Radial Aquifers

The water influx equation for radial aquifers is:

$$W_e = 1.119\ \phi ch\ r_w^{\ 2} \cdot \frac{\Theta}{360} \sum_{0}^{n} \Delta p\ Q_D \qquad (11)$$

where

Θ = angle subtended by the reservoir circumference, degrees.

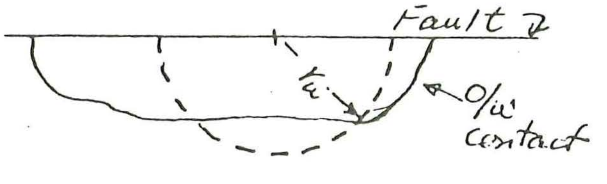
r_w = radius of the aquifer inner boundary, ft.

Q_D = radial efflux functions, dim.

ϕch = aquifer storage number, ft. • psi^{-1}.

Values of Q_D for infinite and limited outer boundaries are available in equation, chart, and tabular form as a function of dimensionless wellbore time, t_{Dw}. Chart 48 in Volume 4 gives Q_D vs. t_{Dw} curves for several limited no-flow aquifers. Tabulated values can be found in Craft and Hawkin's, "Applied Petroleum Reservoir Engineering", pages 212-217.

Quite often a petroleum reservoir lies against or close to a fault so water entry is limited as to direction. This is illustrated by the sketch. This type of situation is handled by defining the "expose angle", Θ, (180^o in the sketch) and computing an r_w consistant with the length of oil-water contact.

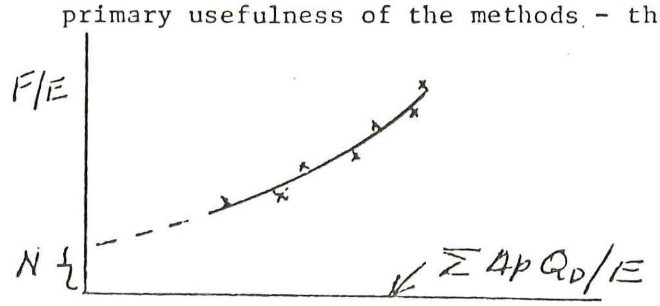


To use the radial influx model in the material balance equation, one plots F/E against $\sum \Delta p\ Q_D/E$. Should a straight line result, the intercept defines the original oil in place, N, and the slope defines the aquifer storage, $1.119\ \phi ch\ r_w^{\ 2}\ \Theta/360$.

General Comments

The several "type" aquifers described above are not the only ones for which solutions are available. They are, however, the most common ones. There is, of course, no assurance that the petroleum reservoir and aquifer will act such that a satisfactory straight line material balance solution is obtained for any of the "type" aquifers' responses. This may be because of poor reservoir data (noteable pressure data) or it may be because the aquifer does not respond in accordance with the "type" solutions.

The fact that a straight line is not achieved does not destroy the primary usefulness of the methods - the determination of original oil in place. The adjacent sketch illustrates the situation where a non-linear plot of F/E vs. $\sum \Delta p\ Q_D/E$ is obtained.



Extrapolation of the best smooth curve to the X=0 axis will yield as good a value of N as possible to get. Note that it would be incorrect procedure to place a straight line through the points and extrapolate it to X=0.

Having developed a satisfactory straight line (or curved line for that matter) material balance relationship, the relationship can be used as a prediction tool for future reservoir behavior by extrapolation. However, note that in making the extrapolation there is an assumption that all reservoir and aquifer responses in the future have been manifested in past behavior. This is not always the situation as, for example, sometimes other petroleum reservoirs in the same aquifer are to be put on production and effect the influx into the original reservoir. A second example is where a reservoir is against a sealing fault and the fault develops "leaks" when the reservoir pressure drops to a low threshhold value.

M.B.Standing

Reservoarteknikk II

Notes On Water Influx Equations in Material Balance Calculations

Many petorleum reservoirs are in contact with aquifers capable of supplying quantities of water into the reservoir as a result of pressure reduction. The actual shape, size, and ability of the aquifer to supply water generally is not known, although one can often make use of regional geology and seismology studies to develop ideas of the general aquifer properties to be expected.

From an analytical point of view, the aquifer is best considered as an independent unit which supplies water to the petroleum reservoir in response to the time variation of pressure at the inner boundary of the aquifer. The inner aquifer boundary is normally taken to be the location of the original hydrocarbon-water contact, although one could select some other location to define as the inner boundary. While water encroachment (influx into the petroleum reservoir, but efflux from the aquifer) usually is calculated using boundary pressures, it often is satisfactory to use average reservoir pressure in the calculations in place of boundary pressure.

Havlena and Odeh demonstrated (see reprint in Section 2) how the material balance equation can be arranged to indicate the type of water influx being experienced by the reservoir. Essentially, their method is to assume a type of aquifer, calculate the response of the aquifer to the observed change in boundary pressure, and test whether the assumed aquifer type is correct by determining whether a straight line is obtained when certain material balance parameters are plotted against each other. As pointed out by Havlena and Odeh, the straight line method of solving the material balance makes use of the dynamic sequence of the plotted points and the shape of the resulting plot to develop the proper aquifer characteristics, and differs from the more common material balance methods that rely mainly on averaging techniques.

From what has been said above, it is apparent that finding the proper aquifer characteristics to fit the observed field pressure behavior takes on a trial and error approach. Consequently, it makes good sense to try the simplest aquifer characteristic first and then, if not successful, proceed to aquifer characteristics requiring more complicated calculations. This is the approach that will be used in presenting the several standard aquifer responses - the easiest to handle first, followed by the more complex.

Small Aquifers

A small, limited aquifer can be represented by the water influx relationship:

$$W_e = C(p_i - p) \qquad (1)$$

where

W_e = cumulative water entering the reservoir, bbl.

$C = V_a \cdot \phi \, (c_w + c_f)$

V_a = aquifer bulk volume, bbl.

ϕ = aquifer porosity, fraction

c_w, c_f = water and rock compressibilities, psi^{-1}

Using this influx relationship yields a material balance equation of

$$\frac{F}{E} = N + C \cdot \frac{(p_i - p)}{E} \qquad (2)$$

where

F = net voidage volume

E = reservoir system expansion

N = original stocktank oil in place

To use this relationship, values of F/E are plotted as a Y coordinate against $(p_i - p)/E$ as an X coordinate. The slope becomes the value of C and the intercept becomes the value of N. Havlena and Odeh point out that the points will plot backward as indicated by their Figure 3B on page 5.

Steady State Aquifers

Experience has shown that the Shilthuis steady state relationship will satisfy more than 50 per cent of material balance calculations. It is the second easiest to apply. If we represent the cumulative amount of water that has crossed the inner boundary at time t, the Shilthuis relationship is expressed by the rate equation:

$$\frac{dW_e}{dt} = k(p_i - p) \qquad (3)$$

where

p_i = initial inner boundary pressure

p = inner boundary pressure at time t

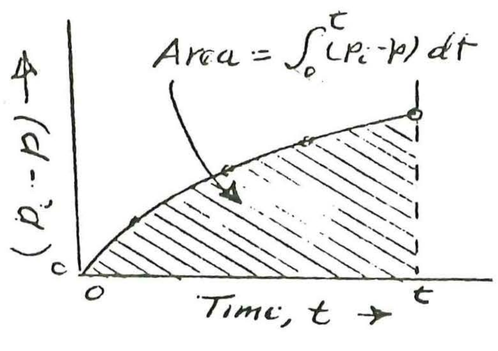
The cumulative influx is then,

$$W_e = k \int_{t=o}^{t} (p_i - p)\, dt \qquad (4)$$

Using this influx relationship in the material balance relationship yields

$$\frac{F}{E} = N + \frac{k \int_o^t (p_i - p)\, dt.}{E} \qquad (5)$$

The straight line plot is prepared by plotting F/E as a Y coordinate against $\int_o^t (p_i - p)\, dt/E$ as an X coordinate. Values of $\int_o^t (p_i - p)\, dt$ at specified time values are obtained by graphical integration of the area under a $(p_i - p)$ vs. t curve as illustrated in the sketch. As in the previous example, value of N and k are determined from the intercept and slope of the resulting straight line.



Infinite Linear Aquifers

An infinite linear aquifer has a response characteristic that is easy to handle. This is because the transient influx function reduces to a simple $\sqrt{t}$ function and does not require estimation of dimensionless time in order to get the influx function. This is explained in the following.

For linear aquifers, the transient response to pressure changes at the inner boundary is represented by:

$$W_e = \frac{bhL\phi c}{5.615} \sum_{o}^{n} \Delta p \cdot Q_D \qquad (6)$$

where

b,h,L = width, thickness, and length of the aquifer, ft.

ϕ = porosity, fraction

c = compressibility, psi^{-1}

Q_D = linear influx function, $f(t_{DL})$

Δp = pressure change, psi

For an infinitely long linear aquifer

$$Q_D = 2\sqrt{\frac{t_{DL}}{\pi}} \qquad (7)$$

where

$$t_{DL} = \frac{6.33(10^{-3})kt}{\phi\mu cL^2} \qquad (8)$$

Solving equations 6, 7, and 8 yields

$$W_e = \left(0.016\sqrt{b^2 \cdot \frac{kh}{\mu} \cdot \phi ch}\right) \cdot \sum_{o}^{n} \Delta p \cdot \sqrt{t} \ . \qquad (9)$$

Using this influx relationship yields a material balance equation of:

$$\frac{F}{E} = N + B \cdot \frac{\sum_{o}^{n} \Delta p \sqrt{t}}{E} \qquad (10)$$

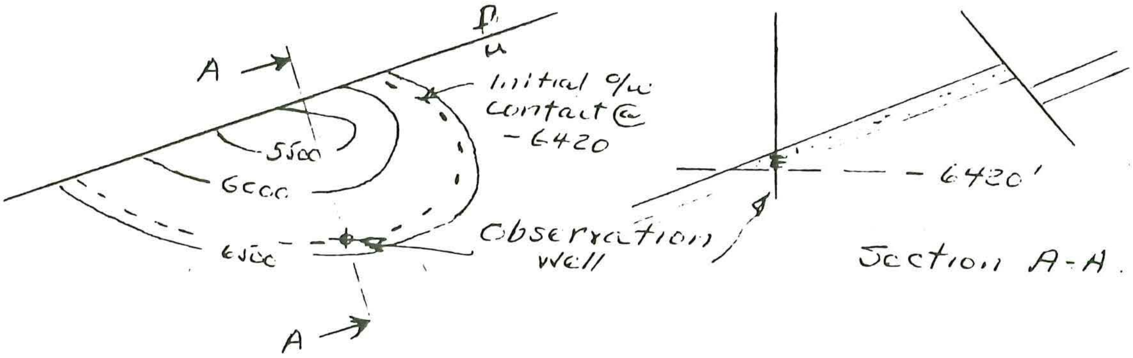
where B is the group in front of the summation sign in Equation 9 and is the slope of the straight line when F/E is plotted against $\sum \Delta p \sqrt{t}/E$. Note that $\sum \Delta p \sqrt{t}$ involves superposition of the pressure changes and square root of time.

