ECONOMICS OF GROUNDWATER WORKS

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ABSTRACT

Cost of various types of dug wells and boreholes for ground-water exploitation are examined. Attention is called to the numerous and varied factors contributing to total expenditure. An analysis is made of deep dug wells, shallow dug wells, hand pumps and boreholes with electric submersible motor-pump groups. Cost of cubic meter of water pumped is also scrutinized. Some case examples are presented illustrating that unit prices change so widely in different geographical areas and under socio-economic conditions that every particular situation requires specific study. Relative weight of each cost component is also mentioned.

1 INTRODUCTION

Works needed to get groundwater generally consist of digging or drilling in the ground and, after water has been found, the installation of a mechanical device to rise water to the place required for distribution.

The variety of physical conditions where groundwater exists, and the many different contrivances to rise water make a comprehensive analysis impossible. We shall only consider single works like dug wells or boreholes.

An important remark should be made in respect to the economic evaluation of those works. Most of available information refers to prices and costs in different countries, currencies and time. To compare them is more than hazardous, and absolute figures given in this paper are to be taken cautiously. Evenmore, when figures refer to a currency and a year, it is to be understood that these figures may be different today because consumer prices change with time. Figures are generally given in U.S.A. dollars.

2 TYPES OF GROUND-WATER WORKS (1) (2)

2.1 Dug wells.

The simplest and more primitive work is a "water hole" that still is found in many rural areas. It is an excavation, by hand or with simple tools of no more than two or three metres deep and one or two metres of diameter. More elaborated is the "common well", also excavated, but requiring specialized labor. These wells are not lined and have at the surface a curbstone made of masonry to prevent users from falling down the hole. More complex are "lined wells" and "sunk wells" (3) that penetrate deeper into the aquifer, warranting a more secure water supply in case of large seasonal changes of water table level; they are also better built and last longer without repairing. Finally, there are also wells with galleries or horizontal drains at the bottom; they are more complex , need advanced technology and hefty budget.

2.2 Drilled wells.

Hand augers and driven wells are simplest. Driven wells use a drive hammer. Jet drilling is another simple method, as it is the hydraulic percussion or the sludger method. More elaborated is cable-tool percussion, one of the oldest methods used in well construction and still widely utilized. Rotary drilling exists in a number of combinations: Standard rotary, with direct circulation of the drilling fluid; reverse circulation for large diameters; air rotary drilling for areas where water is scarce or non-existent. In recent years, down-the-hole-hammer drilling is very popular due to its high rates of advance during drilling. Eventually, combination rigs, down-the-hole-hammer with rotary are also common.

3 COSTS

For each method mentioned in the preceding lines, the total cost is different, and for similar methods, their costs are different according to countries, areas, and socio-economic and environmental conditions.

Each well or water work is a particular case and its cost has to be individually examined. References to similar works have to be considered very carefully, specially when they come from different geographic and economic areas.

In identifying costs, three main components should be taken into account and added up to obtain total prize: investment costs, operation costs, and maintenance costs.

A general analysis of costs in drilled wells were made by Custodio and Llamas (4) based in previous studies by Ackermann and Gibb in U.S.A. and Andolz in Spain. In the lines that follow, several examples of cost analysis are shown, identifying the main factors that contribute to a final comprehensive figure.

4 DUG WELL ANALYSIS

4.1 Methodology

Techniques to excavate wells vary according to the nature of rocks or sediments found: dugging with hoes and shovels or using explosives and sledge-hammers; wells unlined or lined with rings of reinforced concrete or steel; with or without filter rings, etc. Most of the times, the method for excavation is not a free choice but imposed by the nature of the rocks. On the contrary, except where sediments are unstable, a choice can be made between lining with reinforced concrete or steel. In general, concrete is less expensive than steel, but in special circumstances (difficult supply, absence of nearby materials, no roads, etc) metalic lining could result more economical.

4.2 Lined wells cost identification

Most of the lines that follow have been taken from (5). Industrial countries, where labour is expensive do not use well digging wery often. Developping countries have limited budgetary resources and large programs of wells contruction, requiring big investments. Costs neeed to be carefully evaluated.

Cost is composed of the following elements:

- -Personnel
- -Equipment and materials
- -Operation
- -Amortization
- -General costs

4.2.a Personnel

For programs of rural water supply with voluntary participations of workers, their cost should not be taken into consideration, but it is always convenient to keep record of the number of hours invested. It is also necessary to include personnel that work partial time at the well site, like drivers, surveyors, foremen, etc.

For each category, expenses should include: wages (or alternatively, displacement expenses and incentives), social charges and annual leaves.

4.2.b Equipment and materials

The main materials are concrete and iron. When there is a "human investment", sand and gravel portions are generally removed by non-paid workers. Prices depend on the volume of materials involved and transportation costs. Table 1 shows the marerials required for a concrete lined dug well.

TABLE 1
Materials required for the construction of a reinforced concrete rings lined well.

