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Conceptual Models in Hydrogeology, Methodology and Results

Teresita Betancur V., Carlos Alberto Palacio T.
and John Fernando Escobar M.
University of Antioquia
Colombia

1. Introduction

The foundation of model analysis is the conceptual model. A conceptual model in hydrogeology is a representation of the hydrogeological units and the flow system of groundwater.

Hydrogeology is far from being a typical quantitative science. Its models and predictions are only hypotheses; they rarely can be proven. There is rarely any proof of hydrogeologic hypotheses. Each model and each prediction is a hypothesis and there are rarely true tests of these predictions. Hydrogeology is mostly a descriptive science that attempts to be as quantitative as possible regarding descriptions, but without the possibility (in many or most cases) of guaranteeing the accuracy of predictions. Indeed, hydrogeologists should strive to make models more quantitative (rather than qualitative) in order to answer real management questions more precisely. But after answering such a question, what proof is there that their particular model is correct? There may be none (Voss, 2005).

A conceptual model is necessary in order to obtain a numeric model. Many aspects of the conceptual model are not possible to represent in numerical model, because the hydrogeological systems are very complex (Wagener, et al. 2007). A review about hydrologic models is in Gosain (2009). Sivakumar (2007), considers three main aspects in the models: processes, scale and objectives.

Groundwater exploration is defined as "all operations or work that allow the localization of aquifers or underground reservoirs from which water can be obtained in suitable quantity and quality for the intended purpose" (Custodio and Llamas, 1997.) The results of hydrogeological explorations are translated into conceptual models. As shown by Andersson and Woessner (1992), a conceptual model is a pictorial representation of the flow system of groundwater, often in the form of a block diagram or cross section. Conceptual models also include the characteristics of the hydraulic parameters of each unit, the positions of the phreatic and piezometric surfaces and also groundwater flow conditions. Besides these things, recharge areas and processes must be identified and reserves must be evaluated. The purpose of creating a conceptual model is to simplify the issue being examined and organize the data so the system can be analyzed effectively. Simplification is necessary because a complete reconstruction of the system is impossible. A conceptual model gives the basic idea or constructed understanding of how systems and processes operate (Bredehoeft, 2005).

As with all models, the quality of hydrogeologic models depends on the quality of the information that can be gathered for its construction, which in turn depends on the availability of financial resources.

It is important to note that a hydrogeological model contains many qualitative and subjective interpretations and proof of its validity can only be achieved by implementing specific research techniques and then constructing a numerical model and comparing the results from the simulation with observations from the field.

Bredehoeft (2005), referring to the certainty of conceptual models, uses the term SURPRISE and relates it to the situation in which the collection of new data invalidates an original conceptual model. Surprise may come from revision of the scientific theory or as a result of new information obtained on a particular site. According to Bredehoeft, surprise occurs in 20-30% of cases studied, indicating that it is not easy to build an appropriate hydrogeological

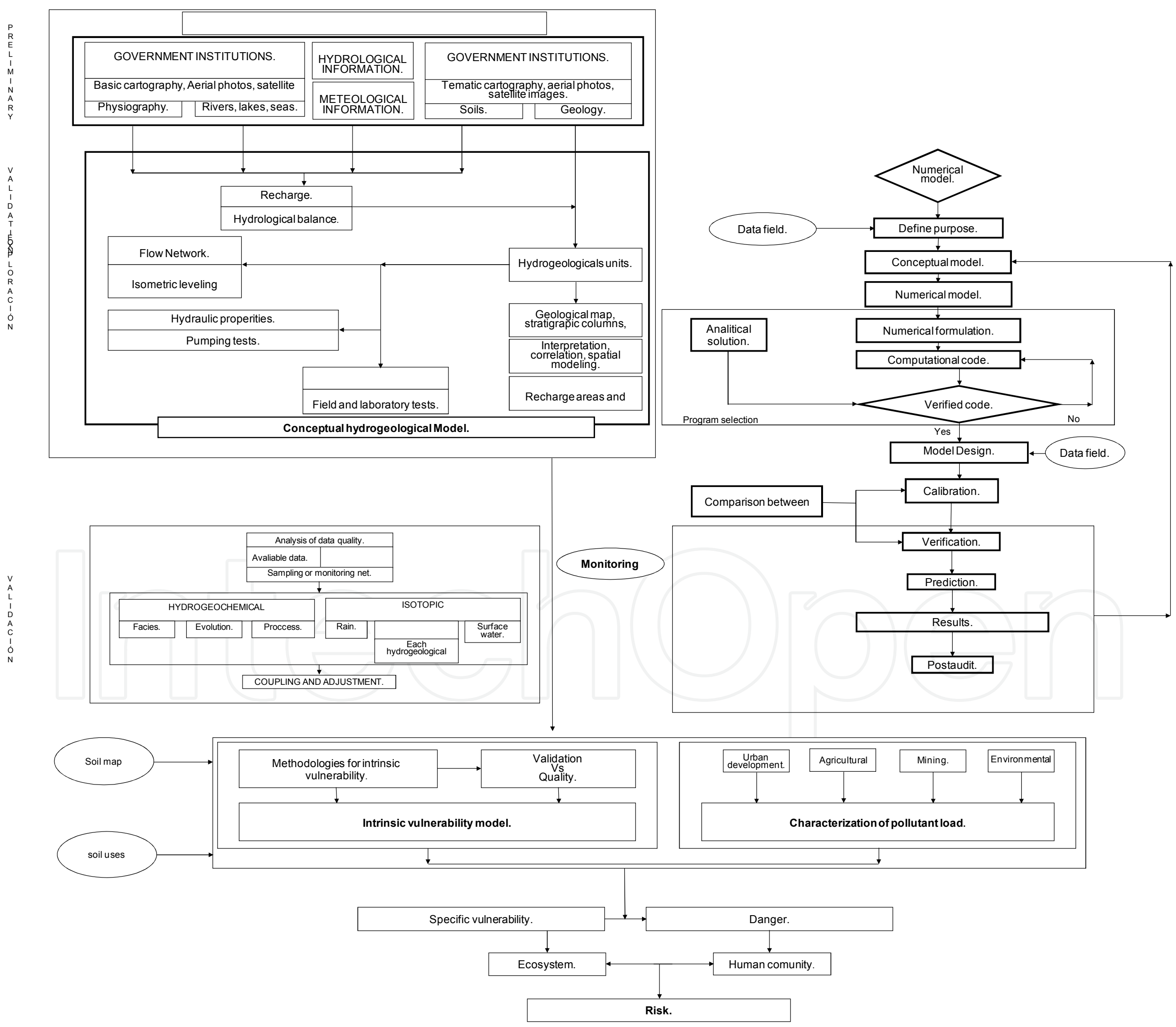


Fig. 1. Hydrogeological models Methodology

model. Carrerea et al. (2005) assert that given the uncertainty inherent in knowledge of the nature of subterranean media for those who deal with information which is quantitative (hard) but also qualitative (soft), it is possible to have several conceptual models for the same system.

The nature of hydrogeological variables is such that they can be interpreted with Digital Terrain Models (DTMs) obtained through geostatistical techniques. Geostatistical analysis includes: a description of information that is intended to quantify the relationship between measures of the same attribute in two locations, the modeling of spatial continuity represented by the variogram ($\gamma(h)$)— the cornerstone of geostatistical modeling, spatial prediction and assessment of uncertainty.

The coupling of hydrogeological research and exploration (Figure 1) involves applying a set of methodologies in search of a conceptual model. This methodological ensemble includes: basic exploration, numerical modeling, hydrochemical characterization, isotopic analysis, etc. Monitoring is the mechanism by which new geodata are obtained, and geographic information systems provide functional tools through spatial analysis to process and synthesize information (Betancur, 2008).

2. Conceptual models in hydrogeology, methods and techniques

A conceptual model is a reality representation, a conceptual model is a hypothesis; in order to obtain a good model in hydrogeology is necessary to join exploration techniques with validation methods. Then the tools for the management are necessary.

In this apart, five topics are considered: i) Hydrogeological data and information, ii) Numerical modeling, iii) Hydrogeochemical characterization and Isotope Hydrology, iv) Risk evaluation, and v) Geodata and geomodeling

2.1 Hydrogeological data and information

A hydrogeological model shows the surface distribution, geometry and hydraulic properties of the aquifer and the sources, zones and magnitude of the recharge as well as the quality of the underground water. The model requires for its construction prior information and knowledge of the physiographic, hydrographic, climatic, soils and geologic characteristics of the region (Figure 2). Available data and the information that can be extracted from them are the input elements to carry out an analysis procedure that can produce results to obtain the desired model.

