ANALYSIS OF TIME AND SPACE CHARACTERISTICS OF EXTREME RAINFALL EVENTS IN THE GILA RIVER BASIN

Final Report for the
Flood Control District of Maricopa County
by

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Table 1

Description of Daily Precipitation Stations

Station	Elevation (feet)	Record Length	Latitude	Longitude	Obs. time
Basin One:					
Bowie	3770	1948-65,68-88	32:20	109:29	1700
Chiricahua NM	5300	1948-88	32:00	109:21	1300
Clifton	3460	1948-88	33:03	109:17	0800
Duncan	3660	1948-88	32:45	109:07	1800
Eagle Creek	2779	1948-73	33:24	109:29	1000
Eagle Creek 2	4870	1973-88	33:21	109:29	0800
Fort Thomas	2680	1958-66	33:02	109:57	unknown
Fort Thomas 2	2800	1966-88	33:01	110:00	1800
Fritz Ranch	4320	1948-80	33:20	109:11	variable
Portal	5000	1948-55	31:54	109:10	sunset
Portal 4	5390	1965-88	31:53	109:12	1800
Safford Ag.	2950	1948-88	32:49	109:41	0800
San Carlos	2640	1948-77	33:21	110:27	1300
San Carlos AP	2890	1977-80	33:23	110:28	1300
San Carlos Res.	2530	1948-88	33:10	110:31	0700
Basin Two:					
Alpine	8050	1948-88	33:51	109:08	1600
Blue	5420	1959-88	33:35	109:10	0800
Anvil Ranch	2750	1948-88	31:59	111:23	0800
Apache Powder	3690	1948-88	31:54	110:15	0800
Arivaca	3680	1956-88	31:35	111:19	1800
Bisbee	5310	1948-61,82-85	31:26	109:55	0800
Bisbee	5310	1961-82	31:26	109:55	0800
Bisbee 2	5600	1985-88	31:28	109:56	1600
Canelo 1 NW	5010	1948-88	31:33	110:32	1800
Coronado NM	5550	1955-60	31;22	110;17	1700
Coronado HQ	5240	1960-88	31:21	110:15	1700
Cortaro 3 SW	2270	1948-76	32:20	111:07	1600
Fort Grant	4830	1948-74	32:37	109:57	1900
Fort Huachuca	4660	1954-81	31:34	110:20	1700
Kelvin	1850	1948-83	33:06	110:58	1700
Kitt Peak	6800	1960-88	31:58	111:36	0800
N Lazy H Ranch	3050	1948-88	32:07	110;41	1900
Nogales 6N	3560	1952-88	31:25	110:57	0800
Oracle 2 SE	4510	1950-88	32:36	110:44	1700
Patagonia	4040	1948-77	31:33	110:45	1800
Patagonia 2	4190	1977-88	31:33	110:45	0700
Pearce	4420	1950-88,88	31:54	109:49	1700

Redington	2870	1948-88	32:26	110:29	0800
Ruby Star Ranch	3640	1950-63,65-88	31:55	111:05	1700
Sabino Canyon	2640	1948-82	32:18	110:49	unknown
San Manuel	3560	1954-88	32:57	110:39	1700
Santa Rita Exp R	4300	1950-88	31:46	110:51	1700
Tombstone	4610	1942-88	31:42	110:03	0800
Tucson U of A	2440	1948-88	32:15	110:57	2400
Tucson WSO AP	2580	1948-88	32:08	110:57	2400
Tumacacori NM	3270	1948-88	31:54	111:03	0800
Willcox	4180	1948-57,59-88	32:18	109:51	1700
Winkelman 6 S	2080	1951-57,59-80	32:55	110:43	0630
Y Lightning Ran	4550	1949-88	31:27	110:12	0800
Basin Three:					
Black River	6040	1948-88	33:29	109:46	0700
Cibecue	5050	1948-65,67-79	34:02	110:29	1600
Gisela	2900	1948-88	34:07	111:17	0700
Globe	3550	1948-75	33:23	110:47	0800
Globe 2	3710	1977-81	33:24	110:46	0800
Globe 2	3710	1981-88	33:24	110:46	0800
McNary	7320	1948-88	34:04	109:51	0700
Miami	3560	1948-88	33:24	110:53	0800
Pinetop Fish	7200	1948-88	34:07	109:55	0800
Punkin Center	2360	1973-88	33:53	111:19	0700
Roosevelt	2210	1948-88	33:40	111:09	0700
Sierra Ancha	5100	1948-57,59-79	33:48	110:58	1700
Whiteriver	5120	1948-88	33:50	109:58	1100
Young	5050	1948-63	34:06	110:56	1600
Pleasant Valley	5050	1964-88	34:06	110:56	1600
Basin Four:					
Ashurst Hayden	1640	1956-88	33:05	111:15	0800
Bartlett Dam	1650	1948-88	33:49	111:38	0700
Casa Grande	1400	1948-88	32:53	111:45	1700
Chandler Height	1430	1948-88	33:13	111:41	1700
Deer Valley	1260	1950-85	33:35	112:05	2400
Eloy	1550	1951-88	32:50	111:32	1700
Falcon Field	1320	1948-76	33:26	111:45	1800
Florence	1510	1948-88	33:02	111:23	0800
Granite Reef	1320	1948-79	33:31	111:42	0700
Horseshoe Dam	2020	1948-88	33:59	111:43	0700
Laveen	1120	1948-88	33:20	112:09	2200
Maricopa	1160	1960-88	33:07	112:02	1800
Mesa Exp. Farm	1230	1948-88	33:25	111:52	0800
Morman Flat	1720	1948-88	33:33	111:27	0700
Phoenix WSFO	1110	1948-88	33:26	112:01	2400
Picacho Res.	1510	1956-83	32:52	111:28	0800
Sacaton	1290	1948-88	33:04	111:45	1600
Stewart Mt.	1420	1948-88	33:34	111:32	0700

Sunflower	3720	1948-84	33:54	111:29	1800
Superior	3000	1948-88	33:18	111:06	0800
Tolleson	1030	1951-88	33:27	112:14	1600
Youngtown	1140	1948-62,64-88	33:36	112:18	1700
Marinette	1150	1948-54,56-64	33:38	112:18	1700
Basin Five:					
Ash Fork	5310	1948-75,86-87	35:18	112:29	0800
Beaver Creek RS	3820	1957-88	34:40	111:43	1700
Camp Wood	5710	1948-50-79	34:48	112:52	1800
Castle Hot Sprg.	1990	1949-88	33:59	112:22	1900
Childs	2650	1948-88	34:21	111:42	0800
Chino Valley	4750	1948-88	34:45	112:27	0800
Cordes	3770	1949-88	34:18	112:10	1800
Cottonwood	3380	1949-77	34:45	112:02	1800
Crown King	5920	1948-88	34:12	112:20	1300
Flagstaff WSO	7010	1950-88	35:08	111:40	2400
Irving	3800	1951-88	34:24	111:37	0800
Jerome	4950	1948-88	34:45	112:06	0800
Junipine	5130	1948-82	34:58	111:45	1700
Montezuma Cas.	3180	1948-88	34:37	111:50	0800
Payson	4910	1948-88	34:14	111:20	0800
Prescott	5210	1948-88	34:34	112:26	0700
Sedona RS	4220	1948-57,59-88	34:52	111:46	1600
Seligman	5250	1948-57,59-88	35:19	112:53	0700
Tonto Cr Fish H	6280	1948-75	34:22	111:06	0800
Tonto Cr Fish 2	6390	1975-88	34:23	111:06	0800
Walnut Creek	5090	1948-88	34:56	112:49	1800
Williams	6750	1948-57,59-88	35:15	112:11	1600
Basin Six:					
Aguila	2170	1948-69-74-88	33:57	113:11	0800
Beardsley	1270	1959-78	33:40	112:23	1800
Buckeye	0870	1948-88	33:22	112:35	1700
Gila Bend	0740	1948-88	32:57	112:43	1600
Griggs 3 W	1160	1950-88	33:30	112:29	2400
Groom Creek	6100	1948-76	34:29	112:27	1700
Harquahala Pl.	1190	1952-79	33:31	113:09	1800
Litchfield Park	1030	1948-88	33:30	112:22	0800
Walnut Grove	3760	1948-88	34:18	112:33	1800
Wickenburg	2050	1948-88	33:59	112:44	1600

Estimation of 100-Year Storm Totals

The daily precipitation data were subdivided into two seasons - winter was defined as October-March, summer was defined as April-September. During the winter season, storm totals were determined in a two step process (all computer programs are contained in the appendix). First, the average daily precipitation within the entire basin was determined by averaging the daily precipitation for all stations within the basin. This average daily rainfall for a precipitation event day was determined as $\sum P_i / N$ where P_i is the observed precipitation at station i and N is the number of stations with non-missing data for the given day. Second, because a winter storm could last for several days, the storm total was determined by adding the average daily rainfall for up to **three** prior days. If the average precipitation for the previous day was greater than zero, it was added to produce a two-day storm total. If the average precipitation from two days prior was also non-zero, it too was added to produce a three-day storm total. The record from the third prior day was examined in a similar manner. The cumulative storm total was halted when a prior day had no precipitation. This procedure resulted in a cumulative storm total for the basin for each event.

The summer storm totals were determined in a slightly different manner. Because the summer convective storms in Arizona are relatively short-lived, often lasting only a few hours (Carleton, 1985; Balling and Brazel, 1987), we used only those stations with common observation times (selected only the morning observing stations). If we had not adopted this procedure, we would contaminate the record with a time of observation bias. For example, if two stations are side by side, one with observation at

0800 LST and the other at 2000 LST, an afternoon storm (e.g., from 1400-1600) would be recorded on two different dates. The selection of only those stations with common observation times eliminates this problem. The problems and potential solutions associated with time of observation biases have been reviewed by Karl and Williams (1987), and the solution scheme used in this study is one of the most effective methods of eliminating this problem in the data. Given 47 morning observation stations (Table 1), the summertime average totals over the station network were determined on a one-day basis only; no multiple-day accumulations were generated for the summer convective storms.

The new seasonal matrices of storm totals were screened to determine the largest event within each of the 41 years of record. The new time series of the largest event in each season were used to generate estimates of the 100-year precipitation event across the entire basin. The use of the largest event in each season within each year is strongly suggested in these types of analyses when the high-magnitude, low-frequency events are of interest (Dunne and Leopold, 1978; Hammer and MacKichan, 1981); the various schemes described below to determine the 100-year event are commonly used in the professional literature.

Scheme One: Variable Transformation

The largest storm total (in inches) for the entire basin in each season was assembled in a matrix of 41 rows (one for each year) and 2 columns (one for each season). Recognizing that the extreme precipitation values typically are not normally distributed, a group of commonly-used transformations (Gray, 1970; Dunne and Leopold, 1978) were applied to the data. These transformed distributions were checked for normality (a

Gaussian distribution) using the standardized coefficients of skewness, z_1, and kurtosis, z_2, calculated as:

$$z_1 = \frac{\left[\sum_{i=1}^{N}(x_i - \overline{X})^3 / N\right]\left[\sum_{i=1}^{N}(x_i - \overline{X})^2 / N\right]^{-3/2}}{(6/N)^{1/2}}$$

and

$$z_2 = \frac{\left\{\left[\sum_{i=1}^{N}(x_i - \overline{X})^4 / N\right]\left[\sum_{i=1}^{N}(x_i - \overline{X})^2 / N\right]^{-2}\right\} - 3}{(24/N)^{1/2}}$$

where the resulting z values are compared against a t-value deemed appropriate for a selected level of confidence (e.g., for N=41 years, t=2.02 for the 0.95 confidence level and t=2.72 for the 0.99 level). If the absolute value of z_1 or z_2 exceeds the selected value of t, a significant deviation from the normal curve is confirmed.

The results (Table 2) show that all of the wintertime transformations produce arrays that are normally distributed (or more technically, we could not confirm non-normality). The logarithmic transformation produces the closest fit to the normal distribution. The summertime values are significantly, positively skewed by a few very large precipitation totals observed over the 41 years of record; the logarithmic transformation produces a time series that is closest to being normally distributed (in fact, non-normality could not be confirmed at the 0.99 confidence level).

Table 2

Selected Statistics for Various Transformation Schemes

Transformation	z_1	z_2	Mean	Standard Deviation	P_{100}
Winter:					
Cube Root	0.867	-0.526	1.139	0.141	3.16
Tenth Root	0.334	-0.487	1.039	0.038	3.32
Log_{10}	0.096	-0.426	0.164	0.161	3.45
Summer:					
Cube Root	3.768	2.787	0.812	0.133	1.41
Tenth Root	3.008	1.714	0.937	0.043	1.44
Log_{10}	2.682	1.302	-0.287	0.197	1.48

Inspection of the array of values for the summer events revealed that three very large storms produced the general lack of normality in the data. These three large summer events occurred on August 28, 1951, September 6, 1970, and September 30, 1983. In each of the three cases, the large amount of rainfall across the basin was associated with the intrusion of a tropical storm into Arizona. The August 28, 1951 event was a combination of a remnant Gulf of Mexico hurricane and a tropical storm west of Baja California. The September 6, 1970 storm was the result of moisture from tropical storm Norma off the coast of Baja California. This storm was enhanced by a cold front which moved across the state during the same period. The September 30, 1983 event resulted from an inflow of moisture from tropical storm Octave. Although Arizona may be affected by tropical storm moisture on an annual basis, these three events were sufficiently anomalous to produce rainfall amounts in the basin far above the large events from the remaining years in the record.

After assessing the normality of the extreme-event time series, the mean and standard deviation for the transformed data were determined (Table 2). Recognizing that 1% of the Gaussian distribution lies beyond 2.326 standard deviations from the mean, the 100-year storm, P_{100}, could be estimated by (a) multiplying 2.326 by the standard deviation, (b) adding the product to the mean of the transformed series, and (c) reversing the transformation to convert to the original units of measure (inches).

The results for the winter season range from 3.16" for the cube root transformation to 3.45" for the logarithmic transformation (Table 2). Given the assumption of normality in these analyses, the higher values (approaching 3.5") associated with the more normally distributed data appear to be the best estimates from these calculations. Similarly, the summer estimates of P_{100} range from 1.41" to 1.48"; the more normally distributed logarithmic transformation has an estimate approaching 1.5" for the 100-year event across the basin.

Scheme Two: The Gumbel Distribution

Another popular approach to estimating the 100-year event from time series of extreme hydro-meteorological events involves the use of the Gumbel Distribution (Gumbel, 1945; Dunne and Leopold, 1978; Hammer and MacKichan, 1981; Brazel *et al.,* 1988). The Gumbel is one of many extreme value distributions appearing in the literature; however, the Gumbel is the most widely used and accepted distribution for these types of analyses. The application of the Gumbel technique first involves the determination of the return interval term, RI. The following two steps were used to generate the RI values:

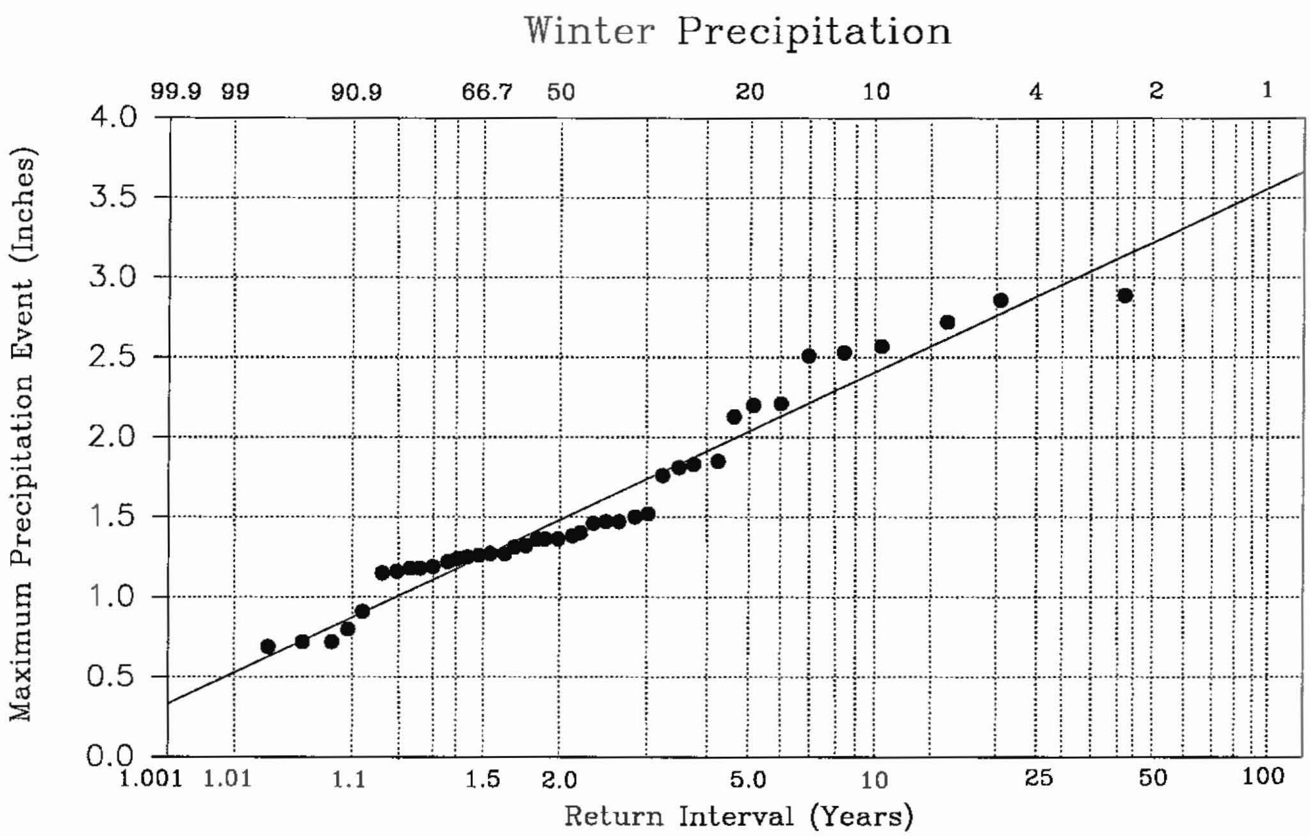
(1) Storm totals were ranked in increasing order with the largest storm having a rank of 1 and the smallest storm (in the array of extreme events) having a rank of 41.