	Diam. 1.8 m	Diam. 1.4 m
Deepening (per metre)		
Volume of materials placed.....	3.14 m3	2.01 m3
Volume of materials used.......	4.70 m3	3.00 m3
Lining (per linear metre)		
Concrete......................	0.60 m3	0.48 m3
Gravel 0.8 m3.................	0.472 m3	0.384 m3
Sand 0.4 m3...................	0.236 m3	0.192 m3
Cement (dosiffied at 300 kg)...	180 kg	144 kg
Surface anchorage (unit)		
Concrete..................... .	1.20 m3	1.00 m3
Gravel 0.8 m3.................	0.96 m3	0.80 m3
Sand 0.4 m3...................	0.48 m3	0.40 m3
Cement (dossified at 300 kg)...	360 kg	300 kg
Intermediate anchorage (unit)		
Concrete......................	0.61 m3	0.505 m3
Gravel........................	0.488 m3	0.405 m3
Sand..........................	0.244 m3	0.202 m3
Cement (dossified at 300 kg)...	214 kg	177 kg
Filter ring (1 metre)		
Inside diametre.............	1.40 m	1.00 m
Outside diametre............	1.60 m	1.20 m
Concrete......................	0.48 m3	0.278 m3
Gravel........................	0.384 m3	0.222 m3
Sand..........................	0.192 m3	0.111 m3
Cement (dossified at 400 kg) .	192 kg	112 kg
Weight.......................	1.200 kg	700 kg
Cutting wedge (unit)		
Concrete......................	0.192 m3	0.142 m3
Gravel........................	0.154 m3	0.113 m3
Sand..........................	0.077 m3	0.057 m3
Cement (dossified at 400 kg)...	80 kg	60 kg
Curbstone		
a)low and large: 0.50*0.40		
Concrete......................	1.33 m3	1.13 m3
Gravel........................	1.08 m3	0.90 m3
Sand..........................	0.53 m3	0.45 m3
Cement (dossified at 300 kg....	405 kg	340 kg
b)high and narrow: 0.20*0.80		
Concrete......................	1.00 m3	0.80 m3
Gravel........................	0.80 m3	0.64 m3
Sand..........................	0.40 m3	0.32 m3
Cement (dossified at 300 kg)...	300 kg	240 kg
Metalic frame		
a)Ring (linear metre)		
8 mm diam..........	28 irons (28 m)	22 irons (22 m)
6 mm diam..........	6 irons (36 m)	6 irons (28 m)
Remark: In case of ring placed during excavation, the previous lenght should be increased by 30% .		
b)Filter ring of 1 m (unit)		
8 mm diam..........	22 irons (22 m)	16 irons (16 m)
6 mm diam..........	6 irons (28 m)	6 irons (21 m)
c)Anchors		
intermediate 8 mm diam.	28 irons (36 m)	22 irons (28 m)
6 mm diam.	4 irons (30 m)	6 irons (23 m)
surface 8 mm diam.	28 irons (28 m)	22 irons (22 m)
6 mm diam.	6 irons (53 m)	6 irons (45 m)
d)Cutting wedge (unit)		
8 mm diam...........	28 irons (31 m)	22 irons (24 m)
6 mm diam...........	5 irons (25 m)	5 irons (19 m)
e)Curbstone (high and narrow)		
8 mm diam...........	28 irons (56 m)	22 irons (44 m)
6 mm diam...........	5 irons (30 m)	5 irons (23 m)

4.2.c Operation costs

They include operation of vehicles, compressors, derrick cranes, etc and replacement of fuel, lubricants, spare parts, tools, etc.

4.2.d Amortization of materials

All materials need periodic renewal and their prices should take in account the corresponding amortizations. Standad durations usually accepted are:

Small materials: from 1 to 3 years.

Mechanical equipment; from 3 and 5 years.

Special equipment, non mechanical (moulds, cranes, etc): from 5 to 10 years.

Buildings: from 30 to 50 years.

Too often amortization of materials is not foreseen. If this is the case, announced prices have no value.

4.2.e General expenses

Every well should include a part of the expenses of the office that design, organize and control the work.

4.2.f Documents required for calculation of costs

Each work must have forms to fill out, recording all details of the operation: consummed materials, working time, kilometres per vehicle, etc. By using these forms, actual costs of the work could be calculated.

4.3 Cost analysis

4.3.a Personnel

Theoretically, wells made with participation of population should not have large personnel expenses. In reality, the need to engage villagers, to have also specialized workers for dificult tasks, to control the work, etc, results in personnel expenses of the order of 10 to 15 % of the total expenses. And this can be higher if the geological formations are difficult. The absence of an especialized and well organized service for digging may force to create one from all sorts, with the result that personnel expenses end being up to 40 % of the total.

4.3.b Equipment and materials

They represent the most important component: up to 40 to 50 % of the expenses. In table 2 unit prices for different materials and equipment, utilized by the OFEDES in Niger (Rounded up prices in 1974 US dollar), are shown.

TABLE 2

Designation	Price
Set of moulds for lining rings	
1.80 m diam.	510
1.40 m diam.	430
Set of moulds for filter rings	
1.40 m diam.	1,100
1.00 m diam.	1,000
Set of moulds for cutting wedge	
1.40 m diam.	450
1.00 m diam.	350
Mould for curbstone	
1.80 m diam.	450
1.40 m diam.	350
Mould for watering cattle	450
Container for 400 l	350
Container for 200 l	300
Container for 50 l	170
Pole (2 t)	220
Water tank (1,000 l)	1,300
Motor derrick-crane on trailer	12,800
Motor for derrick-crane	1,800
Dredge bucket	3,400
Field truck, 5 t	25,600
Field vehicle	8.500
Compressor (4,500 l/min)	12,800
Electric welder	1,700
Autogenous welder	450

4.3.c Amortization

Amortization of materials and equipment takes about 20 to 30 % of total cost. It depends on the importance of the work, but also on the way the equipment is maintained.

4.3.d Operation

Operation costs growth when mechanized equipment becames more sophisticated. For equipment fully utilized and well maitained the figures generally admitted are 5 to 10 %.

4.3.e General expenses

They vary between large limits and no general figures can be advanced.

4.4 Case examples

In the following sections two examples of costs in Niger and Burkina Faso are presented.

4.4.a Niger

In table 3 prices for well construction are shown.

TABLE 3 (5)
Prices for wells of 1.80 m of diameter, 33 m deep, with 4 filter rings (Prices in 1970 US dollar)

Components	Normal work (%)	Work with participation of vilagers (%)
1. Personnel		
Labour............	18.9	7.2
Sector chief......	5.6	6.3
2. Equipment and materials.	33.0	37.8
3. Operation.............	7.3	8.4
4. Amortization............	26.0	29.8
5. General expenses........	9.2	10.5
Total.....................	100.0 (3,400 $)	100.0 (3,000 $)
Cost per metre............	103,0 $	90.0 $

These wells are dug in soft sedimentary formations. It can be seen the importance of equipment and materials (included amortization) which amounts up to 60 to 70 % of the whole. In the case of local participation, an economy of about 14 % is achieved, mainly in the execution of lining.

