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IMPACT OF HYDRAULIC STRUCTURES AND WATER USE ON SOLIDS IN WATER IN THE ANDEAN ARGENTINIAN PIEDMONT: CASE STUDIES OF TUNUYAN AND MENDOZA RIVER VALLEYS

ABSTRACT: LAVIE É., LAGANIER R., MORÁBITO J.A., SALATINO S.E., MEDINA DE DIAS R., MIRALLES S. & HERNÁNDEZ R., *Impact of hydraulic structures and water use on solids in water in the Andean Argentinian piedmont: case studies of Tunuyán and Mendoza river valleys.* (IT ISSN 0391-9838, 2013).

The province of Mendoza has a tradition of irrigation inherited from the Incas, from pre-Columbian times. It contains 36,000 ha irrigated and distributed in oases located on the banks of snow-glacial water-regime rivers from the Andes Mountains. After several years of monitoring the quality of irrigation water in two of the largest basins (Mendoza and Tunuyán rivers; latitude 32°30'S, 33°50'S and longitude 67°50'W, 69°30'W, respectively), this survey seeks to evaluate the quantitative and qualitative variations of dissolved (TDS) and suspended (TSS) solids in water flows. The study takes place in a context of decreasing water availability over short and long temporal scales (future scenarios of climate variability). Methodologically, the historical records of 12 strategically-selected sampling points (6 in each basin) were studied. The results show that the rivers and irrigation canals exhibit a good physical quality (turbidity and salinity) of the natural water used for irrigation. However, the combination of (i) a possible quantitative decrease in supply, (ii) an inadequate maintenance of the hydraulic structures due to regulation (clear water), and (iii) the negative impact of anthropogenic pollution (occasional industrial, domestic, and agricultural wastes, etc.) requires permanent monitoring in order to encourage effective decisions designed to preserve both the quantity and quality of the water for agriculture.

KEY WORDS: Solids, TDS, TSS, Water quality, Irrigation, Mendoza, Argentina.

INTRODUCTION

The Cuyo, a wide depression of the Argentinian Andean piedmont, contains half-a-dozen oases characterised by urban (cities of Mendoza and San Juan; fig. 1), industrial (oil zones of Malargüe and Mendoza), and mostly agricultural uses. Most of the oases are organised into specialised areas, each containing a horticultural sector, fruit and olive trees, and vineyards. They are all located in semi-arid to arid lands and have been developed by the diversion of the Andean rivers for (mainly) gravitational and drip irrigation (Ponte & Cirvini, 1998; Chambouleyron & *alii*, 2002).

However, the topography (oasis sited at high altitude or on an alluvial fan in the valley bottom), water supply, and population (villages or cities) are quite different from one oasis to another, implying adaptations in terms of the choice of agricultural crops and land use. Changes have already been observed empirically, such as the development of stone fruit (especially peach trees) from the East Oasis to the Valle de Uco Oasis due to soil salinisation in the 1990s (Chambouleyron & *alii*, 2002). Although water managers were able to anticipate the drastic decrease in the water supply which occurred in 2008, and improved water distribution in the whole catchment, the risk of groundwater contamination is still not really taken into consideration. Nevertheless, in the last 10 years, pumping restrictions have been imposed in the most saline and exploited areas, downstream of the Mendoza and East Oases.

Following several years of monitoring the irrigation-water quality in two catchments (Mendoza and Tunuyán rivers), this paper focuses on (i) the upstream-downstream and temporal changes in solid discharges (both dissolved

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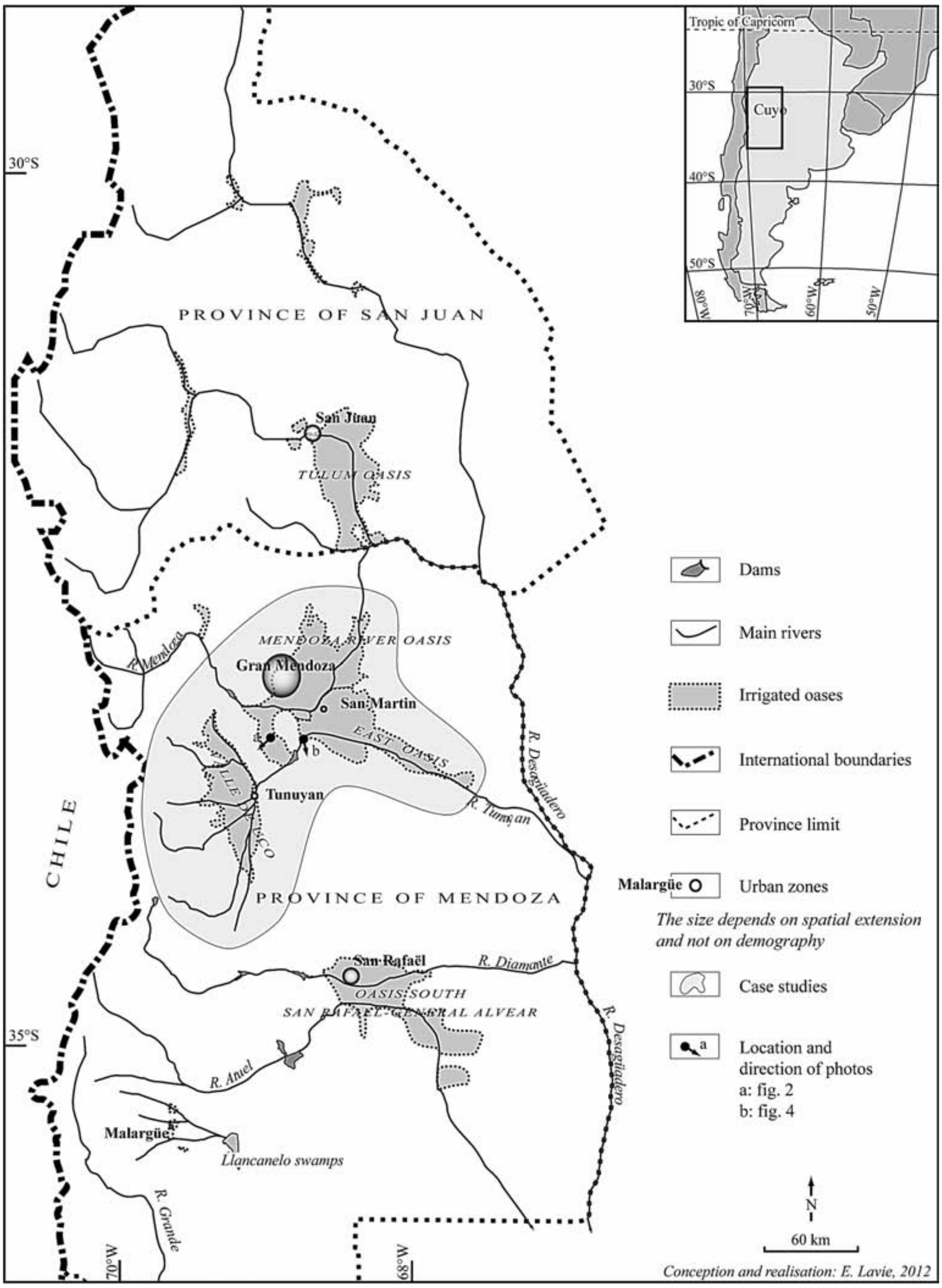


