The tunnel impact on the groundwater level in an urban area: a modelling approach to forecast it

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Abstract: The mitigation of the impact related to the construction of a railway for a high speed train needs a tunnel crossing an important city. The groundwater flow is crossed transversally by the tunnel. A finite difference model has been applied to reproduce the tunnel impact on groundwater level.

Key words: groundwater modelling, tunnel, environmental impact, urban area, wells.

Introduction

The construction of a railway for a high-speed train needs often a tunnel crossing important city to mitigate the environmental impact. A tunnel, in the alluvial deposits is considered as a possible factor, which could induce water table changes. In particular the induced groundwater rising can become a serious problem to urban structures, such as the historical monuments, parking areas, and so on.

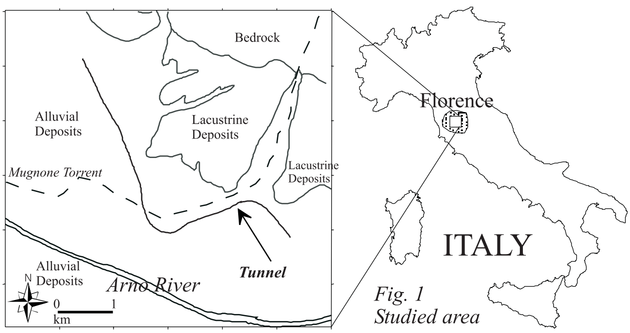

Fig. 1
Studied area

The methodology is applied to Florence city (Italy, Fig. 1), where a tunnel of about 8000 m was hypothesised. From an hydrogeological point of view, the area is characterised, by sand and gravel of the alluvial deposits of the Arno River. An unconfined aquifer is located in this alluvial deposits and the water depth is between 5-10 m. The thickness of the main aquifers is 35-40 m from topographic surface, defined from the drilled boreholes (Capecchi et al., 1975).

Model input data

The aquifer structure and the mass transfer elements have been determinate from a geometric and parametric point of view. However the infiltration due to rainfall can be neglected because the infiltration surface in general is drastically reduced in urban conditions.

The reliable information's belong to more than 500 water wells and stratigraphic logs allowed to reconstruct the hydrogeological cross sections, the isopach map of the aquifer thickness and the depth bottom contour lines, the morphologic shape of the piezometric surface. On basis of 8 pumping tests results and from well construction reports, the permeability values, characterising the alluvial aquifer, range from $1.5*10^{-3}$ to $9*10^{-7}$ m/s. A con-

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tour line distribution of this parameter couldn't to be defined because the permeability tests were not realised in the whole area but only along the tunnel path. The whole area was divided in 5 zones with different permeability value: 0.08 m/g, 0.4 m/g, 80 m/g, 130 m/g, 340 m/g, following the calculated isopach map of the aquifer thickness (Fig. 2).

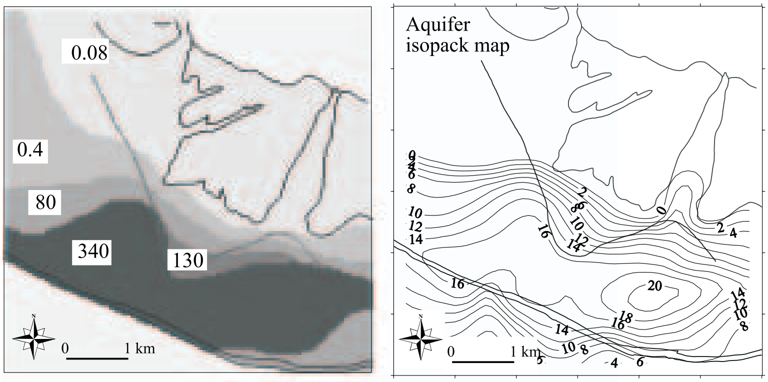

Figure 2. Horizontal hydraulic conductivity (m/d) and the aquifer isopach map (m)

MODEL APPLICATION

The finite difference model MODFLOW has been applied, together with the Groundwater Vistas pre- and post-processor. Some computer techniques have been developed to link different software for model data entry. The spatial discretization of the domain was realised with one layer of 120 rows and 120 columns, with regular cells of 50 m side, covering an area of 36 km^2. All the parameters (groundwater level, permeability, porosity, bottom of the aquifer) were discretized in raster form.

