HYDROGEOLOGICAL ACTIVITIES IN THE CONEJOS-MEDANOS/MESILLA BASIN AQUIFER, CHIHUAHUA PHASE I

ESTADOS UNIDOS MEXICANOS

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1. GENERAL OVERVIEW

1.1 Introduction

Groundwater behavior does not recognize territorial boundaries; aquifers that extend across political borders between two or more countries are known as transboundary aquifers. In these cases, it is common for water that is being extracted in one country to come from rainfall or recharge in another. Therefore, it is important that the countries understand their transboundary aquifers, and jointly coordinate their exploitation and protection as appropriate.

The Conejos-Medanos Aquifer, subject of this study, is a transboundary aquifer between the United States and Mexico, known as the Mesilla Bolson on the U.S. side of the border. One of the biggest unknowns, which generated the interest in studying the hydrogeological characteristics of this aquifer, lies in the fact that because it is a transboundary aquifer, the implications of this for control of withdrawals, subsurface flow patterns and aquifer characteristics are of particular interest to both countries.

On the U.S. side, around 65 Hm^3/yr are extracted from this aquifer (Mesilla Bolson), which are utilized for domestic, industrial and agricultural purposes (Chávez,G, Klein 2000), whereas in Mexican territory (Conejos-Medanos), water withdrawal in 2007 was just 0.59 Hm^3/yr, mainly for domestic and livestock use (SGM. 2007). However, given the growing demand for water in Ciudad Juárez, caused by population growth and the over-pumping of the Ciudad Juárez Aquifer (Hueco Bolson), it became necessary to increase the volumes of pumping on the Mexican side.

As a result, starting in May 2010, a program was implemented to exploit close to 1,000 lps, extracted from 23 wells located on the far north side of the aquifer. Through the Conejos-Medanos Aqueduct, the company CARSO Infraestructura y Construcción S.A. de C.V. delivers this water to Ciudad Juárez Municipal Water and Sanitation Board (JMAS), who in turn provides it to the people.

It took a year and a half to build the Conejos-Medanos Aqueduct, which conveys 1,000 liters per second of water to Ciudad Juárez at an approximate cost of 4.20 pesos per cubic meter to the Water Utility (JMAS). The system has 47.23 kilometers of connection lines between the 23 wells, a booster system, and a steel conveyance pipe that has a diameter of 106 cm and is 23 kilometers long, ending at the final delivery tanks. It is worth noting that by operating the aqueduct, the potential supply to Ciudad Juárez increased 20%. Previously, prior to operation of the wellfield, it was 5 m^3/s, and now there is the ability to receive up to 6 m^3/s.

Given this recent withdrawal of 1,000 lps, the need has arisen to update the hydrogeological understanding of the Conejos-Medanos Aquifer, and in doing so, identify the impact of those withdrawals. Consequently, the International Boundary and Water Commission, United States and Mexico, Mexican Section (IBWC) has commissioned the study *Hydrogeological Activities in the Conejos-*

Medanos Aquifer, State of Chihuahua, Phase I, from the Mexican Geological Service (SGM), under the collaborative agreement CILA-SGM-2010.

This document is the technical report that resulted from the study. It is intended to provide a brief, concise description of the current conditions of the Conejos-Medanos aquifer, with particular interest in the groundwater level trends to be able to determine the impact of the recent increase in the withdrawal volumes.

1.2. Objective.

The overall study objective is cited below, as well as the specific objectives that were met through the development of the study.

General Objective.

Update the knowledge of the hydrogeological conditions (INEGI, 1999; Mexican Geological Service, 2007b) in order to establish a diagnosis of trends in groundwater levels, given the recently started pumping program, and to have the necessary geohydrologic data to determine the average annual groundwater recharge, the impact of intensive pumping of almost one cubic meter per second of water, and the variation in the natural water quality.

Specific Objectives

- Measure the hydrometry of the groundwater withdrawals.
- Quantify the magnitude of the natural and incidental recharge components.
- Obtain values for the regional physical and hydraulic parameters that govern the subsurface movement of water, such as: hydraulic conductivity, aquifer thickness, transmissivity and storage coefficient, which satisfactorily describe the historic and current behavior of the underground resource.
- Refine the conceptual model of the aquifer's behavior, modifying as needed.

1.3 Location and Access Routes.

The area where the Conejos-Medanos Aquifer is found is in the far north of the state of Chihuahua, to the west-southwest of Ciudad Juárez, and occupies a surface area of 6150 Km^2. (Figure 1.1) The primary access route to the aquifer is Federal Highway No. 45 (Panamericana), on the stretch between Ciudad Juárez and the state capital. Another of the main access routes is Federal Highway No. 2, which connects Ciudad Juárez to the cities of Janos and Casas Grandes. There are several dirt and gravel roads into the interior of the aquifer that are driveable throughout most of the year; they connect a series of ranches in the area.

It is worth noting that many of the roads are located between dunes, making them difficult to locate and drive on. In addition, in the area of the lagoon known as El Barreal, it is impossible to drive through there during the rainy season.

There is a railroad line connecting Ciudad Juárez with the state capital, which runs almost parallel to Federal Highway No. 45 (outside the study area). There is also a railroad line (currently not in use) between Ciudad Juárez and Casas Grandes, which crosses east-west through the middle of the study area. At present, it is only accessible in vehicles that have four-wheel drive.

With regard to public utilities, the area encompassed by the Conejos-Medanos Aquifer, except for the area where the Conejos-Medanos Aqueduct boosting station is located, lacks electricity, telegraph, telephone or internet services. The power lines only go to the wellfield, located at the north end of the study area, so the small ranches are only connected by dirt roads; they lack cell phone coverage over most of this area.

1.4 Population and economic activity

Due to climatological conditions and other miscellaneous factors, the population density in the study area is low, with most of it being concentrated towards the northeast side of the aquifer near Ciudad Juárez, specifically along Federal Highway No. 2.

There are some ranches widely dispersed over the study area, most of which are inhabited only during the rainy season; they are primarily used for raising cattle and small-scale agriculture.

It is worth noting that the operation of the well field and the Conejos-Medanos Aqueduct both generate strong economic activity on the far north side of the study area.

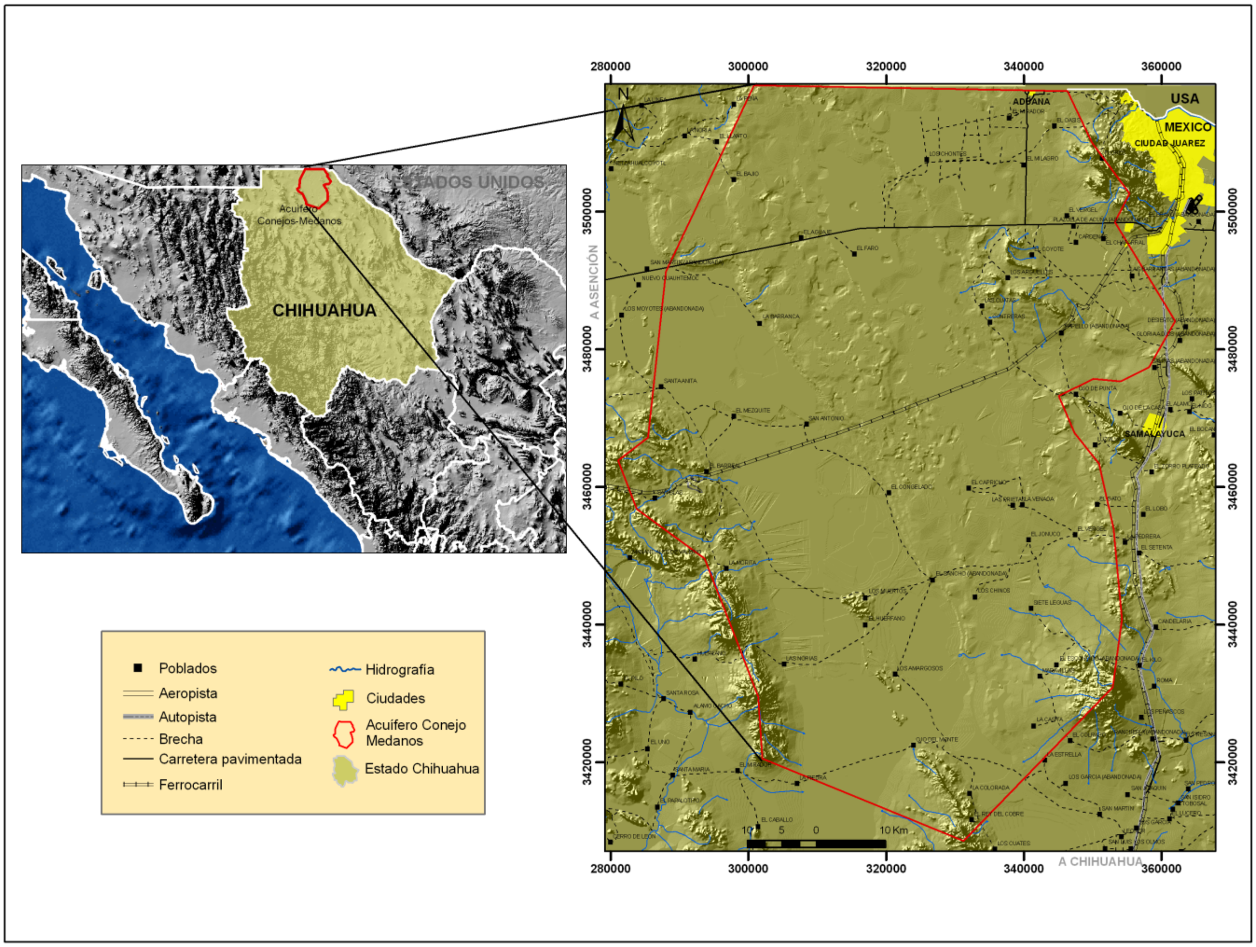


Figure 1.1. Location of the Conejos-Medanos Aquifer.

1.5 Previous Studies

For the last several decades, studies have been carried out in the area for geological, geophysical, and hydrogeological purposes. Their primary objectives included understanding the region's physical characteristics, as well as the aquifer's behavior; the most recent studies have mainly focused on groundwater and establishing behavior patterns in order to extract water to supply the border city of Ciudad Juárez.

The following is a brief summary of the most significant studies, highlighting their achievements and recommendations, so that the reader of this report can get a clear, concise understanding of the previously performed studies.

2007. HYDROGEOLOGICAL ACTIVITIES IN THE CONEJOS-MEDANOS AQUIFER, STATE OF CHIHUAHUA. This report was prepared by the Mexican Geological Service for CONAGUA under a collaborative agreement. The objectives of this study included the integration of existing information, a survey of wells and aquifer piezometry to design a piezometric monitoring network, 11 rim elevation measurements, 7 pumping tests, 40 geophysical (TEM electromagnetic) soundings, and calculation of the hydrometeorological and groundwater balances to determine the groundwater availability in the aquifer.

To carry out these activities, the general overview of the area and its physical framework were outlined. Three geomorphological units were identified: mountains, foothills and bolsons. Hydrographically, the report states that there are no surface water streams, and the existing arroyos form a drainage system of small endorheic basins.

The region's average precipitation is 246 mm; its average maximum temperature is 38°C and the minimum is around -12°C during winter, while the annual average was calculated at 17.41°C. Evapotranspiration is approximately 240 mm/yr and the potential evapotranspiration is 1,982 mm per year. The soils are sandy and usually form dunes, characterized by high permeability. The geological description performed in this study is based on SGM maps 1:250,000 scale.

The total survey for the aquifer included 132 capture sites, of which 126 were wells and 6 were chain pumps. Out of all the wells, 58 are active and 74 inactive; it is worth mentioning that 31 of these wells are in the aquifer wellfield (which in those days was not operational). Using the construction characteristics for the wells, their distribution and access routes, a piezometric monitoring network was established.

The conceptual hydrological model indicates that recharge happens in the mountainous area of the aquifer, comprised of fractured, moderately permeable limestone. The Pliocene basalts also have moderate permeability, as do some intrusive bodies like diorites and quartz monzonites, which have a low permeability. The igneous rocks, such as rhyolitic tuffs that have moderate fracturing, have low permeability, whereas the rocks of sedimentary origin located to the NE have moderate permeability.

In this study, the static level depth and elevation curves are described and graphed, and it is shown that the aquifer has a recharge coming from the Laguna de Patos Aquifer. This recharge circulates from southeast to northwest, following the orientation of the El Barreal, and in the center of the aquifer, the subsurface flow takes on a northeast direction. Another inflow from the El Mauricio and Cerros Bayos mountains was identified, and yet another from the Sierras de las Conchas and Cerro las Tunas.

According to the final report on the Moyotes well drilled by PEMEX, an "aquiferous zone with a NaCl concentration of 10,000 ppm" was reported at an interval of 405 m to 440 m, indicating a confined aquifer with fossil water at said depth.

The units that contain the aquifer are comprised of granular material (sands, gravels, silt and clay), created through erosive processes, with eolic erosion currently being the most important of those processes. The area of greatest interest is in the eolic sands, where the aquifer is considered free. The unit made from folded shales and limestone, with open fractures (Kaim Cz-Lu) contains water, and it is believed to contribute water to the granular material. The other units are considered to have moderate to low permeability, and thus are considered part of the hydrogeological basement. The primary recharge zones are the runoff from the edges of the mountains, comprised of fractured consolidated materials. And to a lesser extent, recharge originates in the granular material itself; due to the environmental temperature conditions, there is a high degree of evapotranspiration.

For the geophysical component, 40 (TEM) soundings were performed, which provided data about the material around the aquifer, and indirectly indicate the groundwater quality. Although these tests were not able to record the hydrological basement, it may be concluded that it is located at a depth greater than 700 m.

Wells were selected for the leveling of 11 rim elevations based on those that will become part of the monitoring network, considering the required characteristics, including easy access, and with the agreement of the National Water Commission. Six hydrostratigraphic units were defined to describe the aquifer behavior: granular material with high, moderate and moderate-low permeability and fractured material with moderate, moderate-low and low permeability.

2003. SYNTHESIS OF GEOGRAPHICAL DATA FOR THE STATE OF CHIHUAHUA. Study published by INEGI for the purpose of making geographical information about the State of Chihuahua available to the public, covering several aspects: Information from the Municipal Geostatics Division is provided, including the state, official names and number of inhabitants according to the latest Population and Housing Census (year 2000), as well as a description of the most important locations. It also describes the main highways, railroads and airports.

1999. HYDROLOGICAL STUDY OF THE STATE OF CHIHUAHUA. Study published by INEGI, with the objective of making the hydrological information for the State of Chihuahua available in a single publication, thus making it possible to study the elements that impact both surface and ground water behavior, use and quality. It contains a detailed analysis of the factors that directly affect the water cycle, and contains an overview of the statewide panorama of water availability and exploitation, existing uses and alternatives, as well as water quality. It also provides practical recommendations and observations to help facilitate the beneficial use of hydrologic resources.

Insofar as the Conejos-Medanos Valley, there is a general reference to the fact that it is a free aquifer formed by bolson deposits and dunes, with sediments that have a thickness greater than 300 m. Its permeability is moderate and it has a transmissivity that varies from $2.0x10^{-3}$ to $4.4x10^{-3}$ m^2/s. Each year

1.58 Mm^3 are withdrawn from the aquifer and its annual recharge is 50 Mm^3. This recharge comes from vertical filtrations, which is the product of precipitation, and from the subsurface flow that originates in the southeast and northwest sectors.

The static level trend for the years 1982 and 1985 shows a drawdown of 1.5 m per year, with piezometric variations of 1 to 120 m. The subsurface flow goes in several directions including to the northeast towards the Rio Grande, southwest towards the Laguna El Barreal, and a possible outlet to the east through the gap that forms between the Sierra de Juarez and Sapello Mountains. In 1982, the water quality was considered to be between acceptable and saline. The water type is Sodium-Bicarbonate-Sulfate, with a tendency towards increasing chlorides. This increase in salts is due to the evapotranspiration of the water table, thus it is considered natural contamination.

1998. DETERMINATION OF NATURAL VERTICAL RECHARGE AND ESTIMATE OF POTENTIAL CONTAMINATION FROM A RADIOACTIVE MATERIAL DISPOSAL SITE IN THE SAMALAYUCA, CHIHUAHUA DESERT. This work was performed by Eng. Melchor Alberto Ortiz for a Master's thesis at the Universidad Autónoma de Chihuahua, with the support of CONAGUA.

The primary objective of this study was to estimate the natural recharge, using an environmental tracer (chlorides) and to evaluate the potential contamination from radioactive waste for a site located in the area of Samalayuca, Chih. It also intended to identify whether the location known as La Pedrera is able to contain radioactive waste, and if it does not possess the necessary characteristics, include proposed actions or adaptations so that the site may be used for that purpose.

The method applied to estimate the natural recharge was the balance of chloride masses; this involved an analysis of existing precipitation information in the area, giving a result of 257 mm. The data for chloride concentrations in rainwater was reviewed, as well as the existing technical information. 314 samples were taken from 7 wells at 15 cm intervals using a manual corer without drill fluid; then the moisture content of the samples was tested and the chlorides were calculated.

To determine the concentrations of chlorides, the depth of each well was divided into 3 sections labeled A, B and C, where it was observed that the recharge values in section A varied between 0.16 mm/yr and 0.78 mm/yr. Section B is the peak in the profile and the average value obtained in 0.04 mm/yr and section C is the deep part of the soil where the chlorides are not influenced by the the root zone nor altered by evapotranspiration. For this reason, it is considered the most representative part of the study area. The average recharge obtained was 0.08 mm/yr, value that was extrapolated as the minimum recharge for the area where the La Pedrera radioactive material containment site is housed, when it was not possible to drill boreholes at the site.

The La Rinconada and La Pedrera sites have very similar environmental characteristics, although at the latter there was evidence in the field of non-piston flows, because of the presence of cracks and fractures near the ground surface. Consequently, the recharge is estimated to be much higher than that of the site studied, thus increasing the risk of transporting radioactive particles until they reach the water table within a relatively short time.

1989. GEOHYDROLOGIC STUDY AND EXPLORATORY DRILLING IN THE CONEJOS-MEDANOS AS AN ALTERNATIVE SOURCE OF DRINKING WATER FOR CD. JUÁREZ, CHIH. This study was conducted by the General Department of Administration and Control of Hydrological Systems, under the Office of Hydraulic Infrastructure at the former Secretariat of Agriculture and Hydraulic Resources (SARH), Chihuahua Regional Office. The goal of this study was to establish whether the area meets the geohydrologic characteristics to be a potential alternative solution to Ciudad Juarez's potable water problem.

The study concluded that the area known as the Conejos-Medanos Aquifer is the first alternative to explore, since it is a continuation of the Mesilla Bolson that begins in the State of New Mexico, United States. In this zone the soil consists of a sandy desert that usually forms dunes, making agricultural development difficult. There are however, small isolated areas southwest of there that are suitable for some crops.

The geology of the zone is made primarily from bolson deposits, gravels, sands, silts and clays, as well as Tertiary-Quaternary eolic deposits (dunes) and some marine sedimentary rock outcroppings that range from Lower Cretaceous to Tertiary, with some additional small igneous rock outcroppings. During the inventory of wells, it was determined that there are 114 wells, 90 of which are shallow and used for livestock, 14 are chain pump wells and are located in the southwestern part of the area, and 10 exploratory drillings. Upon reviewing the withdrawals by means of pumping, it was determined that to be about 2 Mm^3/year, therefore it was concluded that the aquifer is practically in a state of natural equilibrium.

A study phase including sampling, physiochemical and heavy metal analyses was also conducted. The results showed that poor water quality is not an issue in the regional aquifer; only in the east-southeast portion is there a high concentration of Total Dissolved Solids, as well as high values for some salts. According to the hydrogeochemical indices, it was determined that the groundwater flow has a general east to northeast heading.

According to the cited study, as part of the measurements taken in the exploratory wells, 2 pumping tests were performed on 2 observation wells, obtaining transmissivity values of between $2.0x10^{-3}$ m^2/s, and $4.4x10^{-3}$ m^2/s. The specific capacity of the wells varied between 2.2 and 4.3 liters. According to the geohyidrological balance, it is observed that the aquifer system has particularly small inflows and outflows, therefore any withdrawal program would be at the expense of the aquifer storage.

March 1987. GEOPHYSICAL STUDY OF THE CONEJOS-MEDANOS BASIN TO SUPPLY WATER IN BULK TO CIUDAD JUAREZ, CHIHUAHUA. Study conducted by the company Técnicas Geológicas y Mineras, S.A. de C.V. with the primary objective of investigating underground aquifers in the area near Ciudad Juarez that could possibly contribute additional flows, which included 80 VESs with 500 m of exploratory penetration.

Specifically, this study was carried out to determine the thickness and distribution of the granular materials that make up the underground aquifer and its tentative quality, as a first step for future programs to drill exploratory wells and subsequent geohydrologic assessment.

To conduct the VESs, stations were set up on site with a transit and stadia. Field reconnaissance of regional geology was also performed in order to expand existing information and [classify] the structural-geological features using hydrogeological criteria. A survey of existing withdrawals was performed to have information about their construction characteristics. Piezometric levels were taken, as well as operational flow rates, water usage and water sampling for chemical analysis.

Geomorphologically, the area was classified as being in an old age stage, with three distinctive units: Mountains, foothills and bolsons. Lithologically there are 12 units, seven of which are permeable units and 5 that are impervious and act as a groundwater flow barrier. The impervious units are the Ojinaga Group and Cuchillo Formation sedimentary formations, as well as the intrusive igneous peneplains. They are classified this way because of their adverse lithological conditions, the water storage and infiltration conditions and the reduced area of exposure, as well as the fact that some sites act as both horizontal and vertical barriers to groundwater flow. The alluvial deposits occupy restricted zones and have a limited storage thickness. The lacustrine deposits have argillaceous lenses and silts that obstruct their permeability conditions, thus they can be categorized as a semi-pervious unit.

The lithological characteristics of the Finlay, Lagrima and Benigno sedimentary formations, under favorable structural conditions, take on a beneficial role as permeable units; because of their fracturing and solution cavities, they create positive groundwater storage and circulation conditions. The Santa Fe Group lithological constructions and the eolic deposits (except for the clayish-silty lenses) offer acceptable permeability conditions.

Two aquifer systems are found in the study area: the first one has a poor aquifer potential and is contained in the Cretaceous Finlay, Lagrima and Benigno Formations, which occupy the mountainous portions of the Juarez and Sapello mountains. These formations receive water and they convey it through the fracturing, but the small amount of recharge and their structural and topographic positions make them unattractive for exploitation and beneficial use of the aquifer resources. The other aquifer area corresponds to the lithological units that are formed by the basin fill material; the Santa Fe Group and the eolic deposits are the most attractive constituents because of their large horizontal and vertical extension, even though their recharge volumes are scarce and the water quality is potentially saline.

During the survey phase, 23 withdrawals were confirmed, 6 of which were exploratory wells under development. The static level depths varied from less than 20 m to a little over 90 m. Using the piezometric levels, a hydraulic gradient of around 0.0005 a 0.001 was calculated with a west-east heading across the northern sector, southwest-northeast in the middle and northeast-southwest through the southern sector. An annual withdrawal volume of less than 150,000 m^3 per year is considered.

The study showed that the precipitation recharge is distributed over the entire studied area with the most intensity towards the south, where the static levels are the shallowest. Also, narrow subsurface flows were found in the southeast and northwest. The amount of discharge by pumping was considered negligible, while the subsurface outflows were found to the northeast, in the direction of the Rio Grande and to the south-west.

When comparing the available information from the piezometric data taken in 1982 and January 1988, particularly random values were observed for drawdown and recovery of the piezometric levels on both dates. Thus, with the assumption about the low pumping level, it is believed that the aquifer is in a state of natural equilibrium and the fluctuations in the recorded levels are not attributed to pumping. Using a record from Well No. 18, located at Rancho El Girasol, a transmissivity of approximately $2.0x10^{-3}$ m^2/s, a permeability of $8.69x10^{-6}$ m/s, and a specific flow rate of 1.4 to 2.3 l/s was calculated for the first 230 m of thickness.

To understand the water quality, water samples were taken and analyzed. Results showed that the pH varied between 7.4 and 8.26, the electrical conductivity 710 and 1,483 Mmhos/cm; values recorded for calcium ranged between 18.75 and 158.18, magnesium from 26 to 88 mg/l, sulfate 55 to 370 mg/l; chlorides ranged from 6 to 67 mg/l, sodium from 41.86 to 73.37 mg/l; as for the Total Dissolved Solids, although generally they exceeded the maximum acceptable value, in no case did they exceed the maximum allowable value.

The predominate water family types are Mixed Sulfate and Mixed Carbonate, and they are found in the southern and western sectors of the study area. In addition, an analysis of heavy metals is included where it was observed that the water does not contain high levels of lead and arsenic, noting that the reported values fall within the permissible limits. Aside from the water samples, mud samples were taken from the boreholes during suction and discharge at different depths, with results showing that the groundwater in the study area is generally acceptable for human consumption.

It was determined that the annual recharge is very poor, though no calculation of its volume was done due to discrepancies observed in the analysis methods. Thus it was concluded that any groundwater withdrawal should be seen as taking from the aquifer storage, which consequently would only allow for temporary exploitation.

December 1985. HYDROGEOLOGICAL FOLLOW-UP STUDY IN THE CONEJOS-MEDANOS REGION TO SUPPLY WATER IN BULK TO CIUDAD JUAREZ, CHIHUAHUA. Conducted by Lesser y Asociados, S.A.

The objective of this study was to determine the potential of the aquifers on the west side of the Sierra de Juarez Mountains to locate sources of potable water supply for Ciudad Juarez for the medium and long term. For this study, 18 VESs were performed with aperture of 1200 m in order to expand the understanding of the subsurface geometry towards the foot of the Juarez Mountains, and to locate sites for exploratory and exploitative drilling.

In the geomorphological analysis performed in this study, it was determined that the study area is located in an arid region where the scarce vegetation, mechanical erosion and eolic deposits result in a topographic relief that has 4 distinctive units: Mountains, bolsons, foothills and terraces.

The existing rocks were identified and assigned hydrogeological characteristics. The quaternary alluviums, the Santa Fe group, and the limestone in the Finlay, Lagrima and Benigno formations were labeled as permeable rocks. The impermeable units identified are the Ojinaga Group, the Cuchillo Formation and the intrusive rocks. The recharge zone corresponds to the entire bolson surface area, where some of the scarce precipitation infiltrates into the subsurface.

The electrical sounding produced six sections, which were extensively described in the study. In addition, an isometric diagram was made from the geoelectric sections, identifying five zones: The first zone is superficial, which indicated the likely presence of sands and a lower portion saturated with fresh water. The second zone is associated with brackish water. The third corresponds to local lenses of semi-compacted materials that are considered impervious. The fourth is associated with a saturated argillaceous section with very salty water; and the final zone consists of limestone rocks that form part of the prolongation from the Sierra de Juarez. These rocks are faulted and go deep a short distance from the Sierra.

According to the study, it was determined that the recharge of the existing aquifers is done through infiltration of rainwater that falls in the valleys. The bolson subsurface is comprised of several geoelectric units that can be grouped into three horizons: an upper horizon, some 40 m thick, of clayish-sandy granular materials with low permeability, possibly saturated with good quality water in the lower half. The intermediate horizon is located at a depth of between 40 and 150 m, which correlates to an aquifer saturated with only slightly saline water that might have around 1,500 ppm TDS. The deep horizon has low resistive values and is associated with an aquifer saturated with water that has a high saline content, greater than 5,000 ppm TDS.

The other types of materials present are calcareous, and correspond to the limestones that make up the Sierra de Juarez mountains. They are absent from the upper 400 m of the bolson. These limestones are found in the Finlay, Lagrima and Benigno Formations, which given their lithology could be permeable. The Cuchillo Formation is considered impervious because of its argillaceous nature. From a geohydrologic perspective, the limestones represent a disadvantage in that they crop up on the flanks of the Cuchillo Formation. The rocks beneath them are impervious sandstone, therefore deep exploration is not recommended. The Benigno, Lagrima and Finlay Formations that are considered permeable, crop up in the upper part of the mountain range, but they are absent on the west side because of erosion. The permeable limestones in the mountains are truncated and have no continuity heading towards the valley, so the recharge potential is eliminated.

This study defined the geometry of the aquifer units, making it possible to locate areas with hydrogeological characteristics suitable for drilling wells with the possibility of obtaining significant flow rates to be used as supply sources. Although chemical analysis of the water was not included among the initial activities, the suggestions made concerning the aforementioned analysis and the need get a salinity record during the construction of exploratory wells are important. Not only the quantity of water extracted, but also its quality is important, particularly if the objective is to use it for potable water supply.

December 1982. GEOHYDROLOGIC STUDY AND EXPLORATORY DRILLING IN THE CONEJOS-MEDANOS ZONE, IN THE STATE OF CHIHUAHUA. This study was conducted by the company Servicios Geológicos, S. A. Its main objective was to understand the hydrogeological characteristics of the calcareous and volcanic rocks, as well as the continental sediments from the Tertiary and Recent ages in the region in order to propose favorable areas to engage in hydrological exploratory efforts. The activities for this project were carried out in three phases. The first phase consisted of collecting and assessing the previous data, as well as hydrogeological photo interpretation. This was used to distinguish the existing geological formations and different soil types, as well as tectonic features, geomorphological features, lineaments, surface currents and drainage types.

The second phase consisted of the field activities, including geohydrologic point verification, which involved taking 14 samples of sedimentary rocks and 16 samples of igneous rocks for petrographic description. A survey of groundwater wells was conducted; 51 wells and 10 chain pumps were visited, most of which are used for domestic purposes. Additionally, 50 groundwater samples were taken for hydrogeochemical analysis. 35 VESs were performed, distributed over 7 lines, to obtain the soil resistivity.

Based on the primary results of this study, 3 hydrogeological units were identified:
A) The impervious unit consisting of intrusive igneous rocks (Ige) that have no permeability, meaning that they act as horizontal barriers to subsurface flow.

B) Within the semi-pervious unit, formations characterized by their low permeability are grouped, such as the undifferentiated conglomerate located in the spurs of the Sierra El Mauricio mountains, formed by

calcareous marine sediments whose lithological composition is semi-compacted with varied grain size, giving it more or less favorable characteristics for groundwater circulation.
There are also bolson fills in this unit, which are widely distributed throughout the area. Given the heterogeneity of their components and their sedimentation characteristics, they often interfinger or pinch out, resulting in the development of low-yield aquifers or good aquifers that have restricted dimensions. The alluvial deposits are also part of the semi-pervious unit, since based on their lithological constituents they have low to moderate permeability because they include silty-argillaceous and argillaceous-silty materials similar to low-yield aquifers, and gravels and sands like higher-quality, better-yield aquifer zones.

C) This study highlights the wide strip of highly permeable dunes, which could make up important recharge zones for the aquifer. They are comprised of clayish-sandy materials. The permeable unit is made of Benigno and Finlay Formations. These have better permeability conditions, except that there is no continuity between the recharge areas and those that have the potential for exploitation. Also, the Bolson fills have good permeability, since they are made of gravels, sands and conglomerates.

There are also basalts within the unit that have good permeability as a result of their vesicular texture and fracturing, as well as permeable ignimbrites, also fractured, that can serve as runoff and incipient recharge areas for the alluviums and fills.

This study concludes that the Benigno and Finlay Formations form part of a small recharge zone, through which water that feeds other permeable materials is transported, since their lithological and structural characteristics do not lend themselves to the formation of an aquifer system, as they are prevented from doing so by the regional tectonic nature. Based on the above, it is believed that the formations that could feasibly form low-yield, poor water quality aquifers are those made from bolson fill and Tertiary and Quaternary alluvial deposits.

With regard to the bolson fills made up of gravels and sands, there may be aquifers with more capacity and better quality water, at greater depths than the existing ones (150 m). Based on the geophysical soundings performed, it is believed that there are probably gravel and sand bodies at depths of 200 to 450 m. Additionally, a zone with acceptable water quality was detected towards the center of the study area, roughly defining an irregular aquifer zone with good permeability.

The zone with good quality water is found in the strip of dunes, which implies that this zone is made up of eolic deposits; if this is the case, the aquifer has a quick connection to the recharge zone with high natural permeability. On that basis, the existence of an aquifer system is established, but the geological-structural aspects need to be considered, as well as the continental-type sedimentary character, since any continuity is dependent on its complexity, not only in the recharge zones, but also in the aquifer's lateral geometry. Based on the geological analysis performed, it was concluded that it is unlikely that the continuity between the calcareous marine sedimentary formations is maintained, whereas in the fill materials, continuity is based on the sedimentary pattern that occurred when they were deposited and filled the rifts.

As a result of the geophysical analysis, a material with high resistivity was detected, associated with an impervious horizon, probably consisting of calcareous shale and on top of that, only found on one of the profiles, a material associated with a highly fractured limestone. The conglomeratic deposits are heterogeneous and argillaceous. They were found in three of the profiles and in all cases, underlying or wedging out into the alluvium or fill materials, and although this does not constitute a homogenous horizon, it does reach considerable dimensions and thickness of up to 100 m, considered to be semi-pervious given its clayeyness. As for the superficial strata, in almost all of the profiles developed, the sandy and clayey alluvium deposits are found, which have been associated with a probable saline content.

The localized heterogeneous deposits are considered typical of soils with wide ranges of resistivity. The fractured limestone covers only a small area, since it presents lateral variations in resistivity, which probably indicate its truncation or change to argillaceous limestones with probable fracturing. The valleys are large bolsons filled with materials that are mainly gravels, sands or clays, which at some sites are saturated with salts.

As part of this 1982 study, a chemical analysis of the water was done to complement the geohydrologic analysis. The results gave an average value for each parameter tested: Electrical Conductivity 4,090 $\mu\Omega$/cm, which is equivalent to a salinity of over 2,000 ppm; TDS=2,378 ppm, Calcium 27 ppm, Sodium 725 ppm, Magnesium 34 ppm, Sulfates 761 ppm, Bicarbonates 231 ppm and Chloride 577 ppm. With the data obtained at each well, a water type analysis was performed, resulting in most of the samples being categorized as mixed sodium. In this section, it was concluded that the region has high saline concentrations, particularly sodium, and that these salts appear in wells with shallow static levels; the deeper the well, the better the water quality.

As a result of all this, five sites were proposed for exploratory drilling in order to directly evaluate the aquifer potential. The sites were located 8.5 km northwest of Las Cuatas Ranch, 5.5 km northwest of El Aguaje Ranch, northwest of El Faro Ranch, southwest of Los Chontes Ranch and northeast of El Mezquite Ranch.

A favorable alternative for groundwater extraction is located in the center-east portion of the study area, where eolic deposits predominate. The sedimentological nature of the study area allows the presence of restricted, highly pervious aquifer zones to be established that affect the groundwater quality. Most of the area consists of semi-pervious, clayish-sandy deposits that form low-yield brackish aquifers.

1.6 Work Method for the Current Study

The proposed work method for developing this study consists of field and desk activities, which were carried out in alternating stages. Altogether, said activities last six months, beginning in June and ending in December 2010.

It is important to mention that both the field and desk activities, as well as the information taken from previous studies and what was provided by the Ciudad Juarez Municipal Water and Sanitation Board and Grupo CARSO, are the pillars that provide the technical foundation for this report.

The following is a brief summary of the field and desk activities.

1.6.1 Field Activities.

The field activities were carried out during the months of June, July, August, and part of October 2010. During these months, operations personnel from the Mexican Geological Service's Department of Hydrogeology and Environmental Geology formed three field crews, which operated directly out of Ciudad Juarez. Each crew included two geohydrologists, two vehicles and a field guide.

Initially, a survey of the groundwater wells was conducted. Information about the number of existing wells and their UTM coordinates using NAD-27 Datum was collected, taking into account the well type, its use, operational status, equipment characteristics, outlet type, operating and gaging mechanisms. Static levels and physical and chemical parameters such as electrical conductivity, total dissolved solids, temperature, pH, Eh, and salinity were measured. During this phase the feasibility of doing a pumping test and taking water samples was noted.

The survey of groundwater wells was performed, gather information such as: well number, UTM coordinates using NAD-27 Datum, well type, usage (agricultural, domestic, livestock, public urban, etc.), operational status, equipment characteristics: motor type, pump type (submersible or vertical), motor power (rpm), horsepower, outlet type, operating schedule (hours of operation per day, week, month and year), as well as measurements of the static and/or dynamic levels. Physiochemical parameters were measured on site at some of the wells, including: electrical conductivity (EC), Total Dissolved Solids (TDS), temperature (T) and the power of hydrogen (pH).

It is worth noting that it was necessary to visit several of the wells more than once, aside from the 23 located in the Conejos Medanos Aqueduct wellfield, since a resting period of more than 24 hours was needed to measure their static level. During a second visit, it was also possible to measure the physical and chemical parameters of the water withdrawn.

Continuing on with the field activities, initially ten pumping tests were conducted for a short period (between 6 and 8 hours); seven of them in the wellfield and three in wells outside the wellfield. It should be noted that for security reasons of the operations personnel, it was not possible to do longer pumping tests during the initial survey. However, during a second survey, it was possible to execute longer-duration tests using automated equipment (data drivers).

A handheld Garmin GPS, model eTrex Gps 76, was used for the field work, 200 m sonic probes to measure the piezometric levels, and Hatch portable equipment to measure the physical and chemical parameters of the water.

1.6.2 Desk Activities.

At the same time as the field activities were undertaken, the desk activities began. Initially, existing data from hydrogeological, geological and geophysical studies were collected, and a series of maps, plans and articles about the study area were analyzed.

To prepare a base map and the related maps that are incorporated into the current study, topographic maps 1:50,000 scale and digital elevation models, edited by the National Institute of Statistics, Geography and Information (INEGI), and geological mining maps, scale 1:250,000, edited by SGM were used. This was done to integrate everything into a Geographic Information System (GIS) based on ArcMap 9.2 software.

Using mainly the information from the SGM geological mining maps, prior data and data from the field visits, a preliminary geological map was prepared. This map plays an important role in determining how the aquifer functions, since based on the geological behavior, recharge zones and natural barriers zones are confirmed, along with other hydrogeological features.

