Water availability, use and governance in the wine producing region of Mendoza, Argentina

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Abstract

This paper explores current and future issues of water availability and use in one of the world's major wine-producing areas, Mendoza Province in Argentina. The region is located close to the Central Andes and is characterized by an arid to semi-arid climate, which exacerbates pressures on land-use and water resources for wine production. The principal supply of water originates in the snow and ice fields of the nearby Andean peaks. Already under stress today, the environmental, economic and societal structure of the region, highly dependent on the wine industry, is likely to be vulnerable to climate change in the course of the 21st century. In this study, the possible impacts of shifting temperature and precipitation patterns and climate variability linked to extreme events and El Niño/Southern Oscillation ENSO on water resources in the region and consequently on the wine industry will be investigated. While climatic factors already today exert a major control on water availability, water use is also shown to be influenced by non-climatic factors, in particular overexploitation of the resource and a certain degree of opacity of policies related to water rights and water allocation. Climate model results for the future suggest that there may be important changes in the quantity and timing of stream flow, highly dependent on the Andean cryosphere where many glaciers are already rapidly shrinking today. The direct impacts of a changing climate on wineries include extreme events and also decreased water availability for irrigation in the long term. In view of the importance wine as a major income-earner for Argentina, public water policies will need to address both the issues of unreliable current water governance practices and the adaptations necessary to cope with a changing climate.

Key words: Climate variability, glaciers, water availability, sustainability, ENSO, extreme events, water governance

1. Introduction

Wine production in the Province of Mendoza (western Argentina) is both the main source of economic income and the main consumer of water for irrigation. Any sustained change in climate, resulting not only in shifts in temperature and precipitation in the region, but also in the snow and glacier fields of the nearby Andes – the major source for surface waters downstream – may have significant impacts on the wine industry and the local to national economy as a whole. However, climate is not the only source of concern when assessing plausible future changes; indeed, there is a lack of legislation and regulation related to water allocation and use (Carbonneau, 2010) that also need to be taken into account.

The region of Cuyo concentrates 98% of the population on 4% of Mendoza province (Morabito et al., 2009) and receives all its waters, upon which a large fraction of economic activities depends, from glacier melt in spring. The largest fraction of water used in the region is taken up by the wine industry (DGI, 2006), in particular because one of the most common irrigation practices is through inundation techniques that are obviously extremely resource-intensive. Under current climate conditions, the annual water balance is in deficit (i.e., more uptake than supply) and only 75% of the annual demand can be satisfied because of an annual deficit of 32Hm^3 (DGI, Annex 4). However, those quantities remain hard to evaluate because of the lack of control and regulation by local authorities.

By necessity, the development of the region needs to be linked to good water management practices, which is unfortunately far from being the case. Addressing issues of long-term water scarcity thus needs to be a dominant priority for current and future water management policies.

Because of the high climate variability of the region, closely linked to El Niño/Southern Oscillation (ENSO) events in today's climate, and likely increases in extreme events such as heavy rainfall, hail and frost in tomorrow's climate, reductions in the availability of water associated with more intense/more frequent extremes could threaten the viability of the wine industry in the long term. Indeed, wineries are very sensitive to weather and for each grape variety, optimal climate conditions are necessary to ensure an abundant harvest and grapes of high quality (Van Leeuwen et al., 2009).

Grape cultivation is generally viable in climates with a mean annual temperature "bandwidth" between 10 and 20°C (e.g., Tonietto and Carbonneau, 2004). According to the grape variety, some grapes may be more robust at the upper end of the temperature spectrum, but others may be more adapted to cooled temperatures. Overall the quality of wines has been seen to improve in many regions, in part due to an increase in average temperatures in most regions where vines are cultivated, but also to new wine maturation techniques that today reduce the dependency of wine quality on climatic factors alone.

This study will therefore attempt to link both climate and regulatory factors to the wine industry in Mendoza and will focus on water use and water scarcity relations on both the short and long terms. Because much of the available surface waters are related to the presence and behavior of snow and glaciers in the nearby Andes, the rapid decline of ice mass in the mountains as a consequence of atmospheric warming will have a significant influence on the seasonality, quantity and timing of maximum discharge in the future. This study will therefore report on the evolution of snow and glaciers and their influence on discharge of the Mendoza River, as well as shifts in water availability for irrigation of relevance for the wine industry in Mendoza. A further objective of this paper is to provide an overview of political, economic and social impacts of climate variability on the wine industry by highlighting the supply and demand side of water management under current and future climates.

