ECONOMIC USE OF GROUND WATER THROUGH THE DETAILED KNOWLEDGE OF THE AQUIFERS PENETRATED BY THE WELL

A. BENTON
Desarrollo de Recursos Naturales, Minería 145, Col. Escandón, Mexico, D. F., C.P. 11800, Mexico.

ABSTRACT

In order to obtain a better use of ground water resources in a zone, and doing it in the most economical way, it is necessary to have enough information to get a better interpretation and data correlation, and a most complete knowledge of the aquifers penetrated by a well.

To evaluate and obtain a better view regarding its performance and real yield of each aquifer strata, and to make good recommendations and conclusions for the economical use of a well, it is necessary an accurate interpretation of water well characteristic curves, so it can be defined the yield of each strata aquifer, and having obtained their base position, to use this information to make a correlation with other data, like: drilling chippins, electric logs, geologic interpretations, water analysis, etc., and to define more precisely the productive strata of the geological formation and their characteristics.

The information attained, may be used for the design of the pump and well equipment and for water wells to be drilled in the same zone, so they would become more suitable, economic and useful for the ground water development.

The practical advantages of this technical procedure are exemplified with real cases.

1 INTRODUCTION

In many cases, there is no geohydrological information, neither regional, nor from the zone or puntual of the aquifers in study. In some cases, the only evidence of the ground water is a well, with more or less information about the drilling, construction, piezometric level, pumping and yield of the well, through time.

It may happen that there is no information, or that the data collected is very litle. In spite of this, when a water well exists, there is a window to the aquifer and it is feasible to get valuable information through the analysis and interpretation of the characteristic curves, obtained by the flow or pumping test of the well. The shape, slope and development of the curves clarifies its puntual characteristics with a particular piezometric level, at a specific time.

When there is another reliable pumping data of the well, with piezometric level information, it is possible to obtain a better geohydrological point of view of the site, and be able to make a flow prediction with less deviations.

When it is feasible to get more puntual data of other wells in the same zone, it is possible to correlate information and to clearly define the zone of interest.

2 INTERPRETATION OF CHARACTERISTIC CURVES

When a well is drilled, it is possible to find one, two or several aquifers,each one with its particular characteristics.

Through the analysis and interpretation of the characteristic curves, it is possible to find the point in the well where the shape of the curves changes and the well characteristics, and thus the point (drawdown) where the aquifer ends and the place of its base. When the pumping rate of the well is increased, and there is an additional yield with drawdown, one or more deep aquifers are providing this increment.

In this practical way it is possible to define where the base of each yield strata of a well is, once they have been penetrated.

To make the drawdown analysis of a well in relation to the flow, Rorabaugh (1953) modified the equation proposed by Jacob (1947, 1950):

$$s = B\,Q + C\,Q^2 \qquad \text{Jacob}$$

changing the second flow term exponent (2) to a variable value (n)

$$s = B\,Q + C\,Q^n \qquad \text{Rorabaugh (1953)}$$

This equation is the result of using a mathematical device to obtain a straight line instead of a curve. When this equation is used, it is not possible to see important geohydrological information, that the well is showing through the shape and development of its curve.

Because of the above, the following procedure is proposed based on the separation of the slopes characteristic curves, using Jacob's equation, so it can be possible to find the base of each aquifer strata, its yield, and with geologic information, to make a correlation to obtain a better geohydrological knowledge of the well site.

To present the technical procedure, several real cases are exemplified.

The data obtained during the pumping of the well at a specific time, are usually plotted Q - s and s/Q - Q, like:

