

Surface water resources in the eastern slope of the Central Andes (28°-37°S) in a context of hydroclimatic variability

Carolina Lauro¹, Alberto Ismael Juan Vich^{1,2}, Sebastián Alfredo Otta¹, Stella Maris Moreiras^{1,3}, Emilce Liliana Belén Vaccarino Pascuali¹, Luis Bernardo Bastidas Mejías¹

1. Argentine Institute of Snow, Glaciology and Environmental Sciences, Mendoza Scientific and Technological Center, National Scientific and Technical Research Council. 2. Faculty of Philosophy and Letters, National University of Cuyo, Argentina. 3. Faculty of Agricultural Sciences, National University of Cuyo, Argentina

Abstract: The study of hydroclimatic variability in a region contributes to improving water security in communities by providing information for water resource management. The objective is to identify the main modes of variability and the relationship between time series of precipitation, temperature and average annual flows for the last 60 years in some basins in the Cuyo region. Tests were carried out on trends, jumps and periodicities. The results generally show that precipitation and flow tend to decrease and exhibit significant high- and low-frequency cycles. In contrast, temperature shows an upward trend associated with increases in the 1980s, with the most intense periods occurring on an interannual scale. These results provide information for understanding the relationships between hydroclimatic variability patterns and exchanges between the various components of the hydrological cycle in central-western Argentina, which allows for improved decision-making.

Key words: hydroclimatology; precipitation; temperature; streamflow; trend; step change; periodicity

1 Introduction

Climate change across various timescales impacts the hydrological cycle of the Central Andes. The main impacts described include glacial retreat, decreased snowfall, changes in runoff patterns, and changes in the intensity of extreme events, among others (Magrin et al., 2014). Given this evidence, understanding the temporal and spatial distribution of water resources and quantifying them is crucial for long-term planning.

Changes in the various components of the hydrological cycle can alter water availability for the region's socio-economic development, compromising its water security, understood as the capacity of societies to achieve successful and integrated management of their water resources and services (GWP, 2000).

Over the past decade, the cities and productive oases of central-western Argentina have been experiencing a water crisis due to a lack of snowfall during the winter months (Rivera et al., 2021). This meteorological phenomenon is closely linked to climate variability. The main climate driver that modulates winter precipitation is the El Niño-Southern Oscillation (ENSO; Compagnucci et al., 2000; Masiokas et al., 2006; Rivera et al., 2017). Interannual variability in river flows is associated with the ENSO phenomenon, while interdecadal variability is associated with the Pacific Decadal Oscillation (PDO; Compagnucci and Araneo 2007; Masiokas et al., 2010; Rivera et al., 2014, 2017; Gonzalez-Reyes et al.,

2017; Lauro et al., 2016, 2019). Furthermore, the influence of Antarctic circulation anomalies on variables associated with the flows of Andean rivers located south of 37°S is also observed (Lauro et al., 2019).

Hydroclimatic variables are characterized by periodicity, meaning the presence of cycles that repeat with a certain frequency in time series. These cycles have been identified in series of streamflow, precipitation, temperature, and other variables (Rajagopalan and Lall, 1998; Rao and Hamed, 2003). They represent the influence of natural phenomena such as solar cycles, ENSO, and biennial oscillations. Some studies suggest a relationship between solar cycles and runoff, as oscillations of 11–13 years have been found in the San Juan, Atuel, and Colorado rivers. Meanwhile, oscillations of 4–6 years have been associated with ENSO events (Labat, 2008; Mauas et al., 2011; Compagnucci et al., 2013). In the Atuel River, the ENSO signal is observed in interannual variability in the 4-7 year bands and the decadal order variability centered on approximately 20 years (Compagnucci et al., 2000).

In the Central Andes region, forecasts predict a decrease in snowfall in the mountain areas (Rivera and Arnould, 2020), an increase in precipitation in the lowlands during the summer period (Otta et al., 2020), and an increase in temperature (Zazulie et al., 2017). Given this variability, coupled with the water crises experienced in recent years, it is strategic to assess the supply (surface and groundwater) and future demand of irrigated oases in order to develop action plans aimed at conserving water resources in each of the basins of the central-western region of Argentina.

This study focuses on surface water supply and aims to identify the main modes of variability and the relationship between precipitation, temperature, and streamflow time series, from interannual to decadal scales, during the period 1960–2018 in the basins that comprise the Colorado River system in central-western Argentina. The purpose of the study is to provide useful information for water resource management, particularly for each basin analyzed.

2 Study area

The study region is located in west-central Argentina, encompassing the basins of the San Juan, Mendoza, Tunuyán, Diamante, Atuel, Grande, and Barrancas rivers. These rivers extend eastward from the high peaks of the Andes Mountains to the Desaguadero River basin, which ultimately flows into the Colorado River (Figure 1). These rivers supply the region's main agricultural oases. The San Juan River supplies Greater San Juan and the productive valleys of Ullum, Tulum, and Zonda. In the province of Mendoza, the Mendoza River and the lower Tunuyán River supply the northern oasis, where the majority of the province's population is concentrated and where the main industrial activities take place. The upper Tunuyán River supplies the central oasis of the province, and the Diamante and Atuel Rivers supply the southern oasis. The Grande River, the largest river in the province, joins the Barrancas River and supplies water to rural communities in the province of Mendoza. The confluence of these rivers gives rise to the Colorado River.

In the Central Andes region, two precipitation systems are present: a summer system influenced by continental air masses (Compagnucci et al., 2002; Masiokas et al., 2006) located in the lowland areas of the basins, and a winter system over the highest elevations of the Andes. This winter system results from the interaction between moisture flows from mid-latitude synoptic systems in the South Pacific, the topography of the Andes, the occurrence of low-pressure systems during the cold season (Garreaud and Fuenzalida, 2007), and the passage of cold fronts (Seluchi et al., 2006). Average precipitation between 32°S–36°S and 69°W–68°W reaches 600 mm annually (Viale et al., 2019), with peaks during the winter period (Figure 2). The highest average annual rainfall is recorded in the Tunuyán River basin, while the lowest is recorded in the San Juan River basin (Table 1). Temperature in the region decreases with increasing altitude and latitude, with minimum temperatures from June to August and maximum temperatures from December to February (Figure 2). Average annual temperature values show that the lowest and highest temperatures are recorded in the Tunuyán and Barrancas River basins, respectively (Table 1).

