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Integrated Hydrogeological Study of Surface & Ground Water Resources in the Southeastern Buenos Aires Province, Argentina

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ABSTRACT: This paper gives an account of the implementation of geomorphological, hydrogeological, hydrochemical and isotopic techniques to understand groundwater-surface water interactions in a multiple use area, Los Padres-La Brava Corridor (SE of Buenos Aires Province, Argentina). The isophreatic map reveals a regional flow from the SW to NE sector, and allowed us to define the effluent-influent behavior of the permanent wetlands in the area. Hydrochemistry and isotopic analysis confirm this flow system in the unconfined aquifer and the relationships among the different water sources. Obtained data indicate that the recharge to the aquifer is influenced by the natural rainfall input, wetland discharge and the concentration of surface run-off from the range fringes to inter-range depressions. Wetlands in the corridor are considered recharge areas for the aquifer system. Moreover, they contribute to water quality as well as groundwater and stream availability. This study proposes a holistic approach to water resources management recognizing most of the components of the hydrological cycle and its interactions with other natural resources and ecosystems, both aquatic and terrestrial ones. In this sense, the idea of water resources assessment in an integrated way for an efficient management, including wetlands, streams and groundwater, is reinforced in this work.

Key words: Common pool water resources,Environmental isotopes,Hydrochemistry,Hydrogeology

INTRODUCTION

Common pool resources (CPRs) are natural or manmade resources where one person´s use of the commons subtracts from its use by others but there is difficulty in excluding access (Ostrom, 1986; Quinn *et al*., 2007). Hardin (1968) described how each user of the commons would act to maximize their benefits from the open access commons while the costs of their use were shared among all users. As a result, the commons would be subject to overuse and this would lead eventually to degradation and the collapse of the resource.Wetlands, streams and groundwater could be seen as CPR since they exhibit both excludability and rivalry conditions.

Water resources deliver a wide range of ecosystem services, which are defined as “the benefits people obtain from ecosystems” according MA (2005), contributing to human well-being. These include provisioning, regulating, cultural and supporting services. Therefore, their sustainable utilization for the benefit of mankind in a combined way, compatible with the maintenance of the natural properties of the ecosystem is necessary.

Surface water bodies, as streams, lakes, and wetlands in general, are connected to groundwater in most types of landscapes, being integral parts of groundwater flow systems. Because of the interchange of water between these two components of the hydrologic system, understanding the basic principles of the interaction of groundwater and surface water is needed for effective management of water resources (winter, 1999). To understand these interactions in relation to climate, landform, geology, and biotic factors, a sound hydro-geo-ecological framework is needed (Sophocleus, 2002).

The hydrogeochemical interpretation of representative water-sample analyses is a useful tool developed for the analysis of hydrological systems (Martinez *et al*., 2000; Wang *et al*., 2006). Custodio (1991) makes reference to the difficulty connected with the piezometric definition of complex areas as well as to the relative advantages of hydrochemical methods

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such as their reasonably low cost and independence from hydrodynamic methods. Isotopic techniques are also important tools for the validation and adjustment of conceptual hydrogeological models (Fontes, 1980; Clark and Fritz, 1997; Mazor, 1991; Quiroz Londoño *et al*., 2008).

Los Padres-La Brava Corridor is a complex area given that it constitutes a multi-purpose zone used for recreational, residential, touristic and intensive agricultural activities, and also, its water resources are considered as CPR. Groundwater constitutes the main water supply for different uses, while surface waters play a significant role in hydrological processes as aquifer recharge and stream flow regulation. La Brava and Los Padres wetlands, the most important shallow lakes of the area, contribute to the equilibrium of physical and biological systems among several ecosystem services (*i*.e. nutrient cycling, water and climate regulation, recreation). Intensive human use of these ecosystems leads to a disruption in their equilibrium, becoming highly vulnerable systems. Furthermore, they are valuable natural resources which contribute to the life quality of the population, including both close and distant residents (near 750000 inhabitants), representing a multitude of social and ecological benefits.

Water management in the area involves the difficult balance between environmental protection and economic growth through tourism, development, and agricultural production. This zone is at a turning point in its development and the current decision-making and planning may determine the future sustainability of the area. The aim of the present study is to assess groundwater-surface water interactions in a multiple use area by using geomorphological, hydrogeological, hydrochemical and isotopic techniques. Data obtained could provide useful information in order to improve water resource and land use planning in such complex areas.

Los Padres-La Brava Corridor is a portion of the territory named as "Mar del Plata-Balcarce Corridor" located in the Southeastern of Buenos Aires Province, Pampean region, in Argentina (Massone *et al*., 2009) (Fig. 1). It presents a maximum elevation of 250 m asl and it is bounded by the Tandilia Range, a block-mountain system. The location occupies an area of 506.2 km^2, between 38°39'34''- 37°34'23'' S and 59°06'57''- 58°16'28'' W. The climate is dry sub-humid mesothermal type"B2" (Thornthwaite, 1948). Over the past 20 years, annual precipitation values have ranged from 587 to 1,442 mm/year, with an average of 979 mm/year. The highest precipitation values are recorded between December and March. The evapotranspiration potential values estimated for the same period by the Thornthwaite method, ranged from 696 to 766 mm/year, with an average of 732mm/year.

The area has been impacted by intensive and extensive agriculture; mining, residential and recreational activities. Over the last years significant demographic increase, especially in rural-urban fringe and small interior locations like Sierra de Los Padres and La Brava Villages, has been registered in the corridor (Massone *et al*., 2009).

Six land cover categories have been identified in La Brava Basin (Fig. 2) (modified from Zelaya and Maceira, 2007). Their primary characteristics are the following: *Crops*: (soybean, zea may, wheat and sunflower) their grown in the area requires the application of fertilizers and pesticides. Farming methods have modernized and intensified over the years directed towards increasing commercial production; *Pastures:* in the area there is land permanently used for herbaceous forage crops (pastures). Pastures are a mixture of legumes and grasses (Jarrige and Béranger 1992); *Grassland:* native grasslands of the Southern Pampa were mostly replaced by annual crops, except for some small isolated fragments that still remain near the Tandilia ranges (Murillo et al., 2007); *Forest:* there is a reduced sector of land under natural or planted stands of trees; *Hills:* the Tandilia Hills are the unique semi pristine area in the basin, containing forest, shrubs and the only two autochthonous plant species "anchor plant" (*Colletia paradoxa*) and "tala" (*Celtis tala*); *Village:* corresponds to La Brava Village; *Wetland*: in this ecosystem, as in most Pampean shallow lakes, the silverside (*Odontesthes bonariensis)* is the fish that dominates the aquatic system (Grosman et al. 2001); and, *Bulrush:* the litoral zone of La Brava Wetland is mainly dominated by the "giant bulrush" *Schoenoplectus californicus*. Approximately 80 % of the coastline is covered by bulrushes.

