EL NINO - LA NINA IMPLICATIONS ON FLOOD HAZARD MITIGATION

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Abstract

The effects of El Nino and La Nina periods on the maximum daily winter period depths of precipitation are examined using records from five precipitation gages on the Nevada Test Site. The potential implications of these effects are discussed.

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.

One of the few reliable predictive links to anomalous precipitation in the western United States on seasonal time scales involves the connection to large-scale disturbed conditions in the tropical Pacific known as the El Nino-Southern Oscillation (ENSO) (Cayan *et al.*, 1999). Although the ENSO connection to fluctuations in the western

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United States is weaker than in other regions of the world, numerous studies have shown a significant ENSO signal in precipitation, snow accumulation, and stream flow (Andrade and Sellers, 1988; Cayan, 1996; Cayan and Peterson, 1989; Cayan and Webb, 1992; Piechota *et al.*, 1997; and Schonher and Nicholson, 1989). In addition, there is also evidence for an analogous link to La Nina (Redmond and Koch, 1991). That is, during El Nino (negative Southern Oscillation index), the Southwest tends to be wet and the Northwest dry and *vice versa* for La Nina (positive Southern Oscillation index).

In addition to the effect of ENSO events on a seasonal time scale, daily precipitation depths and event frequencies may also be affected (Cayan and Webb, 1992; Gershunov and Barnett, 1998; and Woolhiser *et al.*, 1993). As the foregoing discussion suggests, the primary focus, from a water resources perspective, on ENSO events has been on seasonal precipitation and runoff rather than the potentially significant effects of ENSO events on the identification and mitigation of flood hazard. Of course, there are exceptions to the foregoing statement. Of particular note, is the paper of Reich *et al.* (1990), which deals with series of annual maximum flow events:

> "An earlier test (Reich and Renard, 1981) involved several watersheds .... They found that 'straight-edge lines' were superior to statistically computed curves. Each flood series plotted into two straight lines that were separate from and differently oriented to a large number of much smaller annual maxima."

Although Reich and Renard (1990) ascribed their observations to spatial precipitation differences and channel transmission losses, another possible explanation is the effects of ENSO events. The focus of this paper is testing the hypothesis that ENSO events do have an effect on flood hazard identification and mitigation.

To examine the effect of ENSO events on flood hazard, a data set from 5 precipitation gages located on the U.S. Department of Energy's (DOE) Nevada Test Site (NTS) was analyzed. For the period of record available at each of these gages, the maximum daily depth of precipitation, for the winter period (October through April) was extracted. Since these gages are located in proximity to each other, these data are used to verify the consistency of the statistical results obtained in testing the records for the effects of ENSO events. As winter period precipitation in Southern Nevada is generally the result of frontal systems rather than convective storms, data from gaging stations close to each other should exhibit consistent behavior.

Analysis of NTS Data

In support of the DOE's stewardship and mission at the 3,370 km^2 (1,300 mi^2) NTS, a system of precipitation gages is operated. In this paper, five of the gages with the longest periods of record were used; and the locations and period of record available at these gages are summarized in Table 1. With regard to the data in this table, the following observations are pertinent. First, for the arid West, the gages are closely spaced; and their elevations reflect the topographic relief present on the NTS. Second, the periods of record, from some perspectives, are short but reflect the period of record that is typically available in the mountainous western United States. Third, the maximum daily winter period (October through April) depths of the precipitation for each year of record were abstracted. It is pertinent to observe that in Southern Nevada flood hazard identification and mitigation is typically based on the depth of precipitation resulting from a 100-year; 6-hour precipitation event (CCRFCD, 1999). However, some facilities, including hazardous waste disposal sites, require mitigation from runoff resulting from a storm 24-hours in duration and a 25-year return period. Previous analysis has shown that the greatest depths of precipitation associated with durations of 24-hours occur during the winter period which is typically taken as October through April (Quiring, 1983 and French, 1983).

Table 1: Locations of selected precipitation gaging stations on the NTS along with the period of record available at each station.

Station Name Designation	Station Coordinates (State Plane, NAD, Nevada Central)			
	Easting (m)	Northing (m)	Elevation (m)	Length of Record (yrs)
Desert Rock DRA	209,733	207,797	1,005	41
Well 5B W5B	214,945	227,868	938.8	40
Yucca Yucca	207,532	244,937	1,195	45
Area 12 Mesa A12	192,451	270,937	2,283	42
PHS Farm PHS	208,139	272,991	1,391	33

The first statistical analysis performed on this data set was designed to test the hypothesis that El Nino, Neutral, and La Nina periods result in statistically different data sets; and therefore, potentially different outcomes from rainfall-runoff modeling to estimate flood hazard. Several simple statistical approaches were used to examine the validity of this hypothesis. The second statistical analysis performed was designed to test the hypothesis that when the maximum daily series is placed in ranked order (largest to smallest depths) that precipitation depths associated with El Nino periods constitute a disproportionate number of the largest events.

