

El NINO-LA NINA IMPLICATIONS ON FLOOD HAZARD MITIGATION PHOENIX, AZ. AREA

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Abstract

In a previous investigation (French and Miller, 2006 and 2002), five maximum annual winter period daily depths of precipitation series from gaging stations on the U.S. Department of Energy's Nevada Test Site were examined from the viewpoint of the effects of El Nino - La Nina events on the series. This analysis demonstrated at the five precipitation gages considered, with periods of record ranging from 33 to 45 years, that there were actually two data series; one series associated with El Nino periods and a second series with La Nina events and neutral periods. That is, the precipitation data series contained a mixed population. This has critical implications from both the viewpoints of flood hazard identification and mitigation when rainfall-runoff modeling is used and environmental restoration. In this paper, annual maximum (winter and summer) depths of precipitation are analyzed for five long-term gaging stations in the Phoenix, AZ area.

Introduction

One of the most important sources of year-to-year climate variation in the Southwestern United States is the El Nino/La Nina phenomena of the tropical Pacific Ocean. Under normal conditions, the tropical trade winds blow from the east to west resulting in the concentration of warm water in the western Pacific Ocean. In the eastern Pacific Ocean, the effect of the trade winds is to upwell cold, deep nutrient waters along the Equator from the coast of Equador to the Central Pacific. During an El Nino episode, the trade winds weaken and the upwelling of the cool waters in the Eastern Pacific is reduced. In turn, this allows the warm water in the Western Pacific to drift eastward towards South America. As the central and eastern Pacific warms, atmospheric pressure gradients along the Equator weaken and the trade winds are further diminished. These changes are the defining factors of an El Nino episode and were first noted by Gilbert Walker in the early decades of the Twentieth Century who termed this the "Southern Oscillation." From the viewpoint of hydrology, the net effect of these changes is that Pacific Ocean storms begin to form farther east than is typical under "normal" conditions. This results in the jet stream over the northern Pacific Ocean being pulled further south than normal where it collects moisture and carries this moisture to the Southwest and northern Mexico. An El Nino event can last several seasons, and geologic records suggest that El Nino episodes have been part of the earth's climate for at least several thousand years.

The data on which this analysis is based was recovered and analyzed as a portion of a study conducted by URS Corporation for the Flood Control District of Maricopa County (FCDMC), Phoenix, AZ (URS, 2004). FCDMC operates and maintains 22 flood control dams in central Arizona. In December 1992 - March 1993 storms in Arizona caused unplanned releases (or nearly unplanned releases) from flood mitigation reservoirs at several locations throughout the state. Most of these structures were designed to contain short-duration flood events (e.g., 100-yr, 24-hr events). The rainfall of the 1992-93 period demonstrated that when a series of relatively frequent short duration events can severely stress a system that was designed a singular infrequent event. The lesson was that multiple storm scenarios can govern engineering design where the goal is to prevent flow in unlined emergency spillways. Therefore, the precipitation data recovered for this study is not only maximum daily depths of precipitation but maximum depths of precipitation for 2, 3, 5, 10, 15, 30, 45, and 60 day durations. Imbedded within this overriding concern are the potential effects of ENSO events; that is, El Nino - La Nina events on the design of critical flood mitigation structures. In this analysis, space limitations preclude addressing anything more than the 1 and 60-day maximum depths of precipitation series.

Analysis of Phoenix Area Data

In this study, four precipitation gages with relatively long period of records in critical watersheds tributary to Phoenix metroplex were analyzed; and the locations and period of record available at these gages are summarized in Table 1.

Table 1. Locations of the precipitation gaging stations used in this analysis.

Station Name	**Latitude** (deg)	**Longitude** (deg)	**Elevation** (ft)	**Length of Record Considered** (yrs)
Buckeye	33.37	112.58	889	100
Wickenburg	33.97	112.73	2096	93
Superior	33.30	111.10	2295	82
Crown King	34.20	112.33	5919	88

