Regional Rainfall Frequency Analysis and Drought Reduction in the Tombigbee River Basin

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A regional frequency analysis was conducted for precipitation to bring more detailed information about the amount and distribution of rainfall over the Tombigbee River Basin to promote efficient water resources management in the study area. In addition, the results of the regional frequency analysis were combined with climatological drought reduction information to determine the probability that a cumulative precipitation depth needed to end a drought will be equaled or exceeded at least once in a specific season in the Tombigbee River Basin. A total of 28 precipitation gages in eastern and northeastern Mississippi and western Alabama were included in the study representing 1,352 station years of record. A regional analysis methodology was utilized, and the Tombigbee River Basin was considered a homogeneous region to increase the dataset and improve the reliability of precipitation-frequency estimates. The International Center for Integrated Water Resources (ICIWaRM) Regional Analysis of Frequency Tool (ICI-RAFT) was used to develop the regional frequency analysis. The software involves the application of the L-moments to characterize the variability, skewness and kurtosis of the data, determine heterogeneity in the region, and assist in the identification of appropriate regional probability distribution(s). Verification of results indicated that the selected frequency distributions provide reliable exceedance values for precipitation. Results also showed that spring would be the season with a more probable chance of recovery from a moderate or severe drought in the Tombigbee River Basin.

Introduction

Precipitation in the TRB generally is the result of convective showers from surface heating of moist air or the frontal lifting of moist air over polar continental air masses moving into the states from the north (Paulson et al, 1991).

Rainfall from 28 climate stations within the basin included in the NOAA's National Climatic Data Center (NCDC) (Figure 1) averages 1441 mm annually from 1981 to 2010. Rainfall is distributed geographically, ranging from a high of 1581 mm in the eastern station located in Halleyville, AL to a low of 1337 mm in the southern station located in Gainesville, AL.

The drought termination refers to the moisture needs associated with recharge, demand and runoff that have been brought back to normal or above normal (Karl et al., 1987). The criterion proposed by Palmer (1965) to determine the end of a drought is defined by a PHDI value of -0.5 while drought amelioration is achieved when a PHDI value of -2.0 is reached. Other factor to be considered is the probability that a region will actually receive the amount of precipitation needed to ameliorate or reduce a drought.
A region that does not normally experience excessively heavy precipitation during a specific season may be less probable to receive a sufficient rainfall amount for ending a drought than a region with record of occurrence of extreme precipitation events during the same season.

A RFA was conducted to bring more detailed information about the amount and distribution of precipitation over the TRB to promote efficient water resources management in the area. Results of the RFA were combined with climatological drought reduction information to determine the probability that a cumulative precipitation depth needed to end a drought will be equaled or exceeded at least once in a specific season of the year.

Methods

Regional Frequency Analysis Methodology

The methodology used for deriving rainfall frequency estimates for the Tombigbee River Basin is an Index Flood RFA approach as outlined by Hosking and Wallis (1997). To complete the analysis, the International Center for Integrated Water Resources, ICIWaRM's Regional Analysis of Frequency Tool (ICI-RAFT) was used. The purpose of ICI-RAFT is to estimate the frequency/intensity of a rainfall event of a particular duration using rainfall observations on the ground. ICI-RAFT has been formally reviewed and approved by the USA Corp of Engineers Hydrologic Engineering Center (USACE-HEC) and the Institute for Water Resources (USACE-IWR).

Data Screening. The first step in the procedure of analysis and the use of the software is to test for outliers, inconsistencies, and shifts. The ICI-RAFT software, based on the methodology proposed by Hosking and Wallis (1997), estimates a discordancy parameter based on the difference between L-moment ratios of a site and the average L-moment ratios of a group of similar sites (region). The discordancy parameters can be used to determine abnormalities in a dataset and aid in identifying homogeneous regions. A beginning month on each season (December, March, June and September) and duration in months (3 months) was entered to define the time frame for the analysis.

