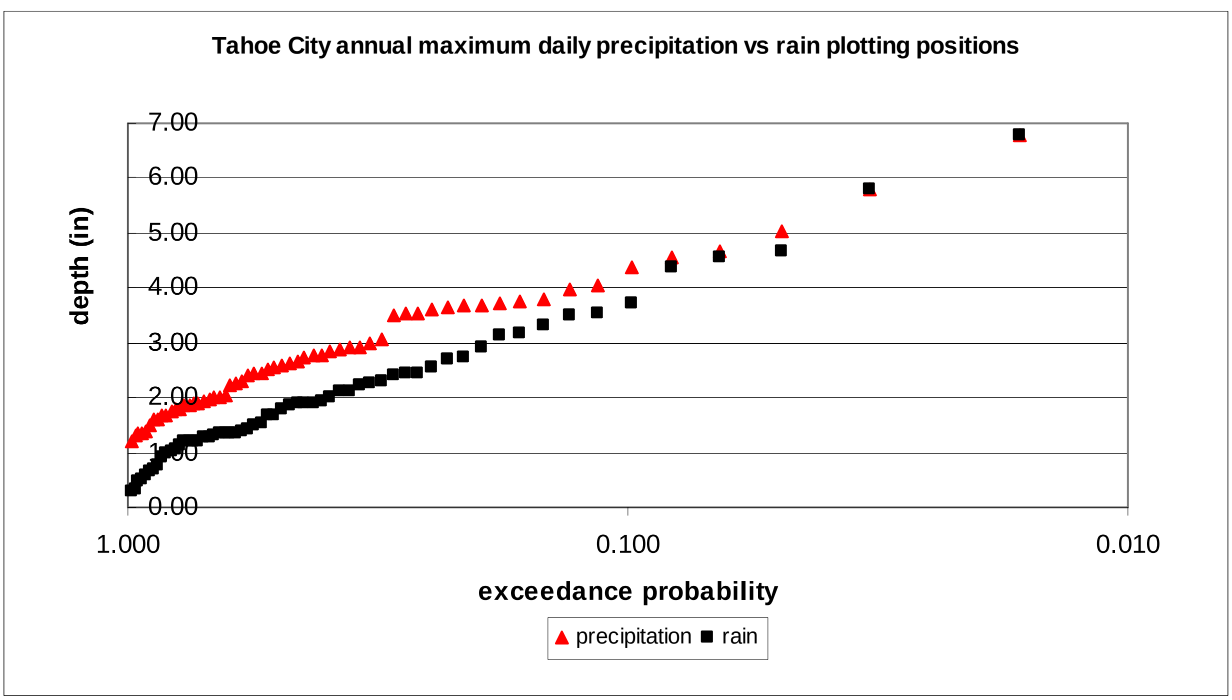

Figure 2.3: Precipitation versus rainfall annual maximum daily frequency curve at Tahoe City gage
(see section 5)

2.5. SNOTEL data filtering

SNOTEL hourly precipitation data provided by the NRCS, which will be referred to as the raw data, is provided in cumulative water year totals (see figure 2.4). As can be seen the raw data, exhibits a significant diurnal fluctuation when: 1) no precipitation is occurring; and, 2) during the summer months. The fluctuations are cause by diurnal variation of temperature that cause the gage fluids to expand and contract. This changes the level of liquid in the gage, causing a diurnal fluctuation in the reported measurements. These fluctuations do not occur during significant precipitation periods in the winter months because the diurnal variation in temperature are limited; and perhaps because, the direct solar heating of the gage is also limited by cloud cover (see figure 2.5).

The raw data was filtered for analysis purposes by recognizing that periods of large diurnal variations in the data were probably not during periods of significant precipitation. The fluctuations were filtered by accepting the maximums (see figure 2.2). Anomalous spikes were also deleted from the data. Anomalous data spikes were identified based on value (very large numbers) or in comparison with other gage records.

The major problem with this algorithm is that short-duration summer precipitation is probably not recognized. Consequently, the only reliable source of information for the summer precipitation is the NOAA gage recordings.

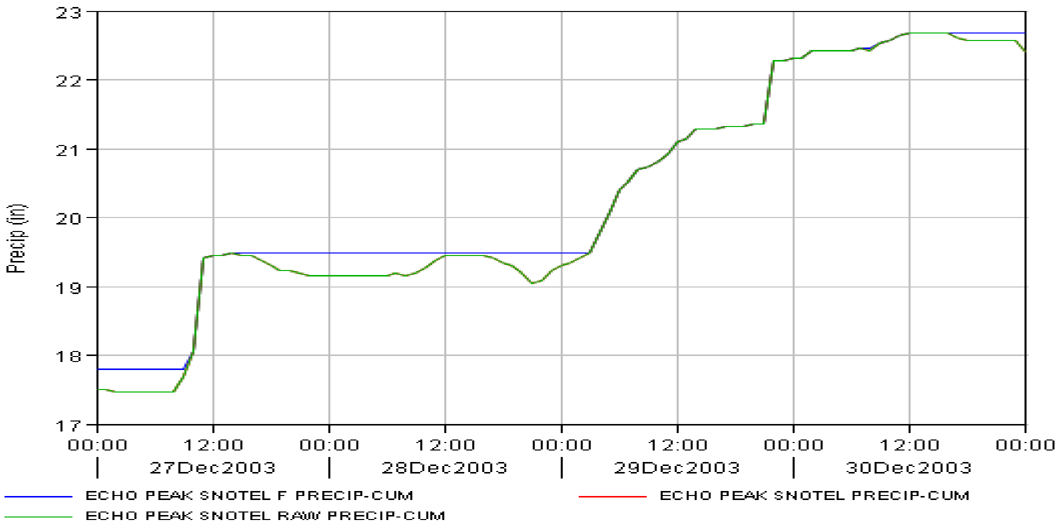

Figure 2.4: Filtering of SNOTEL raw data during precipitation period
(RAW PRECIP-CUM is raw data from NRCS, PRECIP-CUM is data filtered for anomalous spikes (none in this case), and F PRECIP-CUM is the final filtered data)

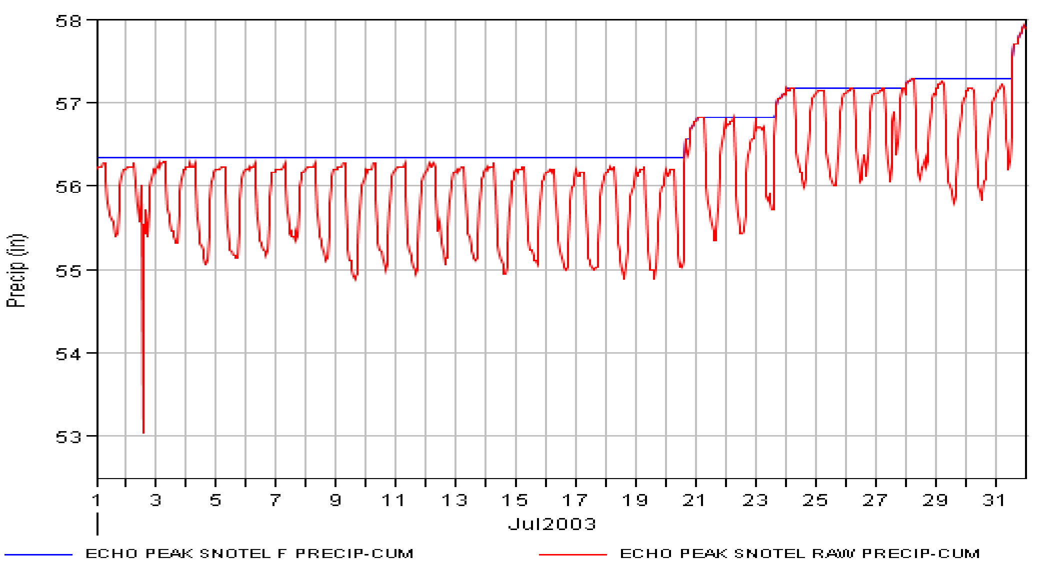

Figure 2.5: Filtering of SNOTEL raw data during no-precipitation periods

3. Ratio 60min/24hr

3.1. Introduction

The analysis performed to develop NOAA14 depth duration frequency curves did not make use of the SNOTEL. The hourly data available from the SNOTEL data is particularly important given the lack of hourly data available in the Lake Tahoe Basin (as well as for elevations above 6,000 feet in the Sierra Mountains as a whole).

The analysis challenge is in estimating these ratios for the largest events in the period of record. Examination of the data indicated that during the largest events many gages do not report. Irregardless, analysis of these storms was performed when data was available. However, the results need to be viewed in the context of the reporting problem.

In section 3.2, a discussion is provided of the new year January 1997 storm because it caused the flood of record at most gages within the basin. Using this storm as part of this study was difficult because of lack of reporting and the mixed interval used in gage recording. Section 3.3 presents a comparison of the 60min/24hr ratios determined from the gage data and those available from NOAA14.

3.2. New year January 1997 storm

The new year January 1997 storm caused significant flooding within the Lake Tahoe Basin. Unfortunately, the SNOTEL data only recorded the first part of the storm at 3hour intervals. It was not until late in the day on 01 January that the recording interval was increased to 1hour. This increase in the observation interval was important because it captured an intense portion of the storm; but, it cannot be assured that the most intense 1hour rainfall for the entire storm was determined.

Figure 3.1 – 3.2 shows both the incomplete record available at the Ward Creek gage and the entire storm measured at the remaining SNOTEL gages. Recordings were not available at other SNOTEL gages. As can be seen from the slope of the recorded data, the latter portion of the storm had a significant portion of the total precipitation. Figure 3.3 shows the NOAA Mt. Rose Christmas Tree gage measurement of this storm (note that the data for the NOAA gages is presented as incremental and SNOTEL as cumulative, as is obtained from each source of data). Data was not available from other gages.

The analysis of water year 1997 revealed that maximum annual 1hour intensity at either the SNOTEL gages did not occur during this storm but later during a 22 January 1997 storm. This is not true for the Mt. Rose Christmas tree gage, where the maximum annual 1hour occurred during the new year storm.

Figure 3.4 shows that a storm was recorded on January 22 at the NOAA Truckee RS and Mt. Rose Christmas Tree gages. This event was also recorded at the SNOTEL gages, but with data errors at some of the gages, as is shown in figure 3.5. Only data from those gages where the data was recorded without any data errors were used in the analysis of the 60min/24hr ratios.

In summary, some reasonable data was obtained for this important storm despite the recording difficulties. Obtaining these estimates is important to the analysis because a valuable data point for an infrequently occurring and extreme event.

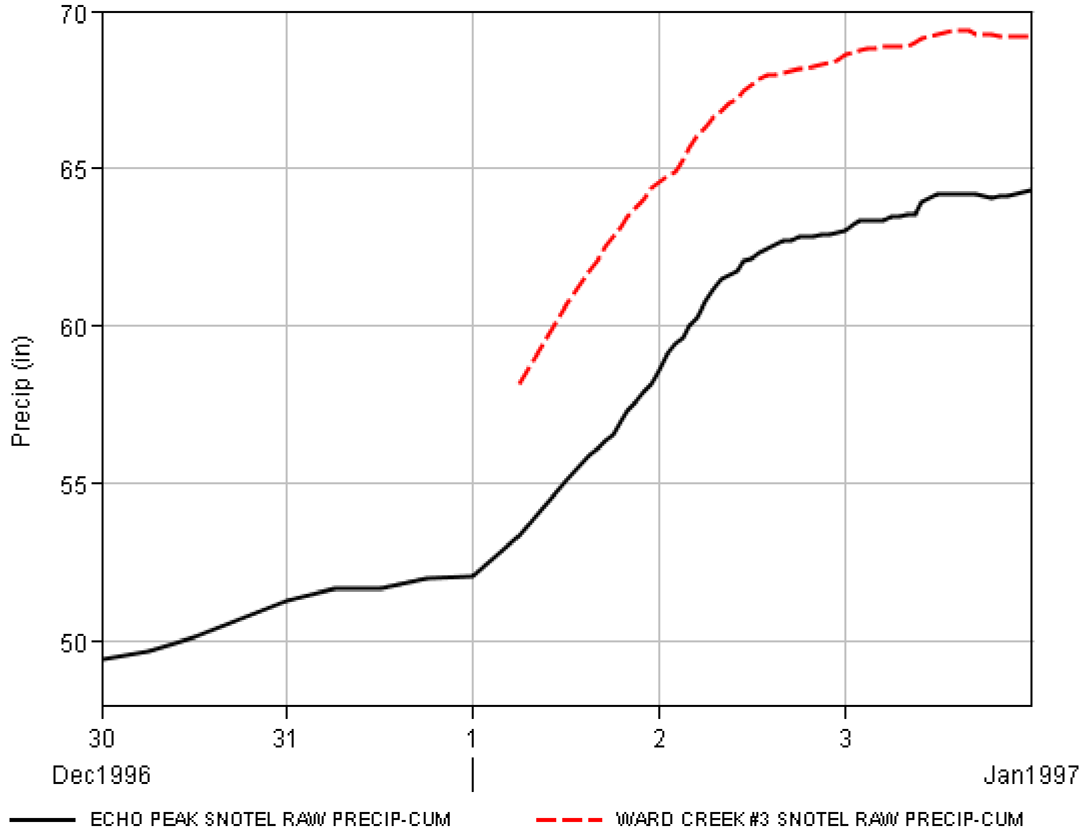

Figure 3.1: Ward Creek and Echo Peak SNOTEL gages, 01Jan1997 storm

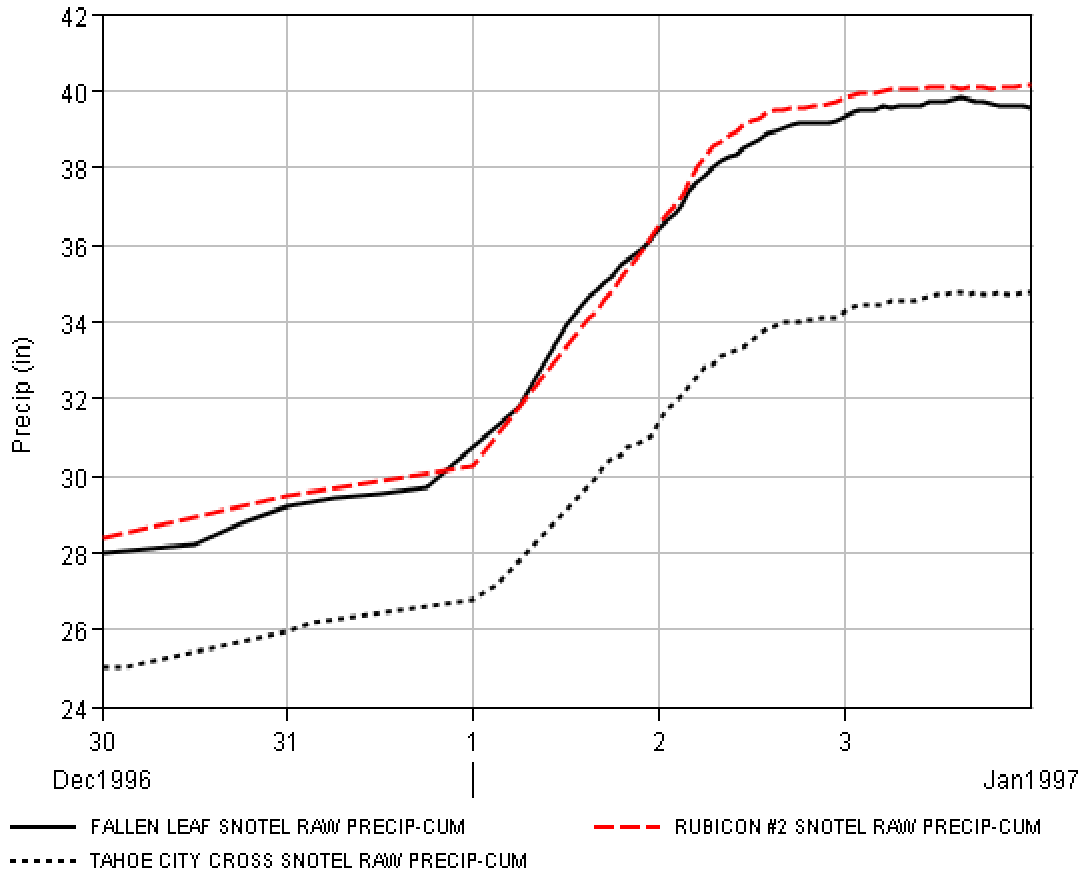

Figure 3.2: Tahoe City Cross, Rubicon and Fallen Leaf Lake SNOTEL gages, 01Jan1997 storm

