Contributions to the management of Chancay-Huaral (Peru) watershed in climate variability scenarios

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Abstract: The Chancay-Huaral watershed is located on the coast of Peru. Coastal zones are particularly vulnerable to climate changes. Therefore, the aim of this project is to approach the implications of such vulnerabilities in this specific watershed, allowing a contribution to the management of the watershed in climatic variability scenarios.

This study distinguishes from previous ones by going deeper into forecasting future climate changes mitigation and adaptation for the Chancay-Huaral watershed, trough the ArcHydro method/program that enables the creation of a Decision-making Support System. The combination of Geographical Information Systems and database, together with mathematical models adds quality and flexibility to the analysis, generating a set of possible scenarios and respective supporting techniques that will enhance policy-makers decision processes.

The region is described, from the standpoint of climatological, hydrological, topographical and land use. A statistical analysis of multiple time series, for the Chancay-Huaral watershed, was conducted in order to study the trends of temperature, runoff and precipitation in watershed and its influence. By means of a hydrological model and the study taken by the IPCC for regional forecasts, changes to the weather patterns are presented to predict water runoff from 2080 to 2099.

Keywords: Climate Change, Vulnerability, Hydrologic Model, GIS, DSS

I. Introduction

The environment has always been influenced by anthropogenic activities**;** however, since the industrial revolution, human activities have, been taking some affectation at a global level in the environment. Today, environmental problems are a major concern of humankind, as result of evidence in the effects of increased greenhouse gases (GHG) emissions and global climate changes on Earth. Overall, the temperature has increased and the amount and distribution of rainfall have changed. According to the International Panel on Climate Change (IPCC), average global temperatures could grow between 1.4 and 5.8ºC by 2100 with increasing concentration of CO_2 in the atmosphere. (IPCC, 2007)

Despite the developments in the study of several scenarios for the global impact of the climate change, a detailed approach in such studies, concerning the impacts and their magnitude, in small watersheds has not been taken into account for many parts of the globe. Hence, the identification of climate impacts at the local level is very important because it allows the identification of the degree of vulnerability of local water resources and planning of adaptation and mitigation.

Coastal zones are characterized by a high population density, associated with significant socio-economic activities, with diverse ecosystems that support and maintain habitats and also a food resource. Thus, coastal areas are considered sensitive ones and climate changes emerge as an additional pressure to these areas due to: rising sea level, changes in frequency and/or intensity of storms and hurricanes associated with floods. This is an increased risk to ecosystems, urban areas, tourism and other economic activities and human health. The threats of climate change on the coastline region have repercussions far beyond the coastal zone. (Michel & Pandya, 2010)

Over the last decades, Latin America has been subject to an increase in climate impacts such

as increased occurrences of El Niño. In addition to weather, the main drivers for the increased vulnerability are the increasing demographic pressure, unregulated urban growth, poverty and rural migration, low investment in infrastructure and services and inter-sectorial coordination.

A decision support system (DSS) is an information system based on computers that combine models and data, with greater involvement of users, DSS is a vaguely defined group of tools, including Information Systems and tools for scenario analysis and optimization approaches. This tool dates back to 1971 with a work of Gorry and Scott-Morton. (Gorry & Morton, 1971).

II. Methodology

The project was based in **three** different approaches, all of them leading to a contribution for the management of the Chancay-Huaral watershed. First, a Geodatabase was created which can be used as a DSS or in some hydrologic modeling in the future. Second, the Mann-Kendall test was used to do an analysis trend to the monitoring station with available data. And finally, a physic model named 'TEMEZ model' was constructed and applied to study the watershed runoff, and projected scenarios were applied to the model, for 2080-2099.

A) ArcHydro Geodatabase

ArcHydro data model is a geospatial and temporal water resource that operates within ArcGIS. This system has an associated set of tools, built jointly by the Environmental Systems Research Institute (ESRI) and Center for Water Research in water Resources (CRWR), which fulfill the attributes of features in data frames, interconnect features in different layers of data and supporting hydrologic analysis, providing a simple and compact storage of the most important geospatial data. (Maidment, 2002)

This system can support basic studies of water resources as well as models; including time series and other ArcHydro components, and may contain information stored in multiple levels.

