Groundwater pollution in Quaternary aquifer of Vitoria – Gasteiz (Basque Country, Spain)

Influence of agricultural activities and water-resource management

I. Arrate · J. M. Sanchez-Perez · I. Antiguedad · M. A. Vallecillo · V. Iribar · M. Ruiz

Abstract As a result of diverse changes in land use and in water-resource management in the high basin of the Zadorra River (Basque Country), an important loss of water resources and an intense contamination by nitrogen compounds has taken place. The purpose of this paper is to detail the land transformations that have taken place on the aquifer since the 1950s: increase of drainage network, change from dry to irrigated farming, and diversion of rivers at the aquifer unit inlet. Furthermore, we analyze the impact of these transformations on the hydrodynamics and water quality of this aquifer system.

Key words Groundwater pollution · Basque Country

Introduction

In the last 20 years, contamination of surface water and groundwater in high-density demographic and industrial zones has reached very important levels. In a great number of cases, water resources have been affected in such a way that they are not available for further use without prior treatment.

Contamination of surface water may disappear within a short period of time, once the discharge source is controlled, but for groundwater, contamination may persist for many years and depuration strategies would require substantial research and financial efforts.

The impact of farming activities on groundwater quality in European alluvial valleys is well known (Gustafson 1983; Andersen and Kristiansen 1984; Bernhard and others 1992). In these areas, agricultural activity combined with water recirculation have caused an increase in concentrations of nitrogen compounds and pesticides in the groundwater (Ritter and others 1990; Arrate and others 1993a, b).

In certain south European countries, construction of dams in order to regulate surface water has also been accompanied by numerous diversions of rivers towards them. In several cases, this has contributed to considerably reducing natural recharge of certain aquifer formations.

The Quaternary aquifer of the city of Vitoria-Gasteiz represents a very well documented example of water resource losses and degradation of groundwater quality due to various land transformations. A change in agrarian practices combined with the diversion of principal rivers traversing the unit and an increment of the drainage network of the aquifer have caused a rapid intense contamination by nitrogen compounds and a reduction of existing resources.

Zone of study

The Quaternary aquifer of Vitoria-Gasteiz is formed by fluvial and alluvial deposits situated near this city (Fig. 1). The area extends approximately 90 km^2 with a thickness approximately 5 m. These deposits form a permeable aquifer with intergranular porosity of a free character, although local phenomena of semiconfinement may exist. The storage coefficient and average transmissivity are, respectively, 0.2 and 40–150 $m^2\,d^{-1}$. The formation presents two distinct sectors (Fig. 2).

The west sector extends over approximately 40 km^2 and has a thickness ranging from 1 to 4 m. It is basically formed by sand–muddy materials. Borders and substratum are constituted, in the northeast area, by a highly

I. Arrate · I. Antiguedad (✉) · A. Vallecillo · V. Iribar · M. Ruiz
Hydrogeology Group, Department of Geodynamics, University of Basque Country, 48940 Leioa (Bizkaia), Spain