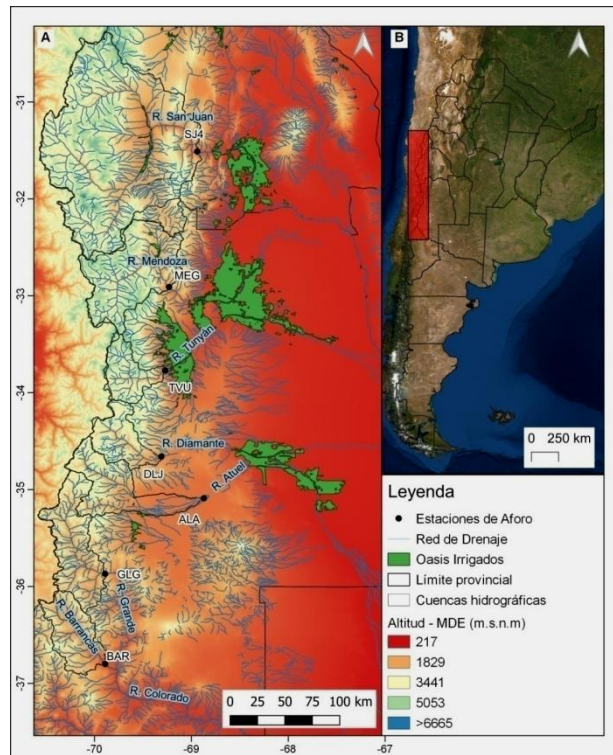


Figure 1. Location of the basins that make up the Colorado River hydrographic system, gauging stations, and main productive oases. See abbreviations in Table 1. (Author's own elaboration.)

Table 1. Average annual values for the recording period for each variable by basin

Basin	San Juan	Mendoza	Tunuyán	Diamante	Atuel	Grande	Barrancas
Station (abbreviation)	Km-101 (SJ1)	Guido (MEG)	Valle de Uco (TVU)	La Jaula (DLJ)	La Angostura (ALA)	La Gotera (GLG)	Barrancas (BAR)
Record Period	1971-2018	1960-2018	1960-2018	1971-2018	1960-2018	1971-2018	1960-2018
Precipitation (mm)							
Mean	243,4	352,1	442,9	502,1	459,8	495,6	374,7
Maximum	534,6	771,1	1048,8	934,3	841,4	886,0	640,8
Minimum	90,14	140,1	169,1	242,9	198,8	167,0	146,3
Standard Deviation	107,3	132,1	163,8	165,3	147,3	154,7	103,7
CV (%)	44,1	37,5	37,0	32,9	32,0	31,2	27,7
Temperature (°C)							
Mean	3,72	2,46	2,19	4,06	7,48	6,45	7,73
Maximum	4,84	3,17	2,96	4,80	8,24	7,05	8,37
Minimum	2,91	1,56	1,18	3,01	6,46	5,42	6,79
Standard Deviation	0,45	0,40	0,41	0,41	0,40	0,40	0,39
CV (%)	12,08	16,47	18,92	10,19	5,39	6,18	5,04
Discharge (m ³ /s)							
Mean	59,99	45,36	28,08	32,54	34,92	104,33	35,53
Maximum	151,72	93,95	54,24	72,69	69,50	202,47	66,87
Minimum	19,98	23,43	15,41	16,73	19,04	41,58	14,70

Standard Deviation	31,56	15,45	9,02	11,52	9,86	40,14	11,70
CV (%)	52,60	34,06	32,14	35,41	28,23	38,47	32,93

Precipitation and temperature data are from the Climate Research Unit database, and flow data are from the National Secretariat of Water Policy. Prepared by the authors.

The basins exhibit an altitudinal gradient from west to east, ranging from over 6,000 to 900 meters above sea level, with a significant area covered by glaciers in the higher elevations. The hydrological regime is snowmelt-glacial, and the hydrological year begins in July. Seasonal variations in flow rate depend on seasonal variations in precipitation, temperature, and the basin's topographic characteristics. The minimum annual flow occurs from June to August, and the maximum annual flow occurs from November to February (Lauro et al., 2018). The highest average annual flow is recorded in the Grande River basin, and the lowest in the Tunuyán River basin (Table 1).

The variables analyzed show interannual variability, the coefficients of variation are higher for the variables precipitation (28 to 44%) and flow (28 to 52%), the two variables being higher for the San Juan river basin.

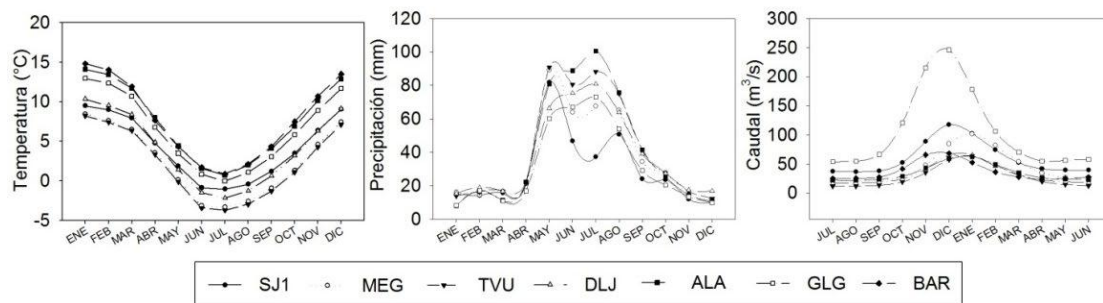


Figure 2. Annual trends in temperature, precipitation, and streamflow.

