

EVALUATION METHODOLOGY FOR WITHDRAWAL COSTS OBTAINED FROM STUDIES ON SOME GROUNDWATER AQUIFERS

F.M. SPAZIANI and M. VURRO

Water Research Institute, National Research Council, Rome-Bari Italy

S. TROISI

Professor of Water Resources Management, University of Calabria,
Cosenza Italy

ABSTRACT

In the field of groundwater resources management very little has been done about the problem of withdrawal costs, mainly because of the large number of different users operating according to their own principles in different hydrogeological situations. For the purpose of finding a method of evaluating withdrawal costs for the potential use of an aquifer, thereby providing the water resources manager with a power tool, a survey has been made of technical and economic data referring to groundwater withdrawal plant. After identifying the main cost items involved in water withdrawal, an analysis is made of budget costs using data supplied by the various companies concerned. These data are then compared with those obtained from certain Management Agencies. This paper presents some results regarding a few generalized cost functions which can serve as a basis for identifying areas allowing more economical utilization.

1 INTRODUCTION

The identification of the cost functions related to the various aspects of water supplies from different sources is of essential importance for rational water resources management (Duckstein, 1982).

However, the lack of systematic observation results and the unrepresentative nature of the available data generally do not allow an analytical evaluation to be made of the real costs related to surface and groundwater withdrawal. It must nevertheless be admitted that objective difficulties stand in the way of obtaining reliable cost data owing to the large number of variables and highly heterogeneous situations involved.

For the purpose of increasing knowledge in this sector the Italian Water Research Institute has made a survey of the construction and running costs of groundwater withdrawal plants. The results of this survey should provide a useful tool for drawing up water resource utilization plans by orienting the choice of management options (Fabiano et. al., 1983).

Groundwater utilization costs actually provide indications at two levels. The first level involves the optimal cost estimation of the use of water resources contained in an aquifer (Casati and Mazzarella, 1979). The second

involves the possibility of comparing the relative cost-effectiveness of using ground and surface water, perhaps withdrawn some distance away, for the purpose of providing global criteria for solving a given water supply problem (Martini et. al., 1981). Of special significance in this connection is the possible use of these results in agriculture. Suffice it to mention that in many situations the very survival of agricultural settlements is dependent on being able to locate groundwater sources and draw on them at costs that are consistent with the cost-effectiveness of the crops grown.

It is difficult to obtain reliable data on the cost of groundwater withdrawal plant because of the specific characteristics of underground water bodies, which are typically very different from one another, and because of the highly heterogeneous nature of groundwater users.

In the present study an attempt has been made to define selection criteria for the various plant types on the basis of data referring to plant that has already come into operation. An analysis has been made of the main withdrawal cost factors, i.e. drilling, hydraulic works, civil engineering works and electromechanical equipment. The survey has been restricted to submerged withdrawal plants in that this type of plants covers the main design fields and is the most economical, being easy to install and requiring little maintenance. The preliminary part of this survey was concerned with budget cost data obtained from specialized companies. These data were then compared and checked off against actual cost data available from several Management Agencies (Consortio per l'acqua etc., 1982; Regione Puglia, 1982).

The body of data collected reflects a wide range of different situations and solutions. Within well-defined limits of validity these data have allowed a number of generalized functions to be identified in order to establish the cost of water supplied by withdrawal plants.

2 SURVEY METHODOLOGY

The survey was carried out in the following stages:

- bibliographic survey and fact finding to ascertain the construction techniques used, operating procedures and methods of well water pumping stations;
- survey conducted by interview to ascertain the cost of single plant components with reference to both plant construction and operation;
- formulation of hypotheses aimed at identifying the laws governing cost variation as a function of a small number of significant parameters, e.g. installed power, geodetic head and withdrawal flow rate;
- choice of a limited but representative number of different situations of existing operational plants and evaluation of relevant costs to be used to check and adjust the cost variation laws hypothesized above;
- contacts with specialized companies operating in the sector in order to obtain information on the technical characteristics and single component costs needed to evaluate the present cost of the plants included in the survey.

Direct data collection was carried out using special questionnaires requesting the following information:

- general information (location, year of construction, head, flow);
- drilling (soil type, method, diameter, lining, cost);
- pump (type, power rating, cost);
- plumbing (material, pipe fittings, valves, implements, costs);

- electrical equipment and cables (control, checking, protection, costs);
- control equipment (flow meters, level and pressure gauges, costs);
- civil construction work (loading tank, sumps, pumping station, sub-station, costs).

