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Najwan T. Shareef
David S. Bowles

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ABSTRACT

A General Model of Well Fields Influenced by

Barrier and Recharge Boundaries

by

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Utah State University, 1981

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This model is designed to calculate the drawdown of a piezometric surface or water table at a given point of interest in a well field. Many different well and aquifer hydraulic conditions can be considered. The effect of field boundaries is solved by the image well theory. Many points of interest, wells (recharge or injection), boundaries (barrier or recharge), and time increments as well as constant and variable pumping rate case have been included in the model. The drawdown at a point of interest can be decomposed into the following components for each real well due to the effect of: the existence of boundaries, partial penetration of the well in the aquifer, and the well loss at the walls of the well due to turbulent flow. Both the International Systems of Units (SI) and the English system are available. The option of using graph of drawdown vs distance or drawdown vs time is also available. Also included in this thesis is a well-spacing design problem as an application of the model.

(103 pages)

CHAPTER I

INTRODUCTION

Background

Groundwater is the body of water which occurs in the saturated zone beneath the ground surface and whose motion is exclusively determined by gravity and by the frictional forces provoked by the motion itself. This body of water in the saturation zone and that in the aeration zone is bounded at the top and bottom by either impervious or semiimpervious strata.

Wells generally serve as devices for extracting groundwater from aquifers, which are geologic formations which contain and transmit water. Wells serve such purposes as for subsurface exploration and observation, disposal of sewage, industrial or radioactive wastes, draining agricultural lands, controlling salt water encroachment, relieving pressures under dams or levees, and artificial recharge of aquifers.

Design features of the well depend on the quantity of water extracted, economic factors, the well's objective and hydrologic conditions. Spacing of wells is largely affected by the drawdown within the region of interest. The greater the spacing of the wells, the less their interference, but the greater the cost of connecting pipelines and power installation. The drawdown itself is affected physically by:

a) Well boundary conditions such as well percentage of penetration through the aquifer, well diameter and gravel envelopes, screens, perforation, amount and duration of pumped (or injected) water, and schedule of pumping.

b) Aquifer characteristics and aquifer boundary conditions such as hydraulic characteristics of the aquifer, its thickness, and the existence of barrier and recharge boundaries which delimit the continuity of the aquifer.

The assumption of infinite areal extent of the aquifer is made for both the equilibrium and nonequilibrium formulas in well hydraulics. Practically, in many instances the existence of boundaries serve to limit the continuity of the aquifer, in one or more directions, to distances ranging from a few hundred feet to as much as tens of miles. The boundaries may be either of the barrier type, such as an impermeable outcrop, also termed a "negative boundary," or of the recharge type such as a stream in a hydraulic contact with the aquifer, sometimes called a "positive boundary." The influence on groundwater movement and storage of hydrologic boundaries, which often exist in the real world, may be determined by means of the image well theory as described by Ferris et al. (1962).

Objective

The objective of this study is to build a computer program to calculate the drawdown of a piezometric surface (for confined aquifer), or the drawdown of a water table (for unconfined aquifer) at any point of interest within a well field for a variety of wells, vertical aquifer, and horizontal aquifer boundary conditions. The program will be designed to be used by engineers for designing well fields influenced by recharge and barrier boundaries. The program will be based on an earlier model by Bowles and Rogers (1973). The specific tasks necessary to fulfill this objective are listed below:

1. To review the literature in well hydraulics, boundary conditions, image wells, and design of well fields.

2. To understand the earlier model by Bowles and Rogers (1973).

3. To modify this model so that it will include the following modifications:

a) The program will handle the following aquifer and well conditions:

i) Steady-state radial flow in isotropic, nonleaky artesian aquifer with fully penetrating well and constant discharge conditions.

ii) Steady-state radial flow in isotropic, watertable aquifer with fully penetrating well and constant discharge conditions.

iii) Unsteady-state radial flow in isotropic-nonleaky artesian aquifer with fully penetrating well and constant discharge conditions.

iv) Unsteady-state radial flow in anisotropic-nonleaky artesian aquifer with fully penetrating well and constant discharge conditions.

v) Unsteady-state radial flow in isotropic-nonleaky artesian aquifer with partially penetrating wells and constant discharge conditions.

vi) Unsteady-state radial flow in isotropic leaky artesian aquifer with fully penetrating wells without water released from storage in aquitard and constant discharge conditions.

vii) Steady-state radial flow in isotropic leaky artesian aquifer with fully penetrating wells without water released from storage in aquitard and constant discharge conditions.

viii) Unsteady-state radial flow in isotropic leaky artesian aquifer with fully penetrating wells with water released from storage in aquitard.

ix) Steady-state radial flow in isotropic leaky artesian aquifer with fully penetrating wells with water released from storage in aquitard.

x) Unsteady-state radial flow in isotropic watertable aquifer with fully penetrating wells and constant discharge conditions.

b) The boundary geometry will be restricted to the following cases:

i) Infinite aquifer

ii) Semiinfinite aquifer

iii) Wedge-shaped aquifer

iv) Infinite-strip aquifer

v) Semiinfinite-strip aquifer

vi) Rectangular aquifer

c) The program will calculate and analyze the following components of the drawdowns:

i) Total interference from other wells

ii) Portion due to partial penetration

iii) Magnitude of well loss (in real well only)

iv) Total drawdown effects from all boundaries

d) The program will be suitable for use as a tool for solving problems with:

i) Constant pumping rate

ii) Variable pumping rate

Finally, the program will use both S.I. and U.S. systems of units.

4. To verify the model by hand calculation and debugging the program.

5. To write thesis in form of a user manual.

Outline

Chapter II reviews the various types of groundwater models, explains the well drawdown equations and image well theory. Chapter III contains a description of the various components of the computer model, and describes the advantages and the limitations of the model. In Chapter IV, model verification and the application to an optimal well spacing problem, are described. Finally, Chapter V gives the summary, conclusions and recommendations for further work.

CHAPTER II

LITERATURE REVIEW

Groundwater Models

Introduction

Groundwater plays an important role in the hydrologic cycle. The amount of water beneath the ground surface is much greater than surface water. So groundwater has great contribution in water resource planning, especially when surface water is rate. Until the advent of groundwater computer models it was difficult to evaluate groundwater availability and quality, the cost of pumping, or effect of groundwater development. The techniques used in groundwater modeling are as follows (FAO 1978).

Physical models

In physical models the groundwater prototype is scaled down to a model of similar materials and has the same basic physical properties such as sand models. San models are useful in demonstration and are powerful to represent unsaturated and multiple fluid flow problems.

Analog techniques

Darcy's law in fluid mechanics, Ohm's law in electricity and Fourier's law in heat transfer are similar in principle and application. Analog techniques are based on the similarities in equations for groundwater flow and the flow of electricity. These analogs are devices with similar input-output or cause and effect relations as the true systems.

Electrolytic rank analogs, resistence network analogs, resistence capacitance analogs, viscous fluid parallel plate model, membrane models, etc. are examples of these techniques (Bouwer 1978, FAO 1978).

Mathematical models

A mathematical groundwater model is a mathematical expression, or group of expressions, that describes the hydraulic relations within the system. It is usually in the form of differential equations together with the auxiliary conditions (the system geometry, the hydraulic characteristics of the system parameters, and the initial and boundary conditions) (Remson, Hornberger, and Molz 1971).

Mathematical models may be grouped into 6 types, each of which is briefly reviewed.

Analytical solutions

These solutions for groundwater problems, which are in the form of partial differential equations, were dominated in the 1950s. In the 1960s and 1970s, there was more attention to numerical modeling because of the invention of high speed computers. But analytical solution is still the ideal way to solve these problems. Many groundwater problems were solved in this method like land subsidence due to artesian pressure, single and multiple boundary aquifer system (Stallman 1963, Vandenberg 1977), fresh water injection in a nonleaky artesian salaquifer (Esmael and Kimbler 1967), and estimating the rate and volume of stream depletion by near by production wells (Theis 1941, Jenkins 1968). Books are available to describe the solution of partial differential equations like deWiest (1965), Verruijt (1970), Kruseman and de Ridder (1970), Walton (1970), Todd (1959), and Bear (1972).

Type curve techniques

In this method the unknown parameters could be solved by superposing the fitting data curve on a "type curve." The various factors can then be computed. These solutions were summarized by Kruseman and de Ridder (1970), and others.

Graphical solutions

These solutions have a limited extent. They are based on the application of numerical techniques in heat flow to groundwater such as the graphical solutions for both linear and radial flow conditions (Thomas 1961).

Differential analyser solutions

This analyser is a device to solve differential equations. It is constructed by fluid, electronic or mechanical means to solve the differential equations (Tyson and Weber 1963).

Inverse problems

This is a trial and error technique to solve the formation factors from water levels and input data, and then adjust the model until historical data reproduced by the model through calibration procedure.

Numerical techniques

Numerical methods are those methods in which algorithms that use only arithmetic operations and certain logical operations such as algebraic comparison. They give approximated solution but not exact one by using digital computers. These methods are used broadly now because of the invention of high speed computers. There are two methodology in this technique:

1) Finite difference method: Finite differences were introduced by Richardson in 1910 to solve partial differential equations. Application of this method for steady-state seepage problems started by Show and Southwell in 1941. There are many books available to describe this technique like Carnahan, Luther, and Wilkes (1969), Remson, Hornberger, and Molz (1971), etc. The finite difference method depends on useful mathematical properties of square grid networks, in which the nodes are of the same size. The basic idea of these methods is to replace derivatives at a point by ratios of the changes in appropriate variables over a small but finite interval (Remson, Hornberger, and Molz 1971). For example, the derivative dH/dX becomes

$$\frac{dH}{dX} = \lim_{\Delta X \to 0} \frac{\Delta H}{\Delta X} = \frac{(H_2 - H_1)}{\Delta X} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (1)$$

in which

H_1 and H_2 are the heads at the grid points numbers 1 and 2

The size of the increment ΔX depends on the problem itself. If ΔX becomes very small, the functional problem is approximated to a continuous one.

2) Finite element method: This method was started in the early 1950s in the aeroscope industry, then it was published by Turner et al. in 1956. Melosh (1965) proved that this method was a variation of the Raleigh-Ritz procedure. Basically, in this method, any continuous quantity can be approximated by a discrete model composed of a set of piecewise continuous functions defined over a finite number of subdomines (Segerlind 1976). This technique is established by starting from a formulation of the fundamental problem, not through a differ-

ential equation and boundary condition. Starting with Darcy's equations and the continuity equation:

$$V_x = -k\ d\phi/dx \quad . \ . \ . \ . \ . \ . \ . \ . \ . \ . \ . \ (2)$$

$$V_y = -k\ d\phi/dy \quad . \ . \ . \ . \ . \ . \ . \ . \ . \ . \ . \ (3)$$

$$\frac{d\ V_x}{dx} + \frac{d\ V_y}{dy} = 0 \quad . \ . \ . \ . \ . \ . \ . \ . \ . \ . \ . \ (4)$$

in which

V_x = the velocity in the x direction

V_y = the velocity in the y direction

x and y are the cartesian coordinates

ϕ is the total head

k is the permeability

Substituting equations 2 and 3 in equation 4 yields the Laplace equation which is:

$$\frac{\partial}{\partial x}\ (k\ \frac{\partial \phi}{\partial x}) + \frac{\partial}{\partial y}\ (k\ \frac{\partial}{\partial y}\ ) = 0 \quad . \ . \ . \ . \ . \ . \ . \ . \ (5)$$

Now the region is subdivided into a large number of subregions R_j, the elements, in which each element produces a contribution V_j to the value of the function V so that

$$V = \sum_{j=1}^{n} V_j$$

where

n is the number of elements

Usually the elements are in a triangular shape. At the nodes the basic parameters are taken. The values of these parameters in the interior of the element varies in a linear relationship (Verruijt 1970).

Equations Used for Different Aquifer Hydraulic Characteristics

Background

Due to hydrologic cycle in nature, earth was formed with different strata or geologic formations. Each stratum had its unique properties like particle size distribution, particle size diameter, chemical components and their chemical behavior, degree of compaction of the soil, capacity to hold and transmit water, which means that the stratum react as a storage for water, etc. These properties might be changed from time to time.

From the groundwater hydrologic point of view, these geologic formations might be classified according to their boundary conditions and amount of water in storage. Bouwer (1978) defined an aquifer as a "groundwater-bearing formation sufficiently permeable to transmit and yield water in usable quantities." Hantush (1964) defined other types of aquifers: "artesian aquifers, also known as confined or pressure aquifers, are those in which groundwater is confined under pressure by impervious or semipervious strata. Water table aquifers, also known as free, phreatic, or unconfined aquifers are those in which the upper surface of the zone of saturation is under atmospheric pressure. Aquifers, whether artesian or water table, that lose or gain water through adjacent semipervious layers are called leaky aquifers. A water table aquifer resting on a semipervious layer that permits slow movement of water is called a leaky water table aquifer. An artesian aquifer that has at least one semipervious confining bed is called a leaky artesian aquifer. If the flow across the confining beds is negligible, the aquifers are called nonleaky aquifers." An aquitard as defined by

Bouwer (1978) is a confined aquifer which is sufficiently permeable to transmit water vertically to or from the confined aquifer, but not permeable enough to laterally transport water like an aquifer.

Hydraulic cases used in the program

A total of eleven cases with different aquifer and well boundary conditions are treated in this thesis. The definition of each case is presented in Table 1. Table 2 gives the drawdown equations, references to the tabular solution if used, and a reference for the derivation of each equation. In Table 3 the definition of the symbols used in Table 2 are given.

Variable discharge

Since the equations of groundwater flow are linear for the confined case, and approximately linear for the unconfined case, if the drawdown due to pumping is small compared with the thickness of the saturated zone, the principle of superposition is applicable. That is, the drawdown at any point of interest is additive for any number of wells and this is the basis of the image well technique.

The principle of superposition can also be applied to the case of variable discharge. If Q_o, Q_1 ..., Q_n are the discharge rates for a certain well at different times, then ΔQ_1, ΔQ_2, ..., ΔQ_n are the changes in discharge at each time. Thus the total drawdown at a point of interest can be estimated by the following equation in which each ΔQ is considered to come from a separate real well located in the same position (Freeze and Cherry 1979).

$$h_o - h = \frac{Q_o}{4\pi T} W(u_o) + \frac{\Delta Q_1}{4\pi T} W(u_1) + \ldots + \frac{\Delta Q_n}{4\pi T} W(u_n) \quad . \quad . \quad . \quad . \quad (6)$$

Table 1. Definitions of well drawdown cases.

Case Number	Steady	Unsteady	Isotropic	Anisotropic	Fully penetrating well	Partially penetrating well	Confined aquifer	Unconfined aquifer	Leaky aquifer	Nonleaky aquifer	With water released from storage in aquitard	Without water released from storage in aquitard
1	X		X		X		X			X		
2	X		X		X			X				
3		X	X		X		X			X		
4		X		X	X		X			X		
5		X	X			X	X			X		
6		X	X			X	X			X		
7		X	X		X		X		X			X
8	X		X		X		X		X			X
9		X	X		X		X		X		X	
10	X		X		X		X		X		X	
11		X	X		X			X				

Table 2. Well drawdown equations.

Case Number	Equation used	Table no. in the reference	Source reference
1	$s = \{Q \ \ell n(\frac{R}{r})/(2 \pi Km)\} \ 40.783^*$	-	Bouwer (1978)
2	$s = \{\sqrt{Q \ \ell n(\frac{R}{r})/(\pi K)}\} \ 40.783^*$	-	Bouwer (1978)
3	$s = 114.6 \ Q \ W(u)/T$	-	Walton (1970)
4	$s = 114.6 \ Q \ W(u_{xy})/\sqrt{T_{xx}T_{yy} - T_{xy}^2}$	-	Walton (1970)
5	$s = 114.6 \ Q \ W(u, \frac{r}{m}, \gamma)/T$	T3.3 p. 140	Walton (1970)
6	$s_p = 114.6 \ Q \ W_p(u, \frac{r}{m}, \gamma)/T$	T3.4 p. 142	Walton (1970
7	$s = 114.6 \ Q \ W(u, r/B)/T$	T2 p. 707	Hantush (1956)
8	$s = 229 \ Q(K_o\frac{r}{B})/T$	T2 p. 704	Hantush (1956)
9	$s = 114.6 \ Q \ W(u,\psi)/T$	TIII p. 313	Hantush (1964)
10	$s = 229 \ Q(K_o\frac{r}{B})/T$	T1 p. 704	Hantush (1956)
11	$s = 114.6 \ Q \ W(u_{ay}, r/B)$	Appendix 2 p. 480	Boulton (1963)

*The constant 40.783 is used to change the units of the equation from S.I. to F.P.S.

Table 3. Definitions of symbols used in Table 2.

Symbol	Definition	Units	
		FPS	SI
B in cases no. 7, 8, and 10	$B = \sqrt{Tm'/p'}$	ft	m
B in case no. 11	$B = \sqrt{T/(\alpha.Sy)}$	$(g/ft)^{1/2}$	m
k	permeability of the aquifer	gpd/ft^2	m/day
$K_o \frac{r}{b}$	well function	-	-
m	thickness of the aquifer	ft	m
m'	thickness of the aquitard	ft	m
p'	permeability of the aquitard	gpd/ft^2	m/day
Q	discharge rate of the well	gpm	$\frac{\text{cubic meters}}{\text{day}}$
r	distance from the pumping well to the observation point	ft	m
R	radius of influence of the well	ft	m
s	drawdown at the observation point	ft	m
S	coefficient of storage of the aquifer	-	-
s_p	drawdown due to partial penetration only	ft	m
S'	coefficient of storage of the aquitard	-	-
S_y	specific yield	-	-
t	time after pumping started	days	days
T	transmissibility of the aquifer	gpd/ft	m^2/day
Txx, Tyy Txy	components of the second-rank symetric tensor of transmissibility	gpd/ft	m^2/day

Table 3. Continued.

Symbol	Definition	Units FPS	Units SI
u, u_a	u or $u_a = \frac{1.87r^2S}{T_t}$	-	-
u_{xy}	$u_{xy} = 1.87\ S\frac{(T_{xx}\ Y^2) + T_{yy}\ X^2\ Txy\ XY)}{t(T_{xx}\ T_{yy} - T_{xy}{}^2)}$	-	-
u_y	$u_y = \frac{1.87\ r^2\ S_y}{T_t}$		
$w(u)$ $W(u,r/B)$ $w(u,r/m,\gamma)$ $w(u_{ay},r/B)$ $w(u_{xy})$ $W(u,\psi)$	well functions	-	-
x,y	coordinates of the observation point	ft	m
α	1/(delay index)	day^{-1}	day^{-1}
γ	percentage of well penetration	-	-
ψ	$\psi = (\frac{r}{4})\sqrt{\frac{s'\ p'}{T\ S\ m'}}$	-	-

in which

$h_o - h$ = the drawdown

$u_i = \frac{r^2 S}{4Tt_i}$

t_i = the time since pumping started for discharge Q_i

$i = 0, 1, 2, \ldots, n$

$w(u_i)$ = the well function at time t_i

Well losses

Because of the small velocity of flow of water in an aquifer, the flow is considered laminar. The formation loss of the aquifer, i.e. the drawdown computed in all well drawdown equations, is directly proportional to the discharging rate of the well. In the vicinity of the well, turbulence occurs due to the well screen, gravel envelope, and the developed zone outside the well casing. This phenomenon causes another head loss called 'well loss.' This loss varies with some power of the discharge Q. The total head loss in the well can be approximated as

$$s_{iw} = C_f\, Q + C_w\, Q^n \quad \ldots \quad (7)$$

where

s_{iw} is the total head loss

Q is the pumping rate

C_f is the formation constant

C_w is the well loss constant

n is the exponent due to turbulence (Bouwer 1978)

Image Well Theory

Definition

Image well theory has been described as follows:

"The effect of a barrier boundary on the drawdown in a well, as a result of pumping from another well, is the same as though the aquifer were infinite and a like discharging well were located across the real boundary on a perpendicular thereto and at the same distance from the boundary as the real pumping well. For recharge boundary the principle is the same except that the iamge well is assumed to be discharging the aquifer instead of pumping from it." (Walton 1970)

Barrier boundary

The barrier boundary is an impermeable barrier. It is assumed that the irregularly slopping boundary can, for practical purposes, be replaced by a vertical boundary, without sensibly changing the nature of the problem. The hydraulic condition imposed by the vertical boundary is that there can be no groundwater flow across it, for the impermeable material cannot contribute water to the pumping well. An imaginary discharging well has been placed at the same distance as the real well from the boundary but on the opposite side, and both wells are on a common line perpendicular to the boundary. At the boundary the drawdown produced by the image well is equal to the drawdown caused by the real well. Therefore, the drawdown cones for the real and image wells will be symmetrical and will produce a groundwater divide at every point along the boundary line. Because there can be no flow across a divide, the image system satisfies the boundary conditions of the real problem.

The resultant drawdown at any point of interest on the cone of depression in the real region is the algebraic sum of the drawdowns produced at that point by the system of real and image wells. The constant profile of the cone of depression is flatter on the side of the real well toward the boundary and steeper on the opposite side away from the boundary than it would be if no boundary were present.

Recharge boundary

In this case, the well in an aquifer is hydraulically controlled by a perennial stream. For thin aquifers the effect of vertical flow component are small at relatively short distances from the stream, and if the stream stage is not lowered by the flow to the real well there is established the boundary condition that there shall be no drawdown along the stream position. So for most field situations it can be assumed for practical purposes that the stream is fully penetrating and equivalent to a line source at a constant head. An imaginary recharging well is assumed to be placed at the same distance as the real well from the line source but on the opposite side. Both wells are situated on a common line perpendicular to the line source. The imaginary recharging well operates simultaneously with the real well and returns water to the aquifer at the same rate that it is withdrawn by the real well. The resultant drawdown at any point of interest on the cone of depression in the real region is the algebraic sum of the drawdowns produced at that point by the system of real and image wells. The resultant profile of the cone of depression is flatter on the landward side of the well and steeper on the riverward side.

Multiple boundary system

Two or more boundaries are required to delimit a wedge-shaped aquifer; two parallel boundaries form an infinite-strip aquifer; two parallel boundaries intersected at right angles by a third boundary form a semiinfinite-strip aquifer; and four boundaries intersected at right angles form a rectangular aquifer. The image well theory could be applied to such cases by taking into consideration successive reflections on the boundaries.

A number of image wells are associated with a pair of converging boundaries. Each primary image well produces an unbalanced effect at the opposite boundary. The actual well angle "A" is approximated as to one of certain aliquot parts of 360° as specified by Ferris et al. (1962) as follows:

If the aquifer wedge boundaries are of a like character, "A" must be an aliquot part of 180°. If the boundaries are not of a like character, "A" must be an aliquot part of 90°. Then the number of reflections required to produce a balance image system is given by the equation

$$N = \frac{360^\circ}{A} - 1 \quad \quad (8)$$

The locus of image well locations is a circle whose center is at the apex of the wedge and whose radius is equal to the distance from the pumped well to the wedge apex.

If the arrangement of two boundaries is such that they are parallel to each other, the number of image wells are extending to infinity. Practically it is only necessary to add pairs of image wells until the next pair has negligible influence on the point of interest.

Generally, geologic boundaries do not occur as abrupt discontinuities with the geometry allowed for by image well theory. However, for the purpose of analyzing drawdown in well fields it is often possible to approximate them as such.

The image well theory could also be applied in case of multiwell field system. If there are n wells working at Q_1, Q_2, ..., Q_n pumping rates at distances of r_1, r_2, ... r_n from an observation point, then the drawdown equation is (Freeze 1979):

$$h_o - h = \frac{Q_1}{4\pi T} W(u_1) + \frac{Q_2}{4\pi T} W(u_2) + \ldots + \frac{Q_n}{4\pi T} W(u_n) \quad . \quad . \quad . \quad . \quad (9)$$

in which

$h_o - h$ is the drawdown at the observation point

$u_i = \frac{r_i^2 S}{4\ Tt_i}$, i = 1, 2, ..., n

t_i = the time since pumping started for the discharge Q_i

CHAPTER III

MODEL DESCRIPTION, ADVANTAGES, AND LIMITATIONS

Background

The drawdown model originated with an earlier version written by Bowles and Rogers (1973). That model calculated the drawdown for three aquifer boundary condition cases, namely; steady state, confined aquifer; steady state, unconfined aquifer; and unsteady state, confined aquifer in the English system of units. It included the analysis of boundary conditions, several wells, several points of interests, change of the drawdown as the discharging time continued, and graph. The model described in this chapter is an expanded version of the earlier model and is capable of holding 11 aquifer and well boundary conditions, English or metric system of units, constant or variable pumping rate.

Model Description

Appendix A contains the program listing and the flow chart illustrating the interrelationship of the main parts of the program. Figure 1 shows the interrelationship between the main program and the subroutines.