With regard to the data summarized in Table 1, a number of observations are pertinent. First, there are substantial elevation differences among the gaging stations considered. In the semi- and arid west, depths of precipitation can be strongly influenced by elevation and orographic effects. Second, at all stations the periods of record are relatively long; and the period of record is such that some of the available data could not be used because a) the ENSO condition is not known and/or b) the dates are not certain. For example, the maximum 1-day precipitation event at the Buckeye gage occurred in 1894 but the month and day are not documented. Third, in a previous analysis of precipitation data from the Nevada Test Site (French and Miller, 2006 and 2002) only winter period precipitation data were considered; however, in this analysis data from the full calendar year are considered. Therefore, there are four series to be analyzed and considered at each station: the full series; Summer (May - September), Winter (October - April) El Nino; Winter Neutral; and Winter La Nina. Division of the year into these periods makes two tacit assumptions a) the climatic precipitation periods in Central Arizona are similar to Nevada, and b) El Nino - La Nina events have no effect on summer period precipitation. In this analysis, space limitations dictate that only the 1- and 60-day maximum depths of precipitation can be considered. The statistics, using a $\log_{10}$ transform, for the data at these stations are summarized in Table 2. Using a log transform involves the tacit assumption that maximum depths of precipitation series can be described by a log probability distribution (see for example, Randerson, 1997).

Table 2. Summary of the $\log_{10}$ statistics for the series analyzed.

Station	Full Series	El Nino	Neutral	La Nina	Summer
Buckeye					
1-Day					
n[1]	99	22	19	12	46
log(mean)	0.0744	0.0579	0.0455	-0.0449	0.1252
log(std. dev.)	0.1762	0.1389	0.1418	0.1945	0.1855
log(skew)	-0.0644	0.2633	0.3978	-1.363	0.0182
60-Day					
n[1]	99	16	31	6	46
log(mean)	0.5213	0.6167	0.5300	0.3426	0.5056
log(std. dev.)	0.2007	0.1362	0.2026	0.1611	0.2085
log(skew)	-0.4278	0.2463	0.5776	-0.3948	-1.023
Wickenburg					
1-Day	93	18	27	7	41
n[1]	0.1795	0.3906	0.1555	0.1330	0.2365
log(mean)	0.1467	0.9017	0.1237	0.1491	0.2664
log(std. dev.)	-0.3637	4.125	-0.5455	0.3696	2.600
log(skew)					
60-Day					
n[1]	93	17	36	7	33
log(mean)	0.6780	0.7668	0.6713	0.5909	0.6582
log(std. dev.)	0.1820	0.1667	0.1741	0.1468	0.1945
log(skew)	-0.4050	-0.9075	-0.3946	0.1516	-0.4137

Station	Full Series	El Nino	Neutral	La Nina	Summer
Superior					
1-Day	83	10	29	10	34
n	0.2526	0.2832	0.2148	0.2082	0.2829
log(mean)	0.1650	0.1897	0.2139	0.0892	0.1155
log(std. dev.)	-2.094	-0.3411	-2.688	-0.6266	0.6888
log(skew)					
60-Day					
n	83	19	33	4	27
log(mean)	0.8604	0.9486	0.8019	0.8502	0.8714
log(std. dev.)	0.2166	0.1161	0.3025	0.1128	0.1196
log(skew)	-4.166	0.2905	-3.562	0.9708	0.0312
Crown King					
1-Day	81	20	26	10	26
n	0.4807	0.5573	0.4830	0.4870	0.4204
log(mean)	0.1815	0.1552	0.1853	0.2420	0.1533
log(std. dev.)	0.2288	-0.5394	0.7572	-0.2786	0.4953
log(skew)					
60-Day					
n	81	13	22	6	40
log(mean)	1.057	1.135	1.099	1.013	1.015
log(std. dev.)	0.1667	0.1973	0.1817	0.1283	0.1415
log(skew)	0.3899	-0.6177	0.9252	-0.8031	-0.0306

[1]Some data from the complete data set were not used because of lack of dates other than years, lack of information regarding El Nino-La Nina conditions, and zero values.

With regard to the data in Table 1, the following observations are pertinent:

1. The generalized skew coefficient of annual maximum streamflow log transformed data series for the Phoenix area is approximately -0.20 (WRC, 1981). In general, the skew coefficients for all series analyzed are either strongly negative or positive. It is well known that extreme events can have a substantial effect on the value of the skew coefficient. At the Buckeye station the maximum 1-day depths of precipitation range from 3.29 in to 0 and at Wickenburg the 60-day depths of precipitation range from 11.64 in to 0. Also recall, that strongly positive or negative skew coefficients are associated with heavy tailed distributions.
2. As is the case with precipitation data in semi- and arid environments, the standard deviations associated with the average values are large.

