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NITRATE CONTAMINATION IN THE PHREATIC AQUIFER OF AN AGROECOSYSTEM OF THE CHACOPAMPEANA PLAIN, CORDOBA, ARGENTINA

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The functionality and pollution potential of the agroecosystem of the Los Jagüeles basin were characterized and an initial spatial assessment of nitrate levels in the phreatic aquifer was made. This aquifer, used for many purposes, is made up of Quaternary materials of alluvial and aeolian origin. It has sodium bicarbonate and sodium sulphate-chlorate waters and shows signs of degradation because of the presence of nitrate. Nitrate levels range from 1 to 70 ppm, and a connection between these values and the present use of soils and their derived pollution activities can be observed. The arrival of nitrates to the aquifer is influenced by many factors, such as lithology of the unsaturated zone, well depths, and soil types. Nevertheless, because of high variability in the basin, it was impossible to arrive at a definite relation between nitrate levels and two selected parameters, water depth and well age.

INTRODUCTION AND OBJECTIVE

The Los Jagüeles basin is used for agricultural and cattle farming practices, and most of the area is an agricultural system or agroecosystem. For that reason, the application of management technology like irrigation, chemical agriculture with an excessive use of different pesticides and fertilizers, and intensive cattle farming practices are potential degradation sources for groundwater, which is used for all purposes (human consumption, cattle farming and irrigation). In this area, there are also several point sources of potential contamination connected to those practices like pesticide and fertilizer warehouses, pig-farms, stockyards, pools of organic effluents from dairy farms, and so on, many of which are located near water supply wells. A significant environmental indicator of this problem is the presence of nitrate in groundwater, which is most likely the result of contamination by the above-mentioned practices. The aim of the present work is to determine the spatial distribution of nitrate in the groundwater of the agroecosystem as a contamination indicator.

Satellite images (1:500,000 and 1:250,000), air photographs (1:60,000, 1:50,000 and 1:20,000) and topographic maps (1:50,000) were used to prepare maps of the study area. A detailed survey of the geological, geomorphological, hydrogeological aspects and present use of soil was made, 96 wells were surveyed, and 68 samples were taken for complete physicochemical analysis.

GEOGRAPHIC LOCATION

The study basin drains a surface area of 40,000 ha and is located in the South of the Río Cuarto Department, Córdoba Province, Argentina, as shown in Figure 1.

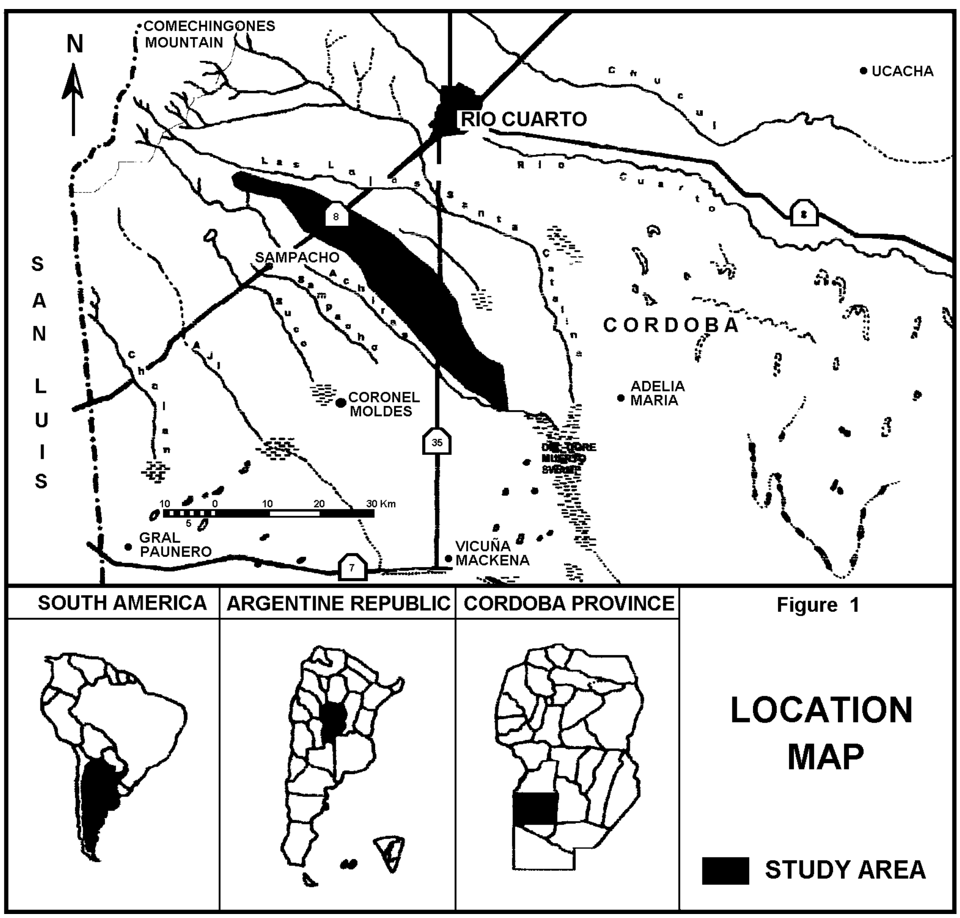


Figure 1. Location map.