Comparison of Average Values

First, the times series of annual, winter period, maximum daily depths of precipitation for each station considered (Table 1) were parsed into three sub-series (El Nino, Neutral, and La Nina winters) and transformed to log series. The log transform involves the tacit assumption that maximum daily depths of precipitation can be described by a log distribution (see for example, Randerson, 1997). The log means and standard deviations for the sub-series were estimated; and given the small sample sizes, a one-sided *t* test was used to determine whether the means of each sub-series were equal at the 5% level of significance. The results of this analysis are summarized in Table 2, and these results are generally consistent. For example,

1. At all stations, the average maximum daily depths of precipitation (log series) for El Nino periods (μ_{EN}) are statistically significantly different from the average maximum depths for the Neutral periods (μ_N) and the La Nina periods (μ_{LN}).
2. At all stations, the average maximum daily depths of precipitation (log series) for La Nina periods (μ_{LN}) were not statistically significantly different from the average maximum depths for the Neutral periods (μ_N).
3. The comparison of the average maximum daily depths of precipitation (log series) of the sub-series for El Nino and La Nina periods with the complete data series yielded some anomalous results. In comparing the average maximum daily depths of precipitation for El Nino periods (μ_{EN}) with the average maximum daily depths for the complete series (μ), there was a statistically significant difference at all stations except the A-12 location. Alternatively, in comparing the average daily maximum depths of precipitation for La Nina periods (μ_{LN}) with the average daily maximum depths for the complete series (μ), there was not a statistically significant difference at all stations except at the W5B location.

The data summarized in Table 2 and the observations regarding these data suggest that the complete time series for each station should be parsed differently. Therefore, the complete time series were re-parsed into two sub-series: the maximum daily depths of precipitation for El Nino periods and the maximum daily depths of precipitation for Neutral and La Nina periods. Again, the log means and standard deviations for the sub-series were estimated; and given the small samples size, a one-sided *t* test was used to determine whether the means of each sub-series were equal at the 5% level of significance. The results of this analysis are summarized in Table 3, and these results are also consistent. That is, there is a significant statistical difference at the 5% level of significance at every station between the average values of maximum depths of precipitation (log series) associated with El Nino periods and those derived from the combined series of Neutral and La Nina periods.

The foregoing analysis suggests that in Southern Nevada there are two maximum daily precipitation data series: one series composed of maximum values derived from El Nino periods and another associated with the Neutral and La Nina periods.

Ranked Series Frequency Analysis

Given the foregoing results, a second hypothesis was asserted and tested. The hypothesis is that if the series of maximum daily depths of precipitation are ranked in descending order, then depths associated with El Nino periods will be disproportionately

Table 2: Summary of results for the *t* test comparison of the average maximum, daily depth of precipitation on the NTS for El Nino, Neutral, and La Nina periods.

Station	Null Hypothesis				
	$\mu_{EN} = \mu_{LN}$ t t_{crit}	$\mu_{EN} = \mu_{N}$ t t_{crit}	$\mu_{LN} = \mu_{N}$ t t_{crit}	$\mu_{EN} = \mu$ t t_{crit}	$\mu_{LN} = \mu$ t t_{crit}
DRA	3.32 1.72 Sig Diff	2.59 1.70 Sig Diff	1.21 1.71 No Sig Diff	2.20 1.68 Sig Diff	1.76 1.76 No Sig Diff
W5B	3.86 1.72 Sig Diff	2.97 1.70 Sig Diff	1.43 1.71 No Sig Diff	2.34 1.67 Sig Diff	2.00 1.68 Sig Diff
Yucca	2.34 1.72 Sig Diff	2.88 1.70 Sig Diff	0.0784 1.70 No Sig Diff	2.08 1.67 Sig Diff	0.96 1.68 No Sig Diff
A-12	1.78 1.72 Sig Diff	2.22 1.70 Sig Diff	0.17 1.71 No Sig Diff	1.63 1.67 No Sig Diff	0.46 1.67 No Sig Diff
PHS	2.03 1.74 Sig Diff	2.06 1.71 Sig Diff	0.46 1.73 No Sig Diff	1.57 1.68 No Sig Diff	1.12 1.68 No Sig Diff

Table 3: Summary of results for the *t* test comparison of the average maximum, daily depth of precipitation on the NTS for El Nino and Neutral + La Nina periods.