Limited Linear Aquifers

Influx from limited or restricted aquifers is calculated by use of Equation 6. Nabor and Barham (Trans AIME 231 (1964) 561) gives efflux (Q_D) function values for constant pressure and no flow (sealed) outer boundary conditions in both chart and tabular form. Superposition principles must be used in applying these aquifer responses to the material balance.

CSD Petroleum Industry Course

Water Influx Problem 1



(The object of this problem is to illustrate the calculation of cumulative water entering an oil field, given the pressure history at an observation well near the original oil-water contact and an assumed aquifer behavior)

The two sketches illustrate an elliptically shaped anticlinal reservoir located against a sealing fault. One of the early development well was apparently completed close to the original oil-water contact (now believed to have been at -6420 feet) as it quickly watered out. Since being abandoned as an oil producer it has been used as a pressure observation well.

Table 1 showes dates and water pressures (corrected to -6400 ft) measured in the observation well. Assuming that the aquifer response could have been that of the Schilthuis steady-state form with a constant, k , of 2 bbl/psi-day, calculate the amount of water that has entered the reservoir at each date.

Table 1. Pressure History - Observation Well #1

Date	Cum. Days Since First Production	-6400 Datum Pressure psig
March 13,1970	0	3000
October 1,1970	202	2995
February 20,1971	344	2982
July 5, 1971	479	2965
December 8, 1971	635	2940
June 1, 1972	811	2900
October 15, 1972	947	2865
January 30, 1973	1054	2841

Water Influx Problem 2

(The purpose of this problem is to make you adept at applying superposition principles to water influx calculations.)

The problem calls for the calculation of the cumulative water influx into the Nabisco Oil Field at one-half year intervals over the first four years of its life. (In case you are wondering, the name Nabisco Field comes from its biscuit-like shape.) Fortunately, the Nabisco Field lies at the exact center of an infinitely large aquifer. Figure 1 illustrates the shape of the field.

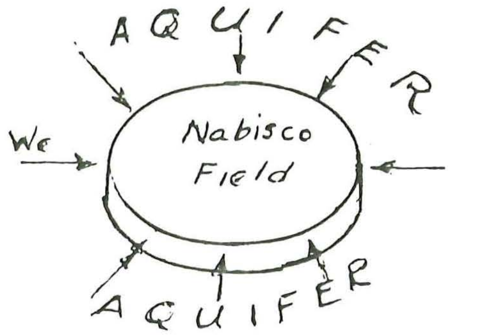


Figure 1. Illustration of Nabisco Field Shape (Not to scale)

1980

Average fluid and rock properties in the oilfield and the aquifer are as follows:

	Oilfield	Aquifer
k(eff), md	237	100
ϕ, fr.	0.21	0.20
μ, cp.	1.67 oil	0.50 water
c, $psi^{-1} \cdot 10^6$		
c_w	3.0	3.0
c_o	11.0	-
c_f *	3.8	3.7
S, fr.		
S_w	0.31	1.00
S_o	0.69	--
h, ft.	40	40
r, ft.	5280 (r_e)	5280 (r_w) ∞ (r_e)

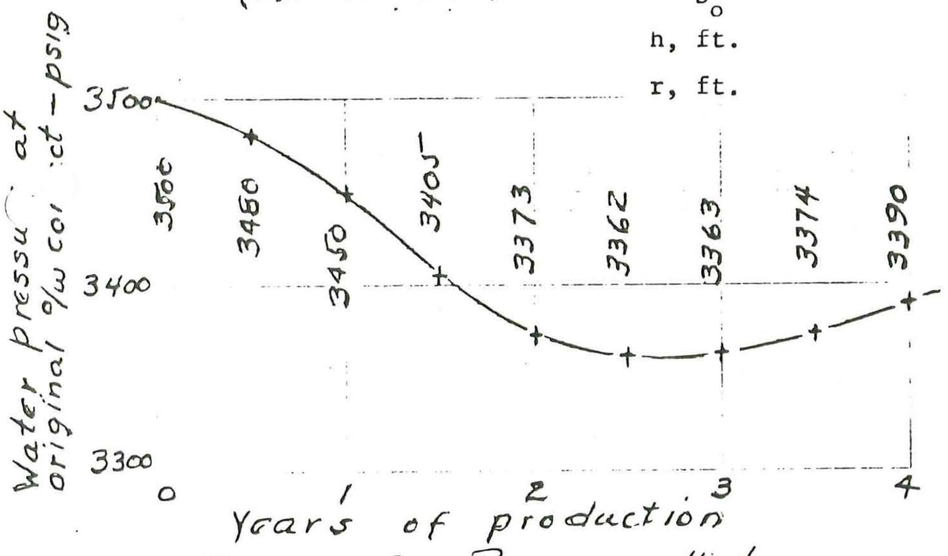


Figure 2 Pressure History - Nabisco Field.

Figure 2 shows water pressure at the location of the original oil-water contact location vs time. The inflection at about 1½ years time reflects a major reduction in off-take at that time.

ASSIGNMENT

(1) Calculate the barrels of water that have entered the oil reservoir at each ½ year time.

(2) What fraction of the oil reservoir volume has been invaded at the end of 4 years if the average water saturation behind the water-oil front is 50 per cent?

* From Hall's correlation, pg 132, Craft & Hawkins.

Guide Answers:

t_D for 1/2 year = 6.2 ; Q_D for 1/2 year = 5.3 ; W_e for 1 year = 368,000 bbl.

Water Influx Problem 3

The Nairobi Zone of the Palo Alto Field is anticlinal in nature and covers approximately 2900 acres in T3W, R7E, Stanford Base and Meridian. As illustrated by the structure map on the sand top (Fig.1) the zone extends from -7292 to -7376 feet subbay. An oil-water contact was identified on electric logs in the first well at the later depth. Because of the small dip of the flanks (less than 1 degree) most of the oil zone was underlayed by water when the field was discovered.

1980

Various maps have been made and data assembled for the purpose of making engineering studies of this zone. Several of these are attached. Pertinent information regarding the maps is:

Figure 1 shows the depth to the top of the oil sand at various parts of the field. The area enclosed by each contour was found by planimetering to be:

Contour	Area -acres
7300	193
7320	789
7340	1648
7360	2266
7376	2880 (oil-water contact)

Figure 2 shows contours of constant sand thickness. Thinning of the sand occurs to the south-east.

Figure 3 shows oil isobars at datum (-7350 ft.) corresponding to January 1, 1977. The initial datum oil pressure was 2056 psig.

Figure 4 is a blank sheet to be used as you see fit.

Production from the Nairobi zone is 30^{o} API.

What's Wanted:

Calculations are to be made to evaluate the water influx into the zone, assuming various size/shape aquifers. Calculations that will involve the Hurst-vanEverdingen transient efflux behavior of the aquifer require equivalent values for r_w, h, and Δp_w for use in the appropriate equations. Please calculate values for the above parameters. Should you need to make assumptions of one kind or another, don't forget to list what they are.

NAIROBI ZONE - PALO ALTO FIELD

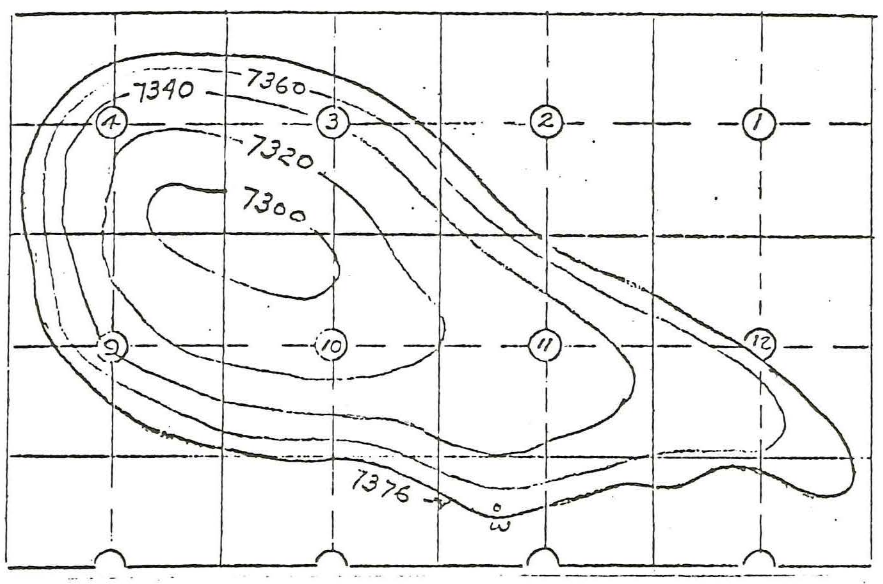


Fig. 1 Contours of top of oil zone

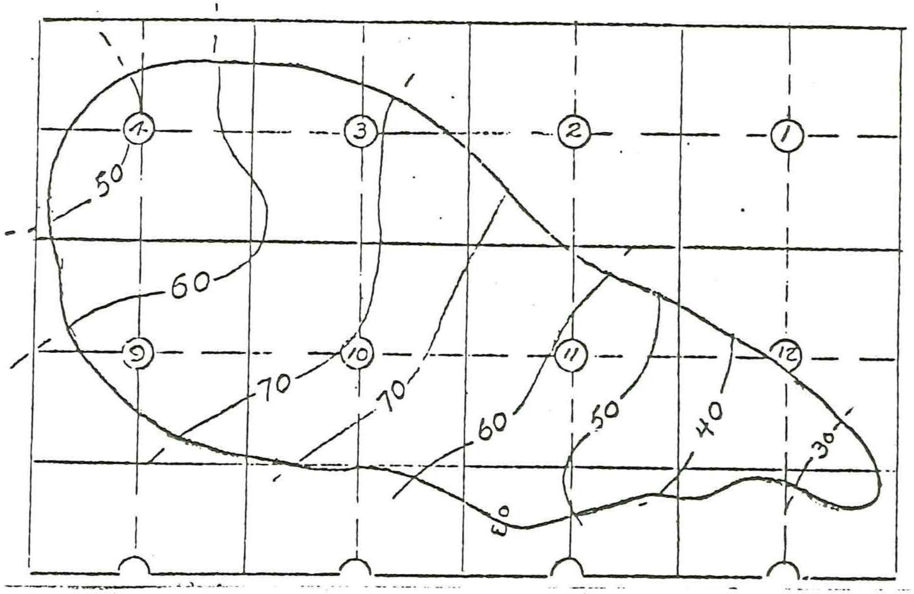


Fig.2 Contours of sand thickness.