The information obtained from the work done in the field was analyzed and processed in the office, operating out of the main SGM offices located in Pachuca, Hidalgo, as well as the Northwest Regional Office, located in Hermosillo, Sonora.

The main result of the desk activities is this document, which gives an overview of the region, including its location, access routes and economic activities, and covers the physical framework, which identifies the physiographic, hydrographic, climatological, and geological characteristics, as wells as other topics of interest. It also covers the aquifer's subsurface hydrology, detailing the results of the well survey, the hydrometry, the very important piezometric behavior and the pumping tests. Likewise, the aquifer's behavior is established, defining its principal hydrostratigraphic units, the system geometry and behavior, indicator features and flow networks. Lastly, a series of conclusions and recommendations are presented, along with the bibliographic references and a series of appendices including the survey forms, pumping tests and tables created for the report.

2 PHYSICAL FRAMEWORK

2.1 Physical Geography

The area covered by the Conejos Medanos Aquifer is located within the Physiographic Province of Sierras, Llanuras y Médanos del Norte [*Northern mountains, plains and dunes*], which is characterized as arid and semi-arid. (INEGI 1999) Furthermore, Raisz (1964) locates the study area within the Sierras y Llanuras del Norte Province, specifically in the Llanura y Médanos del Norte Subprovince, which covers up to 90% of the study area, while the other 10% is located in the Sierras Plegadas del Norte Subprovincia [*Northern fold mountains*]. (Figure 2.1)

The Llanura y Médanos del Norte Subprovince is characterized by the presences of dunes. There are also large floodable, saltpetrous areas that are morphologically flat, the most notable of which is the area known as the Laguna El Barreal. A typical example of the behavior in this Subprovince is the Samalayuca dunes (outside the study area), which is the largest dunefield in the country. On the other hand, the Sierras Plegadas del Norte Subprovince is characterized by large, parallel mountain range with a general northwest-southeast orientation, separated by large depressions, commonly called bolsons, which are filled by continental sediments mainly consisting of sands, silts and clays.

The topography is the area is generally flat, comprised of sand dune plains, interrupted by elevations that form mountains. The mountains have steep cliffs and diverge out into hills and rounded formations with soft slopes as seen in the sierras of Juarez, Sapelló, Samalayuca, Los Muertos, Los Amargosos, La Candelaria, Las Conchas, La Pedrera, El Sancho, El Presidio, San Blas, La Nariz, China and el Chilicote.

The study area has singular features produced by the high level of activity of the weathering agents. Consequently, the area and its surroundings are geomorphologically in an old age stage, where three typical units stand out: a) *sierras/mountains*, which limit the study area, playing a major role in the aquifer behavior. This is the case of the structural elements produced by erosion, which include the folded, fractured and faulted calcareous rocks, with a preferential northwest-southeast orientation. The exceptions are the Sierra La Candelaria, of intrusive, igneous origin, and the Sierra de Samalayuca, of detrital continental sedimentary origin, both with a northwest-southeast orientation; b) *foothills*, comprised of conglomeratic deposits in the form of fans and terraces, which appear as small upward sloping elevations, separated by shallow arroyos. Because of their predominantly high permeability, they play an important role in the aquifer recharge; c) *bolsons*, occupy the majority of the study area, where they fill a large basin with continental sediments that form alluvial plains and lake basins. The most prominent elevations are the dunes, produced by the interlocking of the alluvial deposits that have transformed into eolic deposits, covering over previous physiographic features.

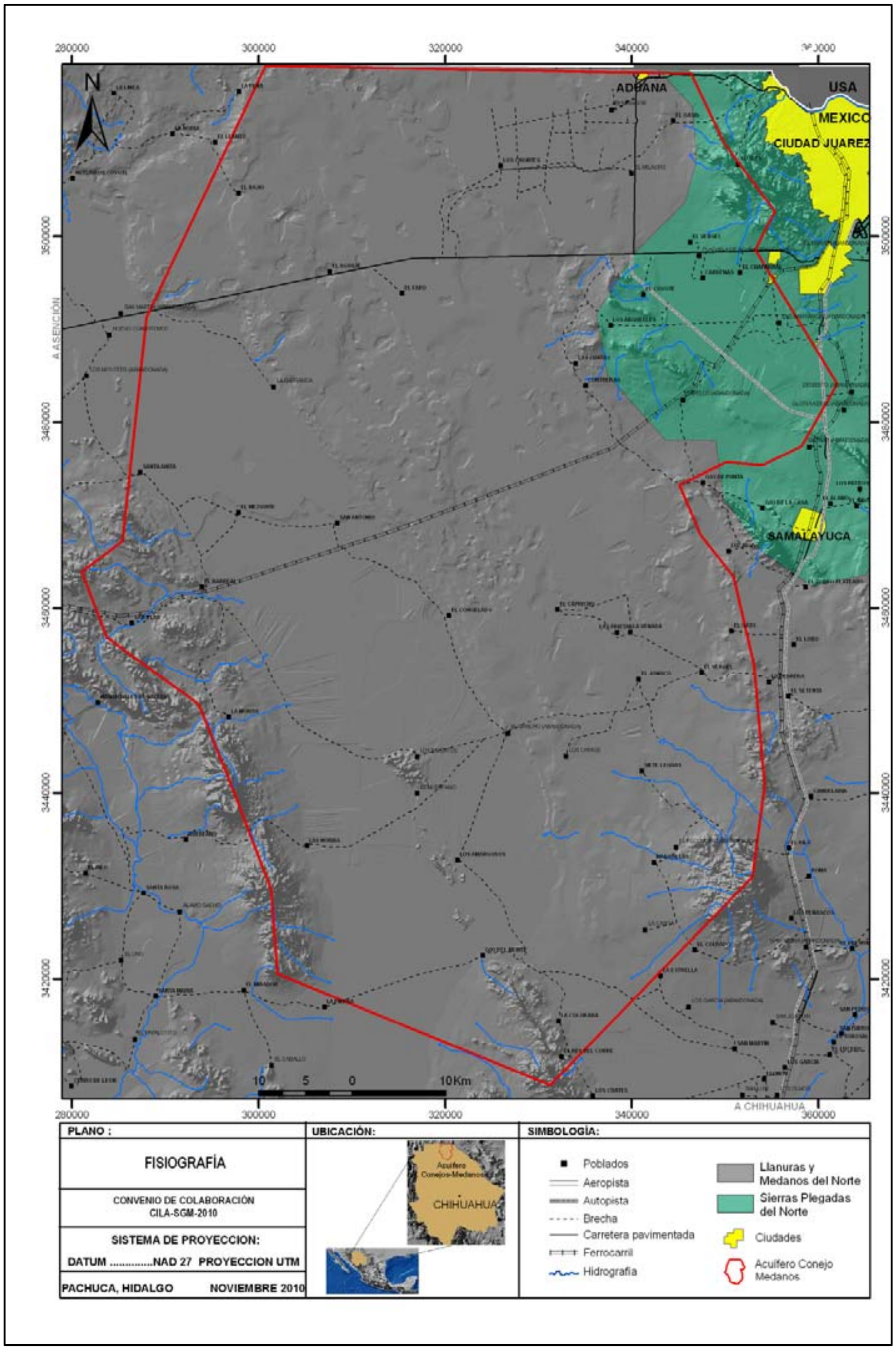


Figure 2.1 Physiographic Subprovinces

2.2 Hydrography.

Given that a large part of the Conejos Medanos Aquifer surface is made up of highly permeable dunes, plus the existence of the Laguna El Barreal, known as the El Barreal zone, adding to that the large demand for moisture on the ground surface, as well as the minimal precipitation in the region, there are no significant surface water currents. (Figure 2.2) There are small arroyos that originate in the high part of the mountains, which have intermittent flow, resulting in a drainage system of small endorheic basins that tend to flood when torrential rainstorms happen. This is an infrequent occurrence in the region, normally during the rainy season.

In light of these hydrographic conditions, there are no surface currents that can be used to capture water. Consequently, all of the capture structures in the aquifer are mostly underground, although there are some levees and a small weir for the purpose of capturing surface water. Even so, the possibility that this weir, located in the south-central sector of the aquifer, receives water from several perennial springs in the area should not be discarded.

Among the areas that flood, the Laguna El Barreal is particularly noteworthy. It is a large floodplain that covers the central, south-central portion of the aquifer, an area where there are also several springs linked to the presence of a fault zone. (See sections 2.7 and 3.1.)

2.3 Climatology

According to the Köepen classification, the existing climate in the area covered by the Conejos-Medanos Aquifer is a dry or extreme steppe-type (BWkw) climate, with summer rains that normally occur during the months of July, August, and September. (Figure 2.3) It is precisely during those months when there is enough moisture for some plant species to grow, such as the Microphyllous and Rosetophyllous Desert Scrub and grasses, as well as halophytic vegetation is areas where there are excess salts in the soil. (INEGI, 2003) The region's average precipitation is 246 mm; its maximum annual average temperature is 38°C during summer and the minimum average temperature is around -12°C in the winter. Evapotranspiration is approximately 2,400 mm/yr.

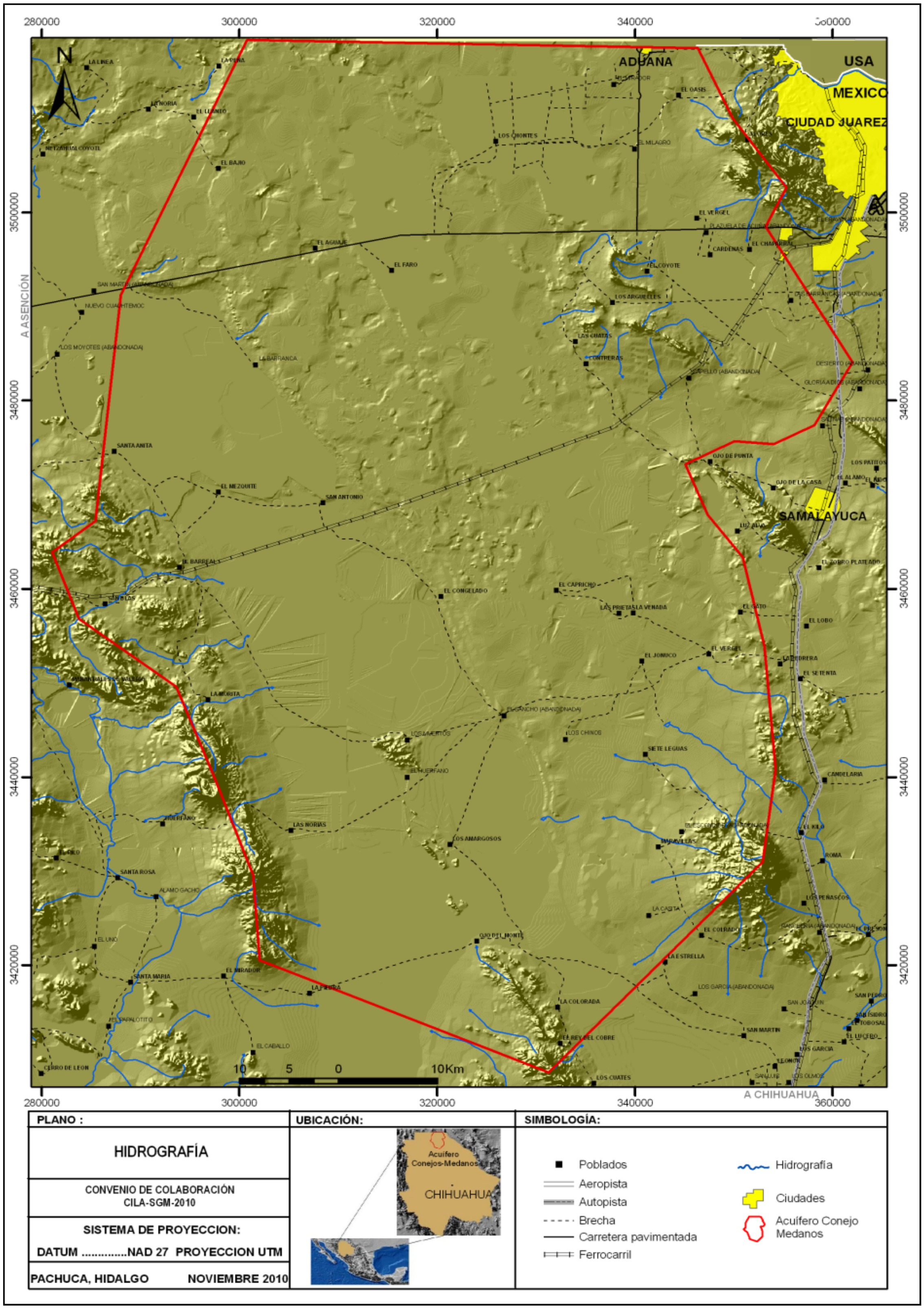


Figure 2.2. Hydrography

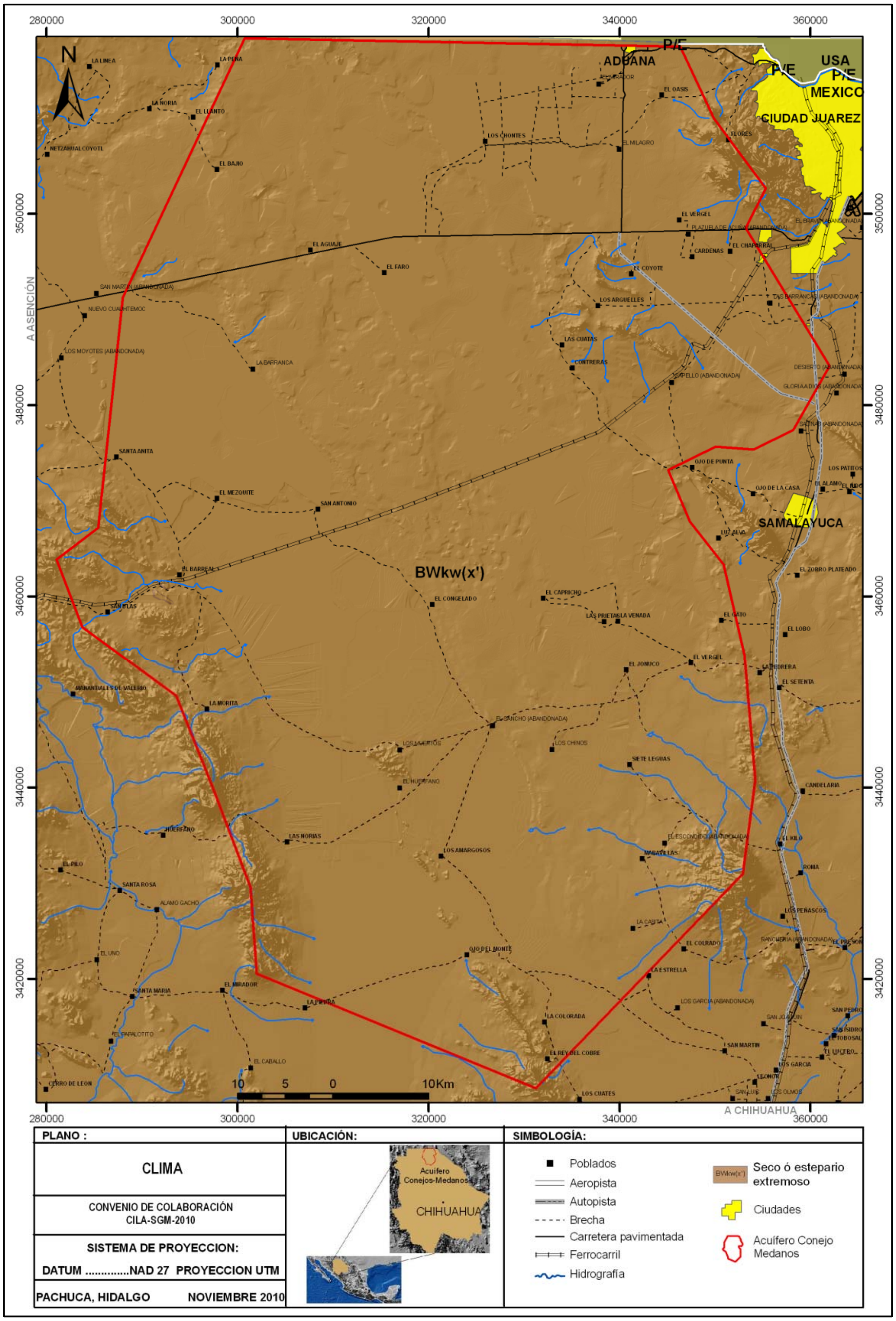


Figure 2.3 Climate

2.4 Hydrometeorological Balance

A database maintained by the National Weather Service, known as "*Computerized Climate System*" (Clicom), was used to get the hydrometeorological balance. This system contains information recorded by national network of conventional weather stations.

The hydrometeorological analysis of the study area was done using the following weather stations: Juarez (8213), Samalayuca (8121), Villa Ahumada (8155), Guzmán (8077) and Palomas (8110), none of which is found within the limits of the aquifer. (Figure 2.4) It should be noted that the monitoring period for the stations is from 1971 to 2000, except for the Juarez Station, whose period of record goes from 1957 to 2007. However, it needs to be added that this station has no temperature records for the 1992 to 1998 period.

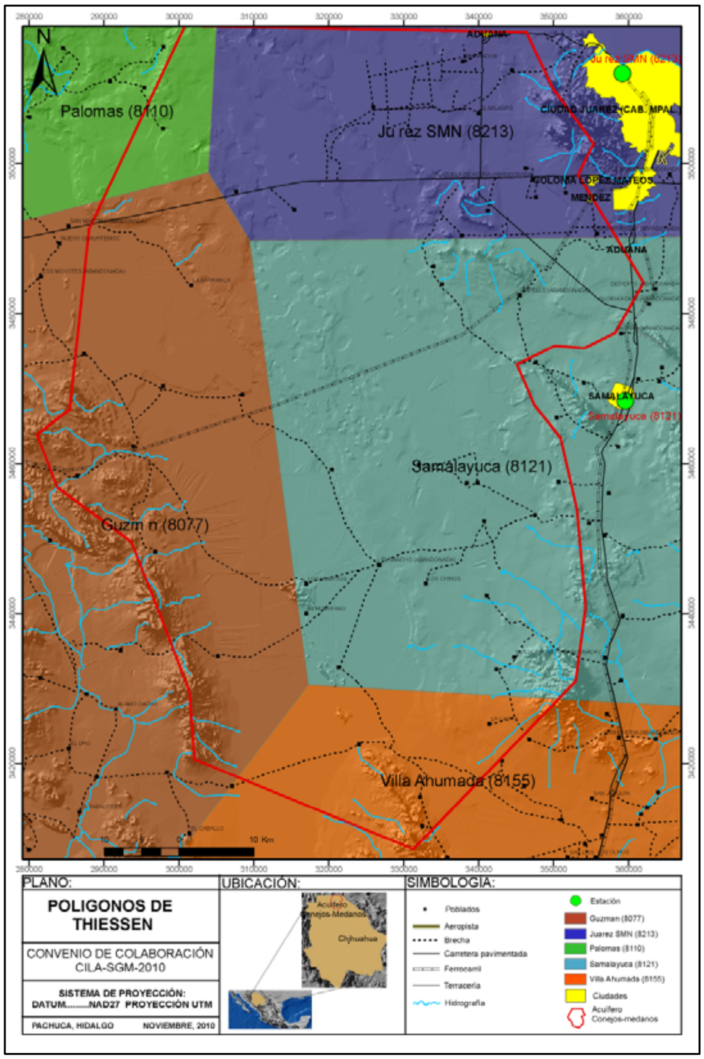


Figure 2.4 Weather Stations and their Area of Influence.

Each one of the factors involved in the hydrometeorological balance, such as temperature, precipitation, evapotranspiration, is described below, along the equation itself that uses these factors.

Temperature.
The record from these stations indicates that the temperature behavior has an annual variation with a parabolic tendency. The intensity becomes greater in the months of May, June, July, August and September, decreasing during the remaining months. The months with the lowest temperature records are December, January and February.

The annual average temperature recorded for the aforementioned stations varies between 16.7 and 18.3 °C. (Figure 2.5) With the information from the weather stations, an analysis was done to get an annual average value for the Conejos-Medanos Aquifer area by calculating the arithmetical average for each station. An annual average temperature for the aquifer of 17.29 °C was obtained. Table 2.1 contains the results and the area of influence for each station used.

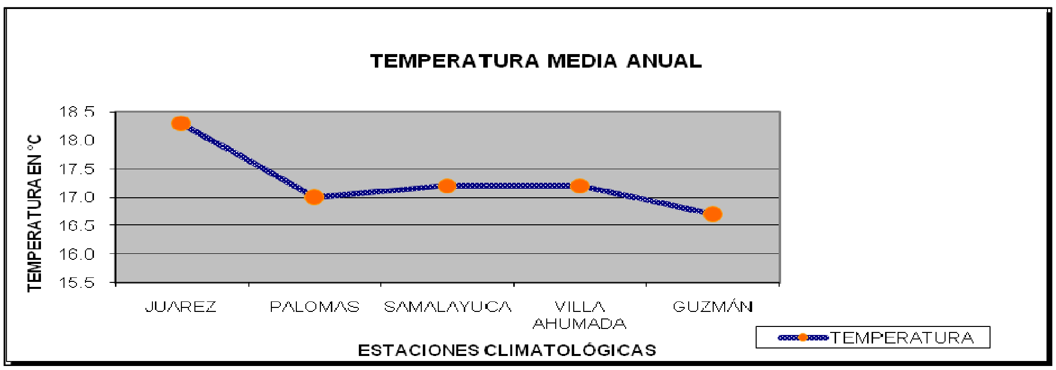


Figure 2.5. Annual Average Temperature

Table 2.1. Area of Influence by Station for the Annual Average Temperature

STATION	X	Y	Temperature (°C)	AREA INFL. (km^2)	(T)*Area of Influence
JUAREZ SMN (8213)	359192.00	3511991.00	18.30	1324.19	24232.677
SAMALAYUCA (8121)	359551.00	3468317.00	17.20	2425.10	41711.72
VILLA AHUMADA (8155)	355052.00	388128.00	17.20	540.46	9295.912
PALOMAS (8110)	250396.00	3517903.00	17.00	184.00	3128
GUZMÁN (8077)	266601.00	3456017.00	16.70	1664.43	27795.981
			Total Surface Area:	6138.18	T(ºC)=17.29

Precipitation.

The Juarez station (8213) has 49 years of monitoring records (1957-2007), except for the year 1995. The annual average precipitation for this station is 258 mm; the months with the most precipitation are July, August, September, part of October and some sporadic rain in the month of December. Occasionally there are some snowstorms in December and January.

The Samalayuca station (8121) has a 29-year record (1971-2000), with an annual average precipitation of 287 mm. The months with the most precipitation are July, August and September, with some rainfall and snow during the months of December and January.

The Villa Ahumada station (8155) has a record from 1971 to 2000, with an annual average precipitation of 341.30 mm. The months with the most precipitation are July, August and September.

The Palomas weather station (8110), with a 29-year record (1971-2000), has an annual average precipitation of 294.50 mm, while the annual average precipitation record at the Guzman station (8077) is 320.30 mm. The graphical values for each station are found in Figure 2.5, which does a comparison for each station.

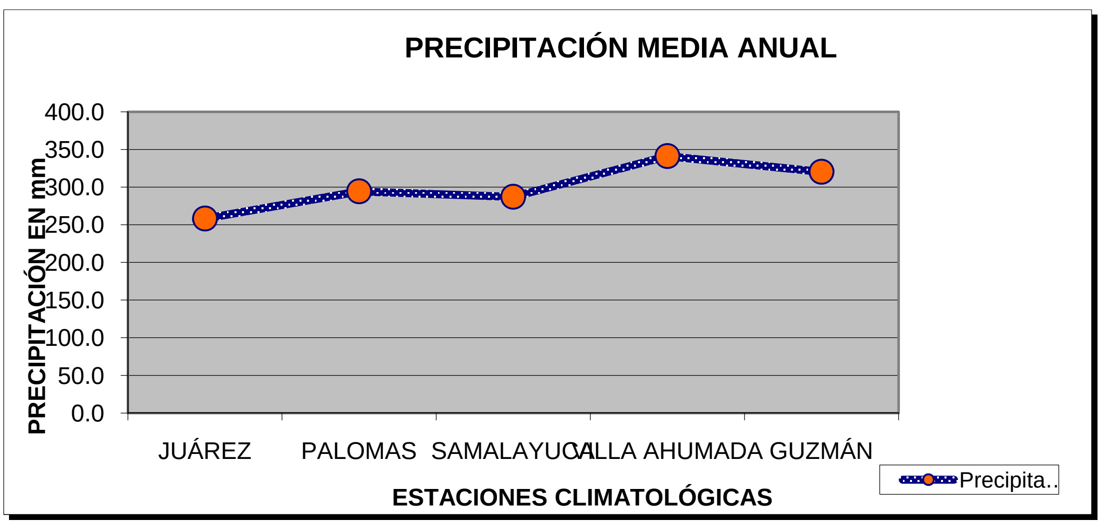


Figure 2.6. Annual Average Precipitation for the Weather Stations

Based on the above, it was determined that the precipitation conditions in the study area are isolated, high intensity and short duration, occurring most often during the months of July, August and September. However, there are rain and snow storms during the months of December, January and February, caused by cold air masses arriving from the north that, when they run into the region's warm air masses, produce low-intensity, long-lasting and widely-spread rainfall.

To calculate the areal precipitation for the Conejos Medanos Aquifer, the Thiessen polygon method was used (Figure 2.4), resulting in an annual mean areal precipitation of 294.98 mm. Table 2.2 provides the annual average precipitation data by station, as well as the area of influence for each station in the study area.

Table 2.2. Annual Average Precipitation for the Weather Stations

STATION	X	Y	Precipitation (mm)	AREA INFL. (km²)	(Precipitation) *(Area infl.)
JUAREZ SMN (8213)	359192.00	3511991.00	258.40	1324.19	342.170696
SAMALAYUCA (8121)	359551.00	3468317.00	287.30	2425.10	696.73123
VILLA AHUMADA (8155)	355052.00	388128.00	341.30	540.46	184.458998
PALOMAS (8110)	250396.00	3517903.00	294.50	184.00	54.188
GUZMÁN (8077)	266601.00	3456017.00	320.30	1664.43	533.116929
			Avg. Prec.: 300.36	6138.18	MAP: 294.98

As can be seen in Table 2.2, the values obtained by calculating the annual average precipitation using the Thiessen polygon method (294.98 mm) are very similar to the average precipitation from the weather stations (300.36 mm); however, the Thiessen method allows us to obtain precipitation data information by area of influence for each of the weather stations in the study area.

Evapotranspiration.

Once the values for annual average precipitation and temperature have been calculated, the evapotranspiration value is found using the L. Turc formula, which establishes the following mathematical relationship:

$$ETR(mm) = \frac{P(mm)}{\sqrt{0.90 + \left(\frac{P^2(mm)}{L^2}\right)}}$$

When: $L = 300 + 25T + 0.05T^3$

Where: T is the temperature (ºC)

P Precipitation in mm.

The real evapotranspiration (ETR) was calculated for each of the weather stations involved in this analysis, resulting in the values that appear in Table 2.3.

Table 2.3. ETR and L-factor Calculation

STATION	Precipitation (mm)	T °C	L	ETR (mm)
JUAREZ SMN (8213)	258.40	18.30	1063.92	263.87
SAMALAYUCA (8121)	287.30	17.20	984.42	289.45
VILLA AHUMADA (8155)	341.30	17.20	984.42	337.90
PALOMAS (8110)	294.50	17.00	970.65	295.68
GUZMÁN (8077)	320.30	16.70	950.37	318.15

Once the ETR value was obtained for each weather station, an annual average value of 301.01 mm was calculated. This was close to the value obtained using the areas of influence for each weather station (Table 2.4), which gave an annual average value of 296.17 mm.

Table 2.4. ETR as a function of area of influence for each station.

STATION	Precipitation (mm)	Temperature (°C)	AREA INFL.(km^2)	ETR (mm)	(Area infl)*(ETR)
JUAREZ SMN (8213)	258.40	18.30	1324.19	263.87	349.41
SAMALAYUCA (8121)	287.30	17.20	2425.10	289.45	701.95
VILLA AHUMADA (8155)	341.30	17.20	540.46	337.90	182.62
PALOMAS (8110)	294.50	17.00	184.00	295.68	54.40
GUZMÁN (8077)	320.30	16.70	1664.43	318.15	529.53
			A_T:6138.18	Avg: 301.01	ETR: 296.17

Water balance equation.

The values obtained are then applied to the water balance equation, which for the upper layer of terrain is proposed to be as follows:

$$P = ETR + Q_S + Q_R + \Delta M$$

Where:

P: Rainfall Precipitation (mm)

ETR: Real Evapotranspiration.

Q_s: surface runoff

Q_R: deep percolation

ΔM: change in moisture in the upper layer of terrain.

While it is believed that on the valley surface the change in moisture and surface runoff are insignificant, meaning they tend towards zero, the deep percolation that indicates the upper limit of the aquifer recharge can be expressed using the following equation:

$$Q_R = P - ETR$$

If the result is negative, this means that the diffuse recharge resulting from rainfall in the study area is null. Using the results obtained in the climatological analysis and substituting them in the previous expression, results in:

$$Q_R = 294.98 - 296.17 = -1.19$$

Because the value obtained is negative, the rainfall recharge for the study area is numerically non-existent; however, the numbers obtained are not valid without the proper interpretation. In other words, while evapotranspiration is high and it exceeds precipitation, through direct observation in the field of rain event, there is rapid infiltration in the sandy areas, as well as zones with intensely fractured caliche; therefore, there is aquifer recharge from rainfall, albeit in small quantities. It should be noted that using the groundwater balance equation, the Mexican Geological Service (2007) established a vertical recharge from rainwater infiltration into the Conejos-Medanos Aquifer of 2.8 Hm^3/yr.

2.5 Surface Hydrology

The area covered by the Conejos-Medanos Aquifer belongs to Hydrologic Region 34, Cuencas Cerradas del Norte (Casas Grandes), including the northern portion of the El Carmen, Santa Maria and Casas Grandes river basins (Figure 2.7), which have an average runoff coefficient of 2.47%, 2.56% and 2.65%, respectively. It is worth noting that none of the abovementioned rivers runs through the study area.

The Santa Maria River Basin is located in northwest Chihuahua and the northwest side of Hydrologic Region 34. It is bordered to the southwest by the Yaqui River Basin (Hydrologic Region 9), to the northeast by the Rio Bravo-Ciudad Juarez Basin (Hydrologic Region 24); to the west-northwest by the Casas Grandes River Basin; to the east-northeast by the Rio del Carmen Basin; meanwhile the southeast side of the aquifer borders the northwest part of the Laguna Bustillos and De Los Mexicanos basin[s]. The last three basins belong to Hydrologic Region 34. The slope fluctuates between moderate and low. The most notable hydrological feature is the Santa Maria River. There are short streams that regularly flow to the intermittent lakes in the basin, such as Laguna El Barreal on the north side of the basin. According to INEGI (1999), the average runoff coefficient for the whole basin is 2.56%, with an annual average drainage volume of 165.718 million m^3, originating from an average volume of precipitation of 6,473.393 million m^3.

The Rio del Carmen Basin is located in the central northern part of the state and in the center of Hydrologic Region 34. It is bordered to the north by the Rio Bravo-Ciudad Juarez Basin (Hydrologic Region 24); to the east by the Laguna Bustillos and De Los Mexicanos basin[s], and to the west by the Santa Maria Basin. The last three basins belong to Hydrologic Region 34. The slope fluctuates from low to moderate. The most important surface stream is the Rio del Carmen river. The average runoff coefficient for this basin is 2.47%, with an annual average drainage volume of 137.585 million m^3 and an annual average volume of precipitation of 5,570.246 million m^3. (INEGI, 1999)

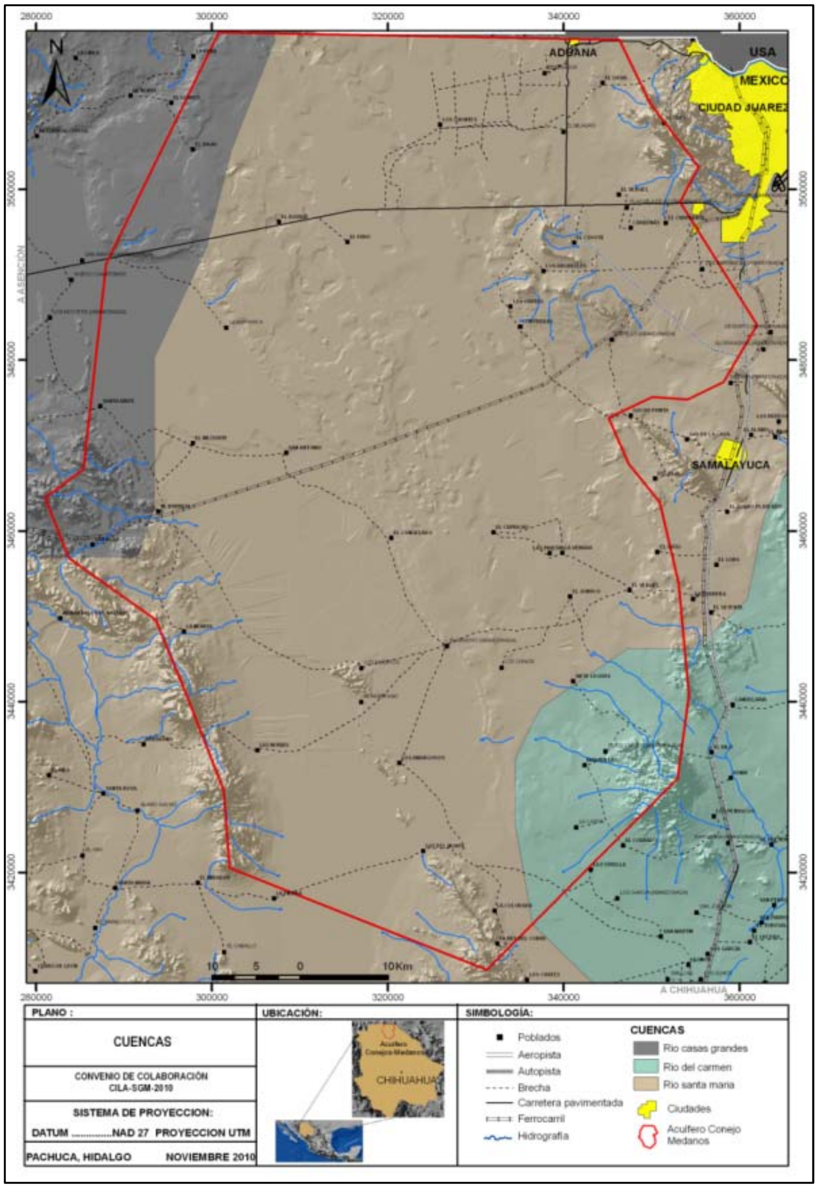


Figure. 2.7. Distribution of Basins.

The existing arroyos originate in the upper part of the sierras, as intermittent streams covering short distances, or temporary streams (mainly in the dune area), which disappear in the dune zone or flow towards the Laguna El Barreal, which itself is intermittent.

In the *Synthesis of Geographical Data for the State of Chihuahua*, it was observed that the runoff coefficient over most of the study area's surface in less than 10 mm. As a result, it can be said that there are no significant surface streams or any streams that can be used on a permanent basis within the study area.

2.6 Soils

According to INEGI (1999), the predominant soil type in the area occupied by the Conejos-Medanos Aquifer is Calcaric Regosol (Rc), in its different physical and chemical phases. Typically, this soil type is calcareous, at least a portion of it, between 20 and 50 cm deep, and it has a very high alkalinity in saline soils, thus the organic content is very poor. It can be said that generally, this soil type doesn't have distinct layers; it is coarse in texture in the dune area and medium textured in the southeast part of the aquifer. This texture applies to the superficial 30 cm. The INEGI soil maps (1999) show that this is the predominant soil found throughout the northern, central and southeastern sectors of the aquifer.

In the northern sector, the secondary soil is Eutric Regosol (Re) in its petrocalcic phase. This soil type has a moderate to high inherent fertility; it's pH varies from moderately alkaline to highly acidic; and the amount of organic material it contains ranges from poor to extremely poor in the surface layer. On the southeastern side of the aquifer, the secondary soil in Orthic Solonchak (Zo) in its saline-sodic phase. In the area covered by the Laguna El Barreal, the predominant soil is Gleyic Solonetz (Sg), and the secondary soil is Zo. To the northeast of the Laguna, the predominant soil is the Gleyic Solonchak (Zg) with a sodic chemical phase. In addition to the accumulation of salts in these soil types (Solonchak), there are very significant quantities of sodium, making them strongly alkaline. The salinity in this type of soils is the result of weathering and very dry climates.

In the central sector, the primary soils are Zo and Luvic Yermosol (Yl), with Zo as secondary soils; the saline, sodic phase is dominant here. In small areas, Lithosol (L) is the predominant soil, although in some zones it is the secondary soil, along with Haplic Xerosol and Calcic Yermosol. (INEGI, 1999)

In summary, the soil is comprised of sandy desert that usually forms dunes, with highly permeable characteristics and a high demand for moisture on the surface. The vegetation includes several varieties of desert plants, shrubs and cacti, such as Microphyllous and Rosetophyllous Desert Scrub. The most numerous species are: creosote bush, mesquite, lechuguilla, tasajillo, escobilla, yucca and palm, in addition to halophytic vegetation typical of saline soils. Because few grasses are native to these soil types, this means that grassy pastures a relatively scarce, and therefore livestock raising is not that common.

Based on the physical and chemical characteristics of the soil, it is difficult to develop this area for agricultural purposes, although there are some isolated area where the terrain is suitable some plant types.

