

THE INTERVENTION OF HYDROGEOPHYSICS IN THE ECONOMICS OF GROUNDWATER EXPLOITATION AND MANAGEMENT IN SICILY

A. CIMINO

Istituto di Geofisica Mineraria, Università di Palermo, Via M. Stabile 110,
90139 Palermo Italy

ABSTRACT

The problem of the preservation of water resources in Sicily presents various aspects, some of which have been treated by a number of works. Among the different applied methodologies, the geophysical ones occupy an important place.

Their contribution, directed to an economic and efficient exploitation and management of groundwaters, can be useful for selected "risk" areas as well as for more regional programmes. In fact, uncontrolled drillings on relatively rich aquifers occur in several zones of this island; the economically disadvantageous exploitation causes also heavy impoverishment and pollution phenomena. The fragmentation of charges and the lack of a planning Regional Body make more difficult any organic elaboration of all the existing field data and the collection of further information. Other social-economical elements, as the recent urbanization of large areas, have aggravated this situation, mostly for the drinkable water needs. Geoelectrical methodologies have been applied in coastal and inland areas of Sicily. Their elaboration, versus time too, can furnish the behaviour of groundwaters as quality and quantity. The author suggests the rational exploitation of certain Sicily aquifers, showing the different costs between a classic survey supported by geological models and the same research carried out with a preliminary geoelectrical prospecting.

1 INTRODUCTION

Surface and underground waters are one of the environmental elements most exposed to heavy modifications, due to impoverishments and different contaminations. In spite to their renewability (hydrogeological cycle), water resources must primarily be protected, because they can condition the economic development of regions like Sicily, already disadvantaged by an unfavourable morpho-climatic situation.

In the field of the water resource management, in Sicily it has often been difficult to follow the most elementary principles of territorial planning. In fact, besides the irregular distribution of waters, there is a continuous decrease of agricultural areas in consequence of a contemporary, chaotic urban-indus-

trial growth. This occurs mainly in well-defined areas of the island, e.g. the coastal belts around the largest towns, where water consumption is concentrated. The present paper proposes the application of geophysical methodologies of research, putting in evidence their economic contribution to a rational exploitation of the water resources, owing to their periodical control too.

2 THE HYDRO-POLITIC PROBLEM IN SICILY

In these last years, the problem connected with the management of water resources has reached, in Sicily, an exceptional gravity. Its numerous aspects are treated by several Public Bodies, in the frame of regional and local projects.

Nevertheless, the realization of research, drawing and distribution works is carried out taking into account neither the social-economical development of the territory nor, consequently, the relations between costs and benefits. Therefore, the causes of the heavy water scarcity are not only attributable to the particular climate of Sicily, but also to the management of these resources: in particular, to the lack of a Central Water Body and definite agencies of the hydro-units. In fact, in spite of the relative aridity, the yearly average pluviometric contribution in Sicily is no less than $18.7 \cdot 10^9 \text{ m}^3$, a part of which constitutes, as efficacious infiltration ($1.3 \cdot 10^9 \text{ m}^3$), a hydrologic potential relevant to the natural underground reservoirs (main aquifers, see Fig. 1).

Recent estimates (Martorana, 1986) consider that the yearly average water needs of Sicily (drinkable, irriguous and industrial) could be fully satisfied by underground resources as well as by artificial basins, these last ones collecting part of the surface flows (Table 1). Therefore, a consistent part of the efforts has to be directed to the groundwater reservoirs: geophysical prospectings can play an essential rôle on the aquifer researches, permitting a planning of their exploitation and distribution for the different purposes.

3 THE MAIN INTERVENTIONS IN SICILY

The Sicilian areas characterized by the heavy anthropic presence are subjected to water supplies crises, seemingly connected with climatic factors only.