4.4.b Burkina Faso (5)

Prices where reconstructed on 120 wells of medium depth of 11,5 m in weathered granite. Average price of 104 US $ per metre is divided in the following way:

1. Personnel	(Enterprise)....	35.0 %
	(Local).........	6.5 %
2. Materials.................		23.2 %
3. Operation.................		12.9 %
4. Equipment	(Vehicles)......	10.3 %
	(Well)..........	4.1 %
5. General expenses..........		8.0 %

The component of personnel is very high, mostly due to expatriate experts.

4.4.c Mauritania (6)

TABLE 4
Situation: Hodh. Aquifer: Dhar de Néma "Continental intercalair". Depth of well: 80 m. Yield 3 m3/h. Manometric head: 75 m. Type of well: lined well, 1.80 m diam.

Amortization	Investment	Lifetime	Annual charges	US $/m3
Construction (80*900)*1.05	75,600	20 years	7,560	0.84
Oper. and maint. (20% of investment every 4 years)			3,780	0.42
Total charges			11,340	1.26

Annual water volume exploitable
3 m3/h * 10 h * 300 d = 9,000 m3. Possiblity of watering 750 cattle heads
Annual charge per cattle head watered = 15,12

4.4.d Comparison

The similarity of prices is not really significant, because they refer to different types of works. The amount of every component in Niger looks more normal than in the Burkina Faso example.

Again it is worth to mention that to compare costs in different developing countries is hazardous, largely because works are technically different (geology, technical methods, level of local participation, etc) and economic conditios vary widely (a ton of cement costed in 1972 60 $ at Cotonou, 84 $ at Niamey and 168 $ at Djamena).

Also it is difficult to compare prices of works made by the Government with those by private firms. In Niger (3), for wells 33 m deep with 3 m of filter rings, (1970 $) we have:

	Well	Linear metre
Private enterprise (150 FED wells)	5,500	167
Goverment (OFEDES)	3,500	106
Id. with local participation	3,050	92

Prices offered by private contractors have lowered in the seventies about 10%. A big company in Ivory Coast in 1966 made wells at about 352 US$ per meter; In 1970 in Dahomey, contracts were accorded at 208 US$ per metre and in 1973 at 220 US$ in Togo.

All those previous prices did not take into account the reconnaissance works prior to the construction of the well. Surveys sometimes amount up to 20 to 30 % of the total costs.

4.5 Hand pumps costs

For some common models of hand pumps, a list of prices is given in table 5.

TABLE 5 (7)

Model	Well	Price(US$)(*)	Origin
Korat 608 A-1	deep	295 (a)	Thailand
Dragon no. 2 (d)	deep(+)	362 (b)	Japan
Moyno 1V 2.6	deep	550 (c) 739 (d)	USA
Nepta-Briau	deep	650 (d)	France
Atlas Copco	deep	670	Kenya
New no. 6	shallow suction	33	Bangladesh
Nira AF76	deep	203 (e)	Finland
Type BP50	shallow(-)	75	Ethiopia
VEW A 18	deep	1,583 (a)	Austria
Mark-II	deep	700	India
Jetmatic	deep	32 (f)	Philippines
Bandung	suction	54	Indonesia
Sumber Banyu	deep	85	Indonesia

(*) Cost if 50 purchased in one order.
(+) supplied as shallow-well pump with additional components for conversion to deep-well use.
(-) 12 metres nominal maximum depth.
(a) Supplied complete for 20 m depth.
(b) Supplied complete for deep-well use.
(c) Pump only.
(d) With 20 m below-ground assembly.
(e) Pump and cylinder.
(f) Without connecting rod and rising main.

4.6 Shallow wells cost data

The Buba-Tombali Water Project (8) is a good example. The region is located south of Guinea-Bissao, in a coastal plain indented by estuaries and rivers. There is generally a shallow aquifer, between 0 and 10 m deep, in lateritic sand and clay. The project, supported by the Government of Guinea -Bissao and The Netherlands was originally planned to produce, on average, 150 wells per year.

Project organization involved numerous staff for social activation (22), survey (10), construction (60), production (18), mechanical and car workshops (34), maitenance (10), geohydrologic surveying (10) and representation in Bissao (12).