The construction is based on the GIS software - ArcGIS using the ArcHydro tool. Initially it was intended to create a Geodatabase (geographic database), where it's created a base model case study in which can be introduced the time series related to precipitation, flow and temperatures.

There are several processes within the ArcHydro. A first one is called Terrain Preprocessing and is one of the most important steps in the preparation of analysis of water in ArcHydro. The role of the pre-processing field is twofold: It aims at developing a correct hydrologic digital elevation model (DEM) and of its derivatives (e.g. direction, accumulation and preferential patterns of flows); also, it develops a series of interconnected layers that optimize the performance of the tools ArcHydro related to watershed delineation and characterization.

The generation of the database will allow future uses to use it at simulation models or as data base on a SAD.

B) Mann-Kendall test

The Mann-Kendall assesses how the tendency of parameters is varying over time and whether the given trend is significant or not. The test takes into account the seasonal data study comparing only the equivalent months from every year. The tendency is to increase or decrease whether the obtained value for the slope is positive or negative, respectively. In this study was used a supplement (add-in) for Excel that enables the Mann-Kendall test to be performed for a period of 21 years.

C) TEMEZ model

The Temez model is a simplification of a classical model, SWM (Stanford Watershed Model) developed by Temez in 1977. The description of the model presented in this work can be found at (Oliverira, 1998).
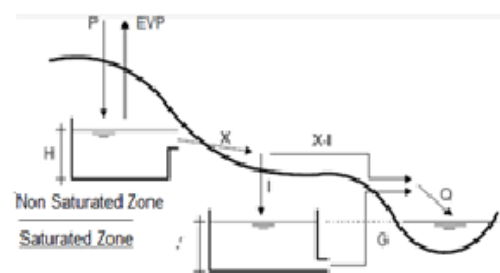

Fig. 1 TEMEZ Model

In the saturated zone, which is represented by the upstream box, is the reservoir where the precipitation (P) first falls till the field is saturated and the water can then be lost either by evapotranspiration (EVP) or by runoff (X). Following the runoff some water will infiltrate (I) and that water will recharge the aquifer till its full

capacity is attained; when it happens, it will lose water by the depletion of the aquifer (G). The lost by the aquifer and the runoff excess (X-I) will give origin to the runoff in the watershed (Q).

III. Study Case

The study area, Chancay-Huaral watershed, is located in the department of Lima, which belongs to the central area of Peru. The study area lies to the north of Peru´s capital that comprises the entire coast of the valley to the heights of *Vichaycocha*. Huaral is the provincial capital limited at North by Huaura and Oyón, at South by Lima and Canta, at East is the Cerro de Pasto and at West by the Pacific Ocean. With an area of approximately 3100 km^2, it comprises 12 districts, namely: Huaral, Chancay, Aucallama, Ihuarí, Sumblica, Pacaraos, Lampián, Atavillos Alto, Atavillos Bajo, 27 de Noviembre, the San Miguel and Santa Cruz de Acos Andamarca.

A) Climate

According to the diagnostic program for the watershed Chancay-Huaral conducted by the National Institute of Natural Resources at request of the Peruvian Ministry of Agriculture: from the coast to the border it is possible to identify five climatic types prevailing in the Chancay-Huaral watershed ranging from arid and semi-hot to cold and raining, with a rainfall of few millimeters on the coast and arid desert, to an estimated average rainfall of 933mm in the Puna area, above this height are presented in the form of snow. Temperatures are variable with values ranging from 21ºC on the coast up to 0°C in the Alps, and a relative humidity of 78% to 65%. (Bernabé, Torres, Omar, Silva, Charles, & Chata, 2001)*.*
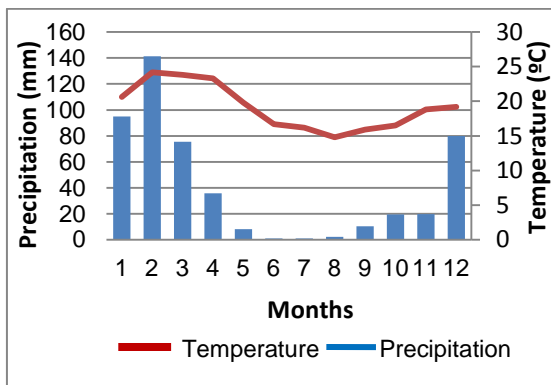