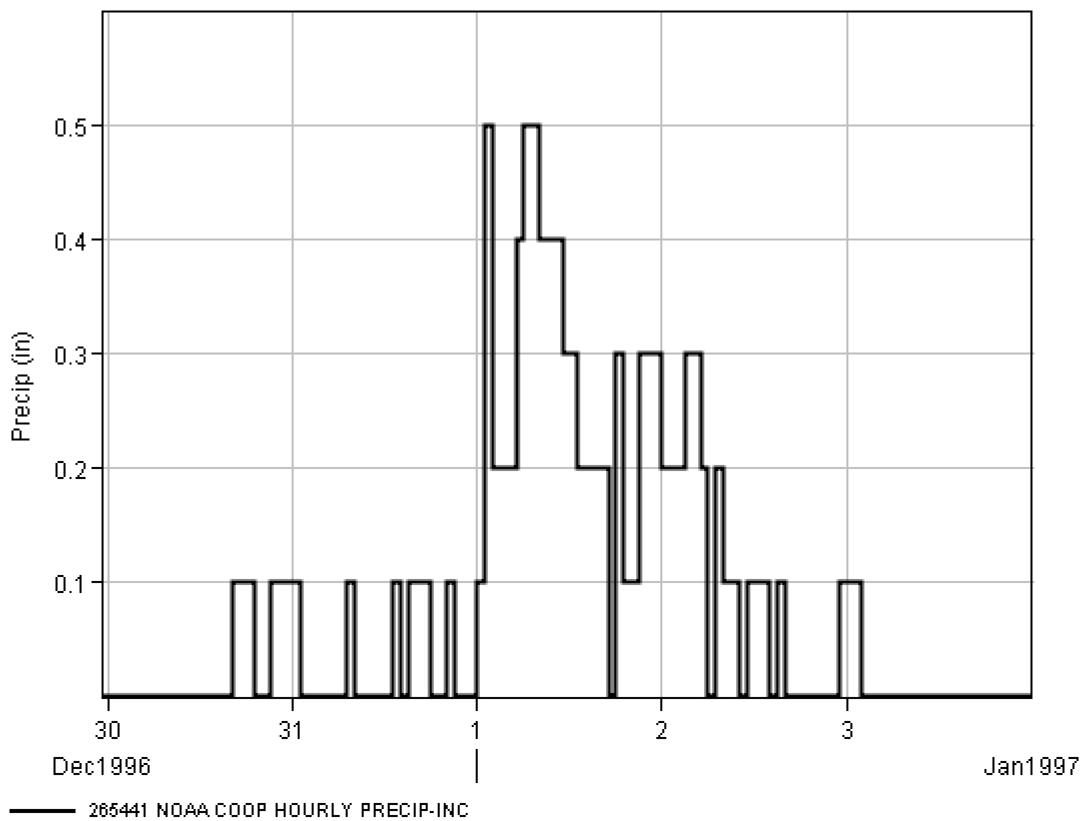

Figure 3.3: Mt Rose Christmas Tree (NOAA) 01 January 1997 event

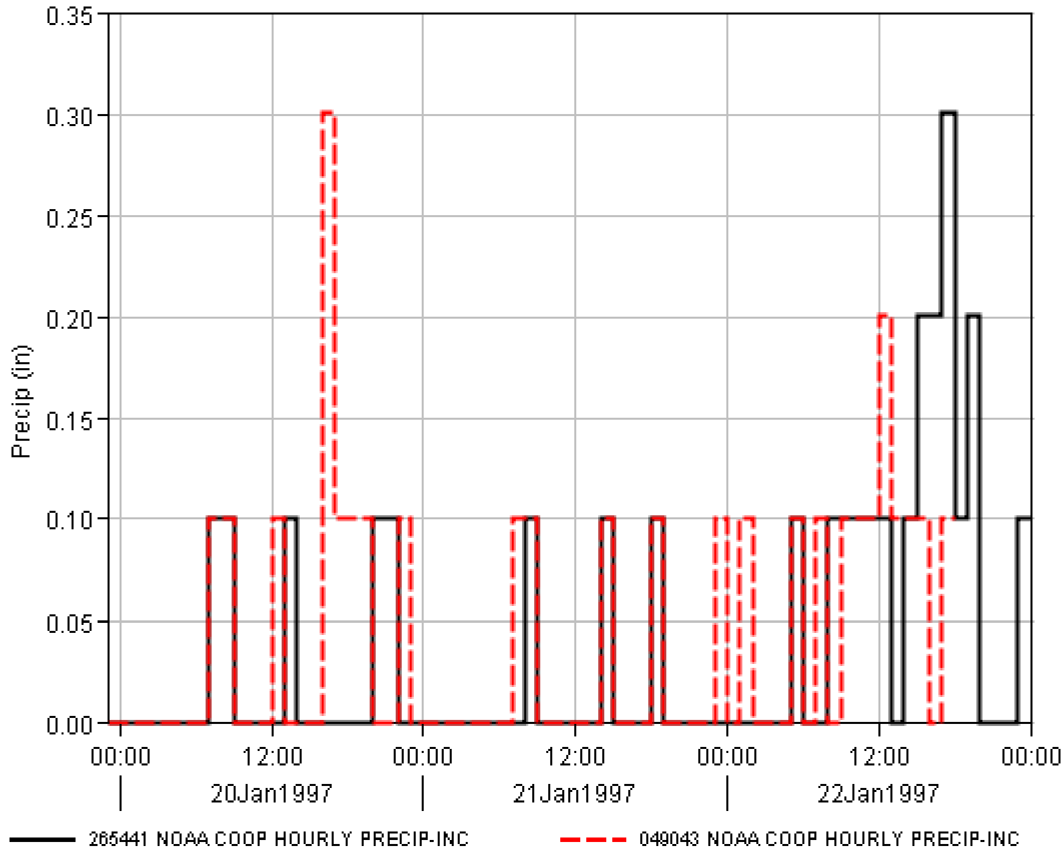

Figure 3.4: Truckee RS (049043) and Mt. Rose Christmas Tree (265441) NOAA gages, 22 Jan 1997 event

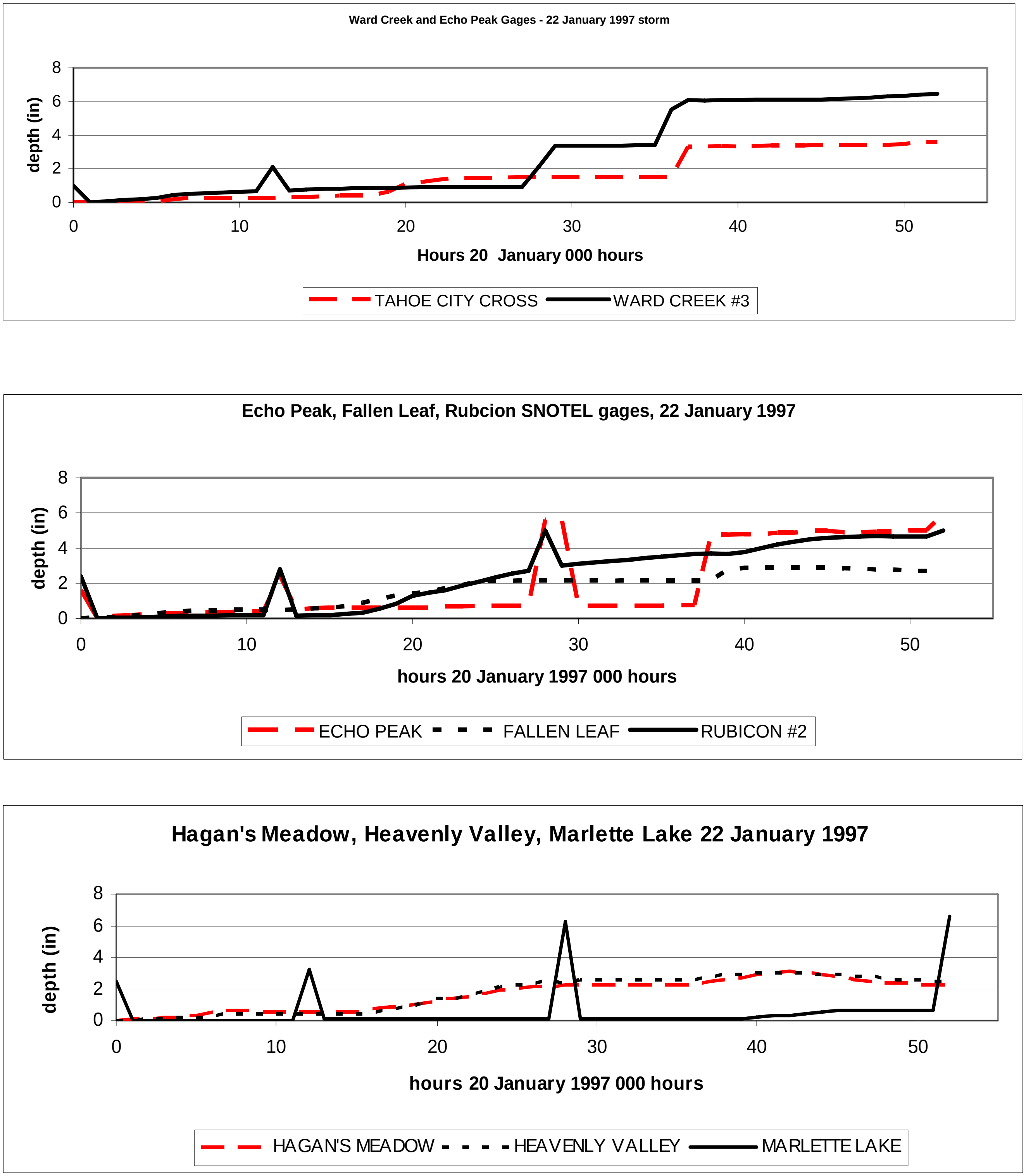

Figure 3.5: SNOTEL gages, 22 Jan1997 storm

3.3. NOAA gages duration ratios

The annual maximum 60min/24hourr ratios for the NOAA Truckee RS and Mt. Rose Christmas Tree gages were obtained by either plotting position estimates for the period of record or estimated exceedance probabilities from NOAA14 depth-duration-frequency (ddf) curves obtained for the gage locations. The plotting position ratios were obtained by ranking the annual maximum 60minute and 24hour values and then computing the ratios for equal ranked observations (see Tables 3.1 and 3.2). The 24 hour annual maximum values were directly obtained from the observed hourly data. However, the maximum 60minute values were obtained by multiplying the clock hour maximum value (e.g., 1:00pm) by the conversion factor given in NOAA14 of 1.14 to convert hourly to 60minute maximum values. As can be seen in figures 3.6 and 3.7, the estimated ratios for Truckee RS over predict and Mt. Rose Christmas Tree under predict the ratios obtained for ddf curves obtained for these gage locations shown in Table 3.3. The bounding of the estimates is perhaps understandable given that these gage were used in the NOAA14 study.

An alternative method for estimating the exceedance probability for each ratio was to use the ddf curves in Table 3.3 to estimate either the return interval of the 60minute or 24hour precipitation. This changes the comparisons slightly as can be seen in figures 3.8 and 3.9 (Note that NOAA14 provides the frequency curves only up to the 0.5 exceedance probability. Consequently, ratios with greater exceedance probability were plotted at 0.5 to provide an indication of the range of possible ratios for smaller events).

Table 3.1: Annual maximum ranked 60min/24hr precipitation ratios, Weibull plotting positions, Truckee RS (NOAA cooperative gage)

year	60 min	year	24hr	ratio	Weibull
1999	1.14	1965	5.00	0.23	0.025
1980	1.03	1951	4.19	0.24	0.050
1988	0.91	1996	3.80	0.24	0.075
1990	0.91	1982	3.50	0.26	0.100
1972	0.80	1984	3.50	0.23	0.125
1987	0.68	1993	3.40	0.20	0.150
1970	0.57	1995	3.10	0.18	0.175
1995	0.57	1983	3.00	0.19	0.200
1965	0.51	1991	2.90	0.18	0.225
1984	0.46	1978	2.80	0.16	0.250
1993	0.46	1979	2.80	0.16	0.275
1950	0.34	1998	2.80	0.12	0.300
1951	0.34	1972	2.70	0.13	0.325
1973	0.34	1980	2.50	0.14	0.350
1974	0.34	1985	2.50	0.14	0.375
1975	0.34	1999	2.50	0.14	0.400
1977	0.34	1970	2.40	0.14	0.425
1979	0.34	1981	2.40	0.14	0.450
1982	0.34	1950	2.39	0.14	0.475
1983	0.34	1960	2.32	0.15	0.500
1991	0.34	1977	2.20	0.16	0.525
1992	0.34	1990	2.20	0.16	0.550
1996	0.34	1967	2.14	0.16	0.575
1998	0.34	1971	2.10	0.16	0.600
1953	0.30	1953	2.01	0.15	0.625
1967	0.29	1968	2.00	0.14	0.650
1955	0.27	1969	2.00	0.14	0.675
1954	0.24	1974	2.00	0.12	0.700
1960	0.23	2000	2.00	0.11	0.725
1964	0.23	1955	1.94	0.12	0.750
1969	0.23	1954	1.92	0.12	0.775
1971	0.23	1973	1.90	0.12	0.800
1976	0.23	1975	1.90	0.12	0.825
1978	0.23	1976	1.90	0.12	0.850
1981	0.23	1992	1.70	0.13	0.875
1985	0.23	1987	1.60	0.14	0.900
2000	0.23	1988	1.50	0.15	0.925
1962	0.13	1962	1.07	0.12	0.950
1968	0.11	1964	0.95	0.12	0.975

Note: All years in record not shown because of missing data (e.g., 1986,1997)

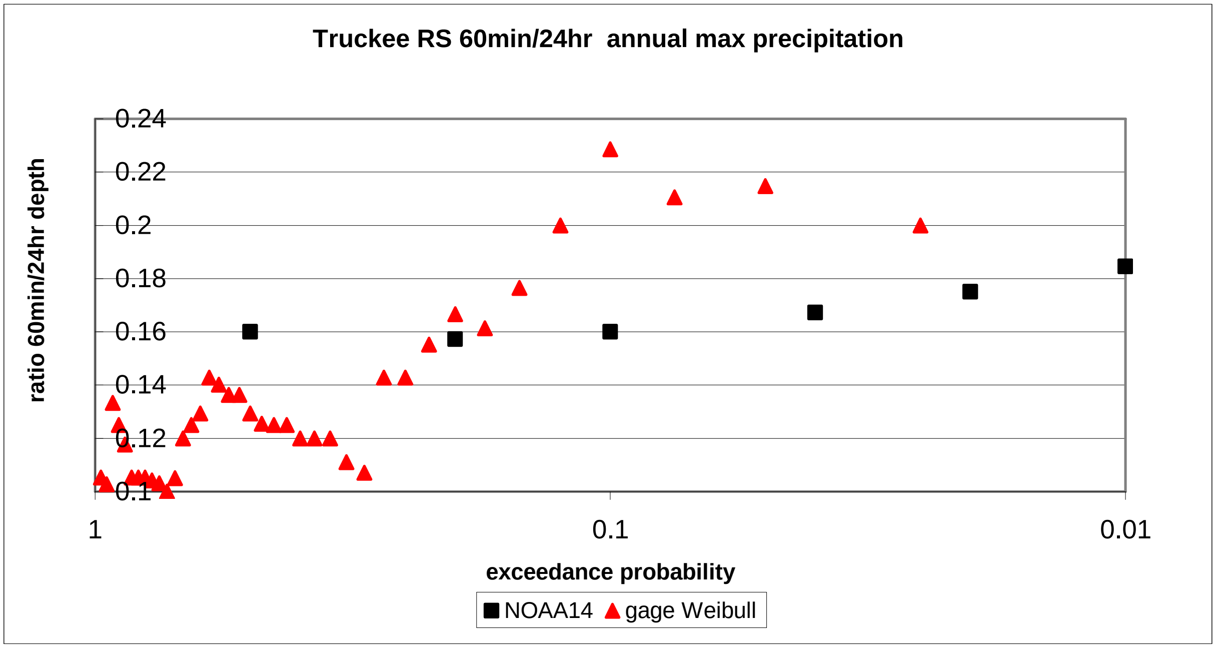

Figure 3.6: Truckee RS (NOAA cooperative gage) comparison of 60min/24hr ratios obtained from period of record Weibull plotting positions and NOAA14 depth-duration-frequency curves