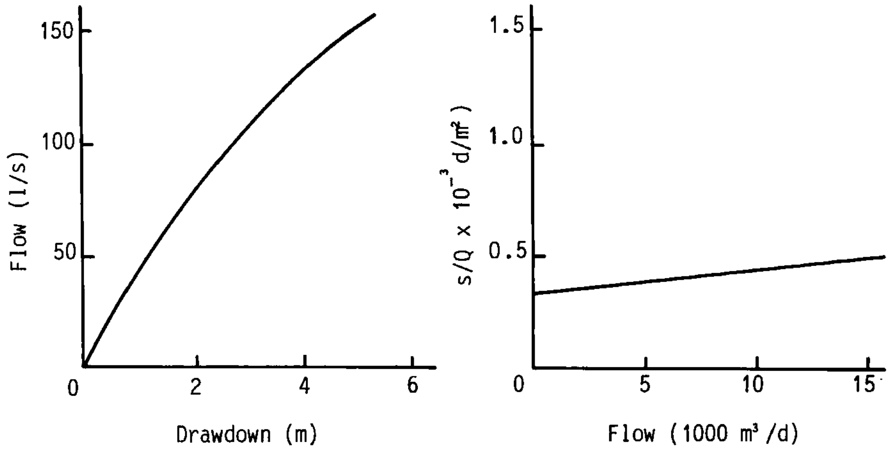

Fig. 1. Diagram showing the characteristic curves of Sta. Cruz Xochitepec well, Xochimilco, México (Jul. 1983)

In this example, in plot s/Q - Q, there is no slope change, so there is no change in the aquifer.

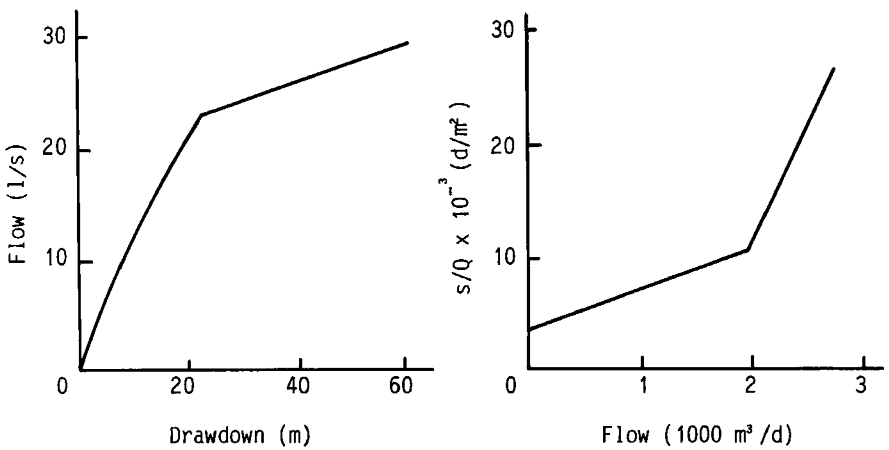

Fig. 2. Diagram showing the characteristic curves of Celaya No. 3 well, Guanajuato (Ago. 1987)

Its this case, plot s/Q, - Q shows a change in the slope of the curve. If the first slope is continued, the new data so obtained makes possible to plot the theoretical curve, Q - s, if the aquifer has not changed.

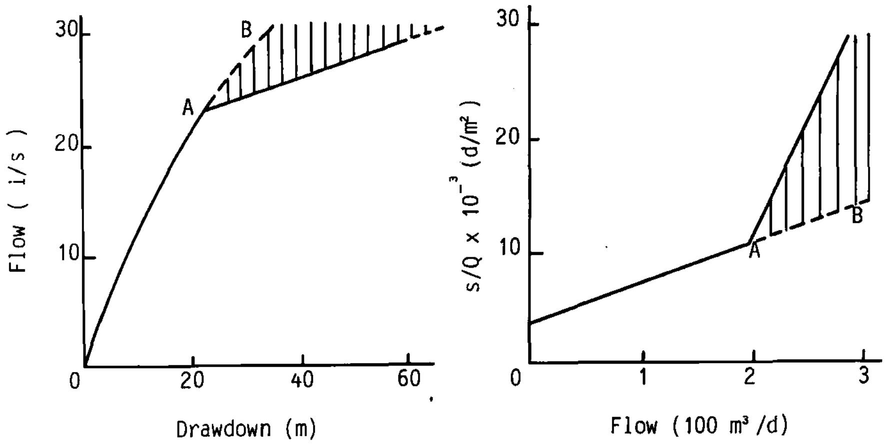

Fig. 3. Diagram showing showing the real and theoric characteristic curves of Celaya No. 3 well, if the first aquifer has not ended at A.

In conformity with the theoretical curve, A - B, the well should have given a better yield.