The temperature and precipitation graphs were created using data from the Climate Research Unit database for the period 1960–2018. Author's own elaboration.

3 Materials and methods

3.1 Data

In the region, instrumental precipitation and temperature records are not long enough or of sufficient quality for climate studies. Therefore, the Climate Research Unit (CRU) TS4.03 gridded precipitation and temperature database (Harris et al., 2014), with a spatial resolution of 0.5° x 0.5°, was used. This database adequately represents climatic variations in the Central Andes region (Rusticucci et al., 2014). The correlation between the gridded data and existing instrumental precipitation and temperature data in some watersheds is significant (Lauro et al., 2021).

This database contains records from 1900 to the present. In this study, the average annual precipitation and temperature were obtained for the period coinciding with the flow record in each of the basins (see recording period in Table 1). A weighted average was calculated between the value of the climatic variable and the area of the cell within the basin boundaries.

Instrumental records of average daily flows in each of the basins were obtained from the database of the Secretariat of Infrastructure and Water Policies of the Nation, from which the series of average annual flow were constructed for the analysis periods 1960-2018 and 1971-2018. The gauging points considered are located upstream of the hydraulic works.

The mean daily flow data were filled in according to the methods explained in Lauro et al. (2016). In addition, the normality, randomness, and independence of the annual temperature, precipitation, and flow series were verified; the tests used are detailed in Lauro et al. (2016). The assumptions are evaluated because they are required conditions in some of the trend and jump tests.

3.2 Trend and jump detection

To detect trends and jumps in precipitation, temperature and average annual flow variables, parametric and non-parametric tests were applied. For trend identification, the tests applied were: Student's t-test (Remington and Schork, 1974), Spearman's Rank Order Correlation (Kundzewicz and Robson, 2000), Mann-Kendall's test (Hirsch et al., 1982; Westmacott and Burn, 1997) and their pre-whitening corrections for autocorrelated series (Yue et al., 2002) and variance (Hamed and Rao, 1998). To detect jumps, the standard test of normal homogeneity (SNHT; Alexandersson, 1986), the Pettitt test (Pettitt, 1979), the Buishand rank test (Buishand, 1982), and the Buishand U test (Buishand, 1984) were applied to detect jumps.

In all tests, $\alpha=0.05$ was used. The mere indication of significant non-homogeneity of any method is taken as a reason to suspect gradual changes or jumps.

3.3 Wave analysis

The periodic variability in the time series of precipitation, temperature, and mean annual flow for each basin was studied using the continuous wavelet transform (CWT). CWT analysis allows for the analysis of periodic phenomena at different frequencies in non-stationary time series. The CWT can decompose a signal and represent it in the time-frequency domain, allowing observation of the dominant mode of variability and how these modes vary over time (Torrence and Compo, 1998). The statistical significance of the power spectrum is tested under the null hypothesis that the generation process data are given by a stationary AR(0) or AR(1) process for a background spectrum of a certain power, in this case, the Fourier mean frequency spectrum.

Then, to study the joint variability of the mean annual flow with precipitation and temperature in each basin, wavelet coherence analysis (WC) was used.

Wave coherence analysis can detect time-frequency intervals where two time series exhibit strong interaction. The concept of wave coherence is analogous to Fourier coherence, yielding a value between 0 and 1 that indicates the cross-correlation between two time series as a function of frequency (Torrence and Compo, 1998). This results in a measure of the covariance strength of the two series in the time-frequency space, which also distinguishes the phase relationship between them and the temporal evolution of the covariation.

The definition of coherence is similar to the traditional definition of the correlation coefficient. High covariability between series implies WC values close to or equal to 1, while if the series do not exhibit any type of synchronization, the WC is close to 0. The phase relationship between series provides information about the synchronization between fluctuations for a given frequency and time, whether in phase, anti-phase, or with a time lag (Grinsted et al., 2004).

The significance level is estimated using a Monte Carlo test with red noise, determining statistical significance at the 95% level (Torrence and Webster, 1999). Detailed information on the calculation and interpretation of results derived from the wavelet methodology can be found in Torrence and Compo (1998) and Grinsted et al. (2004), among other works.

For continuous wave and wave coherence analyses, the R package *biwavelet* was used (Gouhier, 2018). The parent function used was Morlet. This function is commonly used in hydroclimatic studies of the region (Labat, 2008; Agosta and Compagnucci, 2012; Caragunis, 2018). To account for errors in estimating the coefficients at the extremes of the time series, the cone of influence was constructed (Grinsted et al., 2004).

3.4 Results

3.4.1 Trend and jump analysis

The year-on-year variation, trends, and abrupt jumps for the series analyzed in each of the basins are shown in Figure 3.

In the Grande and Barrancas river basins, a significant decreasing trend in precipitation was detected, with coefficients of -3.61 and -2.36 mm/year, respectively. This trend in the Grande river basin was accompanied by a significant negative jump in 1987. In the Mendoza and Tunuyán river basins, significant increases in precipitation were detected in both cases through jump analysis in 1981 and 1976, respectively. No significant changes were found in the other basins.

Regarding temperature series, all sites show significant positive trends, except for the San Juan River basin, which does not show a significant trend, with the average temperature increase in the region being 0.01°C per year. The gradual increase in temperature is accompanied by significant positive jumps, mostly in the 1980s. Specifically, in the San Juan and Mendoza basins in 1984, in Tunuyán in 1985, in Diamante, Atuel, and Grande in 1988, and in Barrancas, two tests indicated 1976 while two others indicated 1984, with the jump in 1976 being the largest.

The trend in the average annual flow series for the region is primarily negative, with the Diamante and Grande rivers being the only statistically significant ones. A significant positive increase was detected in the Mendoza River basin in 1976, resulting in a positive, though not statistically significant, trend. While a decrease in flow was observed in the Mendoza River basin in 2008/2009 (Figure 3), this decrease, in absolute terms, is less than the increase seen in the 1970s. Significant negative increases were detected in the other basins: in 2009 for the Tunuyán, Diamante, Grande, and Barrancas rivers, and in 2008 for the Atuel River. Unlike the Mendoza River basin, the increase detected in the Atuel River basin in 2008 was greater in absolute terms than the increase in the 1970s (Lauro et al., 2019). In other words, the decrease in river flow over the last ten years is greater than the increase that occurred in the 1970s. The decrease in the region's flow over the last decade corresponds to below-average rainfall and above-average temperatures. Generally speaking, the trend in rainfall follows the trend in river flow, while the opposite is true for flow and temperature.

