Geofísica Internacional
ISSN: 0016-7169
silvia@geofisica.unam.mx
Universidad Nacional Autónoma de México
México

Aureli, A.; Carrubba, S.; Cusimano, G.; Dipasquale, M.; Mazzurco, N.; Privitera, A. M. G.; Silluzio, C.; Tosto, S.; Zingale, V.
Vulnerability maps pollution to hydrocarbon and urban waste pollution in seawater intrusion areas
Geofísica Internacional, vol. 43, núm. 4, october-december, 2004, pp. 683-688
Universidad Nacional Autónoma de México
Distrito Federal, México

Available in: http://www.redalyc.org/articulo.oa?id=56843417

How to cite
Complete issue
More information about this article
Journal's homepage in redalyc.org

Scientific Information System
Network of Scientific Journals from Latin America, the Caribbean, Spain and Portugal
Non-profit academic project, developed under the open access initiative

Geofísica Internacional (2004), Vol. 43, Num. 4, pp. 683-688

Vulnerability maps pollution to hydrocarbon and urban waste pollution in seawater intrusion areas

A. Aureli[1], S. Carrubba[2], G. Cusimano[1], M. Dipasquale[2], N. Mazzurco[2], A.M.G. Privitera[2], C. Silluzio[2], S.Tosto[2] and V. Zingale[2]

[1] *Department of Geology and Geodesy, University of Palermo, Italy*

[2] *Component of the Operational Unit (U.O.) 4.17 of the Italian National Group for the Protection Against Hydrogeological Hazards (G.N.D.C.I.) – C.N.R. Palermo, Italy*

Received: July 15, 2003; accepted: June 2, 2004

RESUMEN

De acuerdo con un proyecto nacional promovido por el Grupo Nacional Italiano para la Protección contra Riesgos Hidrogeológicos han sido publicados los mapas de vulnerabilidad (1:50.000) de parte del Territorio Italiano, particularmente algunos mapas de Sicilia: Montes Iblei, Moadonie, Sicani y el Monte Etna. Estos mapas se han vuelto documentos públicos para el manejo local del agua subterránea. Algunos fenómenos muy peligrosos han sido reportados en algunas áreas de Sicilia. Intervenciones antrópicas han creado basureros de residuos tóxicos sobre áreas vulnerables. Esta investigación explica las ventajas del uso de mapas de vulnerabilidad en estudio de tipos peligrosos de contaminación para la situación encontrada en el área de Augusta-Priolo, Sicilia, en la cual un complejo petroquímico ha sido instalado. Aspectos hidrogeológicos y petroquímicos son examinados para evaluar las posibilidades de intervención preventiva y de reclamación. En las mismas áreas, en regiones costeras, la intrusión marina está incrementándose progresivamente.

PALABRAS CLAVE: Vulnerabilidad, contaminación, intrusión marina, riesgo de contaminación, contaminación por hidrocarburos.

ABSTRACT

According to a national project promoted by the Italian National Group for the Protection against Hydrogeological Hazards, vulnerability maps (1: 50.000) of part of the Italian National territory have been published, particularly in Sicilia (Iblei Mounts, Madonie, Sicani and Etna). These maps have become a public document for local groundwater management. Dangerous phenomena have been reported in some zones of Sicily. Anthropic interventions have created toxic waste dumps in vulnerable areas. We explain the advantage of vulnerability maps in the study of dangerous types of pollution for the situation in the Augusta Priolo area, Sicilia, in which a petrochemical complex has been installed. Hydrogeological and petrochemical aspects are examined to assess the possibilities of a preventive intervention and reclamation. In the same areas, seawater intrusion is increasing in coastal regions.

KEY WORDS: Vulnerability, pollution, seawater intrusion, risk pollution, hydrocarbons pollution.

INTRODUCTION

This paper explains the utilization of vulnerability maps in case of hydrocarbon pollution phenomena in the Augusta-Priolo-Siracusa industrial area of Sicily, where large petrochemical and chemical industries are situated.

