Final report

Groundwater resources for small rural and aboriginal communities in Chaco province, Argentina
Abstract

In this final report the main results of the first humanitarian geophysical project founded by GWB in Argentina are presented. The objective of the project is the search of groundwater resources for small rural and aboriginal communities in Miraflores (Chaco) using electrical prospecting methods. The study site faces serious water scarcity and quality problems. It is located on one of the poorest regions of the country with high child malnutrition and infant mortality rates. From a hydrogeological point of view, the only sources of freshwater are small shallow-buried paleochannels which have sandy textures and therefore capacity for storing water. In order to identify these paleochannels, Vertical Electrical Soundings and Electrical Resistivity Tomographies were performed in priority areas. Based on the analysis of geoelectrical data, 10 new wells were drilled and hand-operated pumps were installed to protect and facilitate water extraction. The results of the project have a direct impact on the quality of life of local communities and also provides solid basis for replicating this type of study in other critical areas of Chaco.
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Background

The study site is located in a native tropical forest called “El Impenetrable” in Chaco Province, Argentina. The name refers to the dense and wild vegetation that makes the access to the forest very difficult.

The climate is subtropical continental. Springs and summers are hot, with maximum temperature values that can reach 45 degrees Celsius. The rainy season is from November to April with an annual rainfall ranging from 500 to 750 millimeters. The rest of the year (from May to October) is the dry season with long periods without rainfall and droughts that seriously affect water availability. This season is the most critical one for the inhabitants of “El Impenetrable”. The zone is inhabited by Qom, Toba and Wichi pre-Columbian communities and rural family groups. The economy of these communities is based on agriculture, cattle raising and brickworks.

Figure 1: “El Impenetrable” forest.

The province of Chaco is one of the poorest regions in Argentina. Most of the people are below the poverty line. This region also has the highest child malnutrition rate. There are no official statistics about malnutrition but local authorities acknowledge that in this zone 1600 children are affected by malnutrition.

The town of Miraflores has about 15000 inhabitants and a huge rural zone with about 9500 people. It does not have a water supply system. The nearest aqueduct is 50 km away and 100000 liters of freshwater are transported to Miraflores by truck every week. In order to face this situation, people make wells (8 to 15 meters deep) using picks and shovels. During droughts, wells dry up and the situation gets worse. In 2013 the situation was so
critical that water supply was restricted only to human consumption. Moreover, groundwater usually contains salts and arsenic concentrations that exceed the limit for human consumption established by the World Health Organization.

![Figure 2: Typical house and water well of rural zones.](image)

At the beginning of the project, the hydrological knowledge of the area was virtually non-existent. The analysis of available geological data, the information collected during the campaigns and the geoelectrical surveys have resulted in significant advances in the understanding of groundwater dynamics and in the search of realistic solutions for water supply. From a hydrogeological point of view, the only sources of freshwater are small shallow-buried paleochannels (remnant of an inactive river or stream channel) located at depths from 5 to 15 m. Paleochannels have sandy textures with high porosity and high capacity for storing water. Some paleochannels emerge on soil surface and can be detected in satellite images, but most of them are buried by volcanoclastic loess (fine clayey sediments) with high concentrations of natural arsenic and salts. There is no geophysical evidence that supports the existence of a deeper aquifer with fresh water.

![Figure 3: Water supply in Miraflores.](image)
One of the major problems of “El Impenetrable” is the scattering of population in small groups of families over vast areas of the forest. In rural areas of Mirafl ores there are 99 groups of families, some of them are completely insolated. For aid to be effective, the sources of fresh water should be near to these groups of families. For years now, the proposal of local authorities has been the construction of a 50-km aqueduct from Castelli to Mirafl ores. However this solution would have little impact on the rural and aboriginal communities which are far away from the town and have serious transportation problems. Consequently, local near-surface aquifers (paleochannels) are the best and more realistic option for water supply in rural areas. In this general context, project activities were focused on the identification of groundwater resources using Vertical Electrical Soundings (VES) and Electrical Resistivity Tomographies (ERT). These methods are sensitive to saline concentration changes and can be used to detect fresh water bodies.