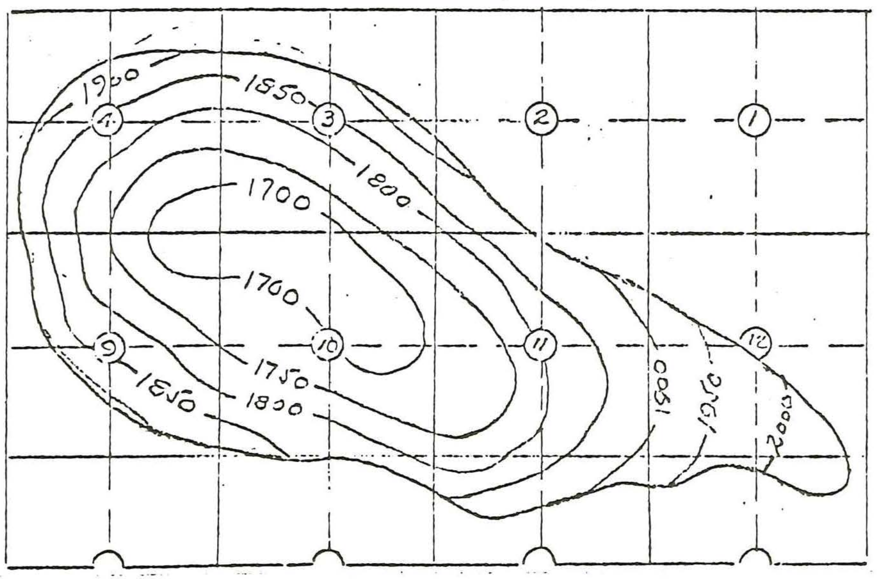


Fig. 3 Datum oil pressure as of 1/1/1977

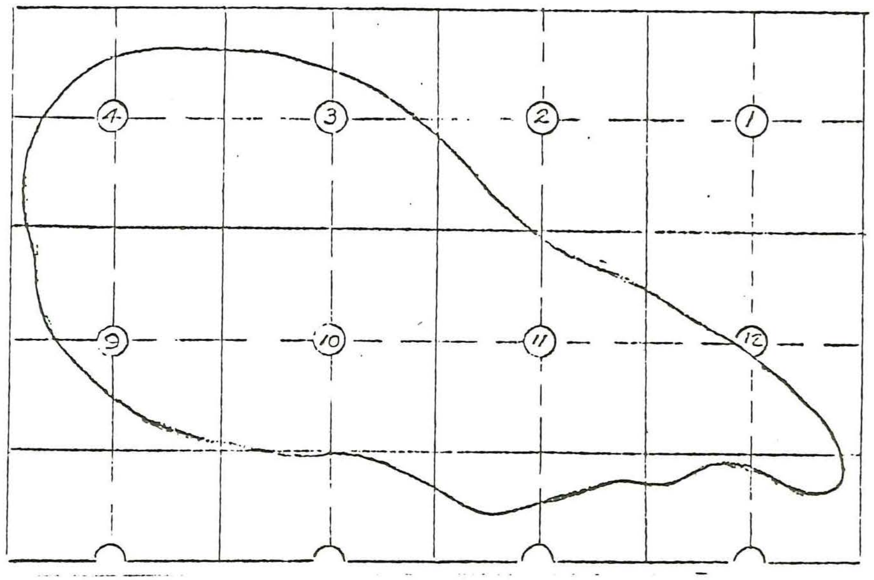


Fig. 4.

Page 2. problem

Solution Water Influx Problem 1

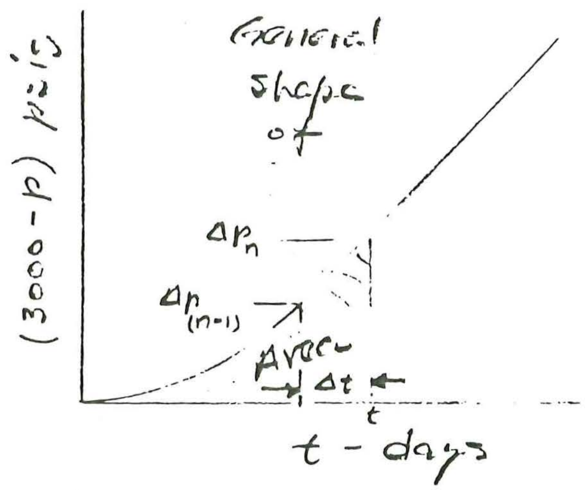
Given: Schilthuis form, $k = 2$ bbl/psi-yr.

$$W_e = k\int_0^t (P_i - p)\,dt \qquad P_i = 3000 \text{ psig}$$

Cum. Days t	$(3000-p)$	Cumulative Area Under $(3000-p)$ vs t curve psi·yr.	W_e bbl.
0	0	0	0
202	5	505 *	1000
344	18	2138	4300
479	35	5715	11 400
635	60	13 125	26250
811	100	27 205	54 400
947	135	43 185	86 400
1054	159	58914	117 800

* Trapezoidal integration

$$\text{Area} = \sum \tfrac{1}{2}(\Delta P_{(n-1)} + \Delta P_n)\cdot \Delta t$$



mpS

Solution Water Influx Problem 2

A. Calc. of dimensionless units

Per 1/2 year real time;

$$t_D = \frac{6.33(10^{-3}) \cdot 100 \cdot 182.5 \cdot t}{0.20 \cdot 0.50\,(3.0+3.7)10^{-6}(5280)^2} = 6.185 \cdot t$$

$$B = 1.12\,\phi c h r_w^2 = 1.12 \cdot 0.20 \cdot 6.7(10^{-6}) \cdot 40 \cdot (5280)^2 = 1673 \text{ Bbl/psi.}$$

i.

Number of 1/2 units	t_D	Q_D
0	0	0
1	6.19	5.3
2	12.37	8.7 ← From Craft & Hawkins
3	18.56	11.7
4	24.74	14.5
5	30.9	17.2
6	37.1	19.8
7	43.3	22.3
8	49.5	24.7

B. Calc. of W_e.

$$W_e = 1673 \cdot \sum Q_D \cdot \Delta p.$$

t.	0 10	1 25	2 37.5	3 38.5	Δp 4 21.5	5 5	6 −6	7 −13.5	8 −8	W_e Bbl
0	0									0
1	53	0								$8.87(10^4)$
2	57	133	0							$3.68(10^5)$
3	117	218	199	0						$8.93(10^5)$
4	145	293	326	204	0					$1.62(10^6)$
5	172	363	439	335	114	0				$2.38(10^6)$
6	198	430	544	450	187	27	0			$3.07(10^6)$
7	223	495	645	558	252	44	−32	0		$3.66(10^6)$
8	247	558	743	662	312	59	−52	−72	0	$4.11(10^6)$

Ans (1)

(2) At end of 4 years $W_e = 4.11(10^6)$ bbl.

ΔS_w in affected volume $= (0.50 - 0.31) = 0.19$

ft³ of affected reservoir $= \dfrac{4.11(10^6)}{0.19} \cdot \dfrac{5.615}{0.21} = 5.78(10^8)$

Fraction of res. affected $= \dfrac{5.78(10^8)}{\pi \cdot (5280)^2 \cdot 40} = 0.165$ Ans

16.5% [illegible]

CSD Petroleum Industry Course

Solution Water Influx Problem 3

Arcs of 1/2 mile (2640 feet) were laid off around the original oil-water contact contour. The average value of p and h of each arc was determined by inspection. This gave the following values:

Segment, j	$\bar{p}_j$	$\bar{h}_j$	Segment	$\bar{p}_j$	$\bar{h}_j$
1	1940	47	11	1990	30
2	1910	60	12	1940	37
3	1880	65	13	1880	48
4	1930	71	14	1850	55
5	1900	72	15	1825	63
6	1880	64	16	1870	71
7	1920	50	17	1900	70
8	1970	41	18	1910	64
9	2020	30	19	1900	56
10	2040	25	20*	1900	46

* Segment 20 is 3/4 · 2640 feet long.

The average sand thickness at the original oil-water contact on the sand top (-7376 contour) is

$$\bar{h}_{o/w} = \frac{\Sigma h_j \cdot L_j}{\Sigma L_j} = \frac{1053 \cdot 2640 \ ft^2}{19.75 \cdot 2640 \ ft} = 53.3 \ ft \text{ Ans.}$$

Not knowing how much water has entered the reservoir as of Jan 1, 1977 it will be assumed that the change in oil pressure at the original oil-water contact level (-7376) will be the same as the change in oil pressure at the -7350 foot datum. An assumption of zero capillary pressure ($P_o = P_w$) at the oil-water contact is also involved.

[signature] 05/21/80

Solution Water Influx Problem 3 Cont.

