Program Documentation
And
User's Manual

Well Field Drawdown Model

IMAGEW-I

Prepared By

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And
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TABLE OF CONTENTS

LIST OF FIGURES

PREFACE

IMAGEW-I, documented herein, presents a methodology for evaluating the drawdown produced from pumping one or more wells in a well field located in either a confined or unconfined homogeneous aquifer. This drawdown can be evaluated at various locations in the aquifer for various elapsed times since pumping has started.

The well drawdown model, IMAGEW-I, utilizes as input the engineering properties of the aquifer, pumping/recharge rates for selected time intervals, and the coordinate locations for all wells (both operating wells and observation wells) in the well field.

The output from the well drawdown model is a table of drawdown levels at every observation well for various elapsed times since pumping began.

The IMAGEW-I model was programmed and tested by Bill Klemt of the San Antonio District Office and William A. White of the Systems Engineering Division of the Texas Water Development Board. This model is essentially a combination of models developed by J.R. Mount, Project Geologist in the Los Angeles Office of Dames and Moore and Bill Klemt.

WELL FIELD DRAWDOWN MODEL
IMAGEW-I

PURPOSE

When ground water is pumped from one or more water wells of a well field, it is often necessary to predict the ground water level changes expected to take place in the field as a result of this pumping. Such predictions are needed because the economics of well field design is greatly affected by the depth of the water level below the ground surface in the pumping wells. If the water level in the wells is lowered excessively, pumping costs increase and, in some cases, the volume of water which can be pumped decreases. In addition, the anticipated future water levels in the wells must also be known in order to set the pumps deep enough in the initial installation.

The computer program described in this documentation allows the rapid solution of complex well field problems when manual solution would be too time-consuming for practical applications. The program is designed to evaluate the drawdown produced from pumping one or more wells in a well field located in a confined or unconfined aquifer. This drawdown can be evaluated at various locations in the aquifer at various time intervals since pumping began.

The computer program can be applied to the solution of some of the following problems:

1. Analysis of existing well fields to predict changes in drawdown produced by increasing or decreasing the pumping rates of existing wells or by adding or removing wells in the system.

2. Design of future well fields to provide maximum production while maintaining adequate water levels.

3. Analysis of well field pumping data to evaluate aquifer characteristics by comparing theoretical drawdown predictions with recorded water levels.

Other applications, such as those connected with ground water basin management, could also make good use of this computer program when combined with analytical tools designed to evaluate the factors involved in the design and operation of ground water basins.

RESTRICTIONS

1. Maximum number of observation wells is 50.
2. Maximum number of operating wells (real and image) is 200.
3. Maximum number of pumping periods is 6.

SOLUTION OPTIONS

The IMAGEW-I model allows the hydrologist three options when solving for individual well drawdown within a proposed or real well field. Option 1 is the nonleaky artesian solution, option 2 utilizes the nonleaky artesian solution with a water table correction in order to simulate pumping and well drawdown under water-table conditions with no recharge, and option 3 utilizes the steady state solution in order to simulate pumping and well drawdown in water-table conditions with uniform annual recharge. Below the hydrologist will find a brief description of each of the options found within IMAGEW-I.

Option 1

The nonleaky artesian solution is used when simulating a well field in an artesian aquifer and when aquifer leakage is not measurable. The nonleaky artesian formula was introduced by Theis (1935) and can be written as

$$s = (114.6\ Q/T)\ W(u) \tag{1}$$

where

$$W(U) = \int_u^\infty e^{-u}/udu = -0.5772 - \ln u + u - (u^2/2\cdot 2!) + (u^3/3\cdot 3!) - (u^4/4\cdot 4!)\ .\ .\ .\ . \tag{2}$$

u = $2693\ r^2\ S/Tt$, (3)

s = drawdown in observation well in feet,

Q = discharge in gpm,

T = coefficient of transmissibility in gpd/ft.,

r = distance from observation well to pumped well in feet,

S = coefficient of storage, and

t = time after pumping started in minutes.

The Theis non-equilibrium equation can be modified to include the interference effects from multiple pumping wells and changes in the pumping rates of one or more of the wells. The relationship between one pumping well and one observation well for a given pumping period can be expressed with Equation 1 as

$$s_{j,n} = \frac{114.6\ \Delta Q_{n,i}}{T} \int_u^\infty \frac{e^{-u}}{udu} \tag{4}$$

where

$$u = \frac{2693\, r_{i,j}^2}{ST\, \Delta t_n} \tag{5}$$

j = the number of the observation well,

n = the number of the pumping period,

i = the number of the pumping well,

$\Delta Q_{n,i}$ = the incremental change in pumping from pumping period n-1 to n for pumping well i in gpm, and

Δt_n = length of pumping period n in minutes.

The drawdown for one observation well due to more than one pumping well is expressed as

$$s_{j,n} = \sum_{n=1}^{N} \sum_{i=1}^{I} \frac{114.6\, \Delta Q_{n,i}}{T} \int_u^{\infty} \frac{e^{-u}\, du}{u} \tag{6}$$

where

N = the total number of pumping periods, and

I = the total number of pumping wells.

Option 2

Option 1 works very well when simulating a well field in a water-table aquifer when there is no precipitation recharge and the solution is corrected for dewatering. Option 2 uses the nonleaky formula and corrects the results for dewatering. Recharge to a water-table aquifer is seasonal in Texas with recharge coming in the spring and fall. During periods when no recharge takes place, the water withdrawn must come from storage. Option 2 will indicate if the water-table aquifer has enough water in storage to carry the proposed well or well field over the drought period.

Under water-table conditions, water is removed from storage by gravity drainage toward the point of discharge. Gravity drainage within the aquifer decreases the saturated thickness and, therefore, reduces the transmissibility of the aquifer. Option 2, using the nonleakly artesian solution, compensates for the decrease in aquifer thickness by use of the following equation which was derived by Jacob (1944)

$$s' = s - (s^2/2m) \tag{7}$$

where

s' = drawdown that would occur in an equivalent nonleaky artesian aquifer not affected by gravity drainage in feet, from Equation 1,

s = observed drawdown which is affected by gravity drainage in feet, and

m = initial saturated thickness of the water-table aquifer in feet.

Option 3

Option 3 uses the steady state solution where simulating a well field in a water-table aquifer with the major source of recharge being precipitation. Option 3 will indicate the practical sustained yield for a well or well field in a water-table aquifer. The formula for the steady state solution was used by Walton (1962) and can be written as

$$s = (114.6\ A/T)\ R(Z) \tag{8}$$

where

$$R(Z) = (Z - \log Z - 1), \tag{9}$$

$$Z = \frac{r^2 W}{2.68 \times 10^5 Q} \tag{10}$$

s = drawdown in observation well in feet,
T = coefficient of transmissibility in gpd/ft.,
Q = discharge in gpm,
W = ground water recharge in inches per year, and
r = distance from pumped well in feet.

Options 2 and 3 should both be utilized when evaluating a water-table aquifer.

Equation 8 can be written for one observation well to consider more than one pumping well as

$$s_j = \sum_{i=1}^{I} \frac{114.6\ Q_i}{T}\ R(Z_{i,j}) \tag{11}$$

where

$$R(Z_{i,j}) = (Z_{i,j} - \log Z_{i,j} - 1), \tag{12}$$

$$Z_{i,j} = \frac{{r_{i,j}}^2 W}{2.68 \times 10^5\ Q_i}, \tag{13}$$

j = the number of the observation well,
i = the number of the pumping well, and
I = the total number of pumping wells.

The limit of applicability of Equation 12 is $1.0 \leq r \leq r_e$ where $r_e = 516.0\ Q/W$.

SIMULATION OF AQUIFER BOUNDARIES

IMAGEW-I simulates geohydrologic boundaries by means of the image-well theory described by Ferris (1959). Image-well theory as it relates to the simulation of ground water aquifers is as follows: the effect of a barrier or recharge boundary on the drawdown of a pumping well is as though the aquifer were infinite and a discharging or recharging well (imaginary) was located across the boundary, perpendicular thereto and the same distance from the boundary as the real pumping well. The recharge or pump rate for the image well is the same as the real well. A negative pump rate in the IMAGEW-I model signifies recharge. Thus, IMAGEW-I models boundary problems as an infinite aquifer in which real and image wells operate simultaneously.

Most geohydrologic boundaries do not occur as abrupt boundaries, however it is often possible to treat them as such. Figure 1, an idealized section through a discharging well illustrates the use of a discharging image well to simulate an impermeable barrier. In order to simulate a recharge boundary the discharging image well would be changed to a recharging image well.