The access to water and sanitation was recognized as a human right by the United Nations (UN) General Assembly on 28 July 2010. This right is also recognized in Argentina through several decisions of the Supreme Court of Justice, but it is not universally guaranteed. In this regard, this GWB Project is also an attempt to make this human right a reality for the community of Mirafl ores.
Field Studies

Hydrogeological characterization

During the first campaigns, a hydrological characterization of the region was performed. Many rural families were visited for collecting data on existing wells and information about their socio-economic status and water uses.

In each well, the GPS coordinates, the piezometric level, the electric conductivity and the range of arsenic concentration were measured. The owners of the wells were also asked about their needs and water usage. Groundwater is mainly used during the dry season for animal and human consumption. During the rainy season they collect rainwater for drinking. More than 70 wells were reported during these campaigns.

Figure 5 shows the map of arsenic concentration in Miraflores. Many of the water samples contain arsenic levels that exceed the limit for human consumption established by the World Health Organization (0.01 mg/l). This map is the first and only study to quantify the range of arsenic concentration in the area of Miraflores. This study was also the starting point for a UNLP project related to arsenic abatement using geomaterials.
Figure 5: Arsenic concentration in Miraflores rural region (Google map).

Figure 6 shows the water electric conductivity on existing wells. Electric conductivity is directly related to the concentration of salts dissolved in water. It is assumed that the electric conductivity of drinking water is in the range 5-50 millisiemens per meters.

Figure 6: Water electric conductivity.
Near-surface aquifers are strongly affected by the climatic conditions of the region, especially by precipitation patterns. The aquifers are recharged during the rainy season from November to April. Groundwater levels decline significantly throughout the dry season and during drought periods wells became completely dry. For this reason we recorded meteorological variables and groundwater levels in a station located in the hose of a local family.

Figure 7: Installation of the meteorological and hydrological stations.

Figure 8 shows the accumulated precipitation registered from August 2015 to September 2016. The dry season is quite evident in the precipitation pattern, even though these data were registered during a very strong “El niño”-southern oscillation which increased the frequency and volume of precipitation.

Figure 8: Accumulated precipitation registered in the weather station.
A first estimation of the recharge of shallow aquifers was performed using precipitation and piezometric data. The analysis period corresponds to the warm and wet season in Miraflores, in which events of precipitation yielded accumulated totals of 105.9 mm, and an aggregated water level rise of 212 mm. The specific yield of the “Pampean” sediments is typically 0.09. Thus, the estimated recharge is close to 18% of the total precipitation in the analyzed period.

Geophysical surveys

Based on the analysis of available geological data and the information collected from local people during several campaigns, we conclude that the only sources of freshwater are small shallow-buried paleochannels. There is no geophysical or geological evidence that supports the existence of a deeper aquifer with fresh water. Paleochannel are remnants of inactive rivers or stream channels located at shallow depths. These structures have sandy textures with high porosity and capacity for storing water, and are also sealed by impermeable streambed. The water stored in the paleochannel is not in direct contact with loess sediments and for this reason is less exposed to salinization and arsenic contamination.

Fortunately, the local hydrological problem can be well described in terms of the electrical resistivity. In sedimentary rocks the electrical resistivity depends on both the mineral composition of the solid matrix and the salinity of water in the pore space. The combination of different soil textures with salt and fresh waters enhances the resistivity contrast between the paleochannel (of high resistivity) and the surrounding sediments (of low resistivity). This significant high contrast in resistivity values makes the electrical method the most promising geophysical techniques for prospecting groundwater in this area.

Figure 9: Vertical Electrical Soundings in progress.
The electrical resistivity method, which is a noninvasive technique, was used to delineate lateral and vertical variations in subsurface geoelectrical structures. The resistivity contrast between fresh water (paleochannel) and saline water (loess) is usually large enough to be detected by vertical electrical soundings (VES) and electrical resistivity tomography (ERT).

