

EXPERIMENTATION FOR A QUANTITATIVE HYDROGEOLOGICAL MAP IN A MOUNTAIN AREA: A CASE STUDY IN THE REGGIO EMILIA APENNINES (NORTHERN ITALY).

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FOREWORD

For the past five years, the Geological, Seismic and Soil Survey has been studying the main aquifers in the Emilia-Romagna Apennines, the mountain area in the southern part of the region. This study includes one research project in particular with distinctly applicative purposes which sets out to build up a semi-quantitative hydrogeological map at 1:25,000, based partly on existing geological and hydrogeological cartography (Plesi and Chicchi, 1999; Panini, 1989; Canedoli et alii, 1994), compiled incorporating the various degrees of permeability of the hydrogeological complexes present in the area, using standard legends (UNESCO and Servizio Geologico d'Italia, 1995).

The area chosen for this experimentation is located in the highest Emilia-Romagna Apennines, corresponding to the Reggio Emilia province. On a regional level, several previous studies in this subject area have already tackled the problem: for example the "Masterplan on geo-environmental hazards" (Viel, De Nardo & Montaguti, 2003) consisting of thematic maps at the scale of 1:250,000. Given the lack of pre-existing, widespread data at regional level, the "Masterplan" maps the main aquifers in mountain areas for the first time. The framework provided by the "Masterplan" could be implemented locally, and this experimentation is carried out with this aim in mind.

GEOLOGICAL FRAMEWORK

The geology of the Reggio Emilia Apennines is characterized by a number of overlying tectonic units having formations with generally low or very low permeability that can be defined aquitards or aquicludes. One exception are the several reservoirs attributable to Triassic evaporites (though yielding groundwater of high salinity or scant value as potable water) and, locally, massive sandstone units of the so-called

"Epiligurian sequence" (Formazione di Pantano, Early-Middle Miocene). There are extensive aquifers associated with quaternary and above all morainic deposits at high altitudes (> 1000 m a.s.l.), situated largely along the Apennine watershed that separates the main Tyrrhenian and Adriatic basins. Within the study area, situated in the high Reggio Emilia Apennines (Collagna municipality), the main aquifer, which is tens of metres thick, consists of coarse grained, debris accumulations of morainic origin (Late Pleistocene), overlying a substratum made up of slices of the "Calcare cavernoso" formation (Triassic evaporites, mostly gypsum), where a local water utility company (Enìa S.p.A.), extracts on average 90 - 100 l/s from main springs (Gabellina and Ponte Barone), with autumn and spring peaks of approximately 120 l/s and summer lows of 65 l/s. These approximated figures clearly reveal that the main problem is how to meet the demand for water during summer months, when availability is lowest but demand is greatest. Average annual rainfall is 1900 – 2000 mm above 1000 m a.s.l. and 1500 mm for locations at approximately 700 m a.s.l.. Smaller yet locally important aquifers are found in the arenaceous-pelitic or arenaceous-marly turbidites of the "Macigno" formation (Late Oligocene-Early Miocene), Arenarie di Monte Modino (Monte Modino Sandstones, Oligocene-Aquitani) and Arenarie di Monte Cervarola (Monte Cervarola Sandstones, Early Miocene). Within these units, springs are aligned with disjunctive faults or follow the overthrust of turbidites on less permeable units (mainly shaly, chaotic units of Cretaceous age).

STUDIES FOR A QUANTITATIVE HYDROGEOLOGICAL MAP: FIRST RESULTS.

Analyses carried out to date deal with the following items:

1) Inventory of springs

In the period 2001-2002 an inventory of springs in the Reggio Emilia Apennines was carried out, as part of a more general database at regional

level; 156 of 662 inventoried springs are to be found in the study area.

2) Structural analysis for hydrogeological purposes.

In the above listed hydrogeological situations, aquifers in fractured rocks are commonly to be found (except for evaporites coupled with moraines). Thus fragile deformation governs hydraulic conductivity locally and groundwater circulation (infiltration pathways) at a wider extent.

