Effects of aquifer overexploitation on the surface infrastructure in the Bogotá Sabana (Colombia)

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Abstract: Intensive use of groundwater in the Quaternary Aquifer in several parts of the Bogotá Sabana is causing local problems on the surface infrastructure. The unconsolidated soils are responding to the lack of water by contraction, cracking and subsidence. The article presents examples of the influence of groundwater alteration on a highway and on a housing development, and their engineering solutions.

Key words: groundwater overexploitation, Bogotá Sabana, Colombia

Introduction

During the last 50 years numerous tube-wells have been constructed in the Bogotá Sabana to supply groundwater for irrigation, several town aqueducts and numerous factories. The potenciometric levels are descending in several parts of the basin and causing local problems on the surface infrastructure such as housing developments, paved highways, farms and the collapse of many wells. This article briefly presents the case histories of a main highway and a housing development, and their engineering solutions.

Geology

The Bogotá Sabana, a plateau at 2,600 m elevation, was a high altitude lake with an extension of 156,250 ha in the center of the Eastern Cordillera of the Colombian Andes, which gradually filled with sediments during the Uppermost Pliocene, Pleistocene and the Holocene. These horizontal sediments of lacustrine, fluvial and fluvial-glacial origin, are mostly clays, with thin intercalated silt, sand and gravel lenticular beds, and numerous peat layers. They also contain many ash layers, which come from the volcanoes of the Central Cordillera, 100 km to the west of the Sabana, and two other volcanoes of the Eastern Cordillera, 150 km to the NE. The aggregate thickness of the Pliocene-Quaternary units is some 600 m in the center of the former lake, and they thin out toward the edges and in the tributary river valleys. They lie uncomfortably on folded and faulted Lower Tertiary and Cretaceous sedimentary formations more than 5,000 m thick. The Holocene sediments are unconsolidated, while the Pleistocene and Pliocene beds are semi-consolidated (Lobo-Guerrero, 1992).

Hydrogeology

The Bogotá Sabana is a closed multiaquifer artesian basin. Surrounding and beneath the whole basin is the Guadalupe Aquifer, in fractured thick sandstones, siltstones and thin claystones of Upper Cretaceous age. Total thickness varies between 750 m and 550 m.

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Transmissivity varies from 5 to 536 m^2/d, and the storability varies from 1 x 10^{-2} to 9 x 10^{-7}. Beneath the Guadalupe Aquifer is the Villeta Group composed of a very thick succession of marine shales with minor cherts and sandstones, in general with a very low permeability. In several of the synclinal valleys there are thick Lower Tertiary claystone formations (confining beds) above the Guadalupe Aquifer. On top of the Lower Tertiary is the Pliocene-Quaternary Aquifer, which contains many, confined, unconfined and perched units in the lenticular silt, sand and gravel beds of the Tilatá, Subachoque, Sabana, Tunjuelo and Chía Formations. The individual aquifers are relatively thin, 0.5 m to 5 m thick, with a transmissivity varying between 2 and 939 m^2/d and a storability between 1 x 10^{-2} and 7 x 10^{-7}. They are separated by very low permeability clay beds. (LOBO-GUERRERO, 1992; CASTRILLÓN AND ARAVENA, 2002).

EFFECTS OF AQUIFER OVEREXPLOITATION ON THE SURFACE INFRASTRUCTURE

There are more than 5,000 wells extracting groundwater in the Bogotá Sabana; the majority of them in the Pliocene-Quaternary Aquifer. The regional lowering of the potentiometric level has caused the disappearance of mountain front springs, streams and wetlands; land subsidence; cracks on the ground, in buildings and highways; well collapses; lowering of submersible pumps; and replacement with deeper wells. (LOBO-GUERRERO, 1992 AND 1995; VESGA, 2000; CAR, 2001).

