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Groundwater level evolution in the Milan area: natural and human issues

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Abstract The history of groundwater level development in Milan province and in Milan city is analysed. It is very well recorded by piezometric data from a monitoring network of 284 wells, with a monthly frequency. In 1915 the water table depth, quite close to Milan city, was about 1 m below the ground surface. The groundwater table has since fallen rapidly, with an historical minimum in the 1970s, some 40 m below ground surface. However, a rapid increase is now occurring and in recent years (1993–1997) the situation in Milan is getting worse. Many areas of the town's subsurface (parking, underground, houses, hospitals) are now flooded by groundwater. A study of the Milan hydrogeological system has been carried out to analyse the natural and human causes determining the groundwater level evolution. The historical sequences of all the different factors of the mass transfer, from the beginning of the century through to 1997, have been analysed to evaluate their synergistic relationships.

STUDY AREA

The study area is located on the Po Plain (Fig. 1) and is characterized by the highest density of urban, industrial and agriculture activities in Italy. Two different work scales are analysed: the Milan province and the area of Milan city. The first is 1989 km^2 in extent and corresponds to 189 municipalities, within which the agricultural area covers 71%. In the province area, 5380 wells were identified and located, of which 1968 are public and 3412 private; 3050 of the wells have stratigraphic logs (Fig. 1). The area of Milan city is about 180 km^2 (Fig. 1) with urbanization covering some 94%; the remainder is occupied by green open space together with private and public gardens. In 1996, the population was 1 340 080 and the groundwater pumping rate was of the order of 280×10^6 m^3 day^{-1}, coming from 1102 wells, among which nearly 250×10^6 m^3 day^{-1} came from 691 public wells and 30×10^6 m^3 day^{-1} came from 411 private wells.

The area is characterized by both natural and anthropogenic hydrographic networks. The natural forms comprise the Adda and Ticino Rivers respectively in the eastern and western boundaries, where they drain groundwater from the plain. The hydrogeological system consists of fluvial and fluvio-glacial deposits, in which gravels and sands are texturally predominant, with local and discontinuous silty and clayey levels (Fig. 2). From a hydrogeological point of view the studied area can be considered as an unconfined aquifer.

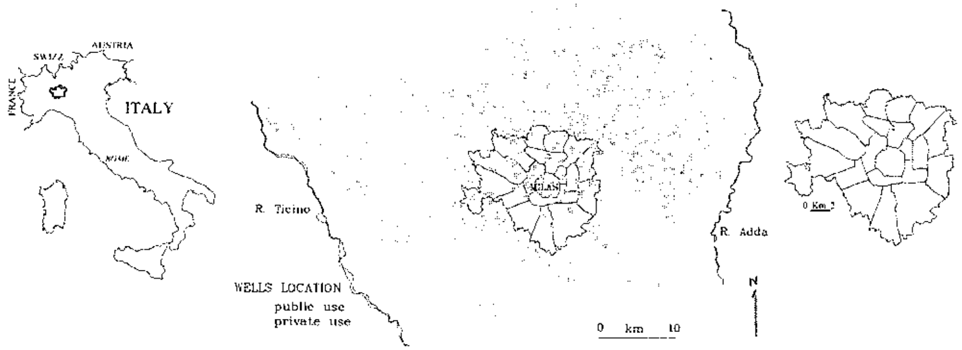

Fig. 1 Location of the study area, in the Po Plain, northern Italy.

HYDROGEOLOGICAL BALANCE FACTORS

The Milan province can be considered as a complete hydrogeological system with the Ticino and Adda Rivers forming the boundaries respectively towards the west and east. In this hydrogeological system the mass balance is characterized by input and output factors which work differently in the area (Fig. 2) and the piezometric level measures the results of their balance. Of course the hydrogeological characteristics and parameters influence this results. Within Milan Province, the determining natural input factor is rainfall with the human factor being irrigation practice; the natural output factors are springs and the human output factors are pumping rates (Fig. 2). In Milan city, the determining factors are always of human origin with the main role played by leakage from the public water supply system and the pumping rates from wells.