FIG. 1 - Location of Cuyo oases.

and suspended parts) and (ii) the impacts of water uses on water quality. Solids in water are significant proxies for evaluating anthropogenic impacts on sensitive environments: dissolved solids can be used to detect water salinisation due to contamination or improper land uses. Furthermore, suspended solids are useful to measure the consequences of hydraulic structures (dams in particular) on water quality, especially the degree of fluvial erosion or the waterproofing capacity of streams (Ghassemi & *alii*, 1995; Haygarth & Jarvis, 2002; Pepina & *alii*, 2010). The observed increase in dissolved solids and decrease in suspended solids, which previously waterproofed the irrigation channels, lead us to explain the decline in water access for the farmers located in the downstream part of catchments.

CONTEXT

The Valle de Uco is a mountain oasis with an area of 825 km^2. Located in a graben between the Frontal Cordillera and foothills (fig. 2), the valley is drained by several Andean rivers, which join at the same point in Costa An-

FIG. 2 - Photograph showing the Andes and foothills. The foothills (background) designate the limit between the Tunuyán River catchment (background) and the Mendoza river catchment (foreground).

zorena (point CA, fig. 6, 8). The Tunuyán River is the largest, with a mean discharge of 30 m^3/s (about 80% of the total volume of surface water). The rivers are diverted upstream to irrigate the cultivated lands (vineyards, agricultural fields). Part of the water infiltrates and supplies the underground aquifer, which rises again upstream of the city of Tunuyán due to the presence of an anticline, creating a network of numerous small streams (fig. 8). All these waters converge at Costa Anzorena, forming a funnel. The Mendoza and East Oases are fan-shaped plain-oases, unlike Valle de Uco. The waters of the rivers Mendoza and Tunuyán (downstream of the Valle de Uco) are diverted into two major agricultural sectors that form the North Oasis (Mendoza and East Oases), the largest oasis in the world with an area of 2411 km^2. The oases are located on the fertile alluvial fans of the rivers. Unlike the Valle de Uco, which has several sources, the Mendoza and East Oases are each dependent on one superficial source only. The hydraulic distribution pattern can be described as follows: (i) in the upstream part, reservoirs (the Carrizal Dam Lake, created in 1971 on the Tunuyán River, and the Potrerillos Dam Lake, created in 2004 on the Mendoza River; fig. 1) regulate the water flow and modify the hydrology; (ii) dams divert water at the entrance to the oases [the Tiburcio Benegas Dam in the East Oasis (point TB, fig. 6, 8), the Cipolletti Dam in the Mendoza River Oasis (point RI, fig. 6, 8)]; (iii) a network of irrigation canals supply water for domestic, industrial, and agricultural needs.

The Valle de Uco is a land occupied by foreigners coming from the major viticultural areas of the world (Napa Valley, Bordeaux, Italy, Spain, The Netherlands, etc.) since few decades; it corresponds to the upstream part of the Mendoza River Oasis that remained lately uninhabited (Robillard, 2009). Conversely, downstream of the East and Mendoza River Oases, farmers are often third generation settlers, the descendants of European immigrants of the early 20th century. Although the three oases were built by and for farmers, in the Mendoza and East Oases these people are no longer a priority, since industry (including oil) has become the leading foreign exchange earner for the province. Furthermore, the Valle de Uco landowners are protected by the authorities because they take only 17% of the superficial discharge, leaving the majority of the volume to the East Oasis, downstream. Besides, they do not need this water because they are authorised to pump from the aquifer. However, the uncontrolled use of groundwater in the Valle de Uco has consequences on the water flow downstream of its exsurgence, since we calculated a 20% fall in the Tunuyán River flow between 2007 and 2011 at point CA.

Farmers receive less water and are increasingly victims of soil salinisation; the most affected being those located in the downstream zones (Chambouleyron & *alii*, 2002; Lavie, 2009). Moreover, the building of dams has turned turbid waters into clear ones, reducing the amount of waterproofing soil in irrigation canals, causing infiltration and depriving downstream farmers of the water flow they need (Salomón & *alii*, 2008). In addition, the agricultural territories of Mendoza, located downstream of the town, receive water polluted by domestic and industrial effluents, while the East Oasis is already supplied with water used for irrigation in the Valle de Uco. These downstream areas are irrigated by low-quantity (losses by infiltration and evapotranspiration from agricultural areas) and poor-quality (contamination) waters (Lavie & *alii*, 2008, 2010). Through the study of the dissolved and suspended solids in water originating from these two basins, we sought to evaluate the relationship between flows and variations in solids in water, in a context of declining water availability in both the short and long term.