2. Data and methods

Despite significant sparseness in the data available for the Mendoza region of Argentina (INV, 2009; INDEC, 2012; DGI, 2012) and inconsistencies in the quality of data (Masiokas et al, 2013; Leiva, 2008; Espizua and Maldonado, 2007; Compagnucci and Vargas, 1998) this work has attempted to highlight a number of climate tendencies of relevance to water availability by using a number of indicators, such as temperature, precipitation, stream flow, and snow water equivalent (SWE).

Temperature data is available for the Mendoza Airport which is located in the plains at the foot of the Andes. Unfortunately, this station is not representative of sites located in the mountains, which would have been more useful for analysing the time evolution of snow accumulation and melt, but many mountain recording sites have many gaps in the data. However, the Guido station, at an elevation of 1550 m (DGI, 2012; SMN, 2012) has been selected because it includes a hydrological gauging site that enables an estimation of the amount of discharge related to snow melt in the Mendoza river catchments (see the Map in fig. 1).

**** Insert Fig. 1 near here ****

As the Cuyo region is considered to be a desert, it is important to highlight the difference between precipitation at high elevations in the mountains and at lower altitudes in the plains. Indeed, the lowlands receive around 200 mm of liquid precipitation per year while the mountains receive on average 500 mm of snow precipitation. According to the season and to the variability of temperatures, precipitation will have a varying influence on snow accumulation and on water availability. ENSO has been based on the ONI (Oceanic Niño Index), which uses sea surface temperature data in the Niño Region 3.4 and analyzed on a monthly basis (NOAA, 2012).

Issues related to water policies, water allocation, and irregularities in the use and distribution have been established on the basis of legal publications, in particular the DGI (DGI, General Plan and 2020 Management Plan). Most of the qualitative analysis comes from interviews realised with local wine producers, local authorities and scientists. The questionnaire that helped establish the qualitative assessments in this study included items pertaining to the activity and production of wine growers (size of domain; whether export-oriented products; possible extension of the domain in the future, …), the perception of local actors to climate change and variability (whether the wine growers have noticed sustained changes in temperature or precipitation patterns; whether they notice different qualities of grapes that they may attribute to climatic conditions; whether they have or are considering adapting to extreme events – e.g., hail protection nets, …), and water usage (what type of irrigation is used; what sources of water are employed; whether there are problems of water salinization or contamination; whether droughts are considered to be a major issue; can wine-growers envisage cultivating grapes by using less water; …). These enquiries were undertaken to understand how local wine growers possibly perceive, if at all, problems of climatic variability, change, and water-scarcity. Although the small number of samples implies that the statistical robustness of the responses by wine-growers may be low, they do shed some light as to the overall feeling in the region that water shortage and climatic change is not an issue. In order to increase the sample size, semi-structured interviews (open discussion) with institutional stakeholders (e.g., water agencies) and scientists specialized in hydrology, glaciology and climate were conducted.

3. The wine industry in Mendoza Province and its dependency on water: current situation

The Cuyo region focuses most of the economic activities of Mendoza Province; wine production is the most developed sector and is one of the main sources of national and foreign income. Further sectors are closely linked to the wine sector, such as wine tourism, transformation industries, and export activities. 75% of Argentinian wine production comes from the Mendoza region, and Argentina holds the 5th rank worldwide as a producer and exporter of wine products. In accordance with INV (National Institute of Wineries) and a study by PWC, the surface area of land dedicated to the wine industry has increased by about 25% since 2000 (PWC, 2009).

The particularity of this region is based on its ability to develop an irrigation “oasis” that receives melt water from the nearby Andean glaciers. All the socio economic activities (agricultural, industrial, domestic use, etc.) have been developed around a complex irrigation system. The installation of dams and reservoirs provides storage of water and a better allocation of the annual distribution of the resource. This extensive production will have an important impact on irrigation systems and on the distribution of water in the future (PWC, 2009), thereby increasing social and economic awareness to the necessity of sustainable management practices.

As in many regions, melt-waters from the snow that accumulates during winter season represent the main supply of water during the warm season and throughout much of the year (Masiokas et al., 2013). In the Mendoza watershed, 70-80% of ground and surface waters originate from snowmelt and glacier melt during the spring season. Around 20% of meltwaters enter into the groundwater table, and are shared among the industrial, agriculture and domestic consumption sectors. However, the dominant consumer of water is the agricultural sector that uses around 80% of the total groundwater available; of this, 70 % is dedicated to wine production (Morabito et al., 2009). These conditions may well change in the future, with a first phase of increasing flows as glaciers melt, but then sharply-curtailed river discharge once the glaciers have all but disappeared (e.g., Kaser et al., 2010). Because of limited climate modelling work in the Andes, it is difficult to quantify the peak beyond which low flow levels become inevitable, but at current rates of glacier decline this could be a matter of decades.