To carry out local hydrogeological studies, a characterization of the physical medium must be made. Slope maps and Digital Terrain Models (DTM's) and three-dimensional views that represent the topographic surface can be obtained using the spatial analysis capabilities of GIS software. Photo interpretation, image processing and control field are all elements whose interpretation, in conjunction with review of papers and books make possible to obtain adequate physiographic and geological characterizations, and characterization of the soil in the study area. Descriptive statistics applied to the hydrometeorological information in the context of regional weather dynamics provide criteria for determining climatic conditions.

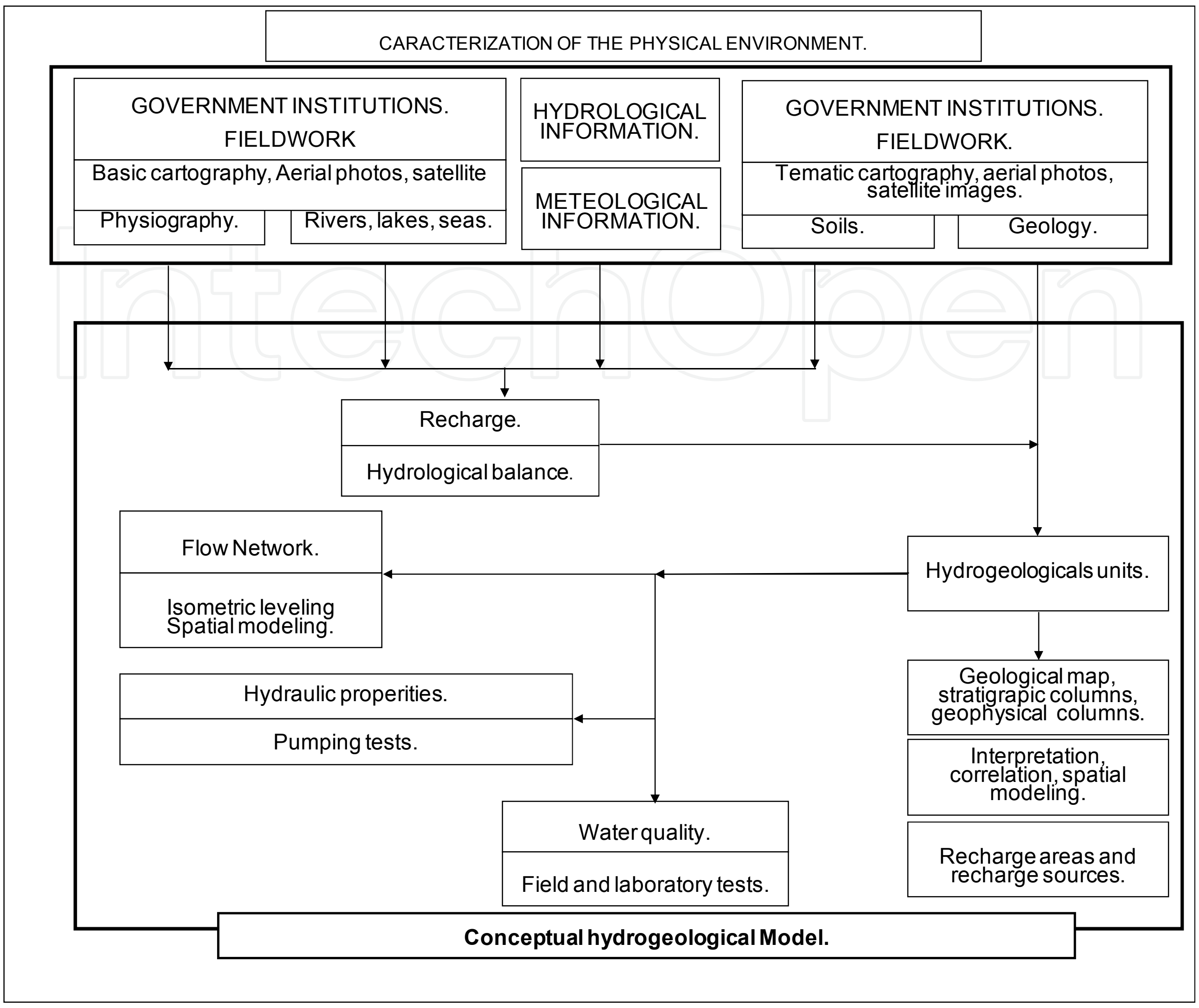


Fig. 2. Hydrogeological exploration methodology

Identification of the hydrogeological units is based on analysis of geology, stratigraphic information taken from inventories of water sampling points, and on geoelectrical data and its later correlation considering correspondence in character and position. For this, textural features, grain size, thickness, continuity and relative position in depth are taken into account for the stratigraphic units of each column.

In respect to the definition of the geometry of the aquifer units and their hydraulic properties and flow, geostatistics is recomended as the better method (Mejia et al., 2007). It is assumed that geostatistical analysis is a multistep process that requires the use of specialized software and includes;

i. exploratory data analysis beginning with the use of descriptive statistics to determine basic facts;
ii. evaluation of the norm and possible changes needed to achieve it;
iii. identification of trends and anisotropies;
iv. construction of a semivariogram and computation of range, plateau and value of the nugget effect between other elements;

v. adjustment of theoretical models to said variograms;
vi. analysis of the nugget effect;
vii. evaluation of grouping (clusters) and
viii. cross-validation until finally managing to create the desired surface.

In light of these conceptual considerations, the process can be implemented using the Geoestatistical analyst module available through software from ArcGIS version 9.1. Kriging is a procedures very used in order to model geological characteristics. Kriging have not a level of precision that would permit that, for each known point, the predicted value be equal to the observed; however surfaces represented with Kriging have clear physical and stratigraphic senses and in consequence a clear hydrogeological sense. For this reason, results obtained by geostatistics are preferred over ones provided by interpolation models such as Spline or IDW.

To determine hydraulic properties, the use of artificial tracers is a good alternative for establishing conductivity and transmissivity conditions; chlorine, fluorescence and bacteria are the most commonly used substances (Divine and McDonnell, 2005). However, this technique has a little use in regional studies. The most common method to obtain hydraulic properties is the pumping tests; which require considerable funds, at least three observation wells and adequate space.

The most critical aspect in the implementation of the hydrogeological exploration projects is the assessment of recharge. In a general context, there are various methods for estimating the amount of water entering an aquifer: direct methods describe recharge as a mechanism of water percolation from the soil to the aquifer, while indirect methods are those that use variables that describe and represent the flow of water through the soil. In direct procedures, measurement devices such as lysimeters or environmental or artificial tracers are used, while with indirect procedures, it is necessary to determine the relationship between flow and the recharge. Of indirect procedures, water balance, which uses precipitation as the main input variable to the system, is the most commonly used.

The water balance equation is a ratio of conservation of mass in which the system inputs are equal to output plus the change in storage. In the long run, it is assumed that the change in storage is not very significant, but at scales of times of a month or more its magnitude is considerable (Equation 1).

$$\mathbf{P = Q + ETR + \Delta R} \quad (1)$$

Where:
P: Precipitation (mm).
Q: Direct Runoff (mm).
ETR: Actual evapotranspiration (mm).
Δ R: Change in storage (mm).

Total storage consists of underground storage and of water storage in the soil, which is available for use by vegetation. There are more complex alternatives for representation that characterize different layers of soil, in each of which exist different processes of hydraulic transport, and various energy transfers.

2.2 Numerical modeling

Besides beings a simulation tools, as they have normally been considered, in hydrogeology, numerical models offer a way to advance the understanding of groundwater systems. Models provide a framework to systematize information from the field and to answer questions about the functioning of an aquifer. They can call the attention of those who make the model to the occurrence of phenomena that had not been considered before, and can help identify areas where additional information is required. Numerical models can be exploratory in nature, and as tools for exploration, their construction may go along with the task of building a conceptual model from the moment information collection begins, through the process of investigation and can continue whenever new information is received or new analyses are applied for the validation of a hydrogeologic system.

Protocols for numerical modeling are clearly established. Up until the time of calibration, modeling is a method of continuous confrontation between available hydrogeological information or new information that is collected and the results that are obtained. The almost simultaneous development of a conceptual and numerical model decreases the level of uncertainty of them both, the interaction between them making them more solid in the sense that a higher level of reliability is acquired through the ongoing back-and-forth of information. This allows for better planning of new goals in the advancement of knowledge. Later, the numerical model becomes the tool for simulation and prognostication of possible scenarios.

From the system of partial differential equations governing the flow of groundwater, analytical solutions can only be applied to very simple and homogeneous systems. In order to solve that situation, a system of nodes is imposed for analysis, and according to the conditions of numeric modeling. A numeric model is obtained for a case of interest that represents the aquiferous medium being considered. The numerical methods that can be used to model a system include: finite differences, finite elements, finite volumes, integrated finite differences, boundary element methods and analytical elements, among others. Of all these, finite differences, finite elements and finite volumes are the procedures currently used most often to solve flow problems.