These land cover categories are associated with five main land uses (1) Agricultural use (related to crops and pastures), (2) Native Nature preservation (coincides with hill and grassland areas), (3) Residential use (town, corresponding to La Brava Village), (4) Recreational use (5) Educational and cultural use and finally (6) Commercial/economical use. The latter three uses are mainly related to the wetland and hills. The natural characteristics of the range system are preserved in the hill area.

The shallow permanent plain lakes located in the corridor, La Brava (400 ha) and Los Padres (216 ha), belong to Balcarce and Mar del Plata District, respectively (Pozzobon and Tell, 1995; Grosman and Sanzano, 1999). Both wetlands have only one influent

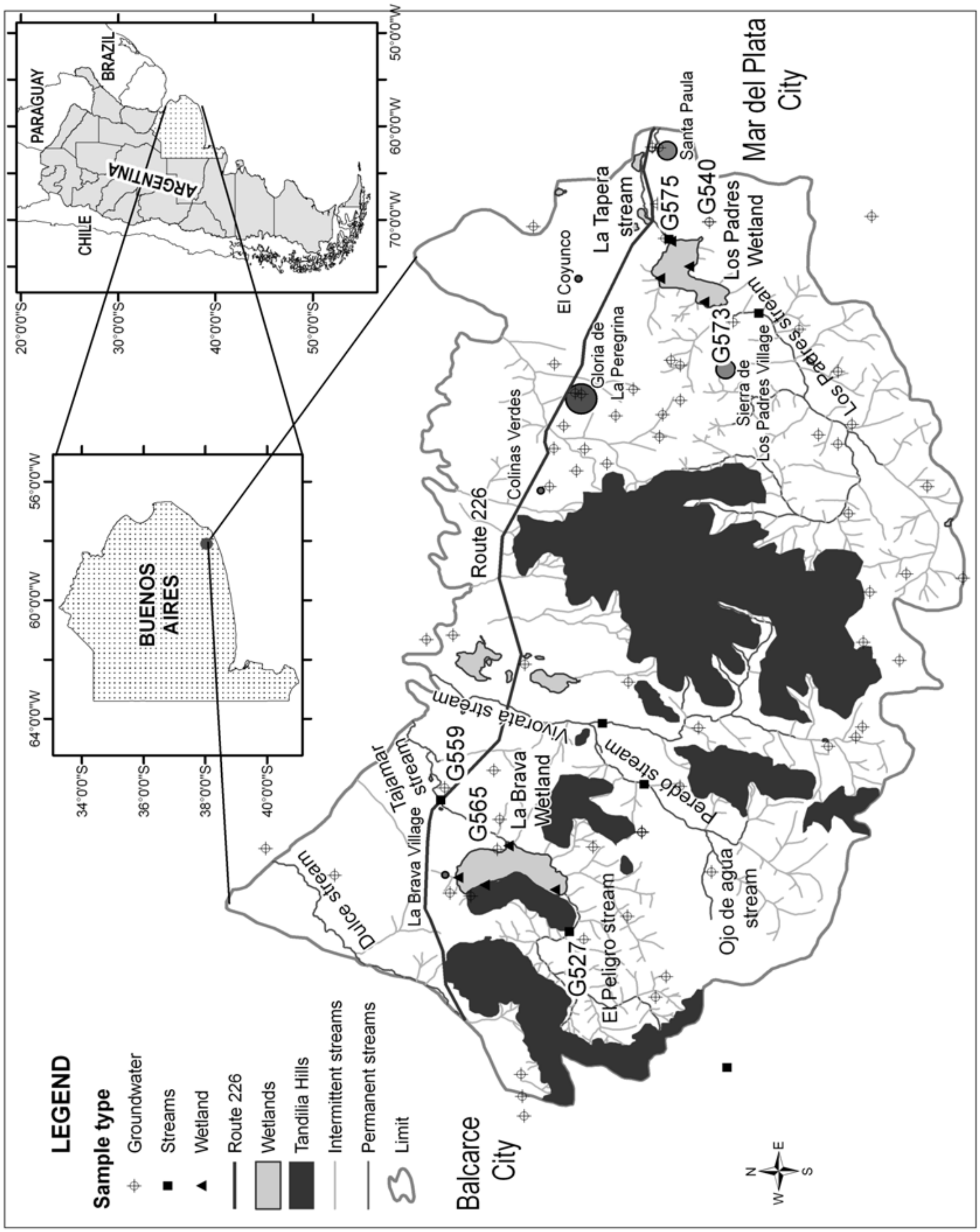

Fig. 1. Location map and sampling sites in Los Padres-La Brava Corridor

stream, located at the highest sector of the basin; and one effluent. Furthermore, as all Pampean shallow lakes, they undergo environmental stress due to the increase of nutrient loading from agriculture activities and urbanization (Quirós and Drago, 1999; Quirós, 2000; Quirós *et al.,* 2002a). Due to the shallowness of wetlands their hydrology is highly dependent on *in situ* rainfall (Quirós *et al.,* 2002b).