Part of the numerous interventions of Public Bodies (drawings of groundwaters by bore-holes and barrages of rivers) are preceded neither by the knowledge of the geostructural conditions, nor by an organic need planning in the expanding areas. Social-economical elements, e.g. local emigrations towards the coastal

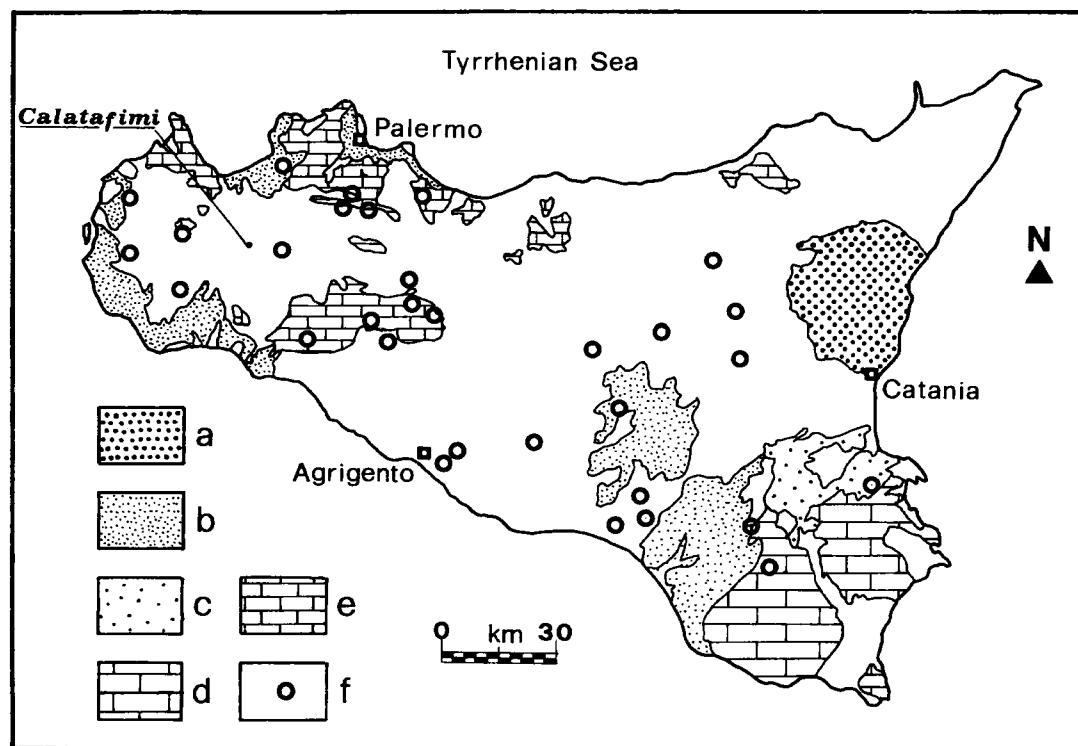
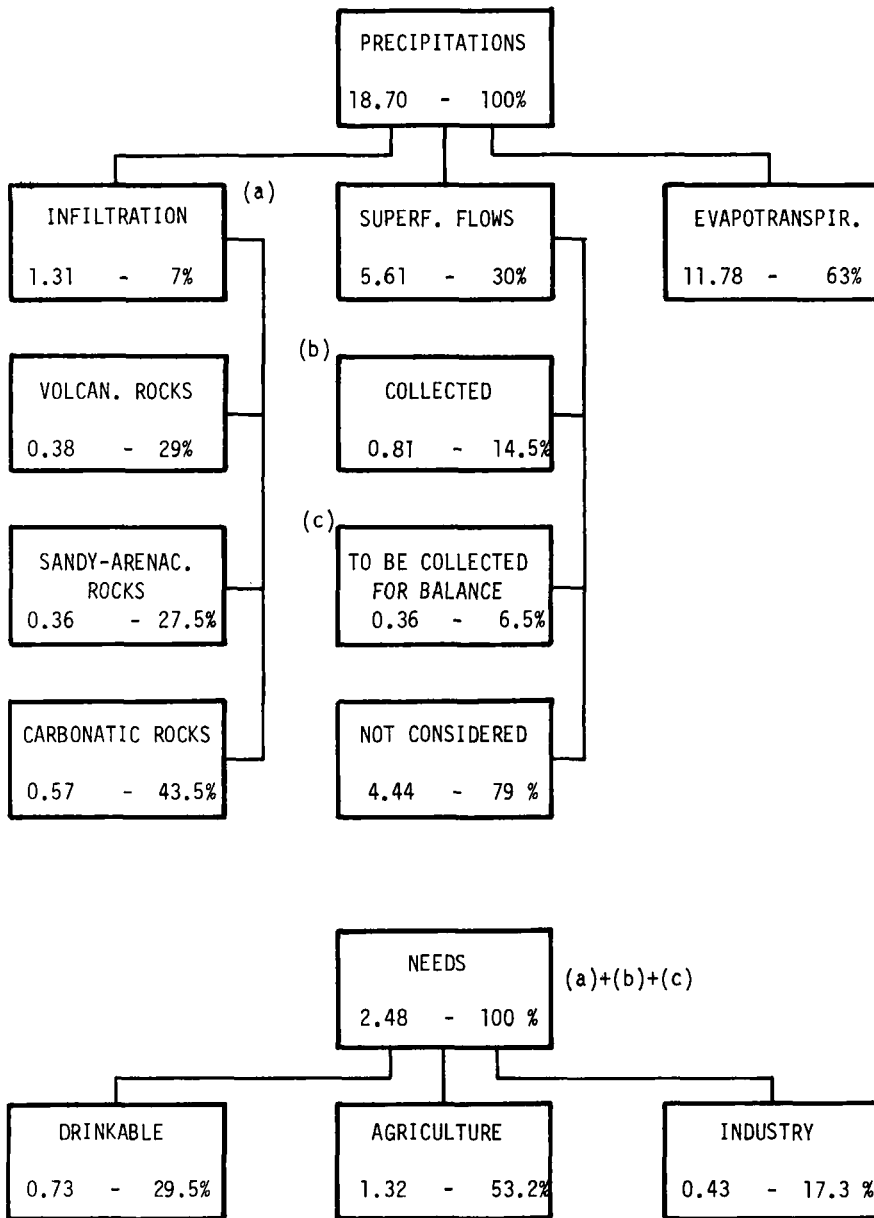


