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MASTER OF SCIENCE (M.Sc.) THESIS

DROUGHT INDICES IN PANAMA CANAL

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Declaration

I hereby declare that I JULIÁN ELI GUTIÉRREZ H. solely authored this master thesis as one of the prerequisite requirements for the M.Sc. degree at the Faculty of Environmental Sciences, Czech University of Life Sciences, Prague.

I have carried out different studies connected to my thesis on my own work and quoted only according to the references listed within. However, contributions of others are involved, especially under the guidance of Doc. Ing. Petr Máca, Ph.D

Prague, 22nd April 2015.

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Julián Eli Gutiérrez Hernández.

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Abstract

Panama has a warm, wet, tropical climate. Unlike countries that are farther from the equator, Panama does not experience seasons marked by changes in temperature. Instead, Panama’s seasons are divided into Wet and Dry. The Dry Season generally begins around mid-December, but this may vary by as much 3 to 4 weeks. Around this time, strong northeasterly winds known as “trade winds” begin to blow and little or no rain may fall for many weeks in a row. Daytime air temperatures increase slightly to around 30-31ºC (86-88ºF), but nighttime temperatures remain around 22-23ºC (72-73ºF). Relative humidity drops throughout the season, reaching average values as low as 70%. The Wet Season usually begins around May 1, but again this may vary by 1 or 2 weeks. May is often one of the wettest months, especially in the Panama Canal area, so the transition from the very dry conditions at the end of the Dry Season to the beginning of Wet Season can be very dramatic. With the arrival of the rain, temperatures cool down a little during the day and the trade winds disappear. Relative humidity rises quickly and may hover around 90 to 100% throughout the Wet Season. Drought forecasts can be an effective tool for mitigating some of the more adverse consequences of drought. The presented thesis compares forecast of drought indices based on seven different models of artificial neural networks model. The analyzed drought indices are SPI and SPEI-ANN Drought forecast, and was derived for the period of 1985-2014 on Panama Canal basin; I've selected seven of sixty-one Hydro-meteorological networks, existing in the Panama Canal basin. The rainfall is 1784 mm per year. The meteorological data were obtained from the PANAMA CANAL AUTHORITY, Section of Water Resources, and Panama Canal Authority, Panama. The performance of all the models was compared using ME, MAE, RMSE, NS, and PI. The results of drought indices forecast, explained by the values of seven model performance indices, show, that in Panama Canal has problem with the drought.

Even though The Panama is generally seen as a wet country, droughts can cause severe problems. Significant drought conditions are observed in the index based on precipitation and potential evaporation found in this thesis; The Standardized Precipitation Index (SPI), the Standardized Precipitation Evapotranspiration Index (SPEI), were used to quantify drought in the

Panama Canal basin, Panama Canal, at multiple time scales within the period 1985-2014. The results indicate that drought indices based on different variables show the same major drought events. Drought indices based on precipitation and potential evaporation are more variable in time while drought indices based on discharge. Spatial distribution of meteorological drought is uniform over Panama Canal.

Keywords: Drought, Forecasting SPEI,SPI, the ANN, Multilayer perceptron (MLP), ME, MAE, RMSE, NS, and PI.

Abstrakt

Panama má teplé, deštivé a tropické počasí. Oproti zemím, které se nacházejí dál od rovníku, Panama nezažije sezóny charakterizované teplotními změnami. Přes to, že v Panamě existuje letní a zimní sezóna. Letní sezóna začíná většinou okolo půlky prosince, ale to může kolísat nejdéle o 3 až 4 týdny. V tomto období, silné severovýchodní větry také známé jako „pasáty", začínají foukat a prší málo anebo vůbec po několik týdnů za sebou. Denní teploty vzduchu se jemně zvyšují na 30 –31ºC (86-88ºF), ale v noci teploty zůstávají okolo 22-23ºC (72-73ºF). Relativní vlhkost klesá při sezóně, dosahuje průměrných hodnot okolo 70%. Zimní sezóna obvykle okolo 1. Května, ale také se to může různit o 1 nebo 2 týdny. Květen je často jeden z nejdeštivějších měsíců, hlavně v okolí panamského průplavu, takže přechod suchých okolností letní sezóny na zimní sezónu může být velmi dramatický. Když přijde déšť, teploty klesají trochu přes den a pasáty zanikají. Relativní vlhkost se rychle zvyšuje a zůstane okolo 90 až 100% při celé zimní sezóně. Předpovědi sucha mohou být efektivní pomůcka k zmírňování několika nepříznivých následků sucha. Tato diplomová práce porovnává předpovědi indexů sucha na základě použití sedm různých modelů umělého nervového modelu sítě. Analyzované indexy sucha jsou SPI i SPEI-ANN předpověď sucha, a odpovídají období 1985-2014 u povodí panamského průplavu; Vybral jsem sedm ze šedesáti jedné hydrometeorologických sítí, existující v povodí panamského průplavu. Meteorologická data byly získané od úřadu panamského průplavu, oddělení vodních zdrojů, úřad panamského průplavu, Panama. Výkon všech těchto modelů byl porovnáván použitím ME, MAE, RMSE, NS, a PI. Výsledky předpovědí indexů sucha , vysvětlené hodnotami výkonových indexů sedmi modelů, ukazují, že v panamském průplavu existuje problém se suchem.

Přes to, že Panama je obecně známá jako dešťová země, sucho může působit těžké problémy. Významné podmínky sucha jsou pozorované v indexu na základě precipitačního a potenciálního vypařování, který se nachází v této práci; Standardizovaný precipitační index(SPI) a standardizovaný precipitační index evapotranspirace (SPEI), byly používané ke kvantifikování sucha v povodí panamského průplavu v období 1985-2014. Výsledky ukazují, že indexy sucha uložené na základě různých proměn ukazují stejné hlavní případy sucha. Indexy sucha na základě precipitace a potenciální evaporace jsou více proměnlivé vůči času oproti indexům sucha na

základě výboje. Prostorová distribuce meteorologického sucha je nepravidelná po celém panamském průplavu.

Klíčová slova: Drought, Forecasting SPEI,SPI, ANN, Multilayer perceptron (MLP), ME, MAE, RMSE, NS, a PI.

TABLE OF CONTENT

CHAPTER 1: INTRODUCTION

1.1 General introduction

This thesis contains the drought indices in Panama to contextualize the phenomenon of drought, It also introduces aspects encompass more than the geographic focus climate and damage, assuming a proactive interest added oriented elements into the analysis index SPI "Standardized Precipitation Index" and SPEI " Standardized Precipitation-Evapotranspiration Index". Drought effects are apparent after a long period with a shortage of precipitation, making it very difficult to determine their onset, extent and end. Thus, it is hard to objectively quantify the characteristics of drought episodes in terms of their intensity. The SPEI fulfills the requirements of a drought index since its multi-scalar character enables it to be used by different scientific disciplines to detect, monitor and analyze droughts. Drought is associated with various climatic and hydrologic processes such as precipitation, temperature, stream flow, accordingly, the measured quantities of these processes are primary indicators of drought and one or more of these indicators are assimilated to compute a drought index, which is generally used to express drought quantitatively.

This Master thesis is focused on Forecasting SPEI-SPI drought indices using the integrated artificial neural networks, in the Panama Canal basin, for the period of 1985-2014. The lists of the Hydro-meteorological networks are: GATUN, GAMBOA, SANTA ROSA, BARRO COLORADO, SAN MIGUEL, DIABLO HEIGHTS, and EMPIRE HILL.

Chapter 2. OBJECTIVE OF THE STUDY

The main aim of diploma thesis is the estimation of SPI and SPEI drought indices for selected time series in Panama Canal. To apply integrated neural network models for forecast of drought indices, and to compare the areas which are vulnerable for periods of drought.

2.1 Specific objective

- ✓ To assess SPEI and SPI Drought forecast.
- ✓ To assess the drought index in the Panama Canal basin.
- ✓ To assess the different results to get of the hydro-meteorological networks, using monthly precipitation (mm) totals and temperature °C.

Chapter 3: Material and Methods

I tested one type of artificial neural network models for forecast of SPEI-SPI drought index. The first ANN model is a multilayer perceptron. The second one is the integrated neural network model. I used this Package: AMORE, lmomco, SPEI, “Crit.r”, “MLP_train.r”, in RStudio to get all the result in my thesis.

3.1 Drought index

The studied droughts were described using the Standardized precipitation evapotranspiration index and Standardized Precipitation Index (SPEI-SPI) [24, 4].

The SPI index is based on the evaluation of precipitation data. The precipitation data are linked to the selected probability distribution, and further transformed using the normal distribution with zero mean and standard deviation of one. It is often expressed as a meteorological drought index *[5]*, and it also serves for other agricultural and hydrological applications [19]. The estimation of SPI consists of the determination of probability distribution of analyzed precipitation data, the calculation of probabilities for measured precipitation data from cumulative distribution function of fitted probability distribution, and applying the inverse of distribution function of normalized normal distribution on probabilities [19, 17].

Positive SPI values indicate greater than median precipitation and negative values indicate less than median precipitation. Drought periods are represented by relatively high negative deviations. Normally, the ’drought’ part of the SPI range is arbitrary split into moderately dry (-1.0 > SPI > -1.49), severely dry (-1.5 > SPI > -1.99) and extremely dry conditions (SPI < -2.0). A drought event starts when SPI value reaches -1.0 and ends when SPI becomes positive again (McKee et al., 1993). These functions use the SPI range defined by National Climatic Data Center (NCDC):

Table 1-This function uses the SPI range by National Climatic Data center.

Exceptionally Moist:	**SPI >= 2.0**
Extremely Moist:	1.60 <= SPI < 1.99
Very Moist:	1.30 <= SPI < 1.59
Moderately Moist:	0.80 <= SPI < 1.29
Abnormally Moist:	0.51 <= SPI < 0.79
Near Normal:	-0.50 <= SPI <= 0.50
Abnormally Dry:	-0.79 <= SPI < -0.51
Moderately Dry:	-1.29 <= SPI < -0.80
Severely Dry:	-1.59 <= SPI < -1.30
Extremely Dry:	-1.99 <= SPI < -1.60
Exceptionally Dry:	SPI <= -2.0

The SPEI drought index is based on the precipitation and temperature (evapotranspiration) data. Its calculation is technically similar to the estimation SPI index, the only difference is that instead the precipitation data the differences are used [24, 4].

The estimation of SPI-SPEI drought index I made using the R package [3].

3.2 Input data

The input variable is a time ordered series of the climatic water balance (precipitation minus potential evapotranspiration) for SPEI-SPI ***[Table 11]***

3.3 Multi-Layer Perceptron (MLP) Model.

Multi-Layer Perceptron (MLP) network models are the popular network architectures used in most of the research applications in medicine, engineering, mathematical modeling, etc. In MLP, the weighted sum of the inputs and bias term are passed to activation level through a transfer function to produce the output, and the units are arranged in a layered feed-forward topology called Feed Forward Neural Network (Venkatesan & Anitha, 2006). MLP networks consist of an input layer, one or more hidden layers and an output layer. Respective layer has a number of processing units and particular unit is fully interconnected with weighted connections to units in the subsequent layer. The MLP transforms *n* inputs to *l* outputs through some nonlinear functions. The output of the network is determined by the activation of the units in the output layer as follows:

$$x_0 = \left(\sum_h x_h w_{ho} \right)$$

where *f()* is activation function, xh: activation of hth hidden layer node and who: is the interconnection between hth hidden layer node and oth output layer node. The most used activation function to is the sigmoid and it is given as follows:

$$x_0 = \frac{1}{1 + \exp(-\sum x_h w_{ho}}$$

The activation level of the nodes in the hidden layer is determined in a similar fashion. Based on the differences between the calculated output and the target value an error is defined as follows:

$$E = \frac{1}{2} \sum_s^N \sum_o^L \left(t_o^{(s)} - x_o^{(s)} \right)^2$$

Where N is the number of pattern in data set and L is the number of output nodes. The aim is to reduce the error by adjusting the interconnections between layers. The algorithm requires a training data that consists of a set of corresponding input and target pattern values to. During training process, MLP starts with a random set of initial weights and then training continues until set of wih and that of who are optimized so that a predefined error threshold is met between x o and to (after Altun & Gelen, 2004).

3.4 Hydrological Indexes-ANN.

The evaluations of simulations of ANN models for training, and for validation datasets were based on following statistics. *[16, 9, 10]*

3.4.1 Mean Error (ME).

- ✓ Estimator systematical error →model underestimates or overestimates.
- ✓ Good model is →0,
- ✓ Positive and negatives error annullates.
- ✓ Most models have it good item systematical error→ biased model.

$$ME = \frac{1}{n}\sum_{i=1}^{n}(DI_0[i] - DI_f[i]),$$

3.4.2 Mean Absolute Error (MAE).

- ➢ Estimator of size of residuals
- ➢ Good model if→ 0
- ➢ Measures the size of residuals
- ➢ Against not differentiable criterion

$$MAE = \frac{1}{n}\sum_{i=1}^{n}|DI_0[i] - DI_f[i]|,$$

3.4.3 Square Root of MSE (RMSE).

- ➢ Estimates of variability of residual ME=0
- ➢ Good model RMSE↔ good model MSE

- Reflects the units, expresses the variability with same units as data.

$$RMSE = \sqrt{\frac{1}{n}\sum_{i=1}^{n}|DI_0[i] - DI_f[i]|}$$

3.4.4 Nash Sutcliffe Efficiency (NS).

$$\mathrm{NS} = 1 - \frac{\sum_{i=1}^{n}(\mathrm{DI_0[i]} - \mathrm{DI_f[i]})^2}{\sum_{i=1}^{n}(\mathrm{DI_0[i]} - \overline{\mathrm{DI_0}})^2}$$

3.4.5 Transformed Persistency Index (tPI)

$$tPI = \frac{\sum_{i=1}^{n}(DI_0[i] - DI_f[i])^2}{\sum_{i=1}^{n}(DI_0[i] - DI_0[i - LAG])^2}$$

3.4.5.1 Persistency Index (PI)

- Similar as NS

$$PI = 1 - tPI,$$

The n represents the total number of time intervals to be predicted, the $\overline{DI_0}$ is the average of observed drought index, $dDIo\,[i] = DIo\,[i] - DIo\,[i - 1]$, and $dDIf\,[i] = DIf\,[i] - DIf\,[i - 1], LAG$ is the time shift describing last observed drought index $DIo\,[i - LAG]$.

3.5 Hydrological Indexes-Summary of Variability of Residue.

Hydrological-Indexes.

The wood Question- What is good model?

The good model = small residuals.

Summary of Residuals location			
Criterion	Range	Good if	Units
ME	$(-\infty,\infty)$	0	[OBS]
MAE	$(0, \infty)$	0	[OBS]
RMSE	$(0, \infty)$	0	[OBS]
NS	$(-\infty,1)$	≈ 1	[-]
PI	$(-\infty,1)$	≈ 1	[-]

3.6 Dataset description

Monthly rainfall data records for PANAMA CANAL station were obtained from the "PANAMA CANAL AUTORITY" The data were part of large dataset prepared within the MOPEX experiment framework. [11,22] The MOPEX dataset provides the benchmark hydrological and meteorological data, which were explored in large number of environmentally oriented studies. [1, 25, 7, 23, 13].

The first Hydro-meteorological network basin was Gatún, the second Gamboa, the third Santa Rosa, the fourth Barro Colorado, the fifth San Miguel, the sixth Diablo Heights, and the seventh was Empire Hill.

The original daily records were aggregated into the monthly time scale. I used the records from the 01.01.1985 to 31.08.2014. The calibration period was formed from period 1985 -1998; the validation dataset consisted of the records from 1998-2014, for all of them.

Chapter 4: LITERATURE REVIEW

4.1 Drought

Meteorologists blame the drought on the weather phenomenon known as El Niño. El Niño is a period of warmer than average waters in the Pacific Ocean off the coast of Central and South America. Drought is hazard to nature. It is often referred to as a "creeping phenomenon" and its impacts vary from land to land. Drought can therefore be difficult for people to understand. Its impacts result from the interplay between the natural event (less precipitation than expected) and the demand people place on water supply, and human activities can exacerbate the impacts of drought. Because drought cannot be viewed solely as a physical phenomenon, it is usually defined both conceptually and operationally.

4.1.1 Types of Drought

The definitions reflect differences in regions, needs, and disciplinary approaches. Wilhite and Glantz categorized the definitions in terms of four basic approaches to measuring drought: meteorological, hydrological, agricultural, and socioeconomic. The first three approaches deal with ways to measure drought as a physical phenomenon. The last deals with drought in terms of supply and demand, tracking the effects of water shortfall as it ripples through socioeconomic systems.

4.1.1.1 Meteorological Drought.

Sequence of drought occurrence and impacts for commonly accepted drought types. All droughts originate from a deficiency of precipitation or meteorological drought but other types of drought and impacts cascade from this deficiency. (Source: National Drought Mitigation Center, University of Nebraska-Lincoln, U.S.A.) Meteorological drought is defined usually on the basis of the degree of dryness (in comparison to some “normal” or average amount) and the duration of the dry period. Definitions of meteorological drought must be considered as region specific since the atmospheric conditions that result in deficiencies of precipitation are highly variable from region to region.

4.1.1.2 Agricultural Drought.

Agricultural drought links various characteristics of meteorological (or hydrological) drought to agricultural impacts, focusing on precipitation shortages, differences between actual and potential evapotranspiration, soil water deficits, reduced groundwater or reservoir levels, and so forth. Plant water demand depends on prevailing weather conditions, biological characteristics of the specific plant, its stage of growth, and the physical and biological properties of the soil. A good definition of agricultural drought should be able to account for the variable susceptibility of crops during different stages of crop development, from emergence to maturity. Deficient topsoil moisture at planting may hinder germination, leading to low plant populations per hectare and a reduction of final yield. However, if topsoil moisture is sufficient for early growth requirements, deficiencies in subsoil moisture at this early stage may not affect final yield if subsoil moisture is replenished as the growing season progresses or if rainfall meets plant water needs.