2.7 Geology

Regional Geological Framework

Geologically, the Conejos-Medanos Aquifer area is located within the Chihuahua Tectonostratigraphic Terrane, which has an approximate thickness of more than 3,000 m, consisting of Paleozoic sandstones, shales, and limestones. (Malpica and De la Torre, 1980 en SGM 2007) Underlying this is the Precambrian crystalline basement of the North American craton, formed from an assemblage of metamorphic crystalline rocks that are comprised of metagranites, amphibolites and to a lesser extent, gneisses and quartzites cropping up in allochthonous blocks. (Handschy, et. al. 1987) This basement crops up in disperse and infrequent structural windows in northern Chihuahua. Given their lithology, they correlate to Precambrian amphibolites from the Sierra del Cuervo (Mauger, et. al. 1983) and Carrizalillo; they correlate with the Grenville Province and together they make up a metamorphic and magmatic strip that appears along the eastern edge of the North American craton, from Canada down to the Oaxaca in Mexico. (Campa and Coney, 1983)

In general, mixed marine and continental sediments from the Mesozoic age predominate. They were deposited in the Chihuahua Basin and are seen in outcroppings over most of the area. The lithostratigraphic units that make up the basin have ages that vary from Middle Triassic-Jurassic to Upper Cretaceous. During the Middle Triassic-Jurassic, the Samalayuca Formation was deposited, forming the foundation of the Chihuahua Basin, filling in the depressions caused by the distensive events.

These sedimentary layers are covered by the Aurora Group formations, spanning the Early and Middle Albian ages, which consist of units of said group, essentially argillaceous in nature with calcareous intervals. In the Middle and Upper Albian, the calcareous, shaly sediments overlying the previous units surface only towards the north side of the aquifer. The Paleogene is made of extrusive igneous rocks that consist of andesite flows emplaced during the Eocene. During the Oligocene, andesites, trachytes, latites, rhyodacites, rhyolitic domes, and basalt flows were emplaced.
During the Miocene, caused by the faulting of the Basins and the Sierras, there are continental deposits made of oligomictic conglomerates and basaltic flows.

The Quaternary is comprised of basalts, thick residual soils (silts and clays), which mainly cover the low parts of the valleys, lacustrine and eolic deposits, and terraces made of silts and sands covered in poorly consolidated conglomerates. The distribution of the units that are exposed in the study area can be found in Figure 2.8.

Stratigraphy.

The following is a brief description of the different geological units that appear in the area of the Conejos-Medanos Aquifer, whose distribution can be seen in Figure 2.8. The Stratigraphic Column is provided in Figure 2.9. It is worth noting that the information was taken from geological mining maps, scale 1:250,000, printed by the Mexican Geological Service.

Middle Triassic-Jurassic

Samalayuca Formation (TRJm Ar-Cgp*). Sediments consisting of a sequence of sandstones and conglomerates formed from subrounded fragments of quartz and chert, with the occasional presence of limestones. It only emerges in the Sierra de Samalayuca mountains. At the same time, the unit is comprised of a sequence of grey, greenish-grey, brown, reddish- and purplish-brown sandstones, with fine to medium quartz grains, cemented with silica that is slightly calcareous. There is fine crossbedding in horizons of up to 10 cm. It contains intercalations of conglomeratic horizons in strips of up to 40 cm, formed from 1-6 cm diameter fragments of subrounded to rounded quartz, chert, scarce sandstone, phyllite and occasional limestone and/or dolomite with sandy matrix.

The thickness measured in the Samalayuca Mountains is 1,184 m. (Valencia R. J. 1968) It is not related to its upper and lower contacts. The field evidence seems to indicate Upper Jurassic sediments above it, since its contacts cannot be seen. The Mexican Geological Service, previously COREMI, has categorized it as a Middle Triassic-Jurassic unit, based on the foliation and schistosity (kinematic indicators) observed in these rocks that are not from orogenies earlier than Laramide.

Upper Jurassic

La Casita Formation (Jkpo Ar-Lu). Carbonate sequence with lithological variations to clayish-sandy sediments and sandy horizons with crossbedding and conglomeratic strata. Found in outcroppings that form the hills surrounding the Samalayuca Mountains, it consists of a sequence of grey and greenish-grey sandstones, with fine to coarse quartz grains and siliceous, slightly calcareous cement. In strata that vary from thin to medium-sized, its primary structures have cross-bedded and laminar stratification. It also contains conglomeratic horizons in 5-10 cm strips, formed from quartz and chert fragments with sandy matrix and siliceous cement. In addition, there are intercalations of claystone, calcareous shale and calcareous siltstone that is dark grey and purple color with argillaceous limestone intervals of 10 to 20 cm. The thickness found in the Samalayuca Mountains is 282 m. (Valencia R. J. *op. cit.*) Based on the lithology and the fauna, this unit represents a coastal platform of marine deposit environment in intertidal and subtidal zones. (Cuevas L. 1985)

* **Translator's Note: All geological unit/rock abbreviations have been left the same as they appeared in the original Spanish text.**

Lower Cretaceous

Navarrete-Las Vigas Formation (Kbeh Ar-Lu). Calcareous, argillaceous sequence with anhydrites and gypsums in its base. Found towards the center-northeast in the Los Argüelles Ranch, this unit is made from a sequence of sandstone and shale, alternating with carbonate and anhydrite horizons towards the base, while towards the top it is made of reddish fine to medium grain quartz sandstones in medium-sized strata. There is crossbedding, slightly sandy limestone intercalations, and shale with petrified wood. It has an approximate thickness of 600 m. This formation contains alluvial deposits over a large tidal plain with zones of evaporites and sandy sediments.

Cuchillo Formation (Kbap Cz-Lu) Barremian-Aptian. Argillaceous limestone sequence with intercalations of shale, calcareous sandstones, evaporites, and biogenic limestones, whose sandy content increases towards the northeast part of the area. Towards the base of the Juarez Mountains, it is believed that the Cuchillo Formation splits into three formational units, which are: La Virgen, Cupido and Peña; it is difficult to differentiate these formations in the study area, so it was decided to keep them grouped together in the Cuchillo Formation. It also emerges to the east of the La Nariz Mountains, northwest of the Los Muertos Mountains, and west of the Presidio Mountains.

In the central part of the Juarez Mountains, it shows up with alternating layers of dark grey limestones, maroon-colored shales and yellow-ochre quartz sandstones with conglomeratic horizons of rounded chert fragments. In the middle section, there is a light-grey, massive limestone body, and towards the top, there is a reddish conglomerate of coarse-grain quartz and sandstone fragments, covered by green shales and yellowish limestones, interstratified with thin strata of grey marls with brachiopods and fossil fragments.

To the southeast of the La Nariz Mountains, near the base it is made from alternating layers of argillaceous limestones and towards the top, from calcareous shales that are dark grey when the rock is fresh and light grey when weathered.

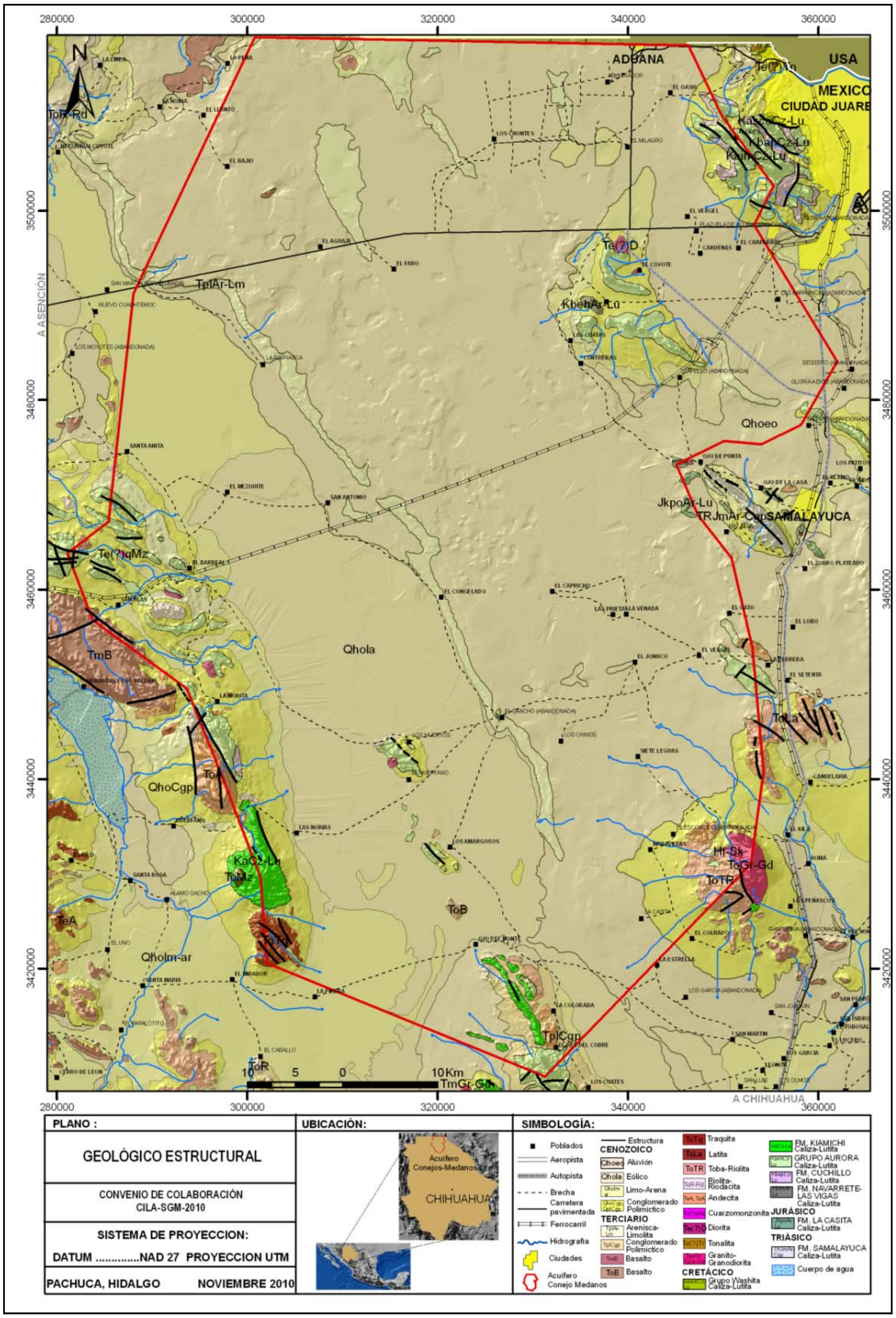


Figure 2.8. Geologic Map of the Conejos-Medanos Aquifer

In the Sierra Los Muertos Mountains, an evaporite sequence is found, made of thinly stratified gypsum with a saccharoidal texture that weatherizes the spongy white soils to a creamy yellow, with transparent to white gypsum crystals organized in small horizons with thin strata of argillaceous limestone. This unit surfaces to the southwest of the Presidio Mountains; it is comprised of a white and yellowish saccharoidal evaporite sequence, with massive structure and some intercalations of anhydritic argillaceous limestone transitioning to cream-colored clayish-sandy limestone in 10 cm layers with microfossil and dasycladacean algae limestones in 60 cm strata.

The Cuchillo Formation sediments suggest a deep-sea environment of relatively deep, still waters, with marine oscillations that created alternating calcareous and argillaceous layers. This formation has favorable conditions for containing gypsum strata, which are exploited to the east of the area in the Presidio and Porvenir mountains.

Aurora Group (Kaim Cz-Lu). Carbonate group in platform facies with argillaceous sequences, it is distributed in the Juarez, Presidio, La Candelaria, Los Muertos, La Nariz, and San Blas mountain ranges and the La Pedrera Ranch. In its basal layer, this group is comprised of brown limestones; in argillaceous parts, thick argillaceous strata from 20 cm to 2 m thick (Coyame Formation). In the middle section, it consists of brown, slightly argillaceous Orbitoline limestones in stratified layers with a thickness of 20 cm to 1.5 m (Benigno Formation). The middle section is also made of dark-grey to black argillaceous limestones, intercalated with black calcareous shales and occasional grey, fine-grain sandy horizons (Walnut Formation).
The thicknesses are variable since there are areas where not all of the units in this group emerge, considering that some thicknesses are greater than 980 m. The lithology represents a shallow to external neritic platform deposit environment with oxygenated water and terrigenous contributions.

Kiamachi Formation (Kams Cz-Lu). Rhythmic sequence of argillaceous-calcareous rocks in thin strata, whose distribution is concentrated to the north of the Juarez Mountains. Lithologically it is made of thin strata of calcareous shale at the base, which weatherizes to a yellow ochre color, with interstratifications of fine-grain sandstone and grey, nodular limestone with yellow ochre shale horizons. The upper portion of this formation consists of alternating layers of light, olive-grey shale with calcareous-clayey lutites in thin strata, sporadic horizons of nodular limestone and thin strata of sandstone with iron oxides. These sediments represent a change in facies to a coastal environment made of clastic or deltaic-type sediment. (Córdoba *et al*, 1971).

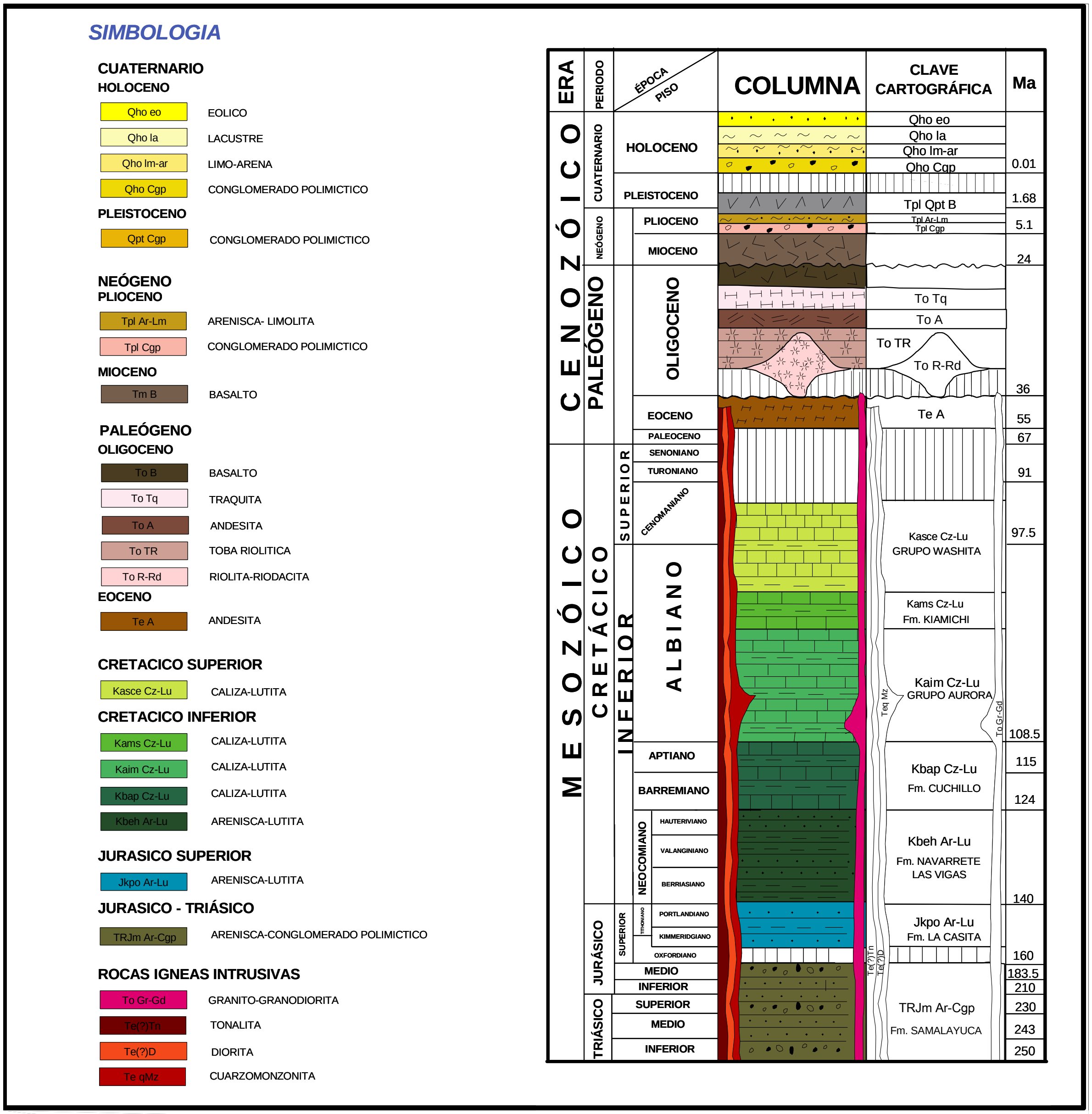


Figure 2.9. Stratigraphic Column

Washita Group (Kasce Cz-Lu). Made of Loma de Plata, Del Rio and Buda formations. It is an argillaceous, calcareous sequence with thin, occasionally folded strata that are intensely weathered. It is only found towards the northeast of the Juarez Mountains. In its basal layer, it is comprised of light-yellow, marly shales, with fossiliferous limestone strata and dark reddish-brown shales towards the middle. The upper portion of this group lithologically consists of alternating layers of yellowish shale and nodular limestone in thin strata, and dense to massive, fossiliferous, bluish-grey limestone.

It has lithological variations and the presence of shallow platform facies in the basal layer, which transition to argillaceous and sandy facies; this would suggest that it originated in an internal neritic zone to shallow subcoastal environment. At these latitudes, this instability is possibly associated with the initial movements in the Laramide Orogeny, which formed isolated local depocenters, causing changes in the sedimentological regime. (PEMEX 1982)

Paleogene-Eocene

Andesite (Te A). This unit of andesites is defined as greenish-grey color, weathers to reddish tones, and has aphanitic and sometimes porphyritic texture. It is distributed in the southern part of the aquifer, specifically on the northern side of the Sierra El Chilicote. Its calculated thickness is 150 meters. It discordantly covers Cenomanian limestones and shales (Kasce Cz-Lu). It has an effusive igneous origin related to fissures.

Quartz Monzonite (Te qMz). Also called intrusive Bismark, white in color with porphyritic texture, it contains ± 2-5 mm anhedral quartz phenocrysts, euhedral orthoclase, plagioclase, biotite, iron and manganese oxides. It is intruding into the sedimentary sequence of the lower Aurora Group unit (Benigno Formation). Within the aquifer, it only emerges in a small window in the central western sector, to the west of the Laguna El Barreal.

Diorite (Te? D). It is defined as a rock of intrusive igneous origin and porphyritic texture, ranging from light to dark grey. It is found to the south and southwest of Estación Barreal, with a length of 1.5 km, and to the southwest of the Juarez Mountains with a length of 1.8 km. It also surfaces in the central southwest portion of the Los Muertos Mountains and in the northeast flank of the Samalayuca Mountains. It consists of a greenish-grey to dark grey rock, phaneritic, porphyritic texture with medium-sized grains, microcrystalline matrix, and albite, biotite and amphibole crystals. It intrudes into the Aurora Group (Kaim Cz-Lu) rocks in the El Barreal area, and in the area of Samalayuca, it affects rocks in the La Casita Formation (Jkpo Ar-Lu).

Tonalite (Te? Tn) Its outcroppings are located north and south of the Sierra de Juarez mountains. This is a light grey rock with green and rusty brown tones, porphyritic, holocrystalline texture, where plagioclase, hornblende and biotite crystals can be found in a fine-grain, grey-color holocrystalline matrix. It has a porphyritic texture with microcrystalline matrix.

Oligocene

Rhyolite-Rhyodacite (To R-Rd). Unit defined by rhyolitic and rhyodacite emplacements, with highly variable textures and structures, anywhere from porphyritic to fluid. It is distributed to the southeast of the San Blas Mountains. Lithologically it consists of a light pink, slightly reddish-color rock, with aphanitic to microcrystalline texture, where some isolated biotite and feldspar crystals are visible.

This unit is covered by Andesites (To A), while its lower contact is not well defined. Its origin is associated with volcanic processes resulting from the faults associated with the distensive process between Sierras and the Basin.

Rhyolitic Tuff (To TR). Unit of rocks defined as the assemblage of rhyolitic tuffs, rhyolitic vitric-crystal tuffs, and crystalline tuffs. It is distributed toward the northeast flank of the Samalayuca Mountains, in the La Nariz Mountains, to the southwest of La Candelaria and north of the Las Conchas Mountains. Lithologically, it is a cream-colored, brown and reddish-brown rock of compact structure, whose primary components, such as orthoclase, quartz, biotite, magnetite-apatite and volcanic glass, form part of the matrix with intermediate lithic fragments dispersed among the rock.

Andesite (To A). Intermediate igneous unit formed by lava flows. It is distributed to the southwest of the La Nariz Mountains, and north and northwest of the La Candelaria Mountains. Dark grey to reddish brown in color, with some yellow tones. It has an aphanitic to porphyritic texture; occasionally it presents with a fluid, compact, massive structure. It is a grey to dark-grey colored rock, vesicular in some parts, petrographically classified as pyroxene andesite. Its thickness is estimated at 300 m. It discordantly overlays rhyolitic tuffs and rests on Oligocene trachytic and latitic rocks. Based on its stratigraphic position, it was dated to the Oligocene age. This unit is the result of igneous activity in the region, related to the distension phase.

Trachytes (To Tq). Rocks of extrusive igneous origin, fractured by pseudostratification. Outcrops to the southeast of the aquifer, south of the Los Chinos Mountains. This unit presents a reddish to light brown color, medium- to large-grained phaneritic texture with feldspar and mica phenocrysts, such as phlogopite and biotite, supported by an aphanitic matrix. It overlays Oligocene andesites and latites, and sits under Oligocene basalts. Based on its stratigraphic relationship and field observations, it was dated to the Oligocene age. Its thickness in other areas varies between 350 m and 1000 m. They are rocks in a continental deposit environment, emplaced as a result of a subduction zone.

Basalt (To B). Large flow rock formed by fissural extrusion. Outcrops to the north of the Sierra Los Amargosos mountains. Dark grey to brown color with aphanitic texture, where sporadic plagioclase crystals can be seen. It has been seen in other locations outside this area with a thickness of over 400 m. It discordantly covers the Oligocene trachytes (To Tq) and is discordantly covered by Miocene basalts.

Granite-Granodiorite (To Gr-Gd). Intrusive igneous rock; light grey in color when fresh and light brown when weathered; phaneritic texture, compact and massive. It is distributed towards the southeast side of the aquifer in the La Candelaria Mountains and southeast of the El Chilicote Mountains. It mostly intrudes into the Aurora Group (Kaim Cz-Lu) limestones, creating a metamorphic contact aureole and hydrothermal solution processes.

Neogene-Miocene

Basalt (Tm B). Mafic igneous volcanic rock, generally forms large flows through fissural extrusion. There are outcroppings of this basalt to the north of Cerro de San Blas peak. Basaltic unit mineralogically formed by labrodorite with accessory minerals like olivine and augite, united by a matrix of sodic plagioclase; the rock appearance is massive, dark-grey to black in color, with occasional reddish tints. It has sporadic intercalations of volcanic scoria horizons. Upon weathering, it develops spheroid forms. Its thickness varies from 20 to 160 m. It was created in a continental environment where fissures associated with the distension phase produced a mobilization of igneous material, which reached the surface and was deposited on the existing paleotopography.

Pliocene

Polymictic Conglomerate (Tpl Cgp). It is distributed in the southern part of the aquifer, around the Sierra El Chilicote. It consists of light grey to grey conglomeratic deposits, primarily made from fragments of extrusive igneous rocks (andesites, rhyolitic tuffs) and to a lesser extent reddish-brown limestones. The fragments vary from angular to rounded, poorly classified, with a clayish-sandy matrix. The upper part is poorly cemented, and the middle and lower portions are more compact.

It approximate thickness goes from a few meters up to 200 m in the lower areas. Based on its stratigraphic position, it was dated to the Pliocene age in a continental context of rifts, basins and paleochannels.

Sandstone-silt (Tpl Ar-lm). Unit comprised of semi-consolidated to consolidated sandstone and siltstone with lacustrine limestone horizons. It is found from the south-central sector up through the north of the area, forming continuous strips and low-elevation scarps, as well as showing up in isolated plateaus. This unit is formed by three lithologically differentiated members: the lower member consists of brown silts, overlaid by brown calcareous sandstones that are then covered by lacustrine limestones. The sandstone has thin horizontal stratification and crossbedding. The lower contact cannot be seen, and it sits under basalts from the Pliocene-Pleistocene age in El Volcan Peak towards the north of the study area, thus it has been classified as Pliocene age. Its origin is lacustrine. (Reeves Jr 1965)

Basalt (Tpl Qpt B) Dark-colored, extrusive igneous rock with aphanitic texture. Outcroppings of this unit can be found on the northwest edge of the area. It is characterized as being a group of cinder cones with repeated alternating layers of effusive activity, continuing north into the United States. This unit it formed by basaltic flows, with intercalations of reddish sandy tuffaceous material in pyroclastic breccias, containing abundant volcanic bombs up to one meter in diameter. Its thickness is estimated at between 30 and 60 m. It covers Pliocene sandstones and siltstones, sitting under Quaternary alluvial and conglomeratic deposits. In 1981, Hawley did a K/Ar radiometry study of three basalt samples from the Palomas volcanic field in the U.S., producing ages of 2.9 to 5.17 ± 0.11 m.y., which places it in the

Pliocene. This unit appears impacted by magmatic differentiation, and based on this, it has been determined that these rocks were transported from the mantle in a short period of time, on the Rio Grande Rift. (Hoffer M. Jerry 1981)

Quaternary

Polymictic Conglomerate (Qho Cgp). Defined as a conglomeratic unit made from igneous and sedimentary rocks. It is widely distributed throughout the topographically low parts, with outcroppings in the low parts of the Samalayuca, Juarez, and Presidio mountains. It is made from fragments of limestones, rhyolites, sandstones, shales and basalts. It is characterized by the appearance of angular and subrounded fragments, which show little transport, poor classification and are united by a sandy silt matrix; the fragments also are not consolidated and have little calcareous cement. At the base, small clasts predominate, from a few to 5 cm; they contain 10 cm sandy horizons with crossbedding. It thickness varies from a few meters up to 35 m on average. It can be found overlying different units. The environment is continental deposits, in some cases as fill in paleochannels or small basins that facilitated deposition.

Silt-sand (Qho lm-ar). These are sedimentary deposits comprised mainly of silts; there are also sands and clays. It is widely distributed over the area. Its thickness, varying from 0.1 to 2 m, discordantly overlaying conglomerates from the Holocene-Pleistocene. It corresponds to the Holocene Age.

Lacustrine (Qho la). Sediments deposited in lakes that have dried up because of evaporation; they are not compacted, nor cemented. They are distributed throughout the central portion of the Laguna El Barreal and to a lesser extent to the south and the west of Sierra Sapelló. They are comprised of fine sands, silts and clays. In some locations, the sands from fragments of lithium, quartz and feldspar have thin layers of carbonates; they have thicknesses that range from 0.5 to 3 m.

This correlates with alluvial plains. Based on its stratigraphic position, it was dated to the Holocene age. Sodium and potassium salts are also present, found in the Laguna El Barreal. Their origin is possibly the result of a series of crumbling and chemical decomposition processes of dolomitic limestones from the Sierra Los Muertos, as well as the oxidation of sulfides in the rocks' strata and fractures, not to mention the weathering of calcareous rocks. During these processes, most of the minerals are transported by surface waters to the basins, where they form brackish water deposits. Evaporation acts quickly in the basins because of the region's hot, arid climate; it is produced by concentrations of soluble salts and there is an oversaturation of $NaSO_4$, it precipitates and forms bodies of crystallized thenardite. (C.R.M. 1990)

Eolian (Qho eo). These deposits are mainly represented by the Samalayuca Dunes, and isolated areas with sands in this region. The unit is comprised of fine-grain, yellow-ochre and light-grey sediments, carried by wind action to form dunes. They are primarily found in the Samalayuca area, and in isolated spots forming smaller-size promontories. The thickest outcroppings are found in the town of Samalayuca, varying from 1 to 15 m. They are made out of sediments of fine-grain sands, silts, and clays with a grain size that corresponds to the size of the sand and their clasts are well-rounded and homogenous. The main components are silts and sands, generated by the disintegration of pre-existing rocks.

Structural Geology

The Conejos Medanos aquifer area is a rift surrounded by horsts, together with the strong presence of folds and intrusive bodies of varied composition. The largest structure is a big rift valley partially filled with bolson deposits known as El Barreal Rift. It is located towards the west side of the aquifer, following a northwest-southeast orientation, forming a large depression that is bounded by two main parallel lineaments. To this rift's west is the parallel block of mountains and to the east, its steps, which extend north into the United States and are characterized by a flat topography with little variation in slope and no appreciable hydrography, forming an endorheic basin.

In the eastern part of the El Barreal Rift, steps decrease as they move towards the center, forming a large depression, oriented northwest-southeast, consisting mainly of clastic sediment deposits that are in turn covered by eolic soil deposits. In contrast to the rift, there are high topographic elevations considered to be horsts, where the Juarez, Sapelló, Samalayuca, Los Muertos, Los Amargosos, La Candelaria, Las Conchas, La Pedrera, El Sancho, El Presidio, San Blas, La Nariz, China and El Chilicote Mountains stand out because of their significant height compared to the average ground level. Other structures include anticlines and synclines, with preferential northwest-southeast headings; the most notable are Presidio, Juarez and San Blas mountains.

A series of volcanic structures are observed, mainly fissural and occasionally with the presence of volcanic systems grouped into fields, where those with intermediate to mafic composition (andesites and basalts) predominate, with horizons of tuffs and hypabyssal bodies of felsic (rhyolitic-rhyodacitic) composition. Among these, a portion of the Sierra La Nariz is noteworthy, with a NW-SE orientation. There is also the El Venado curved lineament, which is located to the east of the Palomas volcanic field, consisting of several curved lineaments right next to one another, made from hypabyssal intrusive igneous rocks.

There are other mountains, less topographically pronounced than the previous set, where structures with a northwest-southeast orientation also prevail. These correspond to anticline and syncline folds that are sometimes truncated. The Samalayuca, Los Muertos and Las Conchas Mountains fall into this category.

One of the primary lineaments is called El Picacho. It is located towards the northern side of the study area, with a west-east orientation, extending longitudinally for approximately 130 km. It is associated with a deep structure, from which several hypabyssal rhyolitic intrusive bodies have originated such as those in Venado and the Palomas volcanic field, where basaltic bodies from the Pliocene-Pleistocene predominate.

The following describes the types of deformation that predominate in the study region:

Ductile Deformation. Found in the Samalayuca Mountains, where there is a sandstone sequence and then poorly classified conglomeratic sandstones belonging to the Samalayuca Formation, which present a moderate to high degree of dynamic deformation. It has a preferential northwest heading of 25 to 30°. This type of deformation is oriented along parallel strips where greater degrees of deformation occur. In some of them, there are fractures filled with light grey quartz segregation, with traces of secondary minerals such as copper, chrysocolla and malachite. These have a northwest-southwest orientation with inclination towards the southeast.

Brittle-Ductile Deformation. Folded structures, reverse and intraformational faults are among this type of deformation, caused by compression. In this case, the weak to moderate dynamic deformation was caused by the Laramide Orogeny, producing the following structures:

Anticlines. In this area, these structures surface with lengths greater than 4 km, where the average length is 15 km and width is 3 km, with northwest 43º southeast orientation, and dip towards the southwest and occasionally towards the northeast. They mostly appear asymmetrically, although there are also some symmetrical and recumbent ones. The rocks where these structures formed are the Cuchillo Formation (Kbap Cz-Lu) and the Aurora Group (Kaim Cz-Lu). The following list describes the most important ones:

Samalayuca Anticline. Located in the mountain range with the same name, south-southwest of Cd. Juarez, it is 13.5 km long, 2.5 km wide with a northwest 45º southeast heading. It is made of sandy clastic rocks and conglomeratic sandstones from the Samalayuca Formation. The anticline is symmetrical, inverted and affected by reverse and wrench faults.

Los Amargosos Anticline. Located in the south-central area of the map, to the southeast of the Sierra Los Muertos mountain range, it is 2.5 km long, 1.5 km wide, with a northwest 40º southeast heading. It has an asymmetrical shape with axis inclined towards the northeast, and is made of rocks from the Aurora Group (Kaim Cz-Lu).

San Blas Anticline. Located in the western sector, to the southeast of the mountain range with the same name, it is 2 km long, 1 km wide and has a symmetrical shape on a northwest 50º southeast heading, comprised of rocks from the Aurora Group (Kaim Cz-Lu).

Synclines. These structures are less common than the anticlines, shorter, with lengths less than 10 km on average, and narrower, with widths less than 2 km. Their predominant orientation is northwest 40º southeast; their shape is generally asymmetrical. The rocks that make up these structures are Cuchillo Formation (Kbap Cz-Lu). Below is a list of the most important ones:

Presidio Syncline. Located in the eastern sector, to the east of the mountain range with the same name, it is 12 km long, 1.5 km wide and has a symmetrical shape on a general northwest 40º southeast heading, with a northeast inclination. It affects the Navarrete-Las Vigas and Cuchillo Formations and the Aurora Group (Kaim Cz-Lu).

Juarez Syncline. Located in the northeast portion of the mountain range with the same name, it is 9 km long and 1.5 km wide with a northwest 40º southeast heading, symmetrical shape and secondary intraformational folds. It affects carbonate rocks in the Aurora Group (Kaim Cz-Lu).

La Pedrera Syncline. Located on the east side of the area, south of the Samalayuca Mountains, it is 5 km long, 3 km wide and has a symmetrical shape, affecting rocks from the Aurora Group (Kaim Cz-Lu).

Thrust and/or Reverse Faults. For this type of structure, some of them have an average length of 7 km, average displacement of 830 m, general orientation of northwest 40º southeast, [and] general dip of 50º to the southwest. There is a smaller area located in the northern Juarez Mountains that is the North Juarez Thrust, located northeast of the mountain range of the same name, with a length of 3 km, northwest 75º southeast heading, and inclination to the southwest of 40º.

Brittle Deformation.

Faults. Normal Faulting. The longer ones are not notable because of their slight or non-existent expression, since the vast majority of them are buried. Some of them are found at the edges of the volcanic and intrusive systems and blocks. The average throw ranges from 50 to 250 m, with a northwest 30º southeast heading and a dip of 77º to the northeast and southwest. With these faults, the longest ones run somewhat parallel to each other, forming the rifts and horsts.

There are shorter, less-visible faults that correspond to a type of wrench faults with mostly sinistral, vertical displacement on a northeast-southwest heading, which divide the northwest-southeast blocks. In addition, there is another type of minor deformation, also lateral, on a north-south heading.

The following is a list of the faults that are of greatest interest:

La Nariz East Fault. Located in the southwest sector, on the east side of the mountain range with the same name. It has a known length of 9 km and a NW 30º SE orientation with inclination of 75º to the SW. It brings Aurora Group (Kaim Cz-Lu) rocks into structural contact with rhyolites (To R-Rd) and andesites (To A). Its throw is estimated at less than 50 m.

La Nariz West Fault. Located very close to the previous fault in the mountain range with the same name. Its known length is 7 km and it has a northwest 10º southeast orientation, with an 80º inclination towards the southwest. It affects Oligocene volcanic rocks, Andesites (To A) and Rhyolitic Tuffs (To TR).

Zapata Fault. Located on the northeast of the Sierra Juarez, in the far northeast of the study area. It is 4.5 long with an orientation that varies from northeast 25º southwest to north-south and an inclination to the southeast and south of 60º to 65º. It affects Lower Cretaceous rocks, emerging in the upper block of rocks in the Cuchillo Formation (Kbap Cz-Lu) and the Aurora Group (Kaim Cz-Lu) block of rocks. It is thought that this fault has an approximate throw of 250 m.

El Nopal Fault. Located in the southwest sector, southwest of the Las Norias ranch. 4.5 km long, with a northwest 35º southeast orientation and inclination of 60º to the northeast, it affects rocks in the Aurora Group (Kaim Cz-Lu). Brecciation is observed on the southeast side.
Figure 2.10 shows the main structural features in the region.

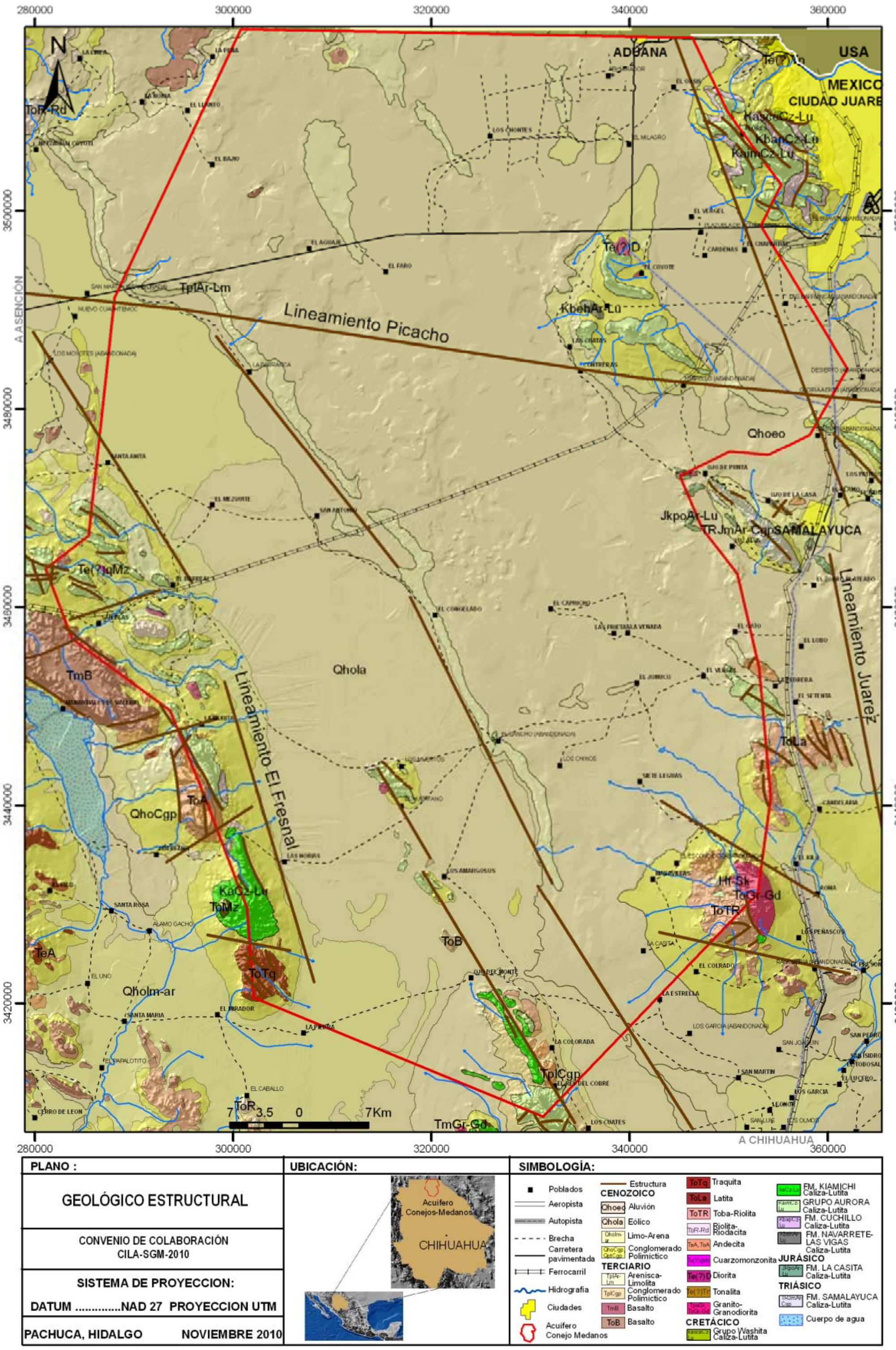


Figure 2.10. Main structural features in the region.

