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EVALUATION AND DOCUMENTATION OF SJRWMD GROUNDWATER MODELS SWUP AND COUAQ FOR USE BY PERMIT APPLICANTS

(Final Project Report)

EVALUATION AND DOCUMENTATION OF SJRWMD GROUNDWATER MODELS SWUP AND COUAQ FOR USE BY PERMIT APPLICANTS

(Final Project Report)

by

Louis H. Motz, P.E.
Faculty Investigator

and

Ozlem Acar
Graduate Research Assistant

Department of Civil and Coastal Engineering

University of Florida

for

Douglas A. Munch
Project Manager

St. Johns River Water Management District
Palatka, Florida

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1.0 INTRODUCTION

1.1 Background and Objectives

In groundwater permit applications to the St. Johns River Water Management District (District), applicants may be required to address pumping impacts in terms of saltwater upconing and drawdown impacts. Extensive hydrogeological investigations that include numerical modeling may be required in some cases to address these issues. However, in other cases, analytical modeling techniques may be sufficient to assess impacts. In particular, analytical modeling techniques are useful in screening for impacts and/or conducting preliminary investigations that may indicate the need for more detailed investigations. The District currently utilizes several analytical groundwater models for these purposes, including a saltwater upconing model and a pumping impact model that are based on solutions by Motz (1992) and Denis and Motz (1998). For these two District models, there is a need to improve their utilization and prepare model documentation in a manner that will make these models more accessible to permit applicants and others through the District's web site. To meet this need, the University of Florida (University) has evaluated the two existing models and modified the computer codes to enhance their capabilities and accessibility to permit applicants. In addition, the University has documented the improvements in the model codes so that the executable codes and documentation can be posted on the District's web site.

1.2 Scope of Work

The investigation described in this report consisted of four tasks:

- Enhancement of the saltwater upconing model;
- Enhancement of the two-layer drawdown model;
- Preparation of a draft final project report (user's manual); and
- Preparation of a final project report (user's manual).

In the first task, documentation was developed for the model that calculates vertical upconing of the saltwater-freshwater interface beneath a single pumping well and beneath multiple pumping wells in a wellfield. Pumping beneath a single well is simulated using the single-well steady-state solution for a leaky aquifer (Motz 1992). The pumping effects of multiple wells are simulated using the steady-state solution for multiple wells pumping from a leaky aquifer (Motz 1994). Benchmark testing of the saltwater upconing solution was performed, and the FORTRAN source code SWUP (Saltwater Upconing Program for single and multiple wells) and executable files for single- and multiple-well applications were submitted to the District for review. In the second task, documentation was developed for the model that is used to calculate pumping impacts on groundwater levels in a two-layer aquifer system. This model, based on Denis and Motz (1998), is used to calculate steady-state and transient drawdowns due to pumping from one or more wells that can be located in either or both layers and can be designated as either pumping or recharge wells. Similar to the saltwater upconing model, benchmark testing of the two-layer drawdown model was performed, and the FORTRAN source code COUAQ (Coupled Aquifer Program for single and multiple wells) and executable files for single- and multiple-well applications were submitted to the District for review. In the third task, a draft report was prepared as a user's manual that included a description of the problem, the solutions used, listings of the source codes, the results of the benchmark testing, and example problems to illustrate how to use the enhanced models. The fourth task consisted of submitting this final project report that incorporates the review comments and suggested revisions resulting from the District's review of the draft report. Along with the final report, electronic copies of the source codes, executable files, and input and output files for the benchmark and example problems will be submitted to the District. In addition, a one-day training session will be provided to District staff.

2.0 SALTWATER UPCONING

2.1 Saltwater Upconing

Freshwater in a groundwater aquifer overlies more dense salty, or brackish, water in many parts of the world (Motz 1994). In response to pumping from a well in the freshwater zone, the saltwater-freshwater interface moves vertically upward toward the pumped well (see Figure 1). Under some conditions, a stable cone in the interface will develop, and the well will continue to discharge freshwater. Under other conditions, however, the cone will exceed some critical height and become unstable, causing the interface to rise abruptly to the bottom of the pumped well and resulting in the discharge becoming salty (Reilly and Goodman 1985). Both sharp-interface and density-dependent solute transport approaches are used to analyze saltwater upconing and determine the critical pumping rate, or the pumping rate at which the cone becomes unstable. The sharp-interface approach is considered an appropriate approximation if the thickness of the transition zone between saltwater and freshwater is relatively small compared to the thickness of the aquifer (Bear 1979).