Fig. 1. Main water resources of Sicily, through infiltrations (aquifers) and superficial flows (barrages). a: Etna volcanic formations (Quaternary): high permeability for fissures; b: sands and calcarenites (Pliocene-Quaternary): good permeability for porosity; c: Lentini volcanic formations (Miocene-Pliocene): fairly good permeability for fissures; d: Ragusa limestones (Oligocene-Miocene): fairly good permeability for fissures and karst; e: limestones and dolomites (Mesozoic-Tertiary): high permeability for fissures and karst; f: artificial basins. Spots discussed in this paper are also indicated (from Martorana, 1986, modif.).



Tab. 1. Synoptic table showing how the different water needs of Sicily can be satisfied by the best management of the infiltration (a) and surface (b) (c) waters. Yearly average values are in 10^9 m^3 (from Martorana, 1986, modif.).

belts, have increased the lack of equilibrium between needs and availabilities in the different areas of Sicily, causing an irrational drawing of water resources (Cimino, 1987). In particular, the industrial development in the coastal planes and some radical modifications have created priority clashes for the water distribution in agricultural sectors. The exploitation of wells in unfavourable hydro-structural conditions has caused heavy pollution phenomena and the general reduction of the spring yields (about 40% less in the last fifty years).

The great projects, partially realized, to collect surface waters contribute to satisfy the needs, especially the agricultural ones, with enormous costs, times and interment risks. These artificial basins are indispensable for the drinkable uses too, but in these last decennia they have furnished only partial solutions to the problem: considering the high costs to realize and administer them (hundreds of millions of USD), the exigence to research and/or exploit aquifers (also the deep ones) is even more felt.