The vulnerability maps in regard to these zones are produced and printed (Aureli *et al*, 1989). Pollution from hydrocarbons was reported in 2001. The utilization of the vulnerability maps has been helpful in order to individualize the source and the pollutant flow directions. The maps help to assess real risk for drinking water plants existing in this area and to foresee the drainage of the polluted area.

For several years, in Sicily, the aquifer vulnerability maps are being enhanced and published. They are edited by Unit O.4.17 of GNDCI. They are considered as an "Official" document which has been issued by the Italian "Protezione Civile" and CNR.

This document represents the state of the knowledge of groundwater of a portion of the national territory which is represented in an individual map (1: 50.000). The vulnerability maps has been realized using the method of the intrinsic vulnerability (Aureli *et al.,* 1987a). Every Map provides all the elements (Geology, Hydrogeology, morphology and human settlement) for explaining the presence and the behaviour (within every single or superimposed aquifer) of the watertable in the interested area. The realization procedure of these maps is the classical one for this kind of scientific document.

The real vulnerability of every watertable was evaluated based mainly on the precise estimation of the permeability features (in regards to the areas forming every aquifer), the altitude and the local stratigraphic relationships. The very accurate and detailed survey of the wells, springs and the use of all the involve water bodies has allowed us the control of the local hydrogeological features.

For the completion of the required controls, all the anthropogenic aspects and/or structures were surveyed. The potential sources of local pollution and also those sources which are considered as preferential ways for the spreading of a probable pollution were highlighting. The document, which is constituted by every map, is used for the programs of "Rational Utilization" of the local water resources and their protection.

The use of these maps gets a greater efficacy when a computerized system is used in conjunction with adequate documentation. This system provides for effective updating of the data which are represented on the same map. The "vulnerability maps" have been proved being resolutive for the cases of pollution which have happened locally.

The individualization of a constant polluting source or, occasionally, a partially diffuse source, can be identified easily when there are evidences from grounwater sampling. These sources are surveyed in exact locations and provide convenient geographic references.

Clearly, both the nature and the quantity of discharged pollutant, occasionally or continuously, play a decisive role in the grounwater contamination. An important incident in this field has been occurred in Augusta and Priolo territory (Sicily).

THE STUDY AREA. AUGUSTA AND PRIOLO TERRITORY

The study area is facing the Gulf of Augusta, in the eastern coast of the Sicily Island, where the urban center of Priolo is located. In the Figure 1, the portion of the vulnerability map (Aureli *et al.*,1989) which includes the area in question is reported. This area has been subjected to considerable urban settlement, due to a very important petrochemical plant.

The studies which were presented, about 12 years ago, enable the drafting of the vulnerability map of the "North-eastern Hyblaean area" (where the Augusta-Priolo area is situated), indicated the presence of two aquifers which are partially superimposed (Aureli *et al*., 1987).

The shallow aquifer is constituted by calcarenites and sands and partially cover the deeper aquifer, which comprises limestones and volcanic rocks. Clays separate the two aquifers. These aquifers are recharged from different sources and exhibit different watertables. The two watertables are widely utilized for various uses: drinking water, industrial and agriculture.

The presence of supernatant hydrocarbon has been identified since some years in wells which have been used for irrigation and drinking water. The use of this toxic drinking water should be reported and a warning of its adverse effects issued. In the Map of the Figure 2, the wells (where the presence of hydrocarbons has been verified) are indicated.

It appears evident, by the analysis of the features of above-mentioned wells, that the pollution was spread mainly in the shallow aquifer and, in a less marked way, in the deeper aquifer too. The relationships existing between the two aquifers are locally different: sometimes the two aquifers are separated by impermeable layers which make the deep aquifers artesian; sometimes the relationships are constituted by direct contacts between the calcarenites of the shallow aquifer and the limestones of the deep one (this contact leads to become them into one aquifer);

Sometimes the deep aquifer outcrops and the water table contained in the limestones appears phreatic (Aureli *et al*., 1987).

The complexity of the relationships is due to a Miocene and Pliocene structural deformation which concerned this area, producing horst and graben structures. For the drafting of the vulnerability map, all the elements necessary for the 3-D reconstruction of the two aquifers were identified. The middle static groundwater level was defined. Also the local dynamic groundwater level was measured and it, in some points, pointed out the presence of the cones of depression with values greater than –100 meters down the middle static level. This situation caused the seawater intrusion reported in the vulnerability maps (Figure1).