4.1.1.3 Hydrological Drought

Hydrological drought is associated with the effects of periods of precipitation, the frequency and severity of hydrological drought is often defined on a watershed or river basin scale. Although all droughts originate with a deficiency of precipitation, hydrologists are more concerned with how this deficiency plays out through the hydrologic system. Hydrological droughts are usually out of phase with or lag the occurrence of meteorological and agricultural droughts. It takes longer for precipitation deficiencies to show up in components of the hydrological system such as soil moisture, stream-flow, and groundwater and reservoir levels. As a result, these impacts are out of phase with impacts in other economic sectors.

4.1.1.4 Socioeconomic Drought

Socioeconomic definitions of drought associate the supply and demand of some economic good with elements of meteorological, hydrological, and agricultural drought. It differs from the aforementioned types of drought because its occurrence depends on the time and space processes of supply and demand to identify or classify droughts. The supply of many economic goods, such as water, forage, food grains, fish, and hydroelectric power, depends on weather. Because of the natural variability of climate, water supply is ample in some years but unable to meet human and environmental needs in other years. Socioeconomic drought occurs when the demand for an economic good exceeds supply as a result of a weather-related shortfall in water supply.

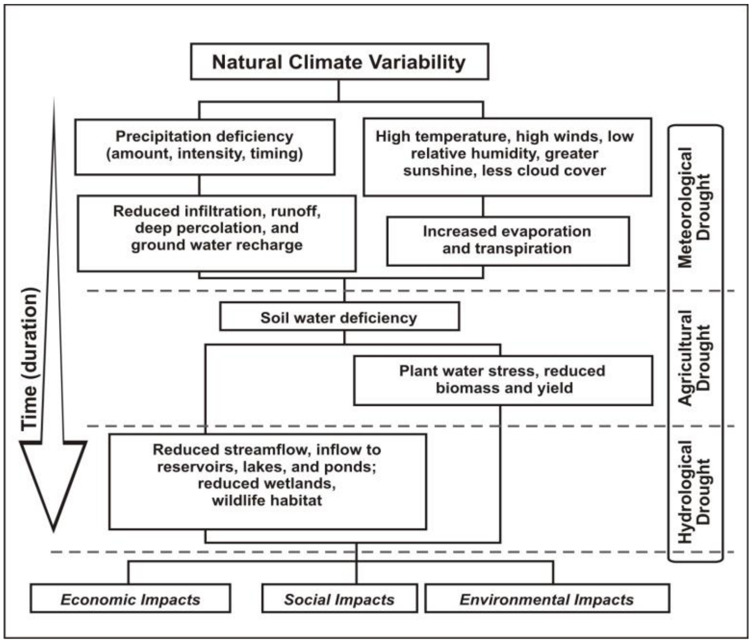

Figure 1: Types of Drought

4.2 Origin and propagation

Most droughts are developed when expected precipitation fails and evaporation rates are higher than normal, most times related to sunny and warm conditions (Teuling et al., 2013). High pressure weather systems can be responsible for long term drought events as result of large-scale anomalies in the global circulation pattern of the atmosphere. Winter drought can develop when winter precipitation is stored as snow and does not lead to replenishment of soil moisture, streams and groundwater. Climate factors such as high wind and low relative humidity can contribute to amplify the intensity of a drought (Sönmez et al., 2005).

A drought typology was developed by Van Loon and Van Lanen (2012). The occurrence of drought types is determined by climate and catchment characteristics. Precipitation can be considered as the carrier of the drought signal (Figure 2.2). Stream-flow (runoff) and groundwater levels can be considered as the last two indicators of the occurrence of a drought (Changnon, 1987). A time lag exists between deficiencies in precipitation and the point where precipitation deficiencies become evident in stream-flow and groundwater (Wilhite, 2006).

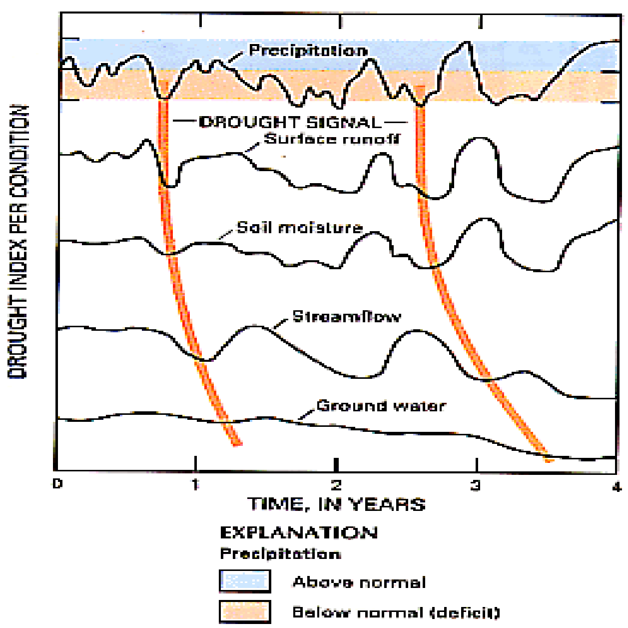

Figure 2: Drought propagation in different hydrological variables (Changnon, 1987).

4.3 The Panama Canal Authority

The Panama Canal is a 77.1-kilometre (48 mi) ship canal in Panama that connects the Atlantic Ocean (via the Caribbean Sea) to the Pacific Ocean. The canal cuts across the Isthmus of Panama and is a key conduit for international maritime trade. There are locks at each end to lift ships up to Gatun Lake, an artificial lake created to reduce the amount of excavation work required for the canal, 26 meters (85 ft) above sea level.

France began work on the canal in 1881, but had to stop because of engineering problems and high mortality due to disease. The United States took over the project in 1904, and took a decade to complete the canal, which was officially opened on August 15, 1914. One of the largest and most difficult engineering projects ever undertaken, the Panama Canal shortcut greatly reduced the time for ships to travel between the Atlantic and Pacific Oceans, enabling them to avoid the lengthy, hazardous Cape Horn route around the southernmost tip of South America via the Drake Passage or Strait of Magellan. The shorter, faster, to cross the Panama Canal it take between to 8 and 10 hours to go over the Panama Canal.

Figure 3: Orthographic map of Panama centered at 8° N, 80° W.

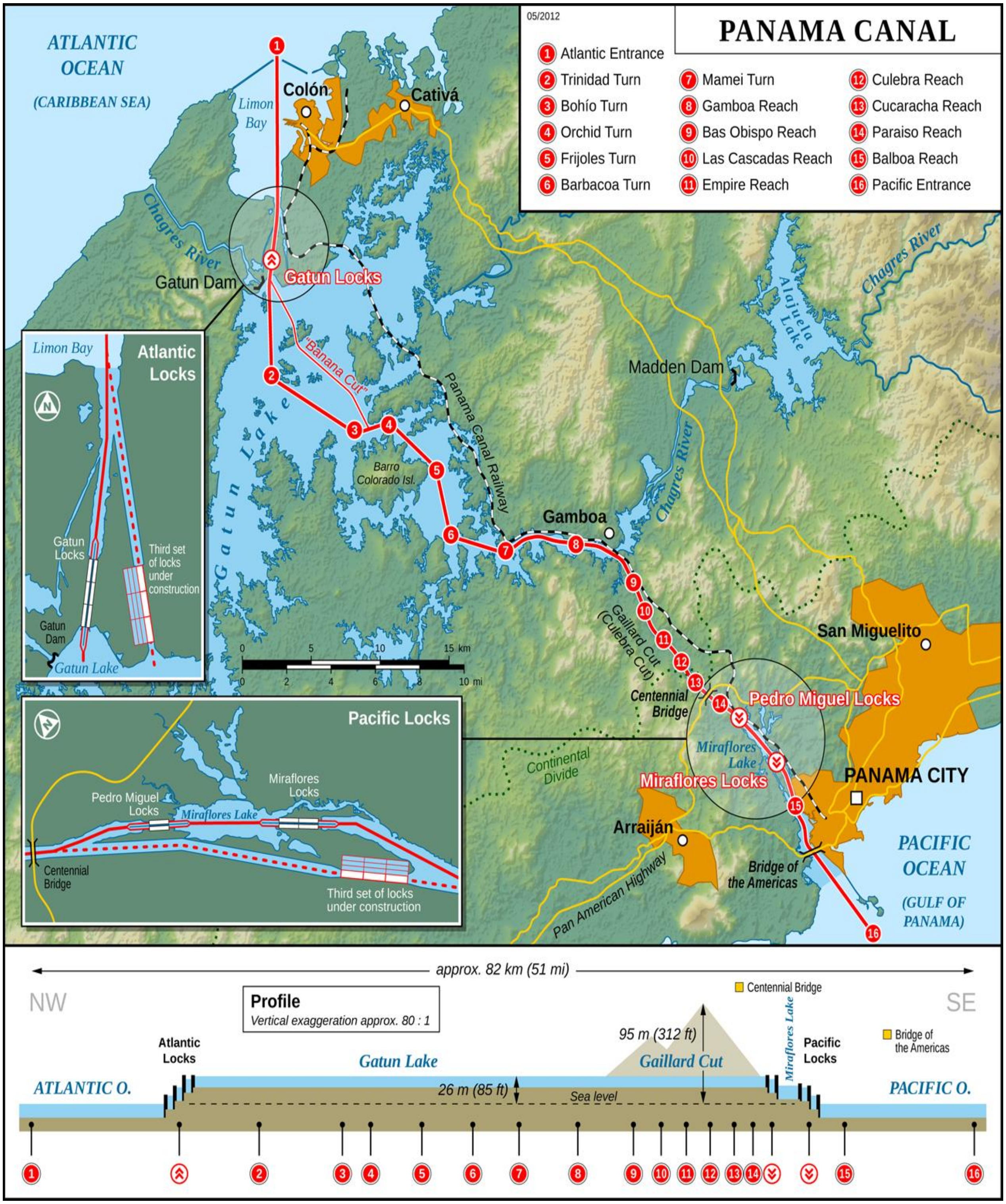

Figure 4: Panama Canal.

4.4 Establishment

The Panama Canal Authority is established under Title XIV of the National Constitution, and has exclusive responsibility for the operation, administration, management, preservation, maintenance, and modernization of the canal. It is responsible for the operation of the canal in a safe, continuous, efficient, and profitable manner.

The Organic Law of the Panama Canal Authority, passed on June 11, 1997, provides the legal framework for the canal's organization and operation.

Figure 5: Panama Canal Authority logo

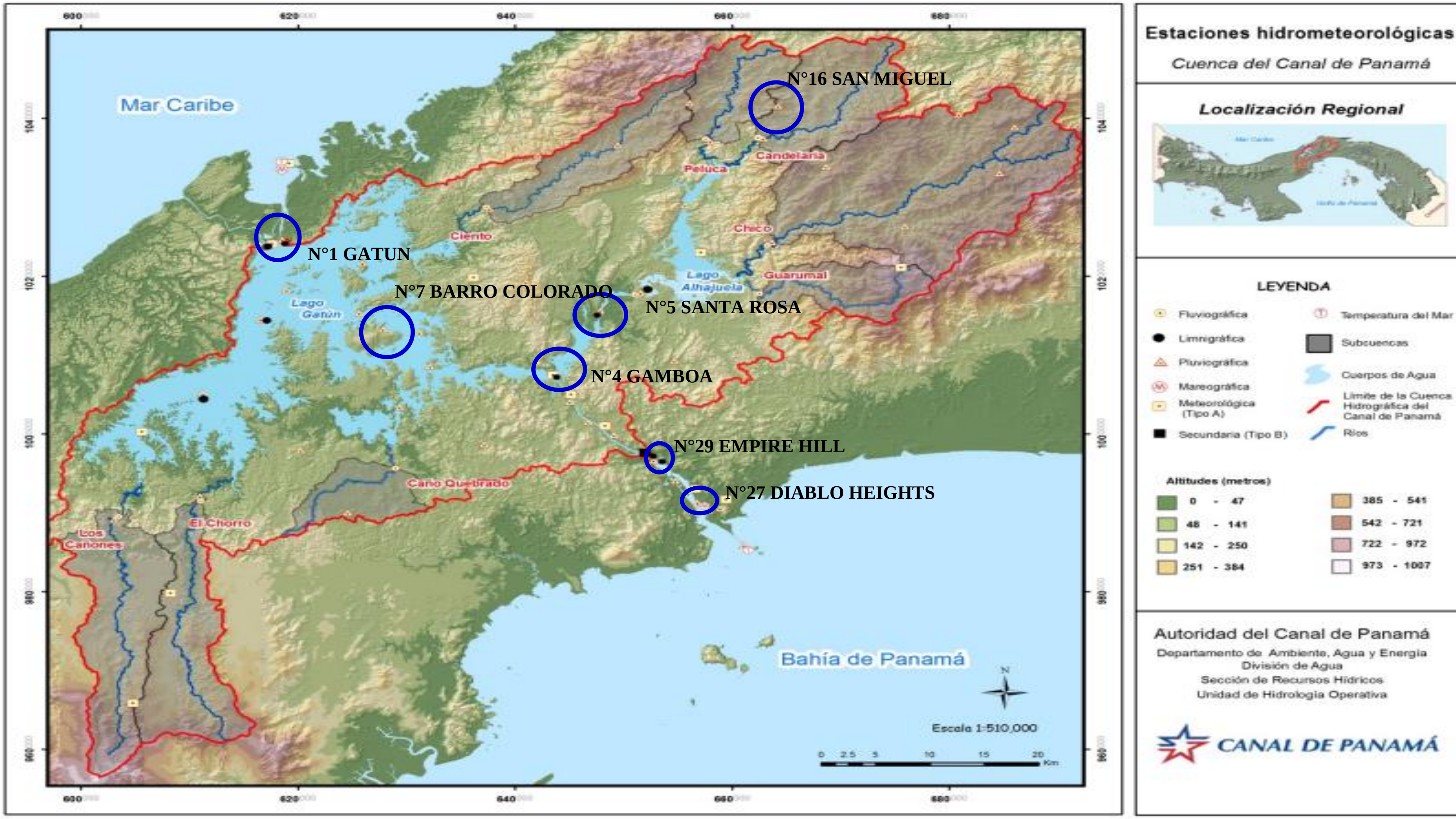

Figure 6: List of the Hydro-meteorological networks.

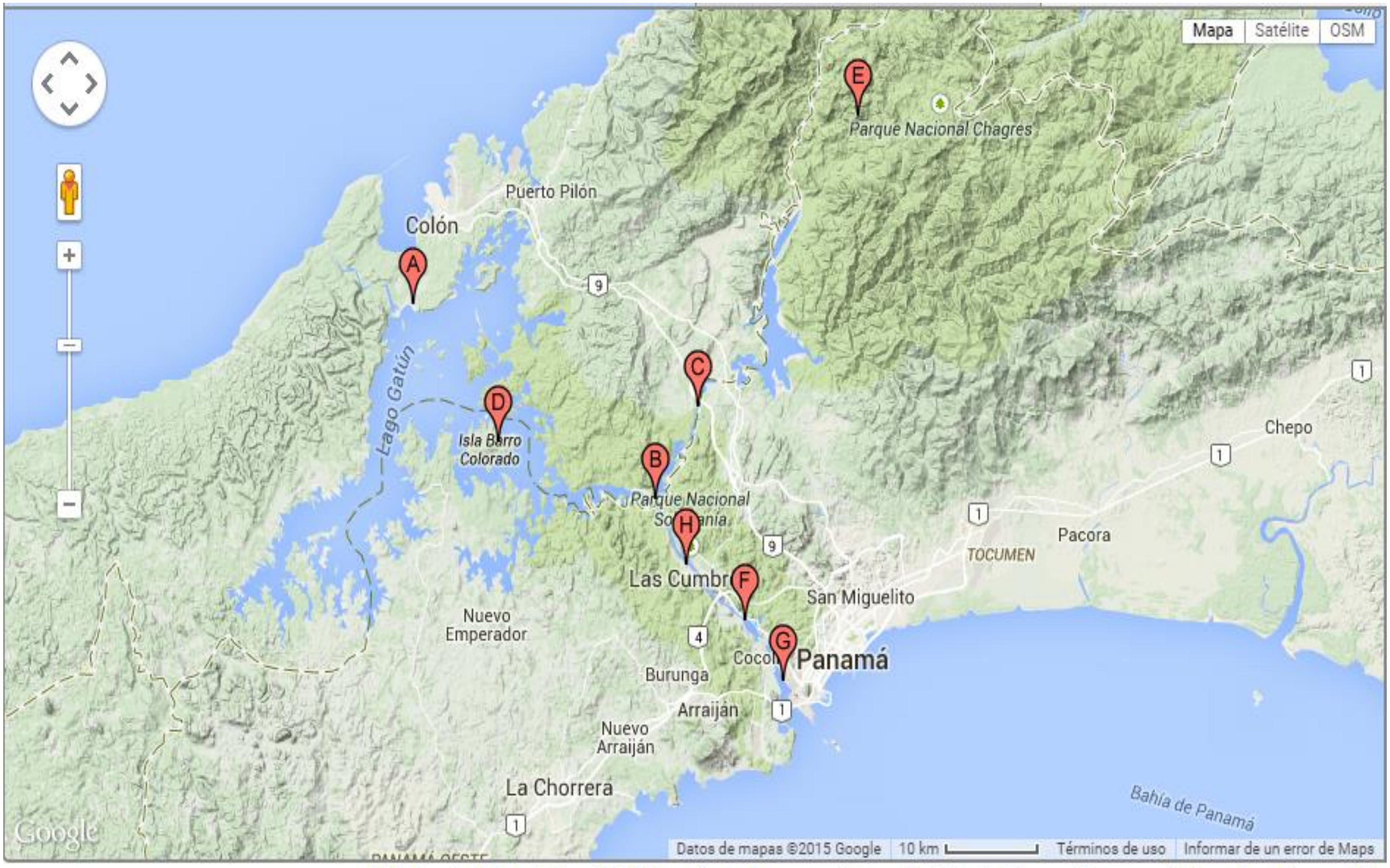

Figure 7: List of the Hydrometeorological networks GPS

Table 2: List of the Hydrometeorological networks.