J. M. Sanchez Perez
CEREG-URA 95 CNRS, 3 Rue de l'Argonne, 67083 Strasbourg Cedex, France

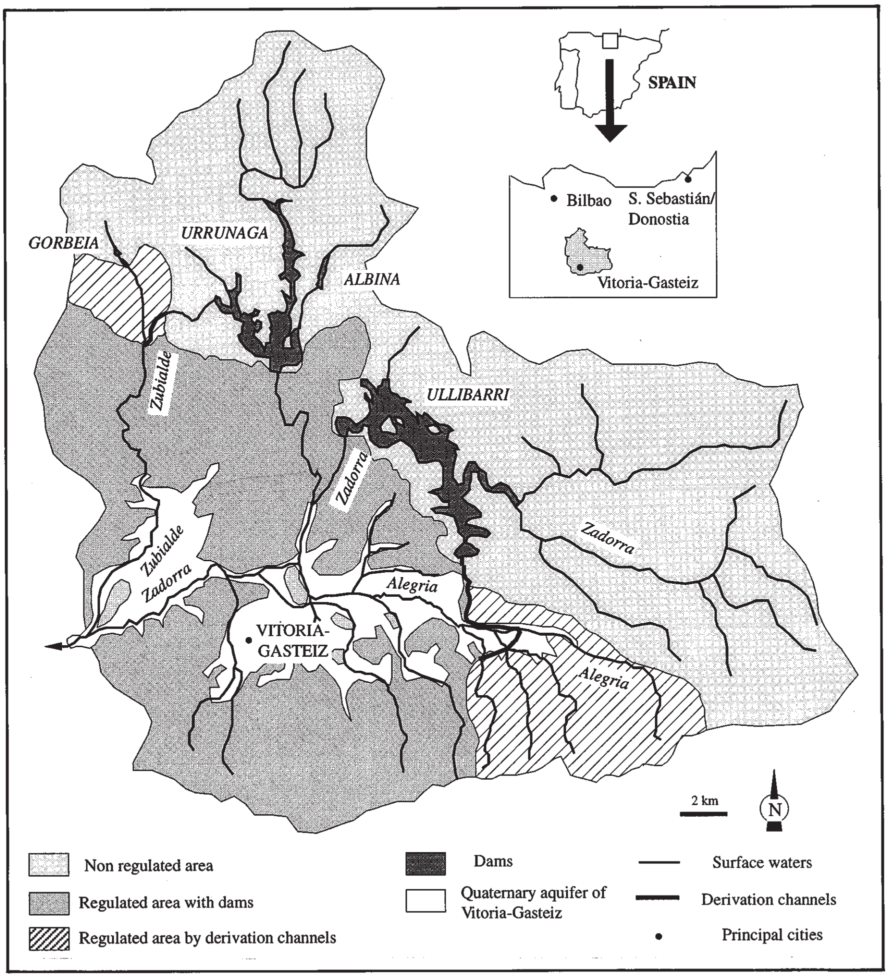

Fig. 1
Geography of the area of study

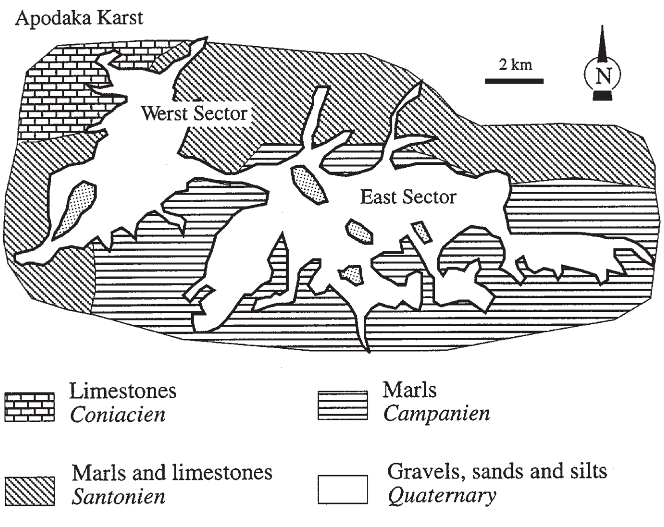

Fig. 2
Geological map of the area of study

permeable carbonated formation known as the Apodaka Karst, and in the southern area, by a marly series of medium permeability. Both formations are hydraulically connected to the Quaternary aquifer.

The east sector has an extent of approximately 50 km^2 and a thickness ranging from 2 to 10 m deep. It is formed by heterometric gravels with an argillaceous sandy matrix. Borders and substratum are marls virtually impermeable.
Presently, almost all aquifer resources are used to satisfy demands of summer sprinkling irrigation of crops in the area. Nevertheless, pumping persists very locally to supply domestic demands. The basin that drains towards the aquifer has an area of 855 km^2, of which 56% is presently regulated by the Zadorra dam system, the main source of drinking water of Bilbao (situated outside the area considered in this study) and Vitoria-Gasteiz. This dam system is composed of the Ullibarri dam (139 hm^3), the Urrunaga dam (69 hm^3), the Albina dam (5 hm^3) and the Gorbeia dam (1 hm^3).

Functioning of Aquifer until the 1950s

Recharge mainly proceeded from precipitation over the Quaternary deposits and, in minor quantities, from infiltration of surface runoff from the borders of the aquifer

Table 1
Chemical evolution of groundwater in several areas of the unit (content in mg l^{-1})

Sector	Na^+	K^+	Ca^{2+}	Mg^{2+}	Cl^-	SO_4^{2-}	HCO_3^-
East							
1968	9.80	1.45	82.35	17.75	12.45	37.60	243.15
1984	12.01	2.06	113.49	8.39	34.62	12.23	254.69
1990	14.97	1.88	131.22	8.25	50.30	70.15	247.52
Northwest							
1968	6.50	0.53	68.38	4.63	9.75	17.00	199.75
1984	7.78	0.72	91.48	3.40	19.78	42.81	205.70
1990	6.40	0.94	64.68	6.46	8.00	31.40	172.00
Southwest							
1968	6.10	0.50	86.10	7.10	7.10	73.50	280.20
1984	13.25	6.43	100.75	8.28	19.25	36.00	247.25
1990	13.35	5.68	126.40	8.46	28.76	93.53	256.25

