Hydrogeological conceptual model of the Puerto Boyacá's aquifer.

E. R. MONROY*, J. P. GONZÁLEZ & V. M. PEÑARANDA****
Civil Engineering Faculty, Saint Thomas University, Tunja, Boyacá – Colombia
*** Civil Engineering Faculty's Dean - emonrroy@ustatunja.edu.co**
**** Civil Engineering Faculty's Researchers – jgonzalez@ustatunja.edu.co / vpenaranda@ustatunja.edu.co**

RESUMEN: Este estudio específico de investigación desarrollado en Puerto Boyacá ha mostrado la complejidad hidrogeológica y las dificultades cotidiana en el uso de las aguas. Esto ha sido escrito claramente en esta investigación donde el acuífero de Puerto Boyacá no ha sido preservado bajo una conceptualización ambientalmente sostenible y esto es necesario para dar una. El acuífero ha venido explotándose con altas tasas de flujo donde las recargas no hacen posible el uso sostenible de altos niveles de agua. Algunas recomendaciones a las autoridades ambientales del gobierno son exhibidas en esta investigación y cómo el daño es causado por la intervención humana.

PALABRAS CLAVES: Acuífero, Modelo Hidrogeológico Conceptual, Agua Subterránea.

ABSTRACT Several specific researches developed in Puerto Boyacá have showed the hydrogeological complexity and current difficulties in the water use. It is clearly stated in this research that Puerto Boyaca's aquifer doesn't preserve an environmental sustainable conceptualization and it is necessary to get one. The aquifer is being exploited at flow rates greater than recharge and it is not possible ensure sustainable use of groundwater levels. Some recommendations to environmental government offices are exhibit in this researches and how damage is causing the human intervention.

KEY WORDS aquifer; hydrogeological conceptual model, groundwater.

INTRODUCTION

This research is supported on available geological information. This research integrates another several interdisciplinary subjects such as hydrogeology, hydrology, agriculture and socioeconomic intervention. The above is supported by GIS mapping analysis in order to characterizing the current state of the aquifer that allows to state necessary strategies for the management and future conservation of the studied aquifer. The scope of this study is getting an approach to the conceptual hydrogeological model and an evaluation of possible annual extraction volumes. With the available records it was successful to establish a management and protection plan of the Puerto Boyacá's groundwater, which involved doing several activities, relating to various environment and sustainable water resources projects. All above was possible mean the jointing action by all interventionists located in the recharge area and the guidance and control of environmental authorities, whose are represented by Autonomous Corporation of Boyacá (CORPOBOYACÁ).

Even there was a great effort by interventionist and environmental authorities, the planning process required the institutional strengthening of public authorities. Although, currently they are awarded of numerous environmental problems, it is weak the work effectuated by them. According to interventionists is necessary to support and provide by analytical tools to this public authorities.

To achieve the conceptual hydrogeological model took into account some of the most important hydrogeological characteristics of every geological formation that emerge in the influence area and the gathering of technical and socioeconomic information (e.g., population grown in the intervened area, locations of groundwater wells, static levels, flows, hydraulic characteristics of aquifers and so on).

GEOLOGICAL DESCRIPTION OF THE STUDY AREA

Puerto Boyacá's town is part of a sedimentary basin known in Colombia as Middle Magdalena Valley Watershed and its configuration is continental, with a predominance of sedimentation and tectonics' cycles. Puerto Boyacá's town is divided into ten sub-basins including a Magdalena River's area which borders the town on its west. Nine sub-basins, which are mentioned above, drain into the river along over seventy (70) miles.

Based on geological information, it was possible to get a description of the existing geologic formations at regional level. This is last is explained by the viewpoint of its ability to store and allow the flow of groundwater, in order to identify the presence of aquifers and differentiate impervious rocks. The main aquifer is composed of the geological formation known Mesa ( ), which is extended

for several kilometres, heading from north to south along the east bank adjacent to Magdalena River's valley. According to that, it is clearly this aquifer is considered as a regional aquifer whish lateral extension is delineated by the emerging zone. It is important to remind that geological infiltrations and recharges, occurs in wherever aquifers remains, i.e., recharge areas coincide with emerging aquifers areas.

