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FLOW AND CLIMATIC VARIABILITY ON A SOUTHAMERICAN MID-LATITUDE BASIN: RÍO ACONCAGUA, CENTRAL CHILE (33ºS)

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I. INTRODUCTION

The exoreic hydrographic river basin of the Aconcagua River is one of the most important in semi-arid Chile because its drained surface area is 7.163 km^2, equivalent to 45% of the Valparaíso Region, but also because a large part of the agricultural and industrial activities contributing to the Gross National Product take place near the mid-lower River basin. Consequently, water availability is an essential aspect of sustainable development, especially if the water demand for irrigation, industry, mining and domestic use is above 500 million m^3 yearly in this same area where almost 30% of the regional population lives. The resources available to satisfy this water demand comes from surface and groundwater with an irrigation structure of 1230 channels and 53 dams, which are principally located in the lower basin. The present paper evaluated the flow behavior of the Aconcagua River Basin for the period 1961-2000 as well as its relations to climatic variability in central Chile, given that some studies have established a progressive diminishment of the snow cover that feeds the Andean mixed regime basins, such as the Aconcagua river Basin, and which is in agreement with other studies of world tendencies. Additionally, the literature has established a strong association between precipitation and climatic variability for meteorological stations in Central Chile (Aceituno & Vidal, 1990; Escobar & Aceituno, 1998; Caviedes & Waylen, 1998) as well as between flow and ENSO phases (Waylen & Caviedes, 1990).

II. MATERIALS AND METHODS

To analyze the flow behavior in the Aconcagua River Basin, monthly and yearly mean flows, recorded in the 13 fluviometric stations located in the study area and belonging to the General Water Direction of the Chilean Public Works Ministry (DGA-MOP), were used. Of these, 11 were used for the descriptive statistical analysis with time series for the period 1950 to 2000. The data were standardized in order to establish a homogenous analysis period. In this way, the database was reduced to the stations that presented coincident records, limiting the period to 1961-2000. Consequently, the analysis considered only 7 fluviometric stations. A descriptive analysis was performed on the annual flow distribution, the maximum flow for the analysis period and the recurrence times. To do this, the Kolmogorov-Smirnov test was applied and the linear trends of the mean annual flows for the summer (DEF) and winter (JJA) seasons were analyzed. The statistical significance of the tendencies was determined by the two-tail Student test. Finally, the linear correlations between the annual and seasonal flows and the ENSO indexes were calculated, using the index of the sea surface temperature (SST) of NOAA (http://www.cpc.ncep.noaa.gov) for the Region Niño 3.4.

III. RESULTS

In the upper Aconcagua River Basin, the contribution from snow during the snowmelt period coincides with the spring season, which occurs between September and January with the maximum flows between December and January. In the case of the Juncal River, the flow variations are only important during the snowmelt period; the rest of the year, the average monthly and yearly flow is 5 m^3/s and 70 m^3/s respectively. The Blanco River, in the upper basin, also presented important variation with respect to the maximum monthly flows with an annual average of 224 m^3/s. According to the behavior in different decades, the maximum values are recorded during the month of January in 1973 and 1983 (90 m^3/s); 1964 (73 m^3/s) and 1992 (60 m^3/s). In the Chacabuquito station, a similar tendency was recorded with respect to the hydrological regime, which is most accentuated in the decades of 1981-1990 and 1991-2000 with maximum monthly winter flows in June (1986) and May (1993) respectively. The maximum monthly flows for decades occurred in December 1972 (190 m^3/s), 1981 (180 m^3/s), 1982 (180 m^3/s), 1953 (177 m^3/s) 1963 (143 m^3/s) and January 1998 (145 m^3/s). In the San Felipe Station (mid-basin), the seasonal and inter-annual variations in the monthly mean flow were marked, especially for the decade 1991-2000.

Analysis of the mean monthly flows identified two hydrological regimes. The first regime corresponds to the upper Aconcagua River, from the origin in the Andes Mountains until the valley, principally with a snow regime. The fluviometric stations on the Juncal, Blanco, Colorado Rivers and at Chacabuquito are representative with maximum monthly mean flows in December in the order of 58.5 m^3/s (Chacabuquito). The second regime corresponds to the mid-lower Aconcagua River, with a snow-rain regime. The most representative fluviometric stations are at San Felipe and Romeral. The decade with the highest flow for the Aconcagua Basin was 1981-1990 and the lowest flow was in the decade 1961-1970, when the values were lower than the annual average of the historic series.

The most extreme monthly mean flows were recorded in the winter months of the years 1972, 1973, 1978, 1979, 1987 and 1997, and are coincident with Niño events. The minimum annual flows coincided with the year of drought, which occurred in 1968. The years 1996, 1998 and 1999 coincided with Niña events. The maximum mean monthly flows were all recorded during the snowmelt periods. The minimum flows presented wide seasonal fluctuations in the years 1969, 1971, 1976, 1981, 1987, 1996 and 1997. The adjustment of the maximum monthly flows recorded for each station with respect to the distinct probability distributions established that the majority of the stations are correctly modeled by the Pearson III distribution. It is notable that the years with the highest flow are associated to a cycle of years with the same characteristic.