CLIMATE

The study area has a sub-humid mesothermal climate. Annual mean rainfall (1969-1995) is 793.5 mm with two well-differentiated seasons: a humid season, corresponding to spring-summer, with 85.3 percent of the total annual rainfall; and a dry season, corresponding to autumn-winter, with 14.7 percent.

THE ECOSYSTEM OF THE LOS JAGÜELES BASIN

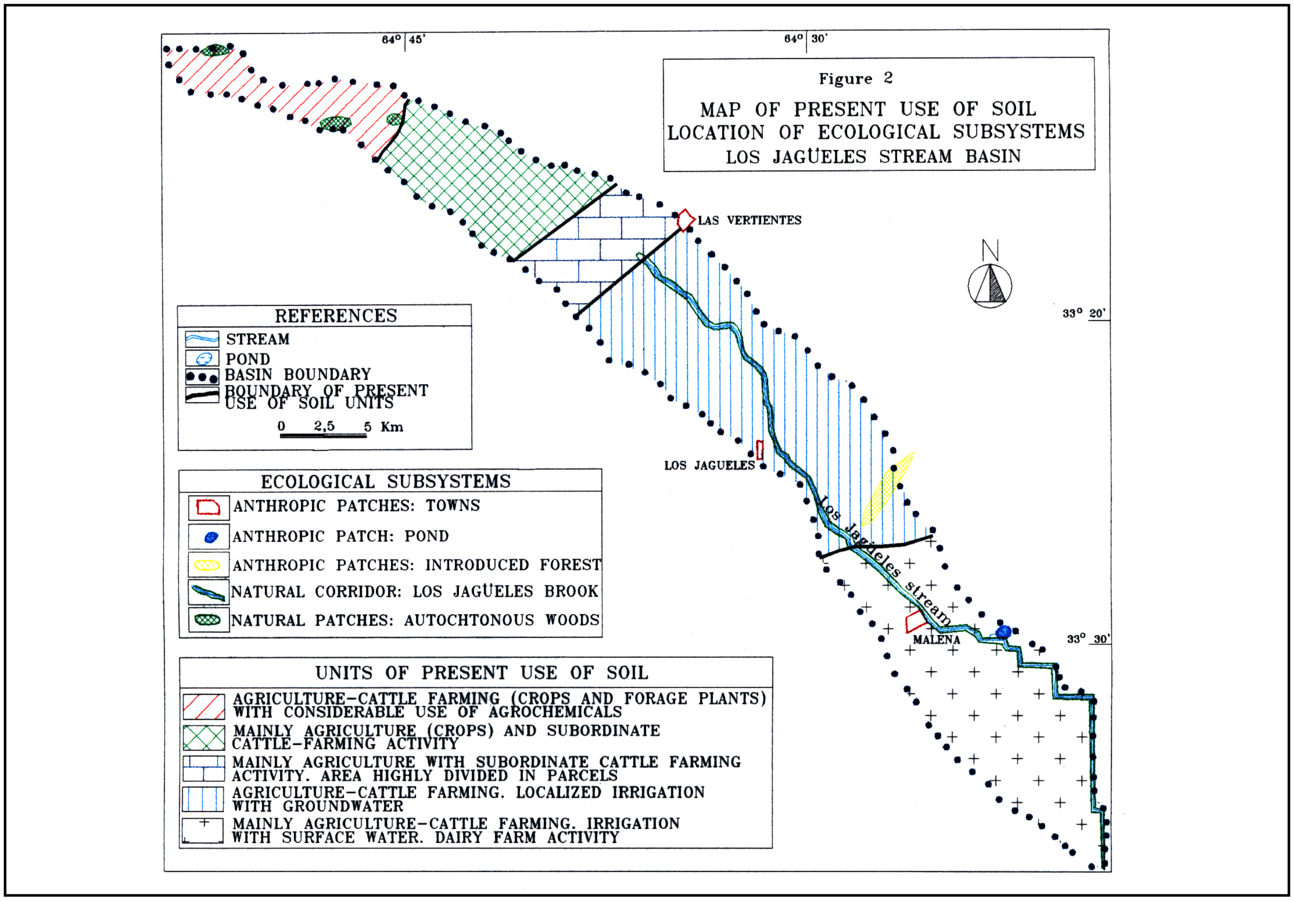
The basin has been defined as an ecosystem or ecological system, just as stated by Odum (1983), as "any unit including the total number of organisms in a given area which behave reciprocally with the physical environment, so that an energy flow will lead to a trophic structure, a biotic diversity and material cycles". The ecosystem of Los Jagüeles basin is an agroecosystem with variations in its stability according to the predominant use assigned to the different parcels. Nevertheless, this ecological system is not homogeneous but it presents small subsystems with their own features (Forman and Godron, 1986). We can differentiate a natural corridor (creek), natural patches (small autochthonous woods) and man-made patches (small artificial ponds fed by the creek, forests introduced by man, and the three towns: Las Vertientes, Malena and Los Jagüeles).

Table 1.