Input

Input to the program is from two sources. A file which contains the tables for well functions, and the data on punched cards which define the scope of the problem to be solved. The data cards define the

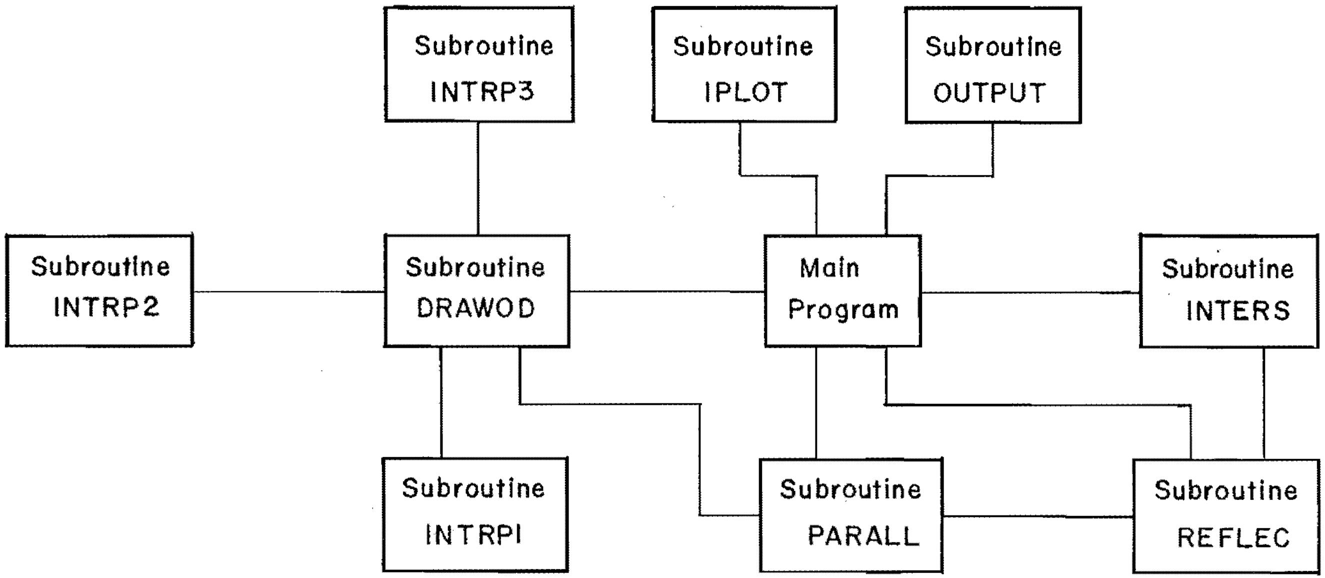

Figure 1. The interrelationship between the main program and the subroutine.

number of cases to be solved, the system of units used, the number of boundaries, the number of points of interest, the number of wells, and the type of aquifer and well boundary conditions. Boundary geometry, points of interest, and the cartesian coordinates of real wells must be specified in another set of cards. Aquifer characteristics for the case study are read separately. Time data are read from another card. Finally, if variable discharge problem is to be analyzed, a set of cards to define the discharges of each well must be specified. Appendix B contains examples of the data cards to be used with their format for several example cases.

Errors might arise if wrong data are used or there is a violation in program limitations. Appendix B contains the error messages which may be printed during the program execution.

If the S.I. system of units is used in the input, then the data are converted in the program to the F.P.S. system. Table 4 contains the conversion factors for all the parameters used in the program. Appendix B contains a description of input data and formats.

Table 4. Conversion factors.

Multiply one	By	To obtain
Meter	3.281	feet
cubic meter/day	0.18345	gallon/minute
square meter/day	2.28	gallon/day/foot
meter/day	0.695	gallon/day/ft^2

Analysis of geometry

The boundary configuration is limited to the following six cases which can be analyzed with the image well theory: no boundaries, one boundary, two intersecting boundaries, two parallel boundaries, three boundaries intersected at right angles, and four boundaries intersected at right angles. Figure 2 illustrates these cases. An error message will be given as an output if the problem to be solved is not one of these cases.

Image well generation

The purpose of image well generation is to find the number and the coordinates of the image wells due to the existence of boundaries, and the distances from the observation point to the image wells. To do this job, three subroutines are used, REFLEC, PARALL, and INTERS subroutines.

Subroutine REFLEC determines the coordinates of the image wells and checks whether the boundary is barrier or recharge one. Subroutine INTERS determines the number of image wells (n) in the case of intersecting boundaries with an angle of (A) using equation number (8). Subrountine INTERS calls Subrountine REFLEC to determine the coordinates and type of the image wells (discharge or recharge). Subroutine PARALL determines the number of image wells in case of parallel boundaries, calls Subroutine REFLEC to find the coordinates and type of the image wells, finds the distance from the point of interest to the image well. Subroutine PARALL then calls Subroutine DRAWDO which calculates the drawdown from each well which is explained in the next section. Subroutine PARALL checks the change in drawdown as additional image wells are added to see if it is within a user-specified convergence limit. The maximum number of image wells is 1000 (see the limitation of the program). Subroutine REFLEC is also used by the main program in the case of a single boundary.

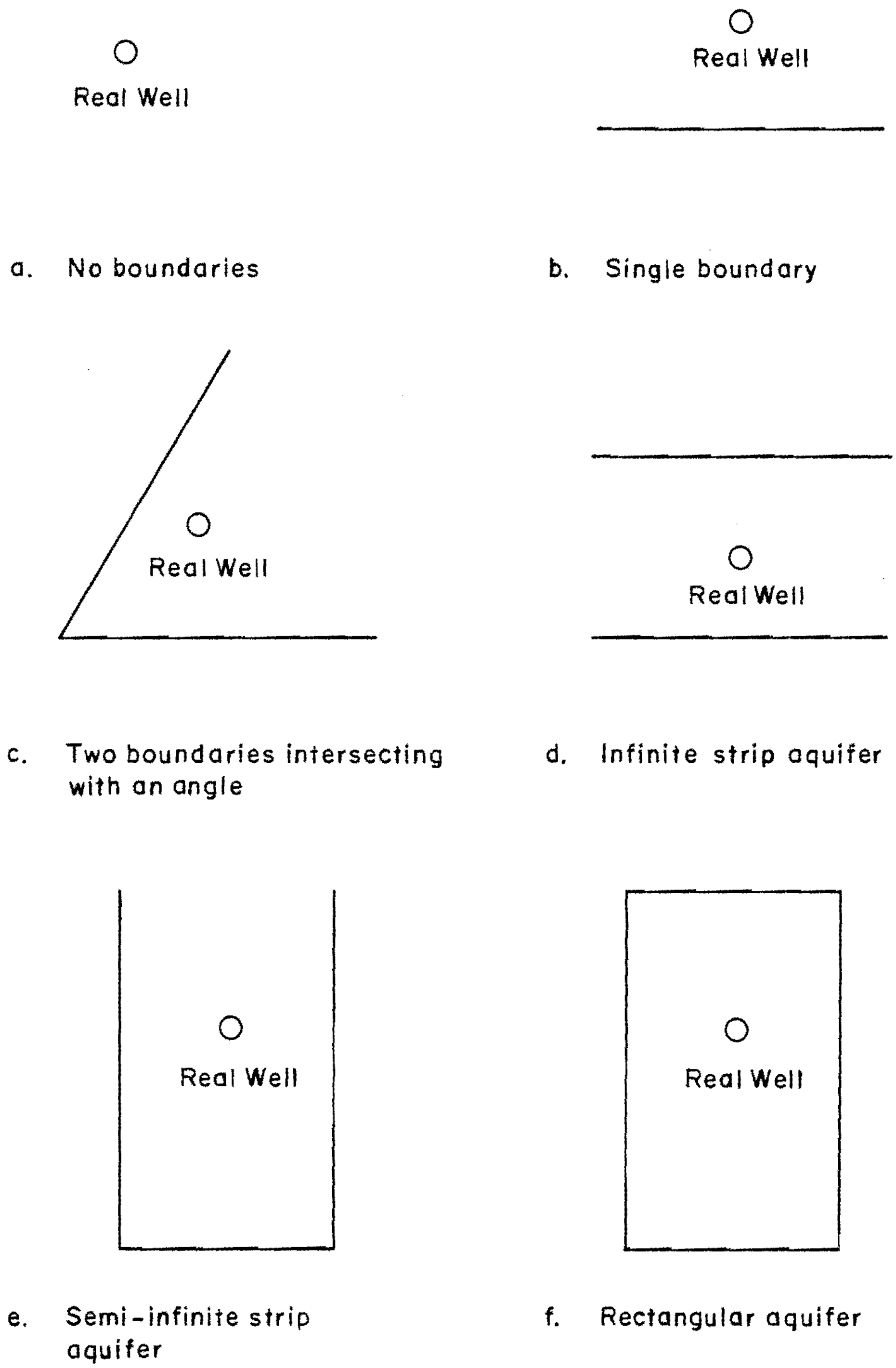

Figure 2. Limitations on the configuration of system of boundaries.

Drawdown computation

The coordinates, type, and number of image wells are stored and then used to evaluate the total drawdown at each point of interest as the algebraic sum of drawdown due to each image well and each real well. The computation of drawdown is perfomred by Subroutine DRAWDO. The first four cases (see Table 2) are solved analytically. The other seven cases (see Table 2) use the well function tables to interpolate linearly the value of well function and substitute it in the drawdown equation. This interpolation is done by two subroutines, INTRP1 and INTRP2. If the well function table is one dimensional, Subroutine INTRP1 is used, and if it is two dimensional, Subroutine INTRP2 is used. In the unconfined aquifer unsteady case (case number 11) two alternative equations are used depending on the time since pumping began. Boulton (1963) gave a graph for estimating the time range of each equation from the value of r/B. This graph was approximated by a table of times which are interpolated using Subroutine INTRP3 using a given value of r/B. An error message is printed by the program if the value of r/B is not within the bounds of the table.

Drawdown may be evaluated for a series of time intervals based on a logarithmic scale. A choice of minutes or days as a time unit and of the number of log cycles of time (up to 3) must be made by the user.

Well losses

The well loss for each well at each pumping rate, if variable discharge rate is used, is calculated as follows:

$$s_w = C_w Q^n$$

in which

s_w = the well loss due to turbulence flow near the well

Q = the pumping rate of the well

C_w = the well loss constant

n = an exponent relating the discharge Q to the well loss, s_w.

The two constants C_w and n are stored in the main program and then used to calculate the well loss directly.

Several real wells

Up to fifteen real wells can be analyzed simultaneously using this program. A separate image well system is generated for each real well. At each point of interest, the drawdown is composed of contributions from all real and image wells. The program could be easily changed to accommodate more than 15 real wells.

Several points of interest

The program can calculate drawdown at up to 15 points of interest at the same time. These points could be positioned to give enough drawdown information to enable to draw contour lines of the water table surface or the piezometric surface. If these points are on a straight line a graph option may be used to show the change of drawdown along the line. A relatively simple change for the program would print more than 15 points.

Variable pumping rate

A variable pumping rate can be justified for any of the unsteady cases (i.e. cases number 3, 4, 5, 6, 7, 9, and 11). Pumping from the real well(s) must be specified for each time interval. The discharge in each step or time interval is considered to be constant. For the variable pumping condition the time intervals must be used in days and each interval must be of the same length.

To explain how to treat this case, suppose there are n pumping rates and m wells. Thus the number of time steps is n+1. Let Q_{ij} represent the discharge for well number i at stage of pumping j. At the initial time of pumping when j=1 the discharge $Q_{i1}=0$ for all wells (i). If the discharge of well k is constant in all time steps, i.e. Q_{kj} is constant for all values of j, while the other wells have a variable discharge, then the values of Q_{kj} should be set equal to the same value in each time step.

The number of time increments and the whole pumping time is stored and then used to calculate the drawdown through double matching do-loops (see Figure 3 and the flow chart). The first do-loop is used to calculate the drawdown for the new change in discharge in the recent time interval, and the second do-loop is used to calculate the drawdown continuation from the previous changes in discharges in the previous time intervals.

Analysis of drawdown components

Drawdown is divided to four components for each real well, the drawdown caused by pumping from the real well excluding the effect of partial penetration and boundaries, the effect of partial penetration in the real well only, the effect of boundaries, and the effect of partial penetration on the boundaries. In the program, the drawdown caused by each real well and the effect of partial penetration is stored. As the computation of drawdown for each real well with its

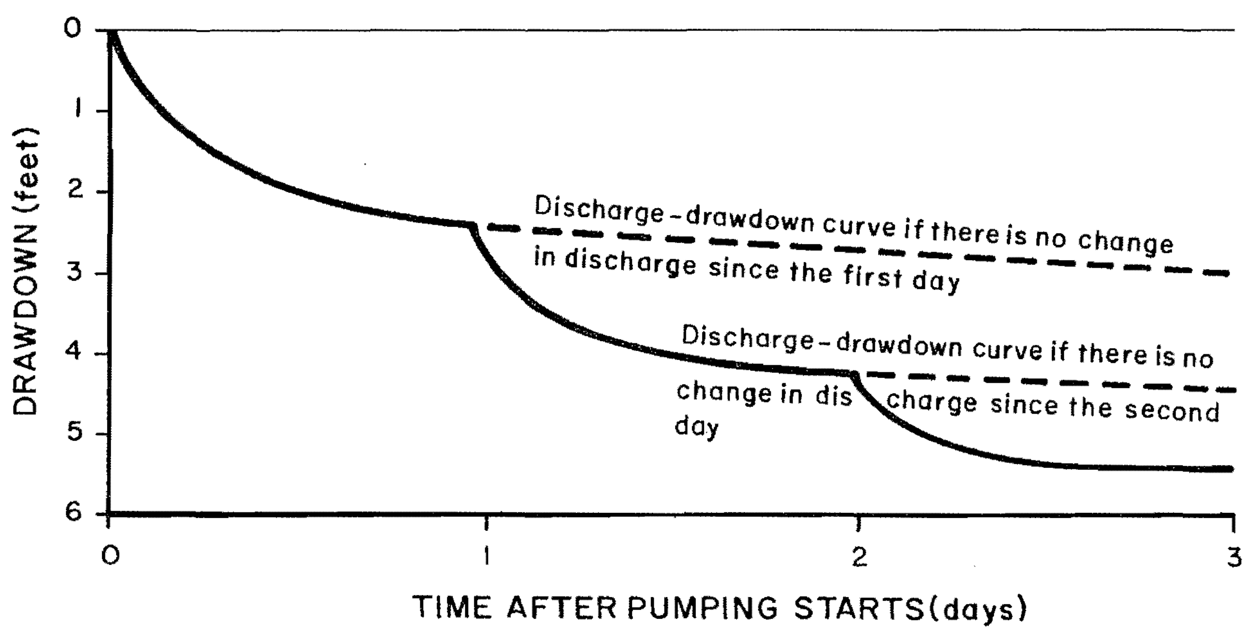

Figure 3. Discharge-drawdown curve for variable pumping case.

image wells is completed the stored value of drawdown is called and subtracted from the total sum of drawdowns caused by real and image wells. This process is repeated twice to find the effect of the system alone, and the effect of partial penetration alone.

Program options

Many options are used in this program to broaden the utility of the program. A full description of these options is given in the user's manual contained in Appendix A. Any number of runs (NCASES) with different parameters can be run sequentially in the same program execution. S.I. or foot-pound-second system of units can be used (JUNIT). Optional tabular output of the drawdown components (ITABLE) and tabular output of individual image and real well calculations (INDIV) is also available. A time unit option (ITUNT) makes an available choice of using days or minutes. Both cases of constant or variable discharge can be handled using the parameter ITMV. One or more time increments can be used to show the change of drawdown as time proceeds by using NTI option. Finally, an optional graph of drawdown vs. distance or drawdown vs. time is available using IPLOT option.

Output

All the equations of drawdown computations in this program use the F.P.S. system of units. If the input data is the S.I. system, then it is converted to the F.P.S. system for the calculations and the results are converted back into S.I. units. The conversion factors are given in Table 4.

Three type of output exist:

1. A basic tabular output of input data and results.
2. Two optional tabular outputs. The first one is for the individual processes of the program containing the coordinates of each image well and its contribution to total drawdown at a point of interest. The second one contains a breakdown of the drawdown components.
3. An optional graphical output of drawdown vs. log (time from the beginning of pumping) or drawdown vs. log (radius from the real well) in case of constant pumping rate. If variable pumping rate is used then a graph of drawdown vs. (time from the beginning of pumping) is drawn.

Examples of the program output are given in Appendix C.

Model Advantages

The purpose of this section is to explain the advantages of model and its practical field application. At this point, the reader should have an adequate understanding of the working of the model. Groundwater models serve as a means to understand the mechanism of groundwater resource in nature and to predict what might happen under various possible future conditions. So groundwater models are a very valuable tool in water resources planning.

Time saving

This model could save a lot of time in hand calculations to predict the drawdown in a well field, especially when the basin is a complex one with many wells, several barrier or recharge boundaries, and there is a variable discharge rate. The task of placing the input data in the required input format saves days or even weeks of longhand error-prone calculations. This capability for rapid calculation of drawdown under complex conditions will also make possible the examination of many alternative designs which would otherwise be impossible. Convenient tables of input data and results are provided by the program.

Education tool

This program with its associated tables are stored in a computer disk file which can be readily transfered to other computers. The program would be useful to students of groundwater in helping them develop a rapid feel for drawdown complicated groundwater systems and to enable them to perform sensitivity studies on wuch factors as hydraulic aquifer characteristics and different boundary conditions.

Groundwater contour map

It is possible to predict water table or piezometric surface maps in a simple or complex basin by using this model. The procedure is to make a run with enough points representing the region of interest to find the drawdown at each point as a result of pumping or recharge. Thus, the contour lines of equal heights of water table or piezometric surface can be drawn through these points.

Model contribution to agriculture

It is important in agriculture to have a permissible range of water table elevations. Maintaining the root zone in the soil with certain percentages of water and air is determined by two factors, soil properties and water table elevation. Using the model, it is possible to predict the water table elevation and then determine the amount and time for pumping so that the plant will not die neither because of wilting, nor because of extra amount of water in the soil pores. It is also possible to determine the schedule of irrigation for a permissible drawdown in the field in the daily, weekly or monthly basis as needed. This problem can be solved by the variable pumping rate case which is one of the most powerful part of this model.

Model contribution to industry

Water is as important in industry as in agriculture. Huge amounts of water are used in different industrial production processes. In some cases, the factories have their own wells to produce water. The amounts of water used in industry varies in each day, week, or month according to the period of working hours, days, or according to the rush production. Using the model helps in the drawdown prediction in the well field. A convenient table of pumping schedule can be easily prepared.

Groundwater recharge

Sometimes it is required to recharge a basin with water to compensate the drought periods. Injection well is one of several means to recharge the basin with water. The rise in the water table or piezometric surface can be computed in the model by specifying the well type in the input data as an injection or a discharging well. A combination of discharging and injection well systems in the basin, if exist, can be analyzed normally.

Construction dewatering

In the construction of building foundations below the water table it is necessary to lower the water table using wells around the periphery of the excavation so that work may be carried out in the dry. Using the model, systems of dewatering wells could be analyzed in an iterative design procedure to find the best layout to achieve the required lowering of the water table.

Model Limitations

Even when the model covers a variety of situations, it is constrained in its logic to some constraints. Sometimes, when the model is blocked to these constraints, there is an error message as an output.

1. Firstly, the model is constrained to a maximum of 15 points of interest, 15 wells, 4 boundaries, and 15 steps in variable discharge case. These numbers are within practical uses. These limitations can be changed simply by increasing the dimensions of the arrays, but then the program will become more expensive to run.

2. Another limitation is the geometric configuration of the boundaries (six kinds of configurations). These configurations, if violated, will result in an error message. In practical situations, the real world should be approximated to one of the six cases if possible.

3. Convergence limit of the drawdown is one of the most important limitations in the program if a pair of parallel boundaries exists. The existence of parallel boundaries will result in an infinite number of image wells. Practically, this number is determined so that the final image well contribution to the drawdown has a negligible effect. This

negligible effect is the value assigned to the convergence limit in the program logic. If a small convergence limit is assigned in the input data, a large number of image wells will result which causes an expensive run. Error message is given as a warning message if the number of image wells exceeds 1000 and the drawdown in the last image well is still more than the convergence limit.

4. The interpolation of well function from the stored tables in the files in the computer memory is done linearly. So the well function curves are approximated to straight lines between the nodal values of the tables. To have more accurate results, a large number of small increments should be used. Also if the point of interest is too close to the well or far away from it, the interpolating value becomes outside the table limitations.

5. In unsteady, water table variable discharge case, it is assumed that if the drawdown is within 10 percent of the aquifer thickness, then water is assumed to flow horizontally from the aquifer to the well and hence the principle of superposition is applied.

6. Some additional limitations arising from the structure of the computer program are:

a. Only one point of interest can be considered when dealing with more than one time increment in the constant discharge case.

b. Only one point of interest can be considered when dealing with more than one time increment in the variable discharge case.

c. Time must be expressed in fractions of a day and not hours or minutes in the variable discharge case.

CHAPTER IV

MODEL VERIFICATION AND APPLICATION

Many examples using different model options have been run and verified by hand calculation. These examples include all boundary types and configurations, aquifer types, equilibrium and nonequilibrium cases, constant and variable pumping cases, and the F.P.S. and S.I. system of units. Several of these cases are described below and example output and output may be found in Appendix C.

Model Verification

A set of selected cases from the above mentioned examples is described below. These examples cover the most important components of the model and are made up of various combinations which could be encountered in the field. Refer to Figure 2 for boundary configurations and Table 1 for the definition of drawdown cases used in these examples.

No boundaries and drawdown case 11

The drawdowns were calculated at a point of interest for four days of variable pumping rates from founr fully penetrating wells in an unconfined aquifer, under nonequilibrium conditions. The metric system of units was used. This run cost 11 cents.

Single boundary and drawdown case 7

The drawdown was calculated over two log cycles of time in days after the start of constant pumping, for a fully penetrating well in a leaky artesian aquifer without water released from storage in an aquitard under nonequilibrium condition. The graph option of drawdown vs. time was used. This run cost 32 cents.

Parallel pair of boundaries and drawdown case 9

Drawdown was calculated at the middle point between two parallel boundaries due to pumping at a constant rate from a fully penetrating well in a leaky artesian aquifer, with water released from storage in aquitard under nonequilibrium condition. Time is in minutes and the S.I. system of units were used. In this run, the tabulation of the individual contributions to drawdown from each real and image well was included. This run cost 19 cents.

90^{o} intersection of two boundaries and drawdown case 5

The drawdown was calculated at a point of interest due to four partially penetrating wells in an unconfined aquifer with various percentages of penetration at each well. The drawdown was calculated at four time increments under variable pumping conditions for the nonequilibrium case. The S.I. system of units was used. This run cost 15 cents.

Semiinfinite aquifer and drawdown case 4

Drawdown was calculated at 15 points of interest laying on a straight line. A fully penetrating well is located in a confined semiinfinite strip anisotropic aquifer. One of the boundaries is a recharge one while the parallel pair are of the barrier type. This run cost 15 cents. The S.I. system of units was used. The computer output in Appendix C includes a graph of drawdown vs. distance.

Two perpendicular parallel pairs of boundaries and drawdown case 1

The rise in the piezometric surface due to the injection of water via a fully penetrating well was calculated in a rectangular, confined aquifer under equilibrium conditions. This rectangular aquifer might represent a water storage basin. The S.I. system of units was used. This run cost 13 cents. The printout, including the tabulation of the individual contributions to drawdown from each real and image wells, is given in Appendix C.

Application to Well Spacing

Purpose

The problem of well spacing is a practical problem facing groundwater engineers. Two objectives should be satisfied in this problem, engineering feasibility and cost minimization. The amount of drawdown at any point of interest depends on the spacing of the wells and the distances between the observation point and the production wells. For a given aquifer and boundary configuration, there are many alternative well field designs, ranging from a small number of wells spaced far apart, and hence less well interference, to a larger number of wells with closer spacing. In the first case, the pipeline cost is more and the well drilling cost plus casing and maintenance cost is less than the second case. A design requirement is that the drawdown be limited and the design pumping rate be obtained. The criterion for selecting an alternative design is that it will have the minimum cost.

Problem statement

It is required to obtain a design discharge of 750 gpm in a well field to be located in a confined aquifer type (drawdown case 3) such that the drawdown in the most affected well is not more than 10.00 ± 0.15 feet to ensure artesian flow conditions and to minimize the installation and operation cost of the pumping unit. The wells should be located on a circumference of a circle, and the discharging water from these wells will be collected, by means of pipelines radiating from the center of the circle. There is a barrier boundary located 15,000 feet from the center of the circle. The following data are available (see Figure 4).

Permeability of the aquifer, k = 400 gpd/ft^2

Thickness of the aquifer, m = 120 ft

Coefficient of storage of the aquifer, S = 0.0005

Well loss constant, C_w = 0.00001

Well loss exponent, n = 1.75

Depth of each well = 150 ft

Maximum period of well system operation = 5 days

Cost of cementing each well = $200

Annual maintenance of each well = $200

Discount rate = 10%

Estimated life span for the wells and pipelines = 30 years

Annual maintenance for the pipelines = $0.

Cost of drilling wells with casing, the pipeline cost, and the permissible discharge for each diameter are given in Table 5 (personal communication with the well drilling companies in Logan, Utah 1980).