(2) The return interval, RI, in years, was determined using the equation $RI = (N_y + 1) / m$ where N_y is the number of years of record and m is the rank determined in step #1 above. Therefore, the largest storm in each season observed over the 41 years of record would have an RI of 42 years.

The 41 RI values were plotted against the maximum precipitation events for the winter and summer (Figure 1) on Gumbel paper. Although many examples in the literature show a near linear plot resulting from this procedure, our analyses produced a slightly non-linear fit. This is particularly true in examining the summer pattern where the three large events stand apart from the remaining extreme events. Nonetheless, a least-squares fit to the Gumbel plot produces an estimate of 3.57" for the winter season and 1.54" for the summer season. Because these estimates are very close to the values determined for the logarithmic transformation described in Scheme One, we have determined that 3.5" represents a reasonable estimate of the wintertime 100-year event while 1.5" represents a good estimate for the summertime value of P_{100}.

Scheme Three: Return Interval Analysis of Final Estimates

As a final test of the reliability of the final estimates of P_{100}, the traditional return interval analyses were applied to the data. The 41 RI values for each season were plotted against the maximum storm totals on



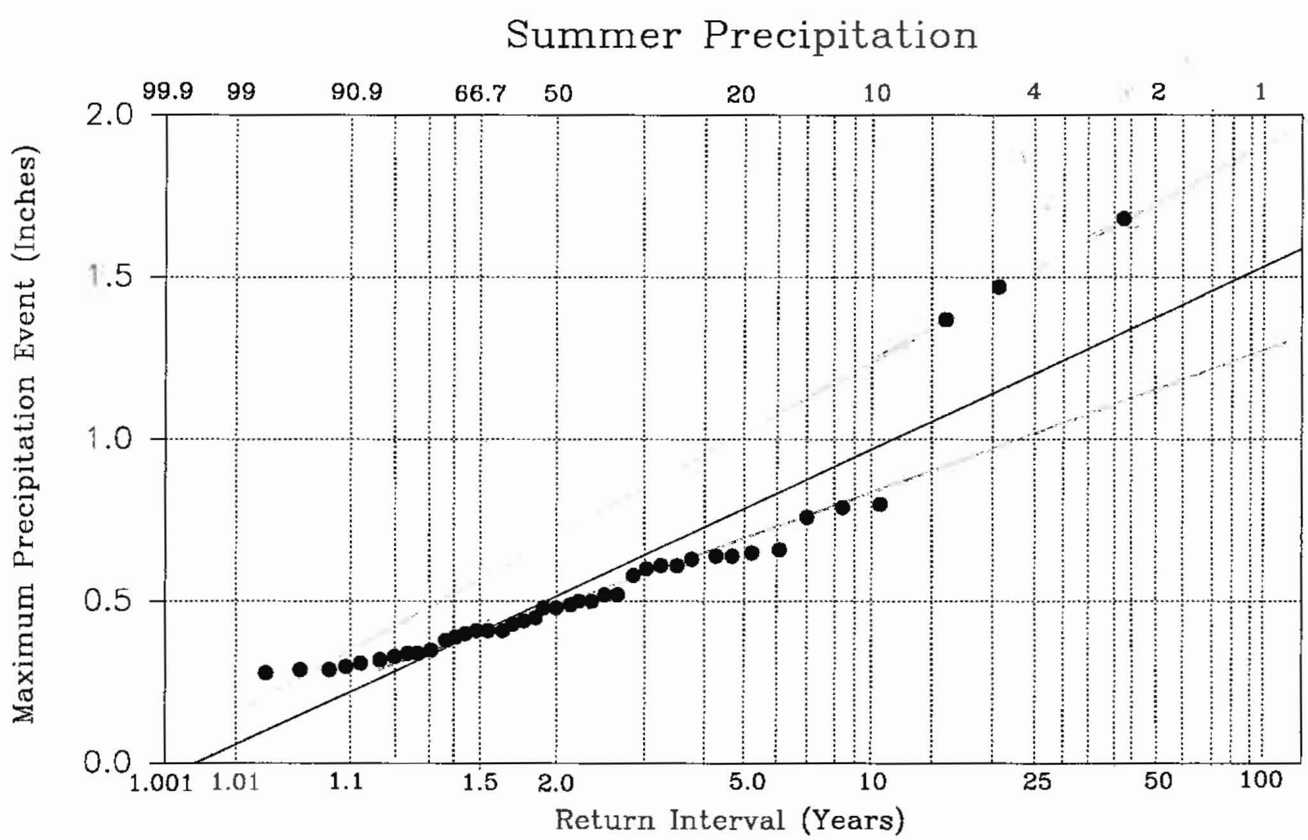


Figure 1. Gumbel extreme value distributions for the winter and summer maximum precipitation events.

log-normal paper. The estimates for the 100-year storm (3.5" and 1.5" for the two seasons) were also plotted on the log-normal paper. In each of the two seasons (Figure 2), the estimate of P_{100} appears to be consistent with the pattern suggested by the 41 RI values.

Identification of Matching Observed Storms

With the results from the two schemes producing a final estimate of the 100-year event in each season, the next step was the identification of an observed storm which is an approximation of the 100-year event (or could be adjusted slightly to approximate the 100-year event). For each season, a storm was selected that had a total rainfall reasonably close to the 100-year estimate. Whenever possible, observed storms from the more recent decades were selected in order to maximize the information (e.g., upper-air soundings, satellite images) available for the event.

Examination of all storm totals revealed the following selections for the representative 100-year events:

(1) The value of P_{100} in the winter season was 3.5". Two events were selected with large amounts of precipitation that came close to the 100-year event. On December 14-17, 1967, an average of 2.89" fell across the basin while on December 17-20, 1978, an average of 2.86" was recorded on average in the basin.

(2) The value of P_{100} in the summer season was 1.5". Once again, two events were selected for further analyses based on their large amounts of basin-wide rainfall. On August 28, 1951, an average of 1.68" was recorded; on September 30, 1983, an average of 1.47" fell across the basin.

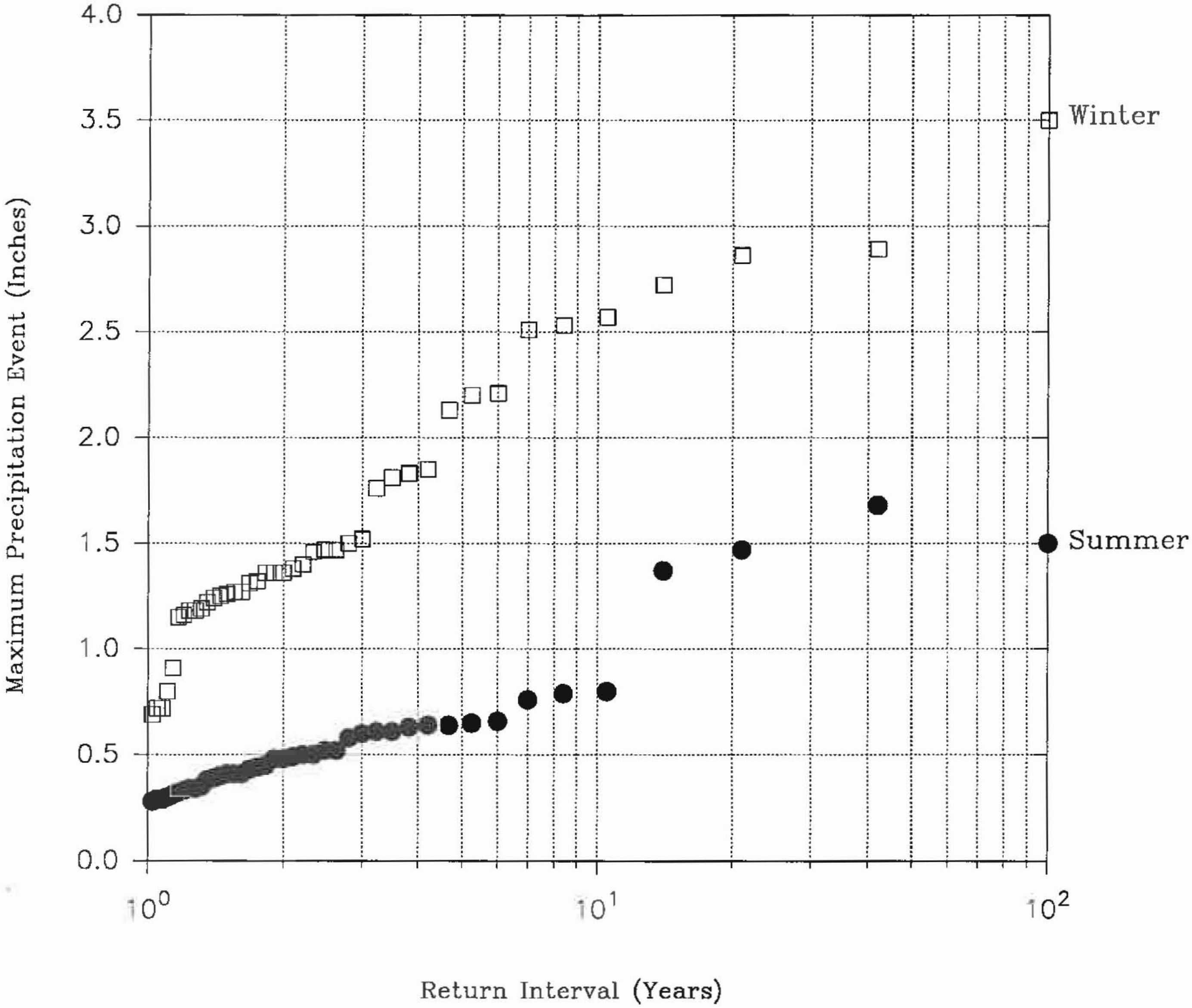


Figure 2. Log normal return interval plot for the winter and summer maximum precipitation events.

Detailed Analyses of Selected Events

For each of the four selected storms (two winter and two summer) total storm precipitation was calculated for each station. These storm totals were then adjusted upward linearly so that the basin storm total equalled that of the estimated 100-year storm. These new station precipitation totals were fed along with station latitude and longitude into standard interpolation routines and a 25-by-23 lattice of grid points was generated over the entire basin. From these new matrices, isohyetal maps of precipitation were constructed for each storm (Plates 2-5).

Storm precipitation patterns for the winter months are quite similar, suggesting that both storms are good indicators of the spatial distribution of precipitation throughout the basin. Correlation analysis between the two winter interpolated grids, shows a significant spatial correlation with an r value of 0.41. Summer storm precipitation patterns are quite different; not a surprising result given the nature of summertime convective activity over Arizona.

In the final analysis, it was decided that the August 28, 1951 and December 17-20, 1978 storms most closely approximated the calculated 100-year summer and winter storms, respectively. The adjusted totals for these storms became the hypothetical 100-year storms for further analysis. Precipitation depths by sub-basin were calculated for both storms (Table 3).

Determination of the 100-Year Storm Areal Coverage

From the outset, we were interested in determining not only the amount of rainfall associated with the 100-year storm, but other characteristics of these storms including the areal coverage. Originally, we had intended to

Table 3

100-Year Storm Totals (inches) by Sub-Basin

Sub-Basin	Winter	Summer
1	3.10	0.18
2	2.53	0.17
3	5.50	1.75
4	3.49	2.44
5	4.25	1.91
6	2.24	1.12
Whole Basin	3.50	1.50

determine the largest areal coverage per year by season over the 1948-1988 study period; after creating the areal coverage matrix, we were going to determine the 100-year areal coverage by a similar procedure to that used in determining the 100-year storm total. However, in plotting the storm totals for the winter storms, we found many events (including our selected winter storms December 14-17, 1967 and December 17-20, 1978) that covered the entire basin and we therefore concluded that the entire basin was completely covered by events far more frequently than once in 100 years. Similarly, we determined the areal coverage for the summer events and determined that many events produced more than 90% coverage of the basin (including our selected summer storms August 28, 1951 and September 30, 1983), and at least five single-day events had more than 95% coverage. We again concluded that complete coverage of the basin by a storm occurs more frequently than once in 100 years.

Determination of the 100-Year Storm Duration

Seven hourly precipitation stations with sufficiently long periods of record were identified in the whole basin (Table 4). A matrix of hourly precipitation values was constructed for both the winter and summer season. Storm durations for each station and for both seasons were determined as follows. Durations for the winter season were based upon a six-hour window of zero precipitation. From the onset of a positive hourly precipitation value, the storm duration increased until six successive hourly values were zero. The total duration for the event ended on the hour with the last positive precipitation preceding the six-hours of zero precipitation. Summer storm durations were determined in the same manner, except that they were based upon two-hour windows of zero precipitation instead of six. From each winter and summer storm duration listings, the yearly maximum and absolute maximum durations were determined.

Table 4

100-Year Durations (in hours) by Season and Station

Station	Latitude	Longitude	Elevation (feet)	100-Year Duration: Winter	Summer
Ash Fork	35:18	112:29	5310	58.3	22.4
Casa Grande	32:53	111:45	1400	38.2	12.6
Cochise	32:04	109:54	4180	45.7	14.0
Phoenix	33:26	112:01	1110	54.5	13.7
Tucson	32:08	110:57	2580	47.7	19.5
Whiteriver	33:50	109:58	5120	58.6	18.9
Black River	33:29	109:46	6040	69.7	21.4

The procedure used to independently determine the 100-year duration of the winter and summer storms was similar to the procedure used to determine the 100-year storm total. To begin, the summer and winter maximum durations for each of the seven stations were checked for normality using the standardized coefficients of skewness and kurtosis. In each of the 14 time series from 1948 to 1987, the raw data were not normally distributed, and a square root transformation was required to produce a normal distribution. Next, the mean and standard deviation for the square roots were determined for each of the 14 arrays. Recognizing that 1% of the Gaussian distribution lies beyond 2.326 standard deviations from the mean, the 100-year storm duration, D_{100}, for each station and season was determined as:

$$D_{100} = (X' + 2.326\ s)^2$$

where X' is the mean of the 40 square roots and s is the standard deviation. The results (Table 4) show that the average 100-year wintertime storm duration for the basin is 53.2 hours while the average 100-year summertime storm duration is 17.5 hours. Recurrence interval analyses confirmed the reliability of these estimates of the 100-year storm durations.

Based upon storm totals, we had selected two summer and two winter storms as reasonably close to the 100-year storm totals. All of these storms produced rainfall across most, if not all, of the study area. Analysis of storm durations showed the following:

(1) The two large winter events, December 14-17, 1967 and December 17-20, 1978, had average durations throughout the basin of 24.0 and 35.6

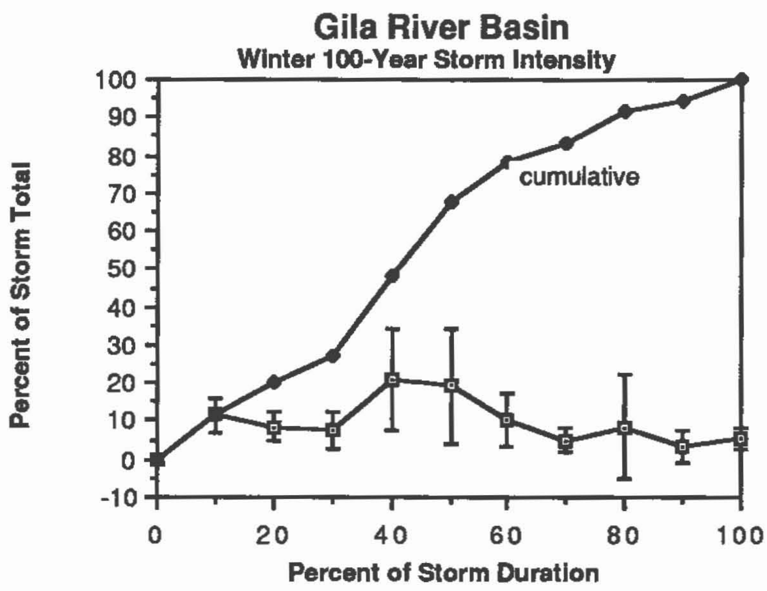
hours, respectively. When compared to the basin-average 100-year duration of 53.2 hours, we see that the 1978 storm is more representative of the 100-year event in terms of storm duration.

(2) The two large summer events, August 28, 1951 and September 30, 1983, had average durations in the basin of 15.0 and 10.6 hours, respectively. With the average 100-year duration of 17.5 hours, it is obvious that the 1951 event is quite similar to the 100-year event in terms of storm duration.

Determination of the 100-Year Storm Intensity

Using the seven stations which had hourly data, we extracted the data from the August 28, 1951 and the December 17-20, 1978 storms. These data were then adjusted in the same manner that we adjusted the daily data to obtain our hypothetical 100-year storm estimates for both summer and winter seasons. Using these new hourly values, we set out to depict the 100-year storm intensities.

For each station, we calculated the amount of precipitation which fell during each ten percent of the storm's duration at that station. This technique allowed us to factor out varying durations between the stations. During this step we assumed that precipitation intensity was linear between the hourly measurements. Next, we expressed these precipitation amounts as percentages of the storm total for that station. This allowed us to factor out varying storm totals between stations. Finally, for each season, we calculated the mean storm intensities, and their standard deviations. The results (Figure 3) will allow cumulative distributions to be calculated for any hypothetical storm.