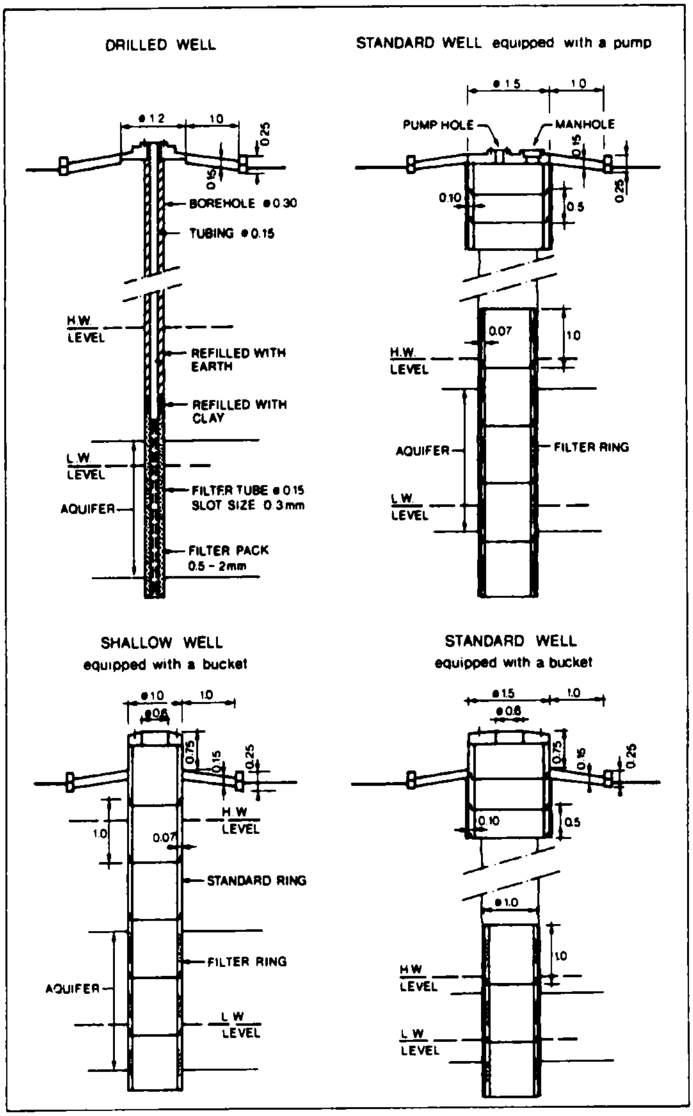
Up to June 1981, project surveys carried out 763 test hand drilling (with auger). 352 of them led to suitable sites for well construction.

The following types of wells were constructed (Figure 1): Dug well with telescopic construction; dug well with constant diameter over full depth; drilled wells; and renovated traditional wells.

4.6.a Investment costs

US$ 3.65 million was the total capital investment during the

FIG. 1


DRILLED WELL
STANDARD WELL equipped with a pump
PUMP HOLE
MANHOLE
BOREHOLE ø 0.30
TUBING ø 0.15
H.W. LEVEL
REFILLED WITH EARTH
REFILLED WITH CLAY
L.W. LEVEL
AQUIFER
FILTER TUBE ø 0.15
SLOT SIZE 0.3mm
FILTER PACK
0.5 - 2mm
FILTER RING
SHALLOW WELL
equipped with a bucket
STANDARD WELL
equipped with a bucket
STANDARD RING

period Sep. 1977 to Dec. 1981, divided as follows:

TABLE 6
Capital investment Buba-Tombali water supply project (1981 US $):

Feasibility studies	185,000	5%
Workshop, offices, housing	425,000	11%
Vehicles	685,000	18%
Equipment	425,000	11%
Material	800,000	22%
Salary	1,100,000	30%
Fuel	100,000	3%
Total	3,650,000	100%

At the start of the project very few facilities were available in Buba and, therefore costs of the workshop, offices and housing were considerable.

Capital investment per well is reflected in table 7.

TABLE 7
Investment per completed well (1980 US $, 150 completed wells).

Section	Imported material	Local expen-ditures	Salaries expatriates	Total per section	%
Social activ.	25	130	815	970	17
Survey	15	105	160	275	5
Construction	660	435	160	1,255	22
Vehic.workshop	560	55	130	745	13
Mech.workshop	255	50	255	560	10
Production	230	185		410	7
Overhead	45	665	670	1,375	25
Total	1,790	1,625	2,190	5,590	100

Very little experience was available for social activation work, so that extensive expatriate input was needed to develop this activity.

4.6.b Cost data of well construction

Table 8 shows data of cost of two different types of wells.

TABLE 8
Construction cost of wells (US $).

Dug well, 12 m depth		Hand-drilled well, 15 m depth	
4 rings 1.50 m diam.	145	5 m filter tubing	100
5 rings 1.00 m diam.	180	10 m tubing 15 cm diam.	140
1 well cover	35	Gravel for filter pack	35
Cement	65	Well cover	35
Generator (30 hours)	40	Cement	65
Transport	350	Transport	300
2 person salaries	225	Salaries	180
Total	1,040	Total	855

From the view point of costs, hand drilling was advantageous over well drilling. Also required less in the way of transport of equipment. The equipment and transport requirements for well digging and drilling are shown in table 9.

TABLE 9

a. Equipment and transport requirements for five teams of two persons; each team producing one dug well/month (US $).

1 truck (for 5 teams)	48,000
1 field vehicle	14,000
4 generators + pump equipment (*)	39,000
Total investment	101,000

b. Equipment and transport requirements for one team of six persons producing 4 drilled wells/month (US $).

1 drilling set	14,000
1 Field vehicle plus trailer	16,000
Total investment	30,000

(*) The steel moulds for the concrete ring production were made in the workshop of the project.

4.6.c Transport costs

The costs of the field vehicles and trucks used in the project were substantial. Unit costs (US $) per kilometer, are presented in table 10.

TABLE 10.
Costs of a field vehicle and a truck, per kilometer.

	Field vehicle	truck
Spare parts	0.36	0.80
Maintenance and repair	0.07	0.07
Insurance	0.01	0.02
Fuel	0.07	0.17
Driver	0.10	0.10
Total	0.61	1.16

Based on 12,500 km per year for the field vehicle
20,000 km per year for the truck

4.6.d Pump production costs

The production costs of the "Buba" pump and those of rope-and-bucket system (locally manufactured) are shown in table 11. The cost data were computed for a production rate of 150 pumps and 50 rope-and-bucket systems per year.

When, in the future, the mechanical workshop will be run by local staff without expatriate assistance, overhead and supervision costs will be less.

TABLE 11
Production costs (US $) of "Buba" pump and rope-and-bucket systems.

	Buba pump, at 12 m depth	Rope-and-bucket
Material	56	66
Salaries (*)	40	20
Rising main	100	
Cylinder	120	
Overhead	100	60
Depreciation	32	18
Total	448	164

(*) Payment of workers was in local currency.