The image-well system for a discharging well in an aquifer bounded by right angle boundaries is shown in Figure 2. The image-well system for a discharging well in an aquifer bounded by parallel boundaries is shown in Figure 3. A recharging well, I_1, and the discharging image well, I_2, are placed as shown; these wells produce the desired effects for each boundary. However, each image well produces a residual effect at the opposite boundary which must be eliminated. It therefore becomes necessary to add a secondary set of image wells, I_3 and I_4, and so on. *The hydrologist should add only as many image wells as are needed for the practical solution of the problem.*

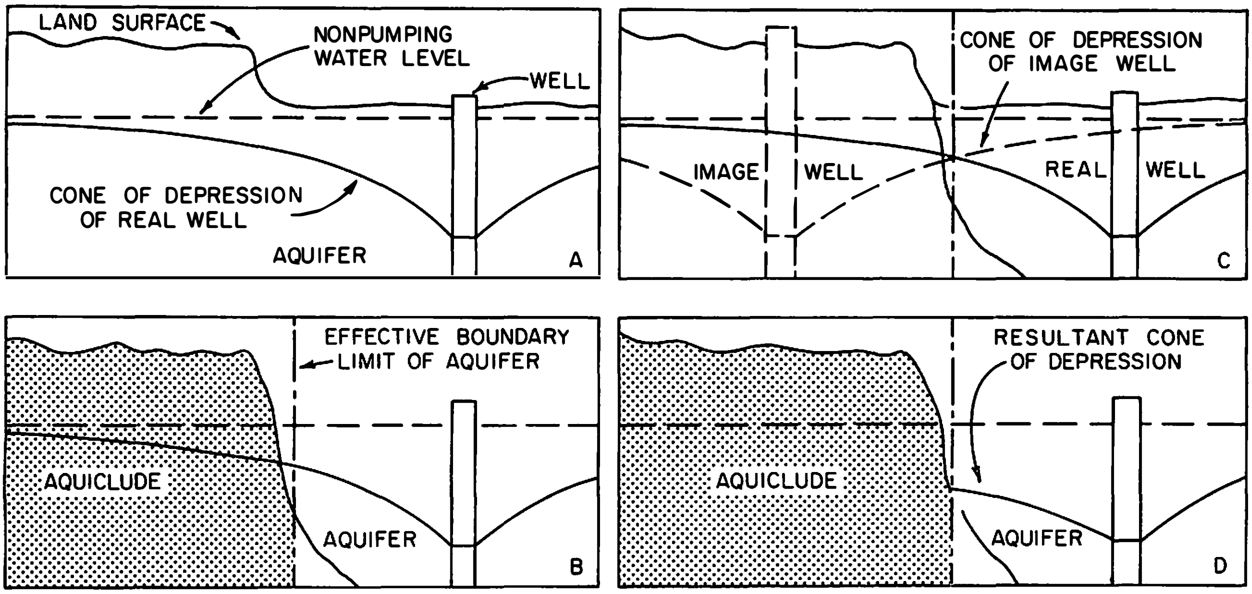


Figure 1

Idealized section through a discharging well illustrating the use of a discharging image well to simulate an impermeable barrier (From Walton, 1962)

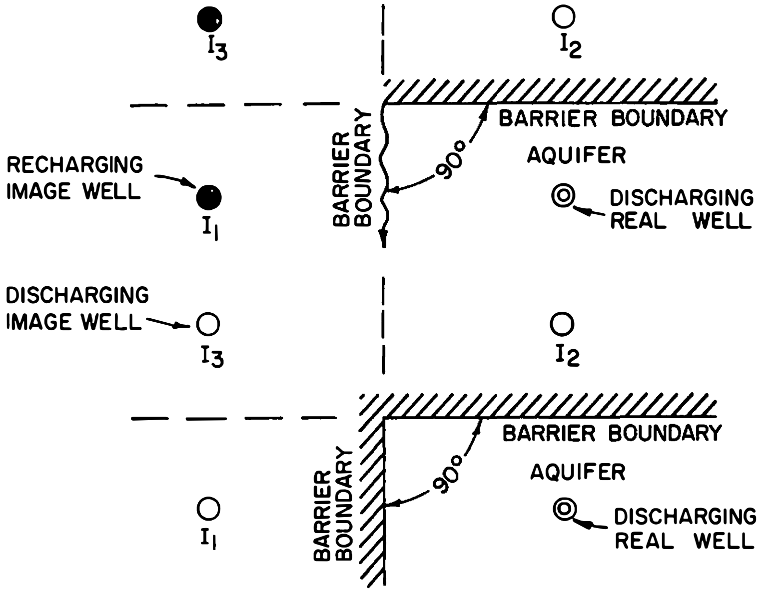


Figure 2

Maps illustrating the use of image wells to simulate right angle boundaries (after Knowles, 1955)

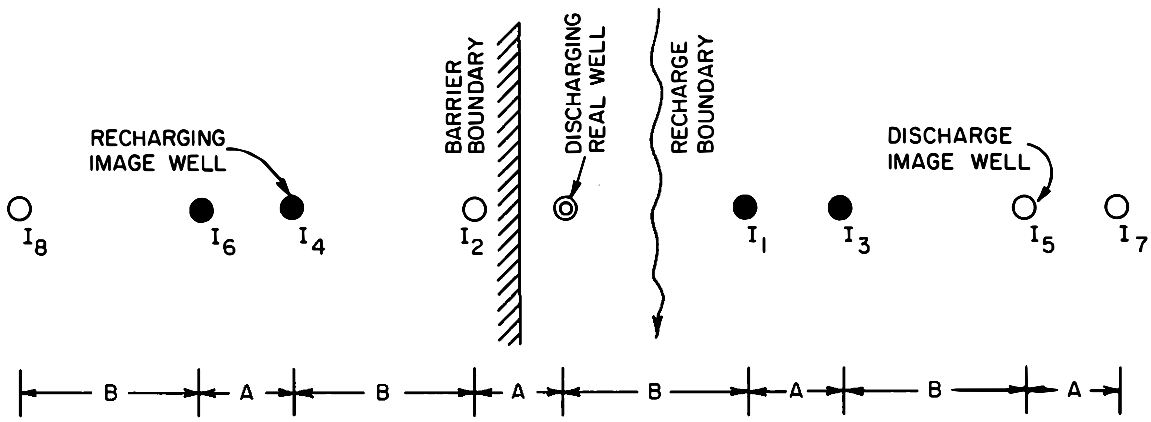


Figure 3

Idealized map illustrating the use of image wells
to simulate a discharging well
in an aquifer bounded by parallel boundaries
(after Knowles, 1955)

EXAMPLES OF IMAGE WELL SYSTEMS USED WITH IMAGEW-I OPTIONS

The authors propose the following image well systems and options for use in simulating certain aquifer systems. Figure 4 illustrates a discharging well in an artesian aquifer being supplied with recharge from the outcrop. The system requires IMAGEW-I option 1 because of the artesian conditions; the position of the boundaries are the base and top of the aquifer where it intersects the surface of the ground. Image well, I_1 (imaginary recharge well), simulates the recharge boundary and image well, I_2 (imaginary discharge well), simulates the impermeable barrier.

The placement of the image well simulating recharge, I_1, the authors feel, is open for discussion. However, the recharge image well should not be placed any closer to the pumped well than twice the distance between the pumped well and the top of the aquifer where it intersects the surface of the ground. The image well should be recharged at the same pump rate as the real well.

The image well simulating the impermeable barrier, I_2, is placed at the pinch-out due to the wedging out (loss) of the aquifer section. The discharge rate for image well, I_2, should be the same as the real well.

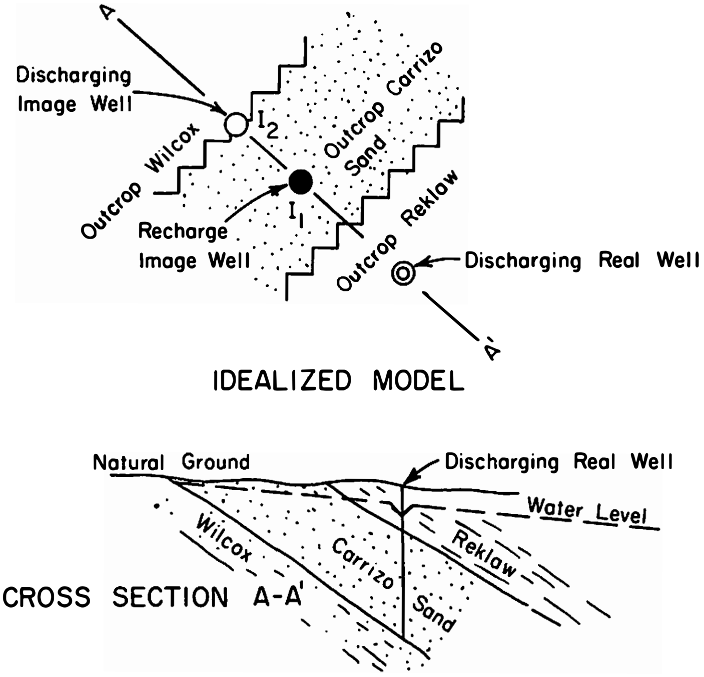


Figure 4

Real and image well system simulating discharging well in an artesian aquifer downdip from recharge zone (outcrop)

Simulation of a discharging well located on the outcrop of an aquifer (water-table conditions) is illustrated in Figure 5. The above conditions dictate that the hydrologist use IMAGEW-I option 2 or option 3 depending on recharge conditions. The position of the impermeable boundary is where the base of the aquifer intersects the surface of the ground. Discharging image well, I_1, simulates the above boundary.

In the above situation, the discharging image well should be placed as if the aquifer were of uniform thickness. The real well is located in the center of the recharge area; hence at this location the aquifer is thining toward the pinch-out and thickening in the opposite direction. There may be a compensating effect on water levels due to the thickening and thining of the aquifer. The discharge rate of the image well should be the same as the real well.