The chosen boundary conditions are: on the southern side a general head boundary was used and the piezometric heads were deduced from the levels of the Arno River; on the northern boundary no flux condition was introduced following the ending limits of the alluvial deposits. Any other conditions were imposed along the other sides. At the bottom of the model an impervious boundary was used to represent the bedrock and, locally, the lacustrine deposits.

After the calibration of the model, predictive simulations were performed with the presence of the tunnel, longer more than 8000 m. The groundwater flow is crossed transversally by the tunnel in the side toward west, while flow and tunnel have an almost equal path in the southern and eastern sides (Fig. 2).

The tunnel is high 10 m and it doesn't reach the topographic surface. Only in three areas the tunnel project foresees to intercept the total thickness of the aquifer, until the surface. They are located in the central path of the tunnel, near the curve.

To compute the eventual rise of the water table due to the presence in the alluvial aquifer of this new tunnel, the tunnel has been considered as a semi-impervious barrier (using the HFB, Horizontal Flow Barrier, package, HSIEH AND FRECKLETON., 1992). Similar results may be obtained using no flux cells (CESANO, 1997; DASSARGUES, 1997). HFB Package simulates vertical low-permeability geological, or others, features that impede the horizontal flow to groundwater. These features are approximated as a series of barriers situated on the boundaries between pairs of adjacent cells in the finite-difference grid. The key assumption underlying the HFB package is that the width of the barrier is negligibly small in comparison with

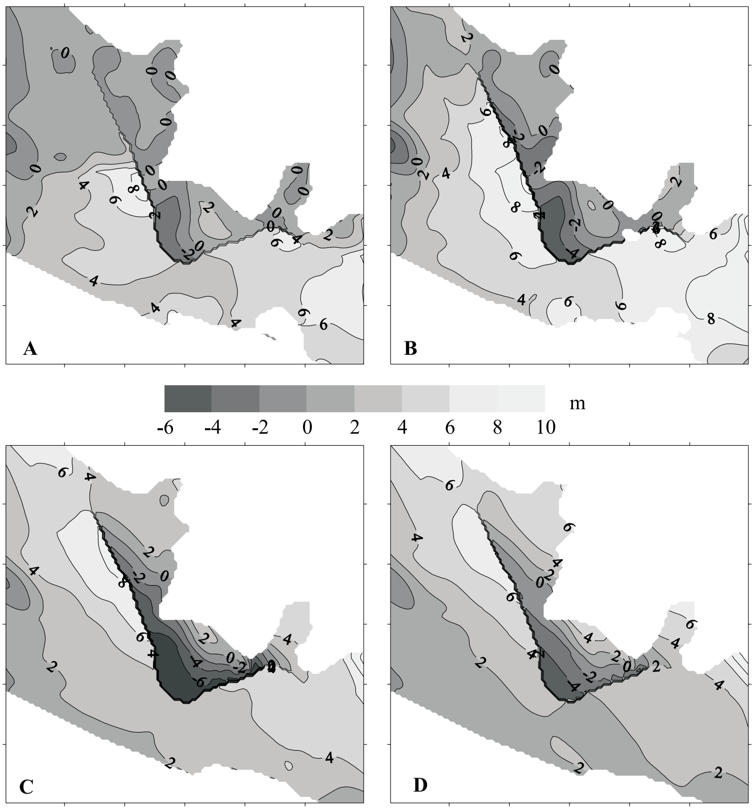

Figure 3. Simulated groundwater rise and decrease (m) using HFB Package with different time period: A 30 days, B 1 year, C 10 years and D 20 years

the horizontal dimensions of the cells in the grid. Barrier width is not explicitly considered in the package, but is included in a hydraulic characteristic defined as barrier hydraulic conductivity divided by barrier width, if the barrier is in a variable trasmissivity layer. The use of HFB Package allows barriers to the horizontal flow of water to be modelled without increasing the number of model cells.

A tunnel can be considered as an artificial feature that impedes the horizontal flow to groundwater. Many simulations have been realised to compute the tunnel impact, using different permeability values. A very small value can simulate a tunnel as a wall. No further changes were computed using a permeability value less than 0.00001 m/g. So this value was assigned to the model cells interesting by the tunnel. The barrier width used is 10 m, except in the areas where the tunnel project foresees to intercept the total thickness of the aquifer, until the surface. Transient conditions were considered for a time period of 30 days, 1 year, 10 years and 20 years were used. The initial condition of highest water level was introduced for each simulation.

