

## WATER SUPPLY FOR EMERGENCIES - ETHIOPIA 1984-86

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## ABSTRACT

The present paper deals with the hydrogeological investigations which have been supported by the Department for Cooperation to Development of the Italian Ministry of Foreign Affairs in the Makallè district (Tigràì-Ethiopia) during the last two years of severe drought and famine.

General land characteristics, hydrogeological considerations and assumptions are outlined for the major townships of the area, where a campaign of drilling operations for 46 productive wells was carried out for the water supply of refugee shelters.

Besides reporting on the specific characteristics of the intervention and the principal results obtained, two possible technical-economic models are presented. These models are to serve as a guide to the planning, execution and management of similar interventions in developing countries, both in normal and emergency conditions.

## 1 INTRODUCTION

The years 1984 - 1986 will be sadly remembered by most African populations for the severe drought and famine, which from the very beginning created a state of extreme emergency and consequent high mortality.

In order to face such a natural calamity, a relief program was immediately carried out by the "Department for Cooperation to Development" of the Italian

Ministry of Foreign Affairs, purposely addressed to the North Ethiopian provinces of Tigrai, Eritrea and Wollo.

In the frame of this program, a groundwater research by means of several drilled productive and fully equipped wells was carried out in the Makallê district and surroundings (Tigrai) by a team of Italian experts with the aid of the most sophisticated equipment expressly sent from Italy.

Besides reporting the main results of this complex research campaign, the present paper aims at pointing out in terms of economic efficiency some aspects of this kind of technical operation in developing countries both in emergency and in normal situations.

## 2 GENERAL OUTLINES OF THE INTERVENTION AREA

The district of Makallê, capital town of the Tigrai province, is located on the northern branch of the Ethiopian Plateau, about 50 kilometers from the Rift Escarpment.

Characterized by a mean height of 2000-2200 metres above sea level, it shows a medium mountain morphology with peculiar high table reliefs, or Ambas, surrounded by deep gorges or flat and rolling valleys of big extent.

Towns and villages are mostly gathered along the main roads, while typical houses and rural urban centres are scattered everywhere in the fields.

The whole area, which is quite heavily populated all the year round, is affected especially in the driest periods by huge migrations of nomads, who come up from the Danakil lowlands, for urgent needs of food and water supply.

The environmental data may be summarized as follows:

- mean yearly rainfall depth:  $600 \div 1000$  mm/a, mainly concentrated in a short span;
- minimum mean yearly temperature:  $13 \div 16^{\circ}\text{C}$ ;
- maximum mean yearly temperature:  $16 \div 20^{\circ}\text{C}$ ;
- potential evapotranspiration :  $80 \div 100$  cm/a;
- discontinuous runoff, generally very poor, seasonal and often limited to the wettest periods;
- extremely variable infiltration rate, due to the uncertain climatic data and hydraulic properties of the soils and rocks.

Even though statistically evaluated, such data do not take into account the

recurrence of the almost periodical drought events caused both naturally and artificially. In fact a heavy deforestation has been continuously carried out by the resident population both to increase the extent of cultivated land and to utilize the wood as combustible or building materials. This has brought to those irreversible desertification processes which in the long run always modify the environmental and climatic conditions of the region.

Within the complex stratigraphic sequence, dating back to the Precambrian, the most productive water-bearing formations of the intervention area have been found to be those belonging to the Mesozoic, as described in the following:

- Adigrat Sandstones: a Jurassic thick horizon of medium to coarse, red to brown sandstones with some shale and laterite bands and abundant silica cement, partially eroded and lightly weathered; aquifers occur at different depths within typical permeable coarse grained or conglomeratic layers;
- Antalo Limestones: a Jurassic thick layer of neritic fossiliferous limestones, mostly sandy at the base with increasing marl content upwards, deeply karstified and often fissile; aquifers occur within the karst-system as they outcrop or reach still economic depths;
- Agula Shales: a Jurassic complex constituted by alternating layers interbedded with karstified fossiliferous limestones and Makallè dolerite sills of the Tertiary; heavy water circulation occurs in peculiar carbonatic layers as they are brittle, fractured and strongly karstified, so that pressure manifold aquifers are normally found always confined by the compact dolerite sills.  
Eventual aquifers occurring in the dolerite sills are mainly due to heavy fracturing along the main tectonic pattern of the area.