	Classification according to energy flow	**Characteristics**
Main ecosystem: Agroecosystem	Ecosystem with solar energy and human subsidies.	Subsidized by solar and fossil (fertilizers, pesticides) energy, and often by water pumped for irrigation.
Anthropic Patch: Pond	Ecosystem with solar energy and human subsidies.	Subsidized by water coming from the brook due to human intervention
Natural Corridor: Los Jagüeles stream	Ecosystem with solar energy and natural subsidies.	Subsidized by the water current, which recycles the nutrients, and ephemeral stream draining into the brook during storms.
Natural Patches: Autochtonous woods	Ecosystems with solar energy and natural subsidies.	Arrival of organisms from other ecosystems and recycling of nutrients.
Anthropic Patches: Introduced forests	Natural ecosystems with solar energy and natural subsidies.	Arrival of organisms from other sub-systems and recycling of nutrients.
Anthropic Patches: Towns	Urban/industrial ecosystems using fuel.	Subsidized by fossil energy for all purposes.

Agroecosystem

From the energetic point of view, the agroecosystems are highly subsidized natural systems because they receive a great contribution from human intervention, not only with the use of sowers and harvesters, but also when applying fossil energy through pesticides (insecticides and herbicides) and fertilizers, and in some cases the subsidy is through water pumped for irrigation. These systems become unstable and change quickly with ecological succession when they are deprived of the human contribution. Both stability and productivity vary in the agroecosystem depending on the use assigned to the parcels: a) predominant agriculture (higher productivity, lower stability), b) both agriculture and cattle farming (similar stability and productivity) and c) predominant cattle farming (lower



productivity and higher stability), (Giayetto, 1993). In the study basin, the agroecosystem is characterized mainly by cattle farming practices (cows) and crops (oleaginous and forage plants) in mono diversified farming. The present use of the soil is shown in Figure 2. The complexity and dependence on energetic subsidies show clearly that the agroecosystem presents a high pollution potential due to irrigation practices, inappropriate and continuous use of pesticides and fertilizers, high animal load per hectare, inadequate disposition of wastes, organic and inorganic effluents resulting from those practices, intensive hog-breeding and poultry-farming, and dairy farms.

AGROECOSYSTEM COMPONENTS OF THE LOS JAGÜELES BASIN

A synopsis of the biotope and biocenosis components is presented. However, a description of the former will be made considering the aims of the present work. Partial references to the biocenosis will be made only for those aspects connected to the use of soil.

BIOTOPE

Geological and geomorphological characterization

Los Jagüeles basin develops completely in the Chacopampeana plain. The basin shows strong structural control, mainly in the high and middle areas, with well-defined structural lineaments that trend 120°-130° N and 035°-040° N. These structures have undergone differential vertical movements, resulting in a block-morphology generally dipping towards the SE. These systems significantly control the configuration of the drainage net.

The bedrock, upper Precambrian-Middle Paleozoic, is made up of medium to fine grained-igneous rocks, and medium grained metamorphic rocks. In the high basin, there are sporadic small

Table 2.

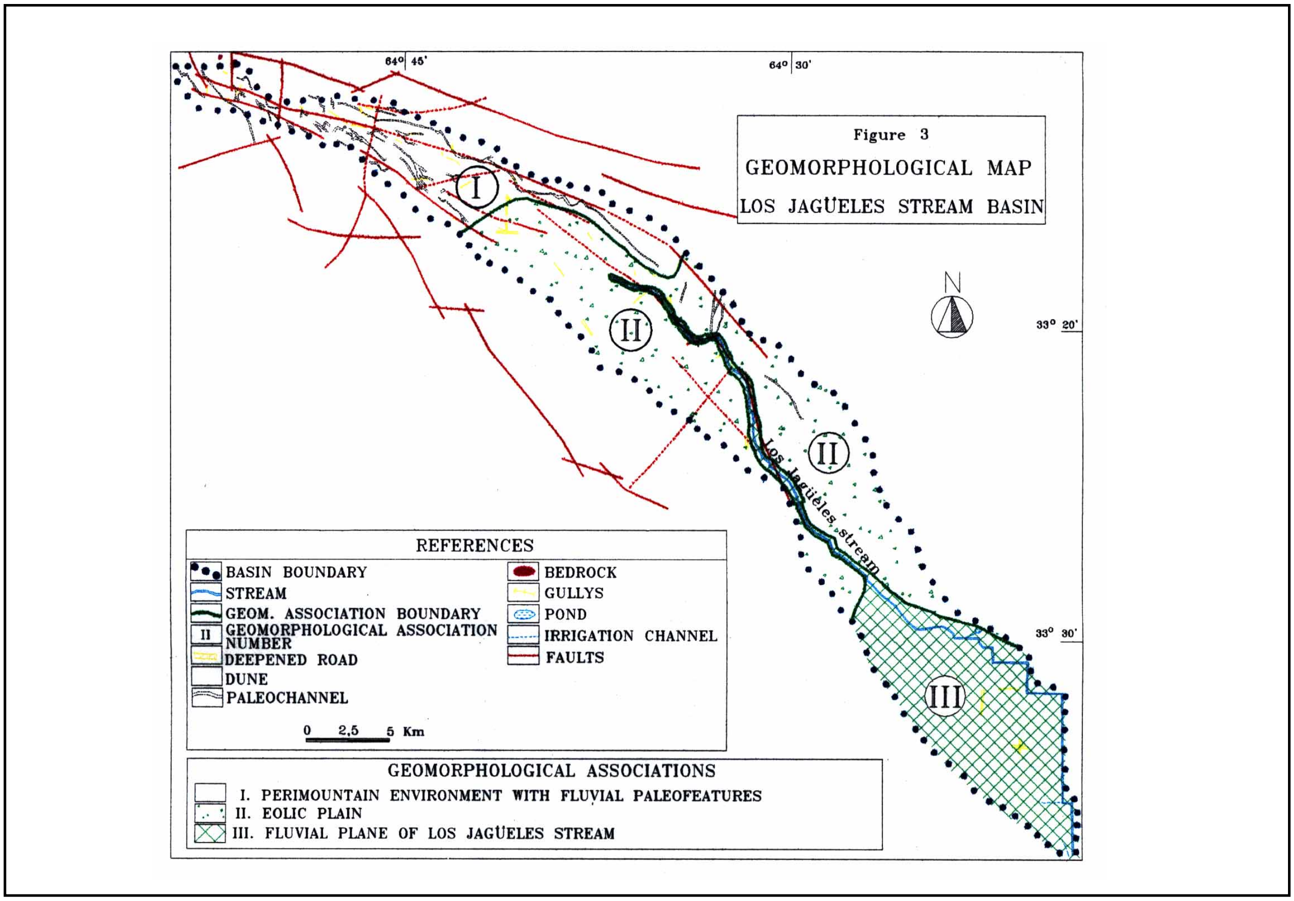
Abiotic Components **BIOTOPE**	**Components** **Inorganic component**. Terrestrial: bedrock and (eolic and fluvial) sediments of diverse granulometry outcrops. Aquatic: surface and groundwater, and salts dissolved in them. Atmosphere: precipitation, humidity, winds, and so on. **Organic components**. Organic wastes of different nature. **Environmental conditions** pH, Eh, temperature and other conditions of surface and groundwater, of soils and air.
Biotic Components **BIOCENOSIS**	**Phytocenosis** **Primary producers**: summer crops (mainly corn, sorghum, sunflower and soybean). Winter crops (wheat). **Zoocenosis** **Primary consumers (herbivorous)**: cattle (cows and sheep), pigs, birds, vizcachas. **Secondary consumers (carnivorous)**: fox and american panthers. **Microconsumers**: bacteria and fungi.