2.2 Upconing Due to Single Well

<u>2.2.1 Analytical Solution for Single Well</u>

In an aquifer overlain by a leaky confining unit, the steady-state drawdown in a piezometer at a depth of penetration z and a distance r from a steadily discharging well that is screened between the penetration depths d and ℓ is given by (Hantush 1964) (see Figure 1):

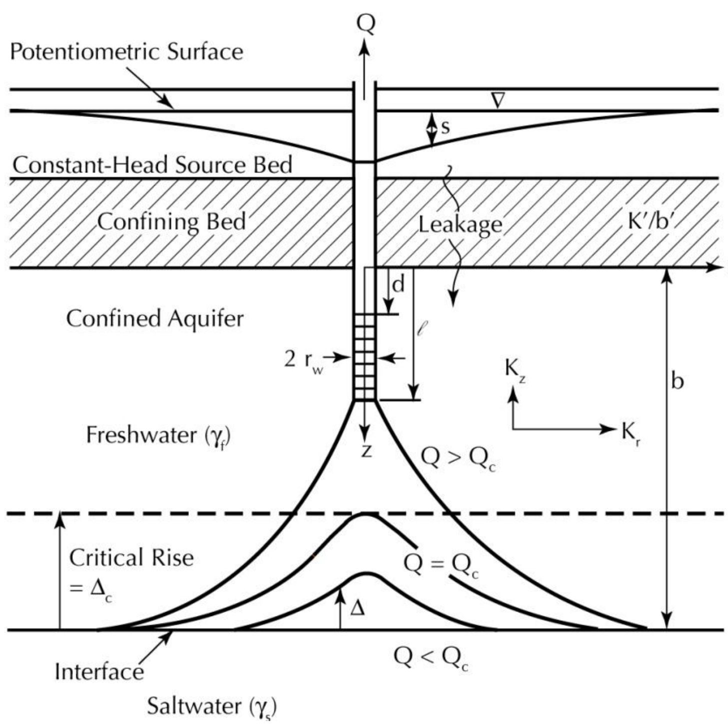

Figure 1. Saltwater upconing due to pumping from a well in a leaky confined aquifer [from Motz (1992)]

$$s = \frac{Q}{4\pi K_r b}\left[2K_0\left(\frac{r}{B}\right) + f_s\right] \quad (1)$$

where s = drawdown; Q = pumping rate of the well; K_r = horizontal hydraulic conductivity of the aquifer; b = thickness of aquifer; K_0 = modified Bessel function of the second kind, zero order; r = radial distance from the well; $1/B = (K'/b'T)^{1/2}$; K'/b' = leakance of the overlying confining unit; T = transmissivity of the aquifer = $K_r b$; and f_s = partial penetration correction factor:

$$f_s = \frac{4b}{\pi(\ell - d)}\sum_{n=1}^{\infty}\frac{1}{n}\left[\sin\left(\frac{n\pi\ell}{b}\right) - \sin\left(\frac{n\pi d}{b}\right)\right]\cos\left(\frac{n\pi z}{b}\right)K_0\left[\left(\frac{K_z}{K_r}\right)^{1/2}\left(\frac{n\pi r}{b}\right)\right] \quad (2)$$

where ℓ = distance from top of aquifer to bottom of well screen; d = distance from top of aquifer to top of well screen; n = summation index; and K_z = vertical hydraulic conductivity of the aquifer.