4.6.e Recurrent costs

For a full cost analysis, all relevant costs should be taken into account. In addition to the investment costs, the recurrent costs of the water supply agency of maintenance replacement of parts and transport should be considered. The investment cost of a pump, for instance, may be not more than 15-25 % of its total "life-time" costs.

As there were few cost data on maintenance and replacement of the Buba pump and of the rope-and-bucket system available, a full cost analysis was not possible at the time of the report. However, it was clear that the production cost as well as recurrent costs of a rope-and-bucket system are considerably lower than those of the pump.

4.7 Case example (Mauritania)

From a U.N. project (6), several well costs have benn calculated, as show in tables 12, and 13 below.

TABLE 12
Situation: Adrar. Aquifer:Oued alluvium. Depth of the well: 5 m. Yield: 1.5 m3/h. Manometric head: 4 m. Type of well: Traditional well, lined in 1.00 m diam. (wood or stones).

Amortization	Investment	Lifetime	Annual charges	US $/m3
Construction (5*80)	400	4 years	140	0.0648
Infrastructure (Chadouf)	200	4 years	70	0.0324
Oper. and maint.	-		-	-
Total charges			210	0.0972

Annual water volume exploitable
1.5 m3/h * 4 h * 360 d = 2.160 m3

TABLE 13
Situation: Tagant. Aquifer: Tamourt-en-Naaj alluvium. Depth of the well: 8 m. Yield 5 m3/h. Manometric head: 5 m. Type of well: lined weel, 1.80 m diam.

Amortization	Investment	Lifetime	Annual charges	US $/m3
Construction (8*680)*1.05	5,712	10 years	571.2	0.0318
Oper. and maint. (20% of investment every 4 years)			285.6	0.0158
Total charges			858.6	0.0476

Annual water volume exploitable
5 m3/h * 10 h * 360 d = 18,000 m3

5. DRILLED WELL ANALYSIS

If the variety of works in dug wells es very large, in mechanical drilling is still bigger. In addition to the possible types of drilling, there are very complex technical operations that contribute to make more difficult cost estimates. In the following lines, a generalized review of how to estimate cost of drilling is summarily described, mostly based on studies by Fernãndez (9) and Candil (10).

5.1 Introduction

The most important variables to stablish the cost of a borehole are:

-Transportation of equipment and materials and conditioning of accesses.

-Previous hidrogeological surveys.

-Method of perforation and type of rig.

-Nature of formations to be drilled.

-Depth and diameters of perforation.

-Type of filter screen.

-Necessary grouting or cementing.

-Duration of pumping test.

-Special treatments to improve the works.

Some simplifying hipotesis will be introduced to reduce the field of possibilities. The analysis has been divided in six parts:

1. Previous expenses and works.
2. Perforation.
3. Casing and grouting.
4. Special treatments.
5. Development and pumping test.

6. Recurrent costs.

Costs are given in US dollars.

5.2 Previous expenses and works

This denomination includes several items to be completed before the actual the drilling. They are:

-Previous hydrogeological survey: The cost could vary between 20 to 60 $ per hectare depending on the existence or not of a regional study covering the area of survey, with a minimun of 2,000 $ per survey.

-Purchase of parcel or spot where the perforation will be located. The cost is difficult to estimate but most of the times is not relevant, because the works take place in the owner's land.

-Conditioning of roads of access and drilling site.

5.3 Perforation

The cost of perforation per metre is a function of the time required to drill each metre of depth, which itself depends on various factors: Method of perforation and type of rig utilized, nature of formations to be drilled, depth, etc. There is also a disparity between different drilling companies: Small, local ones use to work at very low rates, possible because their lower transportation, labour and amortization costs (in many cases the machinery is already amortized). Big companies have higher prices, as correspond to higher costs and guaranties.

For cable-tool percussion drilling, 1987 unit prices (Spain) for tendering are of the order indicated in Table 14.

TABLE 14
Unit prices for percussion drilling (US $/m). Prices include: Labour (50%), fuel and lubricants (20%), amortization and repaining (15%), water and additives (3%), transportation of personnel and equipment (7%) and installation and removal (5%).

Depth (m):	0-100	100-200	200-300
Diameter (mm):			
400-500	96	105	114
300-400	90	99	109
less than 300	86	95	105

For rotary (direct and reverse) drilling, 1987 unit prices (Spain) for a tender are shown in Table 15.

TABLE 15
Unit prices for rotary drilling (US $/m). Prices include: Labour (30%), fuel and lubricants (25%), amortization and repairing (20%), water and additives (5%), transportation of personnel and

equipment (15%) and installation and removal (5%).

Depth (m):	0-100	100-200	200-300
Diameter (mm):			
400-500	78	84	89
300-400	70	75	78
less than 300	62	67	72

For combination down-the-hole-hammer/rotary drilling, 1987 unit prices (Spain) for a tender are shown in table 16.

TABLE 16
Unit prices for combination down-the-hole-hammer/rotary drilling (US $/m). Prices include: Labour (20%), fuel and lubricants (30%), amortization and repairing (25%), water and additives (5%), transportation of personnel and equipment (15%) and installation and removal (5%).

a) Perforation

Depth (m):	0-100	100-200	200-300
Diameter ("):			
6	26	32	38
8-5/8	55	63	68
12-1/4	85	91	97

b) Reperforation

Depth (m):	0-100	100-200	200-300
Diameter ("):			
from 6 to 12-1/4	66	68	70
from 8-5/8 to 12-1/4	34	37	40

5.4 Casing and grouting

Unit prices (US $/m) of steel casing and screen are indicated in table 17.

TABLE 17
Unit prices for tubes and screens. Prices include transportation (about 8%).

Diamteter (mm):	500	400	300	200	180
Casing wall thickness (mm):					
8	6.5	5.3	4.0		
6	4.9	3.9	3.0	2.3	
4				1.8	1.6
Screen wall thickness (mm):					
8	10.2	8.2	6.2		
6	7.4	6.1	4.5	2.8	
4				2.1	2.0

Cost of installation of tubes is estimated at about 3 to 4 $/m placed. Special screens have variable prices and are less frequently utilized. Slots are made directly in the tube, and costs about 5 $/m.