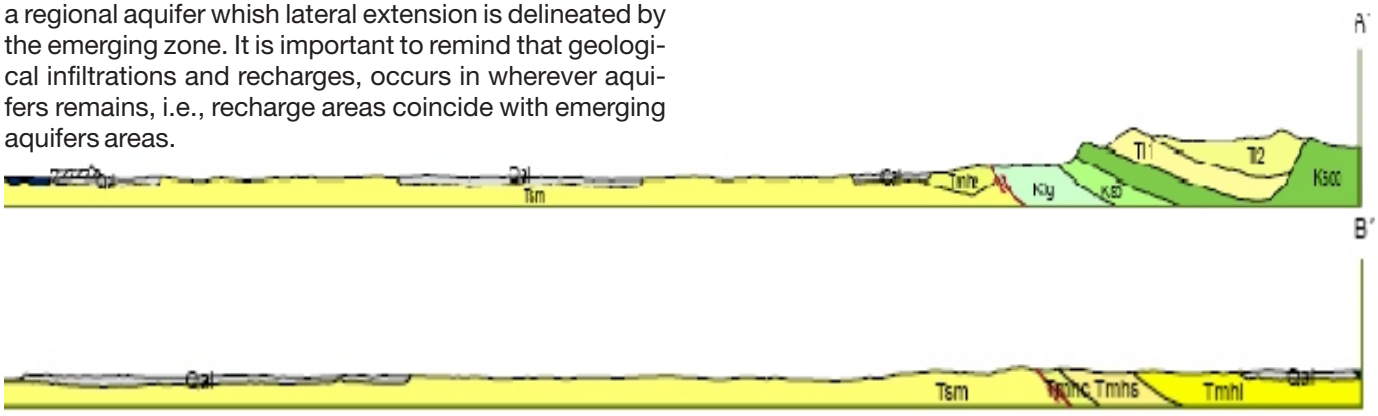

FIG. 1. STUDY AREA GEOLOGICAL PROFILE WHERE IT IS SHOWED SOME OF THE GEOLOGICAL FORMATION.

Because Mesa formation layers rest in flat-lying way, the main recharge occurs at higher levels as there are clay layers that acting as impervious and unfavourable barriers to percolation and vertical flow through lower levels. It is expected that lower levels have not direct recharge because they are isolated within impervious clays. Some of groundwater levels, which are inside the Mesa's formation and not having surface recharge zone, may have a lateral supply from closed emerged zones. In the study area do not emerge from aquifer's discharge zones, even so, the upper level, which is in hydraulic contact with the Magdalena River, possibly deliver a small streamflow through itself, in low flow seasons.

The conceptual hydrologic model identified the main aquifer is composed of gravel and sand layers belong to Mesa formation. This formation has clay layers at either different depths or different thicknesses. This formation lies on Limones formation which is considered a confined aquifer.

HYDROLOGY

The morphometric analysis was developed by mean of processing a digital elevation model (DEM) which is shown in . The DEM is a geo-referenced matrix which stores values of geographic elevation. From this DEM was possible to get some of the most important geographic parameters revealing hydrological characteristic.

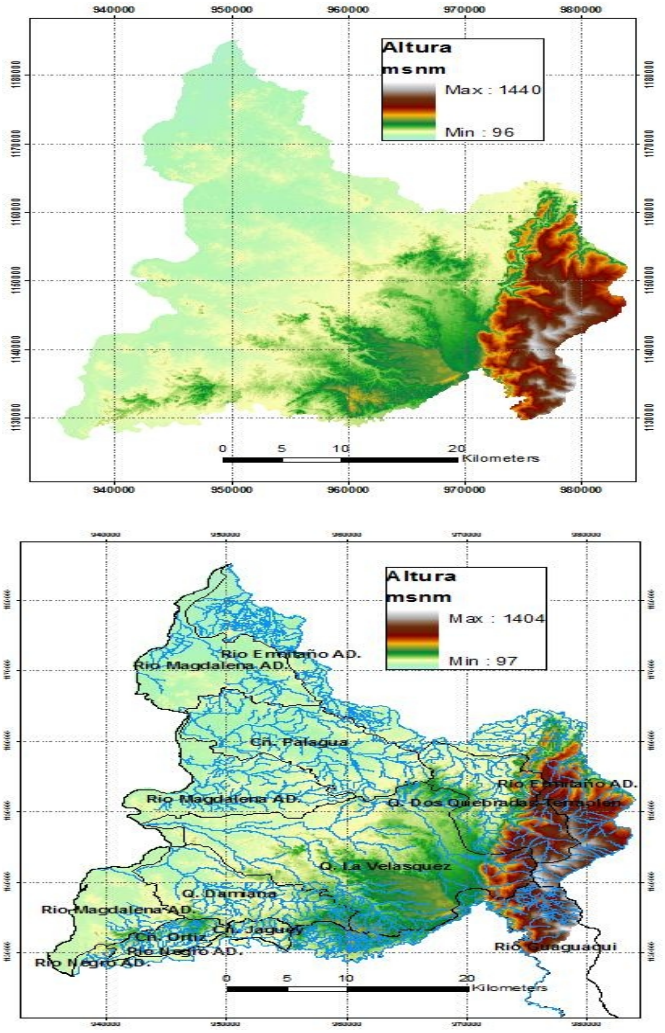

FIG. 2 DIGITAL ELEVATION MODEL OF PUERTO BOYACÁ (BOYACÁ – COLOMBIA) AND DELIMITATION OF SUB-BASINS. THIS DEM WAS TAKEN FROM HTTP://WWW.LANDCOVER.ORG/INDEX.SHTML.

