DETERMINING WELL EFFICIENCY BY MULTIPLE STEP-DRAWDOWN TESTS

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RÉSUMÉ

La qualité d'un puits peut être évaluée par analyse graphique de l'équation approchée :

$$S_w = BQ + CQ^2$$

dans laquelle :
— S_w est le rabattement total dans le puits pour le débit Q.
— BQ représente le rabattement provoqué par la perte de charge de la formation aquifère.
— CQ^2 représente le rabattement provoqué par la perte de charche propre au puits.
Le rendement du puits peut être défini par la valeur du rapport BQ/S_w.

Le rendement d'un puits dépend largement de l'importance de la perte de charge propre au puits et par conséquent diminue très rapidement avec l'augmentation du débit. Le rendement d'un puits dans une formation aquifère ayant un haut coefficient de perméabilité est affecté par la perte de charge propre au puits à un plus grand degré que le rendement d'un puits dans une formation de faible perméabilité, et est moins affecté par une pénétration partielle dans des aquifères de grand coefficient de perméabilité.

Pour un puits foré à un emplacement déterminé, on peut atteindre le rendement optimum en crépinant sur une épaisseur d'aquifère aussi grande que possible, avec une surface de perforation aussi grande que le permet la granulométrie naturelle de la formation. Cette surface perforée peut être augmentée en utilisant une crépine plus longue, une crépine de plus grand diamètre, ou une crépine ayant un coefficient de perforation plus élevé par rapport à la surface totale de la crépine. Le rendement maximum ne peut être obtenu que si le développement du puit sa été effectué à un degré suffisant pour enlever les matériaux fins situés contre la face externe du puits et dans les formations adjacentes de manière à créer un filtre stable de gravier naturel ayant pour effet une perméabilité plus grande au voisinage du puits. De cette façon non seulement on diminue la vitesse d'arrivée de l'eau mais on empêche aussi l'entrée de matériaux fins dans le puits et le pompage de sable.

L'efficacité du développement peut être appréciée en comparant la perte de charge propre au puits à la perte de charge de la formation aquifère. Le degré de détérioration d'un vieux puits peut être apprécié par comparaison des valeurs de la perte de charge propre au puits, ou de préférence en comparant les résultats de tests effectués au moment de l'achèvement du puits et après que le puits a été en service pendant une certaine durée de temps.

En accumulant et en interprétant les données empiriques obtenues par le procédé des essais de rabattements on devrait pouvoir apporter une contribution importante à la compréhension des caractéristiques de qualité des puits, la part étant faite du comportement variable des aquifères. L'appréciation des facteurs affectant le rendement des puits est le seul moyen d'arriver à des économies sur les coûts de construction et les frais d'exploitation.

ABSTRACT

Graphical solution of multiple step-drawdown test data permits an approximate determination of the two components of drawdown in a pumped well; that due to formation loss, and that due to well loss. This in turn permits an engineering estimate of the "efficiency" of a well.

An understanding of the various factors affecting well efficiency is important because savings in well design and construction and operation can be made by increasing the efficiency of a well and thus preventing much needless waste of materials and pumping energy.

Data collected during step-drawdown tests of 32 screened wells tapping alluvial sediments in northern and western Iran are presented, together with data from 16 tests on 11 perforated and 3 screened wells in southeastern Washington State.

1. Introduction

The purpose of ground-water development is to bring about an additional supply of water, whether it be used for agricultural, domestic, industrial, or other purposes. The construction of a water well provides the means for tapping and exploiting the underground reservoir, and the real cost of this well is determined more often than not by pump repairs, maintenance, and pumping costs than by the original investment in materials, drilling, and development.

The step-drawdown test provides a means whereby at any time during the life of a well it should be possible to determine with considerable accuracy the two components of its specific drawdown (i.e. those attributable to formation loss and to well loss). This determination in turn should facilitate an appreciation of the "efficiency" of a well and any change in such due to encrustation or clogging of the screen or sand packing of the gravel wall. Through the accumulation of data in a given area, as wells are developed and placed in operation, such tests should greatly assist in the selection of screen type, length, slot opening, and gravel size — and even the determination of whether or not an artificial gravel pack is required. Much guess work can thus be eliminated and the efficiency of wells increased with the consequent prevention of much needless waste of pumping energy and the proper selection of pump and motor to give optimum performance throughout the life of the well.

This paper describes a procedure for evaluating the data of a multiple step-drawdown test. Because the amassing of empirical values of well-loss constants together with pertinent data on the design and construction of wells may assist others in further appraising the various factors defining the performance of a well, information is presented in tabular form for 47 tests. These data permit comparisons to be made between wells in alluvial aquifers of different permeabilities, between developed and undeveloped wells, and between screened and perforated wells. The data also permit a relative evaluation of the efficiency of production wells at required pumping rates and suggest a method for appraising the effectiveness of well development.

2. Summary of Geohydrologic conditions

The step-drawdown tests reported herein were conducted on wells tapping fluviatile deposits of Quaternary Age. Of the 47 tests, 31 were run on production wells located in northern and western Iran (see Figure 1). The alluvial sediments were penetrated to depths ranging from 50 feet to 330 feet; the material ranging in size from clay to boulders. The groundwater occurred under both water-table and artesian conditions depending on local geologic controls.

Sixteen tests were run on observation wells located in the southeastern part of the State of Washington. Here the saturated sediments consisted of glaciofluviatile sands and gravels ranging from 30-50 feet in thickness, and of 15-220 feet of lacustrine deposits ranging in size from clay through cobbles with the finer fractions predominating. In general, the groundwater occurred under water-table conditions although locally artesian conditions existed due to the existence of cemented deposits or thick clay lenses.

Semi-arid climatic conditions prevailed both in Iran and in southeastern Washington State.

3. Previous Work

The step-drawdown technique has received relatively little professional recognition and only a few papers have been widely published. Hence a brief summary of pertinent papers is justified and appropriate.