[1] Data from IGME (1968, 1986) and Arrate and others (1993)

and from the fluvial network, in flood periods, during which rivers are influent. There was also an important additional recharge in the west sector proceeding from the Apodaka karst (Fig. 2) (Arrate and others 1993b). The outlets of the system flowed towards the fluvial network. This drainage was partially favored by the existence of several trenches 0.5 m deep, historically built with the purpose of avoiding flooding in agricultural areas. However, various wetland zones were still found in discharge areas of the aquifer unit. At the time, there were small-sized pumping stations built to meet domestic demands of small communities situated on the aquifer. The water table was found at a depth ranging from 0 to 1.5 m. Total reserves estimated at the beginning of dry seasons have been evaluated to be 25 hm^3.
Concerning land use, the major part of the aquifer area was dedicated to dry farming, primarily cereal. In the area under study it is interesting to highlight the existence of extended zones of meadowland and broadleaf forest, relics of preexisting autochthonous vegetation. Regarding hydrochemical characteristics, data for this period is very scarce. However, existing analyses (IGME 1968) show calcium bicarbonate waters of low to medium mineralization and an almost total absence of nitrates. It is probable that point source contamination existed in the vicinities of various towns on the aquifer. This is set forth in relation to waste infiltration and loss from cesspools. Measured values of concentrations in the aquifer are noted in Table 1.

Land transformations on the aquifer

The existence of changes in agrarian practices and water-resource management in the high basin of Zadorra, has required several modifications that have appreciably changed the dynamics of the aquifer.

Modification in land use

To satisfy demands of a larger cultivable area, practically all the existing autochthonous forest on the aquifer was felled. Thus, in 1954 the forest area represented 747 ha; in 1968, 395 ha; and in 1982, only 67 ha (Fig. 3).
At the onset of the 1960s, the last existing wetland was drained by means of deepening and modifying of several water courses. In order to avoid possible floods, deepening and widening of the rest of water courses in the unit (Fig. 4) were carried out as well, adapting them to the geometry of the agricultural terrain. Trenches were, on several occasions, more than 2.5 m deep. The drainage density of the analyzed area went from 5.3 km^{-1} in 1954 to 7.7 km^{-1} in 1982 (a similar situation to the present one).
Moreover, a change in crops from traditional cereal to the present potato and sugar beet (Fig. 3) meant a greater demand for water during summer months. Such a need was satisfied with the aquifer water in most of the east sector. However, in the west sector, groundwater resources were not sufficient to meet demands, so it was necessary to pump water from nearby rivers. Moreover, the crop change entailed the use of large quantities of fertilizers and pesticides on the aquifer surface. The area occupied by irrigated farming successively went from less than 1% (1954) to 11.5% (1968) and to 67.5% (1982) of the area of study. This increase has evolved to the detriment of dry farming areas, which have decreased from 78.9% in 1954 to only 11.4% in 1982 (similar situation to the present one).

Diversion of water courses

In order to increase water supplies to Vitoria-Gasteiz at the beginning of the 1970s, complete diversion of the Alegria river and two of its tributaries was carried out at the entrance of the east sector of the aquifer (Fig. 1), sending supplies towards the Zadorra dam system. The average annual volume that was diverted was on the or-

