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Articles

Regional flood frequencies analysis based on the TCEV distribution in Hydrological Region No. 10 (Sinaloa), Mexico

Análisis regional de frecuencias de crecientes con base en la distribución TCEV en la Región Hidrológica No. 10 (Sinaloa), México

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Abstract

Hydraulic works such as reservoirs, dikes, bridges, and urban drainage, are planned, designed, built, and reviewed (the existing) under a hydrological safety, based on the *Design Floods*. Such estimates of the

maximum annual flow associated with low probabilities of exceedance, are called *Predictions*, and are obtained through the so-called *frequency analysis of floods*. This technique consists of selecting a probability distribution function (PDF), which represents the sample of available flows, and based on such a model prediction are sought. When the record of floods is reduced, unreliable, or does not exist at the site of interest, *regional analysis* is used; an approach that extends the length of available records to reduce errors in estimates and allows estimating predictions in locations without data. In this study a *contrast* was made between local and regional predictions; the latter was obtained according to two different methods in the Hydrological Region No. 10 (Sinaloa), Mexico. In the first method, the records of maximum annual flows and their respective dates of occurrence were processed, to define the regions of influence each. For the second method, which is detailed, the same hydrometric information is used and the flood index method, using the TCEV (*two-component extreme value*) distribution as a regional PDF, is suggested for flow records that were generated by two physically different mechanisms and cannot be separated. The exposed regional method is much simpler and leads to fairly approximate predictions by deficit and more accurate by excess, according to the relative errors evaluated. Therefore, its systematic application is recommended in other hydrological regions of the country.

Keywords: TCEV distribution, seasonality index, flood index, detection of outlier's values, normalized regional range test, local and regional predictions, relative error, average annual flood.

Resumen

Las obras hidráulicas como embalses, diques, puentes y el drenaje urbano se planean, diseñan, construyen y revisan (las existentes) bajo una seguridad hidrológica, con base en las *Crecientes de Diseño*. Tales estimaciones del gasto máximo anual asociadas a bajas probabilidades de excedencia, se llaman *Predicciones* y se obtienen a través del llamado *análisis de frecuencia de crecientes*. Técnica que consiste en seleccionar una función de distribución de probabilidades (FDP), que represente a la muestra de gastos disponible y con base en tal modelo, realizar las predicciones buscadas. Cuando el registro de crecientes es reducido, poco confiable o no existe en el sitio de interés, se recurre al *análisis regional*; enfoque que amplía la longitud de los registros disponibles para reducir los errores en las estimaciones y además, permite estimar predicciones en localidades sin datos. En este estudio se realizó un *contraste*, entre las predicciones locales y las regionales; obtenidas estas últimas, según dos métodos diferentes en la Región Hidrológica No. 10 (Sinaloa), México. En el primero, se procesaron sus registros de gasto máximo anual y sus respectivas fechas de ocurrencia, para definir las regiones de influencia de cada uno y en la segunda, la cual se expone con detalle, se utiliza la misma información hidrométrica y se aplica el método del índice de crecientes, utilizando como FDP regional a la distribución TCEV (*two-component extreme value*), sugerida para registros de gastos que fueron generados por dos mecanismos físicamente diferentes y que no es posible

separarlos. El método regional expuesto es mucho más simple y conduce a predicciones bastante aproximadas por déficit y más exactas por exceso, según los errores relativos evaluados. Por lo anterior, se recomienda su aplicación sistemática, en otras regiones hidrológicas del país.

Palabras clave: distribución TCEV, índice de estacionalidad, índice de crecientes, detección de valores dispersos, prueba del rango regional normalizado, predicciones locales y regionales, error relativo, creciente media anual.

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Introduction

Flood frequency analysis

All the hydraulic works required by human society for the rational use of water resources and the protection against their exceedances and shortages are planned, designed, and built based on the so-called *Design Floods*. In addition, the hydraulic works that are already operating must be periodically reviewed from a hydrological point of view, since it is common for physical changes to occur within their basins and in meteorological conditions, due to the impacts of climate change (Mujumdar & Nagesh-Kumar, 2012).

Design floods are estimates of the maximum annual flows associated with low probabilities of exceedance, the reciprocal of which is the return period (Tr) or *average* recurrence interval in years. The most accurate estimates of such *Predictions* are obtained through the so-called *flood frequency analysis* (FFA), the objective of which is to interpret a sample of maximum annual flows in terms of probabilities of future occurrence (Bobée & Ashkar, 1991; Hosking & Wallis, 1997).

For the FFA results to be reliable, the following three requirements must be met: (1) that the maximum annual flows of the sample have been generated by a stationary random process, which implies that they are independent and free of deterministic components; (2) that the probabilistic model or probability distribution function (PDF) used to represent the data and make the estimates is adequate and (3) that the estimation method of the fit parameters of the PDF is accurate (Meylan, Favre, & Musy, 2012).

To meet the first requirement, the statistical quality of the sample is verified through general and specific tests, such as the Wald-Wolfowitz test, the tests of persistence, trend, and change in the mean or variability (WMO, 1971; Bobée & Ashkar, 1991; Rao & Hamed, 2000; Machiwal & Jha, 2012). Regarding the second requirement, there are two approaches: (a) using PDFs that have been established under precept and (b) using PDFs that have a theoretical basis (*parent distribution*) to be accepted as a source or origin model (Houghton, 1978). To address the third requirement, available methods for estimating fit parameters can be applied and results selected based on quantitative indicators of quality of fit, for example, standard error of fit (Kite, 1977; Meylan *et al.*, 2012).

Regional flood frequency analysis

To reduce the uncertainty that is generated when using small samples in the FFA, both in the estimation of the fit parameters of the PDF and in the predictions, the *regional* flood frequency analysis (RFFA) is used. This procedure or *regionalization* is a tool that allows for extend the length of the available historical records and therefore reduces the errors in the estimates. In addition, it makes possible the estimation of predictions in sites or localities within the region, which lack data on maximum annual

flow. In the RFFA, the standardized records of maximum annual flow from various sites are joined or concatenated to form broad series, as long as they show hydrological similarity or homogeneity (Cunnane, 1988; Hosking & Wallis, 1997; Rahman, Haddad, & Eslamian, 2014; Ouarda, 2017).

The TCEV distribution

The probabilistic model TCEV (*two-component extreme value*), suggested by Rossi, Fiorentino, and Versace (1984) allows a reasonable interpretation of the physical phenomena that generate floods and is also capable of reproducing the real characteristics observed in the records of maximum flows. annual, such as the one called by Potter (1958) "dog leg effect" and the one by Matalas, Slack, and Wallis (1975) "condition of separation".

The TCEV distribution considers that the floods of a record were generated by two physically different mechanisms, which cannot be separated. Being a PDF with four fit parameters, its application to individual records generates great uncertainty in the calculation of predictions (Fiorentino, Versace, & Rossi, 1985). For this reason, Francés-

García (1995) has indicated that the usual field of application of the TCEV model is within the RFFA.

Seasonality index

Since the mid-1990s (Zrinji & Burn, 1996; Burn, 1997; Cunderlik & Burn, 2002) it has been suggested that the average occurrence date and the seasonal regularity of the annual floods can be used as measures of similarity of the hydrological response of the basins. It is a fact that the similarity in the temporal distribution and the regularity of the floods of two basins, implies a similarity in physiographic and meteorological characteristics. So, these watersheds can be integrated into a region for RFFA purposes. This regionalization approach, based on the seasonal characteristics of the floods, has the advantage of reserving the use of hydrometric information (annual floods) to ratify such regional homogeneity.

Campos-Aranda (2014a) explains in detail how the date of occurrence of each annual flood is transformed into a directional statistic to obtain the mean day of the floods, whose dimensionless measure of its dispersion is the so-called *seasonality index* ($\bar{r}$), which takes values

between zero and one. A unit value indicates that all floods occur on the same date, while a value close to zero implies occurrences throughout the year.