The analyzed situations are principally located in Puglia, Lombardia, and Emilia Regions and have different objectives. The Agencies pump up about 660 million cubic meters per year.

3 COST FUNCTIONS

The parameters most commonly used for the technical and cost evaluation of withdrawal plants are flow and head. The parameter of power has been included in the present study because a linear correlation with it has been found for certain cost items, i.e. the pump, piping, electric cables and start-up system (Castorani, 1980; Ruggero, 1964). It has thus been possible to simplify the formulation of cost functions. The coefficients contained in the individual analytical expressions were obtained by statistical analysis of the data collected as described above. The costs indicated refer to June 1987 and are expressed in Italian Lire (1\$=1,300 Lit.).

Plant amortization has been calculated on the basis of a maximum of 20 years for equipment and 30 for civil construction works. The choice of interest rates will depend on existing market conditions.

The different cost items are analyzed below.

The first of them is the drilling cost, as expressed by the following relation:

$$C_t = m_t * H + b_t \quad (1)$$

where H is the head (m); m_t and b_t are two coefficients depending on flow rate, well diameter and soil type. Two different soil types have been assumed: a) organic soil, calcareous tuff, clay, sand and gravel; b) solid rock, limestone and hard conglomerates. Table 1 shows the different values of these two coefficients.

Pump and motor cost are a function of the installed power, as expressed in the following relation:

$$C_{eps} = 0.132 * N + 4.586 \quad (2)$$

where N is the installed power (kW).

The third item is related to pipes and pittings and is given by:

$$C_c = m_c * N + b_c \quad (3)$$

where N is the installed power; m_c is a coefficient that is a function of the velocity in pipe; b_c is a constant (3.477). The coefficient m_c changes from 0.359, when the velocity is 1.0 m/s, to 0.238, when the velocity is 1.5 m/s.

The cost of electric cables is:

$$C_{ce} = m_{ce} * N = b_{ce} \quad (4)$$

where N is the installed power; m_{ce} and b_{ce} are two coefficients which are a function of the head. Table 2 shows the values of these coefficients.

TABLE 1

The values of mt and bt of the equation (1).

Flow rate Q (m ³ /h)	Well diameter φ (mm)	Soil type 1		Soil type 2	
		mt	bt	mt	bt
0÷35	160	0.104	2.483	0.171	3.311
35÷55	210	0.127	2.483	0.210	3.311
55÷85	260	0.149	2.483	0.243	3.311
85÷140	300	0.171	2.483	0.276	3.311
140÷200	330	0.194	2.483	0.326	3.311

TABLE 2

The coefficients of the equation (4).

H (m)	mce	bce
100	0.00058H	0.008H
100	0.0013H - 0.074	0.023H - 1.29

The start-up cost is:

$$Ca = 0.074 * N \quad (5)$$

instead the energy cost is:

$$Ce = m * ao * N + h * bo * N \quad (6)$$

where N is the installed power; m is the number of months; h is the number of hours operation per year; ao and bo are two coefficients which are functions of the installed power and the power supply (low voltage and high voltage) and the number of hours of operations. Table 3 shows ao and bo values.

Finally the maintenance and supervision cost is represented by the following

TABLE 3

The coefficients ao (monthly power cost rate) and bo (hourly power cost rate) in equation (6) (1\$=1,300 Lit.).

voltage	ao x 10 ⁻⁶ (Lit/kW)		bo x 10 ⁻⁶ (Lit/kWh)	
	low	high	low	high
seasonal operation	1523	1374	96	88
continuous operation	3013	2781	76	70

equation:

$$C_{em} = M*(C_{eps} + C_c + C_{cc} + C_a) + S \quad (7)$$

where M and S are functions of the number of hours of operation per year; the other symbols are well known.

Having thus defined all the necessary design conditions (i.e. flow, depth, soil type, power supply type, period of operation) the partial and overall costs of the withdrawal plant and the unit cost of water withdrawn can be obtained.