Table 3.2: Annual maximum ranked 60min/24hr precipitation ratios, Weibull plotting positions, Mt Rose Christmas Tree (NOAA cooperative gage)

year	60 min	year	24hr	ratio	Weibull
1976	1.03	1997	6.70	0.15	0.04
1972	0.91	1982	5.50	0.17	0.07
1986	0.68	1986	4.60	0.15	0.11
1998	0.68	1996	4.00	0.17	0.14
1996	0.57	1984	3.10	0.18	0.18
1997	0.57	1989	3.10	0.18	0.21
1982	0.46	1998	2.40	0.19	0.25
1987	0.46	1992	2.20	0.21	0.29
2000	0.46	2000	2.00	0.23	0.32
1973	0.34	1987	1.80	0.19	0.36
1974	0.34	1993	1.80	0.19	0.39
1975	0.34	1972	1.70	0.20	0.43
1978	0.34	1976	1.70	0.20	0.46
1980	0.34	1978	1.70	0.20	0.50
1984	0.34	1990	1.70	0.20	0.54
1985	0.34	1995	1.70	0.20	0.57
1989	0.34	1980	1.60	0.21	0.61
1991	0.34	1974	1.50	0.23	0.64
1992	0.34	1985	1.50	0.23	0.68
1993	0.34	1973	1.40	0.24	0.71
1994	0.34	1999	1.40	0.24	0.75
1999	0.34	1991	1.30	0.26	0.79
1977	0.23	1977	1.20	0.19	0.82
1981	0.23	1994	1.20	0.19	0.86
1990	0.23	1975	1.10	0.21	0.89
1995	0.23	1981	0.90	0.25	0.93
1988	0.11	1988	0.70	0.16	0.96

Note: All years in record not shown because of missing data

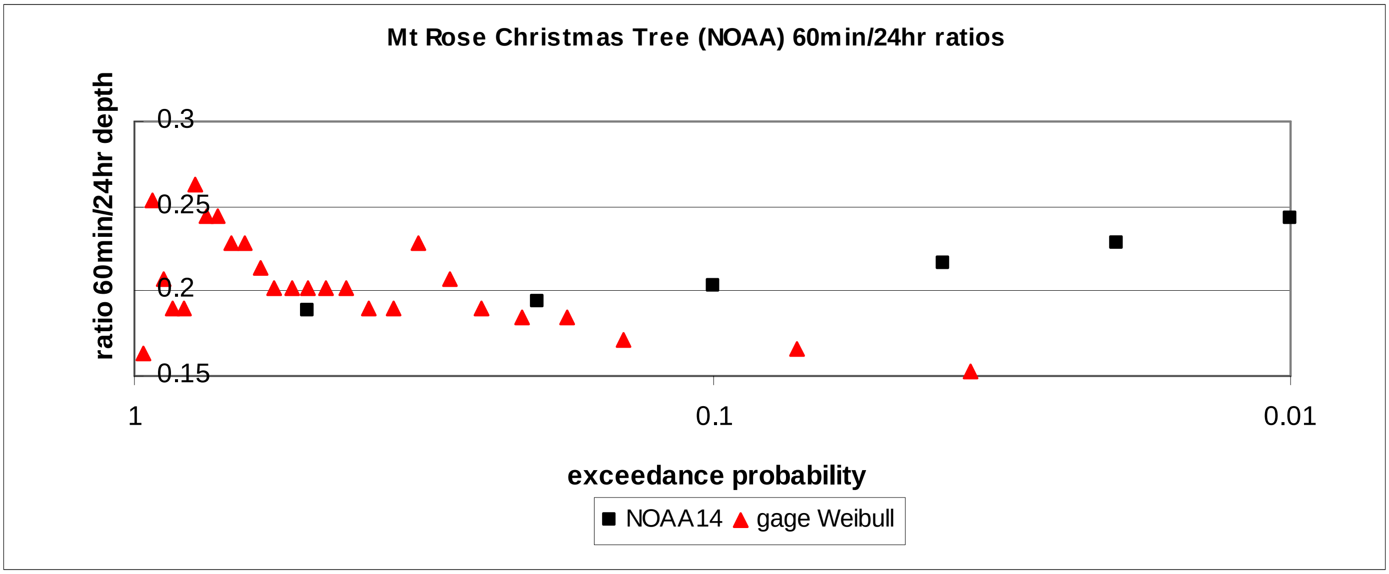

Figure 3.7: Mt. Rose Christmas Tree (NOAA cooperative gage) comparison of 60min/24hr ratios obtained from period of record Weibull plotting positions and NOAA14 depth-duration-frequency curves

Table 3.3: NOAA14 depth-duration-frequency curves NOAA cooperative gages

	Truckee RS		Mt. Rose Christmas Tree	
[1]Probability	[2]24hr	[3]60min	24hr	60min
0.5	2.365	0.378	2.500	0.470
0.2	3.249	0.511	3.460	0.670
0.1	3.880	0.621	4.140	0.840
0.04	4.738	0.792	5.050	1.090
0.02	5.416	0.948	5.770	1.320
0.01	6.132	1.132	6.520	1.580
0.005	6.884	1.348	7.290	1.900
0.002	7.946	1.697	8.380	2.410

[1]Exceedance probability for depth (inches) and duration
[2]Assumed Region 9 growth curve (NOAA14) for 24 hour duration (see text)
[3]Assumed Region 16 growth curve (NOAA14) for 60min duration (see text)

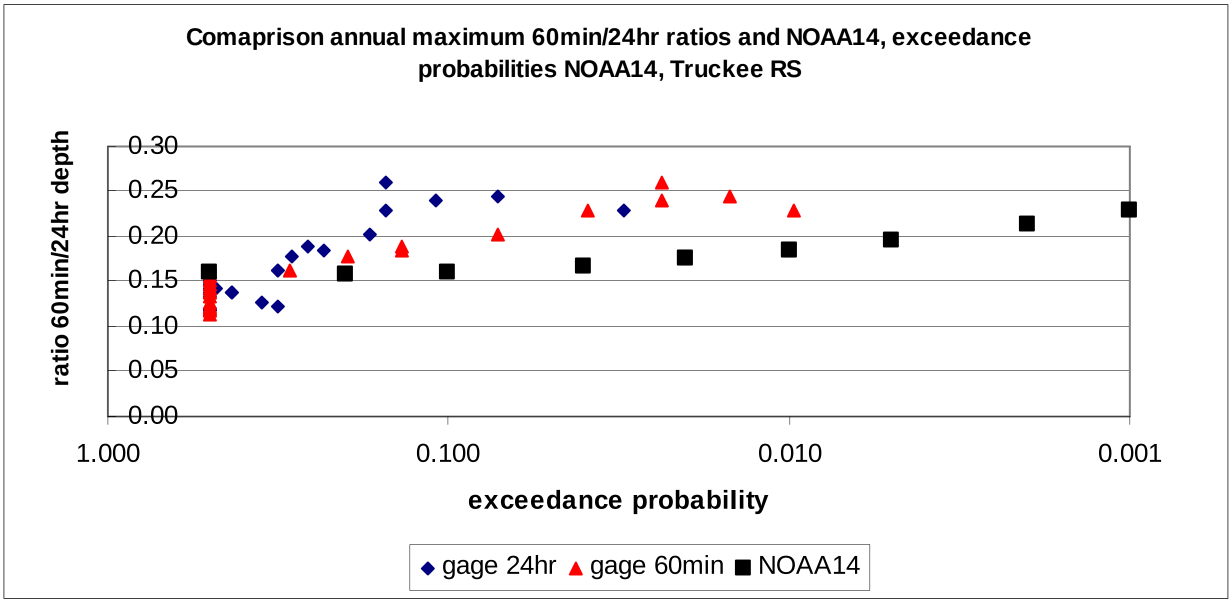

Figure 3.8: Truckee RS (NOOA cooperative gage) comparison of 60min/24hr ratios and NOAA14 (exceedance probabilities gage 24hr and gage 60min exceedance computed using NOAA14 frequency curves probabilities)

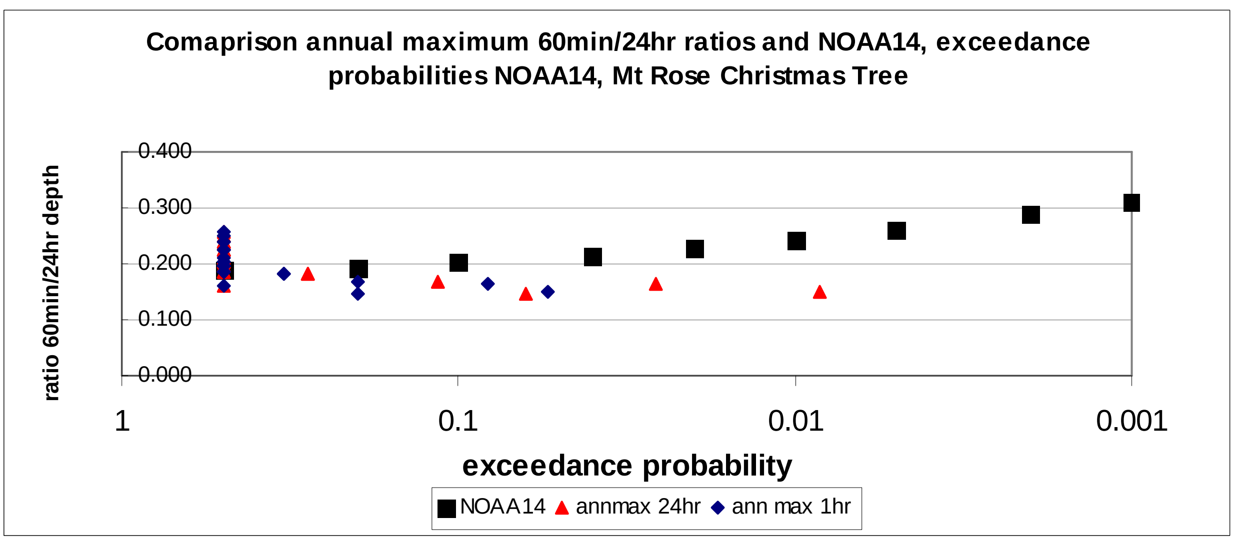

Figure 3.9: Mt Rose Christmas Tree (NOOA cooperative gage) comparison of 60min/24hr ratios and NOAA14 (exceedance probabilities gage 24hr and gage 60min exceedance computed using NOAA14 frequency curves probabilities)

3.4. SNOTEL gages duration ratios

The available SNOTEL data was not sufficient to perform the period of record analysis done for the two NOAA gage described in the previous section. The annual maximum ratios that could be obtained from the available data are shown in Table 3.4. The exceedance probability estimated for each ratio was obtained for the 24 hour duration frequency curve estimated at the location of the gage shown. Of note are the ratios for the relatively infrequent exceedance probabilities obtained for the Rubicon and Ward Creek gages. Comparison of the gage ratios with the ratios obtained from NOAA14 ddf curves figure 3.10 indicate a reasonable agreement given the sample available.

An additional analysis was performed to determine the difference between NOAA14 annual maximum ratios and those for individual storms. The exceedance probabilities for the storm ratios was obtained using the 24hour duration NOAA 14 frequency curve as in the case for the annual maximum ratio analysis. The comparison in figure 3.10 demonstrates that Lake Tahoe Basin storms are generally not balanced (the maximum 60minute ratio is not contained with the maximum 24hour depth within the storm) in comparison with the NOAA14 ddf curves. Consequently, design runoff computed form balanced design storms based on NOAA14 would be conservative in comparison to the expected runoff from actual storms with equivalent 24hour storm depths.

Table 3.4: NRCS SNOTEL gage 1hr/24hr annual maximum values

Gage	date	time	max1hr	date	time	max24hr	ratio	[1]prob
Fallen Leaf	23-Jan-97	660	0.61	2-Jan-97	300	6.003	0.102	0.102
	2-Jan-98	660	0.3	24-Mar-98	900	3.07	0.098	0.098
	13-Sep-99	1020	0.32	7-Feb-99	900	3.42	0.094	0.094
	19-Nov-99	900	0.37	24-Jan-00	1260	3.22	0.115	0.115
	24-Nov-01	480	0.36	22-Nov-01	780	2.37	0.152	0.500
	16-Feb-04	720	0.27	7-Dec-03	240	2.44	0.111	0.500
Echo peak	8-Feb-98	600	1.28	15-Jan-98	900	3.01	0.425	0.500
	3-Dec-01	660	0.8	22-Nov-01	660	4.88	0.164	0.164
	27-Dec-03	660	1.36	30-Dec-03	120	2.93	0.464	0.500
Rubicon #2	**29-Jan-97**	**900**	**1.06**	**2-Jan-97**	**420**	**6.518**	**0.163**	**0.019**
	6-Dec-01	420	0.48	3-Dec-01	0	2.49	0.193	0.500
Ward Creek #3	**23-Jan-97**	**480**	**2.119**	**2-Jan-97**	**0**	**8.94**	**0.237**	**0.028**
	25-Jan-00	540	1.1	14-Feb-00	420	5.13	0.214	0.342
	17-Dec-02	780	1.65	8-Nov-02	1260	6.3	0.262	0.166
Heavenly Valley	17-Dec-02	660	0.34	13-Apr-03	1020	2.76	0.123	0.409
Hagan's Meadow	3-Jan-97	660	0.44	2-Jan-97	480	3.752	0.117	0.213
	30-Jan-98	780	0.37	24-Mar-98	1260	2.22	0.167	0.500
	15-Feb-00	720	0.37	14-Feb-00	240	2.22	0.167	0.500
	17-Dec-02	840	0.41	8-Nov-02	1260	3.13	0.131	0.384

[1]Exceedance probability from NOAA14 24 hour ddf curve

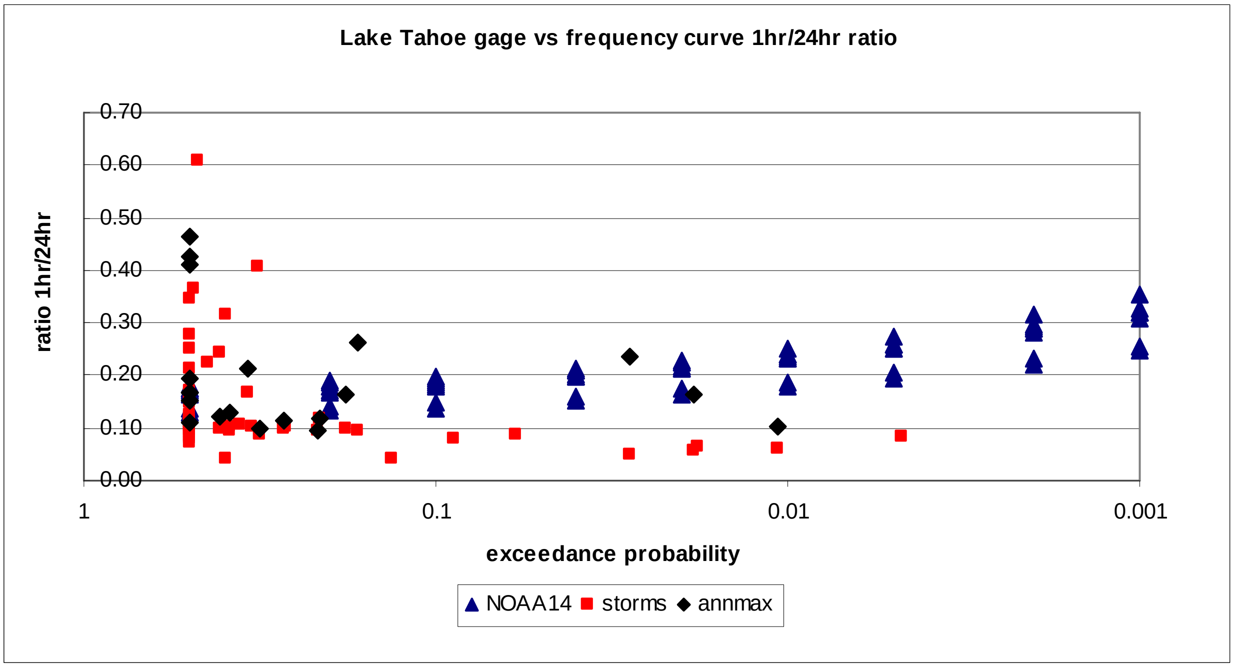

Figure 3.10: Comparison 60min/24hr ratios for NOAA14 ddf curves (at gage locations) and observed annual maximums at SNOTEL gages
(storms and annual max probabilities from NOAA14 24hr duration frequency curves)

3.5. Conclusions

The comparisons of 24hr/60 minute ratios given by NOAA14 ddf curves are in good agreement those obtained from the analysis of both Lake Tahoe NRCS SNOTES gages and available NOAA gages. Consequently, at least based on the comparison of these ratios, NOAA14 seems to be provide useful estimates of the 24hour and 60 minute duration ddf curves in the basin.

