

ECONOMIC ASPECTS OF GROUNDWATER EXPLOITATION

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ABSTRACT

An analysis of the factors that determine the cost-effectiveness of groundwater works - location, design and construction of wells; development; pumping; control and management of civil works; monitoring and control of exploitation and its effects on the aquifer has been made. The costs involved in constructing groundwater works - drilled wells, dug wells and others - are dealt with and tables showing unit prices in Spain are given.

1. INTRODUCTION

The goal of the constructions of groundwater works is to tap underground water resources retained in the sub-soil and make them available for use. The following principles apply to the construction of any groundwater work:

- The natural quality of the groundwater should not be changed and the work itself must not be a way of pollution.
- groundwater should flow freely from the aquifer to the point of withdrawal.
- the cost of the works, taking into account the capital investment and the maintenance costs, is determined by the specific characteristics of the sub-soil, the volume of water to be extracted and its ulterior use.

A wide range of different types of groundwater works exists. Shallow dug wells, drilled well of several hundred of meter deep, tunnels, galleries, ditches, etc. Manually-operated pumps or sophisticated machinery capable of pumping hundreds of litres per second have been installed, and provide groundwater for various uses all over the world.

Those various uses, including urban, agricultural and industrial uses, need amounts of water of a few hundred to millions of litres per year. On the other hand, there are many different types of sub-soils where the groundwater can occur. The design of a specific work should take into account the type of aquifer: water-table or confined, unconsolidated or consolidated, deep or shallow, and the rock formation: detritic, carbonatic, volcanic, etc.

That is the reason for the wide assortment of works and equipment, and the extensive range of factors that should be estimated to make sure that groundwater works constructed are the best for the type of aquifer and the volume and

use of water. However, some general guide-lines can be established.

2. FACTORS THAT DETERMINE THE COST OF GROUNDWATER EXPLOITATION

The cost of groundwater exploitation is defined as the difference between the cost of extraction and the benefits obtained from the extracted groundwater. Whereas it is usually quite easy to calculate the cost of extracting water, it is much more difficult to quantify the second part, the benefits, because very often, these cannot be defined in purely economic terms (QUIST, 1987 and ARLOSOROFF et al., 1987).

Groundwater exploitation is closely related to the availability of financial and technological resources. Thus, the situation in developing countries - where groundwater is used as a source of primary water supply - is very different than that in developed countries where groundwater is often a factor in the development of an agricultural or industrial production process.

In any case, a cost-benefit analysis should be done before undertaking any groundwater work and the different available alternatives should be studied to satisfy the demand, using surface water and/or ground water.

Once the decision of developing groundwater resources has been taken, every effort should be made to optimize all the factors involved in the process.

2.1 Location and design

The following points should be taken into consideration in order to decide where to locate wells:

- The characteristics of the aquifer will determine the amount of available water, and the depth at which extractions will take place, and then, the energy costs.
- Distance from the point of withdrawal to the area to be supplied, and the existing, or proposed, facilities for transporting water.
- Distance from the point of withdrawal to power supplies; the possibility of laying on electricity to the site.
- Easy access for machinery involved in the construction, development, testing, plant installation and subsequent maintenance of the groundwater works.

Well design should also take into consideration the characteristics of the aquifer, the volume and the use of water that is required.

Projects should include a complete plan of the work. It must also be given a detailed report about the different sections, including instructions for the construction. In the case of drilled wells, this information should include: method of drilling; depth and diameter of perforation; plans for auxiliary piping; details of well shafts, position of screens, casing, grouting and completion. It will also provide useful data for the constructor such as the nature of the formation, the occurrence of abrasive materials, the risk of

rockfalls, and specific instructions about the required tests, stoppages, meetings with the Technical Management and any other factor that could help in the construction and the evaluation of the work. Quality control should be very strict, particularly in the materials used in the well and in the details of the equipment and accessories to be installed.

Besides the project, a list of specifications must be prepared, establishing the requirements for the particular case, evaluating the criteria of the proposed tenders and their different prices.