BOGOTÁ-MEDELLÍN HIGHWAY

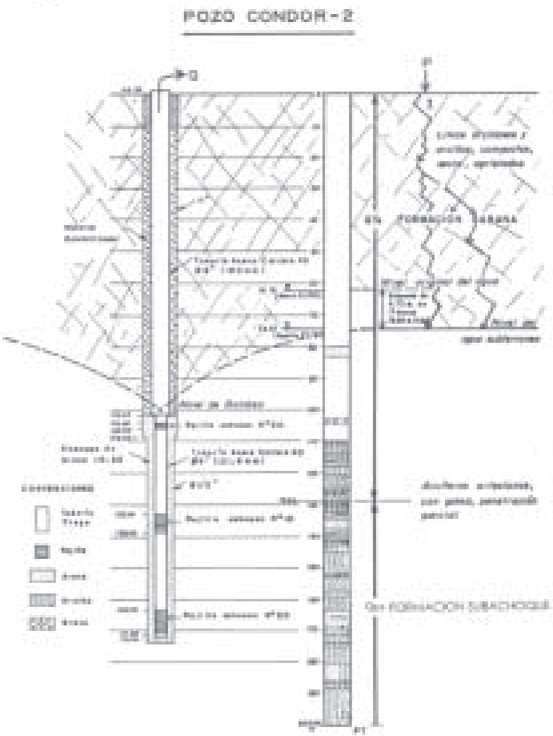
The main highway from Bogotá to Medellín crosses the Bogotá Sabana from SE to NW. From 1970 to 1995 this highway was enlarged and in permanent reconstruction due to unforeseen geotechnical problems in the foundations: cracks in the asphalt pavement, slumps that affected the surface course and seal, the base course (gravel-clay-silt), the subbase (sand), and the shoulders. The subgrade is the Sabana Formation (Pleistocene) with silty clay (volcanic ash layers) and clay layers, which are expansive soils, in an environment with 1,000 mm/yr rainfall, approximately 800 mm/yr evapotranspiration and 200 mm/yr runoff, originating a fissured subgrade. There are many groundwater wells in the fields and towns on both sides of the highway. Figure 1 presents the case of a well in a flower plantation irrigated by surface and groundwater, located 350 m south of this highway. The land surface at 2,580 m elevation is flat. The Condor-1 exploratory well was drilled in 1989, 326 m deep, with a 1.6 lps production, finding the Sabana Fm. (129 m thick) above the Subachoque Fm. (+/- 203 m). The horizontal Pleistocene aquifer lies uncomfortably on top of tilted claystones of the Guaduas Fm.(Maastrichtian-Palaeocene), a 1,200 m thick confining unit outcropping 2 km to the west. The Condor-2 well was constructed in 1990 with the following characteristics: depth:172.70 m; casing diameters: 6"(0-102 m); 4"(102-172.70 m); gravel pack; screens: 104.50-106 m, 133-139 m, 163.70-171.20 m; aquifers: coarse, medium and fine quartz sands in the Sabana and Subachoque Fms.; transmissivity: 66.6 m^2/d; initial potentiometric level: 61.74 m; yield: 3.16 l/s; geohydraulic model: transient, confined, leaky, partial penetration; water quality: bicarbonate-ferric-magnesic, 6.9 pH, 295 ppm total dissolved solids; pumping level: 99 m. In August 1992 the water level had lowered to 73.47 m and the well yield had dropped below 1 lps; besides having iron incrustations the upper