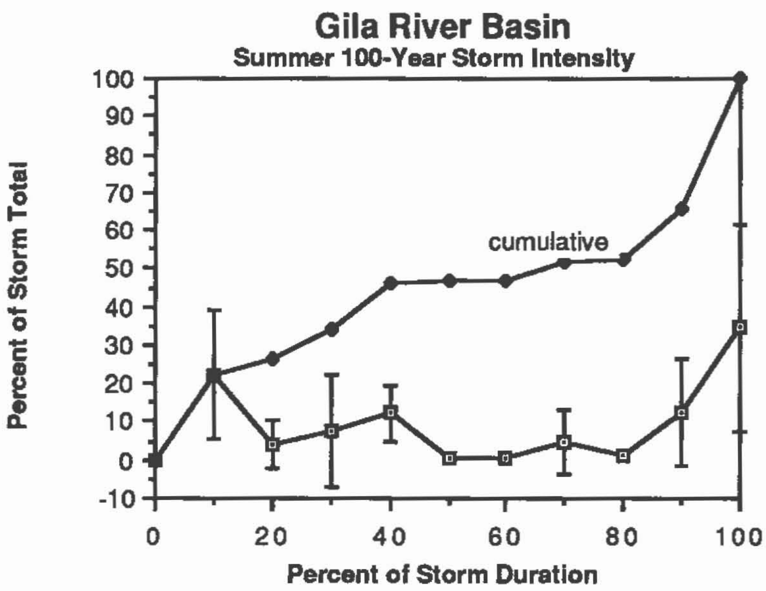


Figure 3. Distribution of rainfall during hypothetical 100-year events (error bars represent one standard deviation).

Winter storm intensity is fairly constant with the greatest percentage of precipitation falling near the midpoint of the storm's duration. For the summer storm, the greatest precipitation percentages fall at the beginning and the end of the storm. Care should be taken in interpreting these results since standard deviations tend to be large at certain points in the storm durations.

100-Year Storm Transpositions

Our final task was to move the hypothetical 100-year storms to different locations in the Gila River Basin. Staff of the Maricopa County Flood Control District selected three new locations for the winter storm and five new locations for the summer storm. To transpose the storms, we followed the method employed by the U.S. Army Corps of Engineers (1982).

Using our hypothetical storm totals for each of the daily stations, we expressed each total as a percentage of the 100-year storm total for that station as depicted in the NOAA2 Atlas (National Oceanic and Atmospheric Administration, 1973). From this we constructed an isopercentual map for both the winter and summer 100-year storms (Plates 6,7). Next we centered these isopercentual patterns over the locations selected by the Flood Control District. These new patterns were combined with the NOAA2 100-year precipitation totals to obtain new precipitation depths for a storm centered over the given points. Finally, we constructed isohyetal maps for the hypothetical storms centered over their new locations (Plates 8-15).

Conclusions

The purpose of this study was to characterize extreme precipitation events in the Gila River Basin. Our analyses gave estimates of the 100-year summer and winter storm total across the basin, 100-year areal extent of these storms, 100-year duration of the storms, and the distribution of rainfall within the 100-year storms. We produced maps showing the spatial patterns in the 100-year rainfall, and we moved the hypothetical storms to a series of locations selected by officials at the Maricopa County Flood District. Along with the information provided in this report, we have given the Flood District personnel a magnetic tape containing all data used in this investigation.

References

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PLATES

Guide to Plates

General

The following color schemes apply to all plates.

Black	Denotes basin and sub-basin boundaries.
Blue	Shows the major rivers.
Green	Precipitation isohyets in inches.

Latitude and longitude are displayed along the bottom and right sides of each plate.

Plate 1

Green asterisks denote precipitation stations used in this study.

Plates 2-5

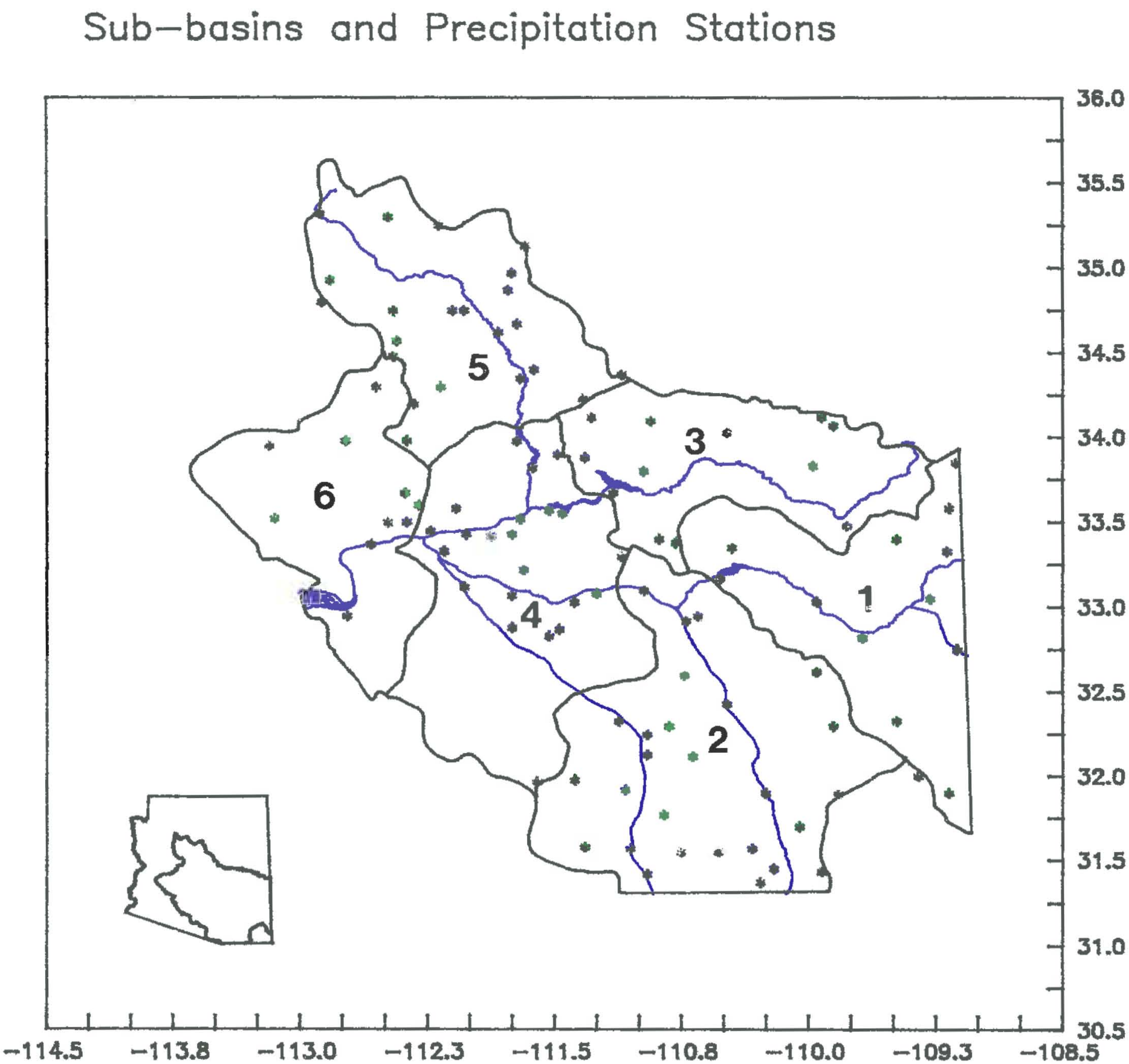
Plates 2-5 show the hypothetical 100-year storms, obtained by adjusting the actual storm amounts from the following storms (in order): (1) Dec. 14-17, 1967; (2) Dec. 17-20, 1978; (3) Aug. 28, 1951; and (4) Sep. 30, 1978. Please see the text for a description of the adjustment process.

Plates 6-7

These plates show our chosen 100-year hypothetical storm amounts as a percentage of the NOAA2 100-year precipitation amounts. These isopercentual maps were used as the basis for storm transpositions (Plates 8-15).

Plates 8-15

Plates 8-15 show the new precipitation patterns for storms moved over a selected point. See the text for a description of this procedure. Red dots denote the new storm center location.



Sub-basins and Precipitation Stations
36.0
35.5
35.0
34.5
34.0
33.5
33.0
32.5
32.0
31.5
31.0
30.5
−114.5
−113.8
−113.0
−112.3
−111.5
−110.8
−110.0
−109.3
−108.5
1
2
3
4
5
6