Table 1.Morphometric characteristics of Puerto Boyacá's sub-basins

Subcuenca	AREA (m2)	Cota Min	Cota Max	Rango cotas	Cota Media
Rio Magdalena	328447000	97	235	138	148,5
Q. Damiana	113124000	137	320	183	175,7
Q. La Velasquez	340192000	138	1197	1059	225,1
Cñ. Palagua	162179000	99	235	136	149,4
Rio Ermitaño AD.	235181000	114	1334	1220	340,5
Q. Dos Quebradas Terraplen	126425000	145	1227	1082	337,1
Rio Negro AD.	16424800	146	231	85	169,8
Rio Guaguaqui	91412800	175	1404	1229	486,3
Cñ. Jaguey	15499000	166	241	75	186,4
Cñ. Ortiz	34033100	154	280	126	190,9

Subcuenca	S min	S max	Rango	S media
Rio Magdalena	0,00	32,29	32,29	4,22
Q. Damiana	0,00	29,61	29,61	4,96
Q. La Velasquez	0,00	71,11	71,11	6,45
Cñ. Palagua	0,00	29,17	29,17	3,74
Rio Ermitaño AD.	0,00	74,26	74,26	10,55
Q. Dos Quebradas Terraplen	0,00	74,34	74,34	12,97
Rio Negro AD.	0,00	28,64	28,64	4,06
Rio Guaguaqui	0,00	75,86	75,86	18,29
Cñ. Jaguey	0,00	30,86	30,86	4,61
Cñ. Ortiz	0,00	26,02	26,02	5,94

Puerto Boyacá's town is divided in 10 sub-basins (see) including a portion of the Magdalena River; this last, borders the town in the west. According to the DEM's processing, some results are exhibit in . These results state that the sub-basins are located in a warming thermal floor, excepting the high location of 4 sub-basin which exceed 1.000 metres above the sea level. The lower part of some sub-basins belongs to Magdalena River's catchment, as it was mentioned above, it is the basin which receives the streamflow from this sub-basins. Slopes of each sub-basin are completely flat in the most cases, and maximum slopes be found in those basins that are located above 1,000 metres. The average slopes range between 10 and 18 percent (see).

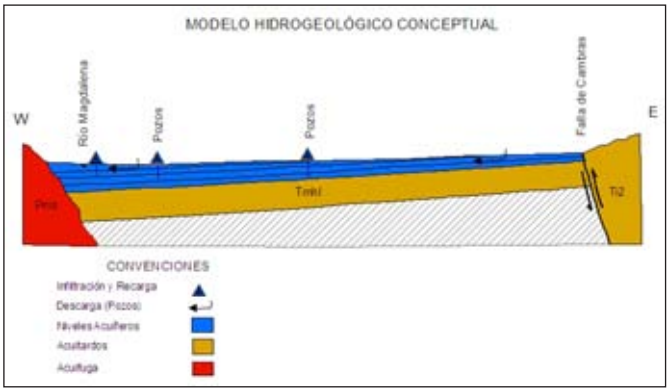

FIG. 1.PUERTO BOYACÁ'S HYDROGEOLOGICAL CONCEPTUAL MODEL. IT'S IDENTIFIED THE MAIN GEOLOGICAL ASPECT OF THE STUDY AREA.

Puerto Boyacá's town have a climate characterizing by an average annual temperature of 28 °C. The lowest temperature is 16 °C and the highest is 40 °C. The months of April, May, October and November have the highest values of relative humidity, which ranges between 80 and 81%. The rest of the year ranges between 75 to 79%. The average monthly rainfall, presents a bimodal regime. In November, the largest amount of rainfall was recorded in May and September, and the lowest amount since December to February. The average annual precipitation is estimated in 2100 mm.

HYDROGEOLOGICAL CONCEPTUAL MODEL

The hydrogeological model (see) defined that the main aquifer is composed of gravel and sand levels from Mesa's formation. This has arcillolite's levels at different depths and thicknesses. This formation lies down under Limones' formation which is considered a confined aquifer and forming an impervious lower boundary.