Regionalization. A homogeneous region is considered a geographic delineated area or the collection of sites with similar characteristics pertinent to the rainfall frequency. In this study, the stations were grouped in a unique homogeneous region. A heterogeneity measure (H) is determined by the model to compare between site variations in sample L-moments for a group of sites with what would be expected for a homogeneous region.

Choosing a Frequency Distribution. The ICI-RAFT software estimates the Pearson's R-values and z-scores for up to 14 standard frequency distributions for which the data is fitted. These parameters give an indication of the closeness of fit of each standard distribution to the sample data of the region being analyzed. A Pearson R-value close to 1 and a z-score close to 0 ($|z| \leq 1.64$) indicate a good fit.

Estimation of the Frequency Distribution. The regional distribution was fit to scaled or normalized site data, the resulting regional exceedence curve will be then multiplied by a mean value representative of the selected site. Two options are available: using the L-Mean (L1) computed from the selected sites rainfall data provided in the input file or using an Index Flood value for that site. The Index Flood method uses the Mean Precipitation for the specified period of analysis. This method of computing the at-site estimate of the X-year storm event should be an improvement over direct at-site estimates.

Precipitation Needed to End a Drought

The probability that a cumulative precipitation depth needed to end a drought will be equaled or exceeded at least once in a specific season at the TRB used results from the RFA previously developed and the climatological drought reduction information generated by NOAA-NCDC at its website (http://www.ncdc.noaa.gov/temp-and-precip/).

The map of the precipitation to end drought for each possible PHDI level at each season of the year (3-month duration) was requested. By using the Pearson Type 3 frequency distribution fitting, the recurrence interval and the exceedence probability of the minimum and maximum precipitation depth to end a drought reported at each requested map for each season was estimated.

Results

Rainfall Regional Frequency Analysis

Screening of data. The screening analysis filtered one station to be included into the regionalization analysis. The exclusion was caused by a limited availability of information into the entire time series of this station (12 complete years with data), which caused the L-skewness and the spread value (L2) to be observed as outlier values within all the stations dataset (Figure 3).

Identification of homogeneous regions. Homogeneity criteria were satisfied with the 27 possible accepted stations. TRB potentially could be treated as one homogeneous region (Table 1).

Table 1. Homogeneity measures for the regionalization schemes examined at 1, 3 and 6 months duration data

Regionalization scheme	Number of sites	H
Winter	27	-1.11
Spring	27	-1.01
Summer	27	0.72
Fall	27	-1.23
Annual	27	-0.35

Selection of frequency distribution(s). The goodness of fit measures Pearson "R" and "z" were used to aid to identify the distribution(s) yielding the robust estimations of quantiles for each season [Table 2 - Pearson Type III (PE3), Log-Pearson Type III (LPE), Log-Normal (LNO) and the General Extreme Value (GEV)]. $|z| \leq 1.64$ corresponds to the failure to reject the hypothesized distribution at a CI of 90% (Hosking and Wallis, 1997).

Exceedence Probability of Precipitation Needed to End a Drought

Summer and fall have similar magnitude of the minimum amount of precipitation needed to end any drought (level -2 to level -6), which is an expected condition as both seasons have relatively similar mean cumulative precipitation depths, 307-mm in winter and 296-mm in spring. Similar condition observed when spring and winter seasons are compared, (401-mm in winter and 398-mm in spring).

Conclusions

A regional index flood model was developed for the four 3-month seasonal duration. One regional scheme (TRB as one homogeneous region) was validated and used to the performance of the complete analysis.

The regional frequency method and the use of the ICI-RAFT software are convenient for delivering reliable and reproducible estimates of rainfall frequencies over areas with big extension such as the TRB.

A future investigation of rainfall frequency in the TRB would include precipitations with different duration (1h, 2h, 3h, 6h, 24 h) to estimate rainfall intensities. Combining the evaluated methodology and computational tools, producing rainfall Intensity-Frequency-Duration estimates would help in updating existing estimates, which are considered for use in the design of storm water management facilities and water supply.