ENSO (El Niño/Southern Oscillation) is known to have an influence (Beniston M., 2003; Masiokas et al., 2006; López-Moreno et al., 2014) on precipitation regimes on both sides of the Andean chain, as well as on glacier recharge in the Andes. During the El Niño phase, precipitation in the Andes is generally much higher than average, and is accompanied by heavy rainfall in regions that are usually arid or semi-arid. At the higher elevations, snow accumulation can be high, thus leading to positive glacier mass balance during El Niño years (Villalba, 2009a). On an annual basis, higher streamflow values are observed during El Niño events and much lower values during La Niña, i.e., the cold phase of ENSO (fig. 2).

**** Insert Figure 2 near here ****

The impacts of a changing climate can have both beneficial and harmful effects on grape harvests. Warm temperatures and more frequent precipitation can have a positive impact on wine, boosting the sugar and alcohol content while extremes of heat and cold, or drought and heavy precipitation can have deleterious impacts on the wine harvests. Hails or frost events during the spring period, where grapes are in their growth phase, can be particularly harmful to the plants and fruit, although changes in phenology could to some extent counter these effects. Springtime temperatures below the freezing point can lead to particularly damaging frost episodes that impede the development of the grapes in their early phases of growth (PWC, 2009; Van Leeuwen et al. 2009). The observations from the Mendoza Airport weather recording station show a decrease in the number of spring days with temperatures below 0°C (fig. 3). This is consistent with the average increase in mean temperatures that leads to a decline in frost hazards, with beneficial side-effects for future grape harvests.

**** Insert Figure 3 near here ****

However, if ENSO events can generate positive impacts on temperatures through this decrease in frost risk, hail on the other hand represents a major threat for grapes throughout their growing period and until their ultimate harvest. Extreme precipitation and hail associated with strong convective storms exerts considerable damage to vineyards between December and March (Caretta et al., 2002). In order to identify days with extreme precipitations, the number of days of rain in summer (from December to March) beyond the 97% quantile (i.e., $p>0.97$) has been selected (fig. 4). Thresholds at p95 (22 mm), p97 (28 mm) and p99 (44 mm) has been defined but as an arid region, percentile p97 was deemed to be more representative of extreme events and statistically more robust.

In the last decades, fig. 4 shows that extreme precipitation in summer has increased in intensity (mm) and in frequency (number of days). Grey bars represent the volume of yearly precipitation above the 97th percentile and black bars represent the number of days with precipitation above the 97th percentile.

**** Insert Figure 3 near here ****

Hail and heavy rainfall not only result in major losses in grape harvests and subsequent wine production; they also weaken the plants that often need several years to recover from heavy damage (Morabito et al., 2009). Increases in the frequency and intensity of these extremes would unfortunately result in economic losses beyond the potential economic gains resulting from reductions in frost damage.

4. The wine industry in Mendoza Province and its dependency on water: future situation

A number of studies (e.g., Quénol et al., 2009) have reported upon the changes in the optimal combinations of temperature and precipitation that are favorable to each grape variety. Any sustained change in climate parameters could modify the geographic distribution of the production optimum, as a function of sugar and alcohol content, acidity, flavor, maturation, etc. An increase in temperatures could oblige a winegrower to move to higher altitudes or to change the grape variety in order to adapt to the new characteristics of climate (Quénol et al., 2009; Van Leeuwen et al., 2009).

Changes in the climatic conditions favorable for wine-growing, namely modest increases in precipitation and temperatures in lowlands, can explain earlier development stages in the growth of the grapes, and a modification of the geographic distribution of the optimum climate for each variety of grape. For example, it is observed in Mendoza that an earlier start of the development of phenological stages of grapes and advances in the dates of harvest have taken place in recent years. In other words, climate variability on the short term will in principle improve the grape harvest and thereby wine quality and quantity but, on the longer term, lack of water for irrigation could change the current model of production (Robillard et al., 2009). This would require shifting to a production model that would consume much less water than today.

As an example of observed changes in the evolution of annual streamflow (Hm^3); fig. 5 highlights the increasing discharge since the last decades in Mendoza River.