A reliable knowledge of the aquifer and data of the previous exploitations are vital to ensure proper location and design of wells.

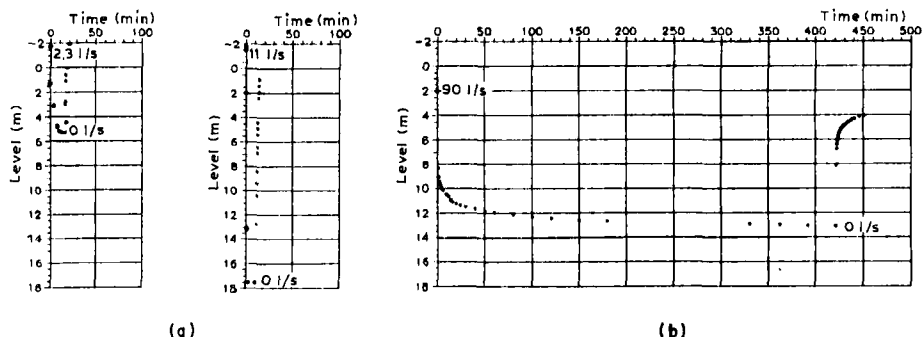


Fig. 1. Drawdown-time curves of two wells located in the same aquifer. The second well (b) was constructed with a previous exploration and a design adequate to the aquifer.

The Fig. 1 gives an example of this. Two wells were drilled in the same aquifer at a distance of 150 m from each other. The costs of both wells were equivalent. The second well was drilled after a previous research and was designed in accordance to the characteristics of the aquifer (Llamas and Molist, 1968). Improper design and construction of wells also contributes to the progressive damage of pumping machinery (Peña and Areguin, 1987).

2.2 Well construction

The following points should be taken into consideration in order to construct a well:

- Availability of adequate machinery and competent personnel for carrying out the proposed project.
- The equipment must be the most suitable for the job and must include tools capable to deal with any unforeseen circumstances that may arise e.g. fishing implements, spare pipes, machinery for the removal of pipes etc.
- Easy access for fuel supplies, tools, materials, large vehicles, etc.
- Personnel in charge of handling the equipment should be qualified: They should have the required technical background and experience to achieve the

proposed results.

Finally, it is needed to estimate the unforeseen circumstances, since they can greatly increase the final costs and the time spent to complete the construction, so goals must be flexible and fit in time-schedules and financial resources.

Cleaning and development. Once the work has been completed, wells should be cleaned to facilitate the flow of water from the aquifer and to remove fine particles from the screens, in order to avoid their entry into the well and to stabilize the aquifer. Generally, once the construction is concluded some fine particles remain in suspension and must be eliminated before the final pump is installed. In any case development of wells increases their output and reduces subsequent costs.

Peña and Areguin (1987) believe that it is a waste of time and money to optimize the electrical and mechanical elements in a well if the hydraulic efficiency has not been optimized.

Treating unconsolidated detritic aquifers with compressed air reduces the amount of fine particles. Therefore maintenance costs of pumping machinery are also reduced. The use of hydrochloric acid in karstic formations makes easier the cleaning and reduces the period of time of shaking clays. In both cases, well efficiency is improved. Often the improvement in limestone formations is spectacular.

A compressed air treatment costs nearly 300,000 pesetas (\$ 2,600 *) including transport of machinery, installations and others, and 8,000 pesetas/h (\$ 70/h) during the developing process itself (Niñerola, J. 1987). A well treatment with 40 tons of commercial hydrochloric acid and its respective additives, compressor group and other necessary elements costs about 1.5 M pesetas (\$ 13,000). The price of the subsequent cleaning by pumping must be added.

The cost of a 200 m deep well located in a limestone formation is about 8 M pesetas (\$ 70,000) including drilling, 8 mm thick steel casing of 550 mm diameter and a 125 m deep pumping chamber. According to our experience, spending an extra-cost of 20 - 25% in cleaning the well, the efficiency can increase between 20 and 300%.

