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Simulation modeling for groundwater safety in an overexploitation situation: the Maggiore Valley context (Piedmont, Italy)

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Abstract

The Maggiore Valley well field plays a fundamental role in supplying drinking water to a large territory of the Piedmont (North-western Italy). However an increasing water demand have led to the overexploitation of groundwater resources: this situation caused a progressive drawdown of the piezometric level (locally up to 0.8 m/year), a spatial reduction of the artesian zone, a local land subsidence and well damages. The main intent of this study is the development of a groundwater flow model of the area for analyzing the aquifer response to various pumping strategies. The groundwater flow simulation, achieved by the application of the MODFLOW code, was calibrated satisfactorily. Then the groundwater response to four scenarios was simulated, in order to suggest the best option to mitigate the problem. In three cases a withdrawal decrease of 110 l/s has been simulated, considering or not the re-location of some wells out of the well field zone of influence; moreover a significant withdrawal reduction of 150 l/s, as a result of the possible connection with the water supply of the Monferrato Aqueduct, located north of the study area, was simulated. All the simulations provide an increase of the piezometric level, even up to 30 m. Nevertheless the most promising management strategy for the Maggiore Valley well field is the connection with Monferrato Aqueduct: indeed the piezometric level rises up to 25 m without the necessity of drilling of new wells.

Keywords
Groundwater overexploitation, environmental impact, scenarios, hydrogeologic model, MODFLOW, Italy

1- Introduction

Groundwater is renewable in very long times and in the last decades it has been more and more exploited, even overexploited. The forecasts of water availability per person in 2025 show that at least 40% of the world's 7.2 billion people will face serious problems with obtaining freshwater for agriculture, industry or human health (Gleick 2001). Moreover, according to IPCC (IPCC 2007) and Mediterranean Groundwater Report (Mediterranean Working Group 2006), climatic change and rising of temperature in the next decade will involve especially Mediterranean countries, among which Italy .

Many aquifer have already reach a condition of overexploitation: an aquifer is considered as overexploited when some persistent negative results of aquifer development are observed or perceived, such as continuous water level drawdown and quality deterioration (Custodio 2000a; 2000b). In addition overexploitation is often linked to negative and undesiderable economic, ecological, social and political results (Custodio 2000a; 2000b). Main environmental processes occurring under aquifer overexploitation conditions include groundwater table drawdown, subsidence, attenuation and drying of springs, decrease of river flow and increased pollution vulnerability (Esteller and Diaz-Delgado 2002).

Groundwater overexploitation situations are present at global scale (Bromley et al. 2001; Changming et al. 2001; Dijon and Custodio 1992; Esteller and Diaz-Delgado 2002; Hani et al. 2006; Johnson 1993; Kallioras et al. 2010; Kouzana et al. 2009; Ma et al. 2011; Uchuya 1993). In Italy groundwater overexploitation situations are evident, especially in coastal aquifers (Alberti et al., 2009; Ambrosio et al. 2009; Avanzini et al. 1997; Barazzuoli et al. 2008; Ghiglieri et al. 2012; Licciardello et al. 2011; Lugoli et al. 2011; Righini et al. 2011; Sappa et al. 2005; Tulipano and Fidelibus 2002).

In Piedmont region (north-western Italy), it is possible to observe a relevant situation of overexploitation in Maggiore Valley well-field. The Maggiore Valley well field plays a fundamental role in supplying drinking water to a large territory of the Asti province. The withdrawals are consistent, in continuous increase: from 1996 to 2009 the extraction from deep aquifer has passed from about 13,400,000 m^3/year to 14,400,000 m^3/year, with a growth of about 1,000,000 m^3. The intense exploitation of groundwater, begun in the early XX century, led to a situation of overexploitation of the area, evidenced by lots of negative results: first of all the drawdown of the piezometric level that, since 1920 (Sacco 1924) to nowadays, reduced of about 50 m. (Beretta et al. 1999; Caviglia 2011). At the end of XIX century the piezometric levels of Maggiore Valley wells was 10 metres above the topographic surface. The increasing exploitation of these groundwater resources led to the progressive deepening of the wells drills and to the piezometric level drawdown. The piezometric level decreased particularly in Maggiore Valley and near valleys, where aquifer is heavily exploited. In Fig. 1 the increasing groundwater withdrawal in Maggiore Valley and the repercussion on piezometric level are schematically represented from 1925 to nowadays. In Fig. 2 the continuous decreasing trend of piezometric level is shown, in a monitoring well in Cantarana town (Maggiore Valley). The tendency shows that water level has not reached yet a steady state. The drawdown of piezometric level in Maggiore Valley is measured in about 0.8 m/year.

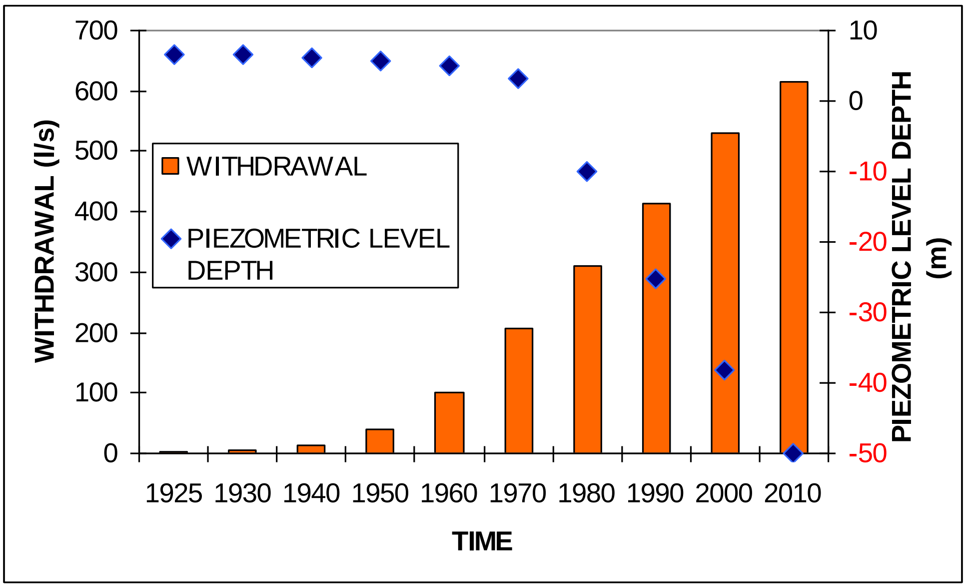


Fig. 1 Variation in groundwater withdrawal and piezometric level depth in Maggiore Valley well field from 1925 to 2010.

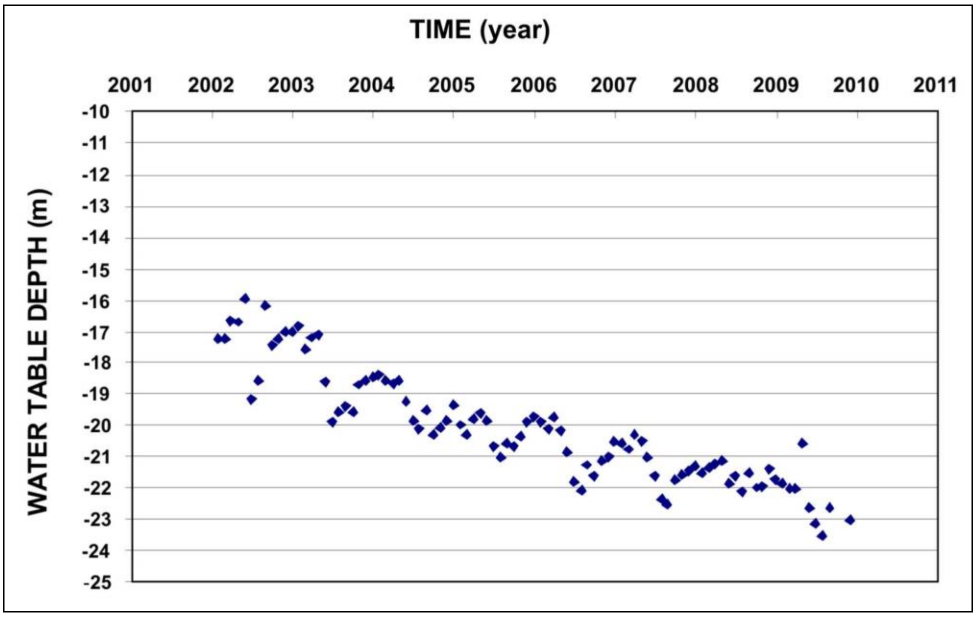


Fig. 2 Deep aquifer piezometric level drawdown, registered by a monitoring point in Cantarana town from 2001 to 2010. This figure shows that water level has not reached yet a steady state. The total drawdown is of 6 meters, and the average yearly drawdown is of 0.8 meters.

The situation of intense groundwater pumping from wells, concentrated in a restricted area, is also complicated by the hydrogeological structure, because of the presence of impermeable boundaries, represented by clayey and marly units; these complexes don't allow a significant aquifer recharge.
Moreover in the early XX century a large artesian area could be identified, with a piezometric level 20 m higher than the ground surface; then, the drawdown of the piezometric level due to pumping wells made the artesian area gradually disappear: today it has significantly contracted, remaining only in the northern sector of the well field. The high drawdown of piezometric level has, moreover, a negative economic consequence that is wells damage, resulting from local land subsidence. However, Maggiore Valley well field is strategically important, as it serves 43 municipalities, including

the city of Asti with about 76,000 inhabitants. Furthermore the deep aquifer is the only source of water for human consumption in the area.