The mathematical combination of the equations of mass balance and Darcy's Law lead to equation 2, which describes the flow of groundwater.

$$\frac{\partial}{\partial x}.(K_x.\frac{\partial h}{\partial x})+\frac{\partial}{\partial y}.(K_y.\frac{\partial h}{\partial y})+\frac{\partial}{\partial z}.(K_z.\frac{\partial h}{\partial z})-W=S_s.\frac{\partial h}{\partial t} \quad (2)$$

Where K_x, K_y, K_z are the hydraulic conductivity of the medium in the x,y,z, $\delta h/\delta x$, $\delta h/\delta y$, $\delta h/\delta z$ is the hydraulic gradient; S_s is the coefficient of specific storage; $\delta h/\delta t$ is the variation in piezometric charge over time; and W the ingresses and egresses of water caused by effects that are external to the aquifer system.

When the groundwater flow does not vary over time, $-\delta h/\delta t,= 0$ - states that the system is in a steady or permanent state, otherwise it is considered to be a transient state. Flow simulation in a transient state assumes temporal discretization of hydraulic heads over intervals of time during which boundaries remain unchanged. These intervals of time intervals of simulation, will be discussed further on, and are known as periods of stress.

Equation 2, along with a number of conditions for piezometric heads or flow at borders and initial conditions, constitutes a mathematical representation of the conditions of groundwater flow. Solving the equation provides the values for the heads as a function of space and time, h(x,y,z,t). Detailed discussions of numerical modeling of groundwater flow can be found in the writings of Wang and Anderson (1982) and Anderson and Woessner (1992).

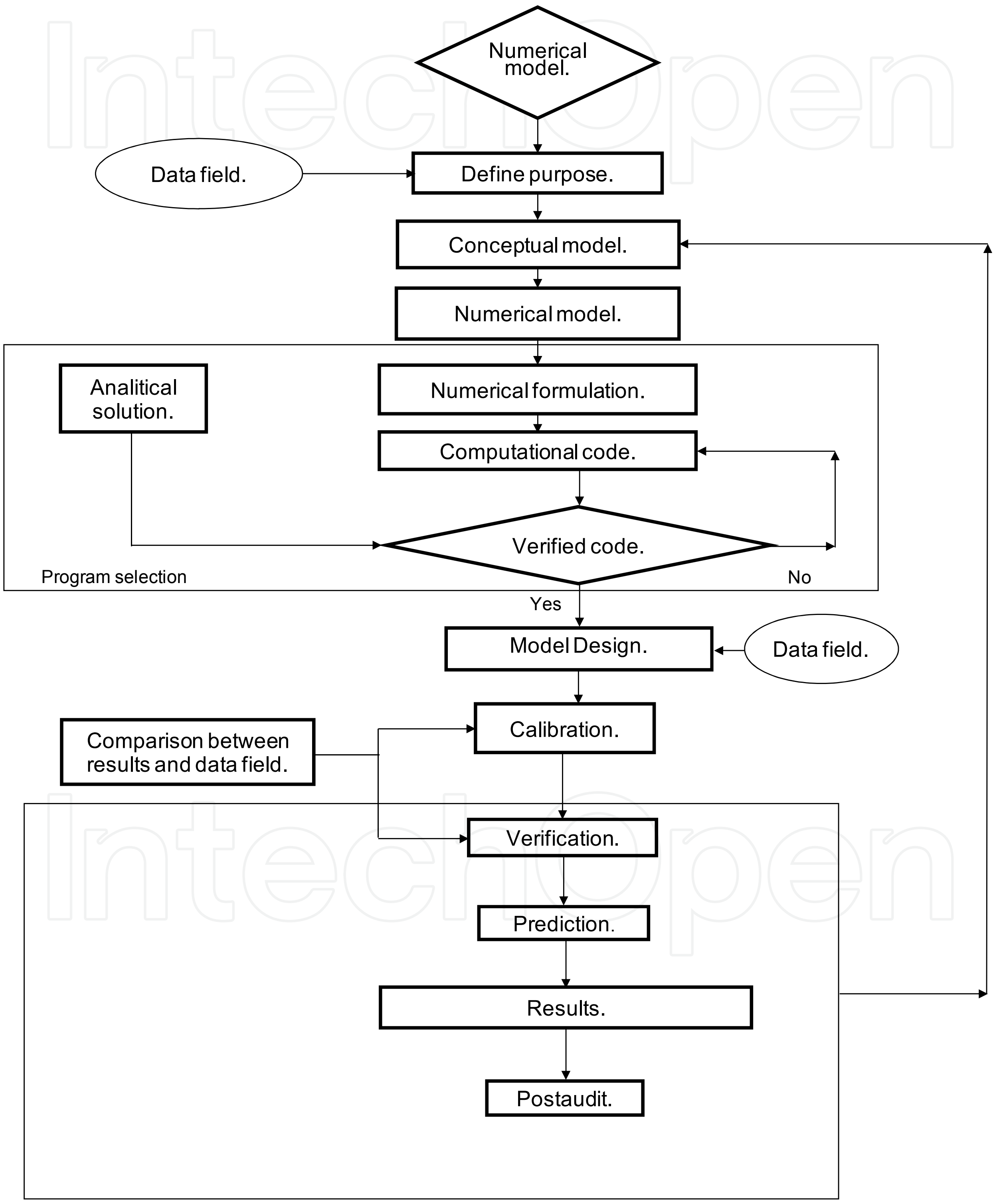


Fig. 3. Numerical modeling methodology

When it has been established that numerical modeling is an appropriate tool for exploring or simulating a hydrogeological system, the next steps are the design and implementation of this model. The suggested steps in modeling protocol are presented in Figure 3. Hydrogeological units and their boundaries should be defined in the conceptual model. The computer software selected for use in the modeling should contain an algorithm to solve numerically the mathematical model; afterwards, the screen is designed and increments of time, boundaries, and starting conditions are selected. The purpose of calibration is to manage, by means of adjustments to parameter values and ranges of simulation, to have the model reproduce field conditions for flow and piezometric heads. Uncertainty in the calibration, boundary conditions and timing of the simulation is quantified by a sensitivity analysis. In general, every modeling exercise should reach this stage. Only rarely is there sufficient information to verify a model, and long-term validation and monitoring—postaudit, is not necessarily a step in the protocol.

2.3 Hydrogeochemical characterization and Isotope Hydrology

In the field of hydrogeology, differences in the chemical and isotopic composition of water are used to check infiltration into groundwater, recognize leakage between aquifers, define areas of saltwater intrusion, assess baseflow contributions to surface currents and investigate recharge conditions through the unsaturated zone. The chemical characteristics of water allow identification of the origin and movement of solutes through subterranean systems. Environmental tracers help at the investigators understand the phenomenon of recharge, establish flow conditions and time scales in relation to groundwater permanence in the aquifer, and have enormous potential for helping to assess sustainability and vulnerability. Information from tracer isotopes and elements in solid and mineral phases has also helped investigators to understand paleohidrological conditions.

In its early stages, hydrogeological exploration provides information on water-rock interaction and thus enables the formulation of hypotheses to lead to validation of the conceptual model and understanding of the evolution of the aquifer. Isotopic characterization of a hydrogeological system is based on earlier hydrogeochemical

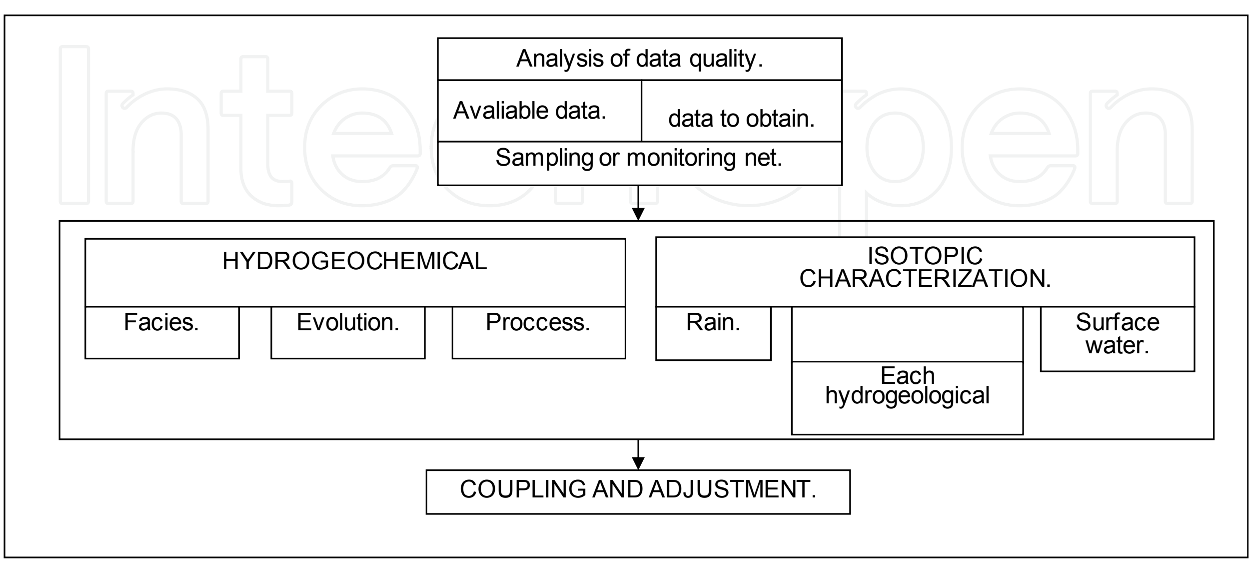


Fig. 4. Hidrogeochemical model methodology

characterization, and the two types of characterization are coupled in a cycle of confrontation and formulation of hypotheses that ultimately results in a validated conceptual model or a new conceptual model which must be subjected to new tests of validity. Questions are formed from hydrochemistry which are hoped to be answered by the isotopic data. For its part, the isotopic information may lead to new interpretations of available hydrogeochemical information.