Within the next twentyfive-thirty years, an increase of the consumptions is forecast in Sicily, from the actual $7.5 \cdot 10^3 \text{ l/s}$ to about $19 \cdot 10^3 \text{ l/s}$ (according the Aqueduct General Plan), with a forecast growth of the resident population of about the 40%. Consequently, unavoidable economic considerations have to be done as regards the difficult water distribution for the different uses as well as their quality: naturally mineralized and uncontaminated waters are often employed for irriguous or industrial purposes; on the contrary, inland collected waters are directed towards great urban-industrial coastal centers, utilizing complex pipe-networks and expensive potability treatments.

4 THE CHOSEN GEOPHYSICAL PARAMETER AND THE RELATIONS WITH THE AQUIFER CHARACTERISTICS

In the rocks, the influence of water occurrence and quality on apparent resistivity (" ρ_a ") has been described by a number of Authors, see for example Astier (1971). For the sicilian considered areas the high resistivity contrast among the hydro-units has allowed to carry out relatively simple interpretations of the geoelectrical measurements. The main prospectings have consisted in the execution of Vertical Electrical Soundings (V.E.S.), periodically too, as in the Palermo Plane (see Cosentino et al., 1979). Such surveys can furnish bi- and three-di-mensional representations (cross-sections and maps) of the buried hydrogeologic-al units for the prospected area. Furthermore, particular elaborations of the ap

parent resistivity versus the interelectrode half-distance ($\rho_a = f(AB/2)$ function) have led, in certain cases, to improvements in the study of the aquifer behaviour, as will be shown in the next paragraph.

5 ECONOMIC CONSIDERATIONS AND EVALUATIONS ON THE PROPOSED METHODOLOGIES FOR SELECTED AREAS

Geoelectrical surveys have been executed in many areas of Sicily: coastal plains as well as inland and mountainous areas have been studied, some of which are in "hydrogeological risk" situations. Among them, the quoted Palermo coastal Plain (Fig. 1) has received a number of contributions (Cimino et al., 1971; Cimino, 1987). In this area, the heavy deterioration of the groundwaters, due to the intense urbanization, has been investigated and circumscribed by resistivity and geochemical methodologies: nevertheless, these efforts have not yet yielded consistent benefits in such a complex sector of Sicily.

As an exhaustive example of rational intervention, the inland area of Calatufimi will be considered in detail (see spot in Fig. 1). This mainly hilly area presents a very variable permeability (Raptis, 1976/77). Hydrogeological considerations should suggest a number of zones to exploit the most important aquifer: this is constituted by limestone formations under a clayey-arenaceous overburden, the thickness of which reaches 200-300 m. As a matter of fact, a large area should be indicated, mainly in the Western and North-Eastern sectors, where it could be presumably suitable to exploit the buried aquifer. Nevertheless, the execution of a group of deep water-wells could not be successful, owing to the complex buried tectonics of the whole region.

Considering that a drilling in such a clayey area requires a proper lining, their cost rises up to 160 USD/m. Even if a good water productivity of part of the drillings is supposed, the total cost of a series of drillings can be higher than 32,000 USD for each of them, for an average depth of 200 m. In fact, the eventual occurrence of water at higher depths (more than 100-150 m) should cause a quicker growth of the exploitation costs, see Fig. 2.

Therefore, such a water research presents, besides a failure risk, a very unsuitable cost/benefit ratio, and a comparison has to be done with the intervention of a preliminar geophysical survey, executed in the same area.