4. L-moment regional frequency estimates 24 hour duration frequency

4.1. Introduction

The purpose of this section is to describe an L-moment regional frequency analysis (see Hosking and Wallis, 1997) of the 24 hour annual maximum precipitation values available from the SNOTEL and NOAA precipitation gages. This was the method used to develop the ddf curves in NOAA14, but will use the SNOTEL gages not used in the NOAA14 analysis.

Section 4.2 provides a trend analysis of the longer record NOAA gages to examine if the data in the region reasonably corresponds to the stationary assumptions of standard frequency analysis. The annual maximum daily flow ranking for water year 1986 and 1997 events are examined to assess the importance of record length in section 4.3. Finally, section 4.4 provides the results of the regional L-moment regional frequency analysis.

4.2.Trend Analysis

A trend analysis of the daily annual maximum precipitation values for both the Truckee RS and Tahoe City gages shows no significant trend (R^2 values close to zero) for the period of record. This indicates that the annual series used for a precipitation frequency analysis are reasonably stationary.

4.3. Effects of period of record, annual maximum daily precipitation, 1986 and 1997 water years

The NRCS SNOTEL record spans the most recent 20 years. To gain a perspective on the severity of events in this period, the ranks of the significant 01 January 1997 and 18 February 1986 storms were examined for both the shorter period of record available at the SNOTEL gages and the longer record NOAA gages which have 50-70 years of data (see Table 2.1).

Table 4.1 compares the ranks of the annual maximum daily precipitation values for water years 1986 and 1997 at the gages shown for the period of record 1978 – 2000 (the period of available SNOTEL data) and over the period of record for the NOAA gages. Notice that the 01 Jan 1997 and 18 February 1986 storms are for the most part, the maximum storms for the water year, but not always. More importantly, notice that the 01 January 1997 and 18 February 1986 events are the top two ranked events for the most part in the SNOTEL period of record, the ranking drop in the longer period NOAA gage records, although these events are still in the top 10.

Consequently, the shorter record SNOTEL probably capture the potential for extreme precipitation. However, performing a frequency analysis that pools data from both gages within the Lake Tahoe Basin and the longer record NOAA gages lying just outside the basin will be useful in assessing the likelihood of extreme precipitation.

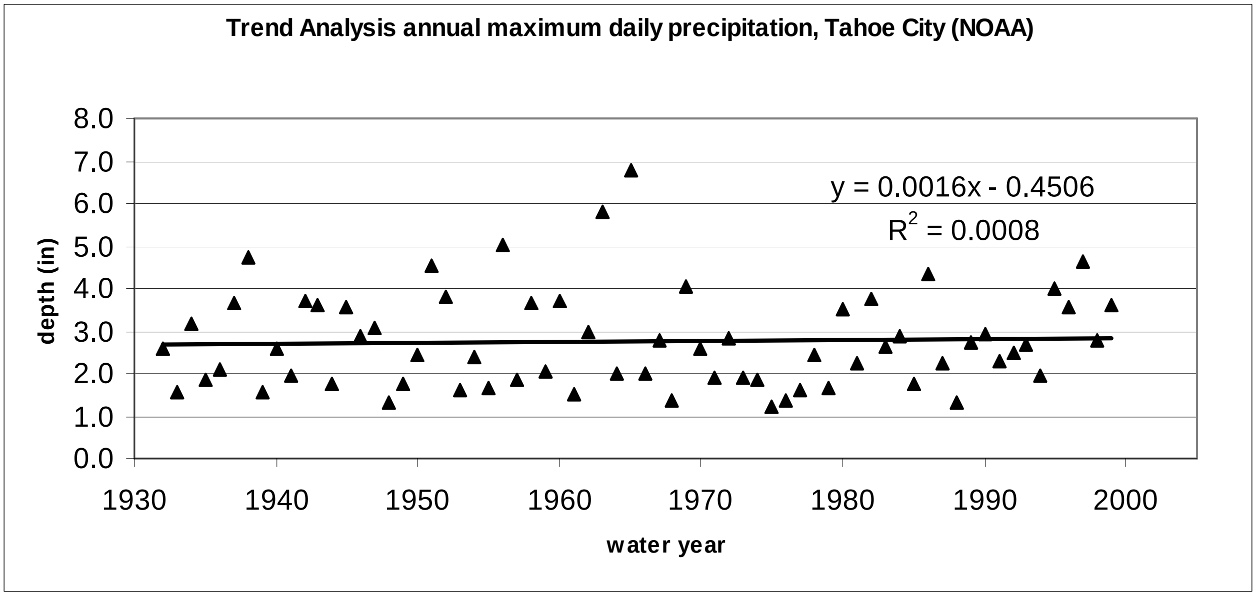

Figure 4.1: Trend analysis annual maximum daily precipitation, Tahoe City (NOAA) gage

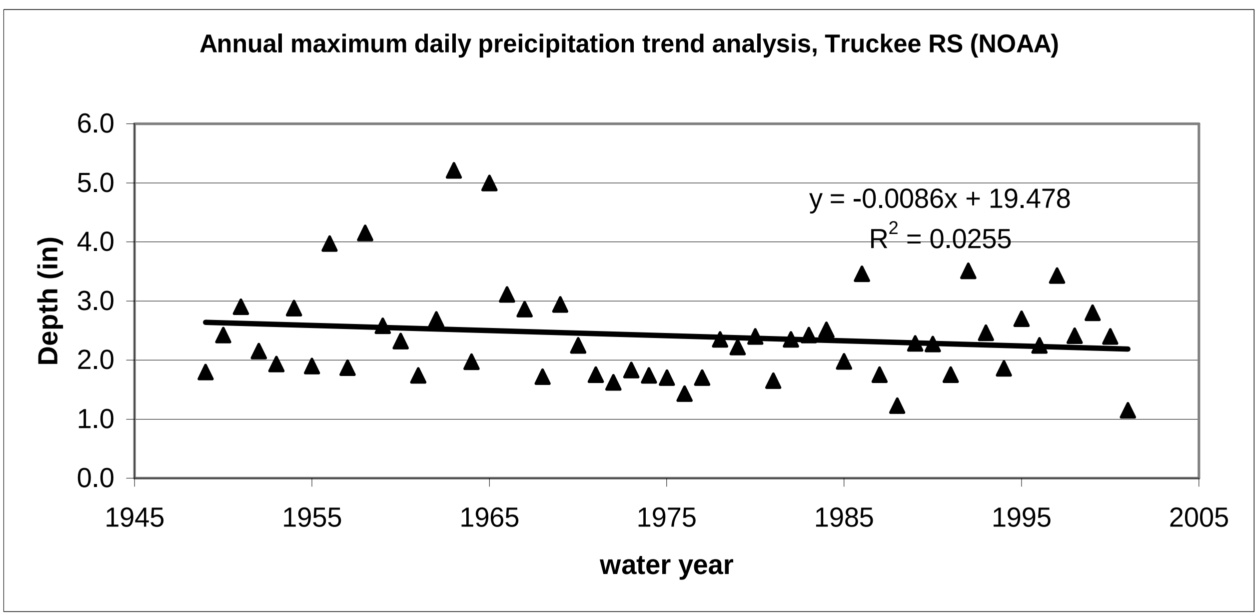

Figure 4.2: Trend analysis annual maximum daily precipitation, Truckee RS (NOAA) gage

Table 4.1: Annual maximum daily precipitation rank for water years 1986 and 1997

Gage	1986 water year	rank	1997 water year	rank
Period of Record 1978 - 2005				
Big Meadow	20-Feb-86	5	22-Dec-96	1
CSSlab	17-Feb-86	2	2-Jan-97	1
Echo Peak	17-Feb-86	4	18-Nov-96	2
Fall Leaf	16-Feb-86	11	2-Jan-97	1
Hagan's Meadow	18-Feb-86	1	22-Dec-96	4
Heavenly Valley	17-Feb-86	4	22-Dec-96	5
Independence Creek	18-Feb-86	1	2-Jan-97	2
Independence Camp	13-Jan-80	2	12-Jan-79	1
Marlette Lake	17-Feb-86	1	23-Jan-97	4
Mt Rose Ski	18-Feb-86	1	2-Jan-97	2
Rubicon	18-Feb-86	2	2-Jan-97	1
Squaw Valley	8-Mar-86	6	2-Jan-97	1
Tahoe CityX	18-Feb-86	3	2-Jan-97	1
Truckee	17-Feb-86	2	2-Jan-97	1
Ward Creek	18-Feb-86	2	2-Jan-97	1
Truckee RS(noaa)	19-Feb-86	2	2-Jan-97	3
Tahoe City(noaa)	18-Feb-86	2	2-Jan-97	1
Glenbrook ck(noaa)	17-Feb-86	8	2-Jan-97	3
Full Period of Record				
Truckee RS(noaa)	19-Feb-86	6	2-Jan-97	7
Tahoe City(noaa)	18-Feb-86	14	2-Jan-97	6
Glenbrook ck(noaa)	17-Feb-86	8	2-Jan-97	3

4.4. Frequency analysis results

An application of the Hosking and Wallis (1997) L-moment regional frequency analysis requires the following two basic steps:

- defining a statistically homogenous region containing the gages to be included in the frequency analysis;
- and estimating the regional growth curve.

The region is initially defined to include gages by considering an area with similar meteorologic characteristics. Statistical discordancy and homogeneity tests are then used to determine if the period of record available for the gages are similar enough to form a homogenous region. Gages which do not pass these tests are not included in the region.

The period of record for the gages within a homogenous region are used to develop a dimensionless frequency curve – termed a regional growth curve. The regional growth curve is developed so that a scaling factor, typically the at-location mean or median precipitation, can be used to compute the at-location frequency curve. In NOAA14, the mean precipitation is the scaling factor that is used. For example, the product of the at-location 24hour mean annual precipitation and the dimensionless growth curve (e.g., the dimensionless 100 year 24hour precipitation) of the regional growth curve is used to obtain the precipitation 24hour annual maximum frequency curve. Of course, this requires an estimate of the mean at the location of interest. In the case of NOAA14, this was obtained through an application of PRISM (Taylor, et al., 1993).

In applying this methodology, the grouping of gages used to develop the regional growth curve was developed as follows:

- The gages shown in Table 4.1 were initially used to formulate a region. These gages are either in the Lake Tahoe Basin or are located close enough to the basin to be affected by the same meteorologic conditions.
- Gages that were identified as statistically discordant were removed from the analysis (Daggett Pass, Big Meadow and Meyers Inspection Station).
- Finally, only gages with the Lake Tahoe Basin were used to form a third and final region.

The annual maximum 24hour flow values used to identify these regions and estimate the regional growth curves is shown in the appendix. The values were multiplied by a factor (1.12) to estimate 24hour maximum values from maximum daily values.

The best 24hour annual maximum daily flow regional growth curves for each region was identified as Generalized Extreme Value (GEV) using criteria developed by Hosking an Wallis (1997). This is the same distribution as identified in NOAA14 for the 24hour maximum regional growth curve. The regional growth curves for each of the three regions analyzed do not differ by any significant magnitude as can be seen in Figure 4.3.

A detailed analysis of the Lake Tahoe Basin region results reveals that the L-moment regional analysis methodology identified three distributions (Generalized Normal, Generalized Logistic and Generalized Extreme Value) as being acceptable, with Generalized Extreme Value performing best. The regional growth curves estimated from any of the regions and the GEV growth curve from NOAA14 all agree very well (see figure 4.3).

Note also that the GEV distribution fit very well the empirical distributions (the distribution obtained from plotting positions) obtained from the gage period of record. Table 4.2 shows that the difference between the empirical distribution estimated at the top ranked plotting position precipitation and the distribution prediction was reasonable, being on the average less than 5%.

As a final comparison, estimates of 24hour annual maximum precipitation frequency curve were obtained at each gage location using the regional growth curve obtained using the SNOTEL gages and those obtained from the NOAA14 web site. A mean annual maximum precipitation obtained from the data shown in the appendix for each gage was used in combination with the GEV regional growth curve to obtain the SNOTEL gage based frequency curves. A comparison of predictions in Table 4.3 shows that NOAA14 results in a greater prediction of about 9% for the 1% chance exceedance probability precipitation on the average in comparison to the SNOTEL gage based estimates. This difference reveals that the critical difference between the SNOTEL gage based estimates and NOAA14 is in the estimate of the mean annual 24hour precipitation. The PRISM analysis used in NOAA14 (and some other additional interpolation procedures) results in a somewhat different estimate than obtained by the at-gage SNOTEL estimates.

In conclusion, the regional frequency analysis performed on the SNOTEL verifies that at least the 24hour ddf curves of NOAA14 are applicable to the Lake Tahoe Basin. The only differences found were due to the use of at gage estimates versus PRISM estimates of the mean 24hour annual maximum precipitation. Given that the interest really is in estimating ddf curves at ungaged locations, the difference in means found from different sources of information are well within an acceptable level.

