Groundwater abstraction in the Zumpango-Pachuca region, central Mexico, and its environmental effects

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Abstract: The lack of control on the groundwater abstraction in Mexico City produces effects that have been linked to severe environmental impacts such as subsidence, inducement of bad quality groundwater, drying of spring. This uncontrolled groundwater management in the study area implies a possibility that abstraction will produce similar environmental impacts
Key words: Uncontrolled groundwater abstraction, Zumpango-Pachuca, México

Introduction

The study area is located in the north-central of the basin of Mexico. It is limited by the topographic elevation line of 2250 m a.s.l, to de south and the 2350 line to the north; the Sierra of Guadalupe to the SSW and by the Sierra of Pachuca to the NNE (Figure 1)
The Zumpango-Pachuca region covers its water demand of estimated 17.7 m^3/s with groundwater. This area also partially supply water to Mexico City and its metropolitan area. The constant population increase and related economic activities in the region have a steady growth in water needs. Related abstraction rate has produced an average drawdown of about 1.5 m/year in the last two decades. It suggests that present groundwater management needs to be reviewed.
Uncontrolled groundwater management in the study area implies a possibility that abstraction will produce similar environmental impacts. Consequently, it becomes necessary to study its hydrogeologic functioning to achieve a rational groundwater use in the Zumpango sub-basin. So, the main objectives of this study deal with the geologic structure, the hydraulic characteristics and their integration in a groundwater flow code (MODFLOW) to: 1) analyse the regional behaviour of the hydraulic gradient, and 2) investigate several alternatives of production thickness.
This investigation was based on the analysis and integration of existing information and the one generated in the field by the authors. Highlighted concepts were: i) the geologic structure of the area Zumpango-Pachuca and ii) the hydraulic parameters. This information was analysed integrally by means of applying visual MODFLOW to cover the outlined objectives.
The measurement of the water level in 16 multipiezometers and 32 extraction boreholes, allowed its analysis, in terms of elevation for the period 1978-1997. Most of the measuring places are located on the plain. The depth of multipiezometers is 90 m and 200 m, in the south and north, respectively; the boreholes have a depth of 150 m, as an average.

Scientific paper

HYDROGEOLOGICAL SETTING

The sub-basin Zumpango-Pachuca (Figure 1), is characterised by a graben structure filled with carbonated rocks and marl-loamy Cretaceous and volcanogenics consolidated material of Oligo-Miocene age, the sequence underlies clastic sediments, lava and pyroclastic material in variable thickness, whose age vary from Plioceno to Quaternary (DE CSERNA ET AL, 1987; CARRILLO-MARTINEZ, 1998). Such deposits in the graben are referred in this investigation as Complex Intergranular. In the lower topographic areas of Zumpango, they are partially covered by a lens of very fine lacustrine deposits. In this Complex Intergranular fissured rocks are found.
The hydrogeologic units that constitute the aquifer system of this sub-basin are here described, from the younger to the oldest:
a) Complex Intergranular. Includes a group of the volcanoclastic material that forms the basin fill of Tertiary and Quaternary age. This material is interstratified with gravel, silt, tuff pumice and andesitic-basaltic volcanic breccia, in variable thickness. The gravel and silt constitute the upper aquifer and are part of the aquifer system where at present the main water abstraction is carried out in the area.
b) Lens of lacustrine deposits. This is a heterogeneous sequence of sediments (tuffs, glass and clays), as well as organic matter and shell microfossils (ostracod and diatom). Such deposits are the upper aquitard that covers partially the Complex Intergranular.
c) Fissured Unit. It is formed by Cretaceous limestone and Quaternary and Tertiary volcanic rocks whose composition vary from basic to acid, that are intercalation with alluvial sediments; these materials are important productive units where cooling structures, fractures and vesicular features, make the production voids.
The hydraulic parameters obtained for the upper aquitard in the area of Texcoco-Chalco are: hydraulic conductivity, 10^{-5} m/s for the pyroclastics and of 6.0×10^{-9} m/s for the clays (RUDOLPH, 1989; VARGAS CABRERA, 1995). The value of the storage coefficient indicates that this unit is highly heterogeneous and it has been calculated between 0.05 and 0.95 (RUDOLPH, 1989).
The hydraulic conductivity of the upper aquifer was obtained from pumping test analysis in

Figure 1. Location of the Zumpango sub-basin in the endorheic basin of Mexico

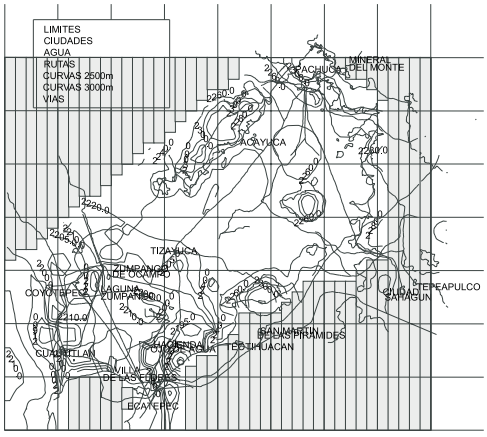

Figure 2. Distribution of potentiometric surface of the Zumpango-Pachuca region, for the year 2010. Contour interval 20 m

boreholes in the neighboring regions of Mexico City and Pachuca reaches 5.8 x10^{-3}, 2 x 10^{-5} and 3 x10^{-4} m/s; for basalts, andesits and alluvium, respectively (Huizar-Álvarez, 1993; Carrillo-Rivera et al., 1999). The storage coefficient values average, 3x 10^{-3}, 7 x10^{-4} and 1 x 10^{-3}, for these units, respectively.

