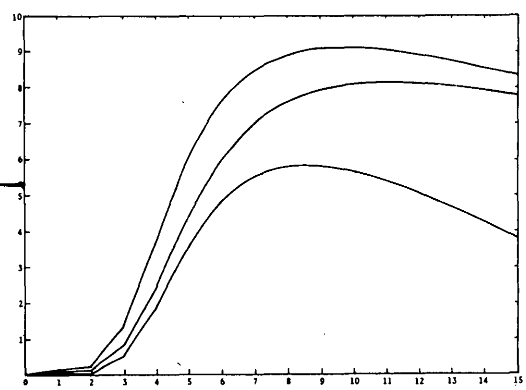
Kernodle 78-356

LINEAR GROUND-WATER FLOW FLOOD-WAVE RESPONSE PROGRAM FOR PROGRAMMABLE CALCULATORS

```
Ø771-- 3 ---Ø3
Ø772-- Ø ---ØØ
Ø773--LBL---51
Ø774--XSQ---12
Ø775-- 2 ---Ø2
Ø776--XTO---23
Ø777-- + ---33
Ø778-- b ---14
Ø779--SFL---54
Ø78Ø--GTO---44
Ø781--S/R---77
Ø782--LBL---51
Ø783-- B ---66
Ø784--CNT---47
Ø785--GTO---44
Ø786--S/R---77
Ø787--LBL---51
Ø788-- C ---61
Ø789--CNT---47
Ø79Ø--XTO---23
Ø791-- 3 ---Ø3
Ø792-- 4 ---Ø4
Ø793--GTO---44
Ø794--S/R---77
Ø795--LBL---51
Ø796-- B ---66
Ø797--CNT---47
Ø798--GTO---44
Ø799--S/R---77
Ø8ØØ--LBL---51
Ø8Ø1-- C ---61
Ø8Ø2--CNT---47
Ø8Ø3--XTO---23
Ø8Ø4-- + ---33
Ø8Ø5-- 3 ---Ø3
Ø8Ø6-- 4 ---Ø4
Ø8Ø7--XFR---67
Ø8Ø8-- 3 ---Ø3
Ø8Ø9-- Ø ---ØØ
Ø81Ø-- UP---27
Ø811--XFR---67
Ø812-- 3 ---Ø3
Ø813-- 4 ---Ø4
Ø814-- X ---36
Ø815--XFR---67
Ø816--IND---31
Ø817-- 3 ---Ø3
Ø818-- 9 ---11
Ø819-- X ---36
Ø82Ø--YTO---4Ø
Ø821-- + ---33
```

```
                    WELLS
                  1     2
X........        ..1.....2...................X
X          .  RIVER . 1     2                X
X          .......... 1     2                X
X                 1     2                    X
XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
                        !------- X ---------!
                  1------------- L ---------!
```



U.S. GEOLOGICAL SURVEY
Open-File Report 78-356

Prepared in cooperation with
THE UNIVERSITY OF KENTUCKY
KENTUCKY GEOLOGICAL SURVEY

LINEAR GROUND-WATER FLOW, FLOOD-WAVE RESPONSE PROGRAM FOR PROGRAMMABLE CALCULATORS

By John Michael Kernodle

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Donald C. Haney
Director and State Geologist

JULY 1978

UNITED STATES DEPARTMENT OF THE INTERIOR

CECIL D. ANDRUS, Secretary

GEOLOGICAL SURVEY

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Room 572 Federal Building
Louisville, Kentucky 40202

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LINEAR GROUND-WATER FLOW, FLOOD-WAVE RESPONSE PROGRAM FOR PROGRAMMABLE CALCULATORS

By

John M. Kernodle

ABSTRACT

Two programs are documented which solve a discretized analytical equation derived to determine head changes at a point in a one-dimensional ground-water flow system. The programs, written for programmable calculators, are in widely divergent but commonly encountered languages and serve to illustrate the adaptability of the linear model to use in situations where access to true computers is not possible or economical. The programs documented in this report are written for the Hewlett Packard 9810A and Wang System 2200* calculators and are written in machine language and a form of Basic respectively.

The analytical method assumes a semi-infinite aquifer which is uniform in thickness and hydrologic characteristics, bounded on one side by an impermeable barrier and on the other parallel side by a fully penetrating stream in complete hydraulic connection with the aquifer. Ground-water heads may be calculated for points along a line which is perpendicular to the impermeable barrier and the fully penetrating stream. Head changes at the observation point are dependent on (1) the distance between that point and the impermeable barrier; (2) the distance between the line of stress (the stream) and the impermeable barrier; (3) aquifer diffusivity; (4) time; and (5) head changes along the line of stress. The primary application of the programs is to determine aquifer diffusivity by the flood-wave response technique.

INTRODUCTION

Aquifer diffusivity, the ratio of transmissivity (T) to storage (S), is a valuable and often easily obtained aquifer parameter. One method of determining diffusivity for aquifers which are bounded by streams is the flood-wave response technique, described by Pinder, Bredehoeft, and Cooper (1969), in which a flood on the stream generates head responses in the adjacent aquifer.

*The use of brand names in this report is for identification purposes only and does not imply endorsement by the U.S. Geological Survey.

A discretized analytical equation which describes, for a one-dimensional ground-water flow system, the head changes along a line perpendicular to a stream was published by Grubb and Zehner (1973). In their report, Grubb and Zehner acknowledge their debt to George F. Pinder for providing a computer program which solves the analytical equation. The program referred to by Grubb and Zehner is written in Fortran IV, level G, and must be executed on a large computer with the appropriate compiler and with statistics and plot subroutines which are called from the main program. The Fortran version is not documented in this report but is occasionally cited as a standard for accuracy and speed of computation.

The programs described in this report determine solutions for the same analytical equation and are in most ways functionally identical to the Fortran version but were written in Basic Language for Wang System 2200 calculators and in machine language for the Hewlett Packard 9810A calculator. The calculators were chosen to provide typical examples of the languages and difficulties which may be encountered. Although computation time is greatly increased with the programmable calculators, the actual elapsed time between submission of input data and return of the calculated head response is comparable to a high job priority on a true computer. Other benefits include minimal cost of operation, the ability of the user to interact rapidly with calculated output and the general accessibility to programmable calculators.

The purpose of this report is to provide documentation for the use of the linear ground-water flow, flood-wave-response program for programmable calculators. Because the primary application of the program is to determine aquifer diffusivity by the flood-wave-response technique, the text of the report includes guidelines on the use of the technique, accuracy constraints imposed by the technique, and errors of approximation inherent in the programs.

ASSUMED AQUIFER CONDITIONS

The aquifer to be modeled is assumed to be bounded below and on one side by impermeable materials and on the opposite and parallel side by a stream which fully penetrates and is in complete hydraulic connection with the aquifer. Both the stream and the impermeable side are assumed to be infinite in length. The aquifer is also assumed to be isotropic, homogeneous and of uniform saturated thickness.

The section line for the head response calculations must be constructed through the aquifer perpendicular to the stream and impermeable side. Head changes at a point along the line are calculated for steps in time as a result of changes in stage of the stream. For situations where the stream does not fully penetrate the aquifer or the stream is not in full hydraulic connection with the aquifer, head changes at an observation point near the stream along the main section line may be used to replace stream stage changes in the model. Figure 1 shows a generalized section through a stream-aquifer system which does not meet the ideal situation of a fully penetrating stream (figure from Grubb and Zehner, 1973).

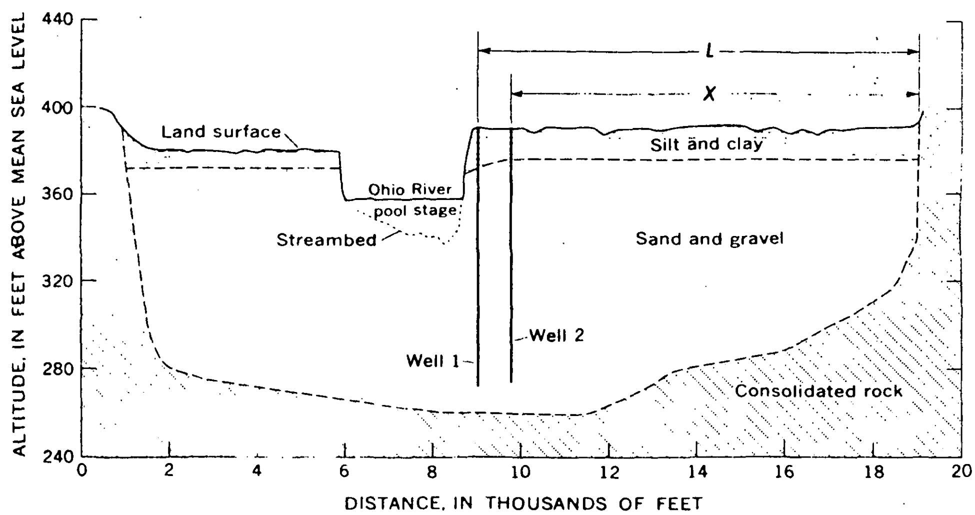

Figure 1.--Generalized cross section of the bedrock valley, showing the alluvial aquifer, the Ohio River, and the observation wells. The position of the wells relative to the river and the impermeable bedrock valley wall is indicated by L and X as defined in equation 1.

DESCRIPTION AND DOCUMENTATION OF THE TECHNIQUE

One-Dimensional Flow Equation

The following equation is used by the programs to obtain theoretical ground-water-level-response curves (Equation 1, Grubb and Zehner, 1973).

$$h_p = \sum_{m=1}^{p} \sum_{n=1}^{\infty} (-1)^{n-1} \Delta H_m \left[\operatorname{erfc} 0.5U \left(\frac{\frac{2n-1}{X/L} - 1}{\sqrt{p-m}} \right) + \operatorname{erfc} 0.5U \left(\frac{\frac{2n-1}{X/L} + 1}{\sqrt{p-m}} \right) \right] \quad (1)$$

where

$$U = \frac{X}{\sqrt{(T/S)\Delta t}}$$

and

L = distance from the river (or well 1) to the impermeable boundary,

X = distance from the point where the aquifer response is observed to the impermeable boundary,

h_p = head at a distance (L-X) from the river (or well 1) at time $\pm p\Delta t$,

ΔH_m = instantaneous rise in stage at the beginning of the time increment $m\Delta t$ where m is an integer,

T/S = diffusivity of the aquifer, and

erfc = complementary error function, which is approximated by:

$$\operatorname{erfc}\gamma = (a_1 b + a_2 b^2 + a_3 b^3) e^{-\gamma^2} - \varepsilon(\gamma) \quad (2)$$

where

$$b = \frac{1}{1+C\gamma}, \qquad |\varepsilon \gamma| \le 2.5 \times 10^{-5}$$

and

$C = 0.47047$ $\qquad a_2 = -0.0958798$

$a_1 = .3480242$ $\qquad a_3 = .7478556$

Constraints and Limitations of the Technique

Phasing and Duration of Time Steps

Because the equation on which the programs are based is a discretized form of the analytic equation published by Pinder and others (1969), certain computational errors occur due to the finite duration of the time steps and to the selection of a head change (ΔH_m) which is representative of the composite of all changes which occurred during the time step. The errors are, in many ways, analogous to those that result when determining the area beneath a curve by constructing a series of rectangles of uniform width (ΔX) and varying height (Y_n), computing the area of each rectangle and adding to obtain a total.

Unless the solution technique of the program is fully understood, the results may easily be misinterpreted. The working equation of the program stipulates that the driving head change occurs at the beginning of each time step and, to avoid division by zero in the calculations, that the resulting calculated head response (h_p) is the head that would be observed as the beginning of the next time step at the observation point. Therefore the calculated response curve exhibits a shift toward the right (an increase) on the time axis relative to the observed response curve. The magnitude of the shift can be reduced by decreasing the time step interval (Δt) and increasing the total number of time steps (not to exceed machine limits), but the benefit of increased resolution is countered by a greater increase in computation time required to obtain a solution.