Ramírez-Orozco, Gutiérrez-López and Ruiz-Silva (2009) establish the following five degrees of seasonality: (1) very strong, when $\bar{r} > 0.90$; (2) strong, when $\bar{r}$ fluctuates between 0.70 and 0.90; (3) mean, when $\bar{r}$ varies from 0.50 to 0.70; (4) low, when $\bar{r}$ changes from 0.10 to 0.50 and (5) very low or weak, when $\bar{r} < 0.10$.

Objective

The basic objective of this study was to contrast local and regional predictions; obtained the latter, according to two different techniques in Hydrological Region No. 10 (Sinaloa), Mexico. In the first, its records of maximum annual flow and their respective dates of occurrence were processed, through the regional approach of the region of influence (Campos-Aranda, 2014a). In the second, which is described in detail, the same hydrometric information is used and the classic RFFA method is applied, that is, the flood index method, using the TCEV distribution as the probabilistic population model.

Operational theory and processed data

Flood index method procedure

The techniques that integrate the *index flood method* are a convenient way to obtain a summary of statistical parameters from the grouping of several different samples or records (Hosking & Wallis, 1997). It was proposed by Dalrymple (1960) to process flood data, also called maximum flows or floods, and hence its name, but it can be applied to any type of data.

When there are flood records in ns sites and each locality k , the number of data is n_i of flows Q_i^k . Then, we have that $Q^k(F)$ with $0 < F < 1$, is the quantile function of the frequency distribution of each k site. The basic hypothesis of the flood index method establishes that the k sites form a *homogeneous region*, which implies that the frequency distributions of the ns sites are identical, except for the scaling factor, which is precisely the *flood index* (IC^k). The equation of the method is:

$$Q^k(F) = IC^k \cdot q(F) \text{ con } k = 1, 2, \dots, ns \quad (1)$$

where, $q(F)$ is the *regional growth curve*, that is, a dimensionless quantile function common to all sites. $q(F)$ is a regional frequency distribution or common function of the values Q_i^k/IC^k . In general, the IC^k is equal to the mean annual flow ($\bar{Q}^k$) of the data from each site, but the median or a truncated mean can be used (Hosking & Wallis, 1997).

In the flood index method, the following five hypotheses are accepted: (1) the floods at each site are distributed identically; (2) the floods of each site are independent; (3) floods from different sites are independent; (4) the frequency distributions at different sites are identical except for the scaling factor and (5) the mathematical form of the regional growth curve is correctly specified (Hosking & Wallis, 1997).

All the RFFA methods, including the flood index method, have two fundamental applications, within the homogeneous region; the first is carried out in sites with short or unreliable records, and the second in localities without hydrometric data, using the previously found equations, for the relationship between the $\bar{Q}^k$ and the basin area, or other physiographic characteristics of the basin and/or the main channel (Campos-Aranda, 2013).

TCEV distribution formulas

The theoretical basis for the TCEV distribution is established by Rossi *et al.* (1984), considering that the random variable X is the annual maximum of a non-negative random variable Z , where the number K of occurrences in the year is also a random variable, and both fulfill the following hypotheses: (1) Z is an identically distributed independent random variable, condition designated "iid"; (2) K is a variable iid that follows the Poisson process and (3) Z and K are independent of each other.

On the other hand, the dog leg effect of a flood record is observed by drawing on the Gumbel-Powell probability paper (Chow, 1964), their data and finding that a large group of flows define a trend and at a final point, another reduced group of higher magnitude floods begin to define another trend with a greater slope. The foregoing indicates the presence of two populations, one basic with the subscript 1 and the other with extraordinary floods with the subscript 2.

Considering that the floods of certain records have been generated by two different meteorological mechanisms, such as local convective storms and storms of cyclonic origin, Rossi *et al.* (1984) formulate a mixed probabilistic model, with which they establish the TCEV distribution, with four fit parameters, this is:

$$F_X(x) = \exp(-\lambda_1 \cdot e^{-x/\theta_1} - \lambda_2 \cdot e^{-x/\theta_2}) \quad (2)$$

making $\varepsilon_j = \theta_j \cdot \ln(\lambda_j)$ for $j = 1, 2$, we obtain that Equation (2) is equivalent to the product of two Gumbel distributions (Fiorentino *et al.*, 1985):

$$F_X(x) = \exp[-e^{-(x-\varepsilon_1)/\theta_1}] \cdot \exp[-e^{-(x-\varepsilon_2)/\theta_2}] \quad (3)$$

$$F_X(x) = F_{X_1}(x) \cdot F_{X_2}(x) \text{ para } x \geq 0 \quad (4)$$

λ_j is the average number of maximum independent flows and θ_j is the average magnitude of such maximum flows, with $j = 1$ for the basic floods and $j = 2$ for the extraordinary ones. When scattered floods do not exist, the TCEV distribution is reduced to the simple Gumbel model. The probability density function of X , according to Equation (2), is (Rossi *et al.*, 1984):

$$f_X(x) = F_X(x) \cdot \psi(x) \quad (5)$$

in which:

$$\psi(x) = (\lambda_1/\theta_1) \cdot \exp(-x/\theta_1) + (\lambda_2/\theta_2) \cdot \exp(-x/\theta_2) \quad (6)$$

Calculation of the fit parameters

Rossi *et al.* (1984) expose the natural logarithm of the *maximum likelihood function* and designate it by L_{fmv} , its expression is:

$$L_{fmv} = \sum_{i=1}^n \ln f_X(x_i) = \sum_{i=1}^n \ln F_X(x_i) + \sum_{i=1}^n \ln \psi(x_i) \quad (7)$$

By setting the partial derivatives of L_{fmv} to zero concerning the four fit parameters and performing various algebraic operations, Rossi *et al.* (1984) obtain the following four equations, which are solved using a numerical technique of successive substitution:

$$\lambda_j = \lambda_j \frac{\sum_{i=1}^n \frac{\exp(-x_i/\theta_j)}{\psi(x_i)}}{\sum_{i=1}^n \exp(-x_i/\theta_j)} \quad \text{for } j = 1, 2 \quad (8)$$

$$\theta_j = \frac{\sum_{i=1}^n \frac{x_i \cdot \exp(-x_i/\theta_j)}{\psi(x_i)}}{\sum_{i=1}^n x_i \cdot \exp\left(-\frac{x_i}{\theta_j}\right) + \sum_{i=1}^n \frac{\exp(-x_i/\theta_j)}{\psi(x_i)}} \quad \text{for } j = 1, 2 \quad (9)$$

To ensure rapid convergence, it is advisable to start with values of λ and θ as close as possible. To search for the initial values, first, the data from the flood register are drawn on Gumbel-Powell paper (Chow, 1964), assigning them a graphic position or probability of non-exceedance through the Weibull formula (Benson, 1962):

$$P(X < x) = \frac{m}{n+1} \quad (10)$$

where m is the order number of the data when they have been ordered from lowest to highest; n is the number of observations, floods, or data. Next, the basic series are identified and represented by a straight line or Gumbel distribution, defining a point $(F1, X1)$ at its beginning and another towards the end of the data that is designated $(F2, X2)$. Then another line or Gumbel model is drawn, with a greater slope to represent the dispersed or extraordinary floods, using as a starting point $(F2, X2)$ and defining an endpoint at $(F3, X3)$, towards the last of the data. These three pairs of values are taken to the following formulas that come from Equation (3) (Campos-Aranda, 2002), to define the initial values λ_j and θ_j :

$$\theta_1 = \frac{(X2-X1)}{\{-\ln[-\ln(F2)]\}} - \{-\ln[-\ln(F1)]\} \quad (11)$$

$$\varepsilon_1 = X1 - \theta_1 \{-\ln[-\ln(F1)]\} \quad (12)$$

$$\lambda_1 = \exp(\varepsilon_1/\theta_1) \quad (13)$$

$$\theta_2 = \frac{(X3-X2)}{\{-\ln[-\ln(F3)]\}} - \{-\ln[-\ln(F2)]\} \quad (14)$$

$$\varepsilon_2 = X2 - \theta_2 \{-\ln[-\ln(F2)]\} \quad (15)$$

$$\lambda_2 = \exp(\varepsilon_2/\theta_2) \quad (16)$$

Based on the initial values, equations (8) and (9) are applied for the first time and the logarithmic function of maximum likelihood (L_{fmv}) is evaluated, with Equation (7) and auxiliary numbers 5 and 6. Next, the new values of λ_j and θ_j become the initial ones, and equations (8) and (9) are applied again. The process is repeated until the value of L_{fmv} stabilizes, that is, it no longer decreases.