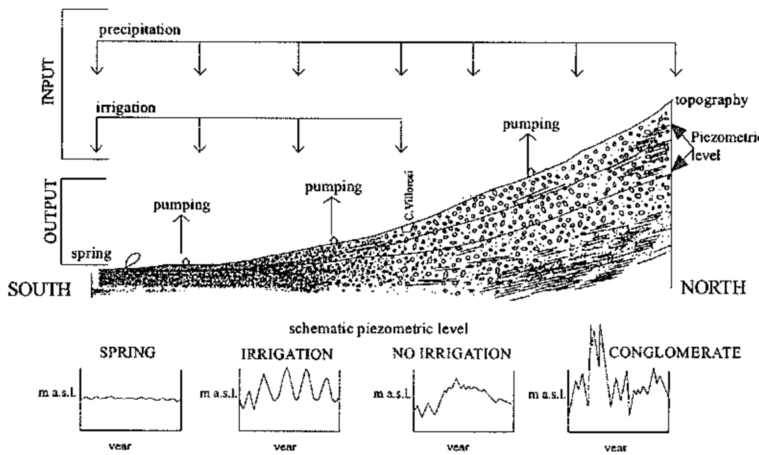

Fig. 2 Schematic of the hydrogeological system of the Milan area. The distribution of the input and output factors is indicated.

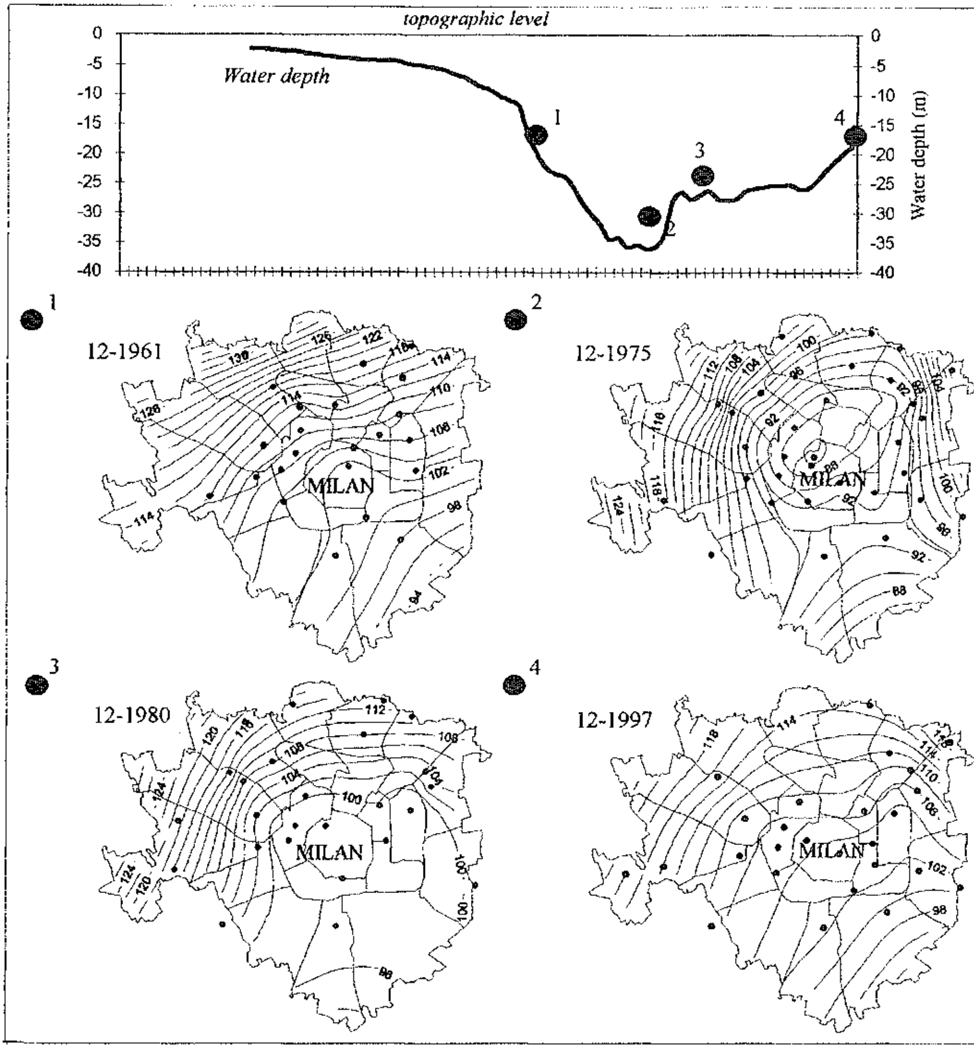

Fig. 3 Groundwater level evolution in Milan for the period 1915–1997 and piezometric surface (in m a.s.l.) in some relevant years (1961, 1975, 1980 and 1997).

GROUNDWATER LEVEL EVOLUTION

The history of groundwater level development in Milan province is very well recorded by monthly piezometric data from a monitoring network of 249 wells. Figure 3 shows groundwater level evolution quite close to the centre of Milan city for the period 1915–1997. In 1915 the water table depth was about 1 m below ground surface; in 1930, 2 m; in 1940 about 4 m; and in 1960 5–6 m. Since the 1950s, all piezometric wells indicate a falling aquifer level. This can be due to two different main causes: decrease in irrigation and increase in pumping rates. The groundwater table has decreased quickly, with an historical minimum occurring in the 1970s, some 40 m below ground surface .