METHODOLOGY

The Centro Regional Andino of the Instituto Nacional del Agua (CRA-INA), associated with the Facultad de Agronomía of the Universidad Nacional de Cuyo (FCA-UNC), both located in Mendoza, have coordinated a number of qualitative hydro-studies, since 2003 in the Mendoza River Oasis, and since 2007 in the Valle de Uco and at the entrance to the East Oasis. Measurements were made almost every month (10 samples per year; in June or July, water is cut in the canals for cleaning; in January, the lab is closed). All the data presented here come from personal sampling and analysis except for the flows of 5 points near dams, which were provided by the Departamento General de Irrigación (DGI) of Mendoza Province.

Water was collected in a small bottle rinsed 3 times with water from the sample, directly in the river or channel, or from a bucket. Among the 30 parameters analysed, we focused on solids. The Total Dissolved Solids (TDS) enable the mineralisation of water to be observed and provide an overview of the risk of soil salinisation. Total Suspended Solids (TSS), the part of non-soluble solids, are an indicator of the turbidity level. Although natural in origin, they can increase due to anthropogenic inputs. The strong presence of TSS can prevent the entry of sunlight into water and therefore limit photosynthesis and promote eutrophication. Although a clean water supply is required for domestic and industrial needs, farmers (surface irrigation methods) prefer turbid water, which waterproofs the canals, minimises bank erosion and provides nutrients to the soil. However, 15% of the irrigated lands have been transformed from using a gravitational system to new pressurised methods, which are more efficient and use clean water but farmers observe more losses in the canal network (Morábito & *alii*, 2012).

The Total Solids (TS) were measured for all sites over the entire period (2003-2011 for the Mendoza River basin and 2007-2011 for the Tunuyán River basin). TSS were analysed only until December 2008 for the Mendoza River and until February 2009 for the Tunuyán River. Five years of measurement were acquired for the Mendoza River (2003-2008) and one year for the Tunuyán River (2007-2008). TS were measured by drying at 103-105°C, then in a muffle furnace at 550°C. TSS were observed in an Imhoff cone. The TDS, not analysed, were calculated by subtracting the TSS from the TS. Flow count is available for each measurement. Flow for 5 points located downstream of a dam (Y, LT, VU, TB, and RI) were calculated from a gauge and provided by the DGI. For the other points, depth was taken from existing gauges (CI, CIII) or derived from measurements of both the cross-sectional area and the flow velocity (width does not vary in canals).

Samples were acquired from 12 sites (fig. 3, 6, 8). For the Mendoza River Oasis, RI (on the Mendoza River) was the test site. This is the incoming point of water in the oasis at the Cipolletti diversion dam; the mean discharge is 50 m^3/s. CI is located downstream of the city, on the main collector canal, the Cacique Guaymallén. The canal receives water from a brewery sector and all the water of urban irrigation: Mendoza city is shaded by an urban canopy, present in all the streets and irrigated by an urban canal network, the *acequias*. These open canals do not receive domestic effluents (except for some losses) but drain urban runoffs; CI is therefore the measurement point of the urban impact on water. Between CI and CII (the Jocoli canal), a wastewater treatment plant discharges domestic effluents, which are superficially treated in lagoons. Between CI and CV (the Auxiliar Tulumaya canal), a drain brings effluents from the food industry (wine making, fruit-canning and vegetables, slaughterhouses, tanneries, etc.). CV is the most polluted point of the oasis (Lavie, 2007; Lavie & *alii*, 2008; Lavie, 2009). Finally, CIII (the Flores canal) and CIV (the San Martín canal) are included in agricultural areas, upstream of the most fertile lands of the oasis (CIV) or downstream (CIII). Both of them receive unpolluted water (apart from a certain amount of agricultural drainage water) close to the values measured in RI, the upstream input point.

Catchment	Sample points	Name	Interest
Mendoza River basin	RI	Mendoza River at Cipolletti Dam	Incoming points of water in Mendoza River Oasis
	CI	Channel 1- Cacique Guaymallén	Measuring Mendoza city impact
	CII	Channel 2- Jocoli	Measuring urban wastes waters impact
	CV	Channel 5- Auxiliar Tulumaya	Measuring industrial impact
	CIII	Channel 3- San Martín	Only few drainage waters, little contamination
	CIV	Channel 4- Flores	
Tunuyán River Basin	VU	Tunuyán River at Valle de Uco Dam	Biggest flow of this basin. One entry in Valle de Uco Oasis
	LT	Las Tunas Dam	3 entries in Valle de Uco Oasis
	A	Aguanda River	
	Y	Yaucha Dam	
	CA	Tunuyán River at Costa Anzorena	Convergence of the 4 former points waters and phreatic exsurgence. Measuring agricultural impact of Valle de Uco Oasis, and of Tunuyán City.
	TB	Tunuyán River at Tiburcio Benegas Dam	Entry of East oasis, downstream Carrizal Dam Lake

FIG. 3 - Typology of the sampling sites.

In the Tunuyán River basin, six measurement points were selected: VU (Valle de Uco Dam), the test site, is located at the diversion dam for irrigation in the Tunuyán River; the mean discharge is 30 m^3/s. Diversion waters were collected in the Las Tunas (LT), Aguanda (A), and Yaucha (Y) canals. For points LT and Y, water was taken from the canal flowing from diversion dams. Unlike the Tunuyán River, these canals do not drain industrial areas and their waters are naturally less mineralised. Downstream of the Valle de Uco Oasis and the city of Tunuyán (40,000 inhabitants), all the surficial canals converge at the same point, where an anticline creates a groundwater exsurgence. This convergence of all the superficial streams and groundwater is named Costa Anzorena, where water (point CA) was sampled.

Finally, a sampling site was chosen at the Tiburcio Benegas diversion dam (TB, fig. 4), in order to observe the impact of the Carrizal Lake on water, and to have an overview of water quality at the entrance of the East Oasis.

RESULTS

We observed a close superposition of the curves of TS and TDS (fig. 5). The main part of TS is composed of TDS, so only a map of TDS has been drawn (fig. 6). TSS, which cannot be compared at the same scale as the TS and TDS, were treated separately (fig. 6, 7).