At the end of this process of successive substitutions, the optimal values of the fit parameters are obtained and with them, Equation (1) is repeatedly applied to obtain pairs of values of x and $F_x(x)$ to build the TCEV model on the Gumbel-Powell paper and obtain the desired predictions associated with return periods (Tr) or average recurrence intervals of 5, 10, 25, 50, 100 and 500 years. Since Tr is the reciprocal of

the exceedance probability, then the mentioned Trs correspond to non-exceedance probabilities $[F_x(x)]$ of 0.80, 0.90, 0.96, 0.98, 0.99, and 0.998, respectively.

Hierarchical regional analysis with the TCEV distribution

To compare data from different rivers or records, Rossi *et al.* (1984) and Fiorentino *et al.* (1985) introduce the dimensionless variable Y , which standardizes the annual floods, this is:

$$Y = \frac{(X - \varepsilon_1)}{\theta_1} = \frac{X}{\theta_1} - \ln(\lambda_1) \quad (17)$$

where θ_1 y ε_1 or λ_1 are the parameters of the basic component or a Gumbel distribution without the extraordinary floods. The PDF of Y is obtained with Equation (2), that is:

$$F_Y(y) = F_X(\theta_1 \cdot y + \varepsilon_1) = \exp(-\lambda_1^* \cdot e^{-y/\theta_1^*} - \lambda_2^* \cdot e^{-y/\theta_2^*}) \quad (18)$$

λ_1^* , θ_1^* , λ_2^* and θ_2^* are the so-called *regional* fit parameters, which allow us to assume that the TCEV distribution defined by Equation (18) represents all the records of a hydrologically homogeneous accepted region. Registers that logically can have different beginnings and amplitudes.

Hierarchical regional flood analysis was initially proposed by Fiorentino, Gabriele, Rossi, and Versace (1987), it is based on Equation (18) and assumes three stages: (1) identification of a homogeneous region where the coefficient of asymmetry (C_s) does not vary from one site to another or among the available records; (2) identification of homogeneous subregions where the coefficient of variation (C_v) can also be considered constant and (3) deduction of regression models to estimate the average annual flow, in localities without hydrometric data. This regional approach has been described and applied by Cannarozzo, D'Asaro, and Ferro (1995); Ferro and Porto (2006), and Boni, Parodi, and Rudari (2006), to process floods and extreme precipitations.

Maximum scattered data detection

Whether the TCEV distribution is applied to a single broad record (local fit) or is used at a regional level, the application of equations (11) to (16), to define the initial values of the fit parameters (λ_1 , θ_1 , λ_2 , θ_2), requires the definition of extraordinary floods or scattered values (*outliers*).

Kottegoda and Rosso (2008) indicate that a simple and practical way of detecting dispersed values (anomalous, discordant, or atypical), consists of ordering the maximum annual flows in a progressive way of magnitude and then reviewing their evolution to detect when a change occurs. the substantial increase between values and thereby establish the start of the scattered values.

On the other hand, if you accept that a river's flood record follows a TCEV probabilistic model, the extraordinary floods of a Gumbel distribution must be detected. Among the existing statistical tests to detect dispersed values, the one based on sample bias or asymmetry has proven to be powerful. This test, called *Test Skew* by Francés-García (1995), was also used by Rossi *et al.* (1984) and Fiorentino *et al.* (1985) and it begins by calculating the statistic G_j with the equation:

$$G_j = \sqrt{n-j+1} \frac{\sum_{i=1}^{n-j+1} (x_i - \bar{x}(n-j+1))^3}{\left\{ \sum_{i=1}^{n-j+1} [x_i - \bar{x}(n-j+1)]^2 \right\}^{3/2}} \quad (19)$$

where x_i is the data ordered from smallest to largest and $\bar{x}(k)$ is the arithmetic mean of the first k largest observations. According to Equation

(19), G_j is an estimator of the sample skewness that does not consider the largest $j-1$ values.

Matalas *et al.* (1975) obtained through Monte Carlo simulation the mean and standard deviation of the sampling bias of the Gumbel distribution, for samples that ranged from 10 to 90 data points. Based on these values, Francés-García (1995) obtains the critical values G_α in a one-tailed test, with a significance level (α) of 5 %, shown in Table 1.

Table 1. Critical values of the statistic G_j with a significance level (α) of 5 %.

Sample size (n)	G_α	Sample size (n)	G_α	Sample size (n)	G_α
10	1.690	40	1.879	70	1.859
20	1.833	50	1.877	80	1.845
30	1.877	60	1.869	90	1.831

Subregional homogeneity tests

Before fitting the TCEV distribution, to a set of flood data belonging to a certain region or subregion that is suspected to be homogeneous from a hydrological point of view, such homogeneity must be tested or verified. To numerically check the suitability of sub-dividing a hydrological region into two or more subgroups of basins, a very simple statistical test can be applied that measures the heterogeneity of a specific area or zone, called the *normalized regional range* of the coefficients of variation of the floods [$RRN(Cv)$], defined by Burn (1990) as:

$$RRN(Cv) = \frac{R(Cv)}{M(Cv)} \quad (20)$$

where $R(Cv)$ and $M(Cv)$ are the range and median of the Cv values of the analyzed subregion or area. Then when the $RRN(Cv)$ applied by subregions is less than that of the total region, the subdivision is convenient or appropriate.

Other statistical tests that allow verifying the hydrological homogeneity of a region and/or of each subregion, are for example: (1) the Wiltshire R Test (Wiltshire, 1986), which contrasts the form of the regional PDF with the local ones; (2) the Gupta, Mesa, and Dawdy (1994) Moment Test, which verifies the homogeneity through the slopes of the moments of order one to four of the local floods, according to the size of the basin and (3) the Test of moments of heavy probability by Kumar,

Guttarp and Foufoula-Georgiu (1994), similar to the previous one. These tests have been applied by Ferro and Porto (2006) in Sicily, Italy.

Records of floods to be processed

They correspond to the 21 processed by Campos-Aranda (2014b) from Hydrological Region No. 10 (Sinaloa), whose statistical characteristics and seasonality index are shown in Table 2, in decreasing order of basin size. Column 4 indicates the amplitudes of each record, covering a total of 777 data. Figure 1 shows the location of Hydrological Region No. 10 in the Mexican Republic.

Table 2. Statistical parameters of the maximum annual flow records of the 21 indicated hydrometric stations of Hydrological Region No. 10 (Sinaloa), Mexico.