Philosophy of Curve Matching with Technique Guidelines

Given the ideal stream-aquifer relationship which was assumed for the derivation of the discretized analytic equation, the observed response through a complete flood cycle (rising limb, peak, receding limb) can be entirely duplicated by the programs if T/S is known.

In instances where the aquifer is not uniform, boundaries are irregular, or recharge from precipitation occur, the match between calculated and observed water-level response degenerates. Commonly, only the rising limb and peak of the flood cycle are of use in determining aquifer diffusivity by the flood-wave response technique because the receding limb is the most likely to be affected by non-ideal conditions. Several guidelines may be followed which minimize the effects of non-ideal conditions:

(1) Choose a site which as nearly as possible meets the assumed conditions for application of the flood-wave response technique. Avoid potential sites where either the line of stress (stream) or the impermeable boundary (valley wall) is strongly curved.

(2) Use water levels in an observation well located near the stream as a substitute for stream stages along the line of stress (see figure 1). This helps offset the effects of partial penetration of the stream or well, and of partial hydraulic connection between the stream and aquifer.

(3) The second observation well (for observed response) should be located as far as possible from the valley wall (to minimize the effects of boundary irregularities), yet at a sufficient distance from the first well that there is an observable time lag between water-level responses in the two wells during the passage of a flood-generated wave through the aquifer. Experience is the best guide for determining the distance between the two observation wells, but best results have been obtained by the author when: (a) the ratio of X/L is in the range of 0.85 to 0.95; (b) the distance L-X is less than 2,000 ft (610 m); (c) several observation wells are maintained at the site (presumably, data from at least one pair will be usable).

(4) Bear in mind that the discretized analytical equation is derived for a constant value of Transmissivity (T). If the aquifer is water table, then its saturated thickness, hence T, constantly changes during the passage of the flood wave. If this is the case, the slope of the rising and receding limbs of the response curve will reflect the change in diffusivity with changing saturated thickness. Peak amplitude will also be affected, but peak arrival time is generally the least affected. Once the best possible match between observed and modeled peak arrival time has been obtained, the hydraulic diffusivity of the water-table

aquifer may be expressed as $K_a b_m/Sy$ where K_a is the hydraulic conductivity of the aquifer b_m is the maximum observed saturated thickness of the aquifer during the passage of the flood wave, and Sy is the specific yield of the aquifer.

(5) All flood events are not equally suitable for analysis. A flood of short duration and moderate-to-large magnitude following an extended period of water-level recession is preferred. Such an event offers good peak resolution at the observation point and minimizes the effect on water levels by delayed recharge from precipitation (usually associated with the flood event). The extended period of water-level recession prior to the event assures near-steady-state conditions in the aquifer upon which the head changes in response to the flood event are superimposed. If the flood event being analyzed follows closely after an earlier event, the two flood-generated waves may interfere constructively or destructively depending upon the time span between the events and the dimensions and hydrologic properties of the aquifer.

(6) The user should recognize that ground-water recession rates may be strongly influenced by the seasonal evapotranspiration rates. A rate of recession observed during summer months may not be applicable to a winter flood event.

These guidelines are intended to help reduce errors in data collection and analysis. They are by no means laws of nature and cannot be expected to apply in all instances.

Need for a Recession Correction to Observed Heads

For non-static water levels prior to the flood impulse the application of a recession correction to observed heads is necessary. If the projected recession is exponential and may be projected for the time of duration of the flood pulse being analyzed, the programs can calculate the projected decay and incorporate the recession in the input values of ΔH_m. If an exponential decay does not satisfactorily describe the recession, segments of observed water-level decay from prior record may be used to manually determine ΔH_m. Also, if the decay is nonexponential, the user should ascertain if this is due to vertical inhomogeniety of the aquifer or to the presence of unknown boundaries, either of which severly limit the applicability of the flood-wave-response technique.

If the recession is found to be exponential, a first try estimate of T/S may be determined by:

$$T/S = \frac{0.933\ L^2 \ \text{Log}\ (H_2/H_1)}{(t_2-t_1)} \quad \text{(By Rorabaugh, 1960)} \qquad (3)$$

where H_1 and H_2 are depth below land surface and the other variables are as explained earlier. Grubb and Zehner (1973) found that this method of estimating diffusivity produced results in close agreement with the flood-wave response method.

The following is a description of the programmed method of recession correction. The programs apply the correction to heads at well 1 only; the user must correct the observed heads for well 2 (h_p).

The following equation is used to determine projected heads:

$$\text{Log}_{10}(H_m) = at_m + b \tag{4}$$

where H_m is the head at well 1 in the appropriate length unit above a definable base level (normal or minimum pool for a regulated stream, or minimum stage of record for an unregulated stream, or lowest water-level elevation of record for a well);

and a and b are regression constants;

a is the slope of the recession

b is the Log_{10} of the head for $t = 0$

These constants may be obtained graphically or may be derived by a regression analysis of several recessions. The user may also make a projection estimate, incorporate the projection in heads entered as H_m and disregard the optional program-applied recession.

Figure 2 shows the composite recession projection which will be incorporated in later examples. Solid lines are observed recession segments from several periods of record, dashed lines are assumed projections and the dotted segments are observed heads at well 1 during the passage of a flood-generated pulse.

Computational Constraints and Limitations

Errors of Approximation and Rounding

Certain concessions to computational accuracy have been made in the programs to reduce the time required to calculate head responses at the observation point. The basis for accuracy comparisons will henceforth be the FORTRAN version of the linear ground-water model because comparisons based on an analytic solution are not possible. It is assumed that the input data sets for the program versions are identical thus eliminating the need to compare the limited time resolution

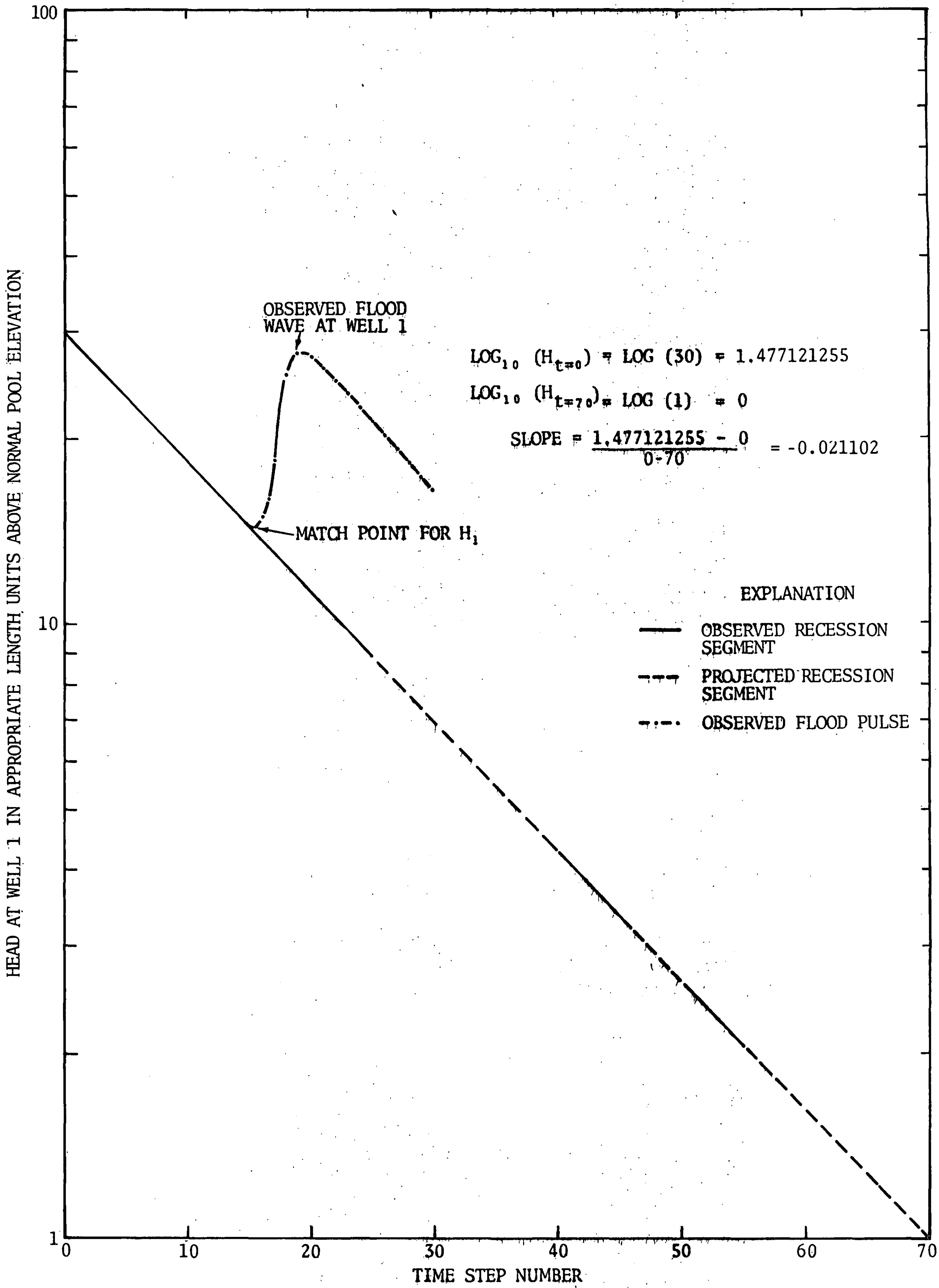

Figure 2.--Projected water level recession and superimposed flood pulse for Well 1.

of the calculator versions with the much greater resolution capability of the FORTRAN version.

The calculator programs have two criteria which are followed to reduce computation time and terminate calculation of the second summation in equation 1. If, for any iteration (value of n) the absolute value of ΔH_m* (erfc γ_1 + erfc γ_2) is less than 0.005 length units calculations for that head contribution are terminated. Also, if γ exceeds or equals 4, the value of erfcγ is assumed to be zero. The second criterion is especially beneficial to the machine language program.

These criteria generally insure that the calculated values of h_p are accurate to two decimal places provided that the maximum input values of ΔH_m are less than 50 length units. If a value of ΔH_m exceeds 50 units, either the unit of measure or the first closure criteria should be changed. In some instances the rational approximation for the complementary error function may prove to be inadequate (equation 2) and another approximation with smaller residual error may be necessary.

The rational approximation for the complementary error function used in the program (Abramowitz and Stegun, 1964) has an error range of $\pm 2.5 \times 10^{-5}$ for $0 \leq \gamma \leq \infty$. This means that for values of $\Delta H_m \leq 50$ units the range of error of ΔH_m *(erfcγ_1 + erfc γ_2) is $\pm 1.25 \times 10^{-3}$. To reduce computation time and prevent problems of underflow the programs assume that erfcγ = 0 for γ greater than 4. In actual practice there is no need to determine erfcγ for γ greater than 3 because the resulting effect on h_p would be less than the first criteria, above. The following table illustrates that although the percent error of the approximation increases rapidly as γ approaches 3 the magnitude of the error remains well below the closure criteria of 0.005 length units.

Table 1.--Errors of approximation of erfcγ for selected values of γ

γ	erfcγ * = 1-erfγ	Rational approximation erfcγ	Percent error	Error in h_p for ΔH_m = 50
0	1	1	0	0
0.25	0.723674	0.723684	0.00144	5.2×10^{-4}
.50	.479500	.479512	.00256	6.1×10^{-4}
.75	.288844	.288826	-.00621	-9.0×10^{-4}
1.00	.157299	.157283	-.01093	-8.6×10^{-4}
1.50	.033895	.33915	.05990	1.0×10^{-3}
2.00	.004678	.004691	.28907	6.8×10^{-4}
3.00	-	.000022	Assumed 100%	1.1×10^{-3}

*Values of erfγ from Abramowitz and Stegun, 1964, table 7.1, p. 310.