List of the Hydrometeorological networks								
N°		**Name**	**Elevation [m]**	**Geographical coordinates**		**Station Type**	**Lake-River**	**Time records[years]**
				Latitude N	**Longitude W**			
1	A	**Gatun**	30.5	09 16 06	79 55 14	Pluviographic	Gatun	1985-2014
4	B	**Gamboa**	31.4	09 06 44	79 41 38	Pluviographic	Gatun	1985-2014
5	C	**Santa Rosa**	27.7	09 11 09	79 39 15	Pluviographic	Chagres	1985-2014
7	D	**Barro Colorado**	33.5	09 09 55	79 50 11	Pluviographic	Gatun	1985-2014
16	E	**San Miguel**	520	09 25 12	79 30 15	Pluviographic	Pequine	1985-2014
27	G	**Diablo Heights**	15.0	08 57 56	79 34 24	Pluviographic		1985-2014
29	F	**Empire Hill**	61.0	09 39 29	79 39 53	Pluviographic		1985-2014

Chapter 5: RESULTS

5.1 Temperature °C vs Years

In Panama City has a tropical monsoon climate with short dry season. The area within 40 km of this station is covered by oceans and seas (37%), forests (33%), and croplands (25%).

The temperature over the course of a year, the temperature typically varies from 22°C to 33°C and is rarely below 20°C or above 34°C.

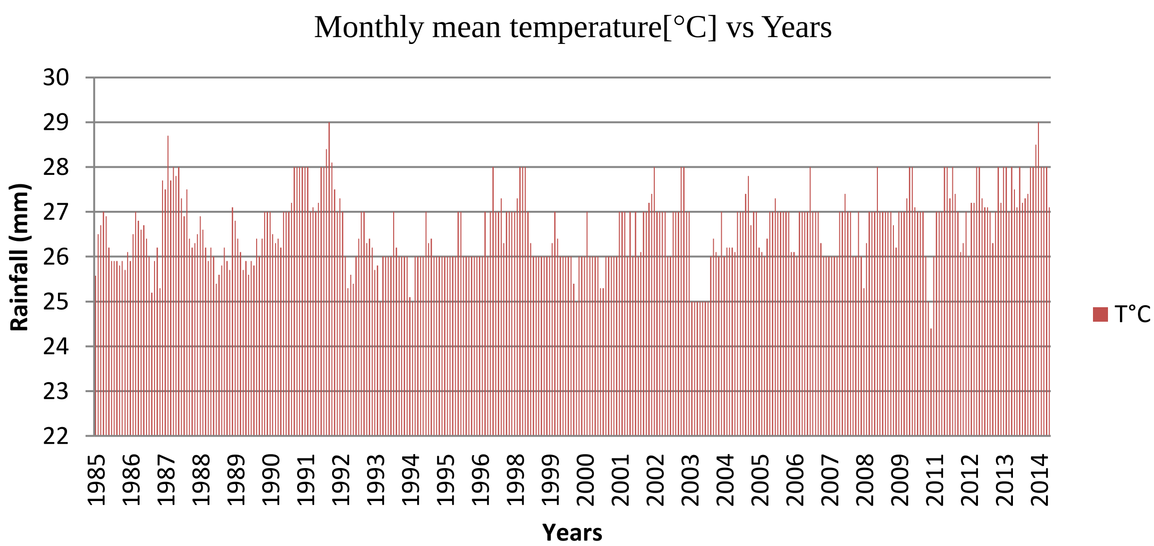

Figure 8: Monthly mean temperature [°C] vs Years

In this picture we can observe that for the years 1987, 1992 and 2014 has the higher temperature, and in the rest of the data are the moderately and severely hot. I can say that of the temperature is maintained and enhanced, due to global warming, and many other exogenous factors, principally the more use is given to the use of different basins.

5.2 Monthly Precipitation [mm] in Panama Canal

In Panama the days are hot and nights are much cooler; temperatures usually range from 32 degrees Celsius (90° Fahrenheit) during the daytime to 21 degrees Celsius (70° Fahrenheit) in the evening. However temperatures can vary according to geography. The climate is less tropical at higher ground. In mountain areas the average annual temperature ranges from 10ºC to 19ºC (50-66ºF). In Panama humidity is very high at about 80 percent. Panama is bequeathed an average of 1904 mm (75 in) of rainfall per year, or 158.7 mm (6.3 in) per month.

On average there are 164 days per year with more than 0.1 mm (0.004 in) of rainfall or 13.7 days with a quantity of rain, per month. The driest weather is in March when an average of 10 mm (0.4 in) of rainfall (precipitation) occurs. The wettest weather is in October when an average of 305 mm (12 in) of rainfall (precipitation) occurs.

Precipitation Gatun vs Years

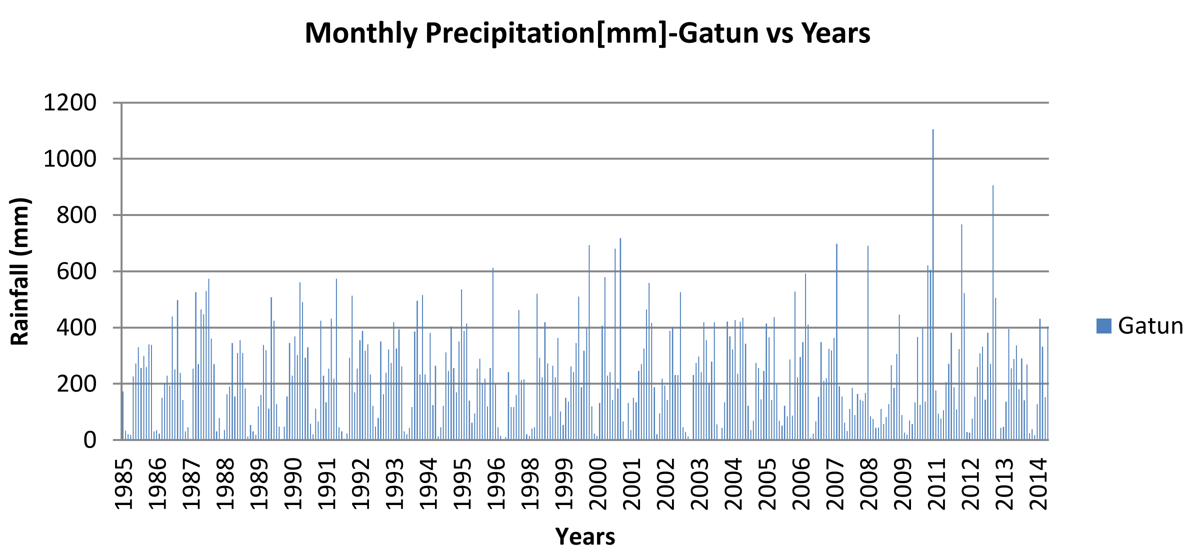

Figure 9: Monthly Precipitation [mm]-Gatun vs Years

In this picture we can observe that for the years 1996, 2000, 2001, 2008, 2010-2012 and 2013 has the higher precipitation and in the rest of the data we can observe that of frequency of rainfall are good. But for the last year in 2014 the rainfall is decreasing.

Precipitation Gamboa vs Years

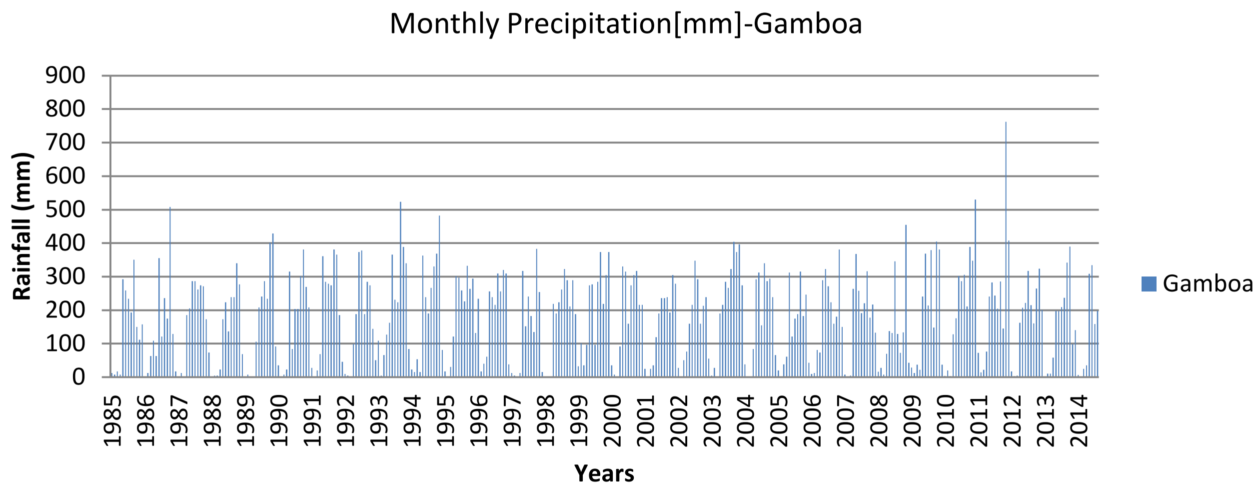

Figure 10: Monthly Precipitation [mm]-Gamboa vs Years

In this picture we can observe that for the years 1986, 1989, 1993, 1994, 1997,2000,2003,2007,2008,2010,2011 and 2012 has the higher precipitation and in the rest of the data we can observe that of frequency of rainfall are good.

Precipitation Santa Rosa vs Years

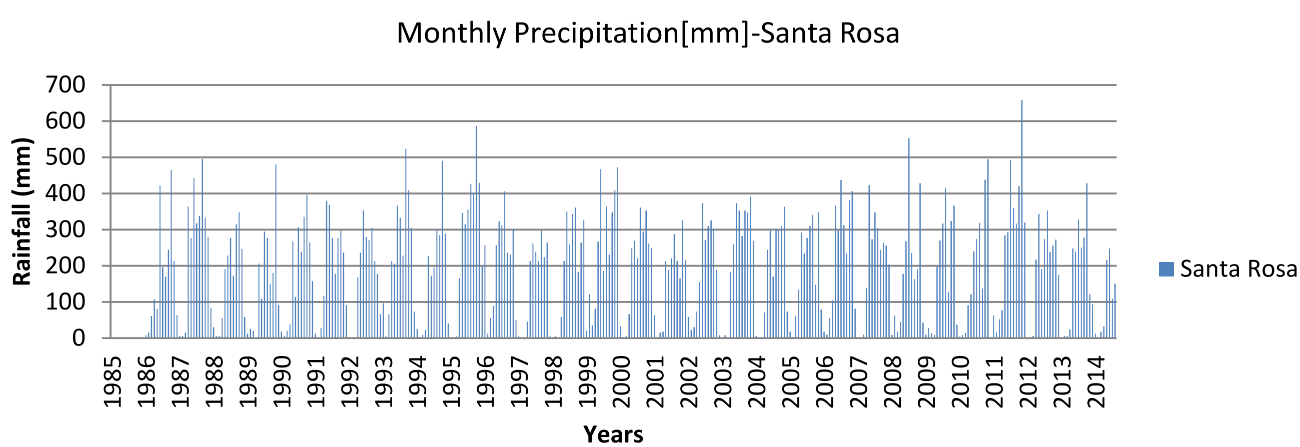

Figure 11-Monthly Precipitation [mm]-Santa Rosa vs Years

In this picture we can observe that for the years 1985, we don't have data base, but for the years 1986, 1989, 1993, 1995, 1997,2000,2003,2007,2008,2010,2011 and 2012 has the higher precipitation and in the rest of the data we can observe that of frequency of rainfall are good.

Precipitation Barro Colorado vs Years

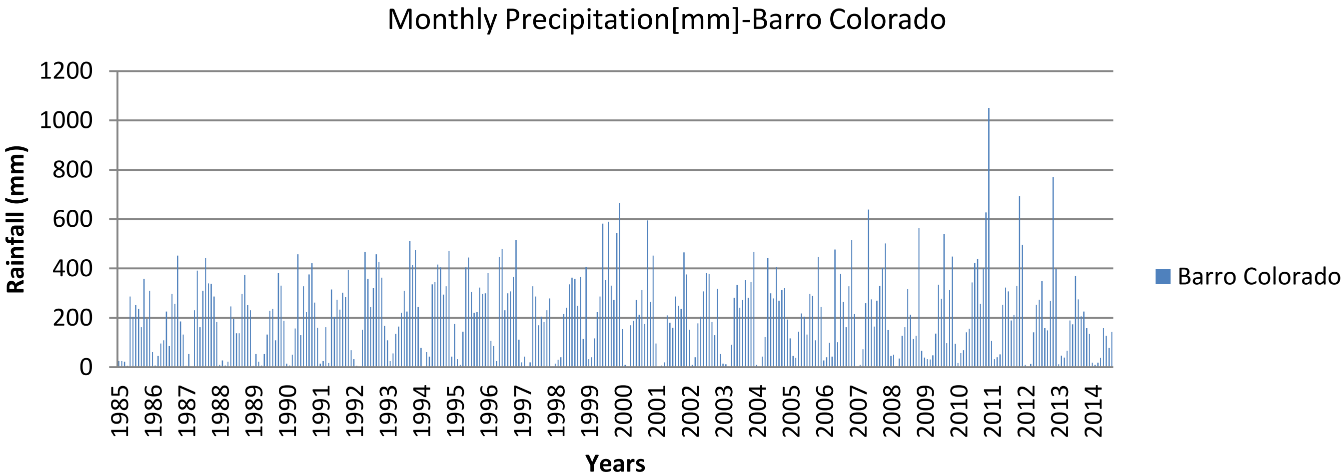

Figure 12: Monthly Precipitation [mm]-Barro Colorado vs Years

In this picture we can observe that for all the years the rainfall the values are between 200-400(mm), and the higher in the years 2000, 2007, 2011,2012 and 2013.

Precipitation San Miguel vs Years

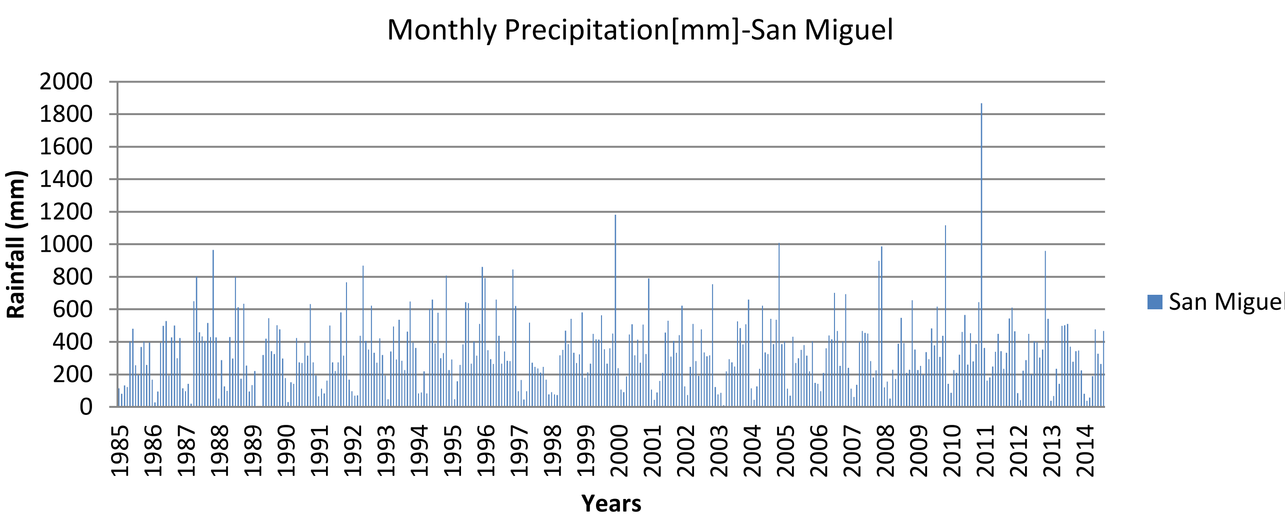

Figure 13: Monthly Precipitation [mm]-San Miguel vs Years

In this picture we can observe that for all the years the rainfall the values are between 200-600(mm), and the higher in the years 1987,1992,1995,1996,2000,2004,2009,2011 and 2013. The principal reason that we have higher values is because the place is located in the mountain.

Precipitation Diablo Heights vs Years

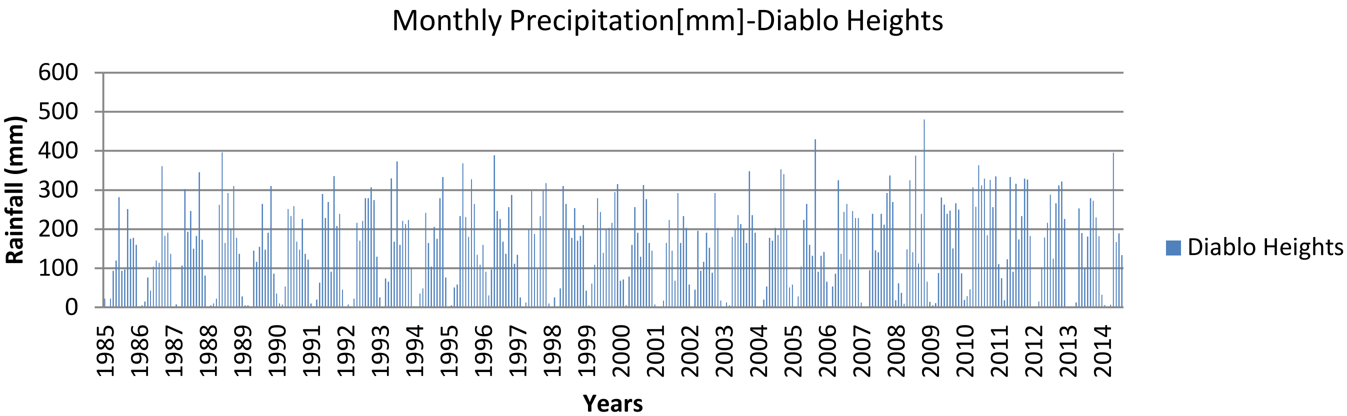

Figure 14: Monthly Precipitation [mm]-Diablo Heights vs Years

In this picture we can observe that for all the years the rainfall the values are between 200-300(mm), and the higher in the years 1987,1988,1992,1995,1996,1997,2000,2004,2006, 2007,2009,2011,2012 and 2013.