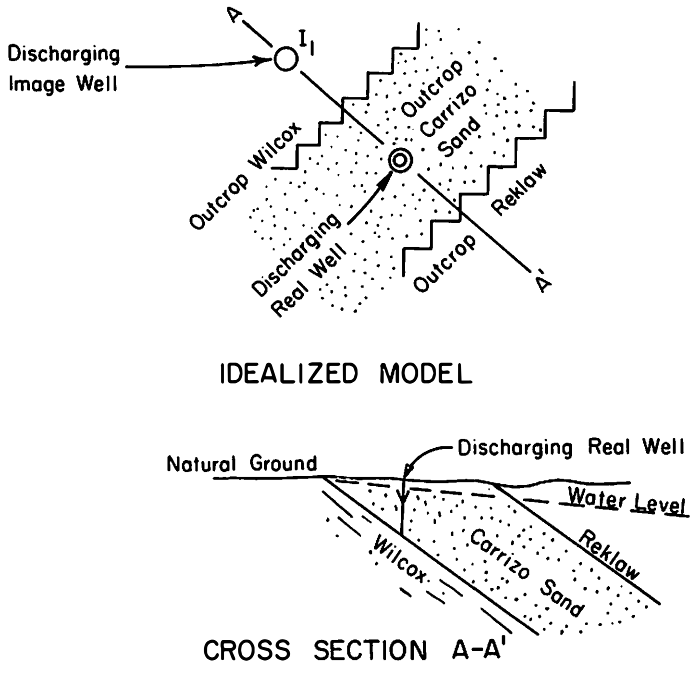
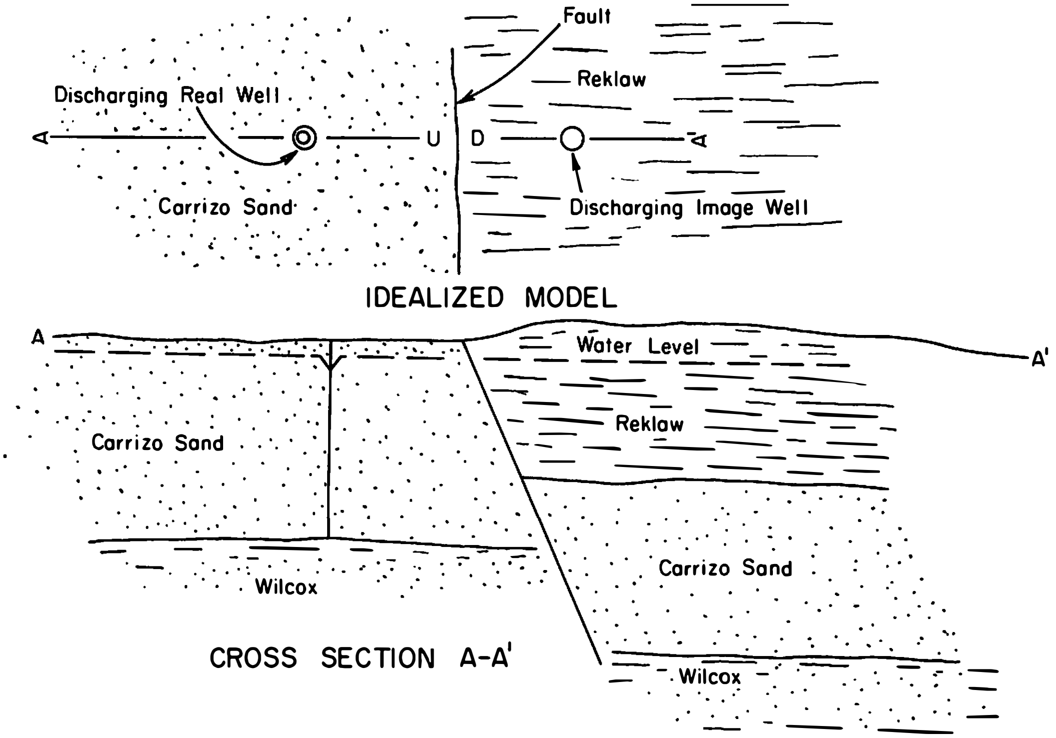


Figure 5

Real and image well system simulating discharging well in a water-table aquifer

Simulation of a discharging well in a water-table aquifer influenced by a fault which displaces three quarters (3/4) of the aquifer is illustrated in Figure 6. Option 2 or option 3 should be used depending on the recharge conditions. Discharging image well, I_1, should be placed as shown and the rate of discharge should be 3/4 of the pumping rate of the real well. This situation can also be applied to a stream (recharge boundary) which penetrates only one quarter (1/4) of the aquifer. The recharge rate assigned to the image well should approximate 1/4 of the pumping rate of the real well.



IDEALIZED MODEL

CROSS SECTION A-A'

Figure 6

Real and image well system simulating discharging well in a water-table aquifer influenced by a fault

The examples outlined in Figures 4 through 6 illustrate how the geometry and full or partial penetration of the aquifer by boundaries (recharge or discharge) affect image well placement and discharge. These examples should be considered as rough approximations and when possible the hydrologist should verify his model by comparing the simulated heads to known historical heads. Adjustments can be made to the model by changing

1. Transmissibility,
2. Storage,
3. Real and image well discharge,
4. Image well placement.

The IMAGEW-I model was developed to simulate small well field operations, however IMAGEW-I can also be used to simulate large areas. William C. Walton (1962) uses this type of model to simulate large areas in Illinois to determine practical sustained yields.

SELECTED REFERENCES

Ferris, J.G. 1959. Ground water, Chapter 7. In C.O. Wisler and E.F. Brater, Ed., Hydrology, John Wiley and Sons, New York.

Jacob, C.E. 1944. Notes on determining permeability by pumping tests under water-table conditions. U.S. Geological Survey mimeo. report.

Mount, J.R. 1968. Analysis of water level drawdown in a Homogeneous Confined Aquifer. Dames and Moore Business Associates.

Theis, C.V. 1935. The relation between the lowering of piezometric surface and the rate and duration of discharge of a well using ground-water storage. Trans. Am. Geophys. Union 16th Annual Meeting, pt. 2.

Walton, W.C. 1962. Selected analytical methods for well and aquifer evaluation. Illinois State Water Survey Bulletin 49.

IMAGEW-I PROGRAM DESCRIPTION

Main Program -- EXEC

The main program reads all input data and calls the necessary subroutines to evaluate the drawdown produced from pumping one or more wells in a well field located in either a confined or an unconfined aquifer. Figure 7 shows the general program flow diagram. EXEC calls three Fortran subroutines.

Subroutine WFUNC1

This subroutine calculates the well function, W(u), for values of u greater than 0 and less than 1.0.

Subroutine WFUNC2

This subroutine calculates the well function, W(u), for values of u greater than or equal to 1.0 and less than or equal to 10.0.

Subroutine QUADRO

This subroutine solves the quadratic equation (Equation 7).

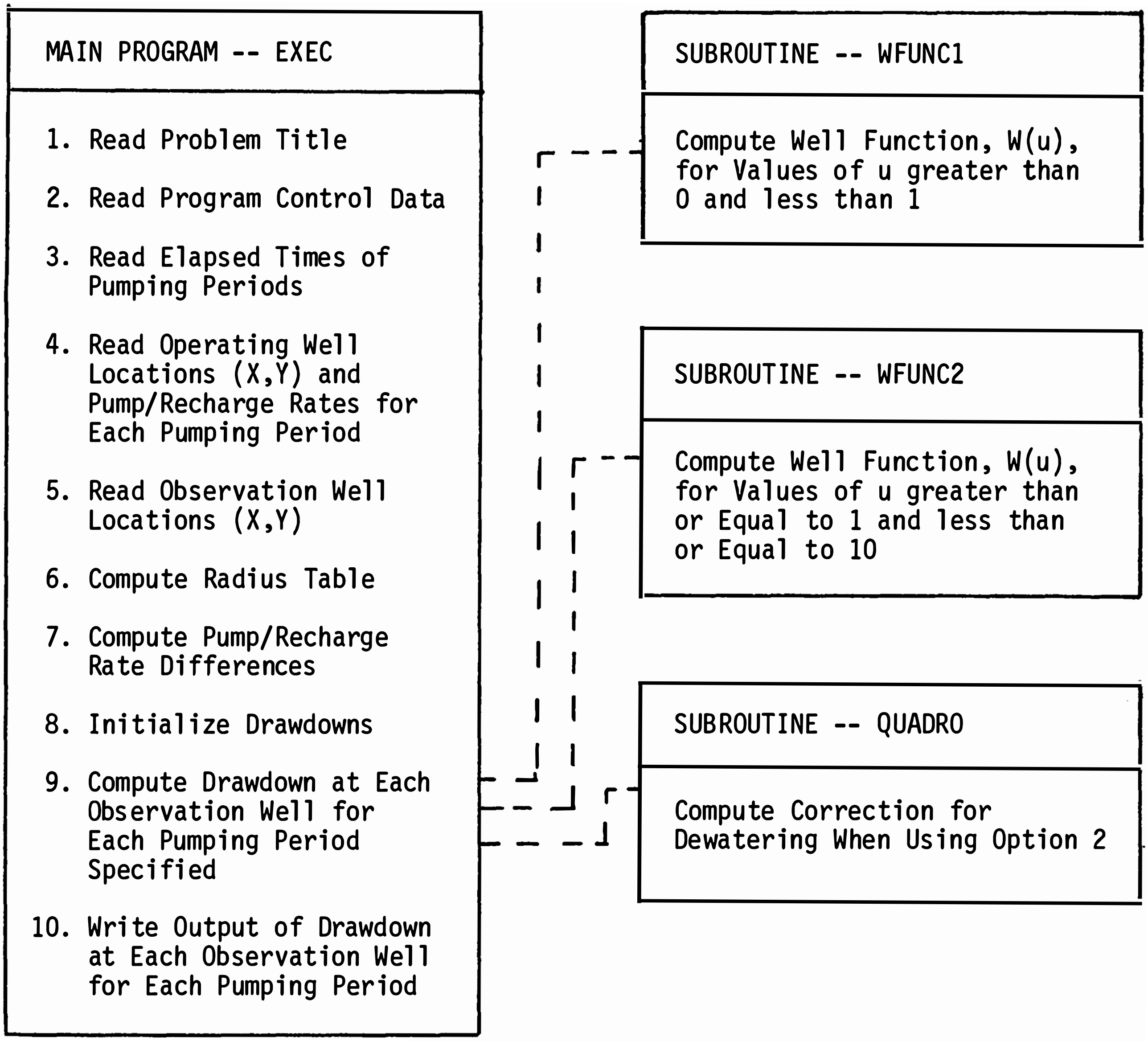


Figure 7

IMAGEW-I General Program Flow Chart

INPUT FILE DESCRIPTION

All of the input data required by IMAGEW-I are in card form. These data are itemized on the input forms shown in Figure 8, and are described in detail by card type in Figure 9. Figure 10 displays the sequence in which the cards must enter the computer. The types of cards permitted are as follows:

Title
PROBLEM NAME
ENDFILE

Program Control
CONTROL
ENDFILE

Elapsed Pumping Times
ELAPSED TIMES
ENDFILE

Operating Wells
OP WELLS
ENDFILE

Observation Wells
OB WELLS
ENDFILE

TEXAS WATER DEVELOPMENT BOARD
ANALYSIS OF WATER LEVEL DRAWDOWN IN A HOMOGENEOUS AQUIFER

IMAGEW-I

* if art. can use any no.