**** Insert Figure 5 near here ****

Fig.4 is an illustration of the contribution of snowmelt to streamflow, which shows an increase in annual discharge of 13Hm3/year. This tendency can certainly be attributed to enhanced snow and ice melt in the Andes as a result of more elevated temperatures at altitude. Andean glacier retreats are now evident and have been largely documented (Villalba, 2009a; Leiva et al.2008; Espuzua and Maldonado, 2007).

Two indices were used to analyse the shift in snowmelt period timing (Cayan et al., 2001). The first one is the “Day of initial pulse of snowmelt runoff” (SP), which is the day of the year where snowmelt begins and corresponds to the day where cumulated anomalies of runoff are less important. The second index is the “Day of centre of mass of flow” (CM), corresponding to the day in the hydrologic year (June-July) where 50% of annual flows are reached.

The present study enabled an identification of SP at day 98 and CM at day 198 (fig. 6a). On the model of the annual hygrogram, the same indices were calculated for the entire period for which data is available (1956-2009) in order to highlight the earlier periods in snowmelt and maximum annual streamflow (fig. 6b). The tendencies show a shift in time for both CM and SP that appear earlier in the year (respectively 1 day and 0,5 day per decade). This can be explained by an increase of temperature with height in the mountains, changing accumulation of snow and streamflow behaviour (Villalba, 2009a).

**** Insert Figure 6 near here ****

In the future, this might become a general trend in the region. In the short term, the Mendoza River will benefit from more water availability from increasing glacier melt; but on the long term, this source of water may no longer be available when glaciers have eventually disappeared. Annual stream flows have been put into relation with ENSO events in order to obtain an extended vision on snow accumulation as a function of the variability of temperatures and precipitation at height (Compagnucci and Vargas, 1998; López-Moreno et al., 2014). Fig. 7 shows the general tendencies for increasing discharge in the presence of El Niño (diamond shape) and decreasing runoff with La Niña (square shape) events.

**** Insert Figure 7 near here ****

El Niño years are known to increase snow accumulation and thus to provide larger quantities of water resulting from spring snowmelt. On the contrary, La Niña events decrease streamflow because of much lower precipitation and thus snow accumulation in the mountains. According to the frequency and intensity of appearance of ENSO events, snow accumulation and streamflow can be highly modulated. If more La Niña were to occur in the future, snow accumulation would also decline (Leiva et al., 2008), with negative consequences for water availability.

Snow accumulation is almost the sole factor that influences the behavior of the Mendoza River watershed (Villalba, 2009b). Snow melt in spring (November to February) provides the largest fraction of annual discharge (over 60%), most of which is used up by the wine industry. Future changes in water supply and demand, in a climate that will tend towards increasing water shortages due to glacier retreat (Villalba, 2009a; Leiva et al., 2008), would require major shifts in water governance paradigms if this very profitable industry is to be sustained well into the future.

Other changes have been observed as a result of current climate trends, but without negative impacts. These include advances in the timing of the wine harvest period due to warmer conditions. Although this does not necessarily affect the wine production, it can change the characteristics of the wine characteristics owing to shifts in phenology and in the optimum conditions for certain grape varieties. According to the wine growers the climate variability for the moment has positive impacts on wine, giving more sugar and more alcohol. Only extreme events, such as hails or frost have negative and direct impacts on production and wine quality in this moment.

5. Current water policies and requirements for improved water governance

According to field observations, interviews, and the analysis of water management plans the current legal framework for water management seams not being adapted to long-term management practices. It is therefore essential to think in terms of new management plans spanning at least 30-50 years in order to integrate the necessary adaptations to climatic change. While this seems to be an obvious statement, it is far from being applied in Argentina, where laws are drafted only for a few years at a time. In this sense, the Strategic Development Plan of Mendoza also called "Water Plan 2020" (DGI, 2012) was edited in 2012, giving only 8 years to reach objectives of massive integrated water resources management and infrastructure inversion. Political instability and the lack of overlap between the different authorities (local, regional, provincial and national) make the decision-making process even more difficult. Just like the Water Act of 1884, which today governs the distribution and management of water, norms and laws urgently need to be updated in light of current realities. It is necessary to rethink the chain of regulations pertaining to water rights and private water operations that are inequitable and opaque. There is much abuse in water withdrawals from the ground-water table, where many of the private wells are both illegal and unrecorded. As a result, this does not allow authorities to monitor the amount of water being extracted. An overhaul of the pricing system would be essential to establish better controls on the amount of water used by private concessions.