Comparative analysis of several data sets by the three versions (Basic, machine language, and FORTRAN) of the linear ground-water model showed no differences in calculated head responses, but it is possible that many aquifer conditions and head changes along the line of stress could lead to differences, after rounding, between results of the versions. The user will, however, notice that the printed output of the Basic Language version does not agree with the displayed output. This is because the printed values of h_p are truncated at the second decimal place whereas the displayed output is rounded to the nearest decimal place.

Program Computation Time

The greatest apparent disadvantage of the use of programmable calculators is their slow computation speed. The approximate elapsed time required for the calculation of the heads h_p (after a value of T/S has been entered) may be determined by the following approximation:

$$\text{Time (seconds)} \approx a*p + b*\sum_{n=1}^{p} \frac{n(n+1)}{2} \qquad (5)$$

where p is the total number of time steps, and a and b are machine dependent constants.

The first term of the approximation describes the time required by the X,Y plotter to draw a line segment at each time step. The second term describes the computation time required to complete head calculations for p time steps.

Table 2 lists the approximate execution times required for 2-24, 25, 30, 35, and 40 time steps, for the two programs described later. These times were determined for the data set where T/S = 2.5 and no recession correction was applied. Computation times for over 24 time steps are given to illustrate the impact of the geometric increase in head calculations should the programs be modified to increase time-step capability.

TABLE 2.--Number of time steps versus computation time for the example programs

Total number of time steps	Number of head calculations	Computation time (min:sec)	
		Machine-language program (b=0.4011)	Basic-language program (b=0.1307)
2	4	0:02	0:00.5
3	10	0:04	0:01.3
4	20	0:08	0:02.6
5	35	0:14	0:04.6
6	56	0:23	0:07.3
7	84	0:34	0:11
8	120	0:48	0:16
9	165	1:06	0:22
10	220	1:28	0:29
11	286	1:55	0:37
12	364	2:26	0:48
13	455	3:03	1:00
14	560	3:45	1:13
15	680	4:33	1:29
16	816	5:27	1:47
17	969	6:29	2:07
18	1140	7:37	2:29
19	1330	8:54	2:54
20	1540	10:18	3:21
21	1771	11:50	3:52
22	2024	13:37	4:25
23	2300	15:23	5:01
24	2600	17:23	5:40
25	2925	19:33	6:22
30	4960	33:10	10:48
35	7770	51:57	16:56
40	11480	76:45	25:00

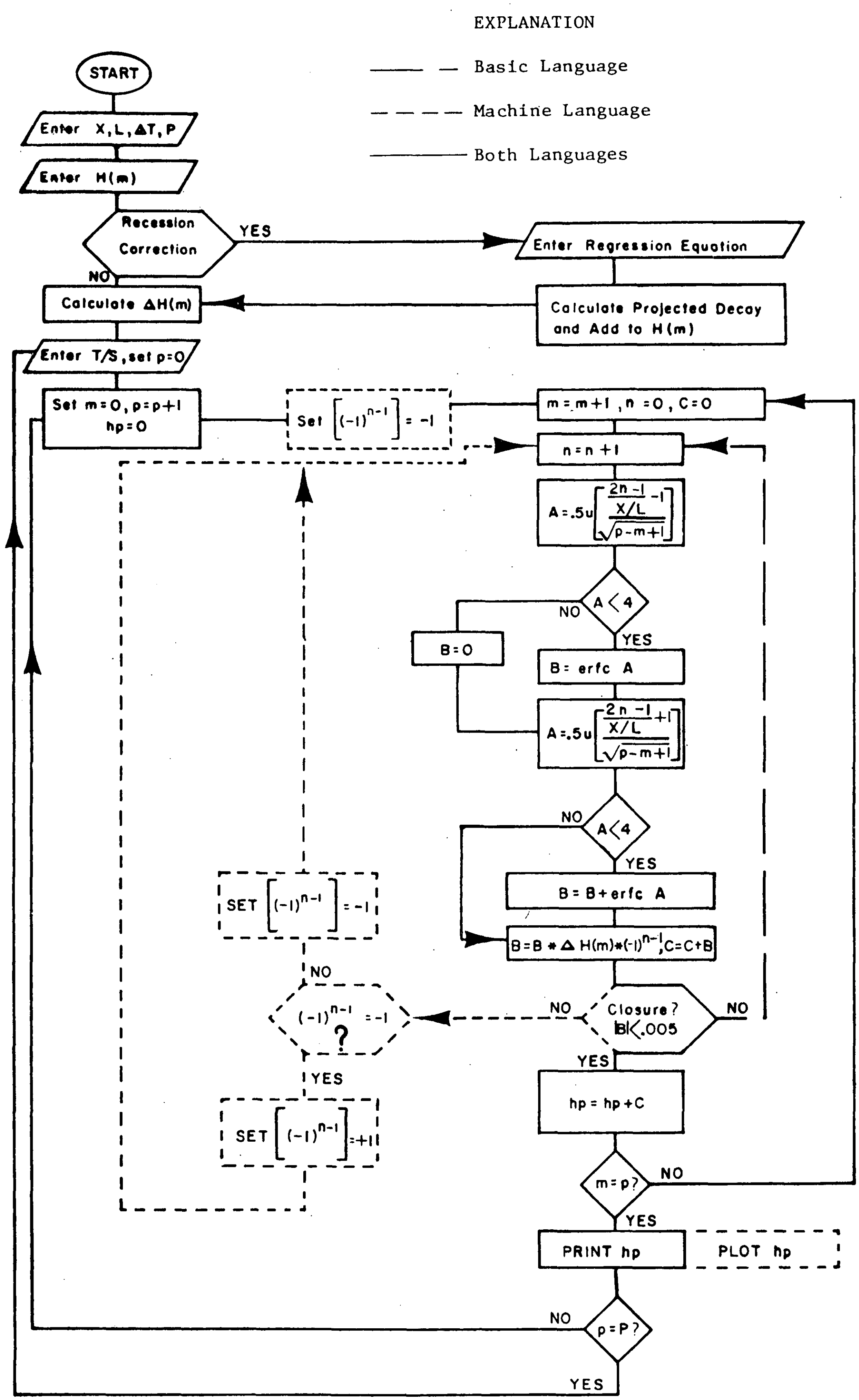

Figure 3.--Flow chart for adaptation of the analytic equation of linear ground-water flow to solution by programmable calculators.

EXAMPLE PROGRAMS

The programs documented in this report exemplify two of the several common calculator languages. The first example program is written in machine language for the Hewlett Packard 9810A programmable calculator. The second program is written in Basic for the Wang System 2200 calculators. Both program languages are sufficiently unique to their host calculators to require modification for use on other calculator brands or generations.

Program Flow Chart

Regardless of the language dissimilarities, both programs follow almost identical flow charts. The minor differences in flow charts are caused by the inability of the machine-language version to evaluate the expression $(-1)^{(n-1)}$. The flow chart is intended for either of the programs documented in this report but could also aid in the adaptation of the technique to other languages or calculators.

Example Machine Language Program

Machine Options Required by the Program

The machine-language program documented in this report employs several optional devices in addition to the basic Hewlett Packard 9810A calculator.

(1) MATH ROM Model 10 #11210A

(2) PRINTER ALPHA/PLOT ROM (Model 10 #11261A

(or separate print and plot ROMS)

(3) X, Y plotter

(4) 2036 Program steps

The program is 1019 statements in length (statement number for "END" is 1018) but may be broken into two parts at statement number 515 (label 8) and instruction commands abbreviated to lower the number of steps per part to less than 500 for standard 9810A calculators. If a plotter is available, the program will produce an X, Y plot of calculated head versus time. Of the options listed above, only the MATH ROM is mandatory because it allows calculation of the expression X^Y which is needed in the approximation of the complementary error function, and for "Do loop" operations.

Program Listing

The following is a list of the statements which comprise the linear ground-water flow flood wave response program for the Hewlett Packard 9810A calculator. The break point for reduction of the program into two parts, and suggested steps to be removed during abbreviation are indicated on the list. Program elements are referenced by label names and never by step number; therefore, user changes may be made without concern about critical step numbering.

LINEAR GROUND
WATER FLOW,
FLOOD WAVE
RESPONSE MODEL

```
ØØØØ--FMT---42
ØØØ1--FMT---42
ØØØ2--CLR---2Ø
ØØØ3--CLR---2Ø
ØØØ4-- L ---72
ØØØ5-- I ---65
ØØØ6-- N ---73
ØØØ7-- E ---6Ø
ØØØ8-- A ---62
ØØØ9-- a ---13
ØØ1Ø--CNT---47
ØØ11-- G ---15
ØØ12-- a ---13
ØØ13-- O ---71
ØØ14--1/X---17
ØØ15-- N ---73
ØØ16-- D ---63
ØØ17--CLR---2Ø
ØØ18--IND---31
ØØ19-- A ---62
ØØ2Ø--XTO---23
ØØ21-- E ---6Ø
ØØ22-- a ---13
ØØ23--CNT---47
ØØ24-- F ---16
ØØ25-- L ---72
ØØ26-- O ---71
ØØ27--IND---31
ØØ28--CLX---37
ØØ29--CLR---2Ø
ØØ3Ø-- F ---16
ØØ31-- L ---72
ØØ32-- O ---71
ØØ33-- O ---71
ØØ34-- D ---63
ØØ35--CNT---47
ØØ36--IND---31
ØØ37-- A ---62
ØØ38--INT---64
ØØ39-- E ---6Ø
ØØ4Ø--CLR---2Ø
ØØ41-- a ---13
```