Plate 1

Hypothetical 100-year Winter Storm 1

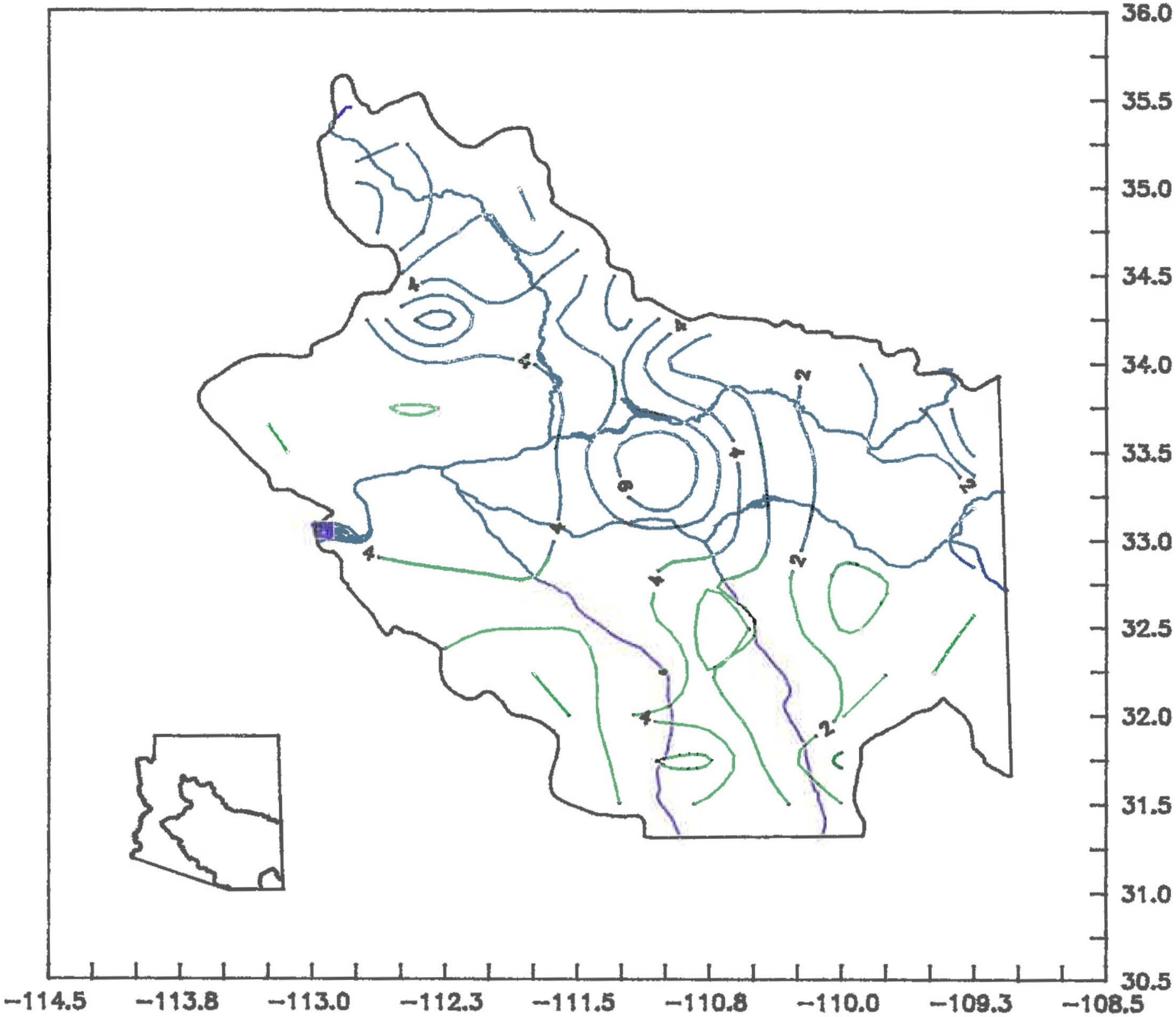


Plate 2

Hypothetical 100-year Winter Storm 2

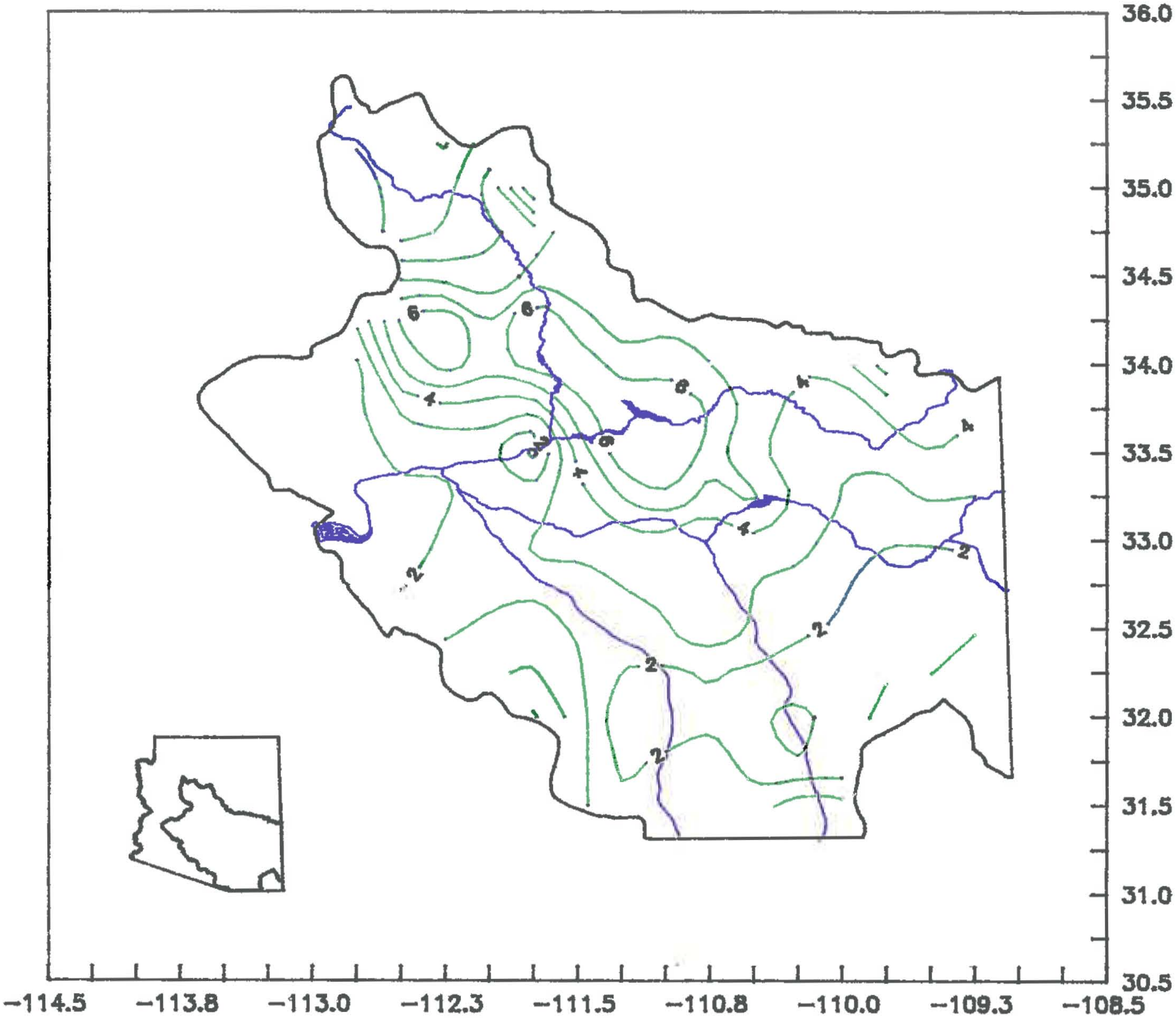


Plate 3

Hypothetical 100-year Summer Storm 1

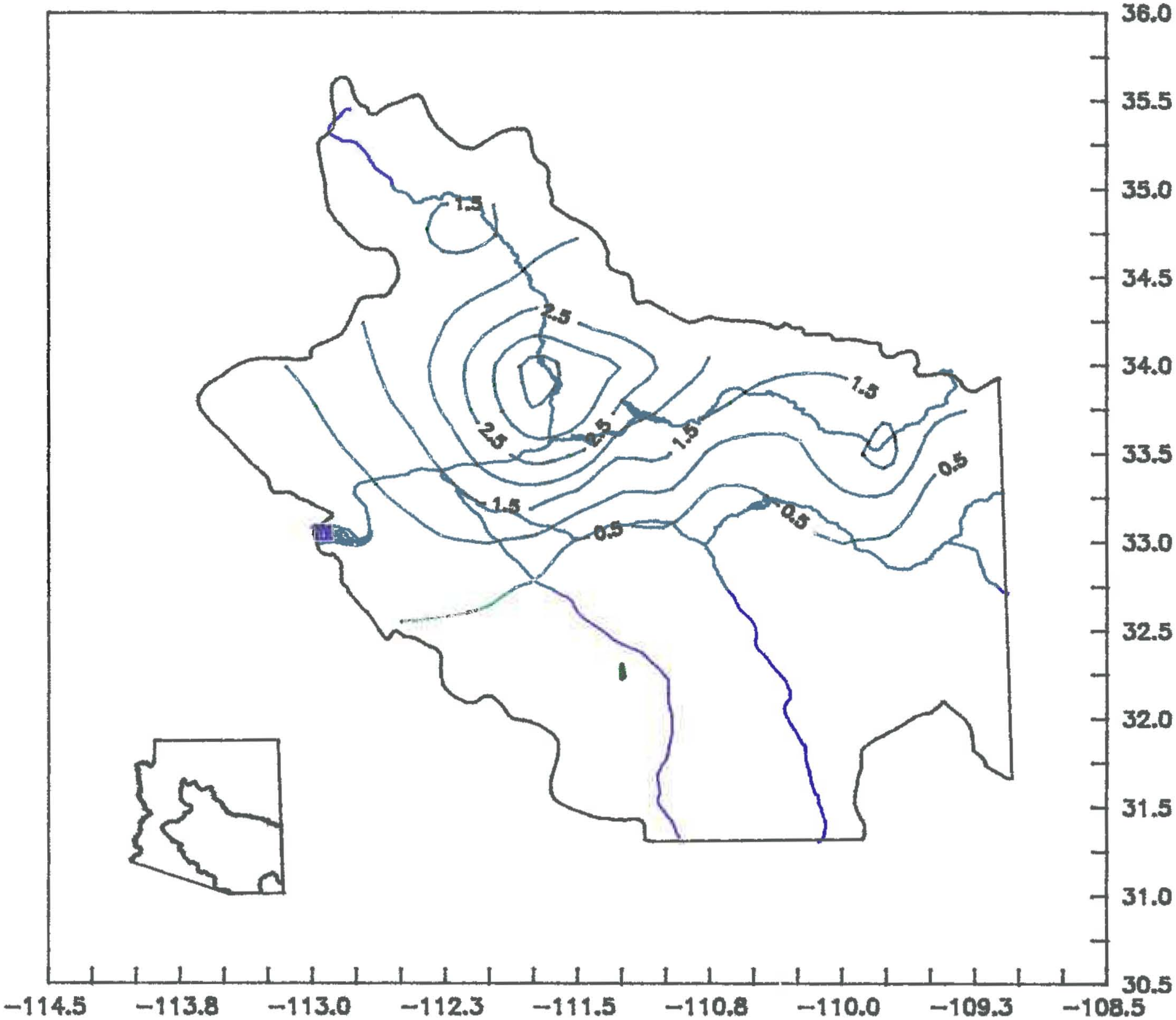


Plate 4

Hypothetical 100-year Summer Storm 2

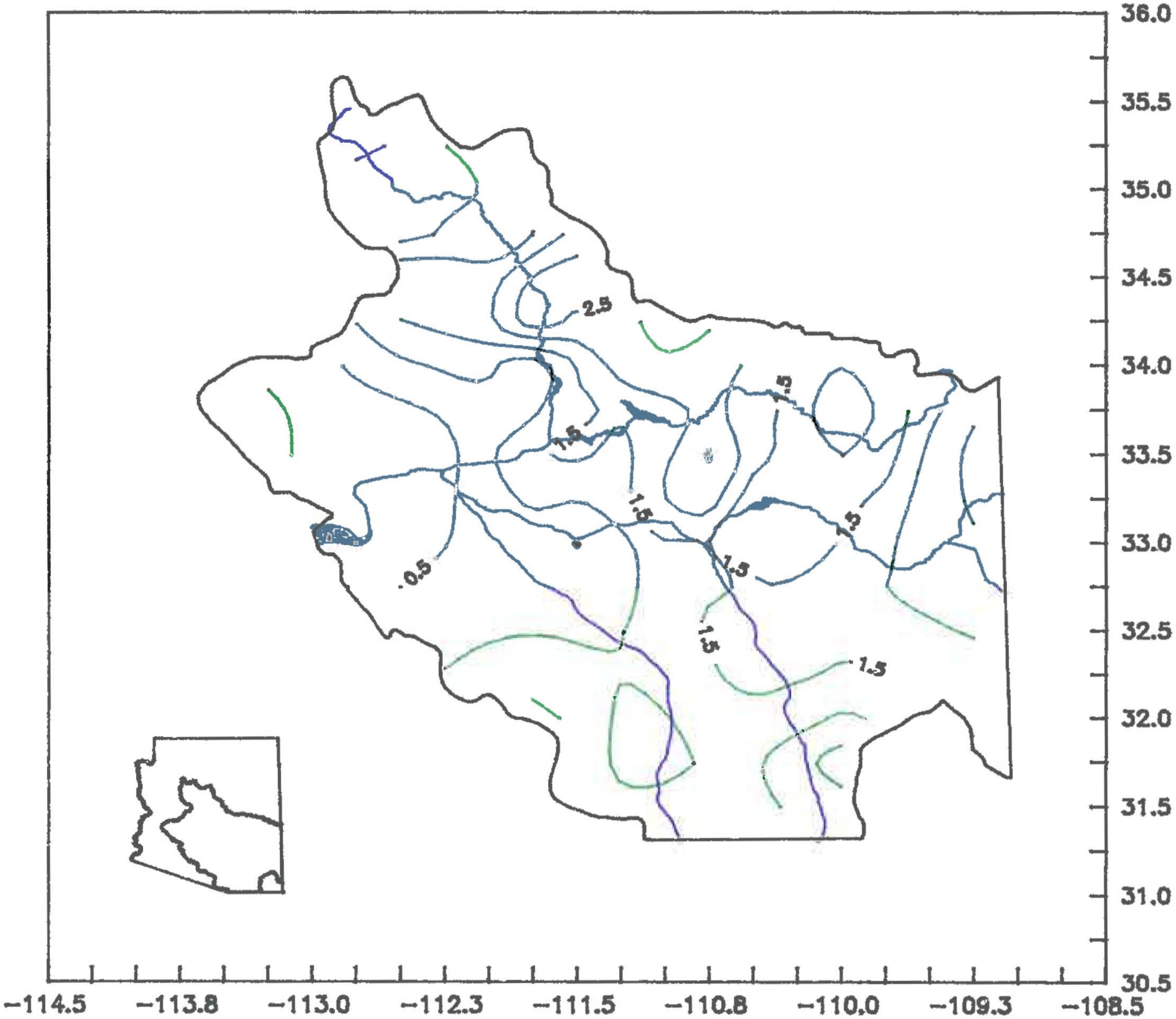


Plate 5

Percent of 100 yr Summer Storm

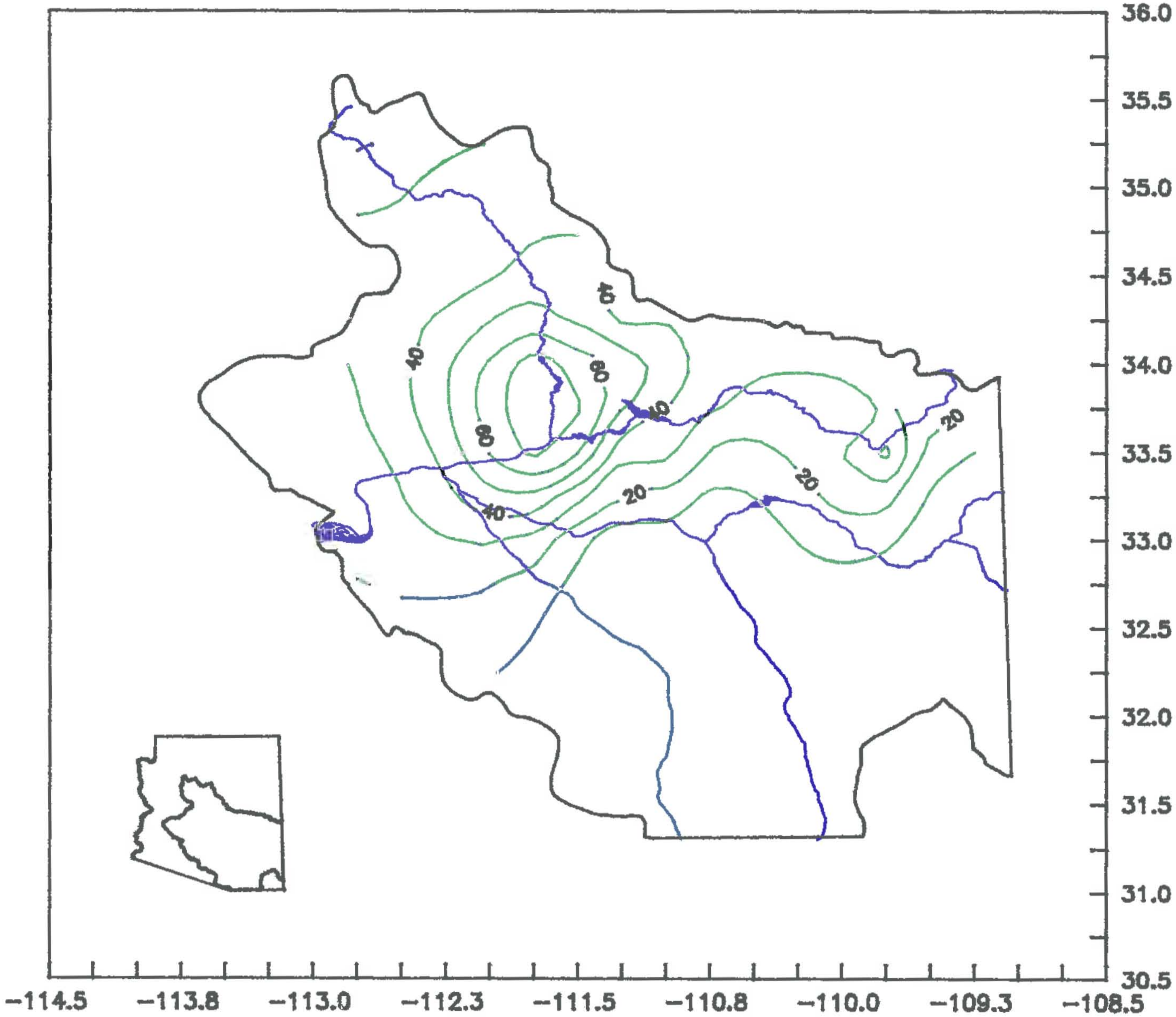


Plate 6

Percent of 100 yr Winter Storm

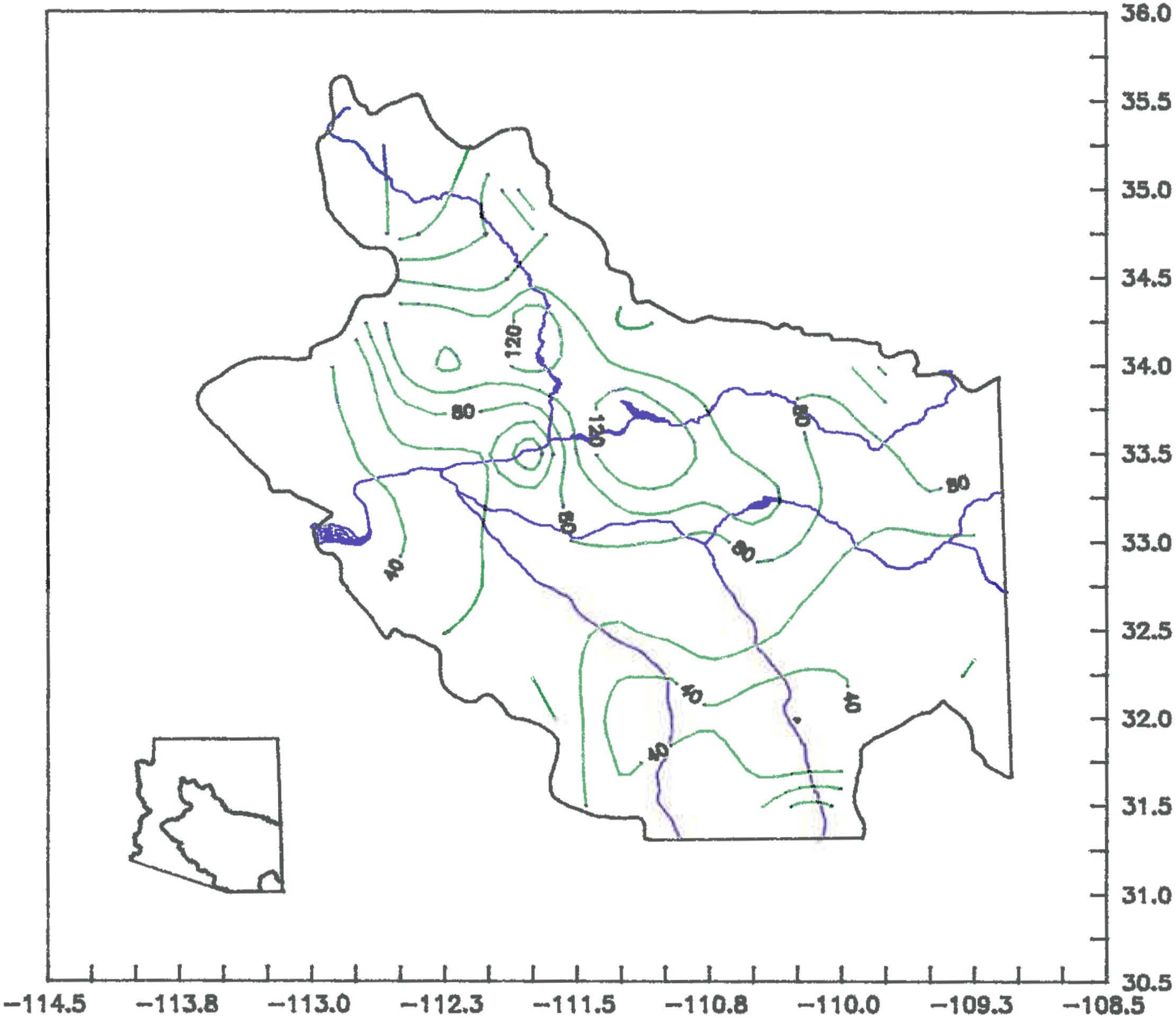


Plate 7

Summer Storm Transposition 1

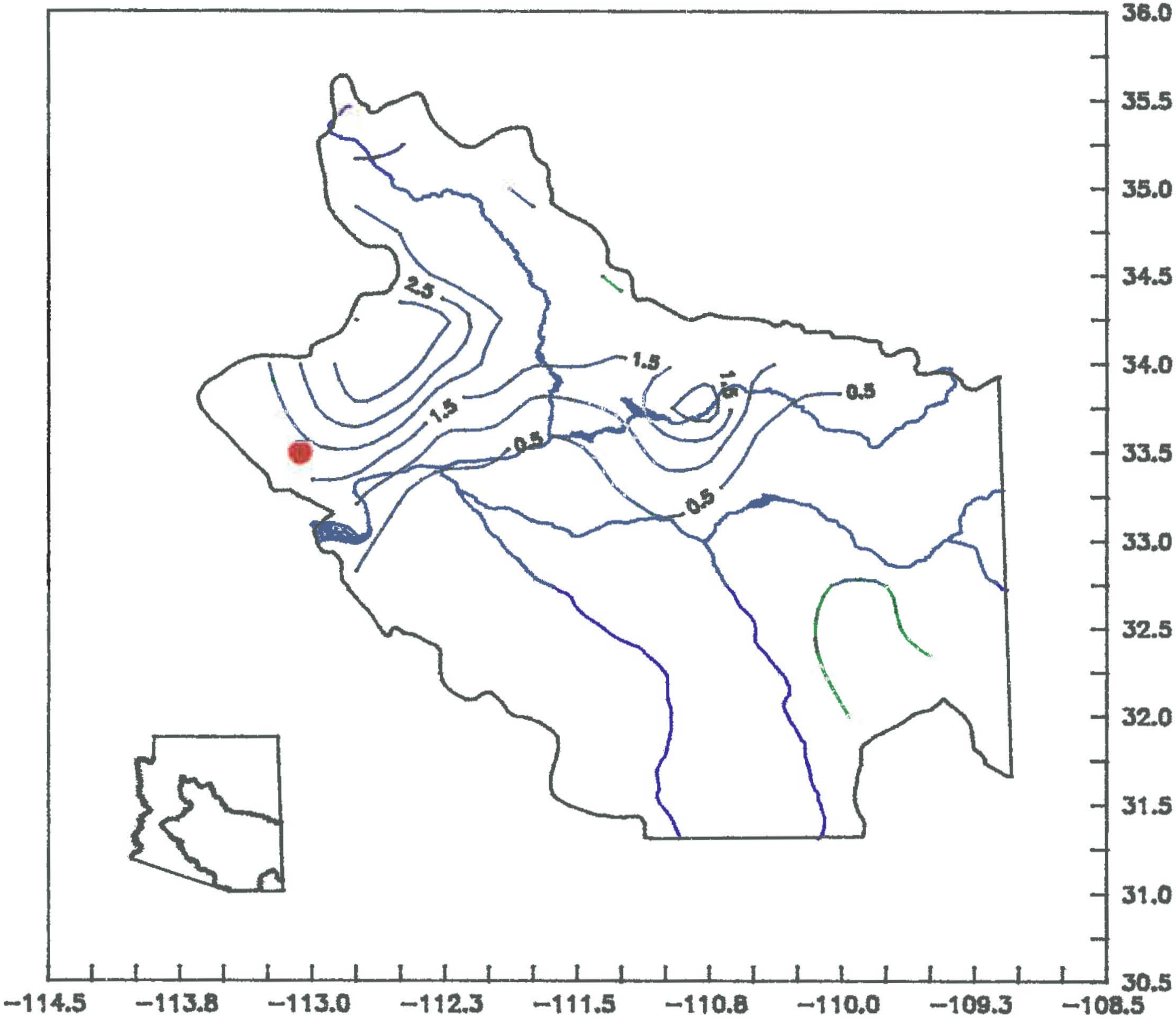


Plate 8

Summer Storm Transposition 2

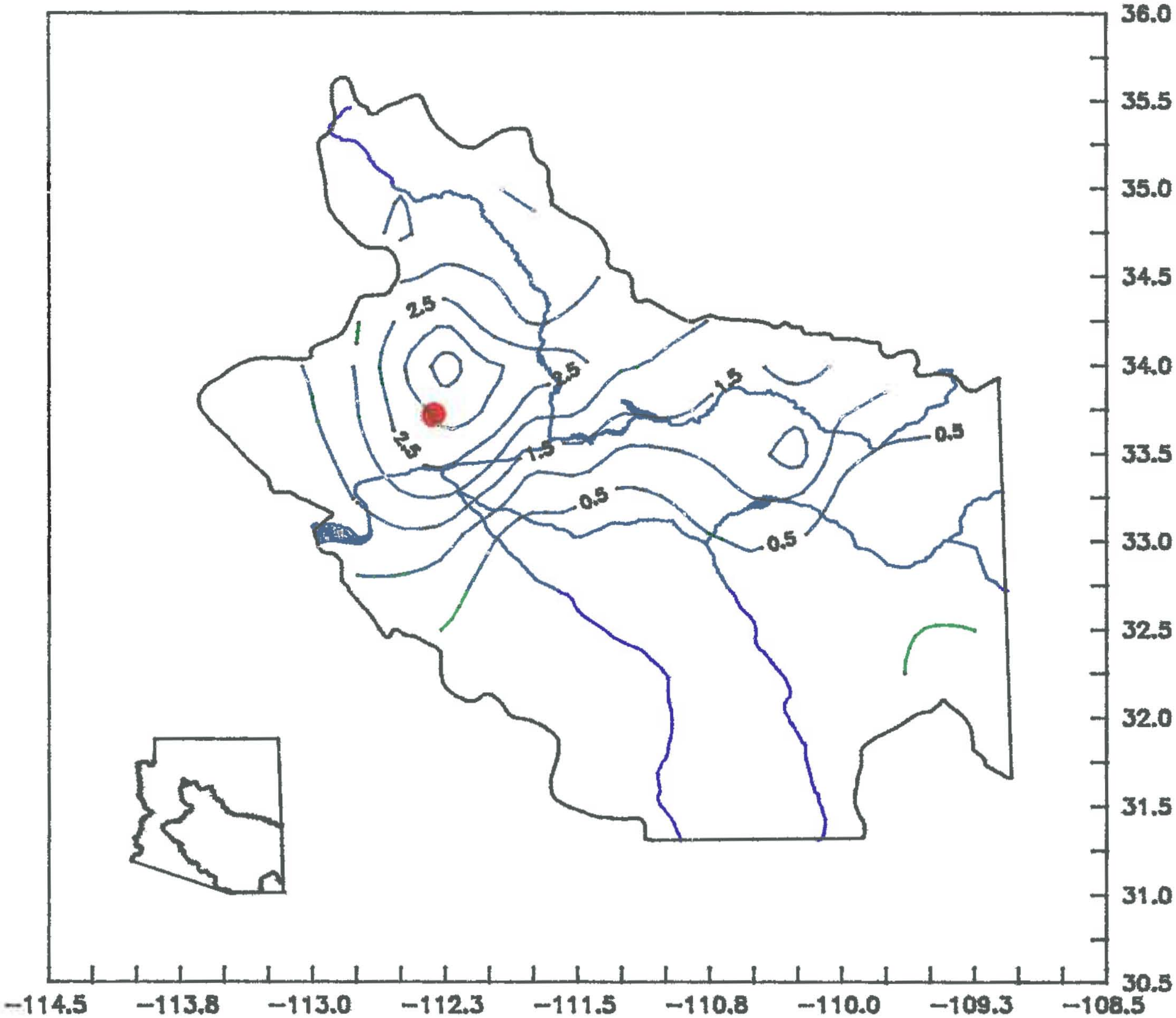


Plate 9

Summer Storm Transposition 3

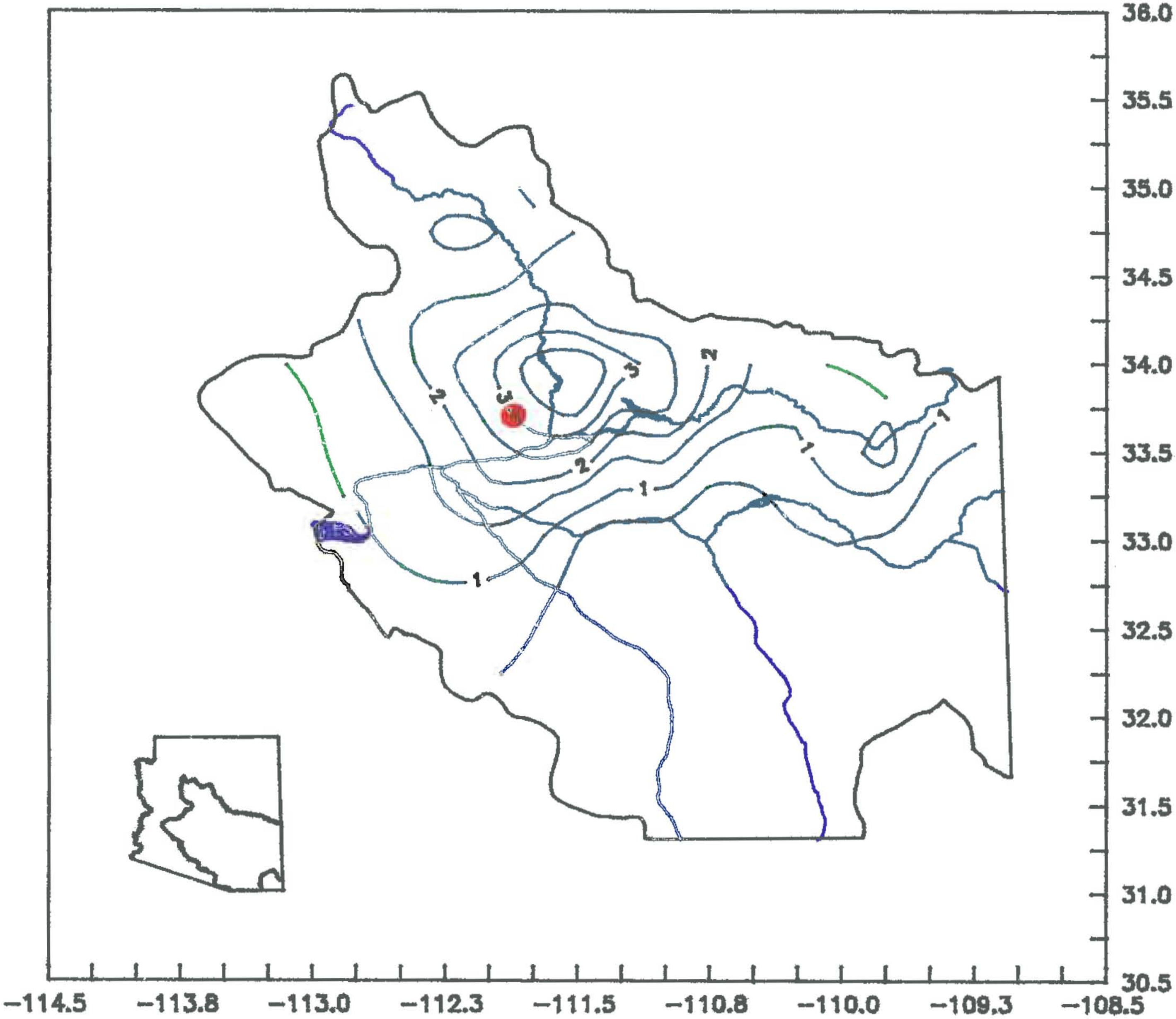


Plate 10

Summer Storm Transposition 4

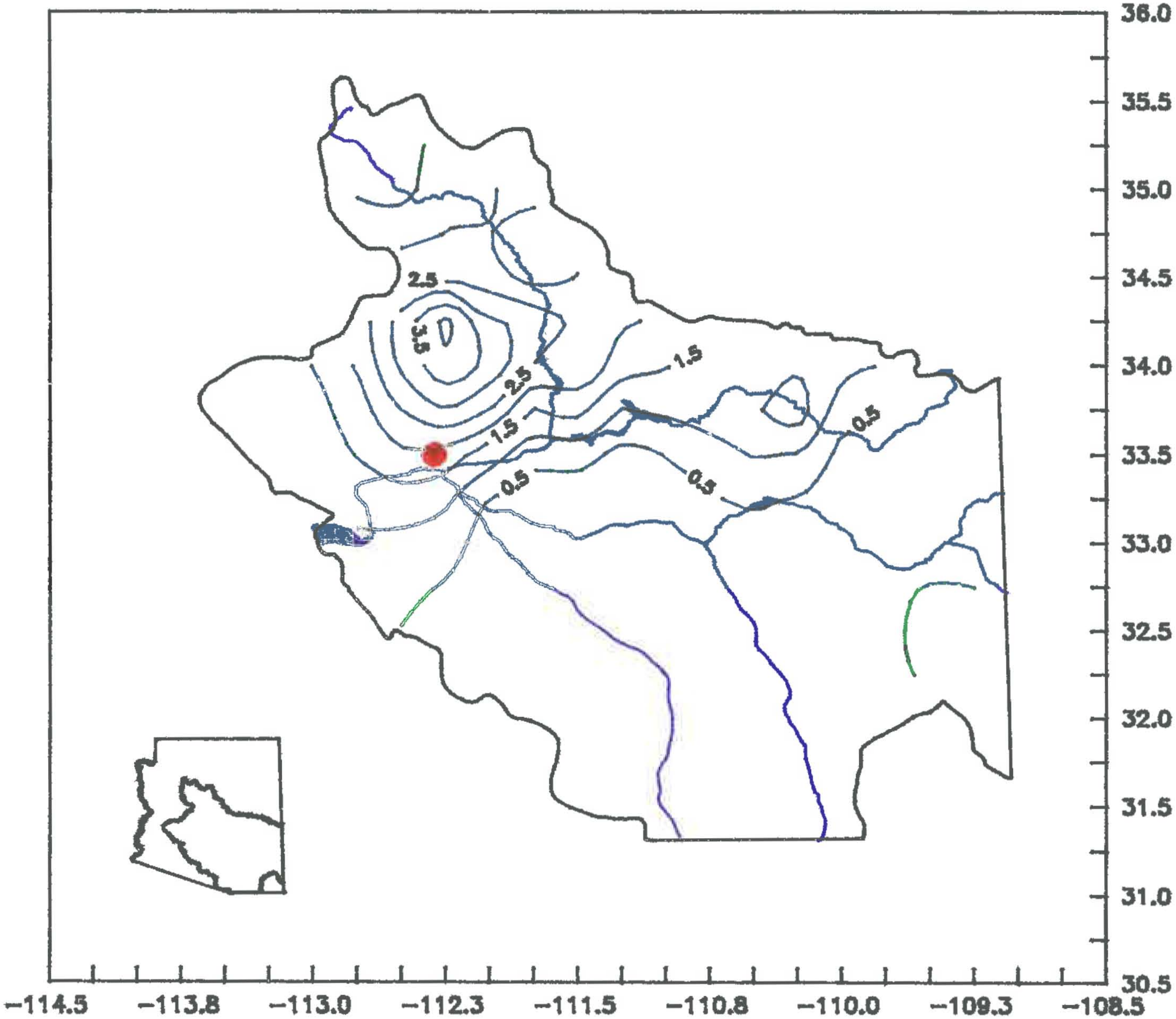


Plate 11

Summer Storm Transposition 5

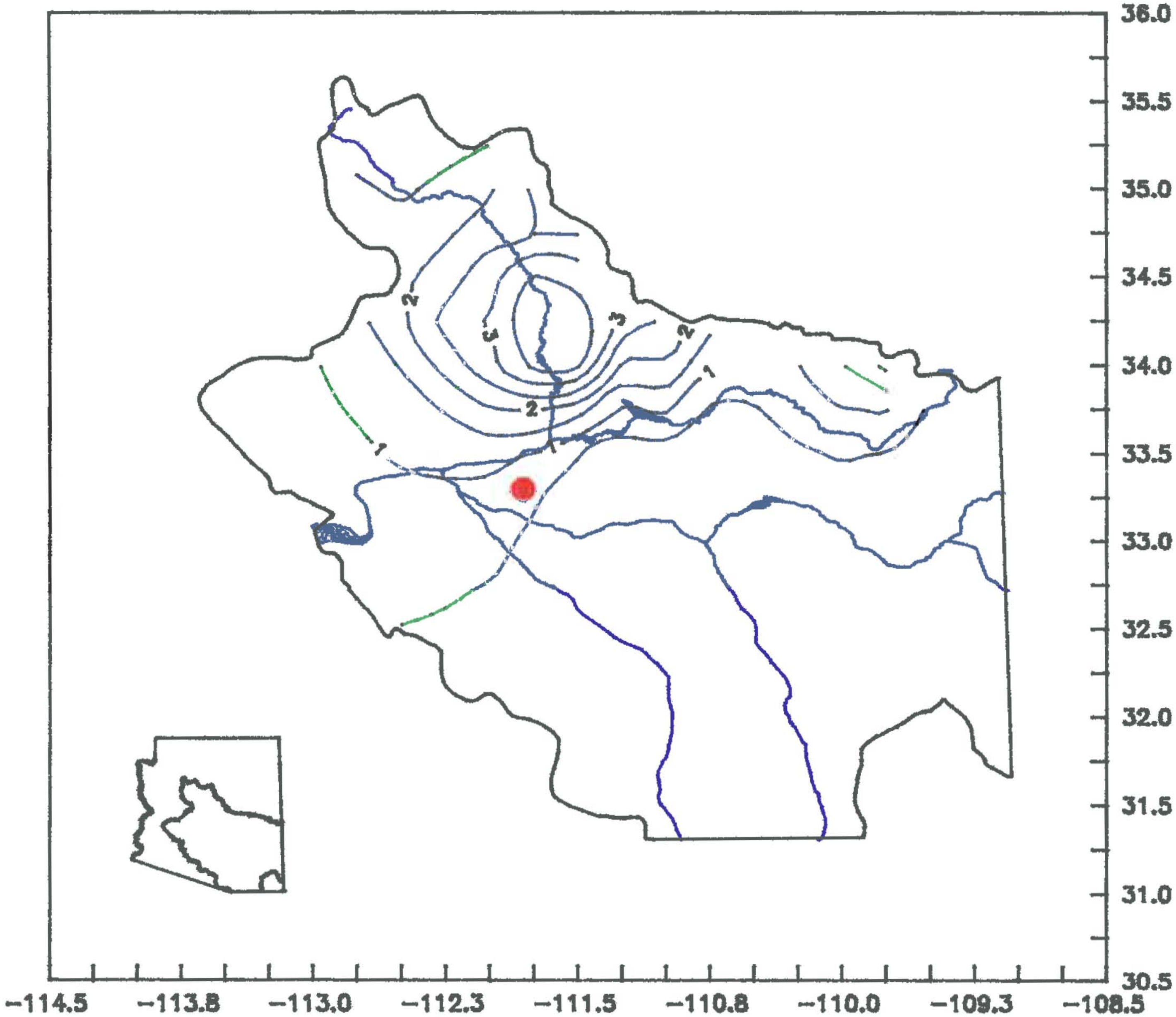


Plate 12

Winter Storm Transposition 1

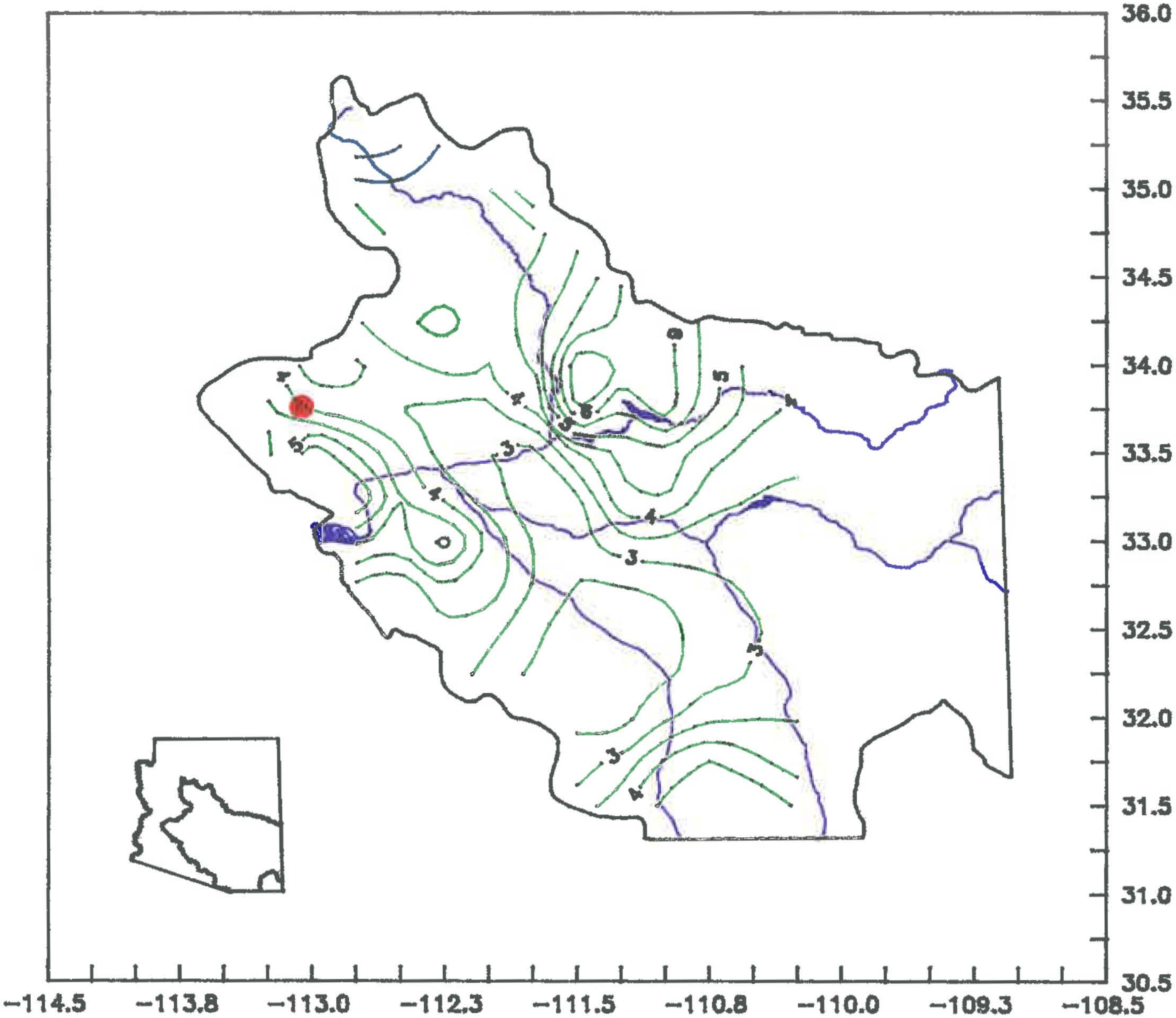


Plate 13

Winter Storm Transposition 2

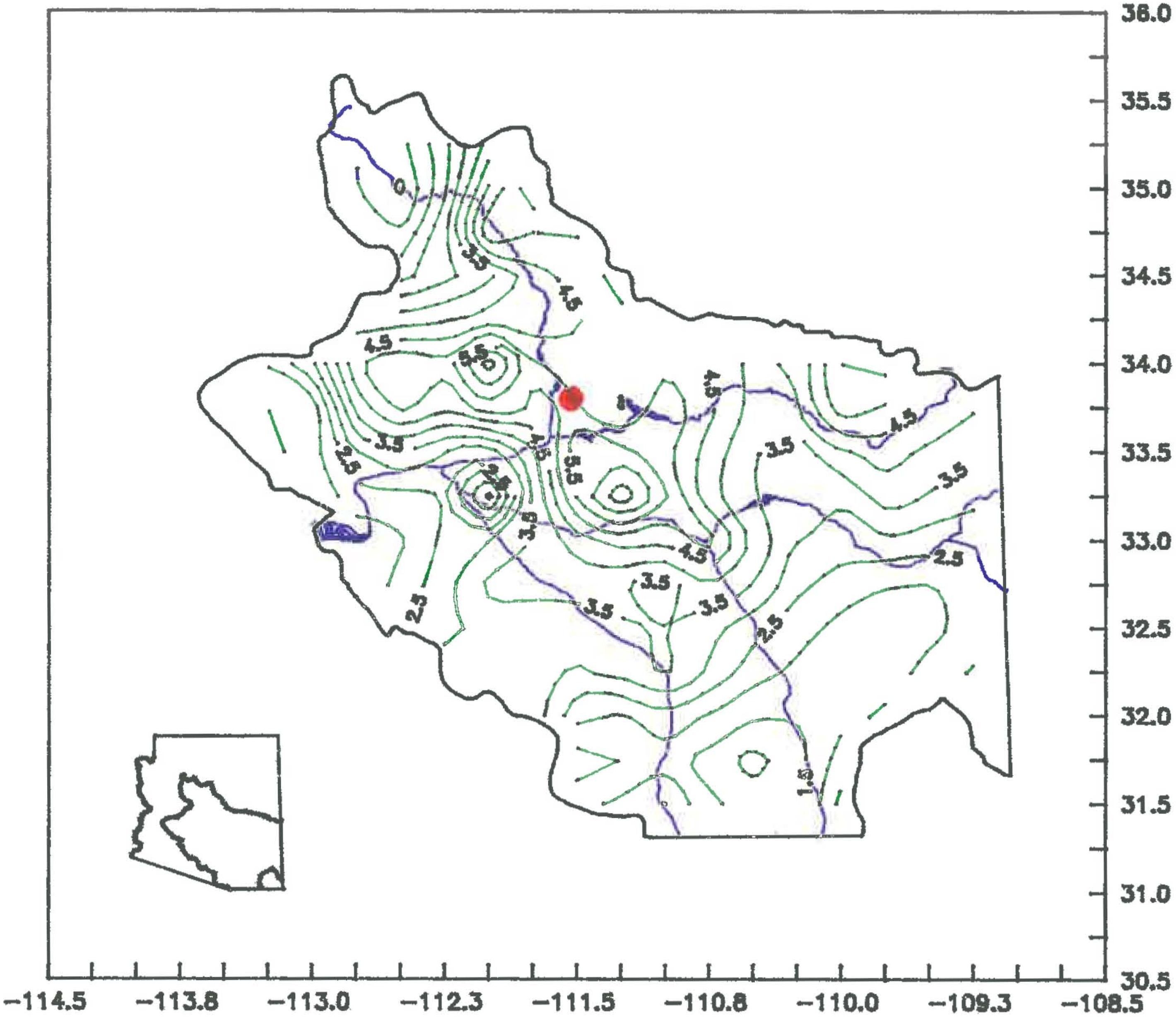


Plate 14

Winter Storm Transposition 3

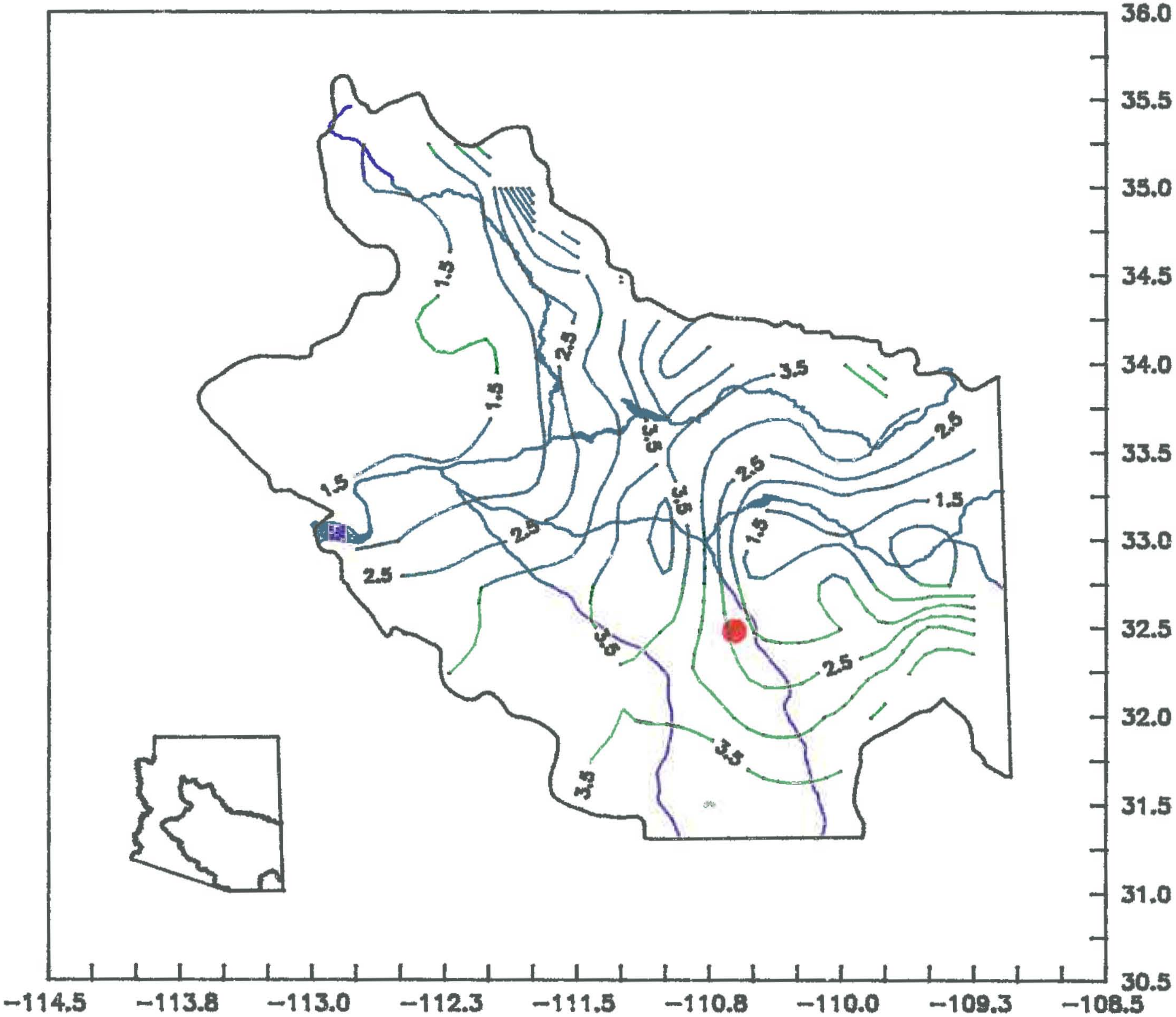


Plate 15

APPENDIX

Normality Testing

The following programs was used to calculate the standardized indices of skewness and kurtosis as described on page 7 of the text.

```
// JOB
// EXEC FORV2CG
//FORT.SYSIN  DD *
C  THIS PROGRAM CHECKS VARIABLES FOR NORMALITY USING STANDARDIZED
C  INDICES OF SKEWNESS AND KURTOSIS.  WRITTEN BY DR. ROBERT BALLING
C   THIS IS W(CASES,VARIABLES)
      DIMENSION W(151,41) ,V(151)
      REAL MISS
C  NV = NUMBER OF VARIABLES
C  NC = NUMBER OF CASES
C  NS = NUMBER OF BLOCKS OF DATA
      MISS=-99.99
      NS=1
      NV=1
      NC=41
      DO 1000 KK=1,NS
      DO 862 I=1,NC
  862 READ(10,10)(W(I,J),J=1,NV)
  10  FORMAT(5X,F7.2)
C *****************************************************************
C     WRITE(6,55)
C  55 FORMAT(1H1,'THE FIRST COLUMN IS THE VARIABLE NUMBER'//
C    +'THE SECOND COLUMN IS THE COEFFICIENT OF SKEWNESS'//
C    +'POSITIVE INDICATES THAT A FEW LARGE NUMBERS ARE FORCING'//
C    +'THE MEAN ABOVE THE MODE'///
C    +'THE THIRD COLUMN IS THE COEFFICIENT OF KURTOSIS'//
C    +'NEGATIVE INDICATES A FLAT DISTRIBUTION'/////)
      DO 21 I=1,NV
      NCASE=NC
      K=0
      DO 22 J=1,NC
      K=K+1
      IF(W(J,I).EQ.MISS)THEN
        NCASE=NCASE-1
      K=K-1
        GO TO 22
       END IF
C  ** TRANSFORM HERE: ****
      V(K)=W(J,I)
      IF(W(J,I).GE.0)V(K)=(W(J,I)**0.33)
      IF(W(J,I).EQ.0)V(K)=0
       V(K)=V(K)
  22   CONTINUE
      IF(NCASE.EQ.0)THEN
       Z1=0
       Z2=0
       WRITE(6,30)I,Z1,Z2,NCASE
       GO TO 21
      END IF
      CALL NORMAL(V,NCASE,G1,G2,Z1,Z2)
      WRITE(6,30)I,Z1,Z2,NCASE
  21  CONTINUE
   30 FORMAT(I5,2F10.3,I5)
 1000 CONTINUE
      STOP
      END
      SUBROUTINE NORMAL(V,N,G1,G2,Z1,Z2)