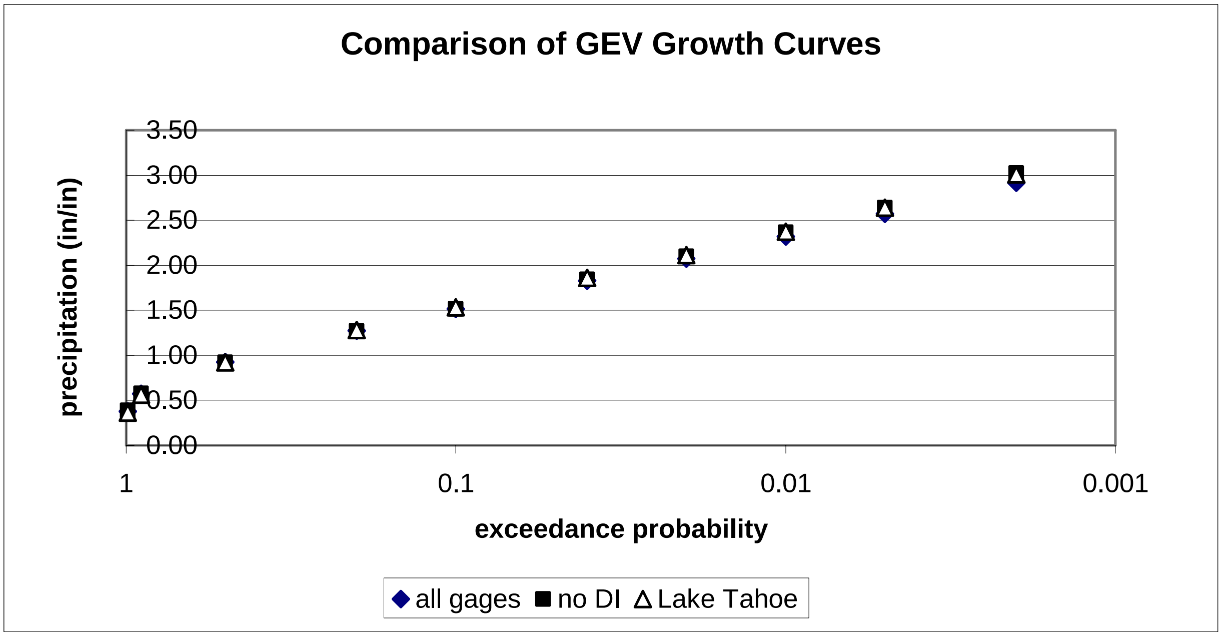

Figure 4.3: Comparison of Generalized Extreme Value (GEV) growth curves from SNOTEL data for regions sets all gages, no discordant gage (no DI) and only Lake Tahoe Gages, 24hour annual maximum duration

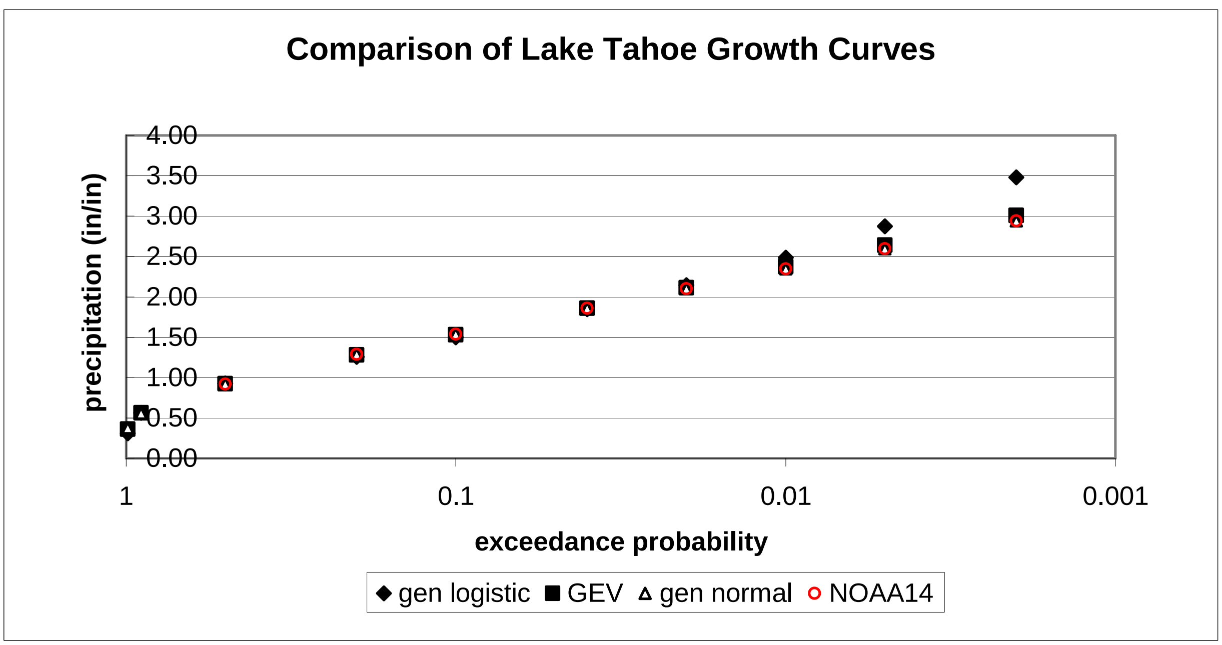

Figure 4.4: Comparison of Lake Tahoe regional growth curves, SNOTEL Generalized Logistic (gen logistic), Generalized Extreme Value (GEV) and Generalize Normal (gen normal) distributions, NOAA14 GEV growth curve, annual maximum 24hour duration

Table 4.2: Goodness of fit GEV distribution to topped ranked plotting position 24hr annual maximum precipitation

Gage	[1]Ppos	[2]GEV	[3]difference
Glenbrook Creek	3.35	3.55	-0.060
Echo Peak	9.12	9.10	0.002
Fallen Leaf	4.56	4.60	-0.009
Hagan's Meadow	4.87	5.70	-0.170
Heavenly Valley	4.33	4.20	0.030
Marlette Lake	4.36	4.70	-0.078
Rubicon #2	5.95	6.20	-0.042
Squaw Valley G.C.	7.61	8.30	-0.091
Tahoe City Cross	4.41	4.60	-0.043
Ward Creek #3	8.79	9.00	-0.024
Tahoe City	6.66	6.77	-0.017
Average			-0.046

[1]Top ranked 24hour daily precipitation in period of record
[2]GEV distribution estimate for plotting position of top ranked daily flow
[3]Fraction difference (Ppos –GEV)/Ppos

Table 4.3: Comparison of 24 hour duration 1% chance exceedance probability estimates

SNOTEL gage	[1]NOAA14	[2]SNOTEL	[3]difference
Echo Peak	8.27	9.16	0.11
Fallen Leaf	6.06	6.12	0.01
Hagan's Meadow	6.67	5.30	-0.21
Heavenly Valley	6.04	5.52	-0.09
Marlette Lake	6.65	5.12	-0.23
Rubicon #2	7.14	6.50	-0.09
Tahoe City Cross	6.68	5.50	-0.18
Ward Creek #3	10.49	10.39	-0.01
average			-0.09

[1]Estimates obtained from NOAA14 web site
[2]Estimates obtained from L-moment analysis of SNOTEL gage data
[3]Fraction difference

5. Precipitation versus rainfall frequency analysis

5.1. Introduction

The purpose of this section is to describe a precipitation versus rain frequency analysis that might be useful for urban or pavement drainage design near lake level in the study area. To do this, ratios will be developed which can be used to convert NOAA14 precipitation ddf curves to rainfall ddf curves

Methods for the application of precipitation ddf curves to estimate drainage design runoff include:

- Watershed model simulation of a design storm, determined from precipitation ddf curves (such as in NOAA14), to produce design runoff. The simulation requires some estimates of temperature variation during the storm and antecedent snow pack conditions.
- Alternatively, simulated runoff from a rainfall design storm could be combined with a base snowmelt runoff amount to determine design runoff.

The simulation of the precipitation design storm is typical, mostly because the assumption is made that the precipitation ddf curves will result in rainfall induced runoff.. In most areas of the U.S., this is probably not a bad assumption; however, this not true for the Lake Tahoe area. To overcome this problem a template storm approach was used to developed guidelines for applying precipitation design storms in Lake Tahoe (Goldman et al., 2005).

The alternative approach would be useful for impervious surfaces, particularly for roadways, when sizing drainage pipes and spacing catch basins. The assumption may be that these surface will be plowed; and if not, a base snowmelt could be added. The application of rainfall ddf curves could be used either to develop rainfall design storms or in applications with the rational method for small drainage areas.

Clearly, the problem is estimating the rainfall ddf curves from gage data, which does not have information on precipitation phase, at least not in the records available in the study. Section 5.2, discusses the use of snow depth and temperature data coincident with the precipitation measurements to estimate a daily rainfall record. The results of the rainfall frequency analysis are presented in section 5.3. Section 5.4 investigates expanding these results to hourly rainfall. Finally, section 5.4 provides recommendation on application of the results to drainage design.

5.2. Identifying precipitation phase, snow versus rain

The identification of the precipitation phase, snow versus rain, is necessarily inexact given the daily precipitation, snow depth and temperature data available. The identification of the phase for any one event is not going to be perfect because of the daily data; but, over a period of record, a useful relationship can be developed between ddf curves for precipitation versus rainfall.

Figure 5.1 displays a typical storm period that was encountered in identifying the phase of precipitation. The storm in this case, begins in the snow phase (November 2nd) as can be seen from the snow depth accumulation, changes to rain (November 3rd) given the decrease in snow depth, and begins snowing again later in the storm given the snow depth increase.

Snow depth decrease is due not only to the occurrence of rain. Rain basically ripens the pack (the release of latent heat due to freezing), bringing the pack to isothermal conditions. Other thermal effects, which can roughly be approximated by air temperature, melt a ripe snow pack. Consequently, a decrease in snow depth during a storm is almost assuredly, at least in part, due to rainfall. However, the snow depth will decrease over a short time period due to both thermal affects (melt and sublimation) and compaction due to the snow pack weight. Figure 5.2 shows this, where, on October 27th there is an apparent rain event causing a decrease in the snow depth, an increase to a maximum snow depth on the October 29th, and then decrease due to melt, etc. after this time.

The identification of rainfall amounts is not always obvious. For example, Figure 5.3 shows that on January 27th a decrease in snow depth that is not particularly great, but is probably due to rainfall.

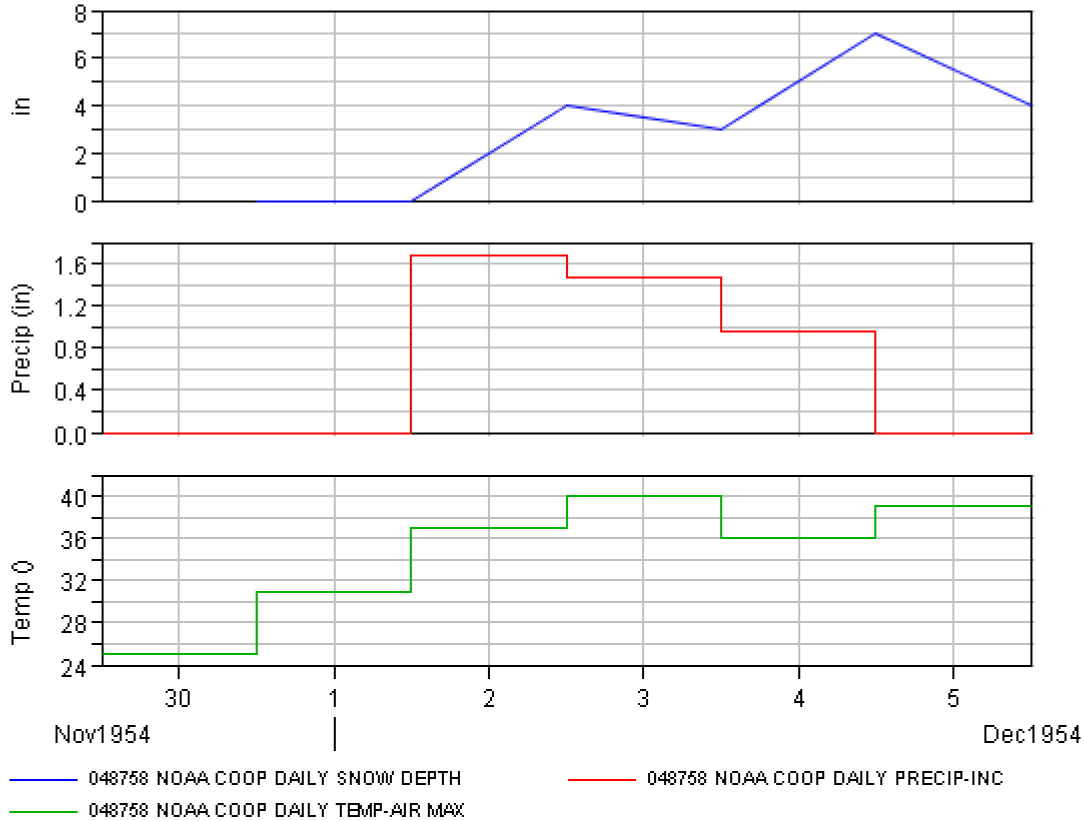

Figure 5.1: Tahoe City (NOAA) gage snow versus rain based on observation of snow depth and maximum daily air temperature.

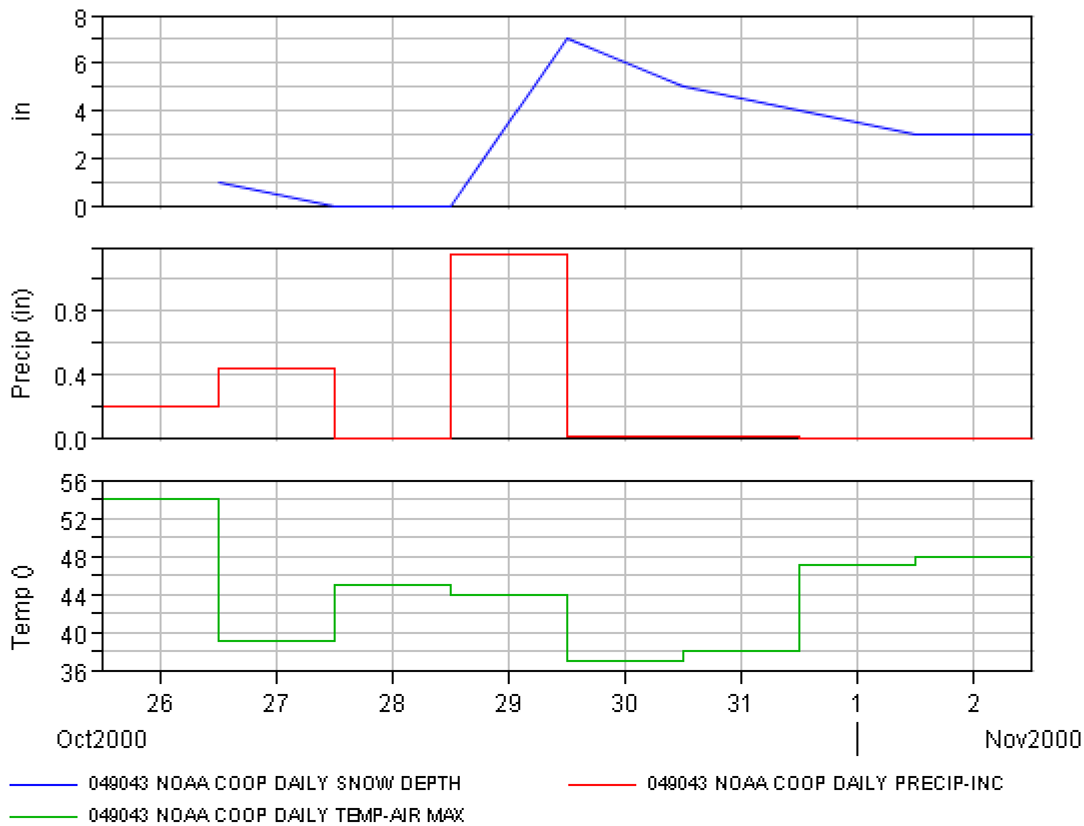

Figure 5.2: Truckee RS (NOAA) gage example of decrease in snow pack due to rain, accumulation due to snow, and compression after the storms passes
(temperature is maximum daily)

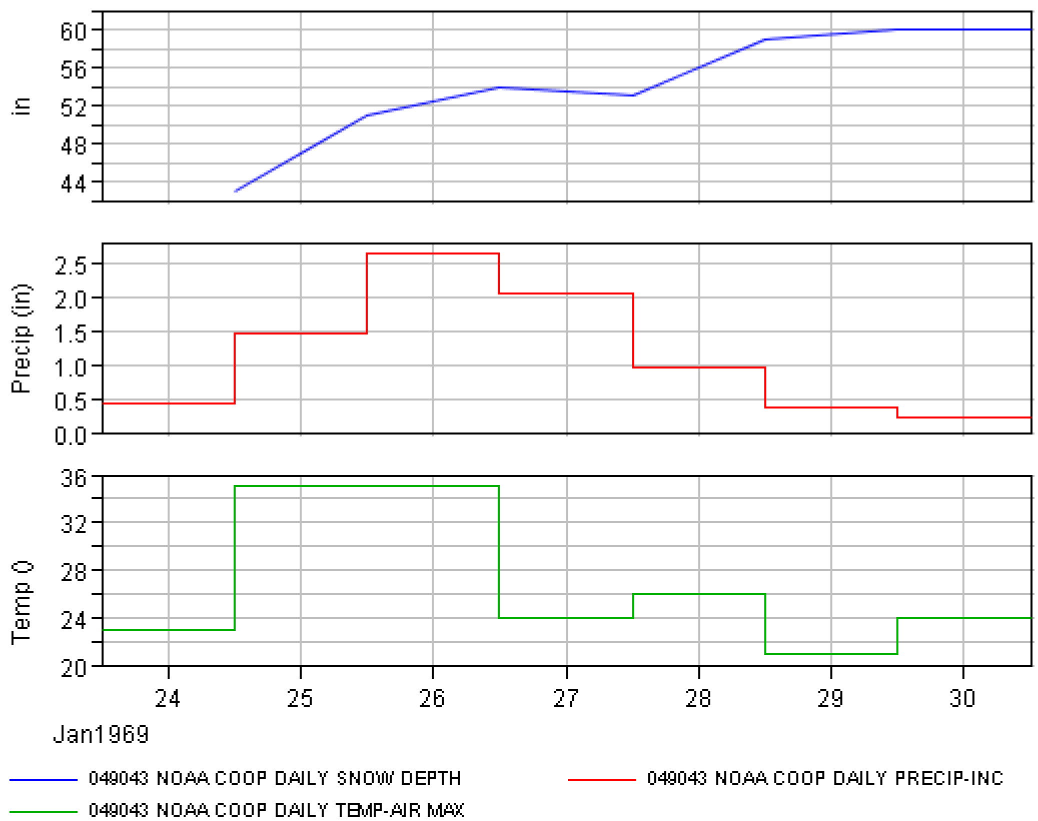

Figure 5.3: Truckee RS (NOAA) gage example of difficulty in identifying snow versus rain periods (temperature is maximum daily)

5.3. Rainfall frequency curves from daily data

Annual maximum rainfall data was determined for both the Truckee RS and Tahoe City NOAA cooperative gages. These gages were selected because of the relatively long period of record available at each gage.

