CANADA-BRAZIL COOPERATION
Northeastern Brazil Groundwater Project

Project Development Mission to Brazil

December 5 to 15, 1998

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Northeastern Brazil Drought Region

Cover photograph

Brazilian and Canadian participants in the December 1998, mission to Ceará, accompanied by the prefect and council members of the town of São José, examine a large-diameter hand-dug well, locally called "amazon", on the outskirts of the village. The 5 to 6 m deep well was located in a dry stream bed, and produces no water. Yet, a cursory examination of the surrounding terrain suggested that water could probably be found nearby. São José would be an excellent area in which to test new technologies for groundwater exploration.

Summary

A mission to develop a project aimed at improving access to safe water for drought-stricken northeastern Brazil, which is to be funded in part by CIDA, was carried out from December 5 to 15, 1998. Taking part in the mission were Dr. Jim Hunter of GSC's Terrain Sciences Division, Professor Frederick Michel of the Department of Earth Sciences, Carleton University and Dr. Yvon Maurice of GSC, coordinator of the Canada-Brazil Cooperation Project. Joining the group in São Paulo was Ms. Susan Southerwood of Water for People, an NGO involved in community level water projects in developing countries.

The parts of northeastern Brazil that are of most concern for the proposed project are those underlain by crystalline Precambrian rocks which represent roughly 50% of the 1 million km^2 area that is currently experiencing drought. These crystalline basement areas have relatively low water retention capacity and the groundwater is more or less confined to open fracture aquifers.

The purpose of the mission was to determine the nature of the drought-related problems in that region, the type and extent of Canadian technological assistance needed, meet with prospective Brazilian collaborators, and discuss ways of implementing a useful project with real benefits to the rural communities that are most in need.

The program, elaborated by our host, CPRM, included technical visits and discussions in Fortaleza, the capital of the state of Ceará, and a field trip to Irauçuba about 250 km west of the city and one of the areas that is hardest hit by the drought.

The Brazilian government has responded to the current crisis by introducing emergency measures (food and water distribution, make-work projects, massive drilling of wells more or less at random, etc.) that bring short term relief but do not address the fundamental problems. Two distinct problems, which Canadian technology may help resolve, were identified: (1) the unavailability in the region of most of the modern groundwater exploration tools used elsewhere, and (2) the fact that 80% of the wells drilled in crystalline bedrock produce water that is too brackish for human consumption or for agriculture.

To address the first problem, improving the groundwater exploration capabilities, we proposed to introduce and test modern ground and, if possible, airborne geophysical methods, combined with state-of-the-art remote sensing and hydrological interpretation techniques. With regards to water quality, a more research oriented approach will be needed. This might include groundwater characterization using geochemistry combined with borehole logging and imagery, as well as testing certain techniques such as water mixing and aquifer flushing. Some of these techniques have been used successfully

elsewhere, in similar environments. The technologies will be transferred directly to those involved in groundwater exploration, distribution and quality control, including as many as possible of the umpteen private consultants who are contracted by the government to locate well sites in the region. CPRM staff, and the next generation of Brazilian hydrogeologists now enrolled in the earth science departments at the local universities (Fortaleza, Natal and Recife), will also be targetted. Several other institutions involved in groundwater projects and research have shown a keen interest in the CIDA project and will be invited to take part. Some of them (e.g. SOHIDRA) have agreed to take an active role in the follow-up phase of our program.

Much discussion revolved around methods of ensuring that project activities and results benefit those that need the water. The consensus is that community involvement will have to be sought for every activity that will be carried out, both at the planning and execution stages. The best way to achieve this is still somewhat nebulous. The main question that remains is how much input do we need from humanitarian/social (NGO-type) organizations to fully attain this objective. Further discussions on this issue are planned.

Not all issues have been resolved during the December 1998 mission and another round of discussions will be needed and is being planned for late April or May 1999. The December mission was very effective in informing a large number of people about the CIDA project, but there was relatively few one-to-one discussions about specific activities, except perhaps in geophysics. The next mission will focus more on non-technical issues such as cost-sharing and social issues. Visits to other centers, Natal and Recife, will also be included.

PROJECT DEVELOPMENT MISSION TO BRAZIL

Part 1: Overview

by
Yvon Maurice
project coordinator

(1) Introduction

In early June 1998, the Geological Survey of Canada (GSC) in collaboration with the Geological Survey of Brazil (CPRM) and the Brazilian Groundwater Association (ABAS), submitted a preliminary proposal to the Canadian International Development Agency (CIDA) for funding under its Canada-Brazil Technology Transfer Fund (TTF) to develop a project aimed at improving access to safe water for one of the most populated drought-stricken, semi-arid regions on earth: northeastern Brazil. The rationale was to transfer Canadian know-how to Brazilian organizations that are engaged in the relief effort, hoping that by introducing new and/or untried technologies, more effective solutions to the drought-related problems would ensue.

The preliminary proposal (concept paper) received favorable reviews by both CIDA and the Brazilian Cooperation Agency (ABC), the Canadian Embassy in Brasilia, as well as by a handful of local organizations that were identified as potential participants in the project: state government agencies, waterworks companies, and research institutions. In a letter dated September 16, 1998, CIDA formally invited GSC and its partners to submit a full proposal in compliance with the TTF protocol. It was agreed that some consultation between the partners and potential participants in the project should take place before the final document is assembled. Thus, with a generous allowance from CIDA, a 10-day Project Development Mission to northeastern Brazil was organized in early December 1998.

This report presents an updated viewpoint on how the proposed project should be molded to respond most effectively to the needs of the population of northeastern Brazil, based on discussions and observations made during the mission. For a more detailed account and daily logs of the trip, the reader is invited to consult accompanying reports by Dr. Jim Hunter, which focuses on the geophysical perspective, and by Professor Frederick Michel on aspects of hydrogeology.

(2) Mission Objectives

The main purpose of the Project Development Mission to Brazil was to:

(a) identify and establish contacts with prospective Brazilian collaborators;

(b) determine the current levels of knowledge, capability and resourcefulness of Brazilian institutions;

(c) obtain a perspective of the water supply situation and needs in the areas of northeastern Brazil that are most severely affected by the drought;

(d) establish the types of technologies and the extent of assistance needed from Canadian sources; and

(e) discuss approaches and options with the various groups concerned and gather the information needed to prepare the final (full) proposal for submission to CIDA.

(3) Agenda and participants

Departing from Canada on December 5th were Dr. Jim Hunter, geophysicist in Terrain Sciences Division of the Geological Survey of Canada (GSC), Dr. Frederick Michel, hydrogeologist at Carleton University in Ottawa, and Dr. Yvon Maurice of GSC, coordinator of the Canada-Brazil Cooperation Program. In São Paulo, we were joined by Ms. Susan Southerwood of Water for People, an NGO involved in delivering sustainable drinking water, sanitation and hygiene projects in developing countries, particularly in Latin America. Ms. Southerwood traveled from Bolivia where she is presently stationed. The group arrived in Fortaleza, a city of 1.7 million and the capital of the state of Ceará (pop. 6.8 million; area 146,000 km^2), in the afternoon of December 6th (Sunday).

The visit was organized by the Ceará Branch of ABAS in collaboration with CPRM. We take this opportunity to thank Clodionor Carvalho de Araújo, head of ABAS's Ceará Branch and recently appointed chief of CPRM's regional office in Fortaleza, for going out of his way to make this meeting the success that it was. Others who had major input into organizing our visit include Fernando Antonio Feitosa and Oderson Antônio de Souza Filho, both hydrogeologists at CPRM's Fortaleza office, geologist Sebastião Milton Pinheiro da Silva, from CPRM's regional office in Recife, João Manoel Filho, professor of hydrogeology at Universidade Federal de Pernambuco in Recife, and Samir Nahass, chief external affairs advisor for CPRM and Brazilian coordinator of the Canada-Brazil Cooperation Project, based in Rio de Janeiro. All are thanked for their amazing efforts.

The following agenda was set for the visit:

December 7: information session in preparation for field trip. Excellent presentations by Fernando Feitosa and Oderson Souza Filho on the hydrogeology and drought-related problems in the state of Ceará; these talks set the stage for the following two days;

December 8 & 9: field trip to the Irauçuba area. Irauçuba is CPRM's pilot study area for water-related projects in Ceará. It covers one map sheet, roughly 2,500 km^2, located about 250 km west of Fortaleza. It is typical of northeastern regions that are most severely affected by drought. The trip included meetings with the leaders of two prefectures: Irauçuba and Tejuçuoca.

December 10 & 11 (morning): general information session. Presentations and discussions with a group of about 30 people representing about a dozen organizations including universities and other research organizations; federal, state and municipal government agencies; waterworks companies; funding agencies; and local community organizations. The meeting was skillfully co-chaired by Dr. Samir Nahass and Prof. João Manoel Filho. Ms. Louise Clément and Ms. Marta Irving of the Canadian Embassy in Brasilia, representing CIDA, and Ms. Amélia Maria Fernandes Alves representing the Brazilian Cooperation Agency (ABC), CIDA's counterpart in Brazil, also took part in the debates. The official list of participants is attached.