      DIMENSION V(230)
      SUMV=0.0
      SUMD3=0.0
      AN=N
      SUMD2=0.0
      SUMD4=0.0
      DO 25 I=1,N
```

```
   25 SUMV=SUMV+V(I)
      X=SUMV/AN
      DO 26 I=1,N
      Y=V(I)-X
      SUMD2=SUMD2+Y*Y
      SUMD3=SUMD3+Y*Y*Y
   26 SUMD4=SUMD4+Y*Y*Y*Y
      IF(SUMD2.EQ.0)THEN
      Z1=0
      Z2=0
      RETURN
      END IF
      G1=(SUMD3/AN)/((SUMD2/AN)**1.5)
      Z1=G1/((6.0/AN)**0.5)
      G2=((SUMD4/AN)/((SUMD2/AN)**2.0))-3.0
      Z2=G2/((24.0/AN)**0.5)
      STD=SUMD2/(N-1)
      STD=STD**0.5
      RETURN
      END
//GO.SYSIN  DD  *
//GO.FT10F001  DD  DSN=WYL.AT.RCB.SUMBIG,DISP=SHR
//  EXEC WNOTIFY
//
```

Storm Characteristics

The following two programs were used to calculate the characteristics of summertime and wintertime storms.

```
// JOB
// EXEC FORV2CG
//FORT.SYSIN DD *
C     GENERAL PROGRAM FOR CALCULATING SUMMERTIME STORM CHARACTERISTICS
C     KST = LISTING FOR MORNING OBSERVATION STATIONS
C     NK = NUMBER OF MORNING OBSERVATION STATIONS
C     PROGRAM WRITTEN BY DR. ROBERT BALLING, ASU CLIMATE LAB
      DIMENSION NCLAS(20),TOT(8000),DAY(8000),KST(47),P(106)
      DATA KST /3,5,9,11,13,14,15,17,24,26,30,35,38,40,41,
     +42,44,45,46,47,48,49,50,52,54,55,61,62,63,66,67,69,71,
     +73,76,80,81,86,87,89,90,91,93,94,95,97,104/
      NK=47
      IDAY=0
      DO 40 I=1,8000
      TOT(I)=0
   40 DAY(I)=0
  100  READ(10,10,END=999)ID,MON,IYR,(P(J),J=1,106)
   10  FORMAT(I2,1X,I2,1X,I4,106F6.2)
      IF(MON.LE.3.OR.MON.GE.10 )GO TO 100
      IDAY=IDAY+1
      N=0
      NR=0
      SUM=0
      DO 50 I=1,NK
      IS=KST(I)
      IF(P(IS).EQ.999)THEN
      P(IS)=0
      GO TO 50
      END IF
      IF(P(IS).EQ.888)P(IS)=0
      SUM=SUM+P(IS)
      N=N+1
  50  IF(P(IS).GT.0)NR=NR+1
      IF(N.NE.0)THEN
      PRAIN=NR/(1.0*N)
      IF(PRAIN.GE.0.80)WRITE(6,586)ID,MON,IYR,PRAIN
  586 FORMAT(1X,3I5,F7.2)
      END IF
      IF(N.GT.0)AVE=SUM/N
      IF(N.EQ.0)AVE=0
  85  DAY(IDAY)=AVE
      IF(AVE.EQ.0)GO TO 100
      IF(IDAY.LT.5)GO TO 100
      STOT=AVE
  87  TOT(IDAY)=STOT
      IF(STOT.GT.1.5)WRITE(6,16)MON,ID,IYR,STOT
      IF(STOT.GT.1.4)WRITE(6,376)MON,ID,IYR,(P(J),J=1,106)
  376  FORMAT(1X,3I5/11(10F7.2/))
  16  FORMAT(1X,3I5,F5.2)
      GO TO 100
 999  DO 990 K=1,7999
      IF(TOT(K).EQ.0)GO TO 990
      CLASSI=0.333333
      DO 989 I=1,20
      CLASL=(I-1)*CLASSI
      CLASH=I*CLASSI
      IF(TOT(K).GE.CLASL.AND.TOT(K).LT.CLASH)NCLAS(I)=NCLAS(I)+1
  989 CONTINUE
  990 CONTINUE
      DO 876 I=1,20
      CLASS=(I*CLASSI)-(CLASSI/2.0)
  876 WRITE(6,17)CLASS,NCLAS(I)
  17  FORMAT(F7.3,I5)
      IC=0
```

```
      DO 777 I=48,88
      N=183
      BIG=0
      DO 776 J=1,N
      IC=IC+1
      IF(TOT(IC).GT.BIG)BIG=TOT(IC)
  776 CONTINUE
      WRITE(6,126)I,BIG
  126 FORMAT(I6,F7.2)
  777 CONTINUE
      STOP
      END
//GO.SYSIN  DD  *
//GO.FT10F001  DD  DSN=GILA1.HOURLY,UNIT=TAPE6250,