Literature Cited

Hosking, J. R. M. and J. R. Wallis. 1997. Regional Frequency Analysis: An Approach Based on L-Moments. Cambridge University Press, Cambridge, UK.

Karl, T., F. Quinlan, nd D.S. Ezell. 1987. Drought termination and amelioration: Its climatological probability. J. of Climate and applied meteorology. (26) 9, 1198-1209.

Table 2. Summary of goodness of fit statistic considering the Tombigbee River Basin a homogeneous region

Duration	Distribution							
	PE3		LP3		LNO		GEV	
	Pearson R	z*	Pearson R	z	Pearson R	z	Pearson R	z
Winter	0.988	-0.49	0.9857	-	0.9881	-2.54	0.987	-1.37
Spring	0.9642	-8.59	0.9705	-	0.9726	-8.71	0.9752	-7.34
Summer	0.9885	2.07	0.989	-	0.9874	0.54	0.9877	2.50
Fall	0.9872	-1.35	0.9841	-	0.9885	-3.69	0.9887	-0.47
Annual	0.9869	-1.25	0.9871	-	0.9874	-1.33	0.9869	-1.50

Palmer, W.C. 1965. Meteorological drought. Research Paper No. 45 US Weather Bureau, Washington DC.

Paulson, R. W.; Chase, E. B.; Roberts, R. S.; Moody, D. W. 1991. National water summary 1988-89: hydrologic events and floods and droughts. Water Supply Paper 2375. 560 pp.

Table 3. Range of precipitation depth needed at each season to end a PHDI level drought in the Tombigbee River Basin

PHDI	Range of Precipitation (mm)											
	Spring			Summer			Fall			Winter		
	Min	Mean	Max	Min	Mean	Max	Min	Mean	Max	Min	Mean	Max
-2	460	556	655	382	420	460	382	420	460	460	787	1250
-3	460	602	746	460	616	775	460	722	990	460	935	1415
-4	460	648	840	460	672	885	460	787	1120	460	1015	1575
-5	610	770	930	610	804	1000	610	927	1245	460	1095	1735
-6	610	815	1020	610	860	1110	610	992	1375	610	1252	1895

Table 4. Recurrence interval of precipitation needed at each season to end a PHDI level drought in the Tombigbee River Basin

PHDI	Range of Recurrence Interval (yr)											
	Spring			Summer			Fall			Winter		
	Min	Mean	Max	Min	Mean	Max	Min	Mean	Max	Min	Mean	Max
-2	4	8	19	4.5	7	10	5	7	10	4	240	>1000
-3	4	12	45	10	82	1000	10	248	>1000	4	>1000	>1000
-4	4	18	110	10	186	>1000	10	526	>1000	4	>1000	>1000
-5	13	55	375	76	>1000	>1000	60	>1000	>1000	4	>1000	>1000
-6	13	88	865	76	>1000	>1000	60	>1000	>1000	17	>1000	>1000