3.4.2 Continuous wave transform analysis

The results of the WTC analysis are presented in Figure 4, where the vertical axis shows the cycles in years present in the series and the horizontal axis shows the years in which the cycles occur; black lines indicate cycles significant at the 90% confidence level. Warm colors indicate cycles (periods) of greater intensity, while cool colors indicate the opposite. The cone of influence (white shade) indicates the area where edge effects are significant.

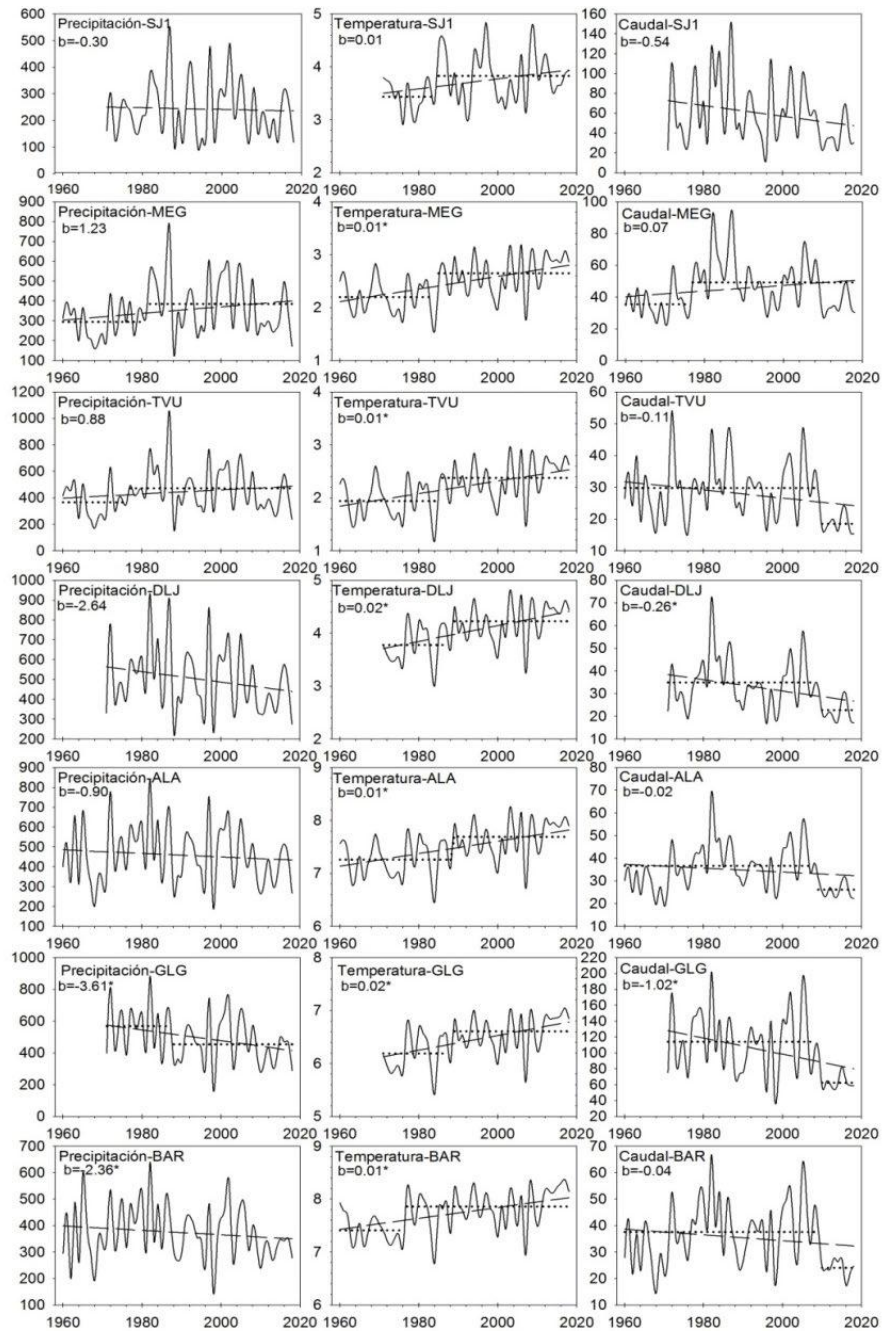


Figure 3. Precipitation (mm), temperature (°C), and flow rate (m³/s) series for all analyzed basins.

The dashed line shows the linear trend; the trend coefficient (b) was included in the variable units, and significant cases are marked with an asterisk. The dotted line indicates the average values of the series in the periods before and after the significant jumps detected. (Author's own elaboration.)