Hence it is necessary to keep in business the well field, while preserving the groundwater and mitigating the negative effects. The main aims of this study are to evidence how to attenuate the negative effects connected to excessive extraction, describe possible solutions and suggest the best option in order to mitigate the problem. A numerical modelling was used, hypothesising different scenarios with different withdrawal and localization of wells.

2 – STUDY AREA

The study area is located in the Piedmont region, north-western Italy (Fig. 3). It is sited mainly in Asti province, and subordinately in Torino and Cuneo provinces, and it covers about 1000 km^2. The area can be splitted, on the basis of topography, in three sectors: the western portion is a part of Po plain, the largest plain in Italy; the central part is referred as to the Poirino Plateaux, with a sub-flat morphology; the eastern sector, that comprises Maggiore Valley well field, has a hilly morphology and is defined as Monferrato.

The Maggiore Valley well field consists of 41 aqueduct wells (37 active) from which approximately 15,000,000 m^3/year of groundwater is extracted; the wells, concentrated in a very small sector (about 3 km^2), give drinking water to 40 municipalities of the Asti province, with a total pumping rate of about 750 l/s, and about 50% of the withdrawal is necessary only for Asti city. Because of the lack of other relevant sources of drinking water in this part of Piedmont region, this well field represents a drinking water reserve of regional importance (Lasagna et al. 2011).

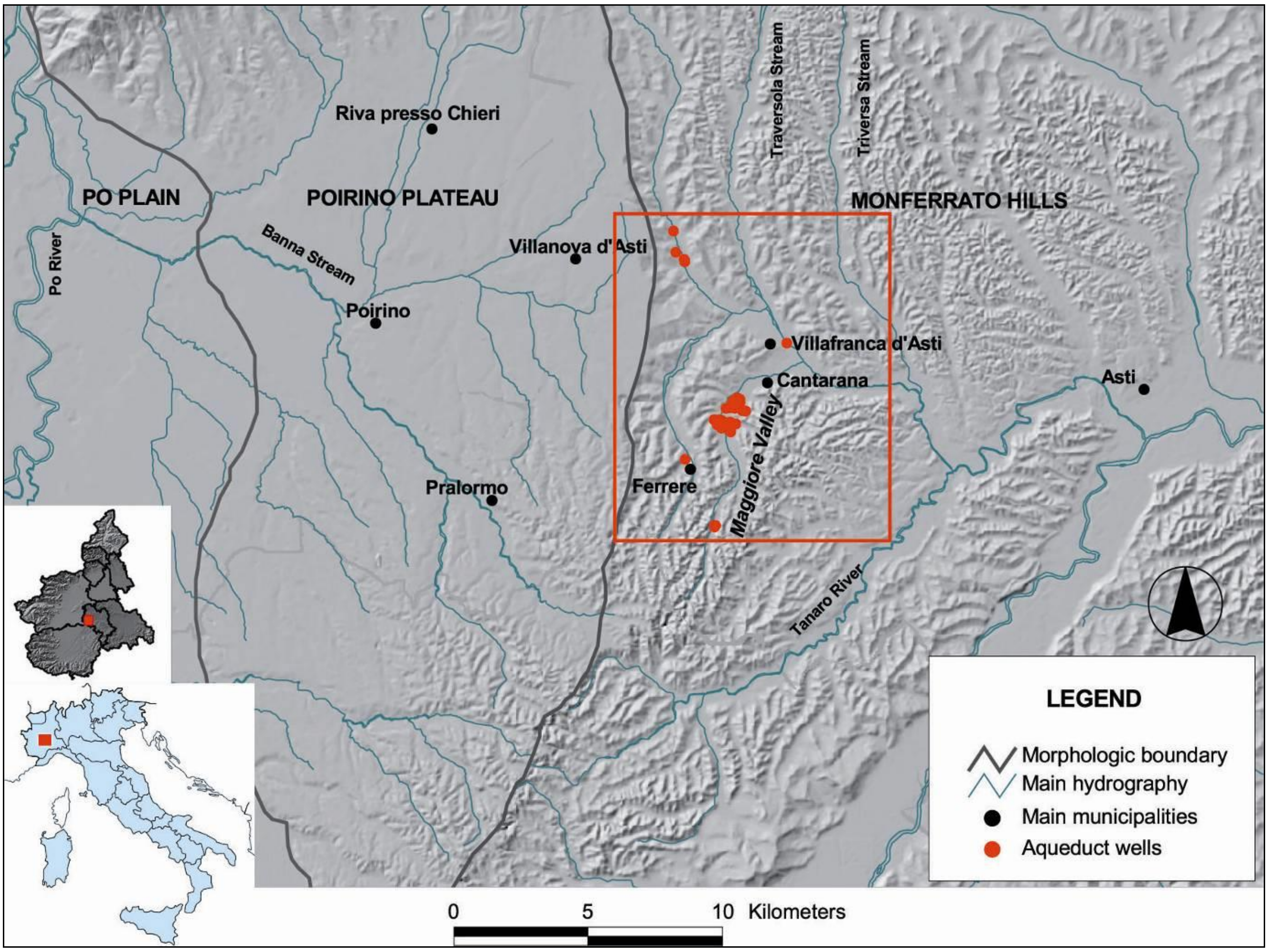


Fig. 3 The study area (north-western Italy). The red rectangular area shows Maggiore Valley well field area.

3 – CONCEPTUAL MODEL OF THE GROUNDWATER SYSTEM

This section provides a generalized description of the hydrogeologic framework of the groundwater system (the conceptual model) of the study area, including descriptions of the lithologic and hydrologic characteristics of the hydrogeologic units.

3.1 Hydrostratigraphic setting

From a hydrogeologic point of view, in the studied area were identified six hydrogeologic units Bortolami et al. 1969a; Bortolami et al. 1969b; Beretta et al. 1996; Beretta et al. 1999; Vigna et al. 2010; De Luca et al. 2011) (Fig. 4):

- Quaternary gravelly-sandy unit
- Pleistocenic silty-sandy unit
- Villafranchian sandy-silty alternations unit
- Pliocenic sandy unit
- Pliocenic silty-clayed unit
- Pre-pliocenic clayed-marly unit

Quaternary gravelly-sandy unit

It includes the alluvial gravelly-sandy deposits of the Torino-Cuneo Plain, belonging to middle Pleistocene-Holocene. This unit is characterized by a high permeability, and a variable thickness: the highest thickness of this deposit was detected in correspondence of the Po river bed, where it is about 50-60 m. This complex hosts a shallow aquifer, in which the water table is directly connected to the hydrographic network.

Pleistocenic silty-sandy unit

It is represented by post-villafranchian deposits (middle Pleistocene), which make up the Poirino Plateau top, in the central zone of the study area. It is made by silty or silty-clayey, sandy and gravelly deposits, locally overlapped, with a thickness variable from 10 to 30 m. This unit is characterized by the presence of a shallow unconfined, locally semi-confined aquifer located in the gravelly sandy deposits.

Villafranchian sandy-silty alternations unit

The Villafranchian sandy-silty alternations Unit (Forno and Boano 1996; Carraro 1996) is characterized by fluvial-lacustrine-delta deposits, with an age comprised between Middle Pliocene-Lower Pleistocene. It is composed by alternations of silty-clayey semipermeable or impermeable layers and sandy-gravelly permeable layers. These deposits have the highest thickness in the central and in the south-western sectors of the study area, where it has a thickness up to 200 m. The thickness becomes lower and lower towards the northern and the eastern sectors. This unit represents a multilayer aquifer, in which water is hosted in the gravelly-sandy permeable layers.

Pliocenic sandy unit

It is represented by mainly sandy deposits of the *Sabbie di Asti* and the overlying deposits of *Unità di Ferrere* (Carraro et al. 1996). The *Sabbie di Asti* consists of marine pliocenic deposits of yellow coarse sands, with shallow-sea fossil layers, more or less stratified, sometimes very hardened; these deposits are alternated with levels of fine sands, clayey sands, local sandy-gravelly lenses, silty-sandy layers and silty-clayey layers. The *Unità di Ferrere* constitutes a body with a thickness between 5 and 35 m, increasing from north to south. It consists of coarse sands, generally cross-stratified, often highlighted by fossils of marine bivalves; it sometimes contains rare interbedded gravelly-sandy layers, with an average diameter of between 2 and 4 cm. Locally it contains fragments of fossil vertebrates. The Unità di Ferrere shows relationships of interdigitation with the *Sabbie di Asti*. This unit has the highest thickness in the western sector of the study area, where it is about 500 m thick, while it has a lower thickness towards the eastern sectors of the study area. In the area of Maggiore Valley it has a thickness of about 150-200 m. The alternation between sediments with good permeability with low permeability levels gives this complex characteristics of an multi-layered aquifer system, in the following called “deep aquifer”. Locally artesian phenomenon is observed in the study area.

Pliocenic silty-clayed unit

This unit is composed of pliocenic clayey and silty deposits described as *Argille di Lugagnano*. It is represented by deposits of marine origin with a fine grain size, like clays and silts, clayey marls and sandy marls with plenty of marine fossils. These deposits, characterized by low permeability, represent a wide and continuous aquiclude.

Pre-pliocenic clayed-marly unit

This unit is made up of a great variability of deposits, of pre-pliocenic age, mainly marly, sandy, clayey, and conglomeratic deposits, very consolidated. They are characterized by very low permeability and for this reasons they don’t contain significant aquifers. They reach the highest thickness in the north-eastern sectors of the study area.

In the study area two kind of aquifers can be identified: a shallow aquifer, hosted in the quaternary gravelly-sandy unit of the Po Plain and in the pleistocenic silty-sandy unit of the Poirino Plateau top, and a deep aquifer, hosted in the pliocenic sandy unit and in the villafranchian sandy-silty alternations unit.

