Groundwater numerical modeling of the Bientina-Cerbaie aquifer system as a tool for water management

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Aquifer mismanagement may have negative impacts on the quali-quantitative status of the groundwater resource, especially in areas where severe conflicts on water use among various stakeholders take place. In this context, relying aquifer exploitation just on the concept of equilibrium given in the traditional water balance (sustainable development=rate of natural recharge) may lead to aquifer overexploitation or even groundwater mining *("the water budget myth"*; Bredehoeft, 2002). This because the increased recharge and decreased discharge induced by pumping introduces an error related to the modification of the aquifer steady-state (Zhou, 2009).

Since groundwater numerical modeling allows the evaluation of response dynamics of groundwater systems, it constitutes a reliable methodology to rigorously cope with the above-mentioned topic. Groundwater numerical modeling using the USGS code MODFLOW-2000 (HARBAUGH *et alii*, 2000) was applied to the groundwater system of Bientina- Cerbaie (Tuscany, Italy), where several well fields supply groundwater for drinkable and industrial uses, within the LIFE06 ENV/IT/255 Action for Systemic Aquifer Protection project (ASAP, 2010). The study area presented during the last 10-20 years phenomena such as continuous water-level drawdown, water quality deterioration, subsidence; all these indicators may be related to aquifer overexploitation (CUSTODIO, 2002). The main aim of the analysis was:

- to evaluate the transient state of the aquifer system,
- to investigate the provenance of the recharge induced by pumping,
- to estimate the impact of a reduction of pumping rates of the drinking water wells on the aquifer head,
- and to test the use of the model as a groundwater management tool.

The geometry and hydrostratigraphy of the aquifer system was conceptualised analysing about 300 stratigraphic data and hydrodynamic parameters available from pumping tests (Fig.2). Several uncertainties arose already at this stage due to the reliability and distribution of stratigraphic data coming from different sources, and to the scarce number of hydrodynamic parameters available compared to the study area vertical and horizontal extension. Because of that, applying the principle of parsimony (HILL & TIEDEMANN, 2007) and following previous interpretation (AGUZZI *et alii*, 2006; BALDACCI *et alii*, 1994), the hydrogeological system was simplified in three main hydrostratigraphic units (HU):

- HU1: clayey to peaty fine deposits;
- HU2: *Conglomerato del Serchio* (gravel) and *Unità delle Cerbaie* (mainly sands and gravel);
- HU3: silty to gravelly sediments Early Pleistocene to (Early?) Middle-Upper Pliocene in age.

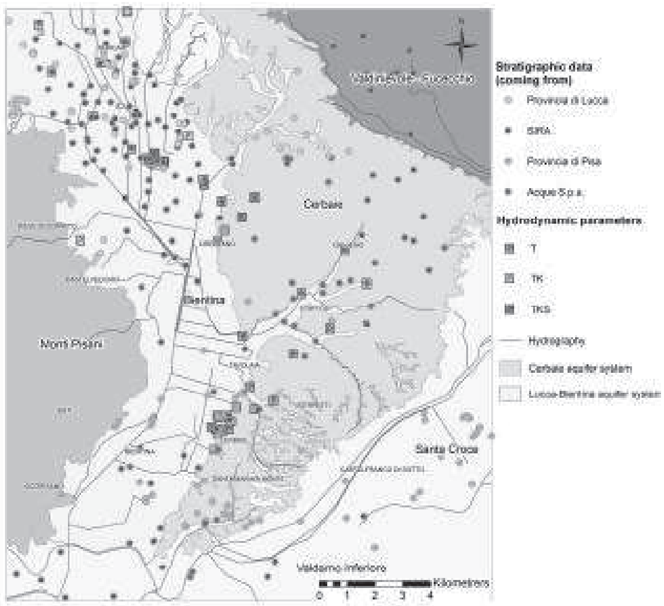

Fig. 1 – Study domain, stratigraphic data and hydrodynamic parameter distribution.

