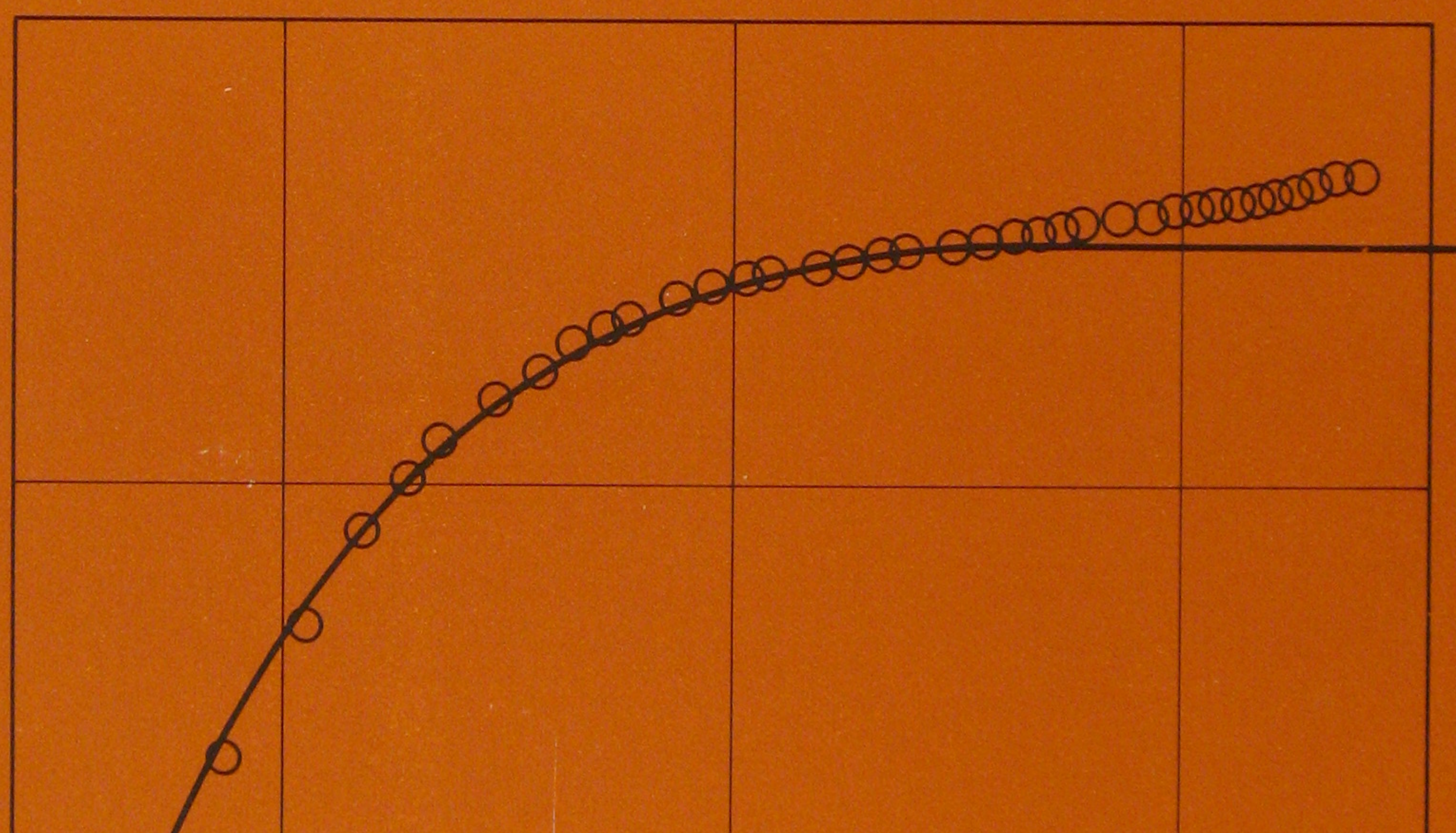
Interactive computer processing and interpretation of pumping test data

A Micro-computer program using dynamic graphics



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A Micro-computer program using dynamic graphics

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ABSTRACT.

This paper presents a computer program for analysing pumping test data. The program is interactive and may be used with a minimum knowledge of computers. It can be applied to a wide range of transient problem types, from one dimensional groundwater flow to flow in anisotropic aquifers, horisontally as well as vertically. Various forms of type curves based on analytical solutions to the groundwater flow equation are available for the interpretation. The paper includes a listing of the entire computer program containing a total of about 1.800 lines. The programming language is a BASIC-version suited for the Tektronix 4054, a graphic screen with a refresh option. This option allows the user to perform type curve matching directly on the screen by moving the chosen type curve to the position where it gives the best fit, in a manner similar to traditional manual chart interpretation. Plots of the measured data may be conveniently reproduced in semilog and log-log diagrams, either on the screen or as a hard copy printed by a plotter. The present version of the program makes use of tape cartridges, both for storing program and data files.

INTRODUCTION.

Due to the very time-consuming processes of manual plotting and interpretation of pumping test data, the need for some sort of computerized system has increased within the last few years. The demand was primarily to develop a system that allowed for an easy interactive interpretation process and was able to reproduce the results quickly and with fairly good quality.

In order to fulfill this task, which for the most part is of graphic type, the present program has become interactive and evaluated in a BASIC-version, specially suited for the

Tektronix 4054, a graphic screen with a refresh option (dynamic graphics) and containing a 64-K microcomputer. Type curve matching can then be performed directly on the screen, in a manner similar to traditional manual chart interpretation. In combination with a small flat-bed plotter and a hardcopy unit, this entire system is a very powerful tool when solving minor computer and plotting tasks similar to the one described later in this paper. The limitations in the application of the system are primarily associated with the rather low memory capacity and the reduced calculation effectivity due to the programming language and the lack of library functions such as the error- and Bessel-functions.

However, the program can be applied to a wide variety of pumping test investigations and interpret data arising from flow problems associated with one, two or even three dimensions. The pumping test data may be plotted on either semi-log diagrams or log-log diagrams and interpreted by means of a number of analytical solutions to the groundwater flow equation. This paper includes a detailed description of the theoretical background for each solution used and the numerical methods applied to solve the integral and regression expressions. Additional type curves for different parameter values are given as attachments, however, no attempt has been made to go deeply into the use of these solutions on geohydrological problems. Discussions concerning these solutions are given in some of the references mentioned, for instance Reed, 1980. The paper further includes a detailed description of how the entire program works step by step, with each subroutine mentioned separately. A total program listing, list of variables and input/output examples are given as attachments. The computer program consists of an input and output part including fourteen subroutines and a main routine controlling the entire program. The program encompasses approximately 1.800 lines. The present version has to be operated by means of tape cartridges for both program storage and data storage.

THEORETICAL BACKGROUND.

The interpretation of pumping test data is usually done by manual type curve matching (Andersen and Haman, 1973; Kruseman and Ridder, 1976; Reed, 1980), primarily to determine the hydraulic properties of the aquifer such as transmissivity and storage coefficient. Various forms of type curves based on analytical solutions are available and will be discussed in more detail later in this section. The analytical solutions of the transient groundwater flow equation (eq. 1) are obtained for a number of cases where certain boundary and initial conditions are prescribed to aquifers having simple (from mathematical point of view) geometry. The differential form of the transient flow equation can, for a homogeneous, anisotropic, confined and leaky aquifer with constant thickness and storage coefficient, be described as:

$$\partial/\partial x_i (K_i \partial s/\partial x_i) - (K'/b')(s/b) = (S/b)(\partial s/\partial t) \qquad (1)$$

$$i = 1, 2, 3$$

The first solution of the transient groundwater flow problem was obtained by C.V. Theis, 1935) for the simplified situation described by eq. 2:

$$\partial^2 s/\partial r^2 + (1/r)(\partial s/\partial r) = (S/T)(\partial s/\partial t) \qquad (2)$$

Eq. 2 is written under the following assumptions: the aquifer is confined and has constant transmissivity and storage coefficient, the flow is radial and there is no leakage.

For a well of infinitesimal diameter, discharging at a constant rate, Q, eq. 2 can be solved to yield the well known expression for the drawdown in water level, s, at a given distance, r, and to a given time, t:

$$s = (Q/4\pi T)W(u) \qquad (3)$$

and

$$u = r^2S/(4Tt) \qquad (3a)$$

W(u) is the "well function", described later.

This is the fundamental equation for solving transient pumping test data. It can be adapted to a wide range of aquifer test problems, also when the basic conditions are not quite fulfilled. However, the need for a more detailed description of the aquifer/aquitard properties has resulted in a number of often more complicated analytical solutions to the flow equation. In the following discussion, the most useful of these solutions and the numerical methods used for generating type curve function values are presented.

The solutions are all evaluated for flow toward a well in an infinite aquifer with constant discharge and infinitesimal diameter. In addition, the aquifer should be confined in order to obtain horizontal flow and permit use the above mentioned linear differential equation. However, most of the solutions may be used directly for unconfined flow where the differential equation is theoretically non-linear. This implies that the drawdowns are small compared with the thickness of the saturated zone. Otherwise, the data has to be corrected for decreasing thickness of the aquifer, a procedure which can be automatically performed by the developed computer program. This correction is used primarily for pumping well data where the drawdowns are inherently greatest. The corrected values for the drawdown data can be calculated from the expression:

$$s_c = s - s^2/2b$$

where s is the observed drawdown and b is the original thickness of the saturated zone. The correction expression for recovery data can similarly be written as

$$s_c = s + (s_o - s)^2/2b$$

where s_o is the drawdown at the beginning of the recovery period.

Additional assumptions relevant to the above, will be given in connection with the discussion of individual situations.

SITUATION 1:

Fully penetrating well in a leaky strip aquifer.

Assumptions:

- Aquifer is overlain or underlain everywhere by a confining bed having uniform hydraulic conductivity (K′) and thickness (b′).

- Confining bed is overlain or underlain by an infinite constant head plane source.

- Hydraulic gradient across confining bed changes instantaneously with a change in head in the aquifer (no release of water from storage in the confining bed).

- Flow in the aquifer is one-dimentional and horizontal (strip aquifer) and flow in the confining bed is vertical. This assumption is closely approximated where the hydraulic conductivity of the aquifer is sufficiently greater than that of the confining bed.

Differential equation:

$$\partial^2 s/\partial x^2 - s/B^2 = (S/T)(\partial s/\partial t) \quad (4)$$

Boundary and initial conditions:

$s(\infty,t)=0, \quad t\geq 0$

$s(r,0)=0, \quad r\geq 0$

$$Q=\begin{cases}0, & t<0\\ \text{constant} >0, & t\geq 0\end{cases}$$

$$\lim_{x\to 0} \partial s/\partial x = -Q/(Tw)$$

Solution (Nguyen and Raudkivi, 1982):

$$s = \frac{QB}{Tw}\left[\exp(-x/B)-\tfrac{1}{2}(\exp(-x/B)\mathrm{erfc}(\xi)+\exp(x/B)\mathrm{erfc}(\eta))\right] \quad (5)$$

where $B = \sqrt{T/(K'/b')}$ (5a)

and
$$\begin{cases}\xi = \tfrac{1}{2}\sqrt{u}(x/B)-1/\sqrt{u} & (5b)\\ \eta = \tfrac{1}{2}\sqrt{u}(x/B)+1/\sqrt{u} & (5c)\end{cases}$$

$$u = x^2S/4Tt \quad (5d)$$

$$\mathrm{erfc}(v) = (2/\sqrt{\pi})\int_v^\infty \exp(-y^2)dy \quad (5e)$$

For the nonleaky case (x/B=0):

$$s = \frac{Qx}{Tw}\left[\exp(-u)/\sqrt{\pi u} - \mathrm{erfc}(\sqrt{u})\right] \quad (6)$$

Definition sketch and selected type curves for different values of x/B are shown in figs. 1a-b, attachment VI.

SITUATION 2:

Fully penetrating well in a leaky aquifer.

Assumptions:

- Aquifer is overlain or underlain everywhere by a confining bed having uniform hydraulic conductivity (K′) and thickness (b′).

- Confining bed is overlain or underlain by an infinite constant head plane source.

- Hydraulic gradient across confining bed changes instantaneously with a change in head in the aquifer (no release of water from storage in the confining bed).

- Flow in the aquifer is two-dimentional and radial in the horizontal plane and flow in the confining bed is vertical. This assumption is closely approximated where the hydraulic conductivity of the aquifer is sufficiently greater than that of the confining bed.

Differential equation:

$$\partial^2 s/\partial r^2 + (1/r)(\partial s/\partial r) - (s/T)(K'/b') = (S/T)(\partial s/\partial t) \qquad (7)$$

Boundary and initial conditions:

$s(\infty,t)=0, \quad t\geq 0$

$s(r,0)=0, \quad r\geq 0$

$$Q=\begin{cases}0 & t<0\\ \text{constant} >0, & t\geq 0\end{cases}$$

$$\lim_{r\to 0} r\,\partial s/\partial r = -Q/(2\pi T)$$

Solution (Hantush and Jacob, 1955):

$$s = \frac{Q}{4\pi T}\int_u^\infty f_i(y)dy = \frac{Q}{4\pi T}W(u,r/B),$$

$$f_1(y) = \frac{\exp(-y-r^2/4B^2y)}{y} \qquad (8)$$

where $u = r^2S/4Tt$ (8a)

and $B = \sqrt{T\,b'/K'}$ (8b)

For r/B=0 (no leakage), the above expression turns into the well known Theis-solution (eq. 3, page 4), which can be written as an infinite series:

$$s = \frac{Q}{4\pi T}W(u) = -0.5772-\ln u-\sum_i^\infty \frac{u^n(-1)^n}{n!n} \qquad (9)$$

For sufficiently small values of u, less than 0.05, corresponding to small r or great t, the equation can be simplified to yield the approximate expression (Jacob, 1946):

$$s = \frac{Q}{4\pi T}(-0.5772-\ln u) \qquad (10)$$

which may be used for straight line interpretation when data are plotted in a semilog diagram. The above equation is mainly used when dealing with pumping well data.

Definition sketch and selected type curves for different values of r/B are shown in figs. 2a-b, attachment VI.

SITUATION 3:

Fully penetrating well in a leaky aquifer with storage of water in the confining beds.

Assumptions:

- Aquifer is overlain or underlain everywhere by confining beds having uniform hydraulic conductivity (K′), thickness (b′) and storage coefficient (S′).

- Confining bed is overlain by 1) an infinite constant head plane source or 2) by an impermeable bed.

- Flow in the aquifer is two-dimensional and radial in the horizontal plane and flow in the confining bed is vertical. This assumption is closely approximated where the hydraulic conductivity of the aquifer is sufficiently greater than that of the confining bed.

Differential equations:

For the confining bed (vertical flow)

$$\partial^2 s'/\partial z^2 = (S'/K'b')\partial s'/\partial t \qquad (11)$$

For the aquifer (horizontal flow)

$$\partial^2 s/\partial r^2 + (1/r)\partial s/\partial r + (K'/T)\partial s'/\partial z = (S/T)(\partial s/\partial t) \tag{12}$$

Boundary and initial conditions:

For an upper confining bed

$s'(r,z,0)=0$

$s'(r,b',t)=s(r,t)$

$$\begin{cases} s'(r,0,t)=0, & \text{for 1) constant head plane source} \\ \partial s'(r,0,t)/\partial z=0, & \text{for 2) impermeable bed} \end{cases}$$

For the aquifer

$s(\infty,t)=0, \quad t\geq 0$

$s(r,0)=0, \quad r\geq 0$

$$Q=\begin{cases} 0 & t<0 \\ \text{constant} >0, & t\geq 0 \end{cases}$$

$$\lim_{r\to 0} \partial s/\partial r = Q/2\pi T$$

Solution (Hantush, 1964):

For small values of time ($t<b's'/10K'$)

$$s = \frac{Q}{4\pi T}\int_u^\infty f_2(y)dy = \frac{Q}{4\pi T} H(u,\beta),$$

$$f_2(y) = \frac{\exp(-y)}{y} \operatorname{erfc} \frac{\beta\sqrt{u}}{\sqrt{y(y-u)}} \tag{13}$$

where $u = r^2S/4Tt$ (13a)

and $\beta = (r/4)\sqrt{K'S'/b'TS}$ (13b)

$$\operatorname{erfc}(v) = 2/\sqrt{\pi}\int_v^\infty \exp(-y^2)dy \tag{13c}$$

For large values of time ($t>5b'S'/K'$)

$$s = \frac{Q}{4\pi T} W(u\delta, r/B) \qquad (14)$$

$$\text{where } \delta = \begin{cases} 1+S'/3S, & \text{for 1) constant head plane source} \quad (14a) \\ 1+S'/S, & \text{for 2) impermeable bed} \quad (14b) \end{cases}$$

and $B = \sqrt{Tb'/K'}$

$r/B = 0$ for 2) impermeable bed (14c)

$W(u,v)$ is as defined previously in solution 2.

Definition sketch and selected type curves for the $H(u,\beta)$ function for different values of r/B are shown in figs. 3a-b, attachment VI.

SITUATION 4:

Partially penetrating well in a leaky aquifer.

Assumptions:

- Aquifer has radial-vertical anisotropy.
- Aquifer is overlain or underlain everywhere by a confining bed having uniform hydraulic conductivity (K') and thickness (b').
- Confining bed is overlain or underlain by an infinitely constant head plane source.
- Hydraulic gradient across confining bed changes instantaneously with a change in head in the aquifer (no release of water from storage in the confining bed).

- Flow is vertical in the confining bed.

- The leakage from the confining bed is assumed to be generated within the aquifer so that no vertical flow results from leakage alone in the aquifer.

Differential equation:

$$\partial^2 s/\partial r^2 + (1/r)(\partial s/\partial r) + a^2 \partial^2 s/\partial z^2 - (s/T)(K'/b') = (S/T)(\partial s/\partial t) \qquad (15)$$

and $$a^2 = K_z/K_r \qquad (15a)$$

Boundary and initial conditions:

$$s(\infty,z,t) = 0, \quad t \geq 0$$
$$s(r,z,t) = 0, \quad r \geq 0$$
$$\left.\begin{aligned}\partial s(r,0,t)/\partial z &= 0,\\ \partial s(r,b,t)/\partial z &= 0,\end{aligned}\right\} \quad r \geq 0, t \geq 0$$

$$Q = \begin{cases} 0, & r<0 \\ \text{constant}>0, & t \geq 0 \end{cases}$$

$$\lim_{r \to 0} r\partial s/\partial r = \begin{cases} 0, & \text{for } 0<z<d \\ -Q/(2\pi K_r(1-d)), & \text{for } d<z<1 \\ 0, & \text{for } 1<z<b \end{cases}$$

Solution (Hantush, 1964):

$$s = \frac{Q}{4\pi T}\left[W(u,r/B) + f(u,ar/b,r/B,d/b,1/b,d'/b,1'/b)\right] \qquad (16)$$

$$\text{where } W(u,r/B) = \int_u^\infty \frac{\exp(-y-r^2/(4B\ y)}{y}\, dy \qquad (16a)$$

and $u = r^2S/4Tt$ (16b)

$B = \sqrt{Tb'/K'}$ (16c)

$$f(u, ar/b, r/B, d/b, l/b, d'/b, l'/b)$$
$$= 2b^2/\pi^2 (l-d)(l'-d)$$
$$\cdot \sum_{n=1}^{\infty} 1/n^2 \ (\sin n\pi l/b - \sin n\pi d/b)(\sin n\pi l'/b - \sin n\pi d'/b)$$
$$\cdot W(u, \sqrt{(r/b)^2 + (n\ ar/b^2}) \qquad (16d)$$

Please refer to fig. 4a, attachment VI concerning the geometry of the system. Selected type curves for r/B=0 and r/B=0.5 with varying depths of drawdown observations are shown in fig. 4b.

SITUATION 5:

Fully penetrating well in a nonleaky fractured aquifer.

Assumptions:

- Aquifer is not leaky.
- Aquifer consists of horizontal fractures and interjacent rock matrix.
- Storage coefficient of the fractures is very low compared with that of the matrix.
- Flow in the aquifer is horizontal and radial in the fractures and flow in the rock matrix is vertical. This assumption is closely approximated where the hydraulic conductivity of the fractures is sufficiently greater

than that of the rock matrix.

Differential equation:

$$\partial^2 s/\partial r^2 + (1/r)(\partial s/\partial r) + q/T_f = (S_f/T_f)(\partial s/\partial t) \quad (17)$$

q is a source term depending on the fracture space, the matrix area and the pressure distribution and hydraulic conductivity of the matrix.

Boundary and initial conditions:

$s(\infty,t)=0, \quad t \geq 0$
$s(r,0)=0, \quad r \geq 0$

$$Q = \begin{cases} 0, & t<0 \\ \text{constant} >0, & r \geq 0 \end{cases}$$

$$\lim_{r \to 0} r(\partial s/\partial r) = -Q/(2\pi T_f)$$

Solution (Najurieta, 1980):

$$s = \frac{Q}{4\pi t_f} \int_{u_c}^{\infty} \frac{\exp(-y)}{y}\, dy = \frac{Q}{4\pi T_f} W(u_c) \quad (18)$$

$$\text{where } u_c = u(\frac{\beta}{1+\beta} + \frac{\beta}{1+\beta} \sqrt{\frac{1}{\alpha u}} \tanh \sqrt{\alpha u} \quad (18a)$$

$$\text{and} \quad u = r^2 (S_{ma}+S_f)/4T_f t \quad (18b)$$

$$\beta = S_f/S_{ma} \quad (18c)$$

$$\alpha = \frac{\gamma\ T_f\ h_{ma}}{r^2(1+S_f/S_{ma})K_{ma}}, \quad \gamma = 1.781 \qquad (18d)$$

ma refers to matrix, f to fractures.

Definition sketch and selected type curves for different values of α and β are shown in figs. 5a-b, attachment VI.

NUMERICAL METHODS.

The above mentioned analytical solutions to the groundwater flow equation all include semi-infinite integrals. As a result, function values cannot be calculated explicitly by simple mathematical relations but have to be approximately computed by means of numerical methods. Primarily in order to save memory capacity, one integration routine is normally applied to different solutions. Only a few basic routines are then needed to perform the calculation of any of the five mentioned type curve functions. Simple integration formulas such as Simpson's rule and the midpoint formula have proved to be rather convenient for this purpose, giving sufficiently accurate values with a reasonably limited computation time. A brief description of the regression routine used for the straight line interpretation method is also presented.

Integration expressions.

The erfc(v)-expression is a part of Situation 1 and Situation 3 (equations 5, 6 and 13).

The integral is computed by means of a rational approximation method (Abramowitz and Stegun, 1970):

$$\mathrm{erfc}(v) \sim (a_1 p + a_2 p^2 + a_3 p^3)\exp(-v^2), \quad p = 1/(1+a_4 v) \tag{19}$$

where a_1, a_2, a_3, and a_4 are constants.

This expression is computed quickly and yields sufficiently exact values.

The semi-infinite integral, W(u,r/B), forms the main part of Situations 2, 4 and 5 (equations 8, 13, 16 and 18).