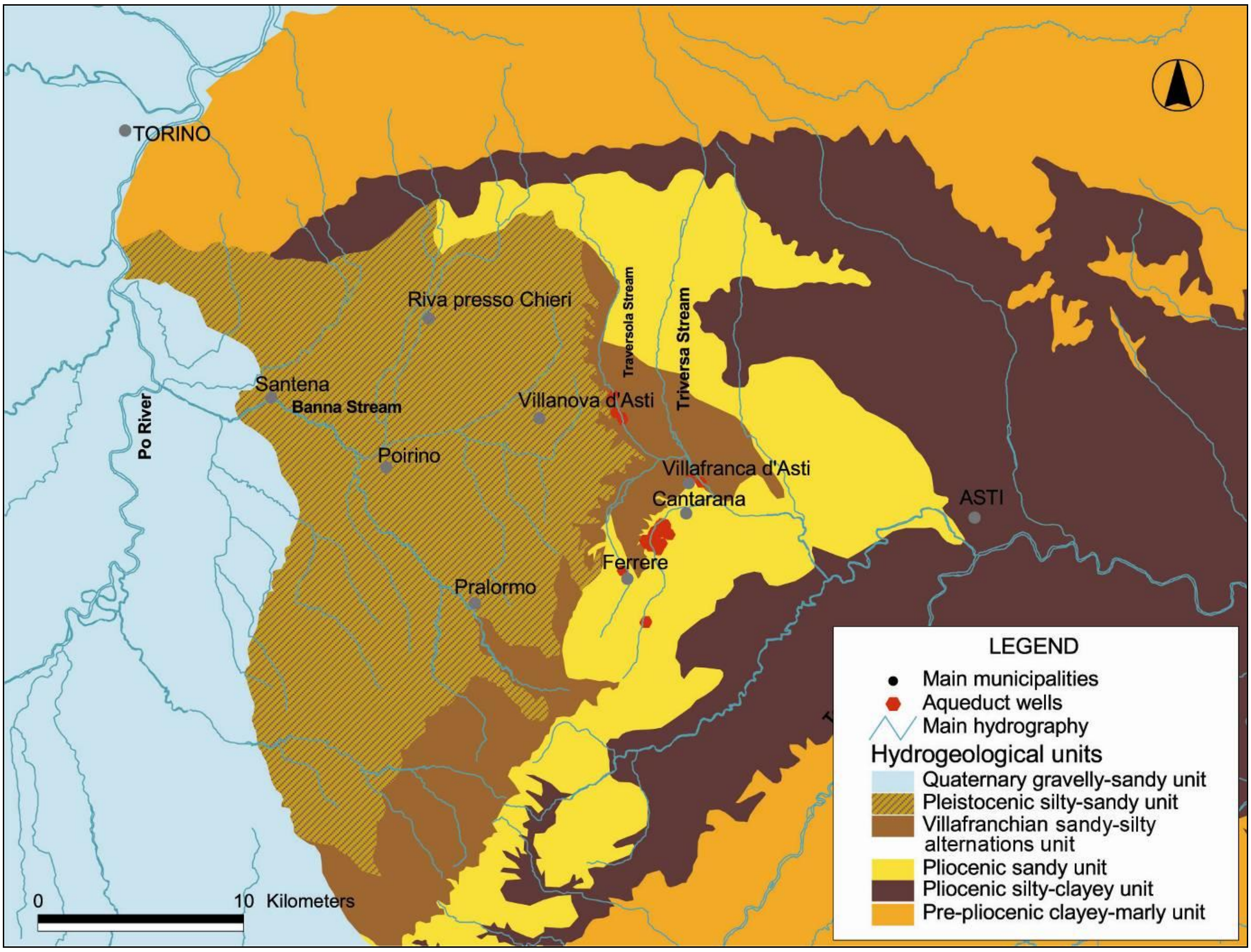


Fig. 4 Hydrogeological units map of the study area.

3.2 - Piezometry of the deep aquifer

The piezometric map of the deep aquifer has been reconstructed by interpolating the groundwater head data collected from 49 wells in the study area. In details the measurement points are 47 irrigation, public supply, industrial supply, private domestic wells and 2 piezometers. The artesian flow was observed in 11 wells. Groundwater levels were monitored between August 2008 and August 2009. Kriging interpolation algorithm was used to interpolate the piezometric data.

The seasonal fluctuation of piezometric level was evidenced through quarterly monitoring campaigns in 4 wells in the period October 2008–October 2009. Moreover continuous piezometric level registration was conducted in 2 wells in the period October 2008 – March 2010 using Mini-Diver datalogger.

The piezometric map of the deeper aquifer is shown in Figure 5. In the wide area around the Maggiore Valley, the water depth is very variable, varying from + 6 m in the artesian area to – 70 m in Poirino plateaux. The groundwater flow is generally directed from west to east; the piezometric surface shows a pronounced cone of depression in the well field, because of the intensive groundwater pumping. The magnitude of the hydraulic gradient in the deep aquifer ranges from a minimum of 1 ‰ in Poirino plateaux to a maximum of 10% in Maggiore Valley well field.

On the basis of the hydrogeological conceptual model (Fig. 6), the recharge area of the deep aquifer is located toward the Po Plain, west of the study area; most likely the deep aquifer is recharged by Po river (Beretta et al. 1996). In this sector recharge is enhanced by highly permeable Quaternary gravelly-sandy unit deposits, and by the predominance of Villafranchian unit deposits with grain coarse size.

As for the seasonal fluctuation of piezometric level, it is minimum in August 2009 and maximum in May 2009. In the study area the fluctuation varies from some cm to some dm. In Porino plateux piezometric level varies of 4 m between May to August 2009.

Shallow aquifer is strongly influenced by the topography and, contrary to deep aquifer, the superficial aquifer is generally directed westward (Beretta et al. 1996; Bove et al. 2005). This aquifer is recharged by precipitations and locally by superficial waters. The River Po acts as drainage in the western part of study area.

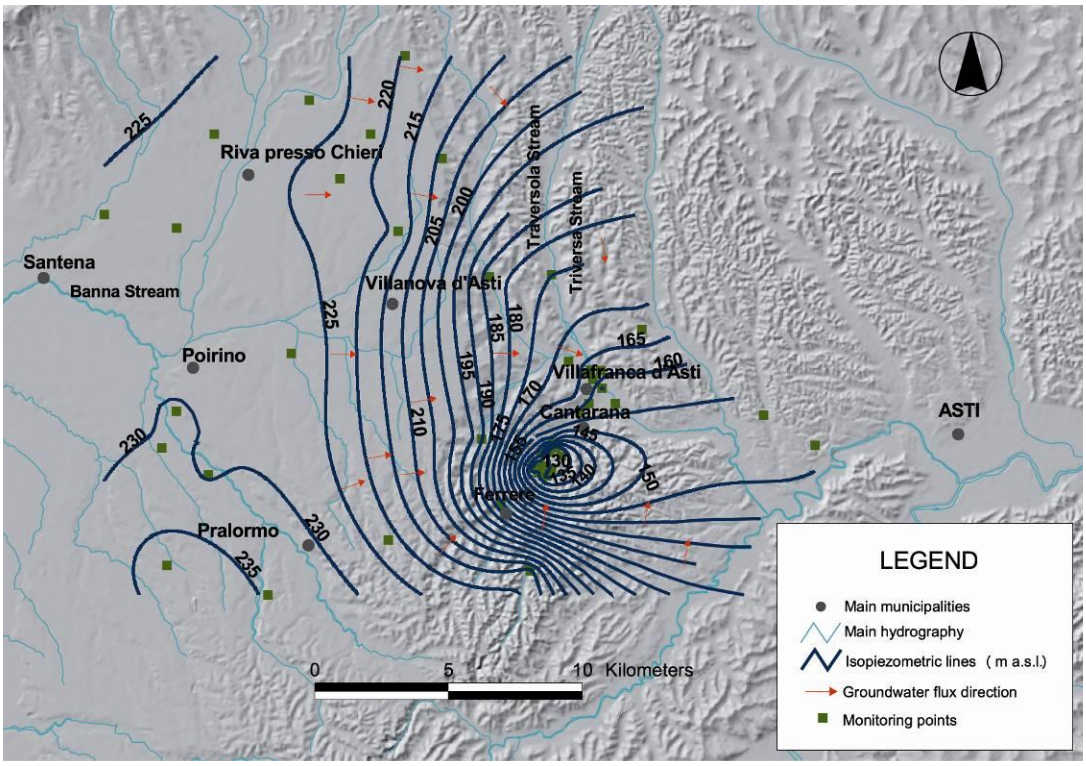


Fig. 5 Piezometric map of the deep aquifer (August 2009).