1	2	3	4	5	7	8	9	10
No.	hydrometric stations	A (km ²)	n	Q _m (m ³ /s)	C _v	C _s	C _k	$\bar{r}$
1	Huites	26 057	51	3 328.333	0.995	2.210	7.7	0.3739

2	San Francisco	17 531	33	1 724.636	0.841	1.885	6.6	0.4133
3	Santa Cruz	8 919	52	1 037.615	1.120	3.231	16.3	0.5507
4	Jaina	8 179	56	1 020.786	1.114	3.358	17.2	0.5281
5	Palo Dulce	6 439	21	1 129.238	1.218	3.844	18.7	0.3405
6	Ixpalino	6 166	45	1 198.978	0.905	2.969	13.7	0.6214
7	La Huerta	6 149	28	945.107	0.593	0.186	2.1	0.4219
8	Chinipas	5098	24	883.083	0.666	1.403	5.6	0.4457
Average value:		-	-	-	-	-	-	0.4619
9	Tamazula	2 241	32	596.875	0.655	2.846	13.8	0.5928
10	Naranjo	2 064	45	633.311	1.053	1.816	6.4	0.7047
11	Acatitán	1 884	43	813.256	1.065	2.331	10.7	0.7497
12	Guamuchil	1 645	32	702.344	0.928	2.826	13.5	0.7299
13	Choix	1 403	38	348.974	0.880	2.903	13.3	0.6889
14	Badiraguato	1 018	26	1 224.346	1.555	3.420	15.9	0.5989
Average value:		-	-	-	-	-	-	0.6775
15	El Quelite	835	33	479.091	0.869	1.558	5.6	0.8035
16	Zopilote	666	56	351.857	0.806	0.774	2.8	0.8322
17	Chico Ruiz	391	19	205.737	0.717	0.339	2.3	0.8161
18	El Bledal	371	56	289.000	0.915	2.693	12.9	0.8458

19	Pericos	270	30	250.800	0.625	1.133	4.1	0.8158
20	La Tina	254	24	104.958	1.471	3.860	19.6	0.7207
21	Bamícori	223	33	189.182	0.933	1.415	4.3	0.8810
Average value:		-	-	-	-	-	-	0.8164

Symbology:

A : basin area.

n : number of data in the record.

Qm : average annual flow (before $\bar{Q}^k$).

Cv : coefficient of variation, dimensionless.

Cs : coefficient of skewness, dimensionless.

Ck : coefficient of kurtosis, dimensionless.

$\bar{r}$: seasonality index, dimensionless.



Figure 1. Location of Hydrological Region No. 10 (Sinaloa), in the Mexican Republic.

Results and discussion

Subregions to be processed

The study of the values shown in the last column of Table 2, led to subdividing the hydrological region No. 10 (Sinaloa), into three *subregions* for the application of the flood index method, such subregions are called: **(A)** of basins greater than five thousand km², whose seasonality index varies from 0.3405 in Palo Dulce to 0.6214 in Ixpalino, with 0.4619 as an average value; **(B)** of basins greater than one thousand km², with seasonality indices that fluctuate between 0.5928 and 0.7497, with 0.6775 as an average value and **(C)** basins of less than one thousand km², with seasonality indices that oscillate between 0.7207 and 0.8810, with a mean value of 0.8164.

Table 3 shows the 8, 6, and 7 hydrometric stations that make up each *subregion*, and the respective results of the *RRN(Cv)* test are shown in italics. It is observed that the subdivision is very convenient for subregion **A** of the large basins but does not imply a great difference in subregions **B** and **C** of smaller basins. However, in general, such a subdivision is convenient (Campos-Aranda, 2013).

Table 3. Application of the Normalized Regional Range test in the three adopted subregions of the Hydrological Region No. 10 (Sinaloa), Mexico, and in itself.

Subregion A		Subregion B		Subregion C	
Hydrometric stations	Cv	Hydrometric stations	Cv	Hydrometric stations:	Cv
Huites	0.995	Tamazula	0.655	El Quelite	0.869
San Francisco	0.841	Naranjo	1.053	Zopilote	0.806
Santa Cruz	1.120	Acatitán	1.065	Chico Ruiz	0.717
Jaina	1.114	Guamúchil	0.928	El Bledal	0.915
Palo Dulce	1.218	Choix	0.880	Pericos	0.625
Ixpalino	0.905	Badiraguato	1.555	La Tina	1.471
La Huerta	0.593	Minimum value	0.655	Bamícori	0.933
Chinipas	0.666	Maximum value	1.555	Minimum value	0.625
Minimum value	0.593	Median value	0.990	Maximum value	1.471
Maximum value	1.218	<i>NRR(Cv)</i>	<i>0.909</i>	Median value	0.869
Median value	0.950			<i>NRR(Cv)</i>	<i>0.974</i>
<i>NRR(Cv)</i>	<i>0.658</i>				

Hydrological Region No. 10 (Sinaloa)			
Minimum value	0.593	Median value	0.915
Maximum value	1.555	<i>NRR(Cv)</i>	<i>1.051</i>

Deleting anomalous records

Once the subregions have been defined to apply the flood index method, the statistical parameters are jointly reviewed to detect discordant or anomalous records. This is equivalent to the first stage of the hierarchical regional analysis. In subregion **A**, the La Huerta record has a C_s and a C_k that differ markedly from the rest and, therefore, it was eliminated. In subregion **B**, no records were eliminated, since the discordant ones: Naranjo and Badiraguato can be considered extreme. Finally, in subregion **C**, the La Tina record has values of C_s , C_k and $\bar{r}$, totally discordant with the rest and therefore, it was eliminated. Based on the above, the *joint* record for sub-region **A** will have 282 flood data (Q_i), that of sub-region **B** will include 216 values, and that of **C** will include 227 data.

Extraordinary flood detection

A routine inspection of the critical values in Table 1 highlights that for the common size (from 30 to 60 data) of the currently available flood records, a general critical value of G_a of 1.87 can be adopted, which coincides with the used by Fiorentino *et al.* (1985), for the rivers of northern Italy. If such a critical value is used, it is observed in Table 4, based on the shaded values, that in most of the records only one extraordinary flood is detected and a maximum of three in Huities and two in Jaina, Ixpalino, Choix, and Badiraguato.

Table 4. Values of the *Skew Test* for ratification of the number of extraordinary floods adopted in each hydrometric station of Hydrological Region No. 10 (Sinaloa), Mexico.

No.	Hydrometric stations	G_1	G_2	G_3	G_4	G_5	G_6	CE
Subregión A								
1	Huities	2.144	2.180	1.966	1.844	1.696	1.659	6
2	San Francisco	1.798	1.511	1.537	1.233	1.037	0.963	4
3	Santa Cruz	3.137	1.846	1.785	1.660	1.324	0.564	6
4	Jaina	3.268	2.176	1.458	1.403	1.332	1.295	8

5	Palo Dulce	3.564	1.435	0.544	0.622	0.617	0.514	2
6	Ixpalino	2.869	2.137	1.259	1.085	0.840	0.690	2
7	La Huerta	0.176	0.173	0.125	0.100	0.089	0.061	0
8	Chinipas	1.314	0.623	0.615	0.639	0.620	0.543	1
Subregión B								
9	Tamazula	2.711	0.912	0.498	0.427	0.371	0.207	2
10	Naranjo	1.755	1.358	1.408	1.412	1.456	1.443	3
11	Acatitán	2.249	1.026	0.928	0.776	0.777	0.767	3
12	Guamúchil	2.692	1.011	0.997	0.867	0.734	0.698	1
13	Choix	2.787	1.955	0.956	0.686	0.668	0.578	3
14	Badiraguato	3.219	2.268	1.624	1.811	1.766	0.773	2
Subregión C								
15	El Quelite	1.486	1.341	0.768	0.709	0.607	0.387	2
16	Zopilote	0.753	0.727	0.665	0.636	0.639	0.636	0
17	Chico Ruiz	0.312	0.290	0.330	0.255	0.308	0.388	0
18	El Bledal	2.620	1.546	1.191	1.099	0.953	0.772	2
19	Pericos	1.075	1.010	0.769	0.479	0.216	0.237	0
20	La Tina	3.614	0.494	0.469	0.435	0.427	0.290	1
21	Bamícori	1.350	1.400	1.214	1.256	1.356	1.488	2

Symbology:

G_k : asymmetric coefficient of the order k .