Grouting could cost about 25 $/m cemented, to which should be added the costs of waiting time for the rig until the grout is set: about 15 to 20 $/hour, with approximatedly 70 hours needed.

5.5 Special treatments

Includes various methods for cleaning and developping the well, like treatment with acid, floculants, mechanical surging or swabbing, etc. Rather common is treatment of dolomite and limestone with hydrocloric acid. Treatment price is about 1.5 US $ per kg of inyected acid, including transportation and operation costs. Total cost of operation should vary from 1,500 to 3,000 US $.

5.6 Development and production (pumping) test

This two operations are usually made using a submersible motor-pump group, driven by compressor or electric generator. Market prices vary from about 25 $/hour for 70 C.V. power groups to 50 $/hour for 200 C.V. groups. Duration of pumping test is variable, usually from 24 to 72 hours, depending on the requested accuracy of results. Duration of development depends on the amount of fine elements and degree of fracturing of the aquifer close to the borehole.

To mentionned prices should be added transportation costs of equipment, about 0.75 $/km.

5.7 Recurrent costs

They include different concepts, like coring or drive-coring, overhead costs of the company, benefits, direction and control of works, etc.

Coring is only utilized in few ocasions. Its costs could be from 5 to 10 % of the total of the works. Direction and control may take also about 5 to 10 % of total costs. Benefits may vary widely. 9 % is a common figure.

6 RISING WATER DEVICES (9)

6.1 Types of motor-pump groups

Prices for hand pumps have already been indicated (Table 5). For mechanical installations, the more common types include motor-pumps groups with mechanical or electric motors.

Mechanical motor groups could pump large volumes of water (up to 1,000 l/s). Due to mechanical losses, the maximum advisable depth of installation is about 50 m. Cost of energy per cubic metre is higher than that of electric motor groups, and maintenance is also expensive. They are used only when no electric energy is available at the vicinity.

Electric motor-pump groups with motors at the surface (vertical axis pumps) are rather similar to mechanical ones.

Submersible pumps are more expensive, but also more efficient and last longer, as can be seen from the example in table 18 (90 l/s from 45 m depth, 1976 US $), where gas-oil motor amortization is estimated in 5 years, with 7,5 % interest:

TABLE 18

	Gasoil motor	Electrical submersible pump
Group + accessories ($)	14,500	17,200
Amortization ($/m3)	0.0045	0.0027
Consumption ($/m3)	0.0085	0.0065
Cost ($/m3)	0.0130	0.0092
Cost of high voltage electrical line/km		5,000
Cost of amortization/km/m3		0.00083

Cost/m3 is 0.0038 cheaper with electrical submersible pumps. Piston engines became competitive only when the distance of electric line to build is hihger than 4.5 km.

Submersible pumps can rise 150 l/s (motors of 2,900 r.p.m.) or 600 l/s (motors of 1,450 r.p.m.) up to about 350 m. They are the most frequent used groups in industrial countries.

6.2 Cost and amortization of submersible pumps

An example of costs (1976 US $) and annuity of amortization is given in tables 19, 20 and 21. Interest rates are 7.5 % . Amortization periods are 10 years for the group, 40 years for the tubes and accessories, and 20 years for electric cable and control pannel. (C=cost, A=Amortization):

TABLE 19
Submersible group.

Head(m)	Yield (l/s):	20	50	80
20	C=	1.58	2.13	3.32
	A=	0.23	0.32	0.48
40	C=	2.17	3.47	4.25
	A=	0.32	0.50	0.62
80	C=	2.80	4.82	5.35
	A=	0.42	0.70	0.78

TABLE 20
Casing plus accessories and installation.

Head(m)	Yield (l/s):	20	50	80
20	C=	1.52	1.97	2.37
	A=	0.12	0.15	0.18
40	C=	1.83	2.43	2.90
	A=	0.15	0.20	0.23
80	C=	2.53	3.38	3.97
	A=	0.20	0.27	0.32

TABLE 21
Electric wire and pannel.

Head(m):	Yiel (l/s):	20	50	80
20	C=	0.40	0.48	0.62
	A=	0.03	0.05	0.07
40	C=	0.52	0.72	1.02
	A=	0.05	0.07	0.10
80	C=	1.07	1.65	2.35
	A=	0.10	0.17	0.23

6.3 Electric tariffs

They vary from place to place and need specific computation for each case. Cost per cubic metre is high, frequentily more than 50 % of total other costs. It is very important for the consumer to use all fiscal advantages in special tariffs available, which require effort and time looking the existing legislation, not always at hand and understandable.

Tariffs change according with power installed and hours of utilization (number of hours, but also time of use, either during the day or night). There is also possibility to apply different systems of tariffs. For an installed power of 100 kw, and a consuption of 26,500 kw.h in active energy and 19,900 kw.h in reactive energy, the cost (Spain, 1976 US $) per kw.h may vary applying different systems of tariffs and utilization from 0.025 to 0.046 $/kw.h.

7 COST OF CUBIC METRE OF WATER AT SURFACE

It includes purchase, installation and amortization costs of borehole and rising water device, plus maintenance costs, plus operation costs (Energy and control and monitoring).

7.1 Amortization costs

Investment costs in works, machinery, and installations should be included. To compute the amortization annuity the following formula is used:

$$A = C * ((1+i)**t) * i / (((1+i)**t) -1)$$

where

A = Amortization annuity

C = Invested capital

i = Rate of interest

t = Period of amortization

The following amortization periods are commonly utilized (year):

Borehole	30
High voltage line	15
Transformer	15
Transf. house	50
Submersible group	10
Metallic tubes	40
Group control pannel	40
Low tension wiring	20
Fibercement pipes	30
Irrigation devices	10

7.2 Borehole

Total cost of a borehole can be estimated, depending on depth, diameter and hardness of geological formations. Once the total cost of borehole is known, amortization costs could be estimated assuming a period of amortization (30 years), an interest rate (7.5) and a number of hours per annum (2,000). For the values indicated, different amortizations are shown in table 22.