The integral is computed by using a simple integration formula, the Simpson's rule, in connection with a convergence criterion. As appears from the diagram, Fig. 1, the shape of the integrand-function, $f_1(y)$, invites the use of Simpson's rule on sub-intervals of increasing length with increasing values of the variable y. The optimum length of each sub-interval is found to be the same size as the value of the respective interval starting point. When the function-variable, y, exeeds the value 10, the calculation stops and the approximate value of the integral exists as a summation of the computed values of the sub-intervals.

The W(u,r/B)-function can then be written as the following series approximation:

$$W(u,r/B) = \int_u^\infty f_1(y)dy$$

$$\sim \sum_{n=0}^{c} (u2^n/6)\left[f_1(u2^n) + 4f_1(3/2u2^n) + f_1(u2^{n+1})\right] \tag{20}$$

where the convergence criterion is given by:

$$u2^c \leq 10 \tag{20a}$$

This calculation routine requires only very little memory capability, is simple to use and gives sufficiently accurate W(u,r/B)-values within a reasonably limited computation time.

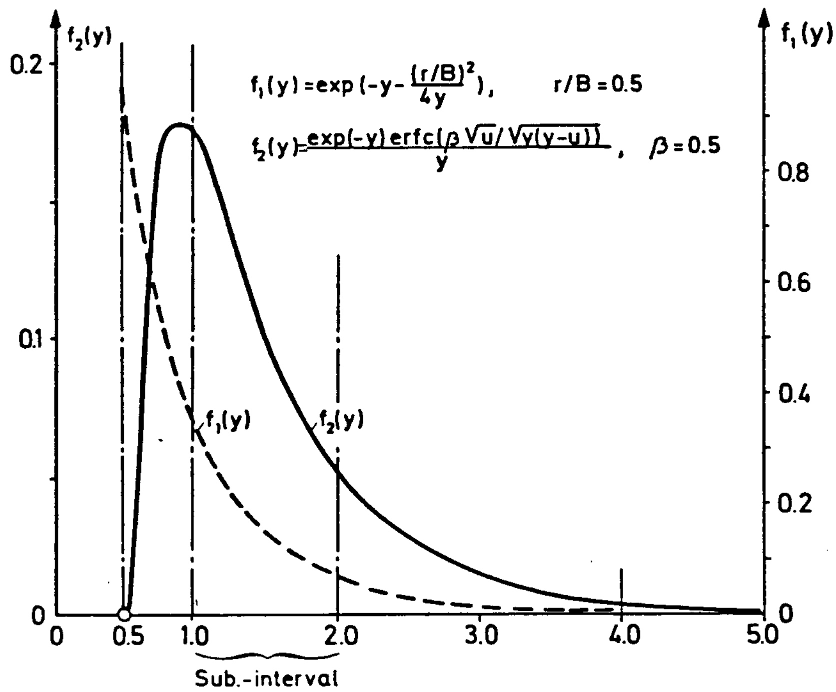

Fig. 1.: Shape of the graphs for the integrand function $f_1(y)$ and $f_2(y)$ for W(u,r/B) and H(u,β)

Although the semi-infinite integral in Situation 5, $W(u_c)$, can be written as an infinite series (according to equation 9, page 9), the calculation of the integral takes place as numeric integration using Simpson's rule on sub-intervals. This procedure is chosen only to use the existing calculation routine and thereby save memory capacity given the realization that the precision cannot be improved essentially, the computation time will be only slightly reduced and the curve drawing time will not be appreciably affected.

Like the method used for the W(u,r/B)-function, the semi-infinite integral, H(u,β), is computed by using simple integration formulas, primarily Simpson's rule, in connection with a convergence criterion. Similarly, the integration formulas are used on sub-intervals of increasing length with increasing variable y, and the calculation stops when the convergence criterion is exceeded. Because the integrand-function, $f_2(y)$, has a singularity for y = u (according to fig. 1), the Simpson's rule will not be applicable at the beginning of the integration interval.

To overcome this problem, the first subinterval is computed by using a simple midpoint integration formula on a subdivision of the interval into 10 intervals of equal length. For the remainder of the subintervals, Simpson's rule is used.

The H(u, β)-function can then be written as the following series approximation:

$$H(u,\beta) = \int_u^{\infty} f_2(y)dy$$

$$\sim 0.1u \sum_{m=0}^{9} f_2((1.05+0.1m)u)$$

$$+ \sum_{n=1}^{c} (u2^n/6) \left[f_2(u2^n) + 4f_2(\tfrac{3}{2}u2^n) + f_2(u2^{n+1})\right] \qquad (21)$$

where the convergence criterion is given by:

$$u2^c \leq 10 \qquad (21a)$$

The erfc(x)-integral in $f_2(y)$ is computed by means of a rational approximation method (Abramowitz and Stegun, 1970), according to Situation 1:

$$\mathrm{erfc}(v) \sim (a_1p + a_2p^2 + a_3p^3)\exp(-v^2), \quad p = 1/(1+a_4v) \qquad (21b)$$

where a_1, a_2, a_3 and a_4 are constants.

The calculation routine makes partial use of the previously mentioned routines and, for that reason, requires rather limited memory capability and gives sufficiently accurate $H(u,\beta)$-values with a reasonably low computation time within the whole range of used β-factors.

Equation 16 in Situation 4 consists of two parts, the normal $W(u,r/b)$-function (eq. 16a) and an additional part, (eq. 16d), an infinite summation of the $W(u,r/B)$-function. Simpson's rule can be adapted under the same conditions as mentioned previously to compute the $W(u,r/B)$-function values. The main problem is then to determine a suitable convergence criterion for the infinite summation in order to get reasonably accurate function values with the lowest possible numbers of summations. Because of the rather complex nature of the partial penetration solution, the calculation routine is mainly a result of a trial and error process. The routine can be written as follows:

$$W(u,v_0) + f = W(u,v_0) + C_0 \sum_{n=1}^{c_1} (1/n^2)C(n)W(u,v_1(n)) \qquad (22)$$

where: $$C_0 = \frac{2b^2}{\pi^2(l-d)(l'-d')} \qquad (22a)$$

$$C(n) = (\sin n\pi l/b - \sin n\pi d/b)(\sin n\pi l'/b - \sin n\pi d'/b) \qquad (22b)$$

$$v_1(n) = \sqrt{v_0^2 + n\pi ar/b)^2} \qquad (22c)$$

and $$W(u,x) = \int_u^\infty f_1(y)dy$$

$$\sim \sum_{n=0}^{c} (2^n u/6)\left[f_1(2^n u) + 4f_1(3/2\ 2^n u) + f_1(2^{n+1}u)\right] \qquad (22d)$$

$$u2^c \leq 10 \qquad (22e)$$

The number of summations, c_1, is determined on the basis of a comparison between the last calculated terms in the summation and the basic term, $W(u,x_0)$. The summation in f_1 and the final computation of a function value is finished when the following inequality is fulfilled:

$$\sum_{n=c-2}^{c} \left|(1/n^2)C(n)W(u,v_1(n))\right| < 0.004(1/C_0)W(u,v_0) \qquad (22f)$$

Under unfavorable circumstances, this summation term can converge so slowly that the number of summations may reach 30-40 steps.

As is seen from the above, the partial penetration calculation routine is the most time consuming of all the solutions presented in this paper. However, the curve drawing time will, under normal conditions, only be increased by a factor of 2-3, so the problem generally seems to be acceptable.

Regression expressions.

The simplified expression for the Theis well-function,

$$W(u) \sim 0.5772-\ln(u), \quad u < 0.55 \qquad (23)$$

is used when analysing data in a semilog diagram. In contrast to the other mentioned solutions, the curve-fitting in this case takes place as logarithmic regression calculation on the data points within a selected time-interval. The regression routine being used has the form

$$C_1 = \frac{\Sigma y \ln v-(1/n)\Sigma y \Sigma \ln v}{\Sigma(\ln v)^2-(1/n)(\Sigma \ln v)^2} \qquad (24a)$$

$$C_2 = (1/n)\Sigma y-(C_1/n)\Sigma \ln v \qquad (24b)$$

where $y = C_2 + C_1 \ln v$

and n is number of pairs (v,y) to be examined.

COMPUTER PROGRAM.

This computer program serves as a means to graphically visualize and analyse measured pumping test data. This may be performed either directly on the screen or by means of a plotter. In this chapter, the structure and special features of the program will be discussed and instructions on how to run the program for both input and output will be given. The BASIC program developed for analysing pumping test data is listed in its full length in attachment I and consists of approximately 1800 written liines including remarks. In order to run the program on a 64 K-bytes computer however all remarks have to be deleted because of the lack of sufficient memory. The definition of all variables used in the program is presented in attachment II. In order to save memory, a part of the internal variables are used for various 'purposes in different parts of the program. The computer program was developed, and has been run for a couple of years, on a Tektronix 4054, a graphic screen containing a 64 K-bytes micro-computer with a refresh option (dynamic graphics).

GENERAL PROGRAM FEATURES.

The program is interactive and asks for each command to be read in. This gives the user the advantage of being able to run the program with only a minimum knowledge of computers. The program is segmented into a main routine and an input and output part containing a total of fourteen subroutines.

The program is operated solely by means of user definable keys (from 1 to 20) which allows one to move freely from one subroutine to another. Each key refers directly to one fixed line number in the program and these keys can be used instead of written commands. The key-operations are pre-programmed in the machine so that the line numbers 4, 8, 12 etc. are activated when pushing the key-buttons 1, 2, 3 etc respectively. In the program, line numbers from 4 through 100 are reserved for key-operations, according to the program listing in attachment I. The subroutines and the corresponding key-numbers are listed in fig. 2.

MENU	KEY 1	
DATA INPUT	KEY 2	
LISTING DATA	KEY 3	
CHANGING DATA	KEY 4	Input part
DELETING DATA	KEY 5	
ADDING DATA	KEY 6	
STORING ON TAPE	KEY 7	
READING THE TAPE	KEY 8	
DECREASING THICKNESS	KEY 9	
WATERLEVEL FLUCTUATIONS	KEY 10	
SEMILOG, SCREEN	KEY 11	
SEMILOG, PLOTTER	KEY 12	
LOG-LOG, SCREEN	KEY 13	Output part
LOG-LOG, PLOTTER	KEY 14	
TEXT, SCREEN	KEY 15	
TEXT, PLOTTER	KEY 16	
REGRESSION, SEMILOG	KEY 19	
TYPE CURVES, LOG-LOG	KEY 20	

FIG. 2: Subroutines and corresponding key numbers.

The program makes use of the dynamic graphics (refresh) of the 4054-computer. The option is used as the most essential tool during the interpretation of the data. It enables figures to be moved all around the screen by means of two thumbwheels, (one for the x and one for the y direction) and to be fixed wherever desired. Type curve matching can then be performed directly on the screen by moving the chosen type curve to the position where it gives the best fit, in a manner similar to the traditional manual chart method.

In order to run the present version of the program, magnetic tape cartridges should be applied (Scotch DC 300A data cartridge). The tape cartridges are used for storage of either data or computer programs.

PROGRAM SEGMENTS.

The main routine.

The program execution is operated by means of the main routine. Subroutines for input and output are called from the main routine by using the user definable keys mentioned in the previous section. The main routine includes the lines 1-960 in the program of which lines 4-98 control the program execution proper. The rest of the routine is chiefly reserved for the program menu (accoring to fig. 2) which can be recalled and listed on the screen during the program execution in order to remember the subroutines and the corresponding keynumbers.

The input part.

This main section of the program takes care of a correct treatment of the data which is to be put in and stored. It includes six subroutines which will be discussed in the following.

Data input (key 2).

All input data are read through this subroutine. These data define the project and location of the test, type of well and observed data, date and time for set up and shut off, pumping capacity, well file no., distance to the center of pumping well, gauge, initial water level and drawdown (recovery) versus time. The data input presently takes place as a manual keyboard operation. Examples are shown in the figs. 1 and 2, attachment IV (corresponds to the plots in figs. 1 - 3, attachment V). A total listing of data input formats is given in attachment III. The subroutine includes the lines 970 - 2990 of which lines 2430 - 2600 take care of the input of drawdown (recovery) versus time data and the lines 2680 - 2990 calculate the maximum and minimum of the drawdown (recovery) data and the corresponding time data in order to determine the size of the coordinate system used for plotting the data.

In order to perform an input, the data have to be divided into either pumping well data or observation well data and these again subdivided into either drawdown or recovery data. When dealing with pumping well data however both drawdown and recovery may be read in parallel. Variable discharge may also be read in as corresponding values of pumping time and observed pumping rate. The last (or single) pair of data should always include the total pumping time.

Data from an unspecified number of observation wells related to the same pumping test can be stored, but due to the rather low memory capacity of the machine, there is a limit to the number of wells that can be handled at one time. In practice therefore, the maximum number of observation wells stored in the same file should not exceed fifteen. Corresponding values of pumping time and observed drawdowns are stored for one well at a time as a data set in two-dimensional arrays. The maximum number of corresponding time-drawdown values that may be read in for each data set depends on the sort and number of data sets (wells) specified. Regarding pumping well data, the maximum number of corresponding time-drawdown values is 80 for both the pumping and recovery period. The maximum number for observation wells is 60 for less than eight wells or 30 for more than seven wells.

The drawdown (recovery) data may be measured either by automatic recording systems (pressurized transducers, water level recorders, etc.) which directly record the drawdowns, or by manual tape soundings, where the position of the gauge is included in the recorded data as a constant. Using the initial water level (rest water level or water level before shut off), the program automatically compensates for this constant and computes the real drawdowns.

Listing, Changing, Deleting and Adding Data (keys 3, 4, 5 and 6).

The drawdown (recovery) data and their corresponding times may be checked and edited by these four subroutines in order to obtain as correct data files as possible. Other input data however, have to be edited by recalling the corresponding parameter (according to attachment II) and using the editing keys. When deleting or adding data, the program automatically takes care of the renumbering process in order to adjust the data sequence. Drawdown data, which according to the listing have to be changed, deleted or added, must be written as real drawdowns. Real drawdowns are here defined as the difference between the rest water level and the level to which the water table has sunk after a given period of time.

The four subroutines include the lines 3060 - 3108, 3190 - 3380, 3390 - 3610 and 3620 - 3800 respectively. Examples on the editing process are given in fig. 2, attachment III.

Storing on tape (key 7).

Data may be stored for later preparation. Each data input has to be stored in different files, consecutively numbered from one and upwards. The program automatically performs the creation of the files and the storing process. Old files may be edited or renewed and stored again in the original file. In order not to delete the following files it is essential that new files and old files are distinguished from one another. The subroutine includes the lines 3860 - 4070.

The output part.

This third main section of the program is the most extensive part and takes care of both processing and interpretation of the data. The output form consists of diagrams showing drawdown versus time, possibly supplemented with an explanatory text and an interpretation consisting of some form of type curve matching. In order to consider changes in the physical assumptions for the idealized interpretation expressions used, the data can be corrected before analysis (decreasing thickness of the aquifer/regional groundwater fluctuations). The output part includes eight subroutines whose contents and purpose are further described in the following.

Reading the tape (key 8).

Data may be retrieved from the files to be analysed or edited. After typing in the number of the specified file, the program automatically seeks out the file and reads the data into the machine. The subroutine includes the lines

4130 - 4390.

Decreasing thickness (key 9).

In order to get reliable results using the analytical solutions for interpreting the pumping test data from unconfined aquifers, the drawdowns have to be corrected for decreasing thickness of the aquifer if the drawdowns are not small compared with the original thickness of the aquifer (according to the theoretical section, page 4 and 5). The only input required is the aquifer thickness. The program then automatically computes the entire number of corrected drawdowns in the concerned data file. It should be mentioned that the program, in order to simplify the routine, uses the maximum recovery value (at the end of the recovery period) instead of the drawdown value at the shut off, s_o. An approximation which should not affect the accuracy of the correction calculation. The subroutine includes the lines 6390 - 6560.

Water level fluctuations (key 10).

Results from pumping tests of longer duration may be affected by regional changes of the water level, caused by external circumstances such as barometric pressure variations, changes in the infiltration rate etc. By using this subroutine, measured drawdowns influenced by such effects can be corrected automatically. Measures of the barometric pressure, converted to column of water or water level, and which should be only slightly affected by the pumping test, have to be stored as ordinary observation well data, constituting a so-called "correction well". When corrections of the pumping test data are to be made, the data set of the well used as correction well has to be stored in a separate array. This will remain unchanged until new correction well data are stored, no matter which data files have been retrieved in the meantime for further preparation. Thus, the data do not necessarily have to belong to the same file as the correction well in order to be corrected. For each data set (well) the "correction factor" can be chosen individually. This factor, which should normally range between 0 and 1, indicates the magnitude by which the correction well data is to be subtracted from the specified well data. If, for instance, the barometric efficiency is estimated to be 45%, the correction factor used is 0.45. It should also be mentioned that the time values for the correction well do not necessarily have to be congruent with the values for the corrected wells. The program automatically computes the time values needed by linear interpolation between known values, so if the fluctuations form a linear variation during the entire pumping or recovery period, the drawdowns for a correction well should consist of only two pairs of data, one arising from the beginning and one from the end of the test period. The corrected drawdown (recovery) data may be stored in files in the same manner as the original data, thus facilitating retrieval for future studies. The subroutine includes the lines 6630 - 7090

Semilog (keys 11 and 12).

This subroutine provides for the plotting of the data in a diagram with a logarithmic time axis (the abscissa) and an arithmetical drawdown (recovery) axis (the ordinate), either on the screen (key 11) or by a plotter (key 12). An example of a plot is shown in the fig. 1, attachment V (corresponds to the data input in fig. 1, attachment VI). The subroutine includes all the lines 7170 - 9900.

The program automatically computes the scale of the axis on the basis of the data set range (according to subroutine "Data input", page 24-26). The drawdown (recovery) axis will thus be divided into subintervals of 0.1 meter, 1.0 meter or 10 meter lengths depending on whether the difference between the maximum and minimum drawdown (recovery) is less than 1 meter, between 1 and 10 meters or above 10 meters. In other words, if the drawdowns are in the range from 3.5 to 6.3 meters, the axis will be divided into 1 meter intervals from 3 to 7 meters. The time axis normally consists of 5 decades, ranging from 1 min. to 100.000 min (10 weeks) or from 0.1 min. to 10.000 min. (1 week), depending on the observation period. For special cases where there are data both below 1 min. and above 10.000 min., the program is also able to choose a 6 decade plot.

For pumping well data, drawdown and recovery data can be plotted with different symbols and interpreted in the same diagram. Observation well data normally have to be plotted separately, but using the plotter the data points may be plotted without text and diagram, so that in practice an infinite number of data sets can be plotted within the same diagram. In addition, recovery data can be plotted as a function of the dimensionless time, $t/(t+\Delta t)$, which is especially useful when the recovery time, Δt, is of the same order of magnitude as the pumping period, t.

The diagram is supplied with explanatory notes and numbers such as well file no., initial water level measures and reference gauge, axis labels, date of plotting and name of the performing institute (Geological Survey of Denmark). Furthermore, when using the plotter, automatically fixed corner-marks will be drawn on each plot in order to fit the diagram plot and the corresponding text plot together (please refer to subroutine "Text", page 32 for more detailed information). The x,y-dimensions of the diagram are fixed at 21.3 x 15.2 cm.

Log-log (key 13 and 14).

By means of this subroutine the data may be plotted on a diagram with a logarithmic time axis (the abscissa) and a logarithmic drawdown (recovery) axis (the ordinate), either on the screen (key 13) or by a plotter (key 14). Examples of plots are shown in figs. 2 and 3, attachment V (corresponds to the data input in fig. 2, attachment IV). The subroutine includes all the lines 11250 - 14430.

The time and drawdown (recovery) axes are divided into 5 and 4 decades respectively, and as is the case for the semilog plots, the scale of the axes are computed by the program (according to subroutine "Data input", page 24-26). The drawdown (recovery) axes ranges from either 0.001 to 10 meters or from 0.01 to 100 meters. The abscissa can be chosen as an ordinary time axis ranging from 1 min. to 100.000 min. (10 weeks) or from 0.1 min to 10.000 min. (1 week) , or as a t/r^2 axis, or as a dimensionless $t/(t+\Delta t)$ axis, the latter an additional option for recovery data. Data form up to five wells can be plotted in the same diagram. Each well has its own symbol (dots, triangles etc.) and is successively listed with its well file no. in the upper left corner of the diagram. The multi-well plots are very useful when the homogenity of the aquifer is to be examined. Type curve interpretation is accomplished however, when data from only one well is plotted.

The diagram is supplied with axis designation, date of plotting and name of the performing institute (Geological Survey of Denmark). When using the plotter, the possibility of plotting two different size diagrams exists. One version has x,y-dimensions of 21.3 x 17.0 cm and is further supplied with corner marks in order to fit the diagram plot and the corresponding text plot together (for more detailed information, please refer to subroutine "Text", page 32). The other version, the "interpretation plot", has x,y-dimensions of 25.0 x 20.0 cm (5 cm per decade). This plot may be useful when ordinary manual chart interpretation is required.

Text (keys 15 and 16).

This subroutine generates a text-plot containing a number of specifications which may be important for a later identification and investigation of the pumping test. The subroutine includes the lines 4490 - 6310.

The following information is listed: Name of the project, geographical location of the test, well file no. of the pumped well, date and time of the pumping period, pumping capacity, well file no. of the specified observation wells, their distances from the pumped well and computed hydraulic parameters (transmissivity, T (m^2/s), storage coefficient of the aquifer, S, storage coefficient of confining layer(s), S′, leakage coefficient, K′/b′ (s^{-1}) and ratio between horizontal and vertical hydraulic conductivity, K_r/K_z). If there is any change in the capacity of the pumped well, there will also, when dealing with pumping well data, be a plot made showing the pumping capacity versus time. Examples of plots are shown in figs. 1 - 3, attachment V (corresponds to the data inputs, figs. 1 and 2, attachment IV).

When using the plotter, automatically fixed corner-marks will be drawn on each plot. It should then be possible to create a "total" plot consisting of a diagram-plot and a corresponding text-plot by plotting the two topics separately and fit the parts together to the size of A3. This size may normally be easily transformed to the more handy A4-size when copied.

Regression (key 19).

Based upon the Jacob modification of the Theis-solution, equation 10 - page 8, this subroutine calculates the best straight line fit to data-points plotted in a semilog diagram and computes the corresponding transmissivity value. The straight line is calculated on the basis of the expression for logarithmic regression, equations 24a, b - page 21. The fixing of the data-interval to be analysed is denoted by a vertical line, generated by the program, when the machine is in the refresh mode. This line can be moved (horizontally) and fixed at the extreme points of the specified interval. When the interval is fixed, the regression line is drawn and the transmissivity value computed. Several different intervals or wells may successively be tested, but only the last computed transmissivity value for either the drawdown or the recovery data is stored. This also applies for the regression line constants, C_1 and C_2, so in order to make a drawing of the regression line using the plotter, this subroutine should be activated immediately after the corresponding semilog plot has been performed. When dealing with a combined drawdown-recovery plot (pumping well data), it should be kept in mind that T1 refers to the transmissivity value based upon the drawdown data and T2 refers to the recovery data. If variations in the pumping rate have occurred (according to subroutine "Data input", page 24-26) and the test data belong to a pumped well, the calculated mean capacity for the specified interval is used for the transmissivity computation. Otherwise, some mean pumping capacity has to be estimated. The subroutine includes the lines 9960 - 11180.