Tables 5.1 and 5.2 together with figures 5.4 and 5.5 provide the corresponding plotting positions for both the precipitation and rainfall period of record analysis. As can be seen, the differences between the frequency curves decreases with increasing precipitation. Of course, there is a problem with sampling error in that in about a 50 year period of record there will not be many large precipitation events. The large storms in the period of record had a high percentage of rainfall, resulting in the exact correspondence between rainfall and precipitation frequency curves for infrequent events.

Table 5.3 provides some estimates based on the plotting position analysis of the rainfall/precipitation ratios as a function of exceedance probability for annual maximum daily frequency curves. These ratios might be applied to the NOAA14 annual 24hour maximum precipitation frequency curves to obtain rainfall frequency estimates. The application can be made to 24 hour values using the daily results since ratios are being used (presuming the conversion factor from daily to 24 hour would be the same rain and precipitation).

Table5.1: Tahoe City (NOAA) period of record annual maximum daily precipitation versus rainfall plotting positions

date	precipitation	date	rain	Weibull	ratio
26-Mar-40	6.77	26-Mar-40	6.77	0.016	1.00
26-Dec-40	5.80	26-Dec-40	5.80	0.033	1.00
2-Dec-41	5.04	25-Jan-42	4.65	0.049	0.92
20-Jan-43	4.65	17-Nov-42	4.56	0.066	0.98
28-Feb-44	4.56	4-Jan-44	4.36	0.082	0.96
9-Nov-44	4.36	1-Feb-45	3.73	0.098	0.86
29-Oct-45	4.03	20-Dec-45	3.54	0.115	0.88
18-Nov-46	3.98	22-Nov-46	3.49	0.131	0.88
1-Jan-48	3.79	7-Jan-48	3.33	0.148	0.88
2-Nov-48	3.74	2-Nov-48	3.18	0.164	0.85
17-Jan-50	3.73	17-Jan-50	3.15	0.180	0.84
19-Nov-50	3.70	19-Nov-50	2.90	0.197	0.78
15-Jan-52	3.67	2-Oct-51	2.73	0.213	0.74
14-Nov-52	3.63	9-Jan-53	2.68	0.230	0.74
13-Feb-54	3.62	9-Mar-54	2.57	0.246	0.71
2-Dec-54	3.55	3-Dec-54	2.45	0.262	0.69
23-Dec-55	3.54	6-Dec-55	2.44	0.279	0.69
13-Jan-57	3.49	5-Mar-57	2.42	0.295	0.69
3-Apr-58	3.05	12-Feb-58	2.31	0.311	0.76
11-Feb-59	3.00	16-Feb-59	2.27	0.328	0.76
8-Feb-60	2.93	8-Feb-60	2.22	0.344	0.76
2-Dec-60	2.90	26-Jan-61	2.12	0.361	0.73
10-Feb-62	2.87	21-Oct-61	2.11	0.377	0.74
1-Feb-63	2.83	1-Feb-63	2.00	0.393	0.71
15-Nov-63	2.76	11-Oct-63	1.93	0.410	0.70
23-Dec-64	2.76	23-Dec-64	1.90	0.426	0.69
25-Dec-65	2.73	14-Nov-65	1.90	0.443	0.70
21-Jan-67	2.67	16-Mar-67	1.89	0.459	0.71
20-Feb-68	2.64	3-Oct-67	1.85	0.475	0.70
21-Jan-69	2.60	20-Jan-69	1.77	0.492	0.68
23-Dec-69	2.57	16-Jan-70	1.67	0.508	0.65
26-Mar-71	2.51	26-Mar-71	1.66	0.525	0.66
29-Dec-71	2.45	25-Mar-72	1.53	0.541	0.62
12-Jan-73	2.44	12-Jan-73	1.49	0.557	0.61
1-Mar-74	2.41	12-Nov-73	1.44	0.574	0.60
22-Nov-74	2.31	25-Mar-75	1.37	0.590	0.59
7-Oct-75	2.25	7-Oct-75	1.36	0.607	0.60
22-Feb-77	2.23	2-Oct-76	1.35	0.623	0.61
22-Nov-77	2.04	22-Nov-77	1.35	0.639	0.66
18-Dec-78	1.99	11-Jan-79	1.35	0.656	0.68
12-Jan-80	1.99	12-Jan-80	1.31	0.672	0.66
28-Jan-81	1.96	14-Feb-81	1.29	0.689	0.66
20-Dec-81	1.93	22-Nov-81	1.28	0.705	0.66
22-Dec-82	1.90	13-Mar-83	1.22	0.721	0.64
11-Nov-83	1.89	11-Nov-83	1.21	0.738	0.64
28-Nov-84	1.87	11-Oct-84	1.21	0.754	0.65
18-Feb-86	1.85	18-Feb-86	1.20	0.770	0.65
13-Feb-87	1.78	5-Mar-87	1.13	0.787	0.63
7-Dec-87	1.77	14-Nov-87	1.05	0.803	0.59
23-Nov-88	1.74	23-Nov-88	1.03	0.820	0.59
26-Nov-89	1.68	8-Jan-90	0.98	0.836	0.58
4-Mar-91	1.67	4-Mar-91	0.90	0.852	0.54
26-Oct-91	1.60	20-Feb-92	0.76	0.869	0.48
9-Dec-92	1.59	21-Jan-93	0.71	0.885	0.45
18-Feb-94	1.50	6-Oct-93	0.64	0.902	0.43
23-Mar-95	1.37	14-Jan-95	0.60	0.918	0.44
12-Dec-95	1.36	12-Dec-95	0.50	0.934	0.37
2-Jan-97	1.34	2-Jan-97	0.48	0.951	0.36
24-Mar-98	1.32	15-Jan-98	0.31	0.967	0.23

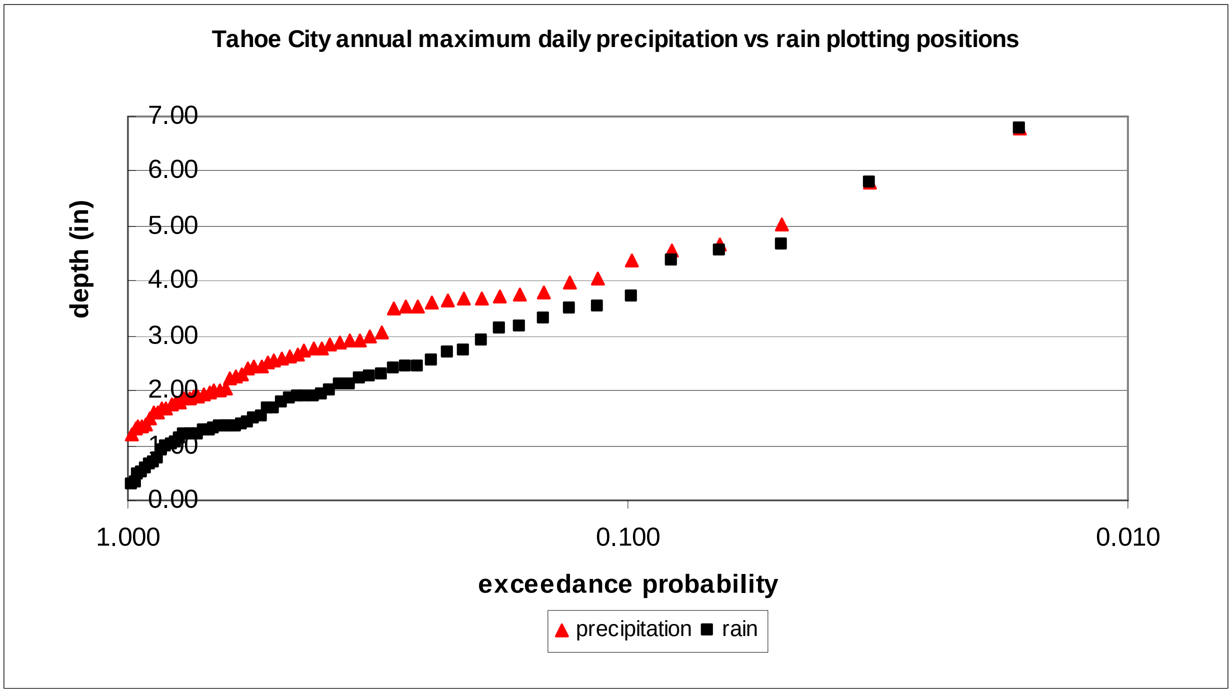

Figure 5.4: Tahoe City (NOAA) period of record annual maximum daily precipitation versus rainfall plotting positions

Table 5.2: Truckee RS annual maximum daily precipitation versus rainfall plotting positions frequencies

date	precipitation	date	rain	weibull	ratio rain/precip
1-Feb-63	5.21	1-Feb-63	5.21	0.019	1.00
23-Dec-64	5.00	23-Dec-64	5.00	0.038	1.00
3-Apr-58	4.15	22-Dec-55	3.58	0.057	0.86
24-Dec-55	3.97	2-Jan-97	3.43	0.075	0.86
20-Feb-92	3.51	18-Feb-86	3.08	0.094	0.88
19-Feb-86	3.46	21-Nov-50	2.90	0.113	0.84
2-Jan-97	3.43	24-Mar-98	2.41	0.132	0.70
29-Dec-65	3.11	12-Jan-80	2.40	0.151	0.77
21-Jan-69	2.94	17-Jan-50	2.33	0.170	0.79
21-Nov-50	2.90	16-Feb-82	2.33	0.189	0.80
17-Jan-54	2.88	8-Feb-60	2.32	0.208	0.81
22-Jan-67	2.86	10-Mar-95	2.18	0.226	0.76
9-Feb-99	2.80	29-Jan-67	2.17	0.245	0.78
11-Mar-95	2.70	27-Jan-69	2.06	0.264	0.76
10-Feb-62	2.69	15-Jan-70	1.98	0.283	0.74
11-Feb-59	2.58	3-Dec-54	1.90	0.302	0.74
11-Nov-83	2.51	26-Oct-82	1.90	0.321	0.76
9-Dec-92	2.46	25-Feb-57	1.87	0.340	0.76
10-Nov-49	2.42	9-Feb-62	1.84	0.358	0.76
22-Dec-82	2.42	12-Jan-73	1.83	0.377	0.76
24-Mar-98	2.41	14-Feb-00	1.83	0.396	0.76
12-Jan-80	2.40	21-Jan-93	1.81	0.415	0.75
25-Jan-00	2.40	26-Mar-71	1.75	0.434	0.73
22-Nov-77	2.35	4-Mar-91	1.75	0.453	0.74
20-Dec-81	2.35	2-Oct-76	1.70	0.472	0.72
8-Feb-60	2.32	25-Mar-75	1.66	0.491	0.72
23-Nov-88	2.28	16-Feb-59	1.64	0.509	0.72
26-Nov-89	2.27	5-Feb-96	1.53	0.528	0.67
24-Dec-69	2.25	23-Jan-54	1.51	0.547	0.67
12-Dec-95	2.25	4-Dec-80	1.50	0.566	0.67
14-Feb-79	2.22	15-Nov-63	1.48	0.585	0.67
28-Dec-51	2.15	2-Feb-52	1.40	0.604	0.65
27-Mar-85	1.98	3-Oct-67	1.40	0.623	0.71
21-Jan-64	1.97	2-Dec-52	1.37	0.642	0.70
7-Dec-52	1.93	17-Nov-65	1.33	0.660	0.69
3-Dec-54	1.90	11-Jan-79	1.31	0.679	0.69
25-Feb-57	1.87	25-Dec-83	1.31	0.698	0.70
18-Feb-94	1.86	23-Dec-77	1.19	0.717	0.64
12-Jan-73	1.83	19-Jan-74	1.09	0.736	0.60
26-Mar-71	1.75	11-Oct-75	0.94	0.755	0.54
13-Feb-87	1.75	3-Nov-84	0.90	0.774	0.51
4-Mar-91	1.75	19-Mar-89	0.84	0.792	0.48
2-Dec-60	1.74	1-Mar-99	0.79	0.811	0.45
17-Jan-74	1.74	4-Jan-88	0.75	0.830	0.43
30-Jan-68	1.72	12-Feb-58	0.71	0.849	0.41
25-Apr-75	1.70	15-Oct-93	0.61	0.868	0.36
2-Oct-76	1.70	8-Jan-90	0.59	0.887	0.35
28-Jan-81	1.65	27-Oct-00	0.44	0.906	0.27
22-Dec-71	1.62	1-Feb-61	0.42	0.925	0.26
1-Mar-76	1.43	29-Feb-72	0.40	0.943	0.28
7-Dec-87	1.23	5-Mar-87	0.37	0.962	0.30
29-Oct-00	1.15	27-Nov-91	0.23	0.981	0.20

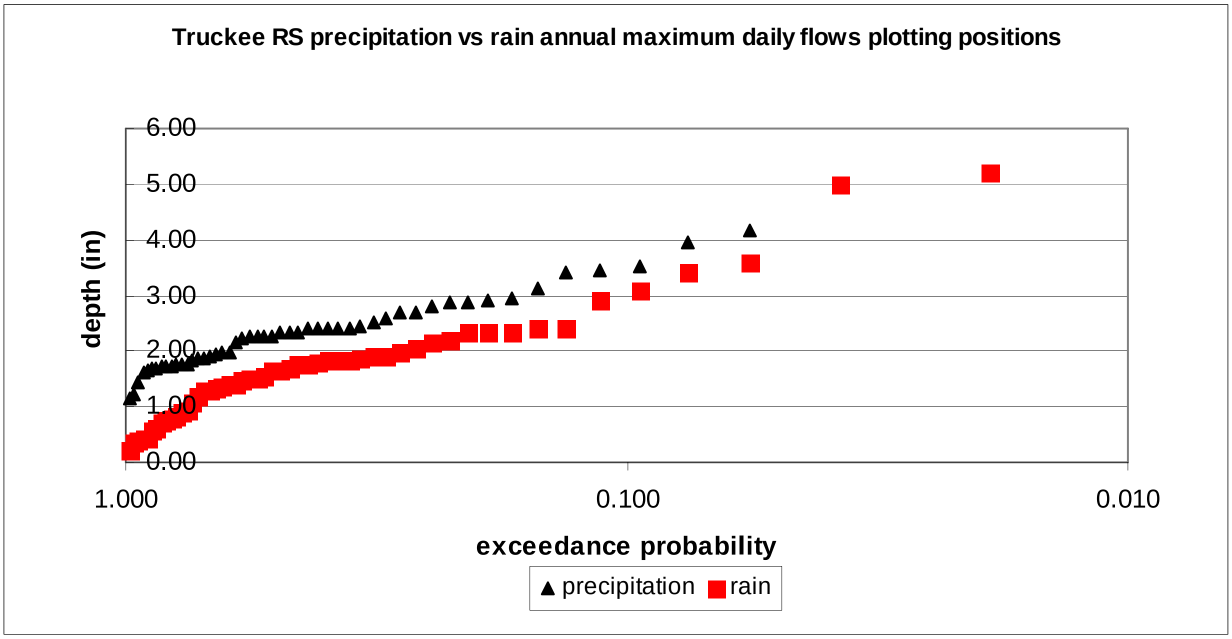

Figure5.5: Truckee RS annual maximum daily precipitation versus rainfall plotting positions frequencies

Table 5.3: Ratios of rainfall/precipitation versus exceedance probability

probability	Truckee RS	Tahoe City
0.01	1.00	1.00
0.10	0.85	0.87
0.20	0.80	0.78
0.50	0.70	0.66

5.4. Rainfall frequency curves for hourly data

Highway drainage design problems will require ddf curves for durations less than an hour. A possible strategy for developing rainfall ddf curves for these smaller durations is to: 1) develop the 1hour rainfall duration frequency curves using the hourly data available for the study area; and 2) apply the ratios used in NOAA14 between 60 minute and shorter duration precipitation frequency curves to obtain shorter duration rainfall duration frequency curves. Obviously, this is not an ideal approach; rather a direct analysis of short duration rainfall data would be optimal. However, this data is not available for the study area. Using the ratios available will allow an approximate estimation of rainfall frequency curves for durations of an hour or less, that are not as conservative as those given for precipitation in NOAA14.