TABLE 22
Incidence ($) of total cost of a borehole in the cost of cubic metre. C = Total cost of borehole.

	Yield (l/s)			
C	20	40	80	120
6,000	0.004	0.002	0.001	0.00066
17,000	0.0098	0.005	0.0025	0.0017
33,000	0.0197	0.0098	0.005	0.0033
50,000	0.0295	0.0148	0.0073	0.0053
67,000	0.0393	0.0197	0.9833	0.0065

7.3 Rising water costs

Next paragraphs examine only submersible pumps, for discharges from 20 to 120 l/s, and manometric heads from 10 to 150 m. Costs (1976 US $) for these type of installations have already been described in precedent lines. Amortization costs can be computed dividing amortization annuities by annual volume of water pumped. The result, assuming 2,000 hours of utilization per year, is shown in table 23.

TABLE 23
Amortization costs ($) of motor-pump groups per cubic metre of water.

	Yield (l/s)			
Head (m)	20	40	80	120
10	0.0062	0.0033	0.0018	0.0017
20	0.0065	0.0037	0.0023	0.0017
40	0.0073	0.0042	0.0028	0.0020
80	0.0090	0.0058	0.0035	0.0028
150	0.0130	0.0087	0.0065	0.0053

Previous costs do not include high voltage lines. Costs for this concept are offered in table 24.

TABLE 24
Amortization and maintenance costs per cubic meter and km of high voltage electric line.

	Yield (l/s)			
	20	40	80	120
Cost($)	0.0047	0.0023	0.0012	0.0008

7.4 Maintenance costs

They include all costs derived from repairing equipment and installations, that have to be made through specialized firms. Their amount should be taken as a percentage of investement costs, as presented in table 25.

TABLE 25

Concept:	
Borehole	1%
Submersible group	5%
Low voltage wires and pannel	2%
Metalic tubes	1%
Transformer	2%
Transformer house	1%
High voltage line	2%

Cost of maintenance is computed in table 26. Cost of annual maintenance of the borehole (periodical cleaning up, about 200 $) is also included.

TABLE 26
Maintenance cost per cubic metre.

	Yield (l/s)			
Head (m)	20	40	80	120
10	0.0023	0.0012	0.0007	0.0005
20	0.0025	0.0013	0.0008	0.0007
40	0.0027	0.0015	0.0008	0.0007
80	0.0030	0.0018	0.0010	0.0008
150	0.0040	0.0015	0.0018	0.0015

7.5 Operation costs

They include costs that are function of the duration of using, like energy cost and labour for control and operation. Electric tariffs are very varying and some hypothesis need to be assumed, to simplify computations.

7.5.a Electric power costs

The electric power "P" (kw) required to rise a discharge of "Q" (l/s) at a manometric head of "H" (m) with a pump of "rb" yield moved by a motor with "rm" yield is given by the formula:

$$P \text{ (kw)} = 0.736 * Q * H / (75 * rb * rm)$$

The electric energy "E" (kw.h) utilized in that installation during a period of operation of "t" (hours) will be:

E (kw.h) = P (kw) * t (hour)

The volume "V" of water pumped during time "t" is:

V (m3) = 3.6 * Q * t

and the kw.h per cubic metre:

E/V = 0.00273 * H / (rb * rm)

For an average price of "e" ($) per kw.h the cost of elevation "C" will be:

C = e * (E/V)

The cost does not depend on the unit discharge Q, but on the manometric head, the yield of the motor-pump group and the average price of the kw.h.

Assuming an average cost of kw.h of:

e1 = 0.0275 + 0.4185 / H

when the use is less than 250 hours/month, and

e2 = 0.0225 + 1.6527 / H

when the use is of more than 250 hours/month, and if the distribution of monthly irrigation is given in table 27,

TABLE 27

Month	Hours of operation per month
January, February, March	0
April	150
May, June	300
July, August	450
September	300
October	50
November, December	0
Year total	2,000

and also taking into account the minimum that shall be paid in periods of nil consumption, average price of kw.h results in:

e = 0.0286 $/kw.h

ant then, the cost:

C = 0.000078 *H / (rb * rm)

and assuming that the combined yield of the group is about 0.65, the cost of electric energy is represented in table 28.

TABLE 28
Cost of energy per cubis metre (2,000 hour of operation per year, and for submersible groups).

	Yield (1/s)			
Head (m)	20	40	80	120
10	0.0012	0.0012	0.0012	0.0012
20	0.0025	0.0025	0.0023	0.0023
40	0.0050	0.0050	0.0048	0.0048
80	0.0100	0.0097	0.0097	0,0092
150	0.0180	0.0180	0.0173	0'0173

7.5.b Operation and control

They include starting and stopping operations and other monitoring works which do not require full time dedication. Under some hypothesis of wages and duration of work, these costs have been estimated (1976, Spain, US $) as shown in table 29.

TABLE 29
Cost of operation and monitoring per cubic meter

	Yield (l/s) 20	40	80	120
Cost	0.0028	0.0015	0.0015	0.0010

7.6 Case examples

With all data obtained in the precedent paragraphs, it is possible to estimate the cost per cubic metre of water at surface, in function of discharge (yield) and manometric head.

7.6.a Spain

The cost (1976 US $) is the sum of amortization cost, maintenance costs, and operation costs per cubic metre. The incidence of the cost of drilling has not been included, and the same with the electric high voltage line, both of which requiring separate calculation. The result is given in table 30.