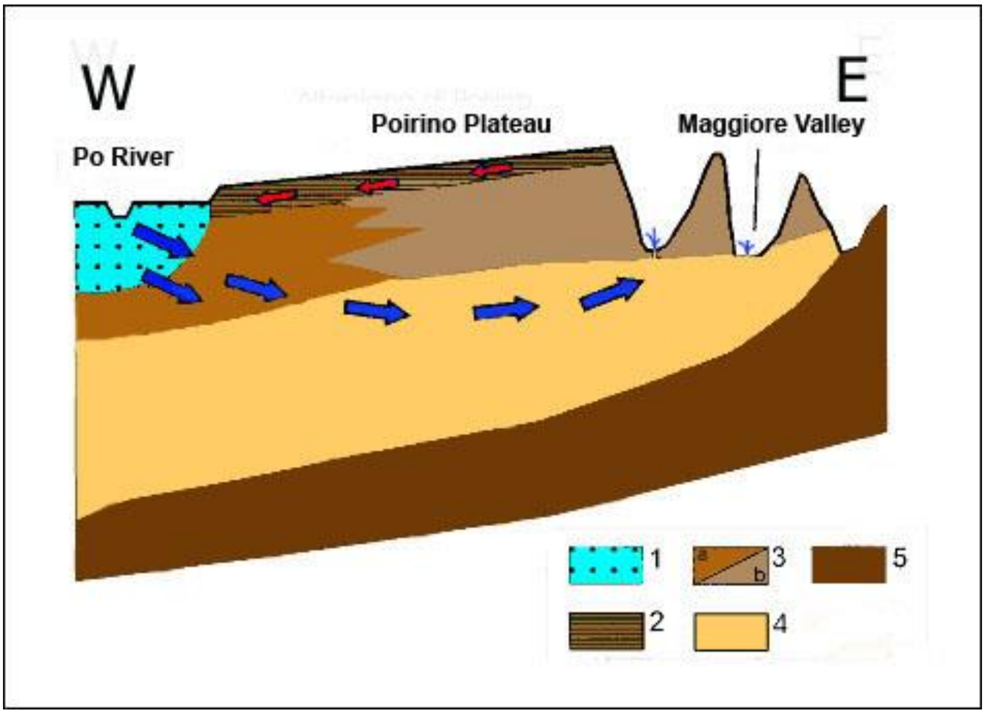


Fig. 6 Conceptual model of the study area. 1: Quaternary gravelly-sandy unit; 2: Pleistocenic silty-sandy unit; 3: Villafranchian sandy-silty alternations unit (a: predominance of silty-clayey levels; b: predominance of gravelly-sandy levels); 4: Pliocenic sandy unit; 5: Pliocenic silty-clayed unit. Blue arrows show deep aquifer groundwater flux direction, from the Po Plain to the Maggiore Valley aquifer; red arrows evidence shallow aquifer water flux from the Poirino Plateaux to Po River (modified after Beretta et al. 1999).

4 - Implementation of the mathematical model

A numerical model of the area was realized with finite-difference MODFLOW code (McDonald and Harbaugh 1988); the graphical user interface (GUI) was Visual MODFLOW v.4.2. The model has the aims to reconstruct groundwater fluxes and to comprise the relationship between groundwater and withdrawals. Moreover it can suggests the best options, between possible solutions, to solve overexploitation problem. After the model implementation and calibration, four different scenarios for a better groundwater management at Maggiore Valley well field have been proposed.

The implementation of the mathematical model consisted of:

- discretization of the modelling area,
- definition of the limits of the study system (boundary conditions),
- definition of the variables within the hydrogeologic system (hydrogeological parameters)
- definition of the external stress to the system (drainage and recharge)

The mathematical model was carried on in steady state conditions, using, as reference, the piezometric level of deep aquifer of August 2009.

4.1 - Discretization of the modelling area

The modelled area was not limited at Maggiore Valley, but has been expanded to a geographically wider area, for a better understanding of flow systems. The area (Fig. 7) comprises a vast zone, included in a rectangle about 36 km wide in the east-west direction and 28 km long in north-south direction; in details, in terms of kilometric UTM coordinates the modeled area is located between the following values:

Longitude X (UTM coordinate ed50): 400600- 437000
Latitude Y (UTM coordinate ed50): 4961500 - 498950

In details, it has been discretized along the X and Y directions with a grid of 138 columns and 112 rows that form cells of about 250 m of side. A higher mesh refinement is used at Maggiore Valley well field (Fig. 7), modelling a squared cells of 12.5 m of side.

With regard to the vertical discretization (Z direction), the simulation domain is divided into two layers. The **layer 1** represents the villafranchian sandy-silty alternations unit and pleistocenic silty-sandy unit; it reaches its maximum thickness (about 200 m) in the central part of the Poirino Plateau, and thins until it disappears in the north, in contact with the Torino Hill and in the east, in the Hills of Asti area.

The **layer 2** represents the pliocenic sandy unit.

The geometric shape of each layer (Fig. 8) was derived from previous geological and stratigraphical reconstruction, and from electrical and sismic prospection (Beretta et al. 1996; C.M.P. 1962; Boni et al. 1970; Carraro et al. 1969; Bortolami et al. 1969a; Bortolami et al. 1969b; Montrasio et al. 1969; Forno 1982; Boano and Forno 1996). The punctual data are then been interpolated in order to obtain the surface of the top and the bottom of the modeled layers.

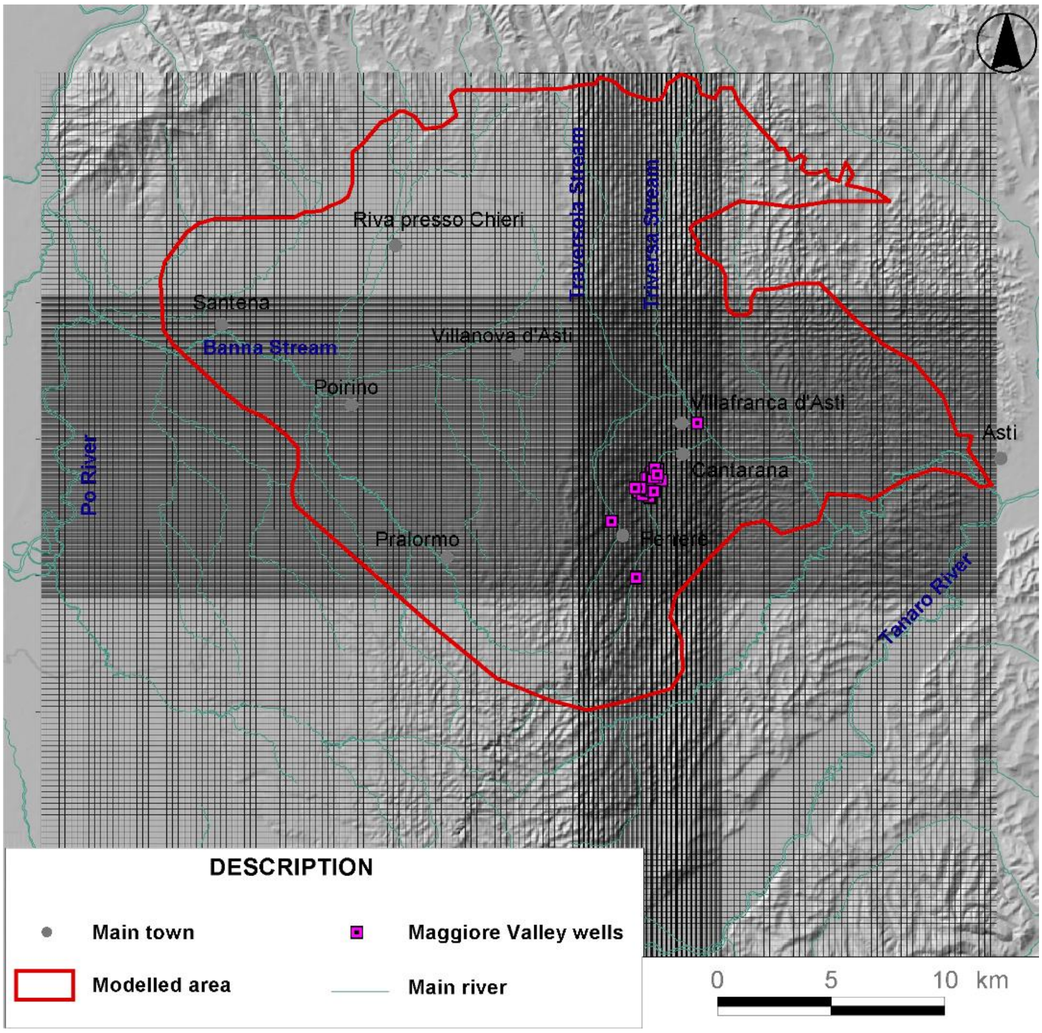


Fig. 7 Discretization of the study area with a mesh refinement in correspondence of Maggiore Valley well field.

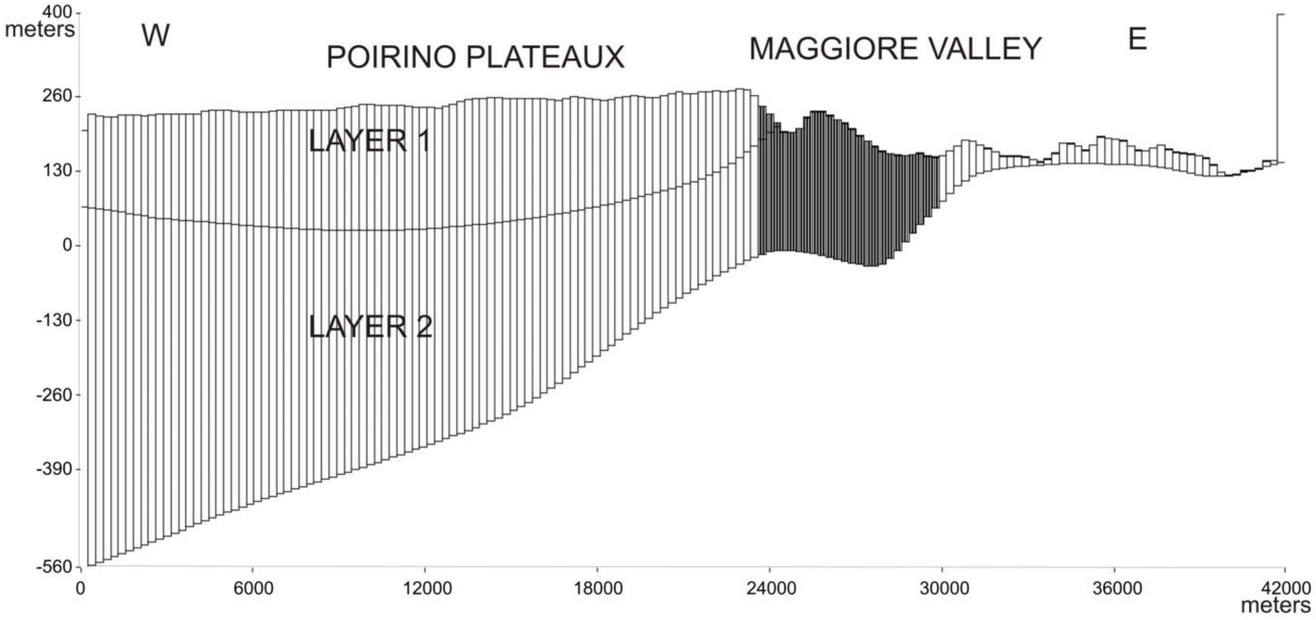


Fig. 8 Vertical discretization of modelled area. The mesh refinement is referred to Maggiore Valley well field area.