Establishing the rainfall frequency curves for the 1hour duration followed the same strategy as discussed in the previous section on daily rainfall. The ratio of rainfall/precipitation as a function of period of record plotting positions would be established from study area gages with long term hourly data. In application, the assumption would be that the ratios could then be used to adjust NOAA14 60 minute precipitation frequency curves to rainfall frequency curves.

As in the case of the daily data analysis, the difficulty was in identifying the 1hour maximum rainfall period as opposed to precipitation in the period of record. The assumption was made that the maximum 1hour rainfall occurred during the same day that the annual maximum daily rainfall occurred.

An analysis of the Truckee RS (NOAA) gage hourly data identified 30 years of precipitation and rainfall 1hr annual maximum values. Both the precipitation and rainfall values were ranked and Weibull plotting positions computed. The resulting relationship between 1hour annual maximum ratios does not reveal any useful relationship with exceedance probability. Basically, the method for identifying annual maximum 1hour rainfall, the length of record available, and the quality of the data (the difficulty in measuring 1hour precipitation) prevents any useful derivation of the ratios desired.

5.5. Recommendations

The rainfall analysis did not result in rainfall frequency curves that would be useful for highway drainage design. Reasonable ratios were developed for converting NOAA14 24 hour precipitation ddf curves to corresponding rainfall values. However, the same cannot be said for 60 minute values.

The results could be used where design storms for detention/retention systems need to be developed for a 24hour duration. A rainfall depth for 24 hour duration could be determined using the ratios applied to the NOAA14 24 hour ddf curve. The hour duration or less values would be assumed to be the NOAA14 60 minute and less duration curves. Depth for durations between 60 minutes and 24 hours could be obtained by interpolation.

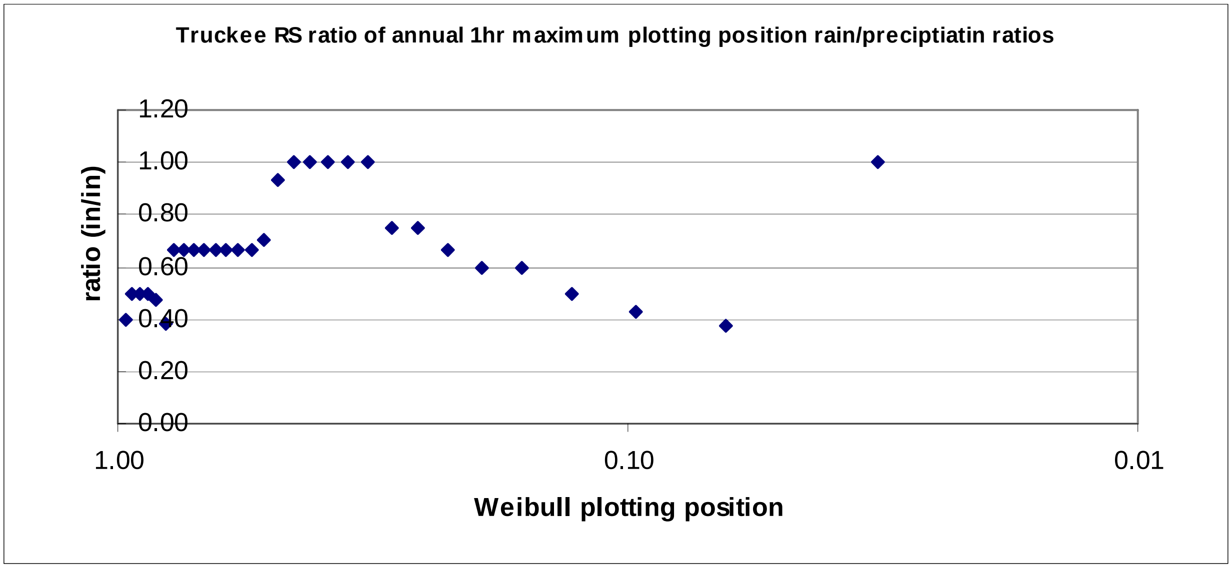

Figure 5.6: Truckee RS (NOAA) gage annual 1hr maximum Weibull plotting position rainfall/precipitation ratios for selected 30 years in period of recorc

6. Appendix

6.1. Annual Daily Maximum Precipitation used in L-moment frequency analysis

Table 6.1: SNOTEL Big Meadow and CSSLAB annual maximum daily values

Big Meadow	year	rank	max	CSSLAB	year	rank	max
25-Nov-83	1984	15	2.00	11-Nov-83	1984	11	3.90
10-Feb-85	1985	7	2.80	29-Mar-85	1985	10	4.10
20-Feb-86	1986	5	3.10	17-Feb-86	1986	2	7.10
4-Jan-87	1987	21	1.60	5-Jan-87	1987	19	2.60
7-Dec-87	1988	16	2.00	29-May-88	1988	21	2.30
24-Nov-88	1989	12	2.30	23-Nov-88	1989	5	4.70
17-Feb-90	1990	10	2.50	17-Feb-90	1990	17	3.00
5-Mar-91	1991	13	2.10	4-Mar-91	1991	7	4.40
18-Nov-91	1992	19	1.90	26-Oct-91	1992	20	2.40
29-Dec-92	1993	8	2.70	1-Jan-93	1993	3	6.20
18-Feb-94	1994	14	2.10	18-Feb-94	1994	15	3.40
11-Jan-95	1995	3	3.20	26-Jan-95	1995	9	4.20
7-Mar-96	1996	4	3.20	13-Dec-95	1996	4	5.50
22-Dec-96	1997	1	3.30	2-Jan-97	1997	1	8.20
25-Mar-98	1998	17	2.00	6-Feb-98	1998	18	2.90
20-Jan-99	1999	11	2.40	9-Feb-99	1999	13	3.60
25-Jan-00	2000	18	2.00	25-Jan-00	2000	12	3.80
30-Nov-00	2001	22	1.00	12-Jan-01	2001	22	2.10
3-Dec-01	2002	6	2.90	27-Jan-02	2002	16	3.10
17-Dec-02	2003	9	2.60	18-Dec-02	2003	8	4.30
30-Dec-03	2004	20	1.90	7-Dec-03	2004	14	3.60
31-Dec-04	2005	2	3.30	31-Dec-04	2005	6	4.70

Table 6.2: SNOTEL Echo Peak and Fallen Leaf Lake annual maximum daily values

Echo	year	rank	max	Fallen	year	rank	max
				12-Jan-80	1980	2	
27-Mar-81	1981	23	2.20	4-Dec-80	1981	19	27-Mar-81
20-Dec-81	1982	5	4.90	20-Dec-81	1982	3	20-Dec-81
9-Feb-83	1983	1	9.10	13-Mar-83	1983	9	9-Feb-83
28-Feb-84	1984	8	3.70	17-Nov-83	1984	22	28-Feb-84
9-Feb-85	1985	18	2.90	27-Mar-85	1985	20	9-Feb-85
17-Feb-86	1986	4	5.20	16-Feb-86	1986	11	17-Feb-86
4-Jan-87	1987	20	2.70	13-Feb-87	1987	8	4-Jan-87
7-Dec-87	1988	22	2.30	7-Dec-87	1988	25	7-Dec-87
14-Nov-88	1989	19	2.90	25-Nov-88	1989	21	14-Nov-88
24-Oct-89	1990	24	2.20	24-Oct-89	1990	18	24-Oct-89
5-Mar-91	1991	10	3.50	5-Mar-91	1991	10	5-Mar-91
18-Nov-91	1992	12	3.30	27-Oct-91	1992	14	18-Nov-91
10-Dec-92	1993	9	3.60	30-Dec-92	1993	13	10-Dec-92
18-Feb-94	1994	16	3.00	18-Feb-94	1994	24	18-Feb-94
10-Mar-95	1995	7	4.40	11-Mar-95	1995	6	10-Mar-95
5-Feb-96	1996	6	4.50	12-Dec-95	1996	4	5-Feb-96
18-Nov-96	1997	2	8.50	2-Jan-97	1997	1	18-Nov-96
25-Mar-98	1998	21	2.40	25-Mar-98	1998	16	25-Mar-98
20-Jan-99	1999	11	3.40	8-Feb-99	1999	12	20-Jan-99
14-Feb-00	2000	13	3.30	25-Jan-00	2000	7	14-Feb-00
30-Oct-00	2001	25	1.40	29-Oct-00	2001	26	30-Oct-00
3-Dec-01	2002	15	3.10	3-Dec-01	2002	17	3-Dec-01
9-Nov-02	2003	3	7.70	9-Nov-02	2003	5	9-Nov-02
30-Dec-03	2004	17	3.00	7-Dec-03	2004	15	30-Dec-03
9-Jan-05	2005	14	3.30	10-Jan-05	2005	23	9-Jan-05

Table 6.3: SNOTEL Hagan's Meadow and Heavenly Valley annual maximum daily values

Hagan's	year	rank	max	Heavenly	year	rank	max
18-Dec-78	1979	12	2.10	22-Jul-79	1979	12	2.30
13-Jan-80	1980	6	2.60	20-Oct-79	1980	10	2.40
1-May-81	1981	15	2.00	19-Dec-80	1981	6	2.80
5-Jan-82	1982	2	3.90	5-Jan-82	1982	2	3.70
19-Nov-82	1983	10	2.20	19-Nov-82	1983	15	2.20
25-Nov-83	1984	18	1.70	25-Nov-83	1984	20	1.70
27-Mar-85	1985	24	1.40	27-Mar-85	1985	25	1.30
18-Feb-86	1986	1	5.70	17-Feb-86	1986	4	3.50
13-Feb-87	1987	22	1.50	4-Jan-87	1987	13	2.30
7-Dec-87	1988	25	1.40	7-Dec-87	1988	27	1.00
24-Nov-88	1989	16	2.00	24-Nov-88	1989	21	1.70
17-Feb-90	1990	19	1.60	26-Nov-89	1990	24	1.50
5-Mar-91	1991	13	2.10	2-Mar-91	1991	23	1.60
14-Aug-92	1992	20	1.60	18-Nov-91	1992	16	2.10
29-Dec-92	1993	17	2.00	29-Dec-92	1993	8	2.70
19-Feb-94	1994	7	2.60	18-Feb-94	1994	19	1.80
10-Mar-95	1995	8	2.40	11-Mar-95	1995	9	2.50
25-Jan-96	1996	14	2.10	25-Jan-96	1996	18	1.90
22-Dec-96	1997	4	3.30	22-Dec-96	1997	5	3.50
25-Mar-98	1998	9	2.30	25-Mar-98	1998	11	2.40
20-Jan-99	1999	23	1.50	8-Feb-99	1999	1	4.20
14-Feb-00	2000	11	2.20	25-Jan-00	2000	17	2.00
8-Apr-01	2001	27	0.90	3-May-01	2001	26	1.20
3-Dec-01	2002	3	3.60	3-Dec-01	2002	7	2.80
9-Nov-02	2003	5	2.70	17-Dec-02	2003	14	2.30
10-Nov-03	2004	26	1.30	26-Feb-04	2004	22	1.70
31-Dec-04	2005	21	1.60	1-Jan-05	2005	3	3.70

Table 6.4: SNOTEL Independence Creek and Independence Camp annual maximum daily values

Creek	year	rank	max	Camp	year	rank	max
				23-Nov-88	1979	11	
				26-Oct-82	1980	5	
4-Dec-80	1981	23	1.60	20-Jan-99	1981	21	4-Dec-80
20-Dec-81	1982	3	4.30	28-Jan-81	1982	3	20-Dec-81
26-Oct-82	1983	10	2.70	29-Dec-87	1983	10	26-Oct-82
11-Nov-83	1984	4	4.20	28-Mar-85	1984	7	11-Nov-83
28-Mar-85	1985	19	1.90	3-Feb-98	1985	20	28-Mar-85
18-Feb-86	1986	1	5.10	13-Jan-80	1986	2	18-Feb-86
13-Feb-87	1987	15	2.10	11-Feb-94	1987	16	13-Feb-87
7-Dec-87	1988	17	2.00	9-Nov-02	1988	25	7-Dec-87
23-Nov-88	1989	5	3.30	19-Mar-87	1989	9	23-Nov-88
17-Feb-90	1990	9	2.80	10-Mar-95	1990	17	17-Feb-90
5-Mar-91	1991	12	2.50	18-Feb-86	1991	8	5-Mar-91
26-Oct-91	1992	20	1.90	5-Mar-01	1992	23	26-Oct-91
30-Dec-92	1993	14	2.20	18-Nov-91	1993	14	30-Dec-92
18-Feb-94	1994	24	1.30	31-Dec-04	1994	27	18-Feb-94
11-Mar-95	1995	6	3.30	11-Nov-83	1995	6	11-Mar-95
5-Feb-96	1996	7	3.20	20-Dec-81	1996	4	5-Feb-96
2-Jan-97	1997	2	4.80	12-Jan-79	1997	1	2-Jan-97
3-Feb-98	1998	21	1.90	5-Feb-96	1998	18	3-Feb-98
8-Feb-99	1999	22	1.90	25-Jan-00	1999	22	8-Feb-99
25-Jan-00	2000	13	2.50	5-Mar-91	2000	13	25-Jan-00
5-Mar-01	2001	25	1.30	2-Jan-04	2001	26	5-Mar-01
3-Dec-01	2002	8	3.00	2-Jan-97	2002	19	3-Dec-01
9-Nov-02	2003	16	2.10	22-Jan-93	2003	15	9-Nov-02
7-Dec-03	2004	18	2.00	7-Mar-02	2004	24	7-Dec-03
31-Dec-04	2005	11	2.60	24-Oct-89	2005	12	31-Dec-04

Table 6.5: SNOTEL Marlette Lake and Mt Rose Ski Area annual maximum daily values

date	year	rank	max	date	year	rank	max
18-Dec-78	1979	11	2.30				
14-Jan-80	1980	13	1.90				
26-Mar-81	1981	20	1.60	4-Dec-80	1981	10	4.30
5-Jan-82	1982	2	3.80	20-Dec-81	1982	3	5.60
26-Oct-82	1983	6	2.60	21-Dec-82	1983	4	4.90
19-Nov-83	1984	21	1.50	6-Jan-84	1984	14	3.90
17-Oct-84	1985	22	1.50	28-Nov-84	1985	16	3.70
17-Feb-86	1986	1	4.70	18-Feb-86	1986	1	10.90
4-Jan-87	1987	19	1.70	13-Feb-87	1987	20	3.00
7-Dec-87	1988	27	1.00	7-Dec-87	1988	24	2.20
14-Nov-88	1989	15	1.80	24-Nov-88	1989	21	3.00
18-Feb-90	1990	24	1.30	26-Nov-89	1990	12	4.20
4-Mar-91	1991	16	1.80	4-Mar-91	1991	17	3.70
19-Nov-91	1992	23	1.40	18-Nov-91	1992	23	2.50
21-Jan-93	1993	3	3.10	29-Dec-92	1993	13	4.00
6-Oct-93	1994	25	1.20	18-Feb-94	1994	18	3.40
11-Jan-95	1995	5	2.90	11-Jan-95	1995	7	4.70
7-Mar-96	1996	7	2.60	13-Dec-95	1996	5	4.90
23-Jan-97	1997	4	3.10	2-Jan-97	1997	2	6.60
25-Mar-98	1998	12	2.30	15-Feb-98	1998	22	2.70
8-Feb-99	1999	9	2.50	9-Feb-99	1999	8	4.70
25-Jan-00	2000	17	1.80	14-Feb-00	2000	19	3.40
9-Nov-00	2001	26	1.10	29-Oct-00	2001	25	1.60
3-Dec-01	2002	10	2.40	3-Dec-01	2002	11	4.30
14-Apr-03	2003	18	1.80	17-Dec-02	2003	15	3.90
25-Dec-03	2004	14	1.90	30-Dec-03	2004	9	4.70
9-Jan-05	2005	8	2.60	31-Dec-04	2005	6	4.80