### 3 INTERVENTION

Due to the heavy emergency situation in the investigated area, the first phase of the intervention consisted of a quick hydrogeological investigation carried out by the Author with the important help of some technical reports

drawn up for the same area by the Hydrogeological Department of the Ethiopian Ministry of Mines and Energy (Chernet et al. 1980).

In a few days this investigation led to recognize the possible technical feasibility of the intervention, to advance the working assumptions and to choose and acquire *in situ* all the most suitable equipment and necessary labour.

Owing to a set of problems and difficulties, the operational research, which lasted about 20 months (March '85 - October '86), led to the construction of 46 productive wells in a wide territory comprising the most important towns located N and S of Makallè.

The whole investigation was carried out in two different phases:

- the first allowed the construction of 25 productive wells in the Makallè area, in order to face most appropriately the most acute stage of the emergency when the concentration of refugees, including those coming from very far, was highest.

The wells were drilled in the outskirts of the town near the shelters or primary infrastructures such as aqueducts, hospitals, feeding centres, schools, etc..

- the second allowed the construction of 21 productive wells near towns or villages where the need for water supply, even though not stressed as in the first phase, was still significantly strong.

The productive wells, drilled by a rotary percussion hydraulic rig at a mean depth of 80 m, yielded an average of  $7 \div 15$  l/s, with a minimum of 2 l/s and a maximum of  $25 \div 30$  l/s.

The same wells were generally equipped with submersible pumps mainly driven by electric power generators and occasionally by the regional electric network. In some cases, depending on local situations, the wells were equipped with hand pumps.

Moreover storage and distribution plants were built to provide a continuous water supply and to satisfy drinking, sanitary and hygienic water demands of the people gathered in the shelters, villages or towns in extremely precarious conditions.

Table 1 shows the most characteristic figures of the whole intervention.

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The most characteristic figures of the whole intervention

Sites	No. of wells	Meters drilled	Yield (l/s)	Population	
				resident	resident & refugees
Makallè	25	1,755	187	80,000	200,000
Ein Alem	2	135	20	2,000	12,000
Enda Jesus	1	118	2	1,000	5,000
Qwiha	4	384	35	5,000	20,000
Wukro	2	173	20	8,000	25,000
Hidagamus	1	103	2	3,000	10,000
Goïa	1	95	2	1,500	5,000
Adigrat	6	565	37	40,000	80,000
Zalambessa	3	305	21	5,000	8,000
Adi Gudum	1	95	2	3,000	6,000
Totals	46	3,728	328	148,500	371,000

#### 4 ECONOMIC MODELS

For a better knowledge of the economic data related to the present hydrogeological research program, the peculiar operational conditions have to be taken into account, because they differ greatly from those characterizing similar interventions in normal situations.

"Operate, operate as soon as possible, operate in the best way", this is the categorical imperative to be assumed in emergency situations; neither plannings nor operational nor sophisticated models for optimizing the construction and development of adequate hydraulic plants, none of these can be considered in such stringent times.

##### 4.1 Planning and execution of programmed intervention

The peculiar characteristics of programmed interventions suitable for satisfying urban, rural and industrial needs of water supply of a certain region or territory, are briefly reported in what follows, while those related to emergency situations will be discussed later on.

First, one supposes to have to satisfy permanent needs of water supply for a given territory, in relation to a given present situation (involved population, agricultural and industrial activities, etc.).

It is a matter of hypothesizing a guide-model for research, for the development of the planning, the construction and the management of the programmed intervention.

Fig. 1 proposes a model where the intervention area is considered as a territory to be both investigated and satisfied.

The objectives of the programmed intervention have to be addressed to the more or less fulfilment of the territory's actual needs.