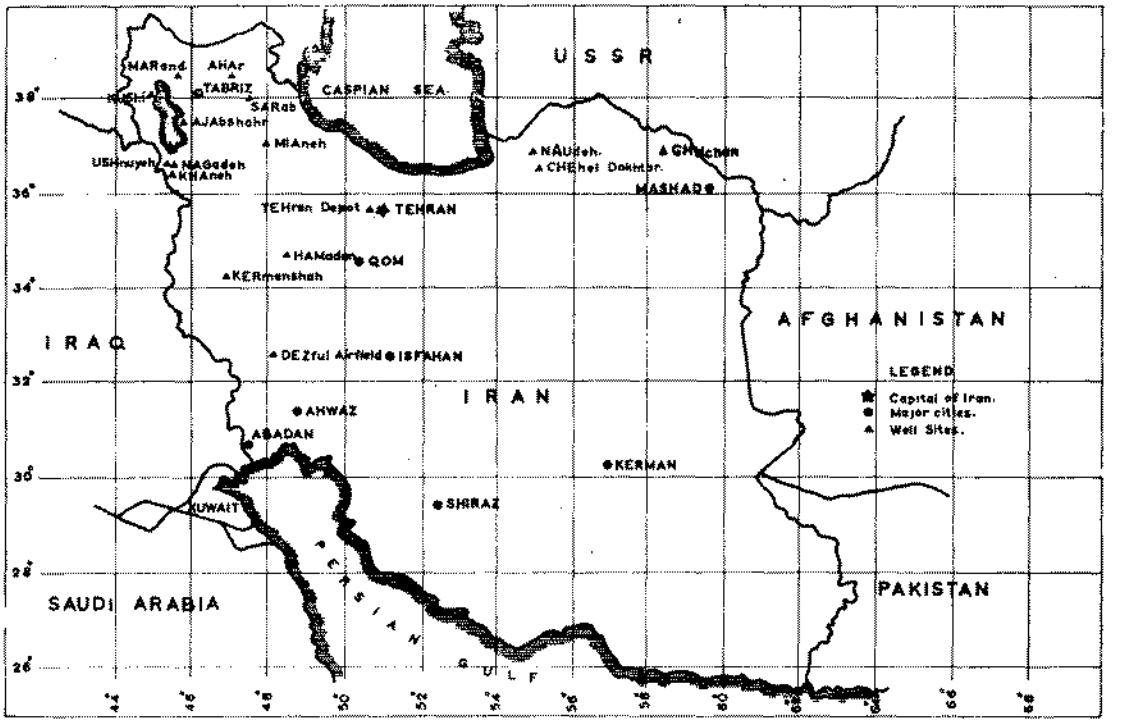


Fig. 1 — Map of Iran showing locations of well sites.

According to Jacob's 1946 paper, ([1]) the drawdown in a well that is pumped has two components : the first, arising from the "resistance" of the waterbearing formation (formation loss), is proportional to the discharge ; and the second, termed "well loss" and representing the loss of head that accompanies the flow through the screen or perforations and upward inside the casing to the pump intake, is proportional approximately to the square of the discharge. The resistance of an extensive formation increases with time as the ever-widening area of influence of the well expands. Consequently, the specific capacity of the well, which is discharge per unit drawdown, decreases both with time and with discharge.

In 1953 Rorabaugh ([2]) presented the empirical equation $s_w = BQ + CQ^n$ which defined the total drawdown of a pumped well more closely than the equation $s_w = BQ + CQ^2$ proposed by Jacob ; in each case s_w is the drawdown in the pumped well ; B, the formation constant ; C, the "well loss" constant ; and Q, the discharge.

Bruin and Hudson ([3]) in 1955 opined that Rorabaugh presented the more exact method despite the complication of having to evaluate the three terms B, C, and n. They concluded that for practical engineering application, Jacob's equation was the more useful.

4. Example of Analysis

The example chosen to illustrate the approximate analysis of the stepdrawdown test is a pumping test of a production well located at Naudeh, in northern Iran.

Well NAU-3 was pumped at five rates, 100, 200, 400, 500, and 550 gallons per minute (gpm), and each rate was maintained for two hours. The first step of the ana-

lysis ([3]) was to plot the test data on semi-logarithmic graph paper with the drawdown on the arithmetic axis and the elapsed time after pumping began on the logarithmic axis. See Figure 2. It can be noted that the recession curve at 100 gpm had a "slope" of 0.30 feet per log cycle. The slopes at higher rates were estimated as shown on the figure. These slopes were used to extrapolate each step of the test beyond the period of pumping of each step as shown by the dashed lines in Figure 2. These extrapolations were used to obtain the incremental drawdown caused by a change in pumping rate. The two-hour incremental drawdowns for stated rates are shown in tabular form on Figure 2 as are