Delete these steps
if program capacity
is 500 steps.

```
ØØ42-- E ---6Ø
ØØ43--YTO---4Ø
ØØ44-- π ---56
ØØ45-- O ---71
ØØ46-- N ---73
ØØ47--YTO---4Ø
ØØ48-- E ---6Ø
ØØ49--CNT---47
ØØ5Ø-- M ---7Ø
ØØ51-- O ---71
ØØ52-- D ---63
ØØ53-- E ---6Ø
ØØ54-- L ---72
ØØ55--CLR---2Ø
ØØ56--CLR---2Ø
ØØ57--FMT---42
ØØ58--FMT---42
ØØ59-- 1 ---Ø1
ØØ6Ø-- 8 ---1Ø
ØØ61-- 2 ---Ø2
ØØ62--CLR---2Ø
ØØ63--FMT---42
ØØ64--FMT---42
ØØ65--CLR---2Ø
ØØ66--CLR---2Ø
ØØ67--EEX---26
ØØ68--EEX---26
ØØ69--CNT---47
ØØ7Ø-- M ---7Ø
ØØ71-- E ---6Ø
ØØ72-- A ---62
ØØ73-- N ---73
ØØ74--YTO---4Ø
ØØ75--CNT---47
ØØ76-- E ---6Ø
ØØ77-- N ---73
ØØ78--XTO---23
ØØ79-- E ---6Ø
ØØ8Ø-- a ---13
ØØ81--CLR---2Ø
ØØ82--CLR---2Ø
ØØ83--EEX---26
ØØ84--EEX---26
ØØ85--CNT---47
ØØ86-- YE---24
ØØ87--CLR---2Ø
ØØ88--CLR---2Ø
ØØ89--FMT---42
ØØ9Ø--STP---41
ØØ91--PNT---45
ØØ92--PNT---45
```

```
ØØ93--XTO---23
ØØ94-- 3 ---Ø3
ØØ95-- 7 ---Ø7
ØØ96-- UP---27
ØØ97--FMT---42
ØØ98--FMT---42
ØØ99--CLR---2Ø
Ø1ØØ--EEX---26
Ø1Ø1--EEX---26
Ø1Ø2--CNT---47
Ø1Ø3-- L ---72
Ø1Ø4--CLR---2Ø
Ø1Ø5--CLR---2Ø
Ø1Ø6--FMT---42
Ø1Ø7--STP---41
Ø1Ø8--PNT---45
Ø1Ø9--PNT---45
Ø11Ø--DIV---35
Ø111--YTO---4Ø
Ø112-- 3 ---Ø3
Ø113-- 1 ---Ø1
Ø114--FMT---42
Ø115--FMT---42
Ø116--CLR---2Ø
Ø117--EEX---26
Ø118--EEX---26
Ø119--CNT---47
Ø12Ø-- D ---63
Ø121-- E ---6Ø
Ø122-- L ---72
Ø123--XTO---23
Ø124--CNT---47
Ø125--XTO---23
Ø126--CNT---47
Ø127--X<Y---52
Ø128-- H ---74
Ø129-- a ---13
Ø13Ø--YTO---4Ø
Ø131--PSE---57
Ø132--CLR---2Ø
Ø133--CLR---2Ø
Ø134--FMT---42
Ø135--STP---41
Ø136--PNT---45
Ø137--PNT---45
Ø138-- UP---27
Ø139-- 3 ---Ø3
Ø14Ø-- 6 ---Ø6
Ø141-- Ø ---ØØ
Ø142-- Ø ---ØØ
Ø143-- X ---36
```

```
Ø144-- DN---25
Ø145--XTO---23
Ø146-- 3 ---Ø3
Ø147-- 8 ---1Ø
Ø148--FMT---42
Ø149--FMT---42
Ø15Ø--CLR---2Ø
Ø151--EEX---26
Ø152--EEX---26
Ø153--CNT---47
Ø154-- N ---73
Ø155--1/X---17
Ø156-- M ---7Ø
Ø157-- B ---66
Ø158-- E ---6Ø
Ø159-- a ---13
Ø16Ø--CNT---47
Ø161-- O ---71
Ø162-- F ---16
Ø163--CLR---2Ø
Ø164--CNT---47
Ø165--CNT---47
Ø166--CNT---47
Ø167--XTO---23
Ø168-- I ---65
Ø169-- M ---7Ø
Ø17Ø-- E ---6Ø
Ø171--CNT---47
Ø172--YTO---4Ø
Ø173--XTO---23
Ø174-- E ---6Ø
Ø175-- π ---56
Ø176--YTO---4Ø
Ø177--CLR---2Ø
Ø178--CLR---2Ø
Ø179--FMT---42
Ø18Ø--STP---41
Ø181--PNT---45
Ø182--PNT---45
Ø183--XTO---23
Ø184-- a ---13
Ø185-- Ø ---ØØ
Ø186--XTO---23
Ø187-- 2 ---Ø2
Ø188-- 5 ---Ø5
Ø189-- a ---13
Ø19Ø--XTO---23
Ø191-- Ø ---ØØ
Ø192--FMT---42
Ø193--FMT---42
Ø194--CLR---2Ø
```

```
Ø195-- E ---6Ø
Ø196-- N ---73
Ø197--XTO---23
Ø198-- E ---6Ø
Ø199-- a ---13
Ø2ØØ--CNT---47
Ø2Ø1-- H ---74
Ø2Ø2-- E ---6Ø
Ø2Ø3-- A ---62
Ø2Ø4-- D ---63
Ø2Ø5--YTO---4Ø
Ø2Ø6--CNT---47
Ø2Ø7-- H ---74
Ø2Ø8--X<Y---52
Ø2Ø9-- M ---7Ø
Ø21Ø--PSE---57
Ø211--CLR---2Ø
Ø212--CLR---2Ø
Ø213--CLR---2Ø
Ø214--FMT---42
Ø215--CNT---47
Ø216--CNT---47
Ø217--GTO---44
Ø218--S/R---77
Ø219--LBL---51
Ø22Ø-- F ---16
Ø221--FMT---42
Ø222--FMT---42
Ø223--CLR---2Ø
Ø224--YTO---4Ø
Ø225-- . ---21
Ø226-- F ---16
Ø227--CNT---47
Ø228--XTO---23
Ø229-- O ---71
Ø23Ø--CNT---47
Ø231--YTO---4Ø
Ø232-- K ---55
Ø233-- I ---65
Ø234-- π ---56
Ø235--CLR---2Ø
Ø236-- a ---13
Ø237-- E ---6Ø
Ø238-- C ---61
Ø239-- E ---6Ø
Ø24Ø--YTO---4Ø
Ø241--YTO---4Ø
Ø242-- I ---65
Ø243-- O ---71
Ø244-- N ---73
Ø245--CLR---2Ø
Ø246-- C ---61
Ø247-- O ---71
Ø248-- a ---13
Ø249-- a ---13
Ø25Ø-- E ---6Ø
Ø251-- C ---61
Ø252--XTO---23
Ø253-- I ---65
Ø254-- O ---71
Ø255-- N ---73
Ø256--CLR---2Ø
Ø257--CLR---2Ø
Ø258--FMT---42
Ø259--FMT---42
Ø26Ø-- 1 ---Ø1
Ø261-- 8 ---1Ø
Ø262-- 8 ---1Ø
Ø263--STP---41
Ø264--IFG---43
Ø265--GTO---44
Ø266--LBL---51
Ø267-- 6 ---Ø6
Ø268--CNT---47
Ø269--FMT---42
Ø27Ø--FMT---42
Ø271--CLR---2Ø
Ø272--EEX---26
Ø273--EEX---26
Ø274--CNT---47
Ø275-- a ---13
Ø276-- E ---6Ø
Ø277-- G ---15
Ø278-- a ---13
Ø279-- E ---6Ø
Ø28Ø--YTO---4Ø
Ø281--YTO---4Ø
Ø282-- I ---65
Ø283-- O ---71
Ø284-- N ---73
Ø285--CLR---2Ø
Ø286--CNT---47
Ø287--YTO---4Ø
Ø288-- L ---72
Ø289-- O ---71
Ø29Ø-- π ---56
Ø291-- E ---6Ø
Ø292--DIV---35
Ø293-- I ---65
Ø294-- N ---73
Ø295--XTO---23
Ø296-- E ---6Ø
Ø297-- a ---13
Ø298-- C ---61
Ø299-- E ---6Ø
Ø3ØØ-- π ---56
Ø3Ø1--XTO---23
Ø3Ø2--CLR---2Ø
Ø3Ø3--CLR---2Ø
Ø3Ø4--FMT---42
Ø3Ø5-- Ø ---ØØ
Ø3Ø6--XTO---23
Ø3Ø7-- b ---14
Ø3Ø8--STP---41
Ø3Ø9--PNT---45
Ø31Ø--XTO---23
Ø311-- 2 ---Ø2
Ø312-- 8 ---1Ø
Ø313-- UP---27
Ø314--STP---41
Ø315--PNT---45
Ø316--PNT---45
Ø317--XTO---23
Ø318-- 2 ---Ø2
Ø319-- 7 ---Ø7
Ø32Ø--XEY---3Ø
Ø321-- UP---27
Ø322--XFR---67
Ø323-- 1 ---Ø1
Ø324-- K ---55
Ø325-- 4 ---Ø4
Ø326--RUP---22
Ø327-- - ---34
Ø328-- DN---25
Ø329--XEY---3Ø
Ø33Ø--DIV---35
Ø331-- DN---25
Ø332--XTO---23
Ø333-- 2 ---Ø2
Ø334-- 6 ---Ø6
Ø335--PNT---45
Ø336--PNT---45
Ø337-- 1 ---Ø1
Ø338--XTO---23
Ø339-- 2 ---Ø2
Ø34Ø-- 5 ---Ø5
Ø341-- a ---13
Ø342-- UP---27
Ø343-- 1 ---Ø1
Ø344-- - ---34
Ø345--YTO---4Ø
Ø346-- Ø ---ØØ
Ø347--CNT---47
```

```
Ø348-- Ø ---ØØ
Ø349--XTO---23
Ø35Ø-- 1 ---Ø1
Ø351--CNT---47
Ø352--CNT---47
Ø353--GTO---44
Ø354--S/R---77
Ø355--LBL---51
Ø356-- G ---15
Ø357--LBL---51
Ø358-- 6 ---Ø6
Ø359-- a ---13
Ø36Ø--XTO---23
Ø361-- Ø ---ØØ
Ø362--CNT---47
Ø363-- Ø ---ØØ
Ø364--XTO---23
Ø365-- 2 ---Ø2
Ø366-- 5 ---Ø5
Ø367--XFR---67
Ø368-- 1 ---Ø1
Ø369--XTO---23
Ø370-- b ---14
Ø371--FMT---42
Ø372--FMT---42
Ø373--CLR---2Ø
Ø374-- D ---63
Ø375-- E ---6Ø
Ø376-- L ---72
Ø377--XTO---23
Ø378--CNT---47
Ø379-- H ---74
Ø38Ø--X<Y---52
Ø381-- M ---7Ø
Ø382--PSE---57
Ø383--CNT---47
Ø384--SFL---54
Ø385--CLR---2Ø
Ø386--CLR---2Ø
Ø387--FMT---42
Ø388--CNT---47
Ø389--CNT---47
Ø39Ø--GTO---44
Ø391--S/R---77
Ø392--LBL---51
Ø393-- I ---65
Ø394--GTO---44
Ø395--LBL---51
Ø396-- 8 ---1Ø
Ø397--LBL---51
Ø398-- F ---16
```

```
Ø399-- 1 ---Ø1
Ø4ØØ--XTO---23
Ø4Ø1-- + ---33
Ø402-- 2 ---Ø2
Ø4Ø3-- 5 ---Ø5
Ø4Ø4--FMT---42
Ø4Ø5-- 1 ---Ø1
Ø4Ø6-- 8 ---1Ø
Ø4Ø7-- Ø ---ØØ
Ø4Ø8--XFR---67
Ø4Ø9-- 2 ---Ø2
Ø41Ø-- 5 ---Ø5
Ø411--PNT---45
Ø412--FMT---42
Ø413-- 1 ---Ø1
Ø414-- 8 ---1Ø
Ø415-- 2 ---Ø2
Ø416--STP---41
Ø417--PNT---45
Ø418--PNT---45
Ø419--XTO---23
Ø42Ø--IND---31
Ø421-- 2 ---Ø2
Ø422-- 5 ---Ø5
Ø423-- K ---55
Ø424--S/R---77
Ø425-- Ø ---ØØ
Ø426--LBL---51
Ø427-- G ---15
Ø428-- 1 ---Ø1
Ø429--XTO---23
Ø43Ø-- + ---33
Ø431-- 2 ---Ø2
Ø432-- 5 ---Ø5
Ø433--XFR---67
Ø434-- 3 ---Ø3
Ø435-- 8 ---1Ø
Ø436-- UP---27
Ø437-- 8 ---1Ø
Ø438-- 6 ---Ø6
Ø439-- 4 ---Ø4
Ø44Ø-- Ø ---ØØ
Ø441-- Ø ---ØØ
Ø442--DIV---35
Ø443--YTO---4Ø
Ø444-- + ---33
Ø445-- 2 ---Ø2
Ø446-- 6 ---Ø6
Ø447--XFR---67
Ø448-- 2 ---Ø2
Ø449-- 8 ---1Ø
```

```
Ø45Ø--XFR---67
Ø451-- X ---36
Ø452-- 2 ---Ø2
Ø453-- 6 ---Ø6
Ø454--XFR---67
Ø455-- + ---33
Ø456-- 2 ---Ø2
Ø457-- 7 ---Ø7
Ø458-- K ---55
Ø459-- 5 ---Ø5
Ø46Ø--PNT---45
Ø461--PNT---45
Ø462--CHS---32
Ø463--XFR---67
Ø464-- + ---33
Ø465--IND---31
Ø466-- 2 ---Ø2
Ø467-- 5 ---Ø5
Ø468--XTO---23
Ø469--IND---31
Ø47Ø-- 2 ---Ø2
Ø471-- 5 ---Ø5
Ø472-- K ---55
Ø473--S/R---77
Ø474-- Ø ---ØØ
Ø475--LBL---51
Ø476-- I ---65
Ø477--FMT---42
Ø478-- 1 ---Ø1
Ø479-- 8 ---1Ø
Ø48Ø-- Ø ---ØØ
Ø481-- 1 ---Ø1
Ø482--XTO---23
Ø483-- + ---33
Ø484-- 2 ---Ø2
Ø485-- 5 ---Ø5
Ø486--XFR---67
Ø487-- 2 ---Ø2
Ø488-- 5 ---Ø5
Ø489--PNT---45
Ø49Ø--FMT---42
Ø491-- 1 ---Ø1
Ø492-- 8 ---1Ø
Ø493-- 2 ---Ø2
Ø494--XFR---67
Ø495--IND---31
Ø496-- 2 ---Ø2
Ø497-- 5 ---Ø5
Ø498-- UP---27
Ø499-- UP---27
Ø5ØØ-- b ---14
```

```
Ø5Ø1-- - ---34
Ø5Ø2-- DN---25
Ø5Ø3--XTO---23
Ø5Ø4--IND---31
Ø5Ø5-- 2 ---Ø2
Ø5Ø6-- 5 ---Ø5
Ø5Ø7--YTO---4Ø
Ø5Ø8-- b ---14
Ø5Ø9--PNT---45
Ø51Ø--PNT---45
Ø511-- K ---55
Ø512--S/R---77
Ø513-- Ø ---ØØ
Ø514--LBL---51
Ø515-- 8 ---1Ø
```