The curves in Fig. 2 show the volume of water pumped from the same well before and after a treatment with hydrochloric acid. A marked growth in the well efficiency is evident (Niñerola and Castiella, 1987)

Programming extractions. The volume of water to be extracted from an aquifer depends on the efficiency of the well and on the natural resources of the aquifer

* \$ is always referred to U.S. dollars.

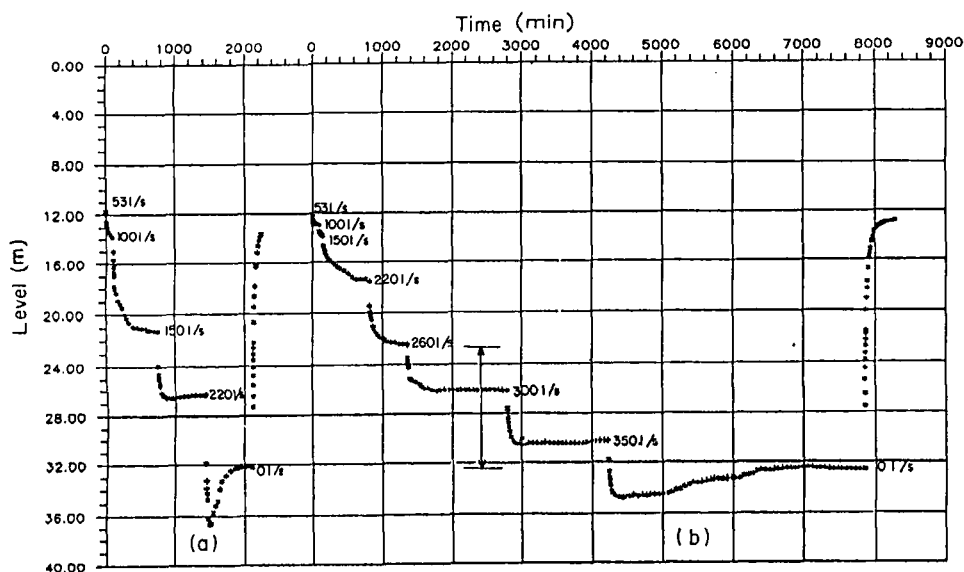


Fig. 2 .- Drawdown-time curves in a well located in a limestone aquifer. The first one (a) is previous to the development by acid, and the second one (b) is latter.

The first factor can be known from pumping tests, and must be carried out under overstressed conditions in order to make sure that figures are not influenced by fluctuations in piezometric levels.

A detailed study of the pumping tests provides an interesting insight into the well/aquifer relationship (Benton, 1987).

The cost of pumping tests varies greatly. Submerged pumps powered by generators are used and their costs include moving, installation, and removal of the plant, as well as energy costs which vary according to the depth where water is being pumped from and the volume of water to be extracted.

In Spain, nowadays, pumping tests of 350 l/s from a depth of 25 m costs about 500,000 pesetas (\$ 4,350) during the first 24 h and thereafter 13,000 pesetas/h (\$ 115/h), 100 l/s from a depth of 100 m costs about 400,000 pesetas (\$ 3,475) in the first 24 h and following this period of time 10,000 pesetas/h (\$ 85/h). Finally, 20 l/s from a depth of 10 m costs about 150,000 pesetas (\$ 1,300) due to the transportation, installation and removal of plant and 5.500 pesetas/h (\$ 50/h) due to pumping (AFORMHIDRO, 1987).

However, in order to plan the extractions, it is usually required not only a good knowledge of the well efficiency, but also proper data about the behaviour of the aquifer. Thus, it should be considered information about exploitation, recharge, and the performance of aquifers and, in the case of coastal aquifers, on saltwater intrusion. Simulation models are very useful in evaluating the effects of different types of pumping programmes on a given aquifer.

Control and supervision of civil works, development and testing. The differ-

ent phases of well construction should be supervised at any time to control the development of the work and to test the fitness between the technical and financial provisions and the actual data. Obviously, the initial project will undergo a continuous process of adaptation according to the results that are being gotten directly from the work. Then, an efficient management and a proper control are the requirements to optimize the investment.