Results and Discussion

The measurement of the water level in 16 multipiezometers and 32 extraction boreholes, allowed its analysis for the period 1986 - 1999.

The water levels measured in the piezometers, show a similar behaviour from 1986 to 1996. The values are 2300 m a.s.l. in the north and 2190 in the south for 1986 and, 2285 m and 2180 m for 1996. Many measuring points were dry due to the effect of abstraction (Figure 2); for the year 2010 under current abstraction 2160 and 2240 m a.s.l. will be achieved, respectively, in the south and north.

There is a hydraulic gradient from north to south of 0.0005. In the Ecatepec area, concentric gradients of the periphery are present toward the centre of the plain, suggesting flow from Tepotzotlan to Zumpango-Ecatepec Figures 2,3,4.

Once established the boundary conditions and carried out the calibration of MODFLOW code, a quantitative simulation of the potentiometric level changes with time was obtained. The configuration of the values measured in the boreholes has a similar distribution to that of the piezometers, a hydraulic gradient of 0.0005, is defined from north to south, with cones of depression in the areas of intense abstraction (Ferrocarril, Ecatepec, Tizayuca - Pachuca and Téllez lines of boreholes).

The results of the simulation (Figures 2, 3 and 4), for the period 2000 - 2010, show that: *i*) to maintain the same yield of groundwater abstraction, the surface area and depth of the drawdown zones will increase. This results suggest a potential compaction of the upper aquitard and consequently, problems in urban constructions as observed in Ecatepec located to the south-west of the study area, *ii*) if the abstraction yield increases, drawdown areas and depth will increase too. It is suggested to carry out new abstractions toward the Zumpango area, in

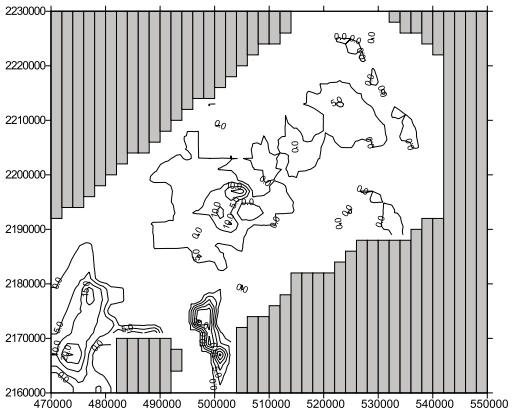

Figure 3. Distribution of drawdown into the domain contour interval 5 m

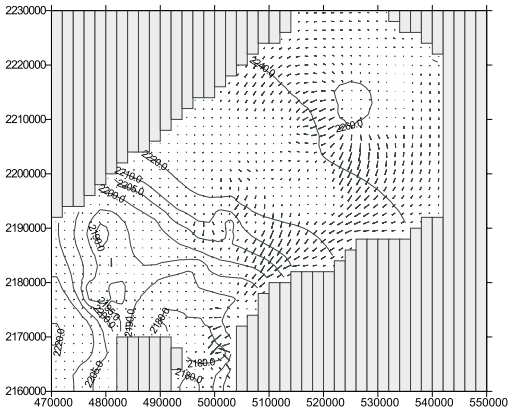

Figure 4. Direction, velocities and magnitudes of groundwater flow in the Zumpango-Pachuca region

order to reduce the effect of compaction in the upper aquitard, and thus to reduce observed problems to the urban infrastructure, as well as, the degradation of groundwater quality as it is observed in city of Mexico and Chalco (HUIZAR-A ET AL., 2000; ORTEGA ET AL., 1993).
The water level data clearly indicate an upward vertical component of groundwater flow, It identifies the area of Pachuca as the main area of recharge and Zumpango that of discharge. Local, intermediate and regional flows where defined; the local flows are abstracted rapidly, so most of current abstraction is directed mainly, to the intermediate flows defined by TOTH (1963).
In general the water level presents a tendency to a continuous drawdown, as a result of present abstraction in the whole area; there are several cones of local depression, the larger one is in the area of Ecatepec, producing a negative evolution of the water level of up to 7m, and an average drawdown of 1.5 m /year
The general behaviour of the water level in piezometers and boreholes, as well as geology and pumping-test results suggest the presence of semiconfined conditions in the centre of the plain, to unconfined conditions toward the edge, while boreholes of the centre of the plain evolve from semiconfined conditions to unconfined.

CONCLUSIONS

The geologic pattern show that the study area is part of a regional aquifer system with groundwater flowing, in the horizontal plane, from north to south. The Pachuca area is a recharge zone and Zumpango a discharge zone. Intermediate and regional flow system where defined, the local flows are diminished in quantity by the abstraction. The main exploitation is directed to the intermediate flows.
In general all water levels have a continuous descent, as a result of abstraction, which induces a negative evolution of the water level and a drawdown average of 1.5 m/year.

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