Add the following steps if program capacity is 500 steps:

```
--FMT---42
--GTO---44
--END---46
```

This will complete the first part of the program if the program capacity is 500 steps (one card side of a standard magnetic card). During execution and after all heads ▲Hm have been calculated the load motor will start for entry of card side two.

```
Ø516-- . ---21
Ø517-- 4 ---Ø4
Ø518-- 7 ---Ø7
Ø519-- Ø ---ØØ
Ø52Ø-- 4 ---Ø4
Ø521-- 7 ---Ø7
Ø522--XTO---23
Ø523-- 2 ---Ø2
Ø524-- 5 ---Ø5
Ø525--CNT---47
Ø526-- . ---21
Ø527-- 3 ---Ø3
Ø528-- 4 ---Ø4
Ø529-- 8 ---1Ø
Ø53Ø-- Ø ---ØØ
Ø531-- 2 ---Ø2
Ø532-- 4 ---Ø4
Ø533-- 2 ---Ø2
Ø534--XTO---23
Ø535-- 2 ---Ø2
Ø536-- 6 ---Ø6
Ø537--CNT---47
Ø538-- . ---21
Ø539-- Ø ---ØØ
Ø54Ø-- 9 ---11
Ø541-- 5 ---Ø5
Ø542-- 8 ---1Ø
Ø543-- 7 ---Ø7
Ø544-- 9 ---11
Ø545-- 8 ---1Ø
Ø546--CHS---32
Ø547--XTO---23
Ø548-- 2 ---Ø2
Ø549-- 7 ---Ø7
Ø55Ø--CNT---47
Ø551-- . ---21
Ø552-- 7 ---Ø7
Ø553-- 4 ---Ø4
Ø554-- 7 ---Ø7
Ø555-- 8 ---1Ø
Ø556-- 5 ---Ø5
Ø557-- 5 ---Ø5
Ø558-- 6 ---Ø6
Ø559--XTO---23
Ø560-- 2 ---Ø2
Ø561-- 8 ---1Ø
Ø562-- a ---13
Ø563-- UP---27
Ø564-- Ø ---ØØ
Ø565--FMT---42
Ø566-- 1 ---Ø1
```

```
Ø567-- 2 ---Ø2
Ø568--FMT---42
Ø569--FMT---42
Ø57Ø--CLR---2Ø
Ø571--EEX---26
Ø572--EEX---26
Ø573--CNT---47
Ø574-- M ---7Ø
Ø575-- A ---62
Ø576-- YE---24
Ø577--CNT---47
Ø578-- H ---74
Ø579-- E ---6Ø
Ø58Ø-- A ---62
Ø581-- D ---63
Ø582--CLR---2Ø
Ø583--CNT---47
Ø584--CNT---47
Ø585--CNT---47
Ø586--X<Y---52
Ø587-- F ---16
Ø588-- O ---71
Ø589-- a ---13
Ø59Ø--CNT---47
Ø591-- π ---56
Ø592-- L ---72
Ø593-- O ---71
Ø594--XTO---23
Ø595--PSE---57
Ø596--CLR---2Ø
Ø597--CLR---2Ø
Ø598--FMT---42
Ø599--STP---41
Ø6ØØ--PNT---45
Ø6Ø1--PNT---45
Ø6Ø2-- UP---27
Ø6Ø3-- Ø ---ØØ
Ø6Ø4--FMT---42
Ø6Ø5-- 1 ---Ø1
Ø6Ø6-- 3 ---Ø3
Ø6Ø7--CNT---47
Ø6Ø8-- Ø ---ØØ
Ø6Ø9-- UP---27
Ø61Ø-- Ø ---ØØ
Ø611--FMT---42
Ø612-- 1 ---Ø1
Ø613-- UP---27
Ø614--LBL---51
Ø615-- 2 ---Ø2
Ø616--XFR---67
Ø617-- 3 ---Ø3
```

```
Ø618-- 7 ---Ø7
Ø619-- UP---27
Ø62Ø--XFR---67
Ø621-- 3 ---Ø3
Ø622-- 8 ---1Ø
Ø623-- UP---27
Ø624--FMT---42
Ø625--FMT---42
Ø626--CLR---2Ø
Ø627--EEX---26
Ø628--EEX---26
Ø629--CNT---47
Ø63Ø--XTO---23
Ø631--DIV---35
Ø632--YTO---4Ø
Ø633--CLR---2Ø
Ø634--FMT---42
Ø635--STP---41
Ø636--PNT---45
Ø637--PNT---45
Ø638-- X ---36
Ø639-- DN---25
Ø64Ø--√x ---76
Ø641--DIV---35
Ø642--YTO---4Ø
Ø643-- 3 ---Ø3
Ø644-- 2 ---Ø2
Ø645--CLX---37
Ø646-- UP---27
Ø647--FMT---42
Ø648-- 1 ---Ø1
Ø649-- UP---27
Ø65Ø--FMT---42
Ø651--FMT---42
Ø652--CLR---2Ø
Ø653-- C ---61
Ø654-- A ---62
Ø655-- L ---72
Ø656-- C ---61
Ø657--1/X---17
Ø658-- L ---72
Ø659-- A ---62
Ø66Ø--XTO---23
Ø661-- E ---6Ø
Ø662-- D ---63
Ø663--CLR---2Ø
Ø664-- H ---74
Ø665-- E ---6Ø
Ø666-- A ---62
Ø667-- D ---63
Ø668--YTO---4Ø
```

Change to (for step Ø663):

--CNT---47
if program capacity
is less than 2036
steps.

```
Ø669--CNT---47
Ø67Ø-- A ---62
Ø671--XTO---23
Ø672--CNT---47
Ø673--IND---31
Ø674-- E ---6Ø
Ø675-- L ---72
Ø676-- L ---72
Ø677--CNT---47
Ø678-- 2 ---Ø2
Ø679--CLR---2Ø
Ø68Ø-- A ---62
Ø681-- a ---13
Ø682-- E ---6Ø
Ø683--CNT---47
Ø684--X<Y---52
Ø685-- H ---74
Ø686--X<Y---52
Ø687-- π ---56
Ø688--PSE---57
Ø689--PSE---57
Ø69Ø--CNT---47
Ø691--SFL---54
Ø692--CLR---2Ø
Ø693--CLR---2Ø
Ø694--FMT---42
Ø695--LBL---51
Ø696-- 3 ---Ø3
Ø697-- Ø ---ØØ
Ø698--XTO---23
Ø699-- 3 ---Ø3
Ø7ØØ-- 3 ---Ø3
Ø7Ø1--XTO---23
Ø7Ø2-- 3 ---Ø3
Ø7Ø3-- 4 ---Ø4
Ø7Ø4--XTO---23
Ø7Ø5-- 3 ---Ø3
Ø7Ø6-- 6 ---Ø6
Ø7Ø7--CNT---47
Ø7Ø8-- 1 ---Ø1
Ø7Ø9--XTO---23
Ø71Ø-- 3 ---Ø3
Ø711-- 5 ---Ø5
Ø712--LBL---51
Ø713-- 4 ---Ø4
Ø714-- Ø ---ØØ
Ø715--XTO---23
Ø716-- 3 ---Ø3
Ø717-- 9 ---11
Ø718--CNT---47
Ø719-- 1 ---Ø1
```