However, many wells are constructed out of supervision or control because the investors think this task is useless. This first saving becomes very expensive in the long run.

The price of controlling and supervising the construction of a well in Spain is about 5 - 10% of the cost and the expenses due to the management of the development, and pumping can be about 20% of the total.

Pumping machinery. The installation must be chosen once the extraction plans have been selected. The following points should be taken into consideration (AFORMHIDRO 1987):

- Volume of water to be pumped
- Depth of the intake, that depends on water levels, pumping flow, diameter of wells and position of screens.
- Water quality: physical properties (fine abrasive particles in water can damage turbines) and chemical properties (different types of material should be used depending on how corrosive water is). All of these characteristics are very important when choosing pump, because an adequate election often means a long-term saving.

Pumps used in wells are usually of the following types:

Vertical pumps. Pumps are powered by an electric or diesel motor located out of the well, an axle connected to the pump by the interior of the impulsion pipe transmits the movement. This kind of pump is usually installed at a maximum of 50 or 60 m deep depending on the well conditions. This is because of the cost and the great technical problems involved.

Submerged electric pumps. In this case, both the motor and the pump are submerged in the water, they use electrical power and are easy to install. Their design is specially adequate for great depths. Since suction problems are avoided because there is always a column of water over the pump, maintenance costs are minimal, particularly when water is clean. The motor is completely submerged into water, so there are not other liquids that could pollute groundwater.

These pumps are smaller in diameter than the vertical ones. Nowadays in Spain, they are the most common type for deep wells.

Horizontal pumps. These pumps are used in shallow wells, not deeper than 6 - 8 m.

2.3 Control and maintenance of installations.

Once the construction has been completed and the well starts working, control and periodic maintenance of installations and/or changes should be carried out to adapt it to changing circumstances. Control of extractions and analysis of the data obtained allow us to compare them with those initially foreseen. Detailed knowledge of the aquifer can be obtained and exploitation can be continually adapted, thus optimizing the cost-effectiveness of wells.

Maintenance often has to be carried out on wells. Peña and Arreguín (1987) studied about 300 wells in an agricultural region in the North-West of Mexico. They conclude that restoring the hydraulic efficiency of wells impaired by the obstruction of wells by sands or carbonatic deposits, a 32% in energy costs would be saved. This would mean about 93,000 kWh per agricultural season. The example is significant and shows the importance of maintaining installations as well as the effect that lack of maintenance can have on running costs. In our opinion, the cost of re-establishing well efficiency is high, the results are not always those expected and there is always the risk of damaging the well.

The progressive deterioration of the wells can be avoided with a good design, careful construction and a correct development.

Normally pumps require regular maintenance depending on the conditions of the wells. The life of a pump will be short if fine particles are transported by the water or if pipes and mechanical parts of the pump may undergo corrosion.

Maintenance costs are usually included in the project as a percentage of the initial capital budget as shown in Table 1 (AFORMHIDRO, 1987):

TABLE-1

Estimated maintenance costs as a percentage of the initial capital budget, for a well intended for irrigation.

Motor-pump group.....	3%
Distribution network.....	1%
Rising main.....	3%
Energy transport costs.....	2%
Power supply.....	2%
Fastening devices	1%
Sprinklers.....	4%

Supply of spare parts for mechanical pumps should always be available to ensure that, in the event of a break-down, pumps can be fixed in a short period of time.

Often, wells have to be deepened because of over-exploitation of the aquifer. In some areas of the South-East of Spain and the Canary Islands, the level of water in wells has fallen about 10 m/year and the quality of the water

in the wells has become greatly impaired . In some wells water is risen about 500 m and in some coastal aquifers concentrations up to 15 g/l of sodium chloride have been found. There are several consequences: water quality decreases, cost rises due to the continuous deepening of wells, pumps must be often replaced by more powerful ones, energy consumption increases, effectiveness drops, etc.