The design and implementation of a network of sampling or monitoring for analysis of chemical and isotopic characteristics of rainwater, surface water and groundwater is based on a preconceived hydrogeological conceptual model. Interpretation of the data allows for an adequate characterization of the system, and from this, adjustment and validation of the conceptual model (Figure 4).

2.4 Risk pollution evaluation

The information contained in the hydrogeological model allows evaluation of the intrinsic vulnerability using different procedures, and knowledge of groundwater quality conditions enables the validation of methods to establish what method will be the most appropriate in a particular region. Knowledge of land use and the main economic activities carried out by the population provide the basis for assessing the potential or actual pollution load that could threaten the quality of water stored underground. The danger of contamination of groundwater is deduced from the relationship between intrinsic vulnerability and pollution load. Once the danger of contamination has been assessed, it is necessary to continue to a calculation of risk, for which an analysis of the susceptibility of the population to be adversely affected by a groundwater contamination must be undertaken (Figure 5).

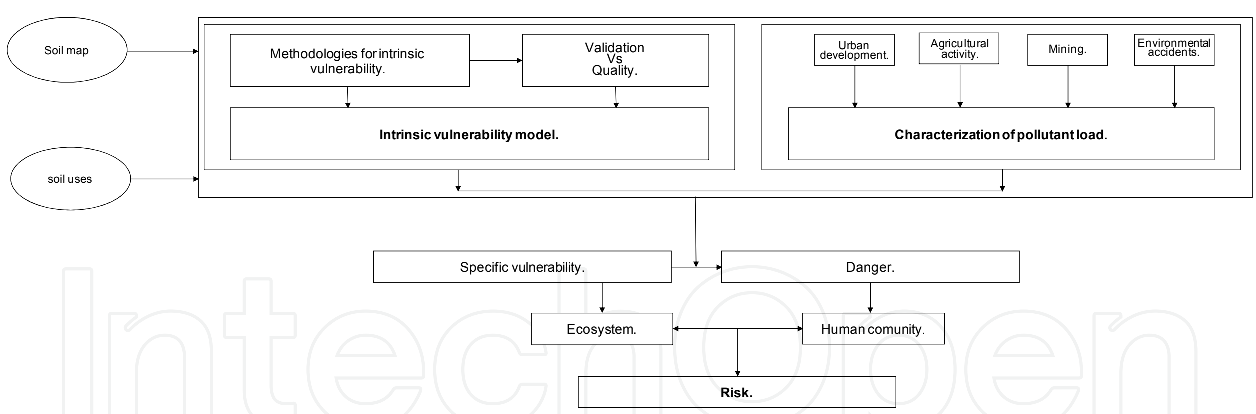


Fig. 5. Risk Evaluation methodology

2.5 Geodata and geomodeling

The establishment of geo-informatics as a technique for the analysis of information has led to the emergence of new ways of seeing and understanding elements and processes that occur in nature. These new ways of seeing and understanding are based on the possibility researchers have of sharing data and methods in order to represent, analyze, understand and model phenomena that vary over time and space, making use of explicit spatial objects and the options for data storage, integration, processing and analysis that are offered by Geographic Information Systems (GIS) and other tools such as remote sensing.

3. Conceptual models in hydrogeology: A case study

After seven years of study in the region of Bajo Cauca of Antioquia, Colombia, development and implementation of this methodology has allowed the construction and validation of a conceptual hydrogeological model and implementation of a monitoring network that continues to operate, providing new data and enabling new interpretations. Current knowledge of this hydrogeological system has offered great benefits to the process of decision making in the management of water resources, now featuring a risk assessment model for contamination of groundwater and moving towards formulating an Environmental Management Plan for the Aquifer (Betancur, 2005)

The Bajo Cauca of Antioquia is located between the last spurs and the foothills of the Western and Central ridges of the Colombian Andes mountain chain system. The alluvial plain of this region has an area of 3,750 km² and it is crossed by the Cauca, Man, Nechí, and Cacerí rivers (Figure 6).

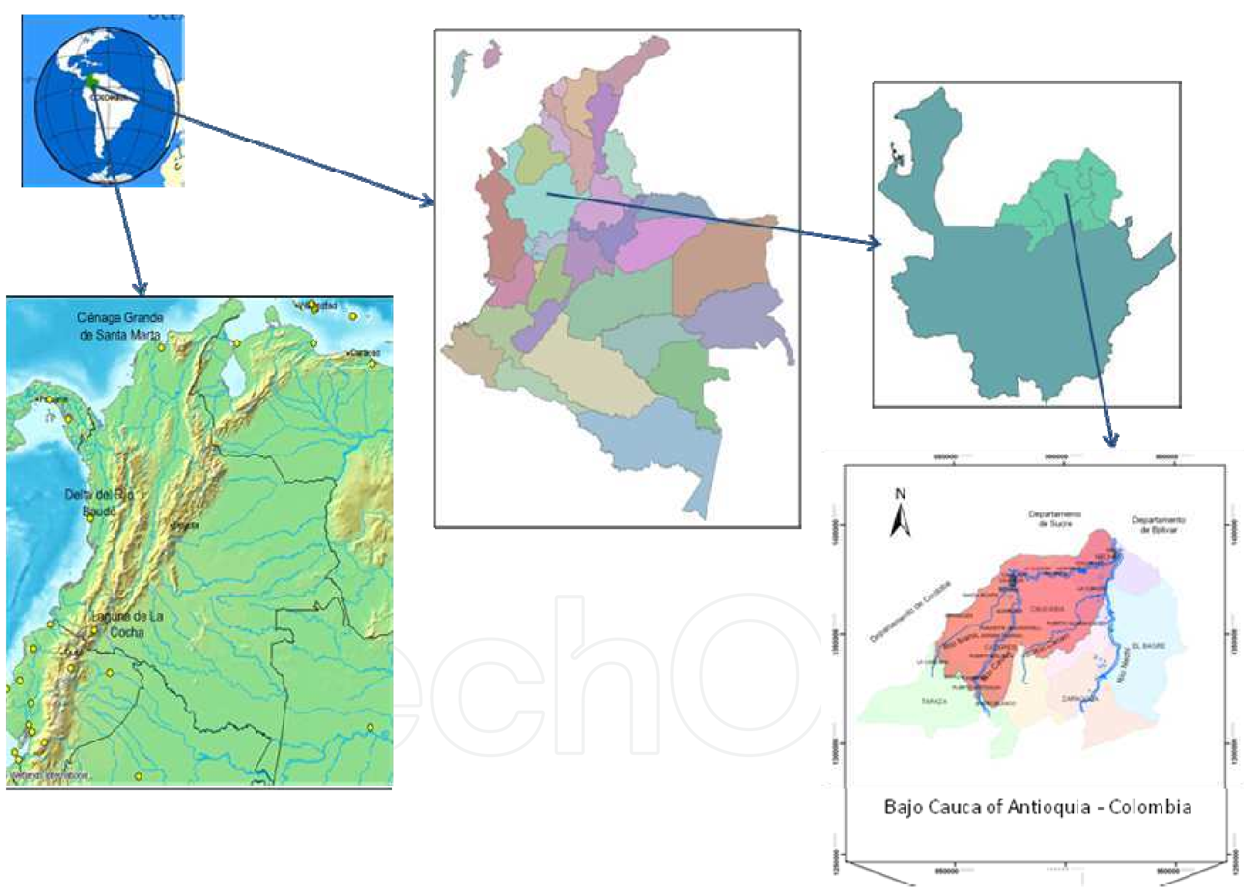


Fig. 6. Bajo Cauca of Antioquia, Study Area

The Bajo Cauca of Antioquia aquifer system is an important system. First, it is vital for communities as a water supply source; second, there is an interrelation between surface water and groundwater. Third, many wetlands depend on this resource. This aquifer system consists of three hydrogeological units: a free aquifer, an aquitard, and a confined aquifer.