TDS

TS were preferred in the analysis because of their longer follow-up time (9 years of TS data against 6 of TDS data for the Mendoza River catchment, 5 years against 2 for the Tunuyán River catchment). The TDS are composed of heavy metals (such as chrome, zinc, copper or lead, mainly coming from pesticides), NPK nutrients, and mainly minerals (calcium, sulphates, magnesium, etc.). The latter are primarily responsible for soil and water salinisation in this arid area, which makes it an important parameter for assessing the sustainability of the oases. In fact, it is estimated that rock weathering in a catchment provides about 60% of the total solid discharge (Cosandey, 2003). Thus, the mineral profile of the Mendoza and Tunuyán Rivers is naturally calc-sulphated (both calcium and sulphates coming from gypsum rocks) but the high evaporation increases the proportion of potassium, chlorides, and sulphates in the downstream areas (Lavie, 2009).

Overall, the test site for the Mendoza River Oasis (RI site) is characterised by a decrease in salinity in spring and an increase in autumn. This natural cycle corresponds to the alternate hydrological regime influenced by ice-jam/ice breakup, which dilutes the minerals in spring and mainly in autumn, and the vegetative cycle, which purifies minerals in spring and recreates them during autumn. Other works on periglacial environments have demonstrated the correlation between flows and TDS, and the thermal effect on mineral variations in glacial and snow regimes. As Beylich and Laute (2012) wrote: «*In all sampling areas, TDS values are clearly highest in the winter period (December-March), reflecting the dominance of the comparably ion rich base flow from the drainage basin during this period of low air temperatures, snow precipitation and low runoff. In most sampling areas, TDS values were lowest in the summer period (July-August), reflecting the dominance of ion-poor glacier melt water in this period of high air temperatures and high runoff*» (see also Caine & Thurman, 1990; Caine, 1995; Beylich & *alii*, 2006).

FIG. 4 - Photograph of the sampling point TB in a canal downstream of the Tiburcio Benegas Dam.

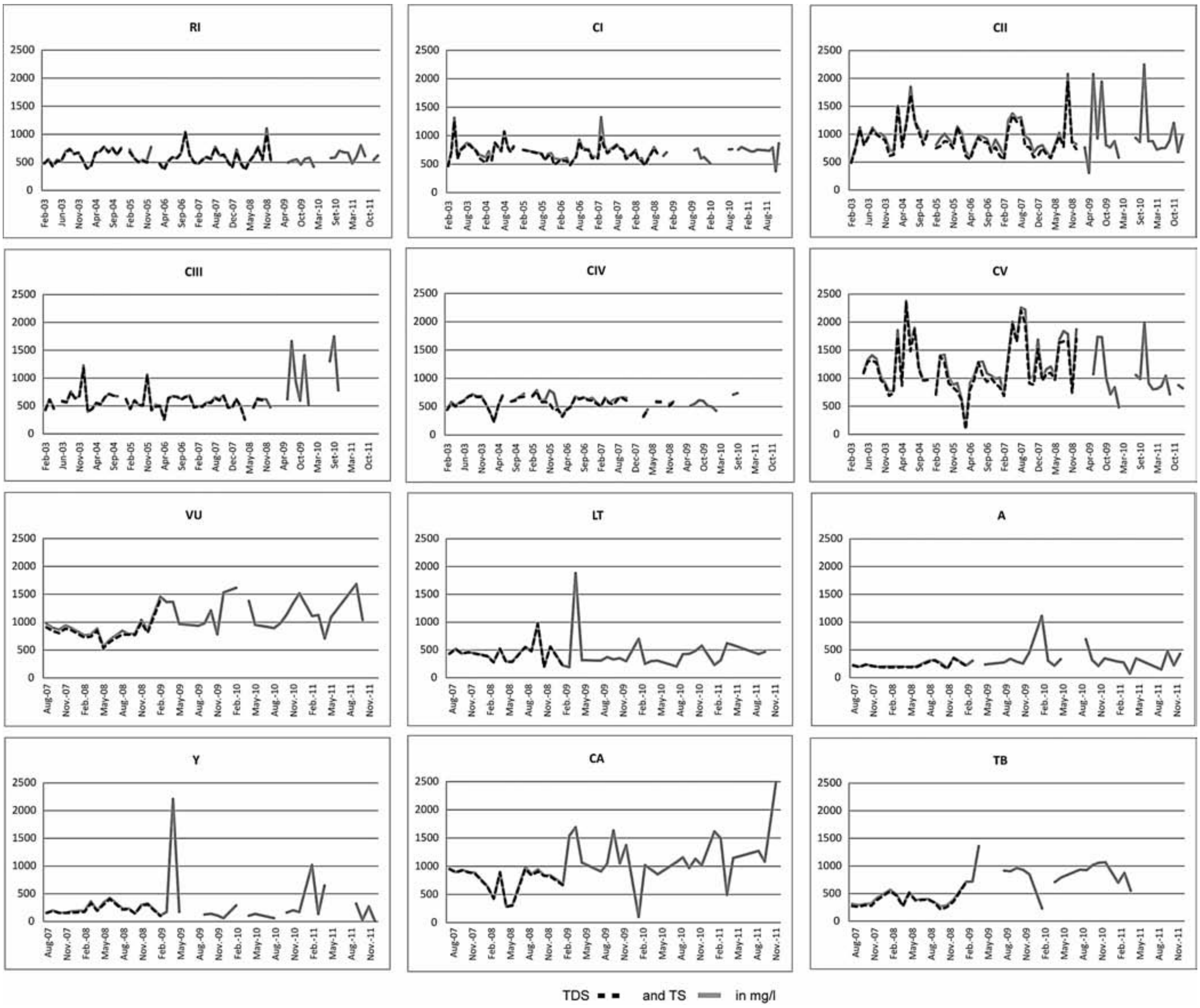
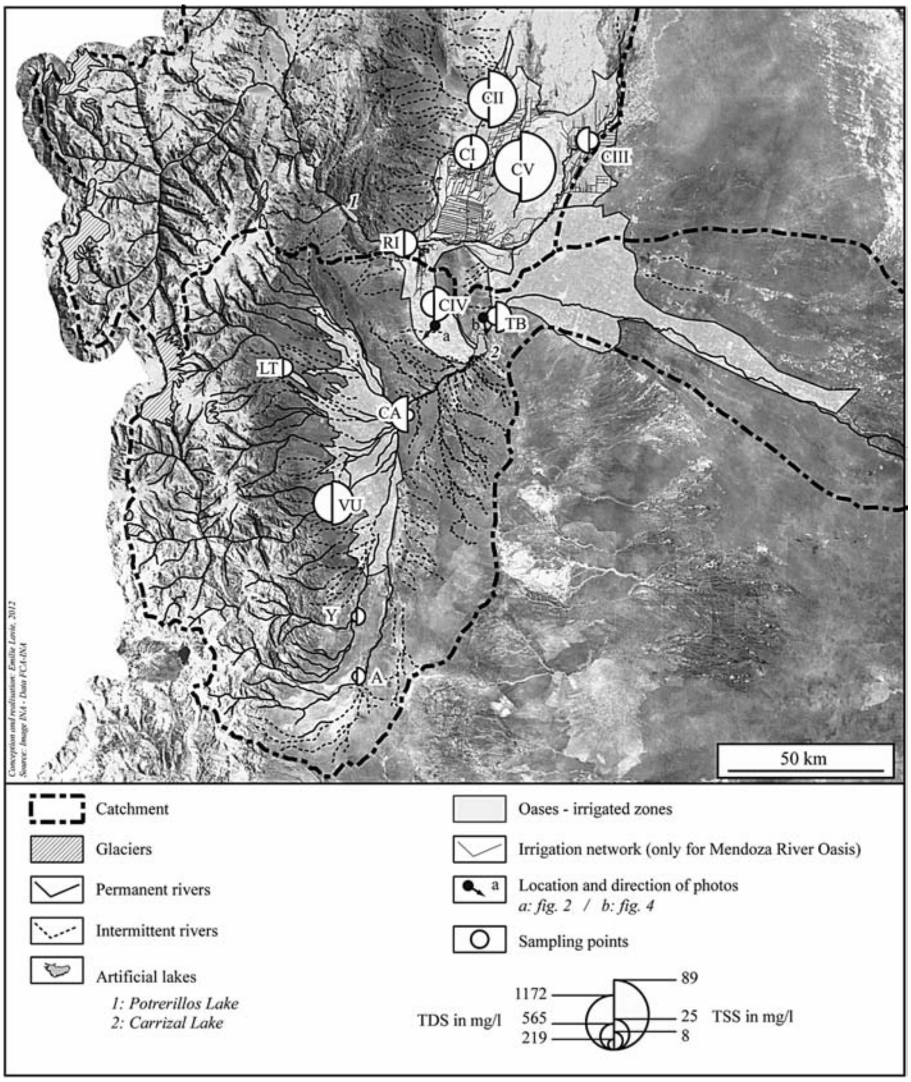