2. W.T
3. Steady st.

PROBLEM DESCRIPTION

FILE A

DATA TYPE** (ONE CARD ONLY)	DESCRIPTION OF PROBLEM (ANY 72 ALPHANUMERIC CHARACTERS)
TITLE	
ENDFILE	

PROGRAM CONTROL DATA

est T   net Sd X10⁻⁶   satd. sd. in aq.

FILE B

DATA TYPE (ONE CARD ONLY)	NUMBER OF OPERATING WELLS	NUMBER OF OBSERVATION WELLS	NUMBER OF PUMPING PERIODS	OPTIONS (SEE INPUT FILE DESCRIPTION)	TRANSMISSIBILITY* (GPD/FT)	STORAGE* COEFFICIENT	SATURATED THICKNESS (FEET) *
	P	P wells & Obs.		for art.			
CØNTRØL			6	1	.0		.
ENDFILE							

ELAPSED PUMPING TIMES

* Use date of Wl. Map?

FILE C

DATA TYPE (ONCE CARD ONLY)	DATE	ELAPSED TIME (YEARS) BY PERIOD* 1	2	3	4	5	6
		(1970)	(1980)	(1990)	(2000)	(2010)	(2020)
ELAPSED TIMES FRØM	04-01-67	7.75	17.75	27.75	37.75	47.75	57.75
ENDFILE							

OPERATING WELL DATA

1970 for 1965-74 Divide = amount all P wells   Ac.-ft./yr X 0.6199 = gpm

* Consider recharge only on steady state

FILE D

DATA TYPE (MAXIMUM OF 50)	*** WELL TYPE	WELL COORDINATES X (FT)	Y (FT)	PUMPAGE AND RECHARGE RATES (GPM) BY PERIOD 1	2	3	4	5	6
ØP WELLS	PW1	1600.	500.						
ØP WELLS	PW2								
ØP WELLS									
ØP WELLS									
ØP WELLS									
ENDFILE									

OBSERVATION WELL DATA

FILE E

DATA TYPE (MAXIMUM OF 50)	*** WELL TYPE	WELL COORDINATES X (FT)*	Y (FT)*	*** WELL TYPE	WELL COORDINATES X (FT)*	Y (FT)*	*** WELL TYPE	WELL COORDINATES X (FT)*	Y (FT)*
ØB WELLS	PW1			PW2			PW3		
ØB WELLS	PW4			OB1			OB2		
ØB WELLS	OB3								
ØB WELLS									
ØB WELLS									
ENDFILE									

* Insert decimal where necessary
** Insert ENDJOB for TITLE to terminate job.
*** Any (4) alphanumeric characters

obs. mo.

2015 10 5 1 ½ — OB1

25

in line

PW1

½

Check it ~~?~~ and between each field eval.

Don't forget — See P-20

FIGURE 8

IMAGEW-I INPUT SHEET

IMAGEW-I INPUT FILE DESCRIPTION

CARD OR FIELD ID	DESCRIPTION	PROGRAM VARIABLE
	PROBLEM DESCRIPTION FILE	
	Listed below are the detailed descriptions of the data required for the problem description (two cards only).	
TITLE	See descriptions below.	
	Narrative description of the problem. Any 72 alphanumeric or other permissible characters can be supplied to this title data array. Columns (9-80) Note: if ENDJOB is used for the card identification, instead of TITLE, the computer interprets this as a command to terminate the job.	TITLE(I)
ENDFILE	This card must follow the above TITLE card except when ENDJOB is used. The computer recognizes this as the last card in this file and expects data from the next file to follow.	
	PROGRAM CONTROL FILE	
	Listed below are the detailed descriptions of the data required for program control (two cards only).	
CONTROL	See descriptions below.	
	Total number of operating wells in the well field. Columns (14-16).	NOPWEL
	Total number of observation wells in the well field. Columns (23-24)	NOBWEL
	Number of pumping periods. Column (32)	NUMPMP
	Program option to determine the type of solution desired. 1. solution for steady-state water table problems. 2. solution for non-leaky artesian problem. 3. non-leaky artesian solution used with a correction for water table conditions. Column (43)	OPTION
	Transmissibility of the aquifer in gallons per day per foot. Columns (53-60)	TRANCF
	Storage coefficient of the aquifer. Columns (63-70)	STORCF
	Thickness of the aquifer in feet for options 2 and 3 or average recharge in inches per year for option 1. Columns (73-80)	ATHICK
ENDFILE	This card must follow the above data cards. The computer recognizes this as the last card in File B and expects File C data to follow.	
	ELAPSED PUMPING TIME	
	Listed below are detailed descriptions of the data required for specifying the elapsed pumping times (two cards only).	
ELAPSED TIMES FROM	See descriptions below.	
	The day, month, and calendar year when pumping began. Columns (23-30)	DATE
	The pumping schedule designating the times when changes in the pumping rate occur in years since pumping started (limited to maximum of six periods) Columns (34-80)	ELTIME
ENDFILE	This card must be the last card in File C. The computer recognizes this as the last File C card and expects File D data to follow.	
	OPERATING WELL DATA	
	Listed below are detailed descriptions of the data required for describing the operating wells.	
OP WELLS	See descriptions below.	
	Identification of well. Any four alphanumeric characters may be used. Columns (10-14)	OPWELL
	X-coordinate of operating well (feet). Columns (15-22)	OPXCOR
	Y-coordinate of operating well (feet). Columns (24-31)	OPYCOR
	The pumping schedule designating the average pumping rates (GPM) in each pumping period specified in File C. Negative average pumping rates indicate recharge wells. Columns	RATE
ENDFILE	This card must be the last card in File D. The computer recognizes this as the last File D card and expects File E data to follow.	
	OBSERVATION WELL DATA	
	Listed below are detailed descriptions of the data required to describe the observation wells.	
OB WELLS	See descriptions below.	
	Well identification. Any four alphanumeric characters may be used. Columns (11-14, 35-38, 59-62)	OBWELL
	X-coordinate of observation well (feet). Columns (16-23, 40-47, 64-71)	OBXCOR
	Y-coordinate of observation well (feet). Columns (25-32, 49-56, 73-80)	OBYCOR
ENDFILE	This card must be the last card in File E. The computer recognizes this as the last File E card and expects no further card input to this problem. Once execution has been completed for this problem, program control is returned to Step 01 in the EXEC routine to determine if another problem is to be processed.	

