COST OF GROUNDWATER EXPLORATION FOR RURAL WATER SUPPLY PROJECTS IN DEVELOPING COUNTRIES

L. ZOPPIS and R. ZOPPIS
C. Lotti & Associati - Via del Fiume, 14 - 00186 Rome Italy
C.M. Consulting and Management - Passeggiata di Ripetta, 35 - 00186 Rome Italy

ABSTRACT

Groundwater exploration for rural water supply projects usually differs widely from one area to another, depending on local hydrogeological conditions. In areas with extensive continuous aquifers, such as sedimentary deposits, hydrogeological investigations are relatively simple and inexpensive, especially if some data on the groundwaters are available. In areas with discontinuous aquifers, such as weathered or fractured basement rocks, hydrogeological investigations are more difficult and expensive, since they also involve photogeological interpretation and geophysical prospecting.

The paper summarizes the results of two rural water supply projects in Chad and Mali, where different hydrogeological conditions prevail; it also deals with the various investigatory methods employed, and the costs thereof.

1 INTRODUCTION

As a result of the severe drought which has stricken many parts of Africa in recent years, especially the Sahelian strip, the provision of water supplies in rural areas has come to be of major importance in many Developing Countries. As a result, international agencies, governments of industrialized countries, other donors and governmental agencies in the countries concerned have begun to focus on the search for water sources and on the implementation of works for their development. Action in this regard has been necessary not only for the immediate solution of the most critical situations but also for programming future groundwater development projects designed to ensure basic self-sufficiency in water, at village level, as this is indispensable for progress in every sector.

The implementation of short-, medium- and long-term programmes has consequently made an outstanding contribution towards the establishment of more adequate systems of groundwater exploration and development in rural projects which, as regards the scope of investigations, dimensions and costs, differ quite considerably from the more usual type of projects involving hydrogeological prospecting. The cost of investigations necessary for groundwater exploration in rural water-supply projects under various hydrogeological conditions is examined briefly in this paper which does not, however, extend to actual project implementation and hence such matters as borehole drilling, well completion, pump installation and the provision of hydrogeological assistance for these operations. The aim is to provide a picture of the different methods of investigation normally adopted. To this end, an assessment is made of the exploration costs of two rural water-supply projects located in Chad and in Mali, considered representative of two different hydrogeological situations, typical of many parts of Africa.

Exploration costs are, of course, affected by numerous factors, depending not only on the technical solution adopted, but also on local factors which vary from country to country.

The results given ahead, therefore, reflect technical and socio-economic conditions in the two countries concerned, but they provide a good guide for groundwater exploration in relatively deep aquifers (max. 100-120 m), generally using rotary and/or down-the-hole drilling techniques.

2 HYDROGEOLOGICAL CONDITIONS

Owing to different climatic, geological and hydrogeological conditions (rainfall, type of surface geological formations, nature and extent of aquifers, depth to water, recharge methods, etc.) the

areas in which rural water-supply projects may be located all call for individual study. However, to simplify and schematize, as can be done in the case of rural water-supply studies, aquifers can be divided into two main groups, namely continuous regional aquifers and discontinuous local aquifers.

2.1 Continuous regional aquifers

Aquifers of this type are usually found on clastic sedimentary formations with primary permeability and fairly constant hydraulic characteristics extending over vast areas.

Examples of such aquifers are encountered in Chad (Plio-Quaternary clayey sandy formations around the shores of Lake Chad), in Senegal (Tertiary "Continental Terminal" deposits) and throughout the Saharan and Sub-Saharan zone with the Mesozoic "Nubian Sandstone" series.

Wells drilled in these aquifers usually provide fair discharges, that are nearly always in excess of the maximum deliveries of the hand-pumps used (1.0 - 1.5 m^3/h). The success rate of exploration in continuous regional aquifers is generally high (95 - 100% productive wells).