Fig 2 Medium Temperature and Precipitation from Huayan Station

B) Hydrology

The Chancay-Huaral watershed has a length of about 3100 km^2, in which 49% (1519 km^2) is a wet zone as it lies above 2500 m above sea level.
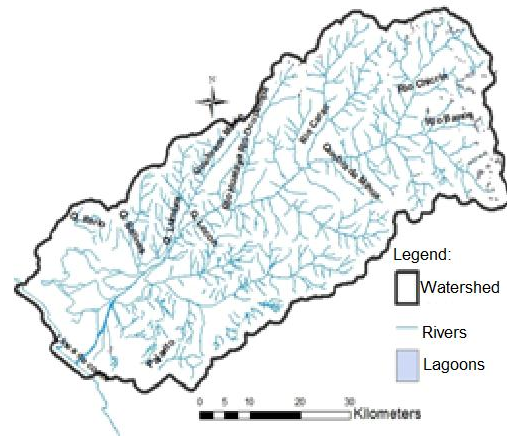

Fig. 3 Hydrology of Chancay-Huaral watershed

The overall topography of the watershed is the same as characterized in general by most of the rivers of the Pacific slope: great depths and steep slopes; bounded by mountain ranges, which reveals a steady decline at the level of the ridges. The Chancay-Huaral watershed is divided into 8 sub-watersheds, two of which (sub-watershed Media and Low) are divided according to the main channel, and the Santo Domingo station lies between the two of them.

The main recharge of the watershed under study is undoubtedly Peruvian glaciers. With 19 glaciers mountain, Peru contains more than half the world's tropical glaciers, most of these are located in the Cordillera Blanca (White Mountains), with approximately 600 glaciers spread over an area of 620 km^2. As all the glaciers, tropical ones tend to shrink or expand with temperature increases or decreases, respectively. (Vuille, Kase, & Irmgard, 2008)

Additionally, the glaciers in major mountain chains regulate the seasonal variations in flow. However, following the global trend, the tropical glaciers have been retreated from the 80's to the present day. Besides the crucial role in regional water supply, tropical glaciers are also sensitive indicators of climate variations. (Vuille, Kase, & Irmgard, 2008)

During the dry season, runoff is almost exclusively because the melting of glaciers. The glaciers have the ability to act as a reserve in the

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annual variations of flow changes with the extent of glaciations.

Agriculture is clearly the player that consumes more water in the central watershed and high activity is mainly non-intensive because the plantations are set to times of rain. Still, in the middle zone of the watershed there are some crops irrigated with rustic small irrigation systems.

In the highlands, in times of greatest drought, there are areas of livestock that consumes water directly from the source, food crops are mainly in the intermediate zone and the fruit trees in the lower middle area. As regards, domestic and rural areas located in the intermediate and high regions, satisfy their needs directly using the sources of water existing in the neighborhood. The rural population is about 10% of the total population, so that most of the consumption is concentrated in the lower zone of the watershed where between rural and urban population is 90% of the total population.
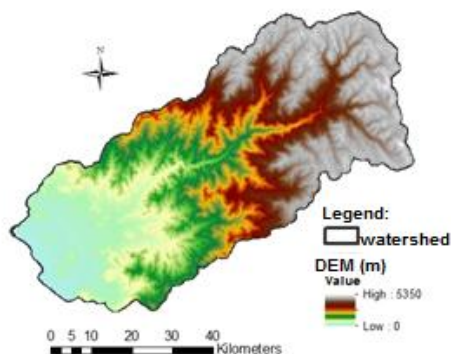
C) Topography and Land Use