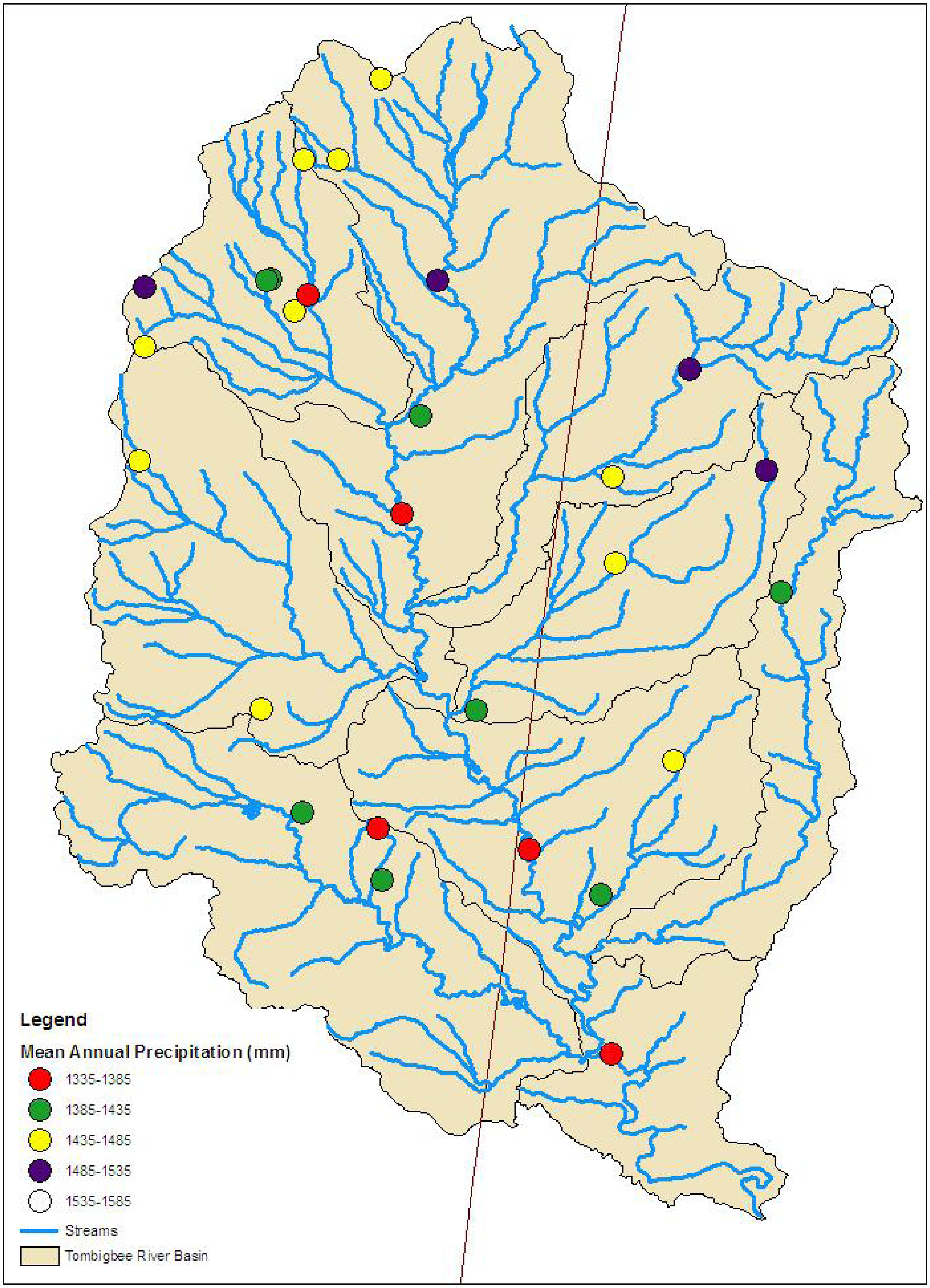


Figure. 1. Location of climatic stations within the TRB

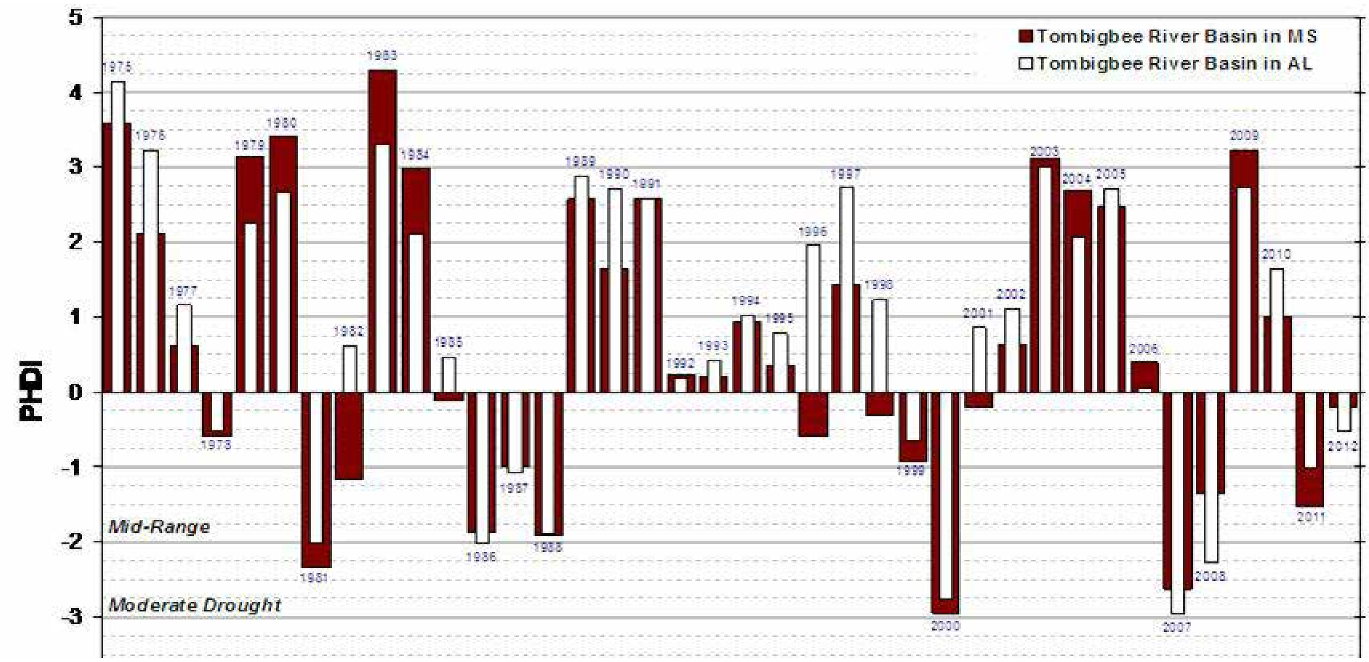


Figure. 2. 12-month (Jan-Dec) Palmer Hydrological Drought Index (PHDI) in the TRB from 1975 to 2012 (Source: NCDC-NOAA)