Comparison of Series Average Values

First, as noted above, the time series for each station were parsed into four sub-series. Second, a one-sided t-test with unequal variances was then performed and the results are summarized in Table 3. Variable definitions are in the table caption. Further, instead of publishing a critical value, the *p* values are summarized. The *p* value is the fraction at which the null hypothesis would be rejected. The results in Table 3 are interesting from a variety of viewpoints and the following observations are pertinent:

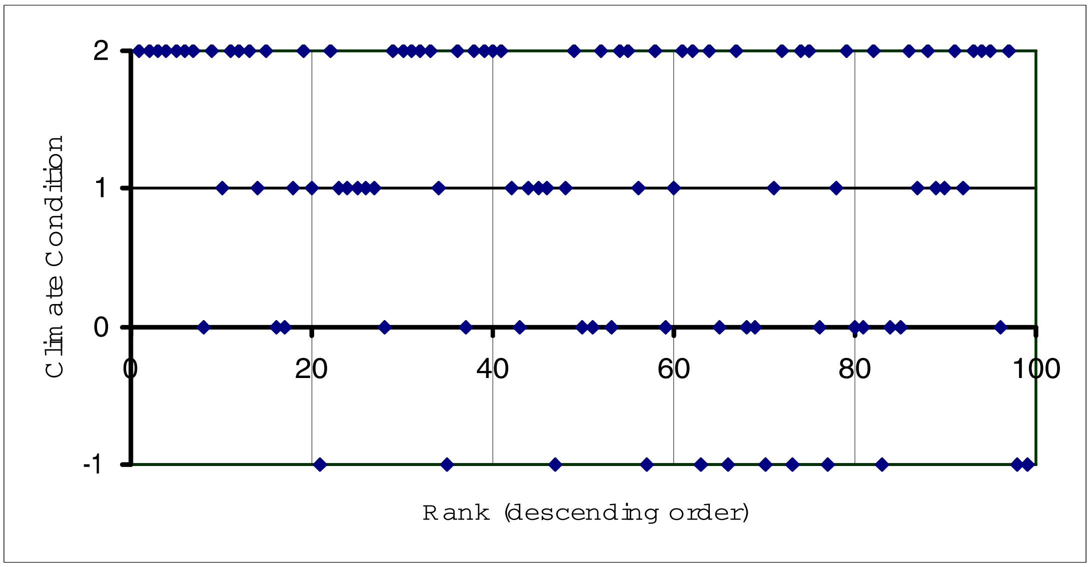
1. These data make it quite clear that statistically the total precipitation data series is a mixed series as are some peak flow flood series (WRC, 1981). That is, both the climatic period (El Nino vs La Nina) and the season result in different series with different statistical characteristics. This observation generally supports the analysis of French and Miller (2006 and 2002) for winter period maximum depth of precipitation series in Nevada Test Site, and the observations of Reich *et al.* (1990) regarding annual maximum peak flows in Arizona.
2. Evaluation of the information in Table 3 must be done in conjunction with Table 2 since a one sided test was used. Furthermore, it must be taken into account that series involving two durations were analyzed - 1-day and 60-day.
3. Maximum depths of precipitation of a **1-day duration** lead to the following observations and conclusions:
    a. At the Buckeye gage, the null hypothesis is rejected, at **approximately** the 5% level of significance, in all cases except three; that is there is not a statistically significant difference between the El Nino and the total and neutral series; nor is there a difference between the La Nina and neutral series. The analysis suggests that maximum daily precipitation at this station is dominated by El Nino and summer precipitation events. This conclusion is qualitatively illustrated in Figure 1 where the integer 2 designates a summer event; 1 an El Nino winter event, 0 a Neutral winter event, and -1 a La Nina winter event the abscissa is the rank of the event (largest to smallest). With reference to Table 2, the full series is composed of 99 usable data points; the summer series has 46 data points; the El Nino series 22 data points; the Neutral series 19 data points, and the La Nina series only 12 data points. While Figure 1 shows only qualitative evidence that the total series is composed of a mixed data set, work is proceeding to demonstrate this assertion in a quantitative fashion.
    b. At the Wickenburg gage, the null hypotheses are accepted in all cases at the 5% level of significance except one; that is, there is a significant difference between the summer and the neutral series. The analysis suggests that the total series is representative of the maximum daily precipitation at this location.
    c. At the Superior gage, the null hypotheses are accepted in all cases at the 5% level. The analysis suggests that the total series is representative of the maximum daily precipitation at this location.
    d. At the Crown King gage, the null hypotheses are rejected, at the 5% level of significance, in three cases; that is, there is a significant difference between the El Nino and both the total and summer series and the summer series and the total series. This suggests at this location special consideration of El Nino periods may be appropriate, depending on the design goal.

Table 3. Summary of results for the *t* test comparisons of the average maximum daily and 60-day period depths of precipitation in the Phoenix, AZ area for the Full (μ_T), El Nino (μ_{EN}), Neutral (μ_N), La Nina (μ_{LN}), and Summer (μ_S) series.

