THE UNIVERSITY OF TEXAS AT AUSTIN

# Analysis of Cenapred’s Rainfall-Runoff methodology for the estimation of streamflow values in the Central Region of Veracruz, Mexico

## GIS in Water Resources

**Final Term Project**
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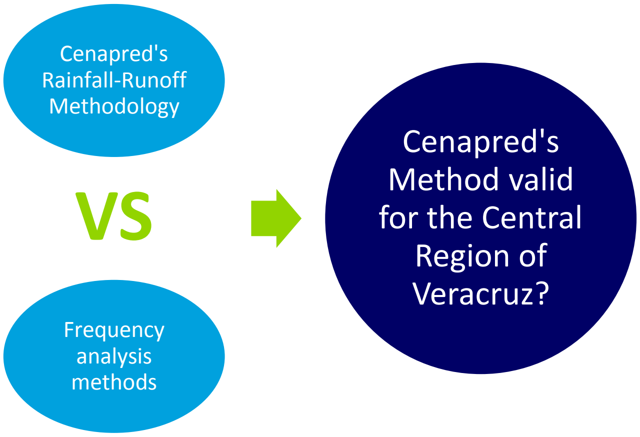
**Fall 2012**

# Contents

# 1. Project Scope

Mexico’s National Center for Disaster Prevention (Cenapred), suggests a Rainfall-Runoff Methodology in order to estimate the magnitude of a streamflow for any region in Mexico. The scope of this project is to evaluate Cenapred’s Methodology in the central region of the estate of Veracruz, Mexico (Actopan, La Antigua and Jamapa Basin). For this, we will base our study with commonly used frequency analysis methods, and data from Mexico’s National Water Commission (Conagua) and Mexico’s National Institute of Geography and Statistics (Inegi).

After comparing Cenapred’s Methodology with an estimated streamflow range from the frequency analysis methods, we will be able to see if Cenapred’s Method is valid to determine, for several return periods (2,5,10,25,50 and 100 years), the streamflow value at any location in the Central Region of Veracruz.



# 2. Background

## 2.1. Region

The state of Veracruz is located at the eastern of Mexico. The state is a crescent-shaped strip of land wedged between the Sierra Madre Oriental to the west and the Gulf of Mexico to the east. Its total area is 78,815 km2 (30,430.6 sq mi), accounting for about 3.7% of Mexico's total territory. It stretches about 650 km (403.9 mi) north to south, but its width varies from between 212 km (131.7 mi) to 36 km (22.4 mi), with an average of about 100 km (62.1 mi) in width. Veracruz shares common borders with the states of Tamaulipas (to the north), Oaxaca and Chiapas (to the south), Tabasco (to the southeast), and Puebla, Hidalgo, and San Luis Potosí (on the west). Veracruz has 690 km (428.7 mi) of coastline with the Gulf of Mexico.

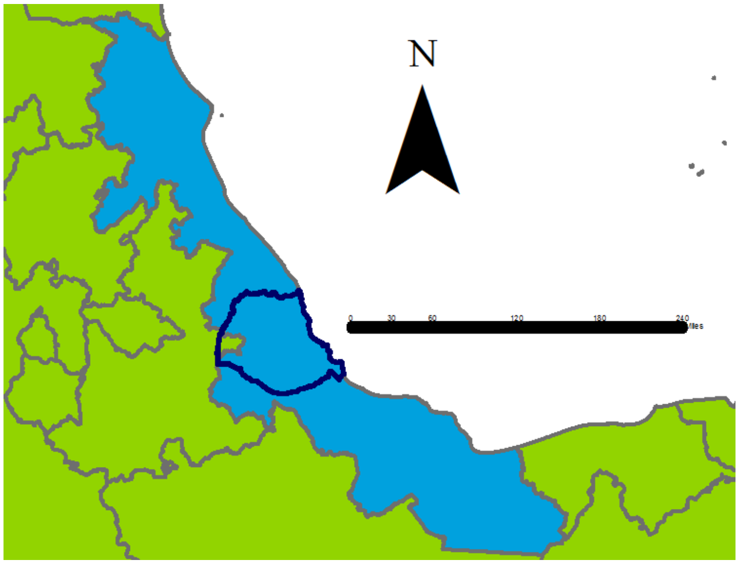
Approximately 35% of Mexico's water supply is found in Veracruz. More than 40 rivers and tributaries provide water for irrigation and hydroelectric power; they also carry rich silt down from the eroding highlands, which are deposited in the valleys and coastal areas. All of the rivers and streams that cross the state begin in the Sierra Madre Oriental or in the Central Meseta, following east to the Gulf of Mexico. The more important rivers in the state are the Actopan, Acuatempan, Blanco, Cazones, Coatzacoalcos, La Antigua, Hueyapan, Jamapa, Nautla, Panuco, Papaloapan, Tecolutla, Tonalá Tuxpan, Tonalá, Tuxpan, and the Xoloapa. Two of Mexico's most polluted rivers are the Coatzacaolacos and the Blanco. Much of the pollution comes from industrial sources, but the discharge of sewerage and uncontrolled garbage disposal are also major contributors. The state has very few waste water treatment plants, with only 10 of the waste water being treated before discharge.

## 2.2. Maps of Location

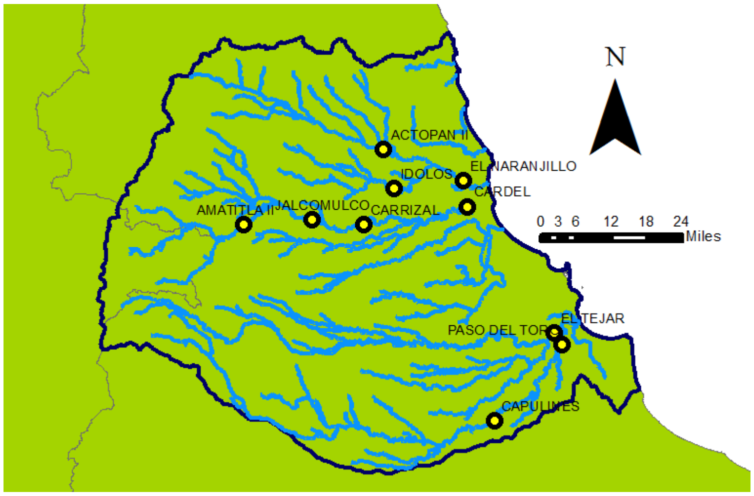
### Mexico respect with United States of America

## State of Veracruz respect with Mexico

## Central Region of Veracruz respect with Veracruz



## Central Region of Veracruz with the location of the 10 streamflow stations



# 3. Methodology

### 3.1 Streamflow Stations Methodology (Frequency Analysis)

To see if the Rainfall-Runoff Methodology proposed by Cenapred is effective, is important to obtain a range in which we can evaluate if the estimated streamflow from this method could be consider as valid. The approximation used to find this range was based on Conagua's data (mean annual data of the 10 streamflow stations from 1950-2006), and by using the Extreme Value Type 1 (EV1) distribution. The EV1 assist us to get the magnitude of the streamflow and the standard error (for return periods T= 2, 5, 10, 25, 50, and 100 years).

