INTERACTION BETWEEN HUMAN ACTIVITIES AND GROUNDWATER RESOURCES
IN THE PROVINCE OF TURIN (ITALY)

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ABSTRACT

As is well known, the Po Plain is one of Europe's most important groundwater reservoirs, and certainly the most important in Italy. The geographical location of the Province of Turin and the geological pattern of its subsoil mean that this part of the Plain holds a highly significant store of water. The industrial and agricultural development of this area, however, coupled with the construction of extensive urban settlements, have been responsible for a whole series of human activities that are greatly interfering with the groundwater resources, as is shown by the repeated occurrence of dangerous signs of degradation.

This paper presents a preliminary overall examination of the coexistence of solid waste disposals, quarries, industrial disposal wells and their influence on groundwater resources. A census has been made of 381 potable water wells, 253 solid waste disposals, 159 quarries and 840 industrial disposal wells and some examples of interaction are presented. The paper ends with a reminder of the need for further extension of the study.

UNDERGROUND WATER RESOURCES

The hydrogeological context

The Province of Turin covers an area of 6830 km² and has 2.324 million inhabitants. From the geomorphological standpoint, it consists of three distinct units (Fig. 1): a plain, an Alpine area, a hilly area. The lowlands form the central section and are bordered by mountains and hills on the West and East respectively. Hydrogeologically speaking (Bortolami et al., 1980), the province can be divided into two parts:

- the lowlands, together with the valley bottoms and subordinate tongues of Quaternary deposits from the mountains and hills, display unconsolidated deposits of varying permeability containing groundwater bodies;
- the mountains and hills are composed of impermeable consolidated rocks. Strictly local areas of fracturing, however, contain water circuits that emerge to the surface in the form of springs.

The size of the lowlands, the texture of their rocks and the possibility of natural recharge make this part of the Province its most important reservoir. In addition to direct precipitation, this
is very largely fed by Alpine hydrographical basins.
The contribution of the hills is very secondary on account of their small extent and smaller precipitation rate (600-700 mm/yr). By contrast, the Alpine basins are not only much larger, but also have a precipitation of 1500-2000 mm/yr that falls on a primarily impermeable substratum.
The recharge area of the lowland groundwater systems is located beyond the points where the watercourses debouch from the valleys. This area consists of coarse, highly permeable rocks forming an undifferentiated aquifer.
The deposits forming the lowlands can be divided into two complexes in terms of their grain sizes and hence their permeability:
a) ancient, recent and modern alluvial, primarily gravelly deposits forming excellent aquifers, in which the presence of usually unconfined groundwater bodies is dependent both on the elevation with respect to the stream network and the presence of virtually impermeable clayey soils at the surface, which impede or diminish infiltration of precipitation water;
b) fine-grain, poorly permeable, Pliocene and Lower-Middle Pleistocene continental and marine deposits, which confine very permeable gravelly and sandy intercalations, capable of confined aquifers.

Employment of the Province's water resources
To give an idea of the consistency of the groundwater resources of the Turin plain, suffice it to say that the Turin Municipal Water Authority alone draws off an average flow of about 5 m$^3$/s from 234 wells serving 12 plants, while a further 5 m$^3$/s are taken for industrial purposes in 11 local municipalities: Turin, Trofarello, Settimo, San Mauro, Rivalta, Orbassano, Nichelino, Moncalieri, Grugliasco, Bruino and Beinasco. It may reasonably be supposed that yet another 5 m$^3$/s are withdrawn for other users of drinking and industrial water, plus all the agricultural users. These figures
show both the potential of the resources and the fast rate at which they are being exploited. On the other hand, since their exact size is not yet known, this exploitation cannot be expressed in percentage terms.

**Features of the drinking water wells and their distribution**

As mentioned earlier, a census was made of 381 potable water wells, including the 234 serving the Turin Water Authority's 12 installations. It probably embraces 90% of the existing wells of this type.

Most wells, of course, are located in the lowland belt. About 5% draw on the aquifer in the alluvial deposits at the valley bottoms, whereas drinking water is mainly obtained by harnessing springs in the valleys themselves.