outcrops. The outcropping Quaternary (Upper Pleistocene-Holocene) materials in the basin are clastic sediments (coarse, medium and fine sands, and limes) of eolic and alluvial origin.

The geomorphological variations of this area respond to the dominant structures, the lithology and the Quaternary climatic oscillations. The basin was divided into three geomorphological associations (Figure 3). Association I is a perimountain environment with a strong to moderately undulating relief showing fluvial paleofeatures of different degrees of preservation, covered with a more modern eolic cover. Soils are typical Haplustols, and in the most important lowlands, typical Argiustols. In this area, features of hydric erosion (incipient ravines and deepened roads), and eolic accumulation (dunes) and erosion forms are observed. Association II is a vast plain, slightly undulating with a significant eolic layer made up of Holocene longitudinal dunes (fine sands and silts) covering the oldest features and deposits. Soils in this area are typical poorly-developed Haplustols. Features of hydric and eolic erosion are observed, even though the former are more important. Association III is made up of the fluvial forms of the Los Jagüeles stream, including the area generated by periodic overflows. Soils are in most cases typical Entisols and Haplustols.

Hydrogeological characterization

The phreatic aquifer is made up of materials of varied granulometry, mainly associated with processes and the resulting morphologies that occurred during the upper Pleistocene-Holocene. From field data, three different sectors can be determined. In the first sector, the aquifer is fine, medium and coarse sand, and gravel sediments which correspond with the perimountain environment with fluvial paleofeatures. The second sector, which is located in the northeast part of the eolic plain association and in the area where the stream overflows, is characterized by the presence of silty materials (with a lower percentage of sands) and cemented silts (calcretes). The third sector shows silty sediments, fine sand sediments, and cemented silty sediments (calcretes), and it corresponds with the southwest sector of the plain. In the high basin, the bedrock acts as the base of the phreatic aquifer, while in the middle and low basin, the base is a 100 m deep layer made up of cemented clays.



The study aquifer shows two different hydrodynamic behaviors (Figure 4). One sector has a west to east flow direction, undulating water table morphology, and about 15 to 5 percent hydraulic gradient which correspond with the environment surrounding the hills. Another sector, with a northwest to southeast flow direction, is geomorphologically associated with the eolic plain and the area of the stream overflows. The water table morphology is slightly undulating with about 1.6 percent hydraulic gradient in the middle basin, and is almost flat in the low basin with 0.5 percent hydraulic gradient. In the high and middle basin, groundwater divides are well defined, while in the lower basin, they are not evident due to the almost flat morphology of the water table. For these different hydrodynamic situations, a structural factor is significant since both sectors are separated by a fault which generates two big blocks of regional character. The net area of regional recharge of the aquifer is the area surrounding the hills, although the entire basin is recharged by infiltrating rain water. In the middle section there are phreatic outcrop areas (discharge zones), while the final canalized section does not reflect the water table. With regard to groundwater abstraction, windmills have been installed in all surveyed wells, and yields are very low. In all cases, wells depths are between 6 and 15 m below the water table.

The total content of salts dissolved in the aquifer shows a significant variation along the groundwater flow direction (Figure 5) with values that range from 350 mg/l to 3500 mg/l. From these data, it is inferred that the distance covered by water is one of the determining factors of salinity, in addition to the lithologies described for the different environments. The aquifer presents sodium bicarbonate water in the high basin and sodium sulfate-chloride water in the intermediate and discharge areas. From the total samples analyzed, 91 percent were inadequate for human consumption because of the presence of high values of fluoride, arsenic and sulfate.