The “Water Plan 2020” implemented by the General Directorate of Irrigation (DGI) reflect the priority given to the management of water resources for the future development of the region whom objectives are to “*integrate efficiency, efficacy, sustainability, equity, quality and competition*”(DGI, 2012 p9). Nevertheless, the goals remain highly focused on advances in technology aimed at stimulating economic growth of Mendoza and do not really take into account the impacts of climate change nor water shortage. More surprising is the total absence of the place dedicated to irrigation in the plan, knowing that this the most important uptake of water in the region (DGI, 2012 p16). Even in the 2020 Argentinean Wine Strategic Plan (FPEA, 2012), the objective is to reach an added value and harmonized development of all social and economical actors. Controlling the extraction, pricing and reform laws relating to water, user awareness and establishing standards of financial incentives could perhaps reduce the overexploitation of groundwater and lead to a sustainable and integral management of water resources, when sustainable management of water and soils never appears as a priority in the future plans.

Independently of considerations pertaining to climatic change, wine growers have already adapted to reduce the risks associated with the negative side-effects of extreme weather (Van Leeuwen et al. 2009; Quenol et al. 2009, Carbonneau, 2010). For example, in order to prevent the risk of hail, anti-hail nets have been installed in many vineyards. These protect the fruit and flowers from the impact of hailstones, without shutting out the sunlight that is essential for stimulating plant growth. This is a very effective and relatively inexpensive technique. Access by wine-growers to real-time weather forecast could also help avert some severe impacts through early warning to extreme weather conditions.

A long-term adaptation technique could ultimately involve changing the grape variety. Each type of grape is related to optimal growth and production conditions. Based on future climate projections and taking into account local conditions, growers may therefore choose to plant new varieties better adapted to new climatic conditions. In addition, agricultural engineers are currently working to develop varieties that are resistant to both disease and also extremes of heat and moisture.

Many adaptive solutions to face climate variability are thus available, especially for water efficiency. For small and medium producers, drop by drop or micro-aspersion irrigation are easy to implement and efficient but the cost remains a brake. For decision makers, concrete actions such as the building of water-storage reservoirs and the implementation of stringent water regulations, through incentives and cost mechanisms, would be among the first steps towards improved water management. The main problem in their implementation concerns the will to invest and to put into force new regulations for a better control of water use. Many irregularities and a lack of transparency concerning the real quantities of water that are used on an annual basis makes the implementation of an integrated water management plans more difficult in the future.

In the contemporary climate, weather conditions in Mendoza are ideal for the wine industry and it is likely that this may continue for another couple of decades. The major problem on a longer term will be to reconcile the needs of water for irrigation, water management for other usages, legislation and social needs. In the context of global warming, it is important to take into account climate projections in order to enable early adaptation of water use so that it can be readily implemented for the future. Adjustments in irrigation systems would probably be a major priority, by establishing less water-consuming systems, but efficient and actionable water regulation would be a further urgent priority. As the land dedicated to the wine industry is continuously increasing, regulations will need to be stricter and incentive policies will have to be imposed in order to put into place a more sustainable model of development in Mendoza. Although competition for water has always existed in the region even without climate change, this will become much stronger in the future.

Water policies thus need to think in terms of decades and not just months or years in order to address the genuine problems that the Mendoza grape and wine industry will be increasingly facing into the future.

6. Conclusions and outlook

This paper has provided an overview of the current problems facing the wine-industry in the Argentinian province of Mendoza, which is the largest source of revenue of the region. It has been shown that the availability of water in this arid part of the country is crucial to the vineyards, and that the amount of surface runoff and the potential for aquifer recharge is heavily-dependent on the contributions of snow and ice-melt in the nearby Andes. The current trend in glacier retreat, linked to a warming atmosphere over a number of decades, is modulated by the behavior of ENSO; the warm, El Niño phase brings higher-than-average precipitation to the Andes and enables glacier mass to recover momentarily from the long-term decline in ice volume. The paper has also shown that climate variability and extremes, frequently linked to the warm or cold phases of ENSO, can exert significant impacts on the grape harvest and thus on the quantity and quality of the wines produced here. However, current climate and its variability is not the only factor that influences water availability and use in the region. Weak implementation of existing water regulations, illegal wells and uptake of water make it difficult for authorities to monitor the amount of water being extracted, and therefore how much water is truly available for the different economic sectors in the region.

