WATER DEFICIT AND SUBSIDENCE IN A INTENSIVE-EXPLOITED ALLUVIAL FAN (RENO RIVER, ITALY): SUBSURFACE HYDROGEOLOGICAL ANALYSIS TO SUPPORT GROUNDWATER RESOURCE MANAGEMENT

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THE PROBLEM

The groundwater of the Reno river alluvial fan is the main source of the water supply for the urban area of the city of Bologna (Emilia-Romagna Region, Italy). From the 1960s on, this area experienced a sharp increase in water abstraction by wells, especially for civil and industrial purposes. This had a detrimental impact on the environment, highlighted by a vast, deep cone of depression in the piezometric surface (over 50 metres below ground level), which was identified by the regional monitoring network as early as 1976, and still exists today. Analogously, subsidence rates of up to 5 centimetres per year (i.e. 20 – 30 times higher than normal) have been observed in the past and indeed continue to be observed.

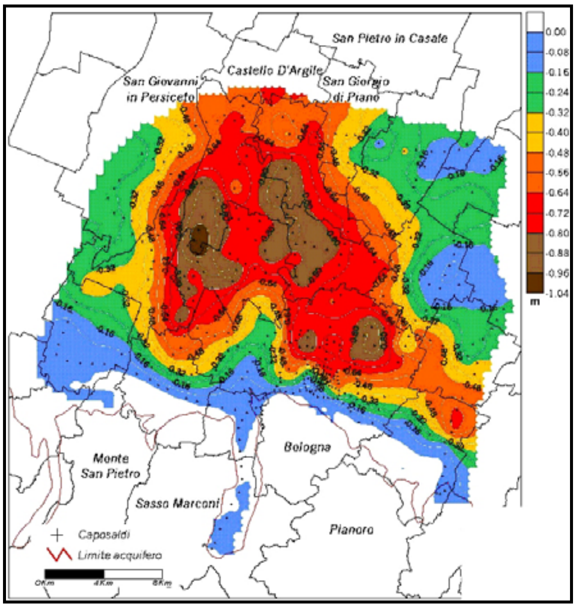

Figure 1 - Land-lowering (meters) of the Reno River alluvial fan during 1983-1999.

The study presented here provides an update on an ongoing project undertaken by a group comprising public bodies and water utility companies. To date, the vast amount of data and information made available through this project has enabled us to create a groundwater flow model and a subsidence model of the entire alluvial fan. The ultimate aim of the project is to utilize the information obtained from these models to achieve better groundwater resources management.

METHODS

The study area in question measures approximately 400 km2 and involves sediment up to 500 metres thick. It has been analyzed using a complex network of geological sections and subsurface maps which have enabled us to develop a three-dimensional geological model of the Reno river alluvial fan. The apical part, at the valley mouth of the river, is characterized by amalgamated gravel bodies which form a single monolayer unconfined aquifer approximately a hundred metres thick. Further downstream towards the open plain, the presence of continuous-surface argillaceous layers has lead to the development of a series of aquitards and confined aquifers. Such a hydrostratigraphy framework is in agreement with the regional aquifers architecture illustrated by Regione Emilia-Romagna & Eni-Agip (1998). The integrated study of geological and hydrogeological information has enabled us to create a model of the aquifer of this alluvial fan.

To allow mathematical modelling of the study area, the latter was divided into a grid with 70 levels vertically and a number of units measuring 500 metres on the horizontal plane, for a total of over 100,000 cells.

Through geostatistical elaboration, accurately and constantly checked against the recognized geological model, reference lithology and hydrogeological parameters were attributed to each cell.

Subsequently a transient three-dimensional groundwater flow model was created for the 1983–1998 period. Model calibration was carried out by comparing calculated piezometric surfaces with those actually measured in the same period in the 40 wells of the regional monitoring network.

In terms of the hydrogeological balance, it emerged that the average recharge from the surface excluding lateral fluxes (1.63 m^3/sec), in the modelling period, is less compared to abstraction by wells (1.78 m^3/sec). This implies a reduction in the fan's storage, reduction of water flux towards the boundaries, and a resulting widening of the cone of depression in the piezometric surface. The reduction of water flux towards the west side was so high that a flux inversion has been detected, showing a certain amount of water captured from out of the system.