//       VOL=SER=802080,LABEL=(5,SL,,IN),DCB=(RECFM=FB,LRECL=800,
//       BLKSIZE=16000)
//    EXEC  WNOTIFY
//
>
```

```
// JOB
// EXEC FORV2CG
//FORT.SYSIN DD *
C    PROGRAM FOR CALCULATING WINTERTIME STORM CHARACTERISTICS
C    NK = NUMBER OF USABLE STATIONS
C    PROGRAM WRITTEN BY DR. ROBERT BALLING, ASU CLIMATE LAB
      DIMENSION NCLAS(20),TOT(8000),DAY(8000),KST(14),P(106)
      NK=106
      IDAY=0
      DO 40 I=1,8000
      TOT(I)=0
   40 DAY(I)=0
  100  READ(10,10,END=999)ID,MON,IYR,(P(J),J=1,106)
   10  FORMAT(I2,1X,I2,1X,I4,106F6.2)
      IF(MON.GT.3.AND.MON.LT.10)GO TO 100
      IF(IYR.EQ.1978.AND.MON.EQ.12)THEN
      IF(ID.GE.17.AND.ID.LE.20)WRITE(6,838)MON,ID,IYR,(P(J),J=1,106)
  838 FORMAT(1X,3I5/11(10F7.2/))
      END IF
      IDAY=IDAY+1
      N=0
      NR=0
      SUM=0
      DO 50 I=1,NK
      IS=I
      IF(P(IS).EQ.999)GO TO 50
      IF(P(IS).EQ.888)P(IS)=0
      SUM=SUM+P(IS)
      N=N+1
   50 IF(P(IS).GT.0)NR=NR+1
      IF(N.GT.0)AVE=SUM/N
      IF(N.EQ.0)AVE=0
   85 DAY(IDAY)=AVE
      IF(AVE.EQ.0)GO TO 100
      IF(IDAY.LT.5)GO TO 100
      STOT=AVE
      IF(DAY(IDAY-1).EQ.0)GO TO 87
      STOT=DAY(IDAY-1)+STOT
      IF(DAY(IDAY-2).EQ.0)GO TO 87
      STOT=DAY(IDAY-2)+STOT
      IF(DAY(IDAY-3).EQ.0)GO TO 87
      STOT=DAY(IDAY-3)+STOT
   87 TOT(IDAY)=STOT
      IF(STOT.GT.1.0)WRITE(6,16)MON,ID,IYR,STOT
   16 FORMAT(1X,3I5,F5.2)
      GO TO 100
  999 DO 990 K=1,7999
      IF(TOT(K).EQ.0.OR.TOT(K+1).EQ.0)GO TO 990
      CLASSI=0.333333
      DO 989 I=1,20
      CLASL=(I-1)*CLASSI
      CLASH=I*CLASSI
      IF(TOT(K).GE.CLASL.AND.TOT(K).LT.CLASH)NCLAS(I)=NCLAS(I)+1
  989 CONTINUE
  990 CONTINUE
      DO 876 I=1,20
      CLASS=(I*CLASSI)-(CLASSI/2.0)
  876 WRITE(6,17)CLASS,NCLAS(I)
   17 FORMAT(F7.3,I5)
      IC=0
      DO 777 I=48,88
      N=182
      IF(I.EQ.48.OR.I.EQ.52.OR.I.EQ.56.OR.I.EQ.60.OR.I.EQ.64.OR.
     +I.EQ.68.OR.I.EQ.72.OR.I.EQ.76.OR.I.EQ.80.OR.I.EQ.84.OR.
```

```
         +I.EQ.88)N=183
          BIG=0
          DO 776 J=1,N
          IC=IC+1
          IF(TOT(IC).GT.BIG)BIG=TOT(IC)
      776 CONTINUE
          WRITE(6,126)I,BIG
      126 FORMAT(I6,F7.2)
      777 CONTINUE
          STOP
          END
//GO.SYSIN  DD  *
//GO.FT10F001  DD  DSN=GILA1.HOURLY,UNIT=TAPE6250,
//       VOL=SER=802080,LABEL=(5,SL,,IN),DCB=(RECFM=FB,LRECL=800,
//       BLKSIZE=16000)
//   EXEC  WNOTIFY
//
>
```

Grid Interpolation and Production of Plates

The plates included in this report were produced using the "Surfer" program from Golden Software Inc.. Basemaps and station locations were digitized in longitude latitude format. Since the original precipitation data were not in gridded form, a 25 by 23 grid was interpolated using Surfer's Krieging algorithm. These new precipitation grids were then used to produce the isohyetal maps presented. The Plates were printed on a Hewlett Packard HP7475A Plotter.