4.2 Boundary conditions

In order to simulate the presence of the impermeable rocks, “no flux” cells were assigned in correspondence of the southern, northern and eastern sides of the modelled area, at the boundary between Pliocenic sandy unit and Pliocenic silty-clayed unit. A no flux boundary was also used at the bottom of layer 2. On the western, north-western and south-eastern side, instead, “constant head” cells were imposed; in details, data values are referred to deep aquifer piezometry (Fig. 9).

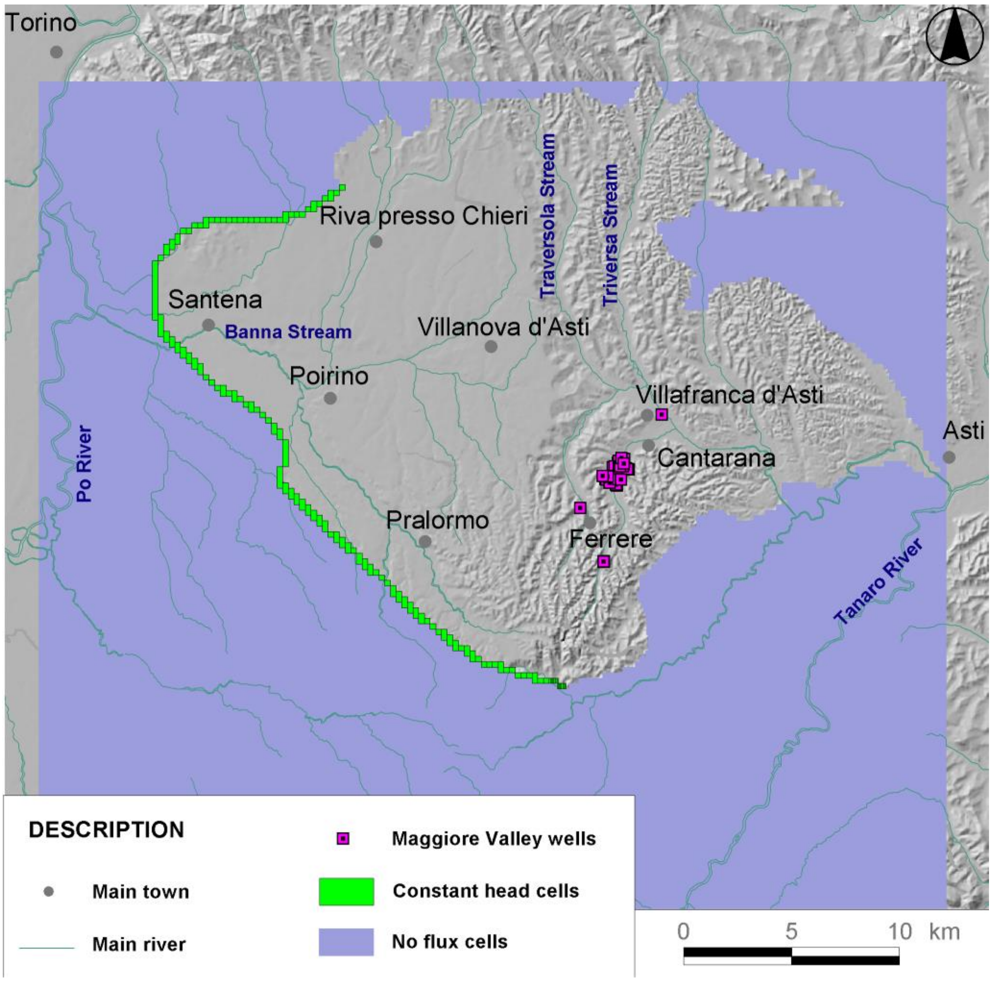


Fig. 9 Boundary conditions of the study area.

4.3 Input data

Input data have been grouped into hydrogeologic parameters and pumping wells.

4.3.1 Hydrodinamic properties and hydrogeologic parameters

Regarding the hydrogeologic characteristics, both of the two layers were modelled as confined. For each layer, hydraulic conductivity and storage parameters were defined by a set of data derived from Earth Science Department (University of Turin) database and previous studies (Beretta et al. 1997; Beretta et al 1999). In details, trasmissivity and hydraulic conductivity of layer 1 were defined by means of pumping tests carried on in the study area; however, these data are insufficient and unevenly located. Thus the distribution of hydraulic conductivity was calibrated in the calibration phase of the model. As for layer 2, trasmissivity values were obtained from pumping tests at Maggiore Valley well field. The hydrogeologic parameters used for the two modelled layers are for layer 1: $K_x = K_y$ (m/s) = 2.69×10^{-4}, K_z (m/s) = 2.69×10^{-5}; for layer 2 : $K_x = K_y$ (m/s) = 5.00×10^{-5}, K_z (m/s)= 5.00×10^{-7}. The recharge area of deep aquifer is located in the quaternary deposits of the River Po (Beretta et al. 1996). In this plain area, the presence of permeable deposits, such as gravels and sands, both in the shallow and in the deep aquifer allows the flow of water from surface in depth.

4.3.2 Pumping wells

A total of 206 pumping wells located in this area were simulated; in details, simulated wells comprise the Maggiore Valley municipal wells, wells of the archive of the regional aqueduct (Regione Piemonte

2000), and industrial and artesian irrigation wells of the area, coming from previous studies (Beretta et al. 1996). Total wells discharge, on the whole area, is about 1270 l/s, with withdrawals from Maggiore Valley aqueduct wells, industrial wells, artesian irrigation wells and wells of the Poirino plateaux.

4.4 Model calibration

The input parameter of the model were then calibrated using PEST (Doherty 2001; Doherty and Johnston, 2003), a nonlinear parameter estimator that can adjust model parameters such that the discrepancies between the pertinent model-generated numbers and the corresponding measurements are minimized. When parameter estimation is used to assist in the calibration of a model, it is asked to minimize an objective function comprised of the sum of the weighted squared deviations between the calculated and observed system responses. In the case of a groundwater model, these system responses are typically head at a point in space, concentration at a point in space, or groundwater flow to a specified zone. The model calibration was carried out by using the piezometric data collected in August 2009. The points used for calibration are in number of 41; all the wells have screens in the deep aquifer. The input parameter of the model that has required a more accurate calibration is the hydraulic conductivity of the layer 1 and layer 2. This parameter has been modified during calibration phase especially in the western part of the modelled area, because of the scarcity or lack of such information. The modelled piezometry with the main direction of groundwater flow are shown in Fig. 10. The calculated vs observed head diagram, obtained during the flux model calibration, shows a good correlation of data (Fig. 11); the correlation coefficient is 0.99 and the standard error of estimate is 0.857 m. The agreement between the calculated and observed piezometric level highlights the high reliability of the simulations.