FIG. 5 - Variations of TDS and TS in the sampling sites.

In the Mendoza River Oasis, the sites CI, CIII, and CIV show results close to RI in terms of average values (fig. 3) and temporalities of TDS (fig. 5). The city of Mendoza, located between points RI and CI, does not seem to have a significant impact. The TDS increased from 592 mg/l to 699 mg/l. On the contrary, points CIII and CIV, downstream of the agricultural areas, do not seem to suffer from pollution by uses since the values fell to 578 mg/l and 565 mg/l, respectively.

However, two sites (CII and CV) reveal the presence of a pollution of anthropogenic origin. Between CI and CII, which are separated by 1 km, a treatment plant discharges domestic wastewater, treated in lagoons, into the canal. The capacity of the plant has long been reached (Lavie & *alii*, 2008), and only the solid effluents are filtered. The liquid wastes (urea, washing water, etc.) are mainly directed into the Jocoli canal, upstream of CII. The increase in TDS is significant in autumn, more than in RI and CI. In addition to the increase in domestic waste in spring, and till late autumn, the decrease in water flow in the oasis is significant in autumn, with a return of nutrients during the vegetative growth cycle. This phenomenon is roughly equivalent at the CV site. Here, the problem comes less from domestic than from industrial effluents, which increase in autumn during the processing of agricultural products. However, besides the increase in average values, few seasonal cycles can be noted, although the peaks are still more frequent in winter. The increase in TDS in winter is linked to the construction of a treatment plant of industrial water in 2003. This plant consists of a battery of eight wells in a deep aquifer, which dilutes polluted water with good quality water. Consequently, the concentration level of polluted matter decreases downstream but the volume of polluted water increases due to the combination of in-

FIG. 6 - Average values of TDS and TSS in the sampling sites.



dustrial water with water originating from boreholes (Lavie, 2007). This dilution is only performed when the polluting concentration exceeds a certain threshold. Furthermore, variations of TDS in CV are linked more to the hydrological regime than to the seasons. Our previous works (Lavie & *alii*, 2008; Lavie, 2009; Lavie & *alii*, 2010) highlighted this pollution/flow relationship in the canals. These pollution peaks are so high because water is not used for irrigation in winter, and the dilution processing plant is not yet operative.

The Tunuyán River, observed in VU, provides 80% of the total flow in CA, which explains why the curves are relatively in phase at both points. It shows a natural increase in salinity, which varies in relation to the water discharge. When the discharge increases, so does the TDS. The phase of dilution does not play the biggest role. Higher volumes can influence the erosion of rocks at high altitudes, especially of gypsum that is very rich in calcium sulphates. For example, VU has a higher mineralisation than the other three canals studied (LT, A, and Y) because of the presence of gypsum in its catchment. Nevertheless, these observations deserve a deeper and longer-term survey of the relationship between flows and salinity, with more data. Thus, we observe in LT, Y, and A, a few exceptional peaks due to artefacts in some measurements or to localised storms (for which we have no data), but not to seasonal or longer-term variations. In CA, the TDS variations are more significant than in VU, but the average is lower because the waters of LT, Y, and A dilute those from VU. However, we have highlighted the seasonality phenomenon and the relationship with water flows is less pronounced than in VU.