Type curves (key 20).

When plotting on log-log diagrams, the determination of the curve of best fit no longer takes place as an automatic regression calculation. Since the system allows objects generated on the screen to be moved however, a visual technique just like the traditional manual chart matching procedure is used, according to the "General Program Features" - page 22-24. The specified type curve is calculated by this subroutine when the machine is in the refresh mode. The curve can then be moved by the thumbwheels and fixed where it seems to form the best fit. Simultaneously, the hydraulic parameters, such as transmissivity, T (m^2/s), storage coefficient of the aquifer, S, storage coefficient of confining bed(s), S′ and leakage coefficient, K′/b′ (s^{-1}), are computed and listed and the next trial can be performed. For each well, only the values of the last computed hydraulic parameters are stored. During the entire analysing process only the very last chosen values of the match-point coordinates and type curve variables are stored. This means that this subroutine should be activated immediately after the corresponding log-log plot has been performed in order to get a proper paper-plot showing the type curve used for the interpretation of the data. When interpreting pumping well data, it should be mentioned that the observation distance (the effective radius of the screened interval) is fixed at 0.1 m. Please refer to the list of symbols, in attachment VII, or to the definition sketches, attachment VI, concerning the definition of the type curve variables to be read in.

The type curves are computed on the basis of a number of analytical solutions to the groundwater flow equation as discussed in the section on the theoretical background. It appears from this that five different solutions are implemented in this subroutine and can be used for interpreting the data. The reservoir configurations to be examined are the following: 1) Leaky strip aquifer, D(u,r/B), 2) leaky radial-symmetric aquifer, W(u,r/B, 3) leaky aquifer with storage in confining bed, H(u,β), 4) leaky aquifer with partially penetrating well, W(u,r/B)+f and 5) nonleaky fractured aquifer, $W(u_c)$. The subroutine includes the lines 14510 - 17690.

CONCLUDING REMARKS.

The data input process is generally the most time-consuming part of this version of the program. Most of the pumping test data that the Geological Survey of Denmark is dealing with are still recorded graphically, either by mechanically working water level recorders or by a combination of pressurized transducers and multi-channel recorders. These data curves are presently digitized manually, which is rather laborous work. Faster digitizing and easier data input from recorded graphs by using digitizing equipment (coordinate table) is a possible and very time saving solution. An alternative solution may be based upon a different way of collecting data using data logging systems (direct storing of measured data on desks or tape cartridges by means of field installed microcomputers). For application of the above-mentioned alternative input techniques, only minor program modifications should be required.

The interpretation of pumping test data by the present version of the program is useful for the analysis of a wide range of aquifer systems and the computation of essential hydraulic parameters. However, the need for analysing more complex aquifer systems (multiaquifer systems etc.) may require the use of more sophisticated type curve generating models than the present analytical solutions represent. More convenient numerical techniques like the finite difference and finite element methods may be used for setting up such interpreting models. Under normal circumstances however, the numerical methods demand much more computer capacity than the present program does. Therefore, in order to generate these more sophisticated type curves access to larger computer facilities may be needed requiring the rewriting of at least the subroutine "Typecurves". Alternatively, the total program may be rewriten into Fortran and run on another Tektronix minicomputer-version, the 4110-series, which also has the dynamic graphics option, but has much greater capacity and a faster speed as well.

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ATTACHMENT I

BASIC program listing.

```
1 GO TO 100
4 PAGE
5 GO TO 450
8 GO TO 1030
12 N7=1
13 GO TO N6 OF 3060,85
16 N7=2
17 GO TO N6 OF 3190,85
20 N7=3
21 GO TO N6 OF 3390,85
24 N7=4
25 GO TO N6 OF 3620,85
28 N7=5
29 GO TO N6 OF 85,3860
32 GO TO 4130
36 N7=1
37 GO TO N6 OF 85,6380
40 N7=2
41 GO TO N6 OF 85,6620
44 Z=32
45 N5=1
46 N7=3
47 GO TO N6 OF 85,7170
48 Z=1
49 N5=1
50 N7=6
51 GO TO N6 OF 85,7190
52 Z=32
53 N5=2
54 N7=4
55 GO TO N6 OF 85,11250
56 Z=1
57 N5=2
58 N7=4
59 GO TO N6 OF 85,11250
60 Z=32
61 GO TO 4490
64 Z=1
65 GO TO 4490
76 GO TO 9960
80 GO TO 14510
85 FOR I=1 TO N
86 FOR J=1 TO C(I)
87 GO TO N2 OF 89,91
88 IF I=2 THEN 91
89 S(J,I)=S(J,I)+V(I)*-1↑N6
90 GO TO 92
91 S(J,I)=W(I)-S(J,I)
92 NEXT J
93 NEXT I
94 GO TO N6 OF 95,97
95 N6=2
96 GO TO N7 OF 7090,7740,7170,11250,3860,7190
97 N6=1
98 GO TO N7 OF 3060,3190,3390,3620
100 INIT
110 REM****************************************************
120 REM                                                   *
130 REM             GEOLOGICAL SURVEY OF DENMARK          *
140 REM              HYDROGEOLOGICAL DEPARTMENT           *
```

BASIC program listing - Continued.

```
150 REM                                                          *
160 REM         PROGRAM FOR ANALYSING PUMPING TEST DATA          *
170 REM                                                          *
180 REM  THE PROGRAM IS INTERACTIVE AND ABLE TO READ, PLOT       *
190 REM  AND INTERPRET PUMPING TEST DATA AND STORE THE DATA      *
200 REM  ON MAGNETIC TAPE.                                       *
210 REM  THE PROGRAM SEQUENCES ARE OPERATED BY MEANS OF          *
220 REM  "USERDEFINABLE KEYS", ACCORDING TO THE MENU             *
230 REM  LISTED BELOW.                                           *
240 REM                                                          *
250 REM              PROGRAMMED BY BJARNE MADSEN                 *
260 REM             LAST REVISION:  27.11.84 BY BM               *
270 REM                                                          *
280 REM*******************************************************
290 DELETE A$,B$,C$,D$,H$,K$,L$,R$,T$,X$
300 DIM A$(20),B$(12),C$(12),D$(8),H$(15),K$(5),L$(20),R$(8),T$(5),X$(9)
310 CHARSIZE 1
320 PRINT "DATE OF TO-DAY  ";
330 INPUT C$
340 CHARSIZE 4
350 PAGE
360 FONT 9
370 PRINT "PUMPING TEST"
380 PRINT
390 PRINT
400 SET KEY
410 CHARSIZE 1
420 PRINT "MENU                       KEY 1"
430 PRINT
440 PRINT
450 PRINT "DATA INPUT                 KEY 2"
460 PRINT
470 PRINT
480 PRINT "LISTING DATA               KEY 3"
490 PRINT
500 PRINT
510 PRINT "CHANGING DATA              KEY 4"
520 PRINT
530 PRINT
540 PRINT "DELETING DATA              KEY 5"
550 PRINT
560 PRINT
570 PRINT "ADDING DATA                KEY 6"
580 PRINT
590 PRINT
600 PRINT "STORING ON TAPE            KEY 7"
610 PRINT
620 PRINT
630 PRINT "READING THE TAPE           KEY 8"
640 PRINT
650 PRINT
660 PRINT "DECREASING THICKNESS       KEY 9"
670 PRINT
680 PRINT
690 PRINT "WATERLEVEL FLUCTUATIONS  KEY 10"
700 PRINT
710 PRINT
720 PRINT "SEMILOG, SCREEN            KEY 11"
730 PRINT
740 PRINT
```

BASIC program listing - Continued.

```
750 PRINT "SEMILOG, PLOTTER         KEY 12"
760 PRINT
770 PRINT
780 PRINT "LOG-LOG, SCREEN          KEY 13"
790 PRINT
800 PRINT
810 PRINT "LOG-LOG, PLOTTER         KEY 14"
820 PRINT
830 PRINT
840 PRINT "TEXT, SCREEN             KEY 15"
850 PRINT
860 PRINT
870 PRINT "TEXT, PLOTTER            KEY 16"
880 PRINT
890 PRINT
900 PRINT "REGRESSION, SEMILOG      KEY 19"
910 PRINT
920 PRINT
930 PRINT "TYPE CURVES, LOG-LOG     KEY 20"
940 PRINT
950 PRINT
960 RETURN
970 REM*****************************************************
980 REM                                                    *
990 REM   DATA INPUT.                                      *
1000 REM  PUMPING- AND OBSERVATIONWELL DATA ARE SEPARATED  *
1010 REM                                                   *
1020 REM****************************************************
1030 PAGE
1040 PRINT "PROJECT  ";
1050 INPUT A$
1060 PRINT "LOCATION  ";
1070 INPUT L$
1080 PRINT
1090 PRINT "PUMPING WELL       1";
1100 PRINT
1110 PRINT "OBSERVATION WELL   2";
1120 PRINT
1130 PRINT "CHOOSE NO.  ";
1140 INPUT N1
1150 GO TO N1 OF 1170,1170
1160 GO TO 1130
1170 PRINT
1180 PRINT "DRAWDOWN DATA 1";
1190 PRINT
1200 PRINT "RECOVERY DATA 2";
1210 PRINT
1220 IF N1=2 THEN 1250
1230 PRINT "DRAWD.+RECOV. 3";
1240 PRINT
1250 PRINT "CHOOSE NO.  ";
1260 INPUT N2
1270 PRINT
1280 PRINT "SET UP,     DATE  ";
1290 INPUT D$
1300 PRINT "            TIME  ";
1310 INPUT K$
1320 PRINT
1330 PRINT "SHUT OFF,   DATE  ";
1340 INPUT R$
```

BASIC program listing - Continued.

```
1350 PRINT "            TIME  ";
1360 INPUT T$
1370 PRINT
1380 D1=0
1390 DELETE Q,P
1400 IF N1=1 THEN 1590
1410 PRINT "PUMPED WELL, DGU file no. ";
1420 INPUT D1
1430 PRINT
1440 DIM Q(2),P(2)
1450 P=0
1460 P5=2
1470 IF N2=2 THEN 1520
1480 PRINT "MEAN OF PUMPING CAPACITY, m↑3/h ";
1490 PRINT
1500 INPUT Q(2)
1510 GO TO 1570
1520 PRINT "PUMPING CAPACITY AT SHUT OFF, m↑3/h ";
1530 PRINT
1540 INPUT Q(2)
1550 PRINT "PUMPING PERIOD, min ";
1560 INPUT P(2)
1570 Q(1)=Q(2)
1580 GO TO 1800
1590 DIM Q(25),P(25)
1600 Q=0
1610 P=0
1620 I=1
1630 PRINT "TIME in min, PUMPING CAPACITY in m↑3/h";
1640 PRINT
1650 INPUT P1,Q1
1660 IF Q1=0 THEN 1710
1670 I=I+1
1680 Q(I)=Q1
1690 P(I)=P1
1700 IF I<25 THEN 1650
1710 P5=I
1720 Q(1)=Q(2)
1730 PRINT
1740 M1=80
1750 GO TO N2 OF 1780,1780
1760 N=2
1770 GO TO 1860
1780 N=1
1790 GO TO 1860
1800 PRINT "NUMBER OF OBSERVATION WELLS ";
1810 INPUT N
1820 PRINT
1830 M1=60
1840 IF N<8 THEN 1860
1850 M1=30
1860 DELETE D,V,W,A,S,T,C,M
1870 DIM D(N),V(N),W(N),A(N),S(M1,N),T(M1,N),C(N),M(N)
1880 D=0
1890 V=0
1900 W=0
1910 A=0.1
1920 S=0
1930 T=0
1940 C=0
```

BASIC program listing - Continued.

```
1950 M=0
1960 N6=1
1970 FOR I=1 TO N
1980 E1=2
1990 PRINT "DGU file no. ";
2000 INPUT D(I)
2010 PRINT
2020 PRINT "GAUGE, m a Surface  ";
2030 INPUT M(I)
2040 PRINT
2050 IF N1=1 THEN 2090
2060 PRINT "DISTANCE TO PUMPED WELL, m ";
2070 INPUT A(I)
2080 PRINT
2090 IF N2=2 THEN 2240
2100 PRINT "REST WATER LEVEL, m b Gauge  ";
2110 INPUT V(I)
2120 PRINT
2130 PRINT "AUTOMATIC WATER LEVEL MEASURES ";
2140 INPUT B$
2150 IF B$="YES" THEN 2170
2160 E1=1
2170 PRINT
2180 PRINT "INPUT DRAWDOWN DATA";
2190 PRINT
2200 PRINT "TIME in min, DRAWDOWN in m b Gauge"
2210 PRINT
2220 E2=1
2230 GO TO 2370
2240 PRINT "WATER LEVEL AT SHUT OFF, m b Gauge  ";
2250 INPUT W(I)
2260 PRINT
2270 PRINT "AUTOMATIC WATER LEVEL MEASURES ";
2280 INPUT B$
2290 IF B$="YES" THEN 2310
2300 E1=1
2310 PRINT
2320 PRINT "INPUT RECOVERY DATA";
2330 PRINT
2340 PRINT "TIME in min, RECOVERY in m b Gauge"
2350 PRINT
2360 E2=2
2370 J=0
2380 REM*****************************************************
2390 REM                                                    *
2400 REM  DRAWDOWN/RECOVERY DATA ARE STORED IN ARRAYS.      *
2410 REM                                                    *
2420 REM*****************************************************
2430 INPUT T1,S1
2440 IF S1=0 THEN 2540
2450 J=J+1
2460 IF E1=1 THEN 2510
2470 IF E2=1 THEN 2500
2480 S1=W(I)-S1
2490 GO TO 2510
2500 S1=S1+V(I)
2510 S(J,I)=S1
2520 T(J,I)=T1
2530 IF J<M1 THEN 2430
2540 C(I)=J
```

```
2550 IF N2=3 THEN 2580
2560 NEXT I
2570 GO TO 2680
2580 IF I=2 THEN 2680
2590 I=2
2600 GO TO 2240
2610 REM***************************************************
2620 REM                                                   *
2630 REM  MAXIMUM AND MINIMUM OF DRAWDOWN/RECOVERY DATA    *
2640 REM  ARE COMPUTED IN ORDER TO CALCULATE THE SIZE OF   *
2650 REM  THE COORDINATE SYSTEM.                           *
2660 REM                                                   *
2670 REM***************************************************
2680 N6=2
2690 R1=1.0E+300
2700 R2=-1.0E+300
2710 R3=1.0E+300
2720 R4=-1.0E+300
2730 FOR I=1 TO N
2740 FOR J=1 TO C(I)
2750 GO TO N2 OF 2770,2790
2760 IF I=2 THEN 2790
2770 S(J,I)=S(J,I)-V(I)
2780 GO TO 2800
2790 S(J,I)=W(I)-S(J,I)
2800 R1=R1 MIN T(J,I)
2810 R2=R2 MAX T(J,I)
2820 R3=R3 MIN S(J,I)
2830 R4=R4 MAX S(J,I)
2840 NEXT J
2850 NEXT I
2860 IF R4-R3<1 THEN 2960
2870 IF R4-R3<10 THEN 2920
2880 V3=INT(R3/10)*10
2890 V4=(INT(R4/10)+1)*10
2900 G2=10
2910 GO TO 4320
2920 V3=INT(R3)
2930 V4=INT(R4)+1
2940 G2=1
2950 GO TO 4320
2960 V3=INT(R3*10)/10
2970 V4=(INT(R4*10)+1)/10
2980 G2=0.1
2990 GO TO 4320
3000 REM***************************************************
3010 REM                                                   *
3020 REM  DATA CAN B LISTED, CHANGED, DELETED AND          *
3030 REM  REPLENISHED.                                     *
3040 REM                                                   *
3050 REM***************************************************
3060 I=1
3070 IF N=1 THEN 3140
3080 PRINT "LIST DATA SET NO. ";
3090 INPUT I
3100 IF I=0 THEN 3800
3110 IF I>0 AND I<=N THEN 3140
3120 PRINT "NO DATA EXIST"
3130 GO TO 3060
3140 FOR J=1 TO C(I)
```

BASIC program listing - Continued.

```
3150 PRINT J,T(J,I),S(J,I)
3160 NEXT J
3170 IF N=1 THEN 3800
3180 GO TO 3060
3190 I=1
3200 IF N=1 THEN 3270
3210 PRINT "CHANGE DATA SET NO. ";
3220 INPUT I
3230 IF I=0 THEN 2680
3240 IF I>0 AND I<=N THEN 3270
3250 PRINT "NO DATA EXIST"
3260 GO TO 3190
3270 PRINT "PAIR OF DATA, NO. ";
3280 INPUT J
3290 IF J=>0 AND J<=C(I) THEN 3320
3300 PRINT "NO DATA EXIST"
3310 GO TO 3270
3320 IF J>0 THEN 3350
3330 IF N=1 THEN 2680
3340 GO TO 3210
3350 PRINT "PRESENT VALUE OF THE PAIR OF DATA : ";T(J,I),S(J,I)
3360 PRINT "SHALL BE CHANGED TO ";
3370 INPUT T(J,I),S(J,I)
3380 GO TO 3270
3390 I=1
3400 IF N=1 THEN 3470
3410 PRINT "DELETE DATA SET NO. ";
3420 INPUT I
3430 IF I=0 THEN 2680
3440 IF I>0 AND I<=N THEN 3470
3450 PRINT "NO DATA EXIST"
3460 GO TO 3390
3470 PRINT "PAIR OF DATA, NO. ";
3480 INPUT J
3490 IF J=>0 AND J<=C(I) THEN 3520
3500 PRINT "NO DATA EXIST"
3510 GO TO 3470
3520 IF J>0 THEN 3550
3530 IF N=1 THEN 2680
3540 GO TO 3410
3550 PRINT "PAIR OF DATA ";T(J,I),S(J,I);"  DELETED"
3560 FOR H=J+1 TO C(I)
3570 S(H-1,I)=S(H,I)
3580 T(H-1,I)=T(H,I)
3590 NEXT H
3600 C(I)=C(I)-1
3610 GO TO 3470
3620 I=1
3630 IF N=1 THEN 3700
3640 PRINT "ADDITION IN DATA SET NO. ";
3650 INPUT I
3660 IF I=0 THEN 2680
3670 IF I>0 AND I<=N THEN 3700
3680 PRINT "NO DATA EXIST"
3690 GO TO 3620
3700 PRINT "INPUT PAIR OF DATA ";
3710 INPUT T1,S1
3720 IF S1>0 THEN 3750
3730 IF N=1 THEN 2680
3740 GO TO 3640
```

BASIC program listing - Continued.

```
3750 C(I)=C(I)+1
3760 S(C(I),I)=S1
3770 T(C(I),I)=T1
3780 IF C(I)=M1 THEN 2680
3790 GO TO 3700
3800 RETURN
3810 REM*****************************************************
3820 REM                                                    *
3830 REM  DATA ARE STORED ON TAPE.                          *
3840 REM                                                    *
3850 REM*****************************************************
3860 PRINT
3870 PRINT
3880 PRINT "STORING DATA ON TAPE"
3890 PRINT
3900 PRINT "INSERT TAPE CARTRIDGE"
3910 PRINT
3920 PRINT "INPUT FILE NO. ";
3930 INPUT Y1
3940 PRINT "NEW FILE ";
3950 INPUT B$
3960 IF B$="NO" THEN 4020
3970 IF Y1>1 THEN 4000
3980 FIND 0
3990 GO TO 4010
4000 FIND Y1
4010 MARK 1,N*M1*25+60*N+610+LEN(A$)+LEN(L$)
4020 FIND Y1
4030 WRITE @33:N1,N2,D$,K$,R$,T$,N,R1,R2,R3,R4,V3,V4,G2,M1,A$,L$,P5,D1
4040 WRITE @33:D,V,W,A,C,S,T,Q,P,M
4050 PRINT "DATA STORED ON TAPE"
4060 CLOSE
4070 RETURN
4080 REM*****************************************************
4090 REM                                                    *
4100 REM  DATA ARE READ FROM TAPE.                          *
4110 REM                                                    *
4120 REM*****************************************************
4130 PRINT
4140 PRINT
4150 PRINT "READING DATA FROM TAPE"
4160 PRINT
4170 PRINT "INSERT TAPE CARTRIDGE"
4180 PRINT
4190 PRINT "INPUT FILE NO. ";
4200 INPUT Y1
4210 PRINT
4220 FIND Y1
4230 READ @33:N1,N2,D$,K$,R$,T$,N,R1,R2,R3,R4,V3,V4,G2,M1,A$,L$,P5,D1
4240 DELETE D,V,W,A,C,S,T,Q,P,M
4250 DIM D(N),V(N),W(N),A(N),C(N),S(M1,N),T(M1,N),M(N)
4260 IF N1=2 THEN 4290
4270 DIM Q(25),P(25)
4280 GO TO 4300
4290 DIM Q(2),P(2)
4300 READ @33:D,V,W,A,C,S,T,Q,P,M
4310 N6=2
4320 DELETE X,Y,B,R,K,B$,H$,X$
4330 DIM X(N),Y(N),B(N),R(N),K(N),B$(10),H$(15),X$(7)
4340 X=0
```

BASIC program listing - Continued.

```
4350 Y=0
4360 B=0
4370 R=0
4380 K=0
4390 RETURN
4400 HOME @Z:
4410 FUZZ 12,1.0E-64
4420 RETURN
4430 REM***************************************************
4440 REM                                                  *
4450 REM  TEXT : BASIC INFORMATIONS AND RESULTS OF        *
4460 REM  INTERPRETATIONS ARE PLOTTED.                    *
4470 REM                                                  *
4480 REM***************************************************
4490 IF P5>2 THEN 4530
4500 V5=0
4510 V6=10
4520 GO TO 4720
4530 R5=1.0E+300
4540 R6=-1.0E+300
4550 Q3=0
4560 FOR J=2 TO P5
4570 R5=R5 MIN Q(J)
4580 R6=R6 MAX Q(J)
4590 Q3=Q3+(Q(J)+Q(J-1))*(P(J)-P(J-1))/2
4600 NEXT J
4610 Q3=INT(Q3*10/P(P5))/10
4620 N4=1
4630 IF R5<50 THEN 4670
4640 R6=INT(R6/10+1)*10
4650 V5=INT(R5/10)*10
4660 GO TO 4690
4670 R6=INT(R6/5+1)*5
4680 V5=INT(R5/5)*5
4690 IF R6-R5<10 THEN 4710
4700 N4=5
4710 V6=3*(INT(R6)+1-V5)+V5
4720 VIEWPORT 10,127,7,80.35
4730 WINDOW V1,V2,V5,V6
4740 PAGE
4750 IF Z=32 THEN 4890
4760 PRINT @Z,17:1,1.88
4770 MOVE @Z:V1,V5
4780 PRINT @Z:"L";
4790 MOVE @Z:V2,V5
4800 PRINT @Z,25:90
4810 PRINT @Z:"L";
4820 MOVE @Z:V2,V6
4830 PRINT @Z,25:180
4840 PRINT @Z:"L";
4850 MOVE @Z:V1,V6
4860 PRINT @Z,25:270
4870 PRINT @Z:"L";
4880 PRINT @Z,25:360
4890 VIEWPORT 30,114,15,64
4900 PRINT @Z,17:2.4,3.7
4910 MOVE @Z:V1+(V2-V1)/2,V6
4920 PRINT @Z:"H_H_H_H_H_H_PUMPING  TEST"
4930 PRINT @Z,17:1,1.88
4940 MOVE @Z:V1+(V2-V1)/2,V6
```