CE: number of extraordinary floods detected.

In theory, the value of G_a should decrease as j increases (Equation (19)) and when it does not, as in the case of the Naranjo, Zopilote, Chico Ruiz, and Bamícori records, it is due to the presence of low extreme values.

On the other hand, the last column of Table 4 indicates the number of extraordinary floods detected in each record, according to the scattered values, that is, those that are far from the general trend. From the analysis of the values in Table 4, it is concluded that the Skew Test is quite *restrictive* for the definition of the extraordinary floods and therefore, the values of the last column are adopted. Therefore, in subregion **A** there are 29 extraordinary floods, in **B** there are 14 and in **C** 7 are adopted. These values help in the adoption of points $F2$, $X2$ of equations (11) to (16).

TCEV distribution fit

Once the flood registers to be processed in each subregion are defined, their data (Q_i) are standardized based on the values in column 5 of Table 2, which are the average annual flows of each register (Q_m). About the

above, in the second row of Table 5, the number of processed stations and dimensionless data (Q_i/Q_m) processed are indicated and in the third row, their respective minimum and maximum values of such concatenated records are cited.

Table 5. The fit of the TCEV distribution according to the numerical substitution method, in the three indicated hydrological subregions of Hydrological Region No. 10 (Sinaloa), Mexico.

Subregion	A	B	C
No. (est.) data:	(7) 282	(6) 216	(6) 227
Minimum and maximum:	0.1008-6.8486	0.0086-7.5510	0.0284-5.4533
$F1-X1$	0.021-0.1214	0.060-0.1037	0.026-0.0995
$F2-X2$	0.890-1.9881	0.908-2.1543	0.961-2.6505
$F3-X3$	0.990-6.5000	0.990-5.6000	0.996-5.4533
$(\lambda_1)_{\text{initial}}$	4.851	3.337	4.353
$(\theta_1)_{\text{initial}}$	0.533	0.608	0.565
$(\lambda_2)_{\text{initial}}$	0.343	0.397	0.349
$(\theta_2)_{\text{initial}}$	1.841	1.523	1.221
$FO(\ln L)_{\text{initial}}$	-315.304	-246.828	-259.935
No. iterations:	46	50	106
$(\lambda_1)_{\text{final}}$	5.693	3.816	4.023

$(\theta_1)_{final}$	0.267	0.299	0.106
$(\lambda_2)_{final}$	0.451	0.551	2.238
$(\theta_2)_{final}$	1.386	1.277	0.678
$FO(\ln L)_{final}$	-238.226	-207.944	-217.299

To establish the start and endpoints of the basic and extraordinary floods, in each joint record their data were ordered in progressive order of magnitude and an empirical probability was calculated based on Equation (10). Then, based on the results of the previous section define the points F_2 , X_2 , and later towards the end of the record the points F_3 , X_3 . The point F_1 , X_1 is chosen at the beginning of the record. The values selected for such points are indicated in the fourth to sixth rows of Table 5. These values allowed the initiation and development of the numerical method of successive substitutions.

In the following five rows of Table 5, the results of equations (11) to (16) and of Equation (7) are shown. After the number of iterations indicated, the minimum value of the maximum likelihood logarithmic function stabilized and with this, we have the final or optimal values of the fit parameters.

Next, Equation (2) is applied for various values of the dimensionless quotients Q_i/Q_m of each concatenated record, to define the subregional TCEV distributions, which have been drawn on Gumbel-Powell paper in Figure 2, Figure 3, and Figure 4, with equal scale. The data for each

concatenated record have been drawn in intervals of ten values for the basic floods and randomly for the group of extraordinary floods.

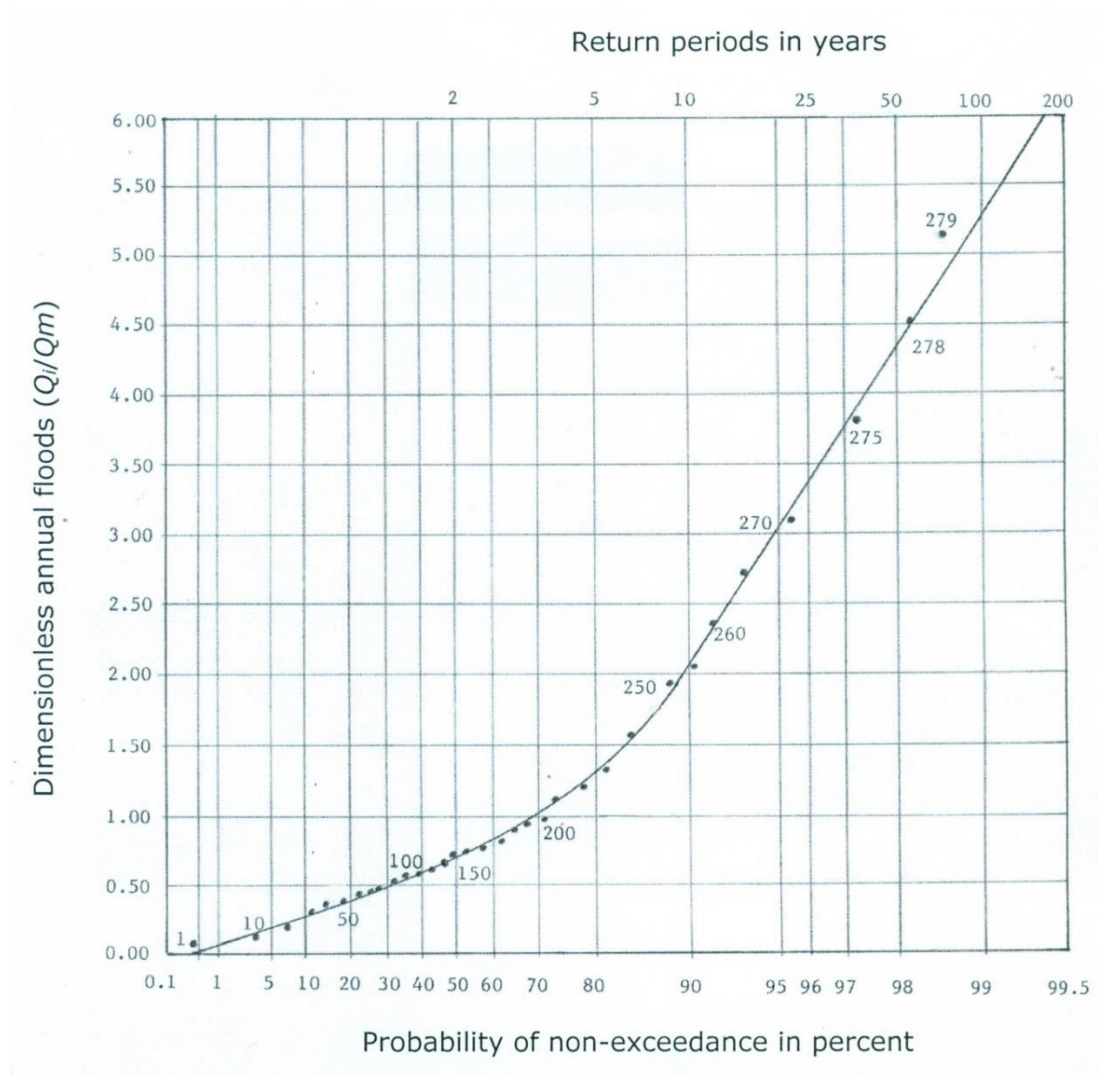


Figure 2. The fit of the TCEV distribution to the concatenated record of 282 dimensionless annual floods (Q_i/Q_m), integrated into subregion A of Hydrological Region No. 10 (Sinaloa), Mexico.