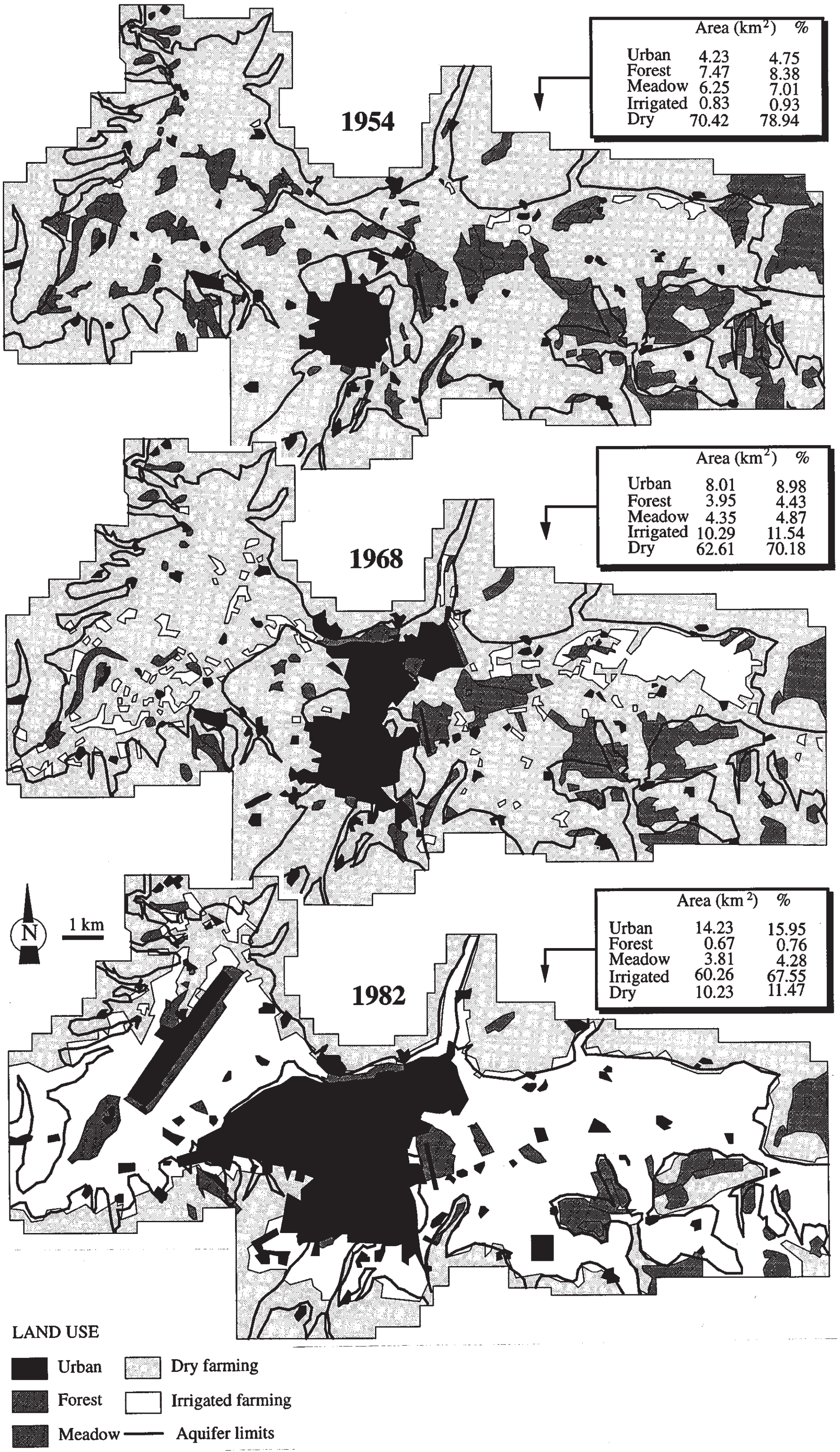

Fig. 3
Evolution of land use in the aquifer

der of 18 hm^3. In order to solve the critical situation of the Zadorra system during the 1989–1991 drought, one of the possible measures was provisional tapping of the Zubialde river (Fig. 1) during the emergency situation. The volume diverted, according to official data, was of 15 $hm^3\ yr^{-1}$, which involved 60% of its supplies.

Impact of land transformations on hydrodynamics of aquifer

Modification of water courses caused a generalized drop of the water table level of 1–2.5 m, resulting in an impor-