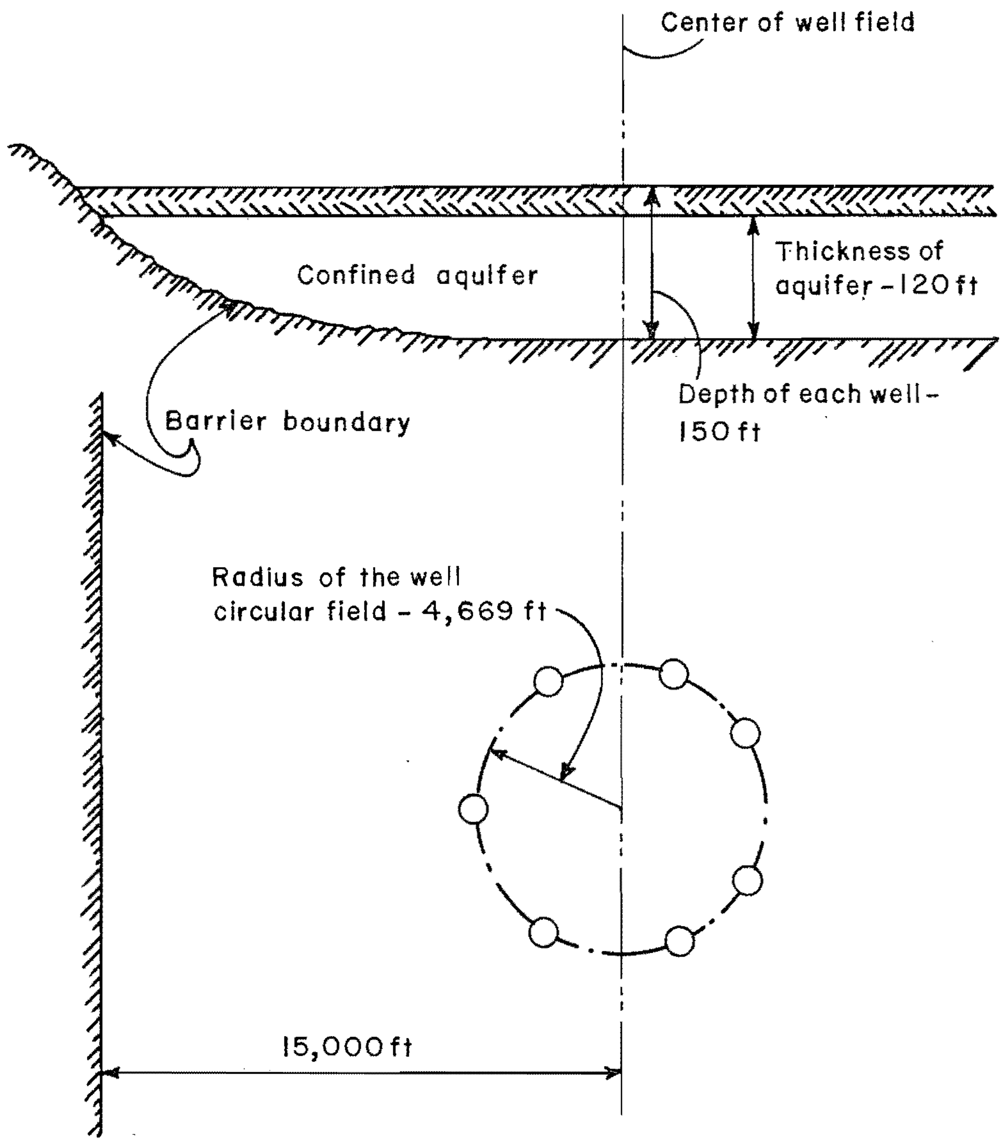

Figure 4. Plan and section of selected well field design.

Table 5. Cost and permissible discharge for various well diameters.

Well or pipe diameter (in.)	Drilling cost of well ($/ft)	Cost of pipeline ($/ft)	Permissible discharge (gpm)
6	21.00	3.00	100
8	24.00	4.30	200
10	32.00	5.25	400
12	39.00	6.25	600

The object of the problem is to design the most economical spacing of the well system.

<u>Solution</u>

The procedure to solve this problem begins by assuming a certain number of wells located on a circle circumference with an assumed radius. The discharge of each well is equal to the design discharge divided by the number of wells. The coordinates of each well are computed and a model run is performed to compute the drawdown at the well nearest to the barrier boundary. Well loss at the well is added to the total drawdown and the resultant drawdown is compared with the maximum permitted drawdown in the aquifer system. By varying the radius of the circular well field the radius at which the selected number of wells results in the maximum permissible drawdown is obtained. For each radius a new model run is made to compute drawdown at the well nearest the barrier boundary. As the radius is increased the interwell interference decreases, but the boundary interference increases in the wells located nearer to the boundary.

The next step is to assume some other numbers of wells and repeat the above procedure to obtain a maximum radius such that the constraint on maximum drawdown is still met.

The result is a set of alternative well field designs (see Table 6), each of which has approximately the same maximum amount of drawdown in the well nearest to the boundary and each of which has the same design discharge. Each alternative differes from the others by the number of wells and their spacing and therefore the cost of installation and maintenance. The total cost of each design is expressed as an equivalent annual amount. It is composed of the equivalent annual amount of all the wells and the connecting pipelines between the wells and the center of the well system circle, and the annual maintenance of the well system. No operation cost is required since no pumping is needed under artesian flow condition. Cost figures are also included in Table 6. The selected design is the one with minimum total cost. From Table 6 it can be seen that this design comprises 7 wells located around a circumference of a circle of 1600 feet diameter. The total annual cost is $4,669. The computer model output for some runs performed in this well spacing case study is included in Appendix C. The role of the computer model in this well field design problem is to define the feasible set of designs that satisfy the maximum drawdown condition.

Table 6. Economical analysis of alternative well field designs.

Number of wells	4	5	6	7	8	9	10
Total drawdown at the well (ft)	9.98	10.01	10.00	10.10	10.09	10.00	9.99
Discharge from each well (gpm)	187.50	150.00	125.00	107.10	93.70	83.30	74.00
Diameter of well (in)	8.00	8.00	8.00	6.00	6.00	6.00	6.00
Radius of center of wells (ft)	5,000	2,750	2,000	1,600	1,400	1,300	1,200
Total pipeline length (ft)	20,000	13,750	12,000	11,200	11,200	11,700	12,000
Total pipeline cost ($)	86,000	59,125	51,600	33,600	33,600	35,100	36,000
Cost of cementing all the wells ($)	800	1,000	1,200	1,400	1,600	1,800	2,000
Cost of drilling all the wells ($)	14,400	18,000	21,600	22,050	25,200	28,350	31,500
Capital investment cost ($)	101,200	78,125	74,400	57,050	60,400	65,250	69,500
Equivalent annual capital cost ($) (Based on 30 yr life, 10%)	5,800	4,477	4,264	3,269	3,461	3,740	3,983
Yearly maintenance ($)	800	1,000	1,200	1,400	1,600	1,800	2,000
Total annual cost	6,600	5,477	5,464	4,669	5,061	5,540	5,983

CHAPTER V

SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

The purpose of this chapter is to give a brief summary of the work, to list the conclusions from the study, and to give recommendations for further work which might continue the process of model improvement.

Summary

This study involves the computation of the drawdown in a well field as a result of removal or recharge of water. A total of eleven different aquifer hydraulic cases which are described in Walton (1970) and Bouwer (1978) have been included in the model.

The problem of a finite aquifer caused by the existence of hydraulic boundaries has been solved using image well theory as described by Ferris et al. (1962). Six cases of boundary configurations, barrier or recharge boundaries, or combinations of both, can be analyzed with this program.

Water table or piezometric surface profiles can be calculated with the model, and can be displayed as a graph of drawdown vs. distance by using many points of interest (up to 15 points) arranged on a straight line from the real well. Another graph option is available to show the change of the drawdown with time as pumping continues.

Frequently, many wells working simultaneously may exist in a well field. Up to 15 real wells (discharging or injection wells) with the well loss computation for each one can be treated by the model.

In addition to constant pumping rate case, a stepped pumping rate case can be analyzed in any of the aquifer, well, or boundary situations. A maximum of 15 time increments for the stepped pumping case can be used. These time increments should be equal in length. A fraction of a day can be used as a time increment. The change of drawdown in each time increment at one point of interest can be displayed on a graphical output but only days as a time unit is permitted in this case.

The drawdown components can be analyzed for each well at each point of interest or at each time increment. Four components have been considered: the effect of pumping from the well only, the effect of partial penetration of the well alone, the effect of the boundaries (if they exist) alone, and the effect of partial penetration by all the boundaries. The total effect of pumping on the drawdown is the sum of these four components.

To make the model more flexible, there is an option to use the S.I. or F.P.S. system of units. Another option is to use a time unit in minutes or days except in the variable pumping case when days must be used.

The output is in a tabular form with a graphical option. The drawdown components table is option. There is another optional output which shows the calculation of drawdown for each image well. Care should be taken in using this option especially if a pair of parallel boundaries exist in the problem because it can become quite voluminous.

A number of error messages are included in the program to inform the user of incorrect input data or violations of the program limitations.

Conclusions

The following conclusions were reached based on the program performance.

1. Convergence limit (CONV). Theoretically, the number of image wells in the case of a pair of parallel boundaries should extend to infinity. A convergence limit (CONV) is assigned by the user to truncate the series of image wells when the drawdown contribution from the latest image well is less than the convergence limit. The affect of changing the convergence limit to the accuracy of results and cost of running depends on the nature of the problem to be solved. In some cases, changing the convergence limit neither changed the accuracy of results nor the cost of running. In other cases, reducing CONV from 0.05 to 0.01 feet, for example, increase the accuracy to $\pm$ 0.025 feet while the cost of running increased by 20 percent. Sometimes in the cases of interpolating the well function from their tables, a little change in CONV will cause the interpolating values to be outside the table bounds.

2. Interpolation error. The effect of linear interpolation from the well function tables cause a small negligible error. This interpolation error in most cases is less than 5 percent than the interpolation from the well function curves.

3. Time until steady state condition achieved. The time at which steady state flow conditions are reduced can be determined using the model by running the unsteady state case with many time increments until the increase in the pumping period has no effect on the amount of drawdown.

4. Factors affecting well spacing. From running the well spacing example, it was found that the cost of the connecting pipeline has more affect on well spacing than the cost of drilling the wells. The cost of yearly maintenance of the well system is very sensitive to the well spacing.

5. Cost of running and compilation of the model. The cost of compiling the program is about $4.50 on the Burroughs B6800 computer. The cost of storing the program in a computer disk plus the cost of storing the well function tables in the files is about $5.50 per month. The cost of running different cases depends on the nature of the problem itself. The cost of running the case study increases with decreases in the convergence limit, and with increases in the number of boundaries, well boundaries, points of interest, and stages in the varible pumping case. The cost of each run is given in each example and ranges from 11¢ to 32¢. These costs are the night computer costs which are 10 percent of the usual daytime costs.

Recommendations

Nothing is complete in the real world because we are human beings. The recent knowledge is built on the previous knowledge and so for the future knowledge. This study needs to be continued, and there are several recommendations for future work.

1) The boundary geometry is limited to six regular cases of boundaries in this model. In the real world the boundaries are located in irregular shapes and curves. Introducing the capability for analyzing well fields defined by such boundary configurations would be a useful addition.

2) Another recommendation is to solve cases 5 through 11 (see Table 1) analytically without using the well function tables and an interpolation procedure.

3) It would also be useful to add the sloping water table situation to the program.

4) A capability for obtaining the drawdown at many points of interest during many time intervals should be included in the model.

5) The model can be adapted to utilize any pumping schedule which might be proposed or used in the field.

6) A graph plotting subroutine can be added to plot drawdown vs time and distance or vs two distances axes.

7) The well spacing analysis described in Chapter IV could be included as a separate subroutine to avoid the current trial and error procedure which involves many separate computer runs.

8) Convert the program to be interactive.

9) A groundwater contour map subroutine should be added to the model.

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APPENDICES

APPENDIX A

Model Component

1. Model flow chart
2. Program listing
3. Variable Dictionary

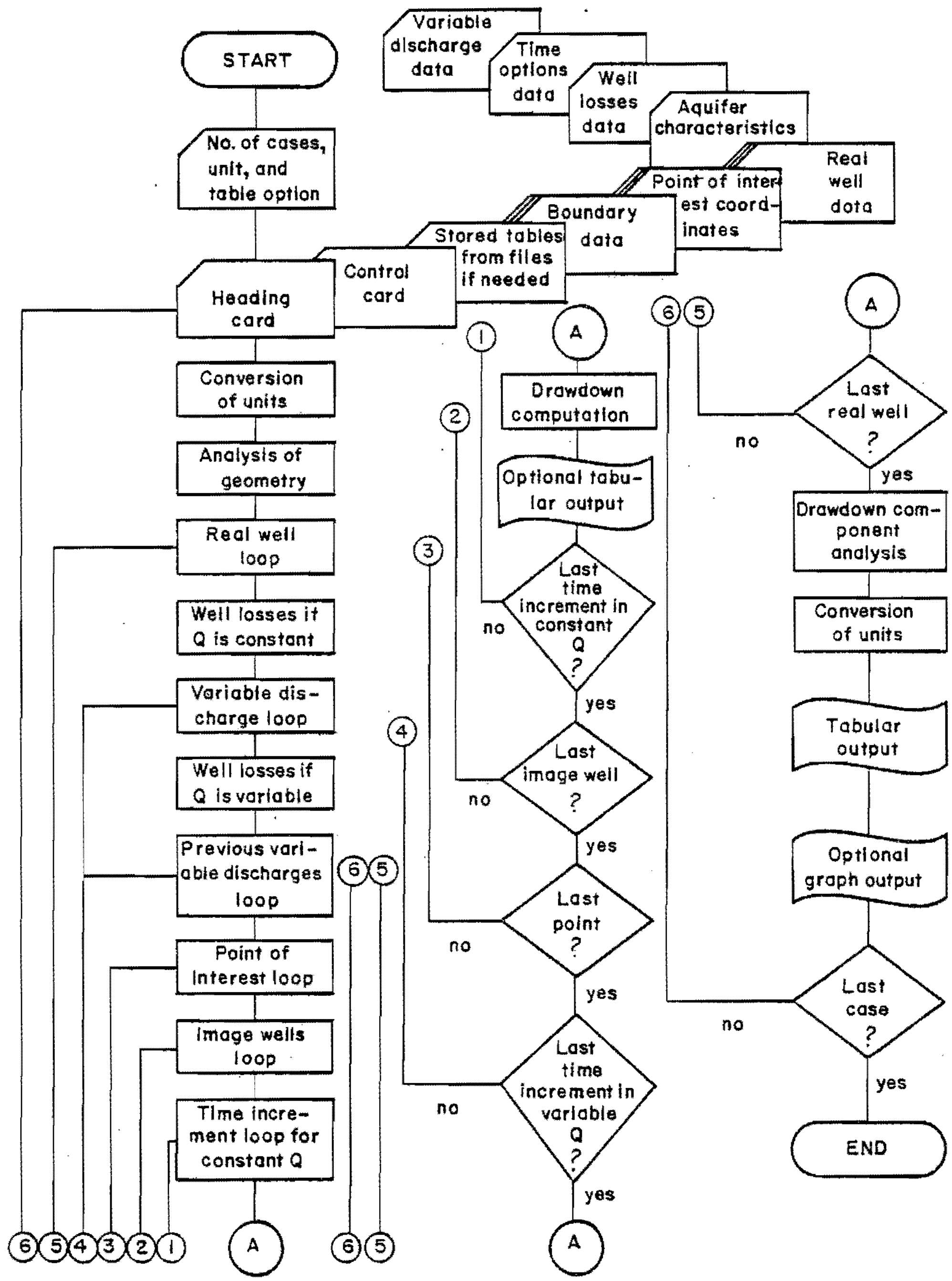


Figure A.1. Model flow chart.

