Integrated management of the coastal aquifer in Mar del Plata, Argentina

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Abstract **Coastal aquifers are sensible structures affected by human activities, where the environmental conditions of the hydraulic systems require an adequate response to correct undesirable situations. The use of indicators of pressure, state and response constitutes a useful tool to achieve an integrated management of groundwater resources in the coastal aquifer of Mar del Plata, Argentina.**

Index Terms **coastal aquifer, indicators, management, Mar del Plata, Argentina**

I. INTRODUCTION

Mar del Plata, located on the Atlantic coast, is the main tourist centre in the country and has a population of 600,000 inhabitants increasing threefold during the summer. Water for urban, agricultural and industrial uses are exclusively supplied by groundwater resources.

The County occupies an area of 1460 km2; its structure reveals a radial scheme converging in the urban area of Mar del Plata, turning this site into the most significant one regarding services, industry and tourism. The rural area, where agriculture and livestock prevail, supplies the city center with fresh products and some necessary building materials, such as bricks and rocks. Due to the law on building (block of flats), especially since 1948, the urban growing process leads to an increase in population density, industrial activities (building, food, textile and fishing) and tourism in the central area.

The main environmental problems related to hydric resources are: uncontrolled urban expansion, saline intrusion, pollution of groundwater, an inadequate waste management and recurrent floods in the urban and periurban areas.

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Several studies have been carried out, characterizing the process of sea intrusion (Bocanegra et al, 1993; Martínez et al, 1996; Bocanegra et al, 2002; Martínez et al, 2002; Martínez et al, 2005) and the impact of leachates of final waste disposal sites on groundwater (Massone et al, 1993; Massone et al, 1994; Massone et al, 1998; Bocanegra et al, 2001; Mascioli et al, 2005).

In order to define the temporo-spatial evolution of coastal environmental processes related to groundwater resources, some indicators addressed to decision-makers were designed to assess the environmental pressure caused by human activity, the aquifer conditions or state and the anthropic response to correct undesirable situations. This indicator selection will allow a temporal follow-up of the evolution of groundwater and integrate hydrogeological and social aspects, so as to respect what was agreed on Chapter 18, section 2 of Agenda 21 (CNUMAyD, 1992), in the mission statement of the Dublin Conference (ICWE, 1992) and objective 7 of the Millenium Development Objectives (UNDP, 2003).

II. LOCATION AND CHARACTERISTICS OF THE AREA

Mar del Plata is located in the northeastern side of Tandilia range, also called "Sierras Septentrionales de la Provincia de Buenos Aires". The Tandilia range has a maximum altitude of about 40 meters above mean sea level in Mar del Plata area. In the study area, the range consists of lower Palaeozoic quartzites, grouped under the name of Balcarce Formation (Dalla Salda and Iñiguez, 1978). Three fault systems, which generate a horst and graben structure, are recognised in the Palaeozoic bedrock (Fig. 1).The quartzitic bedrock is overlain by a sedimentary cover of Upper Tertiary and Quaternary silts and silty-sandy sediments. Miocene clayey-sandy sediments are found at a depth of 60 meters in the grabens. The Quaternary deposits are called "pampean sediments" or "loess-like sediments", and from a hydrogeological viewpoint, they constitute the most important sequence. They are a multi-layered phreatic aquifer, its thickness ranging from 70 to 100 m. Its hydraulic conductivity is 10-15 m/day. Its transmissivity is about 600-800 m^2/day in the urban area and between 1,000-1,400 m^2/day in the rural area. The storage coefficient from pumping tests is 0,001; and the porosity is 0,15. The average rainfall in 1930-2005 was of 895 mm/year in this city. Regarding the warm semester, (October-March) it is often a rainy season, with three rainfall peaks up to 90 mm (October, January and March); the cold semester –on the other hand- (April-September) is less rainy, with values less than 55 mm in June, July, August and September. According to Thornthwaite's method, the potential evapotranspiration (ET) is 733 mm/year, the surplus of ET over rainfall is 198 mm/year; and it occurs mainly between June-October.

Rainfall infiltration in the surface of the area leads to the recharge of the aquifer system. Natural discharge is towards the sea; whereas artificial discharge takes place due to pumping. The drainage network has low density, with the main streams showing a W-E trend.