3.1 Conceptual model

The aquifer system of the Bajo Cauca of Antioquia is comprised of three hydrogeological units (Figure 7); an unconfined aquifer known informally as hydrogeological unit U123, an aquitard, unit U4 and a confined aquifer, unit U5 (Betancur et al., 2009).

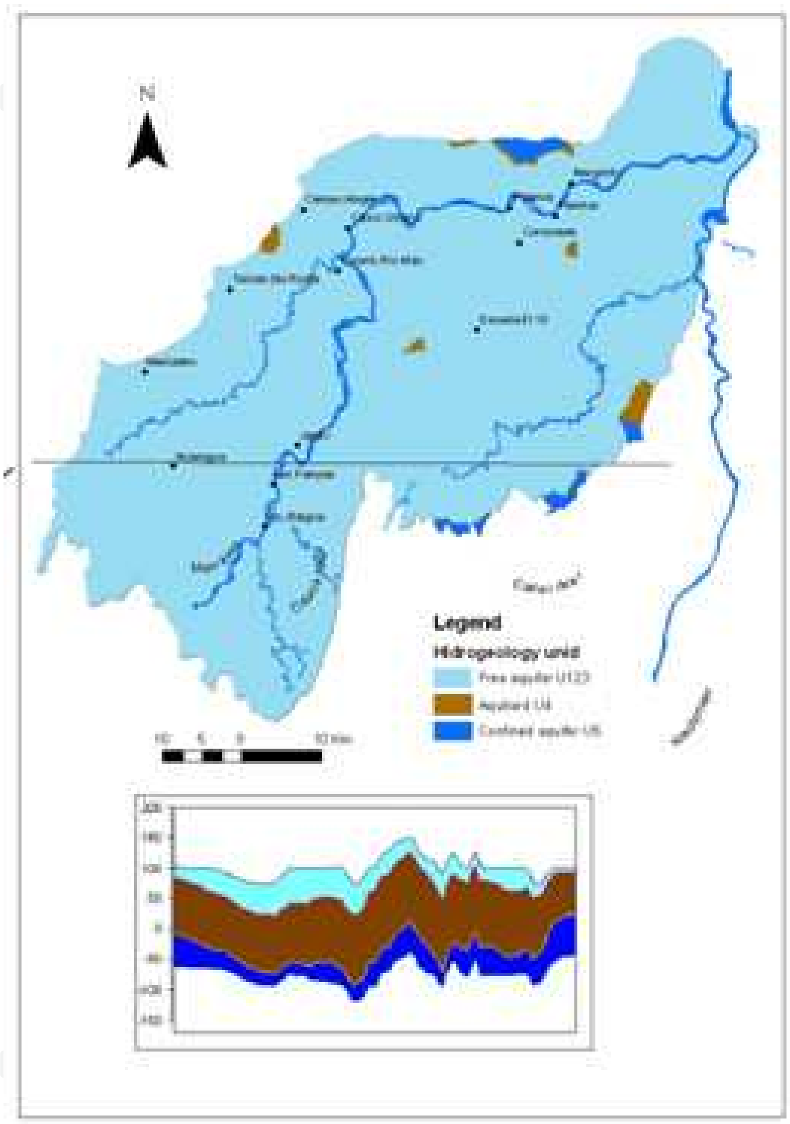


Fig. 7. Lower Cauca of Antioquia Study Area

The unconfined aquifer U123 consists of alluvial deposits from the rivers Cauca, Man, Nechi and Caceri and partially consolidated saprolite from Tertiary sedimentary rock of the Superior Member of the Cerrito Formation. U123 covers the entire study area. Its thickest points, between the Cauca and Man rivers, are greater than 90 meters, and its depth ranges between 40 and 90 meters. Parallel to the course of the Caceri River and towards the confluence of the rivers Cauca and Nechi, the unit has a depth of up to 60 meters. To the north and west, on the border with the department of Córdoba and in the south on the Andean slope, this unconfined aquifer is considerably narrower—even less than 10 meters.

The aquitard U4 is located below U123 and is made up of the Middle Member of the Cerrito Formation. Despite low conductivity, there are various catchments there from which water is extracted. From the center of the study area, following an axis in the direction SW-NE, the thickness of U4 decreases from 100 meters until the unit disappears in the north where U5 emerges or in the south where it intersects the Paleozoic basement. The depth of U4 reaches 160 meters in the center, about 20 meters in the north and less than 10 meters in the south.

The confined aquifer U5, formed by the Lower Member of the Cerrito Formation, is a regional confined aquifer in Bajo Cauca of Antioquia. Its thickness ranges from 10 meters to over 100 meters. This little explored and exploited unit could be an important reservoir of groundwater for the region. As is the case with its thickness, the depth of U5 is uncertain, but surely surpasses 260 meters.

Spatial distribution of hydrogeologic units, geomorphological attributes of the landscape, hydrography, the type of covering, hydraulic characteristics of the soil and hydrometeorological conditions are all factors that influence recharge of an aquifer system. For the study area, three sources of recharge were identified: 1) a recharge distributed across the whole expanse of the plains caused by direct infiltration of rainwater, 2) a recharge produced via the hydraulic interaction between principal bodies of surface water such as the Cauca and Man rivers and from some swamps and dams, and 3) an indirect lateral recharge provided by metamorphic rock of the system as much to the unconfined aquifer as to the confined aquifer. In addition, there is a vertical connection between the units U123, U4 and U5.

The water balances for an average hydrologic scenario, dry season in 1997 and wet season in 1990 show values of 1273 mm/year, 982 mm/year and 1729 mm /year respectively.

With changes in level not exceeding 5 meters between winter and summer, the phreatic level of the unconfined aquifer is located near the surface, and groundwater flow directions are marked by major watersheds. Between the Man river and Cauca river, and between Cauca river and Caceri river, groudwater flows from phreatic levels located between 90 and 140 meters towards the major surface currents which contribute base flow. Also, from the north on the border with the department of Córdoba, groundwater flow is directed towards the Cauca River. To the west, on the left slope of the Man River, the flow towards the channel can only be approximated, along with a possible flow in the opposite direction in some places (Figure 8).

From a series of data about hydraulic conductivity for the unconfined aquifer, was obtained value for this parameter between 1 and 2 m / day, with areas which reach 3 m/day. These results should be used with caution pending more reliable testing for quantification.

From data about groundwater quality taken from the unconfined aquifer (U123), it is observed that 21% of deposits do not meet the quality conditions of color, 19.7% do not meet the quality of turbidity, 22% fail on alkalinity, 19.7% of samples exceed the permissible value of total iron and 62% are outside the acceptable range of pH. For DQO and nitrite, 13% and 11% respectively of samples were found to be outside the acceptable range. Some samples accumulate 4 or 5 parameters with values outside the norm. In all cases in which coliform bacteria were tested for they were found an undesirable situation in water for human consumption.