The Tandilia Range System in the area consists of two big geological units: a Precambrian crystalline bedrock called Complejo Buenos Aires (Marchese and Di Paola, 1975), and a set of sedimentary rocks of Precambrian-Lower Paleozoic origin, grouped under the name of Balcarce Formation (Dalla Salda and Iñiguez, 1978). They are both considered as the hydrogeological bedrock. An inter-range fringe surrounds the blocks; it is formed by hills which quickly give way to the plain

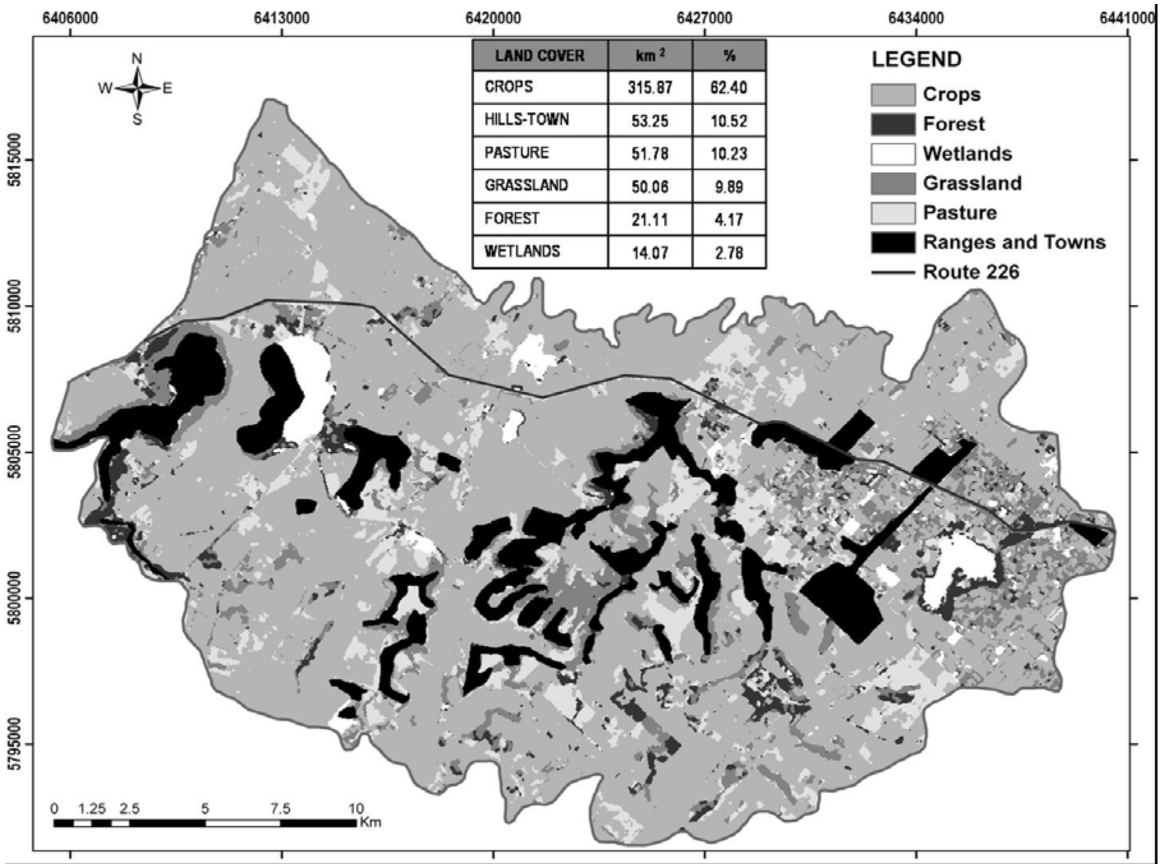

Fig. 2. Land cover map of the study area

areas that reach the sea. Hills and plains are formed by Cenozoic loess-like sediments (especially of Pleistocene-Holocene age).

The upper Pleistocene-Holocene cover of the area is a sequence of silt, silt-clayed and fine sand sediments of aeolian and fluvial origin that constitutes an aquifer system known as Pampeano Aquifer (Sala, 1975). The Pampeano Aquifer in the area is an unconfined aquifer, with a thin unsaturated zone ranging form 0.50 to 25 m. Most typical values of unsaturated zone thickness are in the range from 2 to 10 m. Recharge is due to infiltration of precipitation excess, and discharge occurs towards surface streams, river and water bodies, and directly to the Atlantic Ocean. Recharge in the Pampeano aquifer has been calculated from different approaches, giving results as different as 50 or 200 mm/y. On the other hand, discharge takes place in the streams (Massone, 2003).

MATERIALS & METHODS

Geomorphological features were analyzed from topographical maps in a 1:50,000 scale, satellite images (ASTER and Landsat), aerial photographs and field works. This cartography was digitalized, as a result, a Digital Terrain Model (DTM) was obtained, which allowed both the calculation of slopes and the determination of the altitude of observation points. Five morphodynamic units have been identified and mapped in Los Padres-La Brava Corridor based on lithology and geomorphological processes according to Cendrero and Díaz de Terán (1987) criteria.

Water samples were obtained from November 2007 to April 2009 (Fig. 1). Some of the points were sampled both for hydrochemical analysis and environmental stable isotope determination. Surface water samples were collected from La Brava (N=22) and Los Padres (N=28) wetlands, streams (N=24) and a spring of the area. Groundwater samples (N=65) were collected from domiciliary wells, mills and irrigation wells, and recorded by using a global positioning system (GPS). The collection, preservation and chemical analysis for major ions of water samples were made following the standard methods given by the American Public Health Association (APHA, 1998). Chemical analyses were performed applying standard methods: chloride following Mhor method, sulfate by turbidimetry, calcium and magnesium by complexometric titrations with EDTA, sodium and potassium by flame spectrometry, and carbonate-bicarbonate by potentiometric titrations. Water temperature, pH and electrical conductivity were in situ estimated.

A regional hydrogeological census was performed, with phreatic level depths measured (N=45) with a bipolar electric probe. An isophreatic contour line map of the area was elaborated. Moreover, aquifer recharge was calculated using the annual balance at edaphic level with the Thornthwaite method, for a 20-year period (1985–2005). The recharge value of the total precipitation was obtained using the average value of the annual mean precipitation for the area.

Mixing water calculation by using the chloride ion (Custodio and Llamas, 1976) to estimate the main recharge sources to wetlands has been done. The Cl^- ion was used in this chemical recharge study because of its conservative nature and the absence of external sources of it in the area. The following equation was applied:

$$[Cl]_r = [Cl]_1 * X + [Cl]_2 * (1 - X)$$

Where $[Cl]_r$ = Chloride concentration of the mixing water; $[Cl]_1$ = Chloride concentration of the recharge source Nº 1; $[Cl]_2$ = Chloride concentration of the recharge source Nº 2; X= water percentage of the recharge water Nº 1.