Fig 4 Huaral Topography

In the high zones of the watershed there is an alternation in the geological types, where occurred important phenomena pressure and temperature. Adding to the fact that these high areas at some time formed the seabed and may find themselves further and calcareous beds of coal that give rise to homemade mines as well as other metals that make Huaral an area suitable for mining. Also, soils are generally shallow with little water movement, especially on steep slopes and areas subject to agriculture and livestock for erosion due to overgrazing and irrigation by gravity. There are also many deforested areas with few or very degraded vegetation. (Bernabé, Torres, Omar, Silva, Charles, & Chata, 2001)

In the middle zone (below 4000 m) there are several types of soils but brown soils (rich in organic matter) are more productive and are suitable for agriculture in irrigated areas, usually villages are using these soils for agriculture to sustain themselves.

In the lower middle area there is a mix of land associated with the oldest geological deposits and the latest on the one hand there are rocky soils, and desert brown soils in areas of high slopes with very dry climate and low humidity. (Bernabé, Torres, Omar, Silva, Charles, & Chata, 2001).

D) Socio-Economic Characterization

The urbanization process in recent decades has been observed in all Latin American countries and has been the major factor of spatial redistribution of the population. The migration flows "rural-urban" are evidenced by a rapid population growth in urban areas and predominant effect of migration leading to a decrease of population in rural areas.

The Agricultural sector accounts for about 8% of GDP, generates 9% of total exports and provides employment to 28.5% of the economically active population. In 2010 the GDP increased 8.8% and agriculture 4.4%. Agricultural production grew 3.6% and livestock 5.4%. The problem occurs when domestic production cannot compete with imports. The central issue in agriculture comes down to the low profitability and poor ability to compete. There are several situations for different types of agriculture.(INEI)

E) Monitoring Stations

In Peru there are two main entities responsible for monitoring meteorological and hydrological data, these are the National Water Authority (ANA) and the National Service of Meteorology and Hydrology of Peru (SENAMHI). The first one, ANA has five monitoring stations in the administrative area of the watershed under study, and the second one, the SENAMHI has eight weather stations in the watershed under study and a hydrological station cited above, the station of Santo Domingo.
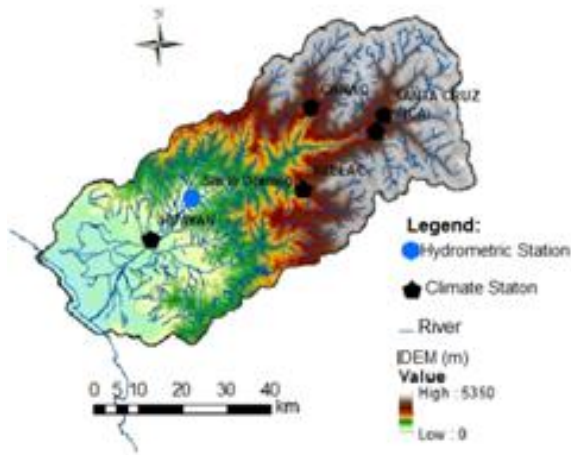
Fig. 5 Monitoring Stations location

IV. Results

A) ArcHydro Geodatabase construction

It is an inventory of all the features of a particular type for the region under study, in this case the model will not only store this information but also the relationship between different attributes.

Once the data is available, the first step is to build the model. Initially, the coordinate system to use has to be chosen, once the data was in the projection system: WGS84 UTM Zone 18S this is the one used in the database ArcHydro.

To be able to create the drainage areas, it is necessary to have the DEM and since this file was not available at the outset, it was created from the contour lines.

At this time and before the creation of DEM, was necessary to define the mesh size to use. It was chosen a grid 100 x 100 since the resolution proved to be satisfactory. First experiments were taken with a mesh 50 x 50 but it revealed a slow process.