Precipitation Empire Hill vs Years

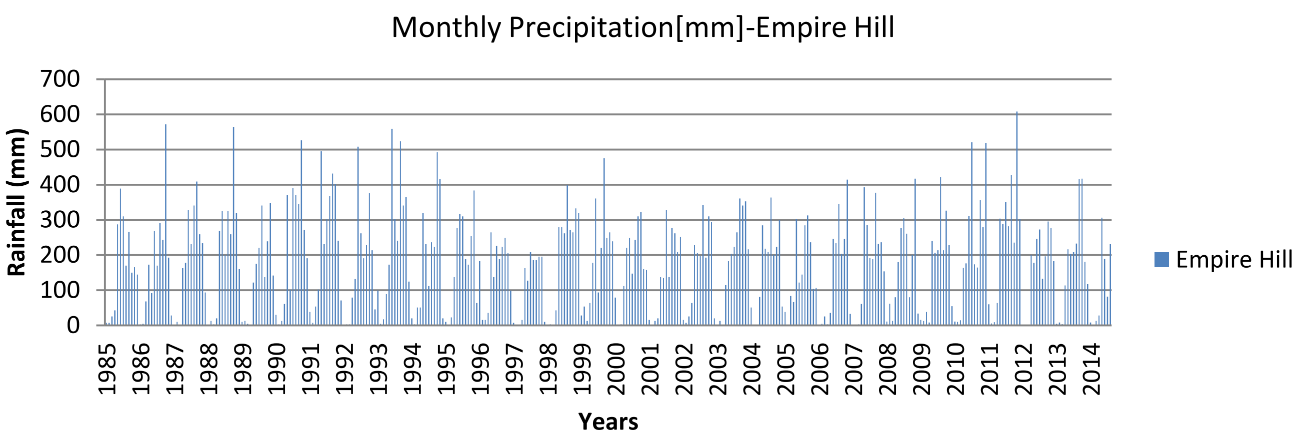

Figure 15: Monthly Precipitation [mm]-Empire Hill vs Years

In this picture we can observe that for all the years the rainfall the values are between 200-400(mm), and the higher in the years 1987,1989,1991,1994,2000,2007,2011 and 2012.

5.3 The Standardized Precipitation Index (SPI).

The Positive SPI values indicate greater than median precipitation and negative values indicate less than median precipitation. Drought periods are represented by relatively high negative deviations. Normally, the 'drought' part of the SPI range is arbitrary split into moderately dry (-1.0 > SPI > -1.49), severely dry (-1.5 > SPI > -1.99) and extremely dry conditions (SPI < -2.0). A drought event starts when SPI value reaches -1.0 and ends when SPI becomes positive again (McKee et al., 1993).

SPI Drought forecast-Gatun

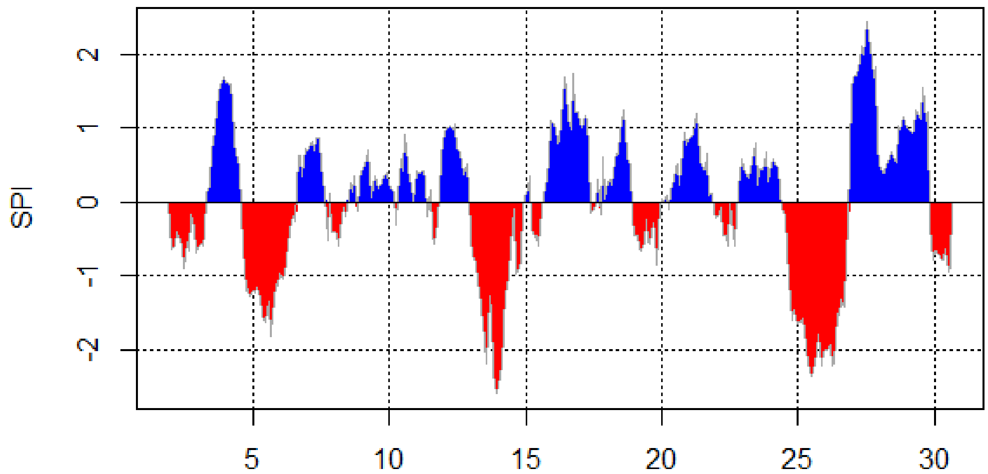

Figure 16: SPI Drought forecast. (N°1 Gatun)

The forecast for Hydro-meteorological network of Gatun is extremely moist and very moist; and severely dry at extremely dry.

SPI Drought forecast-Gamboa

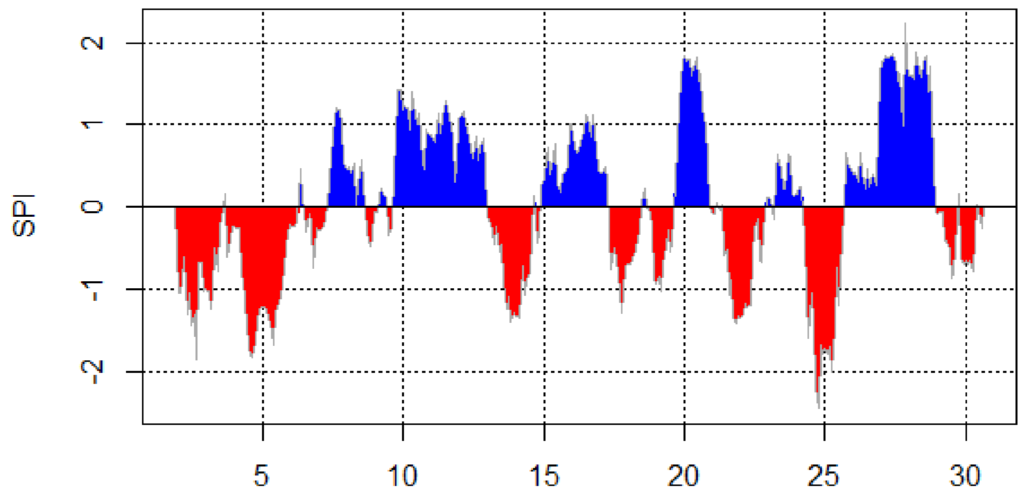

Figure 17: SPI Drought forecast. (N°4 Gamboa)

The forecast for Hydro-meteorological network of Gamboa I have the extremely moist and very moist; and severely dry at extremely dry.

SPI Drought forecast-Santa Rosa

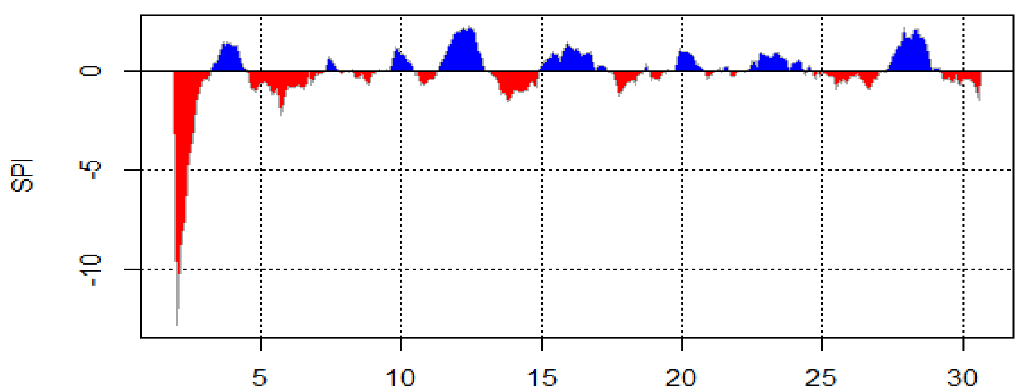

Figure 18: SPI Drought forecast. (N°5 Santa Rosa)

The forecast for Hydro-meteorological network of Santa Rosa, I have the extremely dry, it is because in for this network for the year 1985 we don't have register of precipitation only of temperature, but in general the SPI is extremely moist and very moist; and severely dry at extremely dry.

SPI Drought forecast-Barro Colorado.

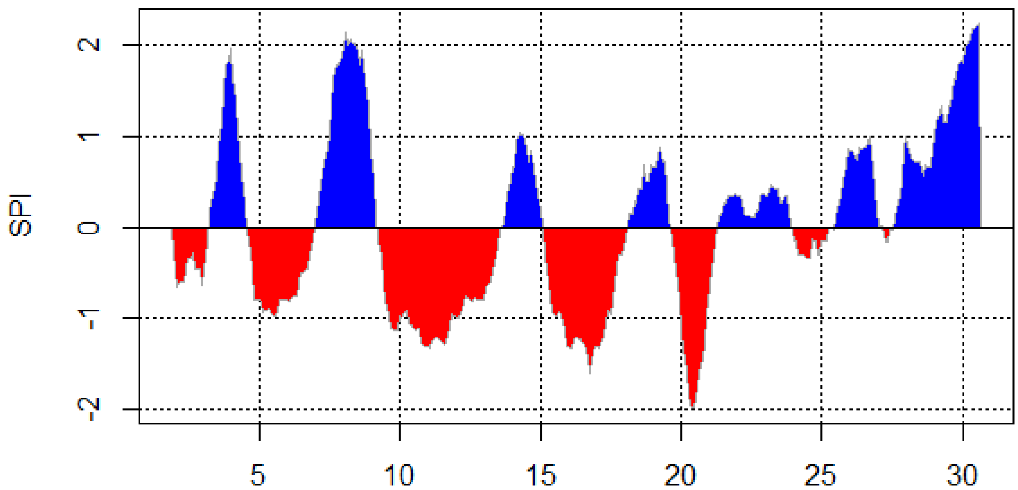

Figure 19: SPI Drought forecast. (N°7 Barro Colorado)

The forecast for Hydro-meteorological network of Barro Colorado I have the extremely moist and very moist; and moderately dry at extremely dry.

SPI Drought forecast-San Miguel.

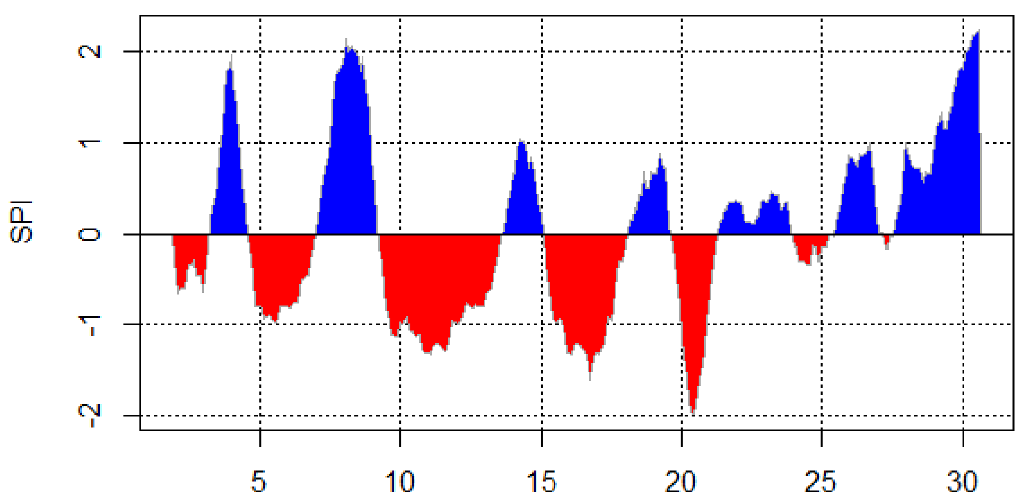

Figure 20: SPI Drought forecast. (N°16 San Miguel)

The forecast for Hydro-meteorological network of San Miguel, the SPI is extremely moist and very moist; and very pronounced the SPI moderately dry at extremely dry.

SPI Drought forecast- Diablo Heights

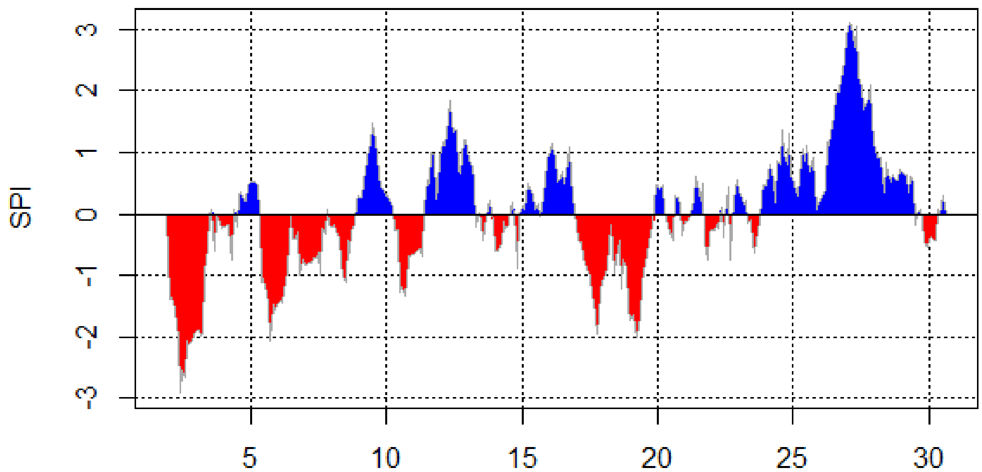

Figure 21: SPI Drought forecast. (N°27 Diablo Heights)

The forecast for Hydro-meteorological network of Diablo Heights, the SPI is extremely moist and very moist; and very pronounced the SPI moderately dry at extremely dry.

SPI Drought forecast- Empire Hill

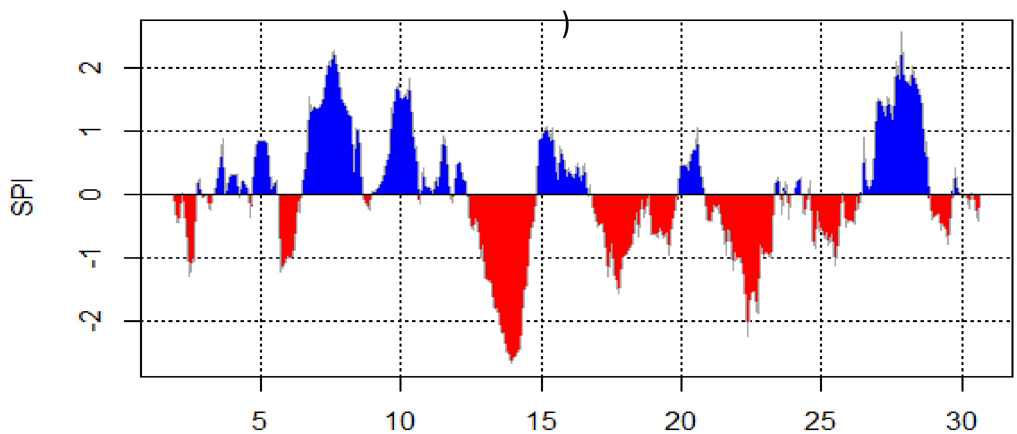

Figure 22: SPI Drought forecast. (N°29 Empire Hill)

The forecast for Hydro- meteorological network of Empire Hill, the SPI is extremely moist and very moist; and very pronounced the SPI moderately dry at extremely dry. Also the dry is more frequent.

5.4 Calculation of the Standardized Precipitation-Evapotranspiration Index (SPEI)-ANN.

A set of functions for computing potential evapotranspiration and several widely used drought indices including the Standardized Precipitation-Evapotranspiration Index (SPEI).

SPEI-ANN Drought forecast- Gatun.

The results for all of them networks models, the SPEI forecast it is show in the [**Table 2 to8].**

SPEI Drought forecast-Gatun

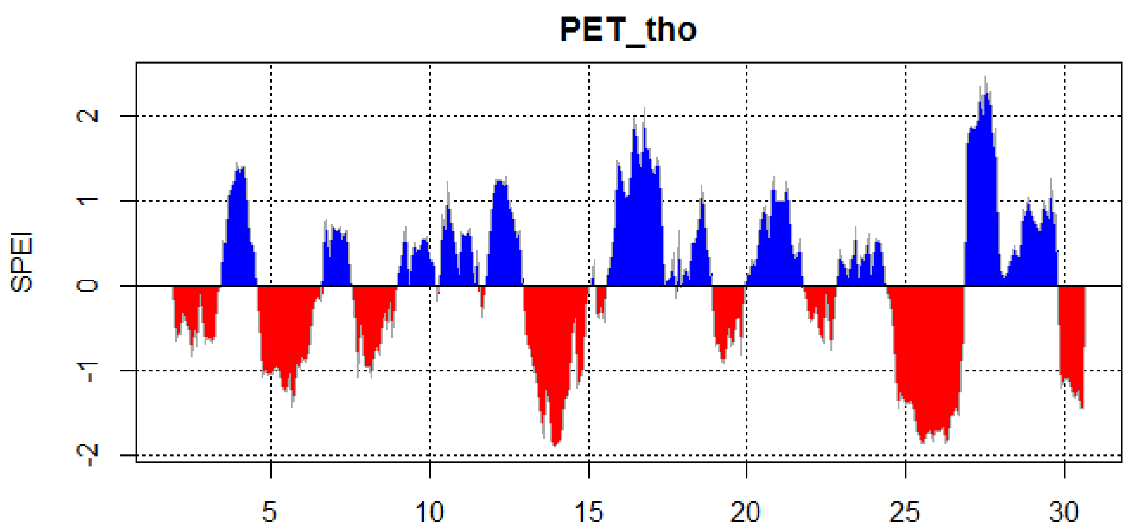

Figure 23: SPEI-ANN Drought forecast- Gatun

The forecast for Hydro-meteorological network of Gatun I have the extremely moist and very moist; and severely dry.