This study also suggested that aquifer levels, that cover the most area, are bounded at the east by the Cambras' failure, crossing from south to north in the whole region. To the east of the fault there are formations considered as confined aquifers which constitutes an impervious boundary at Mesa's formation and do not receive direct recharge from precipitation.

By mean of this model it was determined that the groundwater recharge occurs in outcrop areas which are limited by the presence of arcillolite layers. In addition, the aquifer discharge is presented either at Magdalena River or groundwater well, in seasons of low streamflow. The regional groundwater flow is slow because there is a large area of discharge and a regional geological structure of low dip. In the lower aquifer levels of Mesa's formation, the groundwater water tend to zero because they have no natural drainage area.

The concessions reach a total amount of 15.901,92 cubic metres per day, an average flow equal to 184.05 litres per second. These values correspond to the total groundwater demand; according to the log files that are buried in CORPOBOYACÁ's files (see). The decrease of the static level indicates that the volume of annual groundwater extraction exceeds recharge. The decrease of the static levels indicates that the Mesa's formation aquifer is being over-exploiting in the vicinity of Puerto Boyacá and the current pumping rate is not approached in a sustainable way.

TABLA 8 . CAUDALES OTORGADOS
EN EL ÁREA DE ESTUDIO

NUMERO Y NOMBRE DEL POZO	FECHA DE AFORO	CAUDAL OTORGADO m^3/día	CAUDAL OTORGADO Lit/seg
Pozo Nº 2 Empresas Publicas B. Pueblo nuevo Cra 13 Nº 6 - 48	06/10/2001	319,68	3,7
	08/03/2007	699,84	8,1
Pozo Nº 3 Parqueadero Piscina. Avenida Pto. Niño Con calle 11	AGOSTO DE 1962	1728	20
	08/03/2007	993,6	11,5
Pozo Nº 4 Boqueron Carrera 3 con calle 7 Esquina	08/04/1963	699,84	8,1
	01/03/1988	881,28	10,2
	06/10/2001	881,28	10,2
	08/03/2007	993,6	11,5
Pozo Nº 6 Empresas Publicas B. Pueblo nuevo Carrera 3 con calle 7 Esquina	07/09/1975	0	
	06/10/2001	374,976	4,34
	08/03/2007	614,304	7,11
Pozo Nº 11 Frente ACJ Carrera 2 con Transversal 1A	06/10/2001	881,28	10,2
	08/03/2007	1416,96	16,4
Pozo Nº 12 Carrera 13 con carrera 7	08/03/2007	2073,6	24
Pozo Nº 13 GLORIETA Calle 11 con carrera 5	08/03/2007	907,2	10,5
Pozo Nº 14 Finca las Palmeras, Potrero en predios del Alto de la Virgen	08/03/2007	2436,48	28,2

FIG. 1.APPROVED FLOW IN THE STUDY AREA.
FUENTE CONSULTORES DEL ESTUDIO

According to the water balance is inferred that the annual recharge is about 128.096 cubic metres. This value is lower than the annual discharge is extracted by wells, which is about 3.709.850 cubic metres. From stratigraphic data records, it is suggests that 50% of the total thickness of the formation table corresponds to sand and gravel and the remaining is clay. Therefore the effective thickness of the aquifer is approximately 153 m.

Assuming an effective porosity (for sand and gravel), around 4%, it is estimated that current reserves in Mesa's formation is about 5.437 billion of cubic metres. The aquifer is being exploited at flow rates greater than recharge, therefore, with annual volumes currently extracted, is not possible ensure sustainable use of groundwater levels (currently in production).

Based on these last data is estimated the "safe yield", defined as the volume of water that can be extracted from the aquifer without causing undesirable conditions that may affect as sustainable sources of water supply. The safe yield for Puerto Boyacá's aquifers is estimated in 128.096 cubic metres per year. If aquifer levels are exploited at a rate higher than the safe yield, it will continue drawing water reserves and it will generate undesirable effects in the whole aquifer.

CONCLUSIONS

According to the region geological structure, the infiltration is relatively low because there are clay deposits; such conditions are not favourable for water penetrates in depth. Beside, the water balance state the annual recharge is 128 096 cubic metres. This value is lower than the annual discharge extracted by wells, which is estimated in 3,699,948 cubic metres. Following these results, the geological characteristics of the area, the water balance of the region and the decrease of the static levels indicates that the aquifer is being overfished and keeps an unsustainable production. It is recommended to CORPOBOYACÁ (Boyacá's Autonomous Corporation), require pumping tests before giving groundwater concessions which have to accomplish with a minimal observation records and guarantee the source sustainability.

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