The shadowed zone is the missing flow. From point A, the well has not reached the flow, because at that depth, there has been a change, the first aquifer has ended, and its base is present at this point.

If there is no other aquifer deeper than the base of the first one, the slope should be horizontal. In this example the slope is given by the yield of the deeper aquifer.

The position of point A, where the slope changes, may be obtained, if the operator is plotting the data during the pumping test, in this way, he sees which flows are necessary to test, in order to obtain or verify the change point. Generally, the operator does not take this into consideration or does not even do the plotting during the test, in spite of the cheapness of the result of doing it during the test in comparison to the total value of the pumping.

3 SEPARATION OF THE CHARACTERISTIC CURVES SLOPE METHOD

This method is presented exemplified with the analysis and interpretation of the data and curves from the Reclusorio Sur No.2 well, drilled at 250 m depth into igneous rock in a faulty zone, into a Graven filled with Basalt and near to a surface contact between Tuff and Basalt.

Through this interpretation it was possible to find the place where the well crossed the fault and the yield in each geohydrological formation.

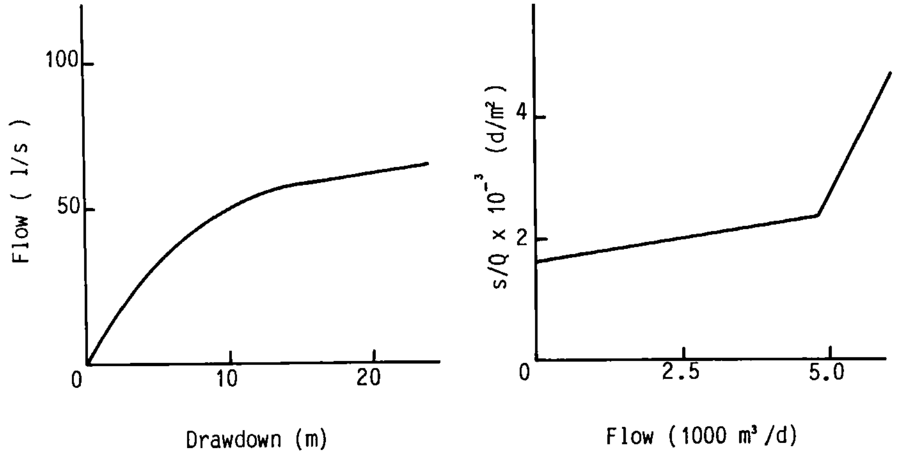

Fig. 4. Diagram showing the characteristic curves of Reclusorio No. 2 well, Xochimilco, México (Dec. 1983)

In the plotting of the data in the example (s/Q - Q), the curve shows two slopes, corresponding to the behaviour of the drawdown, when pumping a well which penetrates two aquifers.

The equation for the first slope is:

$$s = 1.6 \times 10^{-3} Q + 1.49 \times 10^{-7} Q^2$$

and the point of slope change is:

$s/Q = 2.316 \times 10^{-3}$ d/m² and $Q = 4{,}800$ m³/d.
corresponding to a drawdown:

$s = 11.12$ m

When the drawdown increases, the additional flow, comes only from the deeper aquifer and at a drawdown of 11.12 m , the first aquifer ends, and its base is there.

The depth of the static level is at 126.02 m, then, the base of the first aquifer is at 137.13 m and the piezometric level over the base is 11.12 m.

When pumping deeper than 137.14 m the additional flow and drawdown may be plotted s/Q - Q, and obtain the s/Q value. When the abscissa value is zero, it coincides with the drawdown at the base of the first aquifer.

$s = 11.12$ m in this example:

and

$s/Q = 13.17 \times 10^{-3}$ d/m²

then

$$Q = \frac{11.12 \text{ m}}{13.17 \times 10^{-3} \text{ d/m}^2}$$

$Q = 844$ m³/d

this water flows from the deeper aquifer when the drawdown is 11.12 m.

Adding $Q = 844$ m³/d to the value of each additional flow, when drawdown is more than 11.12 m, the real flow value is obtained for each drawdown.