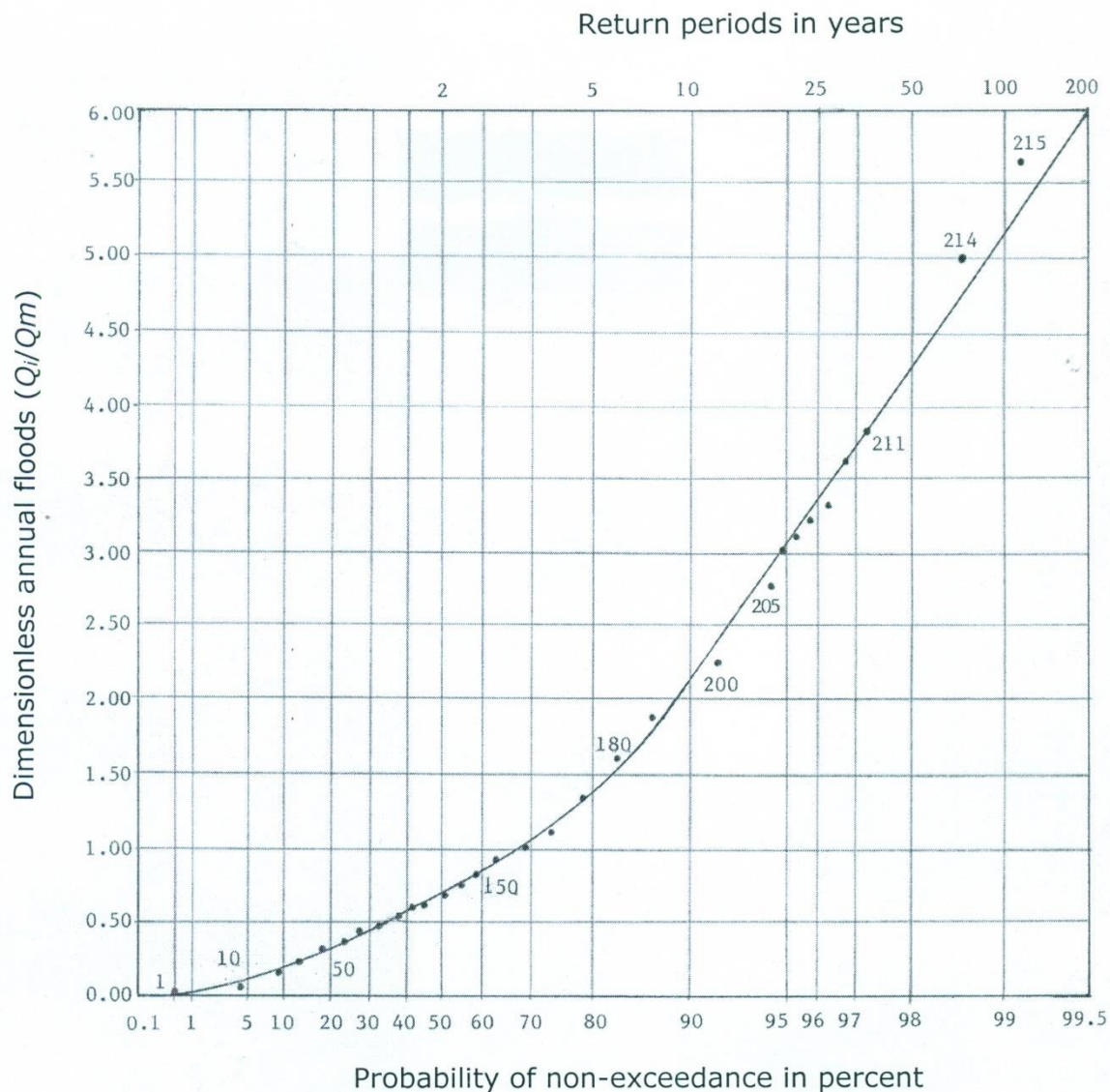


Figure 3. The fit of the TCEV distribution to the concatenated record of 216 dimensionless annual floods (Q_i/Q_m), integrated into subregion B of Hydrological Region No. 10 (Sinaloa), Mexico.

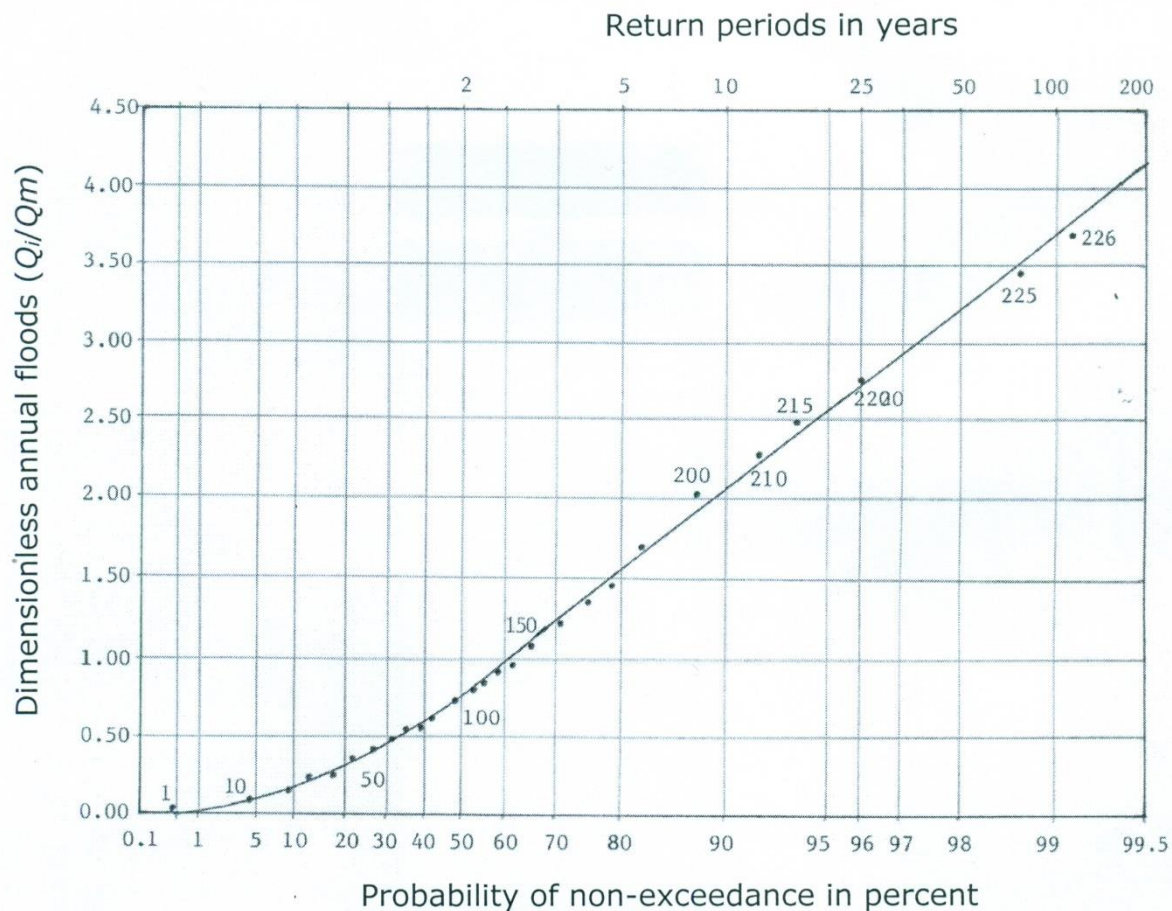


Figure 4. The fit of the TCEV distribution to the concatenated record of 227 dimensionless annual floods (Q_i/Q_m), integrated into subregion C of Hydrological Region No. 10 (Sinaloa), Mexico.