Generally speaking, the location of wells in the lowlands is primarily dictated by the availability of groundwater, and secondarily by the concentration of various user communities (domestic, industrial, agricultural, mixed). The siting of waterworks around the city of Turin reflects both these considerations, whereas their concentration in areas of limited extent and relatively far from heavy users is solely determined by a particularly favourable local hydrogeological context. An example is provided by the Turin Aqueduct's 87 wells in the Municipality of Scalenghe.

As far as the aquifer exploited in the lowlands are concerned, the multi-strata system resting on the Villafranchian complex (upper Pliocene-Lower Pleistocene) is by far the most commonly employed. These aquifers are semi-artesian or artesian, depending on the areal extension and thickness and the texture of the silty-clayey aquitards. A small number of waterworks, on the other hand, still take their supplies from the shallow aquifers in the Middle Pleistocene-Holocene alluvial deposits (e.g. those at "Le Vallette" of Turin, and Ivrea). The aquifers in the Villafranchian complex naturally enjoy a good degree of protection against pollution. Waterworks extracting from the unconfined groundwater, on the other hand, are vulnerable, since there is no natural protection of any kind.

**CENSUS OF PRINCIPAL HUMAN ACTIVITIES**

To determine the interaction between human activities and groundwater resources in the Province of Turin, a census was made of its urban and industrial solid waste disposals, quarries and disposal wells used for industrial purposes.

There are, of course, other human activities capable of interfering with a groundwater system. The magnitude and characteristics of the activities referred to here, however, clearly render them the most capable of interfering with the management and preservation of the Province’s water resources.

**Urban and industrial solid waste disposals**

A total of 252 solid waste disposals (198 still in use, 55 filled) have been counted. Of those still in use, 191 receive solid urban wastes and similar refuse, the remainder special kinds of industrial waste. As a general rule, these dumps occupy spaces left vacant after quarrying operations.

Industrial waste disposals are located near large industrial complexes in the lowlands or valley bottoms. In and around the city of Turin, in particular, the existence of disposal areas is dictated
by the presence of the production plants of a well-known local industrial conglomerate. Most special dumps have been set up and managed by industrial companies from the moment production began. In some areas, therefore, such as the Stura district of Turin, the landfill of special wastes has been in progress for several decades. On the other hand, some private entrepreneurs have recently established as disposal centres areas with existing cavities possessing appropriate natural characteristics, supplemented, where necessary, by waterproofing.

The 228 active and filled solid urban waste disposals virtually amount to one for each of the Province's 315 municipalities, especially since the census cannot be regarded as exhaustive. This wide and wild dissemination is clearly dictated by the idea of proximity between those who produce refuse and the area where it is disposed of. No thought is given to such notions as the natural suitability of dumps, their safety and economics and optimal land use.

Quarries for the extraction of aggregates, clays and stone

The census comprises 159 quarries (131 in operation, 28 abandoned). Those still working include 93 engaged in the quarrying of sand and gravel for aggregates, 15 in the extraction of silty-clayey materials for making bricks and the like, and 23 in the quarrying of ballast and ornamental stone.

The stone quarries are located along the main alpine valleys. Those for the extraction of silt and clay are sited along the southern edge of the Turin Hills, where they work the virtually impermeable, fine-textured Villafranchian deposits and in the eastern part of the Turin plain (Torrazza, Rondissone, Montanaro, Foglizzo table-land), where a Rissian silty-clayey cover, no more than about 10 metres thick, is exploited.

Quarries for aggregates are by far the most numerous. They are primarily to be found around Turin between La Loggia and Chivasso, and along the southern stretch of the Po River as far as the boundary with the Province of Cuneo. Their location partly reflects the proximity of the main users and is partly due to the existence of an alluvial cover with choice aggregates formed by the confluence of several watercourses with the Po within a short distance of each other.

The importance of quarrying along the Po to the South of Turin (almost entirely between the municipalities of Moncalieri and Carmagnola) can be judged by its output of 18000 m$^3$/yr per hectare worked, compared with the 9600 m$^3$/yr average for the Region (Mancini et al., 1981).