Concerning the entrance (upstream) area to the East Oasis (point TB), not enough data were collected (water does not flow continuously because the regime is anthropogenic and controlled by the Carrizal and Tiburcio Benegas Dams), preventing us from drawing robust conclusions. However, the average TDS is almost half that in CA (370 mg/l *vs.* 755 mg/l), which suggests a treatment of minerals by the lake itself. Nevertheless, an increase in mineralisation between 2007 and 2011 is observed.

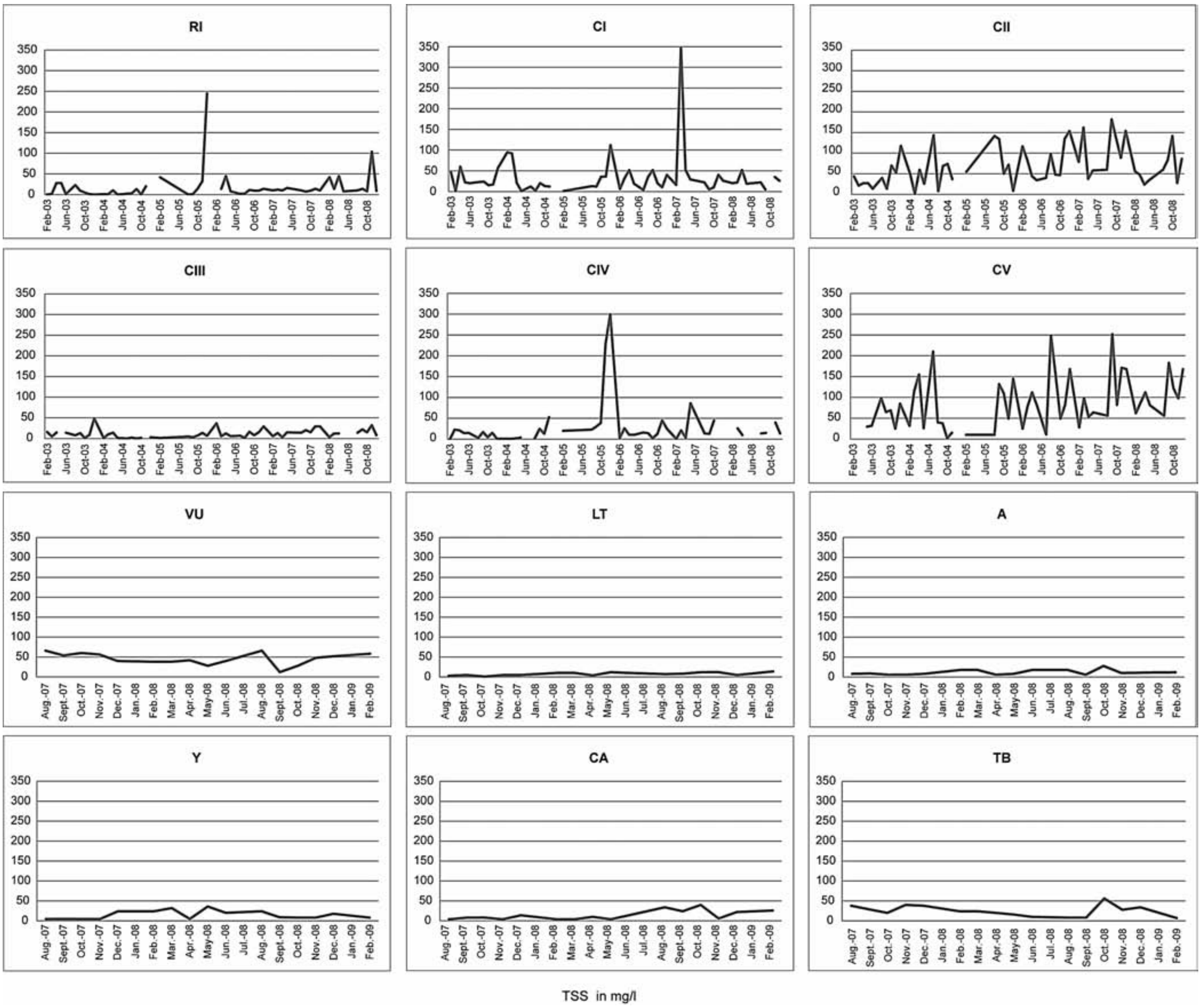


FIG. 7 - TSS variations in the sampling sites.

TSS

The TSS mapping is similar to that of TDS (fig. 6): in spatial terms, the same points are affected except for the TB sampling point. However, in temporal or seasonal terms, no relationship can be made between TDS and TSS. Indeed, unlike TDS, in test site RI, TSS increase in spring and summer, and fall in autumn and winter. Here, quite logically, the TSS vary in phase with the discharge: they increase in ice and snow melting periods and fall during ice-jam times. Water can be quite turbid in spring but overall, Potrerillos Lake allows a decrease in the presence of suspended solids in water (Lavie, 2009). The peaks are presumably due to water released from the reservoir. Unlike TDS, there is more impact of the city of Mendoza on TSS in CI. The same results can be observed concerning the agricultural impact on CIV. In contrast to CIII, TSS values are often lower than in RI. This observation can easily be explained by the waterproofing of concrete canals from 2003. The water is no longer in contact with soil horizons (clayey-sandy soils).

The real problem of TSS in the Mendoza River Oasis is located at points CII (domestic effluent sample test) and CV (industrial effluent sample test). Both values are high (69 mg/l in CII and 89 mg/l in CV), and in CV there is no seasonal relationship with CI and RI. In CII, the impact of the discharge derived from domestic effluent is evident: it increases according to needs in spring and falls again in autumn, when people use less water at home. In contrast, CV demonstrates very large temporal variations, which are partly due to the dilution treatment plant. This hypothesis seems to be confirmed by the decrease in TSS starting from the opening of the plant in October 2004. Nevertheless, we observe that the amplitudes increase again a year later, especially in winter when agricultural needs decline downstream: polluted water does not affect the farmers so much.

