Groundwater recharge processes in the Central Region of Mexico

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Abstract: A conceptual hydrogeological model for the centre-south of Mexico Basin that considers its underground hydraulic communication with neighbouring sub-basins is proposed. The relative importance of recharge zones in a regional scale is discussed in terms of physical and social factors that could be involved.

Key words: groundwater recharge, water management, Mexico Basin, flow groundwater systems

Introduction

Groundwater is the most important source of water supply to the *Zona Metropolitana del Valle de México* (*ZMVM*), which is still included in the basin of Mexico. This third mega-city at global level is regarded one of the principal regions at environmental risk[1].

The Basin of Mexico is a closed surface basin of about 9,600 km^2 in the Mexican Trans-Volcanic Belt (*MTVB*). The basin is located on a graben structure developed during the Oligocene where a thick sequence of volcanic and lacustrine materials was deposited. This magmatic activity resulted in extensive lava flows that formed the Sierra Chichinautzin to the south of the basin and closed it to any superficial natural flow[2].

The site of the *ZMVM* was formerly occupied by a lake system where each one was progressively drained as the city expanded[3]. Between 1950 and 1990 there was a gigantic growth in population numbers and a large industrialization[1]. This caused an uncontrolled groundwater abstraction, which is responsible of severe environmental damage as soil consolidation, lowering of water quality and ecosystems deterioration in both recharge and discharges zones, and an unclear water supply dependence on neighbouring basins. The complexity of this development requires an integrative approach, which focus on the existence of multiple flow groundwater systems (at local, intermediate, and regional scales) that should be taken account, mainly those originated beyond the surface boundaries of the basin.

Table 1. Hydraulic conductivity (m/s) and storage coefficients values for geological units[5] [6]

Layer	Description	K_x, K_y	K_z (m/s)	S_s (m^{-1})
1	Aquitard, found at surface level (flat part of study area)	2.3E-9	2.3E-10	5E-5
2	Quaternary basaltic rocks (Qba)	7.0E-5	1.4E-5	1E-4
	Quaternary alluvium-lacustrine sediments, (Qal)	5.0E-5	1.0E-5	2E-4
	Plio-Quaternary andesite (PQa)	3.0E-5	1.0E-7	1E-4
	Plio-Quaternary piroclastic deposits (PQpd)	8.0E-8	1.6E-8	1E-4
3	Upper Pliocene alluvial and pyroclastic deposits (Papd)	4.0E-6	0.8E-6	1E-4
4	Lower Pliocene pyroclastic, lacustrine deposits; Miocene andesite; Oligocene basalt, rhyolite; Eocene Balsas Group	4.0E-6	0.8E-6	1E-4
5	Cretaceous limestone	9.0E-6	1.8E-6	1E-4

Scientific paper

The relative importance of groundwater recharge zones for the aquifer system related to the *ZMVM* was studied with assistance of a flow-model. It incorporates constant head groundwater inflows from beyond surface basin boundaries. Detailed data about regional distribution of the geological[4] and hydrogeological properties[5] were used (Tab. 1).

RESULTS AND DISCUSSION

A regional groundwater model using ModFlow© code[7] with the graphic interface of Waterloo Hydrogeologic, Inc. (Visual Modflow version 2.8.1) to simulate pre-abstraction conditions in steady-state was implemented (Fig. 1). The steady-state analysis created a hydraulic-head configuration that reproduced former conditions of natural discharge areas and flows through the boundaries. Boundary flows represent natural discharge conditions before abstraction. Xochimilco wetlands and Texcoco lake, as well as ancient springs were reproduced. Hydraulic properties were kept constant, natural recharge[8] was used as initial condition to generate scenarios of potenciometric changes that suggested the influence of recharge at local and intermediate level. Recharge is higher in Sierra Chichinautzin as compared to simulated changes in Sierra Las Cruces (Tab. 2). On the other hand, local discharge systems, that manifest themselves as springs at high elevations of Sierra Las Cruces, were more affected than intermediate systems. Results indicate that recharge in sierras Chichinautzin and Las Cruces is quantitatively more important to local and intermediate flows that discharge in Xochimilco wetlands and at the foothills of these sierras but its influence is negligible to regional flows discharging in the Texcoco area. Different flow contribution has been proposed like leaks from the mains, water from the depressurization of the aquitard[3,6], and vertical ascending flows coming up to boreholes abstraction level[5]. A reported recharge[8] of about 15 to 25 m^3/s in sierras Las Cruces and Chichinautzin was used, however, this yield is not enough to keep the observed negative potenciometric evolution (»1 m/year) due abstraction. Additional inflows from beyond the south basin boundary (lateral inflow) were necessary to attain the observed hydraulic-head evolution and discharge conditions.