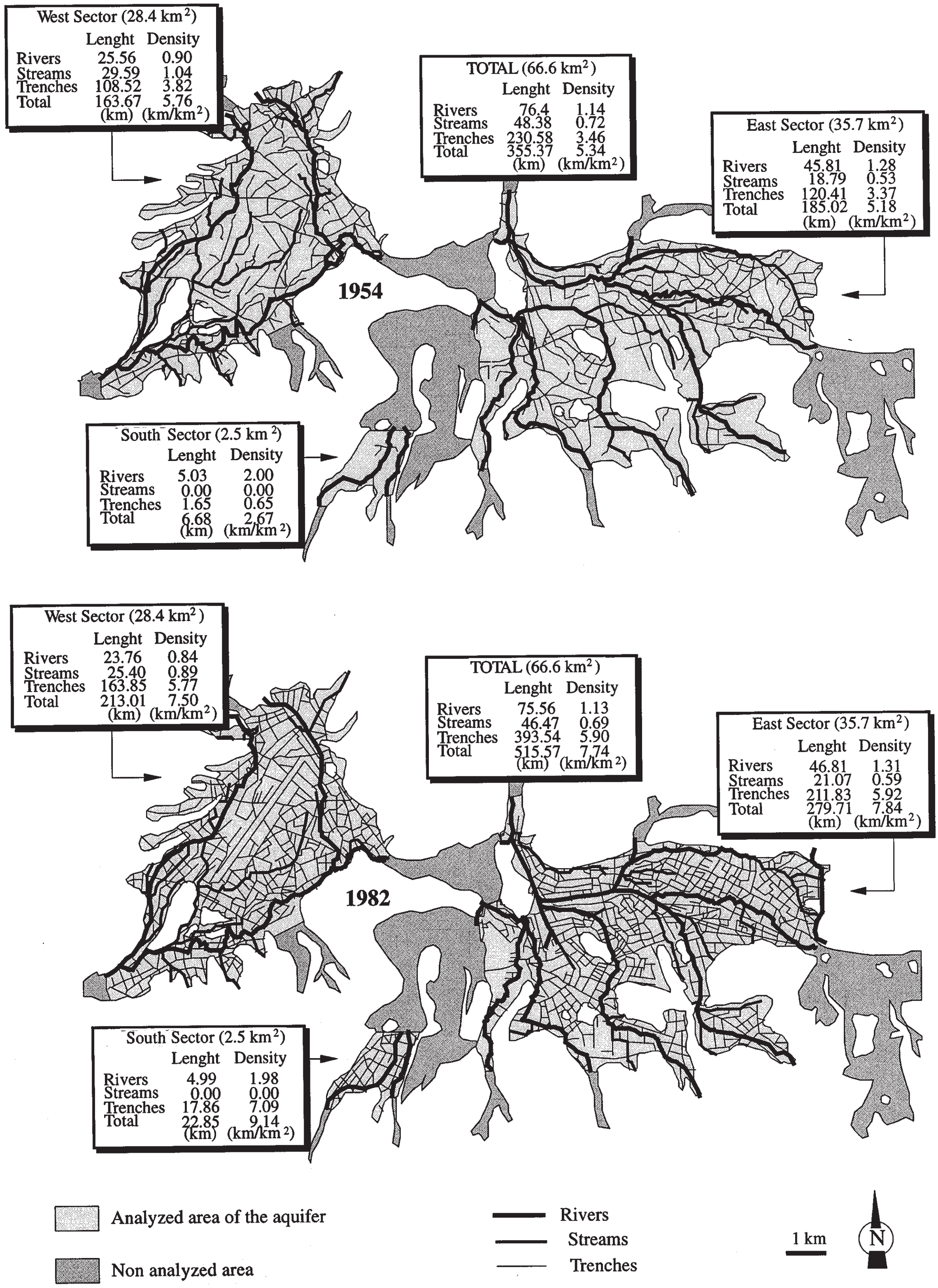

Fig. 4
Drainage network modification carried out on the aquifer

tant loss of regulative capacity of the aquifer. Reserves, at the beginning of low-water periods, have been reduced from 25 to 15 hm^3. Subsequently wetlands disappeared and with them an environment of high ecological interest. In the same way, numerous springs dried up near drainage channels.

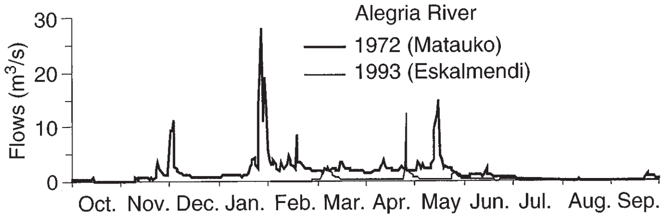

Fig. 5
Hydrograph of the Alegria river one year before its diversion (1972) and later (1993)

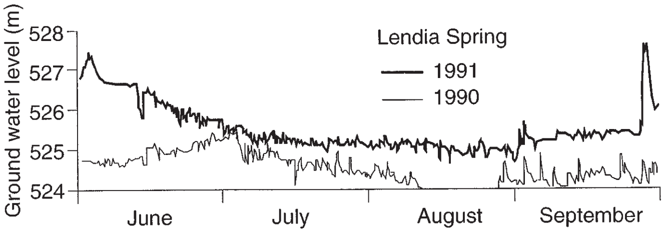

Fig. 6
Evolution of water levels in a spring of the west sector in 1990 (in which the Zubialde river was tapped) and in 1991 (in which no tapping had taken place)

Calibration of a flow model in the east sector has shown that recharge proceeding from the efficient infiltration of precipitation should presently be, in this sector, approximately 3 $hm^3\ yr^{-1}$ compared to 20–25 $hm^3\ yr^{-1}$, which would be foreseeable applying the soil balance methodology. The difference is probably rapidly drained by the dense irrigation network present in the aquifer.
Intense pumping in the east sector created, in some areas, subsidence of up to 5 m. In the west sector, pumping of the aquifer is of little importance and has had few repercussions on groundwater level. The magnitude of pumping is evaluated now at 2.5 $hm^3\ yr^{-1}$ for the entire unit.
The diversion of the Alegria river towards the Zadorra dams (the effects of which are shown in Fig. 5) reduces additional recharge from this river to the northern area of the east sector where pumping is carried out with more intensity.
The Zubialde river constitutes the main water recharge of the Apodaka Karst (Arrate and others 1993b), which in turn feeds laterally the northern part of the west sector of the Vitoria-Gasteiz aquifer. Its tapping during the 1989–1991 drought substantially reduced flows of various springs and streams existing in the latter zone. The complete tapping of flow in low-water periods dried up all springs (Fig. 6). Given that the needs of summer sprinkling irrigation in this sector were satisfied by surface and/or underground water originating directly or indirectly from the Zubialde river, its tapping gave rise to numerous problems of adequately irrigating a large farming surface (2000 ha).