The main characteristic of TSS in the Mendoza River Oasis is the inversion of the upstream-downstream system. Indeed, before the building of the Potrerillos Dam in the early 2000s, the water was naturally turbid and could waterproof irrigation canals, thus limiting water loss along the network. The groundwater recharge occurred in the foothills, between the current dam site and the point RI. Today, the waters are clear in the oasis, which facilitates the treatment of domestic water, but, by losing their waterproofing efficiency, they reduce the available flows downstream. In fact, we think – without being able to measure it now – that the downstream sector, which is irrigated by the Jocoli and Auxiliar Tulumaya canals (points CII and CV), receives less water from the mountains derived in RI, which partly infiltrated the soils, and more polluted water. The water decantation in the Potrerillos Dam Lake transforms water from turbid to clear. Nowadays, water enters the oasis with a very small quantity of suspended solids. The marked increase in turbidity between RI on the one hand, and CII and CV on the other hand, leads to the conclusion that most of the turbidity in this oasis is now anthropogenic.

The Tunuyán River basin is different. The four natural rivers (A: Aguanda; Y: Yaucha; LT: Las Tunas, and VU: Tunuyán) that feed the Valle de Uco Oasis are not cut by a reservoir. There are three rivers in which the water is naturally clear (LT, A, and Y, with 8 mg/l, 12 mg/l, and 15 mg/l, respectively). The relief is fairly flat and sediments are able to settle. On the contrary, the Tunuyán River at the VU site is quite turbid (45 mg/l), which can be explained by its snow-glacier regime and alternating ice-jam/ice breakup, which increases the levels of TSS in the spring-summer periods (Benn & Evans, 1998; Milburn & Prowse, 2000). Contrary to TDS, which are more sensitive to weathering, TSS are sensitive to mechanical erosion, and their transport is more efficient when the discharge is high in a dry region with deficient vegetative cover (Walling & Kleo, 1979; Walling, 1987; Cosandey, 2003; Meybeck & *alii*, 2003); they also present an annual irregularity, with a ratio varying from 1 to 100 (Cosandey, 2003). However, although these catchments are located in dry regions, the TSS discharge remains low according to Meybeck's classification (<100 mg/l; Meybeck & *alii*, 2003). In CA, the turbidity is low (14 mg/l), if one considers that VU constitutes 80% of the discharge. The lower values of TSS can be partly explained by (i) a lower slope between VU and CA (Ortiz, 2011) and (ii) the exsurgence of groundwater downstream of this oasis, which favours the development of numerous small rivers with clear water.

Finally, although the Carrizal Lake allows sediments to settle, TSS appear to be more abundant downstream (TB, 25 mg/l) than upstream. This may be due to the presence of hydroelectric turbines that churn the water and suspended sediments of the river (Morábito & *alii*, 2011).