At the end of the 1970s there was a general groundwater increase over the entire province as well as in the city area, reaching maximum positive fluctuations in the

1980s. Many causes explain this increase: e.g. precipitation (Cavallin & Bonomi, 1996), economic crisis and new industrial technologies. After the 1980s a new groundwater lowering developed, reaching the 1970s level. At the same time, a considerable utilization of the non-saturated subsoil zone was carried out with construction of underground parking areas and below-ground building, etc.. Such urban development has inexorably extended year by year over the city but with no expectation of groundwater levels increasing.

In the recent 1993–1997 period however (Raffaeli *et al.*, 1996), the situation in Milan has become much worse and many subsurface areas (underground parking, houses, hospitals etc.,) are now flooded by groundwater. In particular, the groundwater rise can also become a serious problem for urban structures, such as historical monuments. In the Milan city area, the piezometric level distribution has been calculated and Fig. 3 shows the main scenarios with some relevant years chosen as examples: i.e. 1961, 1975, 1980 and 1997. It can be seen that the actual level has reached the previous 1975 level and is now developing toward the minimum 1960s level.

HUMAN ISSUES

A study of the hydrogeological Milan system has been carried out to analyse the natural and human issues determining the groundwater level evolution. The historical sequences for all the different mass transfer factors for the period 1975–1997 have been analysed to evaluate their synergistic relationships: the monthly piezometric levels, rainfall and temperature data as natural factors; irrigation water and pumping well data as human issues together with socio-economic data.

The human issues which contribute to the groundwater recharge changes are diverse and refer to very different circumstances (Custodio, 1997) if one separately considers the Milan provincial area or the urban Milan area. In the Po Plain, 60% of the area competes for irrigation for farmland plots, generally applying river water distributed by means of canals. The characteristics relevant to the type of irrigation system required are whether plant water needs must be supplied totally or in part, all years or some years, all the year round or just part of the year. In this part of northern Italy, the irrigation needs for successful agriculture are chiefly in the summer season, between May and September. In the Milan provincial area, irrigation practice is the determining factor for the water balance. Figure 4 shows the distribution of monthly irrigation from 1975 to 1997 and of the monthly piezometric level in an area located in the north of the province. The maximum quantity of water due to the irrigation practice reached some 1×10^6 m^3 day^{-1}.

In recent years, social developments are determining a constant decrease in agricultural practice, even if farming is tending to become more mechanised and efficient in use of land and labour. Rising living standards in the towns are producing changing tastes in food and clothing materials which will be reflected in a changing pattern of crop production. In the Milan provincial region, irrigation still has a seasonal cycle (Fig. 4) and in the summer period can reaches 30% of the total input balance. The relationship between the seasonal irrigation cycle and piezometric level is evident.

By comparison, only irrigation of public and private gardens and green areas can be considered a source of recharge in urban areas but in general cities reduce recharge because

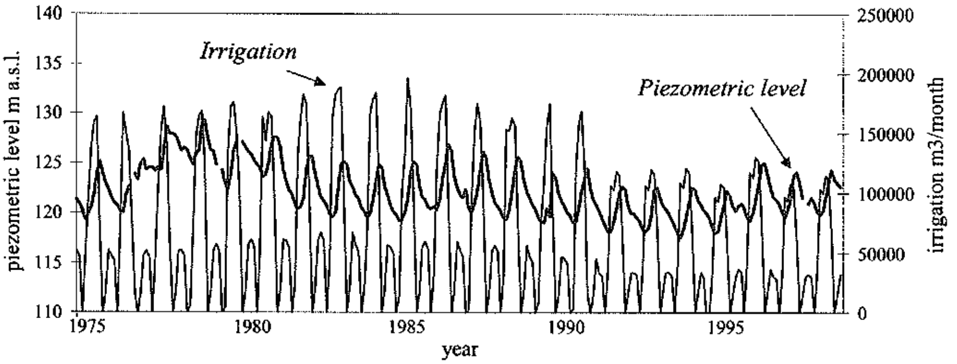

Fig. 4 Monthly piezometric level and monthly irrigation, in the Milan Province, for the period 1975–1996.

of the high proportion of impermeable surfaces (Lerner, 1997). The main sources of recharge water are precipitation and the public water supply system. In the Milan area, as in many big cities, the pumping rates from public and private wells, are the determining output factor of the water budget. At the beginning of the century the rates from public wells were 7 623 483 m^3 rising to 33 927 004 m^3 by 1910. After the war the rates increased until 1971 when they reached their historical maximum values (352 222 000 m^3). Now public well yields are about 250 000 000 m^3 coming from 691 wells although over the last decade pumping rates have decreased by about 50 000 000 m^3 (Fig. 5).