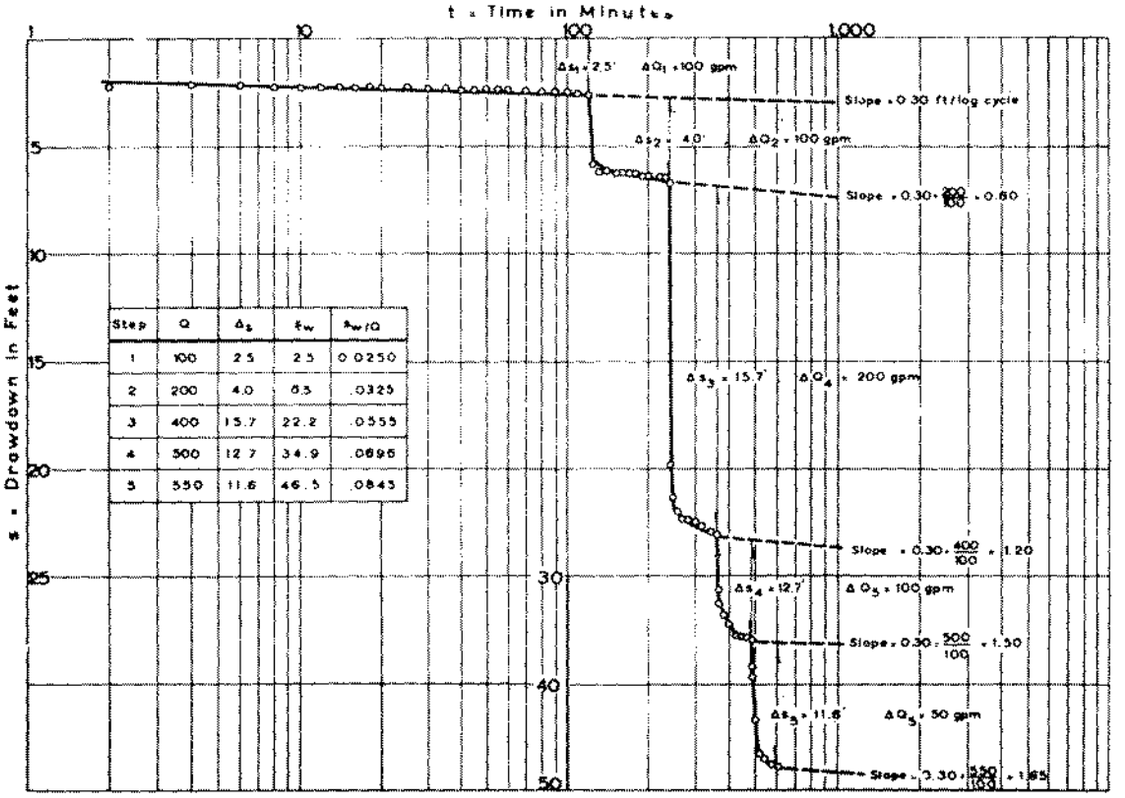


Fig. 2 — Well Nau - 3, Step — drawdown test curves.

the values of s_w and s_w/Q. The values of s_w and s_w/Q were plotted on arithmetic coordinate paper as shown in Figure 3 and the straight-line approximation through the points was extended back to 0 gpm. The equation of the form $s_w/Q = B + CQ$ fits this line. The value of B is the value of the intercept of the line with the s_w/Q axis and the value of C is the slope of the line. The equation $s_w/Q = 0.012 + 0.00012Q$ was determined from which $s_w = 0.012Q + 0.00012Q^2$ which is the form of Jacob's equation ([1]) and is the approximate equation for the drawdown in Well NAU-3 for a pumping period of two hours. Figure 4 shows a plot of this equation and the observed drawdowns for the five pumping rates.

Well NAU-3 was designed to produce 100 gpm for 16 hours daily. The observed drawdown after two hours of pumping at 100 gpm was 2.55 feet, whereas the theoretical drawdown is calculated to be 2.40 feet; half the drawdown being attributable to formation loss and the other half due to well loss. Figure 4 also shows the draw-

down-yield curve for Well NAU-2 which is located 480 feet northeast of NAU-3 and for which the drawdown equation was estimated to be $s_w = 0.08Q + 0.00074Q^2$. A comparison of the two curves readily shows that Well NAU-3 is the superior of the two.

Drawdown equations for longer pumping periods may be determined in the same way as discussed above. The values of C should not be affected by time, but B should be expected to vary with the logarithm of time.

5. Tabulation of data

Well data and the results of 47 pumping tests are given in Table 1. The table is divided into four sections : the first lists wells which tap aquifers with a range in field permeability from 85-700 gpd/ft^2 ; the second, wells tapping aquifers with a permeability range 840-1,700 gpd/ft^2 ; the third, permeability range 2,000-8,700 gpd/ft^2 ; and the fourth, permeability ranging above 10,000 gpd/ft^2.

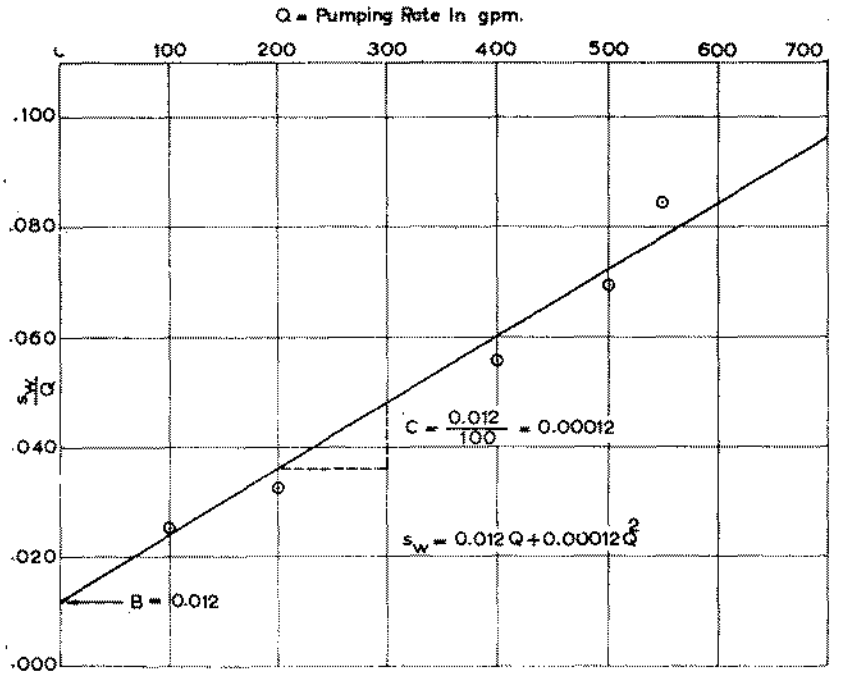


Fig. 3 — Plot of s_w/Q *vs.* Q to solve for values of B. and C.

Wells with a 3-letter prefix are located in Iran (see Fig. 1), and those without the prefix are located in a 500 square mile area in southeastern Washington State. Eleven wells in Washington State are 8-inch diameter cased wells with perforations cut with a Mills knife perforator ; three are 12-inch screened wells. All the 31 wells in Iran were completed with 12-inch Johnson stainless steel well screens. The wells in Washington State are observation and monitoring wells and were not designed for production purposes. The wells in Iran were constructed as domestic water-supply wells, and thus screens were designed to permit entrance of the 50-70 per cent finer by weight sample of the water-bearing formation. The lenght of the screens was usually governed by the Client for economic reasons after due consideration was given to site requirements and aquifer thickness.