After the creation of the MDT it is necessary to fill-in all the water courses of the watershed to continue the development of the database. However, the file available to the network of watercourses was split into several different files to different locations in the watershed, occurring overlapping streams in hydrological network, water lines unconnected, small segments that crossed the intersection points or lines forming circles and do not permit the creation of a flow pattern. However, these conditions were corrected, thereby obtaining a hydro network used in the model.

Then, the pre-processing of the terrain (Terrain Preprocessing) generates the characteristics of the watershed, such as the flow direction, flow accumulation, drainage lines, catchments, sub-watershed, length of longest flow path for each of the sub-watersheds.

With the tool 'Attribute Tools' it was possible to identify each one of the segments (HydroID) of each water line. ID´s have also been developed for each of the monitoring stations within the area of the watershed, allowing the association of a corresponding time series. Thus, the time series of a station will be easily available to a user who wishes to see this GIS data from monitoring stations of the watershed. This geographic database may be used to hydrological modeling of the watershed and as a support in a Decision Support System after setting the focus of this DSS.

B) Statistical Analysis and trends

The trend analysis was done by means of the Mann-Kendall, which according to (Back, 2001) is the most appropriate test for analyzing climate changes in climatological series and also allows the detection and approximate location of the starting point of a certain trend.

From this test it was possible to study the data of Temperature from Huayan station, the precipitation from the five stations available and the flow data from the Santo Domingo station.

To enable a better and reliable study of the time series and the influence they have on each other, a trend analysis of all the series has been conducted including only the years with available data for the most parameters under study.

The first table from 1967 to 1987, in generally for the five weather stations with precipitation data, the trend was downward with the exception of the Santa Cruz station for which there wasn't a significant trend (Table I).
The temperature is generally found to increase in almost all months for this time series (total), and regarding with the flow, it appears that there is not an overall significant trend; except in August, where there was an increase even if the precipitation dropped in two stations and there's no tendency in the other stations and the temperature increase for the same period. These data indicate that the temperature is an

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important parameter in the recharge for the watershed, as said before.

Table I Trends to 1967-1987

	Tends 1967-1987						
	Precipitation					Temp	Flow
Month	Carac	Pirca	Pallac	Huayan	Santa Cruz	Huayan	Santo Domingo
1	↔	↑	↔	↔	↔	↑	↓
2	↔	↑	↔	↔	↔	↑	↔
3	↔	↔	↔	↔	↔	↑	↔
4	↔	↔	↓	↔	↔	↑	↔
5	↔	↔	↔	↔	↔	↔	↔
6	↔	↔	↔	↓	↔	↑	↔
7	↔	↔	↔	↔	↔	↑	↔
8	↓	↔	↔	↓	↔	↑	↑
9	↔	↓	↔	↔	↔	↑	↔
10	↔	↓	↔	↔	↔	↑	↔
11	↔	↔	↓	↔	↔	↑	↔
12	↔		↓	↓	↔	↑	↔
Total	↓	↓	↓	↓	↔	↑	↔

Table II Trend to 1988-2001

	Trends 1988-2001						
	Precipitation					Temp	Flow
Month	Carac	Pirca	Pallac	Huayan	Santa Cruz	Huayan	Santo Domingo
1	↔	↓	↔	↔	↔	↔	↔
2	↑	↓	↑	↓	↔	↔	↔
3	↑	↓	↔	↑	↔	↔	↔
4	↑	↔	↔	↓	↔	↔	↔
5	↔	↔	↔	↓	↔	↔	↔
6	↔	↑	↔	↑	↔	↔	↔
7	↔	↔	↔	↔	↔	↔	↔
8	↔	↔	↔	↑	↔	↔	↔
9	↔	↓	↓	↑	↑	↔	↔
10	↔	↔	↔	↑	↔	↔	↔
11	↔	↔	↔	↑	↑	↔	↔
12	↔	↔	↔	↔	↑	↔	↔
Total	↓	↔	↓	↓	↑	↔	↔