FIGURE 9

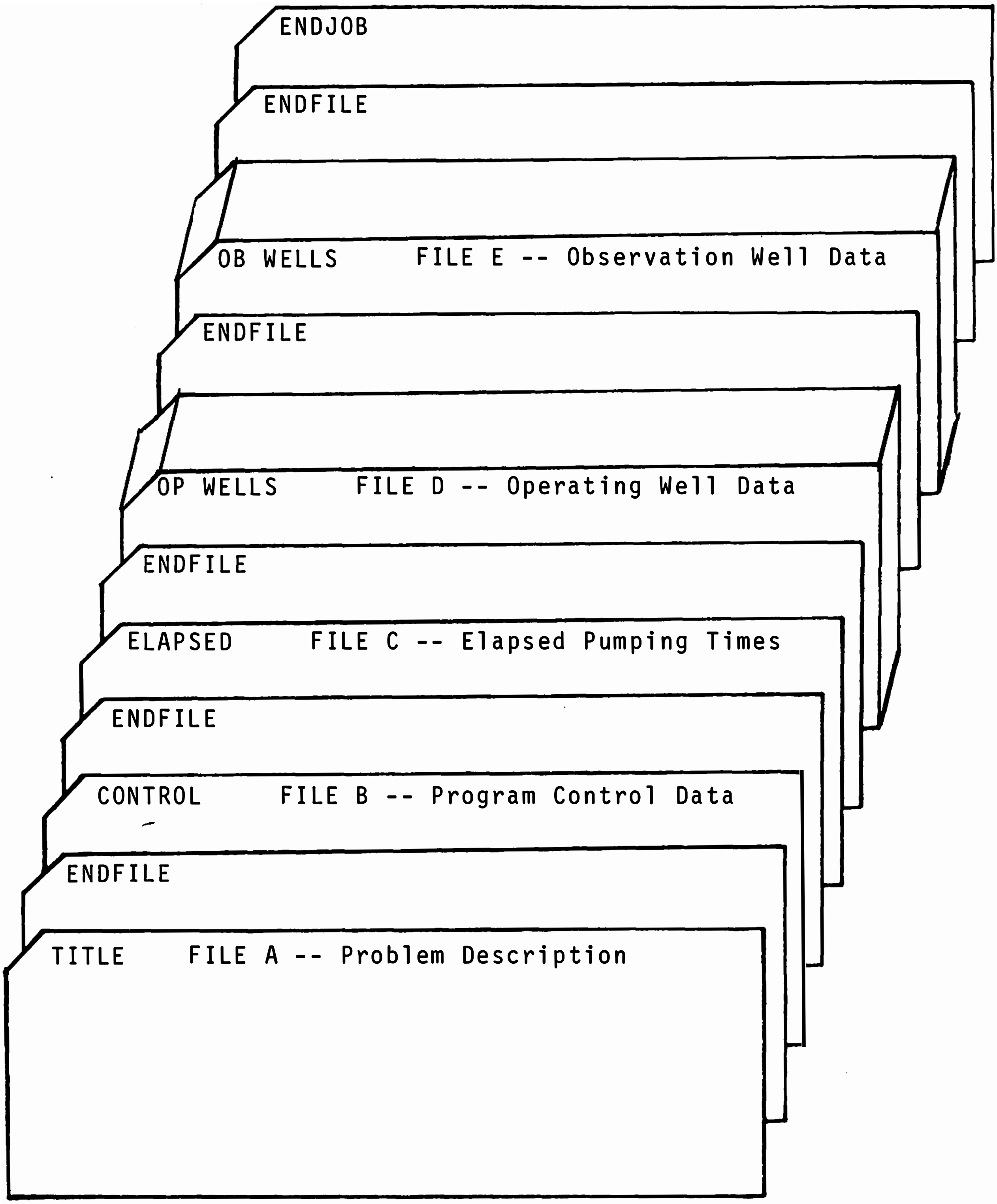


Figure 10

Input Data Organization

OUTPUT FILE DESCRIPTION

The output generated by the IMAGEW-I Program is printer-output and consists of the following two parts:

1. an echo of all input data, and
2. the results given by the program.

Listings of the printer-output produced by the IMAGEW-I program for three different problems to illustrate the use of the three different options in the program are shown on the following pages. Figure 11 shown the well field layout for a problem similar to the one shown in Figure 4 which is analyzed by exercising Option 1 of the program. Figure 12 shows the well field layout for a problem similar to the one shown in Figure 5 which is analyzed by exercising Option 2 or Option 3, depending on whether or not the outcrop is receiving recharge. As discussed previously, Option 3 is used when the aquifer is receiving recharge. The storage coefficient and aquifer thickness are not used in this instance and a value for the recharge in units of inches per year is read in where the aquifer thickness is normally read in. In this example a recharge value of 3.0 inches per year was used.

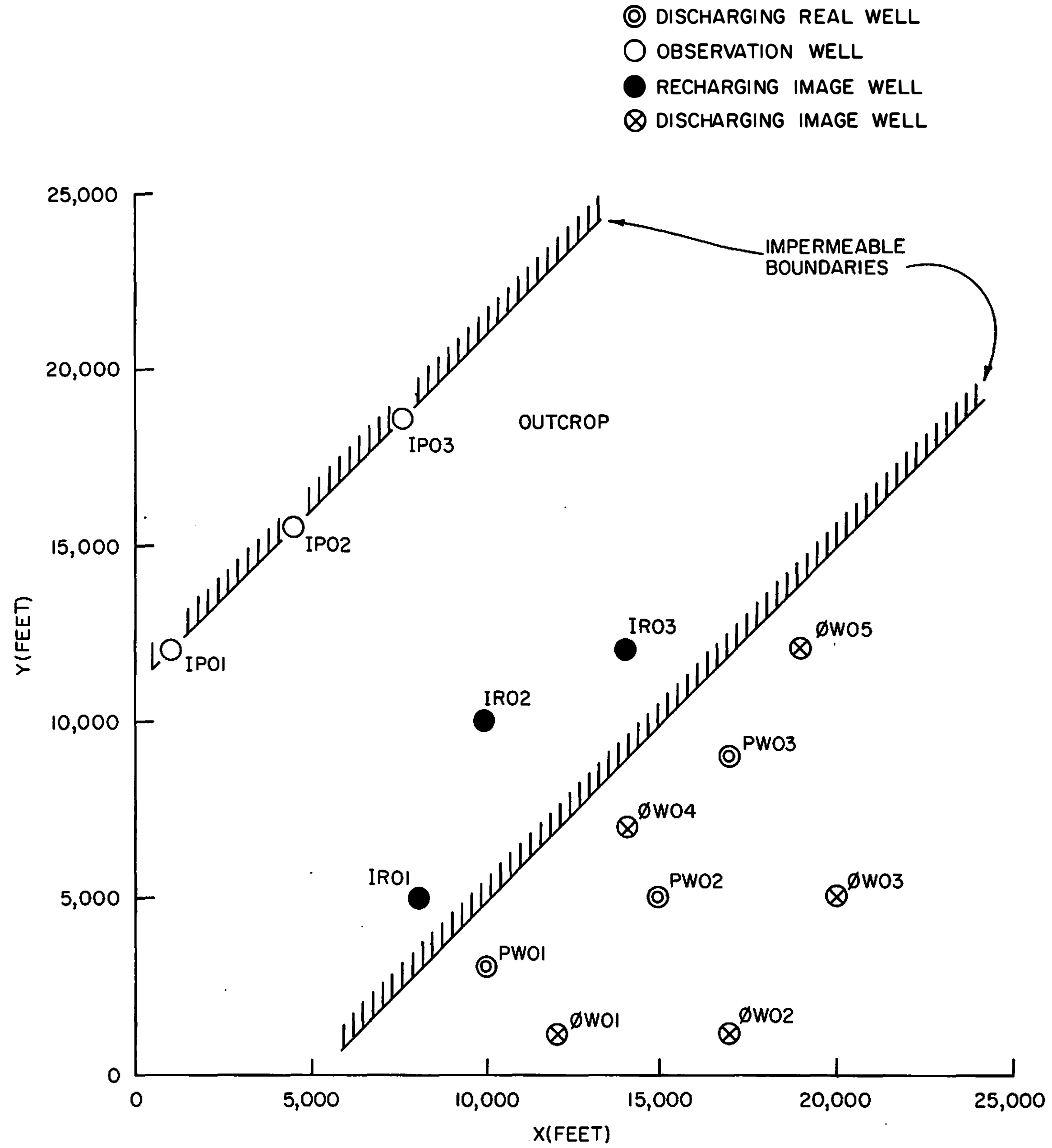


Figure 11

Example Problem - Well Field Layout
Artesian Conditions: Nonleaky Arestian Solution