Figure 3 shows the differential piezometric rises (negative values) and decreases (positive values) due to the presence of the tunnel, using the HFB package, for the different time periods.

The maximum rising occurs in the central part of the tunnel path, near to the curve, where two different causes occur: the first one a lot of water reaches the tunnel due the perpendicular direction of the water flux as regards to the tunnel path; the second one the tunnel itself intercepts the whole aquifer until surface.

The piezometric rising increases during time and it reaches the maximum value after 20 years (more then 6 m, Fig.3D). The whole area on the side NE of the tunnel, where the flux is intercepted, is interested by a general groundwater rising between 0 and 4 m.

Towards the south and west side of the proposed tunnel a positive piezometric difference was computed in each simulations. The groundwater rise reaches 2 m further from the tunnel and 6-8 m near the tunnel.
The simulated piezometric level (Fig. 4) shows very important variations due the tunnel impact both in the flux of groundwater than in the morphologic surface. The influences increase with the longer simulation time steps. In the Figure 4 the simulated piezometric level for a time period of 10 years, is shown.

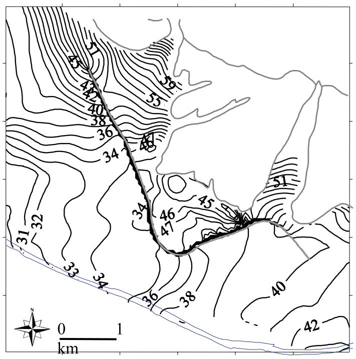

Figure 4. *Simulated piezometric levels (m a.s.l.) for the time period of 10 years*

CONCLUSION

The construction of a railway for a high-speed train needs often a tunnel crossing to mitigate the environmental impact. The construction of the tunnel in the alluvial deposits could induce different water table changes in particular when the groundwater flow is crossed by the tunnel. In the proposed example, the groundwater flow is locally crossed transversally by the tunnel.
To compute the eventual rise of the water table due to the presence in the alluvial aquifer of this new tunnel the tunnel has been simulated as a semi-impervious barrier (using the HFB, Horizontal Flow Barrier, package). The maximum rising occurs in the central part of the tunnel path, near to the curve, where two different causes occur: the first one, a lot of water reaches the tunnel due the perpendicular direction of the water flux as regards to the tunnel path; the second one, in that area the tunnel itself intercepts the whole aquifer until surface. The piezometric rising increases during time and it reaches the maximum value after 20 years: more then 6 m in the simulation using HFB Package and more than 4 m using impervious cells.
The groundwater modelling forecasts that the tunnel impact can generate two different scenarios: along the flux direction and before of the tunnel a groundwater rise is computed and it has maximum values where the aquifer is completely closed; in the other side the tunnel acts as a wall against important and rapid piezometric rises and creates a quickly groundwater decrease.
The results can be considered as a first approach to the problem. The next analysis will contribute to define a complete conceptual model of the system and to attribute a reasonable parameter values to the cells, perhaps introducing more than one aquifer. The developed simulations are the simplest scenarios, but the distributed groundwater models allow to simulate very complex hydrogeological system and to forecast several groundwater scenarios planning.

REFERENCES

CAPECCHI, F., GUAZZONE, G., PRANZINI G. (1975): Ricerche geologiche ed idrogeologiche ne sottosuoolo della pianura di Firenze. *Boll. Soc. Geol. It.,* V. 94, pp. 661-672, Roma.

CESANO, D. (1997): Impact on groundwater level when tunnelling in urban areas. *Groundwater in the Urban Environment: Problems, Processes and Management*. Chilton et al. (eds). Balkema, Rotterdam, 219-224 pp.

DASSARGUES, A. (1997): Groundwater modelling to predict the impact of a tunnel on a behaviour of a water table aquifer in urban conditions. *Groundwater in the Urban Environment: Problems, Processes and Management*. Chilton et al. (eds). Balkema, Rotterdam, 225-236.

HSIEH, P., FRECKLETON J. (1992): Documentation of a computer program to simulate horizontal-flow barrier. *U.S.G.S. Open-file Report 92-477,* 32 pp.