The EV1 distribution is given by:

$$F_x(x) = e^{-e^{-\hat{\alpha}(x-\hat{\beta})}}$$

Where $\hat{\alpha}$ (scale) and $\hat{\beta}$ (location) are the parameters of the distribution calculated by the Method of Moments (MOM):

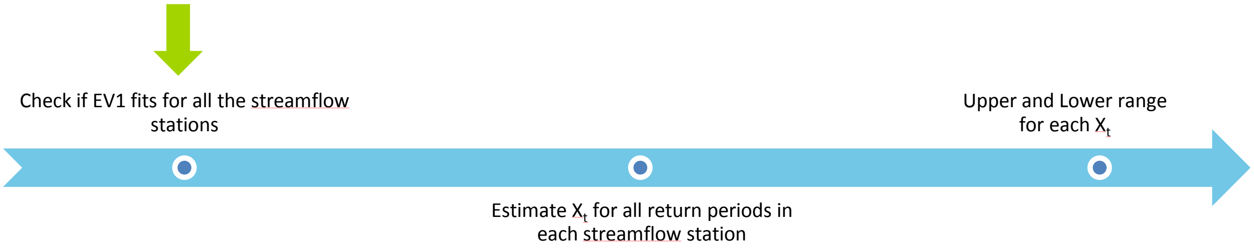
$$\hat{\alpha} = \frac{1.2825}{S_x}$$

$$\hat{\beta} = \bar{x} - 0.45S_x$$

Where $S_x$: Standard Deviation of the data
$\bar{x}$: Mean of the data

The procedure to estimate the magnitude of the streamflow, by using the data of each streamflow station with the EV1 distribution is as follows:

1. Check if the EV1 distribution fits.



In this project, we used the $X_c^2$ test and/or the Probability Plot Correlation Coefficients test (PPCC).

a) $X_c^2$ Goodness of fit test

Hypothesis 0: The distribution fits the data
Hypothesis 1: The distribution doesn't fit

Computational steps:

i. Divide the observations in classes (equal length or equal probability)

ii. Compute the observed and expected number of observation in each class

Test statistic: $x_c^2 = \sum_{i=1}^{k} \frac{(o_i - e_i)^2}{e_i}$

Where: $k$: number of classes
$o_i$: Observed in class i
$e_i$: Expected in class i

iii. Decision rule: Reject Hypothesis 0 if $x_c^2 > x_{1-\alpha,\nu}$

Where: $x_{1-\alpha,\nu}$: from chi square table Haan (2002)
$\alpha$: Significance level (in this case 5%)
$\nu = k - 1 - p$
$p$: Number of parameter obtained (For EV1 → 2 parameters; $\hat{\alpha}$ and $\hat{\beta}$)

b) The Probability Plot Correlation Coefficients (PPCC test) is a test that uses correlation between observed values and the corresponding fitted quantities ($x_i$ expected).

Hypothesis 0: The observations are drawn from the fitted distribution
Hypothesis 1: The observations are not drawn from the fitted distribution

Computational steps:

i. Rank the observations from largest to lowest value

ii. Get the probability of exceedance ($q_i$). As we fitted the EV1 distribution, we use the Gringorten expression:

$$q_i = \frac{i - 0.44}{N + 0.12}$$

Where $i$: Rank number $i = 1, 2, 3, \dots N$
$N$: Total number of observations

iii. Get $x_i$ expected ($W_i$) from the probability of non exceedance $(1 - q_i)$. For EV1 is given by:

$$W_i = G_x^{-1}(1 - q_i) = \hat{\beta} - \frac{1}{\hat{\alpha}} \ln(-ln(1 - q_i))$$

Where $\hat{\alpha}$ and $\hat{\beta}$: Parameters obtained by Method of Moments (MOM)

Compute the test statistic:

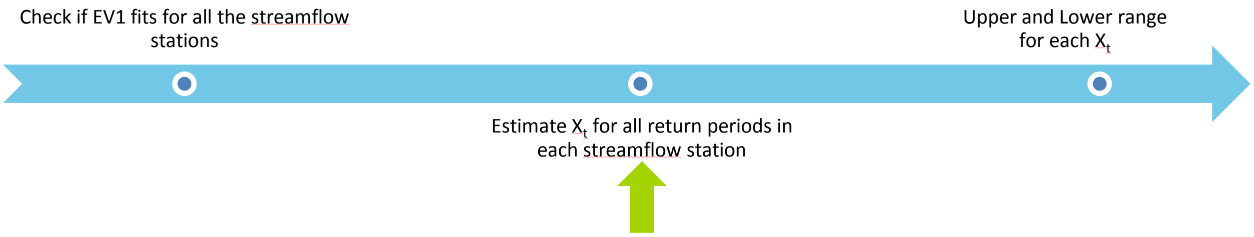
$$r = \frac{\sum(x_i - \bar{x})(W_i - \overline{W})}{\sqrt{\sum(x_i - \bar{x})^2 \sum(W_i - \overline{W})^2}}$$

Where $\overline{W}$: Mean of the series $W_i$
$\bar{x}$: Mean of he data

iv. Decision rule: Reject Hypothesis0 if $r < r_{\alpha,N}$

Where $r_{\alpha,N}$: From table 18.3.3 of Stedinger, Vogel, Foufoula-Georgiou (Chapter 18)
$\alpha$: Significance level (in this case 5%)
$N$: Total number of observations