Equation (2) is also applied to define, by trial and error, the predictions (Q^{Tr}/Q_m) with non-exceedance probabilities of 0.80, 0.90,

0.96, 0.98, 0.99, and 0.998, corresponding to each subregion. Such predictions are cited in italics in Table 6 on the line for each subregion.

Table 6. Relative errors of the contrast between local predictions (m^3/s) and those of the regional flood index method, in Hydrological Region No. 10 (Sinaloa), Mexico.

hydrometric stations	PDF	Return periods, in years					
		5	10	25	50	100	500
<i>Subregión A</i>	<i>TCEV_{adim}</i>	<i>1.29</i>	<i>2.05</i>	<i>3.33</i>	<i>4.31</i>	<i>5.27</i>	<i>7.51</i>
Huities	LP3	4 368	6 679	11 009	15 613	21 776	45 130
	TCEV	4 294	6 823	11 083	14 345	17 540	24 996
	<i>ER</i>	-1.7	2.2	0.7	-8.1	-19.5	-44.6
San Francisco	LP3	2 316	3 390	5 286	7 195	9 635	18 186
	TCEV	2 225	3 536	5 743	7 433	9 089	12 952
	<i>ER</i>	-3.9	4.3	8.6	3.3	-5.7	-28.8
Santa Cruz	LP3	1 525	2 274	3 434	4 447	5 583	8 721
	TCEV	1 339	2 127	3 455	4 472	5 468	7 792
	<i>ER</i>	-12.2	-6.5	0.6	0.6	-2.1	-10.7
Jaina	GVE	1 347	2 029	3 309	4 692	6 589	14 199
	TCEV	1 317	2 093	3 399	4 400	5 380	7 666
	<i>ER</i>	-2.2	3.2	2.7	-6.2	-18.3	-46.0
Palo Dulce	LP3	1 674	2 543	3 906	5 107	6 460	10 215

	TCEV	1 457	2 315	3 760	4 867	5 951	8 481
	ER	-13.0	-9.0	-3.7	-4.7	-7.9	-17.0
Ixpalino	LP3	1 635	2 311	3 410	4 431	5 651	9 450
	TCEV	1 547	2 458	3 993	5 168	6 319	9 004
	ER	-5.4	6.4	17.1	16.6	11.8	-4.7
La Huerta	GVE	1 431	1 718	2 027	2 223	2 393	2 709
	TCEV	1 219	1 937	3 147	4 073	4 981	7 098
	ER	-14.8	12.7	55.3	83.2	108.1	162.0
Chinipas	GVE	1 231	1 626	2 209	2 714	3 283	4 919
	TCEV	1 139	1 810	2 941	3 806	4 654	6 632
	ER	-7.5	11.3	33.1	40.2	41.8	34.8
<i>Subregión B</i>	<i>TCEV_{adim}</i>	<i>1.39</i>	<i>2.15</i>	<i>3.32</i>	<i>4.22</i>	<i>5.11</i>	<i>7.17</i>
Tamazula	LP3	779	1 029	1 421	1 777	2 195	3 476
	TCEV	830	1 283	1 982	2 519	3 050	4 280
	ER	6.5	24.7	39.5	41.8	39.0	23.1
Naranjo	LP3	947	1 473	2 323	3 091	3 973	6 499
	TCEV	880	1 362	2 103	2 673	3 236	4 541
	ER	-7.1	-7.5	-9.5	-13.5	-18.6	-30.1
Acatitán	GVE	1 227	1 779	2 654	3 459	4 422	7 458
	TCEV	1 130	1 749	2 700	3 432	4 156	5 831
	ER	-7.9	-1.7	1.1	-0.8	-6.0	-21.8
Guamuchil	GVE	948	1 351	2 038	2 717	3 579	6 599
	TCEV	976	1 510	2 332	2 964	3 589	5 036

	<i>ER</i>	3.0	11.8	14.4	9.1	0.3	-23.7
Choix	LP3	470	668	999	1 317	1 706	2 976
	TCEV	485	750	1 159	1 473	1 783	2 502
	<i>ER</i>	3.2	12.3	16.0	11.8	4.5	-15.9
Badiraguato	LP3	1 405	2 556	5 330	9 061	15 191	48 733
	TCEV	1 702	2 632	4 065	5 167	6 256	8 779
	<i>ER</i>	21.1	3.0	-23.7	-43.0	-58.8	-82.0
<i>Subregión C</i>	<i>TCEV_{adim}</i>	<i>1.56</i>	<i>2.07</i>	<i>2.72</i>	<i>3.19</i>	<i>3.67</i>	<i>4.76</i>
El Quelite	LP3	722	1 043	1 519	1 919	2 355	3 506
	TCEV	747	992	1 303	1 528	1 758	2 280
	<i>ER</i>	3.5	-4.9	-14.2	-20.4	-25.4	-35.0
Zopilote	LP3	556	730	926	1 051	1 158	1 352
	TCEV	549	728	957	1 122	1 291	1 675
	<i>ER</i>	-1.3	-0.3	3.3	6.8	11.5	23.9
Chico Ruiz	LP3	341	43-1	515	558	589	629
	TCEV	321	426	560	656	755	979
	<i>ER</i>	-5.9	-1.2	8.7	17.6	28.2	55.6
El Bledal	GVE	401	565	834	1 090	1 404	2 446
	TCEV	451	598	786	922	1 061	1 376
	<i>ER</i>	12.5	5.8	-5.8	-15.3	-24.4	-43.7
Pericos	LP3	354	465	620	745	878	1 222
	TCEV	391	519	682	800	920	1 194
	<i>ER</i>	10.5	11.6	10.0	7.4	4.8	-2.3

La Tina	GVE	144	229	393	573	824	1 860
	TCEV	164	217	285	335	385	500
	ER	13.9	-5.2	-27.5	-41.5	-53.3	-73.1
Bamícori	GVE	275	416	649	866	1 125	1 913
	TCEV	295	392	515	603	694	901
	ER	7.3	-5.8	-20.6	-30.4	-38.3	-52.9
No. negative <i>R.E.</i>		12	7	7	10	12	15
Minimum negative <i>R.E.</i>		-14.8	-9.0	-27.5	-43.0	-58.8	-82.0
Sum of negative <i>R.E.</i>		-82.9	-42.1	-105.0	-183.9	-278.3	-532.3
No. positive <i>R.E.</i>		9	14	14	11	9	6
Maximum positive <i>R.E.</i>		21.1	24.7	55.3	83.2	108.1	162.0
Sum of positive <i>R.E.</i>		81.5	109.3	211.1	238.4	250.0	299.4
<i>R.E.</i> indicators in Table 4 from Campos-Aranda (2014b)							
No. negative <i>R.E.</i>		12	13	10	9	7	7
Minimum negative <i>R.E.</i>		-12.8	-12.2	-34.1	-49.4	-61.1	-78.9
Sum of negative <i>R.E.</i>		-71.2	-77.8	-128.0	-152.0	-171.7	-219.2
No. positive <i>R.E.</i>		9	8	11	12	14	14
Maximum positive <i>RE</i>		20.6	21.3	41.3	76.7	122.6	289.1
Sum of positive <i>RE</i>		63.7	70.8	176.4	283.7	423.6	915.5

Symbology:

FDP: probability distribution function.

$TCEV_{adim}$: subregional distribution TCEV, dimensionless.

TCEV: flood index method prediction, m^3/s .

LP3: prediction of the PDF Log-Pearson type III, m³/s.

GVE: prediction of the PDF General of Extreme Values, m³/s.

ER: relative percentage error.