The variations in the public use of drinking water drinking have to be combined with the analysis of the demographical development of Milan city (Fig. 6). In 1900 the total population was 500 000, rising to 1.5 million by 1971 but has since decreased every year and in the last census a total of 1.2 million was recorded.

Comparing the piezometric level evolution and public pumping rates (Fig. 5), there is an evident relationship between pumping and water table both during increasing and lowering periods. Figure 5 shows that when the water table is decreasing, pumping rates have increased and during the last few years, the water table has risen very fast whilst pumping rates have been decreasing.

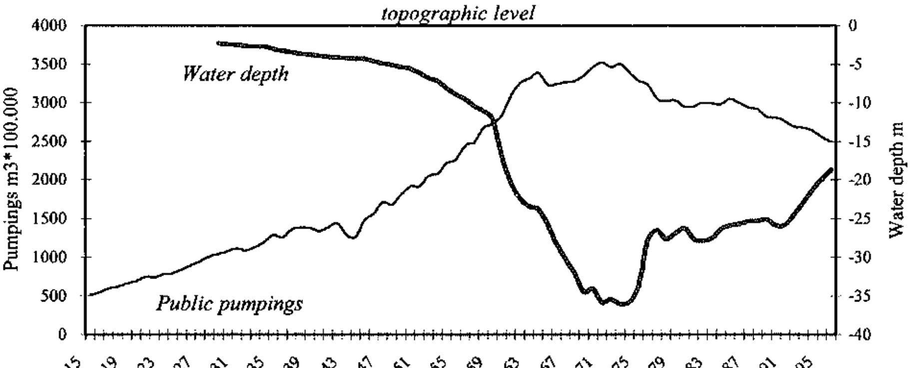

Fig. 5 Water depth and yearly pumping in Milan town, for the period 1915–1997.

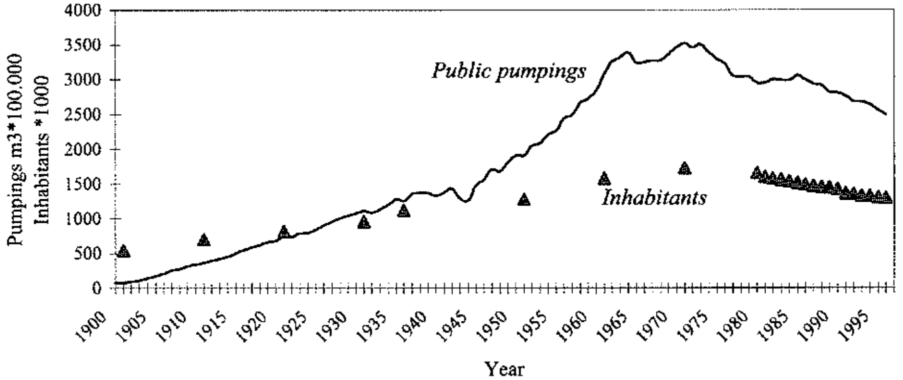

Fig. 6 Annual public pumping and inhabitants, in Milan town, for the period 1900–1997.

Figure 7 shows the correspondence between water depth and the private pumping rates in the period 1979–1996. In 1979, the private yields from wells were 96 005 717 m^3; in 1990, 57 512 430 m^3, and in 1996, 27 272 268 m^3. The decrease between 1990 and 1996 is 30 240 162 m^3, equal to 48%. Over the same period, a regular increase is observed in the piezometric level. Contemporarily, the numbers of private wells are going down: there were 406 in 1988 but only 251 by 1996.

NATURAL FACTORS

In Milan Province, in those areas where irrigation practices are not common, a relationship between rainfall and groundwater table is observed and in particular when an extreme meteorological events occur. During the period 1975–1979 two extreme but very different meteorological events occurred: rainfall some 30% greater than the annual average (997 mm $year^{-1}$) during the five year period when 6300 mm of rain occurred. A maximum monthly rainfall of 373 mm occurred in October 1976; equivalent to the maximum recorded for the period 1900–1993 (Cavallin & Bonomi,