A four electrode collinear Schlumberger array was used for VES measurements. The data was acquired with a direct current resistivity meter and maximum current electrode separation of 200 and 400 m. In order to validate the hypothesis that this geophysical technique can detect buried paleochannels, VES were measured across a paleochannel that can be clearly distinguished in a satellite image. Figure 10 shows sounding curves obtained in three stations across a paleochannel. High apparent resistivity values were obtained on the paleochannel (station B) while very low apparent resistivity values were measured on clayey sediments outside this feature (stations A and C). This field test validates the hypothesis that paleochannels can be detected by VES.

![Figure 10: Three VES curves showing different responses inside and outside the paleochannel (Google map).](image)

For the quantitative analysis of VES data, 1D modeling has been performed using an automatic and interactive inversion code developed in the University of La Plata. The
inversion code is based on the Zohdy algorithm to provide a multilayer model and then, the number of layers is reduced using the equivalence criteria of Dar Zarrouk parameters. The final proposed model has a minimal number of layers to obtain the best fit, with an error of less than 5% between observed and calculated data.

For ERT measurements, an automatic resistivity system ARES was used. This equipment consists of a single unit with a transmitter and receiver. The transmitter could provide 2000V and a maximum current of 5A. The high impedance receiver (20MΩ) is able to measure an input voltage range of ±20 V. This instrument injects direct current in cycles with reverse polarity. During each cycle the apparent resistivity is calculated in order to provide a mean value with a standard deviation (less than 2%). Stainless electrodes are used to inject current and bronze electrodes to measure potential differences.

The ERT is a more precise and detailed technique which provides a 2D resistivity profile of the subsurface. This technique is used to delineate the geometry and to detect the edges or boundaries of paleochannels. ERT data is obtained using a multi-electrode system with 32 electrodes and a 2.5 m separation. This system is connected to resistivity meter via a multi-core cable and is controlled through a switching circuitry that automatically selects the appropriate 4 electrodes for each measurement.

Figure 11: 2D resistivity distribution across a paleochannel (Google map).
ERT data is inverted using the Res2DInv software of Geotomo. This software uses the smoothness-constrained least-square method inversion technique to produce a 2D subsurface model with a large number of rectangular cells from the apparent resistivity data. The resistivity of each cell is allowed to vary in the vertical and horizontal direction, but the size and position are fixed. Data processing involves the calculation of potential values for the 2D forward model. The inverse method starts from a simple initial model and then the resistivity of each cell is changed through an optimization technique.

Again we validate the hypothesis that this geophysical technique can detect the geometry and boundaries of paleochannels by measuring an ERT across a paleochannel that can be distinguished in a satellite image. Figure 11 shows a 2D resistivity distribution obtained from the ERT data in a vertical section that crosses the border of a paleochannel. The 2D resistivity distribution clearly shows both the boundary and depth of the paleochannel.

**Resistivity patterns**

The previous field studies have shown the effectiveness of geoelectrical methods to identify paleochannels. During the different campaigns to Miraflores, 73 short VES (200-400m) were conducted in order to identify shallow aquifers. Also some long SEV of 500m were performed to detect the possible existence of a deep aquifer system, but no evidence was found.

Figure 12: Geoelectrical surveys: VES positions are indicated with white circles and ERT with black squares (Google map).
Figure 13: Typical VES curves of apparent and true resistivities in the study area.

The analysis of VES allows to distinguish two types of apparent resistivity curves. Figure 13 shows some examples of these curves measured at different sites. Curves A, B and C
on the left side of the figure might indicate the presence of near-surface fresh water aquifers (layers with high resistivity values), while curves E, D and F on the right side of the figure are typical curves of salty aquifers (low resistivity values).

On the other hand, the analysis of ERT allows to distinguish two types of patterns in resistivity sections. Figure 14 shows some examples of these sections at different sites. Resistivity sections A and B show typical patterns of saline aquifers (low resistivity values) while sections C and D might indicate the presence of near-surface fresh water aquifers (bodies with high resistivity values).