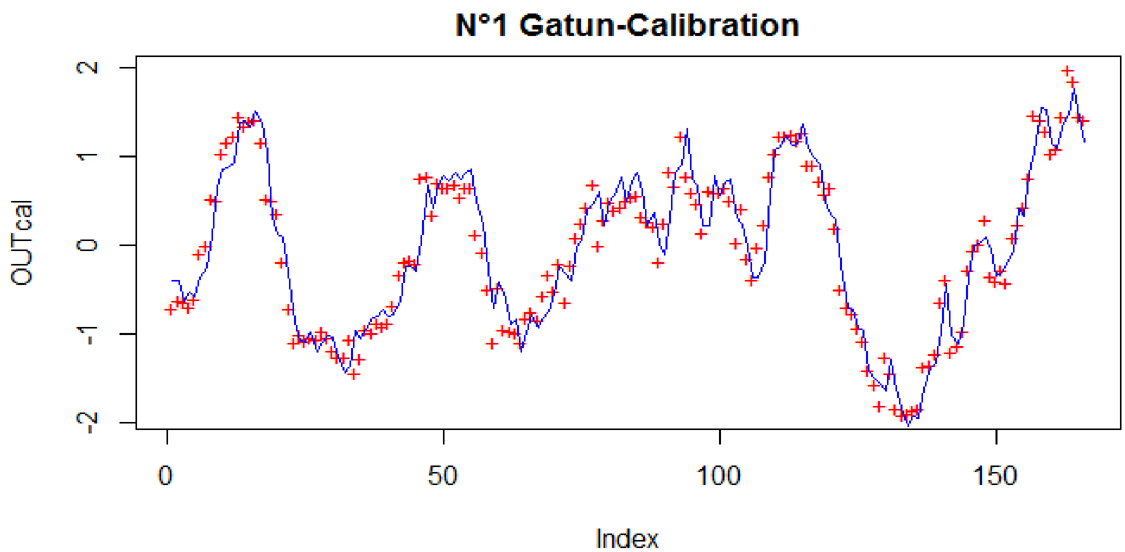

Figure 24: Gatun-Calibration.

A traditional split-sample Calibration test was conducted to Gatun the period 1985–1998 was used for Calibration.

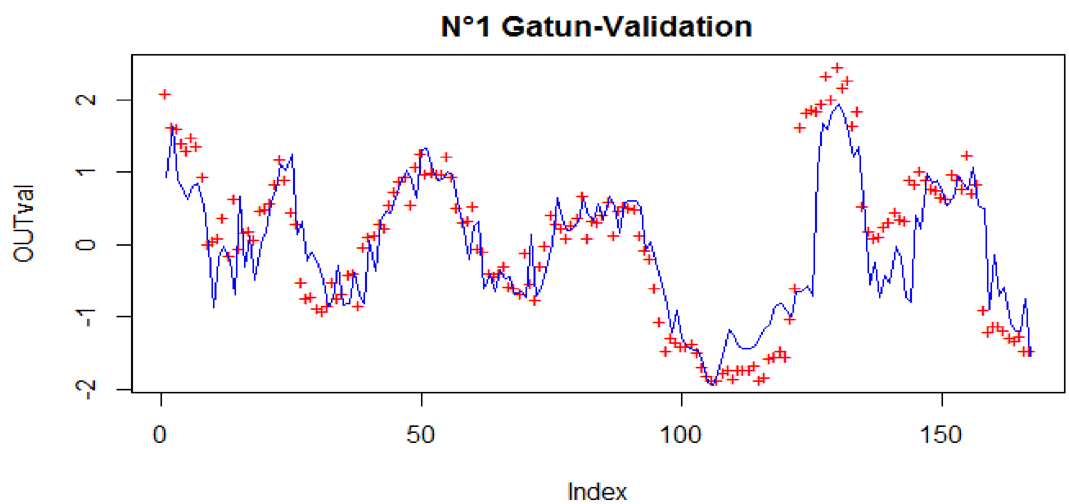

Figure 25: Gatun-Validation

A traditional split-sample validation test was conducted to Gatun; the period 1998–2014 was used for validation. The validation results both with respect to hydrograph shapes, are of the same level of accuracy as the calibration results.

Table 3: ANN model-Gatun.

	ANN Model (Gatun)	
The ANN performance	**Calibration**	**Validation**
ME	-0.00353	0.151
MAE	0.17	0.404
RMSE	0.217	0.604
NS	0.943	0.677
PI	0.499	-1.71

The discussion of this table will be in the Chapter 6 discussion.

SPEI-ANN Drought forecast- Gamboa.

SPEI Drought forecast-Gamboa

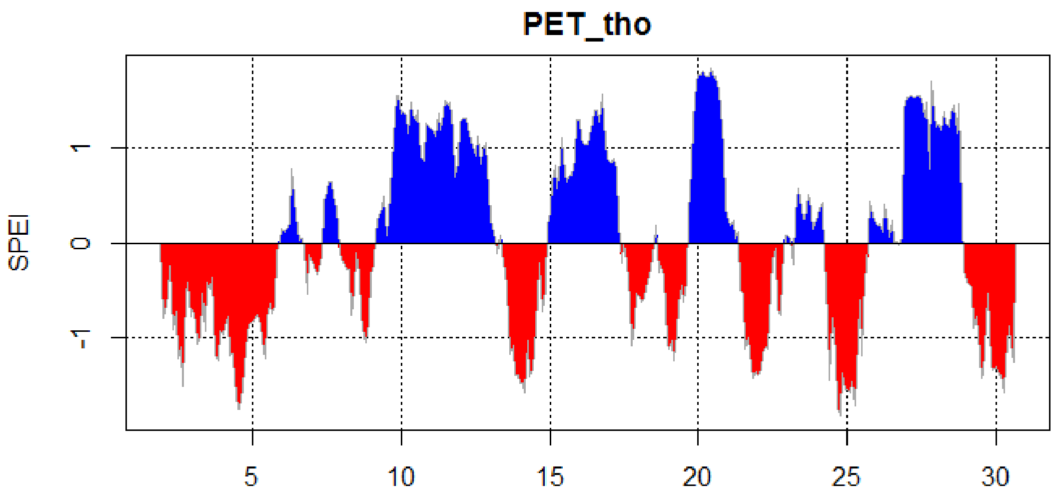

Figure 26: SPEI-ANN Drought forecast- Gamboa.

The forecast for Hydro-meteorological network of Gamboa I have the very moist; and severely dry.

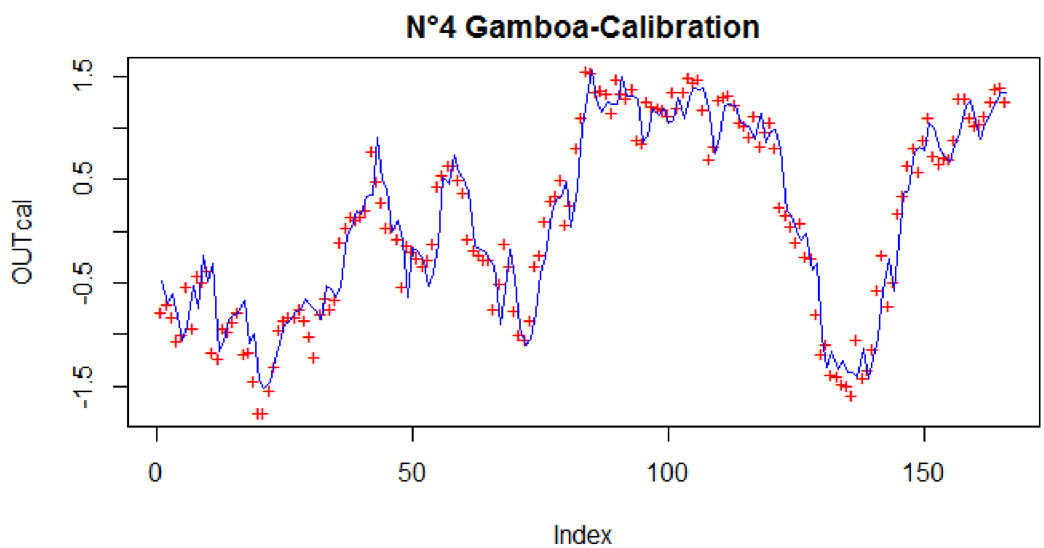

Figure 27: Gamboa-Calibration

A traditional split-sample Calibration test was conducted to Gamboa the period 1985–1998 was used for Calibration.

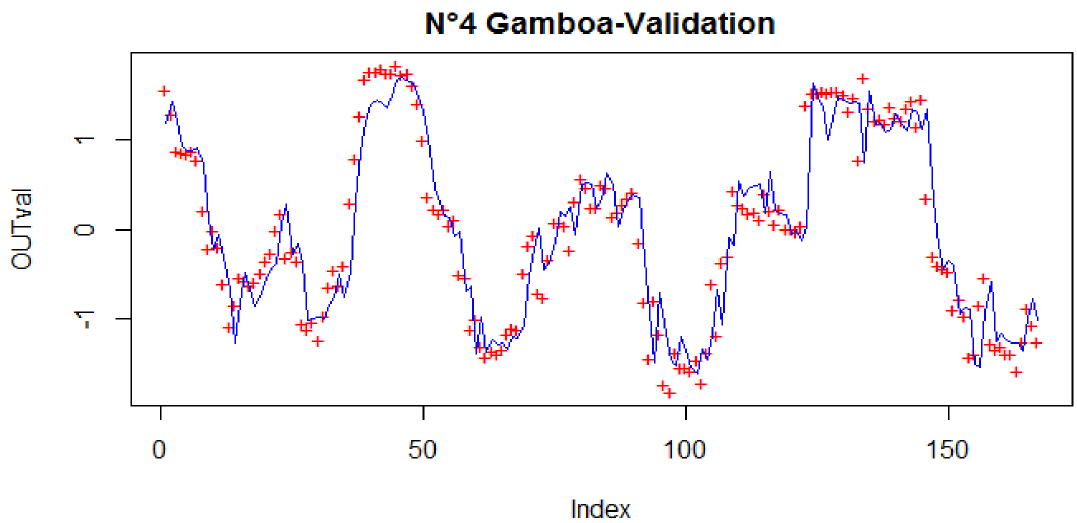

Figure 28: Gamboa-Validation

A traditional split-sample validation test was conducted to Gamboa; the period 1998–2014 was used for validation. The validation results both with respect to hydrograph shapes, are of the same level of accuracy as the calibration results.

Table 4: ANN model-Gamboa.

ANN Model (Gamboa)		
The ANN performance	**Calibration**	**Validation**
ME	-0.00363	-0.0136
MAE	0.177	0.281
RMSE	0.229	0.36
NS	0.94	0.875
PI	0.237	-0.127

The discussion of this table will be in the Chapter 6 discussion.

SPEI-ANN Drought forecast-Santa Rosa.

SPEI Drought forecast-Santa Rosa

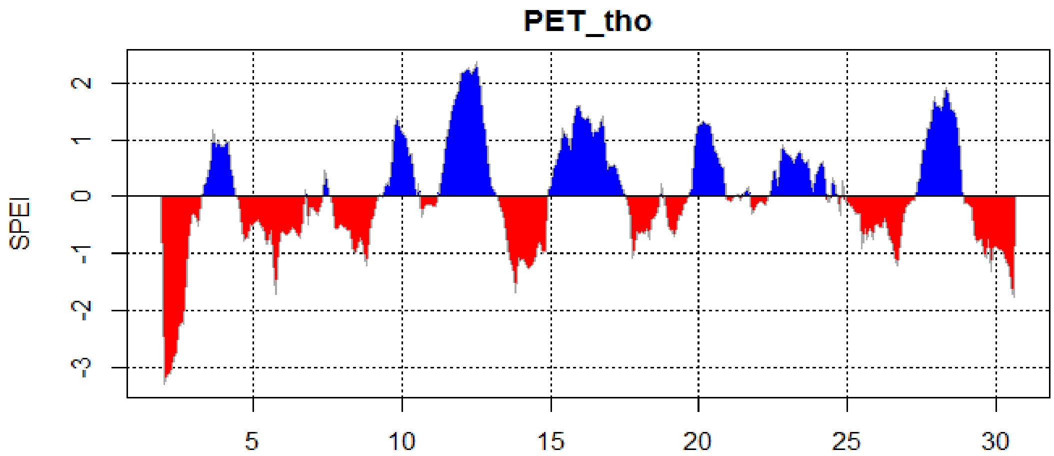

Figure 29: SPEI-ANN Drought forecast-Santa Rosa

The forecast for Hydro-meteorological network of Santa Rosa I have the very moist; and exceptionally dry in the beginning, because for the year 1985 in this weather station, no records of precipitation for this year, and moist severely dry.

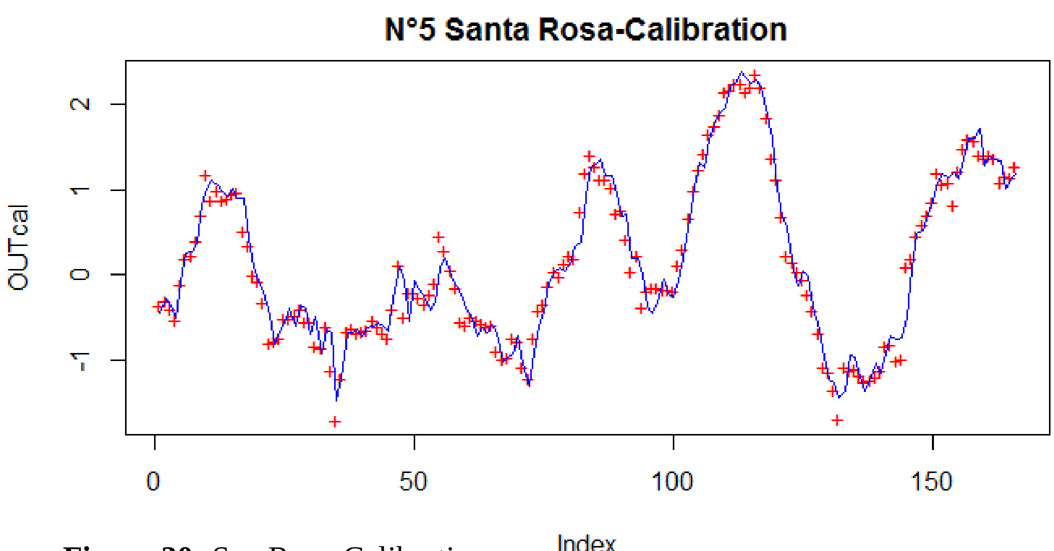

Figure 30: San Rosa-Calibration

A traditional split-sample Calibration test was conducted to Santa Rosa the period 1985–1998 was used for Calibration.

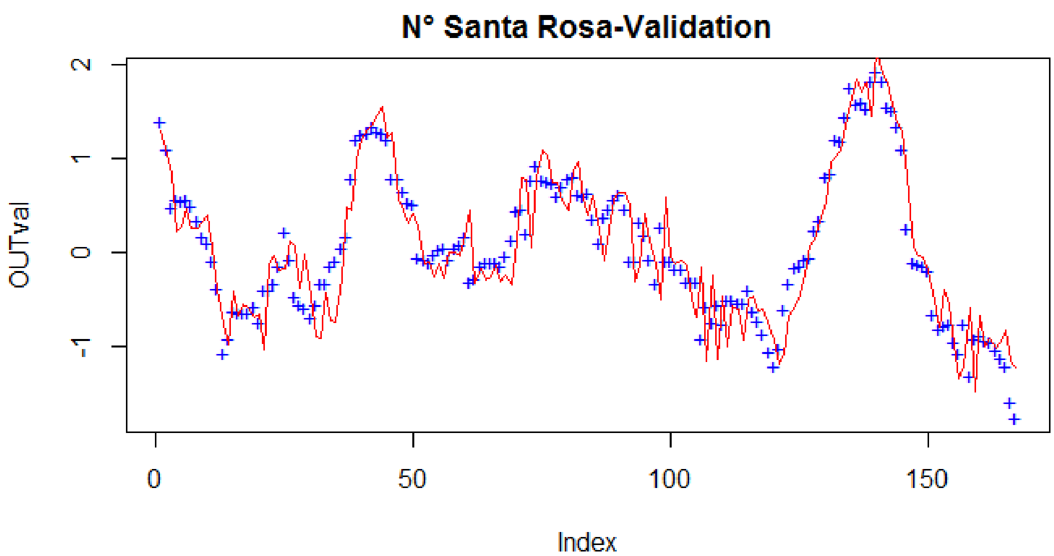

Figure 31: Santa Rosa-Validation

A traditional split-sample validation test was conducted to Santa Rosa; the period 1998–2014 was used for validation. The validation results both with respect to hydrograph shapes, are of the same level of accuracy as the calibration results.

Table 5: ANN model-Santa Rosa

ANN Model (Santa Rosa)		
The ANN performance	**Calibration**	**Validation**
ME	-0.0133	0.00359
MAE	0.12	0.24
RMSE	0.16	0.304
NS	0.972	0.843
PI	0.6	-0.65

The discussion of this table will be in the Chapter 6 discussion

SPEI-ANN Drought forecast-Barro Colorado.

SPEI Drought forecast-Barro Colorado

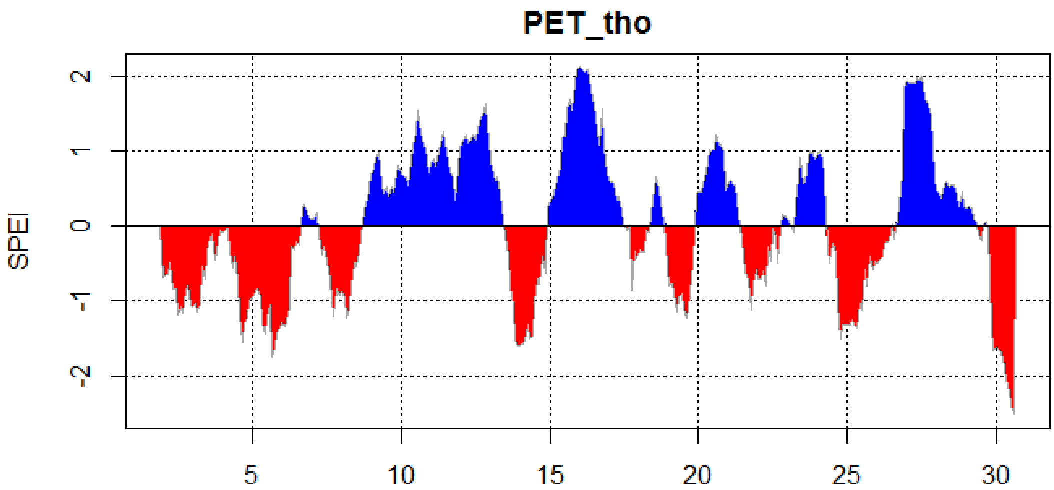

Figure 32: SPEI-ANN Drought forecast-Barro Colorado.