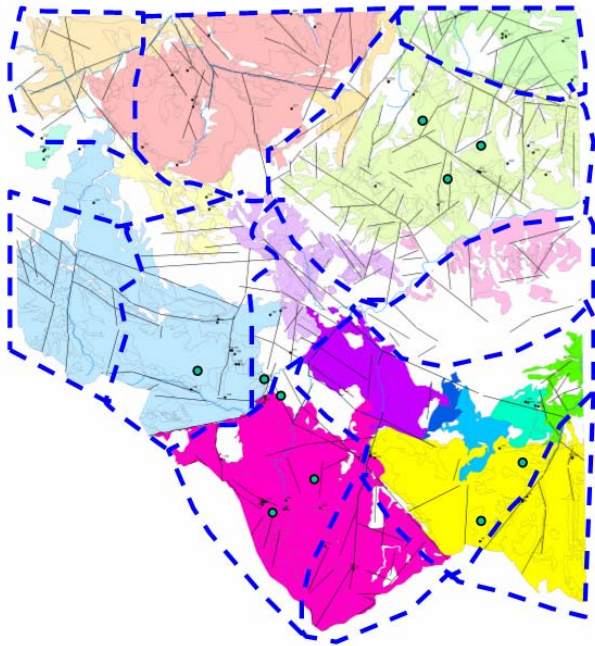


Figure 1

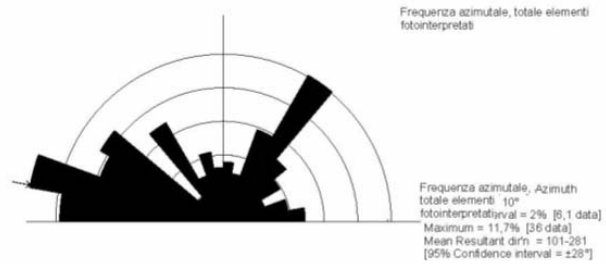


Figure 2

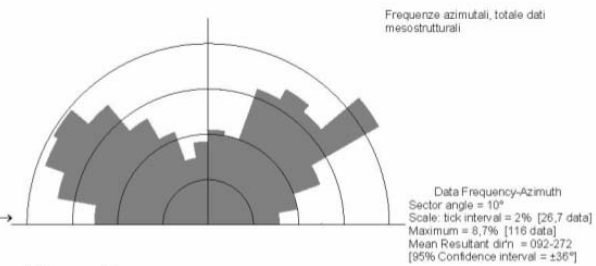


Figure 3

Figures 1, 2 and 3 - Explanations in the text.

On a wider scale (1:25,000 scale), photo-interpreted lineaments have been mapped and eleven “regional” structural domains have been recognized (figure 1, boundaries in dashed lines).

In figure 2, data-frequency azimuth of photo-interpreted lineaments is plotted to be compared with the same diagram, referred to total data-frequency azimuth of directions of planar discontinuities measured at the outcrop scale, for geomechanical surveying (figure 3). Studying fracture systems with different methods according to the scale of observation, it emerges that peak data-frequency follows both an “Apenninic” (approximately NW-SE) and “anti-Apenninic” trend (NE-SW). For this reason, geomechanical surveying has been done; points in simplified figure 1 represent the location of grouped, twenty-four mesostructural stations; nearby the examined outcrops, the main concentrations of springs are to be found. Five mesostructural domains have been pinpointed and local, hydraulic conductivity K has

been assessed according to Snow’s law (1976) with Gemelli (2001) amendments for the Apenninic geological units. These take into account the dilation of fractures due to slope modelling and yield lower values (K values around 10^{-6} / 10^{-7} m/s), in the Arenarie di Monte Cervarola and in the Marne di Marmoreto formations: the former, as well as possessing the highest recorded degree of integrity (70%), are highly resistant to interstitial water passage, indeed, apart from a few springs in correspondence to the base chaotic complexes, there is no other interstitial flow; the latter, on the contrary, possess the lowest RMR value (Bieniawski, 1976), with more evenly distributed springs, but are found in a highly tectonized area (Monte Ventasso).

Values attributable to rock masses that are potential aquifer bodies are those of the “Macigno” formation, at the boundary with the Triassic evaporites (K values around 10^{-3} / 10^{-4} m/s), in the

vicinity of the most significant springs in terms of flow.

It is clear that the degree of rock fracturing, measured on the surface, has a bearing on the possibility of water flow within the rock, although it

does not provide exact K values (overestimated for surface dilation of fractures due to gravity), it amply differentiates relative permeability. These observations will be useful to improve the calculation of local recharge.

Outcrops n°	Formation/Geological Unit	Spring groups	RMR (Bieniawski '76) (%)	Hydraulic conductivity (m/s)
1-5	Arenarie di Monte Modino	Busana – Nismozza - Acquabona	60.30	7.61E-05
6-8	Marne Marmoreto	Nismozza - Acquabona	53.49	4.56E-06
9-16	Arenarie di Monte Cervarola	Oratorio – Cerreto Alpi	67.64	1.20E-07
17-19	“Macigno” - “Calcare Cavernoso” boundary	Berenice - Gabellina	55.88	6.05E-03
20-24	Arenarie di Monte Cervarola	Laghi Cerretani – Caprone – Ferriere – Casenove	59.22	1.62E-04

Table 1 – Summary of resulting parameters.

3) Water budget analysis.

Up-to-date precipitation measurements (for the period 1987-1998) from a number of pluviometric stations (Febbio, Gabellino, Collagna, Ligonchio and Ospitaletto), located in altimetric belts of comparable altitude to that of the main springs, have been collected. Water budget calculation for the Upper Secchia valley has been refined, for a more accurate assessment of Potential Infiltration Coefficient (p.i.c.) values, drawn from previous hydrological studies. The Potential Infiltration Coefficient was obtained from experimental measurement of the low flow along major streams in lithologically homogenous basins. A project currently underway is studying the correlation of these streams with the Basic Flow Index (B.F.I. after AGAC, 1997), which presents values similar

to p.i.c. values in alluvial and morainic deposits and in Triassic evaporitic complexes, but substantially different in arenaceous-marly or arenaceous-pelitic turbidite sequences of the Macigno, Arenarie di Monte Modino and Arenarie di Monte Cervarola formations, namely in aquitards.