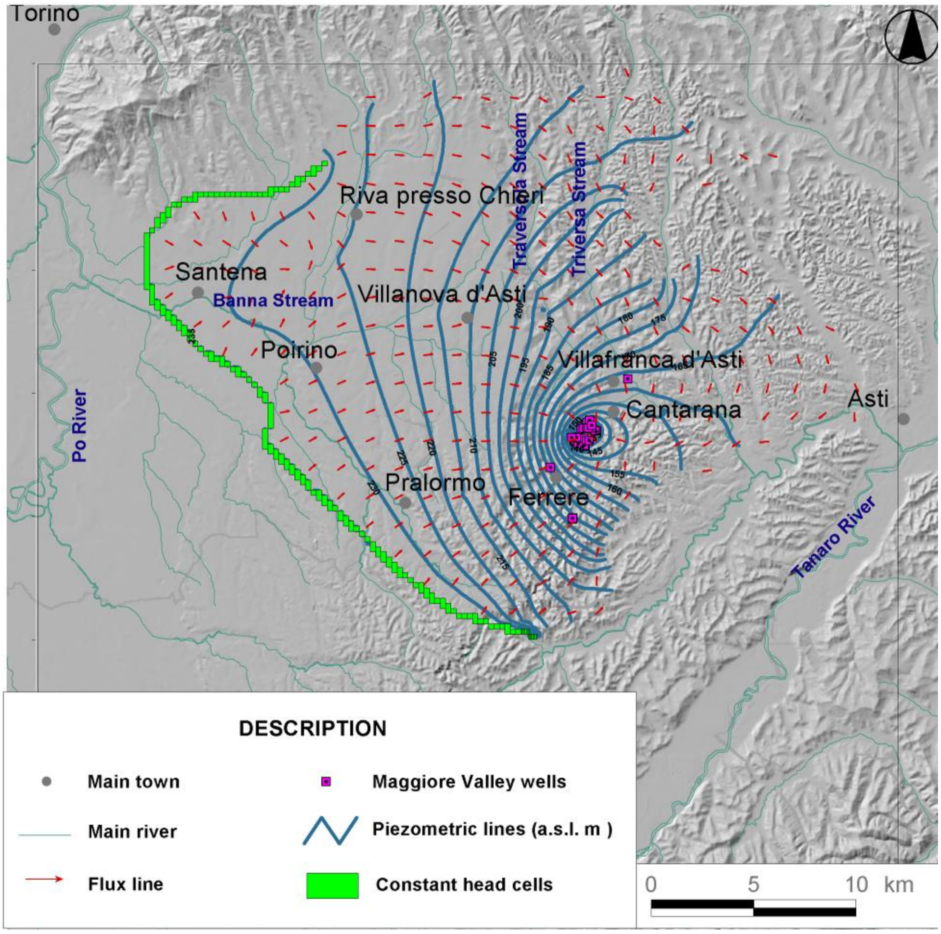
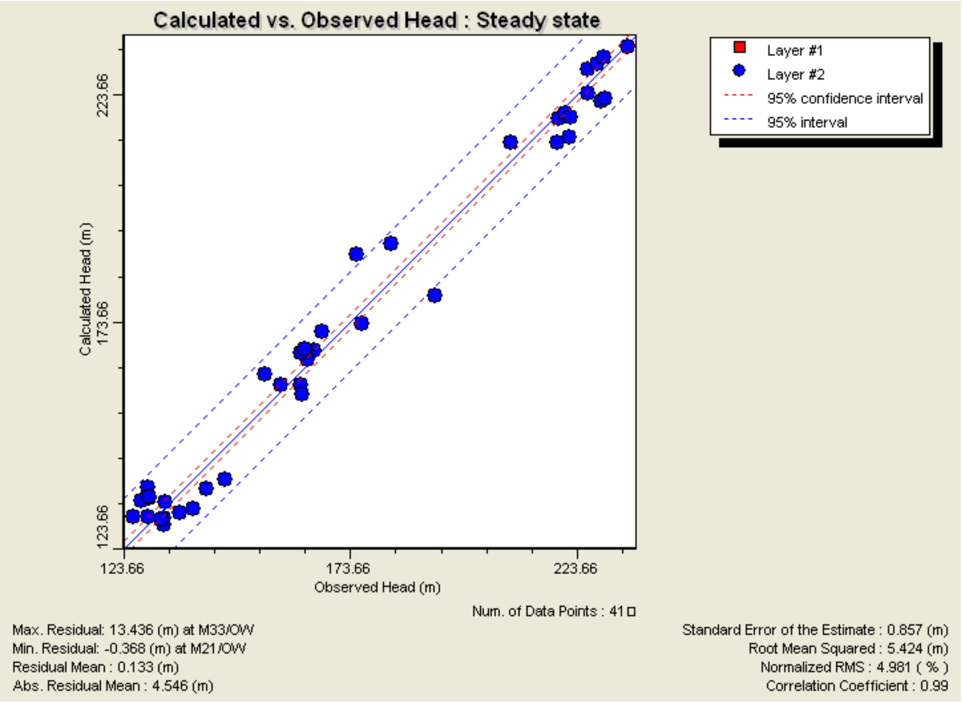


Fig.10 Calculated heads of the deep aquifer (LAYER 2) in the study area.



Num. of Data Points : 41

Max. Residual: 13.436 (m) at M33/OW
Min. Residual: -0.368 (m) at M21/OW
Residual Mean : 0.133 (m)
Abs. Residual Mean : 4.546 (m)

Standard Error of the Estimate : 0.857 (m)
Root Mean Squared : 5.424 (m)
Normalized RMS : 4.981 (%)
Correlation Coefficient : 0.99

Fig. 11 Calculated vs observed head diagram for the deep aquifer (LAYER 2).

The water budget of the modelled area is presented in Table 1. Negative rates indicate outflows from the groundwater system, and positive rates indicate inflows into the groundwater system. There are two inflows to the model: aquifer storage and constant head boundaries; besides there are three discharges: aquifer storage, constant head boundaries and withdrawals from wells. Wells remove the most water with a volumetric rate of 110079 m^3/day. The flow budget indicated that the outflows are higher than the inflows in the study area.

Table 1. Simulated water budget.

WATER BALANCE TERM	(m^3/day)
INFLOW	
Storage	0.015
Constant Head	110432.852
Total INFLOW	110432.867
OUTFLOW	
Storage	0.007
Constant Head	361.590
Wells	110079.297
Total OUTFLOW	110440.891
IN - OUT	-8.023

4.5 Groundwater flow modelling in different scenarios

In order to reduce the overexploitation, four different scenarios for a better groundwater management at Maggiore Valley well field have been proposed and verified, by utilizing Modflow code (GUI: Visual MODFLOW v.4.2). In details, the scenarios hypothesize a reduction of water extraction, a redistribution of the wells location or both of them. An approach including recharge based on surface water treatment, which could make the supply more sustainable, were not proposed because of the lack of availability of surface water; indeed the streams and canals have a very small discharge.

Scenario 1: water withdrawal decrease of 110 l/s in Maggiore Valley; for this scenario, a withdrawal decrease of 20% has been simulated for each pumping well.

Scenario 2: water withdrawal decrease of 150 l/s in Maggiore Valley as a result of the connection with the water supply of the Monferrato Aqueduct, located north of the study area; this connection has been proposed by the territorial authority for drinking water (ATO5). For this scenario, a withdrawal decrease was simulated essentially for pumping wells located nearer the centre of the cone of depression. The reduction of water extraction is not the same for all the wells and varies from 20% to 40% of wells discharge.

Scenario 3: re-location of 8 wells from the centre of the cone of depression to a northern sector (Fig. 12); this area has high groundwater productivity, according the hydrogeologic reconstruction. The current flow rate of wells to re-locate varies between 1.9 and 29 l/s. The hypothesized flow rate for the re-localized wells is 15 l/s. This situation is just one example of various possible solutions; in fact other simulations have provided similar results.

Scenario 4: water withdrawal decrease of 110 l/s in Maggiore Valley well field (current discharge reduction of 20%) plus a concurrent re-location of 8 wells; as for the scenario 3, the pumping wells are re-located from the centre of the cone of depression to a northern sector (Fig. 12). The withdrawal decrease of 20% has been simulated for each pumping well located in Maggiore Valley. The current flow rate of wells to re-locate varies between 1.9 and 29 l/s. The hypothesized flow rate for the re-localized wells is about 15 l/s. This situation is just one example of various possible solutions; in fact other simulations have provided similar results.

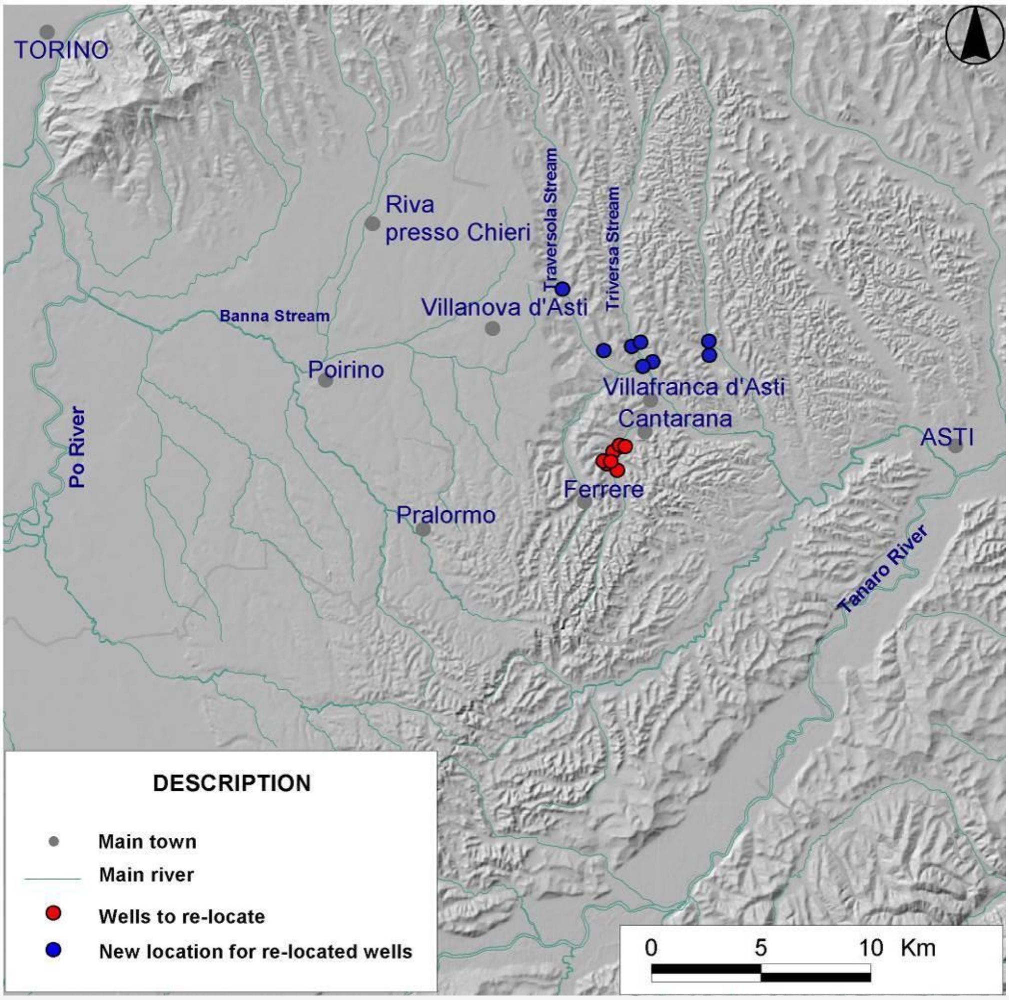


Fig. 12 Re-location of 8 aqueduct wells in a northern sector (scenario 3 and scenario 4).