Program listing.

```
FILE  10(KIND=DISK,TITLE="TABLE",FILETYPE=7)
FILE  11(KIND=DISK,TITLE="TABLE1",FILETYPE=7)
FILE  12(KIND=DISK,TITLE="TABLE2",FILETYPE=7)
FILE  13(KIND=DISK,TITLE="TABLE3",FILETYPE=7)
FILE  14(KIND=DISK,TITLE="TABLE4",FILETYPE=7)


      COMMON/BDS/DM(4),C(4),BTYPE(4),TH(4),NBNDS
     1/PTS/XP(45),YP(45)
     2/WELL/XW(15),YW(15),WTYPE(15),QCONST(15),RADI(15),NWELLS,WW
     3/GEOM/KINT(3,2),KPARA(2,2),KSING,NSING,NINT,NPARA
     4/HYDR/PERM,THCK,CST,HO,SY,WBAR,SBAR,PBAR,ALFA,ALFTWT,TIMT
     5/IMWL/XI(1000),YI(1000),TYPI(1000),QDIF(15)
     6/INDX/O,IP,IW,JJ,JJ1,JJ2,NIMGS,NERR,TI2,TII,NTI,ISMAX,ITUNT
     7/CONT/KPROB,PI,SCONV(2),L(30),CONV,JUNIT,IVV,IM,IRK
     8/OUT/TITLE(20),X(100),Y(100),Z(100),Q(25,11),GAMA(15),TWT
     9/ANIS/XX,YY,TXY,TXX,TYY,NLOG,ITMV,TINC,ITV,TIME(15),QVAR(15,15)
     1/TABL/M(12),N(12),T(300,15),V(75,15),W(65,65,12),WF(300,15)
     2/WLOS/CW(15),WN(15),SEE(15),SE(15,15),YTOT(15,45),ITABLE
     3/WTBL/YWO(15,45),YPN(15,45),YWB(15,45),YPB(15,45),YSP(45),SPTOT

      DIMENSION YW1(15,45),YP1(15,45),YW2(15,45),YP2(15,45),YTOT3(15,45)
      DIMENSION XM(1000),YM(1000)

 500  FORMAT(1X,'    ',F8.1,'    ',F8.1,'    ',F3.0,4X,'    ',F7.1,'    ',F7.
     11,'    ',F4,2)
 501  FORMAT(3X,'        ',I4,'          ',I5,'          ',I5,'          ',I2,'
     1    ',F5.2,2I2)
 502  FORMAT(3X,'    ',F7.1,'    ',F7.1,'    ',F3.0,4X,'    ',F7.1,'    ',F7.
     11,'    ',F4,2)
 503  FORMAT(3X,'        ',E8.2,'          ',F5.0,'          ',E8.2,'      ',F10.4)
 504  FORMAT(1H1,'ERROR NO ',I2)
 509  FORMAT(20A4)
 550  FORMAT(1H1,///,8X,'CONTRIBUTIONS TO TOTAL DRAWDOWN AT POINT OF INT
     1EREST NO',I3,/,8X,'BY REAL WELL NO',I3,' AND ITS ASSOCIATED IMAGE
     2WELL SYSTEM',/,8X,'WITH A DISCHARGE OF ',F7.2,' GPM')
 551  FORMAT(///,8X,'NO   TYPE   X COORD   Y COORD    RADIUS  TIME  DRAW
     1DOWN  CUMULATIVE',/,66X,'DRAWDOWN')
 552  FORMAT(1H ,14X,3(8X,'FT'),4X,'DAYS',5X,'FT',9X,'FT')
 553  FORMAT(1H ,14X,3(8X,'FT'),4X,'MINS',5X,'FT',9X,'FT')
 554  FORMAT(1H0,5X,I4,'   REAL',F9.1,F10.1,F9.1,1X,F8.2,2(3X,F7.3))
 555  FORMAT(1H0,5X,I4,'  IMAGE',F9.1,F10.1,F9.1,1X,F8.2,2(3X,F7.3))
 556  FORMAT(// ,44X,'TOTAL CONTRIBUTION',4X,F7.3)
 557  FORMAT(1H0,5X,I4,'   REAL',F9.1,F10.1,F9.1,'   EQUIM',2(3X,F7.3))
 558  FORMAT(1H0,5X,I4,'  IMAGE',F9.1,F10.1,F9.1,'   EQUIM',2(3X,F7.3))
 559  FORMAT(3X,'        ',E8.2,'          ',E8.2,'          ',E8.2,'      ',E8.2)
 560  FORMAT(3X,'        ',E8.2,'          ',F5.0,'          ',E8.2,'      ',F4.2)
 561  FORMAT(4X,'   ',E8.2,'          ',F5.0,'          ',E8.2,'      ',F5.0,'
     1        ',E8,2)
 562  FORMAT(4X,'   ',E8.2,'          ',F5.0,'          ',E8.2,'      ',F5.0,'
     1        ',E8.2,'       ',E8.2)
 563  FORMAT(4X,'   ',E8.2,'          ',F5.0,'          ',E8.2,'      ',E8.2,'
     1        ',F10.5)
 564  FORMAT(1H1,///,8X,'CONTRIUTION TO TOTAL DRAWDOWN AT TIME INCREMENT
     1 NO',I3,/,8X,'BY REAL WELL NO',I3,' AND ITS ASSOCIATED IMAGE WELL
     2SYSTEM',/,8X,'WITH A DISCHARGE OF ',F7.2,' GPM')
 565  FORMAT(1H1,///,8X,'CONTRIBUTIONS TO TOTAL DRAWDOWN AT POINT OF INT
     1EREST NO',I3,/,8X,'BY REAL WELL NO',I3,' AND ITS ASSOCIATED IMAGE
     2WELL SYSTEM',/,8X,'WITH A DISCHARGE OF ',F7.2,' CM/D')
 566  FORMAT(1H ,14X,3(8X,'MT'),4X,'DAYS',5X,'MT',9X,'MT')
 567  FORMAT(1H ,14X,3(8X,'MT'),4X,'MINS',5X,'MT',9X,'MT')
 568  FORMAT(1H1,///,8X,'CONTRIUTION TO TOTAL DRAWDOWN AT TIME INCREMENT
     1 NO',I3,/,8X,'BY REAL WELL NO',I3,' AND ITS ASSOCIATED IMAGE WELL
     2SYSTEM',/,8X,'WITH A DISCHARGE OF ',F7.2,' CM/D')

C *** COMPUTATION OF DRAWDOWN USING IMAGE WELL THEORY
C      APPLIED TO HYDROGEOLOGIC BOUNDARIES

      READ(5,/)NCASES,JUNIT,ITABLE
      DO 300 ICASE=1,NCASES

C  ** INITIALISE
      NNP=0
      PI=22./7.
      TI=1.
      ITUNT=0
      NTI=1
      TI2=1.
      IDELT=1
      NINT=0
      NPARA=0
      NSING=0
      TIME(1)=0.
      NIMGS=1
      DO 3 ISP=1,36
 3    Y(ISP)=0.
      DO 7 IL=1,2
      DO 5 IPARA=1,2
 5    KPARA(IPARA,IL)=0
      DO 7 IINT=1,3
 7    KINT(IINT,IL)=0
      DO 8 IS=1,15
 8    YSP(IS)=0.
      DO 9 I=1,30
 9    L(I)=I

C  ** INPUT

C   * HEADING
      READ(5,509)(TITLE(I),I=1,20)

.C   * CONTROL CARD
      READ(5,501)NBNDS,NPNTS,NWELLS,KPROB,CONV,INDIV,IPLOT

C *** READ WELL FUNCTION TABLES FROM THE STORED FILES IF NEEDED

      IF(KPROB.LE.4) GO TO 91
      READ(10,/)(M(J),J=1,10),(N(I),I=1,11)
      READ(11,/)((T(I,K),I=1,N(K)),K=1,11)
      READ(12,/)((V(I,K),I=1,M(K)),K=1,10)
      READ(13,/)(((W(I,J,K),I=1,M(K)),J=1,N(K)),K=1,9)
      READ(14,/)((WF(I,K),I=1,N(K)),K=10,11)
```

```
 91   IF(NBNDS,GT,4)GO TO 100
      IF(NPNTS,GT,25)GO TO 100
      IF(NWELLS,LT,15)GO TO 105
 100  NERR=1
      GO TO 400
 105  IF(CONV,LT,0,0000001)CONV=0,01
C   * BOUNDARY DATA

      IF(NBNDS,EQ,0)GOTO 13
      DO 10 IB=1,NBNDS
      READ(5,502)TH(IB),C(IB),BTYPE(IB)
      IF(JUNIT,EQ,1) C(IB)=C(IB)*3,281
      DO 11 NA=1,4
      NAM=NA-1
      IF(TH(IB),EQ,(NAM*90,))GOTO 14
 11   CONTINUE
      TA=TH(IB)*PI/180.
      GO TO 12
 14   TA=0.
 12   DM(IB)=TAN(TA)
 10   CONTINUE

C   * POINT OF INTEREST COORDINATES
 13   DO 15 IP=1,NPNTS
      READ(5,502)XP(IP),YP(IP)
      IF(JUNIT,EQ,1) XP(IP)=XP(IP)*3,281
      IF(JUNIT,EQ,1) YP(IP)=YP(IP)*3,281
 15   CONTINUE

C   * REAL WELL DATA
      DO 20 IW=1,NWELLS
      READ(5,500)XW(IW),YW(IW),WTYPE(IW),QCONST(IW),RADI(IW),DAMA(IW)

C   * AQUIFER CHARACTERISTICS AND CHANGING OF UNITS
      IF(JUNIT.EQ.1) QCONST(IW)=QCONST(IW)*0,18345
      IF(JUNIT.EQ,1) XW(IW)=XW(IW)*3,281
      IF(JUNIT.EQ.1) YW(IW)=YW(IW)*3,281
      IF(JUNIT.EQ.1) RADI(IW)=RADI(IW)*3,281
 20   CONTINUE

      IF(KPROB.LT,4) READ(5,503)PERM,THCK,CST,HO
      IF(KPROB.EQ,4)READ(5,559)TXX,TYY,TXY,CST
      IF(KPROB.EQ.5 ,OR,KPROB,EQ,6)READ(5,560)PERM,THCK,CST
      IF(KPROB.EQ.7.OR.KPROB.EQ.8.OR.KPROB.EQ.10) READ(5,561)PERM,THCK,C
     1ST,HBAR,PBAR
      IF(KPROB.EQ.9)READ(5,562)PERM,THCK,CST,HBAR,PBAR,SBAR
      IF(KPROB.EQ.11) READ(5,563)PERM,THCK,CST,SY,ALFA
      READ(5,/)((CW(IW),WN(IW)),IW=1,NWELLS)

      IF(JUNIT.EQ.1) CONV=CONV*3,281
      IF(JUNIT.EQ.1) HO=HO*3,281
      IF(JUNIT.EQ.1) THCK=THCK*3,281
      IF(JUNIT.EQ.1) HBAR=HBAR*3,281
      IF(JUNIT.EQ.1) TXX=TXX*2,28
      IF(JUNIT.EQ.1) TYY=TYY*2,28
      IF(JUNIT.EQ.1) TXY=TXY*2,28
      IF(JUNIT.EQ.1) PERM=PERM*0,695
      IF(JUNIT.EQ.1) PBAR=PBAR*0,695

      READ(5,/)NTI,ITUNT,TI,NLOG,IDELT,ITMV,TINC
      IF(ITUNT,NE.1,OR .ITMV.EQ.0) GO TO 23
      NERR=2
      WRITE(6,504) NERR

      GO TO 400

 23   IF(ITMV,NE.0)READ(5,/)((QVAR(IW,ITV),IW=1,NWELLS),ITV=1,ITMV+1)
      IF(ITMV,EQ,0) GO TO 22
      IF(JUNIT,NE,1,AND,ITMV,NE.0) GO TO 22
      DO 21 KJ=1,NWELLS
      DO 21 KI=1,ITMV+1
 21   QVAR(KJ,KI)=QVAR(KJ,KI)*0,18345
 22   IF(NLOG,GT,3)NLOG=3
      IF(ITUNT,EQ,1) TI=TI/1440.
      TI1=TI
      IF(IDELT.EQ.0)IDELT=1
      TI2=TI
      IF(NTI,GT,1,AND,ITMV,EQ,0) TI2=9*(10**NLOG)
      IF(ITMV.EQ.0.AND,NPNTS,GT.1,AND,NTI,EQ.1) GO TO 25
      IF(ITMV,EQ,0.AND,NPNTS.EQ.1.AND,NTI,GT.1) GO TO 25
      IF(ITMV,EQ.0.AND,NPNTS.EQ.1.AND,NTI,EQ,1) GO TO 25
      IF(ITMV.GT.0.AND,NPNTS.EQ.1.AND,NTI,GT,1) GO TO 25
      NERR=3
      GOTO 400

C  ** ANALYSIS OF BOUNDARY GEOMETRY AND CHECK FOR COMPLIANCE WITH
C     FERRIS LIMITATIONS

C   * SEPARATE NO BOUNDARY CASE
 25   IF(NBNDS,EQ,0)GOTO 45

C   * SINGLE BOUNDARY CASE
      IF(NBNDS,NE,1)GO TO 26
      NSING=1
      KSING=1
      GO TO 45

C   * FIND PARALLEL PAIRS OF BOUNDARIES
 26   DO 30 IB1=1,(NBNDS-1)
      DO 30 IB2=(IB1+1),NBNDS
      IF(TH(IB1),NE,TH(IB2))GO TO 30
      NPARA=NPARA+1
      KPARA(NPARA,1)=IB1
      KPARA(NPARA,2)=IB2
      GO TO(45,27,30),(NBNDS-1)
 30   CONTINUE

      IF(NPARA.EQ,2)GOTO 43
      GO TO(31,33,39),(NBNDS-1)

C   * ONE PARALLEL PAIR AND SINGLE BOUNDARY CASE
 27   NSING=1
      DO 29 IB=1,3
      IF(IB,EQ,KPARA(1,1))GOTO 29
      IF(IB,EQ,KPARA(1,2))GOTO 29
      KSING=IB
      GOTO 34
 29   CONTINUE

C   * 2 NON-PARALLEL BOUNDARIES - 1 INTERSECTION
 31   NINT=1
      KINT(1,1)=1
```

```
      KINT(1,2)=2
      GO TO 40

C   * 3 NON-PARALLEL BOUNDARIES - 3 INTERSECTIONS
 33   NINT=3
      KINT(1,1)=1
      KINT(1,2)=2
      KINT(2,1)=1
      KINT(2,2)=3
      KINT(3,1)=2
      KINT(3,2)=3
      GO TO 40

C   * CHECK SINGLE BOUNDARY PERPENDICULAR TO PARALLEL PAIR
 34   THDIF=IFIX(TH(KPARA(1,1))-TH(KSING))
      IF(ABS(THDIF).EQ.90)GOTO 45
      NERR=4
      GO TO 400

C   * 4 BOUNDARIES MUST BE 2 PARALLEL PAIRS
 39   NERR=5
      GO TO 400

C   * CHECK INTERSECTION ANGLES COMPLY WITH FERRIS LIMITATIONS
 40   DO 42 IINT=1,NINT
      NN=1
      IF(BTYPE(KINT(IINT,1)).EQ.BTYPE(KINT(IINT,2)))NN=2
      THDIF=ABS(TH(KINT(IINT,1))-TH(KINT(IINT,2)))
      IF(THDIF.GT.90.)THDIF=180.-THDIF
      THD=NN*90./THDIF
      ITHD=IFIX(THD)
      AITHD=FLOAT(ITHD)
      IF((THD-AITHD).LT.0.000001)GO TO 42
      NERR=6
      GO TO 400

 42   CONTINUE
      GO TO 45

C   * CHECK 2 PAIRS OF PARALLEL LINES PERPENDICULAR
 43   THDIF=IFIX(TH(KPARA(1,1))-TH(KPARA(2,1)))
      IF(ABS(THDIF).EQ.90)GOTO 45
      NERR=7
      GO TO 400

C  ** GENERATION OF IMAGE WELLS

 45   DO 85 IW=1,NWELLS

C  *  WELL LOSSES IN CONSTANT PUMPING CASE
      IF(ITMV.EQ.0) SEE(IW)=CW(IW)*(QCONST(IW)**WN(IW))

C *** COMPUTATION OF DRAWDOWN IN CASE OF VARIABLE DISCHARGE

      DO 99 ITV=2,ITMV+1
      IF(ITMV.EQ.0) GO TO 47
      DO 46 IM=1,15
      DO 46 IR=1,15
      YM1(IM,IR)=0.
      YP1(IM,IR)=0.
      YM2(IM,IR)=0.
      YP2(IM,IR)=0.
 46   YTOT3(IM,IR)=0.
 47   STOT=0.
      SPTOT=0.
      IVV=ITV-1

C  *  WELL LOSSES IN VARIABLE PUMPING CASE
      IF(ITMV.NE.0) SE(IW,ITV)=CW(IW)*(QVAR(IW,ITV)**WN(IW))
      IF(ITMV.NE.0)QDIF(ITV-1)=QVAR(IW,ITV)-QVAR(IW,ITV-1)
      TIME(ITV)=TIME(ITV-1)+TINC

      DO 99 III=1,ITV-1
      IF(ITMV.NE.0)TI=TINC*(ITV-III)
      IF(ITMV.NE.0)QCONST(IW)=QDIF(III)
      TI2=TI
      JJ=1
      JJ1=0
      JJ2=0
      NIMGS=1
      XI(JJ)=XW(IW)
      YI(JJ)=YW(IW)
      TYPI(JJ)=WTYPE(IW)

C   * INTERSECTIONS BETWEEN 2 BOUNDARIES
      IF(NINT.EQ.0)GO TO 55
      DO 50 IINT=1,NINT
      CALL INTERS(IINT)
 50   CONTINUE

C   * PARALLEL PAIRS OF BOUNDARIES
 55   IF(NPARA.EQ.0)GO TO 65
      DO 60 IPARA=1,NPARA
      IF(IPARA.EQ.1)GO TO 59
      DO 57 J=JJ1,JJ2
 57   CALL PARALL(IPARA,J)
 59   CALL PARALL(IPARA,1)
 60   CONTINUE

C   * SINGLE BOUNDARY
 65   IF(NSING.EQ.0)GO TO 75
      IF(JJ1.EQ.0)GO TO 73
      DO 70 J=JJ1,JJ2
 70   CALL REFLEC(DH(KSING),TH(KSING),C(KSING),BTYPE(KSING),J)
 73   CALL REFLEC(DH(KSING),TH(KSING),C(KSING),BTYPE(KSING),1)

C  ** COMPUTE DRAWDOWN FOR NPNTS POINTS OF INTEREST

 75   DO 98 IP=1,NPNTS
      IF(ITMV.NE.0) GO TO 79
      DO 76 IM=1,15
      DO 76 IR=1,15
      YM1(IM,IR)=0.
      YP1(IM,IR)=0.
      YM2(IM,IR)=0.
      YP2(IM,IR)=0.
 76   YTOT3(IM,IR)=0.

 79   IF(ITMV.EQ.0) STOT=0.
      IF(ITMV.EQ.0) SPTOT=0.
      IF(INDIV.NE.1)GOTO 78
      IF(ITV.NE.2.AND.III.NE.1) GO TO 78
```

```
      IF(JUNIT.EQ.1.AND.ITHV.NE.0) QVAR(IW,ITV)=QVAR(IW,ITV)/0.18345
      IF(JUNIT.EQ.1.AND.ITHV.EQ.0) QCONST(IW)=QCONST(IW)/0.18345
      IF(ITHV.EQ.0.AND.JUNIT.NE.1) WRITE(6,550) IP,IW,QCONST(IW)
      IF(ITHV.EQ.0.AND.JUNIT.EQ.1) WRITE(6,565) IP,IW,QCONST(IW)
      IF(ITHV.NE.0.AND.JUNIT.NE.1) WRITE(6,564) IVV,IW,QVAR(IW,ITV)
      IF(ITHV.NE.0.AND.JUNIT.EQ.1) WRITE(6,568) IVV,IW,QVAR(IW,ITV)
      IF(JUNIT.EQ.1.AND.ITHV.EQ.0) QCONST(IW)=QCONST(IW)*0.18345
      IF(JUNIT.EQ.1.AND.ITHV.NE.0) QVAR(IW,ITV)=QVAR(IW,ITV)*0.18345
      WRITE(6,551)
      IF(ITUNT.NE.1.AND.JUNIT.NE.1) WRITE(6,552)
      IF(ITUNT.EQ.1.AND.JUNIT.NE.1) WRITE(6,553)
      IF(ITUNT.NE.1.AND.JUNIT.EQ.1) WRITE(6,566)
      IF(ITUNT.EQ.1.AND.JUNIT.EQ.1) WRITE(6,567)

C    * COMPUTE DRAWDOWN CONTRIBUTION BY WELL JJ
 78   DO 80 JJ=1,NIMGS

      XX=ABS(XP(IP)-XI(JJ))
      YY=ABS(YP(IP)-YI(JJ))
      R=SQRT((XP(IP)-XI(JJ))**2+(YP(IP)-YI(JJ))**2)
      IF(R.GT.0.000001)GOTO 77
      NERR=8
      GOTO 400

C *** COMPUTATION OF DRAWDOWN AS TIME VARIES

 77   DO 90 IND=1,(NLOG+1)
      DO 90 ITT=1,9,IDELT
      IF(NTI.EQ.1.OR.ITHV.NE.0) GO TO 101
      TI=ITT*(10**(IND-1))
      TII=TI
      STOT=0.
      SPTOT=0.
      DO 74 IM=1,15
      DO 74 IR=1,45
      YW1(IM,IR)=0.
      YP1(IM,IR)=0.
      YW2(IM,IR)=0.
      YP2(IM,IR)=0.
 74   YTOT3(IM,IR)=0.

 101  IF(TI.NE.0.) GO TO 84
      NERR=9
      GOTO 400

 84   CALL DRAWDO(R,TI,S)
      IF(KPROB.NE.5) GO TO 87
      KPROB=6
      CALL DRAWDO(R,TI,SP)
      KPROB=5

 87   IF(NTI.GT.1.AND.ITHV.EQ.0) IS=ITT+(IND-1)*9
      IF(NTI.GT.1.AND.ITHV.EQ.0) X(IS)=TII
      IF(NTI.EQ.1.AND.ITHV.EQ.0) IS=IP
      IF(NTI.EQ.1.AND.ITHV.EQ.0) X(IS)=R
      IF(NTI.GT.1.AND.ITHV.NE.0) IS=IVV
      IF(NTI.GT.1.AND.ITHV.NE.0) X(IS)=TIME(ITV)
      IF(NTI.EQ.1.AND.NPNTS.EQ.1.AND.ITHV.EQ.0) IS=1

      STOT=STOT+S
      Y(IS)=Y(IS)+S
      ISMAX=IS
      YSP(IS)=YSP(IS)+SP
      SPTOT=SPTOT+SP

C *** DRAWDOWN COMPONENTS
      IF(JJ.EQ.1) YW1(IW,IS)=STOT-SPTOT
      IF(JJ.EQ.1) YP1(IW,IS)=SPTOT
      IF(JJ.EQ.NIMGS) YW2(IW,IS)=STOT-YW1(IW,IS)-SPTOT
      IF(JJ.EQ.NIMGS) YP2(IW,IS)=SPTOT-YP1(IW,IS)
      IF(JJ.EQ.NIMGS) YTOT3(IW,IS)=YW1(IW,IS)+YP1(IW,IS)+YW2(IW,IS)+YP2(
     1IW,IS)

      IF(JJ.NE.NIMGS) GO TO 88
      YWO(IW,IS)=YW1(IW,IS)
      YPN(IW,IS)=YP1(IW,IS)
      YWB(IW,IS)=YW2(IW,IS)
      YPB(IW,IS)=YP2(IW,IS)
      YTOT(IW,IS)=YTOT3(IW,IS)

 88   IF(ITHV.NE.0)TII=TIME(ITV)
      IF(JUNIT.EQ.1) XM(JJ)=XI(JJ)/3.281
      IF(JUNIT.EQ.1) YM(JJ)=YI(JJ)/3.281
      IF(JUNIT.EQ.1) RM=R/3.281
      IF(JUNIT.EQ.1) SM=S/3.281
      IF(JUNIT.EQ.1) SMTOT=STOT/3.281
      IF(ITUNT.EQ.1) TII=TI*1440.
      IF(INDIV.NE.1)GOTO 86
      IF(KPROB.EQ.3.OR.KPROB.EQ.4.OR.KPROB.EQ.5.OR.KPROB.EQ.6.OR.KPROB.E
     1Q.7.OR.KPROB.EQ.9.OR.KPROB.EQ.11) GO TO 81
      IF(JJ.EQ.1.AND.JUNIT.NE.1) WRITE(6,557)JJ,XI(JJ),YI(JJ),R,S,STOT
      IF(JJ.NE.1.AND.JUNIT.NE.1) WRITE(6,558)JJ,XI(JJ),YI(JJ),R,S,STOT
      IF(JJ.EQ.1.AND.JUNIT.EQ.1) WRITE(6,557)JJ,XM(JJ),YM(JJ),RM,SM,SMTO
     1T
      IF(JJ.NE.1.AND.JUNIT.EQ.1) WRITE(6,558)JJ,XM(JJ),YM(JJ),RM,SM,SMTO
     1T
      GOTO 86
 81   IF(JJ.EQ.1.AND.JUNIT.NE.1) WRITE(6,554)JJ,XI(JJ),YI(JJ),R,TII,S,ST
     1OT
      IF(JJ.NE.1.AND.JUNIT.NE.1) WRITE(6,555)JJ,XI(JJ),YI(JJ),R,TII,S,ST
     1OT
      IF(JJ.EQ.1.AND.JUNIT.EQ.1) WRITE(6,554)JJ,XM(JJ),YM(JJ),RM,TII,SM,
     1SMTOT
      IF(JJ.NE.1.AND.JUNIT.EQ.1) WRITE(6,555)JJ,XM(JJ),YM(JJ),RM,TII,SM,
     1SMTOT
 86   IF(ITUNT.EQ.1)TII=TI/1440.
      IF(NTI.EQ.1.OR.ITHV.NE.0) GO TO 80
 90   CONTINUE
 80   CONTINUE
      IF(ITHV.EQ.0.AND.INDIV.EQ.1.AND.JUNIT.EQ.1) WRITE(6,556)SMTOT
      IF(ITHV.EQ.0.AND.INDIV.EQ.1.AND.JUNIT.NE.1) WRITE(6,556)STOT
      IF(ITHV.NE.0.AND.INDIV.EQ.1.AND.ITV.EQ.ITHV+1.AND.III.EQ.ITV-1.AND
     1.JUNIT.EQ.1) WRITE(6,556) SMTOT
      IF(ITHV.NE.0.AND.INDIV.EQ.1.AND.ITV.EQ.ITHV+1.AND.III.EQ.ITV-1.AND
     1.JUNIT.NE.1) WRITE(6,556) STOT
 98   CONTINUE
      IF(ITHV.EQ.0) GO TO 85
 99   CONTINUE
 85   CONTINUE
      IF(ITUNT.EQ.1) TII=TI*1440.
```

```
C   **. OUTPUT
       CALL OUTPUT

C    * PLOTTED OUTPUT
       IF(IPLOT.NE.1)GOTO 120

 125   IF(ITHV.EQ.0) XMIN=ALOG10(X(1))
       IF(ITHV.EQ.0) XMAX=ALOG10(X(1))
       IF(ITHV.NE.0) XMIN=X(1)
       IF(ITHV.NE.0) XMAX=X(1)
       DO 135 IS=1,ISMAX
       IF(ITHV.EQ.0) X(IS)=ALOG10(X(IS))
       IF(X(IS).LT.XMIN)XMIN=X(IS)
       IF(X(IS).GT.XMAX)XMAX=X(IS)
 135   CONTINUE

 130   YMIN=Y(1)
       YMAX=Y(1)
       DO 140 IS=2,ISMAX
       IF(Y(IS).LT.YMIN)YMIN=Y(IS)
       IF(Y(IS).GT.YMAX)YMAX=Y(IS)
 140   CONTINUE

       DO 145 IS=1,ISMAX
 145   Z(IS)=YMIN-5.
       CALL GRAPH(TITLE,X,Y,ISMAX,Z,XMIN,XMAX,YMIN,YMAX,1)

 120   CONTINUE

       GOTO 300

C   ** ERROR MESSAGES
 400   WRITE(6,504)NERR

 300   CONTINUE
       END
```

```
      SUBROUTINE INTERS(IINT)

      COMMON/BOS/DH(4),C(4),BTYPE(4),TH(4),NBNDS
     1/PTS/XP(45),YP(45)
     2/WELL/XW(15),YW(15),WTYPE(15),QCONST(15),RADI(15),NWELLS,NW
     3/GEOM/KINT(3,2),KPARA(2,2),KSING,NSING,NINT,NPARA
     4/HYDR/PERM,THCK,CST,HO,SY,HBAR,SBAR,PBAR,ALFA,ALFTWT,TIMT
     5/IMHL/XI(1000),YI(1000),TYPI(1000),QDIF(15)
     6/INDX/D,IP,IW,JJ,JJ1,JJ2,NIMGS,NERR,TI2,TII,NTI,ISMAX,ITUNT
     7/CONT/KPROB,PI,SCONV(2),L(30),CONV,JUNIT,IVV,IH,IRK
     8/OUT/TITLE(20),X(100),Y(100),Z(100),Q(25,11),GAMA(15),TWT
     9/ANIS/XX,YY,TXY,TXX,TYY,NLOG,ITHV,TINC,ITV,TIME(15),QVAR(15,15)
     1/TABL/M(12),N(12),T(300,15),V(75,15),W(65,65,12),WF(300,15)
     2/WLOS/CW(15),WN(15),SEE(15),SE(15,15),YTOT(15,45),ITABLE
     3/WTBL/YWO(15,45),YPN(15,45),YWB(15,45),YPB(15,45),YSP(45),SPTOT

C   ** THIS SUBROUTINE CONTROLS THE REFLECTION PROCESS IN THE CASE OF
C                                            INTERSECTING BOUNDARIES

      THDIF=ABS(TH(KINT(IINT,1))-TH(KINT(IINT,2)))
      IF(THDIF.GT.90.)THDIF=180.-THDIF
      NR=IFIX((360./THDIF)-1.)
      JJJ=1
      DO 10 IR =1,NR
      IF(IR.NE.1)JJJ=JJ
      IL=((1+(-1)**IR)/2)+1
      CALL REFLEC(DH(KINT(IINT,IL)),TH(KINT(IINT,IL)),C(KINT(IINT,IL)),
     1BTYPE(KINT(IINT,IL)),JJJ)

 10   CONTINUE

      RETURN

      END
```

```
      SUBROUTINE PARALL(IPARA,J)

      COMMON/BDS/DH(4),C(4),BTYPE(4),TH(4),NBNDS
     1/PTS/XP(45),YP(45)
     2/WELL/XW(15),YW(15),WTYPE(15),QCONST(15),RADI(15),NWELLS,WW
     3/GEOM/KINT(3,2),KPARA(2,2),KSING,NSING,NINT,NPARA
     4/HYDR/PERM,THCK,CST,HO,SY,HBAR,SBAR,PBAR,ALFA,ALFTWT,TIMT
     5/IMWL/XI(1000),YI(1000),TYPI(1000),QDIF(15)
     6/INDX/O,IP,IW,JJ,JJ1,JJ2,NIMGS,NERR,TI2,TI1,NTI,ISMAX,ITUNT
     7/CONT/KPROB,PI,SCONV(2),L(30),CONV,JUNIT,IVY,IH,IRK
     8/OUT/TITLE(20),X(100),Y(100),Z(100),Q(25,11),GAMA(15),TWT
     9/ANIS/XX,YY,TXY,TXX,TYY,NLOG,ITHY,TINC,ITV,TIME(15),QVAR(15,15)
     1/TABL/M(12),N(12),T(300,15),V(75,15),W(65,65,12),WF(300,15)
     2/WLOS/CW(15),WN(15),SEE(15),SE(15,15),YTOT(15,45),ITABLE
     3/WTBL/YWO(15,45),YPN(15,45),YWB(15,45),YPB(15,45),YSP(45),SPTOT

C  ** THIS SUBROUTINE CONTROLS THE REFLECTION PROCESS IN THE CASE OF
C                                                 PARALLEL BOUNDARIES
 504  FORMAT(1H1,'ERROR NO',I2)
      DO 5 IPR=1,2
      JJJ=J
      IF(JJ1.EQ.0)JJ1=JJ+1
      IR=0
 1    IR=IR+1
      IF(IR.NE.1)JJJ=JJ
      IPP=IR+1*(IPR-1)
      IL=((1+(-1)**IPP)/2)+1
      CALL REFLEC(DM(KPARA(IPARA,IL)),TH(KPARA(IPARA,IL)),C(KPARA(IPARA,
     1IL)),BTYPE(KPARA(IPARA,IL)),JJJ)

C   * CALCULATION OF RMIN
      DO 20 IP=1,NPNTS
      XX=ABS(XP(IP)-XI(JJ))
      YY=ABS(YP(IP)-YI(JJ))
      R=SQRT((XI(JJ)-XP(IP))**2.+(YI(JJ)-YP(IP))**2.)
      IF(R.GT.0.000001)GOTO 15
      NERR=8
      WRITE(6,504)NERR
      STOP

 15   IF(IP.EQ.1)RMIN=R
      IF(R.LT.RMIN)RMIN=R
 20   CONTINUE
      CALL DRAWDO(RMIN,TI2,S)
      IF(ABS(S).LT.CONV)GO TO 5
      GO TO 1

 5    CONTINUE
      IF(JJ2.EQ.0)JJ2=JJ

      RETURN

      END
```

```
      SUBROUTINE REFLEC(DMH,TTH,CC,BBTYPE,J)

      COMMON/BDS/DH(4),C(4),BTYPE(4),TH(4),NBNDS
     1/PTS/XP(45),YP(45)
     2/WELL/XW(15),YW(15),WTYPE(15),QCONST(15),RADI(15),NWELLS,WW
     3/GEOM/KINT(3,2),KPARA(2,2),KSING,NSING,NINT,NPARA
     4/HYDR/PERM,THCK,CST,HO,SY,HBAR,SBAR,PBAR,ALFA,ALFTWT,TIMT
     5/IMWL/XI(1000),YI(1000),TYPI(1000),QDIF(15)
     6/INDX/O,IP,IW,JJ,JJ1,JJ2,NIMGS,NERR,TI2,TI1,NTI,ISMAX,ITUNT
     7/CONT/KPROB,PI,SCONV(2),L(30),CONV,JUNIT,IVY,IH,IRK
     8/OUT/TITLE(20),X(100),Y(100),Z(100),Q(25,11),GAMA(15),TWT
     9/ANIS/XX,YY,TXY,TXX,TYY,NLOG,ITHY,TINC,ITV,TIME(15),QVAR(15,15)
     1/TABL/M(12),N(12),T(300,15),V(75,15),W(65,65,12),WF(300,15)
     2/WLOS/CW(15),WN(15),SEE(15),SE(15,15),YTOT(15,45),ITABLE
     3/WTBL/YWO(15,45),YPN(15,45),YWB(15,45),YPB(15,45),YSP(45),SPTOT

C *** THIS SUBROUTINE REFLECTS A WELL ABOUT A BOUNDARY

 504  FORMAT(1H1,'ERROR NO',I2)

      JJ=JJ+1
      IF(JJ.LE.1000)GOTO 5
      NERR=10
      WRITE(6,504)NERR
      STOP

C  ** SEPARATE CASE WHEN BOUNDARIES ARE PARALLEL TO COORDINATE AXES
 5    DO 1 NA=1,4
      NAM=NA-1
      IF(TTH.EQ.(NAM*90))GO TO 10
 1    CONTINUE

C  ** EVALUATION OF COORDINATES OF IMAGE WELL
      DK=YI(J)+XI(J)/DMH
      GRADF=DMH**2.+1.
      XI(JJ)=(2.*((DMH**2.)*DK+CC)/GRADF)-XI(J)
      YI(JJ)=(-2.*DMH*(CC-DK)/GRADF)-YI(J)
      GO TO 25

 10   GO TO (15,20,15,20),NA
C   * 0 AND 180 DEG. CASE
 15   XI(JJ)=XI(J)
      YI(JJ)=2*CC-YI(J)
      GO TO 25

C   * 90 AND 270 DEG. CASE
 20   XI(JJ)=2*CC-XI(J)
      YI(JJ)=YI(J)

C  ** EVALUATION OF TYPE OF IMAGE WELL
 25   TYPI(JJ)=BBTYPE*TYPI(J)
      NIMGS=JJ

      RETURN

      END
```

```
      SUBROUTINE DRAWDO(R,TI,S)

      COMMON/BDS/DH(4),C(4),BTYPE(4),TM(4),NBNDS
     1/PTS/XP(45),YP(45)
     2/WELL/XW(15),YW(15),WTYPE(15),QCONST(15),RADI(15),NWELLS,WW
     3/GEOM/KINT(3,2),KPARA(2,2),KSING,NSING,NINT,NPARA
     4/HYDR/PERM,THCK,CST,HO,SY,HBAR,SBAR,PBAR,ALFA,ALFTMT,TIMT
     5/IMWL/XI(1000),YI(1000),TYPI(1000),QDIF(15)
     6/INDX/O,IP,IW,JJ,JJ1,JJ2,NIMOS,NERR,TI2,TII,NTI,ISMAX,ITUNT
     7/CONT/KPROB,PI,SCONV(2),L(30),CONV,JUNIT,IVV,IM,IRK
     8/OUT/TITLE(20),X(100),Y(100),Z(100),Q(25,11),GAMA(15),TMT
     9/ANIS/XX,YY,TXY,TXX,TYY,NLOG,ITMV,TINC,ITV,TIME(15),QVAR(15,15)
     1/TABL/H(12),N(12),T(300,15),V(75,15),W(65,65,12),WF(300,15)
     2/WLOS/CW(15),WN(15),SEE(15),SE(15,15),YTOT(15,45),ITABLE
     3/WTBL/YWO(15,45),YPN(15,45),YWB(15,45),YPB(15,45),YSP(45),SPTOT

C *** THIS SUBROUTINE EVALUATES DRAWDOWN AT POINT OF INTEREST
C  * ASSUMING CONSTANT DISCHARGE AND FULLY PENETRATING WELLS
C     EXCEPT IN CASE NUMBER 5 OR NUMBER 6
C     THE CONSTANT 40,783 IN THE FIRST TWO CASES IS TO CHANGE THE UNITS

 504  FORMAT(1H1,'ERROR NO ',I2)

      GO TO (1,2,3,3,6,6,7,8,9,8,11),KPROB

C  ** STEADY STATE , CONFINED AQUIFER

 1    DD=40,783*QCONST(IW)/(2,*PI*PERM*THCK)
      RR=RADI(IW)/R
      S=DD*ALOG(RR)*TYPI(JJ)
      GO TO 4

C  ** STEADY STATE , WATER TABLE AQUIFER

 2    RR=RADI(IW)/R
      XX=40,783*QCONST(IW)/(PI*PERM)*ALOG(RR)
      IF((HO**2-XX).GT.0.)GOTO 5
      NERR=11
      WRITE(6,504)NERR
      STOP

 5    H=SQRT(HO**2,-XX)
      S=(HO-H)*TYPI(JJ)
      GO TO 4

C  ** UNSTEADY STATE , CONFINED AQUIFER

 3    IF(KPROB,EQ,4) GO TO 12
      DD=QCONST(IW)*114,6/(PERM*THCK)
      U=1,87*(R**2,)*CST/(PERM*THCK*TI)
      GO TO 13
 12   DD=QCONST(IW)*114,6/SQRT(TXX*TYY-TXY**2,)
      U=1,87*CST*(TXX*YY**2,+TYY*XX**2,-2,*TXY*XX*YY)/(TI*(TXX*TYY-TXY**
     12,))
 13   SERIE1=DD*(-0,5772-ALOG(U))
C   * DO FOR EXPANSION OF EXPONENTIAL INTEGRAL
      DO 10 K=1,100
      FACT=1,
      DO 14 I=1,K
 14   FACT=FACT*I
      TERM=((-1,)**(K+1))*(U**K)/(K*FACT)
      SERIE2=SERIE1+DD*TERM
      IF(ABS(SERIE2-SERIE1).LT.CONV)GOTO 20
      SERIE1=SERIE2
 10   CONTINUE
      NERR=12
      WRITE(6,504)NERR
      STOP

 20   S=SERIE2*TYPI(JJ)
      GO TO 4

C  ** UNSTEADY STATE , CONFINED AQUIFER ,PARTIALLY PENETRATING WELLS
C   * TOTAL EFFECT AND EFFECT OF PENETRATION ALONE

 6    UT=1,87*(R**2,)*CST/(PERM*THCK*TI)
      RB=R/THCK
      IF(KPROB.EQ.5.AND.GAMA(IW).EQ.0.75) CALL INTRP2(UT,RB,I,J,1)
      IF(KPROB.EQ.5.AND.GAMA(IW).EQ.0.50) CALL INTRP2(UT,RB,I,J,2)
      IF(KPROB.EQ.5.AND.GAMA(IW).EQ.0.25) CALL INTRP2(UT,RB,I,J,3)
      IF(KPROB.EQ.6.AND.GAMA(IW).EQ.0.25) CALL INTRP2(UT,RB,I,J,4)
      IF(KPROB.EQ.6.AND.GAMA(IW).EQ.0.50) CALL INTRP2(UT,RB,I,J,5)
      IF(KPROB.EQ.6.AND.GAMA(IW).EQ.0.75) CALL INTRP2(UT,RB,I,J,6)
      S=114,6*QCONST(IW)*WW*TYPI(JJ)/(PERM*THCK)
      GO TO 4

C **  UNSTEADY STATE , LEAKY CONFINED AQUIFER WITHOUT WATER RELEASED
C  *  FROM STORAGE IN AQUITARD

 7    UT=1,87*(R**2,)*CST/(PERM*THCK*TI)
      RB=R/SQRT(PERM*THCK*HBAR/PBAR)
      CALL INTRP2(UT,RB,I,J,7)
      S=114,6*QCONST(IW)*WW*TYPI(JJ)/(PERM*THCK)
      GO TO 4

C **  STEADY STATE , LEAKY CONFINED AQUIFER
C  *  WITH AND WITHOUT WATER RELEASED FROM STORAGE IN AQUITARD

 8    RB=R/SQRT(PERM*THCK*HBAR/PBAR)
      CALL INTRP1(RB,1,10)