No data were available about the depth at which a no-flow boundary at the bottom of HU3 could be identified. Hence, the model bottom was set at depth of -150 m a.m.s.l. This assumption was tested to evaluate any impact of the bottom domain boundary condition on the outflow due to pumping rates in the study domain. At such a depth we estimated that it was not affected by any inflow or outflow bottom boundary.

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The conceptual model was translated into a numerical one by means of a grid of 21.0x17.5km, with 100x100 m cells, refined to 25X25 m in the areas of well fields, and three layers, one for each HU. Because of the lack of a regional sketch of the groundwater flow field, assigning boundary conditions was not a straightforward operation. Based on few field studies and on hydrological considerations, we inferred the missing hydrodynamic limits. Boundary conditions were then defined as following:

- inflow from the Lucca aquifer from the northern limit;
- outflow to the Valdinievole-Fucecchio and the Valdarno inferiore-Santa Croce aquifer system on the North/East-East side;
- inflow from the Monti Pisani; and
- outflow from the Bientina plain to the Arno River aquifer system.

Transient simulations, using 15-day time steps, were performed, calibrated and validated for the period January 2003-September 2009, starting by a general steady-state simulation referred to Autumn 2002 (Fig. 2). Results were obtained both for head distribution in time and space during the investigated period and the inflow and outflow from the analysed system. The model solution well represents the groundwater flow field where it was known by previous studies (ASAP, 2010) and it provides head distribution for areas where the flow field is still unknown (i.e. the Cerbaie domain). Results also show that a joint effort in planning the water use is required in some part of the domain, as i.e. in the Porcari area. A 10% reduction in pumping rates at the Cerbaie well field produced a simulated head raise of about 0.3-0.5 m. The latter was in good agreement with head values monitored during the ASAP project, when a real pumping rate reduction took place.

Anyway, because of all the above-mentioned uncertainties within the conceptual model, quantitative flow evaluations may only be considered as preliminary outcomes. Defining reliable and validated boundary conditions, especially on the eastern side of the domain, becomes a crucial step in estimating the water budget or prior to perform predictive simulations, i.e. at Porcari or Cerbaie well field area. Then, before setting any water management scheme, based on unrealistic assumptions, it is necessary that governing authorities finance field work (mainly in terms of hydrostratigraphic and hydrodynamic investigations), as large part of the domain is still not known by an hydrological point of view.

This study shows that we require modeling tools, not only to get quantitative estimates useful for water planning, but also to guide further hydrological investigations and to get the maximum from data obtained by direct or indirect field investigations. Thanks to its capability, groundwater modelling should be an ordinary methodology applied by the water authorities to plan and to manage the water resource, especially in areas where complex withdrawal schemes are present and a continuous new equilibrium is reached.

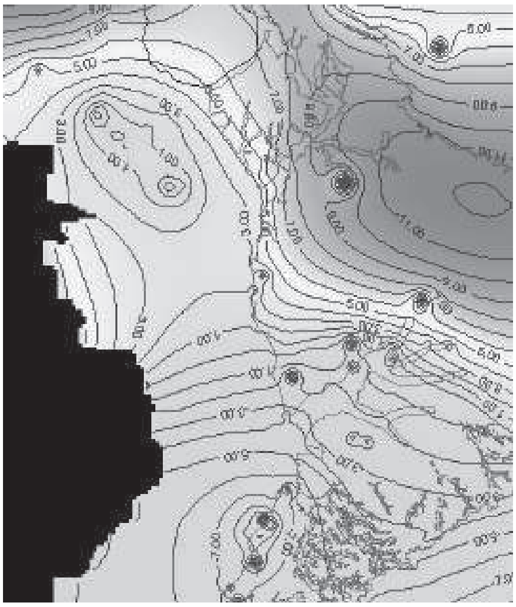

Fig. 2 – Computed head in the steady state simulation related to a general condition of the groundwater flow field in Autumn 2002.

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