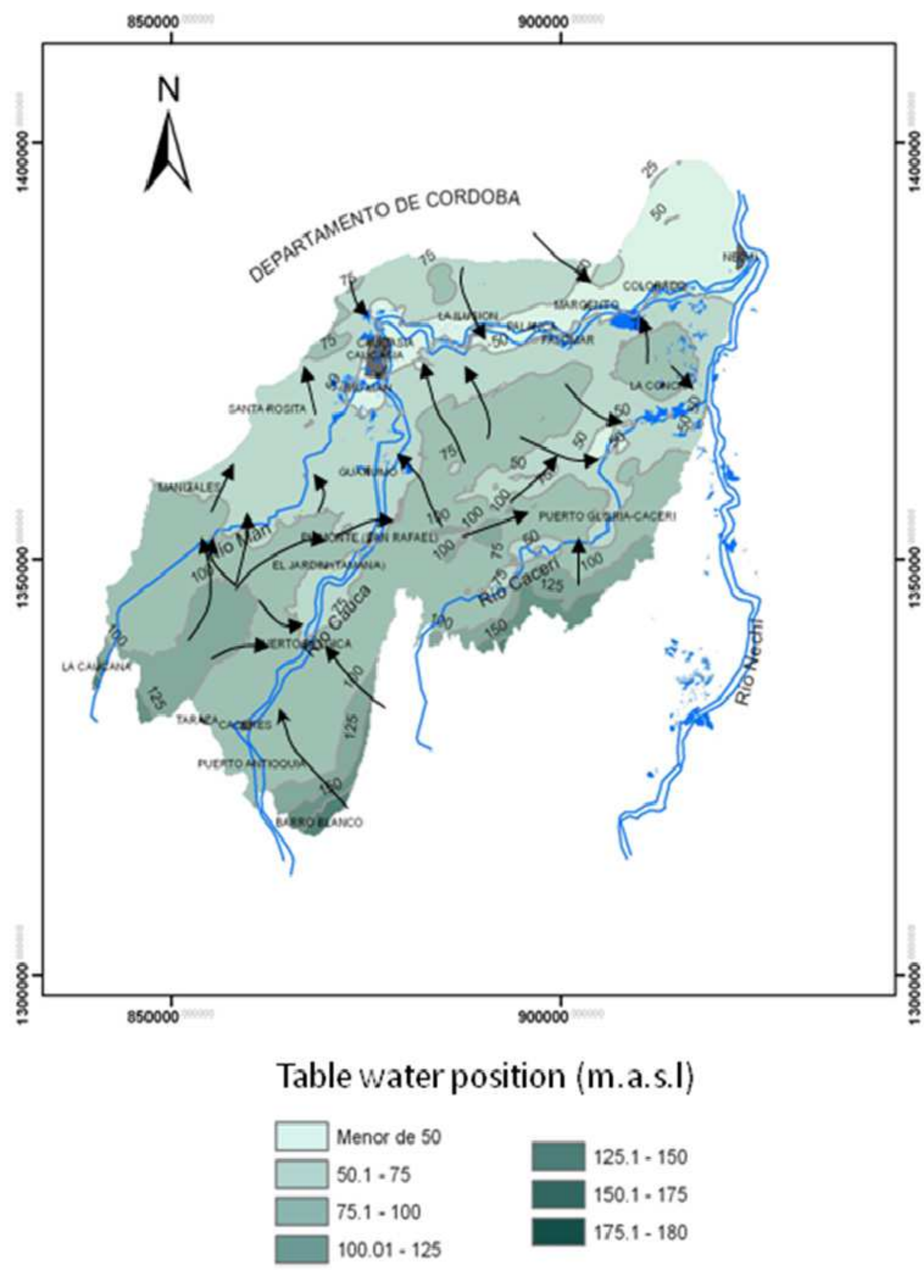


Fig. 8. Water table and groundwater flow

3.2 Numerical model

The scope in numerical modeling for the Bajo Cauca domains corresponds to the possibilities provided by available information. The level of confidence in the calibration for the unconfined aquifer is satisfactory, and although there were not sufficient piezometric monitoring data to allow for a thorough comparison with the transitional period, the results met expectations for the purposes to be achieved with an exploratory model (Figure 9). As for hydrogeological units U4 and U5, the numerical model lent support to ideas about the interactions that occur in the aquifer system and allowed for the identification of information necessary for the creation of a more robust conceptual model (Betancur et al. 2009).

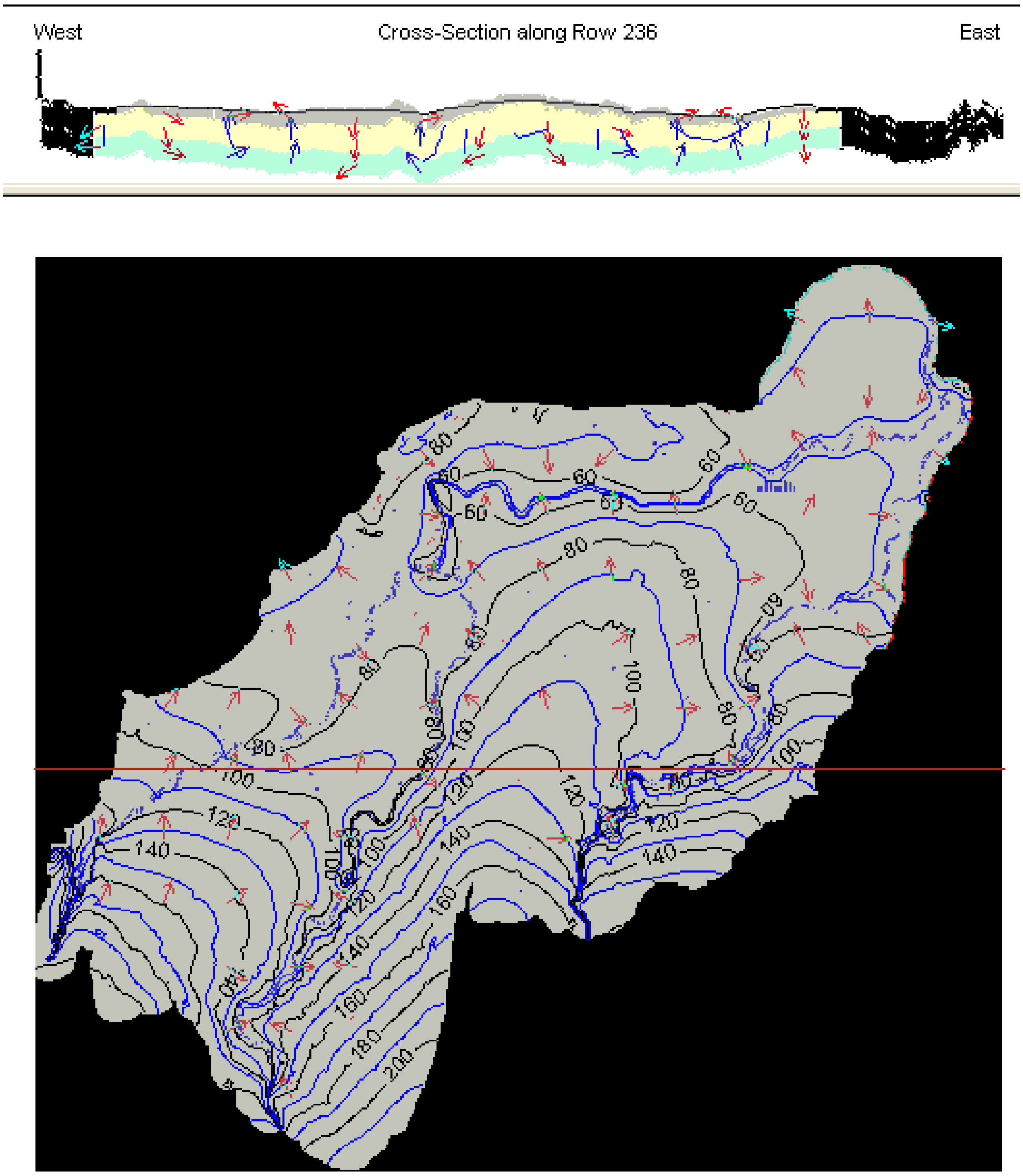


Fig. 9. Groundwater Flow according with the numerical model

3.3 A risk assessment for contamination of groundwater in the unconfined aquifer

The interaction between vulnerability and contaminating recharge allowed us to evaluate the degree of danger of contamination to which the unconfined aquifer of the Bajo Cauca of Antioquia is subject. Its relation to the presence of aquatic ecosystems and human communities allowed for a first assessment of the risks of being affected. The following characteristics were determined:

Vulnerability: from the application and validation of various techniques for assessing vulnerability, it was determined that the map obtained by DRASTIC is the most suitable for application in the case of the Bajo Cauca of Antioquia. According to results, the northwest has a low level of vulnerability and the rest of the system a medium level.

Contaminating recharge: urban-development activities— mainly sanitation systems without sewers and inadequate solid-waste disposal, as well as agricultural activities and mining in all cases generated a high Pollution Load Index (PLI) for the aquifer, an alarming situation If it is considered that a large number of sites where these conditions were found cause the source to be considered diffuse.

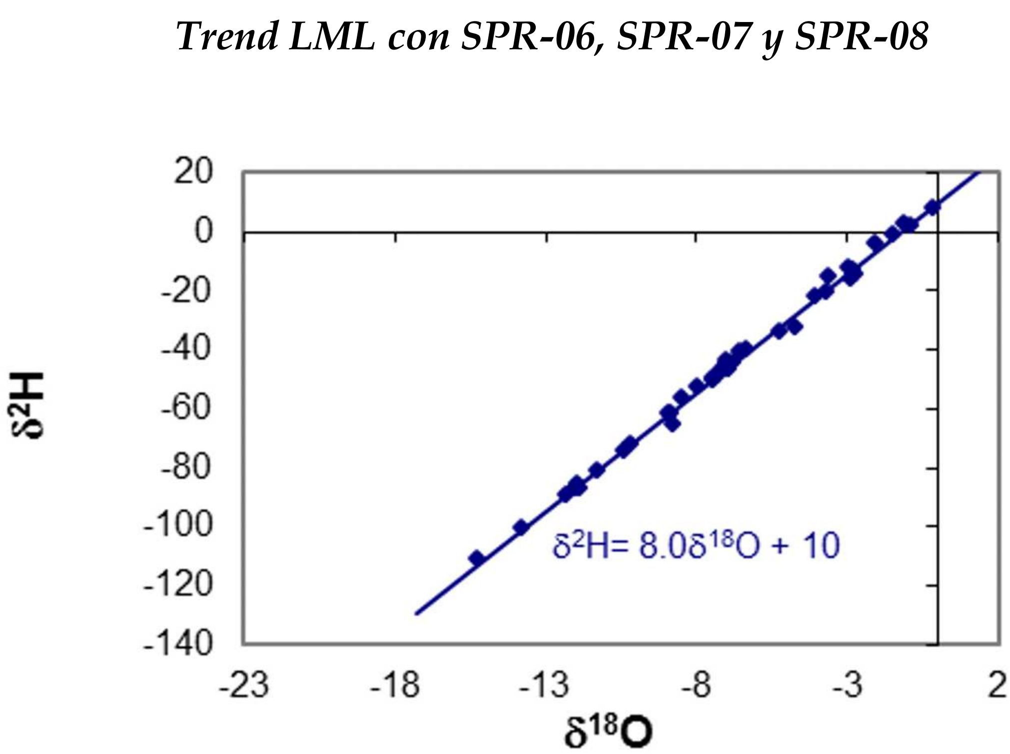
Risk of groundwater contamination: from the interaction between vulnerability and contaminating recharge it was established that urban development and agricultural activities generate moderate to high levels of danger, while for the regions of the Caceri and Nechí rivers, the mining industry reaches categories of extreme danger.