      S=229,*QCONST(IW)*WW*TYPI(JJ)/(PERM*THCK)
      GO TO 4

C **  UNSTEADY STATE , LEAKY CONFINED AQUIFER WITH WATER RELEASED FROM
C  *  STORAGE IN AQUITARD

 9    UT=1,87*(R**2,)*CST/(PERM*THCK*TI)
      SI=0,25*R*SQRT(SBAR*PBAR/(PERM*THCK*CST*HBAR))
      UDBAR=1,87*(R**2,)*CST*(1+SBAR)/(PERM*THCK*TI*3,*CST)
      RB=R/SQRT(PERM*THCK*HBAR/PBAR)
      TIMT1=0,27*HBAR*SBAR/PBAP
      TIMT2=HBAR*SBAP/(10,8*PBAR)
      IF(TI.GE.TIMT1) CALL INTRP2(UDBAR,RB,I,J,7)
      IF(TI.LE.TIMT2) CALL INTRP2(UT,SI,I,J,8)
      IF(TI.GE.TIMT1.OR.TI.LE.TIMT2) GO TO 15
      CALL INTRP2(UDBAR,RB,I,J,7)
```

```
      WW1=WW
      CALL INTRP2(UT,SI,I,J,8)
      WW2=WW
      WW=WW1+(WW2-WW1)*(TI-TIMT1)/(TIMT2-TIMT1)
15    S=114.6*QCONST(IW)*WW*TYPI(JJ)/(PERM*THCK)
      GO TO 4

C **  UNSTEADY STATE , WATER TABLE AQUIFER

11    B=SQRT(PERM*THCK/(ALFA*SY*7.48))
      RB=R/B
      CALL INTRP3(RB,I,11)
      TWT=ALFTWT/ALFA
      UA=0.25*(R**2.)*CST*7.48/(PERM*THCK*TI)
      UY=0.25*(R**2.)*SY*7.48/(PERM*THCK*TI)
      IF(TI.LE.TWT) GO TO 30
      DO 40 J=1,23
40    V(J,K)=V(J,K)/10000.
30    IF(TI.LE.TWT)CALL INTRP2(UA,RB,I,J,9)
      IF(TI.GT.TWT)CALL INTRP2(UY,RB,I,J,9)
      S=114.6*QCONST(IW)*WW*TYPI(JJ)/(PERM*THCK)
      RATIO=S/THCK
      IF(RATIO.LE.0.1.OR .ITMV.EQ.0) GO TO 4
      NERR=13
      WRITE(6,504) NERR
      STOP

4     RETURN

       END
```

```
      SUBROUTINE INTRP1(UT,I,K)

       COMMON/BDS/DH(4),C(4),BTYPE(4),TH(4),NBNDS
     1/PTS/XP(45),YP(45)
     2/WELL/XW(15),YW(15),WTYPE(15),QCONST(15),RADI(15),NWELLS,WW
     3/GEOM/KINT(3,2),KPARA(2,2),KSING,NSING,NINT,NPARA
     4/HYDR/PERM,THCK,CST,HO,SY,HBAR,BBAR,PBAR,ALFA,ALFTWT,TIMT
     5/IMWL/XI(1000),YI(1000),TYPI(1000),QDIF(15)
     6/INDX/O,IP,IW,JJ,JJ1,JJ2,NIMGS,NERR,TI2,TI1,NTI,ISMAX,ITUNT
     7/CONT/KPROB,PI,SCONV(2),L(30),CONV,JUNIT,IVV,IM,IRK
     8/OUT/TITLE(20),X(100),Y(100),Z(100),Q(25,11),GAMA(15),TWT
     9/ANIS/XX,YY,TXY,TXX,TYY,NLOG,ITMV,TINC,ITV,TIME(15),QVAR(15,15)
     1/TABL/H(12),N(12),T(300,15),V(75,15),W(65,65,12),WF(300,15)
     2/WLOG/CH(15),WN(15),SEE(15),SE(15,15),YTOT(15,45),ITABLE
     3/WTBL/YWD(15,45),YPN(15,45),YWB(15,45),YPB(15,45),YSP(45),SPTOT

C *** THIS SUBROUTINE INTERPOLATES THE VALUE OF WELL FUNCTION
C  *  IN ONE DIMENSIONAL ARRAY TABLES

 504  FORMAT(1H1,'ERROR NO ',I2)
      IF(UT.LT.T(1,K) .OR. UT.GT.T(N(K),K)) GO TO 25
      IF(UT.EQ.T(1,K)) GO TO 10
      DO 5 I=2,N(K)
      IF (UT.EQ.T(I,K)) GO TO 15
      IF(UT.LT.T(I,K)) GO TO 20
 5    CONTINUE
 10   WW=WF(1,K)
      GO TO 30
 15   WW=WF(I,K)
      GO TO 30
 20   WW=WF(I-1,K)+(WF(I,K)-WF(I-1,K))*(UT-T(I-1,K))/(T(I,K)-T(I-1,K))
      GO TO 30
 25   NERR=15
      WRITE(6,*/)T(1,K),UT,T(N(K),K)
      WRITE(6,504) NERR
      STOP

 30   RETURN
      END
```

```
      SUBROUTINE INTRP2(UT,RB,I,J,K)

      COMMON/BOS/DH(4),C(4),BTYPE(4),TH(4),NBNDS
     1/PTS/XP(45),YP(45)
     2/WELL/XW(15),YW(15),WTYPE(15),QCONST(15),RADI(15),NWELLS,WW
     3/GEOM/KINT(3,2),KPARA(2,2),KSING,NSING,NINT,NPARA
     4/HYDR/PERM,THCK,CST,HO,SY,HBAR,BBAR,PBAR,ALFA,ALFINT,TIMT
     5/IMWL/XI(1000),YI(1000),TYPI(1000),QDIF(15)
     6/INDX/O,IP,IW,JJ,JJ1,JJ2,NIMGS,NERR,TI2,TI1,NTI,ISMAX,ITUNT
     7/CONT/KPROB,PI,SCONV(2),L(30),CONV,JUNIT,IVV,IH,IRK
     8/OUT/TITLE(20),X(100),Y(100),Z(100),Q(25,11),GAMA(15),THT
     9/ANIS/XX,YY,TXY,TXX,TYY,NLOG,ITMV,TINC,ITV,TIME(15),QVAR(15,15)
     1/TABL/M(12),N(12),T(300,15),V(75,15),W(65,65,12),WF(300,15)
     2/WLOS/CW(15),WN(15),SEE(15),SE(15,15),YTOT(15,45),ITABLE
     3/WTBL/YWO(15,45),YPN(15,45),YWB(15,45),YPB(15,45),YSP(45),SPTOT

C *** THIS SUBROUTINE INTERPOLATES THE VALUE OF WELL FUNCTION
C  *  IN TWO DIMENSIONAL ARRAY TABLES

 504  FORMAT(1H1,'ERROR NO ',I2)
      IF(UT.LT.V(1,K).OR .UT.GT.V(M(K),K))GO TO 101
      IF(RB.LT.T(1,K).OR. RB.GT.T(N(K),K))GO TO 101
      IF(UT.EQ. V(1,K).AND. RB .EQ. T(1,K))GO TO 102
      DO 1001 J=2,N(K)
      IF(RB.LT. T(J,K).AND. UT .EQ. V(1,K))GO TO 103
      IF(RB.EQ. T(J,K).AND. UT .EQ. V(1,K))GO TO 104
 1001 CONTINUE
      DO 1002 I=2,M(K)
      IF(UT.LT. V(I,K).AND. RB .EQ. T(1,K))GO TO 105
      IF(UT.EQ. V(I,K).AND. RB .EQ. T(1,K))GO TO 106
 1002 CONTINUE
      DO 10 J=2,N(K)
      DO 10 I=2,M(K)
      IF(UT.LT. V(I,K).AND. RB .LT. T(J,K))GO TO 107
      IF(UT.EQ. V(I,K).AND. RB .EQ. T(J,K))GO TO 108
      IF(UT.LT. V(I,K).AND. RB .EQ. T(J,K))GO TO 109
      IF(UT.EQ. V(I,K).AND. RB .LT. T(J,K))GO TO 110
 10   CONTINUE
 101  NERR=14
      WRITE(6,504) NERR
      WRITE(6,*/)T(1,K),RB,T(N(K),K)
      WRITE(6,*/)V(1,K),UT,V(M(K),K)
      STOP

      GO TO 111
 102  WW=W(1,1,K)
      GO TO 111
 103  WW=W(1,J-1,K)+(W(1,J,K)-W(1,J-1,K))*(RB-T(J-1,K))/(T(J,K)-T(J-1,K)
     1)
      GO TO 111
 104  WW=W(1,J,K)
      GO TO 111
 105  WW=W(I-1,1,K)+(W(I,1,K)-W(I-1,1,K))*(UT-V(I-1,K))/(V(I,K)-V(I-1,K)
     1)
      GO TO 111
 106  WW=W(I,1,K)
      GO TO 111
 107  W1=W(I-1,J-1,K)+(W(I-1,J,K)-W(I-1,J-1,K))*(RB-T(J-1,K))/(T(J,K)-T(
     1J-1,K))
      W2=W(I,J-1,K)+(W(I,J,K)-W(I,J-1,K))*(RB-T(J-1,K))/(T(J,K)-T(J-1,K)
     1)
      WW=W1+(W2-W1)*(UT-V(I-1,K))/(V(I,K)-V(I-1,K))
      GO TO 111
 108  WW=W(I,J,K)
      GO TO 111
 109  WW=W(I-1,J,K)+(W(I,J,K)-W(I-1,J,K))*(UT-V(I-1,K))/(V(I,K)-V(I-1,K)
     1)
      GO TO 111
 110  WW=W(I,J-1,K)+(W(I,J,K)-W(I,J-1,K))*(RB-T(J-1,K))/(T(J,K)-T(J-1,K)
     1)
 111  RETURN
      END
```

```
      SUBROUTINE INTRP3(UT,I,K)

      COMMON/BDS/DH(4),C(4),BTYPE(4),TH(4),NBNDS
     1/PTS/XP(45),YP(45)
     2/WELL/XW(15),YW(15),WTYPE(15),QCONST(15),RADI(15),NWELLS,WW
     3/GEOM/KINT(3,2),KPARA(2,2),KSING,NSING,NINT,NPARA
     4/HYDR/PERM,THCK,CST,HO,SY,HBAR,SBAR,PBAR,ALFA,ALFTWT,TIMT
     5/IMWL/XI(1000),YI(1000),TYPI(1000),QDIF(15)
     6/INDX/O,IP,IW,JJ,JJ1,JJ2,NIMGS,NERR,TI2,TI1,NTI,ISMAX,ITUNT
     7/CONT/KPROB,PI,SCONV(2),L(30),CONV,JUNIT,IVY,IM,IRK
     8/OUT/TITLE(20),X(100),Y(100),Z(100),Q(25,11),GAMA(15),TWT
     9/ANIS/XX,YY,TXY,TXX,TYY,NLOG,ITMV,TINC,ITV,TIME(15),QVAR(15,15)
     1/TABL/M(12),N(12),T(300,15),V(75,15),W(65,65,12),WF(300,15)
     2/WLOS/CW(15),WN(15),SEE(15),SE(15,15),YTOT(15,45),ITABLE
     3/WTBL/YWO(15,45),YPN(15,45),YWB(15,45),YPD(15,45),YSP(45),SPTOT

C***  THIS SUBROUTINE INTERPOLATES THE VALUE OF TIME FROM THE GRAPH
C  *  THE VALUE OF (R/B)

 504  FORMAT(1H1,'ERROR NO ',I2)
      IF(UT.LT.T(1,K).OR.UT.GT.T(N(K),K)) GO TO 25
      IF(UT.EQ.T(1,K)) GO TO 20
      DO 5 I=1,N(K)
      IF(UT.EQ.T(I,K)) GO TO 15
      IF(UT.GT.T(I,K)) GO TO 5
      GO TO 10
 5    CONTINUE
 10   ALFTWT=(WF(I,K)-WF(I-1,K))*(UT-T(I-1,K))/(T(I,K)-T(I-1,K))+WF(I-1,
     1K)
      GO TO 30
 15   ALFTWT=WF(I,K)
      GO TO 30
 20   ALFTWT=WF(1,K)
      GO TO 30
 25   NERR=16
      WRITE(6,504) NERR
      WRITE(6,*/)T(1,K),UT,T(N(K),K)
      STOP

 30   RETURN
      END
```

```
      SUBROUTINE OUTPUT

      COMMON/BDS/DH(4),C(4),BTYPE(4),TH(4),NBNDS
     1/PTS/XP(45),YP(45)
     2/WELL/XW(15),YW(15),WTYPE(15),QCONST(15),RADI(15),NWELLS,WW
     3/GEOM/KINT(3,2),KPARA(2,2),KSING,NSING,NINT,NPARA
     4/HYDR/PERM,THCK,CST,HO,SY,HBAR,SBAR,PBAR,ALFA,ALFTWT,TIMT
     5/IMWL/XI(1000),YI(1000),TYPI(1000),QDIF(15)
     6/INDX/O,IP,IW,JJ,JJ1,JJ2,NIMGS,NERR,TI2,TI1,NT1,ISMAX,ITUNT
     7/CONT/KPROB,PI,SCONV(2),L(30),CONV,JUNIT,IVY,IM,IRK
     8/OUT/TITLE(20),X(100),Y(100),Z(100),Q(25,11),GAMA(15),TWT
     9/ANIS/XX,YY,TXY,TXX,TYY,NLOG,ITMV,TINC,ITV,TIME(15),QVAR(15,15)
     1/TABL/M(12),N(12),T(300,15),V(75,15),W(65,65,12),WF(300,15)
     2/WLOS/CW(15),WN(15),SEE(15),SE(15,15),YTOT(15,45),ITABLE
     3/WTBL/YWO(15,45),YPN(15,45),YWB(15,45),YPD(15,45),YSP(45),SPTOT

      DIMENSION TIMU(2),TYPW(2),TYPB(2)

C ***  THIS SUBROUTINE PRODUCES TABULAR OUTPUT OF PROBLEM DETAILS

      DOUBLE PRECISION TYPW,TIMU,TYPB
      DATA TYPW/12HDISCHARGE   ,12HRECHARGE    /
      DATA TYPB/12HRECHARGE    ,12HBARRIER     /
      DATA TIMU/8H (DAYS) ,8H (MINS) /

 10   FORMAT(1H1///8H*****   ,20A4/8X,20A4)
 11   FORMAT(///30X,24H** CONVERGENCE LIMIT = ,F5.2,8H FT.  **/)
 12   FORMAT(///31H  ***   AQUIFER CHARACTERISTICS/8X,23H--------------
     1---------)
 13   FORMAT(//12X,13HPERMEABILITY ,18X,F8.0,9H GPD/FTSQ)
 14   FORMAT(1H0,11X,33HDEPTH TO UNDISTURBED WATER TABLE ,F6.0,3H FT)
 15   FORMAT(1H0,11X,21HTHICKNESS OF AQUIFER ,12X,F6.0,3H FT)
 16   FORMAT(1H0,11X,23HCOEFFICIENT OF STORAGE ,15X,E8.3)
 17   FORMAT(///19H  ***   BOUNDARIES /8X,10H----------//11X,3HNO.,4X,10
     1HANGLE WITH,5X,9HINTERCEPT 5X,8HBOUNDARY/17X,13HX-AXIS (DEG.),6X,4
     2H(FT),8X,4HTYPE/)
 18   FORMAT(/11X,I2,8X,F4.0,8X,3HY= ,F7.1,4X,A12)
 19   FORMAT(///20H   **   ANALYSIS OF GEOMETRY/8X,20H-----------------
     1--)
 20   FORMAT(//11X,20HNUMBER OF SINGLES = ,6X,I1,5X,//11X,25HNUMBER OF I
     1NTERSECTONS = ,I2,//11X,22HNUMBER OF PARALLELS = ,4X,I1)
 21   FORMAT(//'  ***  REAL WELL DATA'/7X,'---------------'/7X,'NO. X-AXI
     1S  Y-AXIS   WELL',5X,'RADIUS OF  PENETRA-  WELL LOSS  EXPONENT'/12
     2X,'(FT)    (FT)    TYPE   INFLUENCE(FT)  TION    CONSTANT'/)
 22   FORMAT(1H1///'  ***  PUMPING RATES AND WELL LOSSES'/7X,'----------
     1--------------------'/)
 23   FORMAT(1H0,10X,I2,4X,F6.0,4X,F6.0,5X,A12,3X,F7.0,8X,F6.0,10X,F6.2,
     110X,F5.2)
 24   FORMAT(1H1,/47H *** TABULATION OF DRAWDOWN AT EACH TIME PERIOD/5X,
     141H-----------------------------------------///10X,33H( POINT OF I
     2NTEREST :  X-COORD = ,F7.0,2X,9HY-COORD =,F8.0,2H )///10X,10HTIME
     3AFTER,11X,11HDRAWDOWN AT/9X,14HPUMPING STARTS,5X,17HPOINT OF INTER
     4EST)
 25   FORMAT(1H ,12X,A8,16X,4H(FT))
```

```
26    FORMAT(1H0,14X,F6.0,13X,F6.2)
27    FORMAT(1H1,//53H *** TABULATION OF DRAWDOWN AT EACH POINT OF INTER
     1EST/5X,55H-------------------------------------------------------      )
28    FORMAT(1H0,14X,18HPOINTS OF INTEREST,7X,8HDRAWDOWN/21X,4H(FT),16X,
     14H(FT))
29    FORMAT(1H0,9X,3HNO.,5X,8HX-COORDS,3X,8HY-COORDS/)
30    FORMAT(1H0,10X,I2,4X,F8.1,3X,F8.1,6X,F5.2)
63    FORMAT(//12X,35HANISOTROPIC TRANSMISSIBILITIES ARE //12X,4HTXX ,34
     1X,E8.3,2X,'GPD/FT'//12X,4HTYY ,34X,E8.3,2X,'GPD/FT'//12X,4HTXY ,34
     2X,E8.3,2X,'GPD/FT')
64    FORMAT(////15X,30H( TIME AFTER PUMPING STARTS : ,F8.2,A8,1H)/)
65    FORMAT(/11X,I2,8X,F4.0,8X,3HX= ,F7.1,4X,A12)
66    FORMAT(//12X,35HANISOTROPIC TRANSMISSIBILITIES ARE //12X,4HTXX ,34
     1X,E8.3,2X,'MTSQ/D'//12X,4HTYY ,34X,E8.3,2X,'MTSQ/D'//12X,4HTXY ,34
     2X,E8.3,2X,'MTSQ/D')
71    FORMAT(///72H ****   TYPE OF ANALYSIS : FULLY PENETRATING WELL IN
     1ARTESIAN AQUIFER   /8X,47H----------------   - EQUILIBRIUM CONDITI
     2ONS    )
72    FORMAT(///72H ****   TYPE OF ANALYSIS : FULLY PENETRATING WELL IN
     1WATER TABLE AQUIFER/8X,47H----------------   - EQUILIBRIUM CONDITI
     2ONS    )
73    FORMAT(///72H ****   TYPE OF ANALYSIS : FULLY PENETRATING WELL IN
     1ARTESIAN AQUIFER   /8X,47H----------------   - NON-EQUILIBRIUM CON
     2DITIONS)
74    FORMAT(///84H ****   TYPE OF ANALYSIS : FULLY PENETRATING WELL IN
     1ARTESIAN ANISOTROPIC AQUIFER   /8X,47H----------------   -NON-EQUI
     2LIBRIUM CONDITIONS )
75    FORMAT(///77H ****   TYPE OF ANALYSIS : PARTIALLY PENETRATING WELL
     1S IN ARTESIAN AQUIFER   /8X,48H----------------   - NON-EQUILIBRIU
     2M CONDITIONS )
77    FORMAT(///74H **** TYPE OF ANALYSIS : FULLY PENETRATING WELLS IN L
     1EAKY ARTESIAN AQUIFER/8X,68H----------------   - WITHOUT WATER REL
     2EASED FROM STORAGE IN AQUITARD/27X,28H- NON-EQUILIBRIUM CONDITIONS
     3)
78    FORMAT(///74H **** TYPE OF ANALYSIS : FULLY PENETRATING WELLS IN L
     1EAKY ARTESIAN AQUIFER/8X,68H----------------   - WITHOUT WATER REL
     2EASED FROM STORAGE IN AQUITARD/27X,24H- EQUILIBRIUM CONDITIONS)
79    FORMAT(///74H **** TYPE OF ANALYSIS : FULLY PENETRATING WELLS IN L
     1EAKY ARTESIAN AQUIFER/8X,65H----------------   - WITH WATER RELEAS
     2ED FROM STORAGE IN AQUITARD/27X,28H- NON-EQUILIBRIUM CONDITIONS)
80    FORMAT(///74H **** TYPE OF ANALYSIS : FULLY PENETRATING WELLS IN L
     1EAKY ARTESIAN AQUIFER/8X,65H----------------   - WITH WATER RELEAS
     2ED FROM STORAGE IN AQUITARD/27X,24H- EQUILIBRIUM CONDITIONS)
81    FORMAT(///72H ****   TYPE OF ANALYSIS : FULLY PENETRATING WELL IN
     1WATER TABLE AQUIFER/8X,51H----------------   - NON-EQUILIBRIUM CON
     2DITIONS     )
82    FORMAT(1H1,///,'    ***  DRAWDOWN COMPONENTS',/,8X,'---------------
     1----',/,8X,'WELL  EFFECT    PARTIAL PENET- EFFECT OF  PARTIAL PENE
     2TRA-  TOTAL',/,8X,'NO.   OF WELL   RATION EFFECT  BOUNDARIES TION
     3EFFECT BY    EFFECT',/,14X,'ONLY (FT) BY WELL (FT)   ONLY (FT)  BO
     4UNDARIES (FT)    (FT)'/)
83    FORMAT(1H0,11X,22HTHICKNESS OF AQUITARD ,12X,F5.0,3H FT//12X,25HPE
     1RMEABILITY OF AQUITARD ,6X,F8.0,8HGPD/SQFT)
84    FORMAT(1H0,11X,28HCOEF. OF STORAGE OF AQUITARD,10X,E8.3)
85    FORMAT(1H0,11X,14HSPECIFIC YIELD,24X,E8.3//12X,4HALFA,31X,F5.1,1X,
     1'(1/DAY)')
86    FORMAT(7X,'NO.',6X,'TIME',5X,'PUMPING',7X,'WELL LOSSES'/13X,A8,2X,
     1'RATE (GPM)',8X,'(FT)'/)
87    FORMAT(1H0,10X,I2,4X,F6.0,4X,F6.0,5X,A12,3X,F7.0,8X,F6.0,10X,F7.2,
     110X,F6.2,10X,F5.2)
88    FORMAT(8X,I2,4X,F7.2,5X,F7.2,7X,F7.2,7X,F7.2,6X,F7.2)
89    FORMAT(/1X,'POINT OF INTEREST NO ',I2/1X,'TOTAL DRAWDOWN IS ',F6.2
     1/)
90    FORMAT(/1X,'TIME INCREMENT NO ',I2/1X,'TOTAL DRAWDOWN IS ',F6.2/)
91    FORMAT(7X,I3,3X,F8.2,3X,F6.1,13X,F5.2)
92    FORMAT(5X,I3,2X,F7.0,2X,F7.0,1X,A10,F7.0,6X,F4.2,5X,F6.5,5X,F5.3)
201   FORMAT(///30X,24H** CONVERGENCE LIMIT = ,F5.2,8H MT.  **/)
202   FORMAT(//12X,13HPERMEABILITY ,18X,F8.0,4H M/D)
203   FORMAT(1H0,11X,33HDEPTH TO UNDISTURBED WATER TABLE ,F6.0,3H MT)
204   FORMAT(1H0,11X,21HTHICKNESS OF AQUIFER ,12X,F6.0,3H MT)
205   FORMAT(//'   ***  REAL WELL DATA'/7X,'--------------'/7X,'NO. X-AXI
     1S  Y-AXIS   WELL',5X,'RADIUS OF  PENETRA-  WELL LOSS  EXPONENT'/12
     2X,'(MT)     (MT)     TYPE   INFLUENCE(MT)  TION     CONSTANT'/)
206   FORMAT(1H ,12X,A8,16X,4H(MT))
207   FORMAT(1H0,14X,18HPOINTS OF INTEREST,7X,8HDRAWDOWN/21X,4H(MT),16X,
     14H(MT))
208   FORMAT(1H1,///,'    ***  DRAWDOWN COMPONENTS',/,8X,'---------------
     1----',/,8X,'WELL  EFFECT    PARTIAL PENET- EFFECT OF  PARTIAL PENE
     2TRA-  TOTAL',/,8X,'NO.   OF WELL   RATION EFFECT  BOUNDARIES TION
     3EFFECT BY    EFFECT',/,14X,'ONLY (MT) BY WELL (MT)   ONLY (MT)  BO
     4UNDARIES (MT)    (MT)'/)
209   FORMAT(1H0,11X,22HTHICKNESS OF AQUITARD ,12X,F5.0,3H MT//12X,25HPE
     1RMEABILITY OF AQUITARD ,6X,F8.0,3HM/D)
210   FORMAT(7X,'NO.',6X,'TIME',5X,'PUMPING',7X,'WELL LOSSES'/13X,A8,3X,
     1'RATE (CM/D)',8X,'(MT)'/)
211   FORMAT(///19H   ***   BOUNDARIES /8X,10H----------//11X,3HNO.,4X,10
     1HANGLE WITH,5X,9HINTERCEPT 5X,8HBOUNDARY/17X,13HX-AXIS (DEG.),6X,4
     2H(MT),8X,4HTYPE/)

      WRITE(6,10)(TITLE(J),J=1,19)

      GO TO (101,102,103,104,105,105,107,108,109,110,111) , KPROB

101   WRITE(6,71)
      GO TO 53
102   WRITE(6,72)
      GO TO 53
103   WRITE(6,73)
      GO TO 53
104   WRITE(6,74)
      GO TO 53
105   WRITE(6,75)
      GO TO 53
107   WRITE(6,77)
      GO TO 53
108   WRITE(6,78)
      GO TO 53
109   WRITE(6,79)
      GO TO 53
110   WRITE(6,80)
      GO TO 53
111   WRITE(6,81)
53    WRITE(6,12)

C *** CONVERSION OF UNITS
      IF(JUNIT.NE.1) GO TO 57
      TXX=TXX/2.28
      TYY=TYY/2.28
      TXY=TXY/2.28
      PERM=PERM/0.695
      PBAR=PBAR/0.695
      HO=HO/3.281
```

```
      CONV=CONV/3.281
      HBAR=HBAR/3.281
      THCK=THCK/3.281
      DO 54 IRK=1,15
      XP(IRK)=XP(IRK)/3.281
      YP(IRK)=YP(IRK)/3.281
      XH(IRK)=XH(IRK)/3.281
      YH(IRK)=YH(IRK)/3.281
      Y(IRK)=Y(IRK)/3.281
      SEE(IRK)=SEE(IRK)/3.281
      RADI(IRK)=RADI(IRK)/3.281
      IF(NTI.EQ.1.AND.ITHV.EQ.0) X(IRK)=X(IRK)/3.281
 54   QCONST(IRK)=QCONST(IRK)/0.18345
      DO 55 IC=1,15
      DO 55 ID=1,15
      QVAR(IC,ID)=QVAR(IC,ID)/0.18345
      SE(IC,ID)=SE(IC,ID)/3.281
      YWO(IC,ID)=YWO(IC,ID)/3.281
      YPN(IC,ID)=YPN(IC,ID)/3.281
      YWB(IC,ID)=YWB(IC,ID)/3.281
 55   YTOT(IC,ID)=YTOT(IC,ID)/3.281
      DO 56 IB=1,NBNDS
 56   C(IB)=C(IB)/3.281

C *** WRITE OUT THE AQUIFER CHARACTERISTICS
 57   IF(JUNIT.EQ.1.AND.KPROB.EQ.4) WRITE(6,66) TXX,TYY,TXY
      IF(JUNIT.NE.1.AND.KPROB.EQ.4) WRITE(6,63) TXX,TYY,TXY
      IF(KPROB.EQ.4) GO TO 2
      IF(JUNIT.NE.1) WRITE(6,13) PERM
      IF(JUNIT.EQ.1) WRITE(6,202) PERM
      IF(KPROB.NE.2)GO TO 1
      IF(JUNIT.NE.1) WRITE(6,14) HO
      IF(JUNIT.EQ.1) WRITE(6,203) HO
      GO TO 2
 1    IF(JUNIT.NE.1) WRITE(6,15) THCK
      IF(JUNIT.EQ.1) WRITE(6,204) THCK
 2    IF(KPROB.GE.3) WRITE(6,16)CST
      IF(JUNIT.NE.1.AND.KPROB.GT.6.AND.KPROB.LT.11)WRITE(6,83)HBAR,PBAR
      IF(JUNIT.EQ.1.AND.KPROB.GT.6.AND.KPROB.LT.11)WRITE(6,209)HBAR,PBAR
      IF(KPROB.EQ.9)WRITE(6,84)SBAR
      IF(KPROB.EQ.11)WRITE(6,85)SY,ALFA

      IF(NBNDS.EQ.0)GO TO 9

C *** WRITE OUT BOUNDARY DATA
      IF(JUNIT.NE.1) WRITE(6,17)
      IF(JUNIT.EQ.1) WRITE(6,211)
      DO 3 IB=1,NBNDS
      JB=1
      IF(BTYPE(IB).EQ.1)JB=2
      IF(TH(IB).EQ.0.)GO TO 35
      IF(TH(IB).NE.180.)GO TO 36
 35   WRITE(6,18)IB,TH(IB),C(IB),TYPB(JB)
      GO TO 3
 36   WRITE(6,65)IB,TH(IB),C(IB),TYPB(JB)
 3    CONTINUE
      WRITE(6,19)
      WRITE(6,20)NSING,NINT,NPARA

C *** WRITE OUT REAL WELL DATA
 9    IF(JUNIT.NE.1) WRITE(6,21)
      IF(JUNIT.EQ.1) WRITE(6,205)
      DO 42 IW=1,NWELLS
      KW=1
      IF(WTYPE(IW).EQ.-1.)KW=2
 42   WRITE(6,92)IW,XW(IW),YW(IW),TYPW(KW),RADI(IW),GAMA(IW),CW(IW),WN(I
     1W)
      WRITE(6,22)
      IF(JUNIT.NE.1) WRITE(6,86)TIMU(ITUNT+1)
      IF(JUNIT.EQ.1) WRITE(6,210)TIMU(ITUNT+1)
      IF(ITHV.EQ.0) GO TO 41
      DO 47 IW=1,NWELLS
      DO 47 ITV=2,ITHV+1
 47   WRITE(6,91)IW,TIME(ITV),QVAR(IW,ITV),SE(IW,ITV)
      GO TO 31
 41   DO 49 IW=1,NWELLS
 49   WRITE(6,91)IW,TII,QCONST(IW),SEE(IW)

C *** PRINTOUT - MORE THAN ONE TIME INTERVAL OR MORE THAN ONE POINT OF
C     INTEREST
      IF(NTI.EQ.1)GO TO 8

C  ** SINGLE POINT OF INTEREST CASE - TIME INTERVAL VARIES
 31   WRITE(6,24)XP(1),YP(1)
      IF(JUNIT.NE.1) WRITE(6,25) TIMU(ITUNT+1)
      IF(JUNIT.EQ.1) WRITE(6,206)TIMU(ITUNT+1)
      DO 5 IS=1,ISMAX
 5    WRITE(6,26)X(IS),Y(IS)
      GO TO 6

C  ** SINGLE TIME INTERVAL CASE - POINT OF INTEREST VARIES
 8    WRITE(6,27)
      IF(KPROB.LT.3 .OR.KPROB.EQ.8 .OR.KPROB.EQ.10) GO TO 40
      WRITE(6,64)TII,TIMU(ITUNT+1)
 40   IF(JUNIT.NE.1) WRITE(6,28)
      IF(JUNIT.EQ.1) WRITE(6,207)
      WRITE(6,29)
      DO 7 IS=1,ISMAX
      WRITE(6,30)IS,XP(IS),YP(IS),Y(IS)
 7    CONTINUE

 6    IF(NPARA.NE.0)GO TO 37
      GO TO 38
 37   IF(JUNIT.NE.1) WRITE(6,11) CONV
      IF(JUNIT.EQ.1) WRITE(6,201) CONV

C *** DRAWDOWN COMPONENTS OPTION
 38   IF(ITABLE.NE.1) GO TO 50
      IF(JUNIT.NE.1) WRITE(6,82)
      IF(JUNIT.EQ.1) WRITE(6,208)
      DO 39 IS=1,ISMAX
      IF(ITHV.EQ.0.AND.NTI.EQ.1) WRITE(6,89) IS,Y(IS)
      IF(ITHV.EQ.0.AND.NTI.GT.1) WRITE(6,90) IS,Y(IS)
      IF(ITHV.NE.0) WRITE(6,90) IS,Y(IS)
      DO 39 IW=1,NWELLS
 39   WRITE(6,88)IW,YWO(IW,IS),YPN(IW,IS),YWB(IW,IS),YPB(IW,IS),YTOT(IW,
     1IS)

 50   RETURN

      END
```

```
      SUBROUTINE GRAPH(HEADNG,XX,YY,M,VARY,XMIN,XMAX,YMIN,YMAX,MPAGES)

      REAL LINE,BLANK/' '/,DOT/'.'/,X/'X'/,O/'O'/,Y/'Y'/,PLUS/'+'/
      REAL AST/'*'/

      DIMENSION VARY(101), HEADNG(20)
      DIMENSION LINE(112),XX(100),YY(100),YAXIS(45),XAXIS(101)

      WRITE(6,9) HEADNG
 10   DYMXMN=YMAX-YMIN
      YAXIS(1)=YMIN
      GO TO (12,14),MPAGES
 12   XSPACE=50.0
      MSPACE=51
      GO TO 16
 14   XSPACE=100.0
      MSPACE=101
 16   DO 20 K=2,11
 20   YAXIS(K)=YAXIS(K-1)+0.1*DYMXMN
 30   IF(DYMXMN-1000.0)40,100,100
 40   IF(YMAX-1000.0) 50,100,100
 50   IF(YMIN+100.0)100,100,60
 60   IF(ABS(YMIN)-(1.0E-02))70,70,80
 70   IF(YMIN) 100,80,100
 80   IF(ABS(YMAX)-(1.0E-02))90,90,110
 90   IF(YMAX)100,110,100
 100  WRITE(6,1)(YAXIS(K),K=2,11)
      GO TO 120
 110  WRITE(6,2) (YAXIS(K),K=2,11)
 120  DO 130 J=1,112
 130  LINE(J)=BLANK
      WRITE(6,3) LINE
      KOUNT=0
      IF(XMIN) 140,170,170
 140  IF(XMAX) 170,170,150
 150  DO 160 J=10,112
 160  LINE(J)=BLANK
      GO TO 200
 170  DO 180 J=10,110
 180  LINE(J)=DOT
      DO 190 J=10,110,10
 190  LINE(J)=PLUS
C                                 APPENDIX N
      LINE(111)=BLANK
      LINE(112)=Y
 200  DXMXMN=XMAX-XMIN
      XAXIS(1)=XMIN
      DO 210 KK=11,MSPACE,10
 210  XAXIS(KK)=XAXIS(KK-10)+(10.0/XSPACE)*DXMXMN
      KK=1
      XINVL=DXMXMN/XSPACE
      VARX=XMIN
 220  DO 770 L=1,MSPACE
      IF(YMIN)230,260,260
 230  JY=(100.0/DYMXMN)*ABS(YMIN)+9.5
      IF(JY-110) 250,240,240
 240  JY=9
 250  LINE(JY+1)=DOT
      GO TO 270
 260  LINE(10)=DOT
      JY=9
 270  IF(L-1) 280,330,280
 280  IF(L-11) 290,340,290
 290  IF(L-21) 300,340,300
 300  IF(L-31) 310,340,310
 310  IF(L-41) 320,340,320
 320  IF(L-51) 321,340,321
 321  GO TO (430,322),MPAGEB
 322  IF(L-61) 323,340,323
 323  IF(L-71) 324,340,324
 324  IF(L-81) 325,340,325
 325  IF(L-91) 326,340,326
 326  IF(L-101) 430,340,430
 330  LINE(JY+1)=X
      GO TO 430
 340  LINE(JY+1)=PLUS
      KK=L
      IF(DXMXKN-1000.0) 350,410,410
 350  IF(XMAX-1000.0) 360,410,410
 360  IF(XMIN+100.0) 410,410,370
 370  IF(ABS(XMIN)-(1.0E-02)) 380,380,390
 380  IF(XMIN) 410,390,410
 390  IF(ABS(XMAX)-(1.0E-02)) 400,400,420
 400  IF(XMAX) 410,420,410
 410  WRITE(6,4) XAXI8(KK)
      GO TO 430
 420  WRITE(6,5) XAXI8(KK)
 430  IF((VARX+XINVL/2.0)-ABS(VARX)) 480,440,440
C                                 APPENDIX N
 440  KOUNT=KOUNT+1
      IF(KOUNT-1) 480,450,480
 450  DO 460 J=10,110
 460  LINE(J)=DOT
      DO 470 J=20,110,10
 470  LINE(J)=PLUS
      LINE(111)=BLANK
      LINE(112)= Y
 480  K=0
      KMAX=0
      DO 530 I=1,M
      TRY=XX(I)-VARX
      TTRY=TRY-(XINVL/2.0)
      IF(TTRY)490,530,530
 490  IF(TTRY+XINVL) 500,510,510
 500  GO TO 530
 510  K=(YY(I)-YMIN)*100.0/DYMXMN+9.5
      IF(K-111) 512,525,525
 512  IF(8-K)515,525,525
 515  LINE(K+1)=O
      IF(KMAX-K) 520,530,530
 520  KMAX=K
      GO TO 530
 525  K=0
 530  CONTINUE
      J=(VARY(L)-YMIN)*100.0/DYMXMN+9.5
      IF(J-111) 540,580,580
 540  IF(8-J) 550,580,580
 550  IF(LINE(J+1)-O)  570,560,570
 560  LINE(J+1)=O
      GO TO 590
```

```
570  LINE(J+1)=AST
     GO TO 590
580  J=0
590  J1=J+1
     K1=KMAX+1
     JY1=JY+1
     IF(LINE(112)-Y) 600,720,600
600  IF(JY-J) 620,610,610
610  IF(JY-K) 660,630,630
620  IF(J-K) 660,690,690
630  IF(L-KK) 640,650,640
640  WRITE(6,3)(LINE(JJ),JJ=10,JY1)
     GO TO 750
650  WRITE(6,6)(LINE(JJ),JJ=10,JY1)
C                                    APPENDIX N
     GO TO 750
660  IF(L-KK) 670,680,670
670  WRITE(6,3)(LINE(JJ),JJ=10,K1)
     GO TO 750
680  WRITE(6,6)(LINE(JJ),JJ=10,K1)
     GO TO 750
690  IF(L-KK) 700,710,700
700  WRITE(6,3)(LINE(JJ),JJ=10,112)
     GO TO 750
710  WRITE(6,6)(LINE(JJ),JJ=10,112)
     GO TO 750
720  IF(L-KK) 740,730,740
730  WRITE(6,6)(LIN2(JJ),JJ=10,112)
     GO TO 750
740  WRITE(6,3)(LINE(JJ),JJ=10,112)
750  DO 760 J=10,112
760  LINE(J)=BLANK
     VARX=VARX+XINVL
770  CONTINUE
     IF(DXMXMN-1000,0) 780,870,870
780  IF(XMAX-1000,0) 790,870,870
790  IF(DYMXMN-1000,0) 800,870,870
800  IF(YMAX-1000,0) 810,870,870
810  IF(YMIN+100,0) 870,870,820
820  IF(ABS(YMIN)-(1,0E-02)) 870,870,830
830  IF(ABS(YMAX)-(1,0E-02)) 870,870,840
840  IF(XMIN+100,0) 870,870,850
850  IF(ABS(XMIN)-(1,0E-02)) 870,870,860
860  IF(ABS(XMAX)-(1,0E-02)) 870,870,880
870  WRITE(6,7) XMIN,XMAX,YMIN,YMAX
     GO TO 900
880  WRITE(6,8) XMIN,XMAX,YMIN,YMAX
   1 FORMAT(/,16X,1PE9,2,9(1X,1PE9,2))
   2 FORMAT(/,17X,F7,3,9(3X,F7,3))
   3 FORMAT(1H ,9X,103A1)
   4 FORMAT(' ',1PE9,2)
   5 FORMAT(' ',F9,4)
   6 FORMAT('+',9X,103A1)
   7 FORMAT(/,14X,'XMIN= ',1PE12,5,5X,'XMAX= ',1PE12,5,
    1/,14X,'YMIN= ',1PE12,5,5X,'YMAX= ',1PE12,5)
   8 FORMAT(/,14X,'XMIN= ',F10,6,5X,'XMAX= ',F10,6
    1/,14X,'YMIN= ',F10.6,5X,'YMAX= ',F10.6)
   9 FORMAT('1',20A4)
900  RETURN
      END
```