Fig. 1. Mar del Plata County. (striped, urban area)

III. METHODOLOGICAL FRAMEWORK

The use of indicators has been recently called for designed to be used in environmental and ecologic monitoring and in the general assessment of environmental sustainability at a local, national and international scale (Berger and Iams, 1996). Environmental indicators are variables with a social meaning attached to that of their own scientific entity and whose aim is to briefly describe the interests and preoccupations of the society with regard to the environmental evolution and coherently participate in decision-making processes.

Indicators help answer the four following basic questions:

¿What is going on in the environment? (conditions and trends)

¿What is the reason for this? (causes, relationships between human influences and natural processes)

¿What makes it significant? (economic, ecologic and health effects)

¿What is being done regarding this? (planning and political implications)

There is a wide range of environmental indicators (OCDE, 1993, Cendrero, 1997, Cendrero, et al. 2001), and most of them address decision-makers and are designed to assess:

1) environmental PRESSURE caused by human activity

2) evaluated environmental conditions or STATE

3) anthropic RESPONSE to correct undesirable situations.

Groundwater quality represents a special case for indicators due to the speed with which it changes and its origin (natural and anthropic); thus particular consideration is given to those that better depict the way ecosystems and human beings health is being affected.

IV. PROCEDURE

The groundwater exploitation criteria in Mar del Plata have been based on the need to supply a demographically increasing city with drinking water, which led to the development of different management strategies. During the 1950s, a non-restricted exploitation in urban areas took place; in the 1970s, groundwater was extracted from rural zones and the suburban areas. The year 2000 represents the current situation for the exploitation of this resource.

Since the indicators reveal a specific time's environmental situation, these dates have been chosen to assess the indicators of pressure, state and response.

For pressure caused by human activities the indicators were related to the increase of the population and the urban area, the groundwater exploited volumes, the total population lacking running water and sanitary services, the irrigated areas and the urban waste disposal sites (Table 1).

The indicators related with state were annual aquifer recharge, water table level, chloride concentration in groundwater, nitrate and bacteriological pollution in groundwater (Table 2).

For response, the indicators were: number of exploitation and abandoned wells, drinking water pipeline, sewage, administrative and jurisdictional organization, department budget, staffing, environmental projects, research initiatives and enforcement of environmental regulations (Table 3).

V. RESULTS

A. Pressure

1) Increase of the population

The increase in population, at a rate of 100,000 inhabitants per decade, led to a meaningful expansion of the urban area. Therefore, an increase in territory occupation did not imply an augmentation in density of population. This indicator has been estimated considering that the urban and suburban populations make up 90% of the total, whereas the other 10% corresponds to rural population.

2) Groundwater exploited volumes

The total groundwater exploited volumes increased according to the demographic increase, keeping daily supply values at 550 l/inh. Nowadays, this is the second highest figure of daily water consumption in the country. The highest number corresponds to the city of Buenos Aires, with 865 l/inh.day, although leaks in the running water system are included within this figure. The lowest numbers correspond to the city of Santa Rosa, La Pampa, (with 159 l/inh.) probably due to the fact that the urban area is equipped with running water meters.

Greater exploitation during summer months (December to March) reached 45% of the total annual water extracted in the year 1950. In the year 2000, it amounted to 37%. This may occur because the proportion between stable and tourist populations has decreased in the last few years.

3) Total population lacking running water and sanitary services

Due to the extension of the area counting with running water and sewage systems, it is estimated that by the year 2000, the population with running water supplying reached 80% and with sewage system, 73% of the total population.

4) Irrigated areas and the urban waste disposal sites

The activities on which the socio-economic growth of the region is based are cattle and livestock in the north, extensive agriculture –located chiefly in the majority of the rural areas- and intensive agriculture –located in the NW and SW zones, near the city. The irrigated areas occupy 141 km^2, the annual demand for groundwater for irrigation purposes amounts to 17,913,750 m3, representing 18.4% of the volumes exploited by the Company Obras Sanitarias for urban use.

The urban waste disposal in 1950 was carried out in a non-official dump. In 1970 there existed a 0.3 km^2 dump, controlled by the town hall. The waste was not buried and this resulted in bad smell in the neighborhood and the proliferation of rodents.

The leachate of waste can, after its underground disposal, reach groundwater and affect its quality. Therefore, by the year 2000, all previous waste disposal sites, located in a 1.2 km^2 area lying to the west and southwest of the city, are taken into account. One of these functioned between the years 1970 and 1975. After this period, a recreational facility was built on that land. The lack of proper building steps –contemplating the venting of gases caused by the anaerobic decomposition of waste –resulted in the release of methane gas, which caused a cabin to explode. Between 1975 and 1979 a quarry was used as a disposal site. The leachate produced, with highly organic content, harmed the rock currently in exploitation in a nearby quarry.