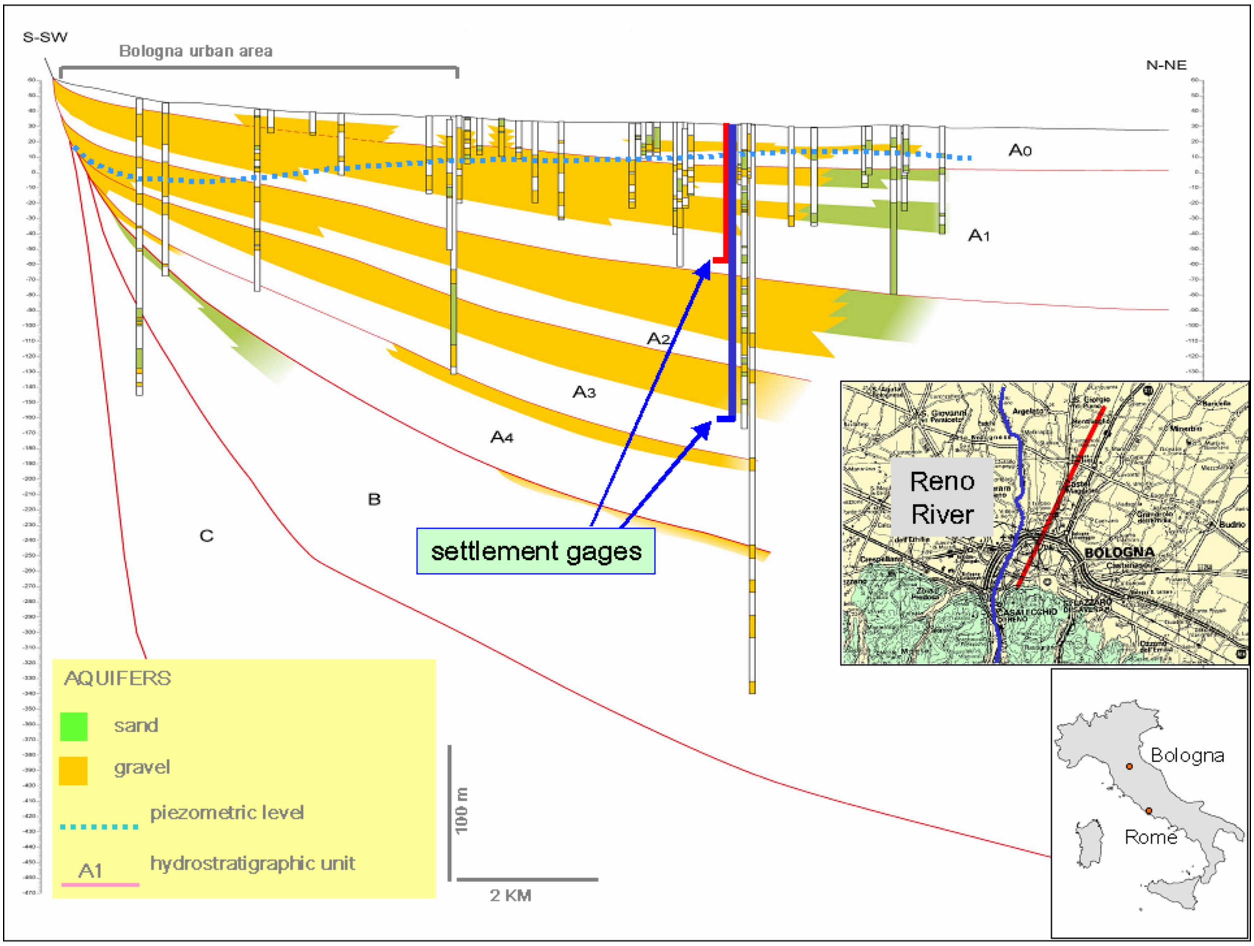

Figure 2 - Geological cross-section (red line in the plain view) describing the subsurface hydrostratigraphic framework and the location of settlement gages for subsidence monitoring. The blue line shows the piezometric level along the section; note the drop due to groundwater pumping in Bologna city

For the subsidence model, spatial discretization of the flow model was utilized; some data was taken directly from the flow model (hydraulic head, permeability and porosity), while other data was attributed to the entire domain (e.g. compressibility). Calibration was carried out by comparing calculated values with data from the numerous monitoring networks and the five settlement gauges located in the area, two of which were installed specifically for this study.

RESULTS

The modelling outlines the extent to which the various aquifers contribute to subsidence. The greatest contribution appears to come from the uppermost portion (the first 100 metres, approximately) characterized by many abstracting wells, even though individual withdrawal values are modest, and by the deepest portions (from 300 to 450 metres, approximately) which are affected by withdrawals by water utility companies and industry. These two intervals alone account for approximately 25% of overall calculated subsidence.

The debate about how to use the results of this modelling to improve groundwater resource management is still ongoing. Among factors that need to be considered, we must bear in mind the uncertainty of modelling, accentuated in this case by the sheer size of the study area and, as a result, by the complexity in the data control. Despite these limitations, we were able to define, and indeed share with key operators and planners of water management, the critical nature of the problem and to formulate a quantitative assessment. A model-based water balance statement was compiled and we were subsequently able to predict the effects of measures taken to reduce abstraction. In particular, a tool was developed that makes it possible to forecast future subsidence situations depending on various strategies adopted to correct the use of groundwater.

REFERENCES

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