Null Hypothesis	Station				
	DRA	W5B	Yucca	A-12	PHS
$\mu_{EN} = \mu_{N+LN}$ t t_{crit}	3.52 1.68 Sig Diff	3.74 1.68 Sig Diff	3.15 1.68 Sig Diff	2.56 1.68 Sig Diff	2.62 1.70 Sig Diff

represented in the upper end of this series. For example, in Table 4, the maximum annual series for the DRA station is shown unranked and ranked; and with regard to the data in this table the following two qualitative observations are pertinent. First, eight out of the top ten events occurred during El Nino periods with the remaining two occurring during Neutral periods. Second, of the smallest ten events, three occurred during El Nino periods, four during Neutral periods, and three during La Nina periods. Therefore, the qualitative conclusion is clear; that is, El Nino periods are over-represented in the portion of the series incorporating the most extreme events; and the issue then becomes one of proving the hypothesis in a quantitative fashion.

Table 4: Summary of maximum daily precipitation at the DRA station for the period of record, unranked and ranked.

Winter Period	Un-ranked Maximum Daily Depth of Precipitation (mm)	Condition	Rank	Ranked Maximum Daily Depth of Precipitation (mm)	Condition
1964-65	74.9	La Nina	1	227.3	El Nino
1965-66	137.7	El Nino	2	217.9	El Nino
1966-67	57.7	Neutral	3	214.9	El Nino
1967-68	78.2	Neutral	4	198.1	El Nino
1968-69	153.7	Neutral	5	197.4	El Nino
1969-70	50.8	El Nino	6	181.6	El Nino
1970-71	35.1	La Nina	7	160.0	El Nino
1971-72	43.9	La Nina	8	153.7	Neutral
1972-73	44.4	El Nino	9	152.1	Neutral
1973-74	64.0	La Nina	10	137.7	El Nino
1974-75	117.3	La Nina	11	137.7	El Nino
1975-76	79.8	La Nina	12	135.9	El Nino
1976-77	43.2	El Nino	13	132.8	Neutral
1977-78	197.4	El Nino	14	124.5	El Nino
1978-79	152.1	Neutral	15	120.1	Neutral
1979-80	132.8	Neutral	16	117.3	La Nina
1980-81	72.1	Neutral	17	112.8	Neutral
1981-82	80.5	Neutral	18	112.0	Neutral
1982-83	135.9	El Nino	19	106.4	Neutral
1983-84	54.4	Neutral	20	84.6	La Nina
1984-85	120.1	Neutral	21	80.5	Neutral
1985-86	106.4	Neutral	22	79.8	La Nina
1986-87	112.8	Neutral	23	78.2	Neutral
1987-88	160.0	El Nino	24	76.7	Neutral

Winter Period	Un-ranked Maximum Daily Depth of Precipitation (mm)	Condition	Rank	Ranked Maximum Daily Depth of Precipitation (mm)	Condition
1988-89	26.4	La Nina	25	74.9	La Nina
1989-90	25.4	Neutral	26	72.1	Neutral
1990-91	61.5	Neutral	27	64.0	La Nina
1991-92	124.5	El Nino	28	61.5	Neutral
1992-93	214.9	El Nino	29	57.7	Neutral
1993-94	49.3	El Nino	30	53.8	Neutral
1994-95	198.1	El Nino	31	53.1	La Nina
1995-96	36.8	Neutral	32	50.8	El Nino
1996-97	50.5	Neutral	33	50.5	Neutral
1997-98	217.9	El Nino	34	44.4	El Nino
1998-99	53.1	La Nina	35	43.9	La Nina
1999-00	76.7	Neutral	36	43.2	El Nino
2000-01	84.6	La Nina	37	41.9	Neutral
2001-02	41.9	Neutral	38	36.8	Neutral
2002-03	137.7	El Nino	39	35.1	La Nina
2003-04	112.0	Neutral	40	26.4	La Nina
2004-05	227.3	El Nino	41	25.4	Neutral

To test the hypothesis from a quantitative viewpoint, the ranked series at each station was parsed into the top and bottom 25% and the middle 50%. A chi-square test was then used to test whether ranked depths of precipitation were proportionally distributed between the three sub-series. For example, at the DRA station over the period of record there were 14 El Nino, 18 Neutral, and 9 La Nina periods. If events from all periods are uniformly distributed throughout the ranked series, the expected number of El Nino, Neutral, and La Nina events in the top 25 % of the series would be 3.4, 4.4, and 2.2, respectively. However, the actual number of El Nino, Neutral, and La Nina events in the top 25% of the series is 8, 2 and 0, respectively. Therefore, a χ^2 test at the 5% level of significance rejects the hypothesis that precipitation events associated with the three ENSO conditions are uniformly distributed in the top 25 percent of events in the ranked series. Table 5 summarizes the results of the χ^2 at the 5% level of significance,

Table 5: Results of the χ^2 at the 5% level of significance.