Table III Trends to 2002-2009

	Trends 2002-2009						
	Precipitation					Temp	Flow
Month	Carac	Pirca	Pallac	Huayan	Santa Cruz	Huayan	Santo Domingo
1	–	↔	↑	↔	↔	↔	↔
2	–	↔	↔	↔	↔	↔	↔
3	–	↔	↔	↔	↔	↔	↔
4	–	↔	↔	↔	↔	↔	↔
5	–	↔	↔	↔	↔	↔	↔
6	–	↔	↔	↔	↔	↔	↔
7	–	↓	↔	↔	↔	↔	↑
8	–	↔	↔	↔	↔	↔	↑
9	–	↔	↓	↔	↔	↔	↑
10	–	↔	↔	↔	↔	↔	↔
11	–	↔	↔	↔	↔	↔	↔
12	–	↔	↔	↔	↔	↔	↔
Total	–	↔	↓	↔	↔	↔	↔

For the second period studied, from 1988 to 2001, most of the weather stations records were a general downward trend of precipitation values (Carac, Pallac and Huayan). At the station of Santa Cruz there was an upward trend and at Pirca there wasn't a significant trend. As regarding with the temperature and flow rate also does not occur a significant tendency for the period in question. It should be noted in this analysis that despite a decline in rainfall in three stations an increase the trend in the flow has not been noted, it was not influenced by these rainfall trends.(Table II).

For most recent years, from 2002 to 2009, (Table III Trends to 2002-2009) there is no general tendency along the months or even a total one. Though, the precipitation in the Pallac station represents a negative trend (downward) for this period. The flow seems to have an upward tendency for July, August and September, even the precipitation shows a tendency to decline in two of the stations which once more suggests that the variation in the flow is not only related with the precipitation.

The correlation map allows for rapid conclusions on the links between the several series. The blank boxes are the ones that have little or no correlation, as the case of precipitation recorded in Huayan station with the remaining stations of precipitation and the temperature.

The temperature shows strong correlations with all stations with rainfall measurements, except for the station Huayan. It was expected this correlation once for the months there are higher temperature are the ones with higher precipitation too. Although there's no significant correlation between precipitation and temperature for the Huayan station it can be due to it´s location in a Per-Arid to Semi-Hot climate zone.

The orange boxes are the ones that have higher correlation (>50%), verifying that the four stations upstream (Pirca, Pallac, Carac and Santa Cruz) are all related to temperature and also have strong correlations to each other, away from the station downstream (Huayan). The flow has no significant correlation with any of the other data series. Between the four stations referred before, they have some particular similar characteristic besides all of them lies over the 2000 m, the rainfall data registered are higher on this stations and they are located closer to each other comparing with the Huayan station. Could be expected a higher correlation between the flow data and the temperature once this last parameter will have strong influence on the watershed recharge. Because the only station with temperature data lies in lower zone it could be consider that this is not a representative temperature station for all watershed.

Variables	Flow	Temp	PCP Carac	PCP Pirca	PCP Pallac	PCP Huayan	PCP Santa Cruz
Flow	1	0.232	0.214	0.275	0.296	0.134	0.282
Temp	0.232	1	**0.758**	**0.637**	**0.742**	-0.049	**0.645**
PCP Carac	0.214	**0.758**	1	**0.725**	**0.793**	-0.023	**0.756**
PCP Pirca	0.275	**0.637**	**0.725**	1	**0.731**	0.074	**0.714**
PCP Pallac	0.296	**0.742**	**0.793**	**0.731**	1	0.108	**0.743**
PCP Huayan	0.134	-0.049	-0.023	0.074	0.108	1	0.025
PCP Santa Cruz	0.282	**0.645**	**0.756**	**0.714**	**0.743**	0.025	1

Fig. 6 Correlation Map

Once obtained the data of precipitation, temperature, humidity and solar radiation proceeded to calibrate the model, it is necessary to estimate evapotranspiration, since these data are not available to stations in the watershed under study.

Thus, for a period from 1964 to 2009 was introduced the values of temperature, solar radiation (m/month) and humidity (%) from Huayan station, and the weighted average of the precipitation from the five stations available.

The model allows the estimation of evaporation through five methods, and the data requirements of each one are different, therefore the one used for this project was the Turc method requiring only values of air temperature, humidity and solar radiation.