Sometimes the effects of this situation are, a) the search and importation of farther and more expensive resources to increase the irrigation efficiency and b), a crop selection in such a way that only those with high economic yield survive. Other times, the exploitations are kept working even if the water has a bad quality if there exists the urgent necessity of supply water to the distribution network. Finally, other times irrigation areas are abandoned because of exhaustion or salt encroachment of aquifers due to over-exploitation produced by the setting of new irrigation areas.

3. COST OF WELL CONSTRUCTION

Wells are designed and constructed in different ways depending on the availability of technology and finance, the type of aquifer as well as the use that will be given to groundwater.

The methods used to drill wells depend on the type of sub-soil, the depths, the volumes of water, etc.

In the following sections, information about the cost of well construction in Spain is given. Presently , there are about 500,000 wells in operation and thousands of million pesetas have been invested over the past 20 years in drilling and constructing wells for the exploitation of groundwater resources.

3.1 Dug wells

The methods used for digging wells don't need to be sophisticated. A few meter deep well can be dug in altered or loose material using simple tools and construction material -bricks, concrete, etc.- that are usually available anywhere. Personnel do not have to be highly qualified.

Quist (1987) and Arlosoroff et al.(1987) point out how important dug wells are, together with other low cost technologies, in solving the problems of primary water supply in developing countries.

Wells can also be dug using mechanical means when these are available. The use of excavators in alluvial aquifers and porous concrete rings to line wells is a common practice, as well as the use of pneumatic drills and explosives.

Although these wells are usually only a few meter deep, they can be tens of meter deep. In the Canary Islands, dug wells can reach depths up to 500 m; horizontal drains are located at the bottom.

The cost of this type of well varies greatly depending on the type of terrain, the method of construction, and the depth of the well. Quist (1987) gives details about the cost per capita of wells used in Ghana. In Spain , the

cost (if undertaken by a drilling firm) is between 40,000 and 100,000 pesetas/m (\$ 348 - 870/m).

3.2. Drilled wells

Well-drilling is becoming an increasingly specialized field as water has to be extracted from greater depths. In developed countries, well-drilling is a common procedure and it is usually offered and easily available.

Techniques used to drill wells vary according to the different situations.

One of the techniques considered to be less sophisticated is the percussion -or cable tool- drilling (although specially trained personnel, a large amount of machinery, tools and implements are required), when wells have to be drilled to great depths and large volumes of water have to be extracted.

The advantage of percussion drilling is that it can be used for different types of terrain and good quality wells can be drilled. Its main disadvantage is that the time for drilling is longer than in other methods.

Another of its advantages, at least in Spain, is that the machinery required to carry out this kind of job is readily available on the market. In some areas it is easy to find a rig, capable of drilling the proper well for the aquifer in the area and at a low cost. Contracting a drilling firm to do the job has the advantage that the firms usually have the machinery necessary to deal with more complicated situations.

Rotary drilling of wells is a highly specialized technique. In Spain, rotary drilling is unusual, and it is normally performed using machinery from other fields of underground exploration.

Lately, attempts have been made to introduce in the market the appropriate machines for this kind of works, capable to drill wells similar in diameter to those performed with the percussion technique and, by different methods, try to get a comparable speed.

However, the cost of the machinery and its accessories, the large number of percussion drills, reverse rotary and air rotary drills already available on the market, and a shrinking market has meant that these attempts have not been successful.

On the other hand, reverse rotary drilling is widely used for drilling wells in unconsolidated detritic aquifers. Its main advantage is its speed and, in this type of terrain, the wells drilled in this way are very adequate. Highly qualified personnel, advanced technology and a large amount of machinery are required.

Air rotary drilling is another technique often used and its main advantage is the high speed of drilling. It also involves highly advanced technology and requires highly qualified personnel. Compressed air and foam are used to drill the well. Drilling is repeated a number of times, increasing the diameter of the well each time. Wells can be drilled quickly using this method and are

perfectly adequate when large volumes of water are not required. In Spain, this type of drilling is readily available almost anywhere in the cost in country. The technique is best used for medium-sized wells. That is the reason why it is used in research programmes. As a rule, the bigger diameter of the well, the higher the construction costs, but in this method this even is more pronounced.