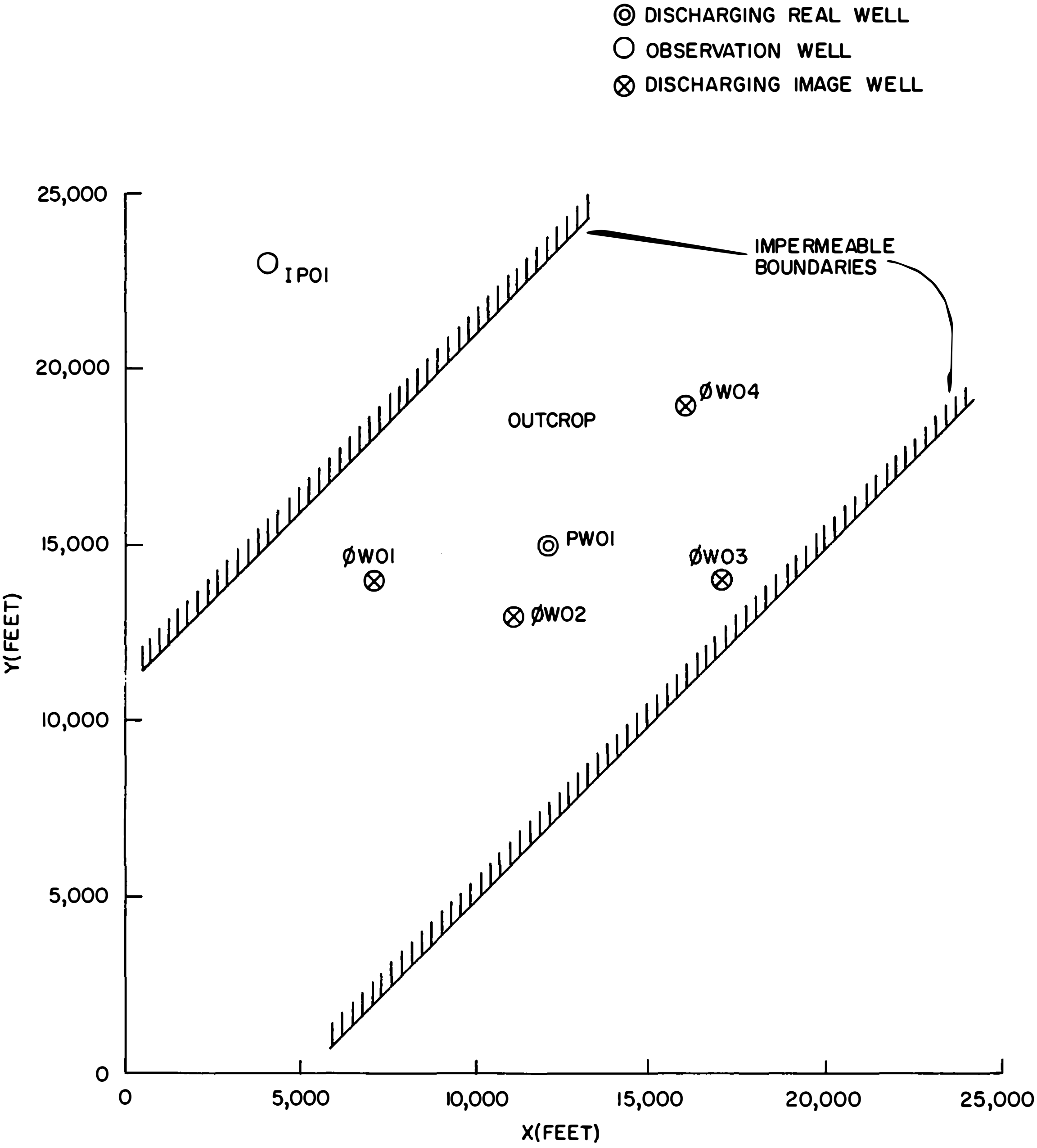


Figure 12

Example Problem - Well Field Layout
Water Table Conditions

IMAGEW-I

EXAMPLE OUTPUT

```
                        *** INPUT DATA PROBLEM NO. 1 ***


 DATA
 TYPE                                DESCRIPTION OF PROBLEM
 ----                                ----------------------
TITLE   EXAMPLE PROBLEM OPTION NO. 1 ARTESIAN CONDITIONS  (NONLEAKY SOLUTION)
ENDFILE


          NO. OF   NO. OF   NO. OF     TYPE       TRANS-                AQUIFER
 DATA     OPER.    OBSR.    PUMPING     OF     MISSIBILITY  STORAGE   THICKNESS
 TYPE     WELLS    WELLS    PERIODS  SOLUTION   (GPD/FT)     COEF.     (FEET)
 ----     ------   ------   -------  --------  -----------  --------  --------
CONTROL      9        8        5         1       150000.0    .000500     500.0
ENDFILE


 DATA                 STARTING              ELAPSED TIME (YEARS) BY PERIOD
 TYPE                   DATE        1        2        3        4        5        6
 ----                 --------    -----    -----    -----    -----    -----    -----
ELAPSED TIMES FROM    01-01-73     1.00     2.00     3.00     4.00     5.00
ENDFILE


 DATA     WELL   WELL COORDINATES     PUMPAGE AND RECHARGE RATES (GPM) BY PERIOD
 TYPE     TYPE    X (FT)    Y (FT)      1        2        3        4        5        6
 ----     ----   ------    ------     -----    -----    -----    -----    -----    -----
OP WELLS  PW01  10000.0    3000.0   1000.0   1000.0   1500.0   2000.0   2000.0
OP WELLS  IP01   1000.0   12000.0   1000.0   1000.0   1500.0   2000.0   2000.0
OP WELLS  IR01   8000.0    5000.0  -1000.0  -1000.0  -1500.0  -2000.0  -2000.0
OP WELLS  PW02  15000.0    5000.0    500.0    500.0    750.0   1000.0   1000.0
OP WELLS  IP02   4500.0   15500.0    500.0    500.0    750.0   1000.0   1000.0
OP WELLS  IR02  10000.0   10000.0   -500.0   -500.0   -750.0  -1000.0  -1000.0
OP WELLS  PW03  17000.0    9000.0   1000.0   1000.0   1500.0   2000.0   2000.0
OP WELLS  IP03   7500.0   18500.0   1000.0   1000.0   1500.0   2000.0   2000.0
OP WELLS  IR03  14000.0   12000.0  -1000.0  -1000.0  -1500.0  -2000.0  -2000.0
ENDFILE
```

```
  DATA      WELL  WELL COORDINATES    WELL  WELL COORDINATES   WELL  WELL COORDINATES
  TYPE      TYPE   X (FT)    Y (FT)   TYPE   X (FT)    Y (FT)  TYPE   X (FT)    Y (FT)
  ----      ----  ------    ------    ----  ------    ------   ----  ------    ------
OB WELLS    PW01  10000.0    3000.0   PW02  15000.0    5000.0  PW03  17000.0    9000.0
OB WELLS    OW01  12000.0    1000.0   OW02  17000.0    1000.0  OW03  20000.0    5000.0
OB WELLS    OW04  14000.0    7000.0   OW05  19000.0   12000.0
ENDFILE
```

```
                              *** PROBLEM NO. 1 ***

    EXAMPLE PROBLEM OPTION NO. 1 ARTESIAN CONDITIONS  (NONLEAKY SOLUTION)

  WELL     WELL  WELL COORDINATES               DRAWDOWN (FEET) BY PERIOD
  TYPE      ID    X (FT)    Y (FT)       1       2       3       4       5       6
  ----     ----  ------    ------      -----   -----   -----   -----   -----   -----
OB WELLS PW01   10000.0    3000.0      22.2    23.5    35.4    47.7    49.2
OB WELLS PW02   15000.0    5000.0      17.3    18.6    28.0    37.9    39.3
OB WELLS PW03   17000.0    9000.0      22.8    24.1    36.3    48.9    50.4
OB WELLS OW01   12000.0    1000.0      10.9    12.2    18.4    25.1    26.6
OB WELLS OW02   17000.0    1000.0      10.2    11.5    17.4    23.7    25.2
OB WELLS OW03   20000.0    5000.0      10.4    11.7    17.7    24.1    25.5
OB WELLS OW04   14000.0    7000.0      11.2    12.6    18.9    25.8    27.2
OB WELLS OW05   19000.0   12000.0      10.1    11.4    17.2    23.5    24.9
```

```
                        *** INPUT DATA PROBLEM NO. 2 ***

  DATA
  TYPE                               DESCRIPTION OF PROBLEM
  ----                               ----------------------
TITLE   EXAMPLE PROBLEM OPTION NO. 2 WATER TABLE CONDITIONS  (NO RECHARGE)
ENDFILE

            NO. OF  NO. OF   NO. OF     TYPE        TRANS-              AQUIFER
  DATA       OPER.   OBSR.  PUMPING      OF      MISSIBILITY  STORAGE THICKNESS
  TYPE       WELLS   WELLS  PERIODS   SOLUTION     (GPD/FT)     COEF.     (FEET)
  ----      ------  ------  -------  ---------   -----------  --------  --------
CONTROL        2       5       4          2          75000.0   .200000      250.0
ENDFILE

  DATA                STARTING             ELAPSED TIME (YEARS) BY PERIOD
  TYPE                  DATE         1       2       3       4       5       6
  ----                --------     -----   -----   -----   -----   -----   -----
ELAPSED TIMES FROM    06-01-72       .08     .17     .24     .50
ENDFILE

  DATA   WELL  WELL COORDINATES     PUMPAGE AND RECHARGE RATES (GPM) BY PERIOD
  TYPE   TYPE   X (FT)   Y (FT)      1       2       3       4       5       6
  ----   ----   ------   ------    -----   -----   -----   -----   -----   -----
OP WELLS PW01  12000.0  15000.0    500.0   500.0   500.0   500.0
OP WELLS IP01   4000.0  23000.0    500.0   500.0   500.0   500.0
ENDFILE
```

```
  DATA     WELL   WELL COORDINATES   WELL   WELL COORDINATES   WELL   WELL COORDINATES
  TYPE     TYPE    X (FT)   Y (FT)   TYPE    X (FT)   Y (FT)   TYPE    X (FT)   Y (FT)
  ----     ----   ------    ------   ----   ------    ------   ----   ------    ------
OB WELLS   PW01   12000.0  15000.0   OW01    7000.0  14000.0   OW02   11000.0  13000.0
OB WELLS   OW03   17000.0  14000.0   OW04   16000.0  19000.0
ENDFILE
```

```
                                   *** PROBLEM NO. 2 ***

    EXAMPLE PROBLEM OPTION NO. 2 WATER TABLE CONDITIONS  (NO RECHARGE)

  WELL    WELL   WELL COORDINATES                  DRAWDOWN (FEET) BY PERIOD
  TYPE     ID     X (FT)   Y (FT)        1        2        3        4        5        6
  ----    ----   ------    ------      -----    -----    -----    -----    -----    -----
OB WELLS  PW01   12000.0  15000.0      11.7     12.3     12.6     13.2
OB WELLS  OW01    7000.0  14000.0        .0       .0       .1       .3
OB WELLS  OW02   11000.0  13000.0        .2       .5       .7      1.2
OB WELLS  OW03   17000.0  14000.0        .0       .0       .1       .3
OB WELLS  OW04   16000.0  19000.0        .0       .0       .0       .2
```

```
                    *** INPUT DATA PROBLEM NO. 3 ***

 DATA
 TYPE                           DESCRIPTION OF PROBLEM
 ----                           ---------------------
TITLE   EXAMPLE PROBLEM OPTION NO. 3 WATER TABLE CONDITIONS  (WITH RECHARGE)
ENDFILE


          NO. OF  NO. OF   NO. OF     TYPE        TRANS-              AQUIFER
 DATA     OPER.   OBSR.   PUMPING      OF      MISSIBILITY  STORAGE   RECHARGE
 TYPE     WELLS   WELLS   PERIODS   SOLUTION    (GPD/FT)     COEF.   (IN/YEAR)
 ----     ------  ------  -------   --------   -----------  --------  --------
CONTROL     2       5        1         3          75000.0   .000000       3.0
ENDFILE


 DATA               STARTING              ELAPSED TIME (YEARS) BY PERIOD
 TYPE                 DATE        1      2      3      4      5      6
 ----               --------    -----  -----  -----  -----  -----  -----
ELAPSED TIMES FROM  01-01-73     .00
ENDFILE


 DATA    WELL   WELL COORDINATES    PUMPAGE AND RECHARGE RATES (GPM) BY PERIOD
 TYPE    TYPE    X (FT)   Y (FT)      1      2      3      4      5      6
 ----    ----   ------   ------     -----  -----  -----  -----  -----  -----
OP WELLS PW01  12000.0  15000.0     500.0
OP WELLS IP01   4000.0  23000.0     500.0
ENDFILE
```

```
  DATA      WELL   WELL COORDINATES    WELL   WELL COORDINATES   WELL   WELL COORDINATES
  TYPE      TYPE    X (FT)    Y (FT)   TYPE    X (FT)   Y (FT)   TYPE    X (FT)   Y (FT)
  ----      ----    ------    ------   ----    ------   ------   ----    ------   ------
OB WELLS   PW01   12000.0   15000.0   OW01    7000.0  14000.0   OW03  11000.0  13000.0
OB WELLS   OW03   17000.0   14000.0   OW04   16000.0  19000.0
ENDFILE
```

```
                          *** PROBLEM NO. 3 ***

   EXAMPLE PROBLEM OPTION NO. 3 WATER TABLE CONDITIONS  (WITH RECHARGE)

  WELL    WELL   WELL COORDINATES               DRAWDOWN (FEET) BY PERIOD
  TYPE     ID     X (FT)    Y (FT)       1       2       3       4       5       6
  ----    ----    ------    ------     -----   -----   -----   -----   -----   -----
OB WELLS PW01   12000.0   15000.0      12.7
OB WELLS OW01    7000.0   14000.0        .1
OB WELLS OW03   11000.0   13000.0       1.0
OB WELLS OW03   17000.0   14000.0        .1
OB WELLS OW04   16000.0   19000.0        .0
```