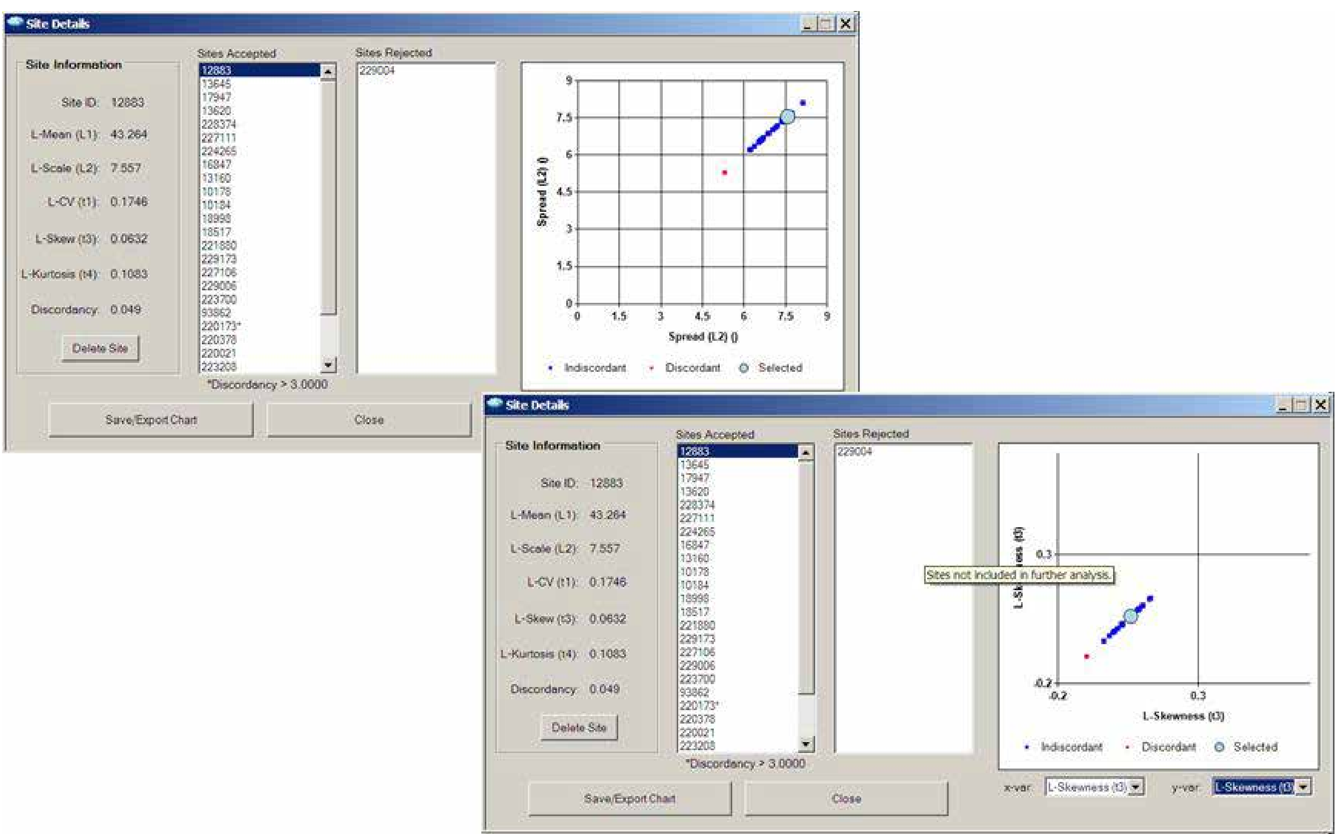
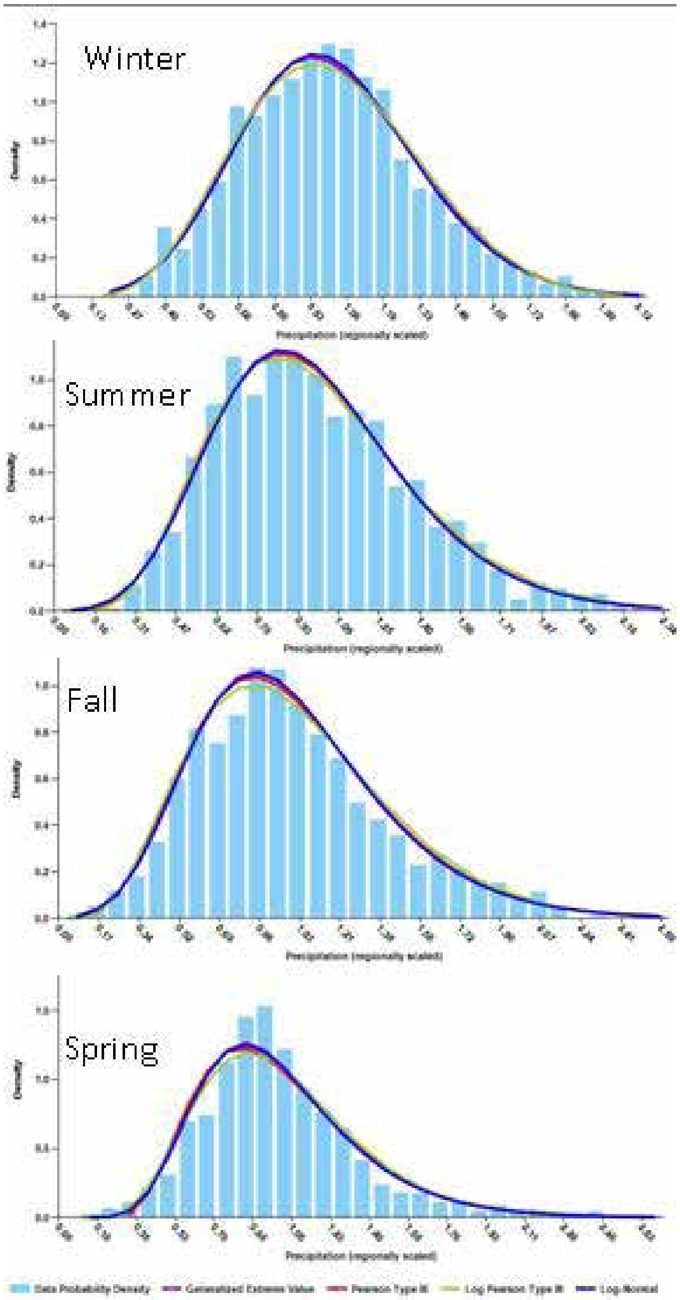