Despite the fact that the Quaternary alluvial plain with its great potential production of aggregates would allow quarries to be opened elsewhere, their present distribution is almost entirely determined by proximity to consumption areas. The few quarries established along the valley bottoms follow the same local use criterion.

Irrespective of the material extracted from them, quarries once abandoned offer a classic example of multiple, though not always correct, land use. Part of the empty space thus remaining has been and can be used for the landfill of refuse of various kinds.
Industrial disposal wells

The 840 industrial disposal wells included in the census are variously concentrated over the whole alluvial plain and main alpine valley bottoms.

An impressive concentration of these wells - 457, i.e. 54.4% of the total - can be found in just 17 municipalities: Turin (12.6%), followed by Collegno, Rivoli, Grugliasco, Rivalta, Villarbasse, Bruino, Leini, Borgaro, Orbassano, Piossasco, Beinasco, Venaria, Volvera, Ciriè, Moncalieri and Settimo in decreasing order.

It is obvious that these plants, which constitute an efficient vehicle for the dissemination of pollutants, are in keeping with the degree of industrialisation of the area concerned. On the other hand, this extremely dangerous method of disposing of liquid wastes must be exposed to condemnation and banned.

GEOGRAPHICAL DISTRIBUTION OF USER ACTIVITIES

The 1633 installations described in this work have been plotted on a 1:100000 map of the Province of Turin.

The first thing to strike the eye is the way these drinking water wells, solid waste disposals, quarries and industrial disposal wells are confined to very small portions of the province, little thought being given to the possibility of interferences with the well-being of the environment and between one type of use and another.

Both water and aggregates have been sought where loose, clean and therefore permeable materials could be found. These two forms of land use are followed by the utilisation of abandoned quarry spaces as waste disposals. All these forms of exploitation, what is more, occur in an area where human activity is very strong, including the inadmissible employment of injection wells for the disposal of industrial liquid wastes.

PROBLEMS ASSOCIATES WITH INTERACTION BETWEEN HUMAN ACTIVITIES AND GROUNDWATER RESOURCES

Interaction between the human activities previously described and groundwater resources may lead to three main types of interference:

- Hydraulic interference between the drawdown cone of drinking well's catchment area and the water surface of the lakes created by the aggregate pits, when quarrying is carried out below the water table, as is almost always the case. Quarrying itself does not degrade drinking water. The open water surfaces that form in quarries, on the other hand, are a potential area for the collection and dispersal of any type of soluble discharge, whether polluting or not.

- Dumps for both solid urban and industrial wastes, devoid of naturally or artificially impermeable bottoms and walls, are likely to be the source from which pollutants spread into groundwater sources.

- Disposal wells are an utterly foolish way of disposing of wastes. While the extent of pollution will obviously depend on the amount of material disseminated and at what depth, the fact remains that such wells are a potential source of pollution and hence dangerous.

Some examples are presented by way of illustration.

Fig. 2a concerns a section of the Province lying across the Po between the areas of Moncalieri and Carmagnola, south of Turin.
Fig. 2. Two typical examples of interaction between human activities and groundwater resources in the Province of Turin. "A" represents a section lying across the Po river, South of Turin, where hydraulic interference between drinking water wells and lakes created by aggregates pits has been proved. "B" represents a highly industrialised area to the SW of Turin, where pollution of drinking water from industrial sources tends to occur frequently. The most recent discovery in this area has been groundwater pollution by chlorine derivatives.
This small zone contains 31 drinking water wells, 27 industrial disposal wells, 21 aggregates quarries (16 in operation), 16 dumps, including 8 for urban solid wastes and the like and 1 special refuse tip. Three of the 7 abandoned dumps are full of special refuse. Seventeen of the drinking water wells belong to the Turin Municipal Water Authority and supply some 14% of the city's requirements. The quarries produce about 3 million m$^3$ of aggregates per year. The zone shown in Fig. 2a represents the most typical example of contemporaneous vertical exploitation of an aquifer, i.e. the removal of its solid for aggregates and the drawing off of drinking water. These are two important social and economic activities. The extent to which they may interfere with each other, however, would have required sufficient prior assessment. Numerous pumping test and geological soundings and the results obtained by a mathematical modelling of the area have made it clear that such interference exists.