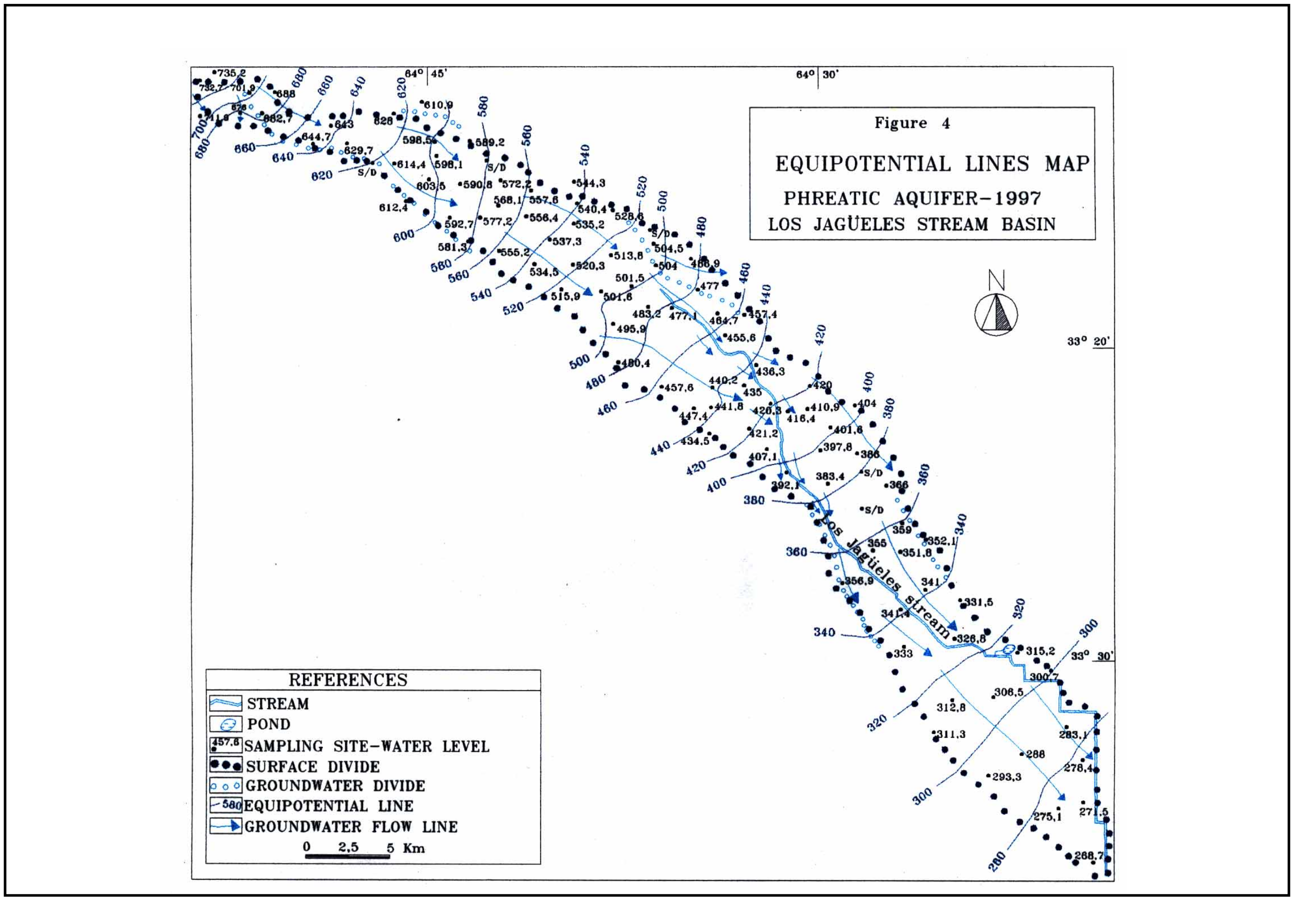


Figure 4
EQUIPOTENTIAL LINES MAP
PHREATIC AQUIFER-1997
LOS JAGÜELES STREAM BASIN
64° 45'
64° 30'
33° 20'
33° 30'
N
Los Jagüeles stream
REFERENCES
STREAM
POND
SAMPLING SITE-WATER LEVEL
SURFACE DIVIDE
GROUNDWATER DIVIDE
EQUIPOTENTIAL LINE
GROUNDWATER FLOW LINE
0 2,5 5 Km