Figure 14: Resistivity section patterns of ERT.
Water wells

Figure 15: Perforation profile in the site “Colegio”.

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Final depth: 11 m
Water table: 9.3 m.
Filter: 3 m
Parapet: 0.5 m
EC [mS]: 0.3 mS
Based on the collected hydrogeological information and geophysical surveys, we select the sites more likely to have freshwater. In these sites 10 wells were drilled to 5-12 m depth. These sites are located in schools or in public places near aboriginal communities.

Figure 15 shows an example of how the resistivity data was used to choose the best site to drill a well. The ERT at the site “Colegio” presents a two order of magnitude resistivity contrast. The well was drilled at local coordinate 84 m of the tomography where a maximum of the resistivity value is observed. The figure also shows the perforation profile with the lithological column obtained from the soil samples. The first 9 meters are composed of a fine unsaturated brown sand associated with high resistivity increase values. Then, the soil texture changes to fine gray sand associated with lower resistivity values. In this well a water conductivity value of 0.3 mS (fresh water) was obtained.

All water wells were cased with PVC pipes and surfer water pumps were installed. Water pumps are robust and adapted for manual use because there is no electricity supply in rural areas. It is important to remark that in the study site most dug wells have diameters greater than 1 m and are exposed to surface contamination by leaves, insects and small animals that may fall into the wells. In this regards drilled boreholes with plastic casing and pumps play a significant role in water quality preservation.

Figure 16: Perforations and manual water pumps.

Figure 17 shows the location of the 10 new wells drilled in rural areas. Manual pumps were installed in all wells and water samples were taken to perform physicochemical analyzes and to determine the arsenic concentration. The wells are located in public places, close to rural schools or to Toba and Wichi aboriginal communities.

These 10 water wells, in conjunction with the hydrological knowledge of the region, constitute the most significant contributions of the project.
Figure 17: Location of drilled water wells.

Well Reference:

1: Costa Rica-Quiroga
2: Costa Rica-school N°903
3: El Zanjón toba community A
4: El Zanjón toba community B
5: San Lorenzo-school N°186
6: Techat wichi community
7: Techat-school N°1074
8: Gómez
9: Pozo de Toro toba community
10: Pozo de Toro-school N°519
The Human Element

This project began when we became aware of the situation suffered by the Miraflores community through the personal experience of a student of our Faculty, who is native to Miraflores. His family lives in the rural area and during the 2013 drought they ran out of water. His testimony mobilized a group of students and professors to find a solution to this problem. The human element was the driving force behind this project.

Generally speaking, the project participants formed two groups. On the one hand, the group formed by members of the University of La Plata (professors, students, graduates and teaching assistants), and on the other, the group formed by the people from Miraflores (local governments, rural families, aboriginals and teachers of rural schools). These two groups were separated by both a distance of 1000 km and very different socioeconomic status. However, the multicultural interaction between all participants was a very enriching experience, mainly for the members of University of La Plata.

The main project partner was La Plata National University. The UNLP team involved researchers, professors and students. The number of students that have participated in the project activities is approximately 60 (50 undergraduate and 10 PhD students). Most participants are undergraduate and PhD students of Geophysics who are also members of the SEG Student Chapter of the UNLP. A few number of undergraduate students of Geology, Meteorology and Astronomy were also involved in the project.

The students of Geophysics from UNLP have a solid theoretical background but little field experience. During this project they have learned how to plan a survey, to acquire geophysical and hydrogeological data, as well as to process and discuss results. This participation represents both an academic and personal enrichment experience for them. Most likely the most important learning for students has been that the geophysical methods can be used to solve humanitarian problems.

Data collected on the frame of the project was also used for academic purposes. The following undergraduate thesis projects were developed using this data:


• Analysis of the quality of the groundwater from physicochemical parameters in Miraflores. Undergraduate thesis for Geology being undertaken by Magali Fornés.