VARIABLE DICTIONARY

Variable	Definition
AITHD	AITHD = FLOAT(ITHD)
ALFA	ALFA = 1/(delay index)
ALFTWT	The interpolated well function
B	$B = \sqrt{PERM.THCK/(7.48\ ALFA.SY)}$
BBTYPE	BBTYPE = BTYPE(I)
BTYPE(I)	The type of boundary
C(I)	The boundary intercept on the X-axis (or Y-axis if the boundary is parallel to the X-axis)
CC	CC = C(I)
CONV	The convergence limit
CST	The coefficient of storage
CW(I)	Well loss constant
DD	$DD = 40.783\ QCONST(I)/2\pi PERM.THCK)$
	DD = 114.6 QCONST(I)/(PERM.THCK)
	$DD - 114.6\ QCONST(I)/\sqrt{TXX.TYY-TXY^2}$
DK	DK = YI(I) + XI(I)/DMM
DM(I)	The tangent of the angle between two intersecting boundaries
DMM	DMM = DM(I)
DRAWDO(A,B,C)	The subroutine which computes the drawdown
FACT	Factorial term
GAMA(J)	The percent of penetration of well in the aquifer
GRADF	$GRADF = DMM^2 + 1$
GRAPH(A,B,C I,D,E,F,G,H,J)	The subroutine which draws the graph
H	$H = \sqrt{HO^2 - XX}$

Variable	Definition
HO	The depth to water table
IDELT	The time increment within a cycle
INDIV	The printout option of individual image well coordinates and contribution to total drawdown
INTERS(I)	The subroutine which controls the reflection process in the case of intersecting boundaries
INTRP1(A,I,J)	The subroutine which interpolates the value of well function in one dimensional array tables
INTRP2(A,B,I,J,K)	The subroutine which interpolates the value of well function in two dimensional array tables
INTRP3(A,I,J)	The subroutine which interpolates the time for a given value of R/B
IPLOT	Graphical output option
ITABLE	Drawdown components table option
ITHD	ITHD = IFIX(THD)
ITMV	The number of stages in variable pumping rate case
ITUNT	The index to the time unit used
JUNIT	The option for the system of units
KINT(I,J)	The number of intersections
KPARA(I,J)	The number of parallels
KPROB	The problem type
KSING(I,J)	The number of singles
M(I)	The number of rows in the well function table
MBAR	The thickness of aquitard
N(I)	The number of columns in the well function table
NBNDS	The number of boundaries
NCASES	The number of cases to be analyzed
NERR	The error number