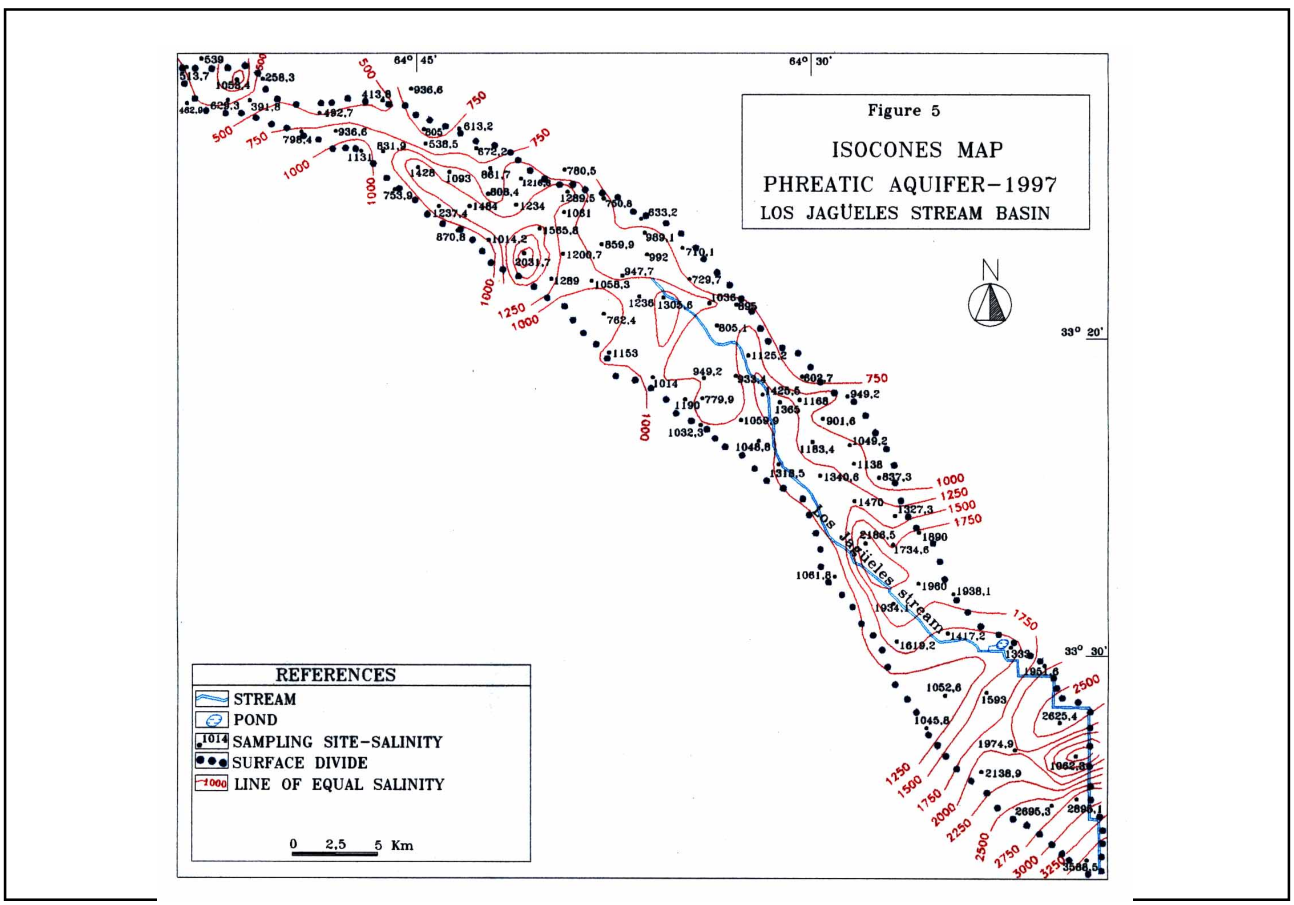


Figure 5
ISOCONES MAP
PHREATIC AQUIFER-1997
LOS JAGÜELES STREAM BASIN
64° 45'
64° 30'
33° 20'
33° 30'
N
Los Jagüeles stream
REFERENCES
STREAM
POND
SAMPLING SITE-SALINITY
SURFACE DIVIDE
LINE OF EQUAL SALINITY
0 2,5 5 Km

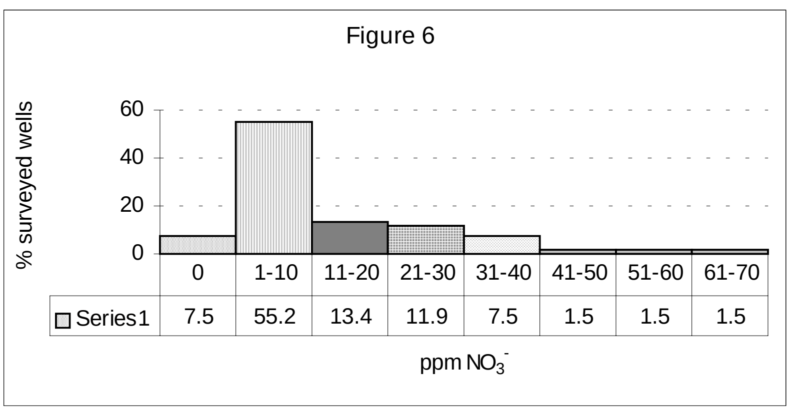
NITRATE ION AS AN ENVIRONMENTAL INDICATOR

The presence of nitrate ion in drinking water is alarming because it affects human health. For that reason, periodic controls of this compound should be made. This ion is the most generalized pollution indicator due to its high mobility and stability in groundwater aerobic systems. The maximum tolerable limit for human consumption recently accepted by the WHO (World Health Organization) is 50 ppm of NO_{3-} (11.1 mg/l NO_3^- -N). This limit has been established by the WHO mainly based on the formation of metahemoglobinanemia in children. High nitrate contents are also associated with esophagus and gastric cancer, and implied in diabetes cases. Concerning water for cattle use, the accepted limits are higher and the presence of nitrates is associated with poor animal growth (values between 1,000 and 3,000 ppm are toxic for cattle).