Stable isotopes (^{18}O and ^{2}H) were measured in wetlands, streams and groundwater. A total of thirty one samples were analyzed by using a laser spectrometry DLT-100 Liquid-Water Isotope Analyzer, Automated Injection designed by Los Gatos Research at the Hydrochemical and Isotopic Hydrology Laboratory (Nacional University of Mar del Plata). The results were expressed like δ (‰), defined as: δ= (1000RS-RP/RP) ‰, where δ is the isotopic deviation in ‰; S is the sample; P, the international reference, and R is the isotopic ratio ($^{2}H/^{1}H$, $^{18}O/^{16}O$). The standard is Vienna Standard Mean Ocean Water (VSMOW) (Gonfiantini, 1978). The analytical uncertainties were ±0.3 and ±2.0‰ for $\delta^{18}O$ and $\delta^{2}H$ respectively.

The hydrochemical information was analyzed following a general statistical characterization and conventional diagrams by Piper (Hem, 1992). Moreover, rainwater composition values from a weather station located 50 km east from the area were included in the isotopic analysis (Quiroz *et al*., 2008). This rainfall data, from November 2008 to August 2009, was used both to obtain the Local Meteoric Water Line (LMWL) and in the mixing water study. Finally, in order to facilitate data handling and ensure reliability, a geographical database managed with SIG tools was created.

RESULTS & DISCUSSION

The five morphodynamic units identified and mapped in Los Padres-La Brava Corridor are described below (Fig. 3). The percentages of the total area covered by each unit are: 51.1 % Aeolian hills, 27.5 % plains, 13.1 % Perirange and piedmont, 6.3 % Flat summits, and 2.0 % Urban.

Flat summit Unit. It corresponds to the plain top of the ranges, with a table mountain aspect due to the horizontal position of the quartzitic strata.

Perirange and piedmont Unit. It is the main body of the block-range system. Vertical and subvertical walls bounding the flat summits and accumulation of quartzitic debris mixed with fine sediments characterized this unit. According to the work scale, mapping these two elements as individual units was not possible. Slopes are higher than 6°.

Aeolian hills Unit. It is formed by silt and silty-sand sediments with frequent beds of caliche. Slopes in this unit range from 1° to 2.5° and it is bounded by the blocks. Well developed soils with excellent agricultural aptitude exist in it.

Plain Unit. It is characterized by slopes lower than 1°, the presence of well developed soils with good agricultural aptitude. Silt and sand sediments formed this unit.

Urban Unit. It occupies just a little percentage of the total area, including the urban settlements known as Sierra de Los Padres and La Brava Villages, Santa Paula, El Coyunco, Gloria de La Peregrina and Colinas Verdes. All these localities are connected by the National Route 226. Man activities have modified some of the pre existing features of this portion of the area. The distribution of the obtained isophreatic contour lines reveals the existence of a regional flow from the SW to NE sector, and allowed us to define the effluent-influent behavior of the permanent wetlands in the area (Fig. 4). This water flow direction reflects the importance of this area in the recharge to the aquifer which provides water supply to Mar del Plata City. La Brava and Los Padres wetlands receive water from groundwater inflow in the higher topographic zones, corresponding to the range areas, and discharge their waters into the aquifer in the lower ones.

The aquifer system recharge depends solely on rainwater infiltration. It should be noted that two predominant factors characterize the dynamics of the hydrological cycle in this type of environment: evaporation and infiltration. These factors are more relevant as a consequence of the low slopes, which favor the aquifer regional recharge during the months when evapotranspiration is lower than rainfall.

A recharge value of 22.02% of total precipitation was obtained using the average value of the annual mean precipitation for the area. The analysis of individual annual values for the same decades indicates that recharge mainly occurs throughout June and October.