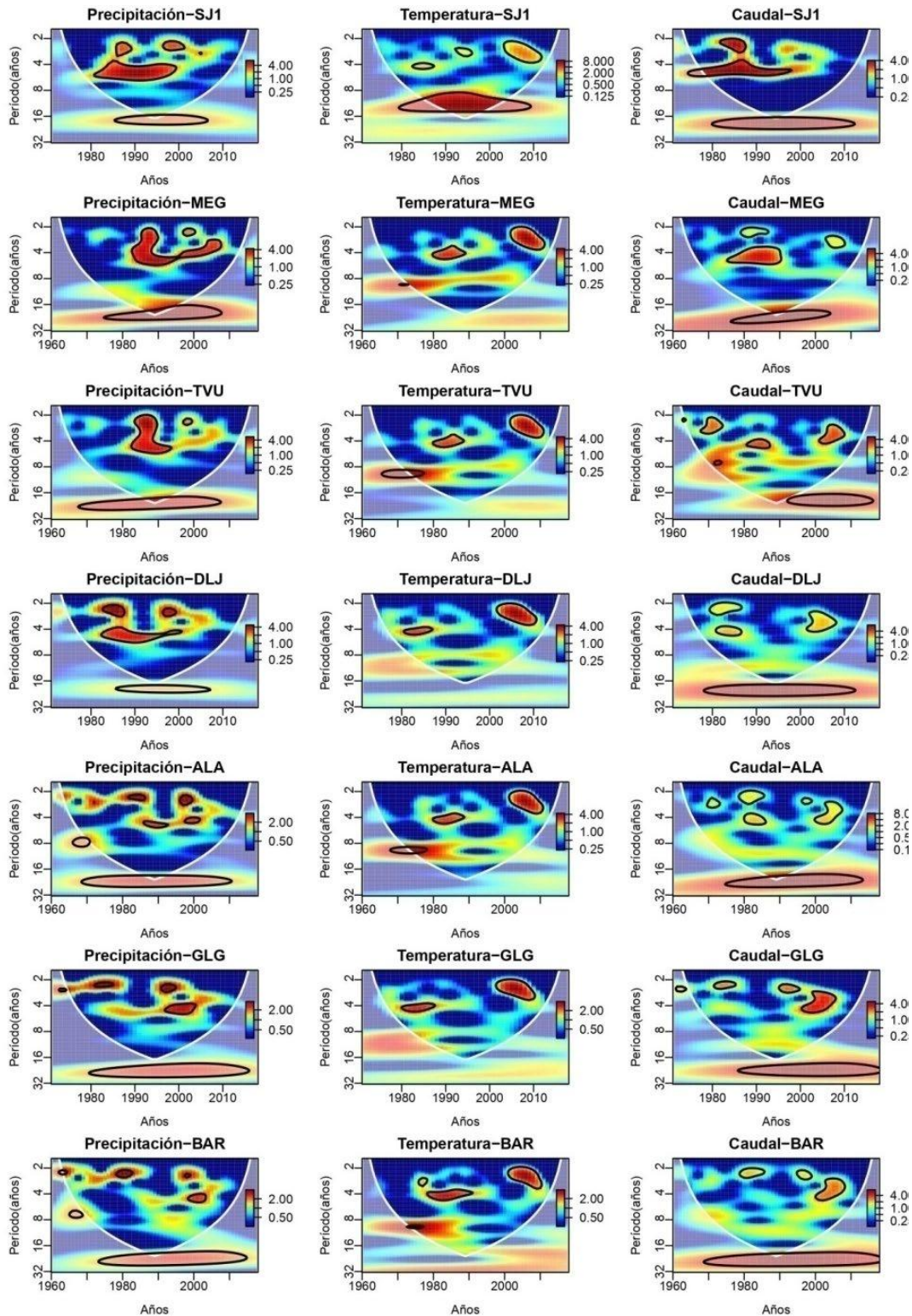


Figure 4. Continuous waveform analysis for precipitation, temperature, and flow rate variables.

Author's own elaboration.

The WTC analysis of precipitation shows similar patterns from north to south, with significant cycles in the 2-6 year band during the 1980s, 1990s, and 2000s. Significant cycles are also observed in the 16-32 year band, approximately from the 1970s/1980s to the 2010s/2000s. Specifically, for the Atuel River basin and Barrancas, significant 8-year cycles are observed during the 1970s.

For the temperature variable, all cases show a similar composition. In the TVU, ALA, and BAR basins, the 8-16 year period present between the 1970s and 1980s is significant. This period is also significant in the San Juan River basin but extends throughout the entire analyzed data series. In all cases, significant cycles are observed in the 4-year band during the 1980s and 1990s. Finally, in the 2000s and 2010s, the 2-4 year periods are significant and generally represent the greatest energy. Low-frequency periods are not significant in any case.

For the flow rate variable in the San Juan River basin, a 4-6 year cycle is observed from 1975 to 2000, with significant bands in the 2-3 year range between 1980 and 1990, and in the 16-32 year range during the period 1980-2010. In the Mendoza River basin, the 2-year and 4-6 year ranges are significant between 1980 and 1990, with the former exhibiting the highest energy. The 2-4 year range is also significant during the period 2000-2010. The 16-32 year band is significant in the 1990s. In the Tunuyán River basin, the 2-4 year band is significant in 1970, the 4-6 year band in 1980-1990, and the 2-4 year band in 2000-2010. From the Diamante River basin to the Barrancas River basin, the analysis shows similar intensities for the periods in the 2-6 year bands present in the 1980s-1990s. Significant cycles are also present in the 4-6 year bands in the 2000-2010s. In the Atuel and Barrancas River basins, the highest energy is observed in the 16-32 year bands in 1970.

In general, the greatest energy activity is concentrated in interannual periods (2-8 years). High power spectra are also observed at lower frequencies (16-32 years), mainly in precipitation and flow variables; although these fluctuations show greater persistence in the spectrum, they are generally found outside the cone of influence due to the length of the analyzed series.

3.4.3 Wave coherence analysis

Wave coherence analysis allows us to identify whether two time series (precipitation-flow rate and temperature-flow rate) oscillate at the same frequency and whether they are coupled. The results are presented in Figure 5. Horizontal vectors oriented to the right (left) indicate that the series are in phase (anti-phase), while vectors with angles between 90° and -90° reflect a delay of one of the two variables of a quarter of a period (period/4).

In general, differences in frequency and temporal distribution between precipitation and flow are observed from north to south, showing a high degree of coherence. Meanwhile, the correlation between temperature and flow in the different basins analyzed shows some similarities.

In the San Juan River basin, flow and precipitation are in phase, meaning there is a linear relationship, for 6-year periods during 1970-2005 and for 16-year periods between 1995-2000. However, during oscillations of 2-4 years, precipitation leads flow. Flow and temperature show a correlation for oscillations of 4-6 years during the period 1980-1990, with flow lagging by 1-1.5 years with respect to temperature.