DISCUSSION AND INTERPRETATION OF NITRATE IN THE AGROECOSYSTEM

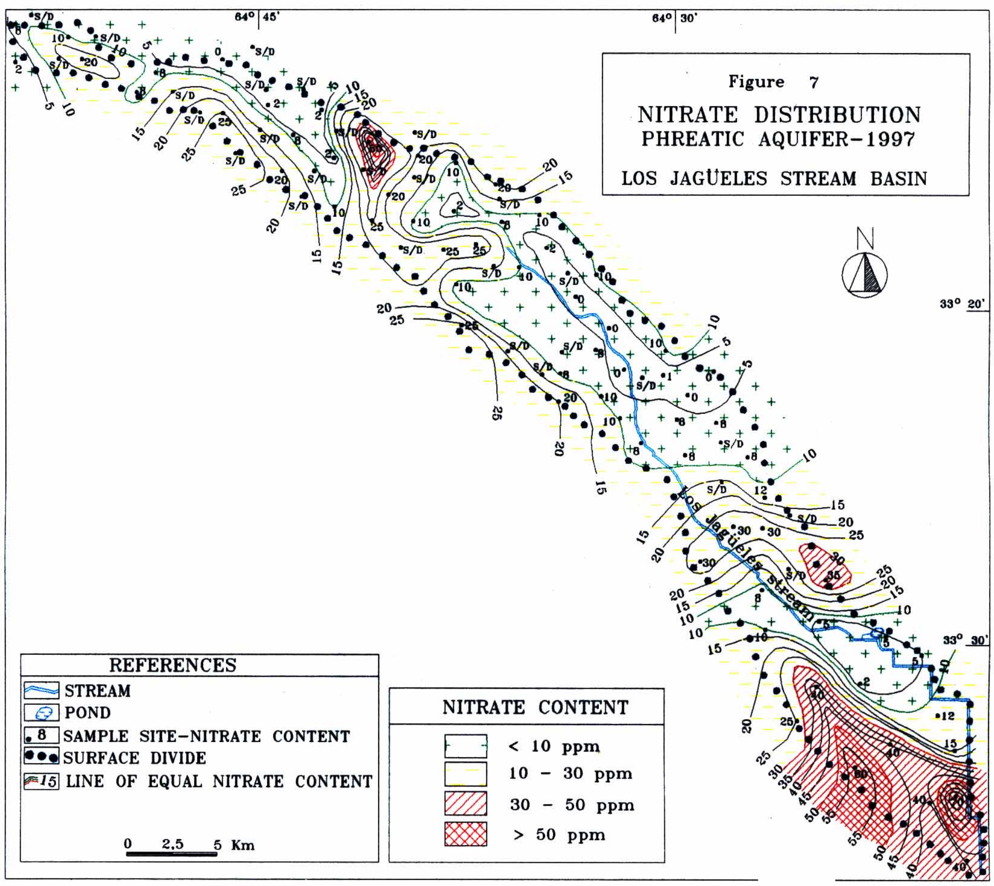
From the total analyzed samples, 7.5 percent do not show nitrates; 68.8 percent have contents between 1 and 20 mg/l, 20.9 percent of these show from 21 to 50 mg/l, and 3 percent of the samples exceed 50 mg/l, reaching the highest content found in the basin at the survey time (70 mg/l) in well Nº 94 in the low basin area (Figures 6 and 7). Nitrate is a major ion (exceeding sulfates and chlorides) only in two of the samples.

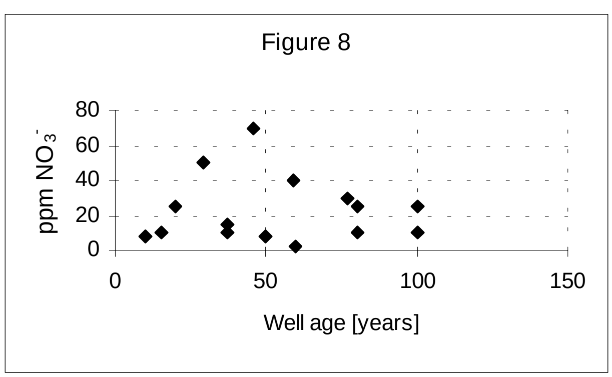
As nitrate is considered a conservative ion, under the same conditions, the oldest wells should show the highest nitrate values. However, it is impossible to conclude from the distribution observed in Figure 8 a specific relation between nitrates and well ages. Numerous factors interfere with this relation, which vary from one point of the basin to another, affecting the nitrate arrival to the well. These factors are the quantity of water that infiltrates into the different sectors of the basin, the different features of the unsaturated zone (texture, granulometry, thickness, and so on), and of wells (depth, length of screen, well discharge, etc.) and the variety of pollution sources (fertilizers, herbicides, drinking places, farmyards, and dairy effluents). On the other hand, it was impossible to determine the age of some wells. Considering this variety of factors, the interpretation of nitrate presence should be made in a more particular way analyzing sectors which show more homogeneity with respect to the above-mentioned characteristics.



Regarding the map of the present use of soil (Figure 2), a corresponding relation is observed between the sectors with nitrate values higher than 20 ppm and some areas of agriculture and cattle farming with an important use of agrochemicals (high basin), and with the sector of the low basin where numerous dairy farms are present. In this sector, some fields are used for agriculture and are also irrigated, and as a consequence, nitrate arrival to the aquifer is favored. One characteristic that should be highlighted is that the presence of nitrates reaches the entire study area, regardless of the fact that values are not so high. This characteristic was not usual for this area of the Chacopampeana plain up to the present. This is because energetic subsidies of the agroecosystem are increasing. Basically, a change of customs has been observed in recent years since irrigation practices and use of fertilizers to increase yields have grown remarkably.