The cost of drilled wells includes the cost of drilling, casing, finishing and other costs such as transport of machinery and accessories, stoppages beyond the contractor's control, taxes etc. In Tables 2, 3, and 4 prices are given for percussion, reverse circulation (PYRSA, MACOMPANY, 1987) and air rotary drilling. All of these techniques are frequently used by engineering firms in Spain.

TABLE 2.

Estimated unit cost of percussion drilling. (1987)

Depth (m)	Diameter (mm)				
	700	600	500	400	300
0 - 100	17,000 (148)	16,000 (139)	15,000 (130)	12,500 (109)	10,000 (87)
100 - 200	18,000 (156)	17,000 (148)	16,000 (139)	13,500 (117)	11,000 (96)
200 - 300	19,000 (165)	18,000 (156)	17,000 (148)	14,500 (126)	12,000 (104)
300 - 400		19,000 (165)	18,000 (156)	15,500 (135)	13,000 (113)
400 - 500			19,000 (165)	16,500 (144)	14,000 (122)
500 - 600				17,500 (152)	15,000 (130)

10000 - cost expressed in pesetas/m

(87) - cost expressed in \$/m

Many times, the exploitation of detritic aquifers requires the use of gravel to stabilize the walls and to retain the fine particles.

The cost of this operation depends on the market price of gravel, the cost of transporting it to the well-site and its placing in the correct position. In Spain, transport and delivery of round-stoned siliceous gravel can cost between 6,000 and 10,000 pesetas/t (\$ 52-87/t) and placing it in position costs between 500 and 1,000 pesetas/m (\$ 4-9/m).

Finishing a well entails sealing the bottom and isolate the aquifer from the surface using concrete. This is normally done during the drilling process.

A ring is placed at the required depth and the space between the well casing and the shaft is filled in with concrete. The cost of this operation in Spain is between 3,000 and 12,000 pesetas/m (\$ 26-105/m) plus the time the drilling rig is stopped while the cement sets. Sometimes a trench is dug around the well and this is filled in with several cubic metres of concrete. The cost of finishing a well, even in this case, is usually less than 5% of the total cost of the well.

TABLE 3.

Estimated unit cost of reverse rotary drilling (1987)

Depth (m)	Diameter (mm)				
	700	600	500	300	400
0 - 100	15,000 (130)	14,000 (122)	12,000 (104)	9,000 (78)	
100 - 200	16,000 (139)	15,000 (130)	13,000 (113)	10,000 (87)	
200 - 300	17,000 (148)	16,000 (139)	14,000 (122)	11,000 (96)	
300 - 400		17,000 (148)	15,000 (130)	12,000 (104)	10,000 (97)
400 - 500			16,000 (139)	13,000 (113)	11,000 (96)
500 - 600				14,000 (122)	12,000 (104)

10,000 - cost expressed in pesetas/m

(87) - cost expressed in \$/m

TABLE 4.

Estimated unit cost of air rotary drilling (1987)

Depth (m)	Diameter of			Widening		
	Perforation (mm)			as from 220 mm		
	380	310	220	445	380	310
0 - 100	15,000 (130)	11,500 (100)	6,250 (54)	15,000 (130)	9,500 (83)	6,500 (57)
100 - 200	18,500 (161)	13,500 (117)	7,200 (62)	19,000 (165)	12,000 (104)	7,500 (65)
200 - 300	22,000 (191)	15,300 (133)	8,000 (70)	24,500 (213)	15,000 (130)	8,700 (76)

10,000 - cost expressed in pesetas/m

(87) - cost expressed in \$/m

Often the problems encountered in drilling deep wells require the use of auxiliary pipes to stabilize the walls of the well to let the process of deepening continue. The use of these pipes cannot be foreseen in the initial project unless very detailed characteristics of the formation to be drilled are known. Their use can greatly raise the total cost of drilling because of the price of the pipes themselves (a 20% plus as depreciation), as well as installation and removal costs, that would be between 500 and 1,800 pesetas/m (\$ 4 -15/m). The cost of auxiliary pipes can account for a significant part of the cost of some wells, particularly percussion-drilled wells where they are most frequently used. They can come to represent over 10% of the total cost of the well.