2. In this particular case, since the distribution fitted in all cases, we get the magnitude of the streamflow ($X_T$) of a given frequency for several return periods by using the formula for the EV1 distribution.



$$X_T = \hat{\beta} - \frac{1}{\widehat{\alpha}} \ln\left(-\ln\left(1 - \frac{1}{T}\right)\right)$$

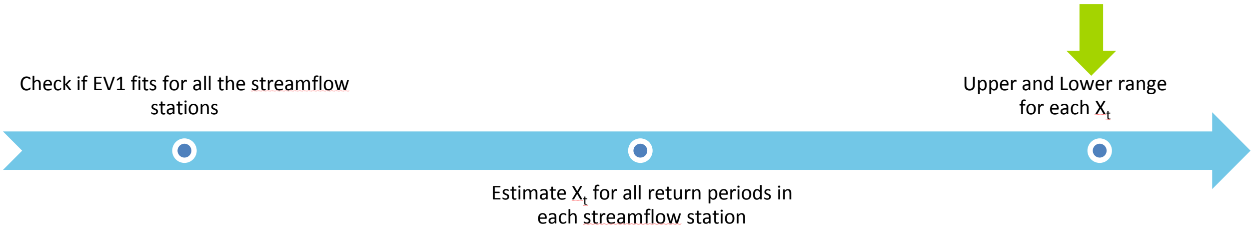
Where: $\widehat{\alpha}$ and $\widehat{\beta}$: Parameters obtained by Method of Moments (MOM)
$T$: Return Period (2, 5, 10, 25, 50, and 100 years)

Once having $X_T$ for each streamflow station, we calculated the Standard Error ($S_{(XT)}$) for EV1 (MOM)

$$S_{(XT)} = \frac{\delta}{\sqrt{N}} S_X$$

Where: $\delta$ : parameter obtained from Table 8.4 of Kite's (1977)
$N$ : Number or years of data
$S_X$: Standard Deviation of data

3. We obtained the upper ($X_T^{upper}$) and lower ($X_T^{lower}$) values for magnintude of the streamflow ($X_T$).



$$X_T^{upper} = X_T + S_{(XT)} Z_{1-\frac{\alpha}{2}}$$

$$X_T^{lower} = X_T - S_{(XT)} Z_{1-\frac{\alpha}{2}}$$

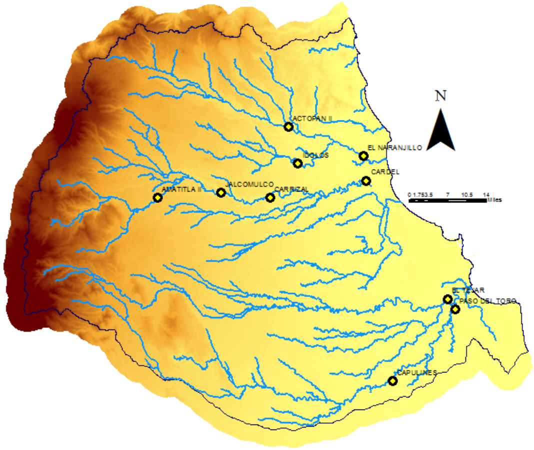
Where: $Z_{1-\frac{\alpha}{2}}$: Obtained from the normal table
$\alpha$: Significance level, in this case was used as 10%

## 3.2 GIS Streamflow Stations watersheds and slope

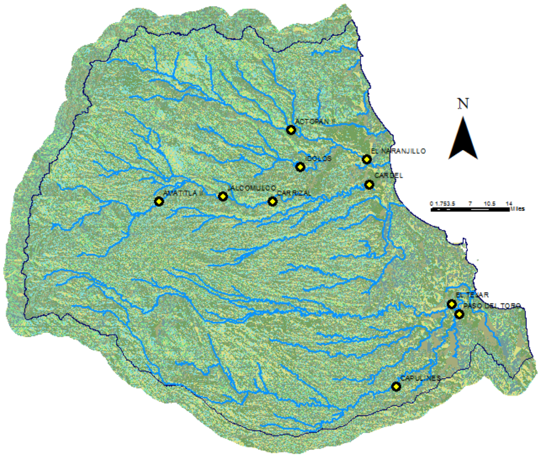
### 3.2.1 Watersheds

In order to follow Cenapred’s Methodology, we need to establish the corresponding watersheds that are related to each streamflow station. For this, we followed the steps listed below using certain GIS tools.

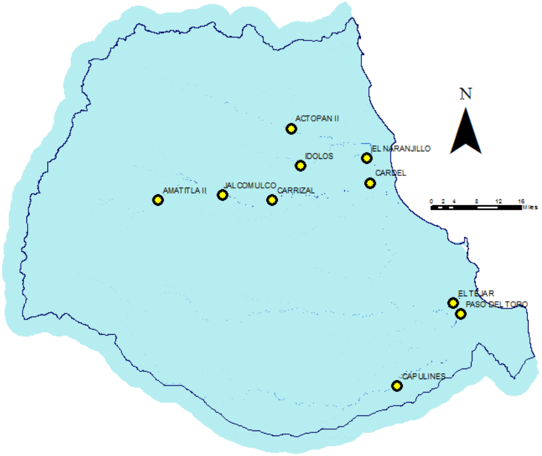
1. From the Digital Elevation Model (DEM), remove the pits (GIS Tool → Fill).



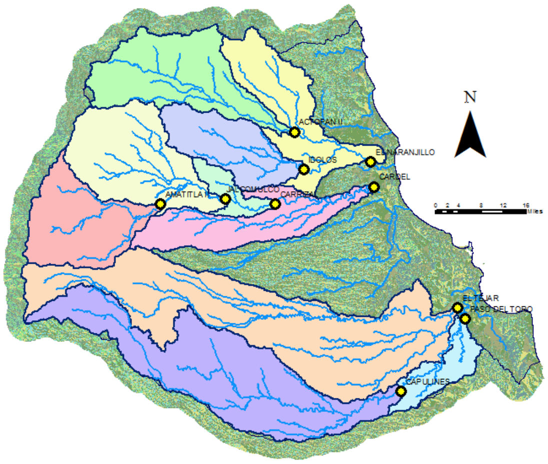
2. After removing the pits, we are able to get the flow direction of the basin (GIS Tool → Flow Direction).