Water salinity usually varies greatly depending on local characteristics, but it is generally high (700 - 1000 mg/l) in these aquifers owing to the fact that they extend over such vast areas, so the groundwater flowpaths tend to be long.

2.2 Discontinuous local aquifers

Aquifers of this type are generally found in Basement Complex rocks, very widespread in Africa, and impermeable sedimentary and volcanic rocks, characterized exclusively by secondary permeability, near fracture lines, dykes, intrusions, etc. Consequently, the aquifers are relatively deep and discontinuous.

Small perched aquifers may also be encountered in the lateritic zones and weathered Basement Complex but on account of their low productivity and the possibility of pollution, they are hardly ever considered as a potential water source for rural water-supply projects.

Discontinuous aquifers are encountered in southwest Mali, Ivory Coast, Cameroon, Zambia, etc. i.e., mainly where the Basement Complex is in outcrop. The discharges of wells drilled in these aquifers can vary greatly, in many cases being less than the maximum capacity of the hand-pump normally used. Consequently, the exploration success rate in these aquifers (75-90% productive wells) is generally less than in continuous aquifers.

Salinity is usually low (50 - 500 mg/l) owing to the relatively short distances covered by groundwater flows and the fact that the reservoir rocks are not very soluble.

3 INVESTIGATIONS

In a village water-supply project, several factors have a bearing on the programme of investigations for locating the most favourable drilling site, for instance:

- water demand is usually low (generally from 3 to 20 m^3/day per well), so it has little effect on the hydraulic balance of the aquifer;
- wells must be located not more than a few hundred metres from the village;
- average depth of aquifers must be less than 100-120 m, and the standing level should be not more than 60 m below the surface to enable hand-pumps to be used.

Investigations should really be planned separately for each project because local hydrogeological conditions differ widely as, too, may knowledge of the Project Area.

In the case of continuous aquifers, only regional investigations are necessary, and well location will depend mainly on the requirements of the villagers. In the case of discontinuous aquifers, however, detailed investigations are also required; these must be concentrated over a small area around the village and conducted with considerable precision to identify particular hydrogeological conditions (faults, fractures, etc.).

Therefore, for both types of aquifers the initial hydrogeological survey must include regional investigations which may be summarized as follows:

- collection and analysis of available climatological, geological and hydrogeological data (with special attention to data from any earlier drilling performed in the Project Area, chemical analyses of the water, etc.); collection of available topographic and geological maps, as well as airphoto cover and satellite imagery when very extensive areas are involved;

- preliminary field missions in order to: perform the hydrogeological investigations needed to establish the existence of either a continuous or a discontinuous aquifer; conduct a sample survey so as to compile an inventory of existing wells; collect water samples for field analyses (pH - electrical conductivity); ascertain the state of the area and the existence of access roads or tracks to the villages, so as to decide on the type of equipment and vehicles necessary;

- preparation of a scheme (or schemes) for drilling the new wells, including characteristics of envisaged drilling rigs, type of drilling procedure, borehole diameters and depths, types and diameters of casings, types of pumps to be installed, etc.

In the case of continuous regional aquifers, these preliminary investigations are usually adequate for siting new wells, but where discontinuous aquifers are concerned, supplementary investigations must be conducted, such as:

- regional photointerpretation of the geolithological, geomorphological and structural characteristics of the entire Project Area, using 1:40,000 - 1:50,000 air photos;

- detailed photointerpretation, at a scale of 1:10,000, using enlargements of available air photos of the area around each village selected, in order to identify all the structural and geomorphological elements needed for correct siting of wells within the village or in the immediate vicinity;

- detailed hydrogeological investigations in the area around each village for photo-geological ground control and so as to draw up a programme of geophysical investigations, if considered necessary;

- geophysical prospecting using geo-electrical methods (vertical electrical soundings and resistivity profiles) and, if need be, seismic and magnetic survey methods.