Risk: The Man and Caceri rivers, the latter in its upper and middle parts, are important habitats for fish and other species. Also, the complex system of wetlands in the Bajo Cauca, more than 150 wetlands, has been declared a protected area under the terms established within the national wetland policy, generated from Colombia's participation in the convention RAMSAR. It is well known that base flows are maintained by the flow of groundwater during droughts. Therefore, if contamination of subterranean waters of the unconfined aquifer is thought of as something that could impact aquatic ecosystems of the region, the danger is obvious. Not only are there zones with moderate, high and extreme levels of danger and low to moderate vulnerability levels, but it is clear from the direction of flow that streams and lentic bodies are receiving the groundwater. The risk to wetlands is imminent, and it is certain that the risk is not low.

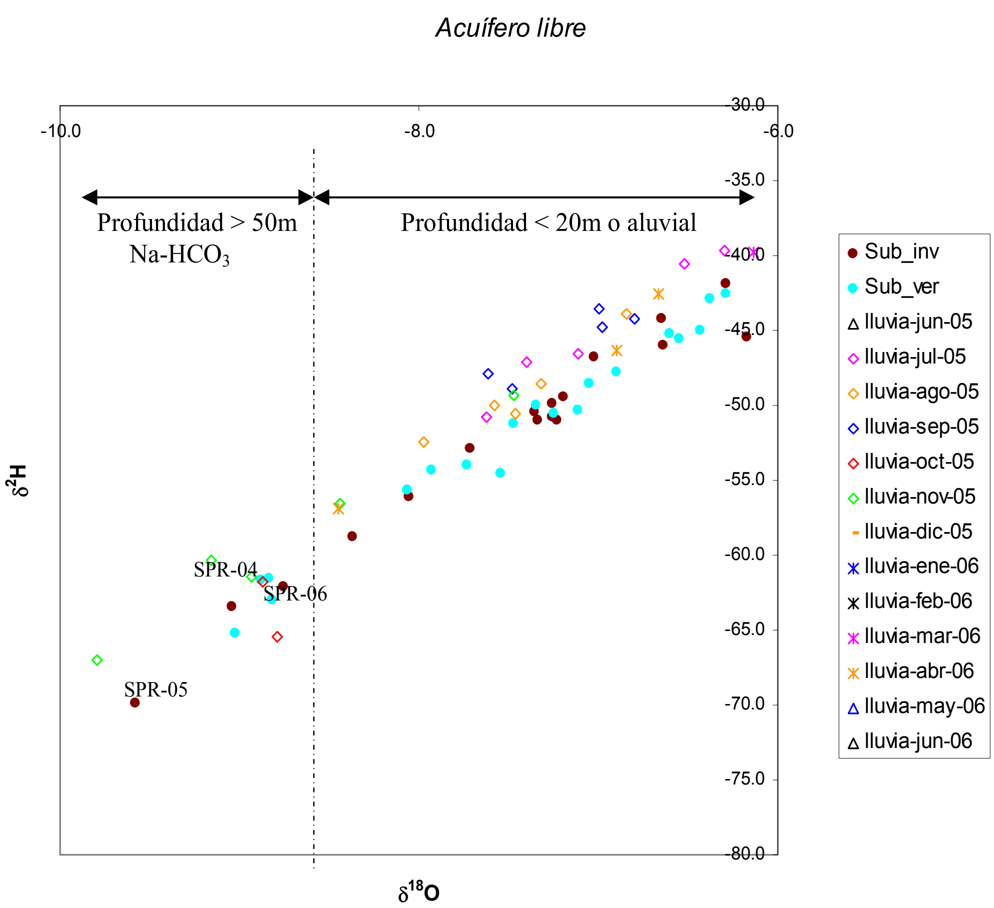
No fewer than 150,000 people rely on the groundwater stored in the Bajo Cauca of Antioquia unconfined aquifer to satisfy their domestic needs. For this reason, the danger described for the aquifer is a danger for more than just the source of supply. So far it can say that the entire population that depends on the unconfined aquifer has a high probability of being negatively impacted with effects on their health, when the added risks of contamination of this hydrogeological unit from activities of urban development, agricultural activities and mining are considered (Gaviria, 2010).

3.4 Validation of the model using hydrogeochemistry and isotoes data

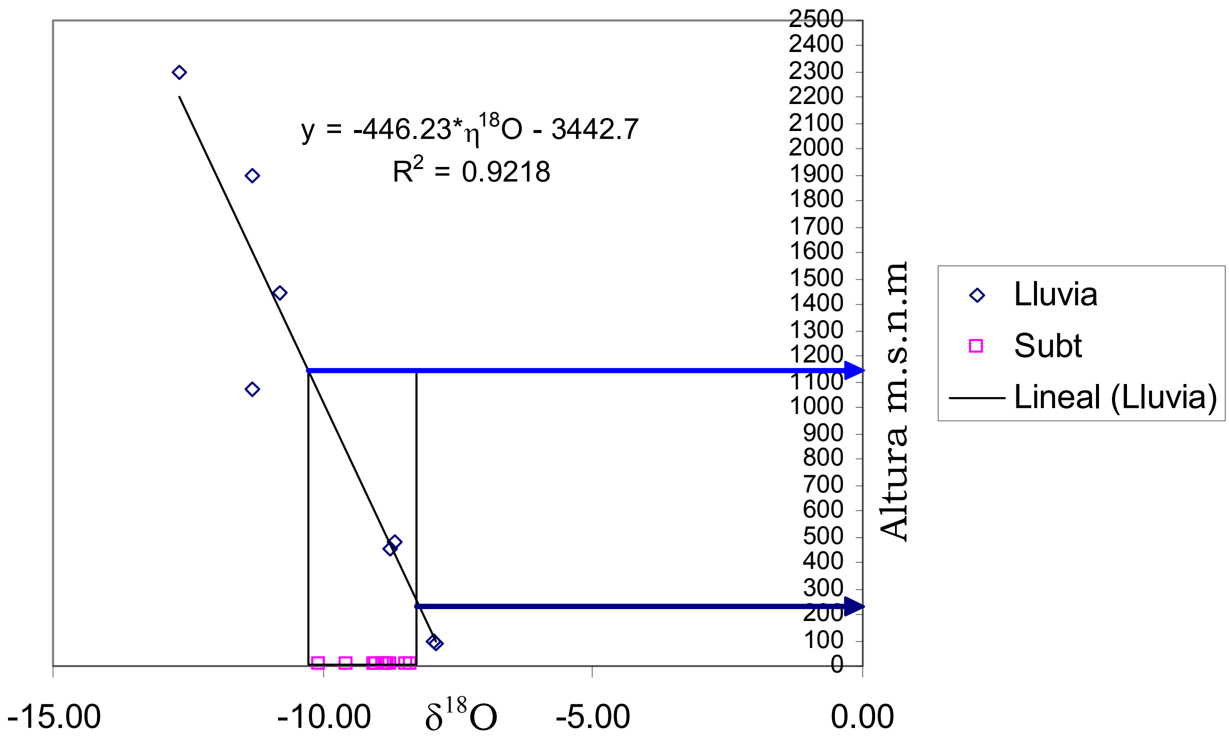
Facies of sodium bicarbonate and calcium bicarbonate to mixed bicarbonate were recorded in the waters of the unconfined aquifer. There are clear indications that the sodium bicarbonate facie samples were taken from wells with depths exceeding 50 meters and respond to the Upper Member of the Cerrito Formation, while samples with less evolved facies correspond to shallower waters with depths less than 20 m or that correspond only to alluvial deposits. It seems then that the unconfined aquifer has hydrogeochemical stratification which can be explained by assuming that water recently recharged by infiltration, which would have less residence time being exposed to a dynamic of rapid flow, is stored at higher levels, due not only to the recharge but also to the intense exploitation subterranean water undergoes at that level. The greater the depth



(a) Local Meteoric Line (LML), Bajo Cauca of Antioquia – Colombia.