None of the perforated wells were ever developed prior to testing. During pumping tests (with a 6-inch Layne-Bowler 4-stage submersible pump) considerable quantities of fine to coarse sand were pumped as the formation flowed through the large perforations. The pumping life of the test pump was less than 500 hours, and twice the impellers had to be replaced because of cavitation due to sand pumping. The three screened wells in Washington State were developed with a surge block for 1-1½ days only.

In Iran all the wells were developed until sand-free water was produced on test for at least six hours. The wells were developed for short periods using a surge block, then for a greater period by surging and pumping with compressed air using either a 315 cfm or a 600 cfm compressor, and finally for a short period with a test pump (10-inch Worthington 6-stage turbine) that overpumped and backwashed the well.

The tabulation of pumping test results includes the results of step-drawdown tests analyzed as in the example above, and the results of drawdown-recovery tests analyzed by one or more of the graphical methods in common use ([4, 5]). The data thus presented give values of the formation and well-loss constants of a pumped well and values of transmissibility and permeability of the tapped aquifer.

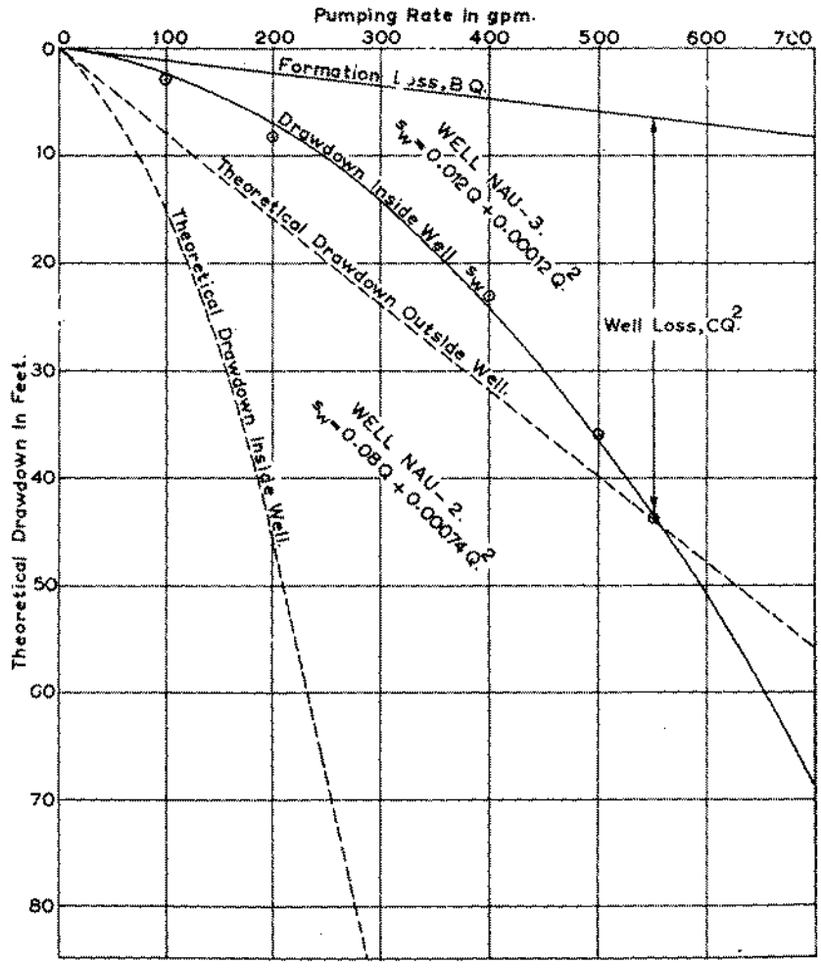


Fig. 4 — Drawdown-Yield Curves.

6. Efficiency of wells

Rorabaugh ([2]) defined "well efficiency" as the ratio of (a) the theoretical drawdown computed by assuming that no turbulence is present (or essentially, BQ) to (b) the drawdown in the well, s_w. Walton ([6]) defines the efficiency of a well as the ratio of the theoretical specific capacity to the actual specific capacity of the well. Factors influencing the actual specific capacity include the hydraulic properties of the aquifer (coefficients of transmissibility and storage), geohydrologic boundaries of the aquifer, the partial or total penetration of the aquifer, the effective open area of the well screen or perforated casing, duration of pumping, and pumping rate. Rorabaugh ([2]) recognized that factors such as well development, not included in theoretical analyses, are important and affect the predictions as to total drawdown and consequent estimates of well efficiency. Thus, the efficiency of a well depends also upon construction features and development of the well — two factors extremely difficult to evaluate.

In Figures 5 through 8 are shown "well-efficiency" curves for the tested wells at various theoretical pumping rates, or plots of BQ/s_w vs. Q. Each figure includes curves for those wells ending in formations with permeabilities in the same order of magnitude as distinguished in Table 1. These curves immediately show a drop in efficiency when discharge is increased. It follows also that a high value for the well-loss constant, C, and a low pumping rate can result in a low well loss (CQ^2) and a high efficiency. Conversely, a low C and a high Q can result in a higher well loss and a lower efficiency. Furthermore, it will be noted that the efficiency of a well in an aquifer having a high transmissibility is affected by well loss to a greater degree than the efficiency of a well in an aquifer having a low transmissibility inasmuch as formation loss, or BQ, varies inversely with T. If T is low, BQ theoretically is great and well loss is a small proportion of the total drawdown in a well; and if T is high, BQ is small and well loss is a large proportion of the actual drawdown.

6.1. *Well Construction Factor*

It is apparent after a brief glance at Figures 5-8 that some of the perforated wells are more "efficient" than some of the screened wells and some are less efficient. Because each well was designed, contructed, and completed for specific reasons in different areas under varying conditions, no reasonable direct comparison is possible. It is reasonable to state, however, *all other factors being equal*, a screened well will be more efficient than a perforated well due to a greater effective open area permitting easier ingress and less resistance to flow.