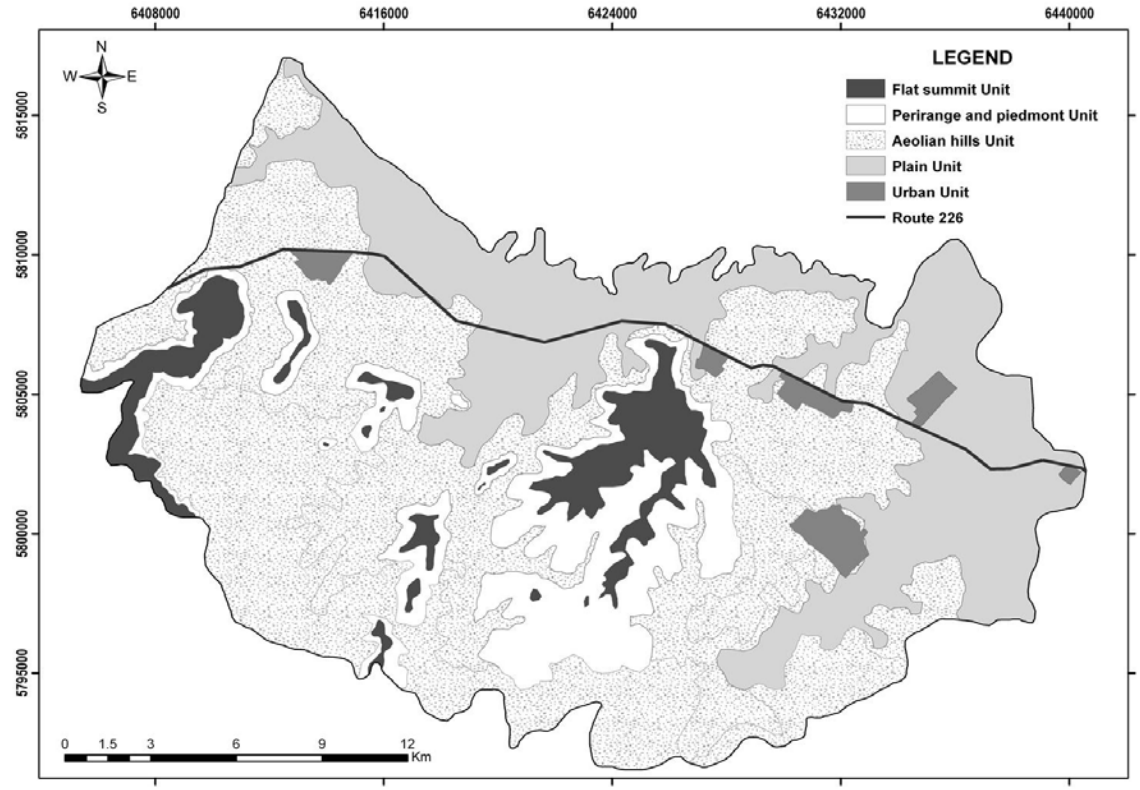

Fig. 3. Morphodynamic unit map in Los Padres-La Brava Corridor

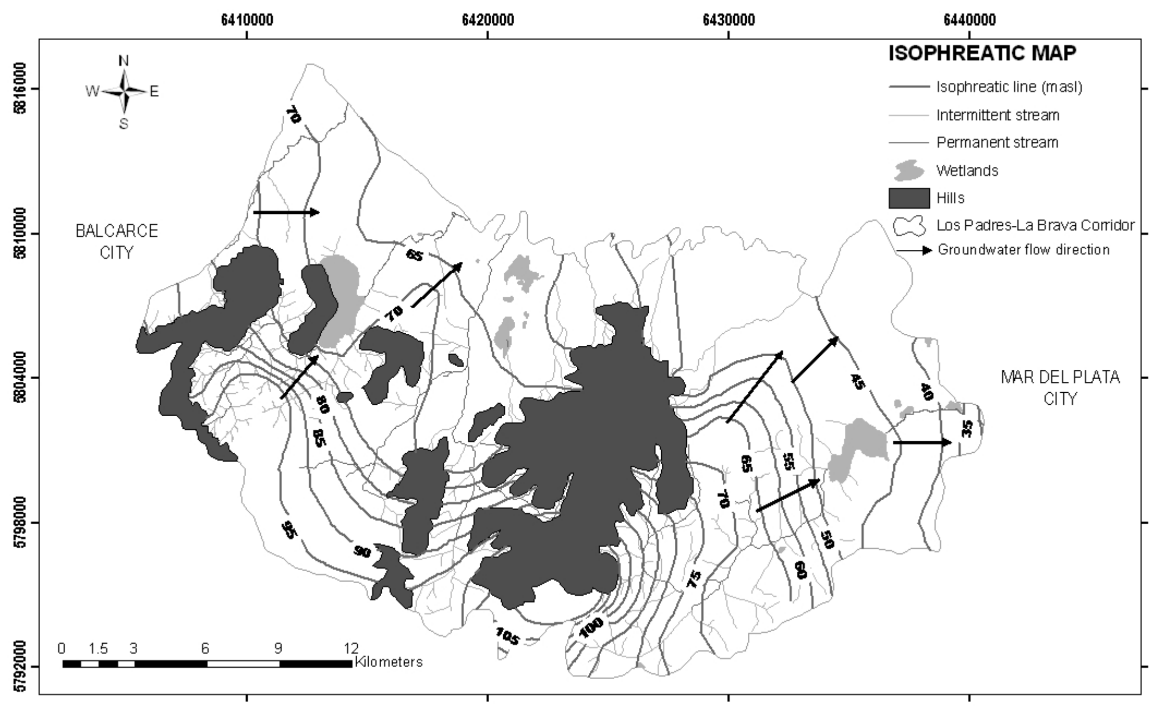

Fig. 4. Isophreatic contours and main groundwater flow directions in Los Padres-La Brava Corridor

Table 1. Water ionic content of groundwater, streams and wetlands in Los Padres-La Brava Corridor

	GROUNDWATER				STREAMS				WETLANDS			
Parameter	Min	Max	Media	St Dev	Min	Max	Media	St Dev	Min	Max	Media	St Dev
Ca^{+2} (mg/L)	4,54	96.00	30.99	22.00	13.50	52.20	28.25	12.25	15.30	61.00	29.62	9.26
Mg^{+2}(mg/L)	3.02	207.00	62.30	47.49	17.00	67.30	33.62	12.34	8.77	91.20	30.50	13.51
Na^{+} (mg/L)	21.40	398.00	154.50	100.14	92.00	306.00	160.43	58.79	82.00	950.00	209.41	152.35
K^{+} (mg/L)	2.20	14.80	6.34	2.42	3.16	9.70	7.33	2.04	2.88	14.84	7.26	1.80
Cl^{-} (mg/L)	28.20	185.90	87.78	32.22	47.10	250.00	102.67	47.56	32.00	253.20	89.72	31.31
HCO_3^{-}(mg/L)	234.30	967.70	509.14	170.28	282.20	1041.20	439.79	190.06	117.10	992.20	454.69	210.53
CO_3^{-2} (mg/L)	0.00	202.30	16.38	35.62	0.00	85.20	24.35	31.99	0.00	172.50	66.43	50.64
SO_4^{-2}(mg/L)	1.00	75.50	21.03	15.99	4.90	76.80	25.56	19.66	2.22	77.60	22.78	14.70
T (ºC)	0.00	26.20	16.00	2.66	9.40	26.40	18.78	4.77	12.90	34.00	19.14	3.91
pH	6.76	8.77	7.51	7.50	7.30	8.98	7.92	7.88	7.55	9.99	8.55	8.31
EC (µS/cm)	140.00	1440.00	719.92	225.26	457.00	1080.00	732.86	135.79	9.99	913.00	647.72	106.12
$\delta^{18}O$	-6.00	-0.35	-4.84	1.34	-5.57	0.28	-3.91	2.81	-2.69	0.25	-0.20	0.66
$\delta^{2}H$	-33.43	-1.92	-26.09	7.33	-29.88	3.72	-20.36	16.15	-14.67	3.68	1.66	4.13

References: Min: minimum; Max: maximum; St Dev: standard deviation; T: temperature; EC: electrical conductivity

As regards water ionic composition (Table 1), sodium and magnesium were the dominant cations in the chemical composition of the aquifer, whose values vary between 21.4 - 398 mg/L, and between 3.02 - 207 mg/L, respectively. As for the anions, bicarbonate (ranging from 234.3 - 967.7 mg/L) and chloride (between 28.2 and 185.9 mg/L) predominate.