The relative diagram develops into the following five phases:

- preliminary feasibility test;
- technical suitability test;
- economic suitability test;
- economic evaluation;
- final decision.

On the basis of both general and local knowledge and experience, together with eventual references and satellite information, the first phase implies a set of *in situ* investigations, whose final results lead to the preliminary feasibility check in the form of the possibility of balance between available water resources and actual water needs.

Taking into account local problems and difficulties (Vernier 1987), the second phase, which is the real project phase, implies proper choices (intervention sites, methodologies, Production Factors, etc.) and evaluations (quantity and quality of Production Factors, expected values of the project, etc.) which lead to the technical suitability check, in the form of the capacity of satisfying the minimum requirements entailed by the project's objectives.

The third phase, as a first economic stage implies the estimation of various economic parameters strictly connected with carrying out the project.

Therefore, the Technical Efficiency of the Production Factors has to be calculated together with their Productive Coefficients (amount of factor per unit product), so that the Matrix of Technique and related initial cost ( $C_0$ ) for each examined project is obtained ( $C_0 = \text{Matrix of Technique} \times \text{Column Vector of the unit prices}$ ).

Besides the initial costs ( $C_0$ ), the actualized running costs ( $C_{fa}$ ) of plants and equipment for a certain number of years have to be calculated for each project, in order to prevent present false savings from leading to unac-