3 SUBSURFACE HYDROLOGY

3.1 Survey of Wells

In order to comply with one of the main study objectives, a survey of hydraulic capture sites was performed during the months of June and July 2010. During this process each site was assigned a consecutively numbered code, which in most cases matched the code assigned during the survey conducted by the Mexican Geological Service in 2007.

A total of 157 wells were surveyed, hence an equal number of survey forms can be found in Volume II of this report, which provide the coordinates for each well (taken with a handheld GPS, using the NAD 27 datum), town, water title holder's name, coordinates, ownership, well type, use, operation and construction data, hydrometry, data for the water physical parameters (pH, temperature, salinity, total dissolved solids and electrical conductivity), static level, rim elevation and dynamic level (if it is one of the ones in operation). Table 3.3 shows the primary characteristics of the surveyed wells.

Of the 157 surveyed wells, the distribution of which can be seen in Figure 3.1, 144 are wells, nine are chain pumps, three are springs, and one is a permanent weir that is apparently fed by a series of springs located under the surface or in the surrounding area.

With regard to the water usage for these different well types (Figure 3.2): five of the nine chain pumps are used for livestock and the remaining four are inactive. One of the springs is used for livestock, while the other two are not in use, meaning that the water infiltrates and/or evaporates without being utilized. Of the 144 surveyed wells, 90 are active; 26 are used to extract potable water (23 belonging to the Conejos Medanos Aquifer wellfield), 54 are used for livestock, four for livestock/domestic use, one for livestock/utilities, one for livestock/agriculture, one exclusively for agriculture and three for utilities. It is worth mentioning that out of the 54 inactive wells, 24 are used to monitor the static levels of the aquifer. The type of ownership of the wells varies from private to municipal or state government, and to a lesser extent there are some that belong to agricultural cooperatives ("*ejidos*"). Most of the active wells use vertical or submergible-type pumps, which operate using electric motors. Another type of pump that is used in this aquifer is a reciprocating pump, activated by eolic energy (windmills) or internal combustion motors (primarily pumpjacks). Other less common, low-capacity pumps are centrifuge-type pumps.

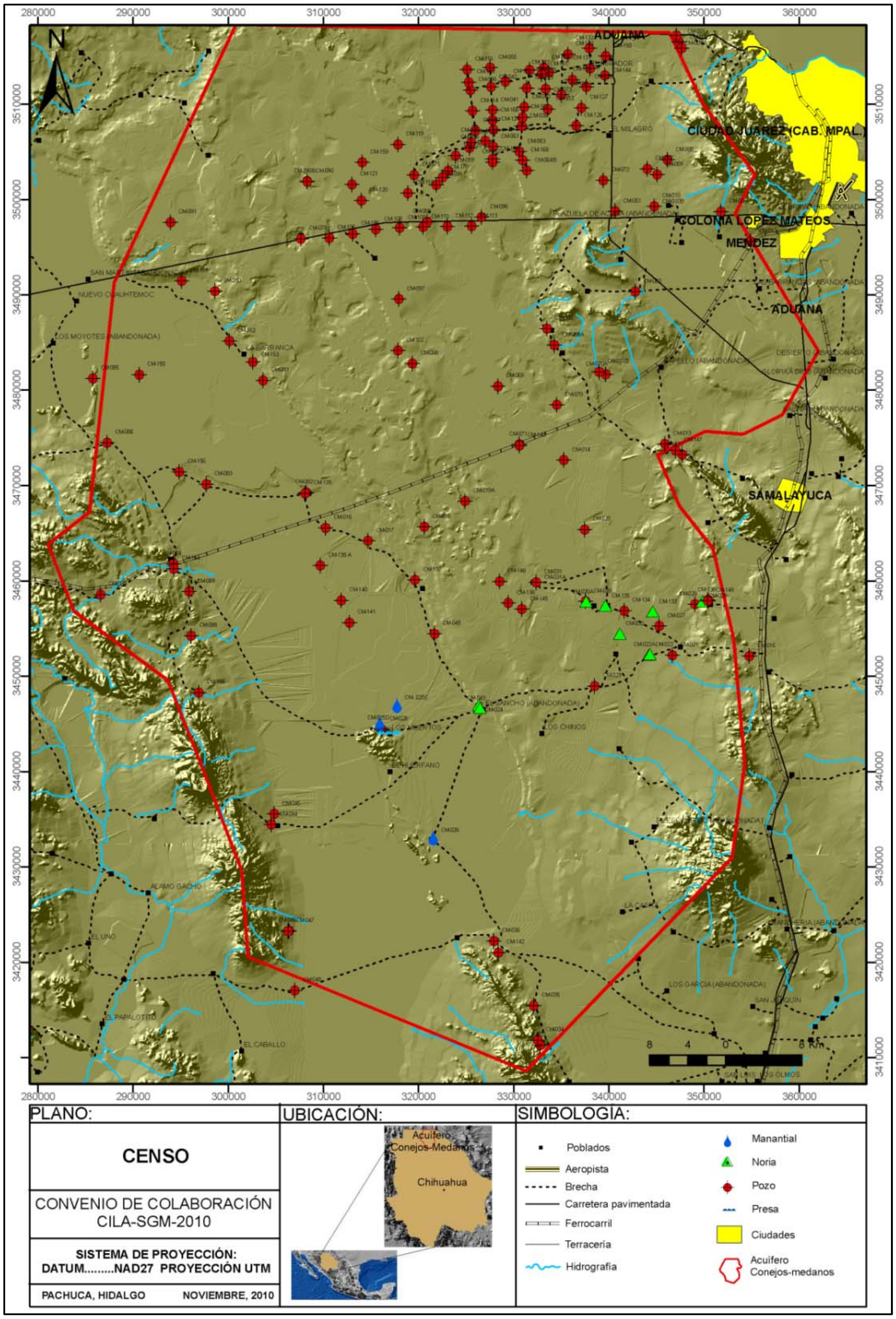


Figure 3.1. Location of the Surveyed Wells.

As for the well usage percentages, according to Figure 3.2, 40.6 % of the wells are used for livestock, followed by inactive wells representing 21.2%, then piezometric monitoring wells with 17%, and 15.8% for public urban use. The remaining 5.4% is divided up into miscellaneous uses.

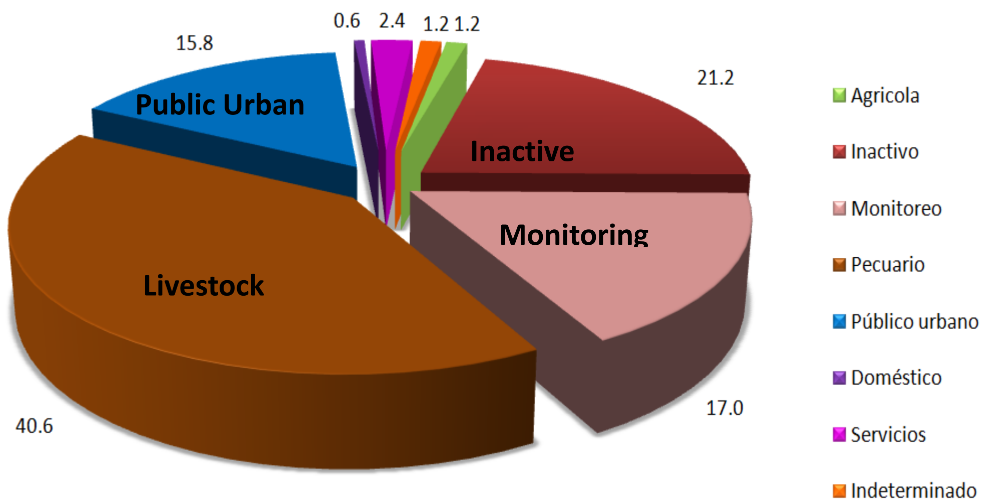


Figure 3.2. Use Percentages for Wells Surveyed in the Conejos Medanos Aquifer

The most commonly used motors on the pumps are internal combustion, eolic, mechanic and electric; the electric motors vary in power from 2 through 75, 100, 125 and 150 HP. In some cases, the users have chosen more than one type of motor due to the regional conditions and the long distances to transport fuel or power lines, so some of the wells use solar panels to generate electricity.

With regard to well construction, most of them are encased with 8" and 14" pipes, although 6", 10", 12" 16" and 18" diameter pipes can also be found. The outlet and suction lines vary depending on use and motor type, and vary from 1 to 8".

During the 2007 Survey of Wells by SGM, 132 wells were surveyed, 126 of which were wells and 6 were chain pumps. Table 3.1 compares the active vs. inactive wells for the two surveys. There are slight variations between the 2007 and 2010 surveys, mainly due to the issue of security for the operations personnel. Some wells surveyed in 2010 were not included in 2007, and likewise, some of the wells surveyed in 2007 were not updated. In both cases, the numbers are very small and they do not affect the development of the study, given that data is available for at least 95% of the existing wells in the aquifer.

Table 3.1. Comparison between the 2007 and 2010 Surveys.

Year / Well	2007		2010			
	Well	Chain Pump	Well	Chain Pump	Springs	Weir
Active	58	6	90	5	3	1
Inactive	68	0	54	4	0	0
Total	126	6	144	9	3	1

Table 3.2 shows the primary variations in well usage between the 2007 and 2010 surveys. The increase in public urban use, from 2% in 2007 to 15.8% in 2010 is notable; meanwhile, the percentage of inactive wells decreased from 44% in 2007 to 17% in 2010. It also shows an increase in wells used to monitor the aquifer, from 12% to 17 % during the same period.

Table 3.2. Comparison between the 2007 and 2010 Well Usage.

Year / Well	2007	2010
Livestock	36%	40.6%
Public Urban	2%	15.8%
Inactive	44%	21.2%
Monitoring	12%	17%
Other/Misc.	6%	5.4

Table 3.3 below shows the significant data for the hydraulic wells surveyed in this study. Table 3.4 also shows a number of other wells surveyed in 2007, which due to several factors, mostly security, could not be updated during this study.

Table 3.3. Data from the Surveyed Wells.

CLAVE SGM	OTRA CLAVE	LOCALIDAD	PROPIETARIO	TIPO	USO	OPERACION	X UTM NAD27	Y UTM NAD27	Z CARTA	ENE	PNE	EXTRACCION M3	OBSERVACIONES
CM-001	3 Anapra			Pozo	Público urbano	Municipal	347399	3516542	1,273			352,512	Pozo funcionando al momento del censo
CM-001B	2 Anapra			Pozo	Público urbano	Municipal	347130	3517209	1,271			345,600	Pozo funcionando al momento del censo
CM-002			JCAS	Pozo	Público urbano		347668	3515888	1,274			808,704	Pozo funcionando al momento del censo
CM-003				Pozo	Servicios	Privado	342798	3490331	1,252			93,312	nadie proporciona datos, no se pude sondear. Muestra de agua tomada de línea (motor apagado)
CM-006		Corral El Quemado	Arturo García	Pozo	Pecuario	Privado	351797	3498719	1,299	1166.33	132.67	13,140	Corrales ganaderos.
CM-007				Pozo	Inactivo	Privado	344053	3503225	1,260	1170.28	89.72	0	No se puede muestrear
CM-008		Las Avestruces		Pozo	Pecuario/Servicios		346166	3504154	1,278			7,200	Criadero de avestruces. Se atora la sonda
CM-009				Pozo	Inactivo	Privado	345073	3502598	1,265	1176.69	88.31	0	No se puede muestrear
CM-010		El Vergelito	Rafael Prieto	Pozo	Inactivo	Privado	344787	3499295	1,260			0	
CM-010B		El Vergelito	Rafael Prieto	Pozo	Pecuario	Privado	344780	3499281	1,261	1261.00		864	No tiene planta para tomar muestra (Cargan la planta cada 15 dias)
CM-012		Pemex Estación Méndez	Pemex	Pozo	Servicios	Privado	354918	3495598	1,285			4,896	Pozo totalmente sellado, no se puede sondear. Profundidad total 138 m
CM-013		Valle de San Jerónimo	Enrique Pastrana	Pozo	Inactivo	Privado	345912	3474355	1,220	1170.32	49.68	0	No se pude tomar muestra.Inactivo al momento del censo.
CM-014		Rancho El Capricho	Luis Varela	Pozo	Pecuario	Privado	335296	3472643	1,230			15,768	Según propietario el nivel estático se encuentra a 120 pies
CM-015		La Piedra		Pozo	Pecuario	Privado	354754	3452069	1,300	1256.87	43.13	7,884	derrumbado a 50 m existeun pozo nuevo, de este se tomaron datos, coordenadas estan defasadas 50m
CM-016		El Zorrito	Valentin Fuentes	Pozo	Pecuario	Privado	310237	3465545	1,185	1178.97	6.03	3,154	
CM-017		El Titin	Valentin Fuentes	Pozo	Pecuario	Privado	314691	3464185	1,195			3,154	
CM-018		El Arenoso	Valentin Fuentes	Pozo	Pecuario	Privado	320627	3465652	1,215	1180.54	34.46	3,154	Tanque circular. Se tomo agua de pila para medir parámetros
CM-019A		El Pilón	Valentín Fuentes	Pozo	Pecuario	Privado	324887	3468353	1,195	1161.10	33.90	3,154	Pila 16x5x1.6m. Se tomo agua de pila para medir los parámetros
CM-020		El Milagro	Valentín Fuentes	Pozo	Pecuario	Privado	337481	3465369	1,220	1190.33	29.67	3,154	Aprox se bombean 22m3 cada terecer día para llenar pila. Se tomo agua de pila para medir los parámetros
CM-021				Pozo	Pecuario	Privado	346689	3452169	1,228	1211.93	16.07	10,407	
CM-022				Noria	Pecuario	Privado	344235	3452278	1,213	1199.08	13.92	10,407	
CM-022A				Noria	Inactivo	Privado	344293	3452286	1,215			0	
CM-023				Pozo	Pecuario	Privado	338536	3448942	1,215	1202.29	12.71	10,407	Se puede tomas muestra cuando hay viento
CM-024		El Sancho	Rene Fuentes	Noria	Pecuario	Privado	326339	3446936	1,205	1205.00		21,024	
CM-025		Sierra Los Muertos		Pozo	Inactivo	Privado	316137	3444406	1,198	1194.30	3.70	0	
CM-025B		Sierra Los Muertos		Manantial	Pecuario		315904	3445061	1,178	1178.00		9,461	Forma un suave montículo con vegetación sobre el plano del barreal; depósitos salinos
CM-025C		Sierra Los Muertos		Manantial			317748	3446927	1,175	1175.00		9,461	Se tomo muestra de sedimentos, no se observa depósitos evaporados
CM-025D		Sierra Los Muertos		Preson			316891	3444088	1,196			0	color amarillento, turbia
CM-026		Los Amargosos	Lauro Ortega	Manantial		Privado	321523	3433023	1,180	1180.00		15,768	varias surgencias en 70m2 aprox. Olor azufroso, corroe tubería de acero, deja depósitos salinos e incrustaciones
		Rancho El											
CM-028			Poncho Gil	Pozo	Pecuario	Privado	349067	3457517	1,280	1264.38	15.62	10,407	Muestra tomada del agua de la pila
CM-029		Rancho Nuevo	Poncho Gil	Noria	Pecuario	Privado	349847	3457827	1,285			10,407	No se tomó muestra porque no habia viento
CM-030		Rancho Las Prietas		Pozo	Pecuario	Privado	337580	3457830	1,215	1195.38	19.62	4,320	
CM-030A		Rancho Las Prietas		Noria	Pecuario	Privado	337616	3457823	1,219	1200.39	18.61	10,407	
CM-031		Rancho Los Valentines		Pozo	Pecuario	Privado	332392	3459833	1,210	1191.49	18.51	63,072	
CM-031A		Rancho Los Valentines		Pozo	Pecuario	Privado	332372	3459824	1,212	1212.00		10,407	
CM-032				Noria	Inactivo	Privado	341141	3454473	1,220	1206.12	13.88	10,722	Estaba equipado pero se encuentra fuera de uso
CM-033		Rey del Cobre	William Scott Ortega	Pozo	Pecuario	Privado	332821	3411260	1,240	1240.00		1,166	1 hr de haberse apagado, se abate. Se recupera en 4 horas , por lo que no fue posible medir parámetros
CM-034		Rey del Cobre	Salvador Ávalos S.	Pozo	Pecuario	Privado	332554	3411762	1,228	1201.42	26.58	329	Profundidad del pozo 6 tubos de 21 pies. Funciona media hora y se abate
CM-035		La Colorada	Marcos Ávalos S.	Pozo	Pecuario	Privado	332133	3415404	1,208	1208.00		3,285	
CM-036				Pozo	Inactivo		327940	3422183	1,180	1179.01	0.99	0	
CM-038	Pozo 18	Bateria de pozos	JMAS	Pozo	Público urbano	Estatal	330852	3507701	1,255	1155.82	98.81	473,040	N.E 94.1 según sensor de telemetría
CM-039	Pozo 2	Bateria de pozos	JMAS	Pozo	Público urbano	Estatal	331673	3513570	1,248			583,416	Se atora la sonda. Según sensor de telemetria N.E 92.1 y N.D. 91.7 m, NE>ND, pero asi se tiene el registro
CM-040	Pozo 10	Bateria de pozos	JMAS	Pozo	Público urbano	Estatal	331116	3509688	1,255	1157.66	97.76	583,416	Pozo desequipado por reparación, al momento del censo
CM-041	Pozo 11	Bateria de pozos	JMAS	Pozo	Público urbano	Estatal	327785	3509377	1,256	1157.80	97.87	583,416	
CM-042	Pozo 12	Bateria de pozos	JMAS	Pozo	Público urbano	Estatal	327640	3511828	1,253	1143.07	109.62	473,040	Pozo prendido al momento del censo, N.D 110 m según sensor
CM-043		El Sancho	Rene Fuentes	Noria	Inactivo	Privado	326465	3446671	1,192	1186.12	5.88	0	
CM-044		La Noria	Eleazar Le Baron	Pozo	Pecuario	Privado	304557	3434408	1,192			2,628	No se puede sondear, se atora lasonda a los 8.45m.
CM-045		Santa Anita	Luis Octavio	Pozo	Pecuario	Privado	304864	3435524	1,189	1189.00		3,154	Pozo funcionando, no se tomó N.E. Funciona 3 horas y se abate, lo dejan que se recupere 1 hr
CM-046				Pozo	Pecuario	Privado	306401	3423265	1,230	1198.86	31.14	19,440	Se tomó agua de pila para la muestra
CM-047				Pozo	Inactivo	Privado	306333	3423228	1,233	1200.94	32.06	0	
CM-048				Pozo	Inactivo	Privado	307031	3416996	1,192			0	Pozo asolvado
CM-049		Agua Fresca	Rene Fuentes	Pozo	Inactivo	Privado	321695	3454420	1,181	1176.89	4.11	0	
CM-051		Agua Park	Ejido	Pozo	Servicios	Ejidal	340664	3498746	1,248	1158.29	89.71	10,541	Análisis de agua se tomó del depósito
CM-053	Pozo 9	Bateria de pozos	JCAS	Pozo	Público urbano	Estatal	333602	3509496	1,248	1152.47	95.96	583,416	Pozo apagado, pertenece a la bateria de pozos de conejos Médanos
CM-054	Pozo 1	Bateria de pozos	JMAS	Pozo	Público urbano	Estatal	333142	3513808	1,244	1151.20	92.80	630,720	Pozo funcionando al momento del censo, ND tomado según sensor
CM-055	Pozo 3	Bateria de pozos	JMAS	Pozo	Público urbano	Estatal	327560	3513839	1,258	1155.87	102.13	583,416	N.E 82.1 y N.D. 91.1 Según sensor de telemetría
CM-056	Pozo 5	Bateria de pozos	JMAS	Pozo	Público urbano	Estatal	325455	3511480	1,255	1154.19	100.81	583,416	Pozo apagado al momento del censo
CM-057	Pozo 6	Bateria de pozos	JMAS	Pozo	Público urbano	Estatal	326004	3507225	1,258	1166.13	91.87	709,560	
CM-058	Pozo 19	Bateria de pozos	JMAS	Pozo	Público urbano	Estatal	325381	3505429	1,255	1158.88	96.12	473,040	NE 91.40 y ND 109.9 Según sensor
CM-059	Pozo 21	Bateria de pozos	JMAS	Pozo	Público urbano	Estatal	323140	3503000	1,235	1158.02	76.98	1,166,832	N.E 71.1 Según sensor

CLAVE SGM	OTRA CLAVE	LOCALIDAD	PROPIETARIO	TIPO	USO	OPERACION	X UTM NAD27	Y UTM NAD27	Z CARTA	ENE	PNE	EXTRACCION M3	OBSERVACIONES
CM-061	Pozo 15	Bateria de pozos	JCAS	Pozo	Público urbano	Estatal	327844	3505539	1,253			583,416	No se puede sondear
CM-062	Pozo 22	Bateria de pozos	JMAS	Pozo	Público urbano	Estatal	327781	3503914	1,249	1160.95	88.05	583,416	Pertenece a la bateria de pozos de conejos Médanos
CM-063	Pozo 16	Bateria de pozos	JMAS	Pozo	Público urbano	Estatal	330610	3505025	1,254	1254.00		741,096	Según sensor ND 96.3 m
CM-064B	Pozo 23	Bateria de pozos	JMAS	Pozo	Público urbano	Estatal	331390	3503024	1,252			583,416	No se tomo parametros ya que no opera al momento del censo, debido a que se robaron equipo no se sondeo
CM-066		El Parabien		Pozo	Pecuario	Privado	320924	3497639	1,246	1180.53	65.47	2,628	
CM-068		Las Cuatas		Pozo	Inactivo	Privado	333514	3486425	1,230	1180.67	49.33	0	Rancho abandonado, pozo desequipado, probablemente habilitable
CM-068A		El Nogal		Pozo	Pecuario	Privado	334288	3484698	1,228	1228.00		3,888	Páneles solares, probablemente sin uso.
CM-069		Contreras	Reyes Zapien	Pozo	Pecuario/Doméstico	Privado	328358	3480409	1,222			2,365	Descarga en tanque cilindrico de 9 m de diámetro y 2m de altura
CM-070			Reyes Zapien	Pozo	Pecuario	Privado	334534	3478441	1,231	1197.49	33.51	1,577	Descarga en pileta de 10x6x2 m
CM-070A		La Laguna	Raúl Rentería	Pozo	Pecuario	Privado	339683	3481641	1,210	1176.50	33.50	10,512	inactivo, pero habilitable rápidamente. Por lo que se observa es de uso pecuario. No se puede muestrear
CM-070B		La Laguna	Raúl Rentería	Pozo	Pecuario/Doméstico	Privado	338993	3481922	1,217			19,710	Papalote y bomba sumergible, alimentada con una planta a combustible cuando no hay viento.
CM-071		Rancho el Traque	Valentin Fuentes	Pozo	Pecuario	Privado	330616	3474286	1,229	1189.78	39.22	10,407	Análisis de agua se tomo del agua de la pila
CM-072				Pozo	Pecuario	Privado	339408	3502021	1,245			4,608	Pozo sellado no se puede sondear. Se tomo agua de la pila para medir parámetros
CM-073	Pozo 14	Bateria de pozos	JCAS	Pozo	Público urbano	Estatal	333369	3511597	1,247	1153.07	94.11	777,600	Pozo apagado, pertenece a la bateria de pozos de conejos Médanos
CM-075		El Espejo		Pozo	Pecuario	Privado	319532	3502576	1,230			10,407	No habia quien proporcionara informes en el rancho, se atora la sonda
CM-078				Pozo	Inactivo	Privado	307667	3495876	1,198			0	Se encuentra abandonado y seco
CM-080		La Laguna		Pozo	Pecuario	Privado	298627	3490369	1,198	1198.00		12,960	Pozo funcionando al momento de censar
CM-081				Pozo	Pecuario		303685	3481018	1,190	1175.05	14.95	1,314	
CM-082		San Antonio	Francisco Corona	Pozo	Pecuario	Privado	308208	3469246	1,180	1180.00		1,314	
CM-083				Pozo	Pecuario	Privado	297733	3470129	1,182	1174.33	7.67	1,314	Por el momento no se observa ganado. No se pudo tomar muestra
CM-084		El Barreal	Ever Chávez	Pozo	Pecuario		294260	3461762	1,200	1179.62	20.38	1,314	No habia quien proporcionara informes en el rancho
CM-085		Nuevo Cuauhtemoc	Pedro Rascón	Pozo	Pecuario/Doméstico	Privado	285776	3481221	1,195	1182.22	12.78	39,168	
CM-086		Santa Anita	Antelmo Fonter	Pozo	Pecuario		287309	3474490	1,190	1181.60	8.40	12,960	Pozo donde se midió el nivel estático esta a 120 m al oeste
CM-087		San Blas	Jesus Terrazas	Pozo	Pecuario	Privado	286614	3458537	1,270			749	Celdas solares y se opera cerca de 12 hras por semana
CM-088		El Borrego	Ever Chávez	Pozo	Pecuario	Privado	296115	3454206	1,205	1178.47	26.53	1,314	
CM-089		El Barreal		Pozo	Pecuario	Privado	295895	3458865	1,203	1179.51	23.49	3,614	Muestra de agua tomada de pila
CM-090				Pozo	Inactivo		308327	3501903	1,250	1170.07	79.93	0	No se puede muestrear
CM-090B			JMAS	Pozo	Monitoreo	Municipal	308318	3501878	1,248	1168.16	79.84	0	Pozo monitoreo, no se puede muestrear
CM-091				Pozo	Inactivo		293944	3497616	1,240	1185.80	54.20	0	Rancho abandonado
CM-095	Pozo 26	Bateria de pozos	JMAS	Pozo	Público urbano	Estatal	321896	3501528	1,230	1230.00		632,034	Pozo prendido al momento del censo, N.D 102.1 m según sensor
CM-096	CNA 16 (4)			Pozo	Inactivo		326650	3498156	1,235			0	Rancho abandonado. Pozo asolvado
CM-097			JCAS	Pozo	Monitoreo	Municipal	317942	3489545	1,230			0	Pozo de monitoreo por la JCAS, pero se encuentra seco
CM-098				Pozo	Pecuario	Privado	319362	3482783	1,228	1179.71	48.29	10,407	Se puede tomar muestra cuando hay viento
CM-102				Pozo	Monitoreo		317869	3484150	1,224			0	
CM-105			JMAS	Pozo	Monitoreo	Municipal	310634	3495966	1,226	1171.72	54.53	0	Piezometría de monitoreo
CM-106	2		JMAS	Pozo	Monitoreo	Municipal	313122	3496390	1,237	1171.41	65.45	0	Se puede muestrear pozo con una botella angosta
CM-108			JMAS	Pozo	Monitoreo	Municipal	315542	3496850	1,231			0	Pozo de monitoreo, esta seco.
CM-109			JMAS	Pozo	Monitoreo	Municipal	318032	3497015	1,235	1170.55	64.93	0	Se puede muestrear con botella angosta
CM-110				Pozo	Monitoreo	Privado	320494	3497099	1,239	1176.43	62.57	0	Se encuentra sellado para muestreo, pero si se puede sondear.
CM-112			JMAS	Pozo	Monitoreo	Municipal	323057	3497172	1,226	1171.12	54.79	0	Pozo de la JMAS para monitoreo. Muestreo con botella muestreadora delagada
CM-113			JMAS	Pozo	Monitoreo	Municipal	325594	3497191	1,227	1168.48	58.82	0	Pozo de oservación para monitoreo. Puede muestrearse con botella angosta
CM-114	Pozo No 7	Bateria de pozos	JMAS	Pozo	Público urbano	Estatal	325700	3509306	1,255	1158.37	96.63	630,720	
CM-116	Pozo No 24	Bateria de pozos	JMAS	Pozo	Público urbano	Estatal	325140	3513637	1,252	1154.85	97.15	632,034	NE 64.9 m y ND 82.1 según sensor de telemetria
CM-118				Pozo	Monitoreo	Privado	318915	3500680	1,235	1166.31	68.69	0	No se puede muestrear
CM-119	JJ-2		JMAS	Pozo	Monitoreo	Municipal	317853	3505770	1,239	1172.53	66.47	0	No se puede muestrear, tiene marcasa de que recientemente fue nivelado
CM-120	JJ-5		JMAS	Pozo	Monitoreo	Municipal	314014	3499902	1,238			0	Pozo asolvado
CM-121				Pozo	Inactivo		313002	3501587	1,235	1170.60	64.40	0	Rancho abandonado
CM-122		Ojo de la Punta	Bruno Chávez	Pozo	Agrícola	Privado	347740	3473204	1,226	1215.37	10.63	777,600	Lo usan varias personas para riego
CM-123	Pozo 13	Bateria de pozos	JMAS	Pozo	Público Urbano	Estatal	331402	3511686	1,255			583,416	Batería de JCMAS; se atasca sonda
CM-124	Pozo 17	Bateria de pozos	JMAS	Pozo	Público urbano	Estatal	327870	3507340	1,255	1156.74	98.76	473,040	N.E 93.0 Según sensor
CM-125	Pozo 25	Bateria de pozos	JMAS	Pozo	Público urbano	Estatal	323924	3504610	1,251	1163.60	87.40	851,472	N.E 67.3 según Sensor
CM-126				Pozo	Inactivo	Privado	336574	3507736	1,246	1151.46	94.54	0	No se puede muestrear
CM-127				Pozo	Inactivo	Privado	337150	3509615	1,243	1150.06	92.94	0	No se puede muestrear
CM-128				Pozo	Inactivo	Privado	337664	3511809	1,249	1159.77	89.23	0	No se puede muestrear
CM-129				Pozo	Inactivo		336207	3512558	1,245	1152.38	92.62	0	Pozo, solo ademe
CM-130				Pozo	Inactivo	Privado	335690	3515237	1,241	1145.89	95.11	0	No se puede muestrear
CM-131				Pozo	Inactivo	Privado	338040	3513775	1,246	1153.31	92.69	0	No se puede muestrear
CM-132				Pozo	Inactivo	Privado	337945	3515866	1,244	1148.67	95.33	0	No se puede muestrear
CM-133		El Papalotito		Noria	Inactivo	Privado	344619	3456795	1,216	1200.57	15.43	0	Estaba equipado con eólico pero se encuentra fuera de uso. Se puede tomar muestra con cubeta
CM-134				Pozo	Pecuario	Privado	341621	3456856	1,226			11,038	Se puede tomar muestra cuando hay viento. Este pozo se construyó para sustituir el CM-133
CM-135		La Venada		Noria	Pecuario	Privado	339664	3457389	1,224	1208.05	15.95	10,407	Se puede tomar muestra cuando hay viento
CM-136		Rancho El Gato	Luis Borjas	Pozo	Pecuario	Privado	350452	3457958	1,286	1273.43	12.57	216	Puede hacerse una prueba de bombeo de 30 min a 1 hr
CM-137		El Congelado	Valentin Fuentes	Pozo	Pecuario	Privado	319654	3460078	1,185	1174.54	10.46	17,496	Hay ademe a 15 m donde fue tomado el N.E.
CM-138		Rancho El Salado	Valentin Fuentes	Pozo	Pecuario	Privado	329462	3457645	1,218	1191.43	26.57	10,800	Pozo recién construido
CM-138 A		Cuatro Vientos	Valentin Fuentes	Pozo	Pecuario	Privado	309683	3461576	1,175	1171.32	3.68	12,960	Se tomó agua de pila para medir parámetros
CM-139		San Antonio	Francisco Corona	Pozo	Inactivo	Privado	308110	3469174	1,177	1169.42	7.58	0	
CM-140		El Tavo	Valentin Fuentes	Pozo	Pecuario	Privado	311896	3457926	1,174	1158.13	15.87	6,912	El pozo tenia poco tiempo de haber sido apagado

CLAVE SGM	OTRA CLAVE	LOCALIDAD	PROPIETARIO	TIPO	USO	OPERACION	X UTM NAD27	Y UTM NAD27	Z CARTA	ENE	PNE	EXTRACCION M3	OBSERVACIONES
CM-140		El Tavo	Valentin Fuentes	Pozo	Pecuario	Privado	311896	3457926	1,174	1158.13	15.87	6,912	El pozo tenia poco tiempo de haber sido apagado
CM-141		El Corachi	Juan Castillo	Pozo	Pecuario	Privado	312749	3455591	1,175	1165.16	9.84	3,285	Se tomó agua de pila para medir parámetros
CM-142		Los Salinas	Jesús Manuel Gándara	Pozo	Pecuario	Privado	328399	3420978	1,210	1190.66	19.34	17,280	Se tomó agua de pila para medir parámetros
CM-143				Pozo	Inactivo	Público	333712	3513320	1,248			0	Pozo recien hecho, sellado, no se puede meter la sonda
CM-144				Pozo	Inactivo		339597	3513024	1,232	1139.56	92.44	0	No se puede tomar muestra
CM-145				Pozo	Inactivo	Privado	330867	3456995	1,189	1170.20	18.80	0	Pozo abandonado, fuera de servicio, se puede tomar muestra con recipiente angosto
CM-146				Pozo	Pecuario	Privado	328533	3459916	1,185	1158.88	26.12	10,407	No se pudo muestrear debodo a que no habia motor conectado
CM-147		Ojo de la Punta		Pozo	Pecuario/Agrícola	Privado	347048	3473654	1,228	1190.67	37.33	10,407	No salió agua pero los datos de la pila s on iguales al CM-122
CM-148		Rancho El Traque	Valentin Fuentes	Pozo	Pecuario	Privado	330612	3474189	1,222	1179.37	42.63	13,140	
CM-149		Rancho El Gato	Luis Borjas	Pozo	Pecuario	Privado	350412	3457885	1,288	1278.80	9.20	10,407	Se puede tomar muestra cuando hay viento. El CM-136 esta a 50 m aprox.
CM-150		Nuevo Cuauhtemoc	Pedro Rascón	Pozo	Pecuario	Privado	290671	3481610	1,187			2,628	No tiene por donde meter la sonda. Sal incrustada en las tuberías
CM-151		La Laguna		Pozo	Pecuario	Privado	295150	3491449	1,187	1170.90	16.10	9,216	Funciona con celdas solares
CM-152		El Millón	Manuel Rivero	Pozo	Pecuario	Privado	300142	3485146	1,189			5,832	Pozo sellado no se puede SONDEAR, 150 ft de profundidad, según propietario esta bombeando a 85 ft
CM-153		Rancho Las Barrancas		Pozo	Inactivo	Privado	302585	3482964	1,198	1177.61	20.39	0	Por el momento fuera de servicio, toda la tuberia esta afuera.
CM-154		Estación El Barreal		Pozo	Inactivo		294295	3461256	1,197	1173.57	23.43	0	Se atora la sonda a los 17 m. Se midio N.E. en pozo a 92 m al oeste
CM-155		La Morita	Ever Chávez	Pozo	Pecuario/Doméstico	Privado	296934	3448254	1,272	1211.61	60.39	2,628	Se tomó agua de pila para medir parámetros
CM-156		El Mezquite		Pozo	Pecuario		294886	3471425	1,183	1176.44	6.56	1,314	No se observa ganado
CM-158				Pozo	Inactivo	Privado	339669	3515048	1,258	1164.95	93.05	0	Bno se puede muestrear
CM-159				Pozo	Inactivo	Privado	314109	3503887	1,241	1177.19	63.81	0	Rancho abandonado, no se puede muestrear
CM-160	Pozo 1		JMAS	Pozo	Monitoreo	Municipal	335041	3510995	1,252	1158.06	93.94	0	Red monitoreo Junta Municipal de Agua y Saneamiento, no se puede muestrear
CM-161	Pozo No. 3		JMAS	Pozo	Monitoreo	Municipal	332964	3513134	1,251	1161.97	89.03	0	Pozo de monitoreo piezométrico
CM-162	Pozo No. 4		JMAS	Pozo	Monitoreo	Municipal	329136	3512357	1,242	1145.81	96.19	0	Pozo de monitoreo piezométrico
CM-163	Pozo No. 6		JMAS	Pozo	Monitoreo	Municipal	325298	3512305	1,256	1156.70	99.30	0	Pozo de monitoreo piezométrico
CM-164	Pozo No. 8		JMAS	Pozo	Monitoreo	Municipal	327782	3504245	1,251	1158.50	92.50	0	Pozo de monitoreo piezométrico
CM-165	Pozo No. 7		JMAS	Pozo	Monitoreo	Municipal	327022	3506171	1,254	1161.36	92.64	0	Pozo de monitoreo piezométrico
CM-166	Pozo No. 5		JMAS	Pozo	Monitoreo	Municipal	327801	3508308	1,255	1160.74	94.26	0	Pozo de monitoreo piezométrico
CM-167	Pozo No. 2		JMAS	Pozo	Monitoreo	Municipal	330958	3508631	1,259			0	Pozo de monitoreo piezométrico; obstruido, no baja la sonda
CM-168	Pozo No. 9		JMAS	Pozo	Monitoreo	Municipal	330938	3504118	1,257	1161.10	95.90	0	Pozo de monitoreo piezométrico
CM-169			JMAS	Pozo	Monitoreo	Municipal	325540	3505987	1,252	1162.79	89.21	0	Pozo de monitoreo piezométrico. Pozo sin terminar
CM-170			JMAS	Pozo	Monitoreo	Municipal	322521	3502304	1,229	1129.75	99.25	0	Pozo de monitoreo piezométrico, Pozo sin terminar, sin ademe ni brocal.
										0.00			

Table 3.4. Wells surveyed in 2007 that were not updated in 2010.