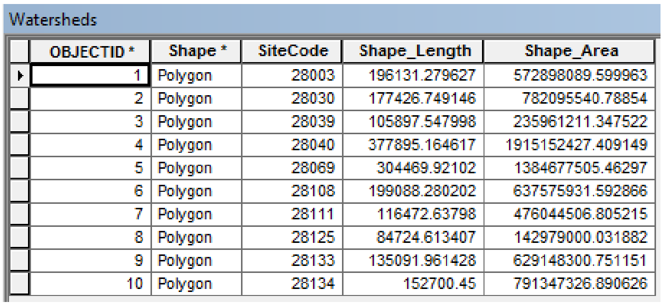
3. With the flow direction, we can estimate the flow accumulation (GIS Tool → Flow Accumulation). The result of this tool assists us to adjust the site locations to the exact location of the flow.



4. Having the exact locations of flow for every streamflow station, and the flow direction, we are able to find the watershed of each station (GIS Tool → Watershed)



5. After getting the raster of the watersheds, we convert it to polygons (GIS Tool → Raster to Polygon). The attribute table of the watersheds includes the area of the corresponding watershed for the streamflow station. From this table, we estimated the area of influence for each streamflow station.



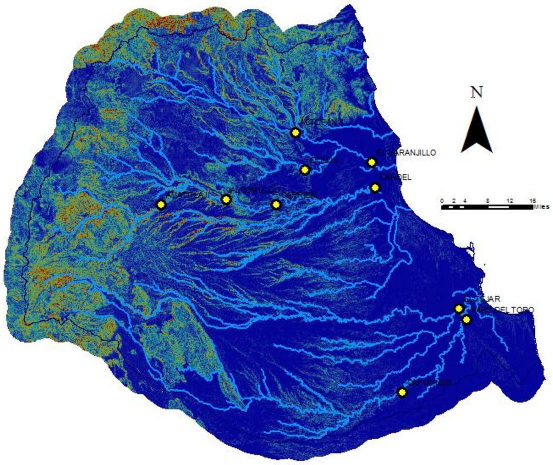
Watersheds

| OBJECTID * | Shape * | SiteCode | Shape_Length | Shape_Area |
|---|---|---|---|---|
| 1 | Polygon | 28003 | 196131.279627 | 572898089.599963 |
| 2 | Polygon | 28030 | 177426.749146 | 782095540.78854 |
| 3 | Polygon | 28039 | 105897.547998 | 235961211.347522 |
| 4 | Polygon | 28040 | 377895.164617 | 1915152427.409149 |
| 5 | Polygon | 28069 | 304469.92102 | 1384677505.46297 |
| 6 | Polygon | 28108 | 199088.280202 | 637575931.592866 |
| 7 | Polygon | 28111 | 116472.63798 | 476044506.805215 |
| 8 | Polygon | 28125 | 84724.613407 | 142979000.031882 |
| 9 | Polygon | 28133 | 135091.961428 | 629148300.751151 |
| 10 | Polygon | 28134 | 152700.45 | 791347326.890626 |

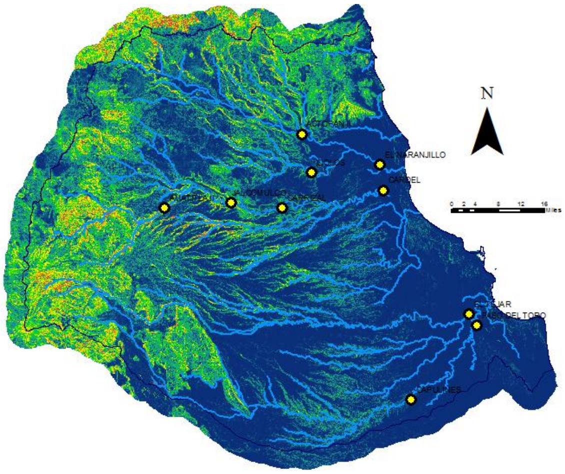
### 3.2.2 Slope

To obtain the slope in each watershed, we followed the next procedure.

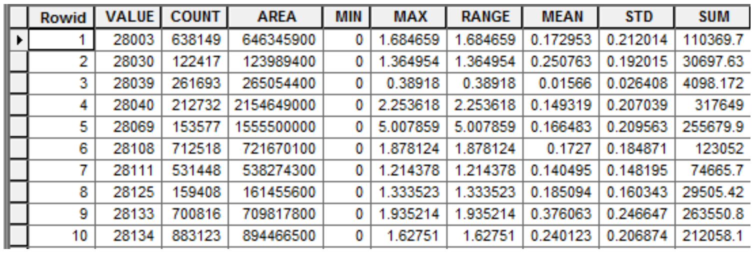
1. Estimate the slope from the Digital Elevation Model (GIS Tool → Slope)



2. As the values in the previous step are given in percentage (%), we divide them by 100 (GIS Tool → Raster Calculator).



3. For obtaining the slope in each watershed, we use the zonal statistic tool to obtain the slope value of the watersheds (GIS Tool → Zonal statistic). From the zonal statistic table, shown below, we estimate the weighted mean for the corresponding watershed taking into consideration the upstream values.