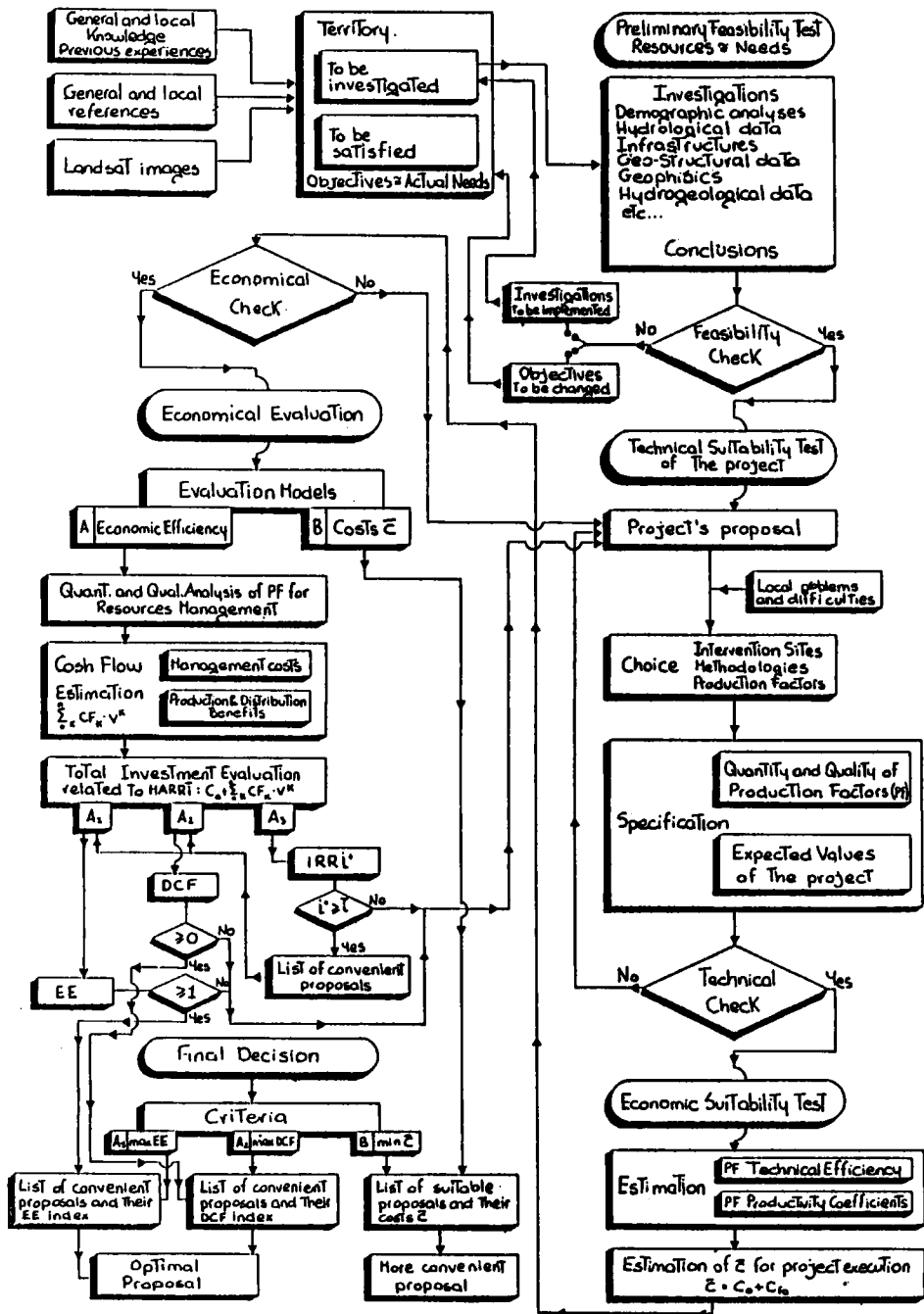


Fig. 1. Guide-Model for intervention in normal situations.

ceptable higher future costs, due to technical inferiority.

The final cost for each project will therefore be given by  $\bar{C} = C_0 + C_{fa}$ . At this point the Economic Suitability of the examined projects has to be checked by comparing only their initial costs  $C_0$  with the total amount of money,  $\bar{S}$ , available for the whole programmed intervention, so that  $C_0 \leq \bar{S}$  should always be valid.

The above mentioned economic analysis follows the Economic Engineering Principles which allow to find the optimum allocation of production factors considering the objectives to be pursued and the times to be kept, by using the most advanced optimization techniques of operational research (assignment of working loads, calculation of transport and distribution networks, etc.) and other more peculiar techniques such as PERT (Program Evaluation and Review Technique) or CPM (Critical Path Method).

The fourth phase implies the economic evaluation of the suitable projects ( $C_0 \leq \bar{S}$ ) in order to choose the optimal proposal.

Two different situations may occur:

- (i) The first is when the management aspect of the available resources is not directly involved and the benefits are only evaluated in terms of social returns (fulfilment of the population's water needs, improvement of the hygienic and sanitary conditions, time saved in the supply of water, etc.). In this case the choice economic criterion based on minimization of costs  $\bar{C}$  is used.
- (ii) On the other hand, if the management aspect of the available resources is involved and the benefits are evaluated in monetary terms, a qualitative and quantitative analysis of the Production Factors necessary for the management of the water resources has to be carried out first, in order to estimate the Cash Flow (CF) by evaluating the fixed and circulating initial costs, the yearly costs deriving from the water production and distribution for a certain number of years ( $5 \div 20$ ), and the corresponding benefits in terms of money returns.

By means of this the above mentioned Cash Flow will be given by:

$$\sum_{k=0}^n CF_k \cdot v^k$$

where  $k = 0, 1, 2, \dots, n$  years and  $v^k = u^{-k} = 1/(1+i)^k$  with  $i$  = rate of interest, while the Total Investment by:

$$C_0 + \sum_{k=0}^n CF_k \cdot v^k$$

Referring to the several bases of economic analysis, the corresponding Evaluation or Characterization Indices have to be chosen in order to establish whether the Investment is economically convenient or not, and reach the Final Decision in terms of optimization of the various indices.

Regarding this fifth phase, if the benefits are evaluated in terms of money returns and the Final Decision in terms of profitability, some of the most significant Evaluation Indices and corresponding selection criteria are reported in the following (Fig. 1):

- (i)  $IRR_i^*$  (Internal Rate of Return)  
 $MARR_i$  (Minimum Attractive Rate of Return)  
 selection criterion: only if  $IRR_i^* \geq MARR_i$
- (ii)  $DCF_i$  (Discounted Cash Flow) rotated to the most probable value of  $MARR_i$   
 selection criterion: only in  $DCF_i \geq 0$
- (iii) EE (Economic Efficiency index) or PI (Profitability index) = Actualized benefits/Actualized costs  
 selection criterion: only if  $EE = PI \geq 1$   
 (Benefits and costs being actualized in function of the most probable value of  $MARR_i$ ).