Delete these steps
if program capacity
is less than 2036 steps.

```
Ø72Ø--XTO---23
Ø721-- + ---33
Ø722-- 3 ---Ø3
Ø723-- 5 ---Ø5
Ø724--XFR---67
Ø725-- 3 ---Ø3
Ø726-- 5 ---Ø5
Ø727--XTO---23
Ø728-- Ø ---ØØ
Ø729--CNT---47
Ø73Ø--CNT---47
Ø731--GTO---44
Ø732--S/R---77
Ø733--LBL---51
Ø734-- A ---62
Ø735--GTO---44
Ø736--S/R---77
Ø737--LBL---51
Ø738-- D ---63
Ø739--CNT---47
Ø74Ø-- Ø ---ØØ
Ø741--XTO---23
Ø742-- 3 ---Ø3
Ø743-- 3 ---Ø3
Ø744-- a ---13
Ø745-- UP---27
Ø746--XFR---67
Ø747-- 3 ---Ø3
Ø748-- 5 ---Ø5
Ø749--X<Y---52
Ø75Ø--GTO---44
Ø751--LBL---51
Ø752-- 4 ---Ø4
Ø753--CNT---47
Ø754--GTO---44
Ø755--LBL---51
Ø756-- 2 ---Ø2
Ø757--LBL---51
Ø758-- A ---62
Ø759-- 1 ---Ø1
Ø76Ø--XTO---23
Ø761-- + ---33
Ø762-- 3 ---Ø3
Ø763-- 9 ---11
Ø764--CNT---47
Ø765-- Ø ---ØØ
Ø766--XTO---23
Ø767-- b ---14
Ø768-- 1 ---Ø1
Ø769--CHS---32
Ø77Ø--XTO---23
```

```
Ø771-- 3 ---Ø3
Ø772-- Ø ---ØØ
Ø773--LBL---51
Ø774--XSQ---12
Ø775-- 2 ---Ø2
Ø776--XTO---23
Ø777-- + ---33
Ø778-- b ---14
Ø779--SFL---54
Ø78Ø--GTO---44
Ø781--S/R---77
Ø782--LBL---51
Ø783-- B ---66
Ø784--CNT---47
Ø785--GTO---44
Ø786--S/R---77
Ø787--LBL---51
Ø788-- C ---61
Ø789--CNT---47
Ø79Ø--XTO---23
Ø791-- 3 ---Ø3
Ø792-- 4 ---Ø4
Ø793--GTO---44
Ø794--S/R---77
Ø795--LBL---51
Ø796-- B ---66
Ø797--CNT---47
Ø798--GTO---44
Ø799--S/R---77
Ø8ØØ--LBL---51
Ø8Ø1-- C ---61
Ø8Ø2--CNT---47
Ø8Ø3--XTO---23
Ø8Ø4-- + ---33
Ø8Ø5-- 3 ---Ø3
Ø8Ø6-- 4 ---Ø4
Ø8Ø7--XFR---67
Ø8Ø8-- 3 ---Ø3
Ø8Ø9-- Ø ---ØØ
Ø81Ø-- UP---27
Ø811--XFR---67
Ø812-- 3 ---Ø3
Ø813-- 4 ---Ø4
Ø814-- X ---36
Ø815--XFR---67
Ø816--IND---31
Ø817-- 3 ---Ø3
Ø818-- 9 ---11
Ø819-- X ---36
Ø82Ø--YTO---4Ø
Ø821-- + ---33
```

```
Ø822-- 3 ---Ø3
Ø823-- 3 ---Ø3
Ø824-- G ---15
Ø825-- . ---21
Ø826-- Ø ---ØØ
Ø827-- Ø ---ØØ
Ø828-- 5 ---Ø5
Ø829--X>Y---53
Ø83Ø--GTO---44
Ø831--LBL---51
Ø832-- + ---33
Ø833--CNT---47
Ø834-- b ---14
Ø835-- UP---27
Ø836-- 1 ---Ø1
Ø837-- Ø ---ØØ
Ø838--X>Y---53
Ø839--GTO---44
Ø84Ø--LBL---51
Ø841--XSQ---12
Ø842--CNT---47
Ø843--LBL---51
Ø844-- + ---33
Ø845--XFR---67
Ø846-- 3 ---Ø3
Ø847-- Ø ---ØØ
Ø848-- UP---27
Ø849-- 1 ---Ø1
Ø85Ø--CNT---47
Ø851--X=Y---5Ø
Ø852--GTO---44
Ø853--LBL---51
Ø854--1/X---17
Ø855--CNT---47
Ø856--XTO---23
Ø857-- 3 ---Ø3
Ø858-- Ø ---ØØ
Ø859--CNT---47
Ø86Ø-- 1 ---Ø1
Ø861--CHS---32
Ø862--XTO---23
Ø863-- b ---14
Ø864--GTO---44
Ø865--LBL---51
Ø866--XSQ---12
Ø867--LBL---51
Ø868--1/X---17
Ø869-- K ---55
Ø87Ø--S/R---77
Ø871-- Ø ---ØØ
Ø872--LBL---51
```

```
Ø873-- B ---66
Ø874-- b ---14
Ø875-- UP---27
Ø876-- 2 ---Ø2
Ø877-- X ---36
Ø878-- 1 ---Ø1
Ø879-- - ---34
Ø88Ø--XFR---67
Ø881-- 3 ---Ø3
Ø882-- 1 ---Ø1
Ø883--DIV---35
Ø884-- 1 ---Ø1
Ø885-- - ---34
Ø886--IFG---43
Ø887--CNT---47
Ø888-- 2 ---Ø2
Ø889-- + ---33
Ø89Ø--CNT---47
Ø891--XFR---67
Ø892-- 3 ---Ø3
Ø893-- 5 ---Ø5
Ø894-- UP---27
Ø895--XFR---67
Ø896-- 3 ---Ø3
Ø897-- 9 ---11
Ø898-- - ---34
Ø899-- 1 ---Ø1
Ø9ØØ-- + ---33
Ø9Ø1-- DN---25
Ø9Ø2--√---76
Ø9Ø3--DIV---35
Ø9Ø4--XFR---67
Ø9Ø5-- 3 ---Ø3
Ø9Ø6-- 2 ---Ø2
Ø9Ø7-- X ---36
Ø9Ø8-- . ---21
Ø9Ø9-- 5 ---Ø5
Ø91Ø-- X ---36
Ø911--YTO---4Ø
Ø912-- 3 ---Ø3
Ø913-- 6 ---Ø6
Ø914--S/R---77
Ø915--LBL---51
Ø916-- C ---61
Ø917--XFR---67
Ø918-- 3 ---Ø3
Ø919-- 6 ---Ø6
Ø92Ø-- UP---27
Ø921-- 4 ---Ø4
Ø922--X<Y---52
Ø923--GTO---44
```

```
Ø924--LBL---51
Ø925-- π ---56
Ø926--CNT---47
Ø927--XFR---67
Ø928-- 2 ---Ø2
Ø929-- 5 ---Ø5
Ø93Ø-- X ---36
Ø931-- 1 ---Ø1
Ø932-- + ---33
Ø933-- DN---25
Ø934--1/X---17
Ø935-- UP---27
Ø936-- UP---27
Ø937--XFR---67
Ø938-- 2 ---Ø2
Ø939-- 6 ---Ø6
Ø94Ø-- X ---36
Ø941-- DN---25
Ø942--XTO---23
Ø943-- 2 ---Ø2
Ø944-- 9 ---11
Ø945-- DN---25
Ø946--XSQ---12
Ø947-- UP---27
Ø948--XFR---67
Ø949-- 2 ---Ø2
Ø95Ø-- 7 ---Ø7
Ø951-- X ---36
Ø952-- DN---25
Ø953--XTO---23
Ø954-- + ---33
Ø955-- 2 ---Ø2
Ø956-- 9 ---11
Ø957--CNT---47
Ø958-- 3 ---Ø3
Ø959--XEY---3Ø
Ø96Ø-- H ---74
Ø961--XEY---3Ø
Ø962--XFR---67
Ø963-- 2 ---Ø2
Ø974-- 8 ---1Ø
Ø965-- X ---36
Ø966--YTO---4Ø
Ø967-- + ---33
Ø968-- 2 ---Ø2
Ø969-- 9 ---11
Ø97Ø--XFR---67
Ø971-- 3 ---Ø3
Ø972-- 6 ---Ø6
Ø973--XSQ---12
Ø974--CHS---32
```

```
Ø975-- J ---75
Ø976-- UP---27
Ø977--XFR---67
Ø978-- 2 ---Ø2
Ø979-- 9 ---11
Ø98Ø-- X ---36
Ø981-- DN---25
Ø982--GTO---44
Ø983--LBL---51
Ø984-- b ---14
Ø985--LBL---51
Ø986-- π ---56
Ø987-- Ø ---ØØ
Ø988--LBL---51
Ø989-- b ---14
Ø99Ø--S/R---77
Ø991--LBL---51
Ø992-- D ---63
Ø993--FMT---42
Ø994-- 1 ---Ø1
Ø995-- 8 ---1Ø
Ø996-- Ø ---ØØ
Ø997--XFR---67
Ø998-- 3 ---Ø3
Ø999-- 5 ---Ø5
1ØØØ--PNT---45
1ØØ1-- UP---25
1ØØ2--FMT---42
1ØØ3-- 1 ---Ø1
1ØØ4-- 8 ---1Ø
1ØØ5-- 2 ---Ø2
1ØØ6--XFR---67
1ØØ7-- 3 ---Ø3
1ØØ8-- 3 ---Ø3
1ØØ9--PNT---45
1Ø1Ø--PNT---45
1Ø11--XEY---3Ø
1Ø12--FMT---42
1Ø13-- 1 ---Ø1
1Ø14-- DN---25
1Ø15--FMT---42
1Ø16-- UP---27
1Ø17--S/R---77
1Ø18--END---46
```

The program uses memory registers a, b, and ∅ through 39, excluding the four registers needed to perform X, Y plots. This arrangement allows calculations for a limit of 24 time steps.

The following registers are used for storage of variables during execution of the program. Because the program may be divided into two parts for execution on the standard 9810A calculator, use of the registers is given for before and after Label 8, the division point. If 111 memory registers are available on the calculator, this list may be used to increase the number of allowable time steps by reassigning register functions, or the list may be used to facilitate program modifications.

REGISTER	BEFORE LAB 8	AFTER LAB 8
a	P final	P final
b	General work area	N
∅	Loop counter	Loop counter
1-24	H_m and ΔH_m	H_m
25	Inverse counter	c
26	t_m seconds	a_1
27	Recession slope	a_2
28	Recession intercept	a_3
29	Not used	$(a_1b+a_2b^2+a_3b^3)$
30	Not used	$(-1)^{n-1}$
31	X/L	X/L
32	Not used	U
33	Not used	h_p
34	Not used	$(\text{erfc}\gamma_1+\text{erfc}\gamma_2)_p$
35	Not used	P working
36	Not used	$\gamma = 0.5U\left(\dfrac{\frac{(2n-1)}{X/L} \pm 1}{\sqrt{P-m}}\right)$
37	X	X
38	Δt (seconds)	Δt
39	Not used	m

Documentation of Program Execution

The data input requirements are deceptively simple; therefore, the user is urged to read the preceding section on constraints and limitations of the technique. With one exception, "DELT T (HRS)", all units are in terms of length (consistently feet, meters, etc.,) and time (seconds). The time-step increment, "DELT T", or Δt in equation 1 was expressed in hours to simplify user response.

Data are entered in the following sequence (See sample output following this explanation):

(1) X, the distance from the observation point (well 2 in figure 1) to the valley wall.

(2) L, the distance from the stream or control well (well 1 in figure 1) to the valley wall.

(3) DELT T (HRS), Δt in equation 1 or the time interval in hours between stage values, H_m, and between calculated head values h_p.

(4) NUMBER OF TIME STEPS, the total number of time steps to be simulated.

(5) HEADS (H(m)), H_m in equation 1: Either stage values, or head values at well 1. The user has two options at this point: the values may be based on mean sea level or an arbitrary datum. If a recession correction is to be applied, the datum must be the same one used for the regression analyses of the recessions.

(6) S.F. (set flag) to SKIP RECESSION CORRECTION

If the stream stage (or head at well 1) is undergoing a significant exponential head decay, and this decay can be described by a semi-log regression analysis, the projected decay may be compensated for in the head calculations for the observation point (well 2 in figure 1).

(A) If the flag is not set and the continue button is pressed, enter REGRESSION SLOPE/INTERCEPT where the slope is the change in Log_{10} of the head, $\text{Log}_{10}(H_m)$, per Δt and the intercept is the head value of t = 0 day. These constants may be obtained by performing a standard semi-log regression analysis of head recession data.

The calculator will immediately respond by printing the match point, in days, for $H_m(1)$ on the recession curve, projected head decay for each time step and then proceed to calculate and print DELT H(m), ΔH_m in equation 1, with recession corrections for all time steps. The user may wish to repeat steps (1) through (6) but opt not to make a recession correction to observe the impact the correction may have on values of DELT H(m).

(B) If the flag is set and the continue button is pressed, no recession correction is applied and the calculator will determine and print DELT H(m), ΔH_m in equation 1, without recession correction for all time steps.

Note: If the program has been divided into two parts, execution will now be transferred to the second card (part 2).

(7) MAX HEAD, If an X, Y plotter is used, enter the maximum anticipated calculated head (well 2) in the appropriate length unit above the starting head as zero datum. The access code for the plotter is assumed to be FMT, 1, (operation).