Appendixes A and B show some numerical examples of costing performed under different design conditions and according to the following calculation hypotheses:

- soil morphology consisting of solid rock and limestone, and hard conglomerates;
- simplifying hypothesis that well depth corresponds to total head;
- a fluid velocity in the pipe of 1.5 m/s;
- low voltage power supply;
- continuous operation has been assumed both for power loads exceeding 35 kW and for more than 2000 h/year operation; seasonal operation of loads of less than 35 kW and 1000 h/year operation;
- 30-year pay-off period for civil construction works and 20 years for equipment; for the sake of example, a 10% interest rate has been chosen.

Figures 1, 2, and 3 show unit costs plotted against installed power and flow for various depths and for different operating periods.

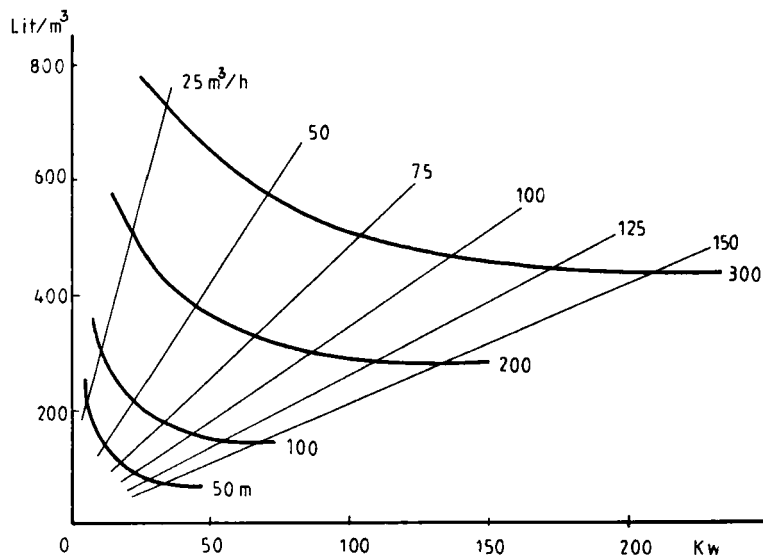


Fig. 1. Unit cost (Lit/m³) of water withdrawn as a function of installed power (operating period: 1000 h/yr; head: 50-300 m; flow rate: 25-150 m³/h; 1\$=1,300 Lit.).

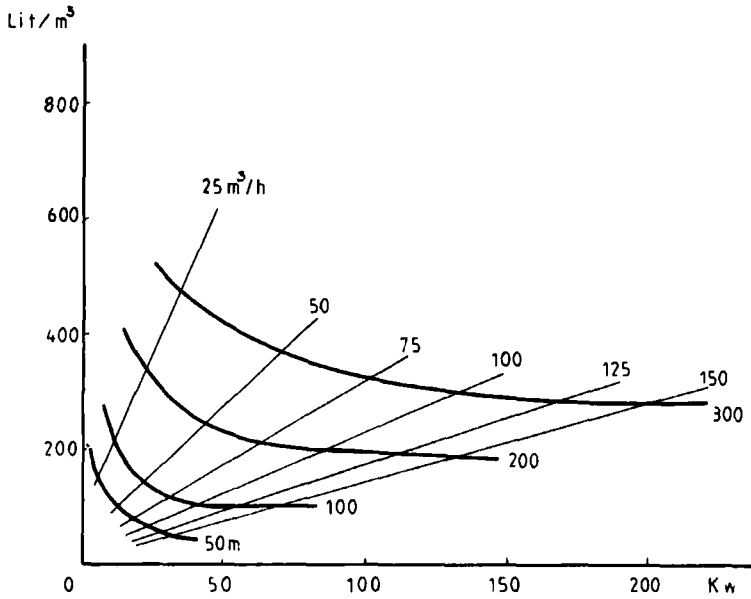


Fig. 2. Unit cost (Lit/m³) of water withdrawn as a function of installed power (operating period: 2000 h/yr; head: 50-300 m; flow rate: 25-150 m³/h; 1\$=1,300 Lit.).