Well-casings are usually made of steel plate. Filter screens are located in specific parts of the casing. The cost of well-casings depends on the cost of installation as given above. Tables 5 and 6 give the price of pipes, bridge slot screens or tool-pressed pipes at the well-site (PYRSA, MACOMPANY, 1987).

TABLE 5.
Estimated unit cost of well casing (1987)

Thickness of plate (mm)	Internal Diameter (mm)										
	700	650	600	550	500	450	400	350	300	250	200
4	8,500 (74)	8,000 (139)	7,000 (61)	6,500 (57)	6,000 (52)	5,500 (48)	5,000 (43)	4,500 (39)	4,000 (35)	3,500 (30)	3,000 (26)
6	15,000 (130)	13,500 (117)	11,000 (96)	10,000 (87)	9,100 (79)	8,200 (71)	7,300 (63)	6,350 (55)	5,600 (49)	4,700 (41)	3,800 (33)
8	17,000 (148)	15,500 (135)	14,800 (129)	13,600 (118)	12,400 (108)	11,200 (97)	9,950 (87)	8,500 (74)	7,500 (65)	-	-

10,000 - cost expressed in pesetas/m

(87) - cost expressed in \$/m

TABLE 6.
Estimated unit cost of bridge slot screens for wells (1987)

Thickness of plate(mm)	Internal Diameter(mm)							
	550	500	450	400	350	300	250	200
6	16,000 (139)	15,000 (130)	13,500 (117)	12,000 (104)	10,500 (91)	9,000 (78)	7,500 (65)	6,000 (52)
8	19,500 (170)	18,000 (156)	16,000 (139)	14,500 (126)	13,000 (113)	10,500 (91)	-	-

10,000 - cost expressed in pesetas/m

(87) - cost expressed in \$/m

Often, a slot is made in the well-casing using a blow. The increase in the in the cost of the well-casing is less than 2,000 pesetas/m (\$ 17/m)

3.3. Other types of wells.

Galleries and tunnels have frequently been used in the past although they have progressively fallen into disuse - probably due to the fact that their construction normally require qualified personnel and machinery and long periods of time.

Nevertheless , in areas such as the Canary Islands, where they have traditionally constituted a main source of water supply, galleries and tunnels continue to be constructed and deepened the existing ones. However there has been a decline in this type of construction and drilled wells are becoming increasingly popular.

The cost of galleries can vary greatly depending on the type of terrain in which they are located and the type of casing required. Costs may be as high as 150,000 pesetas/m (\$ 1,300/m).

Ditches are used where soil is slightly permeable or where water is close to the surface. Mechanical diggers, porous concrete pipes and gravel are used in their construction. Ditches can also be constructed manually using construction materials.

They are quick and easy to construct with materials that are readily available anywhere. Using mechanical means for their construction , prices can range from 10,000 pesetas/m to 30,000 pesetas/m (\$ 87 - 261/m)

Well-points and driving wells have not been often used in Spain over the past few years. The advantages of this type of well lie in the fact that the demand for small quantities of water can be satisfied by connecting them to a manual pump, but in case that large quantities of water are required, the connection of a mechanical pump to a set of this kind of wells may supply the needs

3.4 Withdrawal plant

The type of machinery used in a well is of vital importance for extractions.

The pumping machinery must be chosen according to the type of aquifer and the volume of water required in order to optimize costs. If the pump is too large or inefficient, effectiveness is reduced, energy consumption rises and the total costs increase. Thus, the election of a pump should look for efficiency and good quality of the materials. In the long term, each cubic meter of water will be cheaper, if these factors were taken into consideration.