CLAVE_ SGM	OTRAS CLAVE	LOCALIDAD	PROPIETARIO	TIPO	USO	OPERACION	X_UTM_ NAD2	Y_UTM_ NAD2	Z_CA RTA	ENE	PNE2	EXTRACCION M3	OBSERVACIONES
CM-097	POZO 8 SUR	EL SINAI	CNA-JCAS	POZO	INACTIVO	Estatal	317942	3489545	1,232.9	1171	61		SIRVE COMO PIEZÓMETRO
CM-100	POZO 9 SUR		CNA-JCAS	POZO	INACTIVO	Estatal	325296	3490719	1,226.6	1173	53		POZO DE MONITOREO, SIN EQUIPO. BATERÍA SUR PARA CD. JUÁREZ. SIRVE COMO PIEZÓMETRO.
CM-101	POZO 12 SUR		CNA-JCAS	POZO	INACTIVO	Estatal	324111	3486794	1,220.7	1174	47		POZO DE MONITOREO, SIN EQUIPO. BATERÍA SUR PARA CD. JUÁREZ. SIRVE COMO PIEZÓMETRO.
CM-102	POZO 11 SUR		CNA-JCAS	POZO	INACTIVO	Estatal	317869	3484150	1,224.1	1175	49		POZO DE MONITOREO, SIN EQUIPO. BATERÍA SUR PARA CD. JUÁREZ. SIRVE COMO PIEZÓMETRO.
CM-103	POZO 10 SUR		CNA-JCAS	POZO	INACTIVO	Estatal	310565	3486701	1,209.4	1176	33		POZO DE MONITOREO, SIN EQUIPO. BATERÍA SUR PARA CD. JUÁREZ. SIRVE COMO PIEZÓMETRO.
CM-104	POZO 7 SUR		CNA-JCAS	POZO	INACTIVO	Estatal	310536	3490988	1,215.4	1176	40		POZO DE MONITOREO, SIN EQUIPO. BATERÍA SUR PARA CD. JUÁREZ. SIRVE COMO PIEZÓMETRO.
CM-105	POZO 1 SUR		CNA-JCAS	POZO	INACTIVO	Estatal	310634	3495966	1,226.2	1174	52		POZO DE MONITOREO, SIN EQUIPO. BATERÍA SUR PARA CD. JUÁREZ. SIRVE COMO PIEZÓMETRO.
CM-106	POZO 2 SUR		CNA-JCAS	POZO	INACTIVO	Estatal	313122	3496390	1,236.9	1176	61		POZO DE MONITOREO, SIN EQUIPO. BATERÍA SUR PARA CD. JUÁREZ. SIRVE COMO PIEZÓMETRO.
CM-108	POZO 3 SUR		CNA-JCAS	POZO	INACTIVO	Estatal	315542	3496850	1,231.0	1169	62		POZO DE MONITOREO, SIN EQUIPO. BATERÍA SUR PARA CD. JUÁREZ. SIRVE COMO PIEZÓMETRO.
CM-109	POZO 4 SUR	PARABIEN	CNA-JCAS	POZO	INACTIVO	Estatal	318032	3497015	1,235.5	1169	67		POZO DE MONITOREO, SIN EQUIPO. BATERÍA SUR PARA CD. JUÁREZ. SIRVE COMO PIEZÓMETRO.
CM-112	POZO 5 SUR	Bateria de pozos	CNA-JCAS	POZO	INACTIVO	Estatal	323057	3497172	1,225.9	1171	55		POZO DE MONITOREO, SIN EQUIPO. BATERÍA SUR PARA CD. JUÁREZ. SIRVE COMO PIEZÓMETRO.
CM-113	POZO 6 SUR	Bateria de pozos	CNA-JCAS	POZO	INACTIVO	Estatal	325594	3497191	1,227.3	1169	58		POZO DE MONITOREO, SIN EQUIPO. BATERÍA SUR PARA CD. JUÁREZ. SIRVE COMO PIEZÓMETRO.

3.2 Calculation of Withdrawal Volumes.

Up until May 2010, the volumes extracted had remained fairly constant. INEGI (1999) reported a withdrawal volume from the aquifer of 1.58 Hm^3/year, while the Public Registry of Water Rights (REPDA) as of March 31, 2009, shows an extracted volume of 596,735 m^3/year, a value similar to the one calculated by the Mexican Geological Service in 2007. REPDA data as of September 30, 2010 shows an extracted volume of 593,735 m^3/year, but the data for 2009 and 2010 are still subject to revision.

Field data was used to calculate the volume of groundwater that is currently being withdrawn from the aquifer, based on the average flow rate and the time each well remains in operation, according to the information provided by the ranch owners or operators. It is worth noting that it was not possible to obtain hydrometric information for some of the wells; in these cases, the calculation was based on wells with similar usage under similar conditions.

For the wells that use reciprocating motors (mainly windmills), where the withdrawal period and flow rate are variable, a value for flow rate, time and days in operation is assigned to obtain an approximate annual volume. Some of these wells were assigned an operating period of 24 hours a day for the full year at a reduced flow rate, in order to obtain an approximate value for the majority of this type of wells.

Except for the wellfield that provides water to the Conejos Medanos Aqueduct, which has an average flow of 1,000 lps, the withdrawals from the remaining wells are significantly less. Table 3.5 details the annual withdrawal by water usage. Likewise, the reader should look at Table 3.3, where he will find the detail of the withdrawals for nearly all the surveyed wells, which coincide in some cases with the volumes under concession in the Public Registry of Water Rights (REPDA).

Table 3.5. Groundwater Withdrawal Volumes by Well Usage

Well Usage	Annual Withdrawal in Mm^3	Total % of Withdrawal
Agricultural	1.56	8.50%
Municipal	0.01	0.05%
Livestock	0.58	3.15%
Public Urban	16.01	87.51%
Utilities	0.15	0.79%

Based on the above, the total groundwater withdrawal for 2010 was calculated at 18.31 Hm^3, of which 87.51% was pumped from the wellfield located at the far north side of the aquifer.

It is important to note that the wellfield began operations in mid-May 2010, thus the calculated volume of 18.31 Hm^3/year will only apply to 2010, since under the same operating circumstances in 2011, meaning 12 months of operation, a volume of 33.8 Hm^3/year will be withdrawn from the Conejos Medanos Aquifer, of which only 2.3 Hm^3/year are withdrawn from wells outside of the wellfield.

3.3 Piezometry.

Historical Piezometry.

In order to have a more reliable understanding of the current piezometric behavior, it is important to understand the historical piezometry, as well as the piezometric trend in levels over time. In that sense, the company Técnicas Geológicas y Mineras S.A. (1987) reported static levels in the Conejos Medanos Aquifer with values less than 20 and greater than 90 meters. Additionally, INEGI (1999) reported variations in static levels ranging from 1 to 120 m.

Among the most recent data showing the piezometric behavior of the aquifer are the reports by the Mexican Geological Service in 2007. (Figures 3.3 and 3.4) In 2007, the depth to static level ranged from 1 to 10 m in the Laguna El Barreal area, increasing to 10 to 60 m in the middle of the aquifer, and then reaching levels of up to 100 m in the far north side of the aquifer. It is worth mentioning that there is no contour line deformation, since the aquifer basically maintains its equilibrium.

With respect to the configuration of the static level elevation in 2007 (Figure 3.4), values between 1190 and 1180 m asl are seen in the far south side of the aquifer, showing the presence of subsurface flow towards the Laguna El Barreal area. The central-eastern part of the aquifer is much the same, where the values range between 1240 and 1180 m asl, showing the direction of groundwater flow heading slightly to the northwest, towards the center of the aquifer. Finally, on the far northeast side of the aquifer, the values fluctuate between 1170 and 1140 m asl, showing the subsurface flow continuing its north-northeast direction.

In 2007, as was reported in 1987 and 1999, equilibrium conditions remain, in other words, the groundwater withdrawals do not exceed the recharge. Therefore the flow lines have not been modified, keeping the natural outlet of the aquifer.

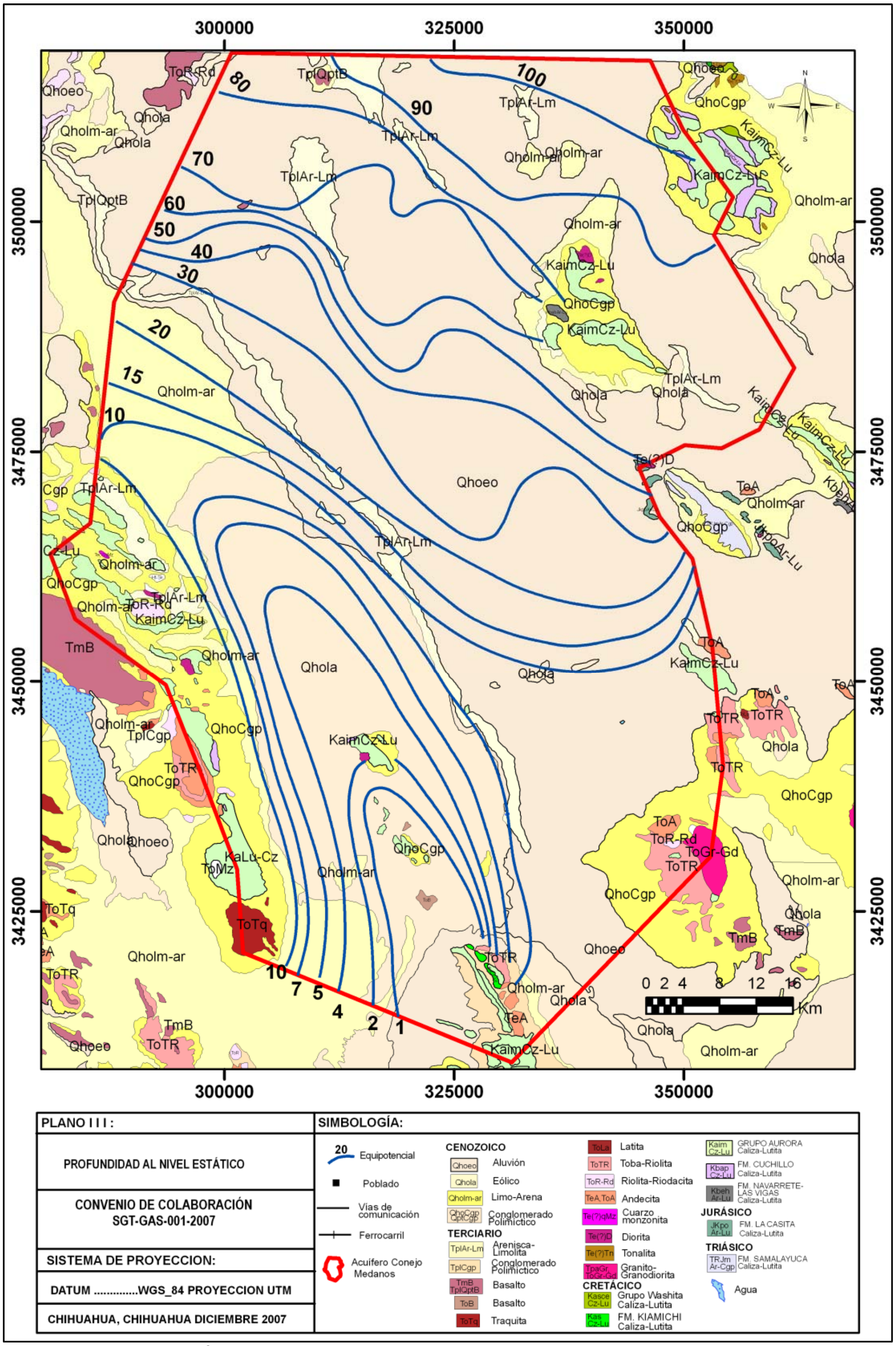


Figure 3.3. Depth to Static Level (SGM 2007 for CONAGUA)

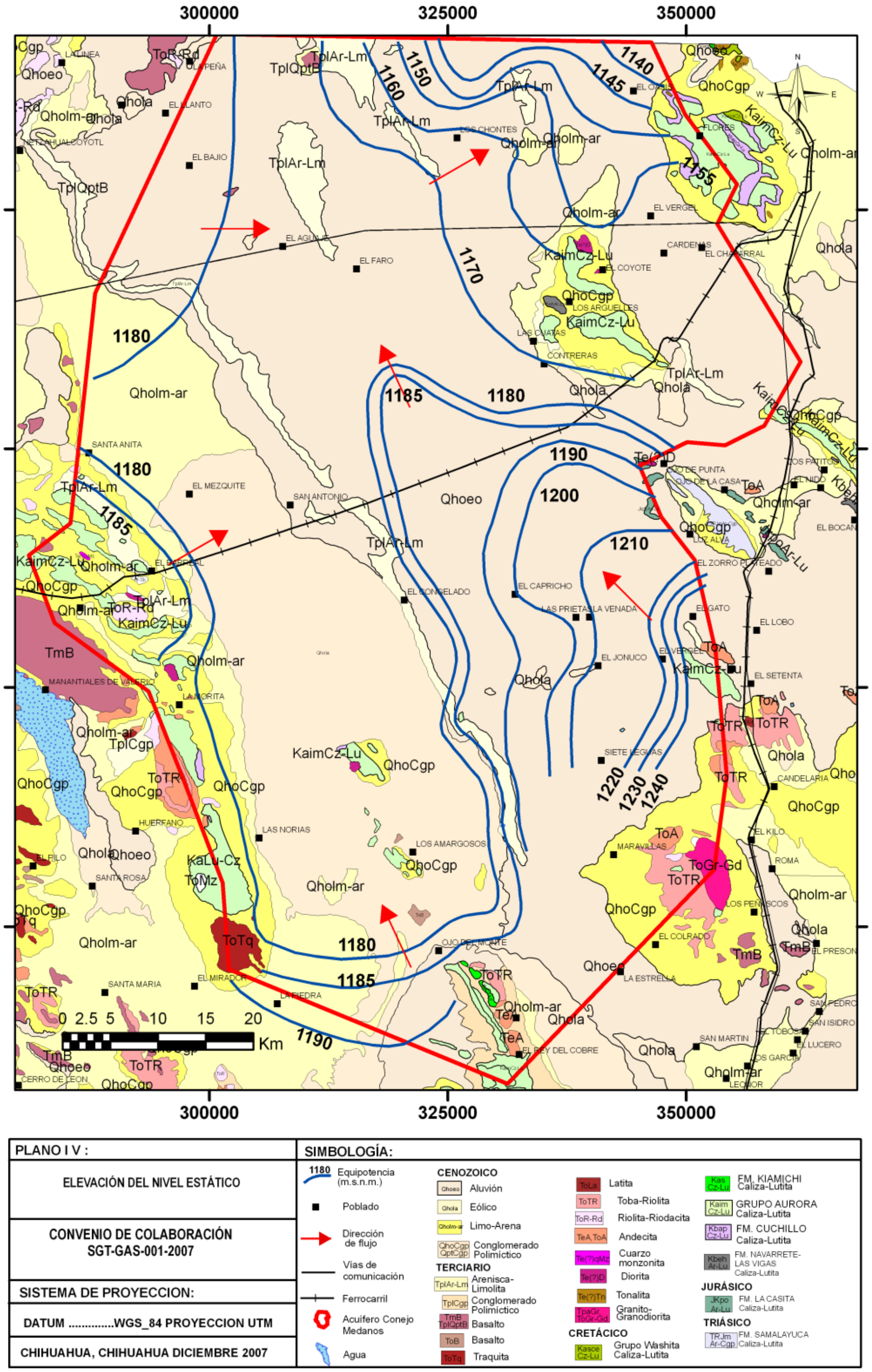


Figure 3.4. Static Level Elevation (SGM 2007 for CONAGUA)

Current Piezometry.

Except for the wellfield area that supplies water to the Conejos Medanos Aqueduct, the aquifer's piezometric behavior is similar to what it was in 2007. As far as depth is concerned, currently in the south of the aquifer, specifically in the El Barreal area, it was observed that mostly shallow static levels predominate with variations between 1 and 10 m, except for the foothills area (El Chilicote and Los Muertos mountains), where levels of up to 30 m are found. These are influenced by the topographic conditions in that area.

On the north, east, and southeast edges of the Laguna El Barreal, a piezometric line can be found at a depth of 10 m. Starting at this line and heading north and east, the static levels increase to 60 m. At the La Barranca, Las Prietas, El Capricho and La Venada ranches, the depths vary from 15 to 21 m, while in the center of the aquifer, which is predominantly sand dunes, the depth levels increase; starting at 30 m, they reach 60 m in the area known as El Faro. This is where the Ciudad Juarez's Municipal Water and Sanitation Board's monitoring wells are located.

In the far northeast of the aquifer, where the wellfield is located, the levels currently vary between 70 and 105 m. (Figure 3.5) It is worth mentioning that a small deformation in the piezometric curves can be noticed in the wellfield area, specifically in the area where the wells coded 3, 5, 12 and 24 are located. Figure 3.6 is a close-up of the depth to static level behavior in the wellfield area, showing the presence of a small drawdown cone on the far north side where the deepest levels are found of between 100 and 105 m.

With regard to the behavior of the depth to static level in the wellfield area (Figure 3.6), the deformation in the isovalue curves can be clearly observed. This is occurring on the far north side of the wellfield; after just two months of operation, the effects can already be seen. It is worth mentioning that no deformations in the curves for the other areas are seen; however, the wellfield has been online for only a short time, so its impact may become evident towards the end of 2010 or beginning of 2011.

Regarding the current static level elevation (Figure 3.7), on the far south side of the aquifer, values ranging from 1190 to 1179 m asl were observed, showing how the subsurface flow continues its path towards the center of the Laguna El Barreal. On the other hand, the subsurface flow in the central-eastern part of the aquifer is towards the middle, where a variation in levels ranging from 1210 to 1180 m asl is observed. The subsurface flow continues towards the center of the aquifer before it bends towards the northeast until it reaches the area where the Conejos Medanos Aquifer wellfield is located. Here, the values are primarily between 1179 and 1140, showing that there is still a natural outflow of groundwater towards the far north side of the aquifer.

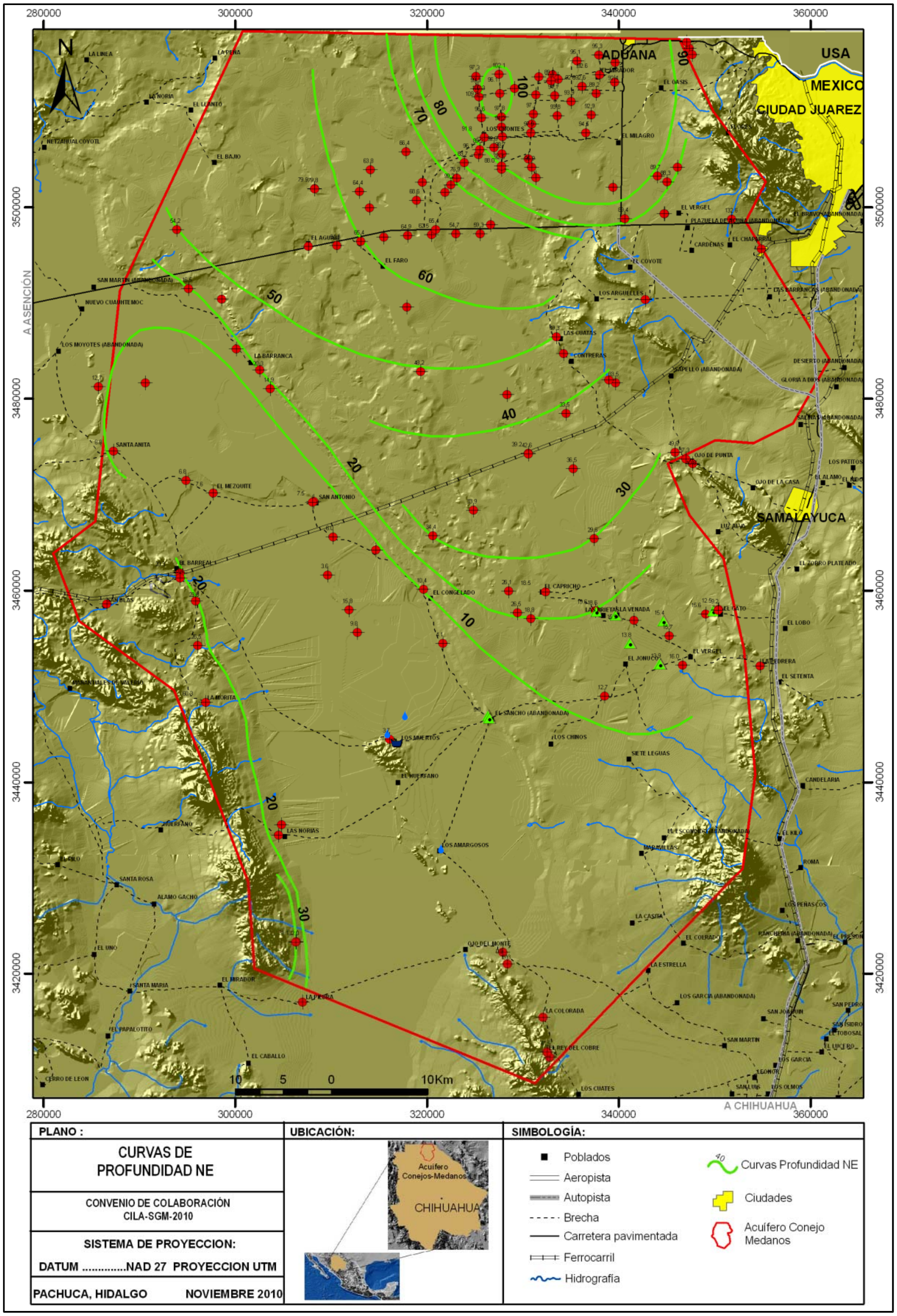


Figure 3.5. Current Depth to Static Level (2010)

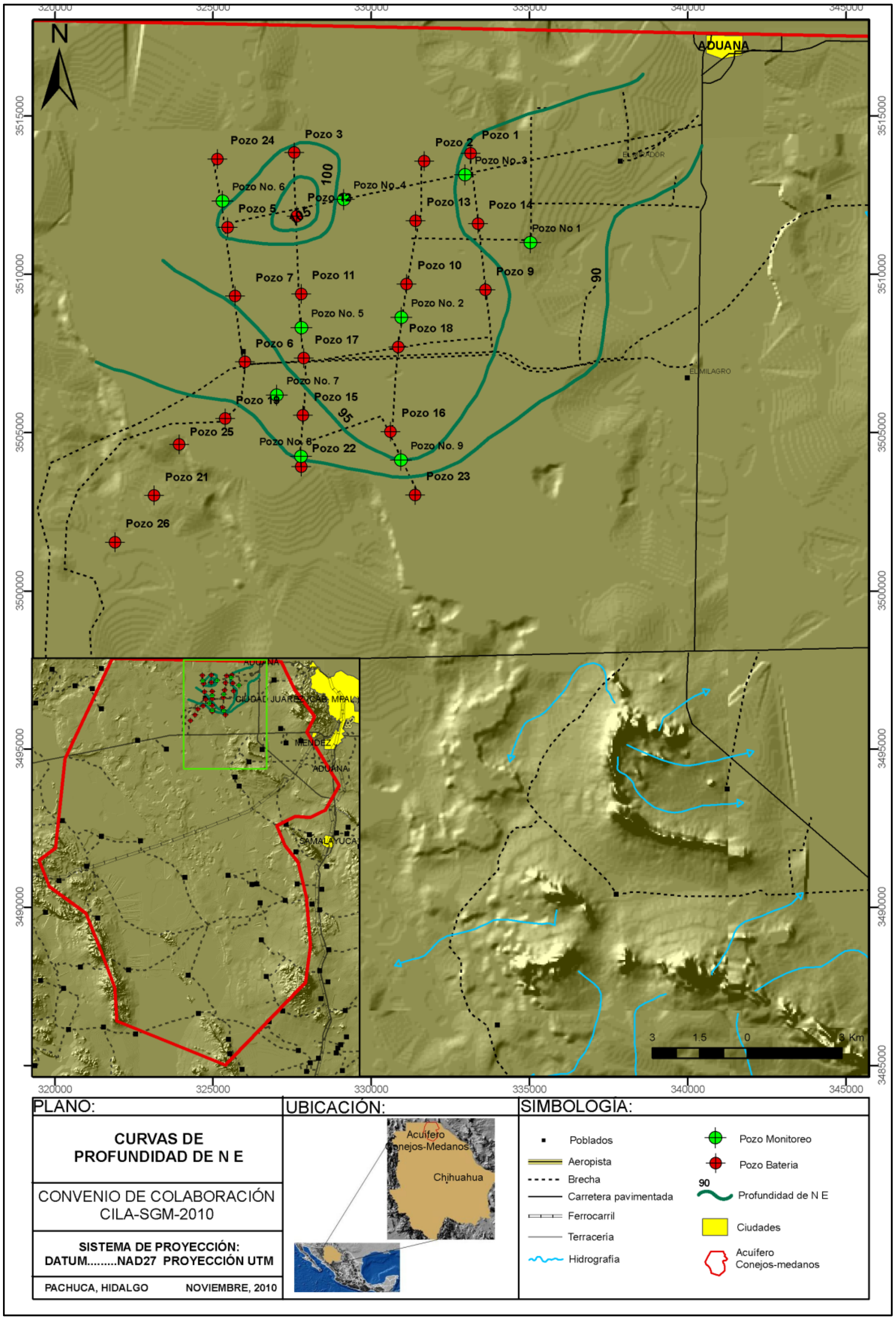


Figure 3.6. Close-up of the Depth to Static Level in the Wellfield (2010).

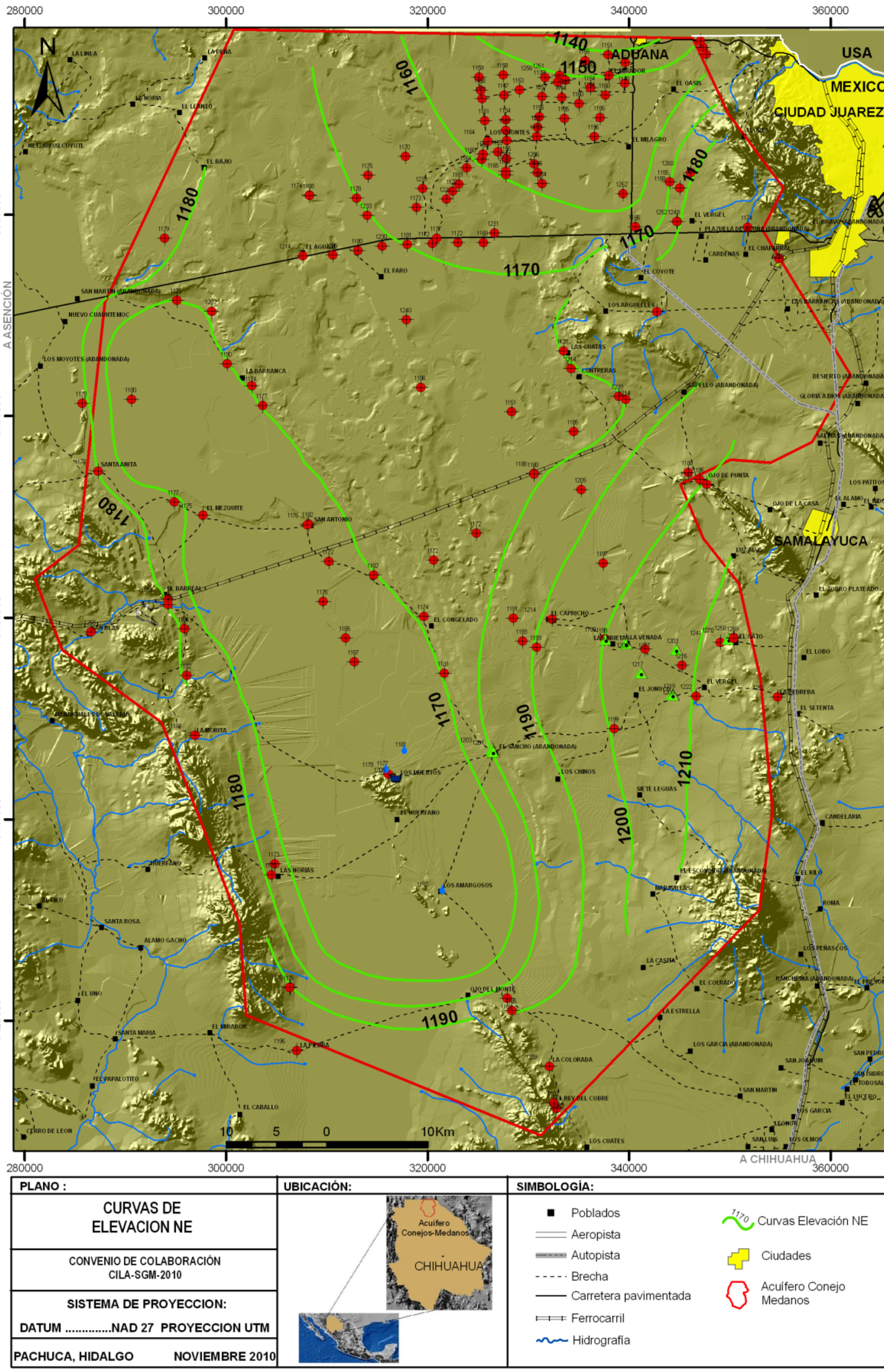


Figure 3.7. Current Static Level Elevation (2010)

Analyzing in detail the behavior of the static level elevation for the wellfield area (Figure 3.8), it shows how on the far north side of the wellfield, the flow lines became deformed causing a small piezometric cone, whose diameter is centered on well #12 in the wellfield. It is noteworthy that the rest of the equipotential lines are not yet deformed, meaning the aquifer maintains some of its natural outflows to the north.

It should be noted that the equipotential curves drawn here have a five-meter interval, therefore small, lesser variations are omitted and the focus is on the site where the strongest tendency is found.

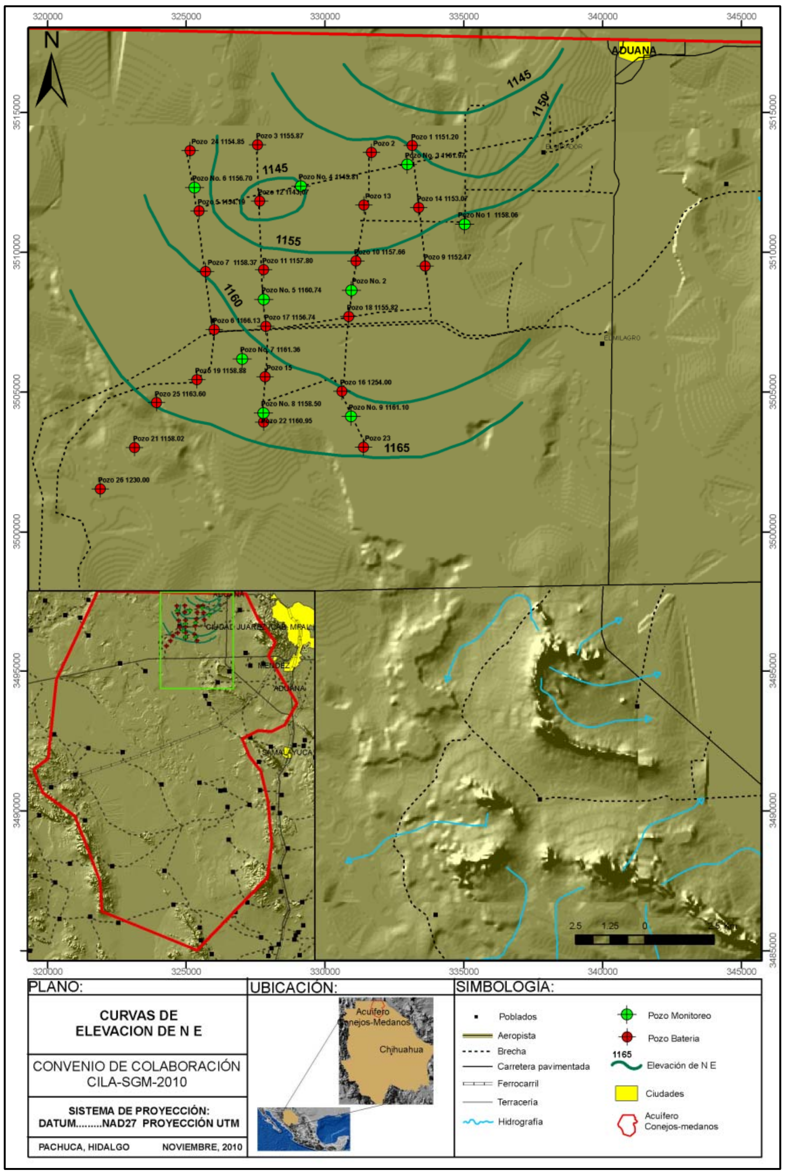


Figure 3.8. Close-up of the Current Static Level Elevation in the Wellfield (2010).

Piezometric Trends.

To get a precise trend in static levels, 50 piezometric measurements, taken in 2007 and 2010, were used. (Table 3.6) Based on that, it can be concluded that most of the aquifer maintains conditions of equilibrium, since there is a natural variation in the piezometric behavior, meaning both positive and negative fluctuations that do not form a piezometric behavior trend. It is worth mentioning that only 50 data were taken into account because a filter was applied to eliminate potential errors that might have occurred during one of the surveys.

The opposite is true for at least eight wells in the wellfield located on the north side of the aquifer, where after two months of operations, a clear drop in the levels is seen, with an average of -1.4 m. The wells that show this decrease are marked with the wellfield code 1, 3, 5, 6, 9, 14, 21 and 22. The wells marked 12 and 24 are also included with these wells, since the static level elevation curves (Figures 3.7 and 3.8), together with wells 3 and 5, show a drawdown cone on the far north side of the aquifer.

It is important to note that through June 2010, not all of the wells in the wellfield are showing continual drawdown; at least the wells coded 7 and 10 maintained stable conditions during their two months of operation.

Table 3.6 Piezometric Trend for the 2007-2010 Period.
[Translator's Note: Table missing from original file.]
* The average annual trend is not applicable for the data marked in red. Since this decrease occurred after May 2010, once the Conejos-Medanos Aquifer wellfield came online.

According to Table 3.7, except for a portion of the wellfield located on the far north side of the aquifer, the piezometric trends are seasonal, meaning that they vary from -0.3 to 0.7 meters per year, which reflects an aquifer system in equilibrium.

Hydrographs are a useful tool for understanding an aquifer's piezometric behavior; data generated in this study (years 2007 and 2010), as well as historical data provided by the Ciudad Juárez Municipal Water and Sanitation Board, including piezometric reading from 1999 to 2004, was used for this purpose. (Table 3.7)

Table 3.7. Databases Used to Construct the Hydrographs.