In the Mendoza River basin, precipitation and streamflow data series are highly powerful and in phase at the 4-8 year frequency during 1980-1990, as well as at the 2-6 year frequency between 2000 and 2010, with a lag in the streamflow series. Temperature data also coincide at the 4-6 year frequency between 1980 and 1990, with a lag in the streamflow series as well. For the period 2000-2010, significant data series power is found with a greater lag in the streamflow series, up to 3 years for the 2-4 year frequency and 4-5 years for the 6-7 year frequency.

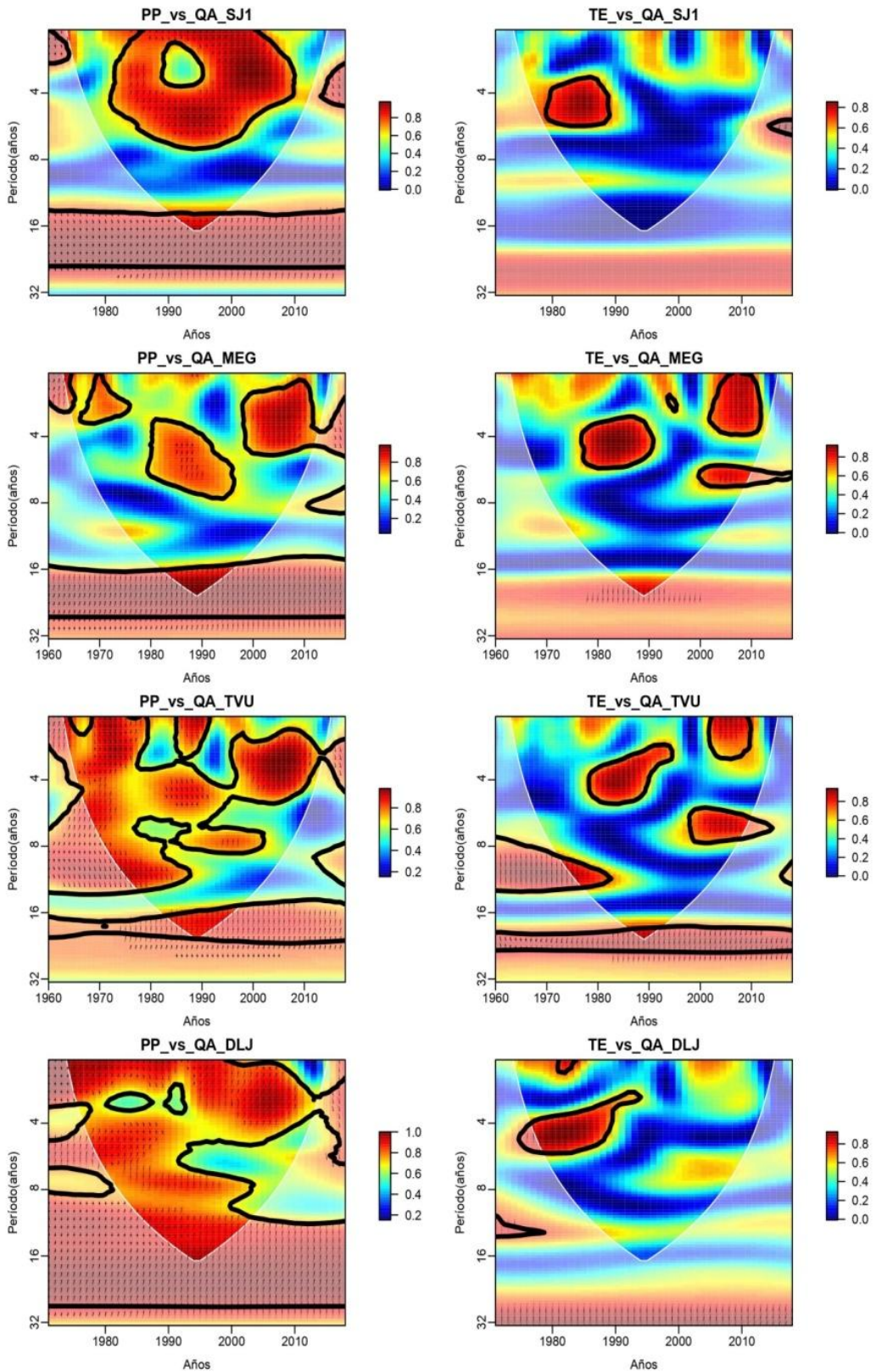


Figure 5. Wave coherence analysis between precipitation-flow and temperature-flow variables.

Author's own elaboration.