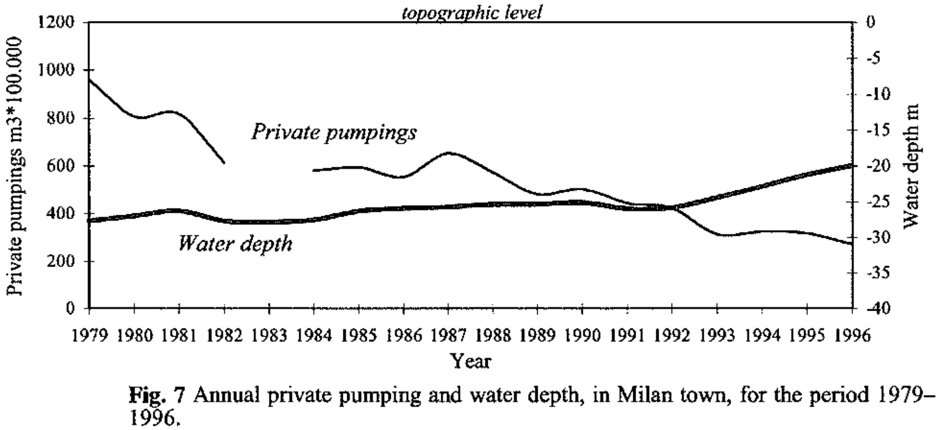

Fig. 7 Annual private pumping and water depth, in Milan town, for the period 1979–1996.

1996). These events produced different effects on the hydrogeological system, but in both cases an increase of the groundwater level was recorded in all monitored wells, both in the provincial (Fig. 8) and urban areas (Fig. 5). Only in the spring zone, south of the area, were no effects observed (Fig. 2).

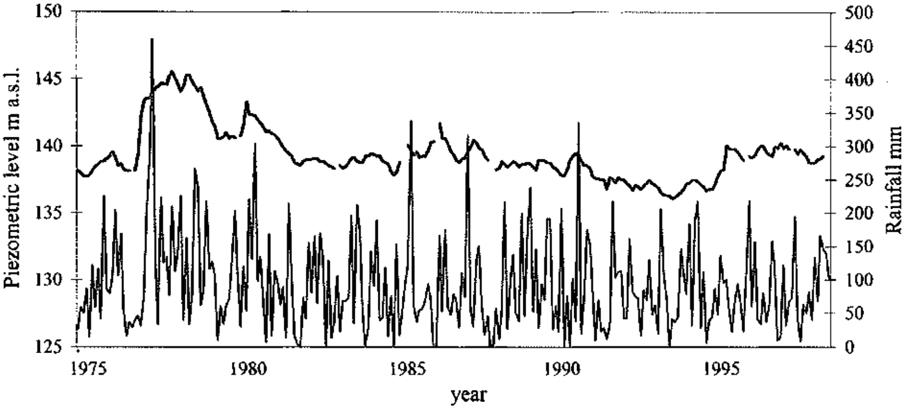

Fig. 8 Monthly piezometric levels and rainfall, in the northern part of the Milan Province, for the period 1975–1996.

CONCLUSIONS

The two different scales of analysis show that the groundwater level evolution in the city area extends its influence to a large circle around the urban area. In fact, in the last few years, the piezometric level is rising also in the province (Figs 4 and 8) even assuming that in these areas any input factors of the water budget may have been increasing and any output factors reducing. This means that global urban planning is necessary to forecast groundwater development. The analysis of the relationships between the different factors of the water budget has established that all the input and output factors contribute synergistically to the water table fluctuations. In particular in the Milan area, which is an area characterized by the highest density of urban, industrial and agricultural activities in Italy, the human issues are the predominant and decisive causes controlling groundwater level evolution.

The socio-economical development is determining many changers in custom. In Milan Province, agriculture is decreasing its relevant weight in the state economy and in consequence irrigation practices have reduced their contribution to aquifer recharge. In the city area, socio-economic development is turning to a better quality of life, with the inhabitants in the metropolitan area having reduced by about 20%, in five years. At the same time, many industries and associated activities have migrated from the urban area to new locations outside the city boundaries. In Milan during the last 5 years, about 150 wells have been closed reducing the privately drawn water by 48%. The result of these developments is a fast rise of the water table which can become a serious problem to urban structures, such as historical monuments, below-ground parking areas etc. During the period 1993–1997, many parts of the Milan subsurface infrastructure (parking, underground, houses, hospitals) were regularly flooded by groundwater. It is very difficult to modify the old urban structures; it is only possible to find very localized remedies. A new global analysis of all the factors could contribute to an understanding of the groundwater evolution; the historical knowledge provides an important basis to forecast the future. In many cases the use of distributed models can offer very practical work-instruments to forecast different hazard scenarios and to assess groundwater development within urban planning.

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