These problems are likely to be exacerbated by a changing climate, compounded by even lower quantities of snow and ice-melt in the Andes and a change in seasonality and amount of peak flows. Although little is known about the possible changes in extreme events in the region, it is possible that more frequent/more severe episodes of extreme heat, drought, rainfall and hail may exert negative impacts on the grapevines and thus on the wine industry as a whole. Water availability and sustainable use of the resource will be the key to the future of the Mendoza wine industry. This will involve technological adjustments (more drought or heat-resistant grape varieties, for example), new infrastructure in the form of reservoirs, but above all will require changes in current water policies. Sustainability of water use will need to consider many factors, including climate change, and a complete overhaul of the current water governance structures will need to be addressed if the region is to remain one of the top wine-producing regions of the planet.

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Figure Captions

Figure 1: Map of the Mendoza region, including the Guido flow gauge station

Figure 2: Impact of ENSO events on streamflow for the Mendoza River

Figure 3: Frost days in spring with temperatures under 0°C

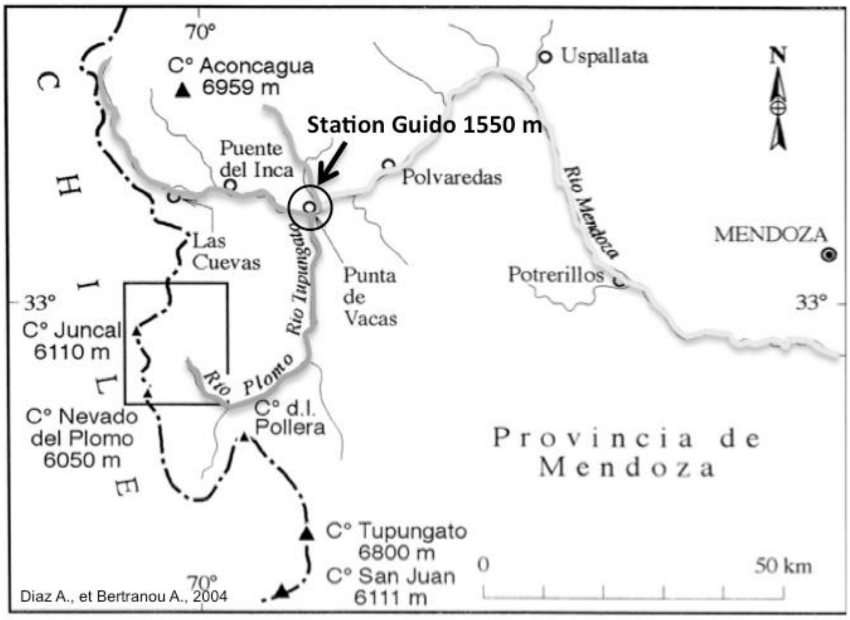
Figure 4: Hail and extreme precipitation in summer

Figure 5: Evolution of annual streamflow in Mendoza River (Hm^3)

Figure 6: Changes in the dates of glacier melt (JP) and 50% annual discharge (CM)

Figure 7: Mendoza River discharge in the presence of La Niña and El Niño events

Figure 1



Diaz A., et Bertranou A., 2004

Figure 2

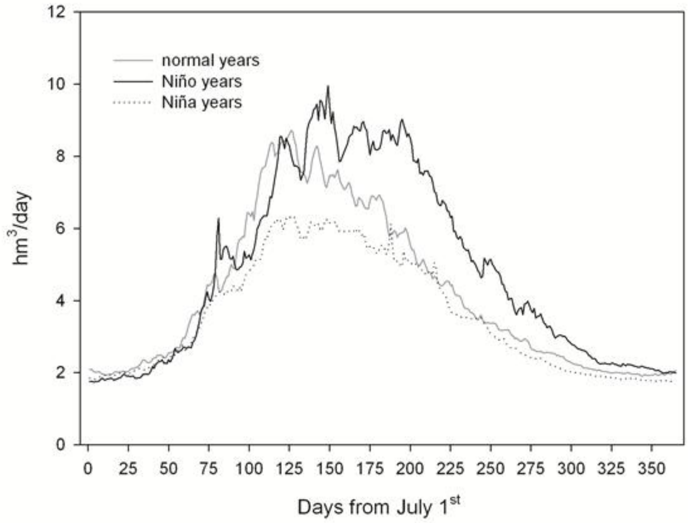

normal years
Niño years
Niña years
hm^3/day
12
10
8
6
4
2
0
0
25
50
75
100
125
150
175
200
225
250
275
300
325
350
Days from July 1st