(b) Rain between 300 and 100 m.a.s.l and groundwater of the free aquifer



(c) Two different groundwater in the free aquifer

Fig. 10. Isotope and validation of the conceptual model.

at which water is located, the more residence time it would have during which ion exchange processes could take place.

Very few water sampling points correspond to the confined aquifer, and most do so in regions where the synclinal structure of the system cause the confinement of the unit to be minimal. Only towards the center of the study area was a sufficiently confined sample taken with sodium bicarbonate composition.

From monthly rainfall samples taken for a year at eight precipitation stations a Local Meteoric Line (LML) very close to the Global Meteoric Line (GML) was obtained (Figure 10).

Individual analysis by season shows the effects of the seasons, altitude and continentality in the area. Besides the calculated values of excess deuterium, there were found to be three different sources of precipitation. The ratio of height vs. composition δ 18O weighted by season indicates a decrease of -0.21% δ 18O per 100m.

According to the conceptual model, recharge to the unconfined aquifer comes from direct infiltration from the surface or lateral recharge from the surrounding rock system in the south. Also, exchanges should be produced by winning or losing currents with surface sources. To test these hypotheses, isotopic ratios at points that correspond to this hydrogeological unit are considered with information about rain taken from stations located in these zones and with samples from bodies of surface water. Tritium data reported for two points of water corresponding to the unconfined aquifer with compositions of 1.5 ± 0.5 TU (Tritum Units), the same as that of rain, effectively indicate that recharge is currently ongoing.

All points of groundwater within a range of δ 18O values between -10.08 and -6.2 are located above or below the meteoric line. This situation suggests a dispersed recharge produced by rain water on occasions after it has undergone light evaporation. The closeness of the points of surface water, both to the line of rain and the points of groundwater, indicates, in principle, that during summer, flow volume is contributed by base flow from the unconfined aquifer, producing in the process an amount of evaporation and that in winter flow volume comes from base flow as well as direct runoff.

Considering seasonal variation in precipitation, it appears that groundwater recharge occurs from water precipitated mainly in the months of July, August and September.

For some groundwater samples that are more isotopically impoverished, in correspondence to altitudinal gradient, recharge would effectively be contributing between 292 and 1050 meters of height.

Tritium data for hydrogeological units U4 and U5 with values of 0.0 ± 0.5 TU indicate in principle that recharge has been occurring for at least 60 years.

4. Conclusion

- A model is a hypothesis; in order to obtain a good model in hydrogeology is necessary to join exploration techniques with validation methods. According with it, five methodology activities were propose: i) Hydrogeological data and information, ii) Numerical modeling, iii) Hydrogeochemical characterization and Isotope Hydrology, iv) Risk evaluation, and v) Geodata and geomodeling.
- Information and data are used in order to obtain geometric model, piezometric surfaces and groundwater flow directions, hydraulic properties, recharge, and quality water conditions. Numerical models can be used in order to explore or in order to simulate aquifer characteristics. Hydrogeochemical characterization and Isotope Hydrology are used in order to validate a conceptual model. Risk evaluation the impact over the population by the use of low quality groundwater.
- The establishment of geo-informatics as a technique for the analysis of information has led to the emergence of new ways of seeing and understanding elements and processes that occur in hidrogeology.
- In the region of Bajo Cauca of Antioquia, Colombia, development and implementation of this methodology has allowed the construction and validation of a conceptual hydrogeological model and implementation of a monitoring network that continues to operate, providing new data and enabling new interpretations.
- The aquifer system of the Bajo Cauca of Antioquia is comprised of three hydrogeological units; an unconfined alluvial aquifer known informally as hydrogeological unit U123, an aquitard, unit U4 and a confined aquifer, unit U5. U5 could be an important reservoir of groundwater for the region.
- For the study area, there are three sources of recharge: 1) a recharge distributed across the whole expanse of the plains caused by direct infiltration of rainwater, 2) a recharge produced via the hydraulic interaction between principal bodies of surface water such as the Cauca and Man rivers and from some swamps and dams, and 3) an indirect lateral recharge provided by metamorphic rock of the system as much to the

unconfined aquifer as to the confined aquifer. In addition, there is a vertical connection between the units U123, U4 and U5.

- Conductivity value for the unconfined aquifer, is between 1 and 2 m / day, with areas which reach 3 m/day.
- From the interaction between vulnerability and contaminating recharge it was established that urban development and agricultural activities generate moderate to high levels of danger, while for the regions of the Caceri and Nechí rivers, the mining industry reaches categories of extreme danger.
- The conceptual model to the hydrogeological system of Bajo Cauca of Antioquia was probed using numerical model, hydrochemical and isotopes data.

5. References

Anderson, M. P. and Woessner, W. W., 1992. Applied Groundwater Modeling. Simulation of flow and advective transport. Academic Press, San Diego. 381 p.

Bredehoeft, J., 2005. The conceptualization model problem—surprise. Hydrogeology journal, 13:37–46

Betancur, T.; 2005, estado actual y perspectiva de la investigación hidrogeológica en el bajo Cauca antioqueño, Boletín de Ciencias de la Tierra No. 17, Universidad Nacional, Medellín, pp. 97-108

Betancur, T., 2008. Una aproximación al conocimiento de un sistema acuífero tropical. Caso de estudio: Bajo Cauca antioqueño. Tesis doctoral, Universidad de Antioquia, 221p.

Betancur, T., Palacio, C. 2009. La modelación numérica como herramienta para la exploración hidrogeológica y construcción de modelos conceptuales (caso de aplicación: bajo cauca antioqueño) . En: Colombia. Dyna - Medellin, Colombia ISSN: 0012-7353 v.76 fasc.N/A p.39 – 49.

Betancur, T., Mejia, O., Palacio, C. 2009. Modelo hidrogeológico conceptual del Bajo Cauca antioqueño: Un sistema acuifero tropical. Revista Facultad De Ingenieria Universidad De Antioquia ISSN: 0120-6230.v.48 fasc.N/A p.107.

Carrera, J., Alcolea, A., Medina, A, Hidalgo, J. y Slooten, L., 2005. Inverse problem in hydrogeology. Hydrogeology journal 13:206–222

Custodio y Llamas 1997. Hidrología subterránea. Omega editores, Barcelona. 584 p.

Divine, C. E. y McDonnell, J. J., 2005. The future of applied tracers in hydrogeology. Hydrogeology journal, 13:255–258

Gaviria, J. I., 2010. Desarrollo y aplicación de una metodología para evaluar el riesgo a la contaminación de las aguas en un acuífero libre, caso de estudio: cuenca baja del río Man, Bajo Cauca antioqueño. Trabajo de Investigación: Maestría en Ingeniería con énfasis en Ingeniería Ambiental. Universidad de Antioquia. 164 p.

Gomez, A., 2010. Generación de un modelo hidrológico conceptual a partir de información secundaria: aplicación a la cuenca del río Man (Bajo Cauca antioqueño). Tesis de maestria, Universidad de Antioquia, 221p.

Gosain, K.A., 2009. Hydrological Modelling-Literature Review. Disponible en internet en: http://web.iitd.ac.in/~akgosain/CLIMAWATER. [Citado en 2010]. Reporte No 1. Octubre.

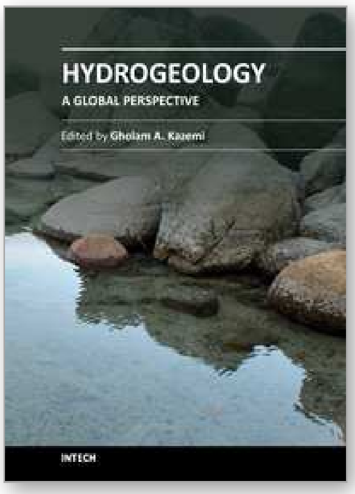
Mejía, O., Betancur, T.; y Londoño, L. 2007 Aplicación de técnicas geoestadísticas en la hidrogeología del Bajo Cauca antioqueño. Medellín, Revista DYNA edición 152, Vol. 74, pp. 137-150.

Sivakumar, B. 2007. Dominant processes concept, model simplification and classification framework in catchment hydrology. En: Stochastic Environmental Research and Risk Assessment. Vol 22. Pg 737–748.

Voss, C. I., 2005. The future of hydrogeology. Hydrogeology journal, 13:1–6.

Wagener, T; Sivapalan, M; Troch, P; Woods, R. 2007. Catchment Classification and Hydrologic Similarity. En: Geography Compas. Vol 1, No 4. Pg 901-931.

Wang, H.F. y Anderson, M.P, 1982. Introduction to groundwater modeling. W.H. Freeman and Company, San Francisco, 237 p.



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