Unfortunately, only one example is available for fair comparison : Wells 55-51 and 55-52 which are located 25 feet apart and both of which are open to and penetrate fully the 45 feet of aquifer. Perforated Well 55-51 has an estimated total of 1,620 square inches of effective open area whereas screened Well 55-52 has 7,640 square inches (Table 1). Figure 8 clearly demonstrates that the screened well has the greater efficiency over the indicated range of pumping rates.

Two examples are available to show that increasing the amount of open area *of a given well* will increase the efficiency. Well S8-19 was completed in August 1950 and the lower 15 feet of casing was perforated 4 perforations per round and 1 round per foot ([7]). The well-loss constant determined in June 1958 was of a value $C = 0.0022$. Immediately after this test the well was gun perforated over an 8-foot section, 4 perforations per round and 4 rounds per foot. A subsequent test gave $C = 0.000062$ (Table 1). Figure 5 shows clearly the great increase in efficiency.

Well 26-15 was first tested in July 1958 to give $C = 0.000090$ and then reperforated using a shaped-charged gun perforator ([7]) and retested to give $C = 0.000012$; Figure 6 shows the increased efficiency obtained after reperforation.

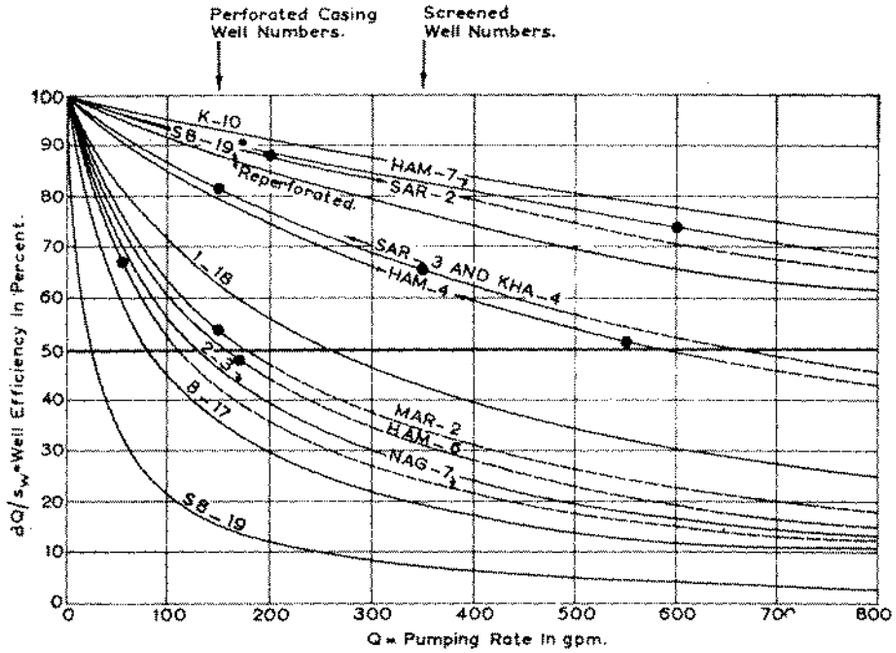


Fig. 5 — Well efficiency curves, permeability 85-700 gpd/ft².

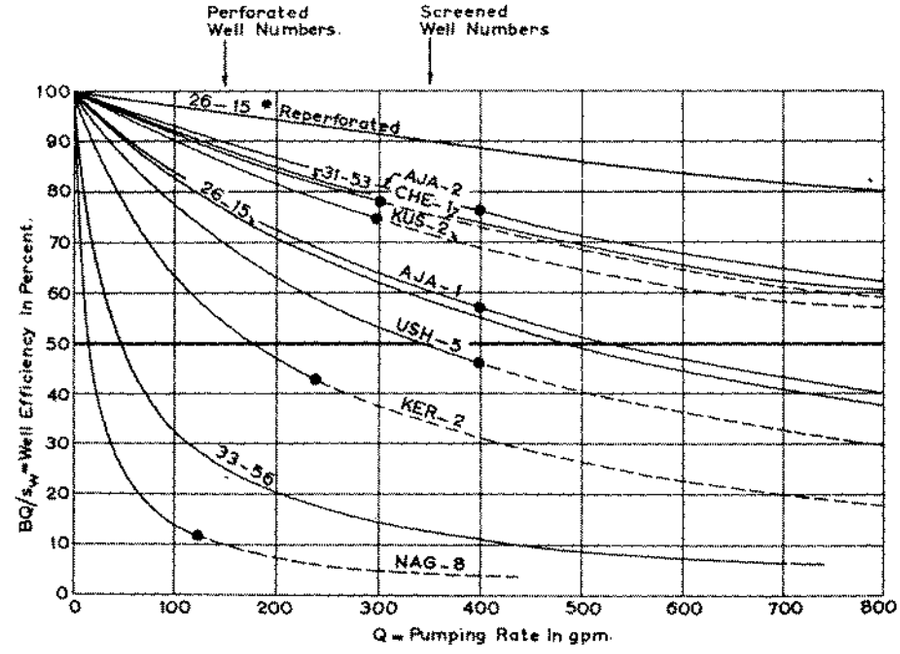


Fig. 6 — Well efficiency curves, permeabillity 840-1,700 gpd/ft².