Fig. 3a shows a map of apparent resistivity values (" ρ_a "), elaborated for an interelectrode half-distance (" $AB/2$ ") of 200 m: an investigation depth up

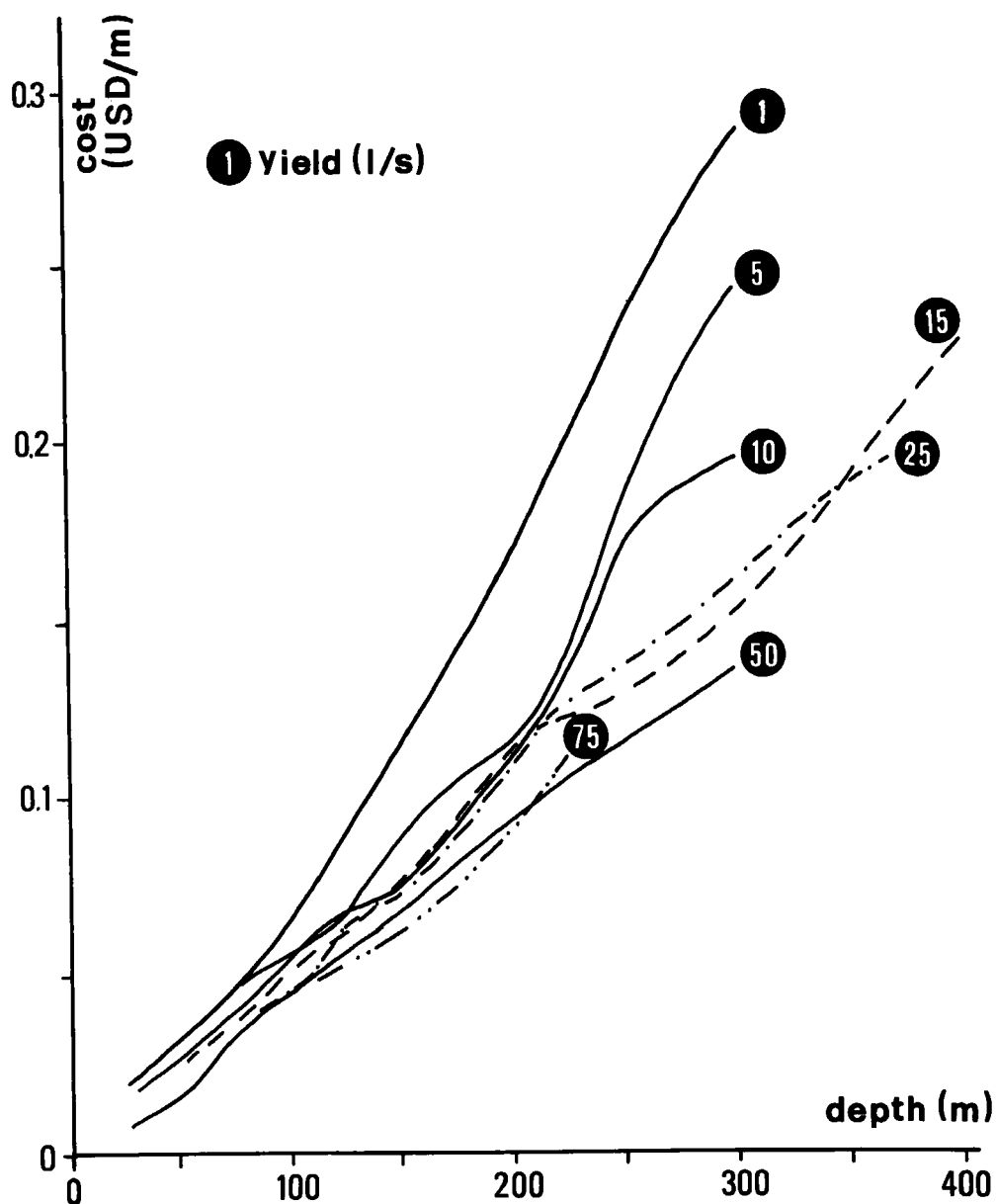


Fig. 2. Diagramme of drawing costs vs. water depths for different well-yields. Quicker cost growths are showed over 100-200 m depths for the most economically favourable and common yields in Sicily (10-25 l/s).