IMAGEW-I

PROGRAM LISTING

```
C     PROGRAM IMAGE-1
      DIMENSION ALPHA(5), TITLE(15), ELTIME(6), OPWELL(200),
     *          OPXCOR(200), OPYCOR(200), OBWELL(50), OBXCOR(50),
     *          OBYCOR(50), RATE(200,6), ERATE(200,6), STO(50,6),
     *          R(200,50), TIME(6), DATE(3)
      INTEGER OPTION
      DATA ENDF/4HENDF/, ENDJ/4HENDJ/, CONST1/195.174/, CONST2/114.5/
C
C                                        STEP-01
C                                        READ PROBLEM TITLE.
C
      NPROB = 0
   99 NPROB = NPROB + 1
      READ (5,1) (ALPHA(J),J=1,5), (TITLE(I),I=1,15)
    1 FORMAT (20A4)
      IF (ALPHA(1).EQ.ENDJ) GO TO 999
      WRITE (6,2055)
 2055 FORMAT (1H1)
      WRITE (6,5051) NPROB
 5051 FORMAT (39X,27H*** INPUT DATA PROBLEM NO. ,I1,4H ***,//)
      WRITE (6,3051)
 3051 FORMAT (15X,40H  DATA                                   ,
     *            40H                                      ,/,
     *        15X,40H  TYPE                              DES,
     *            40HCRIPTION OF PROBLEM                  ,/,
     *        15X,40H  ----                              ---,
     *            40H--------------------                 )
      WRITE (6,2) (ALPHA(J),J=1,5), (TITLE(I),I=1,15)
    2 FORMAT (15X,20A4)
      READ (5,1) (ALPHA(J),J=1,5)
      WRITE (6,2) (ALPHA(J),J=1,5)
      IF (ALPHA(1).NE.ENDF) GO TO 3077
      WRITE (6,2056)
 2056 FORMAT (1H0)
C
C                                        STEP-02
C                                        READ PROGRAM CONTROL DATA.
C
      READ (5,3) (ALPHA(J),J=1,2), NOPWEL, NOBWEL, NUMPMP, OPTION,
     *           TRANCF, STORCF, ATHICK
    3 FORMAT (2A4,5X,I3,6X,I2,7X,I1,10X,I1,7X,3F10.0)
      IF (OPTION.EQ.3) GO TO 11
      WRITE (6,3052)
 3052 FORMAT (15X,40H                  NO. OF  NO. OF   NO. OF      ,
     *            40HTYPE             TRANS-              AQUIFER ,/,
     *        15X,40H DATA             OPER.   OBSR.  PUMPING     ,
     *            40H OF          MISSIBILITY  STORAGE  THICKNESS,/,
     *        15X,40H TYPE              WELLS   WELLS  PERIODS  SO,
     *            40HLUTION         (GPD/FT)    COEF.     (FEET) ,/,
     *        15X,40H ----              ------  ------  -------  ---,
     *            40H-------     -----------  --------  --------)
      GO TO 12
   11 WRITE (6,3050)
 3050 FORMAT (15X,40H                  NO. OF  NO. OF   NO. OF      ,
     *            40HTYPE             TRANS-              AQUIFER ,/,
     *        15X,40H DATA             OPER.   OBSR.  PUMPING     ,
     *            40H OF          MISSIBILITY  STORAGE  RECHARGE,/,
     *        15X,40H TYPE              WELLS   WELLS  PERIODS  SO,
     *            40HLUTION         (GPD/FT)    COEF.   (IN/YEAR),/,
     *        15X,40H ----              ------  ------  -------   --,
     *            40H-------     -----------  --------  --------)
   12 WRITE (6,4) (ALPHA(J),J=1,2), NOPWEL, NOBWEL, NUMPMP, OPTION,
     *            TRANCF, STORCF, ATHICK
    4 FORMAT (15X,2A4,5X,I3,6X,I2,7X,I1,10X,I1,7X,F10.1,F10.6,F10.1)
      READ (5,3) (ALPHA(J),J=1,2)
      WRITE (6,4) (ALPHA(J),J=1,2)
      IF (ALPHA(1).NE.ENDF) GO TO 3077
```

```
C
C                                        STEP-03
C                                        READ ELAPSED TIMES OF PUMPING
C                                        PERIODS.
C
      WRITE (6,2056)
      WRITE (6,3053)
 3053 FORMAT (15X,40H  DATA                 STARTING          ,
     *            40H  ELAPSED TIME (YEARS) BY PERIOD        ,/,
     *        15X,40H  TYPE                   DATE           1  ,
     *            40H    2         3         4         5     6  ,/,
     *        15X,40H  ----                 ---------       -----,
     *            40H   -----     -----     -----     -----     -----)
      READ (5,5) (ALPHA(J),J=1,5), (DATE(K),K=1,3),
     *           (ELTIME(I),I=1,NUMPMP)
    5 FORMAT (8A4,6(1X,F7.0))
      WRITE(6,6) (ALPHA(J),J=1,5), (DATE(K),K=1,3),
     *           (ELTIME(I),I=1,NUMPMP)
    6 FORMAT (15X,8A4,6(1X,F7.2))
      READ (5,5) (ALPHA(J),J=1,5)
      WRITE (6,6) (ALPHA(J),J=1,5)
      IF (ALPHA(1).NE.ENDF) GO TO 3077
C
C                                        STEP-04
C                                        READ OPERATING WELL LOCATIONS
C                                        (X,Y) AND PUMP/RECHARGE RATES
C                                        FOR EACH PUMPING PERIOD.
C
      WRITE (6,2056)
      WRITE (6,3054)
 3054 FORMAT (15X,40H  DATA   WELL   WELL COORDINATES     PUMP,
     *            40HAGE AND RECHARGE RATES (GPM) BY PERIOD   ,/,
     *        15X,40H  TYPE   TYPE    X (FT)    Y (FT)      1   ,
     *            40H    2        3         4         5       6   ,/,
     *        15X,40H  ----   ----   ------   ------      -----,
     *            40H   -----    -----    -----    -----     -----)
      DO 20 I = 1, NOPWEL
      READ (5,7) (ALPHA(J),J=1,2), OPWELL(I), OPXCOR(I), OPYCOR(I),
     *           (RATE(I,N),N=1,NUMPMP)
    7 FORMAT (2A4,1X,A4,2(1X,F8.0),1X,6(1X,F7.0))
      WRITE (6,8) (ALPHA(J),J=1,2), OPWELL(I), OPXCOR(I), OPYCOR(I),
     *           (RATE(I,N),N=1,NUMPMP)
    8 FORMAT (15X,2A4,1X,A4,2(1X,F8.1),1X,6(1X,F7.1))
   20 CONTINUE
      READ (5,7) (ALPHA(J),J=1,2)
      WRITE (6,8) (ALPHA(J),J=1,2)
      IF (ALPHA(1).NE.ENDF) GO TO 3077
C
C                                  STEP-05
C                                        READ OBSERVATION WELL LOCATIONS
C                                        (X,Y).
C
      WRITE (6,2055)
      WRITE (6,3055)
 3055 FORMAT (15X,40H  DATA    WELL  WELL COORDINATES  WELL  ,
     *            40HWELL COORDINATES  WELL  WELL COORDINATES,/,
     *        15X,40H  TYPE    TYPE   X (FT)   Y (FT)  TYPE  ,
     *            40H X (FT)   Y (FT)  TYPE   X (FT)   Y (FT),/,
     *        15X,40H  ----    ----  ------   ------  ----  ,
     *            40H ------   ------  ----   ------   ------)
      CARDS = NOBWEL / 3.0 + 0.75
      NCARDS = CARDS
      L = -2
      DO 60 N = 1, NCARDS
      L = L + 3
      K = L + 2
      IF (K.GT.NOBWEL) K = NOBWEL
```

```
      READ (5,9) (ALPHA(I),I=1,2), (OBWELL(J),OBXCOR(J),OBYCOR(J),DEL,K)
    9 FORMAT (2A4,3(2X,A4,1X,F8.0,1X,F8.0))
      WRITE (6,10) (ALPHA(I),I=1,2), (OBWELL(J),OBXCOR(J),OBYCOR(J),
     *              DEL,K)
   10 FORMAT (15X,2A4,3(2X,A6,1X,F8.1,1X,F8.1))
   60 CONTINUE
      READ (5,9) (ALPHA(I),I=1,2)
      WRITE (6,10) (ALPHA(I),I=1,2)
      IF (ALPHA(1).NE.ENDF) GO TO 3077
C
C                                       STEP-06
C                                       COMPUTE RADIUS TABLE.
C
      DO 100 J = 1, NOBWEL
      DO 100 I = 1, NOPWEL
      R(I,J) = 1.0
      IF (OBWELL(J).EQ.OPWELL(I)) GO TO 100
      XDIFF = OPXCOR(I) - OBXCOR(J)
      YDIFF = OPYCOR(I) - OBYCOR(J)
      R(I,J) = SQRT(XDIFF * XDIFF + YDIFF * YDIFF)
      IF (R(I,J).EQ.0.0) R(I,J) = 1.0
  100 CONTINUE
      IF (OPTION.NE.3) GO TO 444
      CONST3 = 268000.0
      RECHRG = 2.5
      DO 500 J = 1, NOBWEL
      STD(J,1) = 0.0
      DO 500 I = 1, NOPWEL
      FACT1 = RECHRG / (CONST3 * RATE(I,1))
      QOW = RATE(I,1) / RECHRG
      RE = 510.0 * SQRT(QOW)
      IF (R(I,J).GT.RE) GO TO 500
      Z = R(I,J) * R(I,J) * FACT1
      RZ = Z - ALOG(Z) - 1.0
      FACT2 = CONST2 * RATE(I,1) / TRANCF
      STD(J,1) = STD(J,1) + FACT2 * RZ
  500 CONTINUE
      GO TO 555
  444 CONTINUE
C
C                                       STEP-07
C                                       COMPUTE PUMP/RECHARGE RATE
C                                       DIFFERENCES.
C
      DO 200 I = 1, NOPWEL
      ERATE(I,1) = RATE(I,1)
      DO 200 N = 2, NUMPMP
      ERATE(I,N) = RATE(I,N) - RATE(I,N-1)
  200 CONTINUE
      TIME(1) = ELTIME(1)
      DO 250 N = 2, NUMPMP
      TIME(N) = ELTIME(N) - ELTIME(N-1)
  250 CONTINUE
C
C                                       STEP-08
C                                       INITIALIZE DRAWDOWNS.
C
      DO 40 J = 1, NOBWEL
      DO 40 N = 1, NUMPMP
      STD(J,N) = 0.0
   40 CONTINUE
C
C                                       STEP-09
C                                       COMPUTE DRAWDOWN AT EACH
C                                       OBSERVATION WELL FOR EACH
C                                       PUMPING PERIOD SPECIFIED.
C
      DO 300 N = 1, NUMPMP
      ETIME = 0.0
      K = N
   88 ETIME = ETIME + TIME(K)
      DO 350 J = 1, NOBWEL
      DO 350 I = 1, NOPWEL
      DENOM = CONST1 * TRANCF * ETIME
      FACT1 = STORCF / DENOM
      U = R(I,J) * R(I,J) * FACT1
      FACT = 0.0
      IF (U.GT.10.0) GO TO 350
      IF (U.LT.1.0) CALL WFUNC1(U, WU)
      IF (U.GE.1.0) CALL WFUNC2(U, WU)
      FACT = CONST2 * ERATE(I,K) * WU / TRANCF
  340 IF (ERATE(I,K).NE.0.0) STD(J,N) = STD(J,N) + FACT
  350 CONTINUE
      K = K - 1
      IF (K.GE.1) GO TO 88
  300 CONTINUE
      IF (OPTION.NE.2) GO TO 370
      A = 1.0 / (2.0 * ATHICK)
      B = - 1.0
      DO 360 N = 1, NUMPMP
      DO 360 J = 1, NOBWEL
      C = STD(J,N)
      CALL QUADRD (A, B, C, ROOT1, ROOT2)
      STD(J,N) = AMIN1 (ROOT1, ROOT2)
  360 CONTINUE
  370 CONTINUE
C
C                                       STEP-10
C                                       WRITE OUTPUT OF DRAWDOWN
C                                       AT EACH OBSERVATION WELL
C                                       FOR EACH PUMPING PERIOD.
C
  555 CONTINUE
      WRITE (6,2055)
      WRITE (6,5052) NPROB
      WRITE (6,2057) (TITLE(I),I=1,15)
 2057 FORMAT (25X,15A4)
      WRITE (6,2056)
 5052 FORMAT (44X,16H***, PROBLEM NO. ,I1,4H ***,//)
      WRITE (6,2009)
 2009 FORMAT (15X,40H WELL     WELL   WELL COORDINATES          ,
     *            40H     DRAWDOWN (FEET) BY PERIOD            ,/,
     *        15X,40H TYPE      ID      X (FT)    Y (FT)       1   ,
     *            40H     2        3        4        5        6  ,/,
     *        15X,40H ----     ----    ------    ------     -----,
     *            40H  -----    -----    -----    -----    -----)
      ALPHA(I) = 4HOB W
      ALPHA(2) = 4HELLS
      DO 400 J = 1, NOBWEL
      WRITE (6,6) (ALPHA(I),I=1,2), OBWELL(J), OBXCOR(J), OBYCOR(J),
     *              (STD(J,N),N=1,NUMPMP)
  400 CONTINUE
      GO TO 99
 3077 WRITE (6,3066)
 3066 FORMAT (15X,27H***. ERROR IN INPUT DATA ***)
  999 STOP
      END
```