Additionally, it is notable that low to normal flow is associated with a strong influence of the «dry years», such as 1968 and 1996, characterized by extreme droughts as well as the years before these. Indeed, there is a general tendency to a diminished flow over time. Consequently, in the Aconcagua River Basin, 50% of the fluviometric stations have water deficit: Juncal, Río Blanco, Río Colorado and Putaendo. The remaining stations present above normal levels and tend to have increasing flows: Chacabuquito, San Felipe, Catemu and Romeral. The greatest tendency towards flow deficit with respect to the historical average are recorded in the Blanco River station with 11.3% and the Colorado River station with 6%. The most relevant flow increase is found in the Romeral and San Felipe Stations with 32.1% and 17.9%, respectively.

A positive, significant correlation was observed between the flows and the SST index for the same period of time, indicating that an increase in summer flows is directly related with an increase in ocean surface temperature due to ENSO. In this sense, the correlations between the Chacabuquito and San Felipe stations have significance values between 0.5 and 1. For winter flows, only the San Felipe station presented a significant correlation. Additionally, three stations did not present correlation. Significant correlations were found between the SST and station flows only for the mid-Basin stations, where the highest, most significant value was observed between the winter ENSO and the summer flow at the Chacabuquito station. No significant correlation was found between the winter and previous summer values in any station.

IV. DISCUSSION AND CONCLUSIONS

Several authors who have analyzed the influence of ENOS (El Niño, Anti-Niño and normal years) on South American river responses (Waylen and Caviedes, 1990; Caviedes y Waylen, 1998, among others) have found a seasonal behavior for monthly river flow in central Chile: flow increases due to Niño events (EN) and diminish in Anti-Niño conditions (AN), where the Aconcagua has shown to be one of the best examples of this type of behavior. The present study found similar results: the cold ENSO phase is a abrupt diminishment of intercalated flows in normal years (1962 and 1981), although the general behavior is towards a gradual drop in water flow as found during the historical water droughts in 1968 and 1996. In this last case, Castillo (2003) verified sea surface temperature (SST) anomalies for the Region Niño 3, two periods of the Niña: July 1995 to December 1996 and September 1998 to May 2000. The fluviometric stations that best reacted to these hot and cold ENOS phases are Chacabuquito and San Felipe in the mid-lower Basin; these also presented high correlations with the SST values especially in the summer.

In the last 40 years, only the decade 1981-1990 surpassed the historic average for each fluviometric station. This result could be related to the predominance of hot ENOS phases that were stronger and more common than earlier decades. Beginning in 1990, all the stations presented a marked drop in flow. However, this tendency was not universal, although some of the stations located in the upper basin have established an important flow deficit. Thus, even though the Juncal, Aconcagua River-Blanco River crossing, Blanco River, Colorado River and Putaendo stations have a water deficit of up to 11.3% with respect to the historic annual mean flow, the mid-lower basin stations, such as the Chacabuquito, San Felipe, Catemu and Romeral stations, record an increasing tendency that even reaches 32.1% in the Romeral station.

Nevertheless, the positive trend of the fluviometric stations of the lower Aconcagua River Basin does not suggest that there are abundant water resources since the tendency adjusted in 2000 is less abundant than previous decades. For the period 1999-2006, the Romeral station has a annual mean flow of 392.1 m^3/s less than the historic average, while the Colmo Bridge Station (actually out of use) for the period 1997-2002 records an average of only 132 m^3/s. In the same period, the Romeral station has an annual mean flow of 400.6 m^3/s, i.e. a value close to the historic average of 428.8 m^3/s. This result suggests that there is an excess of water resources in the Aconcagua River's mean flow due to the contribution of subterranean waters into the river although these waters do not reach the lower part of the river probably due to consumption.

A negative flow tendency was recently established by Givovich (2006) when analyzing the monthly behavior of sub-basins of the Maipo and Aconcagua Rivers in relation with possible climate change effects. The author associated the increasing flow tendency found in the stations of Chacabuquito (Aconcagua River) and El Manzano (Maipo River) with climate change, i.e., higher temperatures resulted in more snowmelt. Even when a relation between increased temperatures and precipitations and the deglaciation process that would be affecting the glaciers of central Chile and the Patagonia (Rivera *et al*., 2000), the mass balance study of some glaciers, such as Echaurren Norte (Maipo River) present strong variability and the tendency to be more related with the ENOS cycles than with climatic change. Additionally, it has been established that the glaciers can present distinct behavior with respect to the same scenario, both temperature and precipitation, and consequently response times are different (Fernández *et al.,* 2006).

Flow behavior in the basin is an important aspect of water management, and the General Water Board evaluated several aquifer sectors in for water rights sustainability, establishing that some sectors of the lower river present a demand that is greater than a sustainable flow. Additionally, the increase in irrigation water rights and the location of northern basins, such as Copiapó and Huasco, have been affected by more arid climatic conditions and actually suffer from important deficits in groundwater principally caused by use in mining.

Finally, a sustainable flow should be defined and established with bio-indicators (fito and zoo) from flow records and flows in order to establish the system's ecological flow. This fact combined with the establishment of physical observations of flow variations requires the search for bio-physical patterns of flow variation. With this information, water codes for extraction and use can be precisely established in order to assure sustainable water resources in the long term.

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