Plotting the values so obtained, it is possible to get the equation for the second slope of the curve s/Q - Q, in the example:

$$s = B_2 Q_2 + C_2 Q_2^2$$

$$s = 13.03 \times 10^{-3} Q_2 + 1.62 \times 10^{-7} Q_2^2$$

Verifying the theoretical drawdowns obtained with the real values of the test, it can be seen how reasonably they can fit, and if the interpretation has been correctly made.

Following this procedure, it is easy to get the flow from each aquifer.

In this example (Reclusorio Sur No. 2, Xochimilco):

The total flow (Q), when the drawdown $s = 11.12$ m, is:

$Q = 4{,}800$ m³/d

The deep aquifer flow, when $s = 11.12$ m. is:

$Q_2 = 844$ m³/d

and so, the maximum flow from the first aquifer when the drawdown is - $s = 11.12$ m corresponding with its base would be:

$Q_1 = Q - Q_2 = 4{,}800$ m³/d - 844 m³/d

$Q_1 = 3{,}956$ m³/d

The well performance may be represented by two characteristic curves, the first one corresponding to the combined performance of the two aquifers, when the drawdown is more than $s = b_1 = 11.12$ m.

For the combined performance:

$$sp = [B\ Q + C\ Q^2]_0^{b_1}$$

and deeper than b_1 :

$$sp = [B_2 \ Q_2 + C_2 \ Q_2^2]_{b_1}^{b_2}$$

b_2 , is the depth of the second aquifer base, from the static level.

It is feasible to represent the well performance, with an equation like - this:

$$sp = [B \ Q + C \ Q^2]_0^{b_1} + [B_a \ Q_a + C_a \ Q^2]_{b_1}^{b_2}$$

$$Q_a = Q - Q_1$$

B_a and C_a , are the values obtained when plotting (s/Q - Q), the additional flow and drawdown, when it is more than $s = b_1$; $b_1 = 11.12$ m in this - example.

Q is the flow, when the drawdown is $b_1 \leqq 11.12$ m.

Q_a is the additional flow after Q (after $b_1 = 11.12$ m)

In the example, Reclusorio Sur No. 2, its equation is the following:

$$sp = [1.6 \times 10^{-3} \ Q + 1.49 \times 10^{-7} \ Q^2]_0^{b_1} + [13.17 \times 10^{-3} \ Q + 3.158 \times 10^{-7} Q_a^2]_{b_1}^{b^2}$$

The equation was verified with the real drawdowns and they were tightly fitted.

The water well, Reclusorio Sur No. 2 was located in a Graven, near to the regional fault that limited it. This fault is the contact between Basalt flows and Tuff.

The well penetrated the Basalt and then the Tuff. There were no chippings recovered; there were geophysical logs and a cross section of the possible geology of the site.

The pumping test made it possible to locate the geohydrological change point precisely. In this well, the point where the slope change in the characteristic curves fits with the Tuff formation.

The specific capacity in the Basalt aquifer was. 5.1 l/s/m and 0.86 l/s/m in the Tuff aquifer.

The conclusion in this well, was to pump 55.6 l/s/m to 137.0 m depth, instead of a bigger flow with a greater drawdown.

Because the especific capacity in the Tuff was little in comparison with the Basalt it was convenient to drill more wells farther from the regional fault and the contact Tuff-Basalt.

Another well, Reclusorio Sur No. 1,was drilled farther from the fault into the Basalt and it did not show any slope change in the characteristic curves, the yield was greater that the one from example Reclusorio Sur No. 2, the specific capacity was 43.3 l/s.

With this correlation and with all the data obtained, the conclusion was to drill more wells inside the Graven into the Basalt.

4 APPLICATION OF THE METHOD TO REAL CASES

Following are real cases presenting the application of the method exemplified with curves obtained from data taken during the pumping test. These curves are accurate and more representative of each well and through its interpretation, it is possible to obtain a better scope of the aquifers penetrated by the well.

In the Island of Cancún, Quintana Roo, a pumping test was made to get data for the design of a recharge well. The well was drilled at 40.0 m depth in carbonate rock. Several data was taken and plotted in the field during the test until the curves were well defined, like it is showed.