5 - Results

For each of the four hypothesised scenarios, the piezometric level change ∆PL maps have been elaborated and reported. The variation of piezometric level ∆PL (m) is calculated as:

∆PL = scenario calculated piezometric level – calibrated piezometric level of August 2009

As for scenario 1 (Fig.13), a water withdrawal decrease of 20% (total of 110 l/s) was modelled in Maggiore Valley well field; this new configuration of water extraction from the wells is responsible for a modification of the piezometric surface, equivalent to a rise in piezometric levels variable between 0 and to 20 m.

The scenario 2 (Fig.14) simulates the connection with the water supply of the Monferrato Aqueduct, and so a water withdrawal decrease of a total of 150 l/s for pumping well located nearer the centre of the cone of depression; this water extraction configuration causes an increase of the piezometric levels up to 27 m, especially in correspondence of the cone of depression; the groundwater rising phenomenon reduces toward western sectors of study area.

Regarding the scenario 3 (Fig.15), the re-location of 8 wells from the centre of the cone of depression to a northern sector is reflected in lowered groundwater levels (up to 15 m) in the northern sector and raised levels (up to 20 m) in the south, coincident with the centre of the cone of depression.

At last, the scenario 4 (Fig.16), with the re-location of 8 wells plus the water withdrawal reduction of 20% in Maggiore Valley well field, evidences the rising of the piezometric level up to 30 m in correspondence to the centre of the cone of depression; moreover a limited drawdown of the piezometric level up to 10 m is present in the north sector, area of new wells localization.

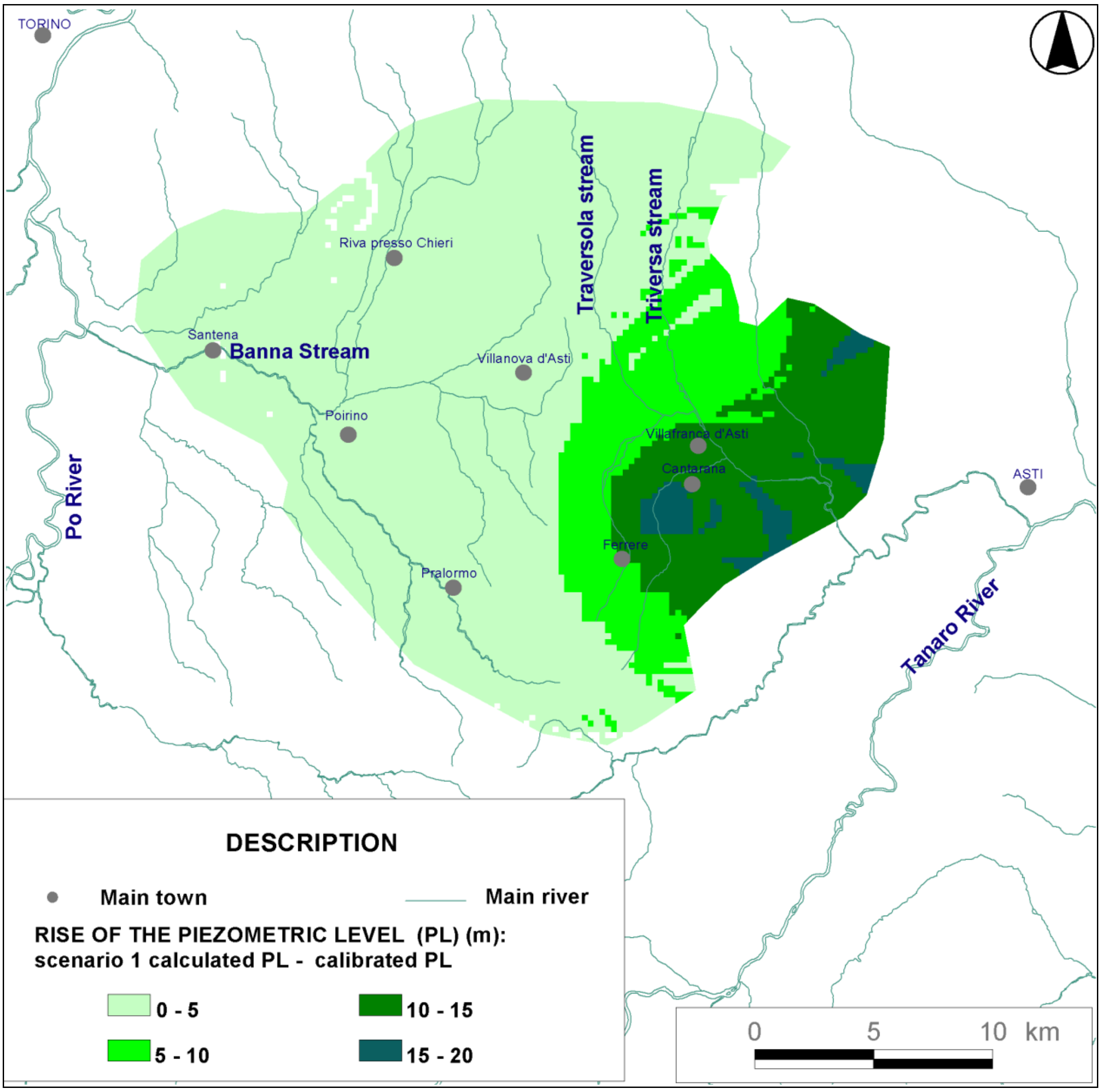


Fig. 13 Piezometric level change map for Scenario 1.

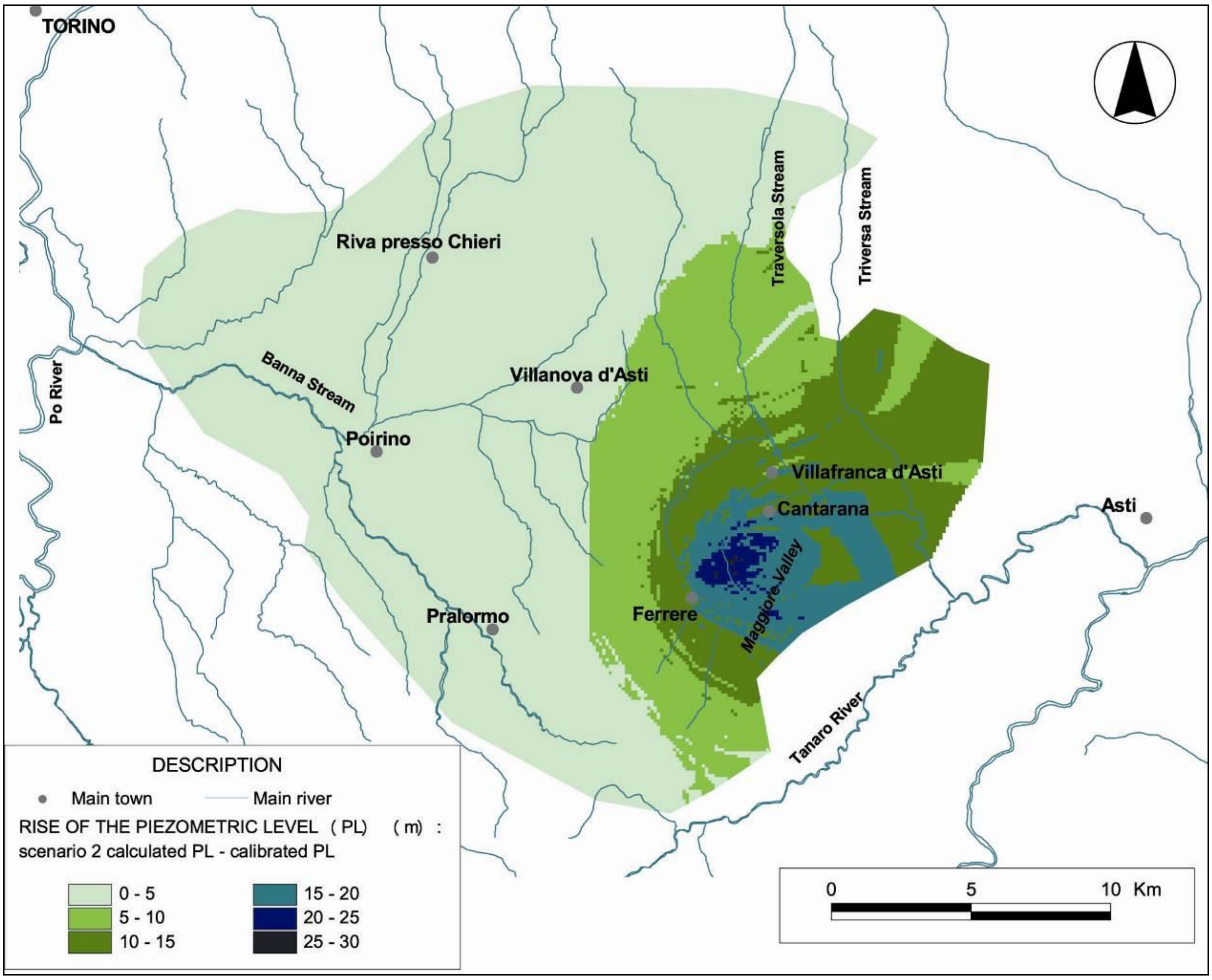


Fig. 14 Piezometric level change maps for Scenario 2.