Hydrochemical facies analysis was conducted by a Piper triangular diagram (Fig. 5). The Piper diagram allows for the identification of two main water types, magnesium- or calcium-bicarbonate and sodium bicarbonate. The first group is associated with the recharge areas located in ranges and hills, with electrical conductivity (EC) values lower than 850 µS/cm. Waters of the other group are more common in the area and they are distributed all along the corridor, with a mean EC value of 752 µS/cm, reaching a maximum value of 1100 µS/cm.

In relation to surface water, the main streams in the area were sampled: Los Padres Stream (SLP) and El Peligro Stream (SEP), both inflow streams, and the outflow streams Tajamar (STJ) and La Tapera (SLT) of La Brava and Los Padres Wetlands, respectively. The ionic composition of these samples was represented in a Piper diagram, which allowed establishing some differences among them. In general, inflow streams of both wetlands show a similar cationic composition with a sodium bicarbonate water type and higher calcium and magnesium concentrations in comparison to the effluents. The anionic content, instead, shows a more variable behavior in SEP, being in some cases chloride bicarbonate water. In SLP, bicarbonate is always the dominant anion in the chemical composition of the stream. The mean EC values were 658 µS/cm and 808 µS/cm for SEP and SLP, respectively. Mean EC values of 646 (STJ) and 822 µS/cm (SLT) were detected in the outflow streams. Moreover, the magnesium and chloride contents in SLT are higher than in STJ.

Wetlands present a homogenous ionic composition with sodium and bicarbonate predominance. In Los Padres wetland, some chloride dominance was detected during summer. EC in la Brava wetland ranged between 349 and 859 µS/cm, with a mean value of 635 µS/cm. Los Padres wetland shows a mean EC value of 635 µS/cm, ranging from 461 to 913 µS/cm.

In the mixing water calculation rainwater, spring water, groundwater and/ or inflow stream samples were considered as recharge sources to the wetlands. Chloride concentrations of each of these sources were used in the mentioned formula. Two groundwater samples from recharge to discharge areas in each wetland were selected. The first analysis includes samples from wells G527 and G559 in La Brava Wetland Basin. The second analysis includes samples from wells G538 and G575 in Los Padres Wetland Basin (Fig. 1). Chloride content in SEP, STJ, SLP and SLT was an average of all available data for each stream.

Mixing water estimation to identify the proportions in which recharge sources contribute to La Brava wetland water shows that 50.77 % of it corresponds to groundwater and 49.23 % to spring water. The mixing ratio analysis for SEP shows the base flow dominance in the stream, so it was not considered a different recharge source. On the contrary, it was included as a channeled component of groundwater. The high contribution of spring water indicates a direct and indirect wetland recharge via surface and subsurface runoff from the ranges, preferentially through the quartzite fracture system. For STJ, the same analysis shows that this stream is a mostly wetland water with some evaporation evidence.

In Los Padres Wetland the water mixing study, using the same ion, shows that groundwater is the main recharge source to it. As in SEP, SLP is maily groundwater. The same analysis performed for SLT indicates that it receives water from the wetland (68.82%) with certain evaporation level, possibly as a consequence of a gate located in it which gives it lentic system characteristics. For well G575, located downstream of the wetland, it is determined that it constitutes a mixed from rainwater (62.05%) and the wetland (37.95%).

The isotopic composition of 23 groundwater samples, 4 stream samples, and 4 samples in each wetland (La Brava and Los Padres) within the corridor was analyzed. Isotopic data jointly with the global meteoric water line (GMWL) and a preliminary local meteoric water line (LMWL) were plotted in a conventional diagram δ^2H vs. δ^{18}O (Fig. 6). The 81% of the groundwater samples appear grouped around a mean value ($\delta^{18}O$ = -5.41‰ and δ^2H= -29.23‰), showing relatively constant isotopic composition. This fact indicates that it is a well-mixed system. The other 19 % of the samples indicates the action of several local processes of evaporation which alter the isotopic composition of groundwater and, reveals wetland contribution mixes.

Evaporation lines for each wetland, considering groundwater as the starting point, were calculated and defined by the following equations: $\delta^2H = 5.96\ \delta^{18}O + 2.93$ and $\delta^2H = 5.38\ \delta^{18}O - 0.19$ for La Brava and Los Padres wetlands, respectively. Well G565, located near La Brava wetland, presents an isotopic fingerprint similar to this water body (Fig. 1). Similarly, well G575