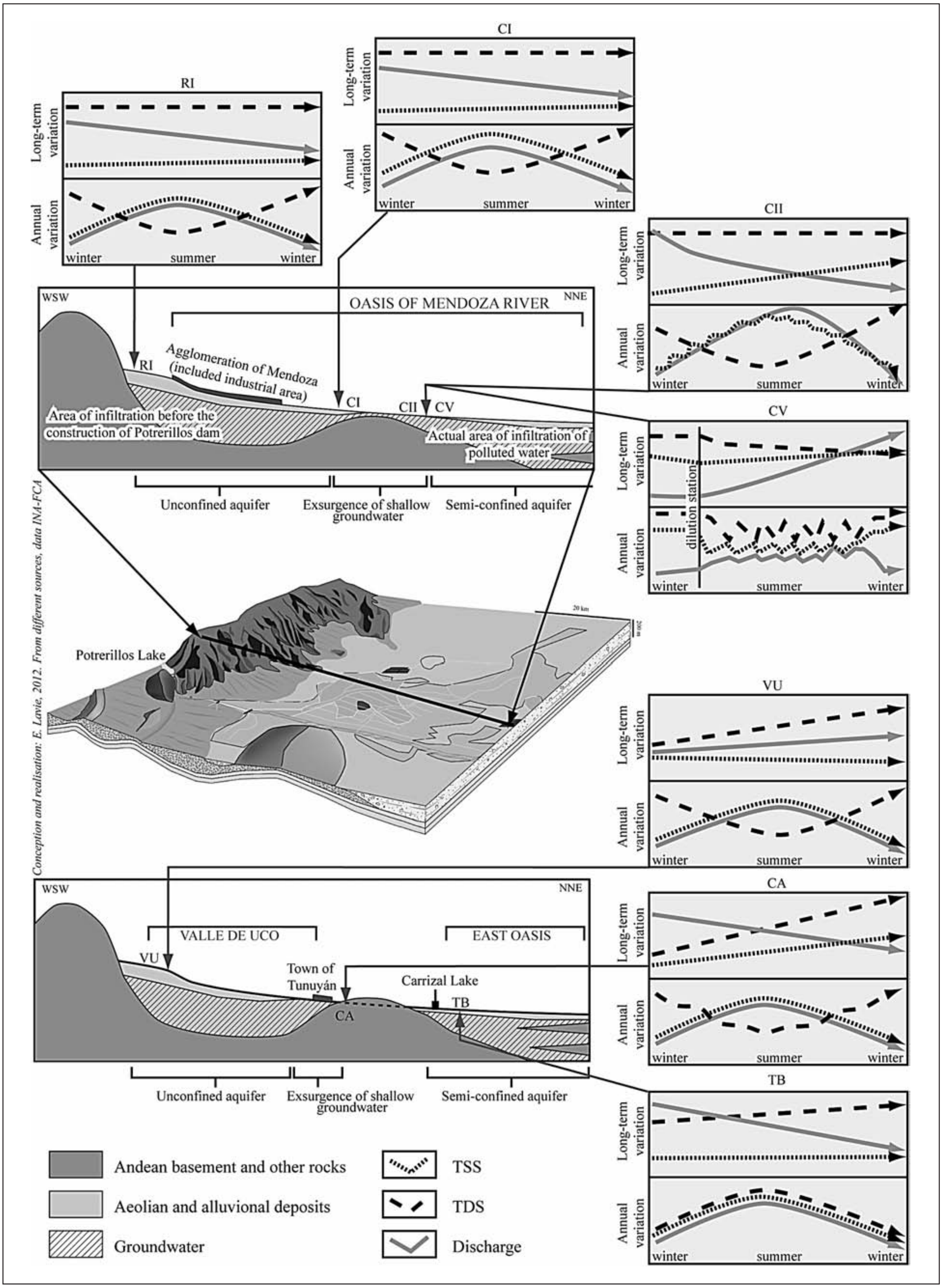
DISCUSSION

On the sites characterised by little or no pollution (Mendoza River in RI; Channel Flores, CIII; rivers of the Valle de Uco upstream of the oasis: LT, VU, A, and Y), patterns of seasonal variations of TDS and TSS evolve in opposite ways (fig. 8). In fact, the mineralisation decreases when the discharge increases (water supply through ice-melt from the upper catchment), which, fortunately for farmers, corresponds to the growing period of vegetation. Vegetative growth can also play its role, consuming some minerals. In contrast, the turbidity is in phase with the discharge and increases with the ice breakup, fed by snow and glacial flour.

Moreover, slight anthropogenic pollution is observed in some canals (CI, CIV) of the Mendoza River Oasis and on the Tunuyán River (CA and TB) downstream of the Valle de Uco Oasis, with an increase in average values of pollution. Only points CII and CV (domestic and industrial drainage canals) show a significant anthropogenic contamination. CII is characterised by a clear increase in average values compared to CI, demonstrating the impact of the discharge from the sewage treatment plant on the turbidity and salinisation of water for irrigation in the downstream areas. CV is an unusual site, which features not only high average values (higher than CI) but also temporal variations due to non-natural seasonal cycles. The dilution treatment plant plays a limited role as a buffer surrounded by significant industrial pollution. In fact, although there is no temporal relationship between CV and other sites, because of anthropogenic dilutions of the station that regulates water flow, the high values of pollution are obviously due to industrial discharges.

Figure 8 shows schematically the results of seasonal variations, where each graph represents the long-term variation (2003-2011 for the Mendoza River basin and 2007-2011 for the Tunuyán River basin) of flows, TDS (*via* TS) and TSS. For the Mendoza River over the short (seasonal) term, the TSS are in phase with the discharge, unlike the TDS; but this generalisation is not true over the long term. For example, while the discharges drop in RI and CI, the change in solid discharge (TDS and TSS) is not very large. In the Valle de Uco, the relationships are reversed, with the TDS in phase with the discharge, unlike the TSS.

Discharges generally decline in the points observed here, with the exception of CV – since the treatment plant performs an anthropogenic dilution – and in VU, unlike the forecasts made by the DGI (2011). The observation period being short here (2007-2011), it is difficult to find an explanation: nevertheless, it is possible that the 2010 Niño-ENSO caused an increase in snowfall in the Andes and therefore higher discharges occurred in spring. Downstream sampling sites, which receive already-used waters (CII, CA), very logically show a reduction in discharge and long-term increases in TSS, but not in TB. In fact, although the increase in the agricultural areas in the Valle de Uco Oasis had no impact on water withdrawals from rivers (17% of total volume), it increased pressure on groundwater. The wells are increasing (Robillard, 2009),



Conception and realisation: E. Lavie, 2012. From different sources, data INA-FCA

FIG. 8 - Synthetic evolution of solids in water *vs*. hydrogeological cross-section.

especially in the western upstream lands. Groundwater withdrawals have a quantitative impact that can be noticed in CA by lower water volumes at the exsurgence point. The East Oasis receives less water, since the discharge measured in TB changed from 45 m^3/s to 35 m^3/s. However, we also know that the water manager (the DGI) provides water from the Carrizal Lake over short periods to this East Oasis.

As expected, there are upstream-downstream dynamics, especially in the Mendoza River, with a spatial increase in physical pollution, in terms of mineralisation and turbidity. However, this qualitative decline makes sense in a context of quantitative changes in the availability of water: in fact, in addition to a decrease in availability, snow and glacier melting is taking place earlier in the year, and rivers are gradually transforming from glacier-snow to snow-glacier regimes (Lavie, 2009, for the Mendoza River, and Robillard, 2009, for the Tunuyán River; in both cases, observations are based on hydrological data from the DGI). However, this time lag is no longer in line with the growth cycle, which needs more water in summer than in spring.

In addition to this time lag, which limits the availability of water in summer, there is a loss by seepage from irrigation canals in the Mendoza River Oasis, due to the presence of clear waters that have lost their waterproofing capacity since the construction of the Potrerillos Dam. Furthermore, downstream areas, which already have less water (Barbier, 2011), receive water that is both more mineralised and polluted by domestic and industrial effluents.

Regarding the Tunuyán River, turbidity is quite modified by human activities on a seasonal scale. However, although turbidity is almost constant over the long-term in VU, it reveals a tendency to increase downstream of the Valle de Uco Oasis. In addition, hydraulic structures can cause barriers that create some clarity in the water, but no major anthropogenic discharges. Finally, for TDS (observed here through the TS), while this variation is difficult to see for the other sampling sites, TB seems to reveal a slight increase in salinity over time. This observation again tends to confirm the salinity of water irrigation in downstream areas, associated with lower discharges due to withdrawals for new agricultural areas of the Valle de Uco.

CONCLUSION

This hydro-qualitative survey of 12 points in rivers and irrigation canals reveals a good physical quality of the natural water destined for irrigation. On the one hand, these waters are turbid enough for waterproofing and limit losses from upstream to downstream; on the other hand, the levels of salinity also make them suitable for irrigation. Nevertheless, the combination of (i) a quantitative decrease in water supply, (ii) hydraulic structures that create clear waters, (iii) industrial and domestic wastes, and (iv) mineral water pollution due to the water uses in upstream areas, is already depriving downstream agricultural areas of satisfactory water in terms of quantity and quality. Declining agricultural yields have already been observed in the East Oasis and the downstream sectors of the Mendoza River Oasis should ultimately strengthen. In the context of climate change and dynamic modes of land and water uses, water-quality monitoring seems therefore an important element of the diagnosis, which may stimulate debate and provide arguments capable of guiding decisions regarding water management.

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