The hydrocarbon free phase was present in some wells (as reported in Figure 2), and the source of this pollution is being pursued. This contamination remains due to the persistence of the hydrocarbons, even after extended pumping. Since the leakage of hydrocarbons seems to be constant, it is considered prudent to analyse all the hydrocarbon reservoirs existing in the zone mainly the reservoirs located upstream of the polluting wells.

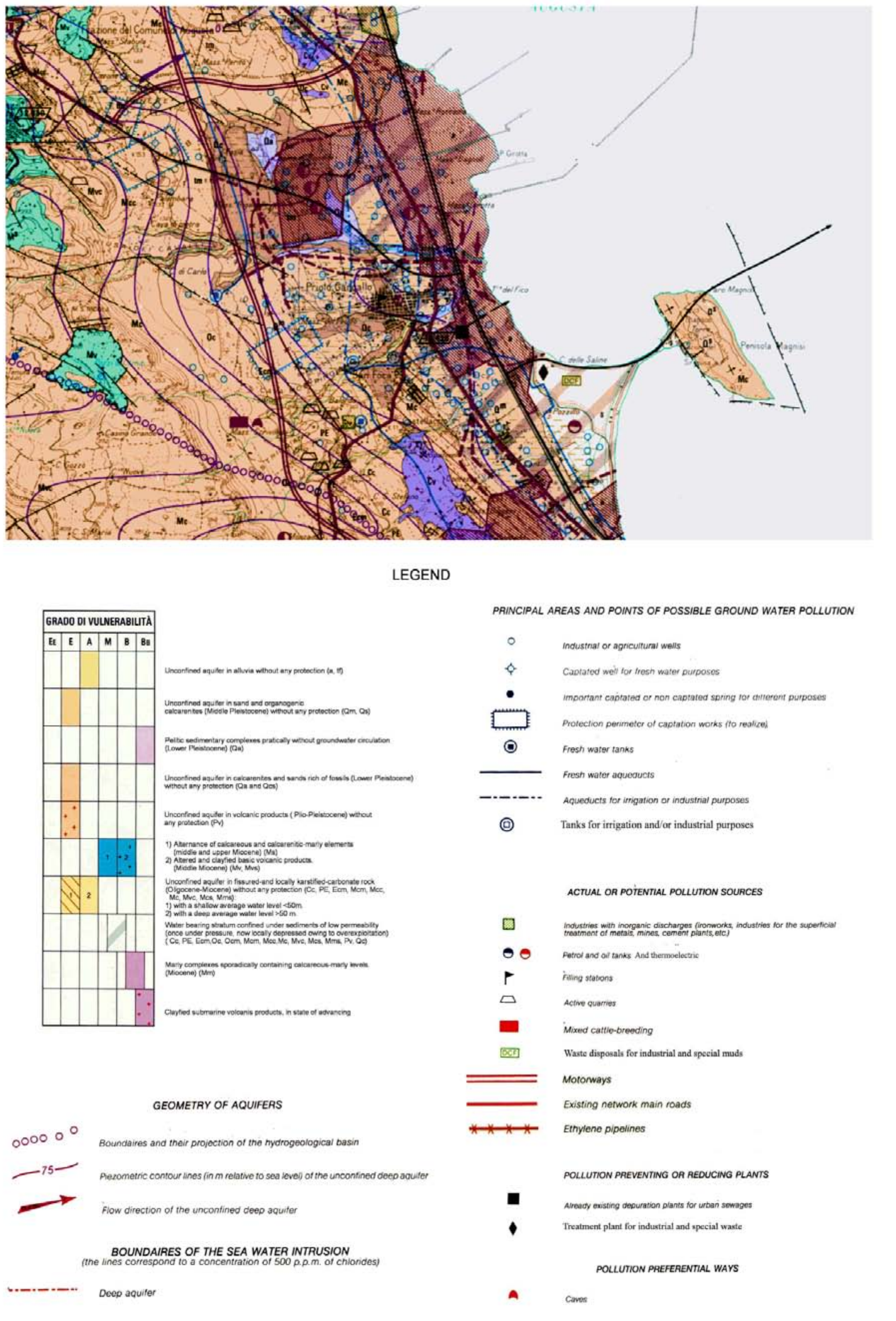

Fig. 1. Vulnerability map of the Aquifers North-Oriental Sicily (Scale 1:50 000).