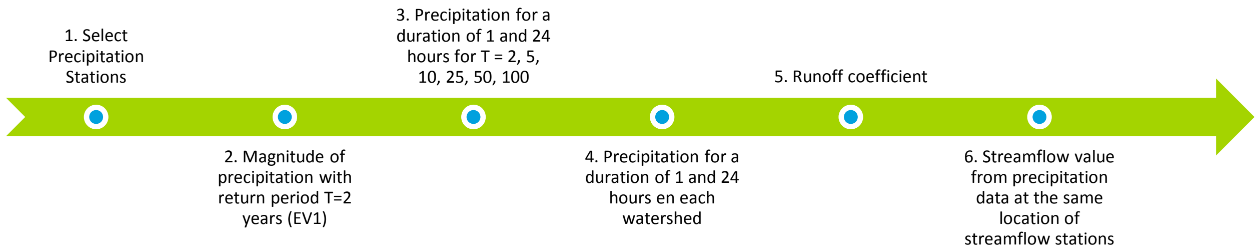
| | Rowid | VALUE | COUNT | AREA | MIN | MAX | RANGE | MEAN | STD | SUM |
|---|---|---|---|---|---|---|---|---|---|---|
| ▸ | 1 | 28003 | 638149 | 646345900 | 0 | 1.684659 | 1.684659 | 0.172953 | 0.212014 | 110369.7 |
| | 2 | 28030 | 122417 | 123989400 | 0 | 1.364954 | 1.364954 | 0.250763 | 0.192015 | 30697.63 |
| | 3 | 28039 | 261693 | 265054400 | 0 | 0.38918 | 0.38918 | 0.01566 | 0.026408 | 4098.172 |
| | 4 | 28040 | 212732 | 2154649000 | 0 | 2.253618 | 2.253618 | 0.149319 | 0.207039 | 317649 |
| | 5 | 28069 | 153577 | 1555500000 | 0 | 5.007859 | 5.007859 | 0.166483 | 0.209563 | 255679.9 |
| | 6 | 28108 | 712518 | 721670100 | 0 | 1.878124 | 1.878124 | 0.1727 | 0.184871 | 123052 |
| | 7 | 28111 | 531448 | 538274300 | 0 | 1.214378 | 1.214378 | 0.140495 | 0.148195 | 74665.7 |
| | 8 | 28125 | 159408 | 161455600 | 0 | 1.333523 | 1.333523 | 0.185094 | 0.160343 | 29505.42 |
| | 9 | 28133 | 700816 | 709817800 | 0 | 1.935214 | 1.935214 | 0.376063 | 0.246647 | 263550.8 |
| | 10 | 28134 | 883123 | 894466500 | 0 | 1.62751 | 1.62751 | 0.240123 | 0.206874 | 212058.1 |

### 3.2.3 Length of the upstream for each watershed

Having the watersheds for each streamflow stations, we can get the length of the main stream for each station (upstream length; in meters). This length ($L$) is needed for Cenapred's Rainfall-Runoff Methodology.

## 3.3 Cenapred's Rainfall-Runoff Methodology

This methodology helps us to estimate the streamflow in the same location of the streamflow stations. The steps for this methodology are as follows.



1. Select 15 precipitation stations in the basin we are analyzing.

2. With the average daily data and following the same procedure as for $X_T$ (described in 3.1), we estimate the magnitude of the precipitation with a return period of two years ($P_2$, in mm).

3. Obtain the precipitation value for duration of 1 ($hp_T^1$) and 24 ($hp_T^{24}$) hours for several return periods (T= 2, 5, 10, 25, 50, and 100 years).

$$h_T^d = (0.35ln(T) + 0.76)(0.54d^{0.25} - 0.5)P_{2y}^{60}$$

Where $d$: Duration in minutes (1hour=60 min; 24 hours=1,440 min)
$T$: Return period in years
$P_{2y}^{60}$: Is given by the expression (in mm)

$$P_{2y}^{60} = RP_2$$

Where $R$: Value between 0.1 (dry) and 0.8 (humid). In this region, the coefficient is 0.4.
$P_2$: The daily magnitude calculated for a return period of 2 years (step 2 of 3.3)

4. For this step, we made a tool for GIS (Precipitation Values Tool) that assists us by following the next procedure:

   Estimate $hp_T^1$ and $hp_T^{24}$ mean for each watershed of the streamflow stations (delineated in step 4 of 3.2.1) for all the return periods.

   a) Interpolate (GIS Tool → Empirical Bayesian Kriging) the precipitation values ($hp_T^1$ and$hp_T^{24}$) obtained in step 3 of 3.3.2.

   b) Compute the precipitation mean values ($hp_T^1$ and$hp_T^{24}$) for each watershed (GIS tool → zonal statistics).

5. To calculate the runoff coefficient ($C$), the procedure is as follows

   a) From the soil map of the region, obtained from Mexico's authorities (INEGI), and the book of Breña and Jacobo (2006), we get the value of the coefficient for each type of soil in the region. This coefficient has to be between 0 and 1 depending of the type and use of the soil.

   b) With a tool we adapted (Soil Values Tool); we estimate the mean runoff coefficient for each watershed (GIS tool → zonal statistics).

6. Finally, to be able to compute the streamflow from the precipitation data at each streamflow station, we made a GIS tool (Compute Flow Rates Tool) that follows the next procedure:

   a) From $hp_T^1$ and $hp_T^{24}$ mean values for each watershed, calculate the precipitation with duration equal to the time of concentration in the watersheds for all the return periods.

$$hp_{tc} = \frac{hp_T^1 - hp_T^{24}}{3.1781}(\ln(t_c)) + hp_T^1$$

Where: $t_c$: Time of concentration in each watershed, given by:

$$t_c = 0.000325\frac{L^{0.77}}{S^{0.385}}$$

Where: $L$: Upstream length for each station, obtained in 3.2.3 (meters)
$S$: Slope calculated in 3.2.2 (dimensionless)

   b) Compute the intensity ($i$) in each watershed for all the return periods. The intensity is the amount of precipitation water per unit of time.

$$i = \frac{hp_{tc}}{t_c}$$

   c) Estimate the Flow rates for all the return periods

$$Q_p = 0.278CiA$$

Where $A$: Area of influence (km$^2$) for each streamflow station (upstream)

# 4. Results

### 4.1 Streamflow Stations Range

### Actopan River Streamflow Stations

| Actopan II Streamflow Station (No. 28030) | | | | |
|---|---|---|---|---|
| Magnitude Freq. Analysis | | | $XT^{Lower}$ $m^3/s$ | $XT^{upper}$ $m^3/s$ |
| $XT_{2years}$ = | 16.687 | $m^3/s$ | 15.957 | 17.417 |
| $XT_{5years}$ = | 19.894 | $m^3/s$ | 18.604 | 21.184 |
| $XT_{10years}$ = | 22.018 | $m^3/s$ | 20.250 | 23.785 |
| $XT_{25years}$ = | 24.700 | $m^3/s$ | 22.285 | 27.116 |
| $XT_{50years}$ = | 26.691 | $m^3/s$ | 23.803 | 29.579 |
| $XT_{100years}$ = | 28.666 | $m^3/s$ | 25.294 | 32.039 |