Go To

```
      SUBROUTINE WFUNC1(U, WU)
      EPSLON = 1.0E-07
      CONST = - 0.57721566 - ALOG(U)
      K = 1
      TERM = 0
      WU = 0
      N = 1
      NFACT = N
   10 TOLD = TERM
      N = N + 1
      IF (N.GT.100) GO TO 20
      NFACT = NFACT * N
      NDENOM = N * NFACT
      DENOM = NDENOM
      K = -1 * K
      AK = K
      AU = AU * U
      ANUM = AK * AU
      TERM = TERM + ANUM / DENOM
      DIFF = ABS(TERM - TOLD)
      IF (DIFF.GT.EPSLON) GO TO 10
   20 WU = CONST + TERM
      IERR = 0
      IF (N.GT.100) IERR = 1
      RETURN
      END
```

```
      SUBROUTINE WFUNC2(U, WU)
      DIMENSION A(4), B(4)
      DATA A/8.6347608925,18.0590169730,8.5733287401,1.0/
      DATA B/21.0996530827,25.6329561486,9.5733223454,1.0/
      AA = 0.2677737343
      BB = 3.9584969228
      UA = 1.0
      DO 200 J = 1, 4
      UA = UA * U
      AA = AA + A(J) * UA
      BB = BB + B(J) * UA
  200 CONTINUE
      FACT = U * EXP(U)
      WU = AA / (BB * FACT)
      RETURN
      END
```

```
      SUBROUTINE QUADRO(A,B,C,X1,X2)
      D = B*B -4.*A*C
      IF(D)2,3,3
    2 DS = SQRT(-D)
      X1 = -B/(2.*A)
      X2 = DS/(2.*A)
      I = 2
      RETURN
    3 I = 1
      DS = SQRT(D)
      IF(B)4,5,5
    4 X1 = (DS-B)/(2.*A)
      X2 = 2.*C/(DS-B)
      RETURN
    5 X1 = -2.*C/(DS+B)
      X2 = -(DS+B)/(2.*A)
      RETURN
      END
```

IMAGEW-I

VARIABLE DESCRIPTIONS

Variable Descriptions for Program

IMAGEW-I

Variable Name	Definition
ATHICK	Average thickness of aquifer, in feet.
DATE	The day, month, and calendar year when pumping began.
ELTIME(N)	The elapsed time at the end of period N since pumping began, in years.
ERATE(I,N)	The incremental change in pumping for operating well I during period N, in GPM.
NOBWEL	The total number of observation wells.
NOPWEL	The total number of operating wells, that is, wells that are either pumping or recharging.
NUMPMP	The total number of pumping periods.
OBWELL(J)	Identification of observation well J. Any four alphanumeric characters may be used.
OBXCOR(J)	X-coordinate location for observation well J, in feet.
OBYCOR(J)	Y-coordinate location for observation well J, in feet.
OPTION	Option to select the type of solution that is desired. Option = 3: indicates that the solution is to be for a steady-state water table condition. Option = 1: indicates that the solution is to be for a non-leaky artesian condition. Option = 2: indicates that the solution to be used is a non-leaky artesian type with a correction for water table conditions.
OPWELL(I)	Identification of operating well I. Any four alphanumeric characters may be used.

OPXCOR(I)	X-coordinate location of operating well I, in feet.
OPYCOR(I)	Y-coordinate location of operating well I, in feet.
R(I,J)	Distance between operating well I and observation well J in feet.
RATE(I,N)	Pumping rate at operating well I during pumping period N. Negative pumping rates indicate recharge. Units are GPM.
RECHARG	Uniform recharge rate over the aquifer, in inches per year. Used only for Option 1.
STO(J,N)	The drawdown at observation well J at the end of pumping period N, in feet.
STORCF	The average storage coefficient of the aquifer.
TIME(N)	The length of pumping period N in years.
TITLE	Narrative description of the problem being run. Any 72 alphanumeric characters may be used.
TRANCF	The average transmissibility of the aquifer in gallons per day per foot.