THE CONTAMINATION PROCESS

The investigation pointed out the existence of a very large industrial reservoir-park (barely well-known for the population), in which are located dozens of reservoirs, everyone with a capacity between 150 000 and 250 000 hectolitres. These reservoirs are used for the temporary storage of coal oils, directly coming from Ragusa and Gela oilfields or discharged by oiltankers in the Augusta Bay, and for the temporary or permanent storage of industrial derivation products from a local refinery. Frequently, extremely dangerous chemicals are stored e.g. chloride, phenol, etc., which the petrochemical industry produces from industrial processes (Aureli *et al*., 1987).

In the vulnerability map is possible to assess the piezometric trend in the two local aquifers and therefore, to obtain a rather precise indication about the flow directions in the two aquifers. The location of the polluted wells was compared with the water flow directions which had been obtained from the trend of the piezometric level. This comparison permitted to localize the probable source of the pollutant to a rather narrow zone.

In the delimited zone, with some spatial variability too, if an occasional detectable leakage of hydrocarbons was verified, it could be easily identified within this defined zone even if some spatial variability was present. In this case, in the upstream hydraulic area of the polluted wells, some very large reservoirs were located. It is practically impossible, both for dimensional and structural reasons, to verify the existence of the leakages from the reservoirs which, even a small percentage of the stored volume, representes a dangerous polluting source. The investigation was refined, comparing the specific nature of the pollutants (i.e. the physico-chemical composition) with the nature of the stored substances at each reservoir.

Since the pollutant leaked only from some reservoirs, it was necessary to determine the origin and transport mechanisms. Apparently it seemed that the investigation had resolved the main question (the source), but by direct observation (free phase in different points) it was evident that the polluting source could be multiple and it was necessary to ask for further investigations to formulate resolute and effective intervention strategies (Aureli *et al*., 1987).

Some reservoirs, located near the polluted wells contained a product which was similar to the found in the polluted wells. Other reservoirs were located in series, approximately along the water flow direction, making the individualization of these reservoirs responsible for the leakage problem. The method of investigation was based on a series of geognostic sounding tests (piezometric and sampling sounding).

They were located permitting the progressively excluding of the various areas in which the reservoir-park could be subdivided. There was the hazard that drilling could cause hydraulic communication between the polluted aquifer and the deeper one. This event had certainly characterized the