(8) T/S, Enter the known or estimated aquifer diffusivity in units of length squared per second. If the user is dissatisfied with early calculations of h_p a new value of T/S may be entered at any time by stopping execution of the program and returning to LABEL 2: (STOP, GO TO, LAB, 2, CONTINUE)

The program will now calculate, print and plot heads h_p for the observation point (well 2) for each time step excluding the first (equation 1 cannot be solved when p = 1). Calculated head values are in the appropriate length unit above the starting head as zero datum. Upon completion of computations for one value of T/S, execution will return to step (8) and call for the entry of another value of T/S.

```
LINEAR GROUND
WATER FLOW,
FLOOD WAVE
RESPONSE MODEL



→→MEANS ENTER

→→X

        6ØØØ.ØØ*

→→L

        7ØØØ.ØØ*

→→DELT T   (HRS)

          24.ØØ*

→→NUMBER OF
  TIME STEPS

          15.ØØ*
```

```
ENTER HEADS H(M)

          1.
      14.7Ø*

          2.
      15.ØØ*

          3.
      18.5Ø*

          4.
      24.6Ø*

          5.
      27.7Ø*

          6.
      27.4Ø*

          7.
      26.2Ø*

          8.
      24.9Ø*

          9.
      23.7Ø*

         1Ø.
      22.5Ø*

         11.
      21.4Ø*

         12.
      2Ø.3Ø*

         13.
      19.4Ø*

         14.
      18.4Ø*

         15.
      17.6Ø*
```

```
S.F TO SKIP
RECESSION
CORRECTION

→→REGRESSION
 SLOPE/INTERCEPT

   -Ø.Ø21Ø64ØØ*
    1.477Ø35ØØ*

   14.7Ø364913

   14.ØØ4Ø3975

   13.341Ø292Ø

   12.7Ø94Ø838

   12.1Ø769117

   11.53446179

   1Ø.98837152

   1Ø.46813548

    9.97252962

    9.5ØØ38783

    9.Ø5Ø59924

    8.6221Ø554

    8.21389855

    7.825Ø1781

    7.45454833
```

```
DELT H(M) =

        1.
      Ø.ØØ

        2.
      1.ØØ

        3.
      4.16

        4.
      6.73

        5.
      3.7Ø

        6.
      Ø.27

        7.
     -Ø.65

        8.
     -0.78

        9.
     -Ø.7Ø

       10.
     -Ø.73

       11.
     -Ø.65

       12.
     -Ø.67

       13.
     -Ø.49

       14.
     -Ø.61

       15.
     -Ø.43
```

→ →MAX HEAD
(FOR PLOT)

10.00*

→ →T/S

2.50*

CALCULATED
HEADS AT WELL 2
ARE (H(P)) =

2.	0.13
3.	0.81
4.	2.41
5.	4.40
6.	5.99
7.	7.01
8.	7.60
9.	7.94
10.	8.11
11.	8.16
12.	8.13
13.	8.06
14.	7.95
15.	7.81

→ →T/S

4.00*

CALCULATED
HEADS AT WELL 2
ARE (H(P)) =

2.	0.23
3.	1.35
4.	3.67
5.	6.08
6.	7.67
7.	8.53
8.	8.94
9.	9.12
10.	9.14
11.	9.06
12.	8.92
13.	8.76
14.	8.56
15.	8.35

```
LINEAR GROUND
WATER FLOW,
FLOOD WAVE
RESPONSE MODEL


→ →MEANS ENTER

→ →X

         6ØØØ.ØØ*


→ →L

         7ØØØ.ØØ*

→ →DELT T (HRS)

           24.ØØ*


→ →NUMBER OF
   TIME STEPS

           15.ØØ*
```

```
ENTER HEADS H(M)



              1.
          14.7Ø*

              2.
          15.ØØ*

              3.
          18.5Ø*

              4.
          24.6Ø*

              5.
          27.7Ø*

              6.
          27.4Ø*

              7.
          26.2Ø*

              8.
          24.9Ø*

              9.
          23.7Ø*

             1Ø.
          22.5Ø*

             11.
          21.4Ø*

             12.
          20.3Ø*

             13.
          19.4Ø*

             14.
          18.4Ø*

             15.
          17.6Ø*
```

S.F TO SKIP
RECESSION
CORRECTION

DELT H(M) =

1.
Ø.ØØ

2.
Ø.3Ø

3.
3.5Ø

4.
6.1Ø

5.
3.1Ø

6.
-Ø.3Ø

7.
-1.2Ø

8.
-1.3Ø

9.
-1.2Ø

1Ø.
-1.2Ø

11.
-1.1Ø

12.
-1.1Ø

13.
-Ø.9Ø

14.
-1.ØØ

15.
-Ø.8Ø

```
→ → MAX HEAD
    (FOR PLOT)

          1Ø.ØØ*
```

```
— → T/S

          2.5Ø*

CALCULATED
HEADS AT WELL 2
ARE (H(P)) =


             2.
          Ø.Ø4

             3.
          Ø.53

             4.
          1.88

             5.
          3.58

             6.
          4.86

             7.
          5.56

             8.
          5.83

             9.
          5.84

            1Ø.
          5.69

            11.
          5.42

            12.
          5.Ø7

            13.
          4.68

            14.
          4.26

            15.
          3.82
```

Figure 4 is a sample plot generated by the X, Y plotter. The curves were created during execution of the three sample sets of calculations, and illustrate the importance of a recession correction when the aquifer system is dynamic prior to the flood wave pulse under analysis. Axis markings were not generated by this program. Figure 4 also illustrates the effect a change in simulated diffusivity has on aquifer response curves.

Example Basic Language Program

Machine Options Required by the Program

The Basic Language program documented in this report was written for Wang System 2200 calculators equipped with the following I/O devices and optional Basic Language statements:

I/O devices:

(A) Typewriter printer

(B) Disk drive

Optional statements:

(A) Convert

(B) Init (initialize)

None of the above devices or potential statements are fundamentally essential to the program. The "convert" statement is used solely to construct a more presentable output format for the typewriter and the "init" statement is merely a simplified means of initializing a variable to a hexadecimal value; for example, Init (09) R$ replaces LET R$ = HEX(09090909···). If a typewriter printer is not available, (eliminating the need for the convert statement) program statements 440-480 and 720-740 should be deleted. The disk drive is used only to store values of H(m). If the disk drive is not available, statements 270 and 320 can be deleted or modified to allow cassette tape storage of data.

The exact memory requirement of the following program is difficult to estimate because the user may employ longhand rather than single byte keyword statements and statement numbers. The author's program, which contains a mixture of both of these, uses 4618 bytes of memory.

Program Listing

The following is a list of the statements which comprise the linear ground-water flow, flood-wave response program for Wang System 2200 calculators.

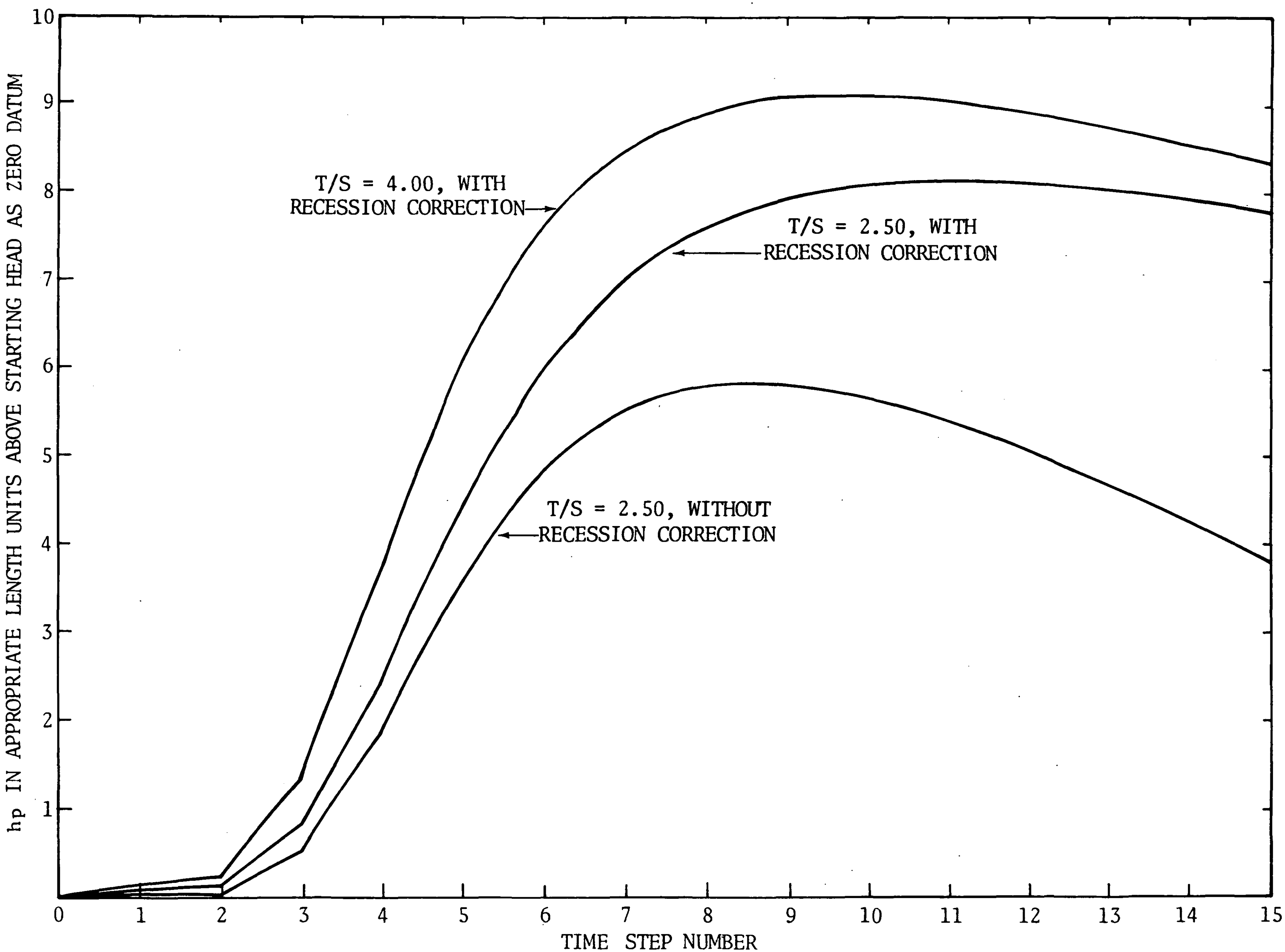

Figure 4.--Calculated head values versus time for selected values of T/S and with and without a recession