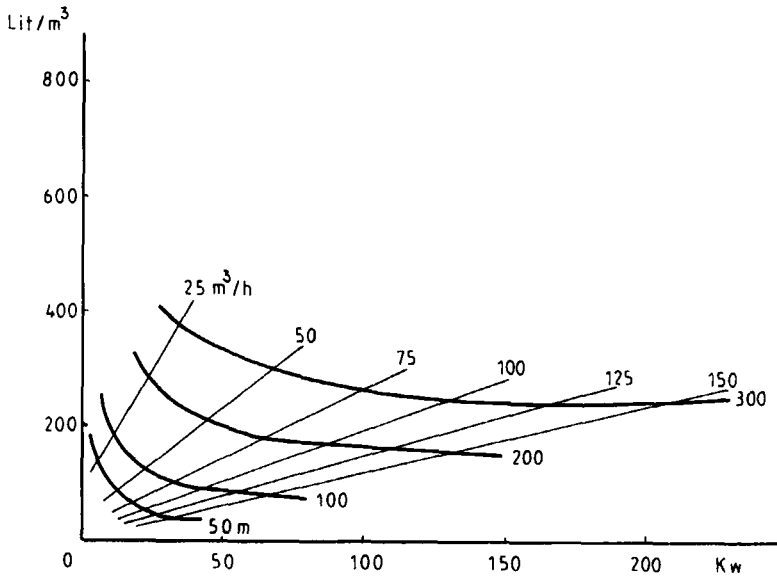


Fig. 3. Unit cost (Lit/m³) of water withdrawn as a function of installed power (operating period: 3000 h/yr; head: 50-300 m; flow rate: 25-150 m³/h; 1\$=1,300 Lit.).

On the basis of the above hypotheses, the processing of the data obtained from the various cost functions has effected a simple and easy-to-use general function for the unit withdrawal cost:

$$C = p*N + q \quad (8)$$

where: C is the unit withdrawal cost (Lit/m³); N is the installed power (kW); p and q are variable flow-dependent parameters.

Using a simple technique these two parameters can be computed as a function of different flow rates and number of hours' operation at given conditions.

To all practical intents and purposes interpolation procedures cause no appreciable error for flow rates in the range indicated in the figures.

4 CONCLUSIONS

In the present study a cost analysis has been made of submerged plants for water withdrawal from an aquifer on the basis of data obtained from the plant constructors and management agencies. Carefully defined hypotheses have been used to define a law of variation for each cost item as a function of a limited number of significant parameters. The above functions have then been used to determine the cost per cubic meter of water withdrawal under different conditions and according to various hypothetical implementations. A number of cost maps have been derived as a function of installed power, withdrawal flow rate and number of hours' operation. Lastly, a general formula of practical utility has been derived to obtain the unit cost of the water withdrawn.

The considerable body of data collected during the survey has confirmed that there are wide variations in the prices offered by both supplying and installing companies. This fact, together with certain restrictive calculation hypotheses, has led to a difference of about 15% between real and calculated costs. The calculated values must be considered as fairly realistic for medium-low depths, while they can introduce comparatively large errors in the case of greater depths.

Maintenance and supervision costs are those found to vary most since they are often influenced by factors extraneous to the technical management conditions.

5 REFERENCES

- Casati, P. and Mazzarella, S., 1979. Consumi e Riserve idriche sotterranee nel Milanese, Acqua e Aria, 10.
- Castorani, A., 1980. Gli impianti di sollevamento: la condotta premente, Training Course on Hydraulic Works, University of Bari.
- Consorzio per l'acqua potabile ai comuni della Provincia di Milano, 1982. Statistiche di gestione anni 1979,80,81.
- Duckstein, L., 1982. System approach to groundwater resources, International Conference on Modern Approach to groundwater resources management, Capri, October.
- Fabiano, M., Lampignano, L., Ruggero, U., Spaziani, F.M. and Troisi, S., 1983. Indagine sui costi di emungimento da falda sotterranea, Quaderni IRSA, 68.
- Martini, P.L., Merolle, L., Rossi, L. and Spaziani, F.M., 1981. Costi e prezzi dell'acqua, Edagricole.
- Regione Puglia - Assessorato all'Agricoltura, Foreste e Pesca, 1982. L'utilizzazione di acque sotterranee per l'irrigazione collettiva in

provincia di Bari - Risultati dell'esercizio 1981.

Ruggero, U., 1964. Problemi di convenienza degli impianti di sollevamento d'acqua ad uso irriguo: considerazioni critiche, L'Irrigazione, 11, 2-3.