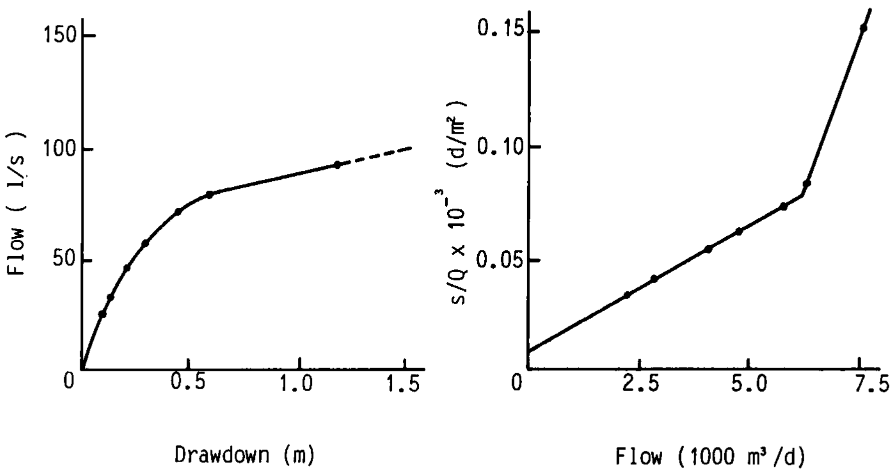

Fig. 5. Diagram showing the real characteristic curves of Cancún well (Apr. 1987)

In the plot, the slopes and the slope change point have been well defined and through its interpretation, it was possible to obtain: its characteristic curves, the position of the first aquifer base 0.53 m below the static level, its total flow (65.0 l/s), the flow from the deeper aquifer when drawdown is 0.53 m (11.2 l/s) and when it is 1.16 m (24.1 l/s), and the total flow (89.1 l/s) when s = 1.16 m.

In this case, it was decided to use only the specific capacity of the first aquifer for recharge purposes.

5 ECONOMIC ANALYSIS

Once the aquifers have been established as well as its position and flow, it is possible to get more economic solutions in the use of ground water.

When each aquifer is known by its precise site of the base and geology, a better well design may be made and the screen can be appropiately located in the right place, to get the maximum flow when drawdown is at its base, with the dynamic level at this place and not at a biger depth, as it usually happens when the aquifer position is unknown.

The well depth can be the adecuate in order to drill through the aquifers and have the necessary head on the pump when drawdown, to obtain the projected flow.

The above said is exemplified with a real case of a well, drilled into the alluvium in the Rio Presidio Delta, contained and limited by igneous rock.

With the data of this well, a more economical design of other wells should be made for municipal purposes in the same aquifers.

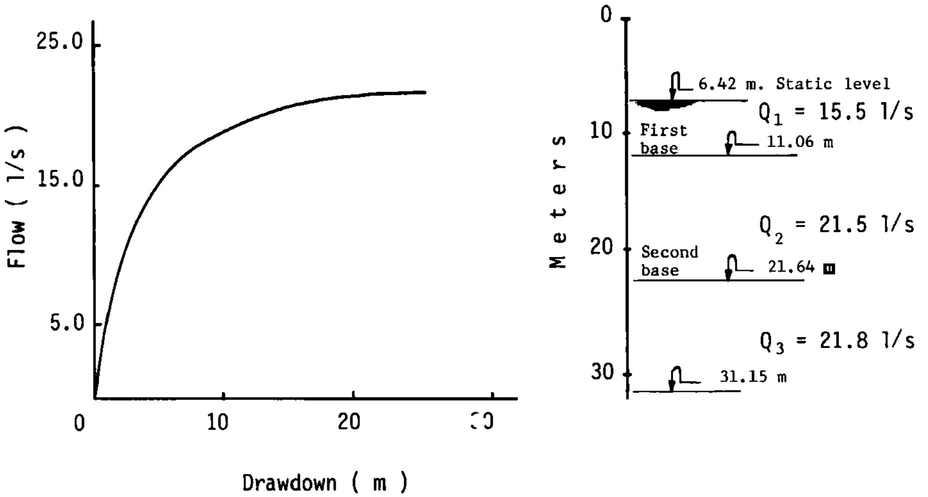

Fig. 6. Diagrams showing the curve s-Q (a) and the position of the first and second aquifers base (b)

Fig. 6.b shows the data obtained from the analysis of the well test, the base of each aquifer and the position of the alluvium base.