The model has four parameters to be estimated through a calibration process which attempts to reproduce historical situations. Once calibrated, the model can be used to simulate the hydrological cycle of the watershed and for the four future climate scenarios.(**Error! Reference source not found.**)

The tendency of climate in the watershed under study, following the lines of regional weather forecasts of the IPCC which is predicting how the climate in the study watershed would be affected for a period of 2080-2099, the precipitation being the main factor determinant of spatial and temporal variability of water balance, however, these predictions are generally made for all of Central America and South America, distinguishing only three regions and they may not correspond exactly to the planned changes for small watersheds such as the watershed under study. This study predicts that annual average temperature will rise from 1.8 to 5.9ºC till 2080-2099 and precipitation will suffer a variation between -21 to 14% for the same period. These predictions were applied to to the average regional temperatures and precipitations forecasts for 1980-1999, in order to obtain 4 different scenarios for the years 2080- 2099.
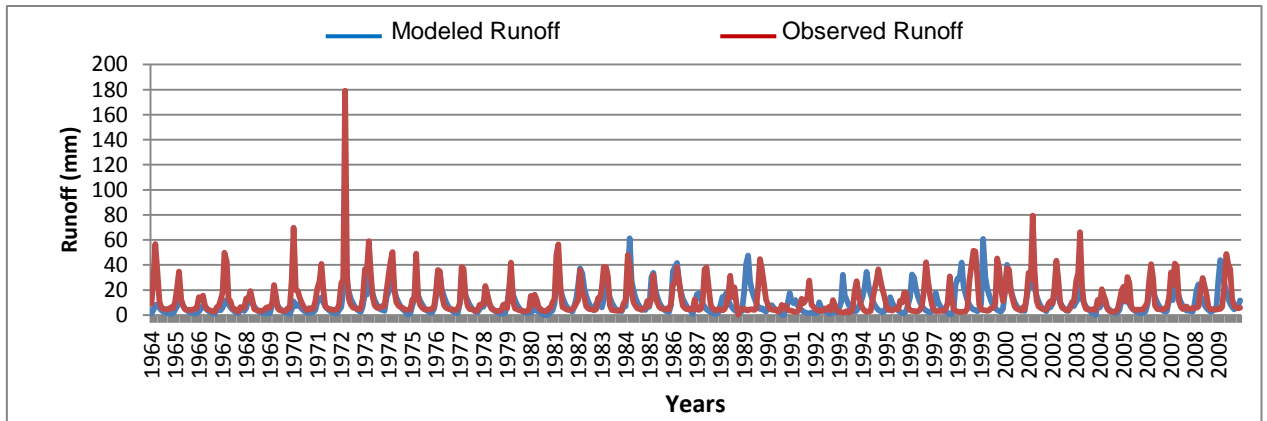
Fig 7 Hydrologic Model (observed runoff vs modeled runoff)

The data used for the projection made are the average regional temperatures and precipitation forecasts for 1980-1999 from which was obtained the data to 2080 to 2099.
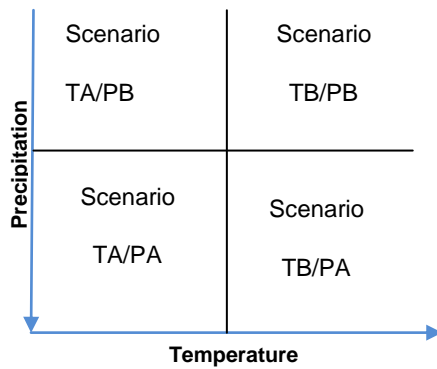

Fig 8 Possible Scenarios

Table IV Regional averages from temperature and precipitation projections to 20080-2099 (IPCC M. G., 2007)