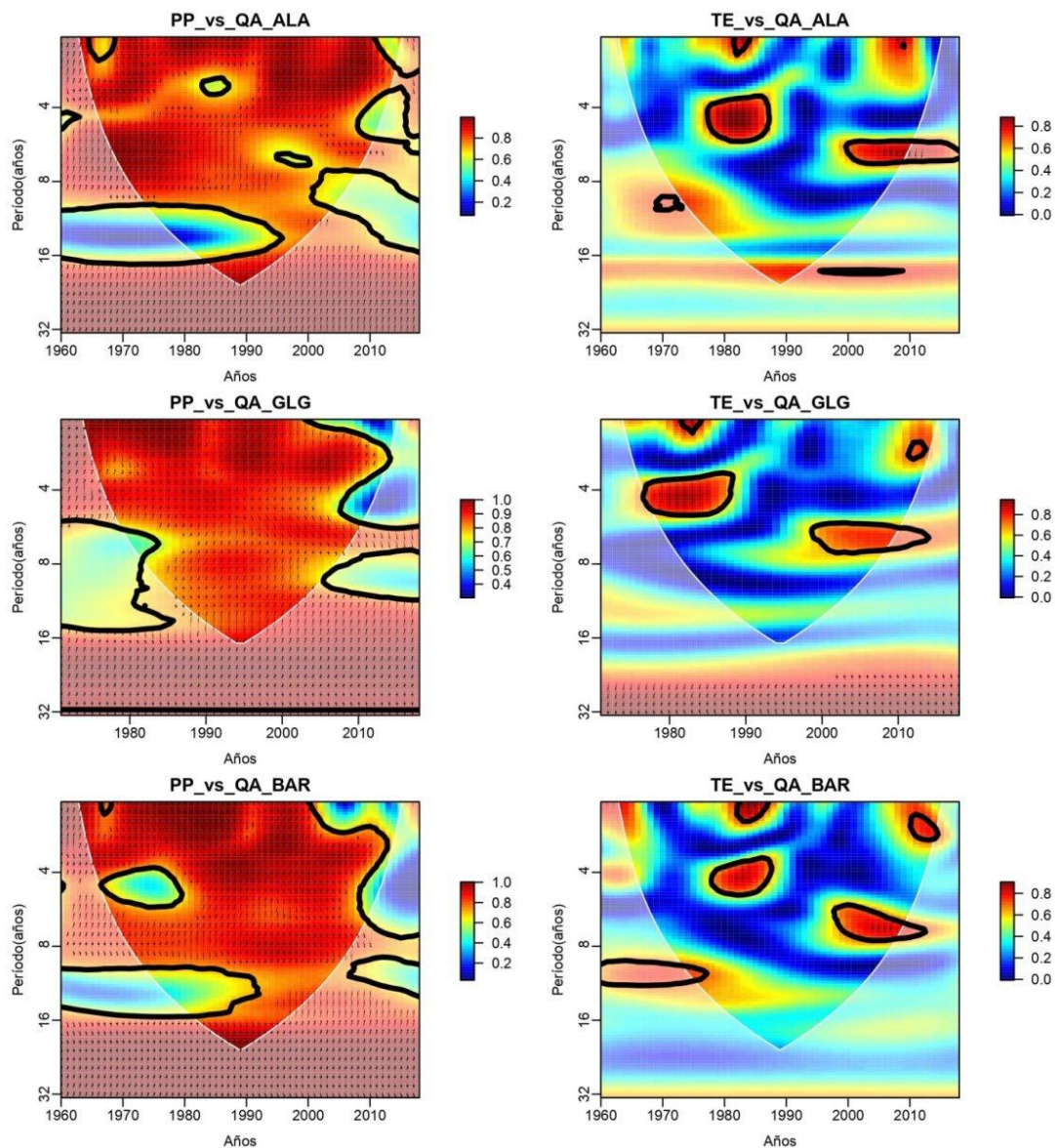


Figure 5 (continued). Wave coherence analysis between the precipitation-flow rate and temperature-flow rate variables.
(Author's own elaboration.)

In the Tunuyán River basin, streamflow and precipitation series show high power for 2–4 year cycles, in phase during 1960–1980, with precipitation leading at the end of the analyzed period. For 4–6 year cycles, both series are in phase in 1980–1990. For 16-year cycles, high variability power is also observed, with the precipitation series leading. Regarding the relationship between streamflow and temperature, the results are similar to those described for the Mendoza River basin.

For the Diamante River basin and the basins located south of it, the precipitation-runoff relationship behaves similarly. A high correlation exists for frequencies between 2 and 16 years throughout the analyzed period. In the Diamante River basin, the strongest precipitation-runoff relationship occurs during 2-year cycles in 2000-2010, with precipitation occurring earlier than usual. A linear relationship between the two variables is observed during 4- to 8-year cycles in 1980-1990. Significant periods of 8- to 16-year cycles are also noted between 1990 and 2000; this relationship is also significant in the Grande River basin. It can be observed that for 8- to 16-year cycles in the Atuel and Barrancas River basins, there is no correlation between 1980 and 1990. Regarding the temperature-flow relationship, in all cases there are significant cycles of

4-8 years in the period 1980-1990 and another between 2000-2010.

It is observed that while the precipitation-flow relationship shows high levels of coherence at most frequencies throughout the entire time series, the temperature-flow relationship is significant only for some frequencies and time periods.

4 Discussion

Understanding the variability of the hydroclimatic system in the central-western region of Argentina is of great importance for the management of water resources for populations settled at the foot of the Andes Mountains.

Given that the watersheds in the Cuyo region have a snow-glacier hydrological regime (Lauro et al., 2016), it is expected that the temporal evolution of precipitation and temperature variables will accompany runoff behaviour. The results show that while temperature tends to increase in all basins, which is consistent with global warming (Magrin et al., 2014) and projections made using various global models (Zazulie et al., 2017), precipitation trends accompany trends in river flows. An exception to this situation is the Tunuyán River basin, where the positive (non-significant) precipitation trend does not accompany the decrease in runoff associated with the negative jump in 2009.

The study of historical data reveals that since the late 19th century, the flow of the Atuel River has shown a sustained decrease with cycles of floods and droughts (Rojas and Prieto, 2020). Instrumental data analyzed from the mid-20th century to 2018 show that average values tend to decrease in the long term, driven by a negative drop in the 2010s. However, abrupt changes above the average were identified in the 1970s (Lauro et al., 2019). In the frequency domain, interannual cycles of 2–6 years were found. Regarding low-frequency variability, cycles of 16–32 years were observed. Caragunis (2018) identifies a significant decadal component in the flows of the Atuel River.

Since trend analyses are linked to the length of the data series, the incorporation of a decade's worth of streamflow data from recent years reverses the trend results obtained by Lauro et al. (2019) for the Diamante and Barrancas rivers. Meanwhile, for the Grande River, its negative trend coefficient increases. It is worth noting that the incorporated data coincide with an extraordinary hydrological drought event, due to its extent, duration, and severity, in the region over the last 50 years (Vaccharino et al., 2020; Rivera et al., 2021).