Figure 3

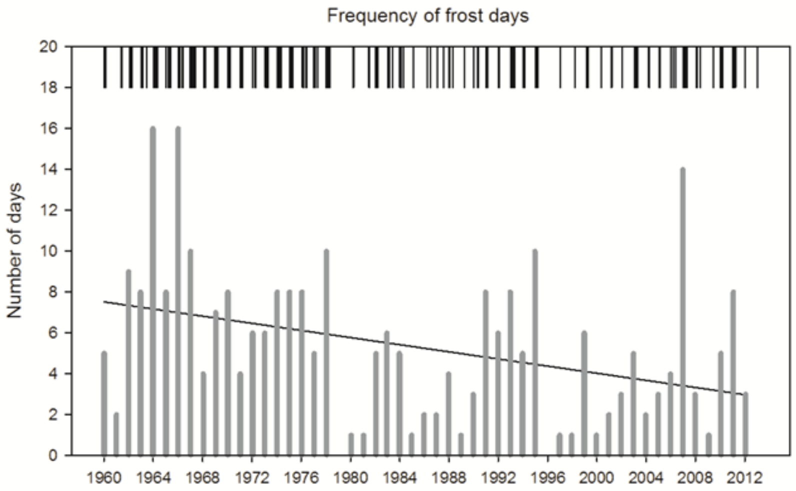

Frequency of frost days
Number of days
20
18
16
14
12
10
8
6
4
2
0
1960
1964
1968
1972
1976
1980
1984
1988
1992
1996
2000
2004
2008
2012

Figure 4

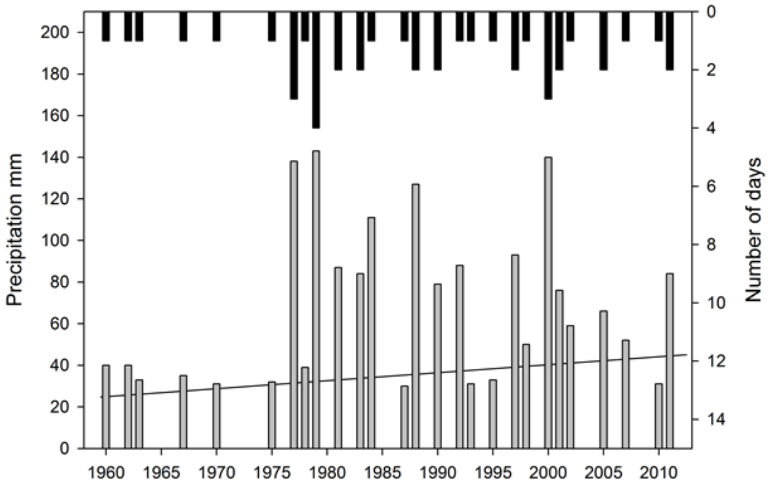

Precipitation mm
0
20
40
60
80
100
120
140
160
180
200
Number of days
0
2
4
6
8
10
12
14
1960
1965
1970
1975
1980
1985
1990
1995
2000
2005
2010