December 11 (afternoon): technical visits to local institutions. Three institutions were visited: (1) the geophysics department of the Federal University of Ceará (UFC); (2) the Fundacão Cearense de Meteorologia e Recursos Hídricos (FUNCEME), a state government organization involved in collecting meteorological, hydrological and land use data in the state of Ceará; and (3) CAGECE (Companhia de Água e Esgotos do Ceará), a government enterprise involved in water distribution projects in urban areas. Through an organization called SISAR (Sistema Integrado de Saneamento Rural), CAGECE is also involved in a water distribution project in a rural area in the northwestern part of the state . The group visited the installations of SISAR in Sobral during the field trip. CAGECE also conducts educational programs on water conservation and sanitation in rural settings.

December 12 (morning): travel to Rio de Janeiro;

December 14: visits to the hydrogeology and geophysics departments at CPRM head office in Rio de Janeiro;

December 14 (evening): return to Canada.

(4) A perspective on the water supply situation in northeastern Brazil

Water doesn't appear to be a major preoccupation in the city of Fortaleza, but there is no doubt that it is the most important issue in the interior. Although we were not exposed to major hardship during the field trip, there are reports that some 10 million people are severely affected by the drought and 5 million of them are at risk of starvation (see for example: http://www.fao.org/News/GLOBAL/GW9815-e.htm). The 3-year drought has had a devastating effect on agriculture, the main source of food and revenue for the rural population.

The land is very dry and we saw little farming activity going on at present. Everyone seems to be waiting for the rains which were due to begin in mid December and continue until May. The normal annual rainfall ranges from 300 to 1,000 mm. The past three rainy seasons, however, have been disappointing with rainfalls much below seasonal averages.

The only surface water that we saw during the field trip was in reservoirs. There are literally hundreds of reservoirs throughout the state of Ceará, large and small, but during periods of drought, most are either completely dry or are at very low levels. The communities that are fortunate enough to be located near one of the larger reservoirs have a reliable supply of good drinking water and even enough for some irrigation. This water is generally treated (chlorinated) and piped to the town.

But for a large proportion of the population (44% according to CAGECE), water comes from wells. CPRM recently carried out a survey of all the rural wells in the state of Ceará. Out of 13,300 wells, 67% are in crystalline rocks tapping fractured bedrock reservoirs. Of these, 34% are not producing for various reasons (some were drilled and never produced while others have been abandoned due to poor yields, well collapse or defective surface equipment such as pumps, etc.). In the last year, the government ordered 700 new wells to be drilled as an emergency measure. These wells were drilled haphazardly without any attempt to optimize their location using scientific information. Consequently, these wells are generally poor producers. Therefore, water continues to be in very short supply and distribution by tanker trucks is necessary to meet the minimum required for survival. The state has a fleet of some 700 tanker trucks that it operates at very high cost.

Another important factor is that the majority of the wells (80%) in crystalline rocks produce water that is too salty for human consumption. The water from most of these wells is used only for domestic purposes, including, to a certain extent, for the consumption by farm animals. Saline or brackish water cannot be used for irrigation because, in the long run, it causes soil degradation.

The problem of water salinity exists in drought years as well as in normal years, but it is worse during long dry spells. Desalinization is one solution to the salt problem but, due to the high initial cost of the equipment, the government will only install it on high-yielding wells that serve a minimum number of families. Desalinization plants are relatively simple to run, but they require maintenance which, in a rural settings where parts and technical know-how are often lacking, can be a problem. Therefore desalinization plants are not very widespread in the region.

The situation regarding other contaminants does not seem to pose major problems. There are no industries to speak of and agricultural contamination is probably minimal. However, there may be some organic contamination due to improper disposal of human and animal waste. Analytical data sheets examined during the field trip revealed high nitrate contents in some wells which could reflect organic waste contamination. We have not seen any data on the heavy metal content of well waters. On the other hand, salt build-up in aquifers in the vicinity of desalinization plants may be a problem due to the improper disposal of the waste brines coming out of the desalinization equipment. Remediation, is this case, would consist of training the maintenance personnel.

(5) Evaluation of needs

It is surprising that so many people would chose to live in a region that is so inhospitable as northeastern Brazil. But whatever the reason, the Brazilian government wants to avoid at all cost a massive migration out of the rural northeast into the cities or other parts of Brazil, because the rest of the country simply couldn't cope with the influx. The government, therefore, has no option but to try to improve the region's water supply.

The measures put forth by the government in response to the current emergency situation were clearly meant for the short term and offer no lasting benefits: food distribution, indiscriminate drilling of wells, construction and repairs to dams mostly to create employment, facilitating private loans for minor waterworks projects, and increased distribution of drinking water by tanker trucks. What is really needed are long term solutions that will permit the population to cope during periods of drought without the need for government handouts or expensive and inefficient emergency measures.

Even in periods of severe drought, no one is left without drinking water, a basic necessity of life. However, this water comes at a very high price, as it has to be continuously delivered to each community by a costly armada of aging tanker trucks. We heard from officials at CAGECE that the elimination of the tanker truck has become a government priority. But for the survival of the communities in the interior, water to support farming is just as important as drinking water. Agriculture provides food, another basic necessity of life.

What is needed for the long-term improvement in the water supply are wells that will not go dry during long periods of drought and that will produce sufficient water to justify government investments in desalinization equipment. It may be possible, with proper planning and water management practices, to eliminate the need for water distribution by tanker trucks over entire sectors of the northeast. Also, wells with better than average flow rates are likely to be less saline than low-yielding wells and/or may lend themselves to salinity control techniques which could make them suitable for animal consumption and irrigation.

(6) Which technologies to transfer?

The results of our discussions with representatives of various Brazilian institutions as well as our observations during the field trip led to the conclusion that Canadian technology should be directed initially at two aspects of the water supply problem in northeastern Brazil:

(1) improvement in the groundwater exploration techniques;

(2) mitigation of the problems related groundwater quality, particularly the high salinity.

Increasing the success of groundwater exploration in the crystalline rocks of northeastern Brazil using geophysics, both ground and airborne, was discussed at length during the trip. An excellent account of these discussions with recommendations is presented in the accompanying report by Dr. Jim Hunter. Dr. Hunter commented that the geophysical capabilities in groundwater exploration of northeastern Brazil institutions are currently lagging and he suggested that hydrogeologists and groundwater consultants would benefit greatly by being introduced to modern, up-to-date geophysical instrumentation, as well as to state-of-the-art remote sensing and hydrogeological interpretation techniques.

The salinity problem will require a more research oriented approach. The phenomenon itself is not well understood and there is little data on the actual chemistry of the groundwater. Because we don't know which salts and other dissolved species are present in the groundwater, there is uncertainty as to how using this water affects human and animal health, crops and soils. Thus, chemical characterization of the groundwater is important and should be done early in the project.

Hydrogeological methods may also provide solutions to the salinity problem that are less costly than installing desalinization equipment. Techniques involving water mixing and aquifer flushing have been used elsewhere with good results and their application in northeastern Brazil should be investigated. Also, modern well development techniques, combined with such tools as borehole geophysical logging and imagery, could be used to improve yields of new and existing wells.

(7) Brazilian partners and collaborators

More than 30 people representing about a dozen Brazilian organizations were present at the information sessions on December 10 & 11. Others, including community organizations leaders, were met during the field trip. All showed a great deal of interest in the proposed project and expressed their willingness to collaborate. Most will probably become involved in one form or another.

But the December 10 & 11 meetings were mainly for the purpose of informing the Brazilians of the CIDA project, and, with the exception of the universities, there were few opportunities to discuss project specifics one-to-one. Furthermore, it was pointed out that for the most part, the representatives that were in attendance at the meeting were not in a position to commit resources by their organizations, which is an important requirement in order for the CIDA project to proceed. The meeting ended with a request being made to each organization to prepare a "proposal" detailing how they visualize their involvement in the project, what resource they would be willing to commit, and which activities they would like to see develop. It was also recognized that additional meetings would have to take place with each respondent to discuss details. It was tentatively agreed that Dr. Maurice would return to northeast Brazil for this purpose in late March 1999.

Although the specifics have yet to be worked out, we have a good idea of which Brazilian organizations will become involved in the project.

CPRM's strong presence in the northeast and its deep commitment to the water issues in the region makes this organization an ideal partner in the project. Furthermore, GSC and CPRM have a long history of successful collaboration and there is no doubt that the new project will benefit greatly from the strength of this relationship. Equally important will be our association with ABAS, the single most important organization to provide links between all the groups that are involved in the groundwater issues in northeastern Brazil; ABAS is also extremely efficient in public relations.