Over the last 25 years, two landfills have been built in recharge areas on surface watersheds, which lie directly on the hydrogeologic basement or on the permeable fills of few meters in thickness, overlying the basement in this area. Contaminated plumes coming from these landfills have been identified in groundwater.

The daily waste produced amounts to 500g/per person. This number may reach 1kg per person if the waste generated by industrial activity and street sweeping is considered.

TABLE 1
PRESSURE INDICATORS

Indicators/Year	1950	1970	2000
Population	123811	323350	564056
Urban area (Km^2)	30	76	150
Population density (inhab/km^2)	3714	3854	3384
Annual exploited Volume (m^3)	25372539	64830175	97570220
Summer exploited Volume (%)	45	42	37
Daily water supply (liter/inhab)	561	549	539
Population lacking water supply (%)			20.8
Population lacking sewage (%)			27.1
Irrigated areas (km^2)	< 10		141
Official urban waste sites (km^2)	0	0.3	1.2
Annual waste weight (ton)	56138	146612	255500

B. State

1) Annual aquifer recharge

The annual aquifer recharge has been analyzed from the serial hydric balance in the period 1930-2005 (Fig. 2). Nevertheless the great temporal variability, the agreement between surplus and precipitation, and the growing temporal trend can be noticed. The deficit is also connected to the precipitation, in rainy years or in dried years preceded by very rainy years, the deficit is zero.

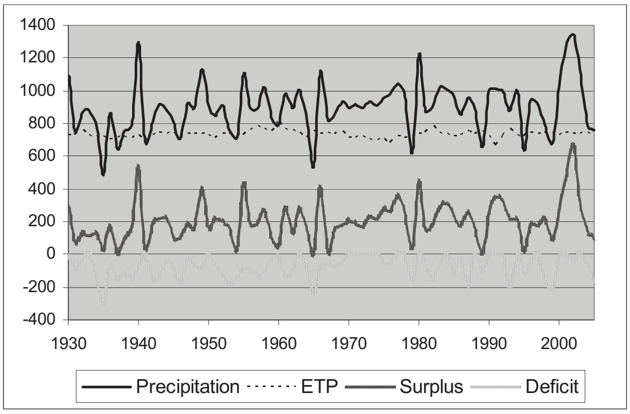


Fig. 2. Evolution of the terms of the hydric balance

2) Water table level

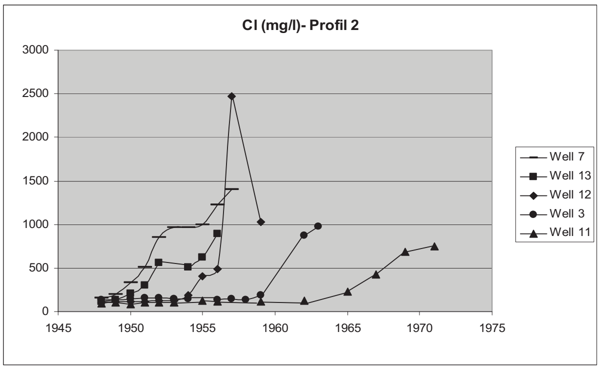
The number of wells with phreatic levels below sea level –

with respect to the total number of working wells –and the lowest phreatic level registered have been chosen as indicators. In the 1950s and 1970s, over 50% of these wells registered negative phreatic levels. In the 1950s this situation affected wells located near the coastline, whereas in the 70s the affected wells were located over 3 km away from the coastline. In the year 2000, 14% of these wells correspond to wells in rural areas.

The lowest phreatic level registered in the history of Mar del Plata being –27,1m, in 1970. Nowadays, practically no negative values are observed.

3) Chloride concentration in groundwater

The indicator related to the process of sea water intrusion is the number of wells with chloride concentration higher than 200 mg/l, with respect to the total number of wells. This value was selected on the basis of the statistic criteria which consider as anomaly the data higher than the average mean plus the standard deviation. In 1950, 27% of the exploited wells showed traces of the beginning of the salinization process. This process has continued to occur in 1970, although it is not observed in 2000. The maximum chloride concentration was 3780 mg/l, reached in 1954. The evolution of chloride concentration in wells located in 2 profiles perpendicular to the coastline (Fig.3) reveals that the abandonment of a well due to an increase in its chloride concentration led to the quick salinization of the next inland well.