Appendix A

Cost of single components and overall withdrawal plant cost for flow rates from 25 to 75 m³/h (as at June 1987; 1\$=1,300Lit.). (*Cost: 10⁶ Lit).

Flow rate (m ³ /h)	Head (m)	Installed power (kw)	Drilling cost*	Pump cost*	Pipe cost*	Electric cable cost*	Start-up sys.cost*	Total cost*	h/year operation	Energy cost*	Maintenance super.cost*	Unit cost (Lit./m ³)
Q	H	N	Ct	Ceps	Cc	Cce	Ca	Ctot		Ce	Cem	c
									3000	1.50	6.08	135.3
25	50	5.67	11.86	5.33	4.83	0.56	0.42	23.00	2000	1.07	4.24	157.5
									1000	0.60	2.40	222.7
									3000	3.00	6.44	177.8
25	100	11.34	20.41	6.08	6.18	1.65	0.84	35.16	2000	2.13	4.54	211.4
									1000	1.19	2.64	309.1
									3000	5.99	7.52	273.4
25	200	22.68	37.51	7.58	8.87	7.53	1.68	63.17	2000	4.27	5.44	334.1
									1000	2.38	3.36	509.4
									3000	8.99	8.91	377.9
25	300	34.03	54.61	9.08	11.58	16.36	2.52	94.15	2000	6.40	6.60	468.8
									1000	3.58	4.29	732.4
									3000	3.00	6.34	82.9
50	50	11.34	13.81	6.08	6.18	0.73	0.84	27.64	2000	2.13	4.46	96.8
									1000	1.19	2.59	137.4
									3000	5.99	7.00	119.8
50	100	22.68	24.31	7.58	8.87	2.28	1.68	44.72	2000	4.27	5.01	142.6
									1000	2.38	3.01	207.3
									3000	11.98	8.95	202.9
50	200	45.37	45.31	10.57	14.28	11.75	3.36	85.27	2000	8.54	6.63	246.7
									1000	5.09	4.32	378.3
									3000	17.98	11.48	294.5
50	300	68.05	66.31	13.57	19.67	27.11	5.04	131.70	2000	12.80	8.75	362.7
									1000	7.63	6.01	567.2

Appendix B

Cost of single components and overall withdrawal plant cost for flow rates from 100 to 150 m³/h (as at June 1987; 1\$=1,300Lit.). (*Cost: 10⁶ Lit).

Flow rate (m ³ /h)	Head (m)	Installed power (kW)	Drilling cost*	Pump cost*	Pipe cost*	Electric cable cost*	Start-up sys.cost*	Total cost*	h/ year operation	Energy cost*	Maintenance super.cost*	Unit cost (Lit./m ³)
Q	H	N	Ct	Ceps	Cc	Cce	Ca	Ctot		Ce	Cem	c
100	50	22.68	17.11	7.58	8.87	1.06	1.68	36.30	3000	5.99	6.88	56.5
									2000	4.27	4.91	66.3
									1000	2.38	2.93	93.8
100	100	45.37	30.91	10.58	14.88	3.55	3.36	62.68	3000	11.98	8.13	90.4
									2000	8.54	5.95	107.5
									1000	5.09	3.77	158.7
100	200	90.74	58.51	16.56	25.07	20.19	6.71	127.04	3000	23.97	11.80	166.8
									2000	17.07	9.01	201.7
									1000	10.18	6.22	306.6
100	300	136.10	86.11	22.55	35.87	48.62	10.07	203.22	3000	35.95	16.64	251.6
									2000	25.61	13.04	307.7
									1000	15.26	9.45	476.1
150	50	34.03	19.61	9.08	11.58	1.39	2.52	44.18	3000	8.99	7.42	47.5
									2000	6.40	5.35	55.7
									1000	3.58	3.29	78.9
150	100	68.05	35.91	13.57	19.67	4.82	5.04	79.01	3000	17.98	9.26	80.3
									2000	12.80	6.89	95.2
									1000	7.63	4.52	140.2
150	200	136.10	68.51	22.55	35.87	28.62	10.07	165.62	3000	35.95	14.64	153.9
									2000	25.61	11.38	185.6
									1000	15.26	8.12	280.4
150	300	204.16	101.11	31.54	52.07	70.12	15.11	269.95	3000	53.93	21.79	236.2
									2000	38.41	17.34	287.7
									1000	22.90	12.89	442.4