For these conditions:

$$\Delta P_w \Big)_{o/w}^{1/1/77} = \Delta p_o \Big)_{-7350 \text{ datum}}^{1/1/77} = 2056 - \frac{\sum P_j \ell_j}{\sum \ell_j}$$

$$= 2056 - \frac{1{,}000\,(10^8)\text{ psi feet}}{19.75 \cdot 2640 \text{ feet}} = 2056 - 1918$$

$$\Delta p \Big)_{o/w} = \underline{138 \text{ psi}} \text{ ans}$$

The equivalent r_w of the initial oil-water contact can be calculated by two means. The method proposed by Craft and Hawkins is

$$r_w' = \sqrt{\frac{\text{area}}{\pi}} = \sqrt{\frac{2880 \text{ acres} \cdot 43560 \frac{ft^2}{acre}}{\pi}} = \underline{6319 \text{ ft}}, \text{ ans}$$

The method proposed by Kucik & Brigham is

$$a = 60\text{mm} \cdot \frac{4 \cdot 5280 \text{ ft}}{116 \text{ mm}} = 10924 \text{ ft}$$

$$\text{Area}, A = 2880 \cdot 43560 = 1.255\,(10^8)\text{ ft}^2$$

For an ellipse $A = \pi a b$

$$\therefore b = \frac{1.255\,(10^8)}{\pi \cdot 10924} = 3657 \text{ ft}$$

From Kucck & Brigham

$$\frac{r_w'}{a} = \frac{(a+b)}{2a} \quad \text{or} \quad r_w' = \frac{a+b}{2}$$

$$\therefore r_w' = \frac{(10924 + 3657)}{2} = \underline{7290 \text{ ft.}} \text{ ans}$$

AMT Standing
05/21/80

Notes on Determining Steady-State Influx Constants When Influx is Known From Material Balance Calculations.

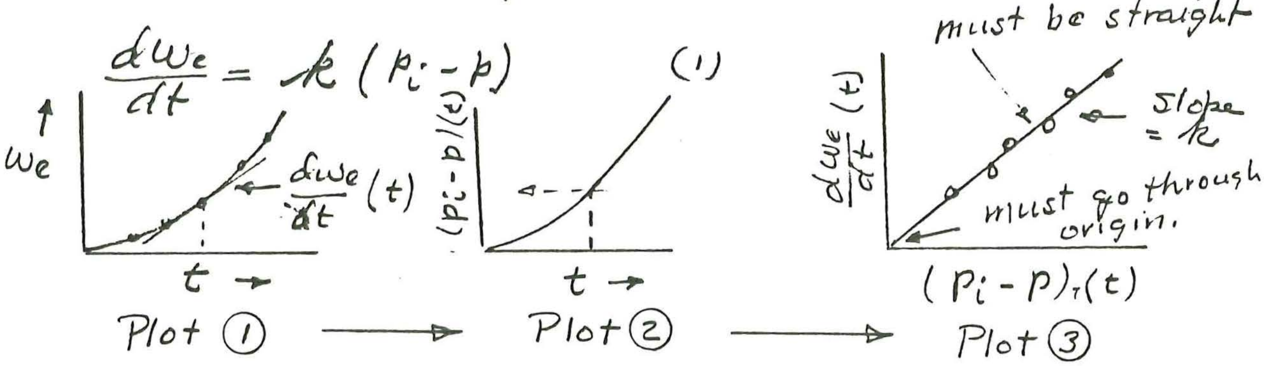
Ref: Craft & Hawkins pgs 224 – 230

(1) Cumulative water entering reservoir is known as a function of time. $W_e = f_1(t)$

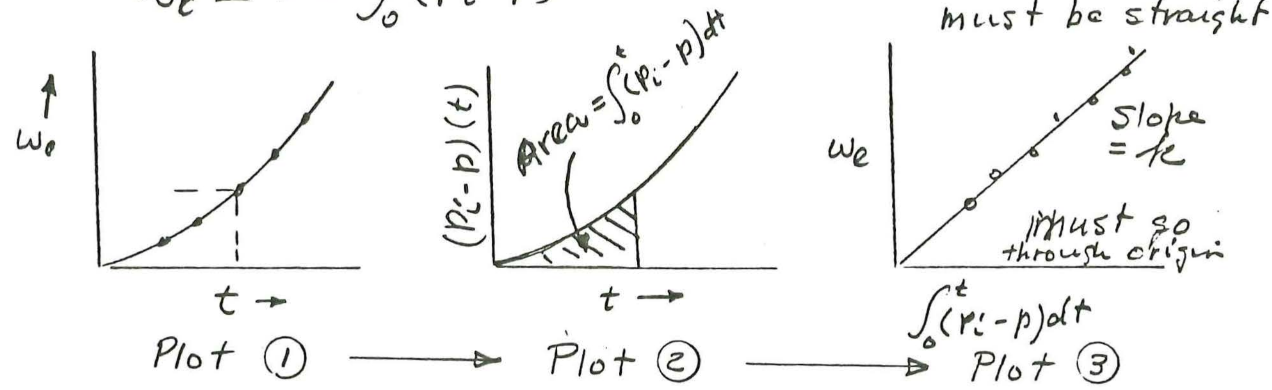
(2) Field water pressure at location of original aquifer location is known as a function of time. $p = f_2(t)$.

1. Schilthuis Steady-State Form.

$$\frac{dW_e}{dt} = k(P_i - p) \quad (1)$$



$$W_e = k\int_0^t (P_i - P)\,dt \quad (2)$$



Schilthuis form valid only if suitable straight line of Plot 3 is obtained that goes through origin. Curved trend of Plot 3 indicates form of water influx is not Schilthuis steady-state.

MPBS
07/21/72

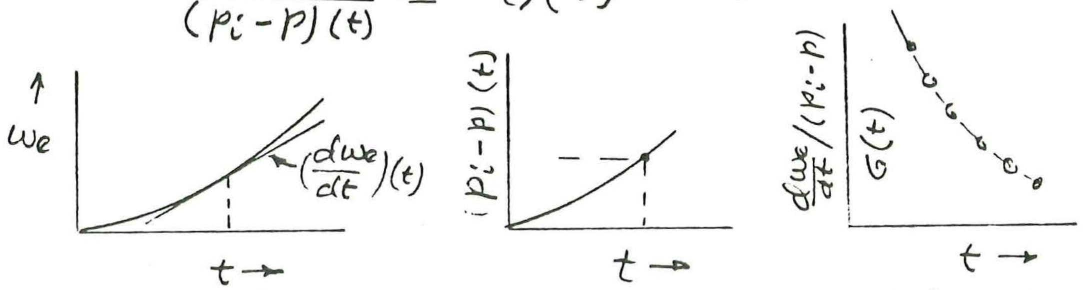
2. Hurst Modified Steady-State Form

$$\frac{dW_e}{dt} = \frac{c\,(p_i - p)}{\log at} \qquad (3)$$

$$W_e = c \int_0^t \frac{(p_i - p)\,dt}{\log at} \qquad (4)$$

Let

$$\frac{\frac{dW_e}{dt}(t)}{(p_i - p)(t)} = G(t) \qquad (5)$$



Plot ① ⟶ Plot ② ⟶ Calculate G(t) values

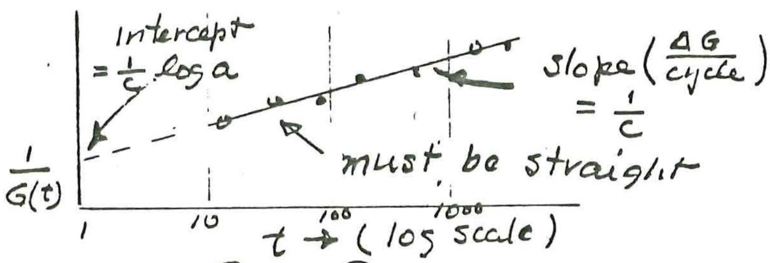
from equation 3

$$G(t) = \frac{c}{\log at} \qquad (6)$$

$$\frac{1}{G(t)} = \underbrace{\frac{1}{c}\log a}_{b} + \underbrace{\frac{1}{c}}_{m}\underbrace{\log t}_{x} \qquad (7)$$

$$y = b + m\,x$$

Eq 7 is straight line when $\frac{1}{G(t)}$ is plotted vs log t.



Plot ③

Hurst Modified form valid only if suitable straight line on Plot 3 is obtained.

mpStanding
07/21/1972

Linear Aquifer Equations

$$\frac{W_e}{\Delta p} = \frac{\phi c_t h b L}{5.615} F(t_D) \qquad \frac{\Delta p}{q} = \frac{5.615 B_w \mu L}{k h b} F(t_D)$$

$$t_D = \frac{6.33(10^{-3}) k t}{\phi \mu c_t L^2}$$

Outer Boundary Condition	Constant Pressure Inner Boundary	Constant Rate Inner Boundary.
Infinite	$F(t_D) = F_{1/2}(t_D)$	$F(t_D) = F_{1/2}(t_D)$
Closed (No Flow)	$F(t_D) = F_0(t_D)$	$F(t_D) = F_1(t_D)$
Constant Pressure	$F(t_D) = F_1(t_D)$	$F(t_D) = F_0(t_D)$

For $t_D \lessapprox 0.25$ $\quad F_0(t_D) = F_{1/2}(t_D) = F_1(t_D) = 2\sqrt{t_D/\pi}$