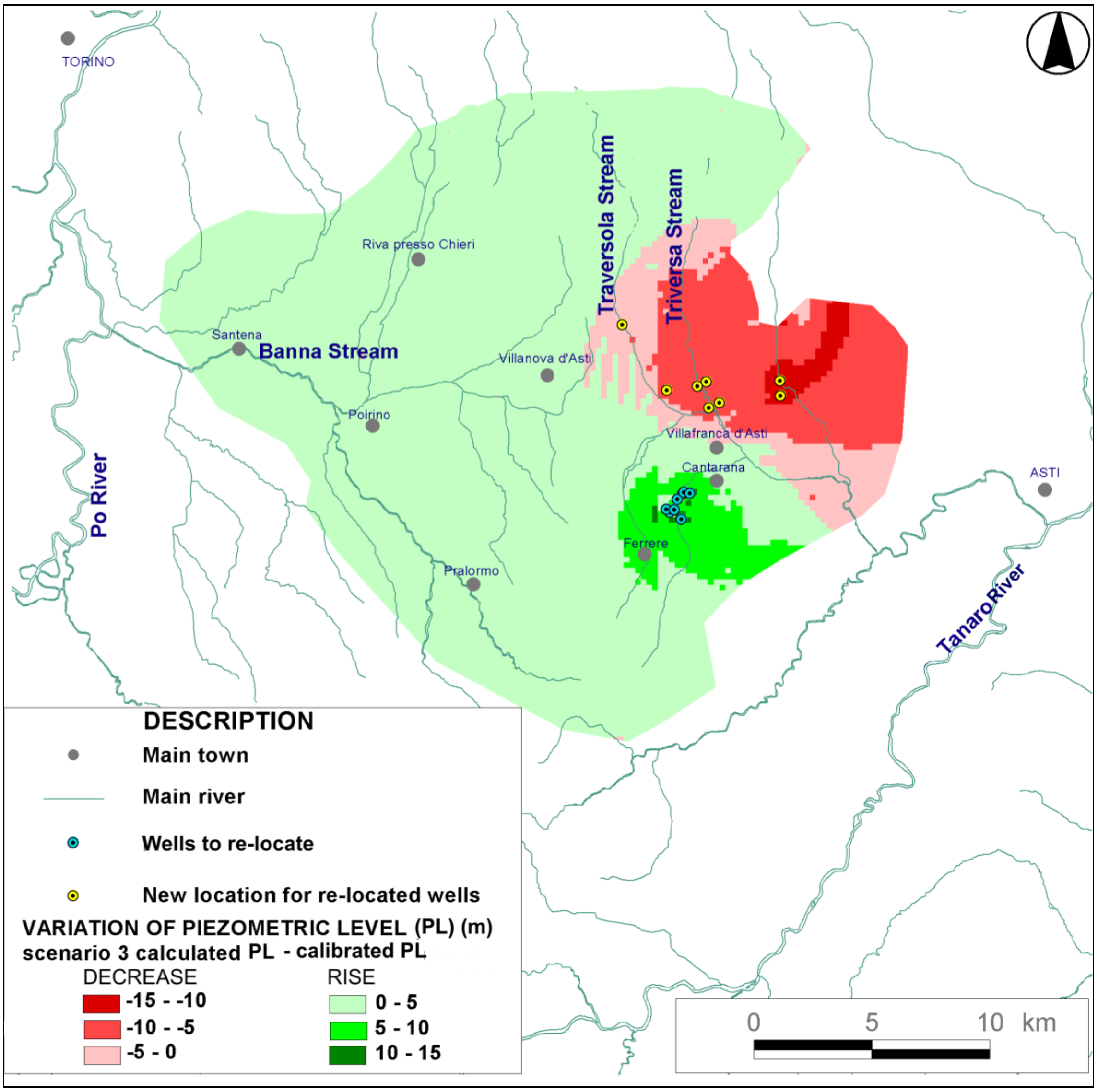


Fig. 15 Piezometric level change maps for Scenario 3 .

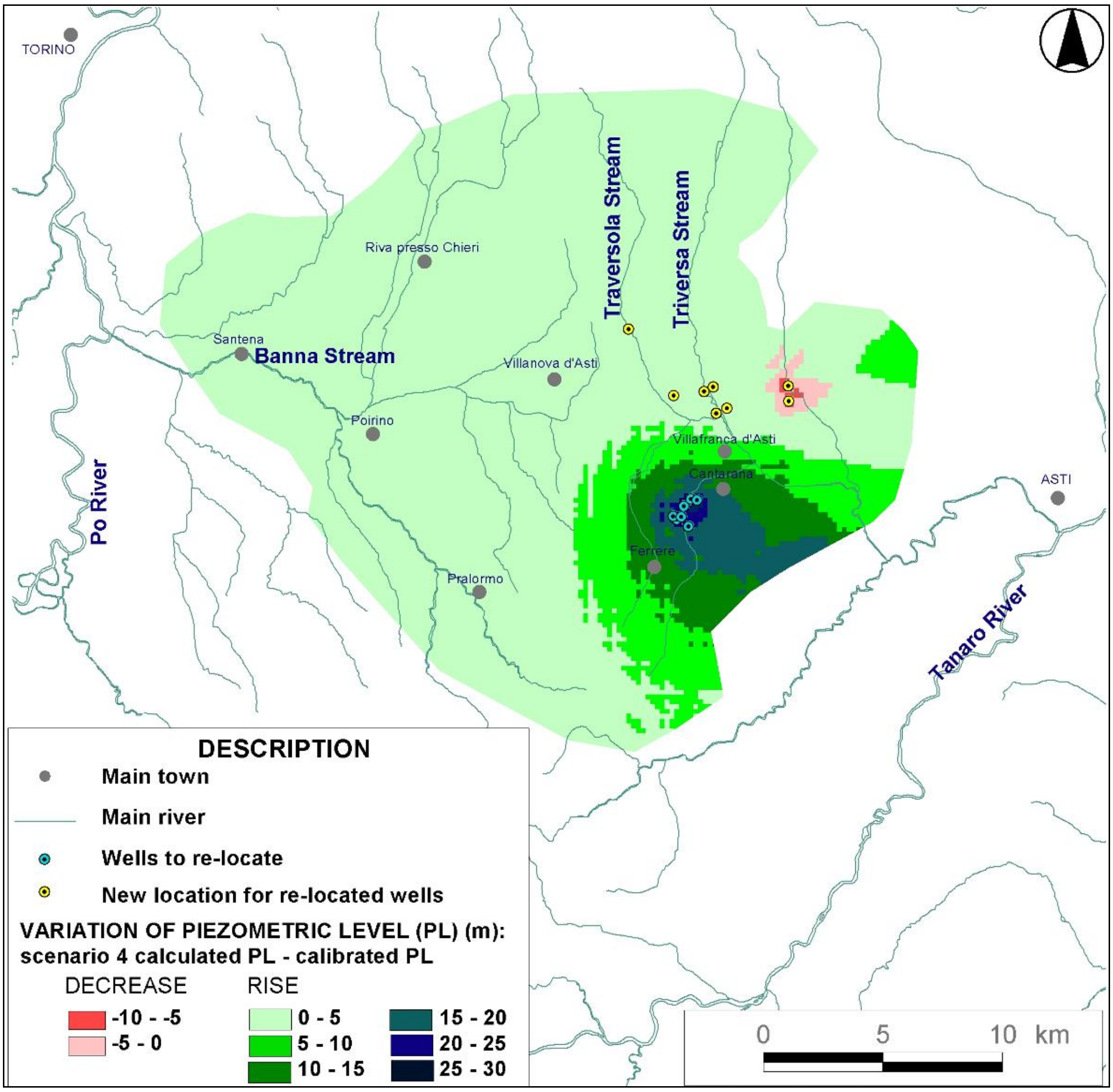


Fig. 16 Piezometric level change maps for Scenario 4.

6 Conclusions

A study case of groundwater overexploitation is presented here. Maggiore Valley well field has a fundamental importance for water supply in the eastern sector of the Piedmont region (north-western Italy) and it must be preserved.

The increasing groundwater withdrawal, caused by the elevate water demand, caused the overexploitation of groundwater resources; the effects of the degradation of groundwater resources are piezometric level drawdown, land subsidence and the spatial reduction of the artesian area.

In this situation a sustainable development could be reached with the maintenance of the water supply for human use, nevertheless avoiding the drying of artesian area and the progressive drawdown of the piezometric level, and consequently troubles in water extraction and quality.

In order to mitigate this situation different quantitative management of the groundwater resources of the study area is required. For this reason an hydrogeological model was applied, using Modflow code, in order to study in detail the geological-hydrogeologicl structure and to simulate groundwater flux. Moreover the model hypothesises four possible scenarios in order to reduce the overexploitation; the scenarios simulate a reduction of water extraction, a redistribution of the wells location or both of them.

All the simulations provide an increase of the piezometric level in the heavily overexploitated area, up to 30 m. The scenario 2, consisting in a water withdrawal reduction of 150 l/s in the Maggiore Valley, with the supply of the Monferrato Aqueduct, seems to ensure the better performances according to the model: indeed the piezometric level rises up in the Maggiore Valley area up to 25 m without the necessity of drilling of new wells. Hence, in addition to good results from a hydrogeological point of view, this scenario avoids the complications connected to socio-politic problems following from the wells re-location and, most of all, this solution could be a strategic choice to mitigate the problem of the progressive drawdown of the piezometric level in the area.

Nevertheless the re-location of wells, with or without a concurrent water withdrawal reduction (scenario 3 and 4), could also be a useful and applicable solution for a groundwater rationalization and a sustainable development. These scenarios, indeed, could allow the rising of the piezometric level (up to 30 m) in correspondence to the centre of the cone of depression, with only a limited drawdown of the piezometric level (up to 10 m) in the northern sector.

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