BASIC program listing - Continued.

```
4950 FOR J=1 TO (LEN(A$)+LEN(L$)+3)/2
4960 PRINT @Z:"H_";
4970 NEXT J
4980 PRINT @Z:"J_J_";A$;" - ";L$;
4990 MOVE @Z:V1,V6-(V6-V5)/5
5000 IF N1=2 THEN 5030
5010 PRINT @Z:"Pumping Well Data ,     DGU file no.";D(1);
5020 GO TO 5040
5030 PRINT @Z:"Observation Well Data, Pumped Well - DGU file no.";D1;
5040 MOVE @Z:V1,V6-(V6-V5)/3.5
5050 IF LEN(D$)<2 THEN 5070
5060 PRINT @Z:"Set up, date ";D$;"  time ";K$;"      ";
5070 IF LEN(R$)<2 THEN 5090
5080 PRINT @Z:"Shut off, date ";R$;"  time ";T$;
5090 MOVE @Z:V1,V6-(V6-V5)*0.35
5100 IF P5>2 THEN 5160
5110 GO TO N2 OF 5130,5150
5120 GO TO N3 OF 5130,5150,5130,5150
5130 PRINT @Z:"Pumping Capacity, Q = ";Q(2);" m3/h";
5140 GO TO 5160
5150 PRINT @Z:"Capacity at the Shut off, Q = ";Q(P5);" m3/h";
5160 IF N5=2 THEN 5280
5170 MOVE @Z:V1,V6-(V6-V5)*0.46
5180 IF X1=0 THEN 5220
5190 PRINT @Z:"Drawdown:   T = ";X1;" m2/s"
5200 MOVE @Z:V1,V6-(V6-V5)*0.46
5210 PRINT @Z:"J_J_";
5220 IF X2=0 THEN 5240
5230 PRINT @Z:"Recovery:   T = ";X2;" m2/s"
5240 IF N1=1 THEN 5790
5250 PRINT @Z:"J_J_J_";
5260 PRINT @Z:"Observation Well, DGU file no. ";D(I);
5270 GO TO 4400
5280 FOR J=1 TO E2
5290 MOVE @Z:V1,V5+(V6-V5)*0.4
5300 IF P5<3 THEN 5320
5310 RMOVE @Z:0,(V6-V5)*0.2
5320 IF J>1 THEN 5350
5330 PRINT @Z:"DGU file no.  Distance (m)    T (m2/s)     S          S'";
5340 PRINT @Z:"          K'/b' (s-1)    Kr/Kz"
5350 J2=1
5360 MOVE @Z:V1,V5+(V6-V5)*0.4
5370 IF P5<3 THEN 5390
5380 RMOVE @Z:0,(V6-V5)*0.2
5390 GO TO J OF 5440,5430,5420,5410,5400
5400 PRINT @Z:"J_J_";
5410 PRINT @Z:"J_J_";
5420 PRINT @Z:"J_J_";
5430 PRINT @Z:"J_J_";
5440 PRINT @Z:"J_J_J_";
5450 GO TO J2 OF 5460,5490,5530,5560,5600,5670,5740
5460 PRINT @Z:D(O(J));
5470 J2=2
5480 GO TO 5360
5490 PRINT @Z:"                ";A(O(J));
5500 IF X(O(J))=0 THEN 5780
5510 J2=3
5520 GO TO 5360
5530 PRINT @Z:"                              ";X(O(J));
5540 J2=4
```

BASIC program listing - Continued.

```
5550 GO TO 5360
5560 PRINT @Z:"                              ";Y(O(J));
5570 IF B(O(J))=0 THEN 5640
5580 J2=5
5590 GO TO 5360
5600 FOR J1=1 TO 26
5610 PRINT @Z:"  ";
5620 NEXT J1
5630 PRINT @Z:B(O(J));
5640 IF R(O(J))=0 THEN 5710
5650 J2=6
5660 GO TO 5360
5670 FOR J1=1 TO 31
5680 PRINT @Z:"  ";
5690 NEXT J1
5700 PRINT @Z:R(O(J));
5710 IF K(O(J))=0 THEN 5780
5720 J2=7
5730 GO TO 5360
5740 FOR J1=1 TO 38
5750 PRINT @Z:"  ";
5760 NEXT J1
5770 PRINT @Z:K(O(J));
5780 NEXT J
5790 IF P5=2 THEN 4400
5800 MOVE @Z:V1,V5
5810 DRAW @Z:V2,V5
5820 MOVE @Z:V1,V5
5830 DRAW @Z:V1,R6
5840 F1=V1
5850 FOR P1=2*10↑F1 TO 10↑(F1+1) STEP 10↑F1
5860 MOVE @Z:LGT(P1),V5
5870 DRAW @Z:LGT(P1),V5+(V6-V5)*0.008
5880 NEXT P1
5890 F1=F1+1
5900 IF F1<V2 THEN 5850
5910 FOR P1=V5 TO R6 STEP N4
5920 MOVE @Z:V1,P1
5930 IF P1/10=INT(P1/10) THEN 5960
5940 DRAW @Z:V1+0.02,P1
5950 GO TO 5970
5960 DRAW @Z:V1+0.05,P1
5970 NEXT P1
5980 FOR P1=V1 TO V2 STEP 1
5990 MOVE @Z:P1,V5
6000 CHARSIZE 2
6010 PRINT @Z:"H_J_J_10";
6020 CHARSIZE 1
6030 PRINT @Z,17:0.8,1.4
6040 PRINT @Z:"K_";P1;
6050 PRINT @Z,17:1,1.88
6060 NEXT P1
6070 MOVE @Z:(V1+V2)/2,V5
6080 PRINT @Z:"H_H_H_H_H_J_J_J_J_TIME (min)";
6090 MOVE @Z:V1,V5
6100 PRINT @Z:"H_H_H_H_";V5;
6110 MOVE @Z:V1,INT(R6)
6120 PRINT @Z:"H_H_H_H_";R6
6130 MOVE @Z:V1,(V5+R6)/2.1
6140 PRINT @Z:" ";
```

```
6150 PRINT @Z,17:1.5,2.8
6160 PRINT @Z:"H_H_H_K_Q";
6170 PRINT @Z,17:0.8,0.8
6180 PRINT @Z:"H_K_";
6190 PRINT @Z,17:1,1.88
6200 PRINT @Z:"H_H_H_J_J_(m3/h)";
6210 MOVE @Z:V1,Q(1)
6220 FOR J=2 TO P5
6230 DRAW @Z:LGT(P(J)),Q(J)
6240 NEXT J
6250 MOVE @Z:V1+(V2-V1)+0.39,R6+(R6-R5)*0.3
6260 PRINT @Z,17:1.5,2.8
6270 PRINT @Z:"Q";
6280 PRINT @Z,17:1,1.88
6290 PRINT @Z:"mean = ";Q3;" m3/h";
6300 IF N1=2 THEN 5280
6310 GO TO 4400
6320 REM*****************************************************
6330 REM                                                     *
6340 REM  CORRECTIONS FOR DECREASING THICKNESS OF            *
6350 REM  THE AQUIFER.                                       *
6360 REM                                                     *
6370 REM*****************************************************
6380 PRINT "THICKNESS OF THE AQUIFER, m ";
6390 INPUT D0
6400 IF N2=2 THEN 6500
6410 FOR I=1 TO N
6420 FOR J=1 TO C(I)
6430 S(J,I)=S(J,I)-S(J,I)↑2/(2*D0)
6440 NEXT J
6450 IF N2=3 THEN 6480
6460 NEXT I
6470 IF N2=1 THEN 4420
6480 I=2
6490 GO TO 6510
6500 FOR I=1 TO N
6510 FOR J=1 TO C(I)
6520 S(J,I)=S(J,I)+(S(C(I),I)-S(J,I))↑2/(2*D0)
6530 NEXT J
6540 IF N2=3 THEN 4420
6550 NEXT I
6560 RETURN
6570 REM*****************************************************
6580 REM                                                     *
6590 REM  CORRECTIONS FOR WATERLEVEL FLUCTUATIONS.           *
6600 REM                                                     *
6610 REM*****************************************************
6620 IF N1=1 THEN 6800
6630 PRINT "CORRECTION WELL - DATA SET NO. ";
6640 INPUT P1
6650 IF P1=0 THEN 6800
6660 IF P1>0 AND P1<=N THEN 6690
6670 PRINT "NO DATA EXIST"
6680 GO TO 6640
6690 PRINT D(P1)
6700 GO TO N2 OF 6710,6750
6710 DELETE G,L
6720 DIM G(M1,2),L(M1,2)
6730 E1=C(P1)
6740 GO TO 6760
```

```
6750 E2=C(P1)
6760 FOR J=1 TO M1
6770 G(J,N2)=S(J,P1)
6780 L(J,N2)=T(J,P1)
6790 NEXT J
6800 PRINT "CORRECTION FACTOR ";
6810 INPUT B1
6820 IF B1=0 THEN 4420
6830 IF N>1 THEN 6860
6840 I=1
6850 GO TO 6900
6860 PRINT "CORRECTION OF DATA SET NO. ";
6870 PRINT
6880 INPUT I
6890 IF I=0 THEN 6800
6900 GO TO N2 OF 6920,6950
6910 IF I=2 THEN 6950
6920 F1=E1
6930 NO=1
6940 GO TO 6970
6950 E1=E2
6960 NO=2
6970 FOR J=1 TO C(I)
6980 FOR J1=1 TO F1
6990 IF L(J1,NO)>T(J,I) THEN 7010
7000 NEXT J1
7010 IF J1=1 THEN 7060
7020 GO=G(J1,NO)-G(J1-1,NO)
7030 LO=L(J1,NO)-L(J1-1,NO)
7040 S(J,I)=S(J,I)-B1*(G(J1-1,NO)+GO*(T(J,I)-L(J1-1,NO))/LO)
7050 GO TO 7070
7060 S(J,I)=S(J,I)-B1*(G(J1,NO)*T(J,I)/L(J1,NO))
7070 NEXT J
7080 GO TO 6860
7090 REM***************************************************
7100 REM                                                  *
7110 REM  SEMILOG-PLOTS , TIME/DRAWDOWN:                  *
7120 REM  OBSERVATION WELLS ARE PLOTTED SEPARATELY.       *
7130 REM  FOR PUMPING WELLS IT IS POSSIBLE TO PLOT BOTH   *
7140 REM  DRAWDOWN-AND RECOVERY DATA IN THE SAME DIAGRAM. *
7150 REM                                                  *
7160 REM***************************************************
7170 X1=0
7180 X2=0
7190 V2=5
7200 IF R1<1 THEN 7240
7210 V1=0
7220 F1=0
7230 GO TO 7280
7240 V1=-1
7250 F1=-1
7260 IF R2>10000 THEN 7280
7270 V2=4
7280 DELETE E
7290 DIM E(M1,N)
7300 FOR I=1 TO N
7310 FOR J=1 TO C(I)
7320 E(J,I)=T(J,I)
7330 NEXT J
7340 NEXT I
```

```
7350 N3=3
7360 I=1
7370 E1=(V4-V3)*0.008
7380 E2=(V2-V1)*0.0045
7390 PRINT @Z,17:1,1.88
7400 PRINT @Z,18:1
7410 IF N=1 THEN 7480
7420 PRINT "PLOT DATA SET NO. ";
7430 INPUT I
7440 IF I=>0 AND I<=N THEN 7470
7450 PRINT "NO DATA EXIST"
7460 GO TO 7420
7470 IF I=0 THEN 4400
7480 GO TO N2 OF 7670,7550
7490 IF I=2 THEN 7550
7500 PRINT "RECOVERY DATA IN THE SAME DIAGRAM ";
7510 INPUT B$
7520 IF B$="NO" THEN 7670
7530 N3=1
7540 GO TO 7670
7550 N3=4
7560 PRINT
7570 PRINT "T/(T+DT)-PLOT ";
7580 INPUT B$
7590 IF B$="YES" THEN 7610
7600 GO TO 7670
7610 N3=2
7620 FOR J=1 TO C(I)
7630 E(J,I)=10↑(5-LGT(1+P(P5)/T(J,I)))
7640 NEXT J
7650 V1=0
7660 V2=5
7670 PAGE
7680 REM****************************************************
7690 REM                                                   *
7700 REM THE COORDINATE SYSTEM IS PLOTTED WITH TIC MARKS.   *
7710 REM                                                   *
7720 REM****************************************************
7730 VIEWPORT 10,127,2,94
7740 WINDOW V1,V2,V3,V4
7750 S1=0
7760 IF Z=32 THEN 7960
7770 IF N1=1 THEN 7840
7780 PRINT "DO YOU WANT TO PLOT THE COORDINATE SYSTEM "
7790 INPUT B$
7800 IF B$="YES" THEN 7840
7810 VIEWPORT 30,114,25,85
7820 S1=1
7830 GO TO N2 OF 9060,9650
7840 PRINT @1,25:
7850 MOVE @Z:V1,V3
7860 PRINT @1:"L";
7870 MOVE @Z:V2,V3
7880 PRINT @1,25:90
7890 PRINT @1:"L";
7900 MOVE @Z:V2,V4
7910 PRINT @1,25:180
7920 PRINT @1:"L";
7930 MOVE @Z:V1,V4
7940 PRINT @1,25:270
```

BASIC program listing - Continued.

```
7950 PRINT @1:"L";
7960 VIEWPORT 30,114,25,85
7970 MOVE @Z:V1,V3
7980 DRAW @Z:V2,V3
7990 DRAW @Z:V2,V4
8000 DRAW @Z:V1,V4
8010 DRAW @Z:V1,V3
8020 FOR P1=2*10↑F1 TO 10↑(F1+1) STEP 10↑F1
8030 MOVE @Z:LGT(P1),V3
8040 DRAW @Z:LGT(P1),V3+E1
8050 NEXT P1
8060 F1=F1+1
8070 IF F1=V2 THEN 8100
8080 DRAW @Z:F1,V4
8090 GO TO 8020
8100 F1=V1
8110 FOR P1=2*10↑F1 TO 10↑(F1+1) STEP 10↑F1
8120 MOVE @Z:LGT(P1),V4
8130 DRAW @Z:LGT(P1),V4-E1
8140 NEXT P1
8150 F1=F1+1
8160 IF F1<V2 THEN 8110
8170 F1=V3
8180 FOR P1=F1+G2/10 TO F1+G2 STEP G2/10
8190 MOVE @Z:V1,P1
8200 DRAW @Z:V1+E2,P1
8210 NEXT P1
8220 F1=F1+G2
8230 IF F1=V4 THEN 8260
8240 DRAW @Z:V2,F1
8250 GO TO 8180
8260 F1=V3
8270 FOR P1=F1+G2/10 TO F1+G2 STEP G2/10
8280 MOVE @Z:V2,P1
8290 DRAW @Z:V2-E2,P1
8300 NEXT P1
8310 F1=F1+G2
8320 IF F1<V4 THEN 8270
8330 REM**************************************************
8340 REM                                                 *
8350 REM  TEXT AND NUMBERS ARE PLOTTED.                  *
8360 REM                                                 *
8370 REM**************************************************
8380 PRINT @Z,25:360
8390 H$="DGU file no. "
8400 MOVE @Z:V1+(V1+V2)*0.38,V4+(V4-V3)/5
8410 GO TO N2 OF 8440,8440
8420 D(I)=D(1)
8430 M(I)=M(1)
8440 PRINT @Z:H$;D(I);
8450 FOR P1=V1 TO V2 STEP 1
8460 MOVE @Z:P1,V3
8470 CHARSIZE 2
8480 PRINT @Z:"H_J_J_10";
8490 CHARSIZE 1
8500 PRINT @Z,17:0.8,1.4
8510 IF N3=2 THEN 8540
8520 PRINT @Z:"K_";P1;
8530 GO TO 8550
8540 PRINT @Z:"K_";P1-5;
```

BASIC program listing - Continued.

```
8550 PRINT @Z,17:1,1.88
8560 NEXT P1
8570 IF N3=2 THEN 8600
8580 H$="TIME (min)"
8590 GO TO 8610
8600 H$="t/(t+Dt)"
8610 MOVE @Z:(V1+V2)/2,V3
8620 PRINT @Z:"J_J_J_J_";
8630 FOR P1=1 TO LEN(H$)/2
8640 PRINT @Z:"H_";
8650 NEXT P1
8660 PRINT @Z:H$
8670 GO TO N2 OF 8740,9260
8680 IF I=2 THEN 9260
8690 REM*****************************************************
8700 REM                                                    *
8710 REM  THE DRAWDOWN TEXT IS PLOTTED.                     *
8720 REM                                                    *
8730 REM*****************************************************
8740 MOVE @Z:V1,V4
8750 PRINT @Z:"K_K_K_Gauge ";M(I);" m a Surface";
8760 MOVE @Z:V1,V4
8770 PRINT @Z:"K_Rest Water Level ";V(I);" m b Gauge";
8780 FOR P1=V4 TO V3 STEP -G2
8790 MOVE @Z:V1,P1
8800 IF G2=0.1 THEN 8830
8810 IF V4+V3-P1<10 THEN 8850
8820 IF V4+V3-P1<100 THEN 8840
8830 PRINT @Z:"H_";
8840 PRINT @Z:"H_";
8850 PRINT @Z:"H_H_";V4+V3-P1;
8860 NEXT P1
8870 B$="DRAWDOWN"
8880 MOVE @Z:V1-(V2-V1)/12,V3+(V4-V3)*0.6
8890 IF Z=32 THEN 8960
8900 PRINT @1,25:45
8910 PRINT @1:"+";
8920 PRINT @1,25:270
8930 PRINT @1:"  J_";B$;" (m)";
8940 PRINT @1,25:0
8950 GO TO 9060
8960 FOR P1=1 TO 8
8970 X$=SEG(B$,P1,1)
8980 PRINT X$;"H_J_";
8990 NEXT P1
9000 PRINT "H_J_(m)"
9010 REM*****************************************************
9020 REM                                                    *
9030 REM  DRAWDOWN DATA ARE PLOTTED.                        *
9040 REM                                                    *
9050 REM*****************************************************
9060 FOR J=1 TO C(I)
9070 MOVE @Z:LGT(E(J,I)),V4+V3-S(J,I)
9080 SCALE 1,1
9090 RMOVE @Z:-0.3,-0.3
9100 RDRAW @Z:0.6,0.6
9110 RMOVE @Z:-0.6,0
9120 RDRAW @Z:0.6,-0.6
9130 RMOVE @Z:-0.3,0.3
9140 WINDOW V1,V2,V3,V4
```

BASIC program listing - Continued.

```
9150 NEXT J
9160 IF N=1 THEN 9800
9170 IF N2=1 THEN 9800
9180 IF N3=3 THEN 9800
9190 REM*****************************************************
9200 REM                                                     *
9210 REM  THE RECOVERY TEXT IS PLOTTED.                      *
9220 REM                                                     *
9230 REM*****************************************************
9240 I=2
9250 IF N3=1 THEN 9280
9260 MOVE @Z:V1,V4
9270 PRINT @Z:"K_Gauge ";M(I);" m a Surface";
9280 CHARSIZE 2
9290 FOR P1=V3 TO V4 STEP G2
9300 MOVE @Z:V2,P1
9310 PRINT @Z:" ";P1;
9320 NEXT P1
9330 CHARSIZE 1
9340 B$="o RECOVERY"
9350 MOVE @Z:V2+(V2-V1)/12,(V4+V3)/2
9360 IF Z=1 THEN 9390
9370 PRINT "K_K_K_K_K_";
9380 GO TO 9450
9390 PRINT @1:"J_J_J_J_J_";
9400 PRINT @1:"K_";
9410 PRINT @1,25:90
9420 PRINT @1:B$;" (m)";
9430 PRINT @1,25:0
9440 GO TO 9500
9450 FOR P1=1 TO 10
9460 X$=SEG(B$,P1,1)
9470 PRINT X$;"H_J_";
9480 NEXT P1
9490 PRINT "H_J_(m)";
9500 MOVE @Z:V2,V4
9510 H$="WL at Shut off"
9520 X$=STR(W(I))
9530 B$=" m b Gauge"
9540 PRINT @Z:"K_";
9550 FOR P1=1 TO LEN(H$)+LEN(X$)+LEN(B$)
9560 PRINT @Z:"H_";
9570 NEXT P1
9580 PRINT @Z:H$;X$;B$
9590 CHARSIZE 2
9600 REM*****************************************************
9610 REM                                                     *
9620 REM  RECOVERY DATA ARE PLOTTED.                         *
9630 REM                                                     *
9640 REM*****************************************************
9650 FOR J=1 TO C(I)
9660 MOVE @Z:LGT(E(J,I)),S(J,I)
9670 SCALE 1,1
9680 IF Z=32 THEN 9710
9690 RMOVE @Z:-0.35,-0.3
9700 GO TO 9720
9710 RMOVE @Z:-0.35,-0.7
9720 PRINT @Z:"o";
9730 IF Z=32 THEN 9760
9740 RMOVE @Z:0.35,0.3
9750 GO TO 9770
```

BASIC program listing - Continued.

```
9760 RMOVE @Z:0.35,0.7
9770 WINDOW V1,V2,V3,V4
9780 NEXT J
9790 HOME
9800 IF S1=1 THEN 4400
9810 CHARSIZE 1
9820 MOVE @Z:V1,V3-(V4-V3)*0.22
9830 PRINT @Z,17:0.8,1.4
9840 PRINT @Z:C$;
9850 PRINT @Z,17:1.2,1.88
9860 IF Z=32 THEN 4400
9870 MOVE @Z:V2-(V2-V1)*0.395,V3-(V4-V3)*0.22
9880 PRINT @Z:"GEOLOGICAL SURVEY OF DENMARK"
9890 GO TO 4400
9900 REM***************************************************
9910 REM                                                   *
9920 REM  THE TRANSMISSIVITY VALUES ARE COMPUTED BY MEANS  *
9930 REM  OF LOGARITMIC REGRESSION.                        *
9940 REM                                                   *
9950 REM***************************************************
9960 IF Z=32 THEN 9990
9970 IF N2=1 THEN 10700
9980 GO TO 10560
9990 F3=0
10000 PRINT @Z,17:1,1.88
10010 F4=0
10020 F5=0
10030 F6=0
10040 R0=0
10050 PRINT "J_J_";
10060 PRINT "T‾";
10070 IF N3=1 THEN 10090
10080 GO TO 10200
10090 INPUT I
10100 IF I=>0 AND I<=N THEN 10130
10110 PRINT "NO DATA EXIST"
10120 GO TO 10060
10130 IF I=0 THEN 4400
10140 REM**************************************************
10150 REM                                                 *
10160 REM  THE INTERVAL FOR THE T-VALUE COMPUTATION IS    *
10170 REM  CHOOSEN BY MEANS OF THE "THUMB WHEELS".        *
10180 REM                                                 *
10190 REM**************************************************
10200 POINTER T1,S1,X$
10210 FOR J=1 TO C(I)
10220 IF E(J,I)>10↑T1 THEN 10240
10230 NEXT J
10240 J1=J
10250 POINTER T2,S1,X$
10260 FUZZ 2
10270 IF T2=T1 THEN 4400
10280 FOR J=J1 TO C(I)
10290 IF E(J,I)>10↑T2 THEN 10310
10300 NEXT J
10310 J2=J-1
10320 B2=0
10330 B3=0
10340 B4=0
10350 B5=0
```