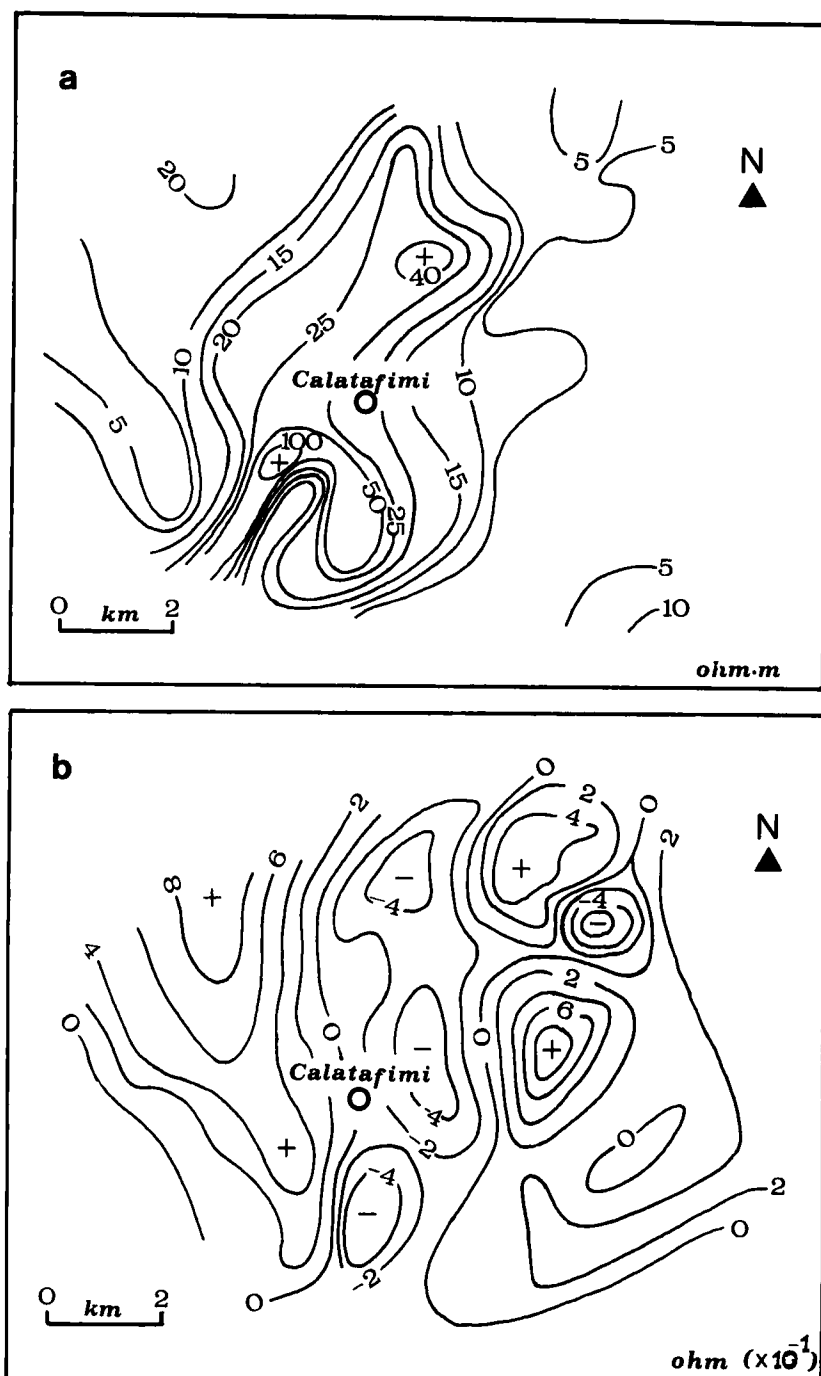


Fig. 3. Map of apparent resistivity (ρ_a) (upper), and map of the gradients of the $\rho_a = f(AB/2)$ function (lower) for the Calatafimi area, both elaborated for a 200 m interelectrode half-spacing ($AB/2$) of Vertical Electrical Soundings (V.E.S.). Their simultaneously interpretation individuates the most favourable zone for the deep aquifer exploitation (South-West of the village). See also Fig. 1 for the location of this area.

to 100-150 m is assured. Fig. 3b shows a map of the "gradient" of the same function, i.e. $\rho_a = f(AB/2)$: it is obtained computing the slopes of the V.E.S. curves in correspondence to the same $AB/2$ value chosen for the previous map (200 m).