Sub-basin Precipitation Totals

The following spreadsheets were used to calculate the Sub-basin precipitation totals presented in Table 3.

Gila River Winter 100 year Storm
December 17-20, 1978

Total(hyp)= 3.50 Factor= 1.2237762
Total(actual)= 2.86

Station	Day1	Day2	Day3	Day4	Total	Long.	Lat.	Adj. Total	Total SubBasin	NOAA2 100yr	Adj. as % of 100 yr
1.00	0.40	0.60	0.40	0.00	1.40	-109.48	32.33	1.7133		3.9	43.93042855
2.00	0.30	0.80	1.50	0.00	2.60	-109.35	32.00	3.1818		4.4	72.31404959
3.00	0.00	1.00	0.80	0.00	1.80	-109.28	33.05	2.2028		3.8	57.96834744
4.00	0.30	0.80	0.40	0.00	1.50	-109.12	32.75	1.8357		3.4	53.99012752
5.00	0.00	1.80	0.40	1.00	3.20	-109.48	33.40	3.9161		4.1	95.51424186
6.00	0.70	1.20	0.10	0.00	2.00	-109.95	33.03	2.4476		4	61.18881119
7.00						-109.18	33.33			3.8	0
8.00	0.50	1.60	1.30	0.00	3.40	-109.17	31.90	4.1608		4	104.020979
9.00	0.00	0.40	0.80	0.00	1.20	-109.68	32.82	1.4685		3.4	43.19210202
10.00	0.80	1.40	1.00	0.00	3.20	-110.45	33.35	3.9161		4.2	93.24009324
11.00	0.10	3.00	1.80	0.10	5.00	-110.52	33.17	6.1189	3.0961538	4.4	139.06548
12.00	0.20	1.90	1.10	0.00	3.20	-109.13	33.85	3.9161		4.5	87.02408702
13.00						-109.17	33.58			4.4	0
14.00	0.40	0.50	0.00	0.00	0.90	-111.38	31.98	1.1014		4.9	22.47752248
15.00	0.20	0.10	0.10	0.00	0.40	-110.25	31.90	0.4895		3.8	12.88185499
16.00	0.30	1.20	0.30	0.10	1.90	-111.32	31.58	2.3252		4.8	48.44114219
17.00						-109.92	31.43			4.2	0
18.00	0.30	1.10	0.40	0.00	1.80	-110.53	31.55	2.2028		4.7	46.86802559
19.00	0.60	2.20	1.00	0.00	3.80	-110.28	31.37	4.6503		5.3	87.74244623
20.00						-111.12	32.33			4.9	0
21.00						-109.95	32.62			4.2	0
22.00	0.20	0.90	0.60	0.00	1.70	-110.33	31.57	2.0804		4.1	50.74194099
23.00	0.00	2.30	0.90	0.00	3.20	-110.97	33.10	3.9161		4.6	85.13225905
24.00	0.00	2.10	2.20	0.30	4.60	-111.60	31.97	5.6294		5.5	102.3521933
25.00	0.30	0.50	0.00	0.20	1.00	-110.68	32.12	1.2238		4.2	29.13752914
26.00	0.10	0.90	0.90	0.10	2.00	-110.95	31.42	2.4476		4.6	53.2076619
27.00	2.60	0.40	0.40	0.00	3.40	-110.73	32.60	4.1608		4.7	88.52849278
28.00	0.00	0.90	0.80	0.00	1.70	-110.75	31.55	2.0804		4.6	45.22651262
29.00	1.50	0.50	0.00	0.00	2.00	-109.82	31.90	2.4476		4.3	56.91982436
30.00	0.00	1.10	0.80	0.20	2.10	-110.48	32.43	2.5699		4	64.24825175
31.00	0.30	0.30	0.50	0.00	1.10	-111.08	31.92	1.3462		4.8	28.04487179
32.00	0.40	1.70	0.00	0.00	2.10	-110.82	32.30	2.5699		4.3	59.76581558
33.00	0.20	1.40	0.00	0.10	1.70	-110.65	32.95	2.0804		4.3	48.38185071
34.00	0.40	1.60	0.00	0.70	2.70	-110.85	31.77	3.3042		5	66.08391608
35.00	0.00	0.50	0.30	0.00	0.80	-110.05	31.70	0.9790		4	24.47552448
36.00	0.40	1.10	0.00	0.00	1.50	-110.95	32.25	1.8357		4.5	40.79254079
37.00	0.30	0.70	0.10	0.00	1.10	-110.95	32.13	1.3462		4.3	31.3059034
38.00	0.20	0.90	0.20	0.10	1.40	-111.05	31.57	1.7133		4.8	35.69347319
39.00	0.50	0.60	0.40	0.00	1.50	-109.85	32.30	1.8357		4.2	43.70629371
40.00	0.70	1.00	0.60	0.00	2.30	-110.72	32.92	2.8147		4.3	65.45779802
41.00	0.00	2.00	1.80	0.00	3.80	-110.20	31.45	4.6503	2.5275686	4.1	113.4231622
42.00	0.00	1.00	1.40	0.10	2.50	-109.77	33.48	3.0594		4.2	72.84382284
43.00						-110.48	34.03			4.4	0
44.00	0.00	2.50	1.20	0.00	3.70	-111.28	34.12	4.5280		5.5	82.32676414
45.00	0.10	1.80	1.70	0.10	3.70	-110.78	33.38	4.5280		4.6	98.43417452
46.00	0.00	2.80	2.90	0.40	6.10	-109.85	34.07	7.4650		5.3	140.8497163
47.00	0.10	3.50	2.20	0.10	5.90	-110.88	33.40	7.2203		5	144.4055944
48.00	0.00	0.00	3.70	0.20	3.90	-109.92	34.12	4.7727		5.2	91.78321678
49.00	0.00	3.90	1.10	0.10	5.10	-111.32	33.88	6.2413		5.5	113.4774317
50.00	0.00	3.90	1.40	1.00	6.30	-111.15	33.67	7.7098		4.4	175.2225048
51.00	2.10	3.30	0.50	0.00	5.90	-110.97	33.80	7.2203		7	103.1468531
52.00	0.00	1.00	1.50	0.20	2.70	-109.97	33.83	3.3042		4.2	78.67132867
53.00	1.30	1.40	0.90	0.00	3.60	-110.93	34.10	4.4056	5.4958678	5.5	80.10171647
54.00	1.70	1.10	0.10	0.00	2.90	-111.25	33.08	3.5490		4.2	84.4988345
55.00	3.40	0.00	0.00	0.00	3.40	-111.63	33.82	4.1608		4.8	86.68414918
56.00						-111.75	32.88			4.6	0
57.00						-111.68	33.22			3.5	0
58.00	1.10	0.70	0.10	0.00	1.90	-112.08	33.58	2.3252		3.8	61.18881119

59.00	0.50	1.40	0.20	0.00	2.10	-111.53	32.83	2.5699		4.3	59.76581558
60.00						-111.75	33.43			3.4	0
61.00	0.20	2.50	0.10	0.00	2.80	-111.38	33.03	3.4266		4	85.66433566
62.00	0.10				0.10	-111.70	33.52	0.1224		3.8	3.220463747
63.00	0.10	3.50	1.60	0.00	5.20	-111.72	33.98	6.3636		5	127.2727273
64.00	1.00	0.50	0.10	0.00	1.60	-112.15	33.33	1.9580		4.2	46.62004662
65.00	0.80	1.00	0.20	0.00	2.00	-112.03	33.12	2.4476		4.2	58.27505828
66.00	0.20	1.60	0.30	0.00	2.10	-111.87	33.42	2.5699		3.6	71.38694639
67.00	0.00	3.20	0.90	0.30	4.40	-111.45	33.55	5.3846		4.4	122.3776224
68.00	0.90	1.00	0.00	0.00	1.90	-112.02	33.43	2.3252		3.8	61.18881119
69.00	0.10	1.80	0.60	0.10	2.60	-111.47	32.87	3.1818		4.3	73.99577167
70.00	0.00	2.00	0.50	0.10	2.60	-111.75	33.07	3.1818		3.8	83.73205742
71.00	2.70	0.80	0.10	0.00	3.60	-111.53	33.57	4.4056		4.2	104.8951049
72.00	1.90	1.50	2.80	0.00	6.20	-111.48	33.90	7.5874		6.5	116.7294244
73.00	0.20	2.80	2.00	0.20	5.20	-111.10	33.30	6.3636		5.5	115.7024793
74.00	0.80	0.70	0.10	0.00	1.60	-112.23	33.45	1.9580		3.8	51.52741995
75.00	0.80	1.10	0.10	0.00	2.00	-112.30	33.60	2.4476	3.4909827	3.8	64.40927494
76.00						-112.48	35.30			3.7	0
77.00	0.00	1.40	1.50	0.00	2.90	-111.72	34.67	3.5490		4.6	77.15110976
78.00						-112.87	34.80			5.6	0
79.00	2.20	1.40	1.30	0.00	4.90	-112.37	33.98	5.9965		4.8	124.9271562
80.00	0.10	2.50	3.90	0.00	6.50	-111.70	34.35	7.9545		5	159.0909091
81.00	0.30	0.40	0.20	0.10	1.00	-112.45	34.75	1.2238		4.4	27.81309599
82.00	0.90	1.30	0.50	0.00	2.70	-112.17	34.30	3.3042		4.5	73.42657343
83.00						-112.03	34.75			4.6	0
84.00	0.00	4.60	3.70	0.00	8.30	-112.33	34.20	10.1573		6.5	156.2668101
85.00	1.20	2.60	0.40	0.00	4.20	-111.67	35.13	5.1399		4.6	111.73609
86.00	0.10	1.50	1.90	0.00	3.50	-111.62	34.40	4.2832		4.8	89.23368298
87.00	0.90	1.30	0.00	0.10	2.30	-112.10	34.75	2.8147		4.6	61.18881119
88.00	0.90	2.70	2.30	0.00	5.90	-111.75	34.97	7.2203		6	120.3379953
89.00	0.00	1.30	0.50	0.00	1.80	-111.83	34.62	2.2028		4.6	47.88689571
90.00	0.50	2.80	0.10	0.10	3.50	-111.33	34.23	4.2832		5.5	77.87666879
91.00	0.10	1.40	0.90	0.20	2.60	-112.43	34.57	3.1818		4.7	67.69825919
92.00	0.00	1.80	1.40	0.00	3.20	-111.77	34.87	3.9161		4.7	83.32093438
93.00	0.40	1.00	0.20	0.00	1.60	-112.88	35.32	1.9580		3.4	57.58946935
94.00	0.00	2.30	1.80	0.30	4.40	-111.10	34.37	5.3846		6.4	84.13461538
95.00	0.50	1.70	0.20	0.10	2.50	-112.82	34.93	3.0594		4.9	62.43756244
96.00	0.10	0.30	0.30	0.00	0.70	-112.18	35.25	0.8566	4.249223	4.7	18.2264544
97.00	0.30	0.80	0.00	0.00	1.10	-113.18	33.95	1.3462		4	33.65384615
98.00						-112.38	33.67			3.9	0
99.00	0.50	0.60	0.30	0.00	1.40	-112.58	33.37	1.7133		4.1	41.78748081
100.00	0.10	0.80	0.10	0.00	1.00	-112.72	32.95	1.2238		4.1	29.84820058
101.00	1.40	0.50	0.00	0.00	1.90	-112.48	33.50	2.3252		4.1	56.7115811
102.00						-112.45	34.48			5	0
103.00						-113.15	33.52			4.1	0
104.00	0.70	1.00	0.20	0.00	1.90	-112.37	33.50	2.3252		3.8	61.18881119
105.00	1.50	2.30	0.30	0.00	4.10	-112.55	34.30	5.0175		4.8	104.5308858
106.00	1.00	0.40	0.00	0.00	1.40	-112.73	33.98	1.7133	2.2377622	4.2	40.79254079

Gila River 100 year Summer Storm
August 28, 1951

Total (hyp)= 1.5 Factor= 0.8928571
Total(actual)= 1.68

Station	Total	Adj. Total	Long.	Lat.	Total SubBasin	NOAA2 100yr	Adj. as % of 100 yr
1			-109.48	32.33		3.9	0
2			-109.35	32		4.4	0
3	0.1	0.089286	-109.28	33.05		3.8	2.34962406
4			-109.12	32.75		3.4	0
5	0.3	0.267857	-109.48	33.4		4.1	6.533101045
6			-109.95	33.03		4	0
7			-109.18	33.33		3.8	0
8			-109.17	31.9		4	0
9	0.2	0.178571	-109.68	32.82		3.4	5.25210084
10			-110.45	33.35		4.2	0
11			-110.52	33.17	0.1785714	4.4	0
12			-109.13	33.85		4.5	0
13			-109.17	33.58		4.4	0
14	0	0	-111.38	31.98		4.9	0
15	0.1	0.089286	-110.25	31.9		3.8	2.34962406
16			-111.32	31.58		4.8	0
17	0.2	0.178571	-109.92	31.43		4.2	4.25170068
18			-110.53	31.55		4.7	0
19			-110.28	31.37		5.3	0
20			-111.12	32.33		4.9	0
21			-109.95	32.62		4.2	0
22			-110.33	31.57		4.1	0
23			-110.97	33.1		4.6	0
24			-111.6	31.97		5.5	0
25			-110.68	32.12		4.2	0
26			-110.95	31.42		4.6	0
27			-110.73	32.6		4.7	0
28			-110.75	31.55		4.6	0
29			-109.82	31.9		4.3	0
30	0.2	0.178571	-110.48	32.43		4	4.464285714
31			-111.08	31.92		4.8	0
32			-110.82	32.3		4.3	0
33			-110.65	32.95		4.3	0
34			-110.85	31.77		5	0
35			-110.05	31.7		4	0
36			-110.95	32.25		4.5	0
37			-110.95	32.13		4.3	0
38	0.2	0.178571	-111.05	31.57		4.8	3.720238095
39			-109.85	32.3		4.2	0
40	0.1	0.089286	-110.72	32.92		4.3	2.07641196
41	0.5	0.446429	-110.2	31.45	0.1658163	4.1	10.88850174
42	2.1	1.875	-109.77	33.48		4.2	44.64285714
43			-110.48	34.03		4.4	0
44	3.6	3.214286	-111.28	34.12		5.5	58.44155844
45	0.4	0.357143	-110.78	33.38		4.6	7.763975155
46	2.4	2.142857	-109.85	34.07		5.3	40.43126685
47	1.7	1.517857	-110.88	33.4		5	30.35714286
48	2.4	2.142857	-109.92	34.12		5.2	41.20879121
49			-111.32	33.88		5.5	0
50	2.1	1.875	-111.15	33.67		4.4	42.61363636
51			-110.97	33.8		7	0
52	1	0.892857	-109.97	33.83		4.2	21.2585034
53			-110.93	34.1	1.7522321	5.5	0
54			-111.25	33.08		4.2	0
55	4	3.571429	-111.63	33.82		4.8	74.4047619
56			-111.75	32.88		4.6	0
57			-111.68	33.22		3.5	0
58			-112.08	33.58		3.8	0