Station	ENSO Cond.	Top 25% Events			Middle 50% Events			Bottom 25% Events		
		Obs. No. Evt.	Exp. No. Evt.	χ^2	Obs. No. Evt.	Exp. No. Evt.	χ^2	Obs. No. Evt.	Exp. No. Evt.	χ^2
DRA	El Nino	8	3.4	6.2	3	7.1	2.4	3	3.4	0.05
	Neutral	2	4.4	1.3	12	9.2	0.85	4	4.4	0.04
	La Nina	0	2.2	2.2	6	4.6	0.43	3	3.4	0.05
	$\Sigma\chi^2$ $\chi^2_{0.95}$			9.7 6.0 Reject			3.7 6.0 Accept			0.14 6.0 Accept
W5B	El Nino	7	3.5	3.5	6	7.0	0.14	1	3.5	1.8
	Neutral	3	4.2	0.34	9	8.4	0.04	5	4.2	0.15
	La Nina	0	2.3	2.3	5	4.6	0.03	4	2.3	1.3
	$\Sigma\chi^2$ $\chi^2_{0.95}$			6.1 6.0 Reject			0.21 6.0 Accept			3.2 6.0 Accept
Yucca	El Nino	9	3.3	9.8	5	7.6	0.89	1	3.3	1.6
	Neutral	2	5.2	2.0	12	10.8	0.13	7	5.2	0.62
	La Nina	0	2.2	2.2	6	4.6	0.43	3	2.2	0.29
	$\Sigma\chi^2$ $\chi^2_{0.95}$			14 6.0 Reject			1.45 6.0 Accept			2.5 6.0 Accept
A12	El Nino	8	3.3	6.7	3	7.3	2.5	3	3.3	0.03
	Neutral	1	4.5	2.7	14	9.9	1.7	4	4.5	0.06
	La Nina	1	2.2	0.65	5	4.8	0.01	3	2.2	0.29
	$\Sigma\chi^2$ $\chi^2_{0.95}$			10. 6.0 Reject			4.2 6.0 Reject			0.38 6.0 Accept
PHS	El Nino	3	1.3	2.2	0	2.3	2.3	2	1.3	0.38
	Neutral	2	2.4	0.07	6	4.2	0.77	1	2.4	0.82

Station	ENSO Cond.	Top 25% Events			Middle 50% Events			Bottom 25% Events		
		Obs. No. Evt.	Exp. No. Evt.	χ^2	Obs. No. Evt.	Exp. No. Evt.	χ^2	Obs. No. Evt.	Exp. No. Evt.	χ^2
	La Nina	0	1.3	1.3	3	2.3	0.21	2	1.3	0.38
	$\Sigma\chi^2$ $\chi^2_{0.95}$			3.6 6.0 Accept			3.3 6.0 Accept			1.6 6.0 Accept

and these results demonstrate that at all stations except PHS the distribution of events in the top 25% of the ranked series is not uniform. That is, El Nino events are over-represented and La Nina events are under-represented. It is pertinent to observe that with the exception of A12 there are no La Nina events in the top 25% of events.

Conclusions for the NTS Analysis

The analysis of the precipitation depth data at the NTS suggests that ENSO events have an effect on the winter period average and maximum daily depth of precipitation and the ranked winter period daily depths of precipitation. These results have both environmental and flood hazard analysis implications. That is, during El Nino periods more precipitation can be expected; and therefore, activities that are enhanced by wet soils should be undertaken during those periods. These may include construction activities that may generate substantial dust during drier conditions, or revegetation of reclaimed areas or landfill covers. Also, when determining a design event for a particular flood mitigation project, it would be more conservative to develop the design total depth of precipitation by analyzing precipitation from the El Nino periods. Finally, the data and analysis presented here may explain the observations of Reich *et al.* (1990) that the flood series they analyzed appeared to be composed of two straight lines; that is, rather than spatial precipitation differences and channel transmission losses, the origin is two different hydrometeorologic data sets: El Nino and Normal including La Nina.

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