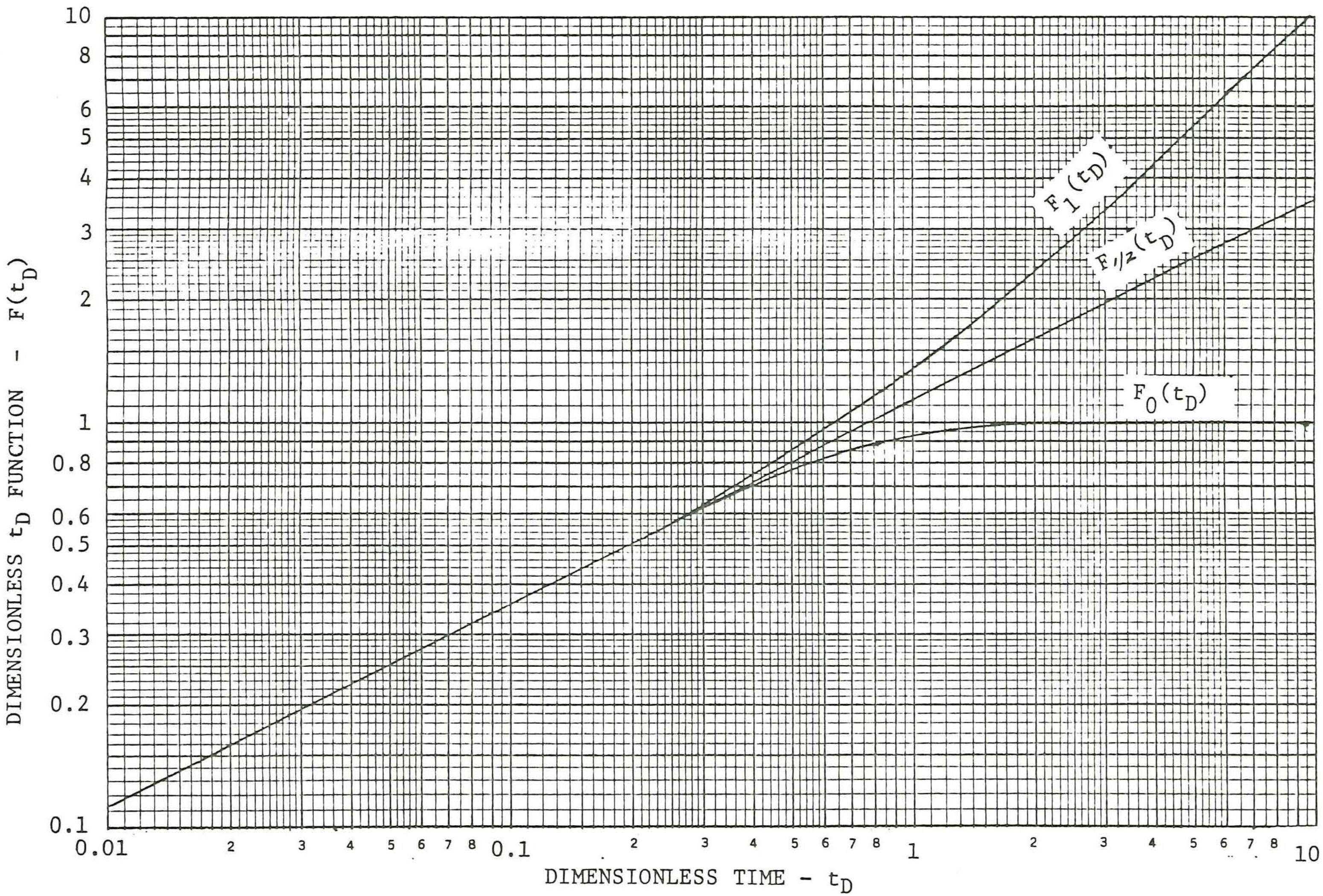
For $t_D > 2.0$ $\quad F_0(t_D) = 1$; $F_{1/2}(t_D) = 2\sqrt{\frac{t_D}{\pi}}$; $F_1(t_D) = t_D + 1/3$.

For $0.25 < t_D < 2.0$ $\quad F_0(t_D) \neq F_1(t_D)$ Use Chart ; $F_{1/2}(t_D) = 2\sqrt{t_D/\pi}$

W_e = cum. bbls
Δp = psi
ϕ = fraction
b = width, ft.
h = thickness, ft
L = length, ft
t = time, days
c_t = total compressibility, psi^{-1}
μ = viscosity, cp.
q = surface rate, bbl/day
k = permeability, md
B = form. vol. fact., dim.

Reference: Nabor & Barham
Trans. AIME (1964) 231, pg 561

MB Standing



DIMENSIONLESS PRESSURE CHANGE and EFFLUX FUNCTIONS - LINEAR AQUIFERS

Ref: Nabor and Barham
Trans AIM_E (1964) 231, 561

TABLE 1—PRESSURE DROP AND CUMULATIVE INFLUX FUNCTIONS FOR LINEAR AQUIFERS

t_D	$F_0(t_D)$	$F_{1/2}(t_D)$	$F_1(t_D)$
$1.00(10^{-2})$	$1.128379(10^{-1})$	$1.128379(10^{-1})$	$1.128379(10^{-1})$
$1.10(10^{-2})$	$1.183454(10^{-1})$	$1.183454(10^{-1})$	$1.183454(10^{-1})$
$1.25(10^{-2})$	$1.261566(10^{-1})$	$1.261566(10^{-1})$	$1.261566(10^{-1})$
$1.40(10^{-2})$	$1.335116(10^{-1})$	$1.335116(10^{-1})$	$1.335116(10^{-1})$
$1.60(10^{-2})$	$1.427299(10^{-1})$	$1.427299(10^{-1})$	$1.427299(10^{-1})$
$1.80(10^{-2})$	$1.513880(10^{-1})$	$1.513880(10^{-1})$	$1.513880(10^{-1})$
$2.00(10^{-2})$	$1.595769(10^{-1})$	$1.595769(10^{-1})$	$1.595769(10^{-1})$
$2.25(10^{-2})$	$1.692569(10^{-1})$	$1.692569(10^{-1})$	$1.692569(10^{-1})$
$2.50(10^{-2})$	$1.784124(10^{-1})$	$1.784124(10^{-1})$	$1.784124(10^{-1})$
$2.80(10^{-2})$	$1.888139(10^{-1})$	$1.888139(10^{-1})$	$1.888139(10^{-1})$
$3.10(10^{-2})$	$1.986717(10^{-1})$	$1.986717(10^{-1})$	$1.986717(10^{-1})$
$3.50(10^{-2})$	$2.111004(10^{-1})$	$2.111004(10^{-1})$	$2.111004(10^{-1})$
$4.00(10^{-2})$	$2.256758(10^{-1})$	$2.256758(10^{-1})$	$2.256758(10^{-1})$
$4.50(10^{-2})$	$2.393654(10^{-1})$	$2.393654(10^{-1})$	$2.393654(10^{-1})$
$5.00(10^{-2})$	$2.523133(10^{-1})$	$2.523133(10^{-1})$	$2.523133(10^{-1})$
$5.60(10^{-2})$	$2.670232(10^{-1})$	$2.670232(10^{-1})$	$2.670232(10^{-1})$
$6.20(10^{-2})$	$2.809641(10^{-1})$	$2.809641(10^{-1})$	$2.809641(10^{-1})$
$7.00(10^{-2})$	$2.985411(10^{-1})$	$2.985411(10^{-1})$	$2.985411(10^{-1})$
$8.00(10^{-2})$	$3.191537(10^{-1})$	$3.191538(10^{-1})$	$3.191539(10^{-1})$
$9.00(10^{-2})$	$3.385133(10^{-1})$	$3.385138(10^{-1})$	$3.385141(10^{-1})$
$1.00(10^{-1})$	$3.568234(10^{-1})$	$3.568248(10^{-1})$	$3.568262(10^{-1})$
$1.10(10^{-1})$	$3.742370(10^{-1})$	$3.742410(10^{-1})$	$3.742451(10^{-1})$
$1.25(10^{-1})$	$3.989280(10^{-1})$	$3.989423(10^{-1})$	$3.989566(10^{-1})$
$1.40(10^{-1})$	$4.221615(10^{-1})$	$4.222008(10^{-1})$	$4.222401(10^{-1})$
$1.60(10^{-1})$	$4.512368(10^{-1})$	$4.513517(10^{-1})$	$4.514665(10^{-1})$
$1.80(10^{-1})$	$4.784617(10^{-1})$	$4.787307(10^{-1})$	$4.789997(10^{-1})$
$2.00(10^{-1})$	$5.040878(10^{-1})$	$5.046265(10^{-1})$	$5.051652(10^{-1})$
$2.25(10^{-1})$	$5.341424(10^{-1})$	$5.352372(10^{-1})$	$5.363320(10^{-1})$
$2.50(10^{-1})$	$5.622335(10^{-1})$	$5.641896(10^{-1})$	$5.661456(10^{-1})$
$2.80(10^{-1})$	$5.936127(10^{-1})$	$5.970821(10^{-1})$	$6.005516(10^{-1})$

t_D	$F_0(t_D)$	$F_{1/2}(t_D)$	$F_1(t_D)$
$3.10(10^{-1})$	$6.226824(10^{-1})$	$6.282549(10^{-1})$	$6.338276(10^{-1})$
$3.50(10^{-1})$	$6.581891(10^{-1})$	$6.675581(10^{-1})$	$6.769283(10^{-1})$
$4.00(10^{-1})$	$6.978819(10^{-1})$	$7.136496(10^{-1})$	$7.294231(10^{-1})$
$4.50(10^{-1})$	$7.329537(10^{-1})$	$7.569398(10^{-1})$	$7.809461(10^{-1})$
$5.00(10^{-1})$	$7.639503(10^{-1})$	$7.978846(10^{-1})$	$8.318760(10^{-1})$
$5.60(10^{-1})$	$7.964332(10^{-1})$	$8.444016(10^{-1})$	$8.925272(10^{-1})$
$6.20(10^{-1})$	$8.244456(10^{-1})$	$8.884866(10^{-1})$	$9.528875(10^{-1})$
$7.00(10^{-1})$	$8.558930(10^{-1})$	$9.440697(10^{-1})$	$10.331309(10^{-1})$
$8.00(10^{-1})$	$8.874029(10^{-1})$	$10.092530(10^{-1})$	$11.332578(10^{-1})$
$9.00(10^{-1})$	$9.120229(10^{-1})$	$10.704744(10^{-1})$	$12.333052(10^{-1})$
1.00	$9.312597(10^{-1})$	1.128379	1.333323
1.10	$9.462902(10^{-1})$	1.183454	1.433329
1.25	$9.629049(10^{-1})$	1.261566	1.583332
1.40	$9.743799(10^{-1})$	1.335116	1.733333
1.60	$9.843590(10^{-1})$	1.427299	1.933333
1.80	$9.904512(10^{-1})$	1.513880	2.133333
2.00	$9.941705(10^{-1})$	1.595769	2.333333
2.25	$9.968541(10^{-1})$	1.692569	2.583333
2.50	$9.983024(10^{-1})$	1.784124	2.833333
2.80	$9.991902(10^{-1})$	1.888139	3.133333
3.10	$9.996137(10^{-1})$	1.986717	3.433333
3.50	$9.998560(10^{-1})$	2.111004	3.833333
4.00	$9.999581(10^{-1})$	2.256758	4.333333
4.50	$9.999878(10^{-1})$	2.393654	4.833333
5.00	$9.999964(10^{-1})$	2.523133	5.333333
5.60	$9.999992(10^{-1})$	2.670232	5.933333
6.20	$9.999998(10^{-1})$	2.809641	6.533333
7.00	$10.000000(10^{-1})$	2.985411	7.333333
8.00	$10.000000(10^{-1})$	3.191538	8.333333
9.00	$10.000000(10^{-1})$	3.385138	9.333333

Ref: Nabor and Barham
Trans AIME 231, (1964), 56

Dimensionless Efflux Functions, Q_D

Radial Infinite Aquifer.