The forecast for Hydro-meteorological network of Barro Colorado I have the very moist; and severely dry during the last time.

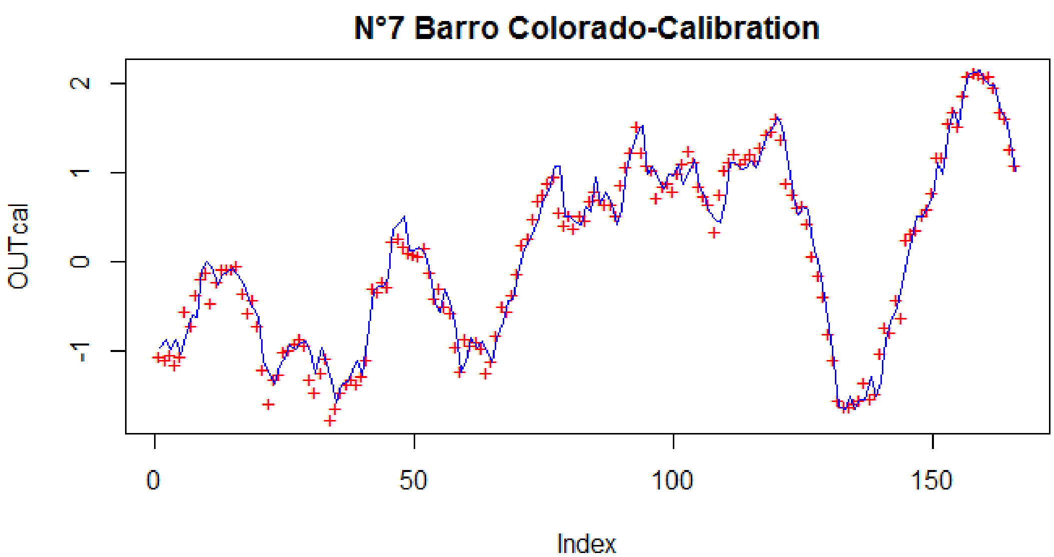

Figure 33: Barro Colorado-Calibration

A traditional split-sample Calibration test was conducted to Barro Colorado the period 1985–1998 was used for Calibration.

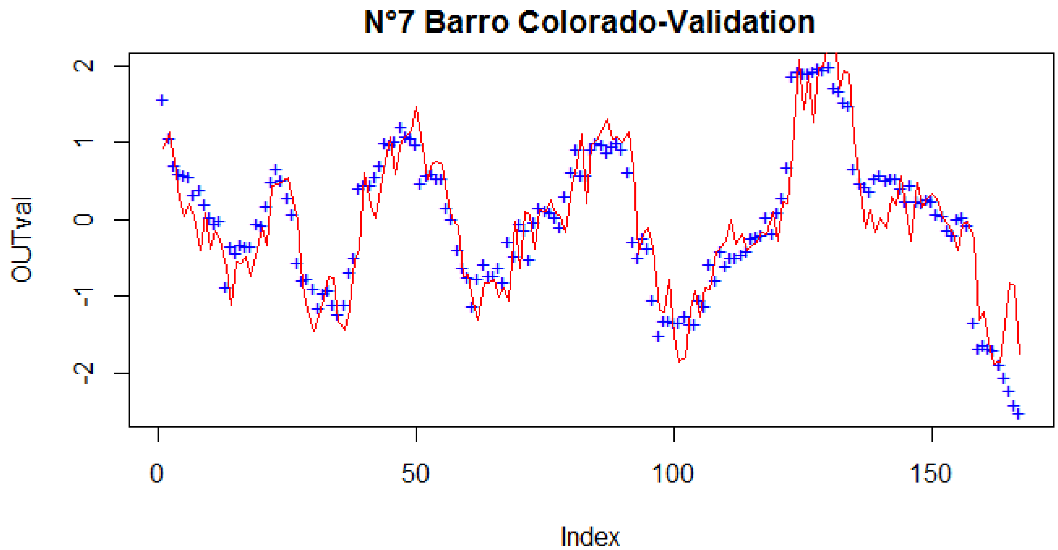

Figure 34: Barro Colorado-Validation

A traditional split-sample validation test was conducted to Barro Colorado; the period 1998–2014 was used for validation. The validation results both with respect to hydrograph shapes, are of the same level of accuracy as the calibration results.

Table 6: ANN model-Barro Colorado

ANN Model (Barro Colorado)		
The ANN performance	Calibration	Validation
ME	-0.0136	0.0601
MAE	0.124	0.278
RMSE	0.162	0.363
NS	0.975	0.849
PI	0.52	-0.631

The discussion of this table will be in the Chapter 6 discussion

SPEI-ANN Drought forecast-San Miguel.

SPEI Drought forecast-San Miguel

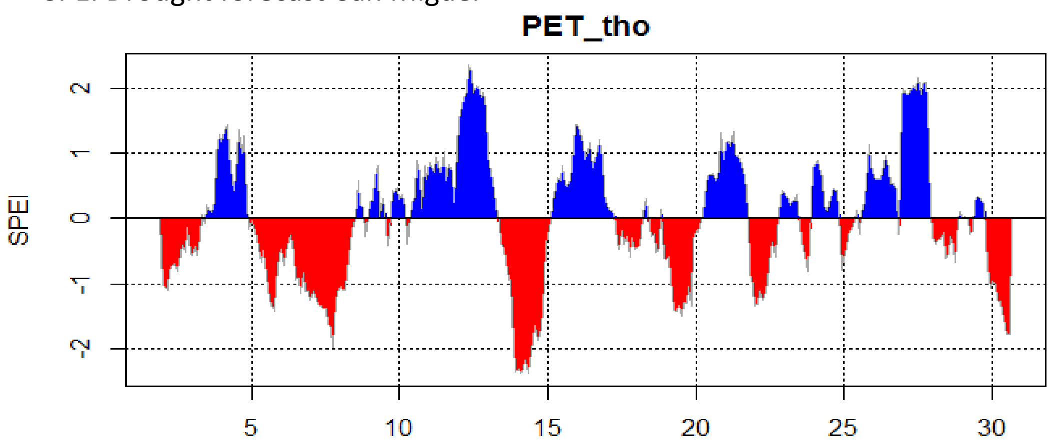

Figure 35: SPEI-ANN Drought forecast-San Miguel.

The forecast for Hydro-meteorological network of San Miguel, I have the very moist; and severely dry during the last time.

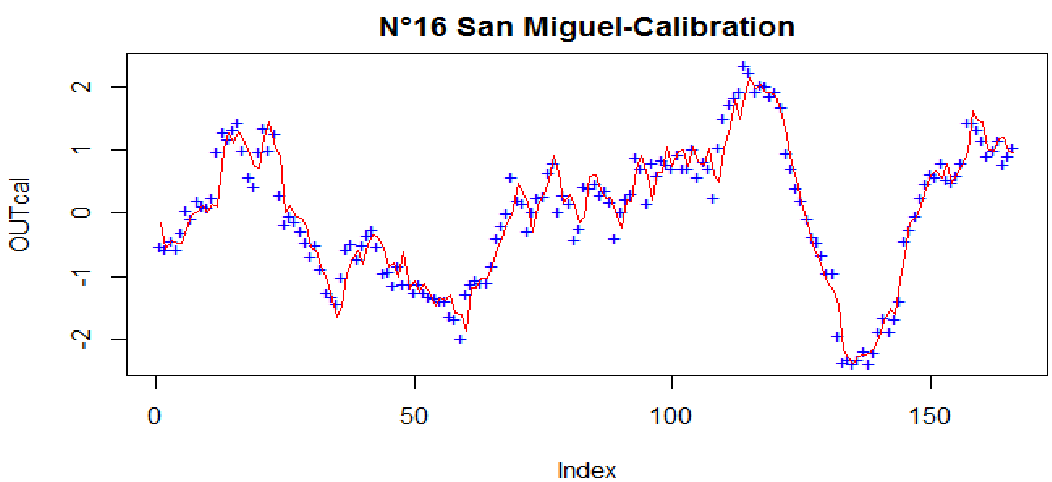

Figure 36: San Miguel-Calibration

A traditional split-sample Calibration test was conducted to San Miguel the period 1985–1998 was used for Calibration

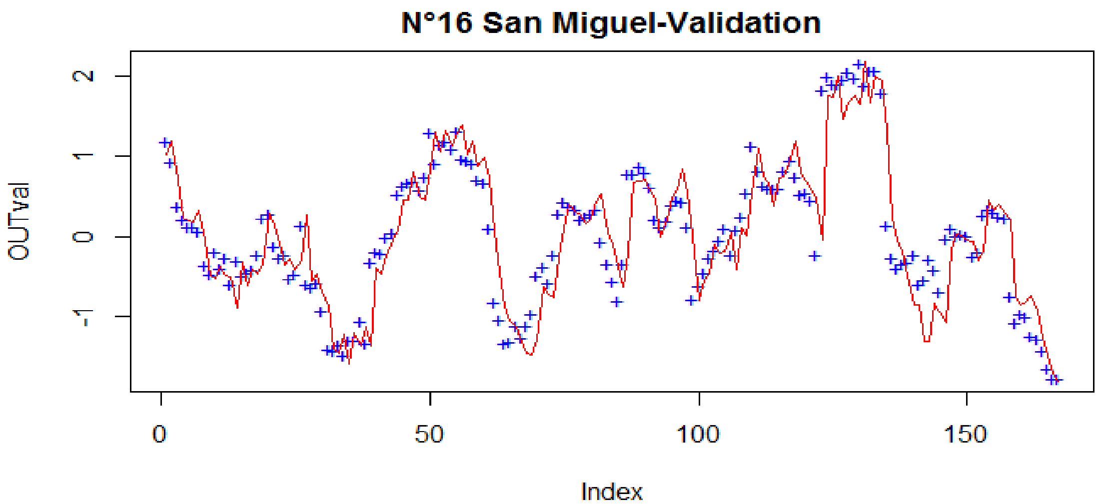

Figure 37: San Miguel-Validation

A traditional split-sample validation test was conducted to San Miguel; the period 1998–2014 was used for validation. The validation results both with respect to hydrograph shapes, are of the same level of accuracy as the calibration results.

Table 7: ANN model-San Miguel

ANN Model (San Miguel)		
The ANN performance	**Calibration**	**Validation**
ME	0.000321	0.0243
MAE	0.191	0.285
RMSE	0.256	0.392
NS	0.944	0.798
PI	0.346	-0.196

The discussion of this table will be in the Chapter 6 discussion.

SPEI-ANN Drought forecast-Diablo Heightsl

SPEI Drought forecast-Diablo Heights

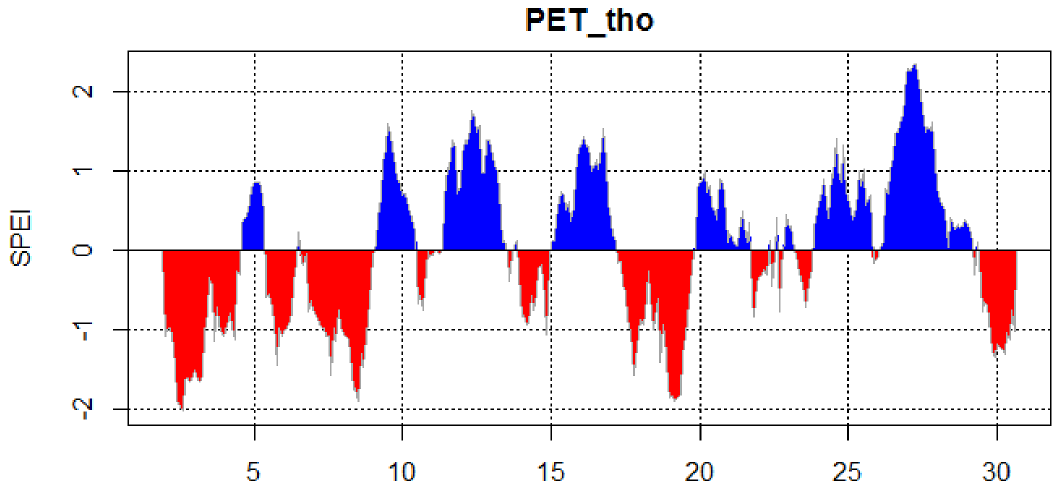

Figure 38: SPEI-ANN Drought forecast-Diablo Heights.

The forecast for Hydro-meteorological network of Diablo Heights, I have the very moist; and severely dry during the last time.

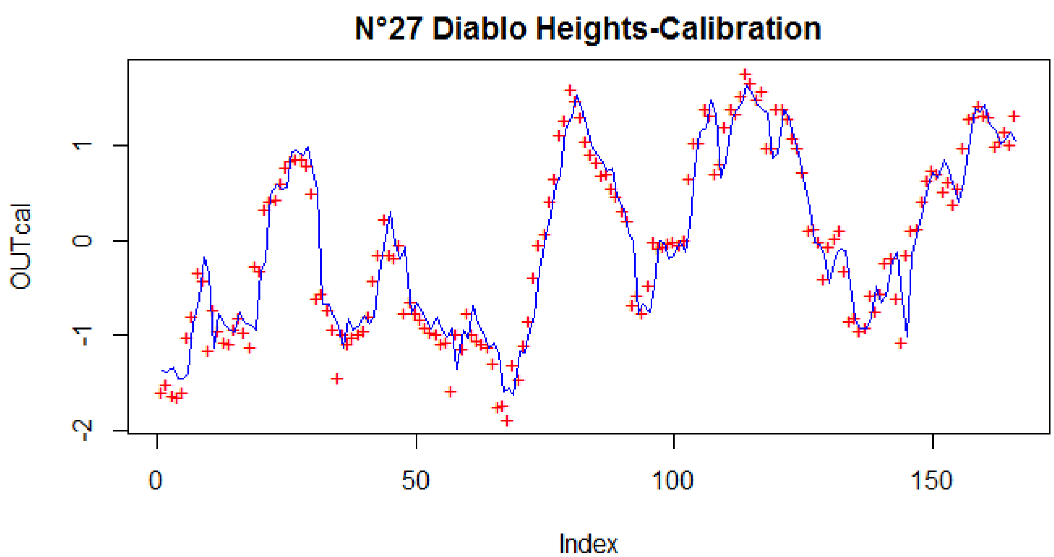

Figure 39: Diablo Heights-Calibration

A traditional split-sample Calibration test was conducted to Diablo Heights; the period 1985–1998 was used for Calibration

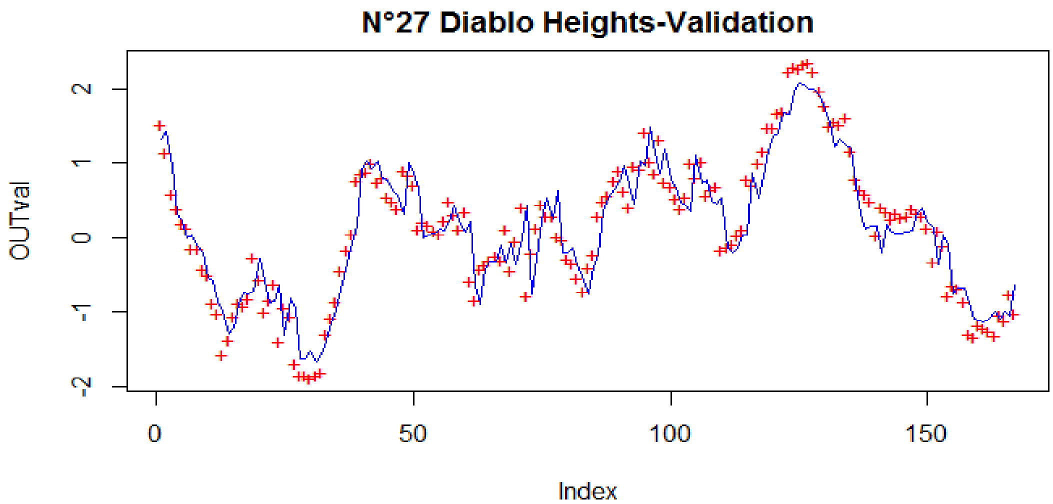

Figure 40: Diablo Heights-Validation

A traditional split-sample validation test was conducted to Diablo Heights; the period 1998–2014 was used for validation. The validation results both with respect to hydrograph shapes, are of the same level of accuracy as the calibration results.

Table 8: ANN model- Diablo Heights

ANN Model (Diablo Heights)		
The ANN performance	**Calibration**	**Validation**
ME	-0.00794	0.0167
MAE	0.201	0.253
RMSE	0.272	0.318
NS	0.917	0.887
PI	0.189	-0.0408

The discussion of this table will be in the Chapter 6 discussion

SPEI-ANN Drought forecast-Empire Hill.

SPEI Drought forecast-Empire Hill

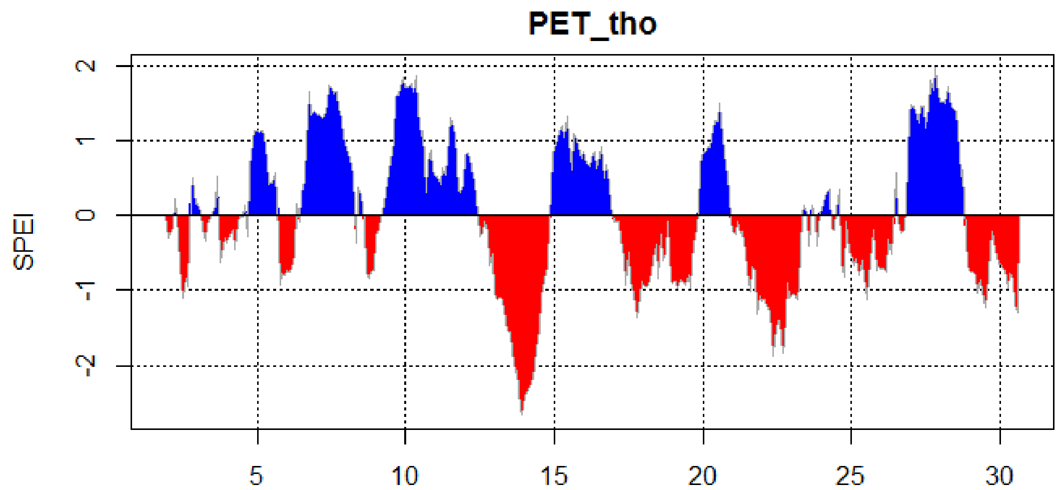

Figure 41: SPEI-ANN Drought forecast-Empire Hill.