PROGRAM LISTING FOR

LINEAR GROUND-WATER MODEL

```
10 COM X,L,U,C,A1,A2,A3,D9,E
20 COM H(24),H9(24),H8(24)
30 COM S,P,B,R$64,R2$64
40 READ A0,A1,A2,A3
50 DATA .47047,.3480242,-.0958798,.7478556
60 INIT(09)R$:INIT(20)R2$:SELECT #2310
70 DEFFN'12:P=C
80 PRINT HEX(03);"LINEAR GROUND-WATER MODEL (SF '12)":PRINT
90REM          1         2         3         4         5
100REM 34567890123456789012345678901234567890123456789O
110 %                        WELLS
120 %                       1     2
130 %   X........       ..1.....2....................X
140 %   X        ; RIVER ; 1     2                    X
150 %   X        ;........; 1     2                   X
160 %   X                   1     2                   X
170 %   XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
180 %                             !------- X ----------!
190 %                       !------------- L ----------!
200 PRINTUSING 110:PRINTUSING 120:PRINTUSING 130:PRINTUSING 140:
PRINTUSING 150:PRINTUSING 160:PRINTUSING 170:PRINTUSING 180:PRIN
TUSING 190:PRINT
210 INPUT "ENTER THE VALUE FOR 'X'",X
220 PRINT HEX(0C0C0C0C);STR(R$,1,34);X:PRINT HEX(0A0A);STR(R2$,1
,64);HEX(0C)
230 INPUT "ENTER THE VALUE FOR 'L'",L
240 PRINT HEX(0C0C0C);STR(R$,1,34);L:PRINT HEX(0A);STR(R2$,1,64)
;HEX(0C)
250 INPUT "NUMBER OF TIME STEPS",P:INPUT "TIME STEP DURATION (HO
URS)",D9
260 PRINT HEX(0C0C0C0909);P;" TIME STEPS";STR(R2$,1,64);STR(R2$,
1,64);HEX(0C);:INPUT "DO YOU WANT TO ENTER HEADS FROM DISK",Y$:I
F Y$="N"THEN 280:IF Y$="NO"THEN 280:INPUT "FILE NAME",S$
270 DATA LOAD DC OPEN T#2,S$:DATA LOAD DC #2,H9():GOTO 330
280 PRINT "OBSERVED HEADS AT WELL 1"
290 FOR I = 1 TO P
300 PRINT I;")":PRINT HEX(0C);STR(R$,1,9):INPUT H9(I):PRINT HEX(
0C);STR(R2$,1,64);HEX(0C)
310 NEXT I
320 INPUT "DO YOU WANT TO SAVE THESE HEADS ON DISK",Y$:IF Y$="N"
THEN 330:IF Y$="NO"THEN 330:INPUT "FILE NAME",S$:DATA SAVE DC OP
EN T#2,10,S$:DATA SAVE DC #2,H9()
330 INPUT "DO YOU WANT A RECESSION CORRECTION",Y$:IF Y$="N"THEN
360:IF Y$="NO"THEN 360
```

```
340 INPUT "SLOPE",S7:INPUT "INTERCEPT",I7:D7=INT((-.933*(L↑2)*S7
/86400)*100)/100:PRINT "BY THE WAY, T/S=";D7;" WOULD BE A GOOD F
IRST TRY":FOR I=1TO 100:NEXT I
350 T7=((LOG(H9(1))/LOG(10))-I7)/S7:PRINT "DAY OF FIRST INTERCEP
T =";T7:FOR I=2TO P:T7=T7+D9/24:H9(I)=H9(I)+(H9(1)-10↑(T7*S7+I7)
):NEXT I:FOR I=1TO 100:NEXT I
360 H(1)=0:C=P:FOR I=2TO P
370 H(I-1)=H9(I)-H9(I-1)
380 NEXT I
390 D8=D9*3600
400 PRINT HEX(03):INPUT "(SF '0).DO YOU WISH TO ESTIMATE U OR T/
S",Q$
410 IF Q$="U"THEN 420:INPUT "ENTER T/S",G1:U=X/SQR(G1*D8):PRINT
"U EQUALS ",U:GOTO 430
420 INPUT "ENTER U",U:G1= ((X/U)↑2)/(D8):PRINT "T/S EQUALS ";G1
430 REM ***** THE FOLLOWING CALCULATES HEAD RESPONSE ****
440 SELECT PRINT 215(132):PRINT HEX(0C0E0A0A):CONVERT UTO U$,(##
##.###):CONVERT G1TO G1$,(####.###):F1=0
450 F1=F1+1:IF STR(U$,F1,1)<>HEX(30)THEN 460:GOTO 450
460 F2=0
470 F2=F2+1:IF STR(G1$,F2,1)<>HEX(30)THEN 480:GOTO 470
480 PRINT "Calculated Response For Well 2":PRINT HEX(0E0A);"When
 U = ";STR(U$,F1,7);", Or T/S = ";STR(G1$,F2,7):PRINT :SELECT PR
INT 005(64)
490 FOR J=2 TO P
500 H1=0
510 FOR K=1 TO J-1
520 H2=0
530 L1=0
540 L1=L1+1
550 E1=(2*L1-1)/(X/L)
560 E2=SQR(J-K)
570 E3=.5*U
580 B1=E3*(E1-1)/E2
590 B2=E3*(E1+1)/E2
600 B=B1
610 GOSUB '1(B):REM ERFC
620 S1=S
630 B=B2
640 GOSUB '1(B):REM ERFC
650 S1=S1+S
660 T=((-1)↑(L1-1))*H(K)*S1:IF ABS(T)>.005 THEN 670:GOTO 690
670 H2=H2+T
680 GOTO 540
690 H1=H1+H2
700 NEXT K
```

```
710 PRINTUSING 750,K+1,H1
720 CONVERT (K+1)TO K$,(##):CONVERT H1TO H1$,(###.##):F1=0:IF ST
R(K$,1,1)<>HEX(30)THEN 730:STR(K$,1,1)=HEX(20)
730 F1=F1+1:IF STR(H1$,F1,1)<>HEX(30)THEN 740:STR(H1$,F1,1)=HEX(
20):GOTO 730
740 SELECT PRINT 215(132):PRINT "Time Step ";K$,"Head ";H1$:SELE
CT PRINT 005(64)
750 %  TIME STEP ##            ###.##
760 H8(K)=H1
770 NEXT J
780 INPUT "DO YOU WISH TO TRY AGAIN",B$:IF B$="N"THEN 850:IF B$=
"NO"THEN 850:GOTO 400
790 DEFFN'1(B):REM ********   CALCULATE ERFC     *******
800 IF B<4 THEN 810:S=0:RETURN
810 B3=1/(1+A0*B)
820 S=(A1*B3+A2*B3↑2+A3*B3↑3)*EXP(-B↑2)
830 RETURN
840 DEFFN'0:GOTO 400
850 END
```

Documentation of Program Execution

As with the machine-language program documented earlier in this report, the data input requirements for the Basic Language program are deceptively simple and the user is again urged to read the section on constraints and limitations of the technique. Much of the following documentation is unaltered from the previous documentation of the machine-language program but is presented, nonetheless, because it would be inconsiderate and impractical to expect the potential user to assimilate the prior documentation and then incorporate a list of departures to be applied to the Basic Language version.

Because most, and possibly all, of the machine output is presented on a CRT (cathode ray tube) display, the sequence and not the format of data entry is documented.

With one exception, "TIME STEP DURATION (HOURS)" all units are in terms of length (consistencly feet, meters, etc.) and time (seconds). The time-step increment, Δt in equation 1, is expressed in hours to simplify user responses.

Data are entered in the following sequence:

(1) X, The distance from the observation point (well 2 in figure 1) to the valley wall.

(2) L, The distance from the stream or control well (well 1 in figure 1) to the valley wall.

(3) NUMBER OF TIME STEPS, the total number of time steps to be simulated.

(4) TIME STEP DURATION (HOURS), Δt in equation 1, or the time interval in hours between stage values, H_m, and between calculated head values, h_p.

(5) DO YOU WANT TO ENTER HEADS FROM DISK, respond YES, or Y; NO, or N.

   (A) YES or Y , head values, H_m, which were previously stored on disk will be retrieved for reanalysis after entering the FINE NAME, not to exceed eight characters. Processing will then transfer to 7 below.

   (B) NO or N, observed head values, H_m, will be entered for each time step. The user has two options at this point: the values may be based on mean sea level or on an arbitrary datum.

If a recession correction is to be applied the datum must be the same one used for the regression analysis of the recessions.

(6) DO YOU WANT TO SAVE THESE HEADS ON DISK, respond YES, or Y; NO, or N.

(A) YES or Y, enter the FILE NAME, not to exceed eight characters, which you wish to assign to the data set. All heads H_m will be stored on disk for later analysis (see 5, above).

(B) NO or N, the heads H_m will not be stored on disk.

(7) DO YOU WANT A RECESSION CORRECTION, respond YES, or Y; NO, or N.

(A) YES or Y, (refer to equation 4).

(1) SLOPE, enter the recession slope, a, as determined by regression analysis or graphical determination where the slope is the change in Log_{10} of the head per time Δt.

(2) INTERCEPT, enter the log of the intercept, b, head value for t = 0.

These constants may be obtained by performing a standard semi-log regression analysis of head-recession data.

The calculator will then calculate and display a suggested starting value for diffusivity (see equation 3), followed by a display of the DAY OF FIRST INTERCEPT (see figure 2) which is the match-point time, in days, for equivalent values of head for $H_{m(1)}$ and the heads of the semi-log recession.

The calculator will then proceed to determine ΔH_m (equation 1) with recession correction for all time steps.

(B) NO or N, no recession is applied and the calculator will determine ΔH_m in equation 1, without recession correction, for all time steps.

(8) DO YOU WISH TO ESTIMATE U OR T/S, (default value "T/S").

(A) T/S, enter the trial value for aquifer diffusivity. The calculator will display and print the corresponding value of U and then proceed to display and print the calculated head responses at the observation point.*

(B) U, enter the trial value for U. The calculator will display and print the corresponding value of T/S and then proceed to display and print the calculated head responses at the observation point.*

(9) Return to 8, above.

*It is possible that one of several things may, or may appear to go awry at this point. If the calculator appears to lock up for over 10 seconds after displaying but not printing the corresponding value of U or T/S:

(1) The printer is not on,

(2) The select code (215) used in this program is not suitable to the printer,

(3) No typewriter printer is available and program statements 440-480, 720-740 were not deleted.

If the first few values of calculated head appear to be in error:

(1) Consider the possibility that a recession correction should be applied to heads at the observation point, perhaps then a match will be obtained.

(2) Check for convergence between the calculated and observed head values. If these values converge there is a good chance that the peak values will agree in time and magnitude.

(3) If the user is dissatisfied with the early values of calculated heads H_p halt computation, depress the Special Function '1 key and enter another trial value of U or T/S (see step 8).

The following are reproductions of the printed output of values of h_p for the three test cases employed earlier to demonstrate the machine language program. The first set of calculated values are for an aquifer diffusivity value of 2.5 L^2S^{-1} with no recession correction applied to values of H_m. The second and third sets of calculated values are for aquifer diffusivities of 2.5 and 4.0 L^2S^{-1} but with a recession correction applied to values of H_m. As can be observed, these results agree with the values of h_p determined by the machine language program.

Calculated Response For Well 2

When U = 12.909 , Or T/S = 2.500

Time Step	2	Head	.03
Time Step	3	Head	.53
Time Step	4	Head	1.88
Time Step	5	Head	3.58
Time Step	6	Head	4.86
Time Step	7	Head	5.56
Time Step	8	Head	5.83
Time Step	9	Head	5.84
Time Step	10	Head	5.68
Time Step	11	Head	5.41
Time Step	12	Head	5.06
Time Step	13	Head	4.67
Time Step	14	Head	4.25
Time Step	15	Head	3.81

Calculated Response For Well 2

When U = 12.909 , Or T/S = 2.500

Time Step	2	Head	.12
Time Step	3	Head	.81
Time Step	4	Head	2.41
Time Step	5	Head	4.39
Time Step	6	Head	5.98
Time Step	7	Head	7.00
Time Step	8	Head	7.60
Time Step	9	Head	7.94
Time Step	10	Head	8.10
Time Step	11	Head	8.16
Time Step	12	Head	8.13
Time Step	13	Head	8.05
Time Step	14	Head	7.94
Time Step	15	Head	7.81

Calculated Response For Well 2

When U = 10.206 , Or T/S = 4.000

Time Step	2	Head	.22
Time Step	3	Head	1.34
Time Step	4	Head	3.67
Time Step	5	Head	6.08
Time Step	6	Head	7.67
Time Step	7	Head	8.52
Time Step	8	Head	8.94
Time Step	9	Head	9.11
Time Step	10	Head	9.13
Time Step	11	Head	9.06
Time Step	12	Head	8.91
Time Step	13	Head	8.75
Time Step	14	Head	8.55
Time Step	15	Head	8.35

SUMMARY

The linear ground-water flow, flood-wave response program, as adapted for programmable calculators, is intended to provide an alternative to the use of true computers for the solution of the discretized analytical equation of one-dimensional ground-water flow. The use of programmable calculators rather than true computers has several advantages:

(1) The general accessability to programmable calculators.

(2) Minimal cost of operation.

(3) Rapid user interaction with computer output.

The only apparent disadvantage is the slow computation speed of the calculators.

The primary application of the program is to determine aquifer diffusivity by the flood-wave response technique. The aquifer is assumed to be semi-infinite, bounded on one side by an impermeable barrier and on the other parallel side by a fully penetrating stream in complete hydraulic connection with the aquifer. The aquifer is also assumed to be uniform in thickness and hydrologic characteristics. Ground-water head changes in response to stage changes of the stream may be calculated for points along a line which is perpendicular to the impermeable barrier and the fully penetrating stream. Modeled values of diffusivity are adjusted until the calculated and observed head changes agree.

Because the primary application of the program is to determine aquifer diffusivity by the flood-wave response technique the two example calculator programs were used to analyze identical sets of flood-wave response data. Both example programs, one written in machine language for the Hewlett Packard 9810A calculator and the other written in Basic for Wang System 2200 calculators, produced identical calculated head responses.

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