Figure. 3. Representation of L-Skewness and Spread outlier extreme values for a station within the TRB rejected for inclusion in the regional analysis



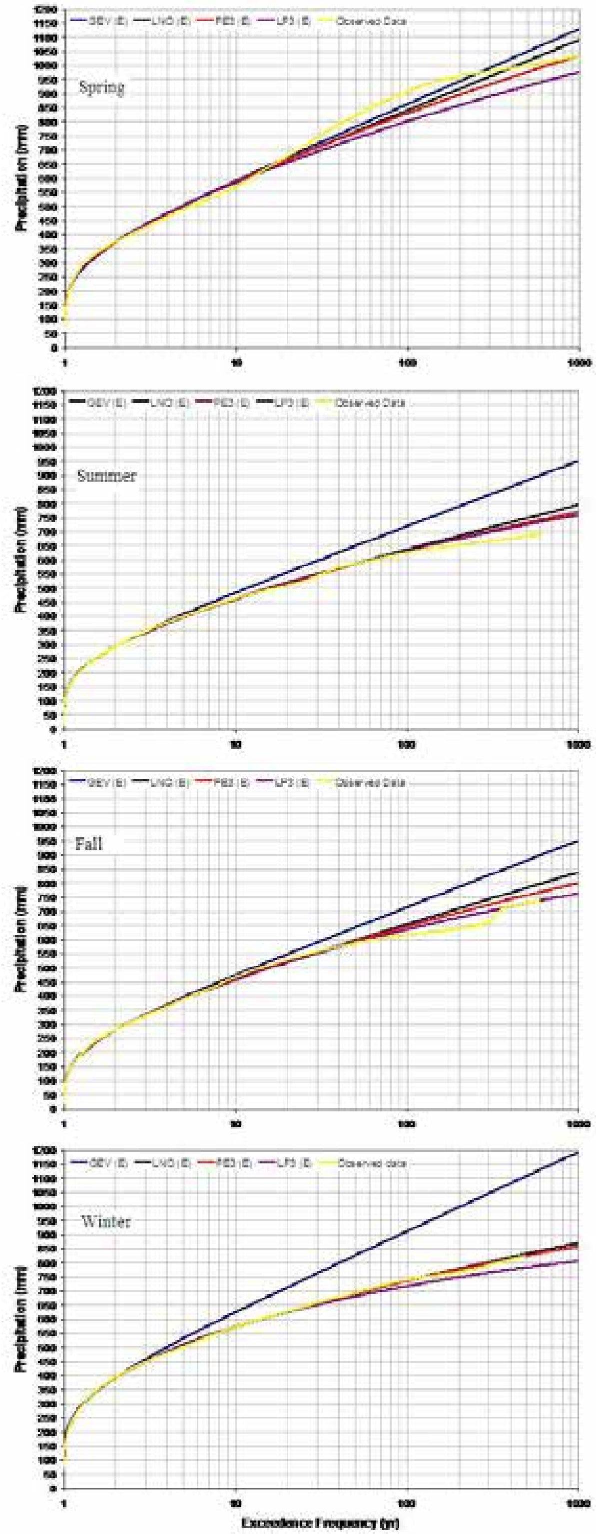


Fig. 4. Probability distribution for each season (3-months duration) rainfall dataset.