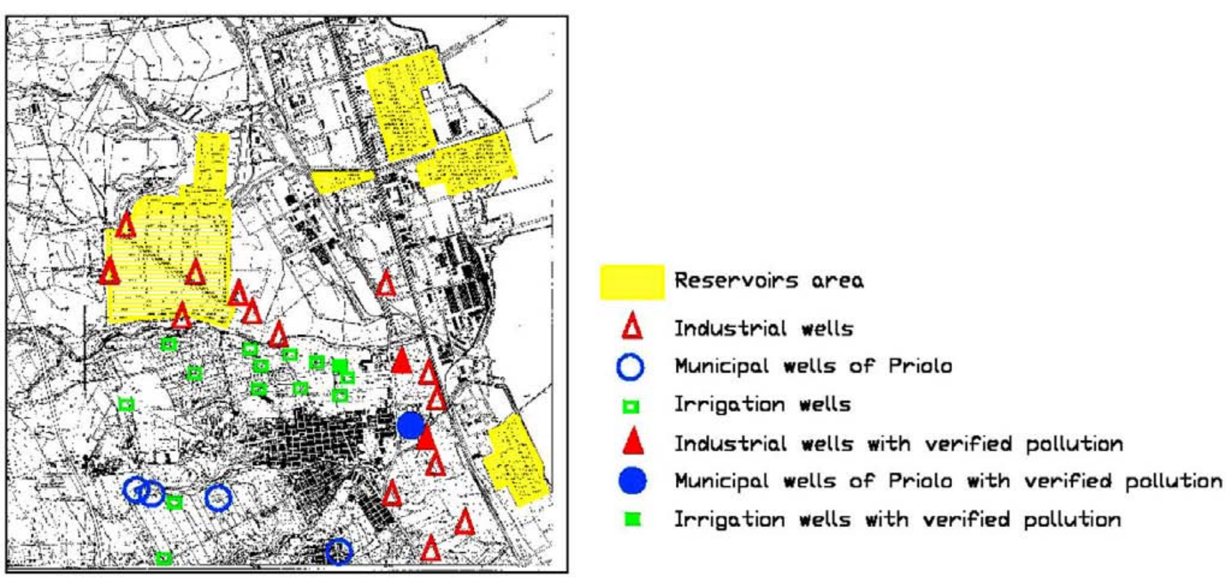

Fig. 2. Reservoirs area and different wells in Priolo territory.

local situation from some existing wells which had not been isolated at various levels. Therefore, there has been particular care for avoiding this hazard.

THE REMEDIATION PROPOSAL

The precise location of the polluting source, i.e. the specific leaking reservoir, enabled the planning of the proposed interventions strategy to be made. These interventions were planned in the following way:

1) Closing and emptying of the leaking reservoir.

2) The achievement of a geognostic and piezometric drilling line, perpendicular to the water flow direction and located between the reservoir and the well at a distance comprising the influence area of the well.

3) The constant monitoring of groundwater from wells and drillings.

4) Pumping test, for determining the depression cone of the polluted well.

5) The storage of the polluted water, extracted from the well in an empty reservoir. This extraction will cause the partial washing of the terrains below; in fact the separation of water and the supernatant product, within the same reservoir, is expected.

6) The continuation of the cycle for the necessary time to verify the progressive decrease of the free phase in the polluted wells.

7) When the extracted water in the reservoir will contain less pollutants than the Italian standard for groundwater, this water will be introduced, by injection, in the drilling line which is indicate at previous point 2.

8) The discharge, extracted from the polluted well, must be carefully evaluated in relation to the chances of storage in the reservoir and the transfer of water to the drilling line.

It is evident that the methods of intervention must be planned on the basis of the obtained data for achieved positive results and not on empiric data which are not tested. The variations which were induced to the local hydrodynamics must be carefully checked. In particular, the recycling of the polluted water between the polluted well and the leaking reservoir must be planned, trying to evaluate the travel times of the pollutant from the reservoir to the well, using hydraulic tracers.

The water recycling will last some time, which may be at least treble the necessary travel time to the transfer. Evidently, during this operation, all the free phase (which the recycling water will bring again on it) will have to be extracted from the reservoir. Part of the polluting substance will remain however in the recycling water. The injected water could have dissolved phases that will be added to the local flows. Such a situation must be evaluated (Aureli *et al.*, 1986).

It is estimated that treble washing cycle can reduce (over 50%) the quantity of pollutant, which will continue to arrive in the well. The washing operation will be repeated until the analyses confirm the quasi-total disappearance of the pollutant in groundwater. However it must be remembered that the hydrocarbons spread in the aquifer (at least for a first time) and therefore, part of pollutant can be transferred downstream of the well; some drillings will permit the concentrations monitoring. The monitoring results can allow to include in the washing cycle (well-reservoir) those drillings located downstream of the principal polluted well. The quality of the polluted water table can be re-established but its recovering will happened rather slowly.

Some of the above mentioned considerations started from local experiences, but these considerations can not be always generalized. There are some specific cases which are more dangerous than others; they are connected with secondary polluted products which have been produced during the chemical-industrial transformation cycles of the hydrocarbons: chloride, phenol, dioxin, etc.

In this case the remediation strategy must be carefully planned. The main objective must be the protection of the quality of the compromised watertable flow, with appropriate barriers, and interventions also on the rocks or terrains constituting the aquifer. Promoting a survey on a worldwide scale will produce a big benefit to the workers of this sector. An initiative like it could be promoted by the participants in this issue.