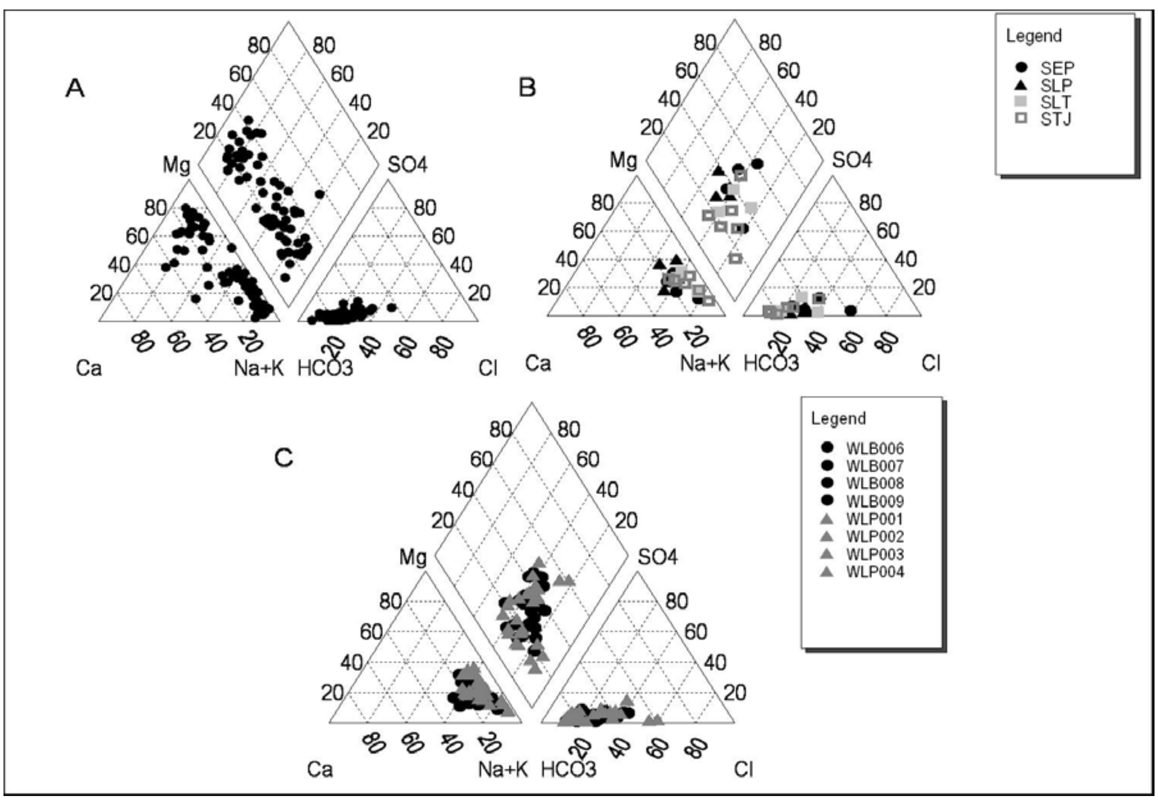

Fig. 5. Water ionic content in Los Padres-La Brava Corridor. A. Groundwater. B Stream water, and C. Wetlands

shows an analogue isotopic content to Los Padres wetland. Following the flow path from these two wetlands, isotopic composition indicates water mixing of these wetlands and the aquifer (wells G559 and G540). In this way, the effluent- influent behavior of la Brava and Los Padres wetlands is confirmed. Moreover, groundwater recharge function of these wetlands is remarked.

Isotopic composition of the inflow stream waters of both wetlands is similar to groundwater, indicating groundwater contribution in the stream discharge. On the other side, outflow streams of La Brava and Los Padres wetlands acquiring its isotopic fingerprint. Tajamar Stream (STJ) showed similar isotopic values in comparison to La Brava wetland with probably processes of evaporation 3 km away from its origin.

Wetland ecosystem services (provision of habitant and food for species, recreation, etc.) are important not only within the wetlands themselves, but also to related systems. Groundwater recharge function of wetlands is of significant importance since it provides water to the aquifer system and contributes to the maintenance of phreatic levels. Moreover, wetlands improve water quality through filtering sediments and potential pollutants (through aquatic macrophytes) from groundwater and its drainage basin. They also influence groundwater physical and chemical characteristics, and in this sense, water quality for domestic and agricultural uses. In this context, threats to resource availability and quality could generate both, an increase in the dissatisfaction of water users and a consequent change in land and water use behavior of people in the area.

The water quality of wetland is highly dependent on the upstream land use or the upstream run-off waters, although other factors such as lake structure and configuration, geomorphology, ecosystem characteristics and so on, also affect their water quality. Most of the eutrophication problems in lakes are consequence of the different activities that take place within their drainage basin (Quirós *et al.*, 2002a). It is generally known that the nitrogen concentration in wetlands is highly dependent on the condition of upland fields (Nakasone and Kuroda, 1999). As an example of agricultural activity consequences in the area, some recent studies have shown that fish in La Brava Wetland contain varying levels of organochlorine pesticide residues. In addition, concentrations of organochlorine pesticides were detected in some water samples; always under the Argentinean guideline values (Menone *et al.*, 2004). All these confirm the land use impact on the water quality of the region.

Over the last years, an important permanent population growth within La Brava and Los Padres wetlands (La Brava and Los Padres Villages) is evident. Such developments will not only reduce the wetland

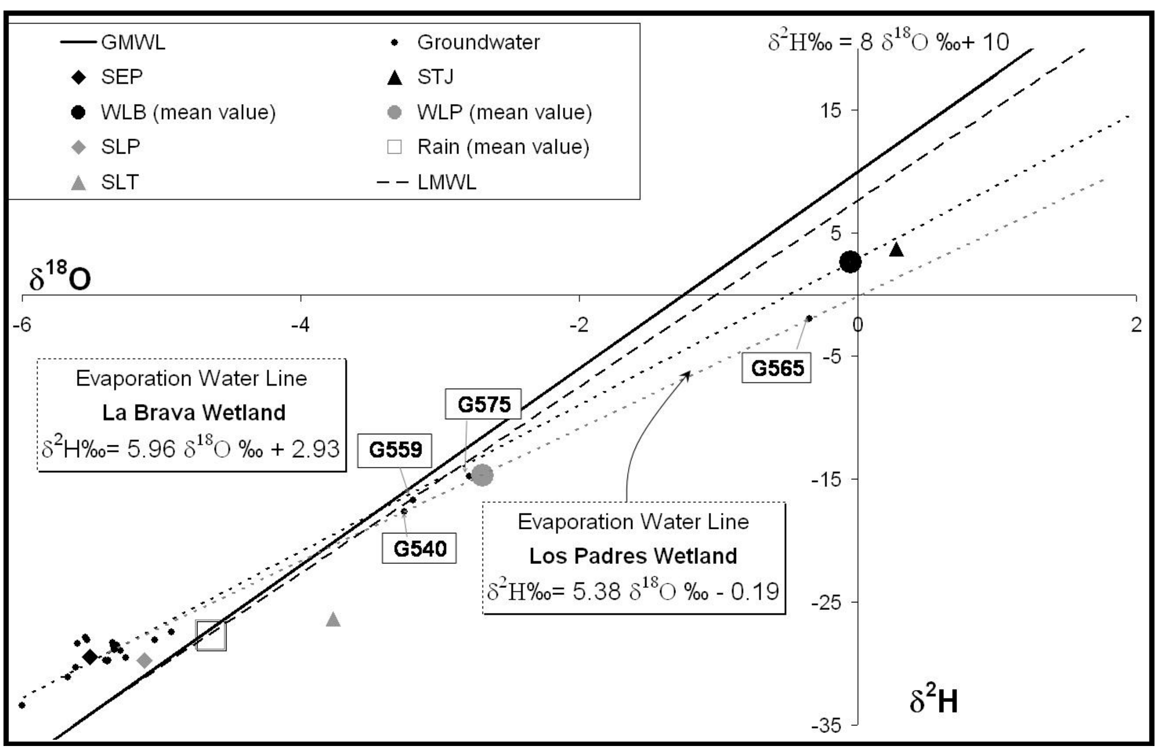

Fig. 6. $\delta^{18}O$ and δ^2H content in groundwater, wetlands and stream water

coverage, but also increase its water pollution from liquid and solid waste disposal.