SOHIDRA, the organization that carries out most of the water infrastructure projects in rural Ceará, including drilling wells and installing desalinization equipment, will provide the essential follow-up to the project's results and recommendations. The SOHIDRA representative at the meeting, Dr. Francisco Edson Pessoa Pinheiro, indicated that his organization would be very interested in participating and would commit the necessary resources. Their contribution will likely make up a large proportion of Brazil's financial input in the project.

The main recipients of the Canadian know-how will necessarily have to be organizations and individuals who possess a good technical base that will allow them to absorb the new technologies and put them to use for the benefit of the community. Also, the transfer of Canadian technology to Brazil will not be a one-way process; Canadian specialists will have to learn as much about Brazilian geological environments and processes from Brazilian geoscientists as the latter will learn from the Canadians. The experience gained from testing these technologies in Brazil will also benefit the Canadian specialists.

CPRM and the universities have the required personnel and technical background to participate fully in the project and they are obvious candidates for the technology transfer. Another important group that will be targeted, and which we have not met during this mission, are the private consultants who are hired on contract by SOHIDRA to locate well sites. We were told that their level of competence is highly variable, but that the majority presently use antiquated methodologies to do their work.

Personnel from the three universities that were present at the meeting (Pernambuco, Rio Grande do Norte, and Ceará) were amongst the most enthusiastic about participating in the project. A proposal was received from Prof. Emanuel Ferraz Jardim de Sá of Universidade Federal do Rio Grande do Norte during the meeting and the others will submit theirs early in the new year. Although the universities have well established teaching and research programs in geophysics, hydrogeology and other disciplines that are relevant to the water issues in the northeast, they admit that most of their research activities have been carried out so far without much attention being paid to the specific needs of communities and social issues. This will change since the Canada-Brazil Groundwater Project will focus all of its activities towards solving real problems at the community level.

(8) Social aspects

In order for it to succeed, it will be necessary for the project to respond to actual needs, and community involvement will be important. Before setting out on this mission, it was thought that one way to achieve community involvement would be by supporting an NGO-type organization to set-up a program based on education, training and simple community level projects. Under this scheme, the NGO personnel would work within the community, assess and prioritize its needs, inform the community leaders and residents of our technical project, and provide feedback. Ms. Susan Southerwood of Water for People joined the mission to examine whether it would be feasible and useful to establish such a program in northeastern Brazil.

After the mission and many hours of discussion with Ms. Southerwood, the other Canadians on the trip and our Brazilian colleagues, we slowly arrived at the conclusion that such a program, implemented on the scale which would be needed to have an impact

in this huge area, is beyond the scope of our project. To have someone stationed in northeastern Brazil on a permanent or quasi-permanent basis, requiring salary, living allowance, accommodation, transportation, and enough equipment to perform meaningful tasks, would consume a large part of the budget, even if a significant proportion was to be paid by Brazil. Besides, Ms. Louise Clément of CIDA doesn't think that any part of such a program could be supported by CIDA because the costs would have to be considered as "local costs" and, therefore, would have to be borne by Brazil.

Also, it may not be necessary to do much additional probing to determine the needs of each community. Several organizations, including CPRM, SOHIDRA, CAGECE and FUNCEME, maintain excellent databases on the water situation throughout the state, including individual community needs, distribution of wells, production, water quality, precipitation, etc. Some of them (e.g. CAGECE) already conduct awareness and education programs at the community level. All this, however, does not remove the necessity for us (CIDA project participants) to establish close ties with the communities and do whatever is necessary to ensure that our activities respond to their needs and are welcomed by the population. However, this may be best achieved through our own efforts to establish those contacts, possibly with the help of a Brazilian NGO. We have witnessed, for example, that CPRM maintains excellent rapport with the communities in which they work, and there is no reason why similar relationships could not be established within the CIDA project.

We plan to meet with representatives of Brazilian humanitarian relief organizations during our next mission to discuss these issues. Discussions will also continue with Water for People and/or other Canadian NGOs to examine other options for their involvement, perhaps in an advisory capacity.

(9) Project delivery format

After recognizing that the water problems in the northeast could perhaps be alleviated by introducing more efficient exploration techniques and by dealing with the salinity question, it was suggested that ground geophysics, particularly electromagnetic techniques, should be the focus early in the program (see Dr. Jim Hunter's report, attached). This could be combined with geochemical investigation of the water salinity, and hydrological interpretation techniques. Later, borehole logging techniques and airborne geophysics could be brought in.

The question of how the transfer of technology will take place was discussed during the meeting. The proposed format, whereby each activity would consist of a classroom-type seminar followed by field demonstrations and/or pilot-scale surveys, was considered satisfactory by the majority. The challenge will be to ensure that the field work is planned so that the results provide real benefits to the communities in need. Therefore,

the areas where the field work will be done will have to chosen with great care, preferably with direct input from the communities concerned. Follow-up, whether by drilling wells with the participation of SOHIDRA or conducting large-scale surveys, will have to be planned and monitored closely.

Another question that was raised is whether all field activities should be carried out within the same "pilot" area or whether they should be spread throughout the region. CPRM's Fernando Feitosa provided excellent arguments in favor of concentrating the activities in the Irauçuba map area where a good database has already been assembled. The area also satisfies social requirements because it is a highly populated area where the effects of the drought are particularly severe. Observations made during the field trip also pointed to several target problems in that area that could be tackled with geophysics.

It was agreed that Irauçuba would be an ideal area in which to carry out field tests during the early phase of the project, but keeping open the option to expand to other areas should there be interest in the part of the scientists or communities to do so. Another consideration is that the project will be active in at least three states, perhaps four (northern Bahia may eventually be included), and each state should have its own test area(s).

(10) What's next?

Although a final decision has not yet been taken, it appears that another round of discussions with key organizations will be needed before the final proposal can be assembled and submitted to CIDA. The mission would take place in late March and would involve only Dr. Maurice from Canada.

The purpose of the March mission to Brazil would be:

(1) To meet one-to-one with the respondents to the request for proposals solicited at the end of the meeting on December 11.

(2) To meet one-to-one with managers of some key institutions to discuss the extent to which their organizations will be involved in the project and ascertain their commitment for financial and other support. Among them will be SOHIDRA (and their counterparts in Pernambuco and Rio Grande do Norte), the main provider of waterworks projects in rural Ceará.

(3) To visit and meet the staff of the federal universities of Pernambuco in Recife and Rio Grande do Norte in Natal. These two establishments are prime candidates for the transfer of Canadian technology.

(4) Meet with as many private consultants involved in groundwater exploration in northeastern Brazil as possible, and discuss details of the project and their participation.

(5) Meet with members of Comunidade Solidária, a high profile humanitarian relief program that operates throughout Brazil. Discuss ways of incorporating a strong social component to our project.

Before the March mission, we hope to write a draft version of the final proposal to be submitted to CIDA. The return Brazilian visit, originally scheduled to take place in mid-March, to coincide with the PDAC, will be postponed until the summer (i.e. June or July). The final proposal should be assembled and submitted to CIDA soon after.

Also, within the next month or so, we intend to officially inform Canadian organizations and the private sector of our proposed program in Brazil, and call for expressions of interest. To reach the maximum number of potential Canadian participants and collaborators, we plan to use the Public Works and Government Services Canada's source lists.

PROJECT DEVELOPMENT MISSION TO BRAZIL

Part 2: A Geophysical Perspective

by
James Hunter
Geophysicist

(1) Introduction

At the request of Dr. Yvon Maurice (MRD), I joined an information-gathering team travelling to N.E. Brazil. Besides Dr. Maurice as the team leader, other members included Dr. Fred Michel (groundwater hydrologist, Carleton University) and Ms. Susan Southerwood (Water For People, Bolivia).

The objectives of the team were to obtain sufficient information on the geoscientific and social aspects of the groundwater problem in order that a project proposal to the CIDA funding agency could be developed.

N.E. Brazil has historically been an area of low precipitation, and has suffered periods of drought. Recent dry periods (probably related to El Niño-triggered changes in weather patterns) have exacerbated the problem, and have triggered periods of civil unrest resulting in emergency actions by the Brazilian state and federal governments. Such aid is primarily in the form of provision of emergency water supplies (a band-aid solution using tanker trucks) to remote communities, and is only seen as a short-term "fix". It has been suggested that CIDA-funded aid may help to provide more stable long-term solutions to water supply in this semi-arid region.

Prior to this information mission, and as a result of Dr. Maurice's previous experience in the area, it was known that the worst drought areas were in the Brazilian states of Ceará and Pernambuco, and primarily in the interior areas underlain by Precambrian crystalline rock. Hence, from an applied geophysics point of view, it was assumed that most of the current problems were related to the search for potential rock-fracture aquifer systems and the potential for successfully applying geophysics were deemed to be quite high. Terrain geophysics has previously been applied to similar problems in other semi-arid parts of the world; further, geophysical expertise that could be applied to the problem can be found within the Geological Survey of Canada, other Canadian government departments, and within the Canadian private sector.