Variable	Definition
NIMGS	The number of image wells
NINT	The number of intersections
NLOG	The number of time increment cycles for which drawdown is to be evaluated
NN	NN = 1 or 2
NPARA	The number of parallels
NPNTS	The number of points of interest
NR	The number of reflections required in the case of intersecting boundaries
NSING	The number of singles
NTI	The option for the number of time increments
NWELLS	The number of the real wells
OUTPUT	The subroutine which produces tabular output of problem details
PARALL(I,J)	The subroutine which controls the reflections process in the case of parallel boundaries
PBAR	The permeability of aquitard
PERM	The aquifer permeability
QCONST(I)	The constant well pumping rate
QDIF(I)	The difference between two sequent variable pumping rates
QUAR(I,J)	The variable well pumping rate
R	The distance between the observation point and the well
RADI(I)	The radius of influence of the real well
RB	The vertical coordinate which interpolates the well function
REFLECT(A,B, C,D,I)	The subroutine which reflects a well about a boundary
RM	RM = R/3.281

Variable	Definition
RMIN	The minimum allowable distance between the observation point and the well
RR	RR = RADI(I)/R
S	The drawdown at the observation point
SBAR	The coefficient of storage of aquitard
SE(I,J)	The well loss in variable pumping rate case
SEE(I)	The well loss in constant pumping rate case
SERIE1	SERIE1 = DD(-0.5772 - ALOG(U))
SERIE2	SERIE2 = SERIE1 + (DD.TERM)
SI	The vertical coordinate which interpolates the well function in case number 9
SM	SM = S/3.281
SMTOT	SMTOT = STOT/3.281
SP	The drawdown due to partial penetration effect only
STOT	The total sum of drawdown at the observation point
SY	The specific yield
T(I,J)	The value of the horizontal coordinate of the well function table
TA	The angle the boundary makes with the X-axis in radius
TH(I)	The angle the boundary makes with the X-axis in degrees
THCK	The aquifer thickness
THD	THD = 90 NN/THDIF
THDIF	The angle between two boundaries
TI	The time interval after which drawdown is required

Variable	Definition
TI2	TI2 = TI
TII	TII = TI
TIME(I)	The time since variable pumping rate starts
TIMT1	TIMT1 = 0.27 MBAR.SBAR/PBAR
TIMT2	TIMT2 = 0.27 MBAR.SBAR/(74.8 PBAR)
TIMU(I)	The double precision for time in days or minutes
TINC	The time interval for each variable pumping stage
TITLE(I)	The title of the analysis
TTH	TTH = TH(I)
TWT	TWT = ALFTWT/ALFA
TXX	The XX component of the second rank symmetric tensor of transmissibility
TXY	The XY component of the second rank symmetric tensor of transmissibility
TYPB(I)	The double precision for boundary type
TYPI(I)	The type of the image well
TYPW(I)	The double precision for well type
TYY	The YY component of the second rank symmetric tensor of transmissibility
U	$U = 1.87\ R^2.(ST/(PERM.THICK.TI)$ in case no. 3
	$U = 1.97\ CST \dfrac{TXX.YY^2 + TYY.XX^2 - 2\ TXY.XX.YY}{TI(TXX.TYY - TXY^2)}$ in case no. 4
UA	$UA = 0.27\ R^2.CST(7.48/PERM.THCK.TI)$
UDBAR	$UDBAR = 1.87\ R^2\ (1 + SBAR)/(3\ PERM.THCK.TI)$
UT	$UT = 1.87\ R^2.CST/(PERM.THCK.TI)$
UY	$UY = 0.25\ R^2\ SY(7.48/PERM.THCK.TI)$
V(I,J)	The value of the vertical coordinate of the well function table

Variable	Definition
W(I,J,K)	The value of the well function in the two dimensional array table
W1	The horizontal interpolation of the well function
W2	The vertical interpolation of the well function
WF(I,J)	The value of the well function in the one dimensional array table
WN(I)	Exponent due to turbulent flow
WTYPE(I)	The type of well
WW	The interpolated well function
X(I)	The time since pumping started or the distance from the pumped well to the observation point
XI(I)	The X-coordinate of the image well
XM(I)	XM(I) = XI(I)3.281
XMAX	The maximum distance or time used
XMIN	The minimum distance or time used
XP(I)	The X-coordinate of the observation point
XW(I)	The X-coordinate of the real well
XX	XX = ABS(XP(I) - XW(I))
Y(I)	The accumulated drawdown
YI(I)	The Y-coordinate of the image well
YM(I)	YM(I) = YI(I)/3.281
YMAX	The maximum accumulated drawdown
YMIX	The minimum accumulated drawdown
YP(I)	The Y-coordinate of the observation point
YP1(I,J)	The total drawdown due to the partial penetration effection in the real well only
YP2(I,J)	The total drawdown due to the effect of partial pentration at the image wells

Variable	Definition
YPB(I,J)	YPB(I,J) = YP2(I,J)
YPN(I,J)	The partial penetration effect due to the real well and its associated image wells
YSP(I)	The accumulated drawdown due to the partial penetration effect
YTOT(I,J)	YTOT(I,J) = YTOT3(I,J)
YTOT3(I,J)	The total drawdown due to the real well and its associated image well including the partial penetration effect
YW(I)	The Y-coordinate of the real well
YW1(I,J)	The drawdown due to the real well excluding the partial penetration effect
YW2(I,J)	The drawdown due to the image wells excluding the partial penetration effect
YWB(I,J)	YWB(I,J) - YW2(I,J)
YWO(I,J)	YWO(I,J) = YW1(I,J)
YY	YY = ABS(YP(I) - YW(I))
Z(I)	Z(I) = YMIN - 5

APPENDIX B

Tables and Notes

1. Table B-1. Description of the input data and their formats.
2. Table B-2. Data cards used in the verified examples.
3. Table B-3. Interpretation of error codes.
4. Notes on the use of input data.

Table B-1. Description of the input data and their formats.

Card No.	Identifier	Definition	Col. No.
1		Basic Data (Free Format)	
	NCASES	The number of cases to be analyzed	1
	JUNIT	Unit option (if JUNIT = 1, S.I. system of units must be used, if JUNIT ≠ 1, F.P.S. system of units must be used)	3
	ITABLE	Drawdown components table option (if ITABLE = 1, table given)	5
2		Heading (Format 509)	
	TITLE	The title of analysis	1-80
3		Control Card (Format 501)	
	NBNDS	The number of boundaries (NBNDS $\leq$ 4)	10-13
	NPNTS	The number of points of interest (NPDNTS $\leq$ 15	21-25
	NWELLS	The number of real wells (NWELLS $\leq$ 15)	34-38
	KPROB	The problem type	45-46
	CONV	The convergence limit of drawdown, meters or feet	53-57
	INDIV	Printout option (if INDIV = 1, tabular output of individual image well coordinates and contribution to total drawdown given), meters or feet	60
	IPLOT	Graphical output option (if IPLOT = 1, graphical output given)	62
4		Boundary Data, one card for each boundary (FORMAT 502)	7-13
	TH(IB)	The angle the boundary makes with the X-axis in degrees measured counterclock wise	
	C(IB)	The boundary intercept on the X-axis, or on the Y-axis if the boundary is parallel to the X-axis, meters or feet	17-23
	BTYPE(IB)	The boundary type (BTYPE(IB) = +1. for barrier boundary, BTYPE(IB) = -1. for recharge boundary)	27-29
5		Point of Interest Data, one card for each point (Format 502)	
	XP(IP)	The X-coordinate of the point, meters or feet	7-13
	YP(IP)	The Y-coordinate of the point, meters or feet	17-23
6		Real Well Data, one card for each well (Format 50)	
	XW(IW)	The X-coordinate of the real well, meters feet	5-12

Table B-1. Continued.

Card No.	Identifier	Definition	Col. No.
6 (cont)	YW(IW)	The Y-coordinate of the real well, meters feet	16-23
	WTYPE(IW)	The type of well (WTYPE(IW) = +1. for discharging well, WTYPE(IW) = -1. for recharging well)	27-29
	QCONST(IW)	The well pumping rate, not used in variable pumping case, m^3/day or gpm	37-42
	RADI(IW)	The radius of influence of the well, meters or feet	47-53
	GAMA(IW)	The percent of penetration of the well in the aquifer	57-60
7		The Aquifer Characteristics	
a		For KPROB < 4 (Format 503)	
	PERM	The aquifer permeability, m/day or gpd/ft^2	9-16
	THCK	The aquifer thickness, not used if KPROB = 2, meters or feet	23-28
	CST	The coefficient of storage of the aquifer, not used if KPROB < 3	33-40
	HO	The depth to water table, used only for KPROB = 2, meters or feet	45-50
b		For KPROB = 4 (Format 559)	
	TXX	The XX component of the second rank symmetric tensor of transmissibility, m^2/day or gpd/ft	9-16
	TYY	The YY component of the second rank symmetric tensor of transmissibility, m^2/day or gpd/ft	22-29
	TXY	The XY component of the second rank symmetric tensor of transmissibility, m^2/day or gpd/ft	35-42
	CST	The coefficient of storage of the aquifer	48-55
c		For KPROB = 5, or KPROB = 6 (Format 560)	
	PERM	The permeability of the aquifer, meter/day or gpd/ft^2	9-16
	THCK	The aquifer thickness, meters or feet	23-27
	CST	The coefficient of storage of the aquifer	33-40
d		For KPROB = 7, 8, or 10 (Format 561)	
	PERM	The permeability of the aquifer, meter/day or gpd/ft^2	7-14
	THCK	The aquifer thickness, meters or feet	23-28
	CST	The coefficient of storage of the aquifer	35-42
	MBAR	The aquitard thickness, meters or feet	49-54
	PBAR	The permeability of the aquitard, meter/day or gpd/ft^2	60-67

Table B-1. Continued.

Card No.	Identifier	Definition	Col. No.
7 (cont.)			
e		For KPROB = 9 (Format 562)	
	PERM	The permeability of the aquifer, meter/day or gpd/ft^2	7-14
	THCK	The aquifer thickness, meters or feet	23-28
	CST	The coefficient of storage of aquifer	35-42
	MBAR	The aquitard thickness, meters or feet	49-54
	PBAR	The permeability of the aquitard, meter/day or gpd/ft^2	60-67
	SBAR	The coefficient of storage of aquitard	73-80
f		For KPROB = 11 (Format 563)	
	PERM	The permeability of the aquifer, meter/day or gpd/ft^2	7-14
	THCK	The thickness of the aquifer, meters or feet	23-28
	CST	The coefficient of storage of aquifer	35-42
	SY	The specific yield of the aquifer	49-56
	ALFA	The delay index inverse, 1/day	64-70
8		Well loss Data (Free Format)	
	CW(IW)	Well loss constant for each real well	-
	WN(IW)	Exponent due to turbulence for each real well	-
9		Time Option Cases (Free Format)	
	NTI	NTI = 1 for one increment, NTI > 1 for more than one time increment	1
	ITUNT	Time unit option (ITUNT = 1 for time in minutes, ITUNT = 0 for time in days)	3
	TI	The time interval after which drawdown if required, not used in steady state cases or in variable pumping cases, minutes or days	5-9
	NLOG	The number of time increment cycles for which drawdown is to be evaluated (NLOG $\leq$ 3)	11
	IDELT	Time time increment within a cycle, IDELT may be set to 1, 4, or 8	13
	ITMV	The number of stages in variable pumping case (if ITMV = 0, constant pumping case is used)	15-19
	TINC	The time interval for each variable pumping stage, days	21-24
10		Variable Discharge Data, not used if ITMV = 0 (Free Format)	
	QUAR(IW,ITV)	The pumping rate for each real well at each time increment, m^3/day or gpm	-

Table B-2. Data cards used in the verified examples

Case Study Example		Card Numbers Used									
		1	2	3	4	5	6	7	8	9	10
Example 1	No boundaries	X	X	X		X	X	X	X	X	X
Example 2	Single boundary	X	X	X	X	X	X	X	X	X	
Example 3	Parallel pair of boundaries	X	X	X	X	X	X	X	X	X	
Example 4	A 90° intersection of two boundaries	X	X	X	X	X	X	X	X	X	X
Example 5	Three boundaries with two of them parallel	X	X	X	X	X	X	X	X	X	
Example 6	Two perpendicular parallel pairs of boundaries	X	X	X	X	X	X	X	X	X	

Table B-3. Interpretation of error codes.

ERROR NO.	MEANING
1	The limits off the following has been exceeded, NBNDS, NPNTS, and NWELLS.
2	In variable discharge, time unit must be used in days.
3	Only one point of interest is permitted when more than one time increment is specified (in variable or constant discharge cases).
4	A single boundary must be perpendicular to a pair of parallel boundaries.
5	Two nonparallel boundaries are not permitted with a pair of parallel boundaries.
6	The angle between two intersecting boundaries violates Ferris's limitation.
7	Two pairs of parallel lines should be mutually perpendicular.
8	Point of interest should not be coincident with the real well.
9	The time at which drawdown is to be evaluated is zero.
10	The program limit of 1000 image wells has been reached.
11	The undisturbed water depth specified for the equilibrium water table case is too small and thus results in complex drawdown values.
12	The convergence limit has not been met in computing the drawdown. This is a warning message.
13	The ratio of drawdown to the aquifer thickness in variable discharge case is more than 10 percent. This results in nonlinearity of flow motion equation which should not be applied in this case.
14	The interpolating values are not within the two-dimensional table limitation for well function.
15	The interpolating value is not within the one-dimensional table limitation for well function.
16	The interpolating value is not within the table limitation which defines the graph of (r/B) vs. (α twt).

Notes on the Use of Input Data

Frequently, errors might arise due to incorrect input data. The following notes help in performing successful runs.

There should be at least one of the following card numbers for each case study, 1, 2, 3, 5, 6, 7, 8, and 9. The number of cards 4, 5, and 6 are the same as the number of boundaries, points, and wells respectively. If there are no boundaries, card number 4 must not be used.

In some cases, part of the input data must be read and they are not going to be used like the radius of influence, percent of well penetration, constant discharging rates in variable pumping case, etc. In case of variable pumping rate, the pumping rates for all real wells at the first stage should be read as zeros, because the computation is held at the end of each time increment and not at the beginning. The second set of pumping rate values will stand for the first time increment and so on. The time unit in the variable pumping case should be used in days or fraction of days only.

More than one point of interest is not permitted in using more than one time increment in either constant or variable pumping rate.

If there are more than one case study, then the input data sequence from card numbers 2 to 10 is repeated except where indicated above.

APPENDIX C

Computer Output for Examples in Chapter IV

1. No boundary, variable pumping rate.
2. Example on graph of drawdown vs. time.
3. Example on drawdown component table, variable pumping rate.
4. Example on parallel boundaries.
5. Example on graph of drawdown vs. distance.
6. Example on rectangular aquifer, injection well.
7. Example on well spacing design.

THE DATA CARDS USED IN THIS EXAMPLE ARE :

```
? USER 804260/YOUSEA
? RUN NAJWAN
? DATA DATH
1,1,0
   EXAMPLE: NO BOUNDARIES,VARIABLE PUMPING RATE
   NBNDS=   0 NPNTS=    1 NWELLS=    4 KPROB=11 CONV=.05   0 0
   XP=100.   YP=70.
 XW=000.0   YW=100.0   WT=+1.    QC= 400.  RI=2200.  GM=1.00
 XW=100.0   YW=000.0   WT=+1.    QC= 600.  RI=2100.  GM=1.00
 XW=100.0   YW=100.0   WT=+1.    QC= 500.  RI=2500.  GM=1.00
 XW=000.0   YW=000.0   WT=+1.    QC=500.0  RI=7500.  GM=1.00
    P=  5.0E02   THCK= 100.   CST= 3.6E-02   SY= 2.0E-03  ALFA=  50.
0.000006,1.15,0.000008,1.2,0.000008,1.25,0.0000063,1.3
2,0,5.,3,1,4,1.,
0.,0.,0.,0.,1000.,4000.,800.,5000.,2000.,4500.,1000.,6000.,3000.,5000.,1500.,
7000.,4000.,5500.,5000.,8000.,
? END
```

**** EXAMPLE: NO BOUNDARIES,VARIABLE PUMPING RATE

**** TYPE OF ANALYSIS : FULLY PENETRATING WELL IN WATER TABLE AQUIFER
- NON-EQUILIBRIUM CONDITICNS

*** AQUIFER CHARACTERISTICS

PERMEABILITY	500. F/D
THICKNESS OF AQUIFER	100. FT
COEFFICIENT OF STORAGE	.360E-01
SPECIFIC YIELD	.200E-02
ALFA	50.0 (1/DAY)

*** REAL WELL DATA

NO.	X-AXIS (FT)	Y-AXIS (FT)	WELL TYPE	RADIUS OF INFLUENCE(FT)	PENETRA-TICN	WELL LOSS CONSTANT	EXPONENT
1	0.	100.	DISCHARGE	2200.	1.00	.00001	1.150
2	100.	0.	DISCHARGE	2100.	1.00	.00001	1.200
3	100.	100.	DISCHARGE	2500.	1.00	.00001	1.250
4	0.	0.	DISCHARGE	7500.	1.00	.00001	1.300

*** PUMPING RATES AND WELL LOSSES

NO.	TIME (DAYS)	PUMPING RATE (CM/D)	WELL LOSSES (MT)
1	1.00	1000.0	0.00
1	2.00	2000.0	0.00
1	3.00	3000.0	0.00
1	4.00	4000.0	0.00
2	1.00	4000.0	0.01
2	2.00	4500.0	0.01
2	3.00	5000.0	0.01
2	4.00	5500.0	0.01
3	1.00	800.0	0.00
3	2.00	1000.0	0.00
3	3.00	1500.0	0.00
3	4.00	5000.0	0.01
4	1.00	5000.0	0.01
4	2.00	6000.0	0.02
4	3.00	7000.0	0.02
4	4.00	8000.0	0.03

*** TABULATION OF DRAWDOWN AT EACH TIME PERIOD

(POINT OF INTEREST : X-COORD = 100, Y-COORD = 70,)

TIME AFTER PUMPING STARTS (DAYS)	DRAWDOWN AT POINT OF INTEREST (MT)
1.	0.80
2.	1.00
3.	1.26
4.	2.04

** CONVERGENCE LIMIT = 0.05 MT. **

THE DATA CARDS USED IN THIS EXAMPLE ARE :

```
? USER 884264/YOUSEA
? RUN NAJHAN
? DATA DATH
1,0,0
   EXAMPLE ON GRAPH OF DRAWDOWN VS. TIME
   NRUDS=   1 NPNTS=    1 NWELLS=    1 KPROD= 7 CONV=.05   0 1
   TH=0.     CB=50.    HT=+1.
   XP=0.     YP=98.
 XW=500.0   YW=100.0   WT=+1.    QC=500.0  RI=7500.  GM=1.00
    P=  1.0E03   THCK= 100.   CST= 1.0E-01   H'= 150.   P'=  1.0E02
0.000005,1.75
2,1,5.,1,1,0,1.
? END
```

**** EXAMPLE ON GRAPH OF DRAWDOWN VS. TIME

**** TYPE OF ANALYSIS : FULLY PENETRATING WELLS IN LEAKY ARTESIAN AQUIFER
----------------- - WITHOUT WATER RELEASED FROM STORAGE IN AQUITARD
- NON-EQUILIBRIUM CONDITIONS

*** AQUIFER CHARACTERISTICS

PERMEABILITY	1000. GPD/FTSQ
THICKNESS OF AQUIFER	100. FT
COEFFICIENT OF STORAGE	.100E+00
THICKNESS OF AQUITARD	150. FT
PERMEABILITY OF AQUITARD	100.GPD/SQFT

*** BOUNDARIES

NO.	ANGLE WITH X-AXIS (DEG.)	INTERCEPT (FT)	BOUNDARY TYPE
1	0.	Y= 50.0	BARRIER

** ANALYSIS OF GEOMETRY

NUMBER OF SINGLES = 1

NUMBER OF INTERSECTIONS = 0

NUMBER OF PARALLELS = 0

*** REAL WELL DATA

NO.	X-AXIS (FT)	Y-AXIS (FT)	WELL TYPE	RADIUS OF INFLUENCE(FT)	PENETRA-TION	WELL LOSS CONSTANT	EXPONENT
1	500.	100.	DISCHARGE	7500.	1.00	.00000	1.750

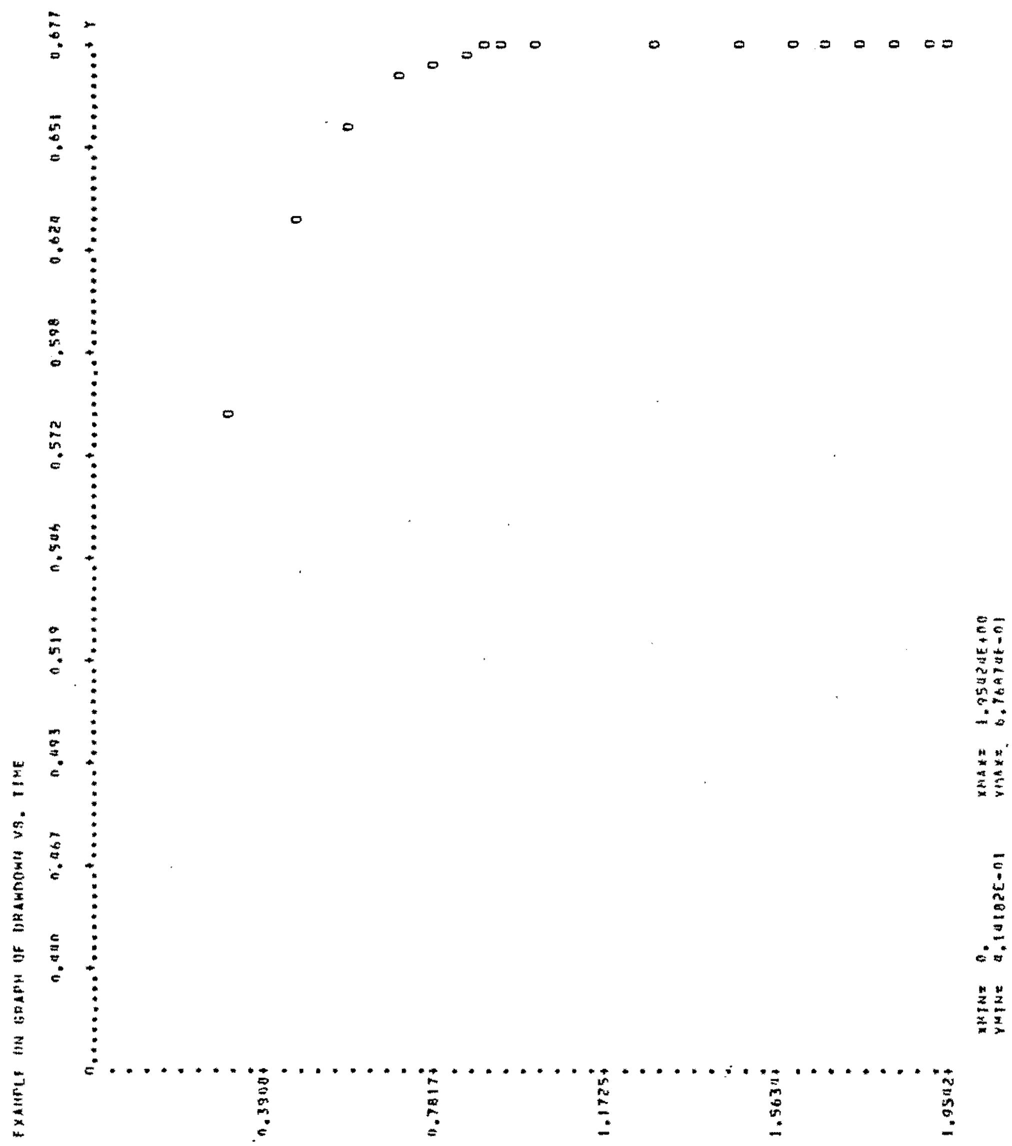
*** PUMPING RATES AND WELL LOSSES

NO.	TIME (DAYS)	PUMPING RATE (GPM)	WELL LOSSES (FT)
1	90.00	500.0	0.26

*** TABULATION OF DRAWDOWN AT EACH TIME PERIOD

(POINT OF INTEREST : X-COORD = 0. Y-COORD = 98.)