| Idolos Streamflow Station (No. 28111) | | | | |
|---|---|---|---|---|
| Magnitude Freq. Analysis | | | $XT^{Lower}$ $m^3/s$ | $XT^{upper}$ $m^3/s$ |
| $XT_{2years}$ = | 4.269 | $m^3/s$ | 3.875 | 4.663 |
| $XT_{5years}$ = | 5.788 | $m^3/s$ | 5.085 | 6.491 |
| $XT_{10years}$ = | 6.794 | $m^3/s$ | 5.828 | 7.760 |
| $XT_{25years}$ = | 8.065 | $m^3/s$ | 6.598 | 9.532 |
| $XT_{50years}$ = | 9.008 | $m^3/s$ | 7.426 | 10.590 |
| $XT_{100years}$ = | 9.944 | $m^3/s$ | 8.095 | 11.792 |

| El Naranjillo Streamflow Station (No. 28108 | | | | |
|---|---|---|---|---|
| Magnitude Freq. Analysis | | | $XT^{Lower}$ $m^3/s$ | $XT^{upper}$ $m^3/s$ |
| $XT_{2years}$ = | 14.052 | $m^3/s$ | 12.775 | 15.330 |
| $XT_{5years}$ = | 19.091 | $m^3/s$ | 16.816 | 21.366 |
| $XT_{10years}$ = | 22.427 | $m^3/s$ | 19.301 | 25.552 |
| $XT_{25years}$ = | 26.642 | $m^3/s$ | 22.463 | 30.820 |
| $XT_{50years}$ = | 29.768 | $m^3/s$ | 24.652 | 34.885 |
| $XT_{100years}$ = | 32.872 | $m^3/s$ | 26.896 | 38.849 |

### La Antigua River Streamflow Stations

| Amatitla II Streamflow Station (No. 28133) | | | | |
|---|---|---|---|---|
| Magnitude Freq. Analysis | | | $XT^{Lower}$ $m^3/s$ | $XT^{upper}$ $m^3/s$ |
| $XT_{2years}$ = | 24.137 | $m^3/s$ | 22.875 | 25.400 |
| $XT_{5years}$ = | 28.893 | $m^3/s$ | 26.636 | 31.150 |
| $XT_{10years}$ = | 32.042 | $m^3/s$ | 28.938 | 35.145 |
| $XT_{25years}$ = | 36.020 | $m^3/s$ | 31.771 | 40.269 |
| $XT_{50years}$ = | 38.972 | $m^3/s$ | 33.886 | 44.057 |
| $XT_{100years}$ = | 41.901 | $m^3/s$ | 35.960 | 47.843 |

| Jalcomulco Streamflow Station (No. 28134) | | | | |
|---|---|---|---|---|
| Magnitude Freq. Analysis | | | $XT^{Lower}$ $m^3/s$ | $XT^{upper}$ $m^3/s$ |
| $XT_{2years}$ = | 48.132 | $m^3/s$ | 46.022 | 50.242 |
| $XT_{5years}$ = | 56.178 | $m^3/s$ | 52.409 | 59.948 |
| $XT_{10years}$ = | 61.506 | $m^3/s$ | 56.323 | 66.688 |
| $XT_{25years}$ = | 68.237 | $m^3/s$ | 60.830 | 75.644 |
| $XT_{50years}$ = | 73.230 | $m^3/s$ | 64.741 | 81.720 |
| $XT_{100years}$ = | 78.187 | $m^3/s$ | 68.269 | 88.106 |

| Carrizal Streamflow Station (No. 28125) | | | | |
|---|---|---|---|---|
| Magnitude Freq. Analysis | | | $XT^{Lower}$ $m^3/s$ | $XT^{upper}$ $m^3/s$ |
| $XT_{2years}$ = | 44.480 | $m^3/s$ | 41.786 | 47.174 |
| $XT_{5years}$ = | 54.508 | $m^3/s$ | 49.686 | 59.329 |
| $XT_{10years}$ = | 61.147 | $m^3/s$ | 54.514 | 67.779 |
| $XT_{25years}$ = | 69.535 | $m^3/s$ | 60.662 | 78.409 |
| $XT_{50years}$ = | 75.759 | $m^3/s$ | 64.889 | 86.629 |
| $XT_{100years}$ = | 81.936 | $m^3/s$ | 69.235 | 94.636 |

| Cardel Streamflow Station (No. 28003) | | | | |
|---|---|---|---|---|
| Magnitude Freq. Analysis | | | $XT^{Lower}$ $m^3/s$ | $XT^{upper}$ $m^3/s$ |
| $XT_{2years}$ = | 53.686 | $m^3/s$ | 50.895 | 56.477 |
| $XT_{5years}$ = | 65.841 | $m^3/s$ | 60.906 | 70.775 |
| $XT_{10years}$ = | 73.888 | $m^3/s$ | 67.124 | 80.652 |
| $XT_{25years}$ = | 84.056 | $m^3/s$ | 75.024 | 93.089 |
| $XT_{50years}$ = | 91.599 | $m^3/s$ | 80.545 | 102.653 |
| $XT_{100years}$ = | 99.087 | $m^3/s$ | 86.179 | 111.995 |

## Jamapa River Streamflow Stations

| El Tejar Streamflow Station (No. 28040) | | | | |
|---|---|---|---|---|
| Magnitude Freq. Analysis | | | $XT^{Lower}$ $m^3/s$ | $XT^{upper}$ $m^3/s$ |
| $XT_{2years}$ = | 16.907 | $m^3/s$ | 15.618 | 18.196 |
| $XT_{5years}$ = | 22.520 | $m^3/s$ | 20.241 | 24.799 |
| $XT_{10years}$ = | 26.237 | $m^3/s$ | 23.113 | 29.361 |
| $XT_{25years}$ = | 30.933 | $m^3/s$ | 26.761 | 35.105 |
| $XT_{50years}$ = | 34.417 | $m^3/s$ | 29.312 | 39.522 |
| $XT_{100years}$ = | 37.875 | $m^3/s$ | 31.913 | 43.837 |