A group of students also obtained funds from the UNLP to develop three small projects for dissemination of geophysical issues in Miraflores. The objective of these projects was to disseminate topics related to groundwater in rural primary and secondary schools. Our students designed didactic games to explain the origin of groundwater, its quality and good uses. These activities complemented the GWB project because they provided useful information to the future beneficiaries on the sustainability of groundwater resources.

Figure 18: Lecture on groundwater topics in a secondary school of Miraflores.

It is interesting to mention that three geophysics students (Santiago Actis, Abelardo Romero and Sol Bejarán) who actively participated in the project have won the SEG Challenge Bowl competition. In 2018 Santiago and Abelardo were World Champions in Anaheim, California, and in 2019 Sol was World Champion in San Antonio, Texas. It is the first time that an Argentine university wins this international competition.

Figure 19: 2019 Challenge Bowl Winners: Rosario Etchegoyen and Sol Bejaran (San Antonio); 2018 Challenge Bowl Winners: Santiago Actis and Abelardo Romero (Anaheim).
The group of professors who participated in the project (Claudia Tocho, Lia Botto, Jerónimo Ainchil, Eduardo Agosta and Luis Guarracino) organized a round table on “Contribution of Geophysics to social problems: the experience of Geoscientist Without Borders in Argentina”, at the National Congress of the Argentine Association of Geophysicists and Geodesists (AAGG) in 2017. This activity was included in the official activities of the congress and was a complete success. Students from all over the country attended the round table and it was the first time that humanitarian issues were discussed in this organization.

The topic of humanitarian geophysics was also included in the undergraduate course General Geophysics. At our university, Geophysics is almost exclusively associated with the oil industry, the inclusion of this new concept was one of the greatest learning for professors and students. The project director (Luis Guarracino) has given many conferences on this topic in different institutions and events.

![Figure 20: Round table on “Contribution of Geophysics to social problems: the experience of Geoscientist Without Borders in Argentina” (AAGG).](image)

The community of Miraflores was both the beneficiary and partner of the project. Two cooperation agreements were signed between the University and Miraflores municipality in order to facilitate the development of the project.

The community was involved in almost all phases of the project. Authorities provided local support like an extra van and local guides to arrive at the most remote aboriginal communities. Rural families and teachers of rural school provided information about water uses and their knowledge of local hydrology. Manual pumps in regular use need some kind of maintenance. Local people are in charge of maintaining and protecting wells to guarantee a sustainable supply, especially during dry seasons.
Interaction with rural inhabitants and teachers was key for understanding the hydrological problem. The local knowledge they provided about the region's water wells allowed us to better define the geological context and to find realistic solutions. The rural population is widely dispersed in the “El Impenetrable” forest, making schools reference places for the community. Teachers helped us organize talks with local people. On more than one occasion, when we have not found accommodation in the town, we have slept in schools. People were very friendly and offered us all kinds of valuable help during the campaigns to Miraflores.

Figure 22: Teachers and rural people provide their knowledge and experience.
Lessons learned

The lessons learned were many and very intense, fortunately most of them very positive indeed. The main lesson was that it is possible to help people in need, regardless of our profession or institution. Professional and academic activities often seem to be completely dissociated from the needs of the society. This project taught us that it is possible to help people, and that we have many tools and resources that can be used for humanitarian aid.

Another lesson, as important as the previous one, is that people from rural and aboriginal communities (who do not belong to the academia) have a lot of empirical knowledge that can help to understand and solve a complex problem. For Miraflores people, the random distribution of underground resources was a mystery. Wells separated by a distance of 10 meters could provide water of very different quality. Furthermore, the maximum depth of freshwater wells did not exceed 15 meters. This information provided by local people allows us to propose the paleochannels (buried remnants of ancient rivers) as the formations with the capacity to store fresh water. This working hypothesis was validated with electrical methods since the paleochannels have higher electrical resistivity than the host sediments (loess). They also taught us to value water much more and how to use it efficiently.