screen had collapsed. The screens are stainless steel N°63 high resistance wire (37.4 kg/cm^2), 0.020"slot size. Calculated lithostatic pressure at that depth is 23.16 kg/cm^2. When the well started pumping there was also a calculated hydrostatic pressure of 4.20 kg/cm^2. On 08/22/99 the potentiometic level had dropped to 73.47 m with a calculated hydrostatic pressure of 3.07 kg/cm^2. The lithostatic pressure had to increase 50 % to produce the screen collapse (Lobo-Guerrero, 1995).
The total stress due to the materials on top of an unconsolidated aquifer is the sum of the pore pressure and the effective pressure between the grains. When the potentiometric level drops, as is the case in this artesian basin, the pore pressure decreases and consequently the effective stress increases. The sands and gravels of the Sabana and Subachoque Fms. are confined between leaky, unconsolidated clay/silty-clays. As the potentiometric level falls the aquitards are slowly compressed while the aquifers, with much less compressibility, are releasing groundwater under the transient flow system of pumping. The Sabana Fm. has been slowly consolidating since the Upper Pliocene and is a fissured clay near the surface, actively expanding and contracting in the present climate, and whose upper surface oscillates some 0.50 m between the rainy and dry cycles. The effective stress increase reduces the porosity of the clay/silty-clays, compacts the aquitards, and induces subsidence. The clays and silts are being converted into fractured and fissured claystones and siltstones, consolidated rocks which weigh more than the original materials. The stresses on the well screen were so high that they produced the collapse. Along the entire drawdown cones of the many interfering pumping wells in the area these phenomena have been going on for a long time. The highway could not withstand the stresses. It was entirely rebuilt with a new design: geotextiles, a palisade within a sand subbase, a thinner (0.70 m) and lighter base course (gravel-coal ash), lateral shoulders, etc. (Afanador, 1998).

Housing Development in Bogotá

In the rapidly expanding city many new housing developments lie close to farmlands. Another example of groundwater-engineering geology problems is a development in NW Bogotá. It has an area of 211,400 m^2, with three-story homes, built in 1994. During the past eight years the constructors have been monitoring the subsidence of part of this development which lies close to another flower plantation. The subsidence cone, with a radius of 80 m has reached a maximum of 550 mm near the center and 100 mm in its perimeter. It lies 200 m north of wells 2 and 3 of the plantation. The houses were built on gently sloping ground of the Sabana Fm. 20 to 105 m thick (clay, silt, peat, sand and gravel); beneath and outcropping to the west is the Guaduas Fm., 450 m thick (claystones, sandstones, coal beds). Beneath the Guaduas is the Guadalupe Fm. The Guaduas and Guadalupe form a faulted syncline with a regional NNE-SSW thrust fault parallel to its axis, just to the west of the housing development; there are also several WNW-ESE normal and strike-slipfaults. The Guadalupe Fm. is a regional aquifer with secondary permeability; the Guaduas has low permeability, although the sandstones and coal beds are aquifers with secondary permeability; the Sabana Fm. contains aquitards and perched aquifers in its upper part, and regional aquifers in the middle and lower part; and the large thrust fault is an aquifer. To the south, two wells 399.50 m and 404.00 m deep, pump 9.5 l/s and 12 l/s almost continuously from the Guadalupe Aquifer. The potentiometric level is dropping at a rate of 3.16 cm/month in one of the wells and 9.76 cm/month in the other.

Fig. 1



The soils investigations found the following succession: a surface unit of silt or silty clay 1 to 2 m thick; below clay or silty clay, sometimes fissured, 1 m thick; then the water table; and below, silt, organic silt, peat and fine sand, down to 8 m depth. Further down, are clayey silts down to 11.50 m, then a 0.30 m to 0.60 m peat bed; silty clays down to 18.50 m, and on the bottom fine sands or gravels, mixed with sandy clays. The first 2.50 m are slightly preconsolidated with a resistance of 0.7 to 1.2 kg/cm^2. Below 2.50 m the resistance decreases to values a low as 0.35 kg/cm^2 in soils with a very large pore ratio, very high natural moisture (occasionally as high as 200 %), and very compressible. The resistance is high in the sand and gravel beds that lie below. Four factors acting simultaneously cause differential settlements beneath the houses: very compressible beds with a high pore ratio; fluctuation of the water table responding to the rainfall cycles and causing contractions, fissuration and subsidence of the surface soils; the drop of the potentiometric level of the aquifers with the increase of the effective stress, accelerating the consolidation; and abundance of organic clays and peat in the western part of the lot. Micropiles have been constructed up to the thick gravels beneath the houses to solve the problem.

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