Three points in particular emerge (Di Molfetta and Verga, 1982):

a) the main aquifer exploited by the drinking water wells is of the semi- artesian type (leaky confined aquifer with negligible storage in the semipervious layer) with average values of $0.80 - 3.20 \cdot 10^{-2}$ m$^2$/s transmissivity, $3.8 - 6.6 \cdot 10^{-4}$ for storage coefficient and $44 - 262$ m for leakage factor;

b) its silty-clayey aquitard is 15-20 metres from the surface and has been broken into by quarrying, with the result that there is a hydraulic continuity between the groundwater resources and sheets of water in the pits;

c) three-dimensional mathematical models have shown that in some cases the overall drawdown cone of the catchment area interferes with open water surfaces in the pits.

As matters now stand, the aquifers exploited to supply drinking water have not been degraded, though their vulnerability is evident. The existence of potentially polluting activities such as solid waste disposals and industrial disposal wells increases the possibility that degradation may commence. Fig. 2b illustrates a highly industrialised area to the SW of Turin. The three municipalities of Rivalta, Orbassano and Beinasco have 38 drinking water wells, 58 industrial disposal wells, 10 quarries (3 of which abandoned), and 14 solid waste disposals (including 3 filled). One of the dumps still in use is employed for the disposal of special industrial wastes. Here pollution of drinking water from industrial sources tends to occur frequently. Heavy metals such as hexavalent chromium are primarily involved. The most recent discovery has been pollution by chlorine derivatives, including maximum concentrations of 250 μg/l of trichlorethylene. As a result, several wells have had to be closed and the local authorities have ordered a thorough survey to be carried out to determine the extent of such pollution both in area and depth, and the remedial measures required.

The aquifer system concerned is the Villafranchian multi-stratum complex mentioned earlier though it is protected in this area by a series of impermeable conglomerate partitions. Pollution on the part of chlorine derivatives may thus be presumed to have occurred owing to the by-passing of this protection through disposal wells, since such pollution propagation in the recharge area of the Villafranchian aquifer can be ruled out.
FURTHER PROSECUTION OF THE STUDY WITH A VIEW TO DEVISING A RATIONAL WAY OF USING THE PROVINCE OF TURIN'S RESOURCES

This assessment of the interaction between human activities and the Province of Turin's groundwater resources suggests that action should be taken along two lines. Measures must be taken to secure optimum management of current activities so as to preserve the status quo and give preference to the need for drinking water. At the same time steps should be taken to plan the Province's land use with an eye to the possible optimal relocation of the activities discussed at a later date.

The first objective requires:

a) elimination of all unauthorised disposal of liquid and solid refuse whether on or under the ground;
b) identification, pinpointing and exhaustive and up-to-date description of all waste disposal activities;
c) adoption by the refuse disposal industry of safety criteria at the design stage (waterproofing of dumping sites) and for the purposes of checking and inspection (monitoring and/or reclamation wells);
d) elimination of interference and/or pollution already present through remedial measures and the relocation of individual activities.

Attainment of the second objective requires the observation of various constraints (hydrogeological, preservation of the landscape, etc.). The following steps are needed:

a) identification and priority utilisation, or at any rate the controlled putting in order, of all existing empty sites;
b) concentration of the activities in question, as opposed to their present, irregular widespread distribution;
c) optimum land use through the setting up of quarries and dumps in which the maximum volume is used with the least possible consumption of surface;
d) bearing in mind the need for deeper dumps mentioned in c), a ground thickness of at least 15-20 metres should be required above the maximum fluctuation piezometric level of the first aquifer;
e) relocation of waterworks that are vulnerable and no longer defensible on economics grounds in new exploitation areas, coupled with the drawing up of protection criteria;
f) possible employment of resources salvaged from previous activities (e.g. employment of unconfined surface water in abandoned quarries for the supply of industrial and agricultural aqueducts; the recovery of biogas from waste disposal; the sorting of materials before the landfill to salvage parts of economic value;
g) a unified (and not merely local) policy for the management of resources both in the soil and below it.

To attain both objectives, a further research is already being carried out.
REFERENCES