This project could not have been possible without the financial support of GWB, nor without the participation of the students. The students were deeply involved in all the activities and were the heart and soul of the project. The socioeconomic situation of the Chaco is very hard. The enthusiasm and optimism of the students were key to the success of the project activities. For all of them, the campaigns to Miraflores were a significant personal and professional experience.

This is the first time that our Faculty is involved in a humanitarian project and this project has marked a milestone in our institution. The project introduced for the first time the concept of Humanitarian Geophysics in our university and is expected to motivate other similar activities. The profile of geophysical students has changed in recent years, showing greater interest in environmental issues. In this sense, the project is a good example that geophysical methods can be used in problems that are not related to the oil industry. Humanitarian Geophysics is a new discipline with a promising future as it responds to the demands of today's Argentine society.
The project also had some negative lessons. All of them are related to administrative, bureaucratic or personal difficulties. Unfortunately, the current scientific-academic system does not encourage researchers to participate in this type of projects. On the one hand, these projects are highly valued by research centers and universities, but on the other, these institutions do not take into account the individual situation of project members. The scientific production may decrease during the development of the project and this situation is not considered when evaluating the professional performance and productivity of the participants. Moreover, the situation of some rural inhabitants is critical (extreme poverty, child malnutrition, etc.) and can affect emotionally the project members. The development of the project required extra time and effort.

For future projects it is recommended not to underestimate the extra time and effort required to develop the project activities. The project provides many satisfaction, but it may also have a negative emotional and professional cost associated.
Conclusions

The GWB Project has provided 10 new water wells to Miraflores and has also contributed to increased knowledge of local hydrogeology and groundwater quality that can be used as a starting point for future works in the area. Based on our results and the information provided by local people we conclude that the only groundwater resources for human consumption are shallow paleochannels. These geologic structures have high electrical resistivity contrasts and can be detected using electrical methods like Vertical Electrical Soundings and Electrical Resistivity Tomographies. Near-surface aquifers are recharged by precipitation through the soil and are strongly affected by climatic variability. Preliminary estimates indicate that aquifer recharge is close to 18% of the total precipitation. For the use of the groundwater resource to be sustainable, the rate of extraction should be equal to or less than the rate of recharge.

Another important aspect related to both sustainability and water quality is the type of well construction. In the study site most wells are excavated by hand using picks and shovels (dug wells). These wells have diameters greater than 1 m and are exposed to contamination, which may occur directly by leaves, insects and small animals falling into them. In this regard, drilled wells with plastic casing and pumps play a significant and effective role in water quality preservation. Additionally, several talks were organized in rural schools in order to inform people about topics related to the origin, quality, preservation and sustainable exploitation of water resources.

The impact of the project in the Miraflores community has been very important. The water wells have been built in places of public access in schools or near aboriginal communities. Access to water has been declared as a basic human right by the United Nations and by many other international organizations. In this sense, these water wells not only improve the quality of life of the inhabitants of Chaco, but also help to guarantee this basic human right. The water needs in “El Impenetrable” forest are numerous, only in the rural areas of Miraflores there are 99 groups of families, some of them are completely insolated. An important feature of this project is its replicability. Our studies have shown that the only realistic groundwater sources in the region are paleochannels located between 5 and 15 m deep that can be detected with electrical methods. Historically, the solution for water scarcity proposed by the local authorities has been the construction of an aqueduct from Castelli to Miraflores (50 km). However, if this aqueduct were built, it would only benefit the inhabitants of the town but not the rural and aboriginal communities that are scattered throughout the forest.
It is important to remark that this GWB Project has also marked a milestone in our institution. This is the first time that our Faculty is involved in a humanitarian project and it has opened an interesting debate about the gap between social problems and the scientific community. Undergraduate and graduate students were deeply involved in field and desk activities. The project gave them the opportunity to help people using geophysical methods and also a wider view of both the discipline and social reality.

All these achievements would not have been possible without the financial support of GWB Program.