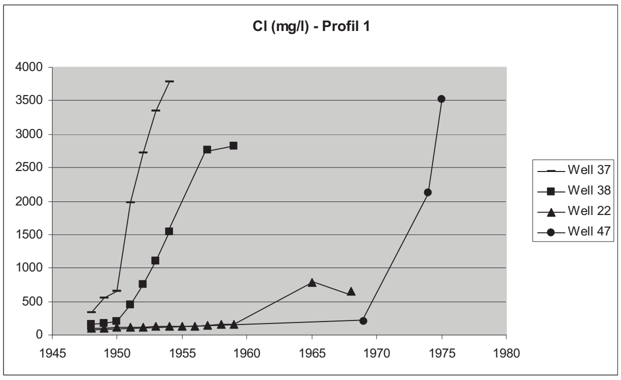


Fig. 3 Evolution of chloride concentration in two profiles perpendicular to the coast line

4) Nitrate and bacteriological pollution in groundwater

Nitrate pollution in groundwater based on the percentage of wells with values higher than 45mg/l reveals similar number for 1950 and 2000. In the first case, this may be connected with cesspools, due to the incipient agricultural activity; in the second case, with that coming from irrigation. Irrigation wells are open and not isolated when their working days are over. This leads to the mixture of waters from different depths, favoring the descent of shallow waters affected by agrochemical products.

The groundwater bacteriological pollution indicator was estimated based on the number of cases of diarrhea in children below the age of 5 in 3 suburban neighborhoods, with a total population of 41,000 inhabitants, lacking running water and sewage services. From a total of 296 water samples, 83% turned out to be non-drinkable and 97% of these presented coliform bacteria bigger than 3 NMP/100 ml, which is the limit settled by the Codigo Alimentario Argentino (Argentine Food Code). Problems regarding the quality of the water used in suburban neighborhoods are related with the shallow depth and improper building of the domestic wells, and the density of population. Therefore, the sanitary risk resulting from using and drinking this water is very high.

TABLE 2
STATE INDICATORS

Indicators/Year	1950	1970	2000
Annual recharge (mm)	164	209	267
Wells (%) h < 0 masl	56	54	14
Lowest phreatic level (masl)	-11.3	-27.1	-2.9
Wells (%) Cl > 200 mg/l	27	9	3
Maximum chloride concentration (mg/l)	1700	1970	366
Wells (%) NO3 > 45 mg/l	16		18
Domestic wells (%) affected by bacteriological pollution			> 83

C. Response

1) Number of exploitation and abandoned wells.

Response indicators connected with the need to supply fresh water to a city showing such a rapid population growth are: the total number of built wells, the working wells and the abandoned wells due to the degradation of the water. In 1950, 10% of the wells built had been abandoned because of their salinization, of marine origin. The process continued to increment until, in 1970, 17% of the wells, located in the downtown and harbor areas, were abandoned. In 2000, this proportion is kept. However, wells abandoned due to a high nitrate concentration coming from rural and suburban areas are incorporated. The temporal evolution of these response indicators is shown in fig. 4.

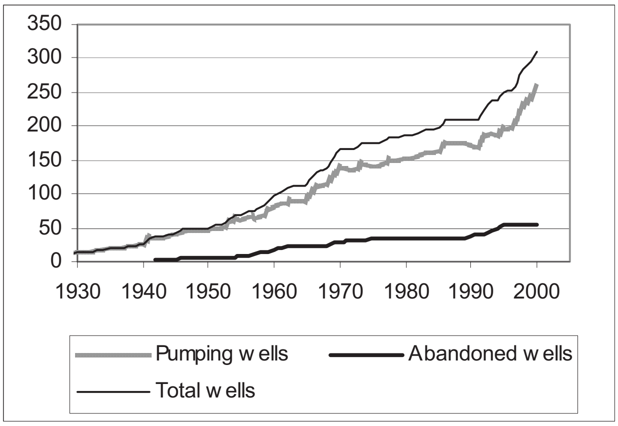


Fig. 4. Temporal evolution of the number of exploitation wells

2) Drinking water supply and sewage system

The extension of the running water and sewage systems in 1950 represented about of 100% of the urban area in that date (30 km^2), in 1970 65% and 70% (76 km^2) and nowadays 88% of the urban area (150 km^2) is equipped with running water and 81% with sewage system.

3) Administrative and jurisdictional organization

The administrative and jurisdictional organization has been evolving, from a national management centered almost completely in Buenos Aires, to a regional management headed in the city of Mar del Plata, taking up the southwest of Buenos Aires province and depending on the national government in 1970, to a municipal management in 2000 (initiated in 1985).