Clave SGM	Clave JCAS	UTM NAD 27		Profundidad del nivel estático (m)									OBSERVACIONES	HIDRÓGRAFO
		Este	Norte	1999	2000	2001	2002	2003	2004	2007	may-10	jul-10		
CM-038	Pozo18	330852	3507701	95.49	95.57	95.01	94.78	95.10	95.58			99.09	BATERIA ACUEDUCTO CONEJOS	SE CONSTRUYÓ HIDRÓGRAFO
CM-039	Pozo 2	331673	3513570	97.16	96.78	96.58	96.48	96.75	97.00	96.36			BATERIA ACUEDUCTO CONEJOS	
CM-040	Pozo 10	331116	3509688	96.25	95.90	95.67	95.74	95.96	96.20	97.68		97.76	BATERIA ACUEDUCTO CONEJOS	
CM-041	Pozo11	327785	3509377	94.40	95.25	95.20	95.19	95.31	95.71			97.87	BATERIA ACUEDUCTO CONEJOS	
CM-042	Pozo 12	327640	3511828	93.58	93.13	93.04	93.00	93.25	93.44			109.62	BATERIA ACUEDUCTO CONEJOS	
CM-52	CNA-8	333817	3507503					92.08	94.06	91.11			EXPLORATORIO (CNA)	
CM-053	Pozo 9	333602	3509496	91.25	90.54	90.25	93.14	90.32	90.90	90.58		95.96	BATERIA ACUEDUCTO CONEJOS	
CM-054	Pozo 1	333142	3513808		88.74	88.08	90.98	88.55	88.90	88.58		92.80	BATERIA ACUEDUCTO CONEJOS	SE CONSTRUYÓ HIDRÓGRAFO
CM-055	Pozo 3	327560	3513839		97.41	97.36	96.85	97.38	97.64	97.44		102.13	BATERIA ACUEDUCTO CONEJOS	SE CONSTRUYÓ HIDRÓGRAFO
CM-056	Pozo5	325455	3511480		98.08	98.21	98.27	98.44	98.48	97.99		100.81	BATERIA ACUEDUCTO CONEJOS	SE CONSTRUYÓ HIDRÓGRAFO
CM-057	Pozo 6	326004	3507225		88.65	89.55	89.64	89.61	89.66	89.38		91.87	BATERIA ACUEDUCTO CONEJOS	SE CONSTRUYÓ HIDRÓGRAFO
CM-058	Pozo 19	325381	3505429		90.00	89.78	90.11	89.67	90.10			96.12	BATERIA ACUEDUCTO CONEJOS	
CM-059	Pozo 21	323140	3503000		72.78	72.12	72.56	72.49	72.46	71.92		76.98	BATERIA ACUEDUCTO CONEJOS	SE CONSTRUYÓ HIDRÓGRAFO
CM-061	Pozo 15	327844	3505539		90.14	90.00	90.08	90.23	90.47	90.20			BATERIA ACUEDUCTO CONEJOS	
CM-062	Pozo 22	327781	3503914		84.10	84.08	83.98	84.08	84.28	83.98		88.05	BATERIA ACUEDUCTO CONEJOS	SE CONSTRUYÓ HIDRÓGRAFO
CM-063	Pozo 16	330610	3505025		93.14	92.94	92.88	92.95	93.67	92.87			BATERIA ACUEDUCTO CONEJOS	SE CONSTRUYÓ HIDRÓGRAFO
CM-064B	Pozo 23	331390	3503024		94.16	93.89	94.11	93.80	96.73	93.58			BATERIA ACUEDUCTO CONEJOS	
CM-068	Las Cuatas	333514	3486425				49.38			54.11		49.33		
CM-073	Pozo 14	333369	3511597	90.26	90.13	89.68	90.74	89.76	90.38	90.18		94.11	BATERIA ACUEDUCTO CONEJOS	SE CONSTRUYÓ HIDRÓGRAFO
CM-095	Pozo 26	321896	3501528		64.28	73.61	64.00	63.93	63.92	63.72			BATERIA ACUEDUCTO CONEJOS	
CM-97	POZO 8 SUR	317942	3489545	60.72	59.87		59.94	59.97		61.42			EXPLORATORIO SUR (CNA-JCAS)	
CM-100	POZO 9 SUR	325296	3490719	53.99	53.72		53.80	53.86	53.84	53.31			EXPLORATORIO SUR (CNA-JCAS)	
CM-101	POZO 12 SUR	324111	3486794	47.41	47.24	47.04	47.29	47.27	47.65	47.26			EXPLORATORIO SUR (CNA-JCAS)	
CM-102	POZO 11 SUR	317869	3484150	49.82	49.71	49.51	49.69	49.67		49.01			EXPLORATORIO SUR (CNA-JCAS)	
CM-103	POZO 10 SUR	310565	3486701	34.13	33.97	33.82	33.43	33.96		33.32			EXPLORATORIO SUR (CNA-JCAS)	
CM-104	POZO 7 SUR	310536	3490988	40.52	40.34	40.22	40.30	40.34		39.63			EXPLORATORIO SUR (CNA-JCAS)	
CM-105	POZO 1 SUR	310634	3495966	53.18	52.88	52.75	52.82	52.90		52.34		54.53	EXPLORATORIO SUR (CNA-JCAS)	SE CONSTRUYÓ HIDRÓGRAFO
CM-106	POZO 2 SUR	313122	3496390	66.41	65.96	65.73	65.93	66.06		61.30		65.45	EXPLORATORIO SUR (CNA-JCAS)	SE CONSTRUYÓ HIDRÓGRAFO
CM-108	POZO 3 SUR	315542	3496850	61.20	60.78	60.66	60.83	60.89		62.15			EXPLORATORIO SUR (CNA-JCAS)	
CM-109	POZO 4 SUR	318032	3497015	66.38	65.48	65.33	65.56	65.60		66.78		64.93	EXPLORATORIO SUR (CNA-JCAS)	
CM-112	POZO 5 SUR	323057	3497172		55.08	54.94	55.08	55.07	55.13	54.78		54.79	EXPLORATORIO SUR (CNA-JCAS)	SE CONSTRUYÓ HIDRÓGRAFO
CM-113	POZO 6 SUR	325594	3497191	-	58.84	58.74	58.76	58.76	58.82	58.43		59.36	EXPLORATORIO SUR (CNA-JCAS)	SE CONSTRUYÓ HIDRÓGRAFO
CM-114	Pozo 7	325700	3509306		95.62	95.93	96.06	95.99	96.10	95.67		96.63	BATERIA ACUEDUCTO CONEJOS	SE CONSTRUYÓ HIDRÓGRAFO
CM-115	CNA-4	325309	3512386				97.78	97.82	97.93				EXPLORATORIO (CNA)	
CM-116	Pozo 24	325140	3513637		94.20	94.06	93.98	94.00	94.18			97.17	BATERIA ACUEDUCTO CONEJOS	
CM-117	CNA-6	325816	3508035					92.70	92.78	92.57			EXPLORATORIO (CNA)	
CM-123	Pozo 13	331402	3511686	96.35	95.87	95.67	95.74	95.82	96.36				BATERIA ACUEDUCTO CONEJOS	
CM-124	Pozo 17	327870	3507340	94.40	94.04	94.01	94.01	94.18	94.62			98.78	BATERIA ACUEDUCTO CONEJOS	
CM-125	Pozo 25	323924	3504610	79.60	79.18	79.47	79.54	79.40	79			99.09	BATERIA ACUEDUCTO CONEJOS	SE CONSTRUYÓ HIDRÓGRAFO

Table 3.7 contains the historical piezometric records for each one of the hydrographs shown in Figures 3.9 and 3.10. The first set includes four hydrographs from observation wells belonging to the National Water Commission, found to the south of the wellfield. (Figure 3.12) These are hydrographs that show a aquifer in equilibrium, where slight seasonal variations are seen.

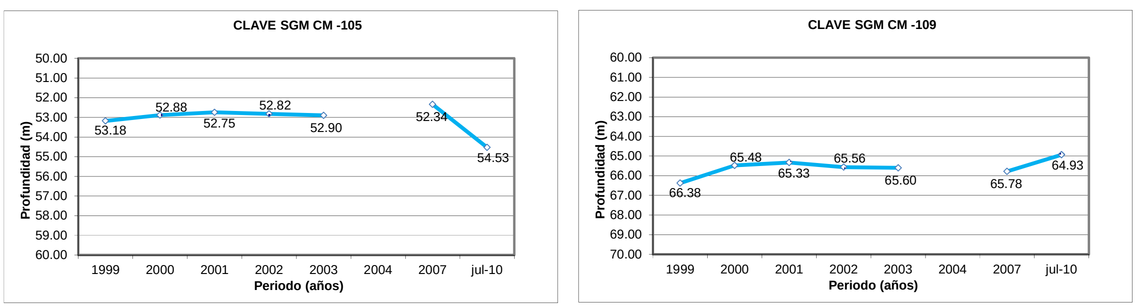


Figure 3.9a Hydrographs for the National Water Commission's Observation Wells.

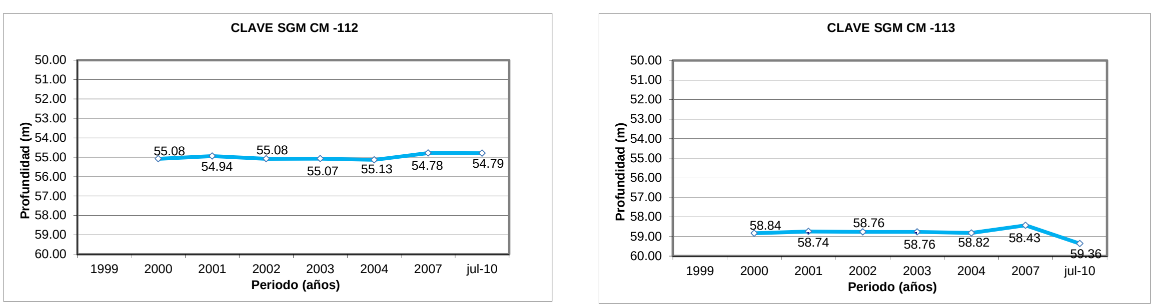


Figure 3.9b Hydrographs for the National Water Commission's Observation Wells.

Figures 3.10 (a and b) depicts 11 hydrographs compiled from piezometric data exclusively from wells in the wellfield. The trend is clear: equilibrium is seen up until the wellfield that supplies the Conejos Medanos Aqueduct came online. Once the pumping began, decreases were seen between May and July of up to 5 meters, mainly on the far north side of the wellfield, where the wells coded 21 and 22 are located, as well as those coded 9 and 3.

Even though the trend in at least 11 of 23 wells that belong to the Conejos Medanos Aqueduct wellfield shows an immediate decrease in static levels, given the short amount of time in operation, it is likely that it represents a quick response from the aquifer to a sudden withdrawal; however, it is likely that over time the aquifer may relax and recover some of the lost elevation.

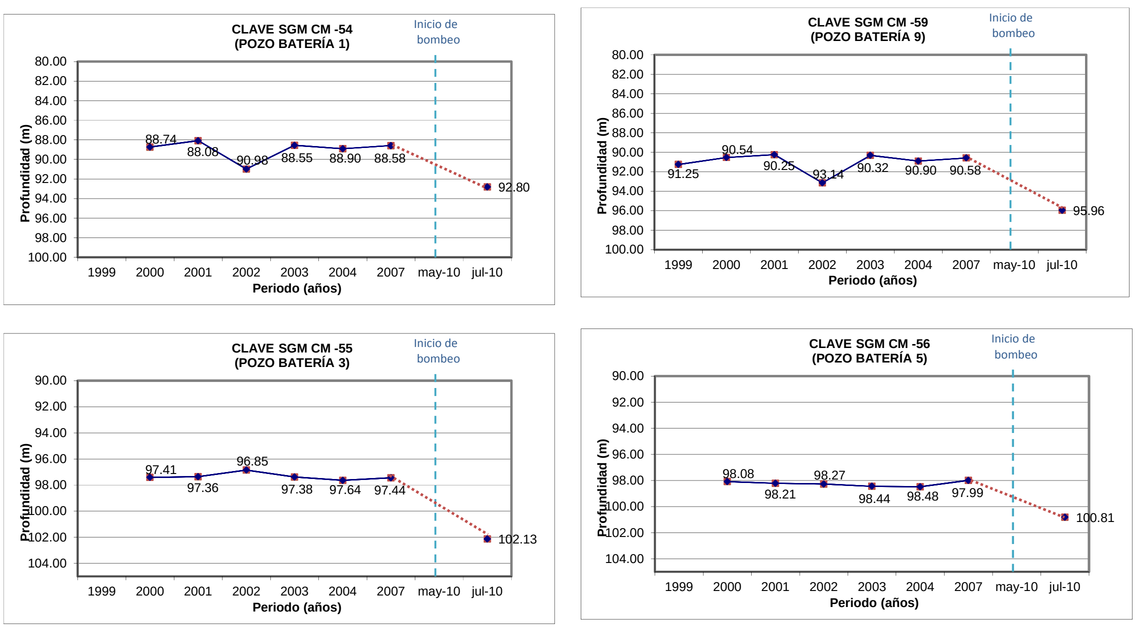
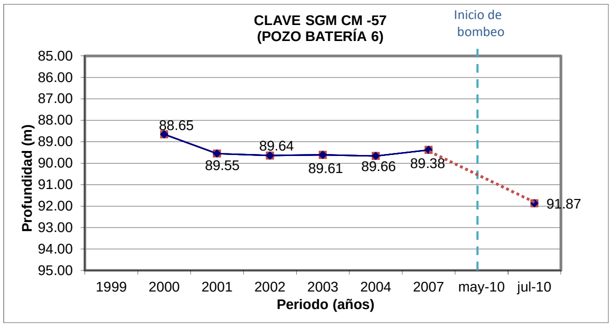
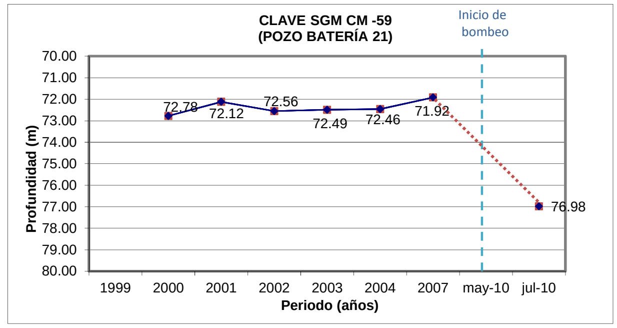
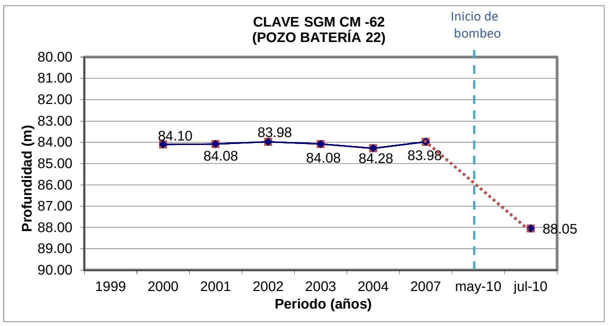


Figure 3.10a. Conejos Medanos Aquifer Wellfield Hydrographs.







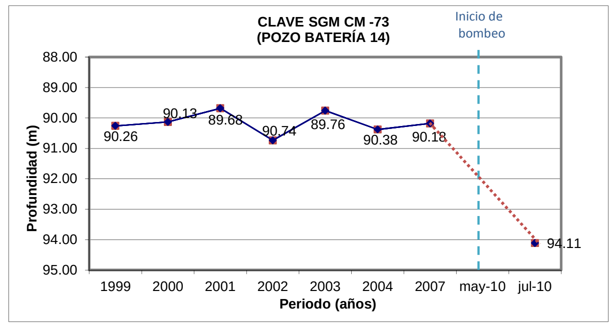
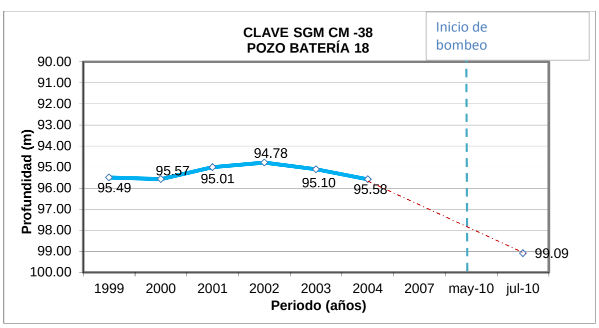
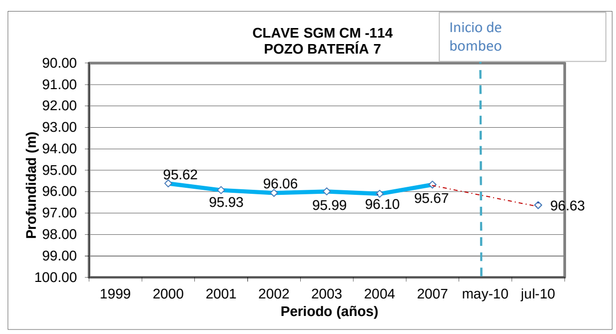
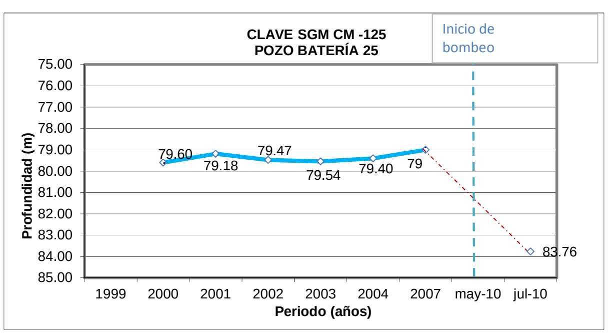


Figure 3.10b. Conejos Medanos Aquifer Wellfield Hydrographs.







Even though there was an extremely drastic drop in levels, several meters (up to 5) in a period of two months, which might indicate probable errors with the well readouts, or perhaps that the wells were not measured at their static level (rather they were still experiencing the effects of the pumping), Figure 3.11 shows hydrographs prepared by the Ciudad Juárez Municipal Water and Sanitation Board, using their data. It is worth noting that these hydrographs are compiled using the observation wells found among the wells in the wellfield, which confirm the trend shown in Figure 3.10, where the drawdown from May to November is up to five meters in the monitoring wells.

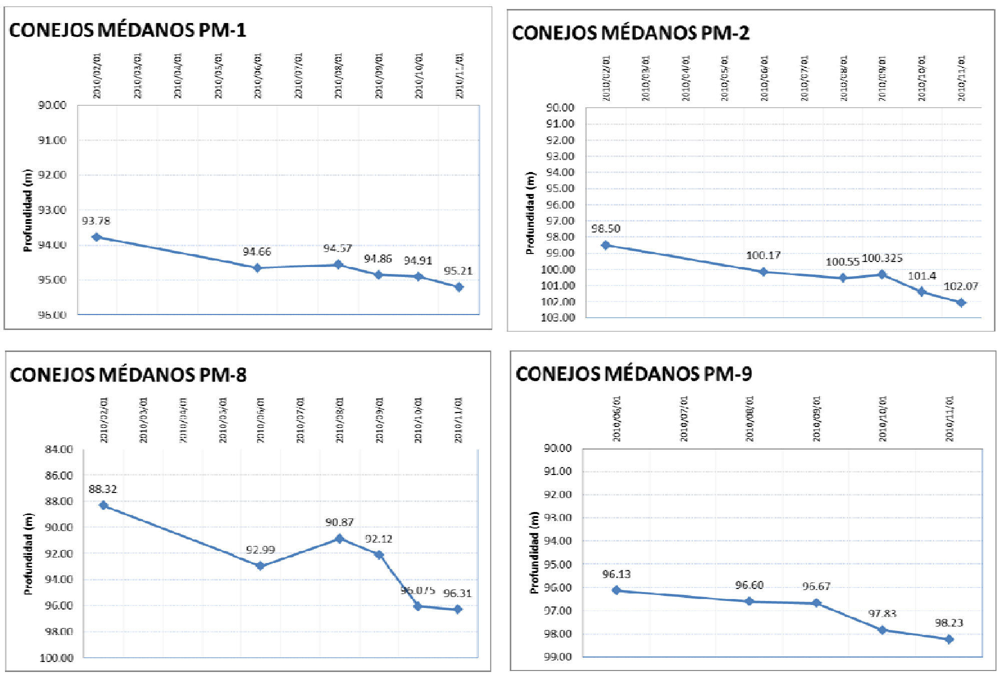


Figure 3.11 Hydrographs for the Observation Wells

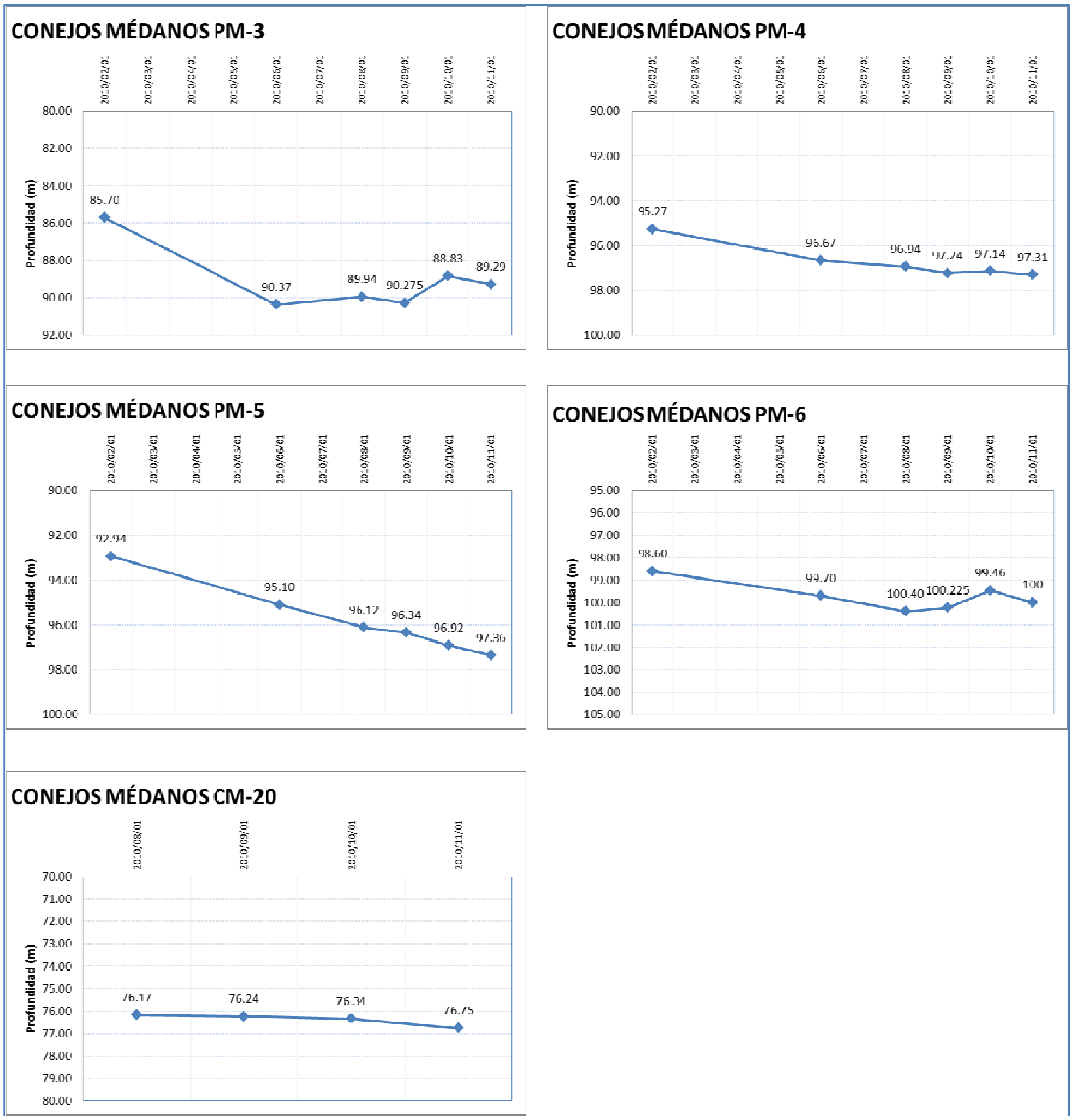


Figure 3.11 Hydrographs for the Observation Wells

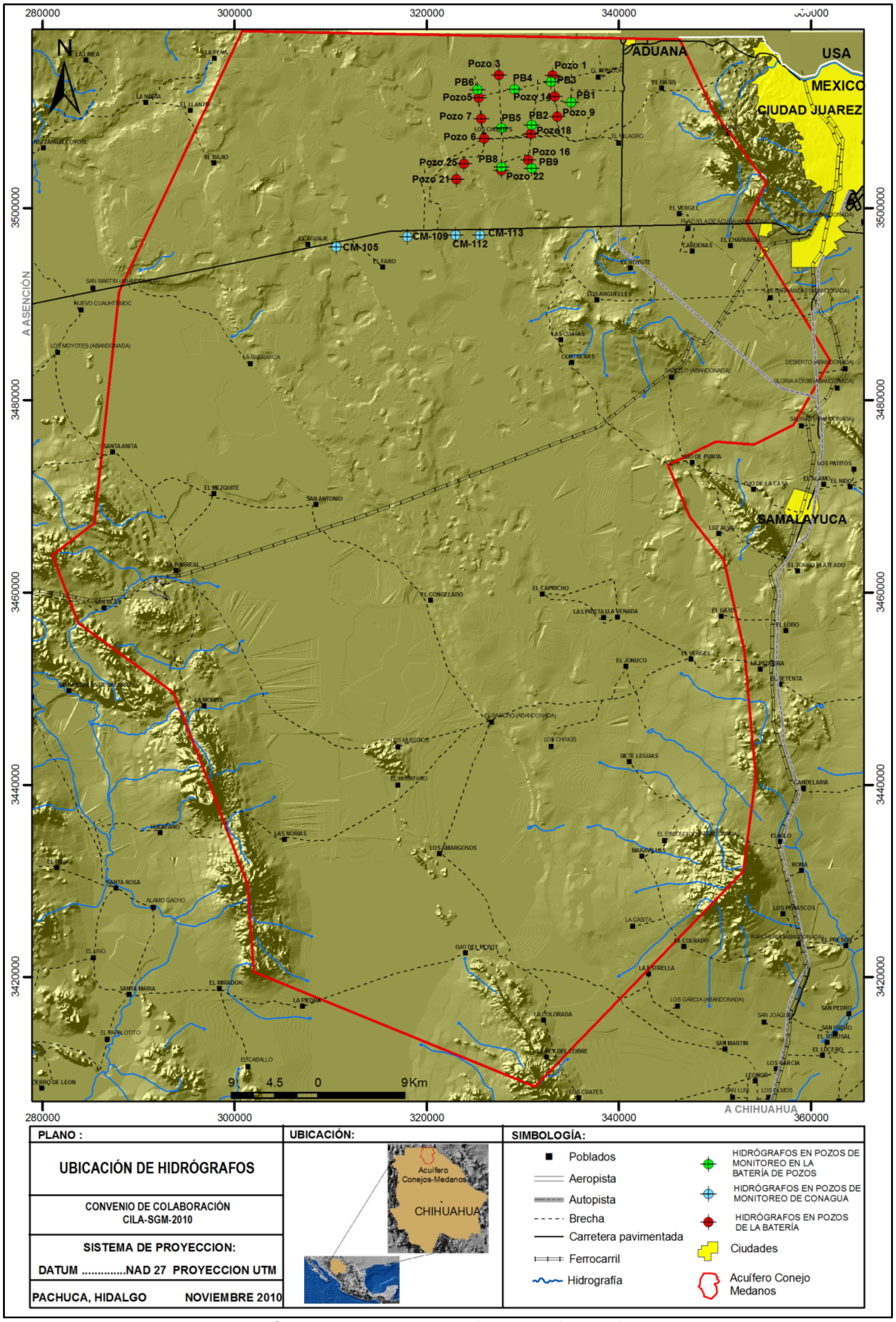


Figure 3.11 Location of Hydrographs.

Figure 3.12 shows a map with the configuration of the static levels trends, which has two distinct characterizations: from the area where to wellfield is located to the southern end was prepared with data from 2007 and 2010 (Table 3.6), whereas the curves showing the trend in the wellfield itself represent the static level trend for the June-November 2010 period.

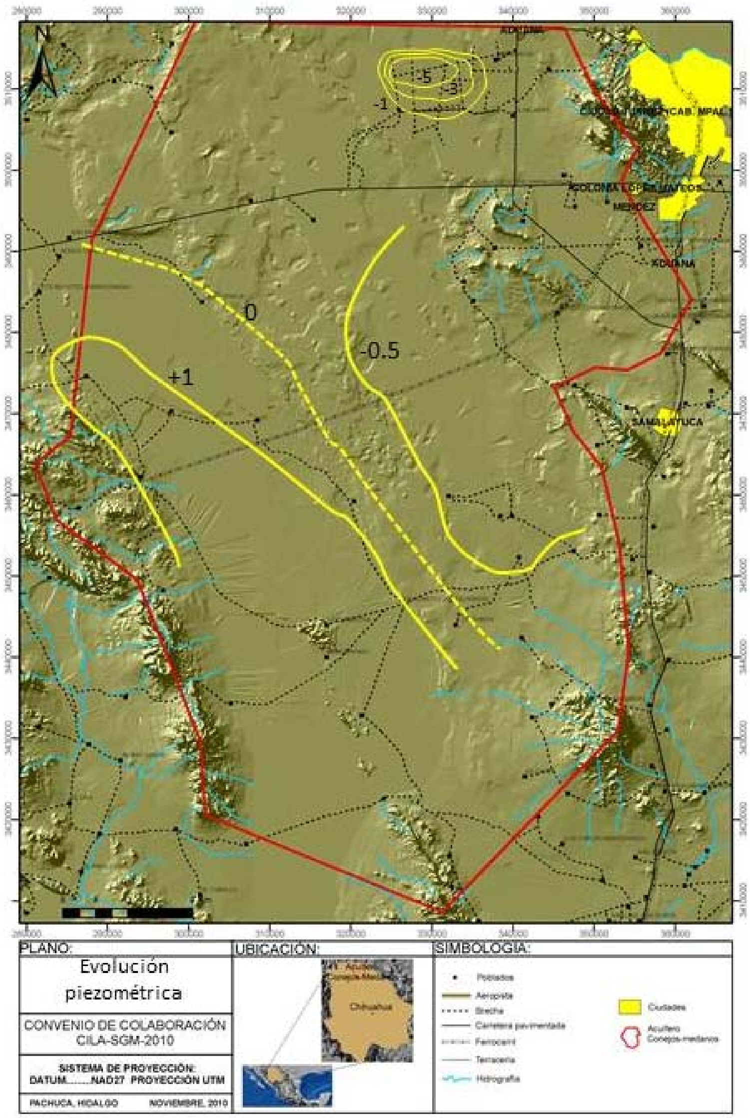


Figure 3.12 Static Level Trend

According to Figure 3.12, the majority of the Conejos-Medanos Aquifer is in conditions of equilibrium, meaning that there are slight seasonal variations, unrelated to any general trend. The opposite is happening in the wellfield, on the far north side of the aquifer, where drops of up to five meters in a short period of time have been observed.

4 PUMPING TESTS

4.1 Methodology

Pumping tests are an important tool for studying the behavior of wells, their flow rates, as well as for obtaining hydraulic parameters that are representative of the aquifer's characteristics. By performing pumping tests, the aquifer's characteristics are determined: hydraulic properties (transmissivity, storage coefficient, the existence or impervious barriers or boundaries, recharge zones, etc.)

Pumping tests indicate a progressive decline in water levels as a result of the expansion of the cone of influence, until the time when recharge becomes equal to pumping and at that point a steady state has been reached.

Ten wells were selected for the Conejos Medanos Aquifer pumping tests, which met criteria that make them reliable for carrying out tests, such as:

- The pump-motor assembly must be capable of operating continually at a constant flow for the duration of the test.
- Both the pumping and observation wells must be easily accessible and easy to sound.
- The site's hydrogeologic conditions must not change within a short distance and should be representative of the area.
- They should have a meter for extracted volumes or be able to be metered to determine the pumping flow rate.
- The pumped water does not infiltrate into the area surrounding the well. Otherwise, the possibility of installing a provisional buffer to isolate the water away from the testing site will be studied. That have not been pumped in the last 24 hours.
- That are more than 1 Km away from wells that are being pumped during the test or that have been pumped in the 24 hours prior to beginning the test.
- Where the construction characteristics of the well are known, such as: flow rate, depth, diameter, casing, geological section and electronic recorder.
- That have adequate conditions to be used as monitoring or pumping wells.

The objective of a pumping test is to determine the hydraulic characteristic of the aquifers; this type of tests that study the aquifer itself and the well, are also known as aquifer tests. When properly planned and executed, they provide basic information to resolve local and regional problems with groundwater flow.

In order to determine the specific capacity or the flow rate/drawdown ratio, to select the proper pumping equipment and the optimum pump rate, flow rate tests are done. These are also considered pumping tests, but they are done in steps, increasing the extraction rate over time.

It is important to note that all the tests were conducted in strictly controlled conditions, so that once the variation for one magnitude and its effect were known, the aquifer characteristics could be determined.

In order to conduct pumping tests, the following conditions were sought:

- That the aquifer was as homogenous as possible.
- That the aquifer responded to a simple model.
- Where there were not any boundaries, or at least well defined boundaries nearby; that no natural changes in permeability were expected.
- Where the geological structure of the subsoil was well known.
- Where there was no pumping nearby (1 km) or other activities that would cause large variations in the water level.
- Where the pumped water does not return to the aquifer.
- The well should have reliable pumping equipment installed, sufficient capacity for the test and the appropriate flow control equipment.
- It must be possible to properly measure the water level in the control well before, during and after the test.

Because over most of the aquifer's surface area, the wells are only equipped with pumps that are wind generated (windmills), internal combustion or chain pumps, they do not meet the requirements needed to perform pumping tests. For this reason, seven of the tests were carried out on the north side where the Conejos Medanos Aqueduct wellfield is located, because of the equipment conditions and the access provided by the operator. Overall, the direction of the subsurface flow throughout the aquifer has the same tendency, in other words, it travels from the mountainous area towards the center of the aquifer; from there, it heads north and northeast until reaching the natural outlet area. It is worth mentioning that in the wellfield area, a small drawdown cone has formed, which has not been able to fully invert the direction of the flow. As a result, the natural outlets to the aquifer remain.
The remaining tests were conducted in low flow wells, thus the results are less reliable than those done in the wellfield.

Given the demand for the volume of water that the wellfield supplies to Ciudad Juárez, the operational conditions of the wells in the wellfield and the security of the operations personnel, the pumping tests performed lasted a short time, between 6 and 8 hours; even so, it was possible to take readings in the first few hours of the day following the start of the test for either of its stages. This allowed the greatest number of readings to be taken.

It is important to remember that changes in the static level of wells can be influenced by several variables, such as: variations in atmospheric pressure and the well's down time, Additionally, the natural flow in most aquifers normally varies from day to day, therefore it is necessary to observe the water depths for some time prior to the test in order to determine the water level trend and use it to calculate drawdowns. The observation period before beginning the test (prior to t=0) should be, as a general rule, at least two times the duration of the test. For this reason, the survey and piezometry activities in the wellfield were performed at least 48 hours prior to carrying out the test.

When carrying out the test, measurements were taken at the beginning, at intervals of 15 and 30 seconds, and 1, 2, 4, 8, 15, 30, 60 minutes; subsequent readings were taken every hour using a pumping form like the one shown in Figure 4.1.

Servicio Geológico Mexicano

GERENCIA HIDROGEOLOGIA

SUBGERENCIA DE MODELADO DE CUENCAS

PRUEBA DE BOMBEO

POZO: CM-51 LOCALIDAD: BALNEARIO

FECHA: 10/08/2010 PROPETIARIO: EJIDAL

PROFUNDIDAD: (m) Φ DESCARG. 2 Φ ADEME: 14

CAUDAL PROM: 4 (lps) CAUDAL ESP: APROVECHAMIENTO: POZO

Cooordenadas PRUEBA DE BOMBEO: PB-01

X= 340662 Y= 3498744 Z= 1246 brocal= 23 cm

ETAPA DE ABATIMIENTO	ETAPA DE RECUPERACION
FECHA: 10/08/2010	FECHA: 10/08/2010
HORA DE INICIO: 08:15 a.m.	HORA DE INICIO: 14:30 pm
HORA DE TERMINACION: 14:30 pm	HORA DE TERMINACION: 15:30 pm
DURACION: 6:15 hrs	DURACION: 1 hr
NIVEL ESTATICO: 89.94 m	N.D.: 90.22

HORA	TIEMPO ACUMULADO	PROFUNDIDAD DEL AGUA (m)	ABATIMIENTO (m)	HORA	TIEMPO ACUMULADO (MIN)	PROFUNDIDAD DEL AGUA (m)	RECUPERACIÓN (m)
08:15	15 seg	89.94	0.00		15 seg	90.11	-0.17
08:15	30 seg	90.02	0.08		30 seg	90.06	-0.12
08:16	1 min	90.10	0.16		1 min	90.03	-0.09
08:17	2 min	90.15	0.21		2 min	90.02	-0.08
08:19	4 min	90.17	0.23		4 min	89.99	-0.05
08:23	8 min	90.20	0.26		8 min	89.99	-0.05
08:30	15 min	90.21	0.27		15 min	89.96	-0.02
08:45	30 min	90.23	0.29		30 min	89.95	-0.01
09:15	1 hora	90.23	0.29		1 hora	89.94	0.00
10:15	2 horas	90.22	0.28		2 horas		
11:15	3 horas	90.18	0.24		3 horas		
12:15	4 horas	90.22	0.28		4 horas		
13:15	5 horas	90.22	0.28		5 horas		
14:15	6 horas	90.22	0.28		6 horas		
14:30	6:15 horas	90.22	0.28		7 horas		
	8 horas				8 horas		
	9 horas				9 horas		
	10 horas				10 horas		
	11 horas				11 horas		
	12 horas				12 horas		
	13 horas				13 horas		
	14 horas				14 horas		
	15 horas				15 horas		
	16 horas				16 horas		
	17 horas				17 horas		
	18 horas				18 horas		
	19 horas				19 horas		
	20 horas				20 horas		
	21 horas				21 horas		
	22 horas				22 horas		
	23 horas				23 horas		
	24 horas				24 horas		
	25 horas				25 horas		

Figure 4.1. Pumping Test Form.

Manual electrical meters (probes) were used for the 10 pumping tests; they indicate water contact using a meter or a buzzer. (Photograph 4.1)

Photograph 4.1. Electrical Probe

The pumping tests were carried out in two stages, drawdown and recovery. The former is when the pumping equipment is turned on and starts to records dropping groundwater levels; then the equipment is turned off and the readings for the recovery phase begin.

All pumping was done in strictly controlled conditions (for the pumping at a constant flow rate), so that once the variation for one magnitude and its effect were known, the aquifer characteristics could be determined. Overall, the pumping was done at a constant flow rate, at least over a certain period of time.

4.2 Results

Average values for hydraulic parameters have been reported by several authors, including Técnicas Geológicas y Mineras S.A. (1987), with transmissivity values of 2.0×10^{-3} m^2/s and a hydraulic conductivity of 8.69×10^{-6} m/s. The now defunct Secretariat of Agriculture and Hydraulic Resources (SARH, 1989) reported transmissivity values between 2.0×10^{-3} and 4.4×10^{-3} m^2/s. In addition, INEGI (1999) reported transmissivity values ranging from 2.0×10^{-3} to 4.4×10^{-3} m^2/s. The Mexican Geological Service (2007) obtained transmissivity values of 4.0 x10-3 m2/s.

Figure 4.2 shows the location of the pumping tests performed for the current study.

Given the erratic behavior of the water levels during the drawdown phase of the pumping tests, these were interpreted with some precaution, using the Theis method for semiconfined aquifers. The Theis-Jacob method was used for the recovery phase, giving results with a high level of confidence. All of these parameters were calculated using the Aquifer Test program. The corresponding graphs can be found in Appendix II, Volume II of this study.

It is worth mentioning that this erratic behavior in the groundwater levels is primarily linked to the fact that when pumping of the well starts, the water is discharged only a few meters away from the well site, within a lapse of time ranging from 15 minutes and one hour, at a flow rate than is greater than the one that is subsequently introduced into the system. It is this variation in the pumped volumes, as well as possible inflows into the system from the pumped water, which causes the water levels to have erratic behavior.

The transmissivity results show a behavior that for the most part matches the data published by several authors, given that the values fall within the 10^{-3} m^2/s range, except for two of them; one located between the Juárez Mountains and the El Sapello Mountains with a transmissivity of 2.28 $x10^{-4}$ m^2/s and the other to the northwest of Samalayuca at the Ojo de la Punta Ranch, with a high transmissivity of 2.29 $x10^{-1}$ m^2/s. It is worth noting that this datum does not represent a behavior of the aquifer, rather of a particular area, which serves as one of the primary recharge zones for the Conejos Medanos Aquifer.

The same goes for the hydraulic conductivity—most values were 10^{-5} m/s except for the wells located outside of the wellfield, where a K= 1.14 $x10^{-6}$ m/s was obtained, and in the case of Ojo de la Punta a K= 1.34 $x10^{-3}$ m/s. Table 4.1 gives the results of the pumping tests, for both the drawdown and the recovery phases. It is worth noting that the pumping tests done in the wellfield have a higher confidence, since greater volumes are withdrawn.