BASIC program listing - Continued.

```
10360 REM**************************************************
10370 REM                                                 *
10380 REM  THE REGRESSION LINE IS CALCULATED AND DRAWN,   *
10390 REM  AND THE T-VALUE IS COMPUTED.                   *
10400 REM                                                 *
10410 REM**************************************************
10420 FOR J=J1 TO J2
10430 B2=B2+S(J,I)*LOG(E(J,I))
10440 B3=B3+S(J,I)
10450 B4=B4+LOG(E(J,I))
10460 B5=B5+LOG(E(J,I))↑2
10470 NEXT J
10480 E2=(B2-B3*B4/(J2-J1+1))/(B5-B4↑2/(J2-J1+1))
10490 E1=(B3-B4*E2)/(J2-J1+1)
10500 GO TO N2 OF 10660,10520
10510 IF I=1 THEN 10660
10520 F5=T1
10530 F6=T2
10540 U0=E1
10550 B0=E2
10560 MOVE @Z:F5,U0+B0*F5*LOG(10)
10570 DRAW @Z:F6,U0+B0*F6*LOG(10)
10580 IF Z=1 THEN 10700
10590 X0=INT(Q(P5)/(E2*PI*1.44))/10000
10600 IF N2=1 THEN 10630
10610 X2=X0
10620 GO TO 10640
10630 X1=X0
10640 HOME
10650 GO TO 11120
10660 F3=T1
10670 F4=T2
10680 U1=E1
10690 B1=E2
10700 MOVE @Z:F3,V4+V3-U1-B1*F3*LOG(10)
10710 DRAW @Z:F4,V4+V3-U1-B1*F4*LOG(10)
10720 IF Z=1 THEN 4400
10730 IF N1=2 THEN 10590
10740 REM**************************************************
10750 REM                                                 *
10760 REM  CALCULATION OF THE MEAN CAPACITY FOR THE       *
10770 REM  CHOSEN REGRESSION - INTERVAL.                  *
10780 REM                                                 *
10790 REM**************************************************
10800 R8=E(J1,I)
10810 R9=E(J2,I)
10820 J0=R9-R8
10830 FOR J=1 TO P5
10840 IF P(J)>R8 THEN 10860
10850 NEXT J
10860 J1=J-1
10870 FOR J=1 TO P5
10880 IF P(J)=>R9 THEN 10900
10890 NEXT J
10900 J2=J
10910 IF J2-1-J1>0 THEN 10940
10920 Q1=(2*P(J2)-R8-R9)*(Q(J1)-Q(J2))/2+Q(J2)*J0
10930 GO TO 11070
10940 B2=P(J1+1)-R8
10950 B3=P(J1+1)-P(J1)
```

```
10960 B4=Q(J1)-Q(J1+1)
10970 Q1=(B2*B4/B3+2*Q(J1+1))*B2/2
10980 IF J2-J1-2=0 THEN 11030
10990 FOR J=J1+1 TO J2-2
11000 IF P(J)=0 THEN 11060
11010 Q1=Q1+(Q(J+1)+Q(J))*(P(J+1)-P(J))/2
11020 NEXT J
11030 B2=R9-P(J2-1)
11040 B3=P(J2)-P(J2-1)
11050 B4=Q(J2-1)-Q(J2)
11060 Q1=Q1+(-B2*B4/B3+2*Q(J2-1))*B2/2
11070 Q1=Q1/J0
11080 REM*******************************************************
11090 X1=INT(Q1/(E2*PI*1.44))/10000
11100 X0=X1
11110 HOME
11120 FOR J3=0 TO R0
11130 PRINT "J_J_";
11140 NEXT J3
11150 R0=R0+1
11160 PRINT "    = ";X0;" m↑2/sec"
11170 PRINT "J_";
11180 GO TO 10060
11190 REM*******************************************************
11200 REM                                                      *
11210 REM  LOG-LOG  PLOTS , TIME/DRAWDOWN:     THE MAXIMUM     *
11220 REM  NUMBER OF WELLS PLOTTED IN ONE DIAGRAM IS FIVE.     *
11230 REM                                                      *
11240 REM*******************************************************
11250 DELETE O,E
11260 DIM O(5),E(M1,N)
11270 V5=-2
11280 V6=2
11290 IF R3>0.01 THEN 11320
11300 V5=-3
11310 V6=1
11320 O=1
11330 E=0
11340 I=0
11350 X1=0
11360 X2=0
11370 E2=1
11380 N3=2
11390 R5=1.0E+300
11400 R6=-1.0E+300
11410 IF N=1 THEN 11510
11420 PRINT "PLOT DATA SET NO ";
11430 PRINT
11440 INPUT P1
11450 IF P1=0 THEN 11500
11460 I=I+1
11470 O(I)=P1
11480 IF I=N THEN 11500
11490 IF I<5 THEN 11440
11500 E2=I
11510 IF N1=2 THEN 11560
11520 IF N2=2 THEN 11580
11530 IF E2>1 THEN 11650
11540 IF O(1)=2 THEN 11580
11550 GO TO 11650
```

BASIC program listing - Continued.

```
11560 PRINT "T/R2 - PLOT    1"
11570 PRINT
11580 PRINT "T - PLOT       2"
11590 PRINT
11600 IF N2=1 THEN 11630
11610 PRINT "T/(T+DT)-PLOT  3"
11620 PRINT
11630 PRINT "CHOOSE NO. ";
11640 INPUT N3
11650 GO TO N3 OF 11720,11820,11940
11660 REM****************************************************
11670 REM                                                   *
11680 REM  COORDINATE TRANSFORMATION.                       *
11690 REM  THE INTERVAL OF THE X-AXIS IS COMPUTED.          *
11700 REM                                                   *
11710 REM****************************************************
11720 FOR I=1 TO E2
11730 FOR J=1 TO C(O(I))
11740 E(J,O(I))=T(J,O(I))/A(O(I))↑2
11750 R5=R5 MIN E(J,O(I))
11760 R6=R6 MAX E(J,O(I))
11770 NEXT J
11780 NEXT I
11790 V2=INT(LGT(R6))+1
11800 V1=V2-5
11810 GO TO 12010
11820 FOR I=1 TO E2
11830 FOR J=1 TO C(O(I))
11840 E(J,O(I))=T(J,O(I))
11850 NEXT J
11860 NEXT I
11870 IF R1<1 THEN 11910
11880 V2=5
11890 V1=0
11900 GO TO 12010
11910 V2=4
11920 V1=-1
11930 GO TO 12010
11940 FOR I=1 TO E2
11950 FOR J=1 TO C(O(I))
11960 E(J,O(I))=1/(1+P(P5)/T(J,O(I)))
11970 NEXT J
11980 NEXT I
11990 V2=0
12000 V1=-5
12010 E1=0.0225
12020 REM****************************************************
12030 REM                                                   *
12040 REM  THE COORDINATE SYSTEM IS PLOTTED WITH TIC MARKS. *
12050 REM                                                   *
12060 REM****************************************************
12070 PAGE
12080 PRINT @Z,17:1,1.88
12090 PRINT @Z,18:1
12100 VIEWPORT 30,114,22,89.2
12110 WINDOW V1,V2,V5,V6
12120 IF Z=32 THEN 12320
12130 PRINT "INTERPRETATION PLOT ";
12140 INPUT B$
12150 IF B$="YES" THEN 12310
```

```
12160 VIEWPORT 10,127,0,92
12170 MOVE @1:V1,V5
12180 PRINT @1:"L";
12190 MOVE @1:V2,V5
12200 PRINT @1,25:90
12210 PRINT @1:"L";
12220 MOVE @1:V2,V6
12230 PRINT @1,25:180
12240 PRINT @1:"L";
12250 MOVE @1:V1,V6
12260 PRINT @1,25:270
12270 PRINT @1:"L";
12280 PRINT @1,25:360
12290 VIEWPORT 30,114,22,89.2
12300 GO TO 12320
12310 VIEWPORT 25,123.35,15,93.84
12320 MOVE @Z:V1,V5
12330 DRAW @Z:V2,V5
12340 DRAW @Z:V2,V6
12350 DRAW @Z:V1,V6
12360 DRAW @Z:V1,V5
12370 FOR P1=2*10↑V1 TO 10↑(V1+1) STEP 10↑V1
12380 MOVE @Z:LGT(P1),V5
12390 DRAW @Z:LGT(P1),V5+E1
12400 NEXT P1
12410 V1=V1+1
12420 IF V1=V2 THEN 12520
12430 IF E2=1 THEN 12470
12440 IF V1>V2-4 THEN 12500
12450 DRAW @Z:V1,V6-1.7
12460 GO TO 12370
12470 IF Z=32 THEN 12500
12480 IF V1<V2-1 THEN 12500
12490 MOVE @Z:V1,V5+1
12500 DRAW @Z:V1,V6
12510 GO TO 12370
12520 V1=V2-5
12530 FOR P1=2*10↑V1 TO 10↑(V1+1) STEP 10↑V1
12540 MOVE @Z:LGT(P1),V6
12550 DRAW @Z:LGT(P1),V6-E1
12560 NEXT P1
12570 V1=V1+1
12580 IF V1<V2 THEN 12530
12590 F1=V5
12600 FOR P1=2*10↑F1 TO 10↑(F1+1) STEP 10↑F1
12610 MOVE @Z:V2-5,LGT(P1)
12620 DRAW @Z:V2-5+E1,LGT(P1)
12630 NEXT P1
12640 F1=F1+1
12650 IF F1=V6 THEN 12710
12660 IF E2=1 THEN 12690
12670 IF F1<V6-1 THEN 12690
12680 MOVE @Z:V2-3.3,F1
12690 DRAW @Z:V2,F1
12700 GO TO 12600
12710 F1=V5
12720 FOR P1=2*10↑F1 TO 10↑(F1+1) STEP 10↑F1
12730 MOVE @Z:V2,LGT(P1)
12740 DRAW @Z:V2-E1,LGT(P1)
12750 NEXT P1
```

BASIC program listing - Continued.

```
12760 F1=F1+1
12770 IF F1<V6 THEN 12720
12780 REM*****************************************************
12790 REM                                                     *
12800 REM  TEXT AND NUMBERS ARE PLOTTED.                      *
12810 REM                                                     *
12820 REM*****************************************************
12830 IF E2>1 THEN 12910
12840 IF N2<3 THEN 12860
12850 D(2)=D(1)
12860 MOVE @Z:V2-3.05,V6+0.2
12870 IF Z=32 THEN 12900
12880 IF B$="YES" THEN 12900
12890 PRINT @Z:"K_K_";
12900 PRINT @Z:"DGU file no.";D(O(1));
12910 FOR P1=V2-5 TO V2 STEP 1
12920 MOVE @Z:P1,V5
12930 CHARSIZE 2
12940 PRINT @Z,17:1,1.88
12950 PRINT @Z:"H_J_J_10";
12960 CHARSIZE 1
12970 PRINT @Z,17:0.8,1.4
12980 PRINT @Z:"K_";P1;
12990 NEXT P1
13000 PRINT @Z,17:1,1.88
13010 GO TO N3 OF 13040,13060
13020 H$="t/(t+Dt)"
13030 GO TO 13070
13040 H$="t/r2 (min/m2)"
13050 GO TO 13070
13060 H$="t (min)"
13070 MOVE @Z:V2-2.5,V5
13080 PRINT @Z:"J_J_J_J_";
13090 FOR P1=1 TO LEN(H$)/2
13100 PRINT @Z:"H_";
13110 NEXT P1
13120 PRINT @Z:H$
13130 FOR P1=V5 TO V6 STEP 1
13140 MOVE @Z:V2-5,P1
13150 CHARSIZE 2
13160 PRINT @Z,17:1,1.88
13170 PRINT @Z:"H_H_H_H_10";
13180 CHARSIZE 1
13190 PRINT @Z,17:0.8,1.4
13200 PRINT @Z:"K_";P1;
13210 NEXT P1
13220 PRINT @Z,17:1,1.88
13230 GO TO N2 OF 13250,13270
13240 IF O(1)=2 THEN 13270
13250 H$="DRAWDOWN"
13260 GO TO 13280
13270 H$="RECOVERY"
13280 MOVE @Z:V2-5.38,(V5+V6)/2
13290 FOR P1=1 TO 4
13300 IF Z=1 THEN 13330
13310 PRINT @Z:"K_";
13320 GO TO 13340
13330 PRINT @1:"J_";
13340 NEXT P1
13350 IF Z=32 THEN 13400
```

BASIC program listing - Continued.

```
13360 PRINT @1,25:90
13370 PRINT @1:H$;" (m)";
13380 PRINT @1,25:360
13390 GO TO 13450
13400 FOR P1=1 TO 8
13410 X$=SEG(H$,P1,1)
13420 PRINT X$;"H_J_";
13430 NEXT P1
13440 PRINT "H_J_(m)"
13450 P1=0
13460 V1=V2-5
13470 IF E2>1 THEN 13500
13480 I=1
13490 GO TO 14270
13500 H$="DGU file no."
13510 FOR I=1 TO E2
13520 MOVE V1,V6
13530 RMOVE @Z:0.2,0
13540 FOR P1=1 TO I
13550 RMOVE @Z:0,-0.3
13560 NEXT P1
13570 P1=1
13580 F1=0
13590 GO TO I OF 13660,13800,13890,13980,14080
13600 REM****************************************************
13610 REM                                                   *
13620 REM  THE DATA ARE PLOTTED WITH DIFFERENT SIGNATURE    *
13630 REM  FOR EACH WELL.                                   *
13640 REM                                                   *
13650 REM****************************************************
13660 SCALE 1,1
13670 IF Z=32 THEN 13700
13680 RMOVE @Z:-0.35,-0.3
13690 GO TO 13710
13700 RMOVE @Z:-0.35,-0.7
13710 PRINT @Z:"o";
13720 IF Z=32 THEN 13750
13730 RMOVE @Z:0.35,0.3
13740 GO TO 13760
13750 RMOVE @Z:0.35,0.7
13760 WINDOW V1,V2,V5,V6
13770 IF P1=0 THEN 14290
13780 IF F1=0 THEN 14210
13790 GO TO 14290
13800 SCALE 1,1
13810 RMOVE @Z:-0.3,-0.3
13820 RDRAW @Z:0.6,0.6
13830 RMOVE @Z:-0.6,0
13840 RDRAW @Z:0.6,-0.6
13850 RMOVE @Z:-0.3,0.3
13860 WINDOW V1,V2,V5,V6
13870 IF F1=0 THEN 14210
13880 GO TO 14290
13890 SCALE 1,1
13900 RMOVE @Z:-0.3,-0.2
13910 RDRAW @Z:0.6,0
13920 RDRAW @Z:-0.3,0.5
13930 RDRAW @Z:-0.3,-0.5
13940 RMOVE @Z:0.3,0.2
13950 WINDOW V1,V2,V5,V6
```

```
13960 IF F1=0 THEN 14210
13970 GO TO 14290
13980 SCALE 1,1
13990 RMOVE @Z:-0.25,-0.25
14000 RDRAW @Z:0.5,0
14010 RDRAW @Z:0,0.5
14020 RDRAW @Z:-0.5,0
14030 RDRAW @Z:0,-0.5
14040 RMOVE @Z:0.25,0.25
14050 WINDOW V1,V2,V5,V6
14060 IF F1=0 THEN 14210
14070 GO TO 14290
14080 SCALE 1,1
14090 IF Z=32 THEN 14120
14100 RMOVE @Z:-0.35,-0.5
14110 GO TO 14130
14120 RMOVE @Z:-0.35,-0.7
14130 PRINT @Z:"*";
14140 IF Z=32 THEN 14170
14150 RMOVE @Z:0.35,0.5
14160 GO TO 14180
14170 RMOVE @Z:0.35,0.7
14180 WINDOW V1,V2,V5,V6
14190 IF F1=0 THEN 14210
14200 GO TO 14290
14210 IF N2<3 THEN 14230
14220 D(2)=D(1)
14230 PRINT @Z,17:0.4,0.5
14240 PRINT @Z:"J_";
14250 PRINT @Z,17:1,1.88
14260 PRINT @Z:"  ";H$;D(O(I));
14270 F1=1
14280 J=1
14290 IF J>C(O(I)) THEN 14330
14300 MOVE @Z:LGT(E(J,O(I))),LGT(S(J,O(I)))
14310 J=J+1
14320 GO TO I OF 13660,13800,13890,13980,14080
14330 IF E2=1 THEN 14350
14340 NEXT I
14350 CHARSIZE 1
14360 MOVE @Z:V1,V5-0.8
14370 PRINT @Z,17:0.8,1.4
14380 PRINT @Z:C$;
14390 PRINT @Z,17:1.2,1.88
14400 IF Z=32 THEN 4400
14410 MOVE @Z:V2-1.98,V5-0.8
14420 PRINT @Z:"GEOLOGICAL SURVEY OF DENMARK"
14430 GO TO 4400
14440 REM**********************************************************
14450 REM                                                         *
14460 REM  INTERPRETATION BY MEANS OF TYPE CURVES FOR DIFFERENT   *
14470 REM  ANALYTICAL SOLUTIONS. THE CURVES ARE GENERATED ON THE  *
14480 REM  SCREEN AND CAN BE MOVED USING THE "THUMB-WHEELS".      *
14490 REM                                                         *
14500 REM**********************************************************
14510 J1=1
14520 IF Z=32 THEN 14590
14530 WINDOW V1,V2,V5,V6
14540 PRINT @1,17:1,1.88
14550 IF Y1<5 THEN 14570
```

BASIC program listing - Continued.

```
14560 X0=X0+0.5
14570 MOVE @1:X0-0.5,Y0-1
14580 GO TO 15310
14590 VIEWPORT 13.2,114,22,89.2
14600 WINDOW V1-1,V2,V5+1,V6+1
14610 PRINT "D(u,x/B)       1";
14620 PRINT
14630 PRINT "W(u,r/B)       2";
14640 PRINT
14650 PRINT "H(u,beta)      3";
14660 PRINT
14670 PRINT "PART.PENETR.   4";
14680 PRINT
14690 PRINT "FRACT.RESERV. 5";
14700 PRINT
14710 INPUT Y1
14720 GO TO Y1 OF 14780,15010,14820,14860,15050
14730 REM***************************************************
14740 REM                                                  *
14750 REM  DATA INPUT :  TYPE CURVE CONSTANTS              *
14760 REM                                                  *
14770 REM***************************************************
14780 PRINT "W(m) = ";
14790 INPUT W1
14800 PRINT "x/B = ";
14810 GO TO 15020
14820 PRINT "K'/b'*1.0E9 (s-1) = ";
14830 INPUT R(O(I))
14840 R(O(I))=R(O(I))*1.0E-9
14850 GO TO 15190
14860 PRINT "b(m) = ";
14870 INPUT D0
14880 PRINT "l(m) = ";
14890 INPUT L1
14900 L1=L1*PI/D0
14910 PRINT "d(m) = ";
14920 INPUT L2
14930 L2=L2*PI/D0
14940 PRINT "l'(m) = ";
14950 INPUT B1
14960 B1=B1*PI/D0
14970 PRINT "d'(m) = ";
14980 INPUT B0
14990 B0=B0*PI/D0
15000 PRINT
15010 PRINT "r/B = ";
15020 INPUT R9
15030 IF R9<0 THEN 4400
15040 GO TO 15130
15050 R9=0
15060 PRINT "alfa = ";
15070 INPUT L0
15080 IF L0<=0 THEN 4400
15090 L1=L0
15100 PRINT "beta = ";
15110 INPUT L2
15120 WINDOW V1-2.5,V2-1.5,V5+1,V6+1
15130 R0=R9
15140 R8=R9
15150 IF Y1<>4 THEN 15280
```

BASIC program listing - Continued.

```
15160 PRINT "Kr/Kz = ";
15170 INPUT K9
15180 GO TO 15280
15190 PRINT "beta = ";
15200 INPUT B0
15210 IF B0<0 THEN 4400
15220 B1=B0
15230 REM*************************************************
15240 REM                                                *
15250 REM  COMPUTATION OF THE SPECIFIED TYPE CURVES.     *
15260 REM                                                *
15270 REM*************************************************
15280 AXIS 0,0,V1-1.5,V6
15290 U3=5
15300 ROPEN 1
15310 N0=1
15320 J2=0
15330 IF Z=32 THEN 15360
15340 U=U3
15350 GO TO 15390
15360 U=5
15370 IF Y1<5 THEN 15390
15380 U=100
15390 IF Y1=3 THEN 15430
15400 IF U>R8↑2/100 THEN 15430
15410 U=1.0E-5
15420 GO TO 16660
15430 J=U
15440 IF Y1<5 THEN 15470
15450 L0=SQR(L1*U)
15460 J=(L2+(EXP(2*L0)-1)/(EXP(2*L0)+1)/L0)*U/(1+L2)
15470 F=0
15480 IF Y1=1 THEN 16400
15490 X1=0
15500 X2=0
15510 B3=1
15520 B4=1
15530 GO TO Y1 OF 1,15810,15590,15810,15810
15540 REM*************************************************
15550 REM                                                *
15560 REM  CALCULATION USING MIDPOINT INTEGRATION.       *
15570 REM                                                *
15580 REM*************************************************
15590 FOR J=U TO 1.9*U STEP 0.1*U
15600 T1=B1*SQR(U)/SQR((J+0.05*U)*(J-0.95*U))
15610 IF T1<25 THEN 15640
15620 B3=0
15630 GO TO 15660
15640 B3=1/(1+0.47047*T1)
15650 B3=(0.3480242*B3-0.0958798*B3↑2+0.7478556*B3↑3)/EXP(T1↑2)
15660 F=F+EXP(-J-0.05*U)*B3/(J+0.05*U)
15670 NEXT J
15680 F=F*U/10
15690 T1=B1/SQR(J)
15700 IF T1<25 THEN 15730
15710 B3=0
15720 GO TO 15820
15730 B3=1/(1+0.47047*T1)
15740 B3=(0.3480242*B3-0.0958798*B3↑2+0.7478556*B3↑3)/EXP(T1↑2)
15750 GO TO 15820
```