Aquifer general recharge areas coincide with the hills, with a magnesium- or calcium-bicarbonate water type and electrical conductivity (EC) values lower than 850 μS/cm, evolving to a sodium bicarbonate water type reaching EC values of 1100 μS/cm. This variation in Ca^{+2} and Mg^{+2} concentrations indicates a softening process (magnesium and calcium exchange for sodium) along the flow path. Groundwater analysis in the rest of the geomorphological units suggests little influence of them in the physical-chemical characteristics of the aquifer, since no significant differences were detected among them.

Isotopic data are consistent with the defined conceptual hydrogeological model for Los Padres- La Brava Corridor, confirming the relationship between surface water and groundwater. Groundwater samples present a relatively homogeneous composition, which can be interpreted as the result of a mixed system. Stream water shows a higher degree of variation along the meteoric line and also evaporation line. The evaporation line crossed the meteorical water line approximately where most of the groundwater samples are represented, and inflow stream water samples are placed around this area. Evaporation effects on stream water are recognized.

Knowledge of the present distribution and area of such agricultural, recreational, and urban lands, is needed by legislators, planners, and state and local governmental officials to determine better land use policy, to identify future development pressure points and areas, and to implement effective plans for regional development. Land use and land cover data are also needed for water-resource inventory, deteriorating environmental quality, destruction of important wetlands, water-supply planning and protection of zones identified as recharge areas for the aquifer (Anderson *et al.*, 1976). Since the 70% of the study area is under agricultural land use, recharge areas coinciding with topographic high zones (ranges and hills) are particularly important to protect because misuse of these areas can lead to depletion of potable water supplies and increased groundwater contamination. Moreover, "wetlands" land cover type is an extremely fragile category as it also acts as a recharge area for the system. The mapping of this data is an important step towards protecting regional surface water and groundwater resources considering as CPRs. To preserve the natural conditions of the study area, it is necessary to predict the dynamics and quality of water resources. This is a difficult task because of the scarcity of historical hydrological and hydrochemical data. In view of these facts, the evaluation of the geological, geomorphologic, hydrogeolgical and land cover/land use characteristics seems a valuable tool for predicting future hydrologic scenarios in the presence of natural or anthropic events. Moreover, integrated water resources management including surface water and groundwater is vital in complex areas, like Los Padres-La Brava Corridor. Setting management tools in order to maintain reasonable balance between stakeholder interests and water resource uses is required in common pool resource areas.

CONCLUSION

A combination of hydrogeological, hydrochemical and isotopic techniques was used to understand and confirm both flow system in unconfined aquifers and relationships among the different water sources in the southeastern of Buenos Aires Province. Preferential recharge areas, flow path, and changes in the relationship between groundwater and surface water can be identified more accurately from these techniques. Isotopic information allowed the determination of the role of wetlands in relation to streams and groundwater. In this particular case, isotopes better represent these relationships in comparison to hydrogeochemical data. The regional flow conditions defined from the piezometric map can be confirmed by the isotopic model, showing the effluent-influent behavior of wetlands in relation to both streams and groundwater. The study suggests that flow lines obtained from usual hydrological surveys in aquifer systems in this type of environments, based on measured groundwater levels, should be confirmed with hydrochemical and isotopic analyses.

The parameters that provide more information to adjust and validate the hydrogeological model of the wetlands were EC (by the identification of preferential recharge areas), Cl^- (by identifying main recharge sources) and isotopic content (by establishing interactions among meteoric water, groundwater and surface water). Isotopic and hydrochemical data indicate that the recharge to the aquifer is influenced by the natural rainfall input, wetland discharge and the concentration of surface run-off from the range fringes to inter-range depressions. Wetlands in the corridor are considered recharge areas for the aquifer system. Moreover, they contribute to water quality as well as groundwater and stream availability.

Ionic content and its distribution is a useful tool in identifying recharge areas. This concept must be applied together with other hydrochemical concepts such as EC distribution. This contribution has allowed for the recognition of recharge areas that are coincident with low EC and high calcium or magnesium concentrations. Aquifer general recharge areas coincide with ranges (perirange and piedmont unit) and hills, with a magnesium- or calcium-bicarbonate water type and electrical conductivity (EC) values lower than 850 μS/cm, evolving to a sodium bicarbonate water type reaching EC values of 1100 μS/cm. This variation in Ca^{+2} and Mg^{+2} concentrations indicates a softening process (magnesium and calcium exchange for sodium) along the flow path. In the other geomorphological units no particular association of hydrochemical and isotopic features were detected.

Mapping land cover/land use associated with geomorphology is an important step towards protecting regional surface water and groundwater resources in an area. In this sense, the identification of fragile areas allows to assess future impacts on environmental quality of water resources. The geomorphological units of ranges and hills are particularly important to protect due to their relevance as recharge areas to the local aquifer and the intensive agricultural uses performed on them.

Land use data are needed in the analysis of environmental processes and problems that must be understood in order to assess and manage areas of critical concern for environmental control such as groundwater exploitation and wetlands, wildlife habitat, recreational and agricultural lands, and areas such as major residential and industrial development sites.

The water management measurements proposed for applying to these types of multiple use areas in a CPR context are: (1) Water quality evaluation, (2) Aquifer, streams and wetland monitoring, (3) Construction of buffer zones including the wetland and inflow stream (which acts as a source of recharge to the wetland), (4) Spring and well inventory with location maps of usable resources, (4) Stakeholder involvement, and finally, (5) Promotion of environmental education and awareness.

This study proposes a holistic approach to water resources management recognizing most of the components of the hydrological cycle and its interactions with other natural resources and ecosystems, both aquatic and terrestrial ones. In this sense, the idea of water resources assessment in an integrated way for an efficient management, including wetlands, streams and groundwater, is reinforced in this work.

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