In order to protect the recharge processes the environmental Mexican laws declared the sierras Las Cruces and Chichinautzin as a Protected Natural Area (PNA). Indicators of these processes were included: *i*) high rainfall rate, *ii*) high hydraulic conductivity and secondary porosity by faults and fractures, *iii*) characteristic vegetation of highlands, *iv*) acid soils and *v*) urban growth. All of which were evaluated in terms of their value as indicators of relative potential for natural recharge. Vegetation was evaluated according to TOTH[9] assigning a relative value of one to that characteristic of a recharge area. Table 3 shows the surface cover of each vegetation type. Table 4 shows the relative values normalized (0, 1, 2) assigned to each geologic unit for its *K* value and extension. The spatial analysis using a SIG (Arc View) allowed the integration of these factors and to generate map (2) in map1 where identified urban sprawl processes (not presented) are linked to areas where present vegetation cover is negligible. These areas are considered of low-potential to the recharge processes, a middle-potential was assigned to areas were alterations to natural vegetation was changed for grass and agriculture use. Map (2) presents the study area in a regional context to show those areas with higher topography than the boundary of the basin of Mexico, which are potential recharge zones of regional flows. Planning strategies to protecting critical recharge zones to *ZMVM* groundwater sources must consider not only at a state level but also at a regional level to achieve a major viability of protection mechanisms to be design.

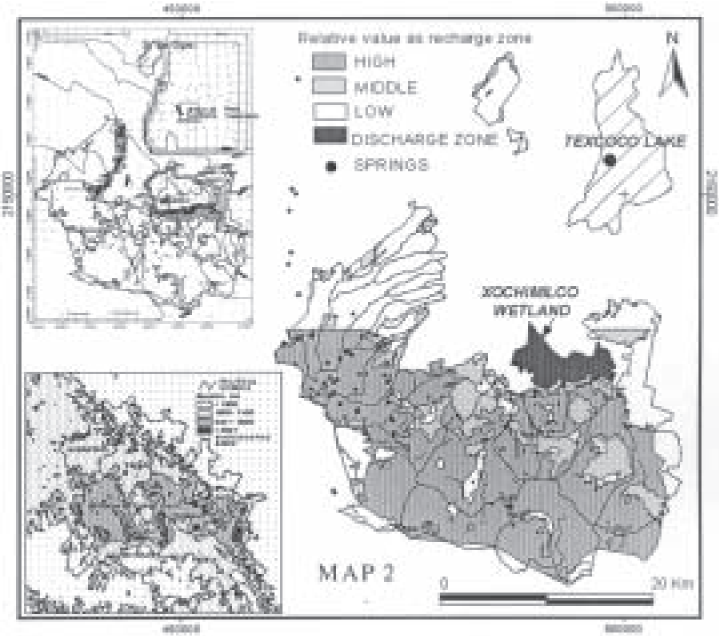

Figure 1. Potenciometric configuration.
Map 1. Relative value as recharge zone; Map 2. The study area in a regional context

Table 2. Changes of potentiometric levels (m) by decreasing in the quantity of recharge

	Recharge decrement		
Geomorphologic unit	5%	10%	20%
Sierra Las Cruces	1.7	3	5
Sierra Chichinautzin	3.0	4.3	7.3

Table 3. Area covered by different types of vegetation, (*)with or without alterations

Type of vegetation	Area (ha)
Crops	26288,19
*Forest	104324,53
Grasslands	19726,84
*Shrubs	247,25
*Meadows	414,17
*Cloud forest	2396,89
*Halo- and gypsophyllous	122,65

Modified from INEGI (IGg, 2000)

Conclusions

The simulated hydraulic head response to quantify relative recharge importance in the bounding sierras to the south of the basin. Response was analysed in terms of the sensitivity of the model and the obtained configuration of discharge areas. It is concluded that the importance of lateral inflows from beyond surface limits of the basin sustain the observed potenciometric heads in a regional level.

Land planning should be pursuing in the recharge zones developing a protection strategy. A medium term target is to protect (or improve) the geographic areas that contribute water to local and intermediate flows. However, in order to avoid a constraint on sustainability of neighbouring regions, the regional recharge area of the aquifer system of *ZMVM* should be considered in all developing plans at the regional scale. The entire groundwater flow system must be defined and use as a logical land planning instrument.

Table 4. Estimation of recharge potential in the different outcrop units

GIS Key	Geologic material	K*A (K, min)	K*A (K, max)	Recharge Potential
Soil	Quaternary alluvium-lacustrine sediments	2.0E-09	2.0E-07	0
Sandstone	Quaternary alluvium sediments	4.4E-05	8.7E-05	1
Basaltic and intermedia tuff	Tarango Formation	2.7E-04	3.1E-03	2
Andesite	Upper Pliocene andesite	5.5E-04	0.10128	2
Volcanic breccia	Plio-Quaternary andesite	2.9E-03	4.6E-02	2
Pyroclastic	Tarango Formation	3.9E-03	3.9E-02	2
Basalt	Quaternary basalt	4.9E-03	1.9694	3

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