With respect to a potential project proposal to CIDA, the primary contact agency within Brazil (and the primary host of the current mission) is CPRM (Companhia de Pesquisa de Recursos Minerais), which has effectively a mandate equivalent to that of the Geological Survey of Canada.

This report deals with those observations from the mission relating to the potential for geophysical methods to be applied to the immediate groundwater-related problem, the geophysical expertise, manpower, and equipment resources currently existing within that area of Brazil, and the potential for technology transfer. Other aspects of the mission (e.g. hydro-geological and social) are reported separately by the other participants.

The subdivisions of this report consist of a summary of the daily work schedule of the team, including field observations and discussions with various geologists and geophysicists, followed by a overall summary with recommendations for terrain geophysics components of a future CIDA project proposal.

(2) Meeting at CPRM, Fortaleza, Dec. 7, 1998

From the Brazilian side, this meeting consisted mainly of CPRM personnel with the exception of Dr. João Filho from the Federal University of Pernambuco. The team was given summary presentations on the drought conditions in the state of Ceará, including details of the water supply and an overall assessment of the geological factors involved.

Current water supply along coastal areas and in some isolated areas in the interior where sedimentary aquifers are being tapped, are considered to be sufficient to meet current and future needs. These are primarily drilled wells. However, the bulk of the problem exists in those parts of the interior where water supplies come from rock-fracture aquifers in Precambrian terrain.

A structural geology study of the Precambrian portion of Ceará state has been done by Oderson Antonio de Souza Filho of CPRM. In the northern part of the Precambrian terrain (migmatitic materials, considerable topographic relief) it is possible to readily identify fracture systems using air-photo interpretation; soil development is minimal and confined to valleys only. In the southern part of the shield area, where the surface topography is low, thicker soil development occurs (up to approximately 4 meters) and the surface expression of fracture systems are more subtle.

Oderson Filho has ground-checked most of the Precambrian area and has produced an interpreted map of rock condition which can be used as a guide for groundwater prospecting. This map involved statistical collation and correlation of three major rock properties:

(1) degree of alteration
(2) strength of rock
(3) fracture density

By assigning weighting factors and developing relative scales for each of the components, a contour map of groundwater potential for the state has been prepared (on a scale of 1:250 K). This map has been ground-checked against yield of existing wells at some locations, and favorable correlations were observed. A complete set of the overheads used in Mr. Filho's presentation were presented to Dr. Maurice.

A summary of wells, and well conditions in the state of Ceará has been done by Fernando Antonio Carneiro Feitosa of CPRM. Over 13,000 wells (dug and drilled) were field-checked for condition, water quality, and other factors.

Of these wells, approximately 8000 were situated on crystalline (Precambrian) rocks; 4640 of these were drilled presumably to encounter fracture systems. Of these 4640 drilled wells, 21% had fresh water (TDS 0–500 mg/l), 40% had brackish water (TDS 500–1500 mg/l) and 39% were saline (TDS >1500 mg/l). As a result of the drought, between September and December 1998, an additional 700 wells were drilled in the crystalline rock, with similar statistics.

There are approximately 6.5 million people in the state of Ceará of which 3.5 million live in the Precambrian shield areas. With the renewed drilling program, and if all wells were functioning at their normal capacity (a large percentage are shut down due to poor repair or lack of desalination facilities), approximately 3.34 million people potentially could be serviced with groundwater. However, in the short term, trucking is the only alternative, and is exceedingly costly.

The Canadian team asked many questions about the methodologies used to prospect for groundwater, especially in the crystalline rock areas. Drilling of wells is done by the state (of Ceará, in this case). As the requirements are recognized in an area, wells are positioned by means of contract geological investigations. These investigations are reported to utilize surface evidence of fracture zones (air photo interpretation) along with geophysical methods.

Questions about which geophysical methods were employed revealed that the most commonly used were DC resistivity (usually one sounding) and possibly VLF profiling (indicating anomalies associated with fracture zones). It was indicated (by CPRM personnel) that contract geophysics left much to be desired, and there was a suggestion (by Professor Filho) that geophysics did not help (i.e. did not result in increased high-yield well production).

We were not made aware of any publications dealing with geophysical applications to this particular problem in N.E. Brazil. Indications from the well survey program by CPRM appeared to suggest to me that high fracture density areas could probably be defined by electrical and electromagnetic methods, since the groundwater is mineralized (significant resistivity anomalies should be associated with high rock-fracture density, even in the case of significant overburden).

(3) Evening, Dec. 7, 1998

While seeking refreshment near our hotel with members of CPRM, we met, by chance, an old Brazilian friend of mine, Dr. Nelson Ellert. Dr. Ellert is a geophysics professor

emeritus at São Paulo University, who teaches periodically at the Federal University of Ceará, in Fortaleza; he accepted our invitation to dine together with CPRM personnel.

Dr. Ellert is well-known internationally as a senior researcher in engineering geophysics with many years experience with IDRC-sponsored geophysics programs in Brazil and other Latin American countries. It was a valuable opportunity to get updated on recent happenings in Brazilian engineering geophysics.

We learned that there is limited application of geophysical methods to the crystalline groundwater problem so far; however, there appears to be funding opportunities through several routes via the Brazilian government (including funding through a Japan-Brazil agreement) to acquire new geophysical equipment, and there is potential applied geophysical capability based at some universities and government institutions in the northeast. According to Dr. Ellert, the problem appears to be one of lack of operational funds to carry out research and/or demonstration surveys. Further, a funding crisis for university personnel is underway throughout Brazil, and the fear is that universities may not have the staff to carry out any research work, despite the availability of new equipment.

(4) Field Trip to the drought-stricken interior of Ceará State (Dec. 8–9/98)

Early in the morning we mustered in front of our hotel, ready for an indicated "difficult drive" into the interior. Unfortunately the CPRM vehicle had mechanical problems, and a rented van was quickly substituted by our hosts.

We left Fortaleza and travelled westerly along BR222; we passed through the coastal sedimentary basin area (apparently no problem with groundwater supply, but possible problems from pollution of wells and sea-water invasion from overpumping).

High topographic relief is associated with the Precambrian terrain in the northeastern portion of Ceará. We entered the Precambrian area, and went initially to a well site where a desalination unit was operating; a good example of modern technology and one of which CPRM personnel were justifiably proud.

We then traveled several kilometers further into this terrain on BR222, then turned south along a secondary road to an area of the Precambrian shield with lower relief (quartzites) and possibly 1 to 4 meters of overburden (weathered bedrock and alluvial valleys).

We stopped at a village (20 houses) which was currently being served only by water trucked from a dammed reservoir several kilometers away. The water truck had been there yesterday, but already the community's central supply tank was empty. The message was clear: the emergency truck haulage technique is not enough.
There were two low-yield (25 l/min.) wells in the village that were not functional. Across the village square one of the wells was pumped by a windmill system. The windmill was rotating rapidly in the breeze, the pump arm was moving up and down, but apparently the

rubber gasket on the pump needed replacement and only a small quantity of water made it to surface. The raised cistern was dry, but there was enough water on surface for a pig wallow, and some puddles for the local stock of goats and burros. Also, the water was saline; since the well produced flow below the official cutoff of 4 l /min., it was not eligible for a state-sponsored desalination unit
Fred Michel and I thought of taking the mechanism apart and fixing the pump by making up a new gasket from local materials, but we then thought that this might not be viewed favorably by the village since it might have meant the end of good quality water being delivered by the truck.

We were then taken to the larger community of Tejuçuoca, a few kilometers away, where the mayor's staff and representatives of all the local organizations and villages were waiting for us. Presentations were made by Dr. Maurice and by local representatives. A hand-written summary of the community's needs was presented to our head of delegation. We were then given lunch prepared by the community members. We left feeling that Canadian help in both technical and social forms would have been welcomed there.

In the afternoon of Dec. 8, we were driven through dry arid areas on back roads south of BR222, going from village to village examining the water situation. There were many examples of wells drilled at a convenient spot in a village without too much thought of the hydrogeological environment. Few of the older wells appeared to be drilled in fracture zones (and subsequently were either now dry or had low yields. Most villagers noted that the water was brackish or saline. Ms. Southerwood interviewed the village women, and reported to us that symptoms of kidney problems related to saline water, were readily evident. Few wells had desalinization facilities (reverse osmosis).

It was noted that since the drought crisis in the area this year, the government had drilled 700 new wells. These were reported to have been positioned using hydrogeological investigations which included geophysical surveys. Closer questioning of the methodologies applied, revealed that the well positioning was done through contracts awarded by the state to private consultants who "may have used" air-photo interpretation for surface indications of fracture systems, along with geophysical methods.