59			-111.53	32.83		4.3	0
60			-111.75	33.43		3.4	0
61	0.2	0.178571	-111.38	33.03		4	4.464285714
62	3.2	2.857143	-111.7	33.52		3.8	75.18796992
63	4.4	3.928571	-111.72	33.98		5	78.57142857
64			-112.15	33.33		4.2	0
65			-112.03	33.12		4.2	0
66	2.6	2.321429	-111.87	33.42		3.6	64.48412698
67	2	1.785714	-111.45	33.55		4.4	40.58441558
68			-112.02	33.43		3.8	0
69			-111.47	32.87		4.3	0
70			-111.75	33.07		3.8	0
71	4.3	3.839286	-111.53	33.57		4.2	91.41156463
72			-111.48	33.9		6.5	0
73	1.2	1.071429	-111.1	33.3		5.5	19.48051948
74			-112.23	33.45		3.8	0
75			-112.3	33.6	2.4441964	3.8	0
76	2	1.785714	-112.48	35.3		3.7	48.26254826
77			-111.72	34.67		4.6	0
78			-112.87	34.8		5.6	0
79			-112.37	33.98		4.8	0
80	2.6	2.321429	-111.7	34.35		5	46.42857143
81	1.8	1.607143	-112.45	34.75		4.4	36.52597403
82			-112.17	34.3		4.5	0
83			-112.03	34.75		4.6	0
84			-112.33	34.2		6.5	0
85			-111.67	35.13		4.6	0
86	2.8	2.5	-111.62	34.4		4.8	52.08333333
87	1.4	1.25	-112.1	34.75		4.6	27.17391304
88			-111.75	34.97		6	0
89	2.1	1.875	-111.83	34.62		4.6	40.76086957
90	2.1	1.875	-111.33	34.23		5.5	34.09090909
91	1.7	1.517857	-112.43	34.57		4.7	32.29483283
92			-111.77	34.87		4.7	0
93	2.1	1.875	-112.88	35.32		3.4	55.14705882
94	2.6	2.321429	-111.1	34.37		6.4	36.27232143
95	2.3	2.053571	-112.82	34.93		4.9	41.90962099
96			-112.18	35.25	1.9074675	4.7	0
97	1	0.892857	-113.18	33.95		4	22.32142857
98			-112.38	33.67		3.9	0
99			-112.58	33.37		4.1	0
100			-112.72	32.95		4.1	0
101			-112.48	33.5		4.1	0
102			-112.45	34.48		5	0
103			-113.15	33.52		4.1	0
104	1.5	1.339286	-112.37	33.5		3.8	35.2443609
105			-112.55	34.3		4.8	0
106			-112.73	33.98	1.1160714	4.2	0

100-year Storm Duration Calculations

The algorithm for determining storm durations is described on page 16 of this report. The following program was used to implement this algorithm.

```
' **********This program reads in a raw data file of hourly *********
' **********precipitation data, strips out blanks and headers, ******
' **********and calculates storm durations for the Gila River  ******
' **********project.                                       ******
' **********This program written in QuickBasic 4.0 by        ******
' **********Tomas A. Miller and Herbert J. Verville of the    ******
' **********Laboratory of Climatology, Arizona State University *****


DECLARE FUNCTION MDY2Jul (Month, Day, Year)
DECLARE FUNCTION Jul2Month (Juldate, Year)
DECLARE FUNCTION Jul2Day (Juldate, Year)
DECLARE SUB ScanData (a$, NumYears!)
DECLARE SUB Duration (Precip(), Year)
DIM Precip(367, 24)


a$ = "c:\tom\gila\crking.hpd"
b$ = "c:\tom\gila\crking.win"
c$ = "c:\tom\gila\crking.sum"


' ***** Initialize Arrays  ********
FOR i% = 1 TO 367
      FOR j% = 1 TO 24
            Precip(i%, j%) = 0
      NEXT
NEXT



ScanData a$, NumYears   ' *** Call ScanData Subroutine ****

'     ********** Open File and Input data one year at a time
OPEN a$ FOR INPUT AS #1
OPEN b$ FOR OUTPUT AS #2
OPEN c$ FOR OUTPUT AS #3

LINE INPUT #1, z$

FOR i% = 1 TO NumYears
      FOR j% = 1 TO 13
            LINE INPUT #1, z$
      NEXT

      OldMonth = 0
      OldDay = 0
      OldYear = 0

ReadYearData:
      LINE INPUT #1, z$
      IF LEFT$(z$, 1) = CHR$(12) THEN GOTO EndYear    ' *** Check for End of Year ***

      Month = VAL(MID$(z$, 26, 2))
```

```
      Day = VAL(MID$(z$, 29, 2))
      Year = VAL(MID$(z$, 32, 4))
      Hour = VAL(MID$(z$, 46, 2))
      Amount = VAL(MID$(z$, 60, 5))


      IF Month <> 0 THEN
            OldMonth = Month
            OldDay = Day
            OldYear = Year
      ELSE
            Month = OldMonth
            Day = OldDay
            Year = OldYear
      END IF


      Juldate = MDY2Jul(Month, Day, Year)
      PRINT Month, Day, Year, Juldate
      Precip(Juldate, Hour) = Amount
      GOTO ReadYearData

EndYear:
      Duration Precip(), Year

 NEXT

CLOSE
END

SUB Duration (pcp(), Year)
DIM d(8790)
      IF (Year MOD 4 = 0) AND (Year MOD 200 <> 0) THEN
            NumDays = 366
      ELSE
            NumDays = 365
      END IF

      we = 91
      wb = 275
      IF NumDays = 365 THEN
            we = 90
            wb = 274
      END IF


      num = NumDays * 24
      FOR i = 1 TO num
      d(i) = 0
      NEXT i
      md6w = 0
      md6s = 0
      md5w = 0
      md5s = 0
```

```
        l = 0
        FOR i = 1 TO NumDays
                FOR j = 1 TO 24
                l = l + 1
                d(l) = pcp(i, j)
                NEXT j
        NEXT i
        ptot = 0
        lb = 0
        l3 = 0
        l7 = 0
        l8 = 1
        l9 = 0
        l2 = 0
        l = 0
311       l = l + 1
        l3 = l3 + 1
        IF l3 = 25 THEN l8 = l8 + 1
        l9 = l8
        IF l3 = 25 THEN l3 = 1
        IF l > num THEN GOTO 400
        IF d(l) = 0 AND l2 = 0 THEN GOTO 311
        IF d(l) > 0 THEN GOTO 500
        GOTO 501
500       IF l2 = 0 THEN lb = l3
        IF l2 = 0 THEN l7 = l9
        l2 = 1
        ptot = ptot + d(l)
        GOTO 311
501       l5 = l + 1
        l6 = l + 2
        IF l5 > num OR l6 > num THEN GOTO 400
        IF d(l5) = 0 AND d(l6) = 0 THEN GOTO 505

        GOTO 311
505       le = l3 - 1
        IF le = 0 THEN
                le = 24
                l9 = l9 - 1
        END IF

        IF l7 < we OR l7 > wb THEN GOTO 300
        GOTO 301
300       PRINT #2, Year, l7; lb, l9; le, ptot
                IF l7 = l9 THEN GOTO 10
                td = ((24 * (l9 - l7)) + le) - lb + 1
                GOTO 11
10                td = le - lb + 1
11                IF td > md5w OR td = md5w AND ptot > md6w THEN GOTO 12
                GOTO 13
12                md1w = l7
                md2w = lb
                md3w = l9
                md4w = le
```

```
            md5w = td
            md6w = ptot
            GOTO 13

301     PRINT #3, Year, l7; lb, l9; le, ptot
            IF l7 = l9 THEN GOTO 710
            td = ((24 * (l9 - l7)) + le) - lb + 1
            GOTO 711
710          td = le - lb + 1
711          IF td > md5s OR td = md5s AND ptot > md6s THEN GOTO 712
            GOTO 13
712          md1s = l7
            md2s = lb
            md3s = l9
            md4s = le
            md5s = td
            md6s = ptot

13      IF l > num THEN GOTO 400
        l2 = 0
        ptot = 0
        lb = 0
        GOTO 311
400     PRINT #2, "Max Duration ", Year, md1w; md2w, md3w; md4w, md5w; md6w
        PRINT #3, "Max Duration ", Year, md1s; md2s, md3s; md4s, md5s; md6s

END SUB

SUB ScanData (a$, NumYears)

'    ********** Scan Input File to Determine the Number of Years *******

OPEN a$ FOR INPUT AS #1
CLS
PRINT "                    SCANNING INPUT FILE"

NumYears = 0
DO WHILE NOT EOF(1)
        LINE INPUT #1, z$
        IF LEFT$(z$, 1) = CHR$(12) THEN NumYears = NumYears + 1
LOOP

PRINT
PRINT NumYears; " Years Identified in the Input File"
CLOSE #1

END SUB
```

100-year Storm Intensity Calculations

The process of determining storm intensities is described on page 18 of the report. The following programs were used to make these calculations.

```
' ***** This program takes hourly precipitation amounts from a storm ****
' ***** and calculates how much precip falls in each 10% of the      ****
' ***** storm's duration.  It assumes a uniform intensity between    ****
' ***** hours.                                          ****
' ***** Written in QuickBasic 4.0 by Tomas A. Miller              ****
' ***** Laboratory of Climatology, Arizona State University        ****
' ***** The Parsing subroutines have been adapted from those in      ****
' ***** the QuickBasic Toolbox by Microsoft Press.              ****


DECLARE SUB ParseLine2 (x$, sep$, a$(), WordCount%)
DECLARE SUB ParseWord (a$, sep$, Word$)

DIM Precip(100), words$(1 TO 100), percents(7, 10)


a$ = "c:\tom\gila\intens.win"
b$ = "c:\tom\gila\percent.win"
sep$ = " " + CHR$(9)

OPEN a$ FOR INPUT AS #1
OPEN b$ FOR OUTPUT AS #2

CLS

aa% = 1
DO WHILE NOT EOF(1)
      LINE INPUT #1, z$
      ParseLine2 z$, sep$, words$(), WordCount%
      NumHours% = WordCount%
      FOR i% = 1 TO NumHours%
            Precip(i%) = VAL(words$(i%))
      NEXT

      FOR j = 10 TO 100 STEP 10
            k = j / 100
            total = 0
            FOR i% = 1 TO INT(NumHours% * k)
                  total = total + Precip(i%)
            NEXT

            IF k < 1 THEN
                  p = (NumHours% * k) - INT(NumHours% * k)
                  total = total + p * Precip(i%)
            END IF
            percents(aa%, INT(j / 10)) = total
      NEXT
      aa% = aa% + 1
      PRINT NumHours%
LOOP


FOR j% = 1 TO 10
      FOR i% = 1 TO aa% - 1
```

```
            PRINT #2, USING "###.### "; percents(i%, j%);
        NEXT
        PRINT #2, ""
NEXT

CLOSE
END

'***********************************************
'** Name:          ParseLine          **
'** Type:          Subprogram         **
'** Module:        PARSE.BAS          **
'** Language:      QuickBasic 4.0     **
'** Date:          Entered 8-17-1989  **
'** Source:        Microsoft Press    **
'** Purpose:  Breaks a string into an array  **
'**          of words, as defined by any     **
'**          characters listed in sep$.      **
'***********************************************
'
' EXAMPLE OF USE:     ParseLine2 x$, sep$, a$(), WordCount%
'
' PARAMETERS:         x$          String to be parsed.
'                  sep$        List of characters defined as word separators.
'                  a$()        Returned array of words.
'                  WordCount%    Count of words parsed from x$.
'
' VARIABLES:          t$     Temporary word string.
'                  i%     Index to array entries.
'
' MODULE LEVEL
'  DECLARATIONS:      DECLARE SUB ParseLine2 (x$, sep$, a$(), WordCount%)
'
'
SUB ParseLine2 (x$, sep$, a$(), WordCount%) STATIC

  t$ = x$
  WordCount% = 0
  DO
      ParseWord t$, sep$, a$(LBOUND(a$) + WordCount%)
      IF a$(LBOUND(a$) + WordCount%) = "" THEN
            EXIT DO
      END IF
      WordCount% = WordCount% + 1
  LOOP UNTIL t$ = ""
  t$ = ""
END SUB

'***********************************************
'** Name:          ParseWord          **
'** Type:          Subprogram         **
'** Module:        PARSE.BAS          **
'** Language:      QuickBasic 4.0     **
```

```
'** Date:          Entered 8-17-1989       **
'** Source:         Microsoft Press        **
'** Purpose:  Breaks off the first word in a$ **
'**           as delimited by any characters  **
'**           in sep$.                    **
'**********************************************
'
' EXAMPLE OF USE:      ParseWord a$, sep$, word$
'
' PARAMETERS:          x$      String to be parsed.
'                  sep$   List of characters defined as word separators.
'                  a$()   Returned array of words.
'
' VARIABLES:           lena%   Length of a$.
'                  i%     Loop index.
'                  j%     Loop index.
'                  k%     Loop index.
'
' MODULE LEVEL
'  DECLARATIONS:       DECLARE SUB ParseWord (x$, sep$, a$())
'
'
SUB ParseWord (a$, sep$, Word$) STATIC
  Word$ = ""
  lena% = LEN(a$)
  IF a$ = "" THEN
     EXIT SUB
  END IF

  FOR i% = 1 TO lena%
     IF INSTR(sep$, MID$(a$, i%, 1)) = 0 THEN
          EXIT FOR
     END IF
  NEXT

  FOR j% = i% TO lena%
     IF INSTR(sep$, MID$(a$, j%, 1)) THEN
          EXIT FOR
     END IF
  NEXT

  FOR k% = j% TO lena%
     IF INSTR(sep$, MID$(a$, k%, 1)) = 0 THEN
          EXIT FOR
     END IF
  NEXT

  IF i% > lena% THEN
     a$ = ""
     EXIT SUB
  END IF

  IF j% > lena% THEN
     Word$ = MID$(a$, i%)
```

```
        a$ = ""
        EXIT SUB
    END IF

    Word$ = MID$(a$, i%, j% - i%)

    IF k% > lena% THEN
        a$ = ""
    ELSE
        a$ = MID$(a$, k%)
    END IF
END SUB
```

```
' ***** This program takes a file containing data on how much rain fell ****
' ***** in each 10 percent of a storm's duration and expresses these    ****
' ***** data in terms of cumulative percentage of the storm's total.    ****
' ***** Written in QuickBasic 4.0 by Tomas A. Miller, Laboratory of     ****
' ***** Climatology, Arizona State University.                      ****


DIM precip1(10, 7), precip2(10, 7)
a$ = "c:\tom\gila\percent.sum"
b$ = "c:\tom\gila\percentc.sum"

NumStations% = 5

OPEN a$ FOR INPUT AS #1
OPEN b$ FOR OUTPUT AS #2

FOR i% = 1 TO 10
      FOR j% = 1 TO NumStations%
            INPUT #1, precip1(i%, j%)
      NEXT
NEXT


FOR j% = 1 TO NumStations%
      precip1(0, j%) = precip1(10, j%)
NEXT

FOR j% = 1 TO NumStations%
      FOR i% = 1 TO 10
            precip2(i%, j%) = precip1(i%, j%) / precip1(0, j%) * 100
      NEXT
NEXT



FOR i% = 1 TO 10
      FOR j% = 1 TO NumStations%
            PRINT #2, USING "###.####  "; precip2(i%, j%);
      NEXT
      PRINT #2, ""
NEXT
CLOSE
END
```

Storm Transpositions

Storm transpositions were carried out following the procedure outlined by the U.S. Army Corps of Engineers (1982). As described on page 20, isopercentual maps were constructed using the Surfer computer software. These isopercentual maps were contructed from 25 by 23 grids of interpolated values in exactly the same fashion as described previously in this Appendix. These isopercentual grids were shifted over the selected storm centers by the following program.

```
' ********* This program shifts a 23 by 25 Surfer Grid to any location desired***
' ********* All blank grids are coded as missing. *********
' ********* Written in QuickBasic 4.0 by Tomas A. Miller *******
' ********* Laboratory of Climatology, Arizona State University **********


DIM noaa2(1 TO 23, 1 TO 25), percent1(1 TO 23, 1 TO 25), percent2(1 TO 23, 1 TO 25), outgrid(1 TO
23, 1 TO 25)

CLS
INPUT "Enter the full noaa2 grid name "; a$
INPUT "Enter the full percentual grid name "; b$
PRINT
PRINT
INPUT "Shift by how many grid cells down "; Gdown%
INPUT "Shift by how many grid cells right "; Gright%
PRINT
PRINT
INPUT "Enter the full output grid name "; c$

OPEN a$ FOR INPUT AS 1
OPEN b$ FOR INPUT AS 2
OPEN c$ FOR OUTPUT AS 3


FOR i% = 1 TO 4
	LINE INPUT #1, z$
	LINE INPUT #2, z$
	PRINT #3, z$
NEXT

LINE INPUT #1, z$
LINE INPUT #2, z$


FOR i% = 1 TO 23
	FOR j% = 1 TO 25
		INPUT #1, noaa2(i%, j%)
		INPUT #2, percent1(i%, j%)
		percent2(i%, j%) = 1.701411E+38
	NEXT
	LINE INPUT #1, z$
	LINE INPUT #2, z$
NEXT


IF Gdown% >= 0 THEN
	Down1% = 1
	Down2% = 23 - Gdown%
ELSE
	Down1% = 1 - Gdown%
	Down2% = 23
END IF
```

```
IF Gright% >= 0 THEN
	Right1% = 1
	Right2% = 25 - Gright%
ELSE
	Right1% = 1 - Gright%
	Right2% = 25
END IF



FOR i% = Down1% TO Down2%
	FOR j% = Right1% TO Right2%
		percent2(i% + Gdown%, j% + Gright%) = percent1(i%, j%)
	NEXT
NEXT




Zlow = 100
Zhigh = 0

FOR i% = 1 TO 23
	FOR j% = 1 TO 25
		IF percent2(i%, j%) <> 1.701411E+38 THEN
			outgrid(i%, j%) = (percent2(i%, j%) / 100) * noaa2(i%, j%)
			IF outgrid(i%, j%) < Zlow THEN Zlow = outgrid(i%, j%)
			IF outgrid(i%, j%) > Zhigh THEN Zhigh = outgrid(i%, j%)
		ELSE
			outgrid(i%, j%) = 1.701411E+38
		END IF
	NEXT
NEXT

PRINT #3, Zlow; "  "; Zhigh

FOR i% = 1 TO 23
	FOR j% = 1 TO 25
		PRINT #3, outgrid(i%, j%); " ";
	NEXT
	PRINT #3, ""
NEXT

CLOSE
END
```