Figure 5

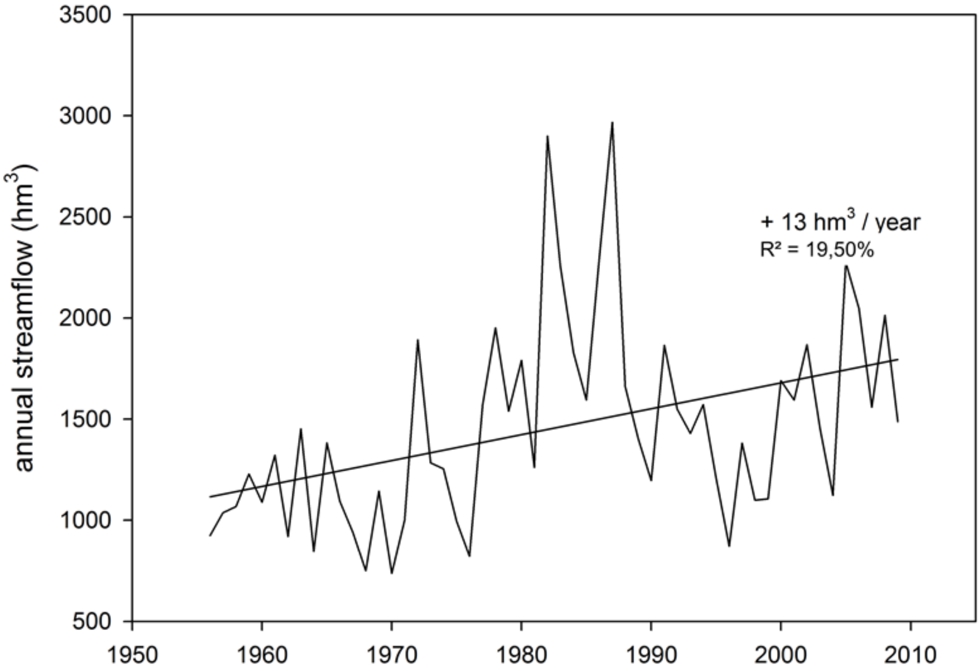

3500
3000
2500
2000
1500
1000
500
annual streamflow (hm^3)
1950
1960
1970
1980
1990
2000
2010
+ 13 hm^3 / year
R² = 19,50%

Figure 6

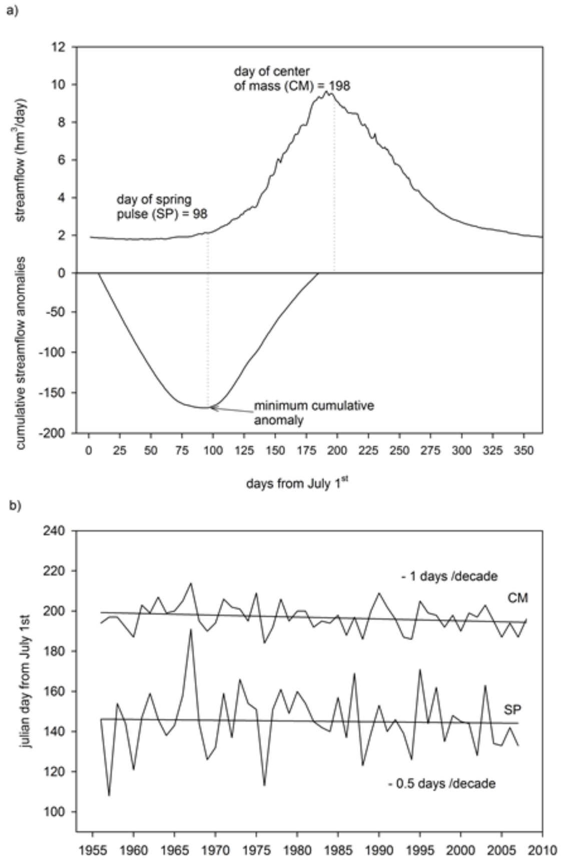
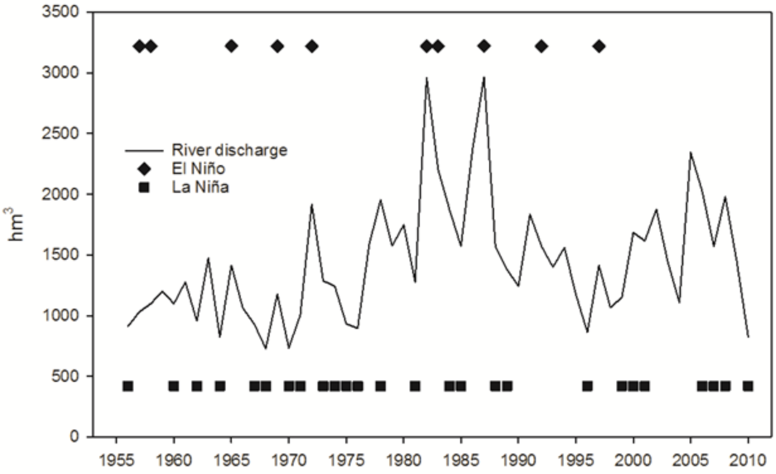

a)
streamflow (hm^3/day)
day of center
of mass (CM) = 198
day of spring
pulse (SP) = 98
cumulative streamflow anomalies
minimum cumulative
anomaly
12
10
8
6
4
2
0
-50
-100
-150
-200
0
25
50
75
100
125
150
175
200
225
250
275
300
325
350
days from July 1st
b)
julian day from July 1st
- 1 days /decade
CM
SP
- 0.5 days /decade
240
220
200
180
160
140
120
100
1955
1960
1965
1970
1975
1980
1985
1990
1995
2000
2005
2010

Figure 7


3500
3000
2500
2000
1500
1000
500
0
hm^3
River discharge
El Niño
La Niña
1955
1960
1965
1970
1975
1980
1985
1990
1995
2000
2005
2010