The present legal framework is:

Type: Municipal and Autarkic Society

State participation: 100%

Shareholder Assembly: Municipal Council

Regulation framework: Local level by-laws and National and Provincial laws.

4) Research initiatives

Hydrogeological research in Mar del Plata started in 1953 with Groeber, who drew a detailed description of the geologic formations of the area, the fracturing, provenience and run-off of groundwater and assessment of water extracted for population supply.

Ruiz Huidobro and Tofalo (1975) presented some aspects related with the salinization of the Mar del Plata aquifer through seawater intrusion.

Throughout the following years, a dynamic for the study of the hydric resource was established, in the form of arrangements between the Company Obras Sanitarias and national universities. Sala et al (1980) from the University of La Plata carried out a hydrogeological research, in order to estimate the available supply of water to support the north aqueduct.

From 1990 on, different agreements with Mar del Plata's National University have helped to assess the impact of urban waste disposal sites on the quality of groundwater, the location of the hydrogeological basement and the evaluation of different aquifer management strategies in Mar del Plata.

5) Environmental projects and regulations

In 1950 the first sewer was built. The second one was built in 1958. In the second historical cut analyzed, the change in the design of the aquifer exploitation, with the construction of the north aqueduct and the third sewer (built in 1980) can be observed. In 2000 a series of environmental projects appear, such as the new south aqueduct, the fourth sewer, the hydraulic barrier for reducing the saline intrusion, the Plant for the pre-treatment of sewage and the assessment of environmental impact for new intervention projects in that territory.

TABLE 3
RESPONSE INDICATORS

Indicators/Year	1950	1970	2000
Total of wells	50	166	310
Working wells	45	137	255
Abandoned wells	5	29	55
Running water system (%)	≈ 100	≈ 65	88
Sewage (%)	100	70	81
Jurisdictional organization	National	Regional / National	Municipal
Annual budget (US$/inhabitant)			30
Cost of water systems (US$/m3)			0.10
Staffing (employer/1000 inhabitant)			1.2
Research initiatives	Groeber (1954)	Ruiz Huidobro y Tofalo (1975)	National Universities: La Plata (1980), Mar del Plata (1990-currently)
Environmental Projects	1st Sewer 2nd Sewer	3rd Sewer (1980) Aqueduct N	4th Sewer. Aqueduct S Pre-treatment of sewage. Hydraulic barrier Assessment of environmental impacts
Environmental regulations	Provincial Law 5965 (1958)	Local regulation on cesspools	Register of well constructors Mechanisms of control Master Plan 2006-2016

Concerning the regulations, in the historical cut of 1950 it could be mentioned the Provincial Law 5965 referring to the protection of water supplying sources, in 1970 the local regulation referred to the construction of cesspools and in 2000 some local regulations related to the register of well constructors, implementation of assessment of environmental impact and mechanisms of control. The Master Plan 2006-

2016 has been created, its actions axis are: the sanitation social dimension, the natural resources conservation, the infrastructure as productive support and the quality of the coastal front as local tourist resource**.**

VI. CONCLUSIONS

The use of indicators of pressure, state and response shows different states of water environmental quality in Mar del Plata. The temporal analysis of the joint evolution of these indicators allows the evaluation of the interrelation of these three processes and the efficacy of the response indicators as regards those of quality. The combination of these indicators into one single quality index is still under discussion. However, its development will lead to the better adjustment of management policies. Some state indicators should constitute requisites of special value, since they show whether water is drinkable or not.In the case of Mar del Plata, it can be appreciated that throughout the last 50 years, and despite the critical political and economic context, there have been satisfactory answers to the problems and demands originated around the issue of the resource

Integrated management of water supply, sewage and storm drainage, by an efficient State office should be highlighted. Despite the setbacks regarding access to information, the pressure-state and response indicator analysis methodology, serves its function as a useful planning tool.

Throughout these years, the lessons learned are:

1) It is not possible to repair the precariousness, do always well works.

2) Respect for the scientific and technician background.

3) Need of the economical, social and environmental linkage to achieve sustainability in coastal areas.

4) Decision makers awareness that an efficient model of local management is possible.

The future challenges to be tackled are free access to information and future demand and trends quantification.

In a general context, the use of indicators of pressure, state and response in the characterization of the strategies management in other coastal aquifers, could help to reach a consensus to propose a methodology to qualify the water environmental quality and establish groundwater exploitation criteria.

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