The following points should be taken into account when selecting a pump for a well:

- Characteristics of the well: depth, diameter, position and type of screens, etc.

- Hydraulic characteristics of the well and the aquifer: yield, static water level and its seasonal changes, dynamic water level, etc.
- Volume, use and destination of the water required (including deposits, reservoirs, etc).
- Availability of power supply and pumping power.

The cost of installing a pumping system can be broken down in:

- The pumps themselves.
- Rising mains, water level sensors, couplings, plates, valves, fittings, elbows, screws, etc.
- Electricity power supply: high and medium voltage, converter, control board, waterproof electric cables, automatic water level sensors, etc.
- Material - transport and installation.
- Civil works.
- Other expenses: plant installation and taxes

Table 7 shows some cost estimations carried out by AFORMHIDRO (1987) in a common situation where water is pumped from a well to a deposit at the surface using submerged pumps (the most popular type in Spain at present). Transport and distribution of the water and electrical expenses must be included in the total charges (near 1,5 M pesetas/km, \$ 13,050/km).

TABLE 7.

Cost estimations for machinery system in a well

Yield 1/s	Deep (m)	Power (HP)	Pump efficiency %	Pump	Cost			
					Pipes, Valves, Anchors, Automatic, Level sensors,...	Electric Cables	Installation	Total Cost
5	25	3	-	175,000 (1,250)	135,000 (1,175)	20,000 (175)	35,000 (300)	365,000 (3,170)
5	100	9	74	285,000 (2,400)	240,000 (3,000)	65,000 (575)	70,000 (615)	660,000 (5,750)
50	300	254	78	2,500,000 (21,750)	1,290,000 (11,250)	1,650,000 (14,350)	130,000 (1,150)	5,570,000 (48,500)
100	100	173	81	1,475,000 (12,825)	778,000 (6,775)	710,000 (6,775)	87,000 (750)	3,050,000 (26,525)
200	100	339	73	3,225,000 (28,000)	968,000 (8,425)	570,000 (4,950)	87,000 (750)	4,850,000 (42,125)

175,000 - cost expressed in pesetas

(1,250) - cost expressed in \$

4. SUMMARY AND CONCLUSIONS

The construction of groundwater works should only be undertaken once cost--benefit analyses have been made and contrasted with other possible alternative sources of supply, e.g. using other groundwater resources or surface water.

Whereas the cost of constructing a well is easy to calculate, it is not so easy to evaluate the benefits obtained from the water extracted. These benefits can be measured in economic terms only when water forms part of an industrial or agricultural process. When the goal of the exploitation is satisfy primary water supply, these benefits only can be measured in terms of social profit or improved standard of living.

In many developing countries, the construction of wells means improvements in public health, less time to collect water, that is, time for other activities, ... thus the development of society.

The cost of groundwater exploitation can not be calculated out of the socio-economic context, that includes management, use and control of the water resources.

The cost-effectiveness of wells depends on factors such as location, design, construction, development, extraction policy, machinery and maintenance of installations.

Many times, the abstraction work can be affected by external factors such as over-exploitation, pollution, etc, that only in some cases can be restored (deepening wells, increasing pumping capacity, sealing wells, etc), in order to go back to the initial values. In any case, that implies new investments and increasing maintenance costs.

The construction of a well combines the available technological and financial resources and must take into account the aquifer and the use of the water.

Projects should detail the complete work and each different part (previous tests, the way to carry out each step, etc), their prices and the maintenance and amortization forecasts.

Operating and maintenance provisions, estimated according to previous experience are not always accurate because data are scarce and incomplete. It is very convenient make the users responsible for the operation, maintenance and even control of the well.

Bearing in mind how important the groundwater resource is, and in order to satisfy the demand for water supplies and the large volumes extracted, it is needed to optimize all the factors that affect the work. The most important ones, among others, are construction, pumping and maintenance. This would save investment costs as well as energy and maintenance expenses.

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