The flow (15.5 l/s) when the drawdown is at 11.06 m depth, the first aquifer base, when it is at 21.64 m (21.5 l/s) and the total flow (21.8 l/s) when the drawdown is at the basement.

This well was drilled through the alluvium, 10.0 meters into the igneous rock, at 42.0 m depth. The aquifers practically end at 21.64 m where the base of the second aquifer is, so the well or new wells should be drilled only to the igneous rock contact at 32.0 m and they will deliver 21.0 l/s with a drawdown of 21.64 m (96% of the total flow) The cost of each well is:

	Depth (m)	Cost (US)	Cost %
Rio Presidio 1	42.0	16,080	142.0
Rio Presidio 2	32.0	11,330	100.0

There will be 42% savings in the construction cost of each well and 40% per l/s effective savings. The construction program will be reduced in time.

The well 7 Av, campo A-B, in San Pedro Sula Honduras, C. A., is another example, of considerable savings during its performance.

Through the interpretation of the curves, using the separation of slopes method, it was possible to know the following:

The base of the first aquifer is at 34.07 m depth and the flow 51.4 l/s, when the dynamic level was at that depth.

The base of the second aquifer is at 50.77 m and the flow 66.6 l/s, when the dynamic level was at that depth.

During the water supply performance, it is necessary to consider pumping 10.0 m higher than the surface level, plus the additional head losses in the column and pipelines (8" Ø), the static level was at 17.0 m.

The necessary energy in each case will be:

		Drawdown	Total head	Energy		Anual Cost
l/s	%	(m)	(m)	kW	%	$ (US)
51.4	100	34.07	57.1	76	100	26,630
66.6	130	50.77	80.5	127	167	44,500

With a price of $ 4.00 (US)/100 kWh, it will represent $ 7,600 (US) and 29% cost savings per l/s in one year performance, pumping 51.4 l/s with 34.07 m drawdown, instead of 66.6 l/s.

If it is necessary to get all the water from the aquifers, with the knowledge of the depth and flow from each aquifer, a more economic possibility may be studied; the ground water may be pumped from each aquifer, using a well for each one; this way there is no possibility of additional piezometric losses when the water flows from the first aquifer when pumping all the aquifers, with the dynamic level down the first aquifer base.

Using the same example, of well 7 Av, the construction cost will be:

Well	Depth (m)	Flow (l/s)	Cost $ (US)	Value %	Flow %
7 Av (1)	100	70.0	68,000	227.0	136.0
7 Av (2)	60	66.6	48,800	136.0	130.0
7 Av (3)	44	51.4	29,920	100.0	100.0

The well 7 Av (1) was drilled at 100 m depth, but it was necessary to drill only to 60 m to get 66.6 l/s and 44 m for 51.4 l/s flow representing 60% of - the construction cost savings in new wells.

Instead of drilling one well at 60.0 m depth, with 14" casing, there may be two wells, one 44 m with 12" and other 60 m deep with 8" casing and screen, so the construction costs will be:

Well	Depth (m)	Cost $ (US)
7 Av 2	60	40,800
7 Av (12")	44	29,920
7 Av (8")	60	28,560

Both, 7 Av (12") and 7 Av (8") wells will cost $ 58,480 (US), $ 17,680 (US) higher than the price of 7 Av 2 well.

The necessary energy in each case will be:

Well	Flow l/s	Flow (%)	Drawdown (m)	Total head (m)	Energy kW	Energy %
7 Av 2	66.6	130	50.77	80.5	127	167
7 Av (12")	51.4	100	34.07	57.1	76	100
7 Av (8")	15.2	30	50.77	80.5	29	38

The total energy pumping the wells 7 Av (12") and 7 Av (8") instead of the well 7 Av 2, will be 105 kW (22 kW less energy).

With a price of $ 4.00 (US)/100 kWh, it will represent annual savings of $ 7,709 (US) during the performance of the wells. In 2.3 years, the additional costs of the two wells will be paid for, and there will be performance savings from there on.

6 REFERENCES

Custodio, E. and Llamas, M.R. 1976.
Eficiencia de un pozo y curvas características, Análisis del descenso en los pozos, Ediciones Omega, S.A., 15.3:826