$$t_D = \frac{\eta t}{r_w^2} = \frac{6.33(10^{-3}) k t}{\phi \mu c \, r_w^2}$$

$$Q_D = f(t_D)$$

For $t_D < 0.01$

$$Q_D = 2\sqrt{t_D/\pi}$$

For $0.01 < t_D < 200$

$$Q_D = \frac{1.12838\sqrt{t_D} + 1.19328\, t_D + 0.269872\, t_D\sqrt{t_D} + 0.00855294\, t_D^2}{1 + 0.616599\sqrt{t_D} + 0.0413008\, t_D}$$

precission 0.02 % ±

For $t_D > 200$

$$Q_D = \frac{-4.29881 + 2.02566\, t_D}{\ln t_D}$$

precission 0.02 % ±

For $0.05 < t_D < 7$ (Standings)

$$Q_D = b\, t_D^m$$

$$b = 1.577 - 0.023 \log t_D - 0.111 (\log t_D)^2$$

$$m = 0.624 + 0.0824 \log t_D + 0.0187 (\log t_D)^2$$

Precission 1 % ±

For $7 < t_D < 1000$ (Standings)

$$Q_D = b\, t_D^m$$

$$b = 1.844 - 0.477 \log t_D + 0.0415 (\log t_D)^2$$

$$m = 0.612 + 0.1236 \log t_D - 0.0139 (\log t_D)^2$$

precission 1 % ±

Craft & Hawkins. Q_D for Limited Radial Aquifers

Table 5.2. LIMITED AQUIFER VALUES OF DIMENSIONLESS WATER INFLUX $Q(t)$ FOR VALUES OF DIMENSIONLESS TIME t_D AND FOR SEVERAL RATIOS OF AQUIFER-RESERVOIR RADII r_e/r_w

$r_e/r_w = 1.5$

Dimensionless time t_D	Fluid influx $Q(t)$
$5.0(10)^{-2}$	0.276
6.0 "	0.304
7.0 "	0.330
8.0 "	0.354
9.0 "	0.375
$1.0(10)^{-1}$	0.395
1.1 "	0.414
1.2 "	0.431
1.3 "	0.446
1.4 "	0.461
1.5 "	0.474
1.6 "	0.486
1.7 "	0.497
1.8 "	0.507
1.9 "	0.517
2.0 "	0.525
2.1 "	0.533
2.2 "	0.541
2.3 "	0.548
2.4 "	0.554
2.5 "	0.559
2.6 "	0.565
2.8 "	0.574
3.0 "	0.582
3.2 "	0.588
3.4 "	0.594
3.6 "	0.599
3.8 "	0.603
4.0 "	0.606
4.5 "	0.613
5.0 "	0.617
6.0 "	0.621
7.0 "	0.623
8.0 "	0.624

$r_e/r_w = 2.0$

Dimensionless time t_D	Fluid influx $Q(t)$
$5.0(10)^{-2}$	0.278
7.5 "	0.345
$1.0(10)^{-1}$	0.404
1.25 "	0.458
1.50 "	0.507
1.75 "	0.553
2.00 "	0.597
2.25 "	0.638
2.50 "	0.678
2.75 "	0.715
3.00 "	0.751
3.25 "	0.785
3.50 "	0.817
3.75 "	0.848
4.00 "	0.877
4.25 "	0.905
4.50 "	0.932
4.75 "	0.958
5.00 "	0.983
5.50 "	1.028
6.00 "	1.070
6.50 "	1.108
7.00 "	1.143
7.50 "	1.174
8.00 "	1.203
9.00 "	1.253
1.00	1.295
1.1	1.330
1.2	1.358
1.3	1.382
1.4	1.402
1.6	1.432
1.7	1.444
1.8	1.453
2.0	1.468
2.5	1.487
3.0	1.495
4.0	1.499
5.0	1.500

$r_e/r_w = 2.5$

Dimensionless time t_D	Fluid influx $Q(t)$
$1.0(10)^{-1}$	0.408
1.5 "	0.509
2.0 "	0.599
2.5 "	0.681
3.0 "	0.758
3.5 "	0.829
4.0 "	0.897
4.5 "	0.962
5.0 "	1.024
5.5 "	1.083
6.0 "	1.140
6.5 "	1.195
7.0 "	1.248
7.5 "	1.299
8.0 "	1.348
8.5 "	1.395
9.0 "	1.440
9.5 "	1.484
1.0	1.526
1.1	1.605
1.2	1.679
1.3	1.747
1.4	1.811
1.5	1.870
1.6	1.924
1.7	1.975
1.8	2.022
2.0	2.106
2.2	2.178
2.4	2.241
2.6	2.294
2.8	2.340
3.0	2.380
3.4	2.444
3.8	2.491
4.2	2.525
4.6	2.551
5.0	2.570
6.0	2.599
7.0	2.613
8.0	2.619
9.0	2.622
10.0	2.624

$r_e/r_w = 3.0$

Dimensionless time t_D	Fluid influx $Q(t)$
$3.0(10)^{-1}$	0.755
4.0 "	0.895
5.0 "	1.023
6.0 "	1.143
7.0 "	1.256
8.0 "	1.363
9.0 "	1.465
1.00	1.563
1.25	1.791
1.50	1.997
1.75	2.184
2.00	2.353
2.25	2.507
2.50	2.646
2.75	2.772
3.00	2.886
3.25	2.990
3.50	3.084
3.75	3.170
4.00	3.247
4.25	3.317
4.50	3.381
4.75	3.439
5.00	3.491
5.50	3.581
6.00	3.656
6.50	3.717
7.00	3.767
7.50	3.809
8.00	3.843
9.00	3.894
10.00	3.928
11.00	3.951
12.00	3.967
14.00	3.985
16.00	3.993
18.00	3.997
20.00	3.999
22.00	3.999
24.00	4.000

$r_e/r_w = 3.5$

Dimensionless time t_D	Fluid influx $Q(t)$
1.00	1.571
1.20	1.761
1.40	1.940
1.60	2.111
1.80	2.273
2.00	2.427
2.20	2.574
2.40	2.715
2.60	2.849
2.80	2.976
3.00	3.098
3.25	3.242
3.50	3.379
3.75	3.507
4.00	3.628
4.25	3.742
4.50	3.850
4.75	3.951
5.00	4.047
5.50	4.222
6.00	4.378
6.50	4.516
7.00	4.639
7.50	4.749
8.00	4.846
8.50	4.932
9.00	5.009
9.50	5.078
10.00	5.138
11	5.241
12	5.321
13	5.385
14	5.435
15	5.476
16	5.506
17	5.531
18	5.551
20	5.579
25	5.611
30	5.621
35	5.624
40	5.625

$r_e/r_w = 4.0$

Dimensionless time t_D	Fluid influx $Q(t)$
2.00	2.442
2.20	2.598
2.40	2.748
2.60	2.893
2.80	3.034
3.00	3.170
3.25	3.334
3.50	3.493
3.75	3.645
4.00	3.792
4.25	3.932
4.50	4.068
4.75	4.198
5.00	4.323
5.50	4.560
6.00	4.779
6.50	4.982
7.00	5.169
7.50	5.343
8.00	5.504
8.50	5.653
9.00	5.790
9.50	5.917
10	6.035
11	6.246
12	6.425
13	6.580
14	6.712
15	6.825
16	6.922
17	7.004
18	7.076
20	7.189
22	7.272
24	7.332
26	7.377
30	7.434
34	7.464
38	7.481
42	7.490
46	7.494
50	7.497

$r_e/r_w = 4.5$

Dimensionless time t_D	Fluid influx $Q(t)$
2.5	[illegible]
3.0	[illegible]
3.5	[illegible]
4.0	[illegible]
4.5	[illegible]
5.0	[illegible]
5.5	[illegible]
6.0	[illegible]
6.5	[illegible]
7.0	[illegible]
7.5	[illegible]
8.0	[illegible]
8.5	[illegible]
9.0	[illegible]
9.5	[illegible]
10	[illegible]
11	[illegible]
12	[illegible]
13	[illegible]
14	[illegible]
15	[illegible]
16	[illegible]
18	[illegible]
20	[illegible]
22	[illegible]
24	[illegible]
26	[illegible]
28	[illegible]
30	[illegible]
34	[illegible]
38	[illegible]
42	[illegible]
46	[illegible]
50	[illegible]
60	[illegible]
70	[illegible]
80	[illegible]
90	[illegible]
100	[illegible]

Table 5.2. (Cont'd.)

$r_e/r_w = 5.0$

Dimensionless time t_D	Fluid influx $Q(t)$
3.0	3.195
3.5	3.542
4.0	3.875
4.5	4.193
5.0	4.499
5.5	4.792
6.0	5.074
6.5	5.345
7.0	5.605
7.5	5.854
8.0	6.094
8.5	6.325
9.0	6.547
9.5	6.760
10	6.965
11	7.350
12	7.706
13	8.035
14	8.339
15	8.620
16	8.879
18	9.338
20	9.731
22	10.07
24	10.35
26	10.59
28	10.80
30	10.98
34	11.26
38	11.46
42	11.61
46	11.71
50	11.79
60	11.91
70	11.96
80	11.98
90	11.99
100	12.00
120	12.00

$r_e/r_w = 6.0$

Dimensionless time t_D	Fluid influx $Q(t)$
6.0	5.148
6.5	5.440
7.0	5.724
7.5	6.002
8.0	6.273
8.5	6.537
9.0	6.795
9.5	7.047
10.0	7.293
10.5	7.533
11	7.767
12	8.220
13	8.651
14	9.063
15	9.456
16	9.829
17	10.19
18	10.53
19	10.85
20	11.16
22	11.74
24	12.26
25	12.50
31	13.74
35	14.40
39	14.93
51	16.05
60	16.56
70	16.91
80	17.14
90	17.27
100	17.36
110	17.41
120	17.45
130	17.46
140	17.48
150	17.49
160	17.49
180	17.50
200	17.50
220	17.50

$r_e/r_w = 7.0$

Dimensionless time t_D	Fluid influx $Q(t)$
9.00	6.861
9.50	7.127
10	7.389
11	7.902
12	8.397
13	8.876
14	9.341
15	9.791
16	10.23
17	10.65
18	11.06
19	11.46
20	11.85
22	12.58
24	13.27
26	13.92
28	14.53
30	15.11
35	16.39
40	17.49
45	18.43
50	19.24
60	20.51
70	21.45
80	22.13
90	22.63
100	23.00
120	23.47
140	23.71
160	23.85
180	23.92
200	23.96
500	24.00