There are noticeably average or typical values for the Conejos-Medanos Aquifer area; however, there are also values outside the average range cause by wells with particular characteristics, meaning, low flows or short time in operation. The three wells outside the wellfield where pumping tests were performed fall into this category. On the other hand, there are also variations in the interior of the wellfield, which are associated with the presence of argillaceous lenses and/or large grain deposits, which cause local impacts, different from the established average trend.

Table 4.1. Pumping Test Results.

Prueba Bombeo	CLAVE SGM	POZO JCAS	X	Y	Método	Etapa		Duración de la etapa (horas)		Transmisividad	Conductividad Hidraúlica
						Abatimiento	Recuperacion	Abatimiento	Recuperacion	(m^2/s)	(m/s)
					Theis	X		6 horas 15 min	1 hora	$9.90\ X10^{-3}$	$9.00\ X10^{-5}$
PB-01	CM-051		340662	3498744	Theis-Jacob		X			$9.55\ X10^{-3}$	$4.77\ X10^{-5}$
					Theis	X		6 horas	5 horas	$2.29\ X10^{-4}$	$1.14\ X10^{-6}$
PB-02	CM-006		351799	3498720	Theis-Jacob		X			$2.28\ X10^{-4}$	$1.14\ X10^{-6}$
					Theis	X		5 horas	1 hora	$8.31\ X10^{-2}$	$4.15\ X10^{-4}$
PB-03	CM-122		347744	3473201	Theis-Jacob		X			$2.69\ X10^{-1}$	$1.34\ X10^{-3}$
					Theis	X		6 horas	6 horas	$4.26\ X10^{-3}$	$2.84\ X10^{-5}$
PB-04	CM-054	1	333137	3513808	Theis-Jacob		X			$5.99\ X10^{-3}$	$2.99\ X10^{-5}$
					Theis	X		6 horas	7 horas	$4.03\ X10^{-3}$	$2.01\ X10^{-5}$
PB-05	CM-056	5	325453	3511473	Theis-Jacob		X			$4.56\ X10^{-3}$	$2.28\ X10^{-5}$
					Theis	X		6 horas	6 horas	$4.94\ X10^{-3}$	$2.47\ X10^{-5}$
PB-06	CM-055	3	327560	3513840	Theis-Jacob		X			$6.39\ X10^{-3}$	$3.19\ X10^{-5}$
					Theis	X		6 horas	5 horas	$1.73\ X10^{-3}$	$8.66\ X10^{-6}$
PB-07	CM-125	25	323930	3504608	Theis-Jacob		X			$1.55\ X10^{-3}$	$7.77\ X10^{-6}$
					Theis	X		5 horas	6 horas	$3.18\ X10^{-3}$	$1.59\ X10^{-5}$
PB-08	CM-038	18	330849	3507703	Theis-Jacob		X			$5.11X10^{-3}$	$2.55\ X10^{-5}$
					Theis	X		6 horas	5 horas	$3.35\ X10^{-3}$	$1.67\ X10^{-5}$
PB-09	CM-053	9	333602	3509498	Theis-Jacob		X			$3.15\ X10^{-3}$	$1.57\ X10^{-5}$
					Theis	X		5 horas	6 horas	$3.57\ X10^{-3}$	$1.78\ X10^{-5}$
PB-10	CM-116	24	325138	3513641	Theis-Jacob		X			$4.34\ X10^{-3}$	$2.17\ X10^{-5}$

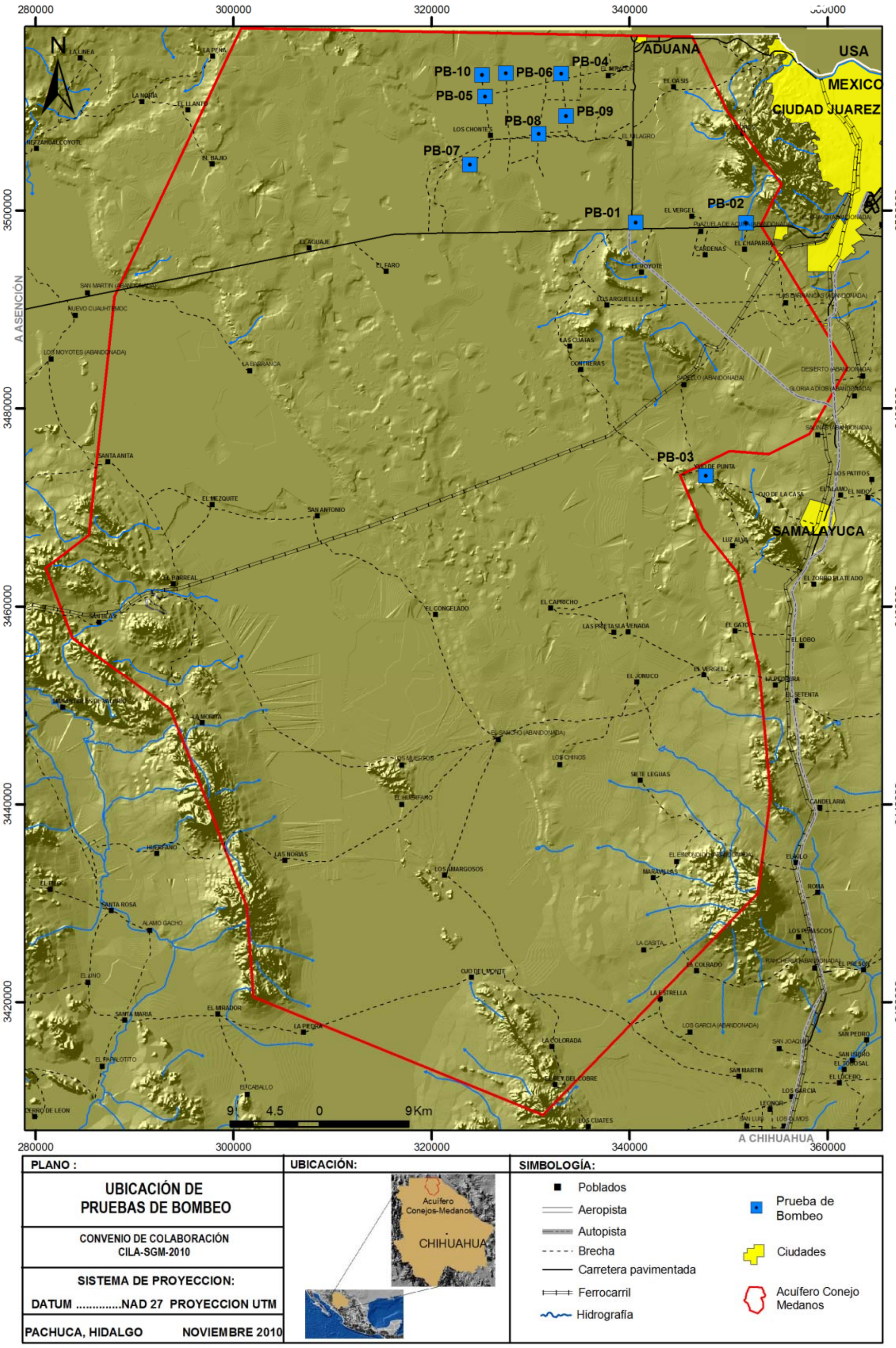


Figure 4.2 Location of pumping tests.

5 AQUIFER BEHAVIOR

5.1 Hydrostratigraphic Units

The hydrogeological units (HU) group together lithologies with similar behavior that permit the flow and storage of groundwater, in other words, characterized by similar hydraulic properties T, K, and S. To classify them, the HU are defined as having high, moderate, low or very low permeability (basement).

The hydrostratigraphic units were defined using the physical characteristics of the rock (compaction and fracturing), by assigning them a value according to the qualitative permeability: high, moderate-high, moderate, moderate-low, low. This was done in order to prepare a hydrogeological map (using the geological map as a starting point) based on the “International Legend for Hydrogeological Maps” jointly published in 1970 by the International Association of Hydrogeologists (IAH), the International Association of Hydrological Sciences (IAHS), UNESCO, and the London Institute of Geological Sciences, which was revised and updated in 1983.

The following units were then identified:

- Granular material with high permeability.
- Granular material with moderate permeability.
- Granular material with moderate-low permeability.
- Fractured material with moderate permeability.
- Fractured material with moderate-low permeability.
- Fractured material with low permeability.

On that basis, the granular material (present in the low-lying topographic areas) is what has the greatest potential to confine groundwater. This is because the material here, in this case consisting of Polymictic Conglomerate (Tpl Cgp and Qho Cgp), Sandstone-silt (Tpl Ar-lm), and the Samalayuca Formation (TRJm Ar-Cgp), has a moderate to high permeability.There is also highly fractured consolidated material associated with a moderate permeability, made from the following units: Basalt (To B, Tm B and Tpl Qpt B), Rhyolitic Tuff (To TR), Aurora Group (Kaim Cz-Lu) and Andesite (Te A). Then there are the low permeability units, considered to be the hydrogeological basement, which limit the aquifer: Tonalite (Te? Tn), Granite-Granodiorite (To Gr-Gd) and Quartz Monzonite (Te qMz).

It is important to note that the depths of the wells in the study area range from 130 m to 350 m, and most of them are found in highly permeable materials (mainly sands), such as these formations: La Casita Formation (Jkpo Ar-Lu) and Navarrete Las Vigas Formation (Kbeh Ar-Lu). Figure 5.1 shows the distribution of the identified hydrostratigraphic units in the Conejos-Medanos Aquifer.

The units that contain the aquifer are mainly those that are shown in shades of blue, comprised of granular material (sands, gravels, silt and clay), labeled on the geological map as: Silt-sand (Qho lm-ar) and Lacustrine (Qho la), created through erosive processes, with eolic erosion currently being the most important of those processes. The area of greatest interest is the eolic sands (the light blue color), represented by the geological unit Eolian (Qho eo), where the aquifer is considered free. The wellfield that provides potable water to Ciudad Juárez is currently located in this type of material. The wells there have a depth of 240 m, and the current static levels are at a depth that ranges between 90 m and 105 m.

The units shown in shades of green have moderate to low permeabilities. Only the unit made from folded shales and limestone, with open fractures (Kaim Cz-Lu), contains water, and it is believed to contribute water to the granular material. The other units are considered to have moderate to low permeability, and thus are considered part of the hydrogeological basement.

Therefore, the primary recharge zones are the runoff from the edges of the mountains, comprised of fractured consolidated materials, as is seen in the configurations for static level elevation and depth to static level. And to a lesser extent, recharge originates in the granular material itself; due to the environmental temperature conditions, there is a high degree of evapotranspiration.

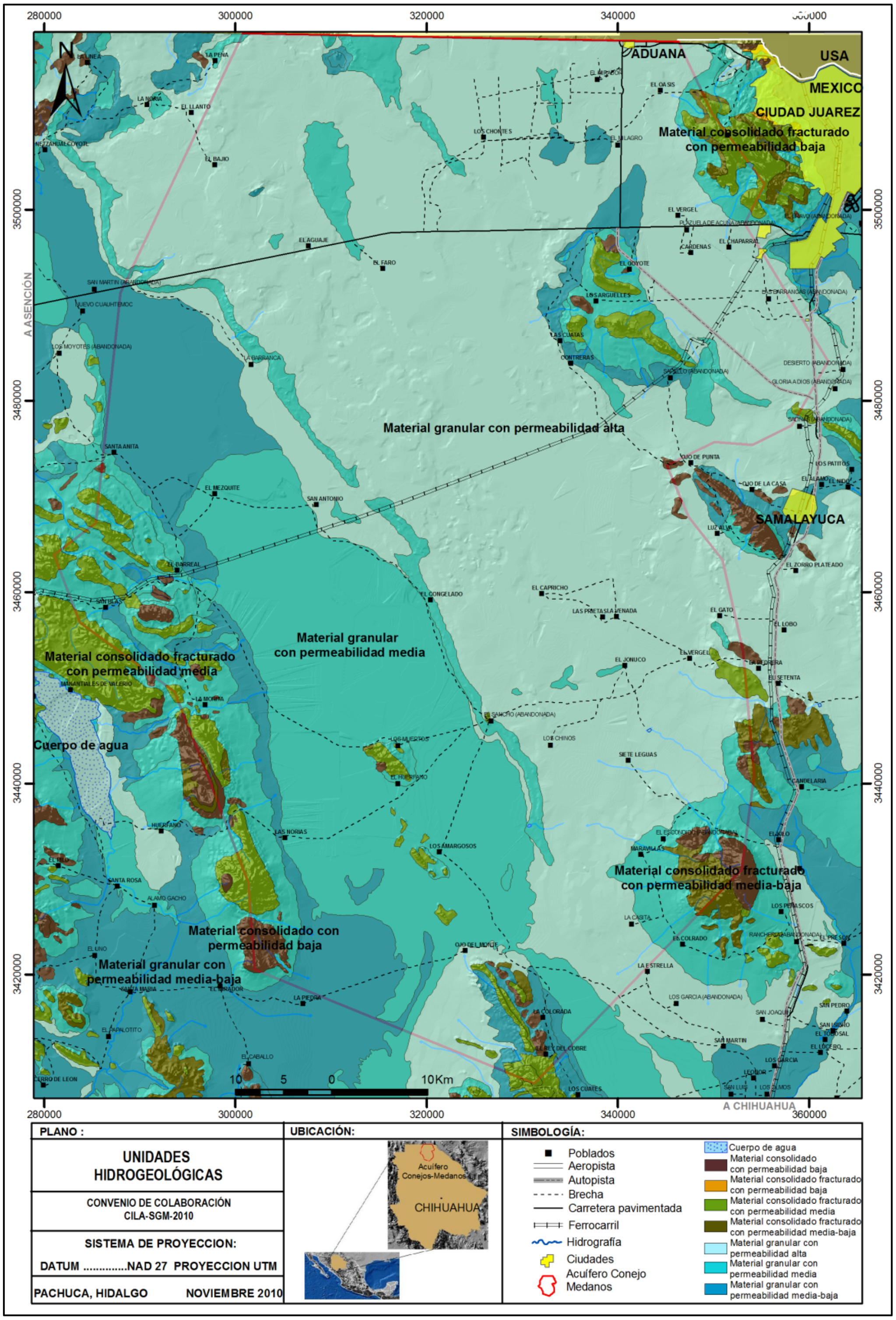


Figure 5.1. Hydrostratigraphic Units

5.2 Geometry of the Aquifer System

The Conejos Medanos Aquifer is located in a rift valley caused by distensive forces after the Laramide Orogeny. This rift (or graben) has been and continues to be filled by granular material generated by the crumbling of the rocks that surround it and form its boundaries. The aquifer itself is found within this granular material, which has some argillaceous horizons, causing some zones to behave locally as a semiconfined aquifer. (Figure 5.2)

It is important to mention that in the final report on the Moyotes well (drilled by PEMEX in 1971), in the section containing the geophysical records from the inductions performed, an “aquiferous zone with a NaCl concentration of 10,000 ppm” was reported at an interval of 405 m to 440 m, indicating a probable confined aquifer with fossil water at said depth.

With the support of the high-resolution aerial magnetic survey provided by the Mexican Geological Service (Figure 5.3), the structural control of the aquifer can be clearly observed, where structures with a preferentially northwest-southeast orientation predominate. Also, in the area known as the El Barreal Rift, it is possible to see that the area is filled by volcanic material lying under the 500 m of argillaceous materials.

The presence of two zones of fill material is notable. These represent the greatest aquifer potential in the area. On one side, the far southwest edge of the aquifer, it forms a small rift; on the other, a strip oriented northeast-southwest, parallel to the rift valley and located east of it.

In order to obtain more information about the aquifer system geometry, Figure 5.4 contains two sections with time-domain electromagnetic soundings. (SGM 2007) On the north section, five geoelectric units are observed: on the surface layer with a thickness of 2 to 20 m with values less than 6 Ohm-m, related to eolic materials, sands, and caliche. The interpretation of the section is found in Figures 5.5 and 5.6.

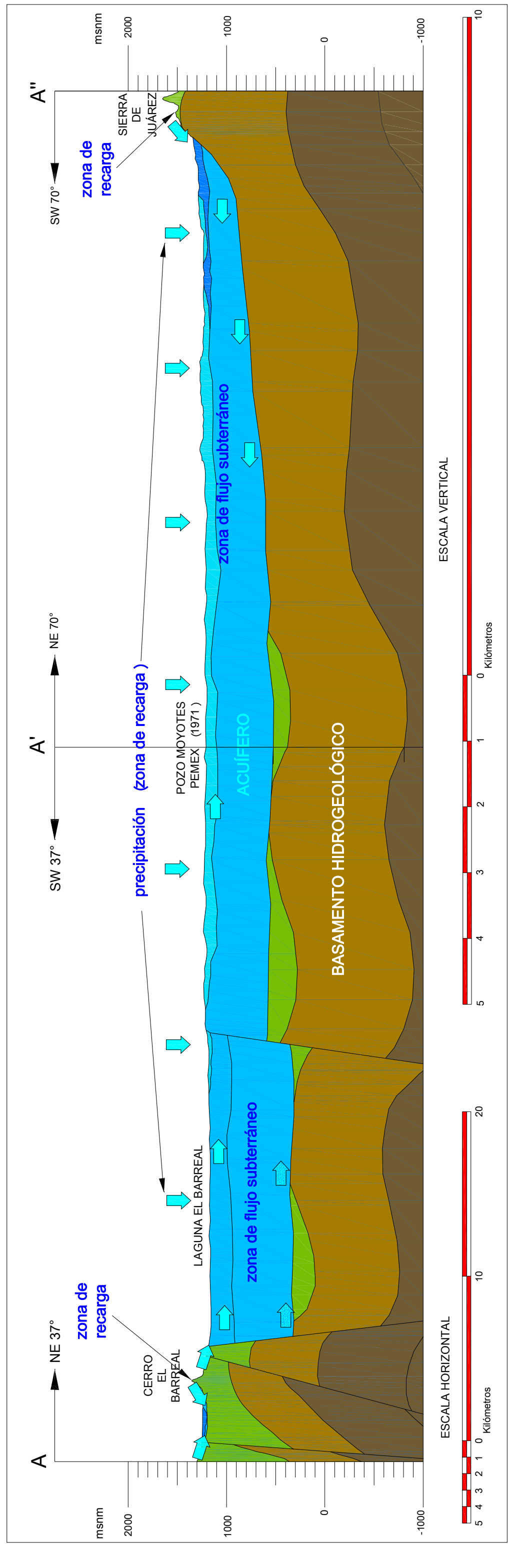


Figure 5.2 System Geometry

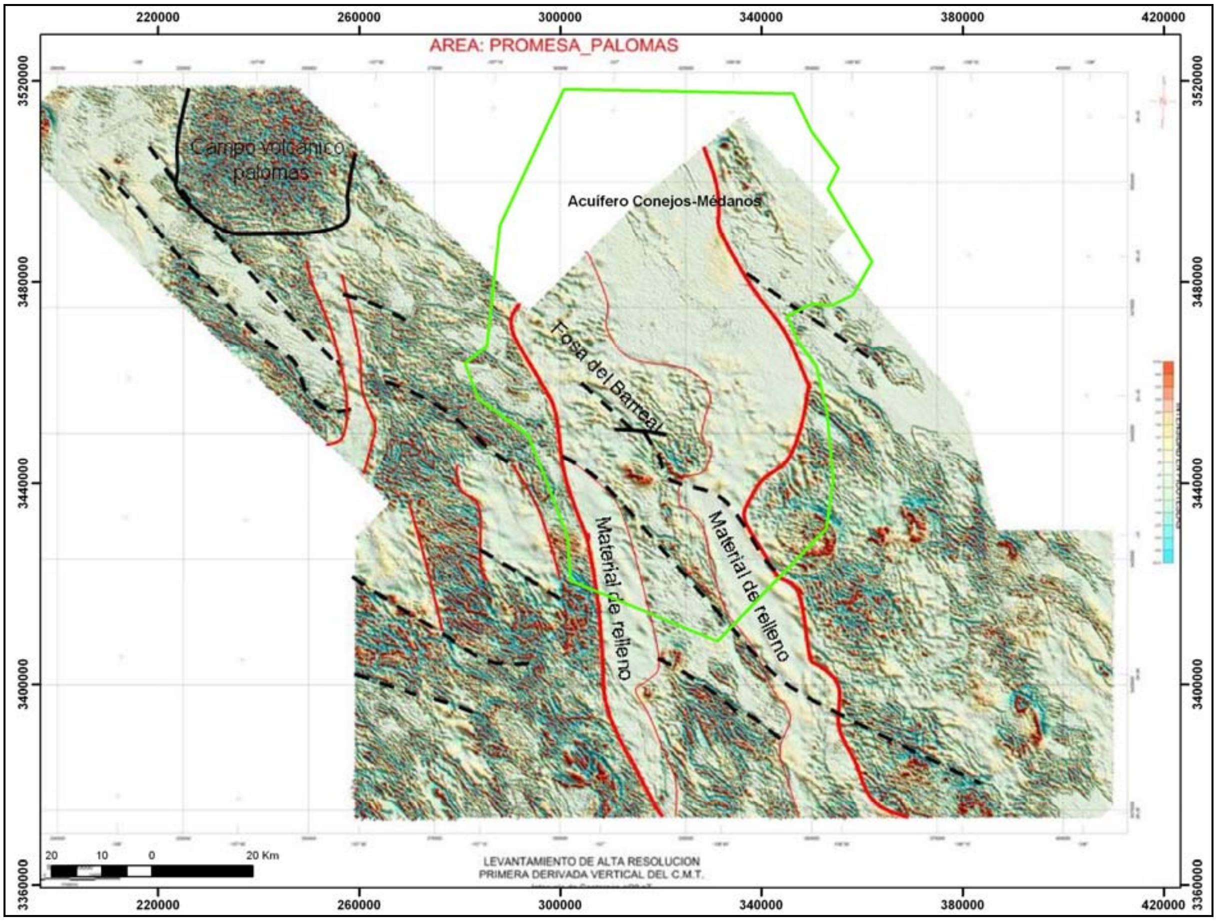


Figure 5.3 Low-resolution Aerial Magnetic Survey.

Deep down, a second unit with resistivity of between 7 and 50 Ohm-m is found linked to a presence of alternating layers of shale and sandy shale, with a thickness ranging from 25 to 400. It is worth noting that bands of high resistivity are found in the center of the section, related to unsaturated sand and gravel horizons.

Deep down, a unit with resistivity of between 6 and 13 Ohm-m is found that can be correlated to argillaceous horizons whose thickness ranges from 315 to 370. Lastly, the presence of units with resistivities between 12 and 30 Ohm-m stands out, which correlate to altered igneous material and conglomeratic sandy shale formed through alteration to the igneous rock. Materials with a resistivity greater than 30 Ohm-m were found, associated with intrusive igneous rocks.

From this, it can be concluded that the granular material in the north-central area has a maximum thickness of 790 m. Figures 5.5 and 5.6 show that the greatest hydrogeological potential is found in the central-west area, at a average depth of 400 m. According to the same results, the wellfield is located in an area with low resistivity, thus the aquifer's poor response to the current pumping.

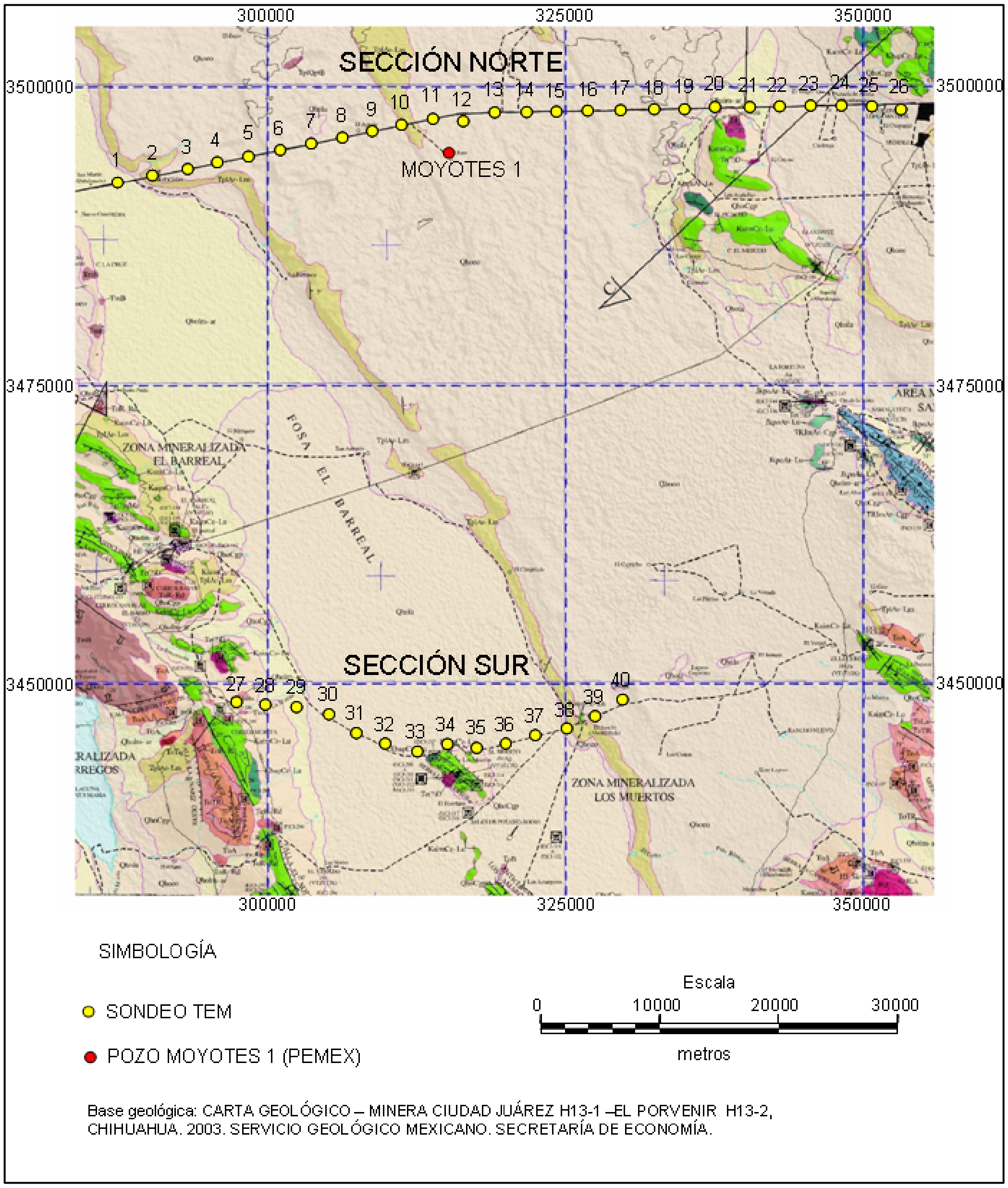


Figure 5.4 Location of the Electromagnetic Soundings (SGM, 2007)

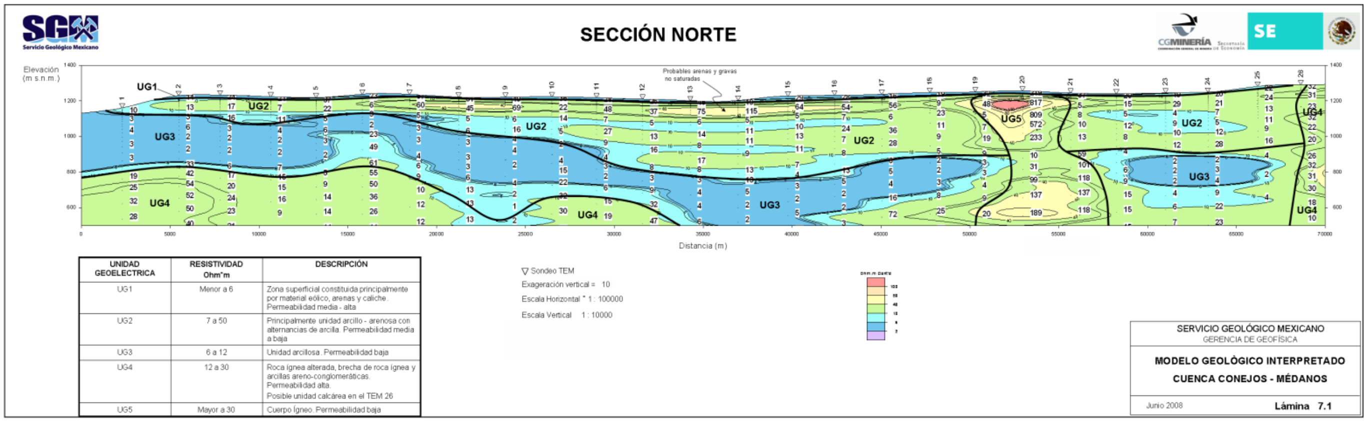


Figure 5.5 Resistivity Distribution on the North Side.

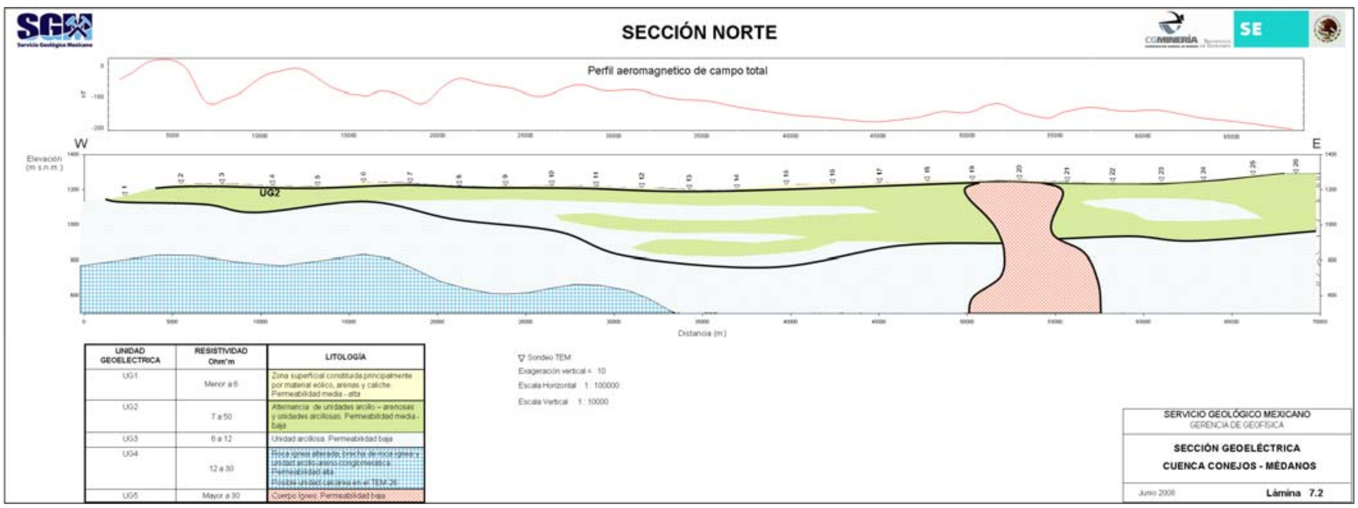


Figure 5.6 North Geoelectric Section.

As was stated previously, the north section is characterized by the presence of several geoelectric units. The area where the Conejos Medanos Aquifer wellfield is located is mainly comprised of alternating argillaceous-sandy units and argillaceous units, which creates a moderate permeability. It is this north section that shows the greatest hydrogeological potential in the wellfield area, but at a greater depth, between 450 and 500 m.

Figure 5.7 indicates the location of a series of lithologic sections provided by the Ciudad Juárez Municipal Water and Sanitation Board. These sections correlate the dominant presence of fine materials with sands, resulting in a moderate permeability zone as stated previously, as evidenced by the lithologic sections shown in Figure 5.8.

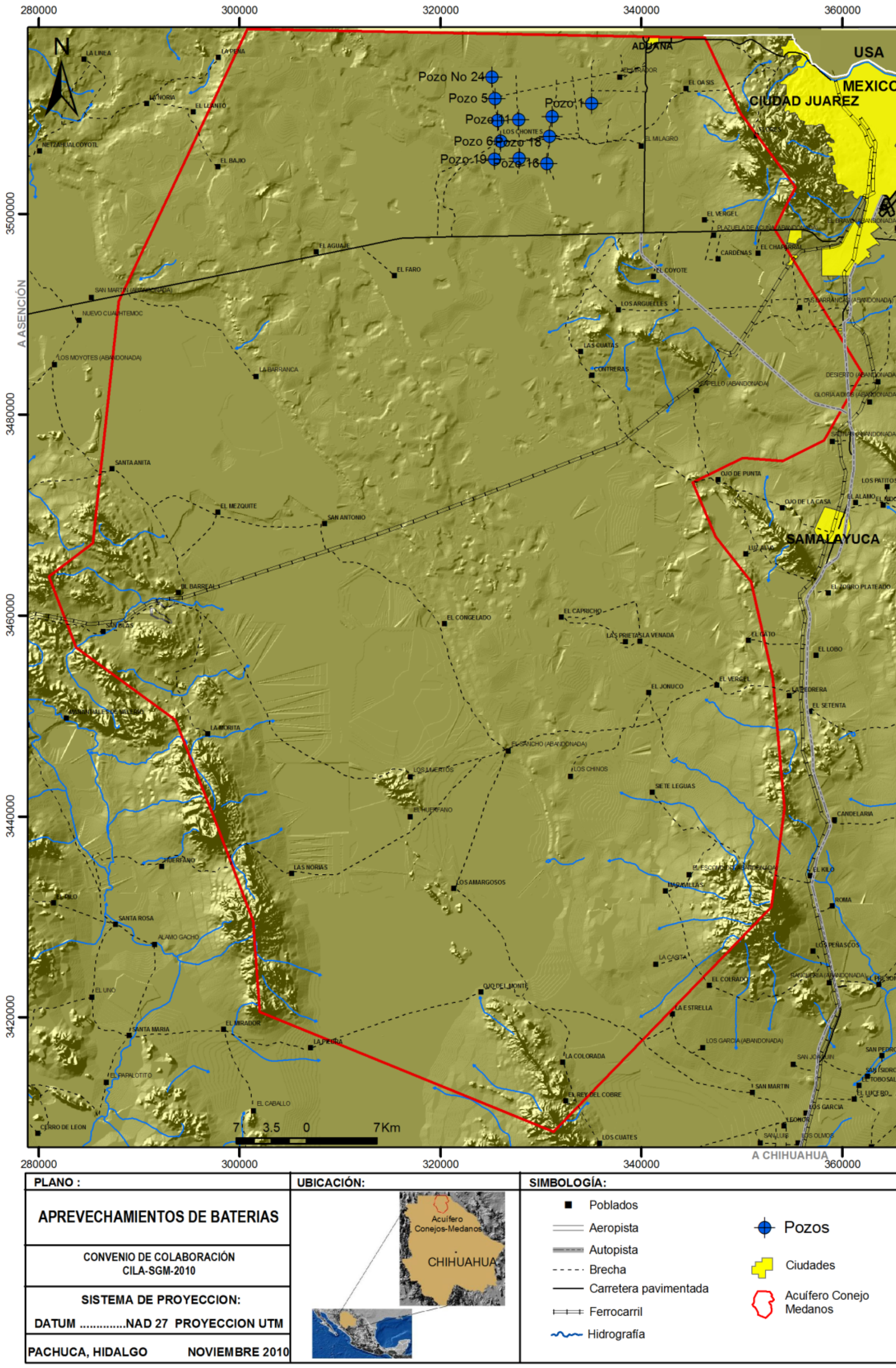


Figure 5.7 Location of Points on the Lithologic Sections.

Junta Municipal
DE AGUA Y SANEAMIENTO
DE CD. JUAREZ, CHIHUAHUA
MEXICO

DIRECCION TECNICA

REPORTE LITOLOGICO DE MUESTRAS DE CANAL DEL **POZO 7**

Ubicación: CALLE: BATERIA **COLONIA:** CONEJOS MEDANOS

Cd. Juárez Chih., FEBRERO 2000

INTERVALO	DESCRIPCION LITOLOGICA	TIPO
0- 2	MATERIAL CALICHOSO COLOR CREMA CON GRANULOMETRIA GRAVAS	I
2- 4	MATERIAL CALICHOSO COLOR CREMA CON GRANULOMETRIA GRAVAS	I
4- 6	MATERIAL CALICHOSO COLOR CREMA CON GRANULOMETRIA GRAVAS	I
6- 8	MATERIAL CALICHOSO COLOR CREMA CON GRANULOMETRIA GRAVAS	I
8- 10	MATERIAL CALICHOSO COLOR CREMA CON GRANULOMETRIA GRAVAS	I
10- 12	MATERIAL CALICHOSO COLOR CREMA CON GRANULOMETRIA GRAVAS	I
12- 14	MATERIAL CALICHOSO COLOR CREMA CON GRANULOMETRIA GRAVAS	I
14- 16	MATERIAL CALICHOSO COLOR CREMA CON GRANULOMETRIA GRAVAS	I
16- 18	ARCILLA CON GRAVA DE MATERIA CALICHOSO	I
18- 20	ARCILLA CON GRAVA DE MATERIA CALICHOSO	I
20- 22	ARCILLA CON GRAVA DE MATERIA CALICHOSO	I
22- 24	ARCILLA CON GRAVA DE MATERIA CALICHOSO	I
24- 26	ARENAS MUY FINAS	I
26- 28	ARENAS MUY FINAS	I
28- 30	ARENAS MUY FINAS	I
30- 32	ARENAS MUY FINAS	I
32- 34	ARENAS MUY FINAS	I
34- 36	ARENAS MUY FINAS	I
36- 38	ARENAS MUY FINAS	I
38- 40	ARENAS MUY FINAS	I
40- 42	ARENAS GRUESA DE MATERIAL CALICHOSO	I
42- 44	ARENAS GRUESA DE MATERIAL CALICHOSO	I
44- 46	ARCILLA COLOR CREMA CON ESCASOS GRAVAS	I
46- 48	ARCILLA COLOR CREMA CON ESCASOS GRAVAS	I
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50- 52	ARCILLA COLOR CREMA CON ESCASOS GRAVAS	I
52- 54	ARCILLA COLOR CREMA CON ESCASOS GRAVAS	I
54- 56	ARCILLA COLOR CREMA CON ESCASOS GRAVAS	I
56- 58	ARCILLA COLOR CREMA CON ESCASOS GRAVAS	I
58- 60	ARCILLA COLOR CREMA CON ESCASOS GRAVAS	I
60- 62	ARCILLA COLOR CREMA CON ESCASOS GRAVAS	I
62- 64	ARCILLA COLOR CREMA CON ESCASOS GRAVAS	I
64- 66	ARCILLA COLOR CREMA CON ESCASOS GRAVAS	I
66- 68	ARCILLA COLOR CREMA CON ESCASOS GRAVAS	I
68- 70	ARCILLA COLOR CREMA CON ESCASOS GRAVAS	I
70- 72	ARCILLA COLOR CREMA CON ESCASOS GRAVAS	I
72- 74	ARCILLA COLOR CREMA CON ESCASOS GRAVAS	I
74- 76	ARCILLA COLOR CREMA CON ESCASOS GRAVAS	I
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126- 128	INTERCALACIONES DE MATERIAL ARCILLOSO COLOR CREMA Y ARENAS MUY FINAS	I
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Junta Municipal
DE AGUA Y SANEAMIENTO
DE CD. JUAREZ, CHIHUAHUA
MEXICO

DIRECCION TECNICA

REPORTE LITOLOGICO DE MUESTRAS DE CANAL DEL **POZO 19**

Ubicación: CALLE: BATERIA **COLONIA:** CONEJOS MEDANOS

Cd. Juárez Chih., FEBRERO 2000

INTERVALO	DESCRIPCION LITOLOGICA	TIPO
0- 2	MATERIAL CALICHOSO DE COLOR CREMA	I
2- 4	MATERIAL CALICHOSO DE COLOR CREMA	I
4- 6	MATERIAL CALICHOSO DE COLOR CREMA	I
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Figure 5.8. Predominance of Fine Materials in the Lithological Sections of the Wells in the Wellfield.