TIME AFTER PUMPING STARTS (DAYS)	DRAWDOWN AT POINT OF INTEREST (FT)
1.	0.41
2.	0.58
3.	0.63
4.	0.66
5.	0.67
6.	0.67
7.	0.67
8.	0.68
9.	0.68
10.	0.68
20.	0.68
30.	0.68
40.	0.68
50.	0.68
60.	0.68
70.	0.68
80.	0.68
90.	0.68


EXAMPLE OF GRAPH OF DRAWDOWN VS. TIME
0.440
0.467
0.493
0.519
0.546
0.572
0.598
0.624
0.651
0.677
Y
0.
0.3908
0.7817
1.1725
1.5634
1.9542
XMIN= 0.
YMIN= 4.14182E-01
XMAX= 1.95424E+00
YMAX= 6.76874E-01

```
THE DATA CARDS USED IN THIS EXAMPLE ARE :


? USER 804264/YOUSRA

? RUN NAJWAN

? DATA DAIM

1,1,0

  EXAMPLE:  PARALLEL BOUNDARIES, S.I.SYSTEM OF UNTIS, TIME IN MINUTES

  NBNDS=   2 NPNTS=    1 NWELLS=    1 KPROB= 9 CONV=.01   1 0

  TH=00.    CB=30.00  DT=+1.

  TH=00.    CB=70.0   DT=+1.

  XP=50.    YP=50.

 XW=48.     YW=50.0    WT=+1.    DC=500.0  RI=7500.  GM=1.00

   P=  1.0E03   THCK= 100.   CST= 2.3E-03   M'=  50.   P'=  1.0E03  S'= 1.0E-04

0.00001,1.75

1,1,9999.,0,1,0,1.,

? END
```

CONTRIBUTIONS TO TOTAL DRAWDOWN AT POINT OF INTEREST NO 1
BY REAL WELL NO 1 AND ITS ASSOCIATED IMAGE WELL SYSTEM
WITH A DISCHARGE OF 6000.00 CM/D

NO	TYPE	X COORD MT	Y COORD MT	RADIUS MT	TIME MINS	DRAWDOWN MT	CUMULATIVE DRAWDOWN MT
1	REAL	48.0	50.0	2.0	9999.00	1.243	1.243
2	IMAGE	48.0	10.0	40.0	9999.00	0.278	1.521
3	IMAGE	48.0	130.0	80.0	9999.00	0.124	1.644
4	IMAGE	48.0	-70.0	120.0	9999.00	0.059	1.703
5	IMAGE	48.0	210.0	160.0	9999.00	0.029	1.732
6	IMAGE	48.0	90.0	40.0	9999.00	0.278	2.010
7	IMAGE	48.0	-30.0	80.0	9999.00	0.124	2.134
8	IMAGE	48.0	170.0	120.0	9999.00	0.059	2.192
9	IMAGE	48.0	-110.0	160.0	9999.00	0.029	2.222

TOTAL CONTRIBUTION 2.222

**** EXAMPLE: PARALLEL BOUNDARIES, S.I.SYSTEM OF UNITS, TIME IN MINUTES

**** TYPE OF ANALYSIS : FULLY PENETRATING WELLS IN LEAKY ARTESIAN AQUIFER
- WITH WATER RELEASED FROM STORAGE IN AQUITARD
- NON-EQUILIBRIUM CONDITIONS

*** AQUIFER CHARACTERISTICS

PERMEABILITY	1000. M/D
THICKNESS OF AQUIFER	100. MT
COEFFICIENT OF STORAGE	.230E-02
THICKNESS OF AQUITARD	49. MT
PERMEABILITY OF AQUITARD	1000.M/D
COFF. OF STORAGE OF AQUITARD	.100E-03

*** BOUNDARIES

NO.	ANGLE WITH X-AXIS (DEG.)	INTERCEPT (MT)	BOUNDARY TYPE
1	0.	Y= 30.0	BARRIER
2	0.	Y= 70.0	BARRIER

** ANALYSIS OF GEOMETRY

NUMBER OF SINGLES = 0

NUMBER OF INTERSECTIONS = 0

NUMBER OF PARALLELS = 1

*** REAL WELL DATA

NO.	X-AXIS (MT)	Y-AXIS (MT)	WELL TYPE	RADIUS OF INFLUENCE(MT)	PENETRA-TION	WELL LOSS CONSTANT	EXPONENT
1	40.	50.	DISCHARGE	7500.	1.00	.00001	1.750

*** PUMPING RATES AND WELL LOSSES

NO.	TIME (MINS)	PUMPING RATE (CM/D)	WELL LOSSES (MT)
1	9999.00	6000.0	0.38

*** TABULATION OF DRAWDOWN AT EACH POINT OF INTEREST

(TIME AFTER PUMPING STARTS : 9999.00 (MINS))

NO.	POINTS OF INTEREST (MT) X-COORDS	Y-COORDS	DRAWDOWN (MT)
1	50.0	50.0	2.22

** CONVERGENCE LIMIT = 0.05 MT. **

THE DATA CARDS USED IN THIS EXAMPLE ARE :

```
? USER P04264/YOUSRA
? RUN NAJWAN
? DATA DAIM
1,1,1
   EXAMPLE: DRAWDOWN COMPONENT TABLE, VARIABLE PUMPING RATE
   NANDS=   2 NPNTS=     1 NWELLS=     4 KPROB= 5 CONV=.05    0 0
   TH=0.      CB= 0.0   BT=+1.
   TH=90.     CB= 0.0   BT=+1.
   XP=2.00    YP=2.00
 XW= 5.00    YW= 5.00    WT=+1.     QC= 500.  RI=2500.  GM=0.25
 XW=25.00    YW=25.00    WT=+1.     QC= 500.  RI=2000.  GM=0.75
 XW= 5.00    YW=25.00    WT=+1.     QC= 500.  RI=1500.  GM=0.5
 XW=25.00    YW= 5.00    WT=+1.     QC= 500.  RI=3500.  GM=0.5
   PERM=  5.0E02 THCK=307.  CSI= 4.0E-02
0.00001,1.56,0.00001,1.75,0.000005,1.6,0.00001,1.85
2,0,5,5,1,3,1.,
0.,0.,0.,0.,500.,600.,700.,800.,750.,800.,1000.,500.,1000.,1000.,1500.,0.,
? END
```

**** EXAMPLE: DRAWDOWN COMPONENT TABLE, VARIABLE PUMPING RATE

**** TYPE OF ANALYSIS : PARTIALLY PENETRATING WELLS IN ARTESIAN AQUIFER
----------------- - NON-EQUILIBRIUM CONDITIONS

*** AQUIFER CHARACTERISTICS

PERMEABILITY	500. M/D
THICKNESS OF AQUIFER	307. MT
COEFFICIENT OF STORAGE	.400E-01

*** BOUNDARIES

NO.	ANGLE WITH X-AXIS (DEG.)	INTERCEPT (MT)		BOUNDARY TYPE
1	0.	Y=	0.0	BARRIER
2	90.	X=	0.0	BARRIER

** ANALYSIS OF GEOMETRY

NUMBER OF SINGLES = 0

NUMBER OF INTERSECTIONS = 1

NUMBER OF PARALLELS = 0

*** REAL WELL DATA

NO.	X-AXIS (MT)	Y-AXIS (MT)	WELL TYPE	RADIUS OF INFLUENCE(MT)	PENETRA-TION	WELL LOSS CONSTANT	EXPONENT
1	5.	5.	DISCHARGE	2500.	0.25	.00001	1.560
2	25.	25.	DISCHARGE	2000.	0.75	.00001	1.750
3	5.	25.	DISCHARGE	1500.	0.50	.00000	1.600
4	25.	5.	DISCHARGE	3500.	0.50	.00001	1.850

*** PUMPING RATES AND WELL LOSSES

NO.	TIME (DAYS)	PUMPING RATE (CM/D)	WELL LOSSES (MT)
1	1.00	500.0	0.00
1	2.00	750.0	0.00
1	3.00	1000.0	0.01
2	1.00	600.0	0.01
2	2.00	800.0	0.01
2	3.00	1000.0	0.02
3	1.00	700.0	0.00
3	2.00	1000.0	0.01
3	3.00	1500.0	0.01
4	1.00	800.0	0.02
4	2.00	500.0	0.01
4	3.00	0.0	0.00

*** TABULATION OF DRAWDOWN AT EACH TIME PERIOD

(POINT OF INTEREST 1 X-COORD = 2. Y-COORD = 2.)

TIME AFTER PUMPING STARTS (DAYS)	DRAWDOWN AT POINT OF INTEREST (MT)
1.	1.78
2.	2.34
3.	2.87

*** DRAWDOWN COMPONENTS

WELL NO.	EFFECT OF WELL ONLY (MT)	PARTIAL PENETRATION EFFECT BY WELL (MT)	EFFECT OF BOUNDARIES ONLY (MT)	PARTIAL PENETRATION EFFECT BY BOUNDARIES (MT)	TOTAL EFFECT (MT)
TIME INCREMENT NO 1					
TOTAL DRAWDOWN IS 1.78					
1	0.08	0.13	0.19	1.04	0.71
2	0.05	0.01	0.16	0.06	0.28
3	0.06	0.04	0.19	0.32	0.39
4	0.07	0.04	0.22	0.37	0.44
TIME INCREMENT NO 2					
TOTAL DRAWDOWN IS 2.34					
1	0.32	0.51	0.09	0.52	1.09
2	0.24	0.03	0.05	-0.02	0.32
3	0.33	0.15	0.08	0.14	0.60
4	0.31	0.14	-0.08	-0.14	0.33
TIME INCREMENT NO 3					
TOTAL DRAWDOWN IS 2.87					
1	0.48	0.73	0.09	0.52	1.46
2	0.33	0.04	0.05	0.02	0.43
3	0.49	0.22	0.14	0.23	0.92
4	0.19	0.07	-0.14	-0.23	0.06

THE DATA CARDS USED IN THIS EXAMPLE ARE :

```
? USER 804264/YOUSRA
? RUN NAJWAN
? DATA DATH
1,1,0
EXAMPLE; THREE PERPENDICULAR BOUNDARIES , GRAPH OF DRAWDOWN VS. DISTANCE
   NBNDS=   3 NPNTS=   15 NWELLS=    1 KPROB= 4 CONV=.05   0 1
   TH=90.     CB=15.    BT=+1.
   TH=90.     CB=-15.   BT=+1.
   TH=00.     CB=0.000  BT=-1.
   XP=0.      YP=10.
   XP=0.      YP=20.
   XP=0.      YP=30.
   XP=0.      YP=40.
   XP=0.      YP=50.
   XP=0.      YP=60.
   XI=0.      YP=70.
   XP=0.      YP=80.
   XP=0.      YP=90.
   XP=0.      YP=100.
   XP=0.      YP=200.
   XP=0.      YP= 300.
   XP=0.      YP=400.
   XP=0.      YP=500.
   XP=0.      YP=600.
 XW=000.0   YW=  5.0   WT=+1.    QC=2700.  RI=2000.  GM=1.00
    TXX=.704E+05 TYY=.621E+05 TXY=.599E+03 CST=.360E-02
0,000006,1.75
1,0,5.,3,1,0,1.,
? END
```

```
****  EXAMPLE; THREE PERPENDICULAR BOUNDARIES , GRAPH OF DRAWDOWN VS. DISTANCE

****  TYPE OF ANALYSIS : FULLY PENETRATING WELL IN ARTESIAN ANISOTROPIC AQUIFER
      ----------------   -NON-EQUILIBRIUM CONDITIONS

 ***  AQUIFER CHARACTERISTICS
      ----------------------

         ANISOTROPIC TRANSMISSIBILITIES ARE

         TXX                                        .704E+05  MTSQ/D

         TYY                                        .621E+05  MTSQ/D

         TXY                                        .599E+03  MTSQ/D

         COEFFICIENT OF STORAGE                     .360E-02

 ***  BOUNDARIES
      ----------

        NO.    ANGLE WITH     INTERCEPT     BOUNDARY
              X-AXIS (DEG.)     (MT)          TYPE

         1          90.        X=    15.0   BARRIER

         2          90.        X=   -15.0   BARRIER

         3           0.        Y=     0.0   RECHARGE

  **  ANALYSIS OF GEOMETRY
      --------------------

        NUMBER OF SINGLES =        1

        NUMBER OF INTERSECTONS =   0

        NUMBER OF PARALLELS =      1

 ***  REAL WELL DATA
      --------------
     NO. X-AXIS  Y-AXIS   WELL      RADIUS OF   PENETRA-  WELL LOSS  EXPONENT
          (MT)    (MT)    TYPE   INFLUENCE(MT)   TION     CONSTANT

     1     0.       5. DISCHARGE   2000.        1.00      .00001     1.750
```

*** PUMPING RATES AND WELL LOSSES

NO.	TIME (DAYS)	PUMPING RATE (CM/D)	WELL LOSSES (MT)
1	5.00	2700.0	0.10

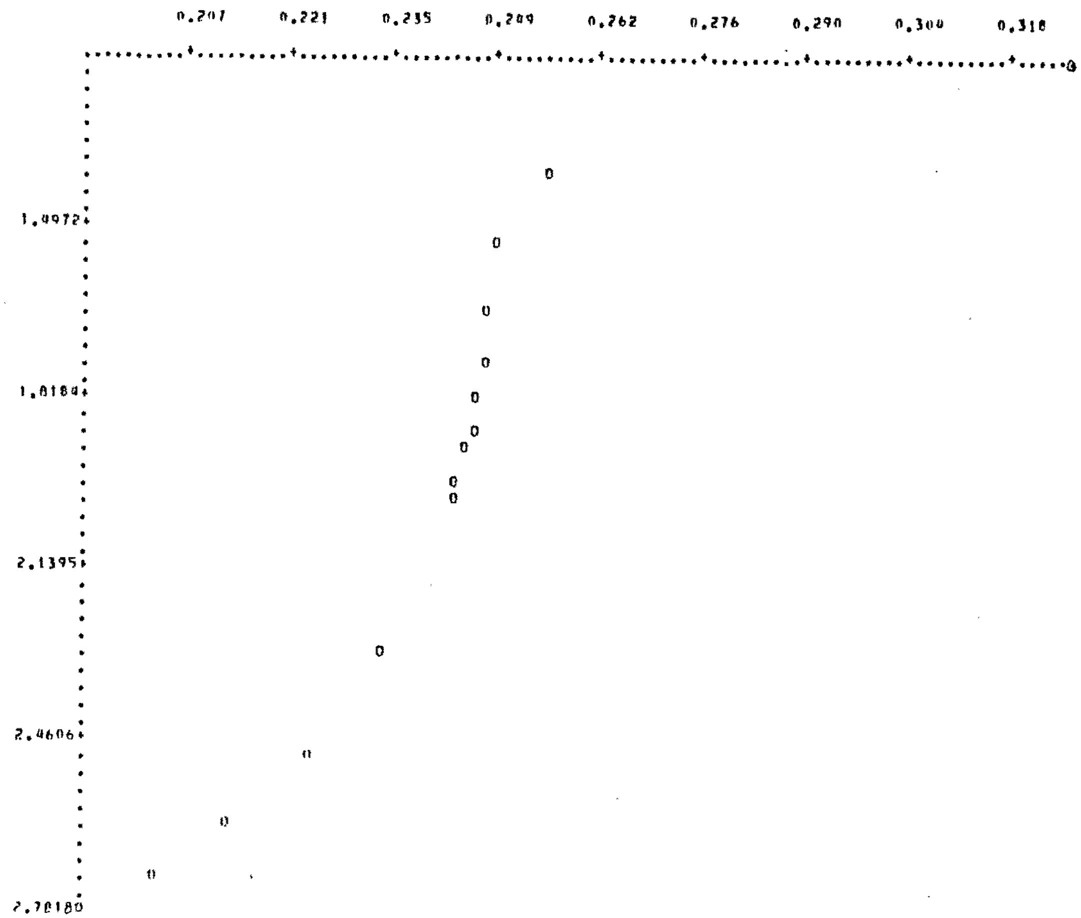
*** TABULATION OF DRAWDOWN AT EACH POINT OF INTEREST

(TIME AFTER PUMPING STARTS : 5.00 (DAYS))

NO.	POINTS OF INTEREST (MT) X-COORDS	Y-COORDS	DRAWDOWN (MT)
1	0.0	10.0	0.33
2	0.0	20.0	0.26
3	0.0	30.0	0.25
4	0.0	40.0	0.25
5	0.0	50.0	0.25
6	0.0	60.0	0.25
7	0.0	70.0	0.25
8	0.0	80.0	0.24
9	0.0	90.0	0.24
10	0.0	100.0	0.24
11	0.0	200.0	0.23
12	0.0	300.0	0.22
13	0.0	400.0	0.21
14	0.0	500.0	0.20
15	0.0	600.0	0.19

** CONVERGENCE LIMIT = 0.05 MT. **

EXAMPLE: THREE PERPENDICULAR BOUNDARIES , GRAPH OF DRAWDOWN VS. DISTANCE



XMIN= 1.176091 XMAX= 2.781755
YMIN= 0.193334 YMAX= 0.331382

THE DATA CARDS USED IN THIS EXAMPLE ARE :

```
? USER 804264/YOUSRA
? RUN HAJWAN
? DATA DATH
1,1,0
   EXAMPLE: FOUR BOUNDARIES, INJECTION WELL
   NBNDS=  4 NPNTS=    1 NWELLS=    1 KPROB= 1 CONV=.04   1 0
   TH=0.      CB=100.0  BT=-1.
   TH=0.      CB=0.     BT=-1.
   TH= 90.    CB=300.   BT=-1.
   TH= 90.    CB= 00.   BT=-1.
   XP=200.    YP=200.
 XW=100.0   YW=100.0   WT=-1.    QC= 500.  RI=2500.  GM=1.00
   PERM=5.00E+01 THCK= 50.0 CST=0.50E-03 HO=50.0
0.00009,1.235.
1,0,30.,3,1,0,1.
? END
```

CONTRIBUTIONS TO TOTAL DRAWDOWN AT POINT OF INTEREST NO 1
BY REAL WELL NO 1 AND ITS ASSOCIATED IMAGE WELL SYSTEM
WITH A DISCHARGE OF 500.00 CM/D

NO	TYPE	X COORD MT	Y COORD MT	RADIUS MT	TIME DAYS	DRAWDOWN MT	CUMULATIVE DRAWDOWN MT
1	REAL	100.0	100.0	141.4	EQUIP	-0.091	-0.091
2	IMAGE	100.0	500.0	316.2	EQUIP	-0.066	-0.157
3	IMAGE	100.0	-500.0	707.1	EQUIP	-0.040	-0.197
4	IMAGE	100.0	1100.0	905.5	EQUIP	-0.032	-0.230
5	IMAGE	100.0	-100.0	316.2	EQUIP	-0.066	-0.295
6	IMAGE	100.0	700.0	509.9	EQUIP	-0.051	-0.346
7	IMAGE	100.0	-700.0	905.5	EQUIP	-0.032	-0.378
8	IMAGE	500.0	500.0	424.3	EQUIP	-0.056	-0.435
9	IMAGE	-500.0	500.0	761.6	EQUIP	-0.038	-0.473
10	IMAGE	-100.0	500.0	424.3	EQUIP	-0.056	-0.529
11	IMAGE	700.0	500.0	583.1	EQUIP	-0.046	-0.575
12	IMAGE	-700.0	500.0	948.7	EQUIP	-0.031	-0.606
13	IMAGE	500.0	-500.0	761.6	EQUIP	-0.038	-0.644
14	IMAGE	-100.0	-500.0	761.6	EQUIP	-0.038	-0.682
15	IMAGE	500.0	1100.0	948.7	EQUIP	-0.031	-0.713
16	IMAGE	-100.0	1100.0	948.7	EQUIP	-0.031	-0.743
17	IMAGE	500.0	-100.0	424.3	EQUIP	-0.056	-0.800
18	IMAGE	-500.0	-100.0	761.6	EQUIP	-0.038	-0.838
19	IMAGE	-100.0	-100.0	424.3	EQUIP	-0.056	-0.894
20	IMAGE	700.0	-100.0	583.1	EQUIP	-0.046	-0.941
21	IMAGE	-700.0	-100.0	948.7	EQUIP	-0.031	-0.971
22	IMAGE	500.0	700.0	583.1	EQUIP	-0.046	-1.018
23	IMAGE	-500.0	700.0	860.2	EQUIP	-0.034	-1.052
24	IMAGE	-100.0	700.0	583.1	EQUIP	-0.046	-1.098

25	IMAGE	700.0	700.0	707.1	EQUIP	-0.040	-1.138
26	IMAGE	-700.0	700.0	1029.6	EQUIP	-0.028	-1.166
27	IMAGE	500.0	-700.0	948.7	EQUIP	-0.031	-1.197
28	IMAGE	-100.0	-700.0	948.7	EQUIP	-0.031	-1.228
29	IMAGE	500.0	100.0	316.2	EQUIP	-0.066	-1.290
30	IMAGE	-500.0	100.0	707.1	EQUIP	-0.040	-1.338
31	IMAGE	1100.0	100.0	905.5	EQUIP	-0.032	-1.366
32	IMAGE	-100.0	100.0	316.2	EQUIP	-0.066	-1.432
33	IMAGE	700.0	100.0	509.9	EQUIP	-0.051	-1.483
34	IMAGE	-700.0	100.0	905.5	EQUIP	-0.032	-1.515

TOTAL CONTRIBUTION -1.515

**** EXAMPLE: FOUR BOUNDARIES, INJECTION WELL

**** TYPE OF ANALYSIS : FULLY PENETRATING WELL IN ARTESIAN AQUIFER
- EQUILIBRIUM CONDITIONS

*** AQUIFER CHARACTERISTICS

PERMEABILITY	50. M/D
THICKNESS OF AQUIFER	50. MT

*** BOUNDARIES

NO.	ANGLE WITH X-AXIS (DEG.)	INTERCEPT (MT)	BOUNDARY TYPE
1	0.	Y= 300.0	BARRIER
2	0.	Y= 0.0	BARRIER
3	90.	X= 300.0	BARRIER
4	90.	X= 0.0	BARRIER

** ANALYSIS OF GEOMETRY

NUMBER OF SINGLES = 0

NUMBER OF INTERSECTORS = 0

NUMBER OF PARALLELS = 2

*** REAL WELL DATA

NO.	X-AXIS (MT)	Y-AXIS (MT)	WELL TYPE	RADIUS OF INFLUENCE(MT)	PENETRA-TION	WELL LOSS CONSTANT	EXPONENT
1	100.	100.	RECHARGE	2500.	1.00	.00009	1.235

*** PUMPING RATES AND WELL LOSSES

NO.	TIME (DAYS)	PUMPING RATE (CM/D)	WELL LOSSES (MT)
1	30.00	500.0	0.01

*** TABULATION OF DRAWDOWN AT EACH POINT OF INTEREST

NO.	POINTS OF INTEREST (MT) X-COORDS	Y-COORDS	DRAWDOWN (MT)
1	200.0	200.0	-1.51

** CONVERGENCE LIMIT = 0.04 MT. **

THE DATA CARDS USED IN THIS EXAMPLE ARE :

```
? USER 804260/YOUSPA
? RUN NAJHAN
? DATA DATH
1,0,0
   EXAMPLE: WELL SPACING DESIGN
   NBNDS=   1 NPNTS=    1  WELLS=    7 KPROD= 3 CONV=.05   0 0
   TH=90.    CB=15000. DT=+1.
   XP=1251.6 YP=998.7
 XW=1250.6      998.7   WT=+1.    QC=107.1  RI=2000.0 GM=1.00
 XW=-1250.6     998.7   WT=+1.    QC=107.1  RI=2000.0 GM=1.00
 XW=-1560.0     -355.2  WT=+1.    QC=107.1  RI=2000.0 GM=1.00
 XW=1560.0      -355.2  WT=+1.    QC=107.1  RI=2000.0 GM=1.00
 XW=694.5       -1441.4 WT=+1.    QC=107.1  RI=2000.0 GM=1.00
 XW=-694.5      -1441.4 WT=+1.    QC=107.1  RI=2000.0 GM=1.00
 XW=0.0         1600.0  WT=+1.    QC=107.1  RI=2000.0 GM=1.00
   PERM=4.00E+02 THCK=120.0 CST=0.50E-03 HO=40.0
.00001,1.75,.00001,1.75,.00001,1.75,.00001,1.75,.00001,1.75,.00001,1.75
0,00001,1.75
1,0,5.,3,1,0,1.,
? END
```

```
****     EXAMPLE: WELL SPACING DESIGN

****   TYPE OF ANALYSIS : FULLY PENETRATING WELL IN ARTESIAN AQUIFER
       ---------------   - NON-EQUILIBRIUM CONDITIONS

 ***   AQUIFER CHARACTERISTICS
       ----------------------

          PERMEABILITY                          400. GPD/FTSQ
          THICKNESS OF AQUIFER                  120. FT
          COEFFICIENT OF STORAGE                  .500E-03

 ***   BOUNDARIES
       ----------

         NO.     ANGLE WITH      INTERCEPT     BOUNDARY
              X-AXIS (DEG.)        (FT)         TYPE

          1          90.         X= 15000.0    BARRIER

  **   ANALYSIS OF GEOMETRY
       -------------------

         NUMBER OF SINGLES =        1
         NUMBER OF INTERSECTONS =   0
         NUMBER OF PARALLELS =      0

 ***  REAL WELL DATA
      --------------
      NO. X-AXIS  Y-AXIS    WELL       RADIUS OF   PENETRA-  WELL LOSS  EXPONENT
           (FT)    (FT)     TYPE    INFLUENCE(FT)  TION      CONSTANT

      1    1251.     999. DISCHARGE   2000.        1.00      .00001      1.750
      2   -1251.     999. DISCHARGE   2000.        1.00      .00001      1.750
      3   -1560.    -355. DISCHARGE   2000.        1.00      .00001      1.750
      4    1560.    -355. DISCHARGE   2000.        1.00      .00001      1.750
      5     695.   -1441. DISCHARGE   2000.        1.00      .00001      1.750
      6    -695.   -1441. DISCHARGE   2000.        1.00      .00001      1.750
      7       0.    1600. DISCHARGE   2000.        1.00      .00001      1.750
```

*** PUMPING RATES AND WELL LOSSES

NO.	TIME (DAYS)	PUMPING RATE (GPM)	WELL LOSSES (FT)
1	5.00	107.1	0.04
2	5.00	107.1	0.04
3	5.00	107.1	0.04
4	5.00	107.1	0.04
5	5.00	107.1	0.04
6	5.00	107.1	0.04
7	5.00	107.1	0.04

*** TABULATION OF DRAWDOWN AT EACH POINT OF INTEREST

(TIME AFTER PUMPING STARTS : 5.00 (DAYS))

NO.	POINTS OF INTEREST (FT) X-COORDS	Y-COORDS	DRAWDOWN (FT)
1	1251.6	998.7	10.06

** CONVERGENCE LIMIT = 0.05 FT. **