Impact of land transformations on hydrochemistry of aquifer

Leaching of nitrogenous fertilizers has recently led to a vertiginous increase of nitrate concentrations in the aquifer water. In order to visualize the evolution in space and in time of NO_3^- contents in the last years, four maps of isocontents were prepared (Fig. 7).
In April 1986 (IGME 1986), analyses indicated that the aquifer water was contaminated by NO_3^- with an average exceeding 50 $mg\ l^{-1}$ (maximum limit permitted for drinking water). Lower concentrations were located in areas liable to be supplied by less-contaminated water courses. Moreover, we may see the clear influence that the recharge, proceeding from the Apodaka Karst, had on contents present in the west sector. Concentrations in its northern half remain under 50 $mg\ l^{-1}$. Areas with higher contents were located near villages situated on the Quaternary unit and were probably related to losses from cesspools and infiltration of domestic sewage.
In February 1990, althoug the situation in the west sector had not essentially changed, contents had doubled in the east sector. In November of 1991, the situation remained stable in the west sector. However, in the northern area of the east sector concentrations had increased by 50% and had reached an average of 170 $mg\ l^{-1}$, with some points showing values higher than 500 $mg\ l^{-1}$. In January 1993, a period during which the east sector was partially monitored, it was observed that average contents in the discharge zone exceeded 200 $mg\ l^{-1}$.
Considering these developments, concentrations of NO_3^- seem to have become stable in the west sector over the last few years. This is fundamentally due to the dilution that has taken place because of additional recharge produced by the Apodaka Karst and to the fact that water needed for irrigation came, almost exclusively, from surface streams having NO_3^- contents lower than 20 $mg\ l^{-1}$. However, in the east sector, concentrations still showed a steady increase because of irrigation returns (Arrate and others 1992), which, in this sector, proceeded from aquifer waters. This situation is worsened by the impossibility, in the northern area of the east sector, of recharge from surface water courses due to a complete diversion of the Alegria river. In Fig. 8 we can observe the temporal evolution of nitrate contents in the most recent years,

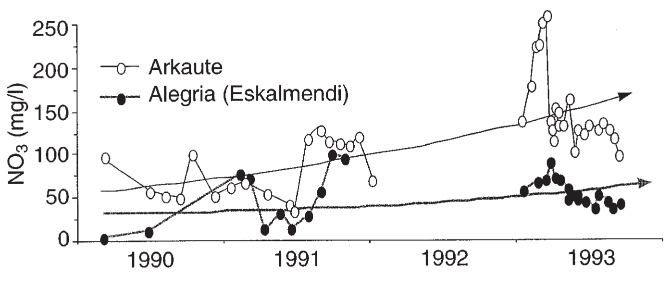

Fig. 8
Evolution of nitrate contents in a well representative of the east sector (Arkaute) and in the outlet of the Alegria river