$r_e/r_w = 8.0$

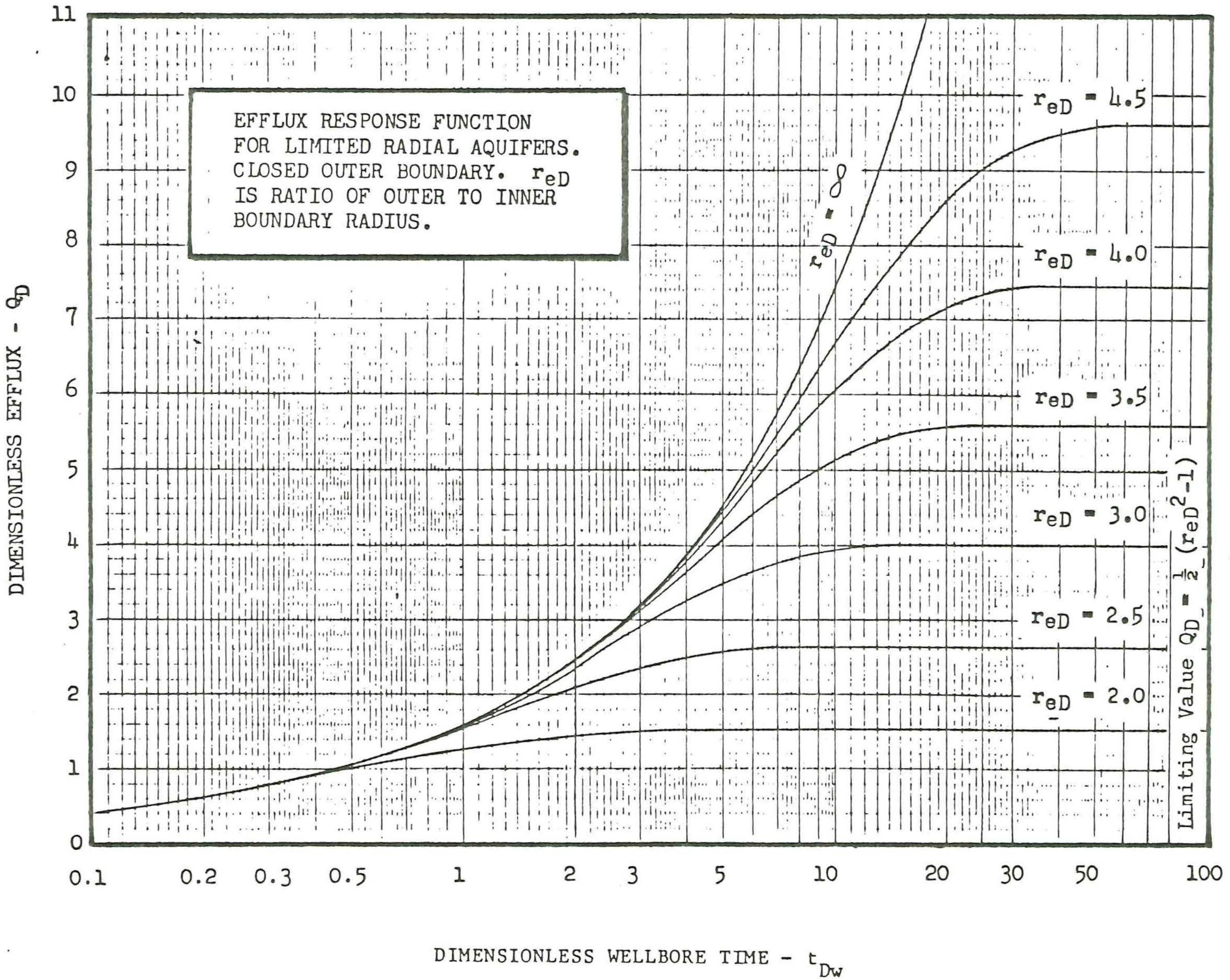
Dimensionless time t_D	Fluid influx $Q(t)$
9	6.861
10	7.398
11	7.920
12	8.431
13	8.930
14	9.418
15	9.895
16	10.361
17	10.82
18	11.26
19	11.70
20	12.13
22	12.95
24	13.74
26	14.50
28	15.23
30	15.92
34	17.22
38	18.41
40	18.97
45	20.26
50	21.42
55	22.46
60	23.40
70	24.98
80	26.26
90	27.28
100	28.11
120	29.31
140	30.08
160	30.58
180	30.91
200	31.12
240	31.34
280	31.43
320	31.47
360	31.49
400	31.50
500	31.50

$r_e/r_w = 9.0$

Dimensionless time t_D	Fluid influx $Q(t)$
10	7.417
15	9.945
20	12.26
22	13.13
24	13.98
26	14.79
28	15.59
30	16.35
32	17.10
34	17.82
36	18.52
38	19.19
40	19.85
42	20.48
44	21.09
46	21.69
48	22.26
50	22.82
52	23.36
54	23.89
56	24.39
58	24.88
60	25.36
65	26.48
70	27.52
75	28.48
80	29.36
85	30.18
90	30.93
95	31.63
100	32.27
120	34.39
140	35.92
160	37.04
180	37.85
200	38.44
240	39.17
280	39.56
320	39.77
360	39.88
400	39.94
440	39.97
480	39.98

$r_e/r_w = 10.0$

Dimensionless time t_D	Fluid influx $Q(t)$
15	9.965
20	12.32
22	13.22
24	14.09
26	14.95
28	15.78
30	16.59
32	17.38
34	18.16
36	18.91
38	19.65
40	20.37
42	21.07
44	21.76
46	22.42
48	23.07
50	23.71
52	24.33
54	24.94
56	25.53
58	26.11
60	26.67
65	28.02
70	29.29
75	30.49
80	31.61
85	32.67
90	33.66
95	34.60
100	35.48
120	38.51
140	40.89
160	42.75
180	44.21
200	45.36
240	46.95
280	47.94
320	48.54
360	48.91
400	49.14
440	49.28
480	49.36



EFFLUX RESPONSE FUNCTION
FOR LIMITED RADIAL AQUIFERS.
CLOSED OUTER BOUNDARY. r_{eD}
IS RATIO OF OUTER TO INNER
BOUNDARY RADIUS.
$r_{eD} = \infty$
$r_{eD} = 4.5$
$r_{eD} = 4.0$
$r_{eD} = 3.5$
$r_{eD} = 3.0$
$r_{eD} = 2.5$
$r_{eD} = 2.0$
Limiting Value $Q_D = \frac{1}{2}(r_{eD}^2 - 1)$
DIMENSIONLESS EFFLUX - Q_D
0
1
2
3
4
5
6
7
8
9
10
11
0.1
0.2
0.3
0.5
1
2
3
5
10
20
30
50
100
DIMENSIONLESS WELLBORE TIME - t_{Dw}