| Paso del Toro Streamflow Station (No. 28039) | | | | |
|---|---|---|---|---|
| Magnitude Freq. Analysis | | | $XT^{Lower}$ $m^3/s$ | $XT^{upper}$ $m^3/s$ |
| $XT_{2years}$ = | 39.717 | $m^3/s$ | 37.359 | 42.074 |
| $XT_{5years}$ = | 49.015 | $m^3/s$ | 44.816 | 53.213 |
| $XT_{10years}$ = | 55.171 | $m^3/s$ | 49.403 | 60.938 |
| $XT_{25years}$ = | 62.949 | $m^3/s$ | 55.238 | 70.659 |
| $XT_{50years}$ = | 68.719 | $m^3/s$ | 59.277 | 78.161 |
| $XT_{100years}$ = | 74.447 | $m^3/s$ | 63.417 | 85.476 |

| Capulines Streamflow Station (No. 28069) | | | | |
|---|---|---|---|---|
| Magnitude Freq. Analysis | | | $XT^{Lower}$ $m^3/s$ | $XT^{upper}$ $m^3/s$ |
| $XT_{2years}$ = | 39.979 | $m^3/s$ | 34.897 | 45.062 |
| $XT_{5years}$ = | 61.508 | $m^3/s$ | 52.505 | 70.511 |
| $XT_{10years}$ = | 75.763 | $m^3/s$ | 63.413 | 88.112 |
| $XT_{25years}$ = | 93.773 | $m^3/s$ | 77.306 | 110.239 |
| $XT_{50years}$ = | 107.134 | $m^3/s$ | 86.943 | 127.324 |
| $XT_{100years}$ = | 120.396 | $m^3/s$ | 96.816 | 143.976 |

## 4.2 Cenapred’s Methodology Results

### Actopan River Streamflow Stations

| Streamflow from Cenapred's Methodology | | | |
|---|---|---|---|
| **Return Period** | **Actopan II $m^3/s$** | **El Naranjillo $m^3/s$** | **Idolos $m^3/s$** |
| T =2 years | 32.391 | 32.786 | 18.690 |
| T =5 years | 42.752 | 43.273 | 24.668 |
| T =10 years | 50.590 | 51.207 | 29.191 |
| T =25 years | 60.951 | 61.694 | 35.169 |
| T =50 years | 68.789 | 69.627 | 39.692 |
| T =100 years | 76.627 | 77.561 | 44.214 |

### La Antigua River Streamflow Stations

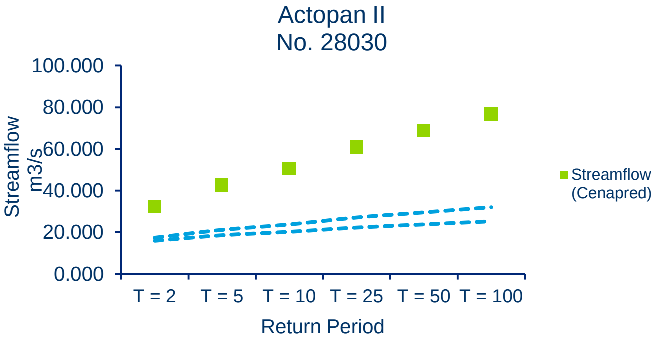
| Streamflow from Cenapred's Methodology | | | | |
|---|---|---|---|---|
| **Return Period** | **Cardel $m^3/s$** | **Carrizal $m^3/s$** | **Amatitla II $m^3/s$** | **Jalcomulco $m^3/s$** |
| T =2 years | 44.881 | 41.335 | 22.594 | 46.176 |
| T =5 years | 59.237 | 54.556 | 29.821 | 60.946 |
| T =10 years | 70.097 | 64.558 | 35.288 | 72.119 |
| T =25 years | 84.453 | 77.780 | 42.515 | 86.889 |
| T =50 years | 95.313 | 87.782 | 47.982 | 98.062 |
| T =100 years | 106.172 | 97.783 | 53.449 | 109.236 |

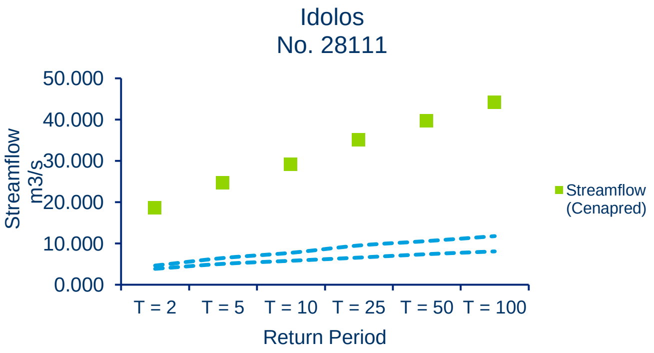
### Jamapa River Streamflow Stations

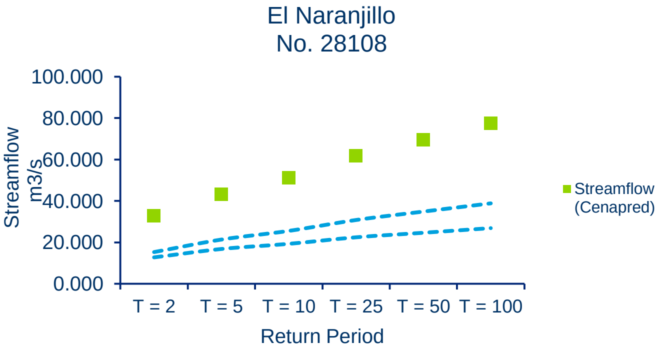
| Streamflow from Cenapred's Methodology | | | |
|---|---|---|---|
| **Return Period** | **Paso del Toro $m^3/s$** | **El Tejar $m^3/s$** | **Capulines $m^3/s$** |
| T =2 years | 20.626 | 28.589 | 28.140 |
| T =5 years | 27.223 | 37.734 | 37.141 |
| T =10 years | 32.214 | 44.652 | 43.950 |
| T =25 years | 38.812 | 53.797 | 52.951 |
| T =50 years | 43.803 | 60.714 | 59.760 |
| T =100 years | 48.794 | 67.632 | 66.569 |