So, a good indication of the curve trend is acquired, eliminating the influence of the absolute ρ_a values. The comparison between these geophysical maps can allow to locate the most favourable spots for reaching the aquifer. For the quoted example, a maximum in the isoanomalous lines is present in both the maps: South-West of Calatafimi village, a favourable exploitation zone is delimited, substantially reducing the number of bore-holes, and minimizing the comprehensive costs. In fact, the geoelectric data have been furnished, for the considered area, by a n. 50 V.E.S. survey (max. electrodic spacing=600-800 m), with a cost of only about 10,000 USD in total. Moreover, it is possible to quantify in detail this evident benefit considering that a group of at least 8-10 drilling were required to prospect all the presumably productive area; while a number of 2-4 of them is sufficient for the selected zone. It is easy, now, to compute a deduced saving of 182,000 USD, with a very high success probability.

6 CONCLUSIONS

The social-economical considerations on the water problems in Sicily, and the geophysical contributions for certain areas allow to propose the application of these methodologies to notably reduce cost/benefit ratios: they have to be considered as an essential tool of research and control at relatively low charges, as seen for the Calatafimi area. Further elaborations and representations of apparent resistivity can be employed, as favourably performed in other sicilian areas (i.e., maps of "anti-harmonic" and "harmonic" averages of ρ_a , see Calafiore and Cimino, 1983). In such a way, many sicilian aquifers can be economically controlled, also periodically, helping to achieve strategies as: a) the repose of the particular aquifer, or part of it; b) the recharge of circumscribed sectors; c) the use of inland groundwaters, especially in sub-exploited, hilly-mountainous areas; d) the collection of surface waters in relatively small basins to satisfy local needs.

Goals of these suggested interventions must be the distributive equity and balance: so, the agricultural and industrial economic development will be encouraged, simultaneously permitting the availability of good-quality waters in the urban areas.

7 REFERENCES

- Astier, J.L., 1971. Géophysique appliquée à l'hydrogéologie. Masson, Paris, viii+277 pp.
- Calafiore, G. and Cimino A., 1983. Selezione ed elaborazione di un gruppo di S.E.V. per una valutazione delle risorse idriche dell'area di Godrano (Sicilia Occidentale). Proceed. of the Nat. Meet. on Environment and Water Resource Protection (Siracusa, Italia), in press.
- Cimino, A., 1987. Ground-water control and protection in areas of Sicily affected by relevant agricultural and human settling down changes. Proceed. of the 19th Congr. of I.A.H. (Karlovy Vary, Czechoslovakia), 19: 367-377.
- Cimino, A., Cosentino, P. and Cusimano, G., 1971. Studio idrogeologico della Piana dei Colli (Palermo). Proceed. of the Int. Symp. on Groundwater in Crystalline Rocks (Cagliari, Italia): 63-81.
- Cimino, A., Dongarrà, G., Abbate, R. and Marchese B., 1987. L'uso integrato di metodi geofisici e geochimici nello studio e controllo di acquiferi in aree costiere (submitted for publication).
- Cosentino, P., Cimino, A. and Riggio, A.M., 1979. Time variations of the resistivity in a layered structure with unconfined aquifer. *Geoexpl.*, 17: 11-17.
- Martorana, F.P., 1986. Il problema dell'acqua in Sicilia e la situazione idrico-potabile dell'Agrigentino. Proceed. of the 2nd Geol. Reg. Meet. (Agrigento, Italia), in press.
- Raptis, N., 1976/77. Studio geoelettrico per scopi idrogeologici del territorio di Calatafimi. Graduation Thesis, University of Palermo, unpublished.