The two popular geophysical methods are DC electrical resistivity sounding and VLF. As indicated to me by CPRM personnel, the geophysics applied at well sites left a lot to be desired, in that: (1) the VLF profiling was often not repeatable but was used however to spot an anomaly, and (2) that only one DC resistivity sounding was done (accumulative apparent resistivity vs. spacing - a kink in the curve indicating the presence of a fluid-filled fracture) over the anomaly to guide drilling.

From our observations, there was limited soil development in the vicinity of many of the wells so that surface expressions of fracture zones might be visible; however there were certainly no obvious indications of fracture zones in the crystalline rock close to most of the wells, that we could see.

The two popular geophysical methods mentioned above are also somewhat dated (many new and efficient techniques have been introduced in similar semi-arid areas of the world in the last 20 years), but they are also quite inexpensive to apply. From discussions with CPRM personnel, there were some hints that less than acceptable groundwater prospecting results had been accepted by the state during the recent emergency.

On our back-roads travels that day, we had two flat tires, which required some enforced delays; this gave the Canadian delegation time to observe closely some aspects of rural life. One of our repair stops was in a small village, where the villagers immediately brought chairs out of their homes so that we visitors could sit. This village also had a community television set, mounted on a pedestal in the middle of the town square. Someone suggested that educational videos concerning groundwater usage, proper care of wells, and related sanitation issues, would be effective ways of reaching the people. Further, there were suggestions that these should be sent to each village priest and introduced (and sanctioned) by him, so as to underline their importance.

Because of mechanical delays, we were unable to see all the sites that CPRM had scheduled for us, and after traveling for some hours after dark, we reached the town of Sobral (towards the western side of the Precambrian shield area of Ceará) where hotel accommodations had been arranged.

Early in the morning of Dec. 9 we visited a pump-repair and well-conditioning shop in Sobral which belongs to a company called SISAR. This company maintains wells and supplies water to several villages on the western side of the survey area. The financing for the start-up of the company and fiscal advice has come from Germany, and a representative of the German government agency stationed in Sobral, met with us to explain how very successful they had been.

The residents of individual communities are charged for water usage (metered water), and SISAR maintains the water distribution system. Issues of water quality and quantity were discussed with SISAR. Their network constitutes a small portion of the problem area, with relatively straight-forward tasking; the more difficult areas where desalination issues are foremost along with the occurrence of social and possibly political resistance, have been bypassed by the company. As I understood, the German agency funding SISAR is doing so as a business investment, and not as a straight foreign-aid donation.

We left Sobral traveling easterly towards the Irauçuba area, in the more topographically rugged area of the Precambrian shield. Since time was at a premium, we elected to bypass some field examples prepared for us by CPRM and go directly to the town of Irauçuba where the mayor of the prefecture and representatives of the nine circumjacent rural communities were waiting for us.
Presentations were made to, and discussions were held (in Portuguese) with, our delegation. During this meeting, a representative of the village of San José (6 km from Irauçuba) complained that for the 72 families in the village area, the state government had recently dug a large well (locally these surface wells are called “amazons”) and drilled two wells into bedrock, all of which were bone dry. Apparently, geological and

geophysical studies had been done at these sites. This perked our interest, and we asked whether we could see this problem area; this was agreed to, at the expense of other sites planned by CPRM.

After lunch, hosted by the mayor of the prefecture, we drove 6 km to the village of San José. We inspected a brand new "amazon" dug well (7–8 m diameter, 5–6 m deep, sides cemented to the bedrock surface). The bedrock (granite gneiss with a fresh appearance) was visible; the fracture density appeared to be quite low, and only a small puddle of water at the bottom of the well could be seen. The well was positioned in a dry stream bed in the middle of the village.
The other two drilled wells (dry) were also positioned roughly in the middle of the habitation, approximately 300 m apart.

In discussions with experienced CPRM hydrogeologists with us (this site was new to most of them as well), we all agreed that there was no indication of lineations, and no indication of surface water (as indicated by vegetation) anywhere in the immediate area of the wells. Upon further questioning the local people (and the mayor) it appears that the well sites were requested by the local people; the state investigated using geological and geophysical techniques, and told them that the sites selected were not suitable for wells. Apparently the people (?) insisted on these particular sites and the state proceeded to do the work with deleterious results.

From examination of the terrain, and noting obvious lineations associated with the surrounding uplands areas, it was the opinion of CPRM and Canadian personnel, that groundwater could probably be found close to the village.

And the plot thickens: currently, the village of San José was being supplied by water truck from a spring about 4 km away. Since the spring was on private land (the mayor seemed to know the owner well), the village was required to pay for the services. The mayor took us to the spring area for a close examination.

It was the opinion of Dr. Fred Michel and some of the CPRM personnel, that the "spring" was a collection of several outcroppings of water on the side of a steep bedrock hill which collectively made their way to the bottom of an alluvial valley where the "spring" was being maintained. Dr. Michel walked the area, examining it closely, and suggested that this valley, and the water confined in it could probably be traced quite effectively (using modern geological and geophysical methods) to an area close to the village. Further, his examination of the groundwater resources upstream from the "spring" area indicated that there was no water shortage (but rather that irrigation was being done—a very rare thing anywhere in the drought area) up slope in the valley from the "spring". The mayor mentioned that his father owned land in this portion of the valley which was being irrigated. All-in-all, this particular site was discussed by CPRM and ourselves as a possible demonstration site, whereby jointly we could probably find water on public land close to the village, by using air-photo/Landsat image processing and interpretation, as well as ground geophysics.

We drove back to Fortaleza on the evening of Dec. 9 along highway BR222.

(5) Meeting at CPRM Fortaleza office, Dec. 10/98

Representatives at this meeting included personnel from CIDA (Brasilia office) and their opposite number from the Brazilian Cooperation Agency, Dr. Yvon Maurice and his opposite number Dr. Samir Nahass from CPRM, several CPRM scientific staff, as well as representatives of state government organizations dealing with water resources, and scientists from Fortaleza, Pernambuco and Rio Grande do Norte (two other northeast states where drought conditions exist in similar Precambrian terrain). Also present were a number of geophysicists from these organizations. A program and a list of participants is attached to this report.

The meeting began with presentations by CPRM personnel (the same ones we had been given on the previous Monday) and then a lively discussion on the proposals for the Canada-Brazil cooperative work ensued, in Portuguese. No translation to English was available for Dr. Michel or myself; however, the discussion was mainly for the information of Dr. Maurice, Dr. Nahass, and the representatives of the two countries agencies.

Dr. Michel and I ferreted out the Brazilian scientific staff in the areas of our expertise (most of whom spoke some English) and informal discussions took place at intervals throughout the day. The following is a summary of the discussions with the geophysicists that I met, along with an assessment of their organization's capabilities and groundwater prospecting experience which could be applied to the current problem in crystalline rock:

(a) ***Dr. Walter Eugênio de Medeiros,***
geophysicist, Universidade de Rio Grande do Norte, centro de Ciencias Exatas e da Terra
E-mail: walter@dfte.ufrn.br
(his command of written English is good, spoken English, fair)

The staff of the research centre for this university submitted a proposal for consideration under the CIDA project, in Portuguese. A copy of the proposal is attached. Although the proposal is a generalized one in which broad objectives in groundwater research are mentioned, Dr. Medeiros spoke to me about specific geophysical goals. Apparently, the university has potential geophysical test sites, one of which is approximately 100 km west of the city of Natal, where there are 15 boreholes drilled into Precambrian rock (average depth 40 m, maximum depth 100 m, cased to fresh bedrock surface and open below this, with hole diameters in the order of 20 cm).
These were drilled as potential wells without the aid of geophysics and the yields are variable. Also, although the geological samples are available, there is no clear indication of the fracture zones from which the water is flowing. It is though that perhaps more than one fracture zone intersects a particular borehole, and perhaps the water quality

(saline versus fresh) may vary between fractures. Also, these holes may have been drilled too deep for the amount of water they yield.

Can surface geophysics indicate correctly the positions of maximum fracture density (highest fracture permeability); can borehole geophysics indicate the location of fracture zones and the water quality associated with them?

The university is keen to try a vast array of surface geophysical techniques at the above site in order to ascertain the ones that are most applicable in this setting. They currently have only DC resistivity and VLF surface geophysical instrumentation capability; they are about to order borehole and seismic equipment from Oyo corporation through a Japan-Brazil aid agreement. The university would very much like the GSC to bring the various EM techniques and equipment to the site as part of the evaluation procedure.