4) Thematic mapping

Lastly, a hydrogeological map has been compiled, incorporating all the themes looked at and analyzed in depth by this study, including the geology of the substratum, quaternary deposits and the (inferred) different degrees of permeability of rock masses, a schematic example of which is provided in figure 4.

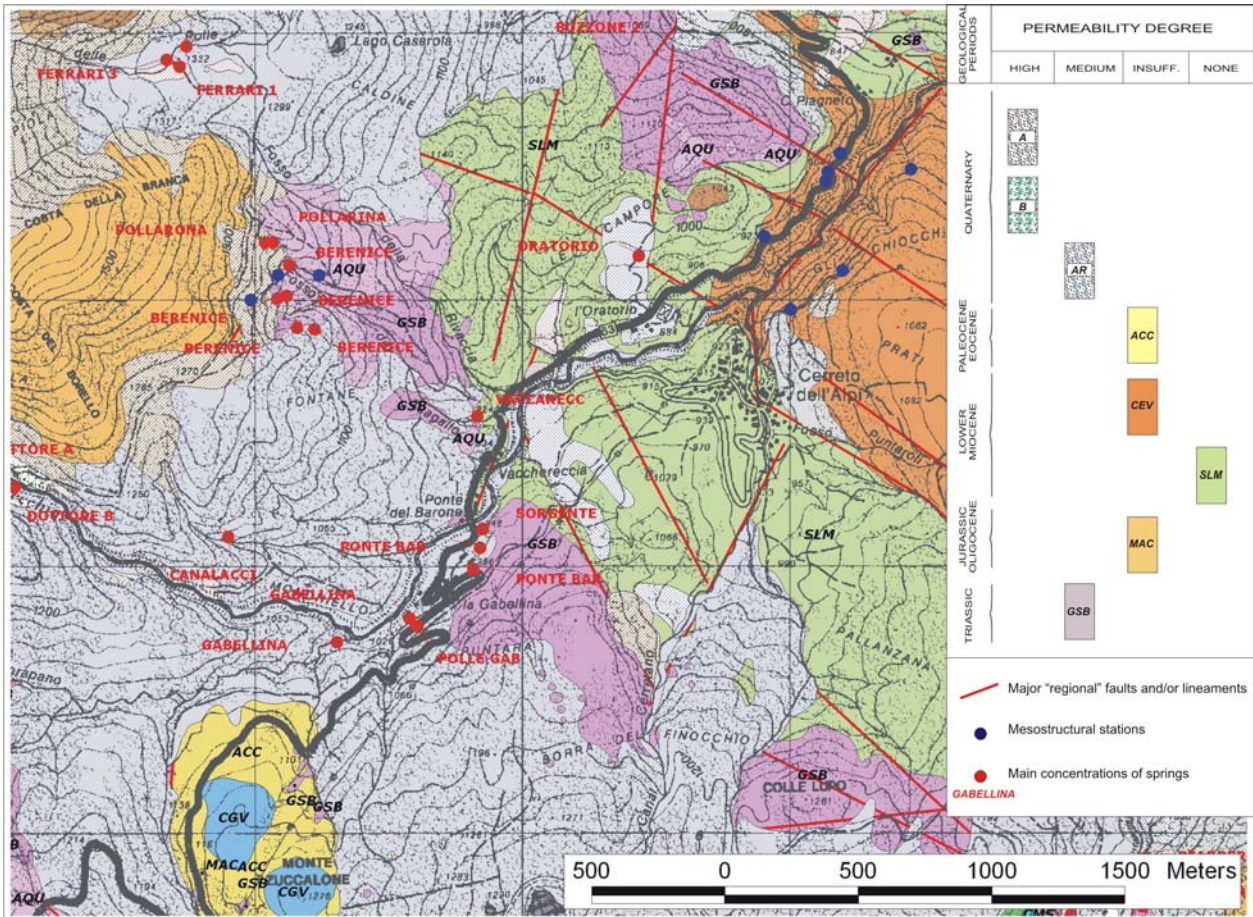


Figure 4 – detail of the new regional experimental, semi-quantitative hydrogeological map. Geological abbreviations with values of $k/p.i.c.$ (m/s - %): **A**) Slope debris and landslide accumulations, $10^{-1} < k < 10^{-2}$ / 40-60%; **B**) Alluvial and alluvial terraced deposits, $k < 10^{-2}$ / 30-40%; **AR**) Morainic deposits, $k < 10^{-3}$ / 15-30%; **ACC**) Shales and limestones, $k > 10^{-5}$ / 5-15%; **CEV**) Arenaceous-marly turbidites, $10^{-6} < k < 10^{-7}$ / 5-10%; **SLM**) Shaly, chaotic Ligurian units, $k > 10^{-7}$ / 2-5%; **MAC**) Arenaceous-pelitic turbidites, $10^{-3} < k < 10^{-4}$ / 20-40%; **GSB**) Evaporites, “Calcare Cavernoso” formation, $k < 10^{-3}$ / 80-90%.

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