Table 6.6: SNOTEL Marlette Lake and Mt Rose Ski Area annual maximum daily values

Marlette	year	rank	max	Mt Rose	year	rank	max
28-Jan-81	1981	16	2.00	1-Apr-81	1981	11	2.40
20-Dec-81	1982	2	3.90	20-Dec-81	1982	4	3.00
13-Mar-83	1983	8	2.60	19-Nov-82	1983	12	2.30
11-Nov-83	1984	7	2.70	11-Nov-83	1984	7	2.90
9-Feb-85	1985	19	1.70	8-Feb-85	1985	20	1.80
18-Feb-86	1986	3	3.90	17-Feb-86	1986	2	4.60
13-Feb-87	1987	22	1.50	13-Feb-87	1987	16	2.00
7-Dec-87	1988	23	1.30	7-Dec-87	1988	24	1.40
23-Nov-88	1989	14	2.10	14-Nov-88	1989	23	1.60
24-Oct-89	1990	20	1.70	17-Feb-90	1990	9	2.80
4-Mar-91	1991	12	2.20	4-Mar-91	1991	17	2.00
26-Oct-91	1992	21	1.60	26-Oct-91	1992	18	1.90
17-Jan-93	1993	17	1.90	29-Dec-92	1993	15	2.10
19-Feb-94	1994	24	1.10	18-Feb-94	1994	21	1.80
11-Mar-95	1995	10	2.40	10-Mar-95	1995	8	2.90
5-Feb-96	1996	4	3.00	13-Dec-95	1996	5	3.00
2-Jan-97	1997	1	4.60	2-Jan-97	1997	1	4.90
25-Mar-98	1998	15	2.10	3-Feb-98	1998	22	1.70
8-Feb-99	1999	11	2.40	8-Feb-99	1999	13	2.20
14-Feb-00	2000	18	1.90	25-Jan-00	2000	3	3.30
21-Apr-01	2001	25	0.80	6-Mar-01	2001	25	0.80
3-Dec-01	2002	9	2.50	3-Dec-01	2002	10	2.70
9-Nov-02	2003	5	3.00	9-Nov-02	2003	14	2.20
27-Feb-04	2004	13	2.20	30-Dec-03	2004	19	1.90
31-Dec-04	2005	6	2.80	31-Dec-04	2005	6	3.00

Table 6.7: SNOTEL Rubicon #2 and Squaw Valley G.C. annual maximum daily values

Rubicon	year	rank	max	Squaw	year	rank	max
28-Jan-81	1981	9	2.60	4-Dec-80	1981	19	2.80
20-Dec-81	1982	3	4.60	20-Dec-81	1982	2	6.90
26-Oct-82	1983	7	3.00	22-Dec-82	1983	5	5.10
17-Nov-83	1984	11	2.50	3-Mar-84	1984	10	4.10
8-Feb-85	1985	14	2.30	28-Nov-84	1985	16	3.50
18-Feb-86	1986	2	5.70	8-Mar-86	1986	6	5.10
4-Jan-87	1987	20	2.00	14-Feb-87	1987	24	2.20
7-Dec-87	1988	23	1.70	7-Dec-87	1988	21	2.40
14-Nov-88	1989	13	2.40	23-Nov-88	1989	9	4.20
18-Feb-90	1990	21	1.80	17-Feb-90	1990	22	2.30
5-Mar-91	1991	4	3.40	5-Mar-91	1991	3	5.40
27-Oct-91	1992	24	1.60	27-Oct-91	1992	20	2.50
29-Dec-92	1993	17	2.20	21-Jan-93	1993	13	3.80
18-Feb-94	1994	22	1.80	18-Feb-94	1994	23	2.30
6-Nov-94	1995	15	2.30	6-Nov-94	1995	15	3.60
5-Feb-96	1996	5	3.40	13-Dec-95	1996	7	4.80
2-Jan-97	1997	1	6.20	2-Jan-97	1997	1	8.30
25-Mar-98	1998	8	2.90	16-Jan-98	1998	17	3.00
10-Feb-99	1999	18	2.20	9-Feb-99	1999	11	4.00
14-Feb-00	2000	16	2.30	14-Feb-00	2000	12	3.90
12-Feb-01	2001	25	1.00	30-Oct-00	2001	25	1.30
3-Dec-01	2002	12	2.50	22-Nov-01	2002	18	3.00
9-Nov-02	2003	10	2.60	9-Nov-02	2003	4	5.40
30-Dec-03	2004	19	2.10	30-Dec-03	2004	8	4.60
28-Mar-05	2005	6	3.40	9-Dec-04	2005	14	3.80

Table 6.8: SNOTEL Tahoe City Cross and Truckee annual maximum daily values

Tahoe	year	rank	max	Truckee	year	rank	max
28-Jan-81	1981	16	2.00	1-Apr-81	1981	11	2.40
20-Dec-81	1982	2	3.90	20-Dec-81	1982	4	3.00
13-Mar-83	1983	8	2.60	19-Nov-82	1983	12	2.30
11-Nov-83	1984	7	2.70	11-Nov-83	1984	7	2.90
9-Feb-85	1985	19	1.70	8-Feb-85	1985	20	1.80
18-Feb-86	1986	3	3.90	17-Feb-86	1986	2	4.60
13-Feb-87	1987	22	1.50	13-Feb-87	1987	16	2.00
7-Dec-87	1988	23	1.30	7-Dec-87	1988	24	1.40
23-Nov-88	1989	14	2.10	14-Nov-88	1989	23	1.60
24-Oct-89	1990	20	1.70	17-Feb-90	1990	9	2.80
4-Mar-91	1991	12	2.20	4-Mar-91	1991	17	2.00
26-Oct-91	1992	21	1.60	26-Oct-91	1992	18	1.90
17-Jan-93	1993	17	1.90	29-Dec-92	1993	15	2.10
19-Feb-94	1994	24	1.10	18-Feb-94	1994	21	1.80
11-Mar-95	1995	10	2.40	10-Mar-95	1995	8	2.90
5-Feb-96	1996	4	3.00	13-Dec-95	1996	5	3.00
2-Jan-97	1997	1	4.60	2-Jan-97	1997	1	4.90
25-Mar-98	1998	15	2.10	3-Feb-98	1998	22	1.70
8-Feb-99	1999	11	2.40	8-Feb-99	1999	13	2.20
14-Feb-00	2000	18	1.90	25-Jan-00	2000	3	3.30
21-Apr-01	2001	25	0.80	6-Mar-01	2001	25	0.80
3-Dec-01	2002	9	2.50	3-Dec-01	2002	10	2.70
9-Nov-02	2003	5	3.00	9-Nov-02	2003	14	2.20
27-Feb-04	2004	13	2.20	30-Dec-03	2004	19	1.90
31-Dec-04	2005	6	2.80	31-Dec-04	2005	6	3.00

Table 6.9: SNOTEL Ward Creek #3 annual maximum daily values

date	year	rank	max
12-Jan-79	1979	16	3.60
14-Jan-80	1980	6	5.50
4-Dec-80	1981	22	2.90
20-Dec-81	1982	4	6.20
26-Oct-82	1983	9	5.20
11-Nov-83	1984	7	5.50
9-Feb-85	1985	23	2.80
18-Feb-86	1986	2	8.10
13-Feb-87	1987	21	3.20
7-Dec-87	1988	25	2.20
23-Nov-88	1989	11	4.60
24-Oct-89	1990	17	3.50
5-Mar-91	1991	10	4.70
27-Oct-91	1992	24	2.80
10-Dec-92	1993	15	3.90
18-Feb-94	1994	26	1.90
10-Mar-95	1995	5	6.20
13-Dec-95	1996	3	6.60
2-Jan-97	1997	1	9.00
16-Jan-98	1998	14	4.10
9-Feb-99	1999	18	3.50
14-Feb-00	2000	12	4.20
15-Dec-00	2001	27	1.50
3-Dec-01	2002	20	3.40
9-Nov-02	2003	8	5.40
7-Dec-03	2004	13	4.20
31-Dec-04	2005	19	3.50

6.2.NOAA COOP gage daily annual maximum flow values

Table610: NOAA Truckee RS and Glenbrook Ck annual maximum daily values

Truckee	year	rank	max	Truckee	year	rank	max	Glenbrook	year	rank	max	Glenbrook	year	rank	
14-Dec-48	1949	40	1.80	14-May-49	1949	50	0.85	1-Mar-76	1976	51	1.43	29-Feb-76	1976	42	1.10
10-Nov-49	1950	19	2.42	10-Nov-49	1950	43	1.09	2-Oct-76	1977	48	1.70	21-Feb-77	1977	39	1.20
21-Nov-50	1951	10	2.90	3-Dec-50	1951	2	2.85	22-Nov-77	1978	24	2.35	17-Dec-77	1978	31	1.35
28-Dec-51	1952	32	2.15	28-Dec-51	1952	21	1.65	14-Feb-79	1979	31	2.22	13-Feb-79	1979	44	1.02
7-Dec-52	1953	35	1.93	7-Dec-52	1953	11	2.10	12-Jan-80	1980	22	2.40	25-Dec-79	1980	12	2.04
17-Jan-54	1954	11	2.88	13-Feb-54	1954	26	1.48	28-Jan-81	1981	49	1.65	4-Dec-80	1981	40	1.18
3-Dec-54	1955	36	1.90	1-Jan-55	1955	28	1.46	20-Dec-81	1982	25	2.35	5-Jan-82	1982	8	2.19
24-Dec-55	1956	4	3.97	24-Dec-55	1956	3	2.79	22-Dec-82	1983	20	2.42	13-Mar-83	1983	4	2.53
25-Feb-57	1957	37	1.87	5-Mar-57	1957	52	0.78	11-Nov-83	1984	17	2.51	17-Nov-83	1984	13	2.04
3-Apr-58	1958	3	4.15	4-Apr-58	1958	9	2.15	27-Mar-85	1985	33	1.98	8-Feb-85	1985	20	1.74
11-Feb-59	1959	16	2.58	16-Feb-59	1959	34	1.31	19-Feb-86	1986	6	3.46	17-Feb-86	1986	14	1.97
8-Feb-60	1960	26	2.32	8-Feb-60	1960	37	1.27	13-Feb-87	1987	42	1.75	13-Feb-87	1987	19	1.80
2-Dec-60	1961	44	1.74	12-Nov-60	1961	41	1.15	7-Dec-87	1988	52	1.23	29-Oct-87	1988	51	0.83
10-Feb-62	1962	15	2.69	9-Feb-62	1962	18	1.80	23-Nov-88	1989	27	2.28	23-Nov-88	1989	25	1.53
1-Feb-63	1963	1	5.21	30-Jan-63	1963	17	1.84	26-Nov-89	1990	28	2.27	26-Nov-89	1990	38	1.21
21-Jan-64	1964	34	1.97	23-Nov-63	1964	33	1.32	4-Mar-91	1991	43	1.75	4-Mar-91	1991	49	0.89
23-Dec-64	1965	2	5.00	23-Dec-64	1965	24	1.59	20-Feb-92	1992	5	3.51	26-Oct-91	1992	23	1.60
29-Dec-65	1966	8	3.11	24-Nov-65	1966	29	1.35	9-Dec-92	1993	18	2.46	20-Feb-93	1993	47	0.91
22-Jan-67	1967	12	2.86	21-Jan-67	1967	1	3.55	18-Feb-94	1994	38	1.86	6-May-94	1994	48	0.90
30-Jan-68	1968	46	1.72	30-Jan-68	1968	46	0.98	11-Mar-95	1995	14	2.70	11-Mar-95	1995	22	1.65
21-Jan-69	1969	9	2.94	20-Jan-69	1969	10	2.11	12-Dec-95	1996	30	2.25	12-Dec-95	1996	5	2.45
24-Dec-69	1970	29	2.25	14-Jan-70	1970	16	1.91	2-Jan-97	1997	7	3.43	2-Jan-97	1997	6	2.27
26-Mar-71	1971	41	1.75	16-Dec-70	1971	15	1.92	24-Mar-98	1998	21	2.41	24-Mar-98	1998	7	2.27
22-Dec-71	1972	50	1.62	22-Dec-71	1972	30	1.35	9-Feb-99	1999	13	2.80	18-Jan-99	1999	32	1.35
12-Jan-73	1973	39	1.83	18-Jan-73	1973	45	1.01	25-Jan-00	2000	23	2.40	14-Feb-00	2000	27	1.47
17-Jan-74	1974	45	1.74	1-Dec-73	1974	35	1.30	29-Oct-00	2001	53	1.15	29-Oct-00	2001	53	0.50
25-Apr-75	1975	47	1.70	9-Feb-75	1975	36	1.28								

Table6.11: NOAA Tahoe City Cross annual maximum daily values

date	year	rank	max	date	year	rank	max
31-Jan-32	1932	33	2.60	25-Dec-65	1966	46	1.99
17-Jan-33	1933	62	1.56	21-Jan-67	1967	28	2.76
29-Oct-33	1934	21	3.15	20-Feb-68	1968	64	1.37
7-Apr-35	1935	52	1.85	21-Jan-69	1969	8	4.03
10-Jan-36	1936	43	2.08	23-Dec-69	1970	34	2.60
4-Feb-37	1937	15	3.66	26-Mar-71	1971	49	1.90
10-Dec-37	1938	4	4.73	29-Dec-71	1972	27	2.83
4-Jan-39	1939	61	1.58	12-Jan-73	1973	50	1.89
26-Mar-40	1940	35	2.57	1-Mar-74	1974	53	1.85
26-Dec-40	1941	48	1.93	22-Nov-74	1975	68	1.22
2-Dec-41	1942	13	3.70	7-Oct-75	1976	65	1.36
20-Jan-43	1943	16	3.63	22-Feb-77	1977	59	1.60
28-Feb-44	1944	56	1.74	22-Nov-77	1978	37	2.45
9-Nov-44	1945	18	3.55	18-Dec-78	1979	57	1.68
29-Oct-45	1946	26	2.87	12-Jan-80	1980	20	3.49
18-Nov-46	1947	22	3.05	28-Jan-81	1981	42	2.23
1-Jan-48	1948	67	1.32	20-Dec-81	1982	11	3.74
2-Nov-48	1949	55	1.77	22-Dec-82	1983	32	2.64
17-Jan-50	1950	38	2.44	11-Nov-83	1984	25	2.90
19-Nov-50	1951	6	4.56	28-Nov-84	1985	54	1.78
15-Jan-52	1952	10	3.79	18-Feb-86	1986	7	4.36
14-Nov-52	1953	60	1.59	13-Feb-87	1987	41	2.25
13-Feb-54	1954	39	2.41	7-Dec-87	1988	66	1.34
2-Dec-54	1955	58	1.67	23-Nov-88	1989	30	2.73
23-Dec-55	1956	3	5.04	26-Nov-89	1990	24	2.93
13-Jan-57	1957	51	1.87	4-Mar-91	1991	40	2.31
3-Apr-58	1958	14	3.67	26-Oct-91	1992	36	2.51
11-Feb-59	1959	44	2.04	9-Dec-92	1993	31	2.67
8-Feb-60	1960	12	3.73	18-Feb-94	1994	47	1.96
2-Dec-60	1961	63	1.50	23-Mar-95	1995	9	3.98
10-Feb-62	1962	23	3.00	12-Dec-95	1996	19	3.54
1-Feb-63	1963	2	5.80	2-Jan-97	1997	5	4.65
15-Nov-63	1964	45	1.99	24-Mar-98	1998	29	2.76
23-Dec-64	1965	1	6.77	9-Feb-99	1999	17	3.62