As can be observed in Figures 5.5 (center right of the section) and 5.8, and in the area where the Conejos Medanos Aquifer wellfield is located, the presence of fine materials is dominant, reducing the site's permeability. Thus, when the amount of water withdrawn exceeds the natural inflow, a drawdown cone is produced, as previously shown in Figure 3.12.

It is worth mentioning that several lithologic sections were consulted during the development of this study, which are available for review in Appendix IV of the study. The sections consulted show a clear tendency towards the presence of fine materials, as well as a depth of less than 300 m, which reduces the withdrawal potential in the wellfield.

On the other hand, the section studying the south-central area is characterized by a resistivity less than 5 Ohm-m, which corresponds to the response of argillaceous material. It demonstrates significant thickness, even exceeding 500 m, and is found as fill in the El Barreal Rift. (Figures 5.9 and 5.10)

Resistivity greater than 20 Ohm-m does occur, defining blocks that can be attributed to the presence of limestone bodies, affected in some cases by the presence of intrusive rock apophysis, which can be interpreted from the magnetic profile.

As for the possibility of being defined as an aquifer in this area, it would be in the center of the section at a depth of at least 200 m.

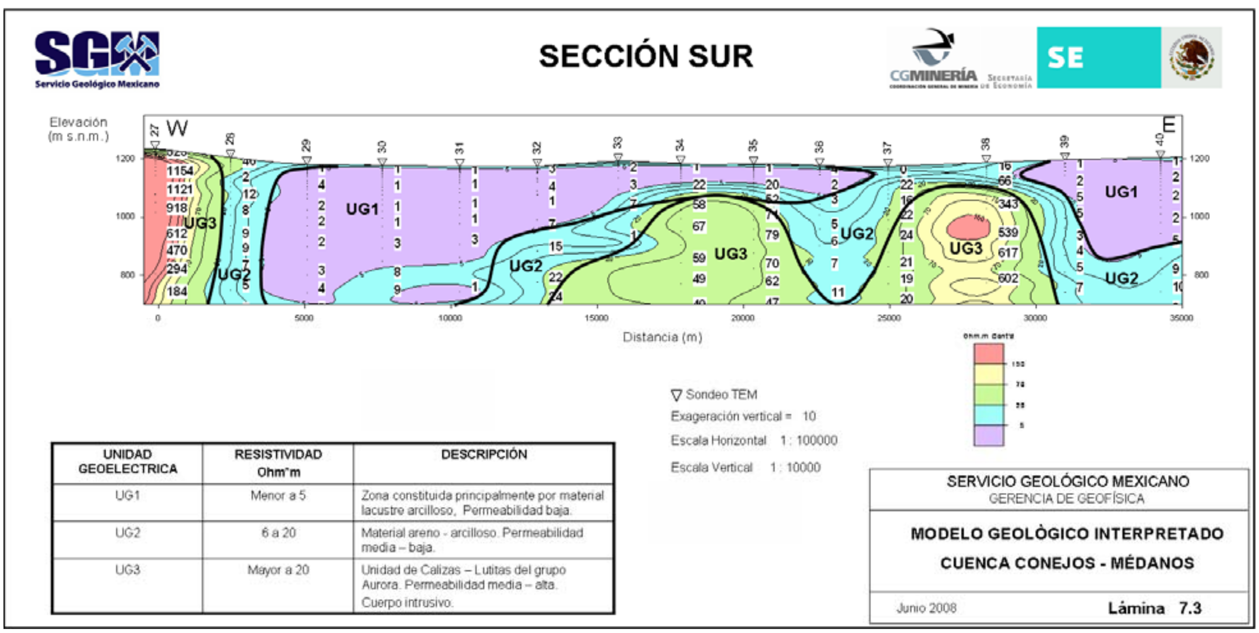

Figure 5.9 Resistivity Distribution on the South Side.

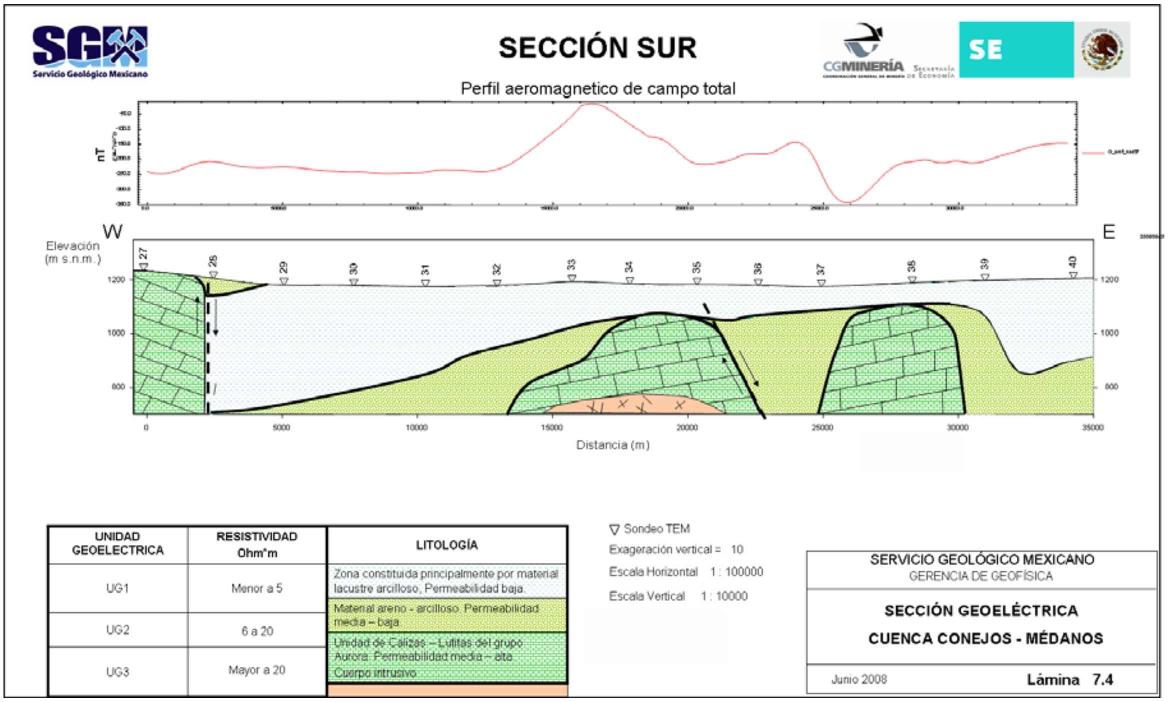

Figure 5.10 South Geoelectric Section.

5.3 Hydraulic Parameters of the System

According to the pumping tests performed for this study, average transmissivity values of between 2.0 and 4.4 $x10^{-3}$ m^2/second were found, while the average hydraulic conductivity values were between 3.19 and 5.12 $x10^{-5}$ m/s. It is worth noting that this data is representative of the area where the Conejos Medanos Aqueduct wellfield is located.

Also worth mentioning, is that it was not possible to perform pumping tests on the observation wells, so no data is available for the storage coefficient. However, according to CONAGUA (2009), the specific storage values (Ss) vary from 1 x 10-7 to 2.8 x10-5. Its average value is 1 x 10-6, therefore the specific yield is considered to have an average value of 0.15. These values are very similar to the ones used in study and simulation models done for the U.S. portion of the aquifer.

5.4 Indicator Features For Regional, Intermediate and Local Flow Systems

According to Toth, 1962; Meyboon, 1966, there are several indicator features for flow systems, such as: topography, piezometry, springs, base flow, presence of phreatophyte vegetation, and soil type distribution. In order to identify the flow systems, it is useful to put together charts that plot the well depth against the static level depth. This helps identify the predominant presence of descending (recharge zones) and ascending (discharge zones) vertical flow and flow in transit (horizontal). (Freeze and

Cherry, 1979) However, this was not possible in this case, since there is not data for well depths, other than for the wells located in the wellfield.

The local flow system originates in the valley area, as the result of vertical infiltration from rainfall. This flow system feeds the shallow part of the aquifer, in other words, the vadose zone, where the its infiltration speed depends on the content of argillaceous material. Its presence is evident in shallow wells with close-to-neutral pH values, and a few hundreds of mg/l in Total Dissolved Solids.

The intermediate flow system sustains the majority of water withdrawn from the aquifer. It is generated by rainfall infiltrating into topographically-high zones, where the permeability conditions are suitable for water infiltration and subsequent transport to the aquifer zone. Its primary indicator is the water family types reported in the literature, for example the mixed sulfate type and the sodium-bicarbonate-sulfate type.

Evidence of this can be seen in Figure 5.11, which plots the depth of some of the wells located on the north side of the wellfield against their static level. In most cases, a zone [with] the dominate presence of recharge coming from the far south and southwest side of the aquifer is observed; to a lesser degree, there are wells found in the groundwater transport zone that has a preferential north-northeast heading. It should be noted that no wells are found in the discharge zone, since the natural aquifer outlet is located outside the administrative boundaries of the Conejos-Medanos Aquifer.

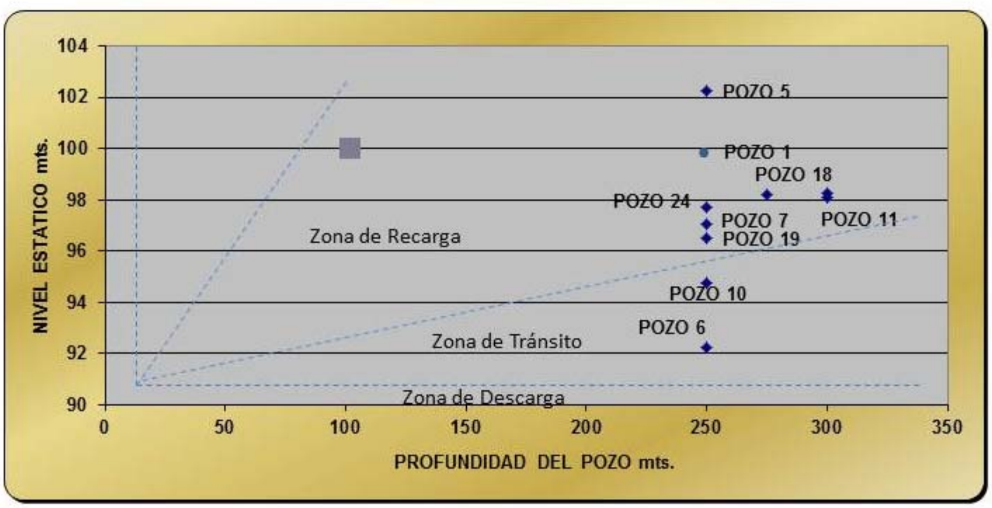

Figure 5.11. Well Depth vs Static Level

Using the configurations taken from the piezometric data and adding to them the presence of springs aligned with the main geological structures in the Laguna El Barreal area, the existence of a regional flow system is likely. This system would also use regional geological structures as its transport conduit. It is worth noting that in the report on the Moyotes well drilled by PEMEX in 1971, the existence of a deep aquifer more than 400 meters down was suggested.

5.5 Groundwater Flow Network.

The preferential direction of the subsurface flow is shown in Figure 4.5, where it can be seen that the aquifer gets recharge from the Laguna de Patos Aquifer. This water circulates, according to the directions of subsurface flow, from southeast to northwest, following the preferred orientation for the area known as El Barreal; it also flows through the center of the aquifer, where the preferential direction of the groundwater flow is to the northeast. (Figure 5.12)

Another groundwater inflow comes from the foothills of the mountains that limit the aquifer; its preferential flow direction is towards the center of the aquifer. This is shown in the data obtained during the piezometry survey, where it was determined that there is an inflow in the eastern part of the aquifer, specifically from the El Mauricio mountains and the area where the Cerro Bayo peak is located. Another inflow that was identified based on the static level elevations comes from southeast side of the aquifer, originating in the Sierra Las Conchas and Cerro Las Tunas mountains.

Overall, the direction of the subsurface flow throughout the aquifer has the same tendency, in other words, it travels from the mountainous area towards the center of the aquifer; from there, it heads north and northeast until reaching the natural outlet area. It is worth mentioning that in the wellfield area, a small drawdown cone has formed, which has not been able to fully invert the direction of the flow. As a result, the natural outlets to the aquifer remain.

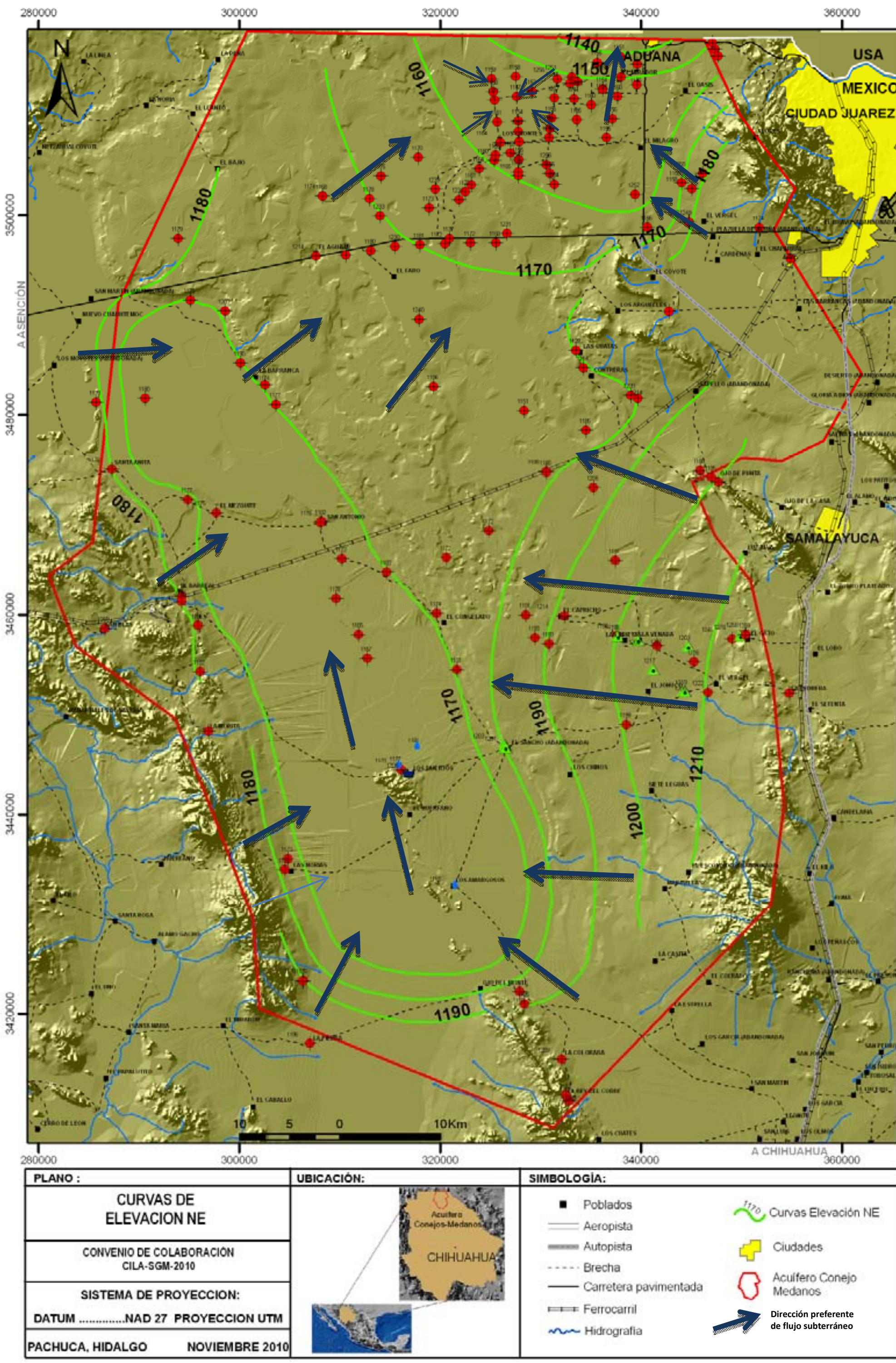

Figure 5.12 Preferential Groundwater Flow Path

5.6 Groundwater Quality

During the well survey, some of the water's physical parameters were measured at each well visited in order to obtain some chemical representations of the water over time and space (TDS, pH, Eh, Temp., EC). Doing so allows some inferences to be made or a specific problem to be confirmed, either because of the type of aquifer or the distribution of groundwater withdrawals or the existing subsurface geological conditions.

Electrical conductivity (Figure 5.13) is the measurement of the water's capacity to conduct electricity, thus it indicates the total ionizable material present in the water that is the product of an acid, a base or a salt dissociated of its ions. The results are expressed in microSiemens/cm (micromhos/cm) (μS). To depict its distribution, EC was measured for almost all the surveyed wells, except for a few sites where it was not possible to measure the parameters because the wells were out of operation. It should be noted that the electrical conductivity was measured at the direct outlet from each well, and where possible, samples were taken inside the casing with a bottle.

The water quality classification for EC is based on three simple ranges, which are as follows:

a) 100 to 2000	μS/cm at 25°C	Fresh water.
b) 2001 to 4000	μS/cm at 25°C	Acceptable water.
c) Greater than 4001	μS/cm at 25°C	Brackish water.

There is consistency in the EC values found in the study area. The maximum values are found in the samples coming from the El Barreal Rift that have as a common denominator values above 4,001 μS/cm, which is associated with the zone of evaporite sediments, and in the springs that have structural influence, where highly saline waters emanate. These salts are deposited in the surrounding soils. Although there are also some local sites to the east and northwest of Ciudad Juárez, which are possibly linked to zones with evaporite sediments.

Values between 2,001 and 4,000 μS/cm occur less frequently and are mostly located on the left edge of the El Barreal Rift and a few local points that are influenced by the evaporite sediments through which the water circulates. Finally, the values between 100 and 2,000 μS/cm are found in the Conejos-Medanos wellfield area, and to the southwest of Samalayuca. In the latter case, there are mostly chain pump wells.

In summary, the relatively fresh groundwater is found in the Conejos-Medanos wellfield area and in some chain pump wells southwest of Samalayuca, while the brackish waters are in the El Barreal Rift. There are some local points within these generalized zones that contradict the predominant values found in the region.

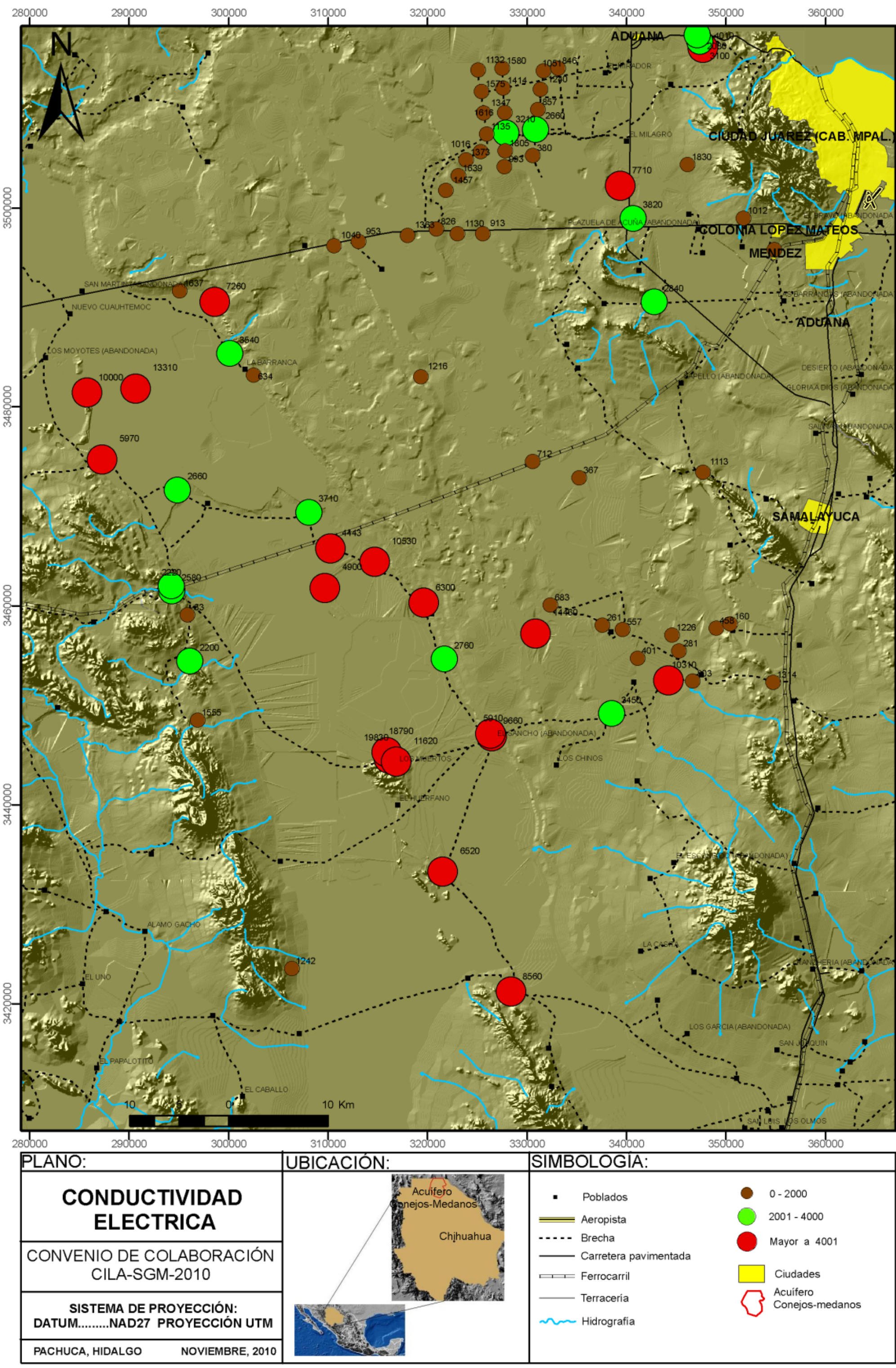

Figure 5.13 Distribution of Electrical Conductivity.

Total Dissolved Solids (TDS)

Total [dissolved] solids are defined as the material residues left in a container after a sample has evaporated and been dried in an oven at a set temperature. The origins of the dissolved solids may be several organic or inorganic sources, from either surface or ground water.

Total Dissolved Solids is the measure that is considered to be the most representative of the water's salt content. It corresponds to the index that is the most useful for hydrogeochemical interpretation, because by looking at its distribution, it is possible to identify recharge zones, direction of subsurface flow, as well as the degree of dissolution shown by the rocks through which the groundwater flows. To classify the concentrations found in the study region, a simple system was used based on 3 categories:

Category	Total Dissolved Solids (mg/lt or gr/m^3)
Freshwater	0–1000
Acceptable water	1001-2,000
Brackish water	Greater than 2,001

Figure 5.14 shows the spatial distribution of the Total Dissolved Solids, where the highest values, those greater than 2,001 mg/L, are located in the El Barreal area. In this area, the predominate weather conditions cause the salts to precipitate, thereby increasing the saline concentrations. The values are also high in the Los Muertos area. This last set of values is associated with a fault with a northwest-southeast heading, where several springs are located contain high concentrations of salts that precipitate into the surrounding area. Similarly, there are individual sites that possibly as the result of local geology, locations adjacent to salt deposits, where their concentrations are between 1,001 and 2,000 mg/L.

Lastly, the minimum values of between 0 and 1,000 mg/L are found in the Conejos-Medanos wellfield area, potentially representing deeper water in the aquifer, which is not affected by climate conditions the way the El Barreal area is. Concerning the area southwest of the town of Samalayuca, there are several shallow wells, mostly chain pumps, which show evidence of recently infiltrated water, and climate conditions don't affect them either. In all of the cases mentioned, these are areas with good water quality.

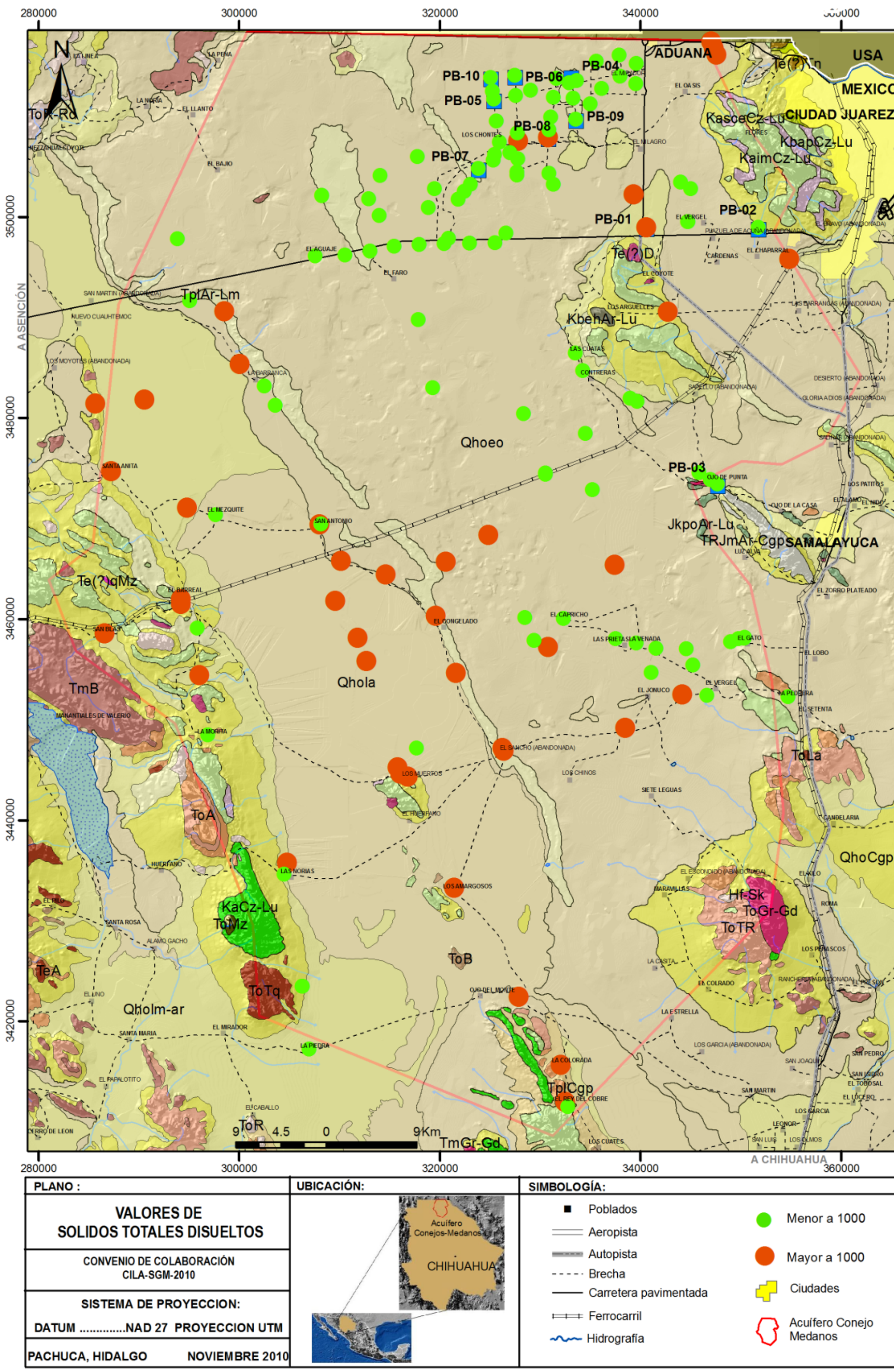

Figure 5.14 Distribution of Total Dissolved Solids

Temperature

Temperature is a physical parameter that can increase with depth or with the geothermal gradient. This gradient has an average of 3°C /100 m. Water temperature is easy to record, and it give us information about the type of environment where the water circulates and the vertical distance to reach the bottom.

In this respect, the following analysis of the characteristics and distribution for this parameter are provided. Figure 5.13 shows the spatial temperature distribution, dividing it up into two categories: less than 29.9ºC and greater than 30ºC. (Figure 5.15)

It is clear: the concentrations of wells with high temperatures [are] in the Conejos Medanos Aqueduct wellfield area, unlike the rest of the wells in the aquifer, except for some local points in the Los Muertos region whose high values are associated with geological faults, whereas in the first area possibly its temperature is due to the influence of a deeply-buried intrusive body, in addition to the simple effect of geothermal gradient.

Low temperatures predominate in the aquifer because the wells are shallow. This is evidence that the water has recently infiltrated. Its high salt content in certain locations is the result of the climate conditions that it is subject to; additionally, the water has circulated through zones with evaporite deposits, which changes the water’s composition.

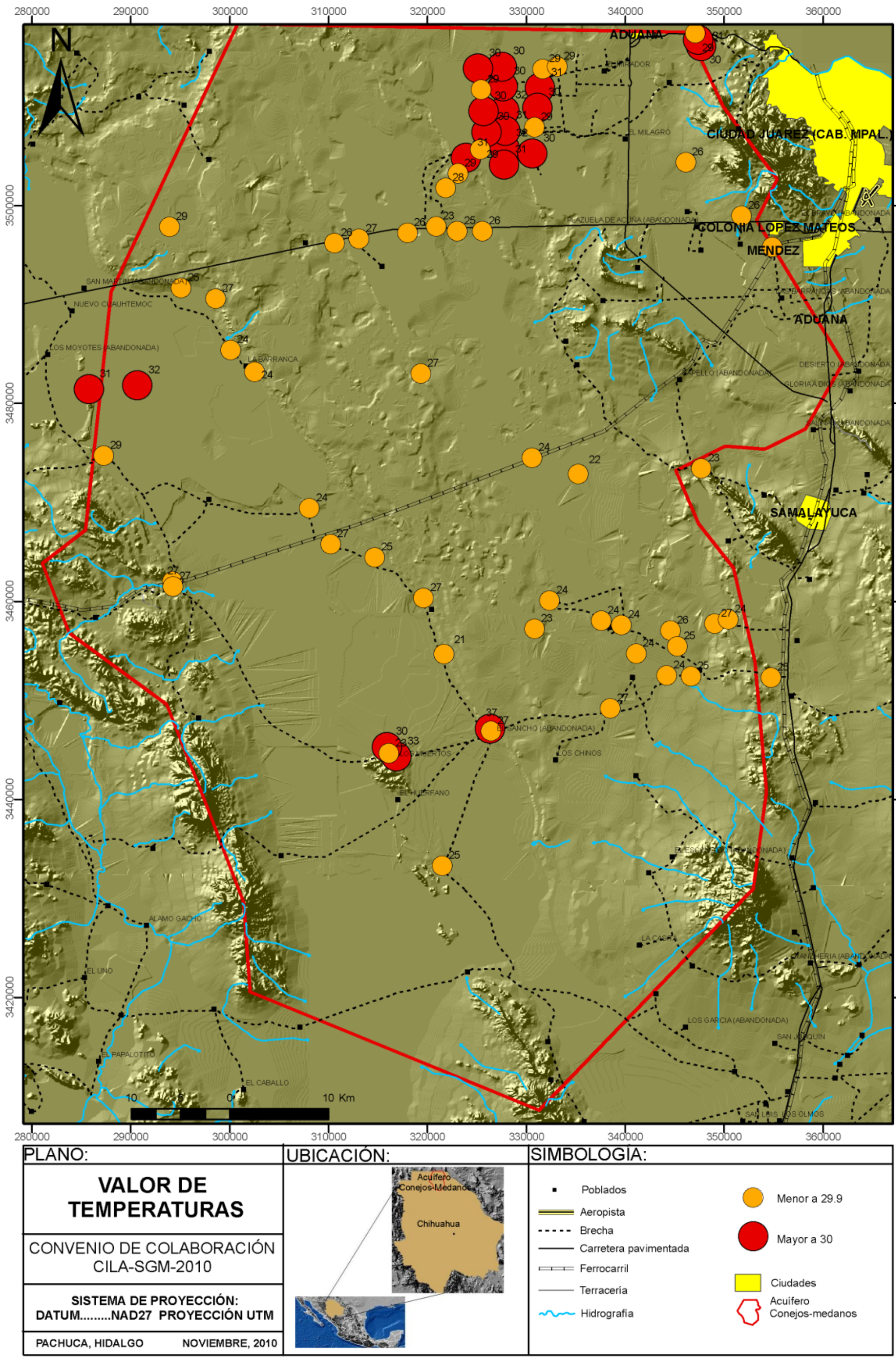

Figure 5.15 Distribution of Temperature

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6 CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

- During the survey phase, piezometric data was obtained (for the well sites where it was possible to obtain it). With this data, the configurations for the depth to static level and static level elevation were calculated, which, with the exception of a small area on the far north side of the wellfield, do not present any deformation of their equipotentials.

- After two months of wellfield operations, the aquifer system shows signs of equipotential deformation on the far north side, although horizontal outflows of groundwater towards the U.S. continue.

- The physical and chemical parameters for groundwater quality have not changed over time.

- The depth to static level is steady at between 1 and 105 meters. At the same time, the static level elevation indicates that there is equilibrium throughout most of the aquifer, which maintains the natural direction of the groundwater flow.

- The withdrawal of 1,000 liters per second of groundwater in the wellfield area has led to an immediate decrease in the static levels.

- Insofar as the well survey in 2007 and 2010, they show an increase in public urban use, from 2% in 2007 to 15.8% in 2010; meanwhile, the percentage of inactive wells decreased from 44% in 2007 to 17% in 2010. It also shows an increase in wells used to monitor the aquifer, from 12% to 17 % during the same period.

- The total groundwater withdrawal for 2010 was calculated at 18.31 Hm^3, of which 87.51% was pumped from the wellfield located at the far north side of the aquifer. It is important to note that the wellfield began operations in mid-May 2010, thus the calculated volume will only apply to 2010, since under the same operating circumstances, the volume that will be extracted in 2011 is 33.8 Hm^3/yr, of which only 2.3 Hm^3 are withdrawn from wells outside of the wellfield.

- The aquifer system, in particular the location of the wellfield, responds quickly to the withdrawals. Within two months of commencing operations in May 2010, it shows signs of a decreasing trend of up to five meters.

- The hydrographs provided by the Central Water and Sanitation Board for some of the observation wells in the wellfield show a drawdown of up to five meters during the May to November 2010 period.

- Even though the trend in at least 11 of 23 wells that belong to the Conejos Medanos Aqueduct wellfield shows an immediate decrease in the static levels, given the short amount of time in operation, it is likely that it represents a quick response from the aquifer to a sudden withdrawal, with the possibility that over time the aquifer may relax and recover some of the lost elevation.

- Hydrographs provided to SGM by the Ciudad Juarez Central Water and Sanitation Board show a drawdown of up to five meters through the month of November 2010 in observation wells located in the wellfield.

- According to the pumping tests performed for this study, average transmissivity values of between 2.0 and 4.4 $x10^{-3}$ m^2/s were recorded, while the average hydraulic conductivity values are represented by 3.19 and 5.12 $x10^{-5}$ m/s. It is worth noting that this data is representative of the area where the Conejos Medanos Aqueduct wellfield is located.

- The Conejos Medanos Aquifer is located in a rift valley caused by distensive forces after the Laramide Orogeny. This rift (or graben) has been and continues to be filled by granular material generated by the crumbling of the rocks that surround it and form its boundaries. The aquifer itself is found within this granular material, which has some argillaceous horizons, causing some zones to behave locally as a semiconfined aquifer.

- Overall, the direction of the subsurface flow throughout the aquifer has the same tendency, in other words, it travels from the mountainous area towards the center of the aquifer; from there, it heads north and northeast until reaching the natural outlet area. It is worth mentioning that in the wellfield area, a small drawdown cone has formed, which has not been able to fully invert the direction of the flow. As a result, the natural outlets to the aquifer remain.

6.2 Recommendations

A new piezometric monitoring study is recommended, in order to confirm if the decrease in static levels in the wellfield continues, or if the aquifer is able to relax, and thus recover its original values.

A water quality sampling study is recommended, including a full test for 32 elements, highlighting those that have a maximum allowable limit according to current water quality regulations.

Develop an operations program for the wellfield based on the aquifer's hydraulic response, thus preventing a larger drawdown cone from forming and [causing] the inversion of the subsurface flow pattern.

Once the hydraulic behavior of the aquifer has been established, as well as how its functions, it is recommended that a mathematical model be developed to predict the behavior of the aquifer levels for one, three and five year periods.

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