BASIC program listing - Continued.

```
15760 REM*****************************************************
15770 REM                                                    *
15780 REM  GENERAL COMPUTATION USING SIMPSON'S RULE.         *
15790 REM                                                    *
15800 REM*****************************************************
15810 X1=RO↑2/(4*U)
15820 F3=EXP(-J-X1)*B3/J
15830 F1=F3
15840 IF Y1=3 THEN 15880
15850 X1=RO↑2/(6*J)
15860 X2=RO↑2/(8*J)
15870 GO TO 15980
15880 T1=B1*SQR(U)/SQR(1.5*J*(1.5*J-U))
15890 T2=B1*SQR(U)/SQR(2*J*(2*J-U))
15900 IF T1<25 THEN 15940
15910 B3=0
15920 B4=0
15930 GO TO 15980
15940 B3=1/(1+0.47047*T1)
15950 B4=1/(1+0.47047*T2)
15960 B3=(0.3480242*B3-0.0958798*B3↑2+0.7478556*B3↑3)/EXP(T1↑2)
15970 B4=(0.3480242*B4-0.0958798*B4↑2+0.7478556*B4↑3)/EXP(T2↑2)
15980 F2=EXP(-J*1.5-X1)*B3/(J*1.5)
15990 F3=EXP(-J*2-X2)*B4/(J*2)
16000 F=F+(F1+4*F2+F3)*J/6
16010 J=2*J
16020 IF J<10 THEN 15830
16030 IF Y1<>4 THEN 16630
16040 IF J2>0 THEN 16120
16050 F4=F
16060 GO TO 16200
16070 REM*****************************************************
16080 REM                                                    *
16090 REM  PARTIAL PENETRATION SUMMATION TERM.               *
16100 REM                                                    *
16110 REM*****************************************************
16120 F=(SIN(J2*L1)-SIN(J2*L2))*(SIN(J2*B1)-SIN(J2*B0))*F/(J2↑2*(B1-B0))
16130 F6=F6+F
16140 IF J2<10 THEN 16170
16150 F7=ABS(F9)+ABS(F8)+ABS(F)
16160 IF F7<0.002*F4*(L1-L2) THEN 16280
16170 IF J2<8 THEN 16190
16180 F8=F9
16190 F9=F
16200 J2=J2+1
16210 RO=SQR(R8↑2+(J2*PI*A(O(I))/D0)↑2/K9)
16220 U9=U+RO↑2/(4*U)
16230 IF U9>700 THEN 16290
16240 IF J2>1 THEN 15430
16250 IF U<0.05*RO↑1.89 THEN 16290
16260 F6=0
16270 GO TO 15430
16280 F5=F6
16290 F=F4+F5*2/(L1-L2)
16300 IF F>1.0E-4 THEN 16320
16310 F=1.0E-4
16320 RO=R8
16330 J2=0
16340 GO TO 16630
16350 REM*****************************************************
```

BASIC program listing - Continued.

```
16360 REM                                                   *
16370 REM  STRIP AQUIFER TYPE CURVE.                        *
16380 REM                                                   *
16390 REM***************************************************
16400 F1=10
16410 U0=R8/(2*SQR(U))-SQR(U)
16420 U2=U0
16430 F3=U2
16440 J=1
16450 U2=-U2*U0↑2*(2*J-1)/(2*J↑2+J)
16460 F3=F3+U2
16470 J=J+1
16480 IF ABS(U2)>1.0E-5 THEN 16450
16490 IF F1<10 THEN 16530
16500 F1=1-F3*2/SQR(PI)
16510 U0=R8/(2*SQR(U))+SQR(U)
16520 GO TO 16420
16530 F2=1-F3*2/SQR(PI)
16540 IF R8=0 THEN 16570
16550 F=(EXP(-R8)-(EXP(-R8)*F1+EXP(R8)*F2)/2)/R8
16560 GO TO 16630
16570 F=1/(SQR(U*PI)*EXP(U))-F2
16580 REM***************************************************
16590 REM                                                   *
16600 REM  THE TYPE CURVE IS DRAWN.                         *
16610 REM                                                   *
16620 REM***************************************************
16630 IF N0>1 THEN 16660
16640 RMOVE @Z:LGT(1/U)+1,LGT(F)-1
16650 GO TO 16670
16660 RDRAW @Z:LGT(1/U)-LGT(1/U1),LGT(F)-LGT(F0)
16670 N0=N0+1
16680 IF F=>1.0E-3 THEN 16700
16690 U3=U
16700 U1=U
16710 F0=F
16720 IF U<0.1 THEN 16750
16730 U=U/1.2
16740 GO TO 16760
16750 U=U/1.4
16760 IF U=>1.0E-5 THEN 15390
16770 IF Z=1 THEN 16890
16780 RCLOSE
16790 CURSOR 1
16800 POINTER X0,Y0,X$
16810 STPOINT 3,X0,Y0
16820 Y0=Y0-0.013
16830 IF Y1<5 THEN 16850
16840 X0=X0+1.5
16850 FIX 1
16860 RINIT
16870 IF Y1=1 THEN 17160
16880 GO TO 17180
16890 MOVE @Z:V2-1.6,V5+0.6
16900 GO TO Y1 OF 16930,16970,17010,17050,17070
16910 MOVE @Z:V2-1.6,V5+0.4
16920 GO TO Y1 OF 16950,16990,17030,16990,17090
16930 PRINT @Z:"STRIP AQUIFER";
16940 GO TO 16910
16950 PRINT @Z:"W = ";W1;"m  x/B = ";R8;
```

```
16960 GO TO 4400
16970 PRINT @Z:"W(u,r/B)";
16980 GO TO 16910
16990 PRINT @Z:"r/B = ";R8;
17000 GO TO 4400
17010 PRINT @Z:"H(u,beta)";
17020 GO TO 16910
17030 PRINT @Z:"beta = ";B1;
17040 GO TO 4400
17050 PRINT @Z:"PARTIAL PENETRATION";
17060 GO TO 16910
17070 PRINT @Z:"FRACTURED RESERVOIR";
17080 GO TO 16910
17090 PRINT @Z:"alfa=";L1;"  beta=";L2;
17100 GO TO 4400
17110 REM***************************************************
17120 REM                                                   *
17130 REM  T, S, S', K'/b'  ARE COMPUTED.                   *
17140 REM                                                   *
17150 REM***************************************************
17160 X(O(I))=INT(Q(P5)*A(O(I))/(W1*0.72*10↑(Y0-2)))/10000
17170 GO TO 17190
17180 X(O(I))=INT(Q(P5)/(0.144*PI*10↑(Y0-1)))/10000
17190 GO TO N3 OF 17200,17200,17220
17200 Y(O(I))=X(O(I))*10↑(X0+1.5)*24
17210 GO TO N3 OF 17240,17230
17220 Y(O(I))=X(O(I))*24*P(P5)/(1/10↑(X0+1.5)-1)
17230 Y(O(I))=Y(O(I))/A(O(I))↑2
17240 IF Y(O(I))<1.0E-3 THEN 17330
17250 IF Y(O(I))<0.01 THEN 17310
17260 IF Y(O(I))<0.1 THEN 17290
17270 Y(O(I))=INT(Y(O(I))*10↑2)/10↑2
17280 GO TO 17340
17290 Y(O(I))=INT(Y(O(I))*10↑3)/10↑3
17300 GO TO 17340
17310 Y(O(I))=INT(Y(O(I))*10↑4)/10↑4
17320 GO TO 17340
17330 Y(O(I))=INT(Y(O(I))*10↑5)/10↑5
17340 IF Y1<>3 THEN 17420
17350 B(O(I))=INT(X(O(I))*Y(O(I))*B1↑2*16000/(A(O(I))↑2*R(O(I))))/1000
17360 IF B(O(I))<0.01 THEN 17450
17370 IF B(O(I))<0.1 THEN 17400
17380 B(O(I))=INT(B(O(I))*10)/10
17390 GO TO 17450
17400 B(O(I))=INT(B(O(I))*100)/100
17410 GO TO 17450
17420 R(O(I))=INT(X(O(I))*10↑10*R0↑2/A(O(I))↑2)/10↑10
17430 IF R(O(I))<10↑-8 THEN 17450
17440 R(O(I))=INT(R(O(I))*10↑9)/10↑9
17450 HOME
17460 IF Y1<>4 THEN 17480
17470 K(O(I))=K9
17480 GO TO J1 OF 17540,17530,17520,17510,17500,17490
17490 PRINT "J_J_J_J_J_J_J_";
17500 PRINT "J_J_J_J_J_J_J_";
17510 PRINT "J_J_J_J_J_J_J_";
17520 PRINT "J_J_J_J_J_J_J_";
17530 PRINT "J_J_J_J_J_J_J_";
17540 PRINT "J_J_J_J_J_J_J_";
17550 PRINT "J_J_J_J_J_J_J_";
```

BASIC program listing - Continued.

```
17560 PRINT "T=";X(O(I));" m2/s";
17570 PRINT
17580 PRINT "S=";Y(O(I));
17590 PRINT
17600 IF Y1<>3 THEN 17640
17610 PRINT "S'=";B(O(I));
17620 PRINT
17630 GO TO 17660
17640 PRINT "K'/b'=";R(O(I));" s-1";
17650 PRINT
17660 PRINT "J_J_";
17670 J1=J1+1
17680 IF J1>7 THEN 4400
17690 GO TO Y1 OF 14800,15010,15190,15010,15060
```

ATTACHMENT II

Definition of program variables.

A(N)	: One dim. array. Distance from center of pumped well to observation point, meters. Stored on tape.
A$(20)	: String variable. Description of the project. Stored on tape.
B(N)	: One dim. array. Computed values of S': The storage coefficient of the semipervious layer(s).
B0	: Internal variable.
B1	: Internal variable.
B2	: Internal variable.
B3	: Internal variable.
B4	: Internal variable.
B5	: Internal variable.
B$(12)	: String variable. Internal parameter.
C(N)	: One dim. array. Contains the actual number of time-drawdown data for each data set (sequence of drawdowns). Stored on tape.
C$(12)	: String variable. Plotting date and initials of the operator.
D(N)	: One dim. array. Contains the well-file no. of the actual data set. Stored on tape.
D0	: Numeric variable. Thickness of the aquifer.

Definition of program variables - Continued.

D1	:	Numeric parameter. The well-file no. of the pumped well. Stored on tape.
D$(8)	:	String variable. Date of set up. Stored on tape.
E(M1,N)	:	Two dim. array. Contains times or converted times. Internal variable.
E1	:	Internal variable.
E2	:	Internal variable.
F	:	Numeric variable. Computed values of the specified type curve function.
F0	:	Numeric variable. Computed values of the specified type curve function.
F1	:	Internal variable.
F2	:	Internal variable.
F3	:	Internal variable.
F4	:	Internal variable.
F5	:	Internal variable.
F6	:	Internal variable.
F7	:	Internal variable.
F8	:	Internal variable.
F9	:	Internal variable.
G(M1,2)	:	Two dim. array. Contains drawdown data used for correction of observed data for external ground-water fluctuations.

Definition of program variables - Continued.

G0	: Internal variable.
G2	: Numeric variable. Vertical axis tic marks, semilog. Stored on tape.
H	: Internal variable.
H$(15)	: String variable. Internal parameter.
I	: Internal variable.
J	: Internal variable.
J0	: Internal variable.
J1	: Internal variable.
J2	: Internal variable.
J3	: Internal variable.
K(N)	: One dim. array. Values of the ratio between horizontal and vertical hydraulic conductivity, K_r/K_z.
K9	: Numeric variable. Ratio between horizontal and vertical hydraulic conductivity.
K$(5)	: String variable. Time for set up. Stored on tape.
L(M1,2)	: Two dim. array. Contains time data used for correction of observed data for external groundwater fluctuations.
L0	: Internal variable.
L1	: Internal variable.
L2	: Internal variable.

Definition of program variables - Continued.

L$(20)	:	String variable. Geographical locality of the project. Stored on tape.
M(N)	:	One dim. array. Gauge, meters above ground surface. Stored on tape.
M1	:	Numeric parameter. Maximum number of time-drawdown data allowed to be stored for each data set. Stored on tape.
N	:	Numeric parameter. Number of data sets. Stored on tape.
N0	:	Internal variable.
N1	:	Numeric parameter. Type of well: pumped well or observation well. Stored on tape.
N2	:	Numeric parameter. Type of data: Drawdown, recovery or drawdown/recovery. Stored on tape.
N3	:	Internal parameter.
N4	:	Internal parameter.
N5	:	Internal parameter.
N6	:	Internal parameter.
N7	:	Internal parameter.
O(N)	:	One dim. array. Contains the specified number of data sets to be plotted. Internal variable.
P(25)	:	One dim. array. Times since set up when changes in pumping capacity occurs. Stored on tape.
P1	:	Internal variable.

Definition of program variables - Continued.

P5	: Numeric variable. Number of capacity/time values. Stored on tape.
Q(25)	: One dim. array. Pumping capacity. Stored on tape.
Q1	: Internal variable.
Q3	: Numeric variable. Computed mean value of the pumping capacity.
R(N)	: One dim. array. Contains computed values of the leakage-factor, K'/b'.
R0	: Numeric variable. Internal.
R1	: Numeric variable. Minimum time in minutes for each data file. Stored on tape.
R2	: Numeric variable. Maximum time in minutes for each data file. Stored on tape.
R3	: Numeric variable. Minimum drawdown in meters for each data file. Stored on tape.
R4	: Numeric variable. Maximum drawdown in meters for each data file. Stored on tape.
R5	: Numeric variable. Minimum pumping capacity. Internal.
R6	: Numeric variable. Maximum pumping capacity. Internal.
R8	: Internal variable.
R9	: Internal variable.
R$(8)	: String variable. Date of shut off. Stored on tape.
S(M1,N)	: Two dim. array. Drawdown/recovery data in meters. Stored on tape.
S1	: Internal variable.

Definition of program variables - Continued.

T1	:	Internal variable.
T2	:	Internal variable.
T$(5)	:	String variable. Time for shut off. Stored on tape.
U	:	Numeric variable. $U = r^2S/4Tt$.
U0	:	Internal variable.
U1	:	Internal variable.
U2	:	Internal variable.
U3	:	Internal variable.
U9	:	Internal variable.
V(N)	:	One dim. array. Rest water level in meters below gauge. Stored on tape.
V1	:	Internal variable. Dimension of the horizontal axis.
V2	:	Internal variable. Dimension of the horizontal axis.
V3	:	Numeric variable. Dimension of the vertical axis, minimum. Stored on tape.
V4	:	Numeric variable. Dimension of the vertical axis, maximum. Stored on tape.
V5	:	Internal variable.
V6	:	Internal variable.
W(N)	:	One dim. array. Water level at shut off in meters below gauge. Stored on tape.

Definition of program variables - Continued.

W1	:	Internal variable.
X(N)	:	One dim. array. Computed values of the transmissivity, using type curves.
X0	:	Numeric variable. Internal parameter.
X1	:	Numeric variable. Computed values of the transmissivity, drawdown. Semilog.
X2	:	Numeric variable. Computed values of the transmissivity, recovery. Semilog.
X$(9)	:	String variable. Internal parameter.
Y(N)	:	One dim. array. Computed values of S: The storage coefficient of the aquifer.
Y0	:	Internal variable.
Y1	:	Internal variable.
Z	:	Internal parameter. Addresses peripherals.

ATTACHMENT III

Data input formats.

The program has to be read into the machine from the program tape cartridge by typing:

FIND <program file no.>:

OLD

The program is activated by typing:

RUN

The program now asks for

DATE OF TODAY <Cs<13>:

and then the total program menu shows up on the screen (according to fig. 2, page 19).

The following listing of input formats is divided according to the concerned subroutines.

Specification of input formats used:

Cs<21: Character string. (Numbers of characters should be less than 21).

In≤5 : Positive integer. (The number should be equal to or less than 5).

Df : Decimal fraction.

PROGRAM QUESTION	INPUT	VARIABLE	COMMENTS
DATE OF TODAY	<Cs<13>:	C$	Date and initials of user should be typed.
PROJECT	<Cs<21>:	A$	Used for heading in the text-plot.
LOCATION	<Cs<21>:	L$	
PUMPING WELL 1 OBSERVATION WELL 2 CHOOSE NO..................................	<1/2>:	N1	
DRAWDOWN DATA 1 RECOVERY DATA 2 DRAWD.+RECOV. 3 CHOOSE NO..................................	<1/2/3>:	N2	3 is used only for pumping wells.
SET UP, DATE	<Cs<9>:	D$	
TIME	<Cs<6>:	K$	These time statements are used for computations, only as headings in the text-plot.
SHUT OFF, DATE	<Cs<9>:	R$	
TIME	<Cs<6>:	T$	

Data input formats - Continued.

PROGRAM QUESTION	INPUT	VARIABLE	COMMENTS	
PUMPED WELL, DGU file no.	<Df>:	DI	For obs. wells only.	DATA INPUT
MEAN OF PUMPING CAPACITY, m↑3/h	<Df>:	Q	For drawd. data in obs. wells only.	
PUMPING CAPACITY AT SHUT OFF, m↑3/h	<Df>:	Q	For recov. data in obs. wells only.	
PUMPING PERIOD, min	<Df>:	P		
TIME in min, PUMPING CAPACITY in m↑3/h	<Df,Df/0,0>:	P,Q	Max. 25 pair of data can be stored. The last pair of data should include the total pumping period. The input is finished with 0,0.	
NUMBER OF OBSERVATION WELLS	<In>:	N	Should not exceed 15	
DGU file no.	<Df>:	D		
GAUGE, m a Surface	<Df>:	M	Should be negative, when gauge is below ground surface.	
DISTANCE TO PUMPED WELL, m	<Df>:	A		
REST WATER LEVEL, m b Gauge	<Df>:	V	Should be negative when level is above gauge.	
WATER LEVEL AT SHUT OFF, m b Gauge	<Df>:	W		
AUTOMATIC WATER LEVEL MEASURES	<YES/NO>:	B$	Indicates whether the drawd./recov. data are directly measured values or includes the initial distance to the water level.	
INPUT DRAWDOWN DATA TIME in min, DRAWDOWN in m b Gauge..........	<Df,Df/0,0>:	T,S	Max. pair of data for each data set: 80 for pumping wells. 60 for observation wells, less than 8 wells. 30 for observation wells, more than 7 wells. The input is finished with 0,0.	
INPUT RECOVERY DATA TIME in min, RECOVERY in m b Gauge..........	<Df,Df/0,0>:	T,S		
LIST DATA SET NO.	<In≤N/0>:	I	The input is finished with 0.	LISTING DATA
CHANGE DATA SET NO.	<In≤N/0>:	I	The input is finished with 0.	CHANGING DATA
PAIR OF DATA, NO.	<In/0>:	J	The input is finished with 0.	
PRESENT VALUE OF THE PAIR OF DATA SHALL BE CHANGED TO.........................	<Df,Df>:	T,S	Present value shows up on the screen. The drawd./recov. value includes the initial distance to the water level.	

PROGRAM QUESTION	INPUT	VARIABLE	COMMENTS	
DELETE DATA SET NO.	<In≤N/0>:	I	The input is finished with 0.	DELETING DATA
PAIR OF DATA, NO.............................	<In/0>:	J	The remaining pairs of data are renumbered.	
PAIR OF DATA DELETED			The input is finished with 0.	
ADDITION IN DATA SET NO.	<In≤N/0>:	I	The input is finished with 0.	ADDING DATA
INPUT PAIR OF DATA	<Df,Df>:	T,S	The drawd./recov. value should include the initial distance to the water level.	
STORING DATA ON TAPE				STORING ON TAPE
INSERT TAPE CARTRIDGE				
INPUT FILE NO..............................	<In>:	Y1		
NEW FILE..................................	<YES/NO>:	B$	Adding a new file/changing an old file.	
DATA STORED ON TAPE				
READING DATA FROM TAPE				READING THE TAPE
INSERT TAPE CARTRIDGE				
INPUT FILE NO..............................	<In>:	Y1		
THICKNESS OF THE AQUIFER, m	<Df>:	D0	All data sets in the file are corrected.	DECREASING THICKNESS
CORRECTION WELL-DATA SET NO.	<In≤N>:	P1	The fluctuations arising from this well are used for the correction of other wells.	WATER LEVEL FLUCTUATIONS
CORRECTION FACTOR	<Df/0>:	B1	The factor should normally be ranging between 0 and 1. The input is finished with 0.	
CORRECTION OF DATA SET NO.	<In/0>:	I	Correction of the specified wells. The input is finished with 0.	
PLOT DATA SET NO.	<In≤N>:	I	For obs. wells only one data set can be plotted at a time.	SEMILOG
RECOVERY DATA IN THE SAME DIAGRAM	<YES/NO>:	B$	Only in connection with pumping well data.	

Data input formats - Continued.

PROGRAM QUESTION	INPUT	VARIABLE	COMMENTS	
T/(T+DT)-PLOT	<YES/NO>:	B$	Only in connection with recovery data.	SEMILOG
DO YOU WANT TO PLOT THE COORDINATE SYSTEM	<YES/NO>:	B$	Only when using the plotter.	SEMILOG
PLOT DATA SET NO.	<In≤N/0>:	0	Up to 5 wells can be plotted at a time. The input is finished with 0.	LOG-LOG
T/R2-PLOT 1 T-PLOT 2 T/(T+DT)-PLOT 3 CHOOSE NO..................................	<1/2/3>:	N3	3 is used only for recovery data.	LOG-LOG
INTERPRETATION PLOT	<YES/NO>:	B$	Only when using the plotter (according the last passage, page 26).	LOG-LOG
T	<1/2/0>:	I	Only when dealing with pumping well data including both drawdown and recovery data. (Drawd.-1/Recov.-2). The input is finished with 0. Beyond that the RETURN - button is used.	REGRESSION
D(u,x/B 1 W(u,r/B) 2 H(u,beta) 3 PART. PENETR. 4 FRACT. RESERV. 5	<1/2/3/4/5>:	Y1	Available type curve solutions.	TYPECURVES
W(m)=	<Df>:	W1	Strip aquifer. The interpretation is finished when the input for x/B is negative.	TYPECURVES
x/B =	<Df>:	R9,(R8,R0)		TYPECURVES
r/B =	<Df>:	R9,(R8,R0)	Leaky aquifer. The interpretation is finished when the input for r/B is negative	TYPECURVES

Data input formats - Continued.

TYPE-CURVES

PROGRAM QUESTION	INPUT	VARIABLE	COMMENTS
K'/b'x1.0E9(s-1)=	<Df>:	R	Storage in the confining bed. The interpretation is finished when the input for beta is negative
beta =	<Df>:	B0,B1)	
b(m) =	<Df>:	D0	Partially penetrating pumping well. The interpretation is finished when the input for r/B is negative
l(m) =	<Df>:	L1	
d(m) =	<Df>:	L2	
l'(m) =	<Df>:	B1	
d'(m) =	<Df>:	B0	
r/B =	<Df>:	R9,(R8,R0)	
Kr/Kz =	<Df>:	K9	
alfa	<Df>:	L0	Fractured reservoir. The interpretation is finished when the input for alfa is equal to or less than 0.
beta	<Df>:	L2	

ATTACHMENT IV

Input data for selected test problems.

```
PROJECT SOLRØD VANDVÆRK
LOCATION  SOLRØD

PUMPING WELL        1
OBSERVATION WELL    2
CHOOSE NO.  1

DRAWDOWN DATA 1
RECOVERY DATA 2
DRAWD.+RECOV. 3
CHOOSE NO.  3

SET UP,       DATE  31.03.81
              TIME  12.35

SHUT OFF,     DATE  04.05.81
              TIME  13.00

TIME in min, PUMPING CAPACITY in m↑3/h
1,28.1
2,26.7
5,26.2
12,26
20,25.3
etc.
0,0

DGU file no. 207.2656

GAUGE, m a Surface  0

REST WATER LEVEL, m b Gauge  0.97

AUTOMATIC WATER LEVEL MEASURES NO

INPUT DRAWDOWN DATA
TIME in min, DRAWDOWN in m b Gauge

1,7.41
2,9.68
3,10.23
4,10.52
5,10.71
etc.
0,0

WATER LEVEL AT SHUT OFF, m b Gauge  15.5

AUTOMATIC WATER LEVEL MEASURES NO

INPUT RECOVERY DATA
TIME in min, RECOVERY in m b Gauge

1.167,5.82
1.5,4.41
2,3.58
2.5,3.11
3,2.84
etc.
0,0
```

Fig. 1.: Test problem 1. Input data for pumping well with variable pumping capacity. Drawdown and recovery data.