Station	Null Hypothesis								
	$\mu_{EN} = \mu_T$ p	$\mu_{EN} = \mu_{LN}$ p	$\mu_{EN} = \mu_N$ p	$\mu_{EN} = \mu_S$ p	$\mu_{LN} = \mu_T$ p	$\mu_{LN} = \mu_N$ p	$\mu_{LN} = \mu_S$ p	$\mu_S = \mu_T$ p	$\mu_S = \mu_N$ p
Buckeye									
1-Day	0.32	0.06	0.39	0.05	0.03	0.09	0.01	0.06	0.04
60-Day	0.01	0.003	0.04	0.01	0.02	0.02	0.30	0.34	0.31
Wickenburg									
1-Day	0.17	0.13	0.14	0.24	0.23	0.36	0.08	0.10	0.05
60-Day	0.03	0.01	0.03	0.02	0.09	0.11	0.16	0.30	0.39
Superior									
1-Day	0.32	0.22	0.18	0.50	0.27	0.40	0.08	0.13	0.07
60-Day	0.01	0.09	0.01	0.02	0.44	0.27	0.37	0.37	0.12
Crown King									
1-Day	0.03	0.21	0.07	0.002	0.47	0.48	0.22	0.05	0.10
60-Day	0.10	0.06	0.30	0.03	0.23	0.11	0.03	0.08	0.03

4. Maximum depths of precipitation of a **60-day duration** lead to the following observations and conclusions:
   a. At the Buckeye gage, the null hypotheses are rejected at the 5% level of significance in all cases except three; that is, there is not a statistically significant difference among the summer and the La Nina, neutral, and total series. The results in Table 1 suggest that, depending on the design objective, special consideration of El Nino periods and the summer may be appropriate.

Figure 1. Plot of the ranked series at the Buckeye gage.



   b. At the Wickenburg gage, the null hypotheses are rejected at the 5% level of significant in all cases except five. The analysis suggest that the El Nino series is significantly different that the other series; and further, it produces the greatest depths of precipitation for this duration, Table 2.
   c. At the Superior gage, the results are similar to those for the Wickenburg gage. That is, the analysis demonstrates that the El Nino series is significantly different than the other series; and further, it produces the greatest (by a small margin) depths of precipitation for this duration. However, at this location the results are not as clear as at the Wickenburg gage.
   d. At the Crown King gage, the results are mixed. However, the results suggest that at this location El Nino period precipitation events are dominant.

Conclusion

Ernest Rutherford once said, “If your experiment needs statistics, you ought have done a better experiment.” Of course, Professor Rutherford was a physicist who could design experiments, in contrast hydrologic engineers are dealing with an experiment designed for us; we have no control and can only deal with the results - statistically. Then, there is the famous quotation attributed by Mark Twain to Benjamin Disraeli, “There are three kinds of lies: lies, dammed lies, and statistics.” Both of these quotations are relevant to the results presented here and the results presented in French and Miller (2006 and 2002). That is, there are differences between the project objectives and climate. For example, French and Miller (2006 and 2002) focused on winter period events because some facilities, including hazardous waste disposal sites, require mitigation from runoff resulting from precipitation events 24-hours in duration and a 25-year return period. In Southern Nevada, 24-hour events generally only occur in the winter period. Further, there was also an environmental object - revegetation in an arid environment. In the Phoenix study (URS, 2004), the objectives were different; that is, FCDMC was concerned with all events that could affect the safety of upstream detention basins from both hydraulic capacity and geotechnical stability; and therefore, the 1-day event was not the only event of concern. Furthermore, there are climatic differences between Central Arizona and Southern Nevada although the locations are separated by only a few hundred miles and the Colorado River Valley. As illustrated in Quiring (1983) and subsequently French (1983), the Colorado River Valley is a major hydrometeorlogic feature.

The results presented in this paper and French and Miller (2006 and 2002) are not conclusive; however, they are suggestive. In the semi- and arid Southwest where rainfall-runoff modeling is often the basis for flood hazard identification and mitigation the maximum depth of precipitation series is a fundamental design requirement. Therefore, as is the case with flood hazard analysis for flow data it is critical that the series used is homogenous and if it is mixed then as noted in WRC(1981) this must be taken into account.

Acknowledgments

The precipitation data recovery and preliminary analysis leading to this paper were funded by the Flood Control District of Maricopa County, Phoenix, AZ. The FCDMC project was directed by the late George Beckwith who was a close and dear friend of the first author. The authors also wish to acknowledge the excellent and tedious data work performed by numerous others.

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