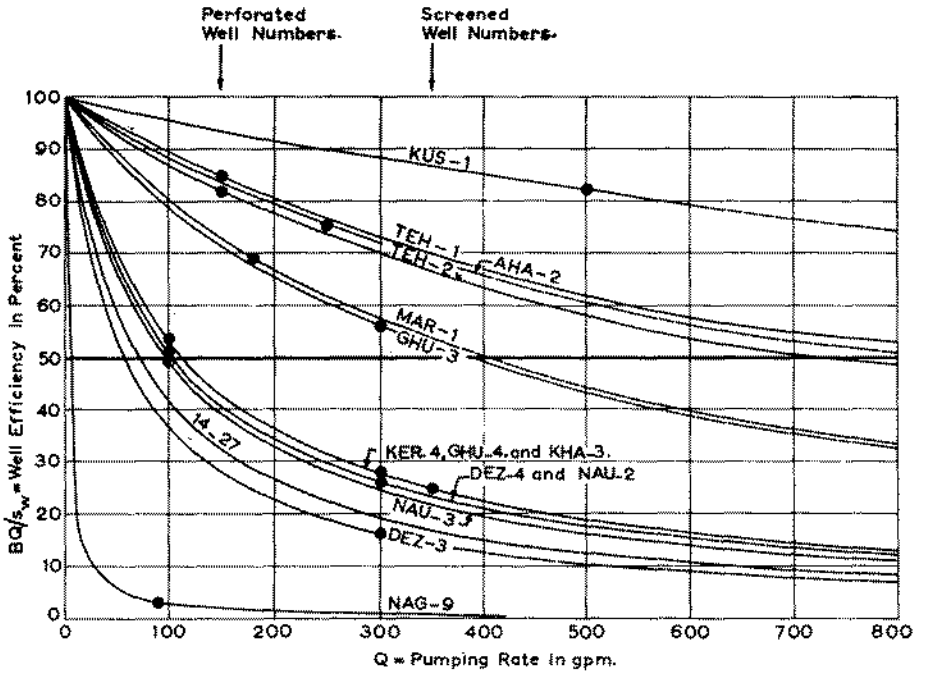


Fig. 7 — Well efficiency curves, permeability 2,000-8,700 gpd/ft^2.

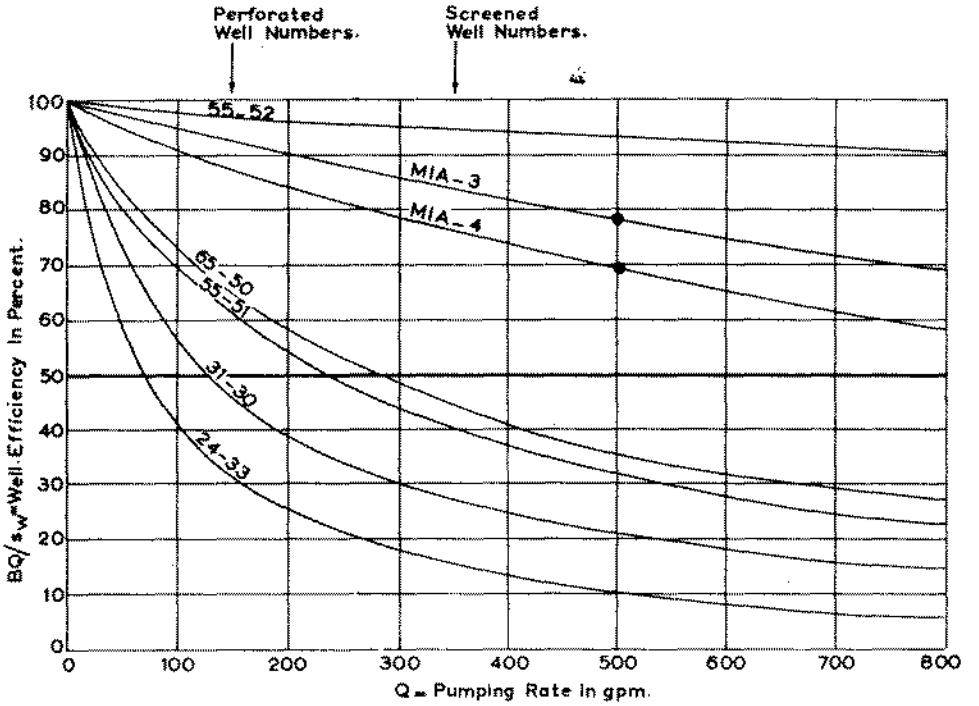


Fig. 8 — Well efficiency curves, permeability > 10,000 gpd/ft^2.

Wells DEZ-3 and DEZ-4 are offered as an example that by increasing the length of screen (and the open area) in a given aquifer, the well-loss constant will be decreased with an accompanying increase in efficiency. Thus, the 15 feet of No. 100 slot screen in DEZ-3 contributed to a well-loss constant value of $C = 0.00017$, and the 20 feet of No. 100 slot screen in DEZ-4 contributed to a lesser constant of $C = 0.00009$. Figures 7 illustrates the difference in efficiency between the two wells.

The efficiency and the specific capacity of a well may also be increased by increasing the radius of the well and by increasing the per cent penetration of the total saturated thickness of the aquifer. As a general rule it has been found that the specific capacity is not greatly increased by increasing the radius of a well because discharge varies as a logarithm of well radius. An increase of about 5 per cent may be expected by increasing the effective radius from 12 to 18 inches, and to only 10 per cent by going to a 30-inchradius. Rorabaugh ([2]), however, demonstrated that the radius becomes more and more important as discharge increases. Thus, the difference of 5 per cent given above increases to more than 20 per cent when discharge rates increased from about 225 gpm to 1,800 gpm ([2]). In practice, factors such as depth, pump characteristics, layout, etc., affect the question of well size more than capacity, and generally speaking, it costs less money to put down and equip two medium-sized wells (8-16 inches) than one large well (24-36 inches and larger); and the combined yield of the smaller wells is almost always greater than the yield of the larger well.

Jacob ([1]) did not mention partial penetration, but it is obvious that the efficiency of a well depends on the degree it penetrates an aquifer. The partial penetration increases the drawdown in a well because some of the water that enters the well must percolate upward from the materials beneath the well or downward from the materials above the screen or the perforations. Water percolating vertically to a well moves a greater distance than if it had percolated horizontally and across planes of greater resistance (i.e. horizontal permeability is greater than vertical permeability), and thus more drawdown occurs than would occur had the well completely penetrated the aquifer. For partially penetrating wells, Rorabaugh ([2]) states that step-drawdown test results are satisfactory for constant-time problems, and can be used for variable-time problems under certain conditions. Walton ([6]) shows that the efficiency of a well varies directly with the amount of penetration and that the efficiency of a well is least affected by partial penetration of aquifers having a high transmissibility.