The forecast for Hydro-meteorological network of Empire Hill, I have the very moist; and severely dry during the last time.

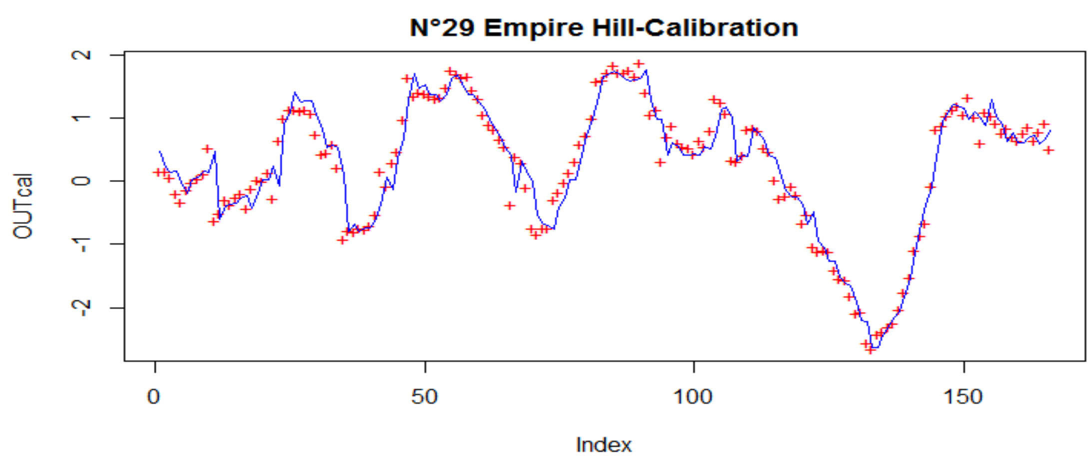

Figure 42: Empire Hill-Calibration

A traditional split-sample Calibration test was conducted to Empire Hill; the period 1985–1998 was used for Calibration

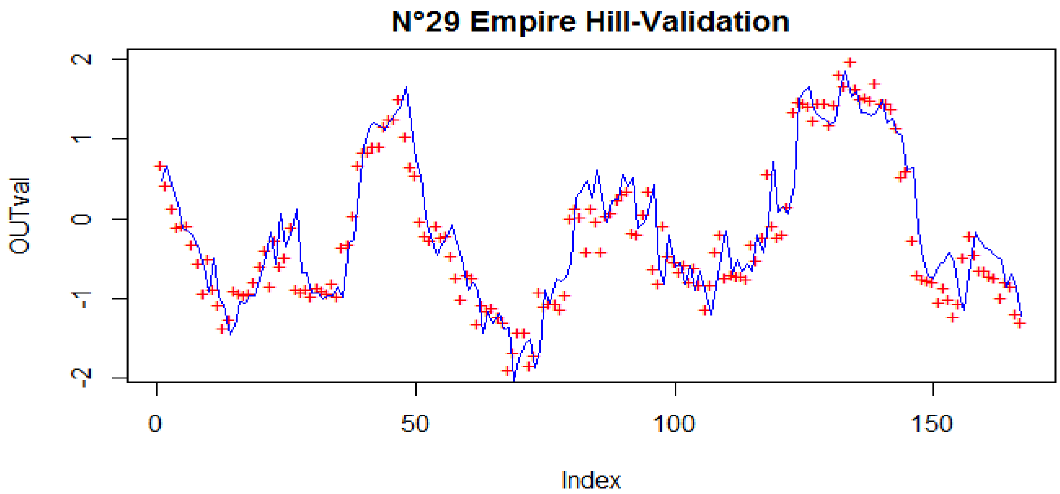

Figure 43: Empire Hill-Validation

A traditional split-sample validation test was conducted to Empire Hill; the period 1998–2014 was used for validation. The validation results both with respect to hydrograph shapes, are of the same level of accuracy as the calibration results.

Table 9: ANN model-Empire Hill

ANN Model (Empire Hill)		
The ANN performance	**Calibration**	**Validation**
ME	-0.00988	-0.0694
MAE	0.185	0.272
RMSE	0.266	0.35
NS	0.934	0.847
PI	0.265	-0.174

The discussion of this table will be in the Chapter 6 discussion

Table 10: The Standardized Precipitation-Evapotranspiration Index (SPEI) Drought forecast

The ANN performance		SPEI-ANN Drought forecast.						
		Gatun	**Gamboa**	**Santa Rosa**	**Barro Colorado**	**San Miguel**	**Diablo Heights**	**Empire Hill**
Calibration	**ME**	-0.00353	-0.00363	-0.0133	-0.0136	0.000321	-0.00794	-0.00988
	MAE	0.17	0.177	0.12	0.124	0.191	0.201	0.185
	RMSE	0.217	0.229	0.16	0.162	0.256	0.272	0.266
	NS	0.943	0.94	0.972	0.975	0.944	0.917	0.934
	PI	0.499	0.237	0.6	0.52	0.346	0.189	0.265
Validation	**ME**	0.151	-0.0136	0.00359	0.0601	0.0243	0.0167	-0.0694
	MAE	0.404	0.281	0.24	0.278	0.285	0.253	0.272
	RMSE	0.604	0.36	0.304	0.363	0.392	0.318	0.35
	NS	0.677	0.875	0.843	0.849	0.798	0.887	0.847
	PI	-1.71	-0.127	-0.65	-0.631	-0.196	-0.0408	-0.174

CHAPTER 6: DISCUSSION

According with the summary of Residuals location the best model for **ME** Calibration is San Miguel and **ME** Validation are: Santa Rosa, Diablo Heights, San Miguel,Barro Colorado and Gatun.

The best models for **MAE** Calibration all the model are good, but the model with value more close to 0 it is the Santa Rosa And **MAE** Validation all the model is good and the model more close to 0 it is the Santa Rosa.

The best models for **RMSE** Calibration all the model are good, but the model with value more close to 0 it is the Santa Rosa And **RMSE** Validation all the model is good and the model more close to 0 it is the Santa Rosa.

The best models for **NS** Calibration all the model are good, but the models with value more close to ≈1 it is the Diablo Heights. And **NS** Validation all the model is good and the model more close to ≈1 it is the Diablo Heights

The best models for **PI** Calibration are all of them because they are all good, but the model with values more close to ≈1 is the Santa Rosa. And **PI** Validation all the model is I get the values negative.

A reduction in precipitation due to climate change will affect the severity of droughts. The influence of a reduction in precipitation on future drought conditions is identified by SPEI and SPI; and in the all the Figures shows the evolution of both indices were calculated using real data base of rainfall during the period (1985-2014), Both the modeled SPI and SPEI showed an increase in the duration and magnitude of droughts. However, climate change scenarios also show a temperature increase during the 20th century. In some cases, such as the greenhouse gas emissions scenario, the models predict a temperature increase that might exceed 28°C with respect to the 1985−2014 average.

En this thesis clearly shows an increase in the duration and magnitude of droughts at the end of the century, in the Panama Canal, which is directly related to the temperature increase for the consequences of climate change. According with the SPEI-SPI values indicate in the Figure (15-22,25,28,31,34,37,40), I can say that the Drought Index in the Panamanian Basin, for the period of 1985 to 2014 Panama was a very moist and extremely dry period because it is a tropical country with high temperature and precipitation. The meteorologists blame the drought on the weather phenomenon known as El Niño. El Niño is a period of warmer than average waters in the Pacific Ocean off the coast of Central and South America

CHAPTER 7: CONCLUSION

In this study I studied the drought index SPEI-SPI, in Panama Canal basin. The rainfall was for the period of 01.01.1985 to 31.08.2014. The selected drought indexes based on different variables show that in Panama Canal has a drought periods, very moist to extremely dry.

According with the summary of Residuals location all the model in general are good, an exception the PI in the case of Validation, because I got the negatives values.

The droughts in the Panama Canal are increasing and this it is bad because the water is the driving force of the Panama Canal, a drought might force it to limit the drafts of container vessels traversing the waterway, reducing the amount of cargo liners can carry. The Panama Canal is not only a landmark in terms of maritime transit, but in terms of environmental protections associated with a massive infrastructure development.

The SPEI fulfils the requirements of a drought index since its multi-scalar character enables it to be used by different scientific disciplines to detect, monitor and analyze droughts; the SPEI can measure drought severity according to its intensity and duration, and can identify the onset and end of drought episodes. The SPEI allows comparison of drought severity through time and space, since it can be calculated over a wide range of climates, as can the SPI. In the Panama Canal (1985-2014) indicated that drought indices are between extremely moist and extremely dry; with the different that now the values of drought depend on the months with longer periods of rainfall.

Now in the Panama Canal basin has problem with drought, Evan in all the Republic of Panama and many country in center America.

All these requirements are met by the SPEI-SPI. However, a crucial advantage of the SPEI over on drought severity is that its multi-scalar characteristics enable identification of different drought types and impacts in the context of global warming.

8. REFERENCES

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Freely accessible databases

Canal de Panama (http://www.pancanal.com/eng/)

9. APPENDIX

Table 11 Input database, "Panama Canal Authority".

					RATE RAINFALL (mm)				
YEAR	**MONTH**	**GATÚN**	**GAMBOA**	**SANTA ROSA**	**BARRO COLORADO**	**SAN MIGUEL**	**DIABLO HEIGHTS**	**EMPIRE HILL**	**T °C**
1985	1	172.72	12.7	0	25.4	114.3	22.86	7.62	26
1985	2	33.02	7.62	0	25.4	81.28	0	7.62	27
1985	3	20.32	17.78	0	22.86	132.08	22.86	25.4	27
1985	4	17.78	7.62	0	5.08	121.92	93.98	43.18	27
1985	5	226.06	292.1	0	287.02	401.32	119.38	287.02	27
1985	6	271.78	259.08	0	203.2	480.06	281.94	388.62	26
1985	7	330.2	233.68	0	251.46	256.54	93.98	309.88	26
1985	8	256.54	193.04	0	236.22	198.12	96.52	170.18	26
1985	9	299.72	350.52	0	162.56	368.3	251.46	266.7	26
1985	10	259.08	149.86	0	358.14	401.32	175.26	149.86	26
1985	11	340.36	111.76	0	195.58	259.08	177.8	165.1	26
1985	12	337.82	157.48	0	309.88	396.24	160.02	144.78	26
1986	1	30.48	0	7.62	60.96	167.64	2.54	2.54	26
1986	2	35.56	12.7	15.24	7.62	27.94	5.08	5.08	26
1986	3	22.86	63.5	60.96	45.72	93.98	15.24	68.58	27
1986	4	149.86	109.22	106.68	96.52	393.7	76.2	172.72	27
1986	5	203.2	63.5	81.28	109.22	497.84	43.18	91.44	27
1986	6	228.6	355.6	421.64	226.06	528.32	104.14	269.24	27
1986	7	193.04	121.92	195.58	86.36	193.04	119.38	170.18	27
1986	8	439.42	236.22	170.18	297.18	426.72	114.3	292.1	26

1986	9	251.46	175.26	243.84	256.54	500.38	360.68	243.84	26
1986	10	497.84	508	464.82	452.12	299.72	182.88	571.5	25
1986	11	238.76	129.54	213.36	185.42	424.18	190.5	193.04	26
1986	12	142.24	17.78	63.5	132.08	114.3	137.16	27.94	26
1987	1	30.48	0	5.08	5.08	96.52	0	0	25
1987	2	45.72	12.7	5.08	53.34	142.24	7.62	10.16	28
1987	3	5.08	2.54	15.24	0	20.32	0	0	28
1987	4	254	185.42	363.22	231.14	650.24	106.68	162.56	29
1987	5	525.78	205.74	276.86	391.16	802.64	302.26	177.8	28
1987	6	269.24	287.02	441.96	162.56	459.74	193.04	327.66	28
1987	7	464.82	287.02	317.5	309.88	434.34	246.38	231.14	28
1987	8	447.04	261.62	337.82	441.96	403.86	149.86	340.36	28
1987	9	530.86	274.32	495.3	340.36	515.62	182.88	408.94	27
1987	10	574.04	271.78	332.74	337.82	429.26	345.44	259.08	27
1987	11	360.68	172.72	279.4	287.02	965.2	172.72	233.68	28
1987	12	269.24	73.66	83.82	182.88	426.72	81.28	93.98	26
1988	1	30.48	0	30.48	10.16	50.8	0	0	26
1988	2	78.74	5.08	5.08	27.94	287.02	5.08	12.7	26
1988	3	2.54	5.08	5.08	7.62	127	10.16	2.54	27
1988	4	35.56	22.86	55.88	22.86	99.06	22.86	20.32	27
1988	5	162.56	172.72	190.5	246.38	429.26	261.62	269.24	27
1988	6	190.5	223.52	228.6	195.58	297.18	396.24	325.12	26
1988	7	345.44	137.16	276.86	137.16	800.1	165.1	200.66	26
1988	8	154.94	238.76	172.72	137.16	612.14	292.1	325.12	26
1988	9	309.88	238.76	314.96	297.18	172.72	200.66	259.08	26
1988	10	355.6	340.36	347.98	373.38	635	309.88	563.88	25
1988	11	309.88	276.86	246.38	251.46	254	177.8	320.04	26

1988	12	182.88	68.58	58.42	231.14	93.98	137.16	160.02	26
1989	1	12.7	2.54	12.7	5.08	134.62	27.94	10.16	26
1989	2	53.34	7.62	25.4	53.34	220.98	5.08	12.7	26
1989	3	30.48	0	20.32	22.86	0	5.08	5.08	26
1989	4	17.78	0	0	7.62	0	0	0	27
1989	5	119.38	106.68	205.74	53.34	320.04	144.78	121.92	27
1989	6	160.02	208.28	109.22	132.08	419.1	116.84	175.26	26
1989	7	337.82	241.3	294.64	228.6	546.1	154.94	220.98	26
1989	8	320.04	287.02	276.86	236.22	342.9	264.16	340.36	26
1989	9	111.76	233.68	149.86	109.22	325.12	147.32	137.16	26
1989	10	508	401.32	180.34	381	502.92	190.5	238.76	26
1989	11	424.18	429.26	480.06	330.2	477.52	309.88	347.98	26
1989	12	127	91.44	91.44	187.96	297.18	86.36	142.24	26
1990	1	48.26	35.56	17.78	15.24	177.8	35.56	30.48	26
1990	2	2.54	0	5.08	7.62	30.48	10.16	2.54	26
1990	3	48.26	7.62	20.32	50.8	152.4	7.62	12.7	26
1990	4	154.94	22.86	38.1	157.48	142.24	53.34	60.96	27
1990	5	345.44	314.96	266.7	457.2	424.18	251.46	370.84	27
1990	6	228.6	83.82	114.3	129.54	274.32	233.68	101.6	27
1990	7	368.3	203.2	307.34	327.66	269.24	259.08	391.16	27
1990	8	302.26	203.2	238.76	223.52	393.7	167.64	370.84	26
1990	9	561.34	302.26	335.28	375.92	314.96	147.32	345.44	26
1990	10	490.22	381	396.24	421.64	632.46	226.06	525.78	26
1990	11	292.1	269.24	264.16	261.62	274.32	137.16	271.78	27
1990	12	330.2	208.28	157.48	160.02	193.04	121.92	190.5	27
1991	1	58.42	27.94	12.7	15.24	66.04	10.16	38.1	27
1991	2	20.32	0	0	25.4	111.76	2.54	7.62	27

1991	3	111.76	20.32	27.94	162.56	83.82	20.32	53.34	28
1991	4	66.04	68.58	116.84	17.78	162.56	63.5	101.6	28
1991	5	424.18	360.68	378.46	314.96	500.38	289.56	495.3	28
1991	6	228.6	284.48	368.3	203.2	274.32	228.6	231.14	28
1991	7	134.62	279.4	276.86	274.32	220.98	269.24	302.26	28
1991	8	254	274.32	177.8	233.68	274.32	91.44	368.3	28
1991	9	431.8	381	276.86	302.26	581.66	335.28	431.8	27
1991	10	218.44	365.76	297.18	284.48	314.96	208.28	401.32	27
1991	11	574.04	185.42	236.22	393.7	767.08	238.76	241.3	27
1991	12	45.72	45.72	91.44	68.58	167.64	45.72	71.12	27
1992	1	30.48	10.16	2.54	33.02	96.52	0	0	28
1992	2	5.08	5.08	0	5.08	68.58	7.62	2.54	28
1992	3	22.86	0	2.54	0	71.12	0	2.54	28
1992	4	292.1	99.06	167.64	152.4	436.88	22.86	78.74	29
1992	5	513.08	187.96	236.22	467.36	868.68	215.9	132.08	28
1992	6	170.18	373.38	353.06	358.14	406.4	170.18	508	28
1992	7	254	378.46	279.4	243.84	353.06	220.98	261.62	27
1992	8	355.6	187.96	271.78	320.04	622.3	279.4	190.5	27
1992	9	388.62	284.48	304.8	457.2	332.74	279.4	228.6	27
1992	10	317.5	274.32	213.36	426.72	271.78	307.34	375.92	26
1992	11	340.36	144.78	177.8	363.22	421.64	274.32	213.36	25
1992	12	233.68	50.8	66.04	167.64	320.04	129.54	45.72	26
1993	1	121.92	109.22	96.52	109.22	193.04	25.4	99.06	25
1993	2	48.26	5.08	5.08	25.4	48.26	0	5.08	26
1993	3	78.74	66.04	66.04	55.88	340.36	73.66	17.78	26
1993	4	350.52	127	213.36	134.62	495.3	66.04	88.9	27
1993	5	162.56	162.56	205.74	165.1	292.1	330.2	172.72	27