Fig. 5. Regional seasonal precipitation frequency for the TRB

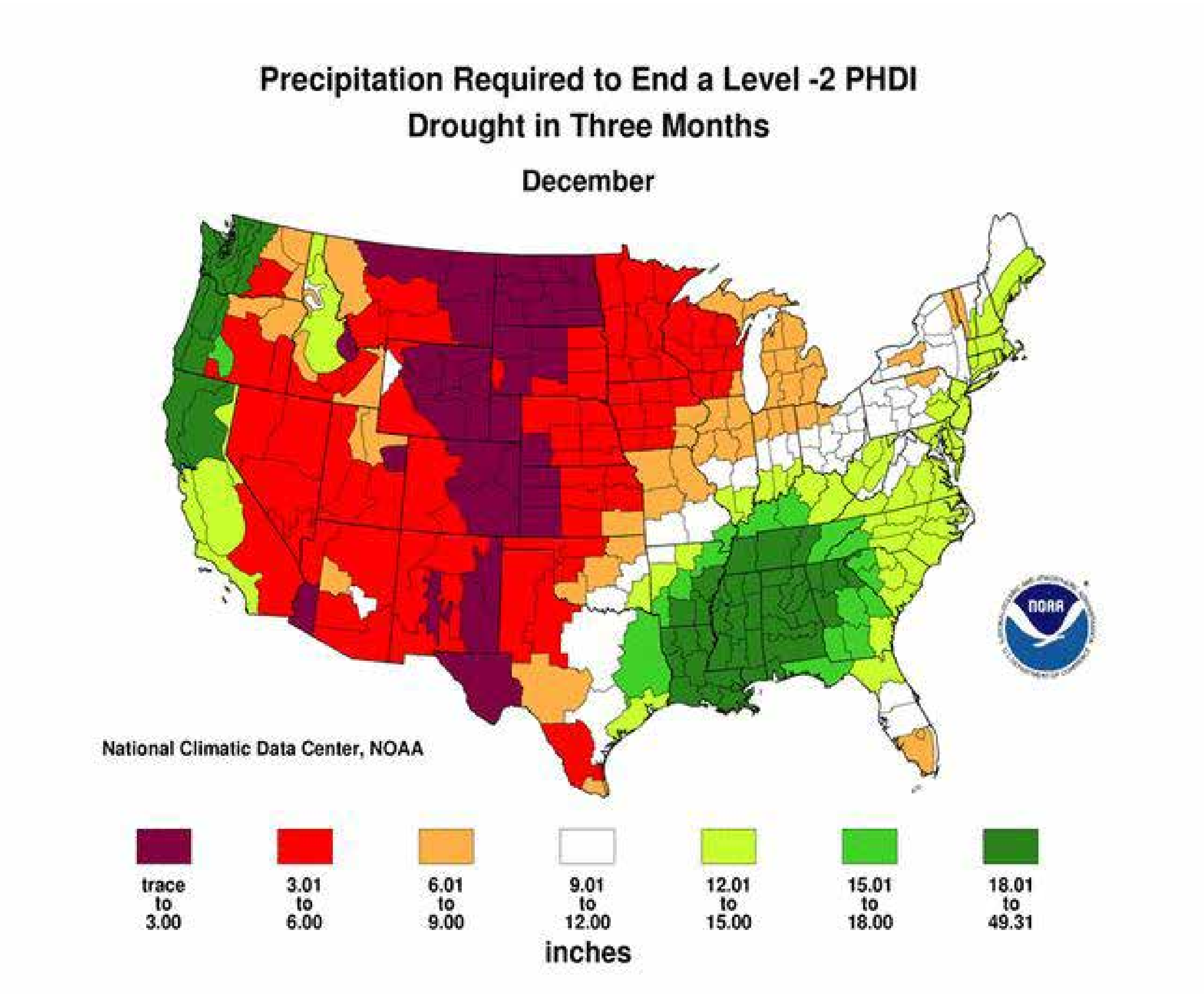


Fig. 6. Precipitation required to end a level -2 PHDI during the winter (Source: NOAA-NCDC)