The leader of the groundwater group is:
Prof. Dr. Emanuel Ferraz Jardim de Sã
Email: emanuel@geologia.ufrn.br
(Very good English speaking)

Commitments:

(i) a question to be answered for Dr. Madeiros: is there a person or group of persons in Canada who have experience and/or software to detect fault zones in crystalline rocks.
(ii) Send information on the EEGS organization as well as SAGEEP.
(iii) Send also our published papers on the tube wave borehole method for identification of fractures open to fluid flow.
(iv) send reprint of recent paper on borehole seismic methods

(b) ***Dr. Nelson Ellert***
Professor Emeritus, São Paulo University
Adjunct Professor, Federal University of Ceará, Fortaleza
also owns a consultant company called:
HIDRO AMBIENTE
Av. Martin Luther King, no. 2210
05352-020 - São Paulo - S.P. - Brazil
Tel: (011) 869-4500
Fax: (011) 869-0483
Web Page: www.hidroambiente.com.br
(Very good English speaking)

As mentioned above, Dr. Ellert has had many years experience with Canada-Brazil cooperation through IDRC auspices. He is currently working with Dr. John Greenhouse (professor emeritus University of Waterloo, Canada) on various engineering geophysical projects in the São Paulo area (I believe these projects are either private contracts or work through IDRC).

Dr. Ellert has taught geophysics for many years, and many of his students are now in government and university research positions around the country (e.g. at Univ. of Fortaleza, and at FUCEME). He has experience with most of the modern engineering geophysical techniques, and I am aware that the São Paulo university has EM-31, EM-34, and EM-39 equipment (all Geonics Canada electromagnetic equipment), some of which is now somewhat dated. Hence his students should be aware of the basic techniques which could be applied to the current groundwater problem in Ceará.

Dr. Ellert mentioned to me that during his work with IDRC, he was head of the Latin America research group, which involved developing engineering geophysical projects in neighboring countries, as well as Brazil; his annual operating budget was $300K U.S.

"Friend-to friend" he cautioned me that the Brazilian hydro-geoscientists would look askance at a "master-servant" relationship in the current project under discussion. He cited a recent case (known throughout Latin America) concerning a well-known Canadian university project in groundwater investigations in Mexico, where it was reported that the "gringos from the north" came in, directed the operation (i.e. the Mexicans doing the footwork), made off with the results, and published the work without due recognition of, and with little input from their Mexican partners. I initially found this story hard to believe, but later received co-oberative evidence (Ms. Southerwood, from our team, heard a similar tale from another Brazilian source, during our trip).

Commitments:

(i) Send information on the EEGS and SAGEEP organizations.
(ii) Send information on borehole radar methods for detecting fractures in rock (inform Peter Annan of Sensors and Software Inc. of the request also).
(iii) Send references on seismic rock anisotropy due to fracture orientation (e.g. Colin Crampin's edited volume from CSEG, circa 1995, and the reference on last year's International Symposium on Seismic Anisotropy in Miami - contact Dr. Jamie Harris, Milsaps College, Jackson, Miss. and ask him to send references directly).

(c) ***Dr. Mariano Castelo Branco***
Geophysicist, Federal University of Ceará, Fortaleza
Email: mariano@ufc.br
Webpage: www.sbgf.coun.br (or sbgf-> search)
(English speaking and writing good)

Dr. Castelo Branco gave a short presentation (in Portuguese) to the assembled meeting, indicating that his university had all the necessary equipment (an impressive array of mainly Canadian equipment), all the necessary expertise, and that all they needed to solve the groundwater problem was operational funds. Apparently, his point of view was hotly contested by several Brazilian representatives; no English translation was available, but body language spoke volumes.

My suspicions were raised when I noted that the overhead pictures of equipment in operation were mainly from published brochures. Detailed questioning, outside the meeting room, indicated that some of the equipment was not quite in hand yet. I asked to visit the University.

Dr. Castelo Branco was a graduate student of Dr. Ellert's, some years ago; the relationship between the two is good, and geophysical equipment appears to be shared between U. of Ceará and U. of São Paulo. From this initial meeting, I got the feeling that there was no Canadian technology that could be transferred to this university; they had it all.

(d) ***Dr. João Manoel Filho***
Hydrogeologist, Federal University of Pernambuco, Recife
Phone: (081) 271-8239
Email: jmfilho@elogica.com.br
(Very good English speaking and writing)

Dr. Filho is an enthusiastic supporter of groundwater research involving geophysical methods. He accompanied us throughout our visit inland, and we had plenty of time to discuss geophysical applications. Apparently at his university, geophysics is not well developed (beyond the use of DC resistivity and VLF) and application and testing of newer geophysical techniques would be welcomed in their area. Unfortunately, due to our shortened trip, we were unable to visit the drought area near Recife. Dr. Filho is interested in applications of borehole and surface electromagnetics, not only in Precambrian areas (fracture permeability) but also in areas where sedimentary aquifers are currently being exploited. Such problems as salt-water invasion and identification of permeable zones in sediments are now being investigated.

After a week of periodic discussions with Dr. Filho, I believe that lectures or short courses on a wide variety of current groundwater geophysical techniques would be welcomed at his university; there is also a possibility of longer-termed joint research, should funds become available

(6) Visits to Institutions in Fortaleza, Dec. 11, 1998

(a) Geophysics lab, Federal University of Ceará (morning)

We met with Dr. Castelo Branco who showed us his labs and graduate students. He indicated that his group was current with computer-aided Landsat and air-photo interpretation of fractures. (Similar work is being done at CPRM in Fortaleza). The geophysics lab currently has a gravimeter with differential GPS, VLF, and DC resistivity equipment. It was stated that the lab has recently purchased a Geonics EM-34XL (but from the Geonics sales department, I knew only of a quote being offered, the week before). That day, the lab was about to receive the Geonics EM-39 borehole logging system, on loan from the University of São Paulo.

We also heard of a new Scintrex (Canada) gravimeter which had been purchased by the Federal University of Pará in Belém. Apparently, this instrument has a severe temperature drift problem and is not being used. The geophysics lab apparently does not have very many dealings with some people in the groundwater hydrogeology lab (I sensed a "geopolitical" problem).

We had lunch with Dr. Castelo Branco; he suggested to us that the water shortage problem in Ceará was of a political nature, that the resources were there to solve the problem, but the political will to get on with it was missing. He felt that recent cut-backs to universities have meant that there will be insufficient trained staff to either teach the new techniques or to get involved in extensive field work. He states that equipment availability is not a problem; he has money for that, but "not enough to buy a litre of gasoline for a vehicle to go to the field sites".

I got the feeling that transfer of geophysical technology from Canada to this university would not be welcome1.

Commitment:

(i) Send info on the EEGS website

(b) Fundação Cearense de Meteorologia e Recursos Hídricos – FUNCEME (afternoon)

This organization compiles hydrologic maps for Ceará and develops predicative weather maps from met stations throughout the state. It is fully modern, computerized, and appears to be well-staffed. We also met with their groundwater geophysical group, consisting of two people:

Nelson Paiva Raulino de Sousa
Email: nelson@funceme.br
(does not speak English)

Fernando Andrade
Email: andrade@funceme.br
(speaks some English)

FUNCEME has an ABEM DC resistivity unit and a Geometrics STRATEGEM (MT & AMT unit). They are currently working with groundwater hydrologists at the U. of Ceará, in Fortaleza, on contamination problems, but they have no connection with the geophysics lab there (interesting in light of "geopolitical" problems mentioned above, also since Andrade was trained in geophysics at that university). Their MT system is currently malfunctioning, and I promised to report this to the company concerned, since English seemed to be a bit of a problem.

1 Since this report was written, Dr. Castelo Branco has indicated his intention to submit a proposal for colaborative work under the proposed Canada-Brazil Groundwater Project before the end of January, 1999.

(c) CAGECE (late afternoon)

The discussions here were entirely in Portuguese, and had no immediate connection to geophysics or groundwater exploration. I am sure that other participants will present a report on this organization.

(7) Visit to CPRM, Monday, Dec. 14, Rio de Janeiro

After meeting with CPRM Director Dr. Antonio Juarez Milman Martins and Samir Nahass, chief advisor for international affairs, we met with Dr. Mario José Metelo, head of geophysics for CPRM and geophysicists Luis Marcelo Mourão (remote sensing interpreter) and Maria Laura Azevedo. We were shown the results of the previous GSC/CPRM/CIDA project results with respect to airborne geophysics, and how these results have assisted CPRM in many of their endeavors.

We then discussed the possibility of testing airborne electromagnetic methods in NE Brazil as part of the future CIDA program. We all agreed that such techniques could be useful in areas where there were no other indications of fracture systems (i.e. from Landsat or air photography), but we realized that such testing would be prohibitively expensive within the constraints of this program.

Dr. Metelo gave me a recent report of joint work between CPRM, the National Observatory of Brazil, the University of Leicester, and the University of Edinburgh, where they have tested ground geophysical techniques in the search for fracture systems in Precambrian rock which are water-bearing. This work, done in 1998 in the state of Piauí, is the first indication of any substantial use of loop-loop electromagnetic methods for groundwater prospecting in Brazil that I have seen. It should be noted that ground and airborne electromagnetic techniques have been routinely used for groundwater exploration in other semi-arid regions of the world for many years. I am aware of publications related to surface electromagnetic responses by G. Palacky (GSC, retired) dating from the 1980's, when he worked in Brazil, but no subsequent follow-up work since that time. It seems incredible that more work has not been done in groundwater prospecting using electromagnetic (loop-loop) techniques, since this technique has been routinely used in Brazil for mineral prospecting.