#### 4.2 Planning and execution of emergency intervention

As said above, in emergency situations the planning and execution of the intervention change considerably, as time becomes the most critical production factor and the most restrictive and important constraint.

The whole intervention is to be completed successfully within a fixed time limit, beyond which it may prove totally unproductive in some cases.

A model of an emergency situation is presented in Fig. 2, but having described the programmed intervention model in Fig. 1 exhaustively, we deem it unnecessary to go over this in detail.

### 5 ECONOMIC ANALYSIS

The fundamental data regarding the final costs and immediate benefits of

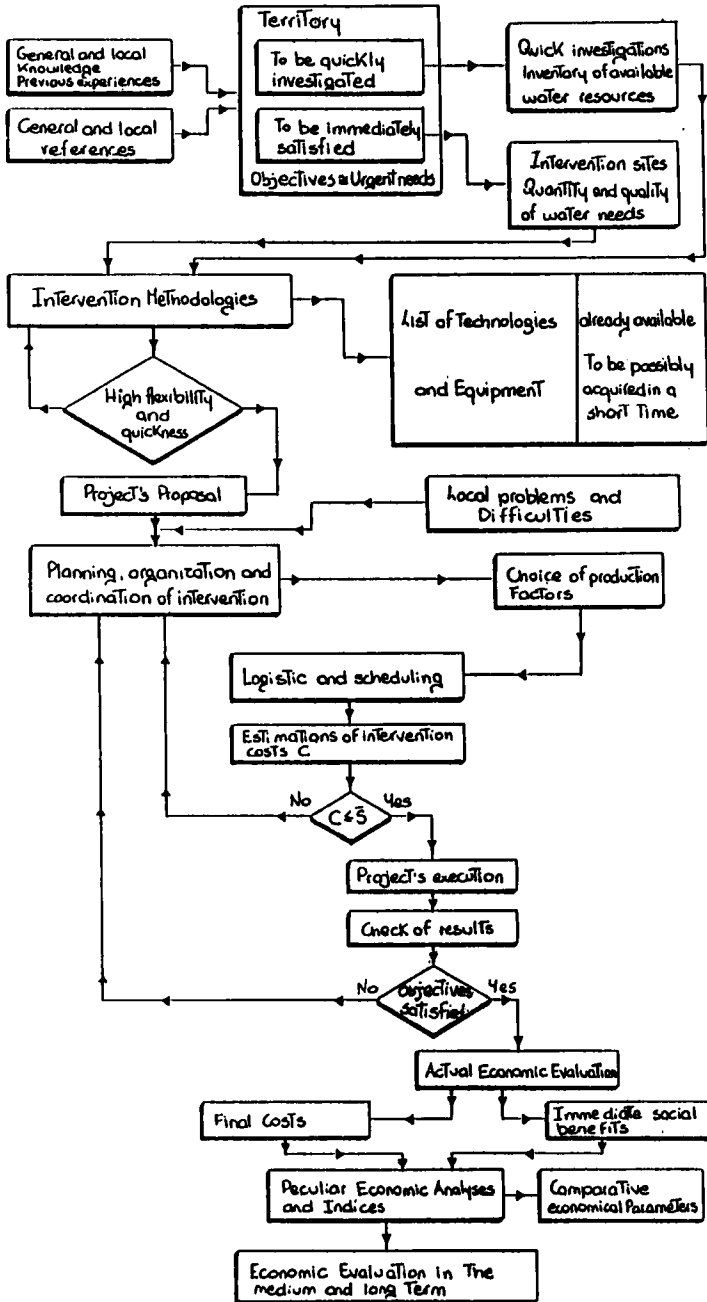


Fig. 2. Guide-Model for intervention in emergency situations.

the whole intervention are briefly reported. The unit costs relating to the fundamental operations are emphasized also in relation to a medium term projection (5 years).