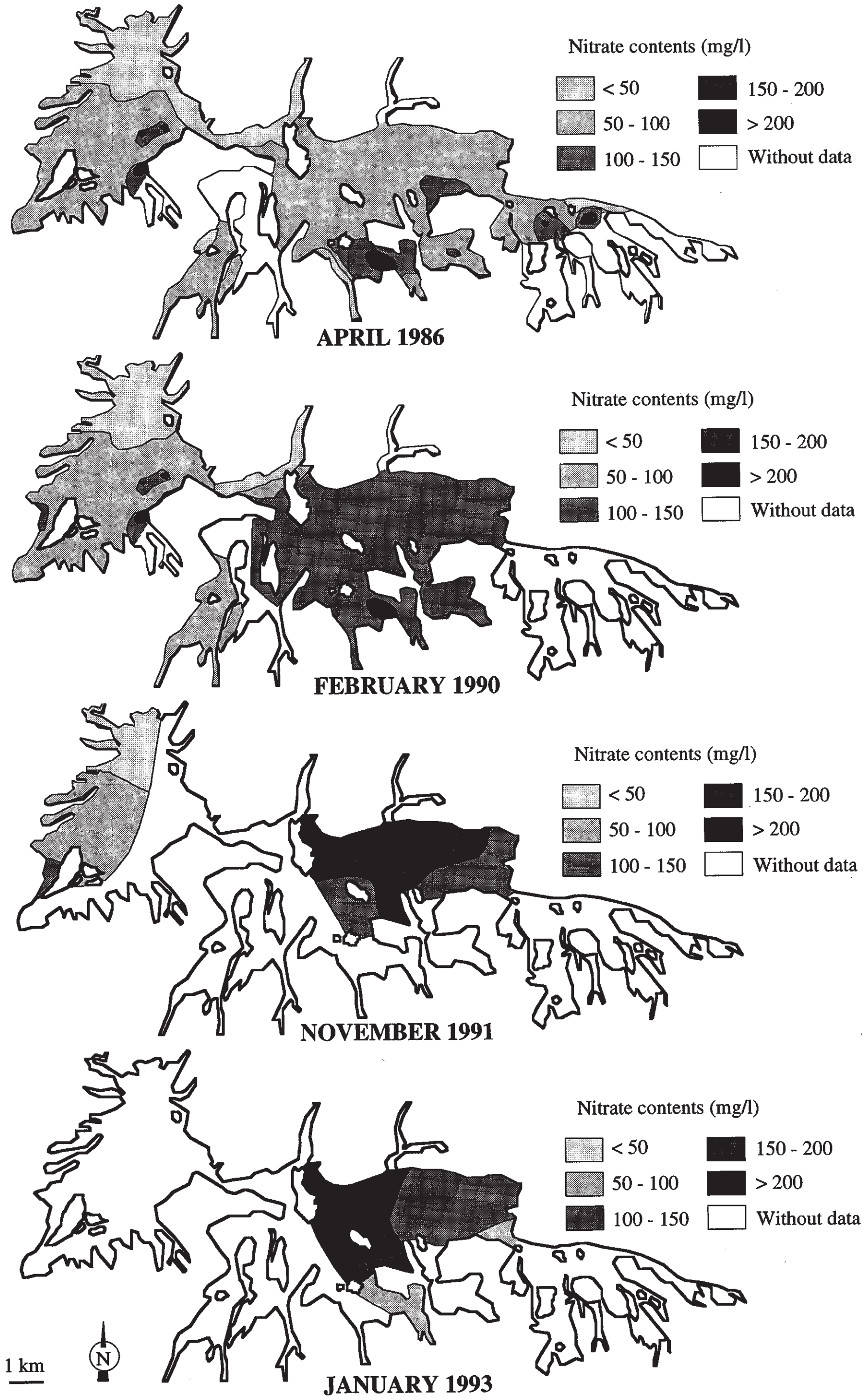

Fig. 7
Maps of nitrate isocontents on April 1986 (IGME), February 1990, November 1991, and January 1993

in a representative well of the east sector (Arkaute) and in the Alegria river at its confluence to the Zadorra river. A trend of increase of about 25 and 6 mg l^{-1} yr^{-1}, respectively, can be seen.

Farming activities not only have led to contamination by nitrogen compounds, but also by pesticides. Atrazine and lindane have been also detected in several wells and surface streams of the unit, although these case studies have not been thoroughly developed.

In comparaison with cultivated areas, the groundwater in forested areas contains very little nitrates (Andersen and Kristiansen 1984; Peterjohn and Correl 1984). Felling of forest areas also has led indirectly to the deterioration of water quality. Normally, waterside forest facilitates an effective depuration of groundwater regarding concentrations of biogenic elements such as N, P, and K (Sanchez Perez and others 1992). The total disappearance of this forest, as early as 1970, has prevented self-depuration of

the contamination caused by nitrogenous materials within the aquifer system.
Fertilization, soil additives, etc., combined with water recirculation, have caused an increase in concentrations of major elements. In Table 1, it is possible to observe average concentrations of specific elements in several zones of the aquifer in 1968 (IGME), 1986 (IGME), and 1990 (personal observation). It can be seen that although in some sectors changes had been minimal (such is the case of the northern area of the west sector, characterized by a lateral recharge of good-quality water proceeding from the Apodaka Karst), in other sectors concentrations had increased considerably, especially relative to Na^+, K^+, and Cl^- with an increase of up to 1000% (case of K^+ in the southern area of the west sector) in 30 years.
Finally, the lack of urban planning in Vitoria-Gasteiz has