Geophysical investigations are generally optional in areas with rainfall in excess of 800 mm/year, but where the rainfall is low (400-800 mm/year) they are essential for the proper siting of wells, so as to ensure an acceptable success rate.

4 RESULTS OBTAINED IN TWO RURAL WATER SUPPLY PROJECTS IN CHAD AND MALI

4.1 Chad project

A multi-sectoral project in the Lac and Kanem regions of the Republic of Chad, financed by the Italian Aid Fund and sponsored by the United Nations Development Programme, provided for the construction of about 200 drilled wells equipped with hand-pumps for rural water supply. This can be considered a typical example of a project in a region where there is an extensive continuous aquifer.

The 21,000 km² Project Area lies in the Sahelian-subdesertic strip, where mean annual rainfall ranges from 200 to 400 mm. Surface geological formations consist essentially of Quaternary deposits (bedded sands and clay) of considerable thickness (up to several hundred metres) forming two separate aquifers, namely:

- A shallow aquifer - Unconfined, from 50 to 100 m thick, recharged partly by direct infiltration (rains) and partly by indirect infiltration (Lake Chad flood waters); water quality (salinity 600-700 mg/l) is generally satisfactory. This is the main aquifer. Project wells are generally 60-80 m deep and have discharges ranging from 5 to 40 m³/h;

- A deep aquifer - Confined, lying at a depth of over 250 m; no data available (the waters are probably fossil due to lack of recharge). Owing to its depth and the lack of data, which would make prospecting and development complex and costly, this aquifer is not considered suitable for rural water supply projects.

Only general hydrogeological investigations were carried out, including:

- collection and analysis of existing data;
- preliminary field missions, during which a sample survey was made to draw up an inventory of existing wells, measure electrical conductivity and pH of the groundwaters, and assess general hydrogeological conditions;
- establishment of drilling programme, well type and drilling methods.

These investigations were sufficient to locate the most favourable drilling sites in the villages; they required only one hydrogeologist for 5 man/months plus support from the Chad office and home office.

Total cost of the operation was:

. 1 hydrogeologist for 5 man/months, including salary, allowances, international and local transportation (4x4 vehicle), at a rate of US $ 15,000 per months	US $ 75,000
. home office and local office support at a rate of US $ 5,00 per month	US $ 25,000
Total cost	US $ 100,000

Therefore, considering the 200 wells involved, the unit cost of the investigations was about US $ 500 per productive well.

As the overall cost of constructing a well in this project - including drilling, completion, installation of hand-pump and supervision - was about US $ 20,000, groundwater exploration accounts for mere 2.5% or so of the total cost of an equipped well.

The project is now being implemented: 80 of the 200 wells envisaged have already been drilled, with a success rate of 100%.

4.2 Mali project

A bilateral Italo-Malian project funded by the Italian government to drill 450 production wells equipped with hand-pumps in about 250 villages in the central part of the country. This can be considered typical of a project in a region that has a discontinuous aquifer.

The 35,000 km² Project Area lies in the southern part of the Soudanese-Sahelian strip, where mean annual rainfall ranges from 500 to 1,000 mm. The outcropping geological formations here consist mainly of Basement Complex rocks (granites and schists) and Infracambrian sedimentary formations (sandstones) often intersected by dolerite dykes.

From the hydrogeological aspect, the Project Area has:

- An upper aquifer - Unconfined, rather shallow, in the weathered cover formations, endowed with primary permeability, subject to very marked seasonal fluctuations and very vulnerable to pollution. Because of these characteristics, this aquifer cannot be developed for rural water supply, although it is the only water-source at present available to the villagers who extract what are generally insufficient amounts of usually very dirty, contaminated water by means of large-diameter hand-dug wells;

- A lower aquifer - Semi-confined, discontinuous, formed in the fractured zones of the various rocks (from 50 to 120 m deep), and endowed with secondary permeability. This is the only aquifer that can be rationally developed by means of drilled wells; it provides pure water, low salinity and dynamic standing levels remain constant throughout the year.