# 5. Conclusions

## Actopan River

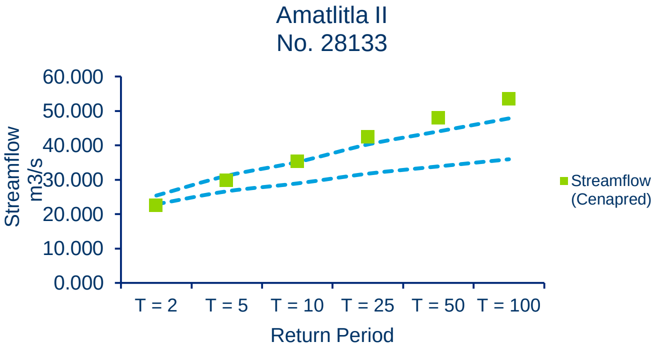


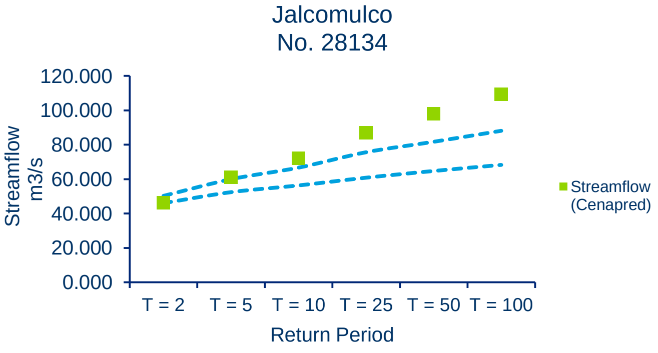


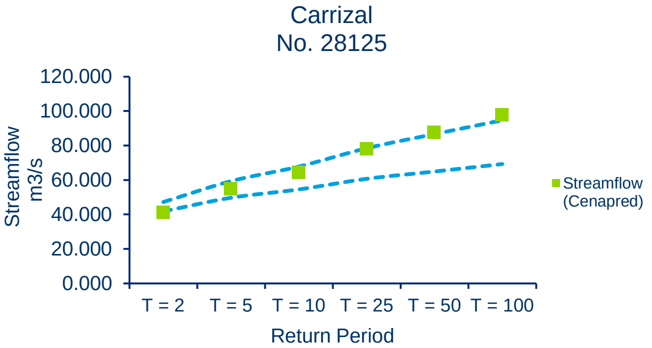


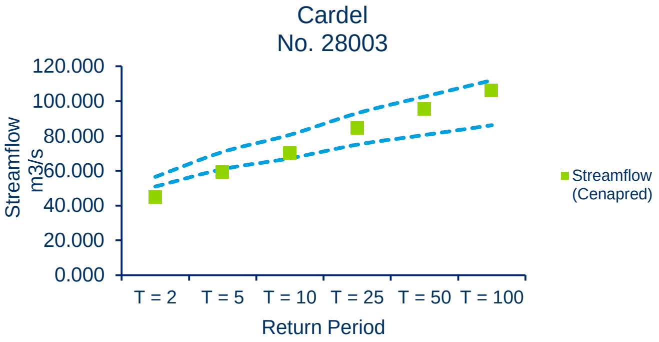
In the Actopan River, the values estimated with Cenapred’s methodology are much higher than the range obtained from the Frequency Analysis. For this, is important to reconsider the values used for the Runoff coefficient in order to state if this method is valid or not in this area of the central region of Veracruz.

## La Antigua River



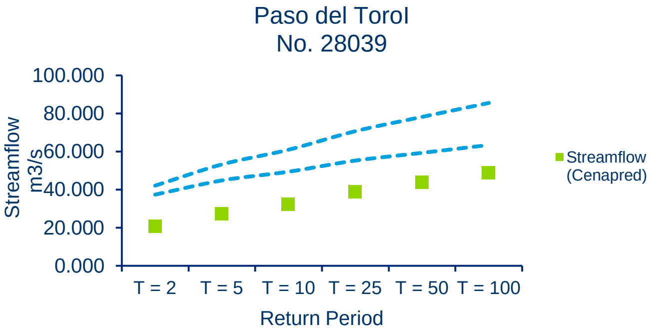


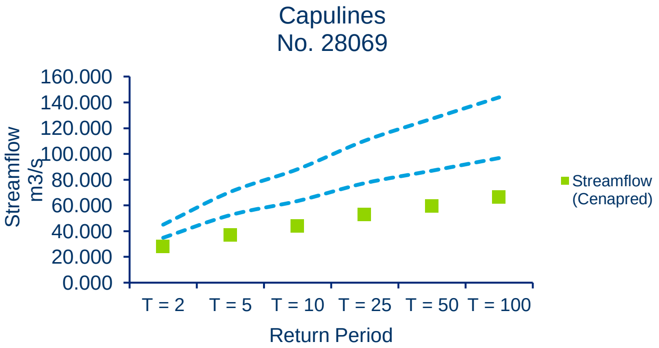

Carrizal
No. 28125

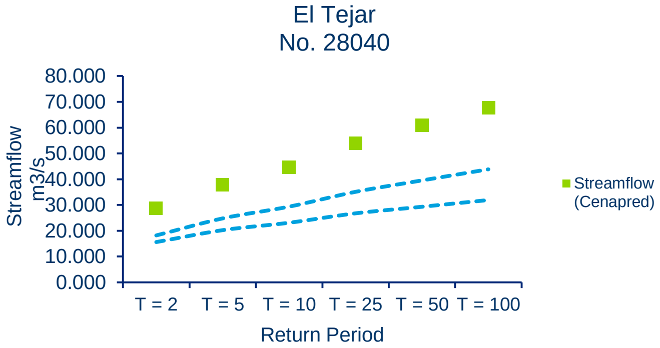

Cardel
No. 28003

In the streamflow stations of La Antigua River, we can see that nearly all the values estimated by Cenapred's Methodology are practically in range. In other words, we can conclude that for this particular area of the central region of the estate of Veracruz, is valid to use this method to calculate the magnitude of the streamflow.

## Jamapa River


Paso del Torol
No. 28039


Capulines
No. 28069


El Tejar
No. 28040

In this region there are two mainly tributaries. Capulines and Paso del Toro stations are located in the same affluent and El Tejar station is located in the other.

From the graphs above, we can see that the values estimated by using Cenapred's methodology in Paso del Toro and Capulines stations is lower than the range calculated by using the frequency analysis. This might be an indicator that there is a dam upstream of these stations. In this case, it is necessary to make a satellite image analysis of the region.

In the other tributary, we can see that the values from Cenapred's Methodology at El Tejar station are higher than the range obtained from the Frequency Analysis methodology. For this, is important to reconsider the values used for the Runoff coefficient in order to state if this method is valid or not in this area.

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