### 5.1 Final intervention costs

The final intervention costs subdivided into the headings A),B),C), and D) are reported:

#### A) Transport costs

##### (i) Air freight from Italy by military carriers

(Machinery, equipment, spare parts, supplies, etc.) 150,000 US\$

##### (ii) Inland transport

- 1 four-wheel-drive car	30,000	"
- hydraulic crane mounted on truck	55,000	"
- fuel, oil, grease, spare parts, maintenance	<u>30,000</u>	"
	265,000	" 265,000

#### B) Drilling costs

- rotary-percussion hydraulic rig mounted on a four-wheel-drive truck and accessories	240,000	"
- air compressor	25,000	"
- 2 tricone rock bit	7,000	"
- 8 tungsten-carbide rock bit	10,000	"
- 2 reamers	1,000	"
- 1 mud pump	25,000	"
- fuel	27,000	"
- bentonite and foam	25,000	"
- oil, grease, spare parts, and maintenance	<u>5,000</u>	"
	365,000	" 365,000

#### C) Well development and production costs

- casing (blank or screen pvc pipes)	46,000	"
- 20 submersible pumps and accessories	60,000	"
- 5 hand pumps	10,000	"
- pumping strings	7,000	"
- gate valves, elbow joints, etc.	2,000	"
- 20 electrical power generators	<u>120,000</u>	"

	245,000	"	245,000
D) Labour costs			
- 2 drilling and mechanical operators	120,000	"	
- 1 supervisor	<u>100,000</u>	"	
	220,000	"	<u>220,000</u>
			1.095,000\$

Note. The costs relating to the following items are not included in the list:

- investigation (provided by the Author)
- local labour (provided by the Ethiopian side)
- distribution and management (provided by the Ethiopian side).

### 5.2 Immediate benefits

The water availability deriving from the intervention allowed the following immediate benefits:

- satisfaction of the drinking needs of the resident population and refugees;
- availability of the hygienic and sanitary water at shelters, hospitals, feeding centres, houses, schools, etc.;
- a more economical use of female labour in that the time saved from water-carrying can be spent in a more productive way;
- the survival of domestic, farm and transport animals;
- support for maintaining the standard agricultural production;
- changes in the eating habits of the population deriving from the experimental plantation of new crops.

### 5.3 Final evaluation of the costs of the intervention

The final data relating to the intervention are briefly reported here. In order to point out the good qualities of the intervention, the following fundamental economical parameters have been obtained from the elaboration of these data:

(i) Data:

- Total investment:	1,095,000 US\$
- Total wells drilled:	51
productive:	46 (90.2 %)

unproductive:	5 (9.8 %)
- Total meters drilled:	4,308 m
productive:	3,728 m (86.5 %)
unproductive:	580 m (13.5 %)
- Total population supplied:	371,000
resident:	148,500
refugees:	222,500
- Estimated productive capacity:	328 l/s $\equiv$ 1,180 m <sup>3</sup> /h
- Mean daily supply per person:	
8h/day prod.:	25.44 l/day/person
24h/day " :	76.33 "

## (ii) Unit costs:

- unit cost per well:	21,470 US\$
- unit cost per metre:	254.18 "
- unit cost per person:	2.95 "
- unit cost per m <sup>3</sup> of water	
in the 1st year:	
8h/day prod. x 365 days:	0.32 US\$
24h/day prod. x 365 days:	0.11 "
- unit cost per m <sup>3</sup> of water	
for a medium term of 5 years:	
8h/day prod. x 365 days/a:	0.06 US\$/m <sup>3</sup>
24h/day prod. x 365 days/a:	0.02 US\$/m <sup>3</sup>

The unit costs are per m<sup>3</sup> of water produced at the well and are only referred to the total investment. They do not take into account the operating, maintenance, stockage, distribution or running costs.

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