6.2. *Well Development Factor*

The well-loss constant, C, is empirically derived and depends on the effective open area of the well screen or perforated casing as indicated above, and on the condition of the well screen or face and the effectiveness of development of the well. By "development" is meant the removal of the silt and fine sand around a well screen so as to produce a natural filter of coarser and more uniform sand or gravel which in turn provides the greatest amount of open space for water to flow through. The larger these openings, the less the velocity; the less velocity, the less friction; the less friction, the greater the efficiency. The effectiveness of development generally can be appraised from the results of a step-drawdown test.

Table I lists numerical values for the well-loss constant, C, for the 31 production wells, and these range from about 10^{-3} to 10^{-6} (ft/gpm^2; converted to Jacob's notation sec^2/ft^5 by multiplying by the conversion factor 2×10^5). Shown also is the pumping rate for which the well was designed, and the corresponding efficiency (BQ/s_w) at this required rate. These values are plotted on Figures 5-8 as points on the curves and show at a glance the relationship to the 50 per cent efficiency line — that point at which the total drawdown in the well is divided evenly between formation loss and well loss.

As stated previously, the production wells in Iran were subjected to lengthy

development work which continued until sand-free water was produced. It is thus assumed that the wells, as designed, were properly developed. Unfortunately, the advantages of this development may in part be offset by poor design or improper choice of screen. Wells with "low" efficiency may fall in this category, and for the purpose of this paper, wells with a pumping efficiency less than 50 per cent are thus categorized.

There is a tendency to ascribe the low efficiency of certain wells to various selective "causes" such as inadequate screen length, too-small screen openings, partial penetration and insufficient development. Realizing that the step-drawdown tests are an after-the-fact procedure and that each results in data that are applicable only to the particular well, it appears that to be prudent it is best to avoid suggesting specific reasons to explain a given performance.

The last column of Table 1 gives the ratio of well loss to formation loss times 100; the resulting figure for each supply well suggesting an empirical grading of the effectiveness of well development. Thus, values of C/B x 100 less than 0.1 suggest "very effective" development; values of 0.1-0.5 indicate "effective" development; values 0.5-1.0 indicate "fairly effective" development; and values greater than 1.0 indicate "poorly effective" development. (Or perhaps the effectiveness of development should be graded "excellent", "good", "fair", and "poor".) The fact that certain wells of "low" efficiency as shown in Figures 5-8 have development values in the "effective" range 0.1-0.5 presents no ambiguity if it is remembered that other "causes" are contributing to the drawdown in the wells.

Walton [6] suggests that the degree of well deterioration subsequent to use be appraised using values of the well-loss constant, C, as criteria. Thus, the value of C of a properly developed stable well is generally less than 5×10^{-6} ft/gpm^2;(or 1 sec^2/ft^5); values of C between 1 and 10 sec^2/ft^5 indicate mild deterioration as screen slots become clogged after heavy pumping; and when C is greater than 10 sec^2/ft^5 clogging is severe. Consequently, if step-tests are run on production wells after a lapse of time, it can be determined whether or not the well has deteriorated and if rehabilitation is required.

7. Summary of findings

The performance of a well may be evaluated through graphical analysis of the approximate equation $s_w = BQ + CQ^2$ where s_w is the total drawdown in the well, BQ represents the drawdown due to formation loss, and CQ^2 represents the drawdown due to well loss. The efficiency of the well may then be defined as BQ/s_w.

The efficiency of a well is governed largely by the magnitude of well loss and thus falls off rapidly as discharge is increased. The efficiency of a well in an aquifer having a high transmissibility is affected by well loss to a greater degree than the efficiency of a well in an aquifer having a low transmissibility, and it is least affected by partial penetration of aquifers having a large transmissibility.

In a given location, a new well may be brought to optimum efficiency by screening as much of the thickness of the aquifer as is practical with as large an area of openings as is consistent with the natural gradation of the formation. This slot area may be increased by using a longer screen, a greater diameter screen, or a screen having a greater per cent of open area with respect to the total surface area of the screen cylinder. Maximum efficiency can then be obtained only if development work is sufficient to remove fine materials from the well face and adjacent formation to produce a stabilized, graded, natural gravel pack which results in a zone of greater permeability about the well. This situation not only reduces the entrance velocity of water but also prevents the migration of fine materials into the well and precludes sand pumping.

The effectiveness of well development may be appraised by comparing the well loss to the formation loss. The degree of deterioration of an old well may be appraised by comparison of well-loss values, or preferably, by comparing steptest results ob-

tained when the well was first completed and then after the well has been producing for a period of time.

Through the accumulation and presentation of empirical data, the stepdrawdown test procedure should aid greatly in understanding the performance characteristics of wells — due consideration being given to the transient behavior of the aquifer. An appreciation of the factors affecting well efficiency can thus lead to savings in construction costs and operating costs.