Input data for selected test problems - Continued.

```
PROJECT  VARMELAGRING
LOCATION  HØRSHOLM

PUMPING WELL          1
OBSERVATION WELL      2
CHOOSE NO.  2

DRAWDOWN DATA 1
RECOVERY DATA 2
CHOOSE NO.  2

SET UP,         DATE  08.01.80
                TIME  12.00

SHUT OFF,       DATE  10.01.80
                TIME  ca 4.

PUMPED WELL, DGU file no. 194.655

MEAN OF PUMPING CAPACITY, m↑3/h
21.5
NUMBER OF OBSERVATION WELLS 5

DGU file no. 194.652

GAUGE, m a Surface  0.1

DISTANCE TO PUMPED WELL, m 90.6

WATER LEVEL, m b Gauge  4.88

AUTOMATIC WATER LEVEL MEASURES YES

INPUT DRAWDOWN DATA
TIME in min. RECOVERY in m b Gauge

3,0.002
7.5,0.007
11.25,0.03
15,0.05
18.75,0.068
etc.
0,0
DGU file no. 194.653

GAUGE, m a Surface  0.5

DISTANCE TO PUMPED WELL, m 180

WATER LEVEL, m b Gauge  1.875

AUTOMATIC WATER LEVEL MEASURES YES

INPUT DRAWDOWN DATA
TIME in min. RECOVERY in m b Gauge

21.25,0.005
25,0.006
32,0.015
64,0.035
118,0.049
etc.
0,0
```

Fig. 2.: Test problem 2. Input data for five observation wells. Drawdown data.

DGU file no. *194.554*

GAUGE, m a Surface *0.38*

DISTANCE TO PUMPED WELL, m *92.9*

REST WATER LEVEL, m b Gauge *2.815*

AUTOMATIC WATER LEVEL MEASURES *YES*

INPUT DRAWDOWN DATA
TIME in min. RECOVERY in m b Gauge

1.5,0.001
3.75,0.005
5,0.013
7.5,0.025
11.25,0.049
etc.
0,0

DGU file no. *194.656*

GAUGE, m a Surface *0.4*

DISTANCE TO PUMPED WELL, m *105.5*

REST WATER LEVEL, m b Gauge *7.535*

AUTOMATIC WATER LEVEL MEASURES *YES*

INPUT DRAWDOWN DATA
TIME in min. RECOVERY in m b Gauge

3.75,0.002
5,0.006
7.5,0.011
11.25,0.021
15,0.027
etc.
0,0

DGU file no. *194.689*

GAUGE, m a Surface *0.5*

DISTANCE TO PUMPED WELL, m *80.7*

REST WATER LEVEL, m b Gauge *5.11*

AUTOMATIC WATER LEVEL MEASURES *YES*

INPUT DRAWDOWN DATA
TIME in min. RECOVERY in m b Gauge

11,0.07
22,0.085
53,0.102
105,0.11
175,0.126
etc.
0,0

Fig. 2. Test problem 2. - Continued.

ATTACHMENT V

Output for selected test problems.

PUMPING TEST

SOLRÖD VANDVÄRK - SOLRÖD

Pumping Well Data , DGU file no.207.2656

Set up, date 31.03.81 time 12.35 Shut off, date 04.05.81 time 13.00

Drawdown: T = 7.0E-4 m2/s

Recovery: T = 0.0012 m2/s

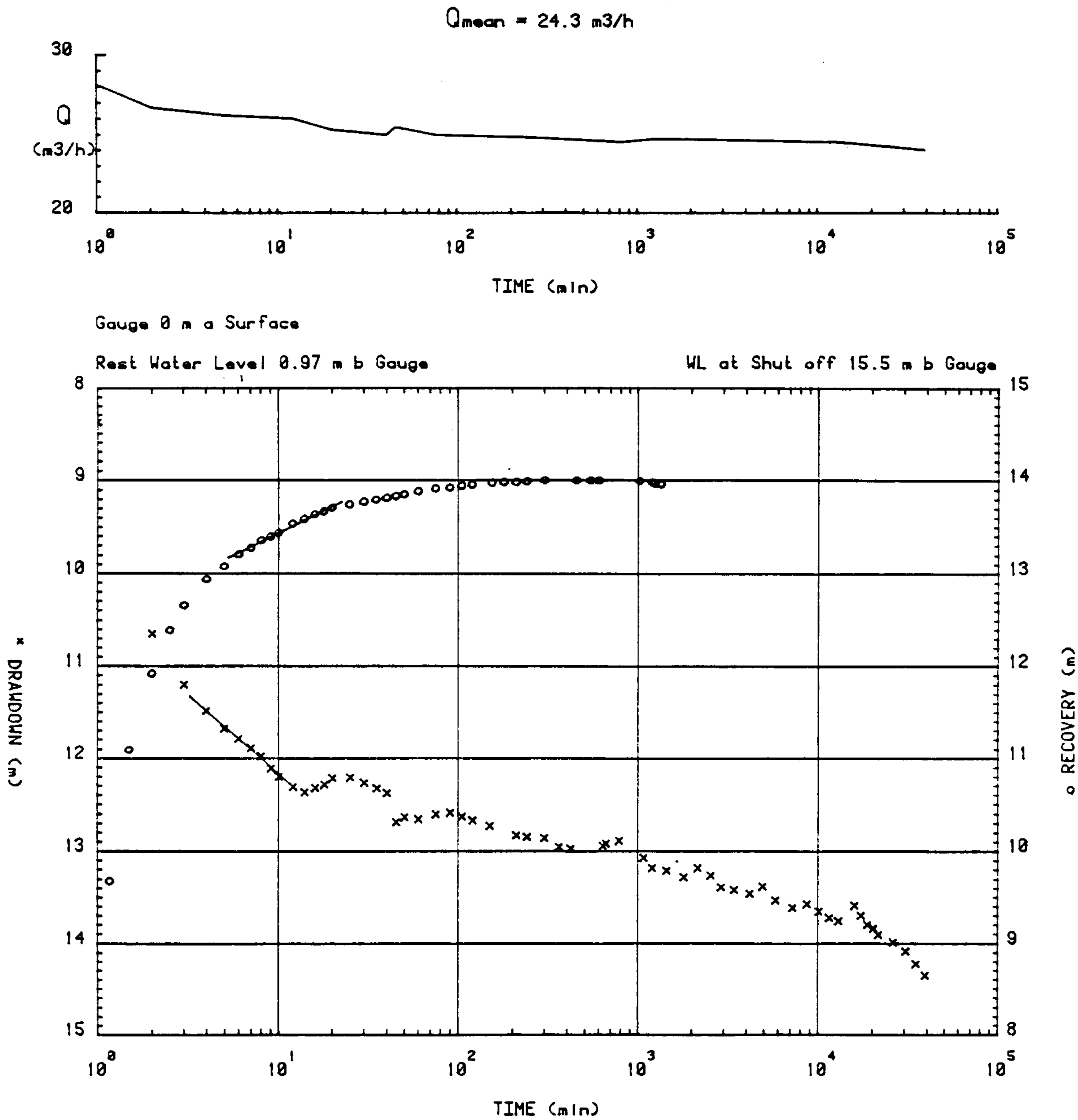

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Fig. 1. Test problem 1. Semilog plot of interpreted drawdown/recovery data.

Output for selected test problems - Continued.

PUMPING TEST

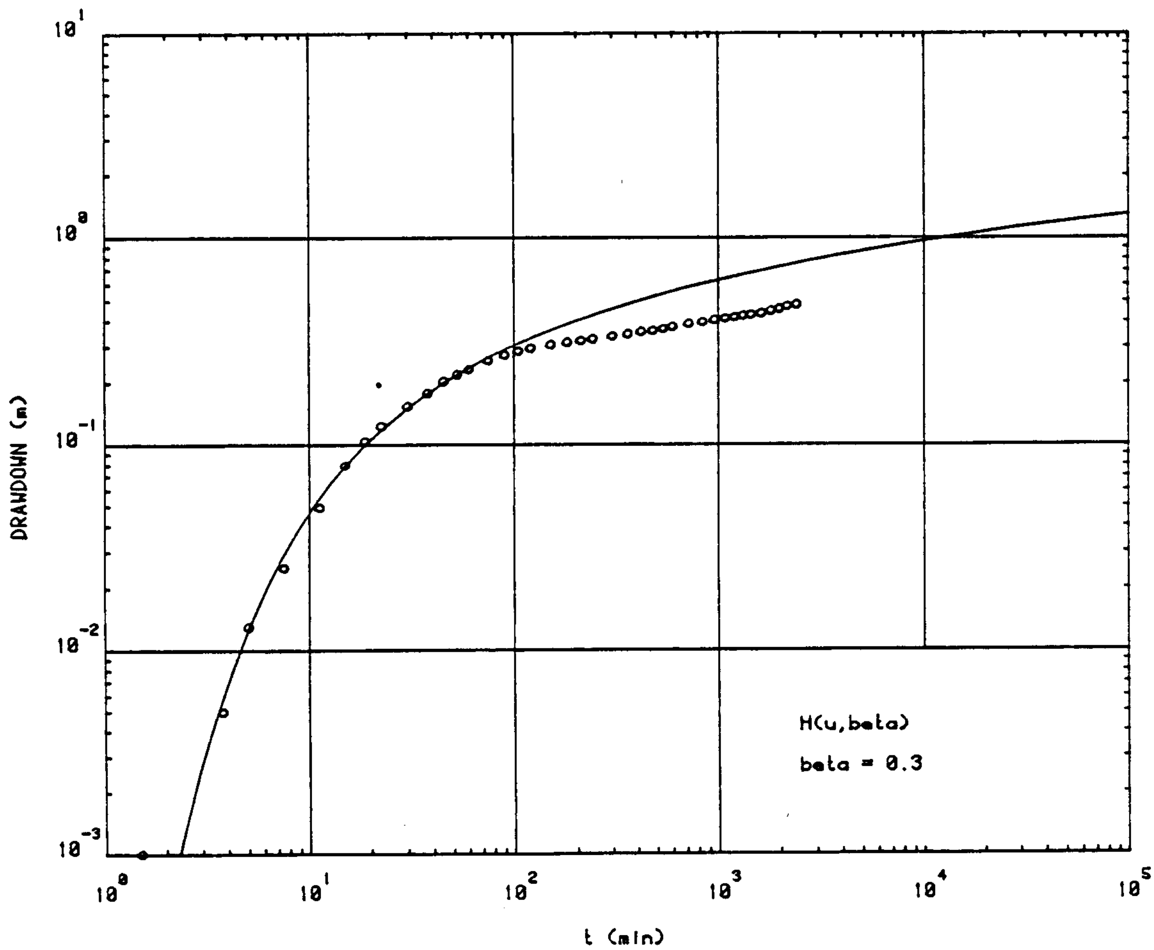
VARMELAGRING - HØRSHOLM

Observation Well Data, Pumped Well - DGU file no.194.655

Set up, date 08.01.80 time 12.00 Shut off, date 10.01.80 time CA 4.

Pumping Capacity, Q = 21.5 m3/h

DGU file no.	Distance (m)	T (m2/s)	S	S'	K'/b' (s-1)	Kr/Kz
194.654	92.9	0.0015	3.5E-4	0.01	5.0E-9	



26.11.84 BM GEOLOGICAL SURVEY OF DENMARK

Fig. 2. Test problem 2. Log-log plot of interpreted drawdown data.

Output for selected test problems - Continued.

PUMPING TEST

VARMELAGRING - HØRSHOLM

Observation Well Data, Pumped Well - DGU file no.194.655

Set up, date 08.01.80 time 12.00 Shut off, date 10.01.80 time CA 4.

Pumping Capacity, Q = 21.5 m3/h

DGU file no.	Distance (m)	T (m2/s)	S	S'	K'/b' (s-1)	Kr/Kz
194.652	90.6					
194.653	180					
194.654	92.9	0.0015	3.5E-4	0.01	5.0E-9	
194.656	105.5					
194.689	80.7					

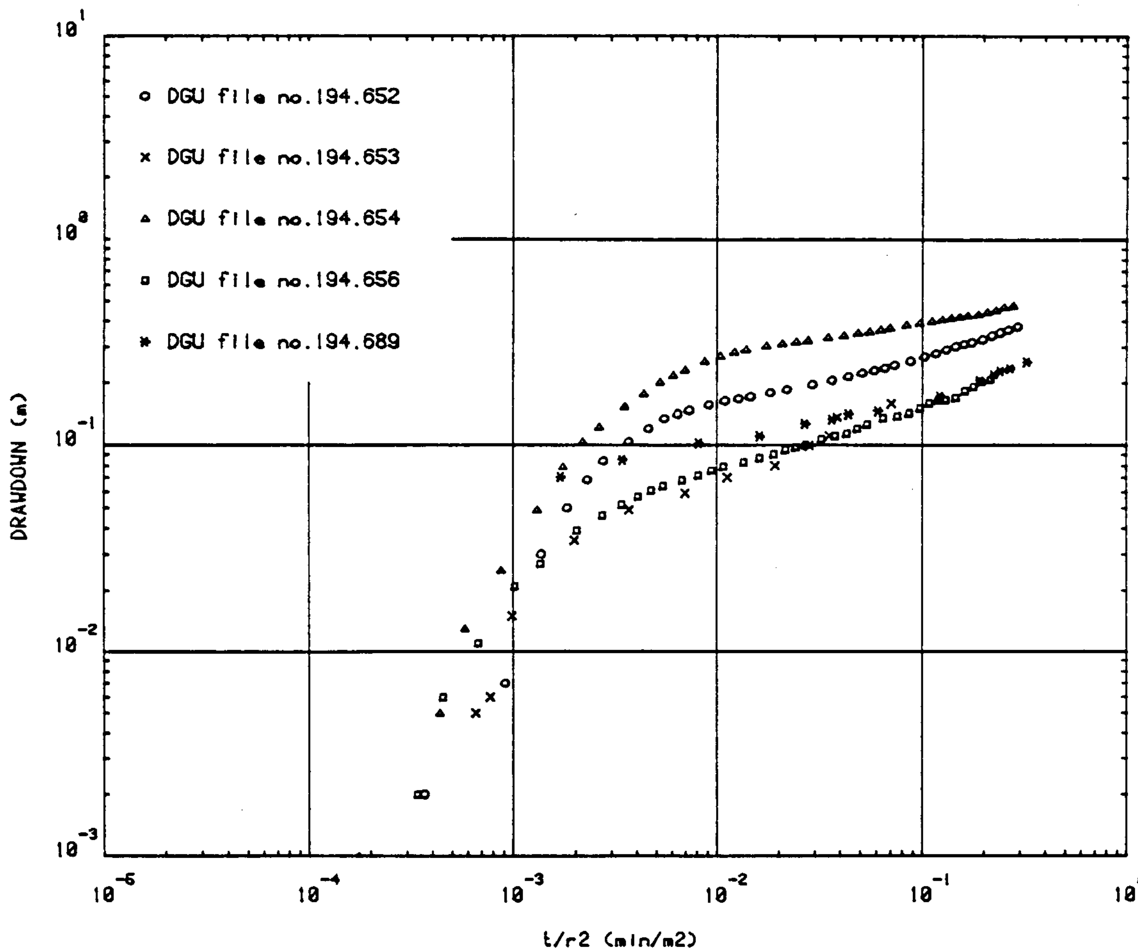


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Fig. 3. Test problem 2. Log-log plot of drawdown data.

Definition sketches and selected type curves.
Situation 1: Leaky Strip aquifer. One-dim. flow.

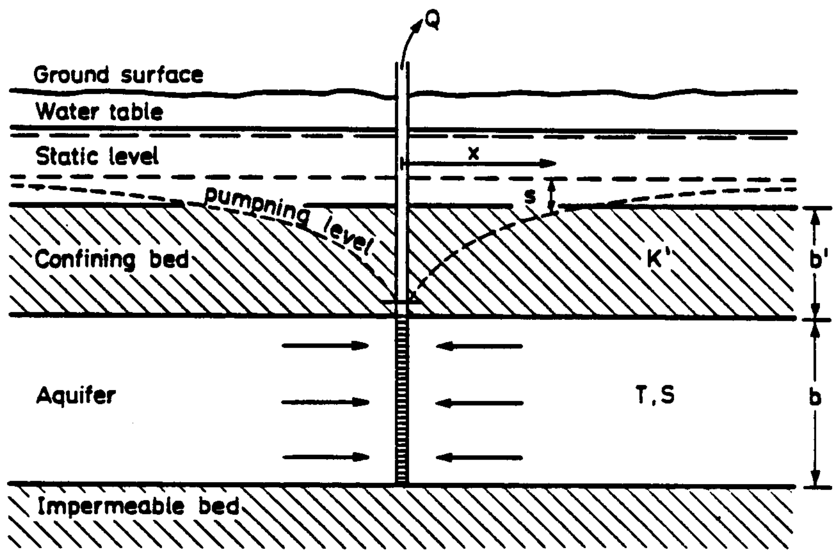

Fig. 1a. Definition sketch. Cross section.

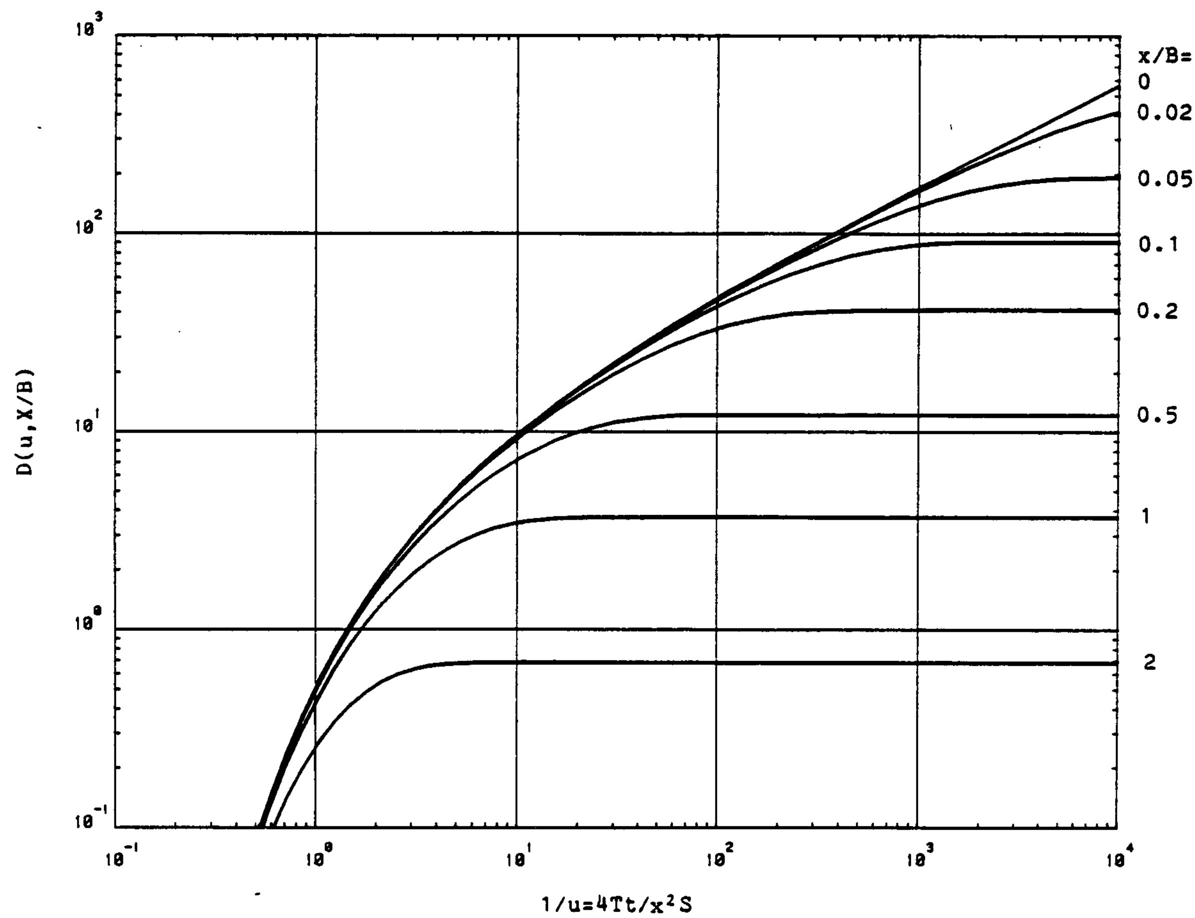

Fig. 1b. Eight selected type curves of dimensionless drawdown (D(u,x/B)) versus dimensionless time (1/u). The curve for x/B=0 shows the equivalent type curve for a nonleaky aquifer.

Definition sketches and selected type curves - Continued.

Situation 2: Leaky Aquifer. Radial Flow.

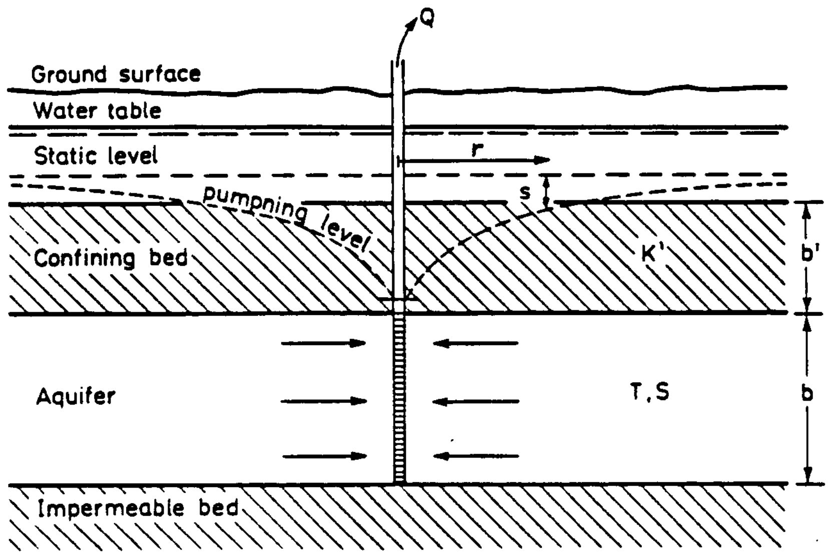

Fig. 2a. Definition sketch. Cross section.