1993	6	238.76	365.76	365.76	220.98	535.94	167.64	558.8	26
1993	7	322.58	231.14	332.74	309.88	284.48	373.38	302.26	26
1993	8	274.32	223.52	228.6	226.06	226.06	160.02	241.3	26
1993	9	419.1	523.24	523.24	510.54	462.28	220.98	523.24	26
1993	10	325.12	388.62	408.94	414.02	647.7	213.36	340.36	26
1993	11	393.7	340.36	304.8	474.98	396.24	223.52	365.76	25
1993	12	261.62	83.82	73.66	243.84	363.22	101.6	124.46	26
1994	1	30.48	22.86	25.4	78.74	83.82	2.54	20.32	26
1994	2	20.32	15.24	2.54	0	88.9	2.54	2.54	26
1994	3	43.18	53.34	10.16	60.96	218.44	35.56	50.8	26
1994	4	116.84	15.24	22.86	43.18	83.82	48.26	50.8	27
1994	5	386.08	363.22	226.06	335.28	601.98	241.3	320.04	26
1994	6	495.3	238.76	172.72	345.44	660.4	165.1	231.14	26
1994	7	233.68	190.5	195.58	416.56	391.16	104.14	111.76	26
1994	8	515.62	266.7	299.72	403.86	579.12	205.74	236.22	26
1994	9	233.68	330.2	284.48	294.64	299.72	175.26	223.52	26
1994	10	198.12	368.3	490.22	327.66	330.2	279.4	492.76	25
1994	11	381	482.6	289.56	472.44	807.72	332.74	416.56	25
1994	12	124.46	81.28	40.64	43.18	226.06	76.2	20.32	26
1995	1	264.16	17.78	0	175.26	292.1	0	10.16	26
1995	2	12.7	2.54	0	33.02	48.26	5.08	0	26
1995	3	45.72	30.48	5.08	10.16	157.48	50.8	22.86	26
1995	4	121.92	121.92	165.1	144.78	259.08	58.42	137.16	27
1995	5	312.42	302.26	345.44	403.86	383.54	233.68	276.86	26
1995	6	246.38	297.18	314.96	444.5	645.16	368.3	317.5	26
1995	7	403.86	259.08	355.6	304.8	637.54	231.14	309.88	26
1995	8	256.54	226.06	426.72	220.98	266.7	180.34	187.96	26

1995	9	170.18	332.74	401.32	223.52	401.32	327.66	172.72	26
1995	10	350.52	264.16	586.74	322.58	314.96	264.16	254	26
1995	11	535.94	294.64	429.26	297.18	510.54	134.62	383.54	26
1995	12	388.62	132.08	198.12	299.72	861.06	109.22	63.5	26
1996	1	414.02	233.68	256.54	381	792.48	160.02	182.88	26
1996	2	139.7	17.78	12.7	106.68	347.98	91.44	15.24	26
1996	3	60.96	40.64	55.88	86.36	294.64	30.48	15.24	26
1996	4	93.98	60.96	88.9	25.4	264.16	96.52	35.56	27
1996	5	254	256.54	256.54	447.04	660.4	388.62	264.16	27
1996	6	289.56	238.76	322.58	480.06	436.88	246.38	137.16	26
1996	7	203.2	215.9	312.42	231.14	266.7	226.06	226.06	26
1996	8	218.44	309.88	406.4	299.72	340.36	167.64	187.96	26
1996	9	119.38	256.54	236.22	307.34	284.48	137.16	223.52	26
1996	10	256.54	320.04	231.14	365.76	281.94	256.54	248.92	26
1996	11	612.14	309.88	299.72	515.62	845.82	287.02	205.74	26
1996	12	198.12	38.1	50.8	111.76	619.76	111.76	99.06	26
1997	1	45.72	12.7	5.08	20.32	96.52	134.62	7.62	26
1997	2	15.24	5.08	0	43.18	165.1	25.4	0	27
1997	3	0	2.54	0	2.54	45.72	0	0	26
1997	4	10.16	12.7	45.72	20.32	96.52	12.7	15.24	27
1997	5	241.3	317.5	213.36	327.66	518.16	200.66	162.56	28
1997	6	116.84	152.4	261.62	287.02	271.78	297.18	127	27
1997	7	116.84	241.3	238.76	170.18	246.38	187.96	208.28	27
1997	8	160.02	182.88	213.36	205.74	236.22	96.52	185.42	27
1997	9	462.28	134.62	297.18	182.88	210.82	233.68	185.42	26
1997	10	213.36	383.54	223.52	231.14	246.38	299.72	195.58	27
1997	11	215.9	254	264.16	279.4	167.64	317.5	195.58	27

1997	12	20.32	15.24	5.08	2.54	76.2	10.16	10.16	27
1998	1	15.24	0	2.54	15.24	91.44	0	0	27
1998	2	40.64	2.54	5.08	30.48	76.2	25.4	2.54	27
1998	3	45.72	2.54	0	40.64	73.66	0	0	28
1998	4	520.7	218.44	58.42	215.9	317.5	48.26	43.18	28
1998	5	292.1	190.5	213.36	241.3	350.52	309.88	279.4	28
1998	6	223.52	223.52	350.52	335.28	469.9	264.16	279.4	27
1998	7	419.1	261.62	259.08	363.22	386.08	200.66	261.62	26
1998	8	271.78	322.58	342.9	358.14	541.02	177.8	398.78	26
1998	9	83.82	289.56	360.68	248.92	332.74	254	271.78	26
1998	10	264.16	210.82	182.88	365.76	269.24	170.18	264.16	26
1998	11	223.52	289.56	264.16	114.3	322.58	182.88	332.74	26
1998	12	363.22	187.96	327.66	406.4	581.66	210.82	320.04	26
1999	1	101.6	33.02	20.32	33.02	180.34	43.18	27.94	26
1999	2	53.34	101.6	121.92	40.64	213.36	5.08	53.34	26
1999	3	149.86	35.56	35.56	116.84	266.7	60.96	12.7	26
1999	4	137.16	96.52	81.28	223.52	449.58	109.22	63.5	27
1999	5	261.62	274.32	266.7	287.02	416.56	279.4	177.8	26
1999	6	241.3	276.86	467.36	581.66	414.02	243.84	360.68	26
1999	7	345.44	96.52	185.42	353.06	563.88	139.7	93.98	26
1999	8	510.54	284.48	363.22	589.28	355.6	198.12	220.98	26
1999	9	187.96	373.38	231.14	330.2	266.7	203.2	474.98	26
1999	10	317.5	218.44	347.98	271.78	360.68	215.9	248.92	26
1999	11	398.78	304.8	408.94	543.56	452.12	294.64	264.16	25
1999	12	693.42	373.38	472.44	665.48	1181.1	314.96	238.76	25
2000	1	119.38	35.56	33.02	154.94	238.76	68.58	78.74	26
2000	2	22.86	7.62	2.54	10.16	106.68	71.12	0	26

2000	3	15.24	2.54	5.08	2.54	91.44	5.08	2.54	26
2000	4	132.08	91.44	66.04	170.18	187.96	78.74	111.76	27
2000	5	406.4	330.2	248.92	187.96	444.5	160.02	220.98	26
2000	6	579.12	314.96	269.24	271.78	508	256.54	248.92	26
2000	7	228.6	160.02	220.98	213.36	317.5	190.5	147.32	26
2000	8	241.3	274.32	360.68	312.42	414.02	129.54	243.84	26
2000	9	142.24	304.8	294.64	175.26	271.78	312.42	309.88	25
2000	10	680.72	317.5	353.06	594.36	505.46	276.86	322.58	25
2000	11	182.88	215.9	261.62	264.16	325.12	165.1	160.02	26
2000	12	718.82	215.9	248.92	452.12	789.94	144.78	157.48	26
2001	1	66.04	25.4	63.5	96.52	106.68	7.62	15.24	26
2001	2	5.08	2.54	0	0	43.18	0	0	26
2001	3	132.08	25.4	15.24	7.62	88.9	0	12.7	26
2001	4	35.56	35.56	17.78	20.32	160.02	17.78	20.32	27
2001	5	149.86	119.38	213.36	210.82	208.28	165.1	137.16	27
2001	6	134.62	190.5	187.96	180.34	457.2	223.52	134.62	27
2001	7	246.38	236.22	220.98	160.02	530.86	144.78	327.66	26
2001	8	269.24	236.22	287.02	287.02	309.88	68.58	137.16	27
2001	9	325.12	238.76	213.36	248.92	406.4	292.1	276.86	26
2001	10	464.82	193.04	165.1	236.22	332.74	165.1	261.62	27
2001	11	558.8	304.8	325.12	464.82	441.96	233.68	208.28	26
2001	12	416.56	279.4	215.9	375.92	622.3	203.2	251.46	26
2002	1	187.96	27.94	58.42	152.4	127	58.42	15.24	27
2002	2	20.32	2.54	22.86	10.16	73.66	0	7.62	27
2002	3	93.98	50.8	30.48	40.64	246.38	45.72	25.4	27
2002	4	218.44	76.2	73.66	177.8	510.54	195.58	63.5	27
2002	5	193.04	160.02	154.94	205.74	281.94	93.98	228.6	28

2002	6	142.24	215.9	373.38	307.34	190.5	116.84	205.74	27
2002	7	388.62	347.98	271.78	381	477.52	190.5	198.12	27
2002	8	401.32	292.1	309.88	378.46	335.28	152.4	342.9	27
2002	9	231.14	160.02	325.12	182.88	312.42	88.9	193.04	27
2002	10	231.14	213.36	302.26	129.54	317.5	292.1	309.88	26
2002	11	525.78	238.76	187.96	317.5	754.38	203.2	294.64	26
2002	12	45.72	55.88	7.62	53.34	121.92	17.78	20.32	27
2003	1	27.94	5.08	0	15.24	76.2	0	0	27
2003	2	12.7	27.94	7.62	12.7	86.36	12.7	12.7	27
2003	3	0	0	0	2.54	10.16	5.08	0	28
2003	4	231.14	190.5	182.88	91.44	218.44	180.34	114.3	28
2003	5	274.32	215.9	259.08	281.94	294.64	198.12	182.88	27
2003	6	297.18	284.48	373.38	332.74	274.32	236.22	203.2	27
2003	7	241.3	266.7	353.06	241.3	248.92	213.36	223.52	25
2003	8	419.1	322.58	281.94	271.78	525.78	200.66	264.16	25
2003	9	355.6	403.86	353.06	353.06	485.14	165.1	360.68	25
2003	10	203.2	373.38	347.98	281.94	383.54	347.98	340.36	25
2003	11	279.4	396.24	391.16	345.44	508	236.22	353.06	25
2003	12	419.1	274.32	269.24	467.36	660.4	190.5	215.9	25
2004	1	55.88	38.1	5.08	10.16	114.3	0	50.8	25
2004	2	2.54	0	0	2.54	43.18	0	0	26
2004	3	43.18	0	0	43.18	127	20.32	0	26
2004	4	134.62	83.82	71.12	121.92	233.68	53.34	81.28	26
2004	5	421.64	292.1	243.84	441.96	622.3	177.8	284.48	26
2004	6	368.3	312.42	297.18	299.72	335.28	170.18	218.44	27
2004	7	322.58	154.94	170.18	279.4	325.12	203.2	208.28	26
2004	8	426.72	340.36	302.26	406.4	541.02	185.42	363.22	26

2004	9	236.22	287.02	299.72	269.24	386.08	353.06	200.66	26
2004	10	421.64	294.64	309.88	312.42	535.94	340.36	223.52	26
2004	11	434.34	238.76	363.22	320.04	1008.38	200.66	299.72	26
2004	12	342.9	66.04	73.66	193.04	386.08	50.8	53.34	27
2005	1	121.92	20.32	17.78	116.84	401.32	58.42	38.1	27
2005	2	35.56	0	2.54	45.72	111.76	0	0	27
2005	3	68.58	38.1	60.96	38.1	68.58	27.94	83.82	27
2005	4	274.32	60.96	134.62	144.78	431.8	104.14	66.04	28
2005	5	256.54	312.42	292.1	218.44	269.24	223.52	302.26	27
2005	6	144.78	121.92	233.68	205.74	299.72	264.16	121.92	27
2005	7	246.38	175.26	276.86	132.08	350.52	160.02	144.78	27
2005	8	414.02	187.96	309.88	297.18	381	132.08	284.48	26
2005	9	365.76	314.96	340.36	289.56	314.96	429.26	312.42	26
2005	10	142.24	182.88	147.32	109.22	218.44	91.44	236.22	26
2005	11	436.88	246.38	347.98	447.04	403.86	132.08	104.14	26
2005	12	198.12	43.18	78.74	243.84	147.32	142.24	106.68	27
2006	1	68.58	10.16	17.78	27.94	142.24	66.04	0	27
2006	2	50.8	12.7	10.16	40.64	96.52	2.54	5.08	27
2006	3	121.92	81.28	55.88	99.06	208.28	53.34	25.4	27
2006	4	83.82	73.66	104.14	43.18	360.68	86.36	2.54	27
2006	5	287.02	289.56	365.76	477.52	439.42	325.12	35.56	27
2006	6	86.36	322.58	297.18	101.6	416.56	137.16	246.38	27
2006	7	528.32	271.78	436.88	378.46	701.04	243.84	233.68	27
2006	8	223.52	223.52	312.42	264.16	467.36	264.16	345.44	26
2006	9	294.64	160.02	233.68	162.56	251.46	121.92	203.2	26
2006	10	347.98	180.34	381	327.66	401.32	246.38	246.38	26
2006	11	591.82	381	406.4	515.62	693.42	228.6	414.02	27

2006	12	411.48	149.86	81.28	215.9	241.3	228.6	33.02	27
2007	1	7.62	7.62	0	0	111.76	12.7	0	27
2007	2	22.86	2.54	2.54	10.16	60.96	0	0	27
2007	3	66.04	5.08	10.16	73.66	137.16	0	2.54	28
2007	4	154	264	139	259	400	95	61	27
2007	5	348	368	423	639	467	239	393	27
2007	6	211	258	273	275	455	146	285	27
2007	7	220	191	348	165	452	141	192	26
2007	8	324	221	303	270	282	239	188	26
2007	9	319	316	243	330	182	211	377	26
2007	10	363	178	264	402	224	292	232	26
2007	11	698	217	256	501	899	337	236	26
2007	12	191	133	203	151	986	269	154	26
2008	1	155	16	9	46	121	18	11	26
2008	2	62	28	63	51	155	62	62	27
2008	3	32	8	19	5	51	37	13	27
2008	4	110	70	45	36	228	9	80	27
2008	5	185	138	178	127	172	148	180	27
2008	6	89	132	268	162	389	325	276	27
2008	7	164	346	553	317	548	141	305	26
2008	8	144	129	235	213	392	388	261	26
2008	9	139	73	163	114	210	112	80	27
2008	10	167	134	190	128	228	239	200	26
2008	11	691	455	428	564	657	480	417	25
2008	12	84	43	43	66	352	66	34	26
2009	1	75	29	10	40	226	14	16	27
2009	2	43	13	28	33	253	5	13	27

2009	3	44	37	14	32	198	11	38	27
2009	4	111	22	9	48	337	88	8	28
2009	5	57	241	198	136	293	281	240	27
2009	6	82	369	270	335	482	263	206	27
2009	7	128	214	317	278	378	239	214	27
2009	8	266	379	416	539	616	247	422	27
2009	9	186	148	128	97	308	151	214	27
2009	10	306	405	324	312	438	266	326	27
2009	11	446	381	366	448	1117	250	228	26
2009	12	89	37	37	95	143	87	55	27
2010	1	26	4	4	17	87	19	11	27
2010	2	19	20	9	57	227	29	10	27
2010	3	69	3	15	69	209	46	15	27
2010	4	57	128	91	142	322	307	164	28
2010	5	134	176	121	156	461	257	176	28
2010	6	367	302	240	343	565	363	311	27
2010	7	125	287	274	422	261	312	521	27
2010	8	399	306	318	438	454	329	174	27
2010	9	137	211	137	257	280	184	165	27
2010	10	621	389	438	400	387	326	356	26
2010	11	606	348	494	627	645	256	279	25
2010	12	1105	530	0	1050	1867	335	519	24
2011	1	176	73	63	107	362	111	60	26
2011	2	93	15	16	33	162	75	6	27
2011	3	76	22	52	41	182	18	9	27
2011	4	106	77	77	52.324	248	123	64	27
2011	5	206	241	284	253	340	333	304	28

2011	6	271	283	293	323	450	91	289	28
2011	7	381	244	493	308	343	316	351	27
2011	8	188	205	360	189	235	174	282	28
2011	9	109	286	317	211	333	233	428	27
2011	10	323	145	420	329	543	329	235	27
2011	11	767	762	658	693	611	327	608	26
2011	12	523	408	319	497	465	183	302	26
2012	1	28	17	0	9	85	0	1	27
2012	2	26	3	0	2	42	1	0	26
2012	3	76	5	6	14	222	15	2	27
2012	4	154	163	217	142	288	103	201	27
2012	5	259	207	343	253	449	179	178	28
2012	6	309	222	191	274	202	216	246	28
2012	7	332	317	274	349	405	288	273	27
2012	8	143	215	353	159	399	125	133	27
2012	9	381	161	238	150	303	266	196	27
2012	10	271	265	256	268	352	312	295	27
2012	11	906	324	272	771	959	322	277	26
2012	12	505	201	175	399	542	226	183	27
2013	1	5	1	0	12	37	0	5	28
2013	2	43	11	6	47	67	0	8	27
2013	3	47	11	5	39	234	0	4	28
2013	4	137	58	24	67	143	13	114	28
2013	5	395	198	248	190	499	253	216	27
2013	6	255	198	239	174	502	190	204	28
2013	7	288	209	328	370	510	99	208	28
2013	8	337	237	250	275	370	181	233	27

2013	9	181	342	278	207	278	279	416	28
2013	10	290	390	428	226	343	273	417	27
2013	11	141	99	121	158	347	230	181	27
2013	12	269	141	94	135	225	182	117	27
2014	1	24	7	12	19	82	32	8	28
2014	2	39	1	0	9	37	6	0	28
2014	3	17	25	18	18	57	0	13	29
2014	4	127	36	33	38	189	7	28	29
2014	5	432	309	216	159	477	395	306	28
2014	6	332	334	248	128	327	167	189	28
2014	7	152	159	110	78	264	189	82	28
2014	8	404	198	150	143.3	468	134	230.667	27

LIST OF FIGURES

LIST OF TABLES