The cycles identified through wave analysis exhibit changes in the variance of the analyzed hydroclimatic variables. It is important to note that these changes are not continuous and vary in intensity and frequency throughout the analyzed time series. Both precipitation and streamflow show cycles corresponding to interannual and decadal variations in the 4-8 year and 16-32 year ranges, respectively. Lauro et al. (2021) explain that high-frequency variability in streamflow series across the region is associated with ENSO, with this relationship being most pronounced during the period between 1970 and 2000. In the San Juan, Atuel, and Colorado rivers, Caragunis (2018) identified significant cycles of approximately 22 years, with the strongest signal between 1970 and 1990. The association between precipitation and streamflow with the ENSO index and the PDO index (Compagnucci et al., 2000; Lauro et al., 2019; Masiokas et al., 2019; Lauro et al., 2021) indicates that ocean-atmospheric forcing induces low- and high-frequency cycles in the Central Andes region. Specifically, increases in annual streamflow are associated with increases in sea surface temperature in the Niño 3.4 region (Carril et al., 1997; Compagnucci and Araneo, 2007; Lauro et al., 2019). During the positive/negative phase of the PDO index, the flows in central-western Argentina are above/below their average values (Masiokas et al., 2010; Lauro et al., 2019).

Runoff from basins located on the eastern slopes of the Andes Mountains (28-37°S) is highly dependent on snow accumulation (Masiokas et al., 2006) and intra-seasonal temperature variability (Araneo et al., 2015), among other factors. The relationship between precipitation and streamflow is strongest within the interannual frequency range present throughout the study period, while in some basins, a relationship was found within decadal frequencies during the 1990s.

For interannual periods, precipitation is observed to be leading, meaning there is a lag between the increase in precipitation and the increase in streamflow. The role of temperature in basins with a nivoglacial regime lies in the processes of nivoglacial melting or its inhibition; this relationship is clearly present with intra-seasonal patterns (Araneo et al., 2015). On an interannual scale, the relationship between temperature and flow rate is observed at frequencies of 4-8 years in the period between 1980-1990, with the temperature leading the flow rate.

Conclusion

The components of the hydrological cycle in basins with snowmelt-glacial regimes over long timescales are linked to global ocean-atmosphere circulation patterns that affect regional climate variability. Understanding the behavior of the various components of the hydrological cycle at different temporal and spatial scales allows for improved water resource management. In particular, the study of hydroclimatic variability in the Cuyo region aims to contribute to the water security of the communities involved, given that it has been compromised over the last decade due to a decrease in water supply caused by reduced precipitation and increased temperatures in the region.

The gradual changes identified in the region do not exhibit homogeneous behavior. The flow rates of the Diamante and Grande rivers are the only ones showing significant negative trends based on statistical analysis, with the decrease in flow in the Grande River basin being the largest in relative terms. It is noteworthy that south of the Tunuyán River, all rivers show a significant negative drop in flow rates at the beginning of the 2010s.

Both precipitation and flow rates exhibited interannual and decadal cycles, which were not uniform throughout the analysis period. The region's temperature tends to increase, showing interannual cycles that were more intense during the 2000-2010 decade.

The relationship between precipitation and streamflow is observed in interannual frequency bands and, in some cases, in decadal bands. Meanwhile, the strongest relationship between streamflow and temperature occurs in the 4-8 year bands. The coherence analysis will be performed on a monthly timescale due to the hydrological regime characteristics of the basins, as the influence of temperature is more significant on seasonal or intra-seasonal scales.

Surface water availability in each basin is subject to long-term changes, as well as interannual and decadal fluctuations associated with macroscale climatic phenomena. Understanding the multiple time scales of these fluctuations, as well as the various processes that cause them, is important for improving runoff prediction models.

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Conflicts of interest

The author declares no conflicts of interest regarding the publication of this paper.

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About the author

Carolina Lauro is an engineer in renewable natural resources from the National University of Cuyo. She holds a PhD in Engineering from the National University of Rosario. She is an assistant researcher at CONICET and works at the Argentine Institute of Snow Science, Glaciology and Environmental Sciences (CCT Mendoza). Her main lines of research focus on surface water resources, regionalization of extreme hydrological variables (droughts and floods), hydrological variability, and its relationship to climate change.

Alberto I. J. Vich, Water Resources Engineer, Master of Science in Soil Science. Adjunct Researcher at CONICET and works at the Argentine Institute of Snow Science, Glaciology and Environmental Sciences (CCT Mendoza). Professor at the Faculty of Philosophy and Letters of the National University of Cuyo. His main lines of research concern flood risk, hydrological process analysis, mathematical modeling, extreme hydrological phenomena, water erosion, regionalization of hydrological variables, and integrated water resources management.

Sebastián Otta is a Renewable Natural Resources Engineer from the National University of Cuyo. He is a CONICET doctoral fellow and works at the Argentine Institute of Snow Science, Glaciology and Environmental Sciences (CCT Mendoza). His main lines of research are: land use, integrated water resource management, and climate change adaptation.

Stella Maris Moreiras holds a Bachelor's degree in Geological Sciences from the National University of San Juan and a PhD in Geological Sciences. She is an Independent Researcher at CONICET (National Scientific and Technical Research Council) and an Adjunct Professor at the Faculty of Agronomy, National University of Cuyo. Her expertise lies in Quaternary geology, landslides, and geomorphology. Her main lines of research encompass Quaternary stratigraphy, paleoseismology, neotectonics, natural hazards, catastrophic floods caused by the rupture of natural glacial dams or

landslides, and recent environmental changes.

Emilce Vaccarino is a professional geographer from the National University of Cuyo. A CONICET doctoral fellow, she works at the Argentine Institute of Snow Science, Glaciology and Environmental Sciences (CCT Mendoza). Her main lines of research are: hydrological droughts, recurrence of hydrological events, spatiotemporal distribution, and social perception of drought events.

Luis Bastidas is a geographer from the University of Los Andes, Venezuela. He is a Master's student in Water and Land Development, specializing in Water Resources Planning and Development, at the Inter-American Center for Environmental and Territorial Research (CIDIAT), University of Los Andes. A CONICET doctoral fellow, he works at the Argentine Institute of Snow Science, Glaciology and Environmental Sciences (CCT Mendoza). His main research interests are environmental flows, wetland conservation, and climate variability and change.