The contrast between local and regional predictions

In Table 6, the local predictions are obtained from Table 2 of Campos-Aranda (2014b), they were obtained with one of the three PDFs that were adjusted, which led to the lowest standard error of fit (Kite, 1977). Such PDFs apply under precept and are the Log-Pearson type III (LP3), the General for Extreme Values (GVE), and the Generalized Logistics (LOG). In Table 6 the regional predictions are designated TCEV and are obtained by multiplying the dimensionless predictions ($TCEV_{adim}$) of each subregion, by the annual average flow (Qm) taken from Table 2. The relative errors (ER) of the predictions calculated with the method of the flood index are obtained with the expression:

$$ER = \frac{(Q^{Tr})_{estim} - (Q^{Tr})_{obser}}{(Q^{Tr})_{obser}} 100 \quad (21)$$

where, the relative error is expressed as a percentage and presents a negative value when the estimated regional flow $(Q^{Tr})_{estim}$ was lower than that calculated as a local prediction or observed $(Q^{Tr})_{obser}$; when it leads to a positive value, the estimated regional flow was higher than that observed.

In the last 13 lines of Table 6, the *ER* indicators are compared, calculated between the local and regional predictions of the TCEV distribution and those obtained by Campos-Aranda (2014b) with the regional method of stations-years and the GVE distribution; applied according to the region of influence approach, which is a much more complicated procedure. The following differences are detected; the first two are not preponderant:

- Regarding the number of the *ER*-negative, which are more important, since they imply an underestimation of predictions, it is observed that it is lower in the low *Tr* and greater in the high *Tr*. The above is a sign of inappropriate behavior.
- In four of the six *Trs* analyzed, the *ER* the extreme minimum was lower, but not the sum, which again is lower in the low *Tr*, but is greater in the high *Tr*.

Where if there are appreciable differences, it is in the *ER*-positive, mainly in the high *Trs*, since both their number, their extreme values, and, importantly, the sums are smaller with the flood index method.

Estimation of local predictions

This application of the flood index method developed is conducted in the five hydrometric stations that Campos-Aranda (2013) used to contrast their average annual flow (Q_m), since their records, in addition to being short, are not reliable. Such stations are: San Ignacio, Piaxtla, Urique II, Cazanate and Los Molinos.

Table 7 shows their basin sizes (A) in km^2 , their recording amplitude (n) in years, and the estimated value of Q_m in m^3/s with the empirical equations of the cited reference. Based on the size of the basins, the first three stations belong to subregion **A**, Cazanate to subregion **B**, and Los Molinos to subregion **C**.

Table 7. Relative errors of the contrast between local predictions (m^3/s) and those of the regional flood index method, in five unreliable records from Hydrological Region No. 10 (Sinaloa), Mexico.

hydrometric stations	PDF	Return periods, in years					
		5	10	25	50	100	500
Subregion A	$TCEV_{adim}$	1.29	2.05	3.33	4.31	5.27	7.51
San Ignacio	LP3	2 068	2 640	3 525	4 319	5 244	8 040

A=10920 km ² (n=19)	TCEV	1 975	3 138	5 098	6 598	8 067	11 496
Qm = 1530.8 m ³ /s	ER	-52.9	18.9	44.6	52.8	53.8	43.0
Piaxtla	LOG	1 518	2 327	4 076	6 250	9 625	26 565
A=5307 km ² (n=16)	TCEV	1 314	2 089	3 393	4 391	5 369	7 651
Qm = 1018.8 m ³ /s	ER	-13.4	-10.2	-16.8	-29.7	-44.2	-71.2
Urique II	LOG	398	475	583	672	769	1 035
A=4000 km ² (n=19)	TCEV	1 136	1 805	2 932	3 795	4 640	6 613
Qm = 880.5 m ³ /s	ER	185.4	280.0	402.9	464.7	503.4	538.9
Subregion B	TCEV _{adim}	1.39	2.15	3.32	4.22	5.11	7.17
Cazanate	LP3	848	1 298	1 956	2 492	3 052	4 418
A=1813 km ² (n=19)	TCEV	827	1 219	1 975	2 564	3 039	4 265
Qm = 594.8 m ³ /s	ER	-2.5	-6.1	1.0	2.9	-0.40	-3.5
Subregion C	TCEV _{adim}	1.56	2.07	2.72	3.19	3.67	4.76
Los Molinos	LOG	219	255	297	328	358	428
A=501 km ² (n=13)	TCEV	468	621	815	956	1 100	1 427

$Q_m = 299.8$ m^3/s	ER	113.7	143.5	174.4	191.5	207.3	233.4
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Symbology:

FDP: probability distribution function.

$TCEV_{adim}$: subregional distribution TCEV, dimensionless.

TCEV: prediction of the flood index method, m^3/s .

LP3: prediction of the PDF Log-Pearson type III, m^3/s .

LOG: prediction of the PDF Generalized Logistics, m^3/s .

ER : relative error, in percentage.

A : basin area, in km^2 .

n : amplitude of the record, in years.

Q_m : average annual flow, in m^3/s .

The records of the five hydrometric stations mentioned come from Escalante-Sandoval and Reyes-Chávez (2002) and in effect have evident sampling errors, for example: (1) the Piaxtla record has maximum flows of 6399 and 3527 m^3/s , which are higher than those of San Ignacio of 4020 and 3075 m^3/s . The above is assumed to be incorrect since the Piaxtla station has a basin area less than half that of San Ignacio. (2) at the Urique II station, with a basin size of 4000 km^2 , its maximum flow is 716 m^3/s and its Q_m is 302.6 m^3/s . Both data are considered quite low. (3) something similar occurs in Los Molinos, with a maximum of 273 m^3/s and a Q_m of 159.2 m^3/s .

Before the probabilistic analysis of the records from the five selected hydrometric stations, the Wald-Wolfowitz Test was applied (Bobée & Ashkar, 1991; Rao & Hamed, 2000; Meylan *et al.*, 2012), to verify that they are composed of independent and stationary data. The estimation of the local predictions was carried out by adjusting the Log-Pearson type III distributions (Bobée & Ashkar, 1991), General of Extreme Values, and Generalized Logistics (Hosking & Wallis, 1997). The selection of local predictions in each record was made subjectively, accepting the representative ones in the return periods of 100 and 500 years. Such predictions are indicated in Table 7, in the line where the name of each hydrometric station appears.

The regional predictions are obtained in the row of the TCEV distribution and come from multiplying Q_m by the dimensionless values of each subregion ($TCEV_{adim}$). Finally, in the last row of each hydrometric station, there are the relative errors ($R.E.$) evaluated according to Equation (21).

At the Cazanate station, the local and regional predictions coincide. At the Piaxtla Station, the regional predictions have ER by deficit, but possibly the local predictions are elevated, due to the presence of their maximum scattered values. The opposite occurs at Urique II, Los Molinos, and San Ignacio stations, whose ER by excess in the return period of 500 years amount to 538.9, 233.4, and 43.0 %, respectively. Considering that the records processed are short and unreliable, the regional predictions are considered more accurate.

Conclusions

The procedure of the regional flood index method, exposed and applied using the TCEV (*two-component extreme value*) distribution, as a regional probabilistic model, is much simpler than the region of influence approach and leads to fairly approximate predictions by deficit and more exact due to excess; according to the relative errors evaluated against the local predictions, which were contrasted at the end of Table 6.

In addition, the exposed procedure allows the contrast between regional and local predictions with low or unreliable records, to have more accurate *Design Floods*, as shown in Table 7.

The fit of the TCEV distribution with the numerical method of successive substitutions did not offer computational difficulties, neither at the beginning nor to converge. Therefore, its application with the exposed scheme, based on equations (11) to (16), is recommended.

Having exposed the three previous advantages, it is recommended the systematic application of the flood index method with the TCEV distribution as a population model, in other hydrological regions of the

country, to obtain dimensionless predictions (Q^T/Q_m) that allow estimating *Design Floods* in basins. without hydrometric data, making use of regional relations $Q_m = f(A)$.

Acknowledgment

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