CONCLUSIONS

The availability of the vulnerability maps has been very helpful and resolutive in the hydrocarbons pollution areas represented in the maps. The vulnerability maps allow the identifying of the pollution causes, the origin of the pollutants and their distribution along the streamline of the water table of interest. Also the drainage and remediation strategies of the area in question can be easily planned using the vulnerability maps. Therefore, it appears evident that the availability of the vulnerability maps is very important in the management of the territory and the prevention of the pollution risk.

Further research must be done related to hydrocarbon residuals, dissolved phases mobility, risks associated to reinjection. The remediation strategy is based on the well-known "pump and treat" scheme.

BIBLIOGRAPHY

AURELI, A. and A. AURELI GRIFEO, 1986. Salt intrusion in a coastal aquifer subjet to overexploitaiton and artificial recharge- 9th Salt Water Intrusion Meeting, Delft maggio 1986- Delft University of Technology 1986, 101-120.

AURELI, A. and F. D'AMBROSIO, 1987. L'elaborazione dei dati idrogeologici ai fini del controllo di gestione di falde acquifere particolarmente sfruttate e soggette al pericolo di intrusione marina – XX AIH Congress, ROMA, aprile 1987 – AIH, Catania 1991, 8 pp.

AURELI, A., G. ADORNI, A. F. CHIAVETTA, F. FAZIO and S. FAZZINA, 1987. Carta idrogeologica di una regione ove sono presenti acquiferi sovrasfruttati – Mem. Soc. Geol. Ital. n° 37, ROMA 1987, 27-34.

AURELI, A., G. ADORNI, A. F. CHIAVETTA and F. FAZIO, 1987. Condizioni di vulnerabilità di acquiferi in zone a forte insediamento industriale di tipo petrolchimico – Mem. Soc. Geol. Ital. n° 37, Roma 1987, 35-52. Pubbl. n° 22 del G.N.D.C.I.

AURELI, A., G. ADORNI, A. F. CHIAVETTA, F. FAZIO and S. FAZZINA, 1987a. Caratteristiche delle linee di flusso dell' intrusione marina influenzate della tettonica in area costiera ove gli acquiferi sono sovrasfruttati – Mem. Soc. Geol. Ital., n° 37, Roma 1987, 481 488. Pubbl. n° 23 del G.N.D.C.I.

AURELI, A., A. P. GATTI, E. KHOCHTCHEVIKOVA and M. ZANONI, 1987. Projet d'études et d'inventions pour la recharge et la protection de l'aquifer côtier dans la plaine de Priolo (Siracuse, Sicilie-Italie) – Séminaire sur la protection du sol et des aquiferes contre la pollution de source non ponctuelle, Madrid, octobre, 1987 – United Nations-Economic Commision for Europe WATER/SEM/. 14/R.38, 12 pp.

AURELI, A., 1987. The Augustas coastal aquifer (Eastern Sicily-Italy) - UNESCO, Groundwater problems in coastal areas. *Studies and Reports in Hydrology, 45,* 557-565.

AURELI, A., G. ADORNI, A. F. CHIAVETTA, F. FAZIO, S. FAZZINA and G. MESSINEO, 1987. Carta della vulnerabilità delle falde idriche. Settore nord-orientale ibleo (Sicilia sud-est)- CNR, Gruppo delle catastrofi idrogeologiche, n°128, SELCA Firenze 1989. Pubbl. n. 128 del G.N.D.C.I.

A. Aureli[1], S. Carrubba[2], G. Cusimano[1], M. Dipasquale[2], N. Mazzurco[2], A.M.G. Privitera[2], C. Silluzio[2], S.Tosto[2] and V. Zingale[2]

[1] *Department of Geology and Geodesy, University of Palermo, Italy*
Email: prof-aureli@iol.it
[2] *Component of the Operational Unit (U.O.) 4.17 of the Italian National Group for the Protection Against Hydrogeological Hazards (G.N.D.C.I.) – C.N.R. Palermo, Italy*