We also met with the hydrological group of the CPRM: Frederico Claudio Peixinho (head) and Claudio Luiz Rebello Vidal. I asked about the use of any geophysical techniques and discovered that borehole geophysical logging is done by this group. They had 14 complete borehole logging units a few years ago, but sold them off. At present, they have only 3 units; these are Gerhart-Owens slim hole tools (the standard suite of resistivity, caliper, gamma, gamma-gamma, neutron, etc.). The GSC used to have such equipment back in the late 60's and early 70's (operated by the Terrain Geophysics Group) but these have been replaced with newer equipment developed and used by the Borehole Geophysics Section (MRD) and the Terrain Geophysics Group (TSD). The

hydrology group at CPRM would probably benefit from a short course on well-log interpretation for hydrogeological surveys, as well as a summary of the availability of new equipment and techniques.

(8) **Summary and Recommendations**

Since the trip to N.E. Brazil was necessarily brief, only limited areas were visited in the state of Ceará. However, from discussions with Brazilian workers from other adjacent areas, it is obvious that the drought is widespread and affecting a large rural population.

The most affected areas are those underlain by Precambrian rocks where groundwater is mainly associated with bedrock fracture systems.

Most "amazon" surface-dug wells which rely on (seasonally variable) alluvial water, are dry (by mid December, 1998). Many drilled wells are often low yield, brackish or saline, and a proportion of these are in a state of disrepair. Desalination units have only been installed by the state government on those wells where flow rates are large; many wells do not qualify. However, it may be possible to find higher-yield wells in the vicinity.

Emergency measures by the State of Ceará consist of either trucking water to villages from areas where water is available from wells or reservoirs, or drilling new wells at a rapid pace with minimal hydrogeological guidance. In my opinion, neither measure provides an effective solution in the long term.

In the Precambrian terrain, there is plenty of potential to discover new sources of groundwater by utilization of mapping techniques to define permeable bedrock fracture zones and applying ground geophysical techniques to position drilled or dug wells.

CPRM and other institutions (e.g. Federal University of Ceará) in Fortaleza appear to have the capability and experience to interpret favourable geological structures for groundwater exploration; however, I would suggest that visits of Brazilian specialists to CCRS might be in order, to ensure that they are aware of all the latest tools of the trade.

From the discussions I have had, and the visits to field sites and labs, it appears that the application of geophysical techniques to the groundwater problem has been less than successful to date. This could be a result of lack of coordination of geophysical resources as well as lack of knowledge of current techniques. The "awareness level" of geophysical methodologies as applied to groundwater exploration is spotty amongst government and university organizations.
[Note: there is also the possibility that I have been inadvertently exposed to a "skewed" sample of available expertise].

It is apparent that the skill level of Brazilian geoscientists is high. It is also obvious that the groundwater problem in N.E. Brazil will only be solved by Brazilian-led exploration efforts along with the backing and resolve of the government.

In my opinion, the main geophysical assistance that Canada can offer is to ensure that Brazilian geoscientists are aware of, and have experience with, the most modern, up-to-date geophysical techniques available. In this way, proper decisions on field methodologies can be made by the responsible Brazilian agencies for a given geological

setting and groundwater problem. Perhaps the most effective ways of transferring geophysical technology are through short-courses (2-5 days duration) and field demonstration/testing in "type" areas.

In my opinion, there are two possible levels of technology transfer:

Level I (short term)

(1) introduce surface methods to solve the immediate "permeable fracture zone location" problem

(a) various (Canadian-designed) electromagnetic (EM) methods (EM-31, EM-34, Max-Min)

(b) capacitive-coupled resistivity (Russian designed, American-built)

(2) integrate these systems with technology transfer of hydrogeological interpretation techniques

(3) perform joint geological-geophysical test surveys at a few selected locations

(4) the objective of this level would be to provide sufficient technology to address the immediate water shortage in the short term (over a year or two).

Level II (long term)

(1) introduce airborne, surface and borehole techniques that are currently either "cutting edge" or in developmental stages. Such methodologies may not be needed to solve the immediate water shortage but serve to broaden the base of groundwater geophysics in Brazil and could eventually lead to more effective and efficient utilization of groundwater resources.
(2) this technology transfer could be in the form of Canada-Brazil joint applied research.

Examples of such potential work are:

(a) testing of current airborne electromagnetic (EM) methods to detect fracture zones in Precambrian rock (perhaps on an opportunity basis if an airborne survey were underway by private industry in a neighboring state - e.g. the Canadian Geoterrex GEOTEM system which is presently based in Belém)

(b) testing of current borehole logging methods to evaluate groundwater yield in drilled wells; this work could be done in conjunction with borehole logging interpretation short courses (Canadian and American expertise)

(i) testing of the downhole seismic tube wave method of identification of fractures open to fluid flow (an established Canadian technique which can be used in place of packer tests)

(c) testing of the "Hydropulse" NMR surface technique to estimate formation porosity. This technique is of Russian origin, developed by the French BRGM, and has undergone preliminary tests by the US Geological Survey.

(d) application of deep-sounding transient EM (EM-47, EM-57, EM-37: Canadian equipment and expertise) for use in identification of "saline fronts" in coastal sedimentary aquifers
(e) application of high resolution shallow seismic reflection techniques to mapping detailed stratigraphy of sedimentary aquifers (Canadian, American, and European expertise)

The levels of technology transfer given above can be accomplished by means of geophysical expertise currently available within both Canadian government and private industry.

It is interesting to note that many of the geophysical techniques and equipment which can potentially be brought to bear on the groundwater problem in N.E. Brazil, have been developed by Canadian companies (assisted by Canadian government applied research). Technology transfer to Brazil can effectively "showcase" Canadian groundwater geophysical expertise with possible long-term economic benefits to both Canadians and Brazilians.

PROJECT DEVELOPMENT MISSION TO BRAZIL

Part 2: A Hydrogeological Perspective

by
Frederick Michel
Hydrogeologist, Carleton University

INTRODUCTION

The mission to northeastern Brazil in December 1998 was a fact finding trip in which we were asked to assess the local knowledge and capabilities for improving the water supply situation in this semi-arid region, especially for those areas underlain by crystalline basement rocks, and to develop a project proposal for the effective transfer of Canadian technologies to Brazil in the area of ground water exploration and management.

Hydrogeology involves the integration of various fields of geological and hydrological knowledge with various technologies to focus on water supply issues, related both to quantity and quality of the resource. Because ground water is generally a widespread but locally derived resource that is essential to the daily life of all people, the question of knowledge must be addressed at all levels, from the individual rural community organization to the institutional levels of universities and state/national agencies. The representatives of both sponsoring agencies, CIDA and ABC, clearly expressed a desire to see the focus of any project be on the direct benefits of water supply to the community. Therefore, it is important to determine the capabilities of the local scientific community to address the water supply problems of the area and to identify what assistance Canada may be able to provide in terms of knowledge and technology.

LOCAL CAPABILITIES AND EXPERTISE

From the perspective of organization, ground water knowledge to varying degrees is present from the individual community to the institutional level. Several universities in northeastern Brazil offer some expertise in hydrogeology, although the resources (personnel and equipment) are limited.

At Pernambuco University in Recife, there are two hydrogeologists in the geology department and two ground water model specialists in civil engineering. Although they are introducing a Ph.D. program, many of the ground water courses must be taught by guest lecturers who often are international visitors. This is primarily a consequence of the lack of expertise in some sub-disciplines related to hydrogeology.

At Rio Grande do Norte University in Natal, the one hydrogeologist on staff is not oriented to the local water supply problems and all lectures are by visiting lecturers. The department has a strong emphasis on structural analysis which is an important aspect of ground water flow in fractured rock.

At Ceará University in Fortaleza, there is a geophysics group and a hydrogeology group (of 2) who apparently do not co-operate. The hydrogeology group is poorly equipped and currently works with the geophysics group at the meteorology institute (FUNCEME). Within the physics department at Fortaleza, there is a small group working studying isotopes related to local hydrogeological problems. They have older basic age dating facilities for tritium and radiocarbon, but no facilities locally for stable isotopes.

All of these groups expressed a strong desire to co-operate with Canadian participants in the proposed CIDA project and felt that there was a need for Canadian expertise.

Within the government institutions, hydrogeological capabilities can be subdivided into national (CPRM) and state/municipal. At the national level, CPRM has a hydrogeological group in Rio de Janeiro, as well as individuals in offices throughout the country. The emphasis by CPRM personnel working in the northeast has been on geological mapping, especially structural mapping. With the recent drought conditions, an inventory (database) of wells has been created. CPRM has also produced an excellent set of practical operation manuals for ground water exploration and for well testing.