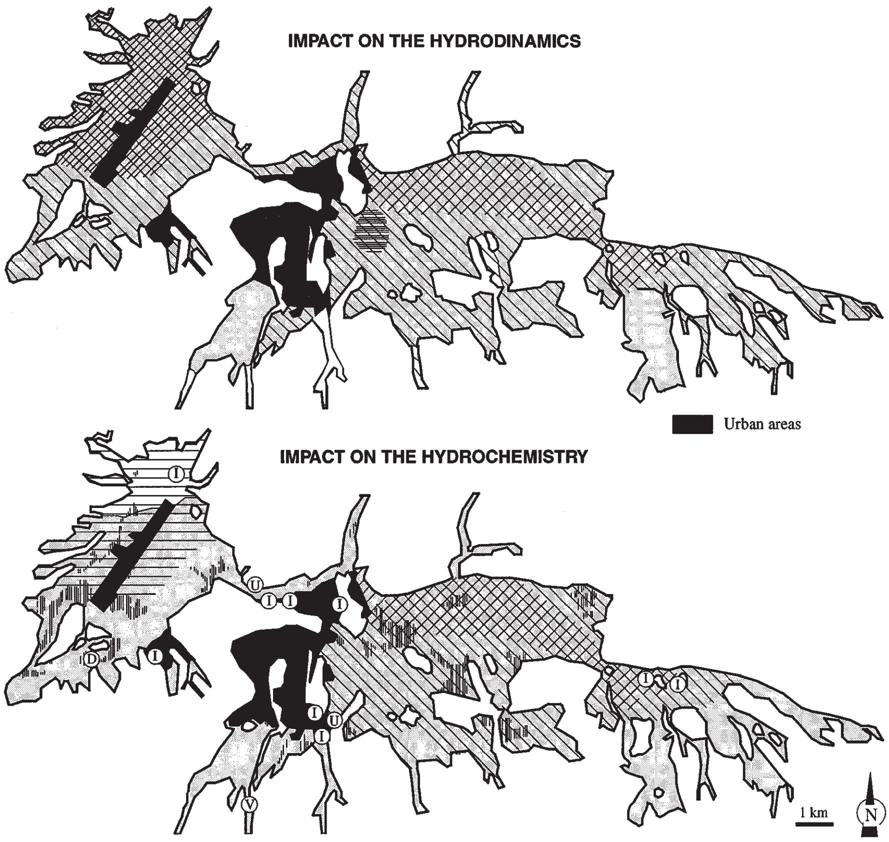

Fig. 9
Spatial distribution of the impact of the land transformation on the hydrodynamics and hydrogeochemistry of the aquifer

Demand or change	Transformations	Hydrodinamic impact	Hydrochemistry impact
Larger cultivated land	1. Increase of drainage drainage network 2. Felling of the autochthonous forest	1.1. Reduction of the regulation capacity and reserve loss 1.2. Disappearance of wetlands	2.1. Reduction of the autodepuration capacity of biogenic compounds
Change in agricultural practices from dry farming to irrigated farming	3. River pumping and aquifer explotation 4. Application of fertilizers and pesticides	3.1. Additional descent of the piezometric level	4.1. Nitrate and soil additive contamination 4.2. Mineralisation increase
Complement of drinking water from Vitoria-Gasteiz The 1989-1991 drought emergency works	5. Deviation of the Alegria river and tapping of the Zubialde	5.1. Recharge reduction	5.2. Dilution reduction of the contamination
Urban and industrial development of Vitoria-Gasteiz	6. Urban areas without sewage works Ⓤ 7. Industrial waste Ⓘ 8. Municipal solid waste landfill Ⓥ 9. Purifying water plant Ⓓ		Land contamination of the aquifer, soil and surface waters

contributed to several point sources of contamination. The existence of several housing and industrial estates, solid waste landfills, etc., unconnected to the sewage works, have introduced numerous pollutants in surface water as well as in groundwater (through introduction in wells). Paradoxically, an important source of pollution in the Zadorra river has come from the purifying plant of Vitoria-Gasteiz. Water, upstream of the plant, is of acceptable quality, whereas downstream water shows elevated PO_4^-, NH_4^+, and NO_2^- contents. It is possible to observe the spatial distribution of the impact of these land transformations on the hydrodynamics and hydrochemistry of the aquifer in Fig. 9.

Conclusions

Because of the change from dry to irrigated farming and the need to enlarge cultivable land, a series of land transformations have taken place in the last 30 years on the Quaternary aquifer of Vitoria-Gasteiz (felling of the alluvial forest, drainage of wetlands, application of enormous quantities of fertilizers, pesticides, etc.). These transformations have led to a notable loss of resources in the unit (evaluated to 40%) and a progressive increase in concentrations of the elements analyzed, particularly nitrogen compounds. Nitrate contamination seems to have stabilized during the last years in the west sector as a result of the effect of the recharge proceeding from the Apodaka Karst, whereas, in the east sector, concentrations have steadily increased (20–30 $mg\,l^{-1}$ of nitrates per year) due to a process of recirculation of irrigation returns. This situation is aggravated by lack of recharge of the Alegria river in its northern area as a result of its diversion towards the Zadorra dam system.

The recovery of the preexisting natural environment (alluvial forest, wetland) and of resources lost as a result of excessive drainage seems impossible at present, because of farming practices presently developed on the aquifer. Nevertheless, judicious use of fertilizers and a more rational and balanced use of water and land resources within the unit may lead at least to moderate improvement of the aquifer's water quality. Thus, partial diversion of the Alegria river (at least in certain periods during the year) would perhaps contribute additional recharge and some dilution of pollutants in the aquifer water. On the other hand, tapping the Zubialde river has already caused problems in several irrigated lands in the west sector of the aquifer. Permanent tapping, a project presently under study, besides preventing optimum development of agricultural activities in a large zone, would entail the risk of increasing nitrogenous compound concentrations in groundwaters of this sector, similar to what has occurred in the east sector; with subsequent losses of available water resources.

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