The general preliminary investigations for this project consisted of data collection, field missions and the preparation of

a drilling programme for about 450 production wells; they required one hydrogeologist for 6 man/months, the cost breakdown being as follows:

. one hydrogeologist for 6 man/months, including salary, allowances, international and local transportation (4x4 vehicle), at a rate of US $ 15,000 per month	US $ 90,000
. home office and local office support, at a rate of US $ 5,000 per month	US $ 30,000
Total cost	US $ 120,000

The following supplementary operations were also needed:

- regional photogeological survey (1:100,000 scale) of over 35,000 km², at a total cost of about US $ 50,000;

- detailed (1:10,000) photogeology of the areas embracing the 250 villages, at a cost of about US $ 100 per village, making a total cost of US $ 25,000;

- detailed hydrogeological investigations for each village, photogeological control, and preparation of the geophysical investigation programme. These investigations required one hydrogeologist for about 12 man/months, including the necessary logistic support, the cost breakdown being as follows:

. one hydrogeologist for 12 man/months, including salary, allowances, international and local transportation (4x4 vehicle) at a rate of US $ 15,000 per month	US $ 180,000
. home office and local support, at a rate of	

US $ 3,000 per month	US $ 36,000
Total cost	US $ 216,000

- geophysical investigations (geo-electric and, in some cases, magnetic) in all 250 villages concerned.

  The geophysical team, made up of one expatriate and one local geophysicist, ten local workmen and four 4x4 vehicles, took about 20 months to carry out the investigations in the 250 villages, the cost breakdown being as follows:

. one expatriate geophysicist 20 man/months, including salary, allowances, international and local transportation (4x4 vehicle),at a rate of US $ 15,000 per month	US $ 300,000
. local geophysicist for 20 man/months including salary and local transportation (4x4 vehicle) at a rate of US $ 3,000 per month	US $ 60,000
. 10 local workmen for 20 man/months including salary, allowance and local transportation (two 4x4 vehicles) at a rate of about US $ 5,000 per month	US $ 100,000
. local office support, rent and maintenance of equipment, miscellanea. Lump sum.	US $ 40,000
Total cost	US $ 500,000

Consequently, the total cost of the investigations involved in this project was:

- Preliminary investigations	US $ 120,000
- Regional photogeological survey	US $ 50,000
- Detailed photogeology	US $ 25,000
- Hydrogeological investigations in 250 villages	US $ 216,000

- Geophysical prospecting in 250 villages	US $ 500,000
Total	US $ 911,000

For 450 production wells, this amounts to about US $ 2,000 per well.

The overall cost of each production well works out at about US $ 25,000, so the investigations accounted for 8% of the total cost of an equipped well.

The project is now in an advanced stage of implementation. Photogeological, hydrogeological and geophysical investigations have been completed in the 250 villages, and about 300 production wells have already been constructed, the success rate being about 85%.

5 REFERENCES

Bajard Y., Draper M. and Viens P. (1981). Rural Water Supply and Related Services in Developing Countries; Comparative Analysis of Several Approaches - Journal of Hydrology - 51-75-88 - Amsterdam.

C.I.E.M.- Comité Interafricain d'Etudes Hydrauliques (Géohydraulique 1978-79). L'eau souterraine des roches cristallines - France.

CILLS - Comité Permanent Inter-Etats de Lutte contre la Sécheresse dans le Sahel (1981). Hydraulique villageoise et développement rural dans le Sahel - Lomé.

UNESCO - Ground Water in Rural Water Supply (September 1983). Report on the Workshop held in Lahnstein, Federal Republic of Germany.

UNESCO - IAH - IAHS (1983)-International Symposium on Groundwater in Water Resources Planning - Koblenz.

D.E. Walling, S.S.D Foster, P. Wurzel (1984). Challenges in African Hydrology and Water Resources - Proceeding of Harare Symposium - IAHS Publication n° 144.