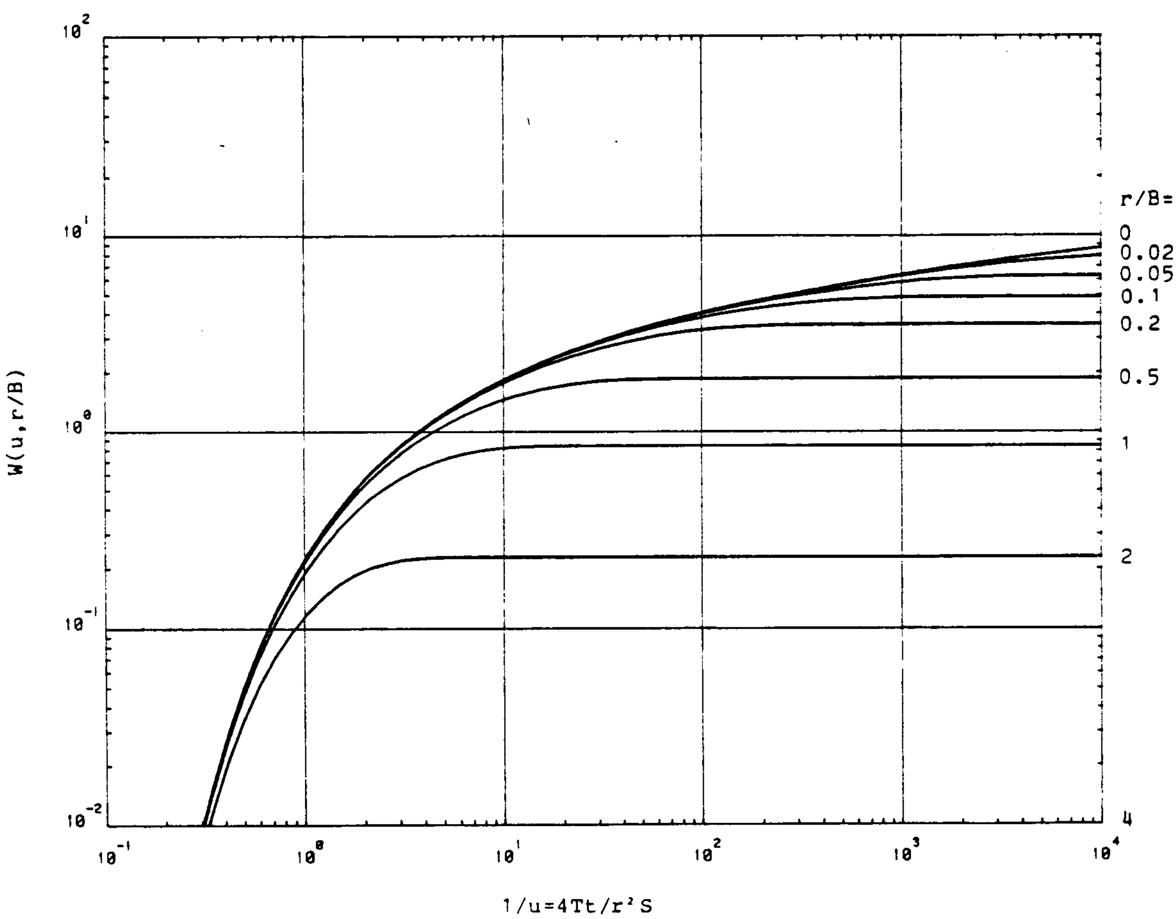

Fig. 2b. Eight selected type curves of dimensionless drawdown (W(u,r/B)) versus dimensionless time 1/u). The curve of r/B=0 shows the equivalent type curve for a nonleaky aquifer (Theis solution).

Definition sketches and selected type curves - Continued.

Situation 3: Leaky aquifer with storage of water in the confining beds. Radial flow.

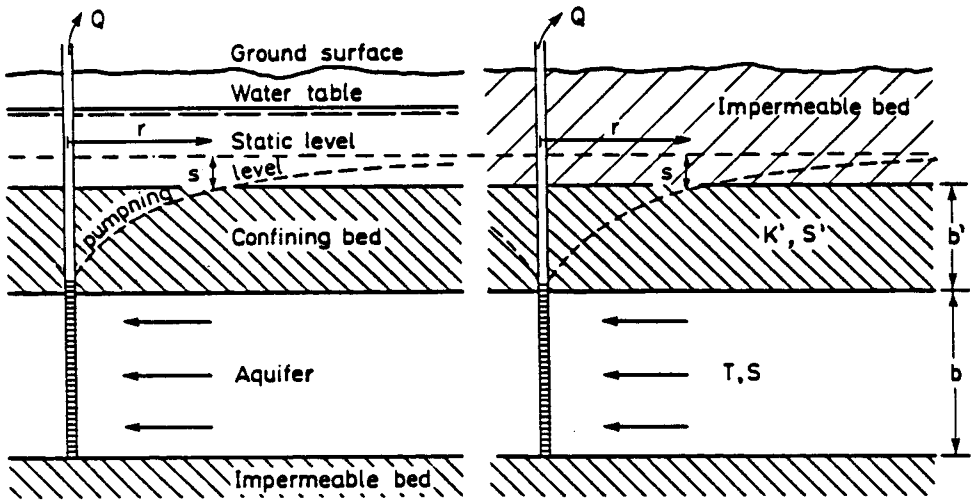

fig. 3a. Definition sketches. Cross sections.

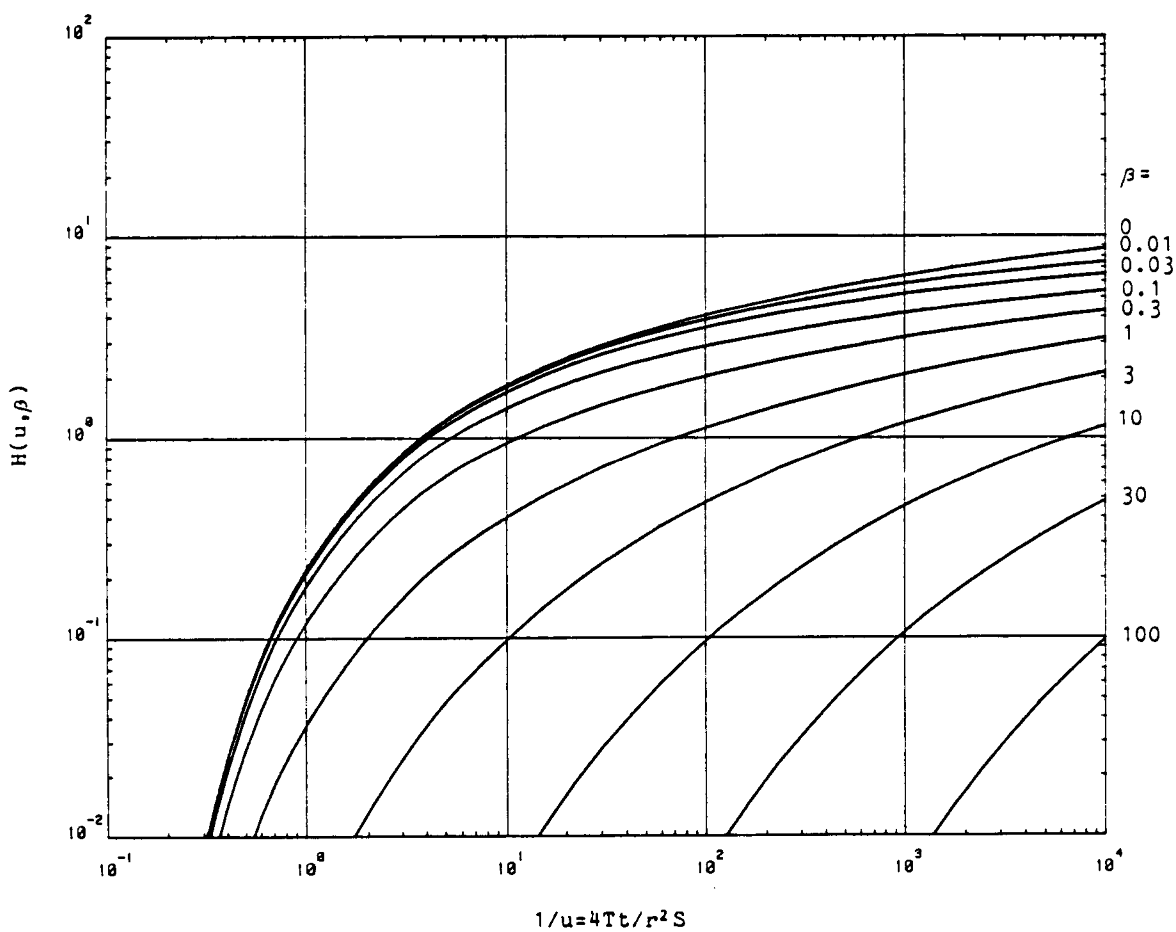

Fig. 3b. Ten selected type curves of dimensionless drawdown ($H(u,\beta)$) versus dimensionless time ($1/u$). The curve for $\beta=0$ shows the equivalent type curve for the Theis solution.

Definition sketches and selected type curves - Continued.

Situation 4: Partially penetrating well in a leaky aquifer. Radial flow.

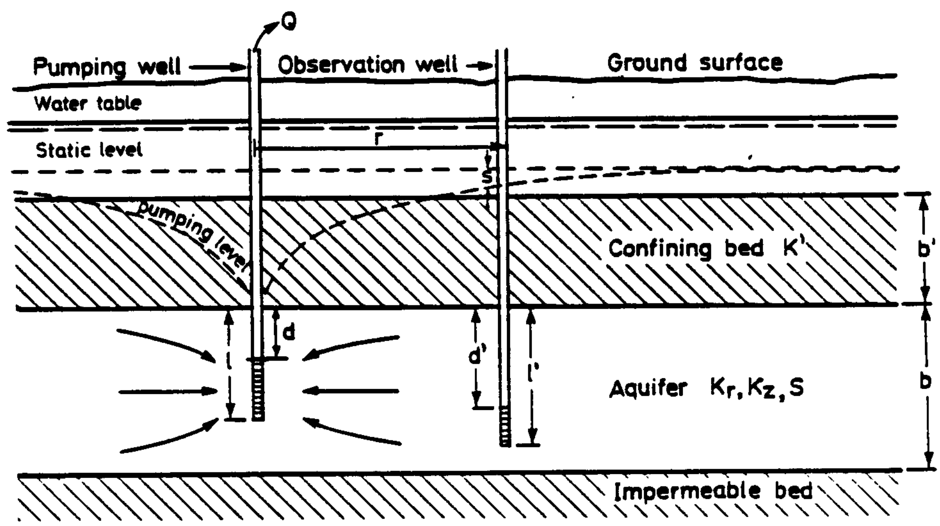

Fig. 4a. Definition sketch. Cross section.

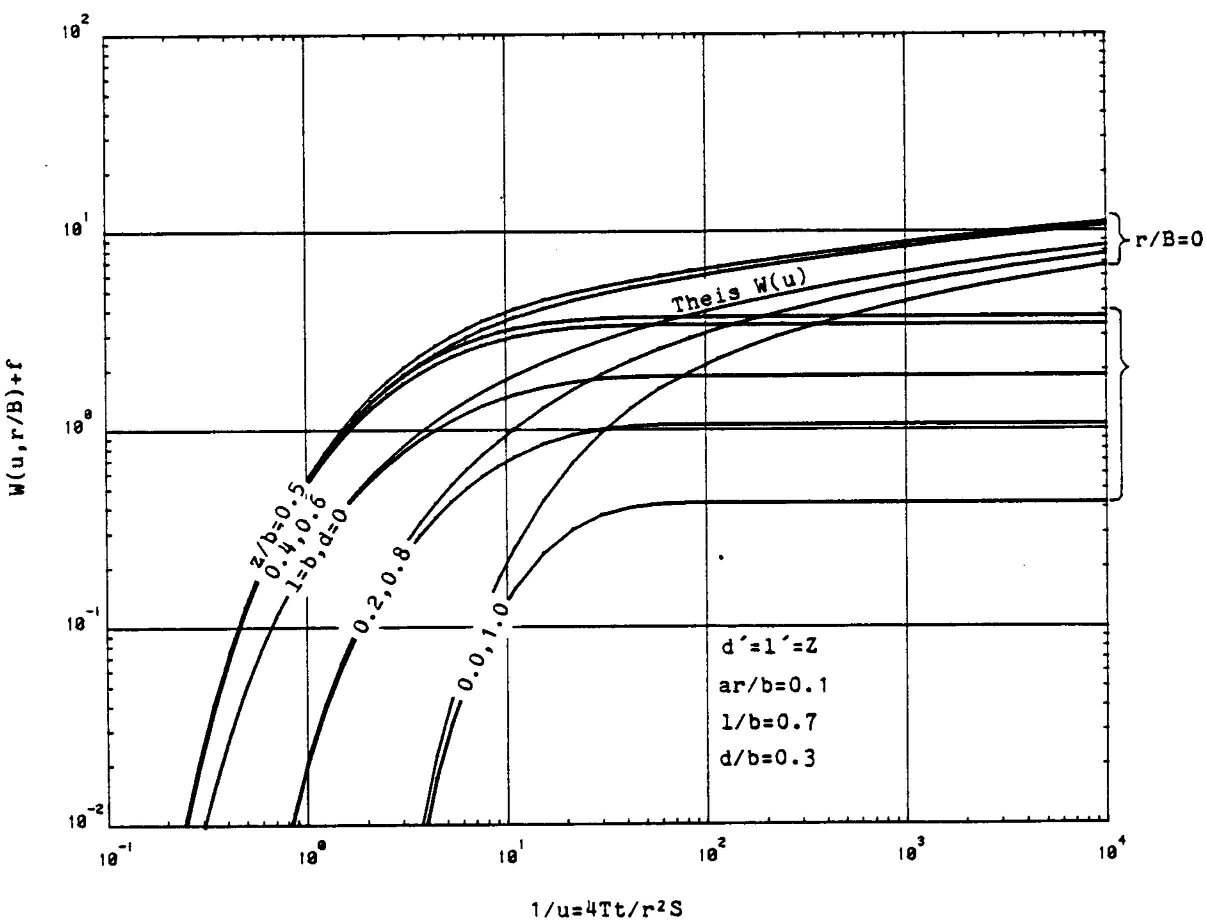

Fig. 4b. Selected type curves of dimensionless drawdown ($W(u,r/B)+f$) versus dimensionless time ($1/u$). The curves for $r/B=0$ show the equivalent type curves for a nonleaky aquifer.

Definition sketches and selected type curves - Continued.

Situation 5: Nonleaky fractured aquifer. Radial flow.

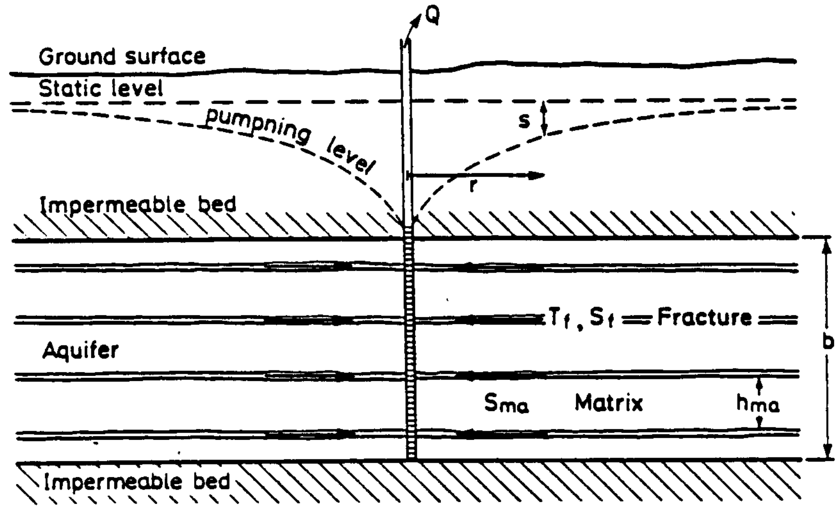

fig. 5a. Definition sketch. Cross section.

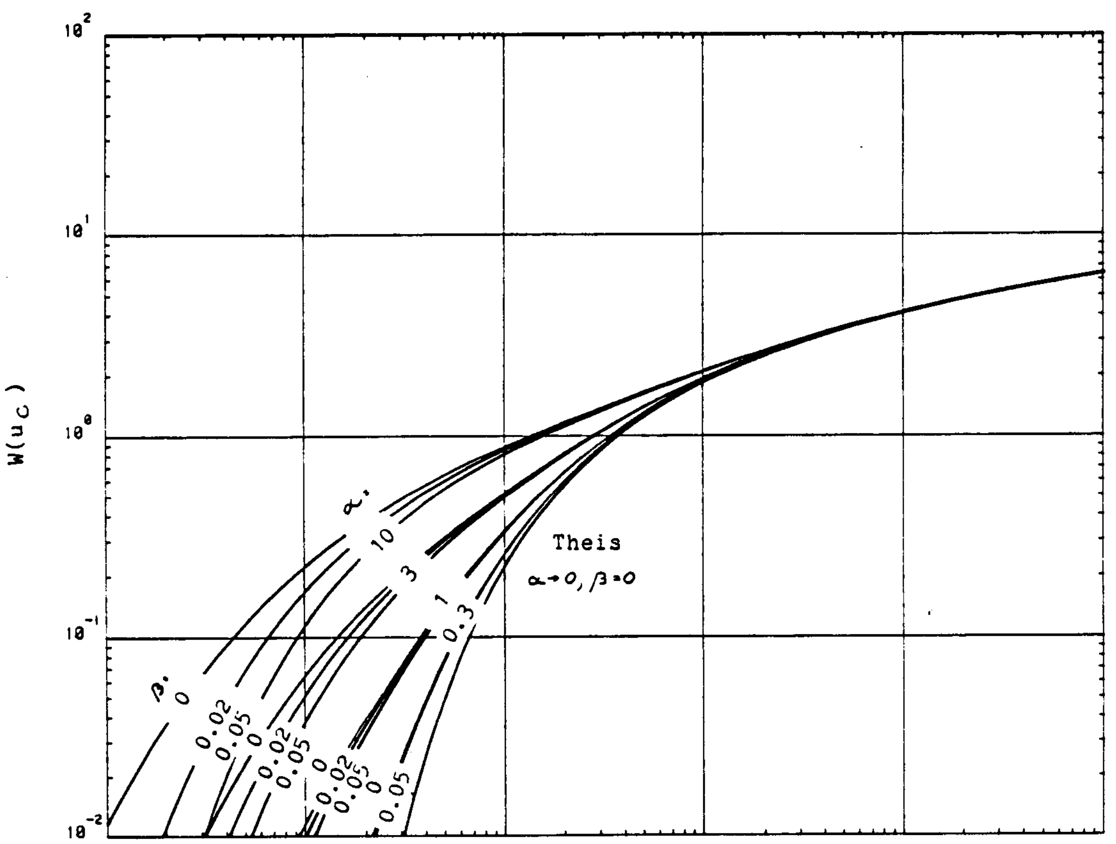

fig. 5b. Selected type curves of dimensionless drawdown (W(u)) versus dimensionless time (1/u). The curve for $\alpha \rightarrow 0$ and $\beta = 0$ shows the equivalent type curve for the Theis solution.

ATTACHMENT VII

LIST OF SYMBOLS, Dimensions and Descriptions.

a		$\sqrt{K_z/K_r}$
B	$[L]$	$\sqrt{T/(K'/b')}$
b	$[L]$	Aquifer thickness.
b'	$[L]$	Thickness of confining bed(s).
$C(n)$		Dummy variable.
C_o		Dummy variable.
C_1		Constant for slope of logarithmic regression curve.
C_2		Constant for interception of logarithmic regression curve.
c		Convergence criterion, numerical integration.
c_1		Convergence criterion, numerical integration.
d	$[L]$	Depth from top of aquifer to top of pumped well screen.
d'	$[L]$	Depth from top of aquifer to top of observation well screen.
h_{ma}	$[L]$	Average thickness of matrix in fractured aquifer.
K	$[LT^{-1}]$	Hydraulic conductivity of aquifer.
$K_i, i=1,2,3$	$[LT^{-1}]$	Components of the hydraulic conductivity tensor along the three principal axes.
K_{ma}	$[LT^{-1}]$	Hydraulic conductivity of matrix in fractured aquifer.

K_r	$[LT^{-1}]$	Hydraulic conductivity of the aquifer in the radial direction.
K_z	$[LT^{-1}]$	Hydraulic conductivity of the aquifer in the vertical direction.
K'	$[LT^{-1}]$	Hydraulic conductivity of confining bed(s).
l	$[L]$	Depth from top of aquifer to bottom of pumped well screen.
l'	$[L]$	Depth from top of aquifer to bottom of observation well screen.
m		Number of summations.
n		Number of summations.
Q	$[L^3T^{-1}]$	Discharge rate.
q	$[LT^{-1}]$	Source term.
r	$[L]$	Radial distance from center of pumping well.
S		Storage coefficient
S'		Storage coefficient of confining bed(s).
S_f		Storage coefficient of fractures in fractured aquifers.
S_{ma}		Storage coefficient of matrix in fractured aquifers.
s	$[L]$	Drawdown in head (change in water level)
s'	$[L]$	Drawdown in confining bed.
s_o	$[L]$	Drawdown at the beginning of the recovery period.

s_c	$[L]$	Drawdown corrected for decreasing thickness of the aquifer.
T	$[L^2T^{-1}]$	Transmissivity.
T_f	$[L^2T^{-1}]$	Transmissivity of fractures in fractured aquifer.
t	$[T]$	Time.
Δt	$[T]$	Time since the beginning of the recovery period.
u		$r^2S/4Tt$.
u_c		$u\left[\beta/(1+\beta)+1/(1+\beta)\ \sqrt{1/\alpha u}\ \tanh\ \sqrt{\alpha u}\right]$
v		Variable of integration.
v_o		Dummy variable.
v_1		Dummy variable.
w	$[L]$	Width of strip aquifer.
x	$[L]$	Distance from the pumped well in a strip aquifer.
$x_i, i=1,2,3$	$[L]$	Components of the distance tensor along the three principal axes.
y		Variable of integration.
Z	$[L]$	Depth from top of aquifer, depth below top of upper confining bed.
α		$\gamma\ T_f\ h_{ma}/r^2(1+S_f/S_{ma})K_{ma}$
β		S_f/S_{ma}

List of Symbols, Dimensions and Descriptions - Continued

γ	Constant $\simeq$ 1.781
δ	$1+S'/3S$; $1+S'/S$.
ξ	$\frac{1}{2}\sqrt{u}(x/B)-1/\sqrt{u}$
η	$\frac{1}{2}\sqrt{u}(x/B)+1/\sqrt{u}$

The paper presents an interactive computer program for analysing pumping test data. The program may be used with a minimum knowledge of computers and applied to a wide range of groundwater flow problems. Various forms of type curves based on analytical solutions to the groundwater flow equation are available for the interpretation.
The programming language is an extended Basic-version with a number of graphical features. This allows type curve matching directly on the screen, in a manner similar to traditional manual chart interpretation.
The paper includes the mathematical background for the flow-models used, a listing of the entire computer program and guidelines for using the program.

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