TABLE 30
Cost of cubic meter at well site.

Head (m)	Yield (l/s) 20	40	80	120
10	0.0125	0.0072	0.0052	0.0043
20	0.0143	0.0090	0.0070	0.0058
40	0.0178	0.0122	0.0100	0.0085
80	0.0248	0.0189	0.0157	0.0138
150	0.0378	0.0307	0.0272	0.0252

7.6.b Mauritannia (6)

The cost (1978 US $) of a tubehole and the cost of cubics metre of water was evaluated as shown at tables 31, 32 and 33

TABLE 31
Cost of tubehole and cubic metre of water.
Aquifer: Rag Amneker. Location: Adrar. Depth of well: 50 m. Unit yield: 20 m3/hour (5.6 l/s). Manometric head: 30 m. Type of well: Borehole with steel casing equipped with submersible group.

Amortization	Investment	Lifetime	Annual charge	US $/m3
Construction (50*300*1.4)	21,000	20	2,100	0.0364
Infrastructure (Rural shelter)	600	3	240	0.0042
Equipment				
motorpump	15,800	5	3,950	0.0686
generator 10 CV	7,000	5	1,750	0.0304
	44,400		8,040	0.1396

Operation		
Energy (carburants)	4,968	0.0862
Maintenance of equip. (3% invest)	5,700	0.0990
	10,668	0.1852
Total charges	18,708	0.3248

Yearly volume of water 20*3,600*0.8=57,600 cubic metre

TABLE 32
Cost of tubehole and cubic metre of water.
Aquifer: Khatt Tabrinkout. Location: Inchiri. Depth of well: 40 m. Unit yield: 20 m3/hour (5.6 l/s). Manometric head: 30 m. Type of well: Borehole with steel casing (6" diam.), vertical axis pump.

Amortization	Investment	Lifetime	Annual chare	$/m3
Construction				
(40*300*1,4)	16,800	20	1,680	0.0292
Infrastructure				
(Rural shelter)	600	3	240	0.0042
Equipment				
Vert. axis pump	14,200	5	3,550	0.0616
Diesel motor * CV	3,500	5	875	0.0152
	35,100		6,345	0.1102
Operation				
Energy (carburants)			3,974	0.0690
Maintenance of equip.(3% of invest.			4,425	0.0768
			8,399	0.1458
Total charges			14,744	0.2560

Yearly volume of water 20*0.8*3,600=57,600 cubic meter

TABLE 33
Cost of tubehole and cubic metre of water
Aquifer: Kiffa. Location Assaba. Depth of well: 40 m. Unit yield: 1 m3/hour (0.28 l/s). Manometric head: 10 m. Type of well: Drilled by percussion (4"1/2, PVC), equipped with hand pump.

Amortization	Investment	Life tim	Annual charge	$/m3
Construction				
(40*280*1.4)	15,680	20	1,568	0.4356
Infrastructure				
Pump basis	100	10	15	0.0042
Equipment				
Hand or foot pump	2,000	5	500	0.1388
	17,780		2,083	0.5786
Operation				
Maintenance (3% investment)			500	0.1388
Total charges			2,583	0.7174

Yearly volume of water 12*10*360= 3,600 cubic metre
(For a village of 500 persons at 20 l/hab.day

7.6.c Cameroon (11)

Figures from a U.N. project, shown in table 34, include net exploration drilling costs from a February-June campaign, with approximately 1,800 m drilled.

TABLE 34

Concept:	Cost ($)
Drilling equipment (including insurance and depreciation)	21,000
Fuel	6,500
Personnel	13,500
Miscellaneous and spare parts	6,800
Transportation	5,750
Total	53,550

Which represents about 30$/m as net cost of drilling.

With regard to exploitation drilling with a rotary drilling rig for eight months (2,880 m) in 1976-1977 (including well development and eventual installation of screens and water pumps), the summary of costs is as described in table 35.

TABLE 35

Concept:	Cost ($)
Drilling equipment (development plus depreciation and insurance)	49,800
Fuel (8 months)	28,900
Personnel	24,200
Miscellaneous and spare parts	14,900
Total	117,800

This represents about 41 $/m without casings, screens and pumps, or about 76 $/m including them.

7.6.d Iran

Another U.N. publication (12) offers some data of ground-water production in Iran, as indicated in table 36. The data are not recent, but still worth of being mentioned.

TABLE 36
Summary of groun-water production in Iran

Method	Approx. number	Discharge (m3/year)	Unit yield (l/s)	Cost ($/m3)
Ghanat	25,000	12,000	10 to 300	0.67
Deep well	3,000	1,000	20 to 200	0.67 to 1.3
Shallow well	+10,000	2,000	5 to 20	0.34 to 0.6

8 PERCENT OF INCIDENCE OF DIFFERENT COMPONENTS IN THE COST OF WORKS

From previous figures, the different percent incidence of each of the components in the total cost of water can be generally assessed (13). This is shown in table 37.

TABLE 37
Approximate percent incidence of different components in the cost of water.

Drilling		
Perforation	3.7 %	
Cementation and casing	3.0 %	
Previous surveys, treatments, development, tests	3.0 %	
Total perforation		9.7 %
Pumping installation		
Submersible group	4.1 %	
Casing and accessories	2.2 %	
Electric wires and pannel	3.0 %	
Transformer and housing	4.1 %	
High voltage lines	1.8 %	
Total installation		15.4 %
Operation and maintenance		
Electric energy	38.5 %	
Labour (operation and control)	2.6 %	
Total operation		41.1 %
Water distribution costs		
Fiber-cement pipes	7.4 %	
Irrigation (or treatment)	7.4 %	
Labour	14.8 %	
Total distribution		29.6 %
TOTAL COST OF WATER		100.0 %

It can be seen that, motor-pump group installation is an important component of the total cost of water, and energy consumption is the most important part of it.

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