Table 5.1. INFINITE AQUIFER VALUES OF DIMENSIONLESS WATER INFLUX $Q(t)$ FOR VALUES OF DIMENSIONLESS TIME t_D

Dimensionless time t_D	Fluid influx $Q(t)$	Dimensionless time t_D	Fluid influx $Q(t)$	Dimensionless time t_D	Fluid influx $Q(t)$	Dimensionless time t_D	Fluid influx $Q(t)$	Dimensionless time t_D	Fluid influx $Q(t)$	Dimensionless time t_D	Fluid influx $Q(t)$
0.00	0.000	79	35.697	455	150.249	1190	340.843	3250	816.090	35,000	6780.2
0.01	0.112	80	36.058	460	151.640	1200	343.308	3300	827.088	40,000	7650.0
0.05	0.278	81	36.418	465	153.029	1210	345.770	3350	838.067	50,000	9363.0
0.10	0.404	82	36.777	470	154.416	1220	348.230	3400	849.028	60,000	11,047.2
0.15	0.520	83	37.136	475	155.801	1225	349.460	3450	859.974	70,000	12,708.3
0.20	0.606	84	37.494	480	157.184	1230	350.688	3500	870.903	75,000	13,531.4
0.25	0.689	85	37.851	485	158.565	1240	353.144	3550	881.816	80,000	14,350.1
0.30	0.758	86	38.207	490	159.945	1250	355.597	3600	892.712	90,000	15,975.3
0.40	0.898	87	38.563	495	161.322	1260	358.048	3650	903.594	100,000	17,586.2
0.50	1.020	88	38.919	500	162.698	1270	360.496	3700	914.459	125,000	21,560.7
0.60	1.140	89	39.272	510	165.444	1275	361.720	3750	925.309	$1.5(10)^5$	2.538(10)
0.70	1.251	90	39.626	520	168.183	1280	362.942	3800	936.144	2.0 ″	3.308 ″
0.80	1.359	91	39.979	525	169.549	1290	365.386	3850	946.966	2.5 ″	4.066 ″
0.90	1.469	92	40.331	530	170.914	1300	367.828	3900	957.773	3.0 ″	4.817 ″
1	1.569	93	40.684	540	173.639	1310	370.267	3950	968.566	4.0 ″	6.267 ″
2	2.447	94	41.034	550	176.357	1320	372.704	4000	979.344	5.0 ″	7.699 ″
3	3.202	95	41.385	560	179.069	1325	373.922	4050	990.108	6.0 ″	9.113 ″
4	3.893	96	41.735	570	181.774	1330	375.139	4100	1000.858	7.0 ″	1.051(10)
5	4.539	97	42.084	575	183.124	1340	377.572	4150	1011.595	8.0 ″	1.189 ″
6	5.153	98	42.433	580	184.473	1350	380.003	4200	1022.318	9.0 ″	1.326 ″
7	5.743	99	42.781	590	187.166	1360	382.432	4250	1033.028	$1.0(10)^6$	1.462 ″
8	6.314	100	43.129	600	189.852	1370	384.859	4300	1043.724	1.5 ″	2.126 ″
9	6.869	105	44.858	610	192.533	1375	386.070	4350	1054.409	2.0 ″	2.781 ″
10	7.411	110	46.574	620	195.208	1380	387.283	4400	1065.082	2.5 ″	3.427 ″
11	7.940	115	48.277	625	196.544	1390	389.705	4450	1075.743	3.0 ″	4.064 ″
12	8.457	120	49.968	630	197.878	1400	392.125	4500	1086.390	4.0 ″	5.313 ″
13	8.964	125	51.648	640	200.542	1410	394.543	4550	1097.024	5.0 ″	6.544 ″
14	9.461	130	53.317	650	203.201	1420	396.959	4600	1107.646	6.0 ″	7.761 ″
15	9.949	135	54.976	660	205.854	1425	398.167	4650	1118.257	7.0 ″	8.965 ″
16	10.434	140	56.625	670	208.502	1430	399.373	4700	1128.854	8.0 ″	1.016(10)
17	10.913	145	58.265	675	209.825	1440	401.786	4750	1139.439	9.0 ″	1.134 ″
18	11.386	150	59.895	680	211.145	1450	404.197	4800	1150.012	$1.0(10)^7$	1.252 ″
19	11.855	155	61.517	690	213.784	1460	406.606	4850	1160.574	1.5 ″	1.828 ″
20	12.319	160	63.131	700	216.417	1470	409.013	4900	1171.125	2.0 ″	2.398 ″
21	12.778	165	64.737	710	219.046	1475	410.214	4950	1181.666	2.5 ″	2.961 ″
22	13.233	170	66.336	720	221.670	1480	411.418	5000	1192.198	3.0 ″	3.517 ″
23	13.684	175	67.928	725	222.980	1490	413.820	5100	1213.222	4.0 ″	4.610 ″
24	14.131	180	69.512	730	224.289	1500	416.220	5200	1234.203	5.0 ″	5.689 ″
25	14.573	185	71.090	740	226.904	1525	422.214	5300	1255.141	6.0 ″	6.758 ″
26	15.013	190	72.661	750	229.514	1550	428.196	5400	1276.037	7.0 ″	7.816 ″
27	15.450	195	74.226	760	232.120	1575	434.168	5500	1296.893	8.0 ″	8.866 ″
28	15.883	200	75.785	770	234.721	1600	440.128	5600	1317.709	9.0 ″	9.911 ″
29	16.313	205	77.338	775	236.020	1625	446.077	5700	1338.486	$1.0(10)^8$	1.095(10)
30	16.742	210	78.886	780	237.318	1650	452.016	5800	1359.225	1.5 ″	1.604 ″
31	17.167	215	80.428	790	239.912	1675	457.945	5900	1379.927	2.0 ″	2.108 ″
32	17.590	220	81.965	800	242.501	1700	463.863	6000	1400.593	2.5 ″	2.607 ″
33	18.011	225	83.497	810	245.086	1725	469.771	6100	1421.224	3.0 ″	3.100 ″
34	18.429	230	85.023	820	247.668	1750	475.669	6200	1441.820	4.0 ″	4.071 ″
35	18.845	235	86.545	825	248.957	1775	481.558	6300	1462.383	5.0 ″	5.032 ″
36	19.259	240	88.062	830	250.245	1800	487.437	6400	1482.912	6.0 ″	5.984 ″
37	19.671	245	89.575	840	252.819	1825	493.307	6500	1503.408	7.0 ″	6.928 ″
38	20.080	250	91.084	850	255.388	1850	499.167	6600	1523.872	8.0 ″	7.865 ″
39	20.488	255	92.589	860	257.953	1875	505.019	6700	1544.305	9.0 ″	8.797 ″
40	20.894	260	94.090	870	260.515	1900	510.861	6800	1564.706	$1.0(10)^9$	9.725 ″
41	21.298	265	95.588	875	261.795	1925	516.695	6900	1585.077	1.5 ″	1.429(10)
42	21.701	270	97.081	880	263.073	1950	522.520	7000	1605.418	2.0 ″	1.880 ″
43	22.101	275	98.571	890	265.629	1975	528.337	7100	1625.729	2.5 ″	2.328 ″
44	22.500	280	100.057	900	268.181	2000	534.145	7200	1646.011	3.0 ″	2.771 ″
45	22.897	285	101.540	910	270.729	2025	539.945	7300	1666.265	4.0 ″	3.645 ″
46	23.291	290	103.019	920	273.274	2050	545.737	7400	1686.490	5.0 ″	4.510 ″
47	23.684	295	104.495	925	274.545	2075	551.522	7500	1706.688	6.0 ″	5.368 ″
48	24.076	300	105.968	930	275.815	2100	557.299	7600	1726.859	7.0 ″	6.220 ″
49	24.466	305	107.437	940	278.353	2125	563.068	7700	1747.002	8.0 ″	7.066 ″
50	24.855	310	108.904	950	280.888	2150	568.830	7800	1767.120	9.0 ″	7.909 ″
51	25.244	315	110.367	960	283.420	2175	574.585	7900	1787.212	$1.0(10)^{10}$	8.747 ″

Craft & Hawkins

Q_D for Infinite Limited Aquifers

Table 5.1. (Cont'd.)

Dimensionless time t_D	Fluid influx $Q(t)$	Dimensionless time t_D	Fluid influx $Q(t)$	Dimensionless time t_D	Fluid influx $Q(t)$	Dimensionless time t_D	Fluid influx $Q(t)$	Dimensionless time t_D	Fluid influx $Q(t)$	Dimensionless time t_D	Fluid influx $Q(t)$
[illegible]	25.633	320	111.827	970	285.948	2200	580.332	8000	1807.278	1.5 ″	$1.288(10)^9$
[illegible]	26.020	325	113.284	975	287.211	2225	586.072	8100	1827.319	2.0 ″	1.697 ″
[illegible]	26.406	330	114.738	980	288.473	2250	591.806	8200	1847.336	2.5 ″	2.103 ″
[illegible]	26.791	335	116.189	990	290.995	2275	597.532	8300	1867.329	3.0 ″	2.505 ″
[illegible]	27.174	340	117.638	1000	293.514	2300	603.252	8400	1887.298	4.0 ″	3.299 ″
[illegible]	27.555	345	119.083	1010	296.030	2325	608.965	8500	1907.243	5.0 ″	4.087 ″
[illegible]	27.935	350	120.526	1020	298.543	2350	614.672	8600	1927.166	6.0 ″	4.868 ″
[illegible]	28.314	355	121.966	1025	299.799	2375	620.372	8700	1947.065	7.0 ″	5.643 ″
[illegible]	28.691	360	123.403	1030	301.053	2400	626.066	8800	1966.942	8.0 ″	6.414 ″
[illegible]	29.068	365	124.838	1040	303.560	2425	631.755	8900	1986.796	9.0 ″	7.183 ″
[illegible]	29.443	370	126.270	1050	306.065	2450	637.437	9000	2006.628	$1.0(10)^{11}$	7.948 ″
[illegible]	29.818	375	127.699	1060	308.567	2475	643.113	9100	2026.438	1.5 ″	$1.17(10)^{10}$
[illegible]	30.192	380	129.126	1070	311.066	2500	648.781	9200	2046.227	2.0 ″	1.55 ″
[illegible]	30.565	385	130.550	1075	312.314	2550	660.093	9300	2065.996	2.5 ″	1.92 ″
[illegible]	30.937	390	131.972	1080	313.562	2600	671.379	9400	2085.744	3.0 ″	2.29 ″
[illegible]	31.308	395	133.391	1090	316.055	2650	682.640	9500	2105.473	4.0 ″	3.02 ″
[illegible]	31.679	400	134.808	1100	318.545	2700	693.877	9600	2125.184	5.0 ″	3.75 ″
[illegible]	32.048	405	136.223	1110	321.032	2750	705.090	9700	2144.878	6.0 ″	4.47 ″
[illegible]	32.417	410	137.635	1120	323.517	2800	716.280	9800	2164.555	7.0 ″	5.19 ″
[illegible]	32.785	415	139.045	1125	324.760	2850	727.449	9900	2184.216	8.0 ″	5.89 ″
[illegible]	33.151	420	140.453	1130	326.000	2900	738.598	10,000	2203.861	9.0 ″	6.58 ″
[illegible]	33.517	425	141.859	1140	328.480	2950	749.725	12,500	2688.967	$1.0(10)^{12}$	7.28 ″
[illegible]	33.883	430	143.262	1150	330.958	3000	760.833	15,000	3164.780	1.5 ″	$1.08(10)^{11}$
[illegible]	34.247	435	144.664	1160	333.433	3050	771.922	17,500	3633.368	2.0 ″	1.42 ″
[illegible]	34.611	440	146.064	1170	335.906	3100	782.992	20,000	4095.800		
[illegible]	34.974	445	147.461	1175	337.142	3150	794.042	25,000	5005.726		
[illegible]	35.336	450	148.856	1180	338.376	3200	805.075	30,000	5899.508		

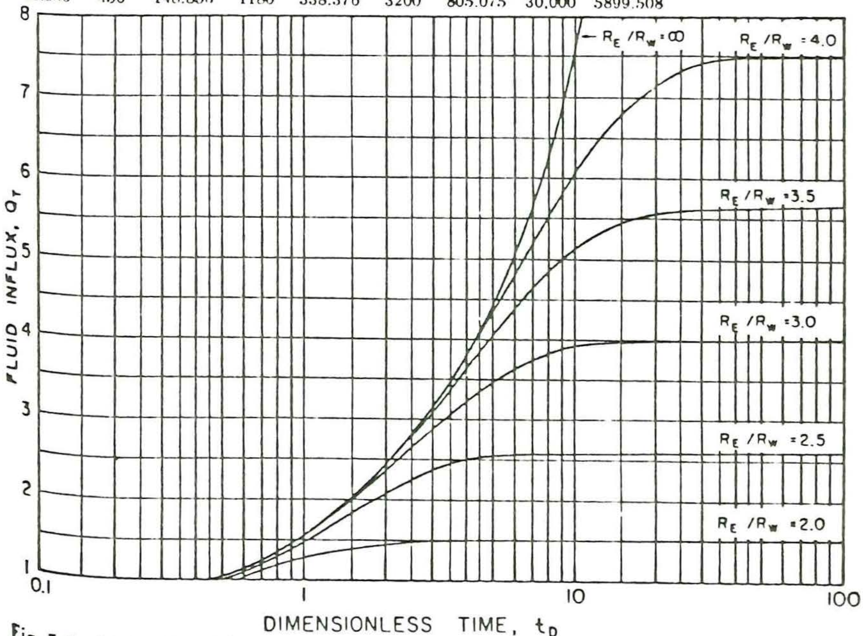


Fig. 5.6. Limited aquifer values of dimensionless influx $Q(t)$ for values of dimensionless time t_D and aquifer limits given by the ratio r_e/r_w.