During our visit I did not get a sense for how strong (or weak) the expertise is at the state level. My impression was that the state has no in-house expertise, but simply hires local consultants and well drillers to locate and drill wells when required, and that the completed wells are then controlled and maintained by local municipal councils. Although geophysical techniques were employed for the location of some wells, the work was not beneficial in many instances; probably due more to the techniques employed and/or the interpretation of data. As far as drilling technology is concerned, both hammer and air rotary drills exist, as do pumping equipment and pump repair capabilities. Educational organizations, such as provided by ABAS and CAGECE, play an important role at the municipal level.

MAIN ISSUES

Although northeastern Brazil receives significant precipitation, essentially all of this occurs within a three month period and the remainder of the year is hot and dry, leading to semi-arid conditions. The presence of adequate supplies of water within adjacent sedimentary basins demonstrates that sufficient precipitation falls and that the problem in the crystalline rock areas is one of limited storage capacity in the subsurface. During the

past five years, less than average precipitation has occurred and this has led to a diminishing water supply for both surface and ground water. Larger municipalities tend to construct dams and reservoirs to supply their water needs. The water is piped and treated. Smaller communities on the other hand are almost entirely reliant on ground water.

Two major issues are present for many of the ground water supplies in the area of crystalline rocks: quantity and quality.

(1) Quantity

The issue of quantity is permanent as the population of the communities increases. With the drier conditions of the past 5 years, water levels in the subsurface have been declining, leading to wells going dry. To alleviate this problem, the government has initiated massive well drilling programs and individual community members have also hand dug large diameter wells. The location of many of these wells has been determined by convenience or by hunch and often the results have been discouraging. Consequently, the government must now truck water to many communities. Management of water supplies is an important secondary issue related to water quantity and will become even more critical if current conditions persist.

(2) Quality

The quality issue centers on the high total dissolved solids (TDS) concentrations encountered at depth. TDS values as high as about 5,000 mg/L were mentioned to us. The widespread existence of salty water at depth has precluded the deepening of most wells. In some instances, reverse osmosis (RO) units have been installed to 'purify' the water. During our field excursion, our visit to an operating RO unit confirmed that the units require significant maintenance and that the brine residual is not being properly disposed and is able to re-enter the system. The high cost of these systems is also a drawback.

Although everyone appears to be aware of these two major issues, there does not appear to be the ability to effectively deal with the problems. There is a need for improving well siting (locating where to put a well) to maximize storage capabilities and for research on the salinity problems.

RECOMMENDATIONS

It is clear that the issues of quantity and quality need to be addressed if the water supply problems of northeastern Brazil are to be overcome. The approach needs to involve (i) co-operative Brazilian - Canadian research to investigate the source(s) of the problems

and to generate innovative solutions; (ii) knowledge transfer through both the educational institutions and at the local community level; and (iii) practical demonstrations of new technologies and solutions at representative sites within the area. Within this framework, the following recommendations are made for development of a project proposal.

(1) Opportunities should be created to facilitate the establishment of co-operative hydrogeological research partnerships between Brazilian and Canadian institutions where the issues of ground water quantity, quality and resource management can be addressed.

(2) The researchers should be in dialogue with local community representatives to ensure that the research is focusing on actual problems and encourage local residents to participate in the work.

(3) Within the research program, new technologies, such as new geophysical techniques and equipment, or well development techniques, should be examined.

(4) Short courses, including field-oriented courses, should be organized and available for university post-graduate students, researchers, local consultants and well drillers. Local educational groups like ABAS should be involved in delivering information and knowledge at the community level.

(5) Demonstration sites should be selected, with community input, to highlight the guidelines, techniques, and equipment best suited to the local conditions.

APPENDIX

Participants at the meeting held December 10 & 11, 1998 in the "Amigo das Águas" auditorium, Fortaleza, Ceará

ABAS: Associação Brasileira de Água Subterânea (Núcleo Ceará); promotes water conservation and related issues through awareness campaigns; organizes events; maintains linkages

- Clodionor Carvalho de Araújo – Presidente

ABC: Agência Brasileira de Cooperação; counterpart to CIDA in Brazil

- Dra. Amélia Maria Fernandes Alves

APRECE: Associação dos Prefeitos do Ceará;

- Jorge Luiz P. de Souza – Representante dos Prefeitos (APRECE) e Presidente do Conselho de Desenvolvimento de Technologias (CONDETEC)

CAGECE: Companhia de Água e Esgotos do Ceará; involved in water distribution in urban areas; also conducts educational programs on water conservation in rural settings

- Dr. Mario Fracalossi Júnior – Coord. Saneamento Rural

CARLETON UNIVERSITY, Ottawa, Canada

- Prof. Frederick Michel – Hidrogeólogo

CEDEC: Coordonadoria Estadual de Defesa Civil do Estado do Ceará;

- Dr. João Alfredo Pinheiro Júnior – Coordenador
- Ademarzinho P. de Holanda

CIDA: Canadian International Development Agency; Brasilia

- Louise Clément – Secretária da Embaixada do Canadá
- Marta Irving – Assessora da CIDA

CPRM: Companhia de Pesquisa de Recursos Minerais;Geological Survey of Brazil

- Antônio de Souza Leal – Coordenador Nacional de Hidrogeologia – SUREG-BH/CPRM
- Clodionor Carvalho de Araújo – Chefe da Residência de Fortaleza – CPRM/REFO
- Fernando Antônio Carneiro Feitosa – Assist. de Produção-Hidrogeologia – CPRM/REFO
- Jader Parente Filho – Geólogo – CPRM/REFO
- Jaime Quintas dos Santos Colares – Coordenador Executivo – CPRM/REFO
- Liano S. Verissimo – REFO/CPRM
- Oderson Antônio de Souza Filho – Geólogo – CPRM/REFO
- Samir Nahass – Coordenador Brasileiro da Cooperação GSC-CPRM
- Sebastião Milton Pinheiro da Silva – Geólogo da SUREG/RE
- Thales Sampaio – Coordenador Nacional Qualidade – CPRM

FUNCAP: Fundacao Cearense de Amparo à Pesquisa; funding agency for science and technology; organizes events and promotes technology transfer and research; administered by university professors; operates under SECITECE

- Josué Mendes Filho – Depto. Física

FUNCEME: Fundacão Cearense de Meteorologia e Recursos Hídricos; is involved with weather prediction and surficial mapping (land use maps, soil maps, etc.);

- Carlos Eduardo S. Leite

GSC: Geological Survey of Canada, Ottawa, Canada

- Dr. Jim Hunter – Especialista em Geofísica do GSC
- Dr. Yvon Maurice – Coordenador Canadense da Cooperação GSC-CPRM

ICCN: Instituto Cearense de Ciências Naturais

- Denise M. Azevedo Ursulino
- Raimundo Humberto C. Lima
- Ferreira – ICCN/UFC

SECITECE: Secretaria de Ciência e Tecnologia do Ceará; promotes science and technology for the well-being of society by formulating and implementing appropriate policies, in Ceará

- Francisco Aurélio Caetano da Silva

SOHIDRA: Superintendência de Obras Hidráulicas do Ceará; carries out waterworks projects such as well drilling, desalinization plants installation and dam building, on behalf of SRH (Secretaria de Recursos Hídricos); exploration for water resources is contracted out by SOHIDRA to private consultants

- Dr. Francisco Edson Pessoa Pinheiro

SUDENE: Superintendência de Desenvolvimento do Nordeste/Ministério do Planejamento; provides funding for development projects in NE Brazil, including water infrastructure projects through PROHIDRO

- Dr. Carlos Almiro Moreira Pinto
- Lúcio Flávio Leitão

UFC: Universidade Federal do Ceará (Fortaleza); strength in geophysics and isotope geochemistry

- Prof. Clóvis Vaz Parente – Coord. Curso Mestrado Geologia
- Profa. Maria Marluce Freitas Santiago – Departamento de Física
- Prof. Francisco Marques Júnior – Chefe do Departamento de Geologia
- Prof. Mariano Castelo Branco – Departamento de Geologia , Geofisica
- Profa. Sonia M. Silva Vasconcelos – Departamento de Geologia
- Prof. Nelson Ellert – Departamento de Geologia

UFPE: Universidade Federal de Pernambuco (Recife);strength in hydrogeology

- Prof. João Manoel Filho – Hydrogeologia

UFRN: Universidade Federal do Rio Grande do Norte (Natal); strength in geophysics & remote sensing

- Prof. Emanuel Ferraz Jardim de Sá – Departamento de Geologia – PPGG
- Prof. Walter Eugênio de Medeiros – Departamento de Física – PPGG
- Prof. Venerando Eustáquio Amaro – Departamento de Geologia – PPGG

VICTORY ASSESSORIA:

- Sra. Silvana Santos
- Sergio Buffat

WATER FOR PEOPLE:

- Suzan Southerwood