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TABLE I

TABLE 1

Well data and step drawdown test data

Well Number	Effective open area			Development Work	Pumping test results				Well efficiency		
	Screen (S) or Perforated Casing (P)				$s_w = BQ + CQ^2$		Transmissability	Permeability	Required Rate	Pumping efficiency	Development Factor
	Length (Ft)	Slot Size or No of Perforations	Area (Sq. In)	(Hours)	B	C	(GPD/Ft)	(GPD/Ft^2)	(GPM)	(BQ/s_w)	$C/B \times 100$
K - 10	17	(P) 68	204	0	0.0544	0.000026	34,000	400	—	—	—
S8-19	15	(P) 60	180	0	0.060	0.0022	80,000	500	—	—	—
S8-19	15	(P) 128	308	0	0.073	0.000062	80,000	500	—	—	—
1-18	100	(P) 228	428	0	0.0122	0.00048	75,000	450	—	—	—
2-3	15	(P) 60	180	0	0.023	0.00018	92,000	575	—	—	—
8-17	15	(P) 60	180	0	0.0125	0.00015	78,000	490	—	—	—
Ham-7	30	(S) No. 80	5,220	78	0.093	0.000055	8,100	510	600	74%	0.059
Sar-2	30	(S) Nos. 60,40	4,700	81	0.248	0.00016	7,400	85	200	89	.065
Sar-3	30	(S) Nos. 60,40	4,700	99	0.380	0.00057	9,400	85	150	82	.15
Kha-4	30	(S) No. 60	5,100	80	0.300	0.00045	14,800	500	350	66	.15
Ham-4	40	(S) Nos. 80, 20, 10	4,670	84	0.130	0.00022	5,600	430	550	53	.17
Mar-2	10	(S) No. 60	1,700	28	0.137	0.00077	45,000	700	150	54	.56
Ham-6	30	(S) No. 80	5,220	70	0.420	0.0027	3,000	130	170	48	.64
Nag-7	10	(S) No. 60	1,700	86	0.185	0.00167	5,800	390	55	67	.90
26-15	90	(P) 190	570	0	0.044	0.000092	67,000	1,500	—	—	—

TABLE 1 (continued)

Well data and step drawdown test data

Well Number	Effective open area			Development Work	Pumping test results				Well efficiency		
	Screen (S) or Perforated Casing (P)				$s_w = BQ + CQ^2$		Transmissability	Permeability	Required Rate	Pumping efficiency	Development Factor
	Length (Ft)	Slit Size or No of Perforations	Area (Sq. In)	(Hours)	B	C	(GPD/Ft)	(GPD/Ft^2)	(GPM)	(BQ/s_w)	$C/B \times 100$
26-15	95	(P) 286	666	0	0.037	0.000012	67,000	1,500	—	—	—
Aja-2	25	(S) No. 80	3,480	89	0.038	0.000030	32,000	840	400	76	.079
31-53	117	(S) No. 35	14,040	24	0.0134	0.000012	108,000	900	—	—	—
Che-1	10	(S) No. 40	1,300	128	0.0205	0.000019	64,000	1,400	300	78	.093
Kus-2	20	(S) No. 60	3,400	52	0.126	0.000140	81,000	950	300	75	.11
Aja-1	20	(S) No. 80	3,480	72	0.018	0.000034	37,000	920	400	57	.19
Ush-5	20	(S) No. 60	3,480	93	0.093	0.000270	204,000	1,400	400	46	.29
Ker-2	50	(S) Nos. 80,60,10	7,260	224	0.100	0.00056	90,000	1,400	240	43	.56
33-56	124	(S) No. 20	9,548	24	0.009	0.00018	155,000	1,700	—	—	—
Nag-8	15	(S) Nos. 60, 40	2,350	134	0.015	0.00090	18,000	1,200	125	12	6.0
14-27	30	(P) 60	180	0	0.00086	0.000012	530,000	2,400	—	—	—
Kus-1	20	(S) No. 80	3,480	73	0.0415	0.000018	142,000	2,400	500	82%	0.43
Teh-1	20	(S) No. 60	3,400	72	0.0052	0.0000062	610,000	4,500	150	85	.12
Aha-2	15	(S) No. 40	1,950	103	0.125	0.00016	88,000	3,000	250	76	.13
Teh-2	20	(S) No.80	3,480	72	0.0056	0.0000080	660,000	4,500	150	82	.14

TABLE 1 (continued)

Teh-2	20	(S) No.80	3,480	72	0.0056	0.0000060	660,000	4,500	130	62	1.4

TABLE 1 (continued)

Well data and step drawdown test data

Well Number	Effective open area			Development Work	Pumping test results						
	Screen (S) or Perforated Casing (P)				$s_w = BQ + CQ^2$		Transmissability	Permeability	Required Rate	Pumping efficiency	Development Factor
	Length (Ft)	Slot Size or No of Perforations	Area (Sq. In)	(Hours)	B	C	(GPD/Ft)	(GPD/Ft^2)	(GPM)	(BQ/s_w)	$C/B \times 100$
Mar-1	10	(S) No. 100	1,800	101	0.071	0.00018	97,000	2,500	180	69	.25
Ghu-3	15	(S) No. 80	2,610	111	0.013	0.000034	130,000	8,700	300	56	.26
Ker-4	30	(S) Nos. 60, 40	4,700	79	0.230	0.0019	95,000	2,000	100	53	.83
Ghu-4	15	(S) Nos. 80, 30	1,970	109	0.0075	0.000065	165,000	4,700	300	28	.86
Kha-3	10	(S) No. 60	1,700	136	0.045	0.00038	63,000	6,300	350	25	.84
Dez-4	20	(S) No. 100	3,600	50	0.0095	0.00009	480,000	3,200	300	26	.95
Nau-2	20	(S) No. 60	3,400	119	0.080	0.00074	163,000	5,400	100	52	.93
Nau-3	20	(S) Nos. 80, 60	3,440	96	0.012	0.00012	145,000	6,600	100	50	1.00
Dez-3	15	(S) No. 100	2,700	100	0.010	0.00017	440,000	3,000	300	16	1.7
Nag-9	10	(S) No. 80	1,740	76	0.010	0.00295	22,000	2,200	95	3	29.5
65-50	55	(P) 220	660	0	0.0115	0.000041	480,000	13,700	—	—	—
55-51	45	(P) 540	1,620	0	0.00082	0.000004	3,000,000	66,700	—	—	—
31-30	67	(P) 134	402	0	0.00115	0.0000085	1,850,000	53,000	—	—	—
24-33	20	(P) 130	390	0	0.00022	0.0000032	2,900,000	64,500	—	—	—
55-52	45	(S) No. 60	7,640	36	0.00122	0.00000017	3,000,000	66,700	—	—	—
Mia-3	20	(S) Nos. 60, 40	3,000	56	0.0074	0.0000042	440,000	20,000	500	78	.057
Mia-4	20	(S) Nos. 80, 40	3,040	101	0.0110	0.000010	660,000	30,000	500	70	.091