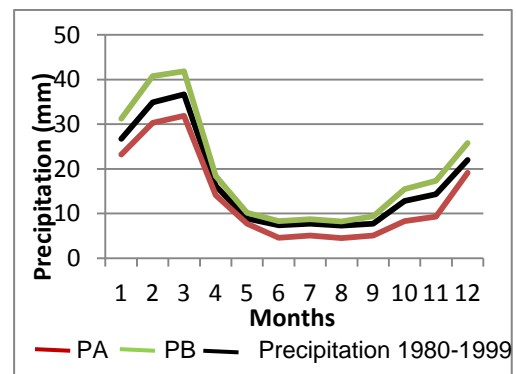| Variations (2080-2099)			
Temperature (ºC)		Precipitation (%)	
Min	Max	Min	Max
Dec,Jan,Feb	1.7	4.6	-13	17
Mar,Apr,May	1.7	4.6	-13	14
Jun,Jul,Aug	2	5.6	-38	13
Sep,Oct,Nov	1.8	5.4	-35	21
Annual	1.8	5.1	-21	14

Fig 9 Precipitation Trends

With regard to temperature, both in setting and in the TA setting TB there is a general increase of the temperature throughout the year, and setting TB in this increase is higher, leading to greater affectation of water.
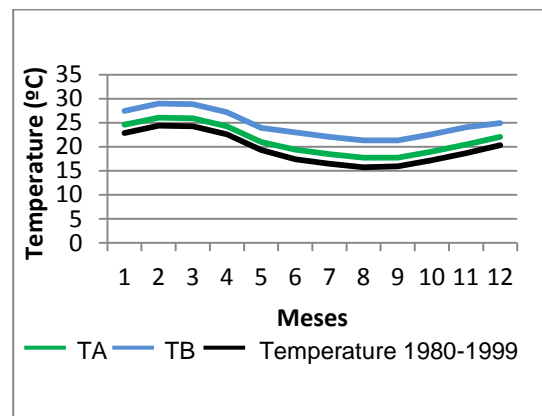

Fig 10 Temperature Trends

Applying these changes to the control series, we obtained new series, which were introduced in Temez model resulting forecasts of runoff for a period of 2080-2099 in the watershed.
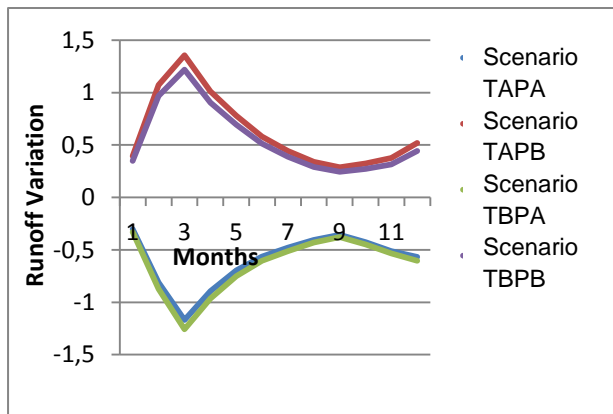
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Fig 11 Temperature Trends

From Fig 11, one can take into account practically only two scenarios, since accordingly to the TEMEZ model, runoff seems to be only sensitive on rainfall variations. (TAPA similar to TBPA and TAPB similar to TBPB).

The TEMEZ model, in spite of allowing the comparison between the runoff for 1980-1999 and 2090-2099, is a precipitation-runoff model and neglects the runoff that results from the melting glaciers. Therefore, it considers only the precipitation as input and disregards the role that temperature might have as regulator of the most important recharger – the glaciers.

V. Conclusion

In this study it was evidenced that temperature has an important role in this watershed and it's variations will produce important changes in many fields of human life, environment and on water resources by itself.

The TEMEZ model is not a very accurate model to apply to this kind of watershed that is recharged by other sources besides precipitation.

In further studies it will be important to have more temperature data from several other stations mainly in the higher altitudes, in order to better understand how the temperature influence the watersheds hydrologic dynamics, and above all, it's importance for the runoff.

Given the deterioration of the glaciers, in a medium-long term it will be important to study the importance of aquifers on this area and it's feasibly since, for this scenario it can represent an important contribution mainly in the coastal areas with high population density, where problems related to water scarcity starts to appear.

VI. References

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