With respect to the relation with water depth (Figure 9), it was found that in the low basin, in sectors between 10 and 20 m depth of water table, higher nitrate contents are observed. Nevertheless, in Figure 10, a definite relation is not shown for the basin owing to unequal pollution sources, the lithologies of the unsaturated zone, type of soil, infiltration rates, and so on. For instance, the unsaturated zone thickness is small in the middle sector of the basin, however, nitrate contents are not high because pollution sources are almost nonexistent. In the low basin, increase in nitrate content would not be controlled only by depth, but would be associated with the dairy farm activity mentioned





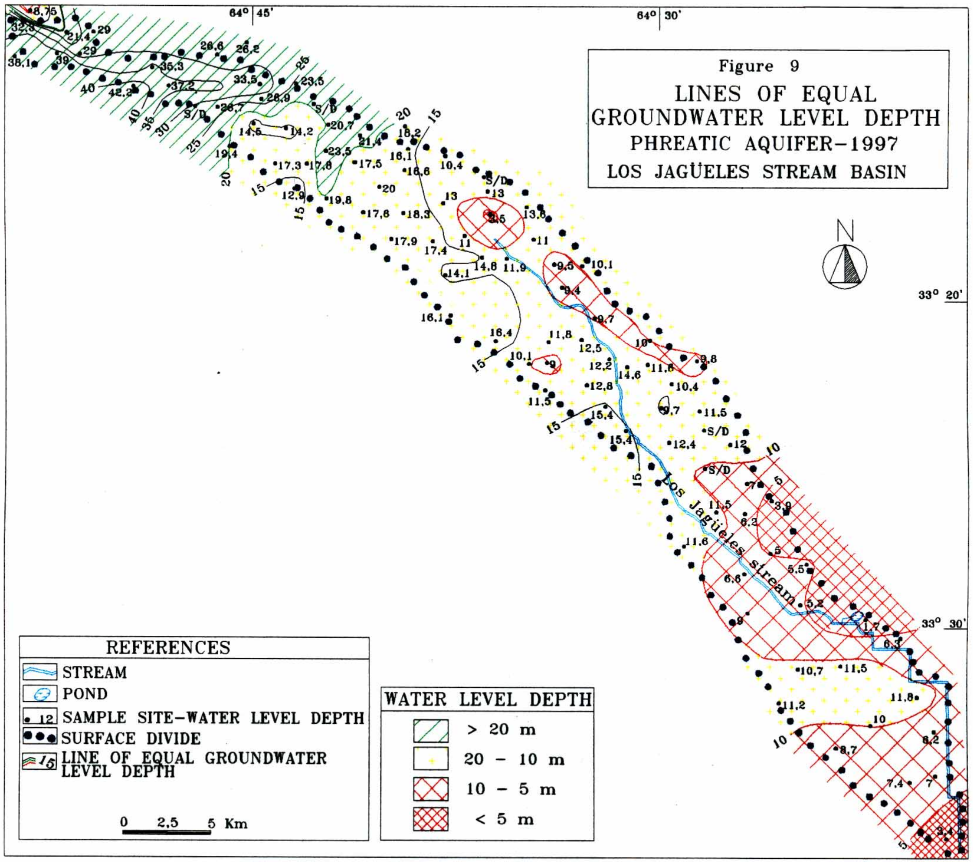
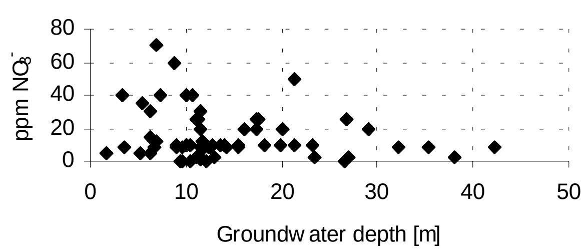


Figure 10



above (Foster et al., 1992).

From results obtained in this first stage of research, it is impossible to arrive at definite conclusions respecting a sole pollution source. Evidence shows that the phreatic aquifer of the agroecosystem exhibits degradation because of the presence of nitrate ion in water. This is a consequence of diffuse pollution sources (excessive use of agrochemicals) and point sources (inadequate disposition of warehouses of chemical containers, pools of dairy farm effluents, hog stockyards, and so on) located in areas near water supply wells.

Microbiological analyses are advised, mainly in those wells used for human consumption where contamination is due to organic effluents resulting from dairy farms and hog-breeding, as these are sources of biological contamination.

Control and protection program for water resources are not available in this area. Therefore, it is important to provide these results to the INTA (Instituto Nacional de Tecnología Agropecuaria) agencies of the zone to advise farmers about the type of agrochemical they should use, appropriate application time, adequate concentrations and best management. The authors of this paper have given farmers the results of the analysis and recommendations for human consumption.

The next stage of research on aquifer nitrates will be related to the temporal evolution of this anion, since new samples will be taken to assess possible variations and their causes. In order to achieve this, more information about soil use and, mainly, the application of agrochemicals in the agroecosystem should be obtained.

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