Based on Equations 1 and 2, the analytical, sharp-interface solution that describes the upconing of saltwater beneath a well pumping freshwater from an aquifer overlain by a leaky confining unit is (Motz 1992):

$$Q_c = \frac{2\pi(0.3)T(b-\ell)}{\delta\left[K_0\left(\frac{r_w}{B}\right) + \frac{f_i}{2}\right]} \quad (3)$$

where: Q_c = critical pumping rate; $\delta = [(\gamma_f/(\gamma_s - \gamma_f)]$; γ_f = specific weight of fresh water; γ_s = specific weight of salt water; r_w = radius of well; and f_i = partial penetration correction factor for drawdown along the saltwater-freshwater interface at z = b:

$$f_i = \frac{4b}{\pi(\ell - d)}\sum_{n=1}^{\infty}\frac{(-1)^n}{n}\left[\sin\left(\frac{n\pi\ell}{b}\right) - \sin\left(\frac{n\pi d}{b}\right)\right]K_0\left[\left(\frac{K_z}{K_r}\right)^{1/2}\left(\frac{n\pi r}{b}\right)\right] \quad (4)$$

The upconing solution in Equations 3 and 4 is based on Muskat's (1946) approach, in which it is assumed that the rise in the saltwater-freshwater interface is small, the interface acts as a streamline, and no flow occurs in the saltwater beneath the interface. Thus, in this solution, the aquifer thickness b is the distance from the top of the aquifer to the saltwater-freshwater interface (see Figure 1). The critical rise of the interface is assumed to occur when the interface has risen to a height equal to 0.3 times the distance between the initial location of the interface and the bottom of the pumped well (Motz 1992).

2.2.2 Single-Well Option in SWUP

The single-well option in SWUP uses Equations 3 and 4 to calculate the critical pumping rate. To start the program, the user clicks on the icon for the program and selects the single-well option. The program can be run interactively with the user inputting the data on the screen, or the user can prepare an input file and select the 'file' option when running the program. If the program is run interactively, the input data and the result for the critical pumping rate are printed to an output file, and the critical pumping rate is also printed on the screen. If the 'file' option is selected, the input data and the critical pumping rate are written to the output file. In this program, $\delta = 40.0$, based on the Ghyben-Herzberg approximation for saltwater (Bear 1979). The Bessel functions in Equations 3 and 4 are calculated by calling the subroutine Bessel.

2.2.3 Benchmark Problem

As described by Motz (1997), the finite-element code SIMLAS (Huyakorn et al. 1993) was used to obtain saltwater upconing results for comparison with results obtained using Equations 3 and 4. The problem chosen for comparison with SIMLAS, which is a numerical sharp-interface model, was based on aquifer parameters and well geometry representative of the Jay B. Starkey wellfield in Pasco County, Florida (Motz 1992) (see Table 1). Using SIMLAS, it was assumed that the aquifer could be represented by a square domain. Only the first quadrant of the domain was simulated, with a pumping well at x = y = 0.0 at the lower left corner of a non-uniformly spaced grid consisting of 1,024 nodes (32 rows by 32 columns). It was observed that the choice of discretization affected the results obtained from SIMLAS. That is, finer discretization resulted in more upconing and smaller critical pumping rates, and coarser discretization resulted in less upconing and larger critical pumping rates. Accordingly, based on Prickett (1967) and Trescott et al. (1976), a discretization factor = 4.81 was used so that the simulated well in SIMLAS would have the same drawdown characteristics as the simulated well in SWUP. In the analytical solution that was compared to SIMLAS, the well radius r_w = 1.0 ft (0.305 m). The spacing in SIMLAS between the node at which the well is located and the nodes in the adjacent row and column was set equal to 4.9 ft (1.5 m), which was obtained by multiplying the well radius by the discretization factor, or 1.0 ft (0.305 m) x 4.81 ≈ 4.9 ft (1.5 m). The spacing between each successive row and column was increased by a factor of 1.293836 so that the x coordinate of the last column and the y coordinate of the last row were 49,215 ft (15,000 m). Constant-head nodes were specified along the last column and last row of the grid. A number of

Table 1. Parameters used in SIMLAS for the saltwater upconing benchmark problem [from Motz (1997)]

Parameter	Value
Initial elevation of the saltwater-freshwater interface	-438.8 m, NGVD (-1,440 ft, NGVD)
Initial freshwater head	10.97 m, NGVD (36.0 ft, NGVD)
Horizontal intrinsic permeability k_{xx}, k_{yy}	9.26×10^{-12} m^2 (9.97×10^{-11} ft^2)
Leakance of the confining bed k'_z/b'	1.45×10^{-15} m^2/s (1.56×10^{-14} ft^2/sec)
Freshwater head in overlying constant head source bed	10.97 m, NGVD (36.0 ft, NGVD)
Freshwater head at constant head boundary nodes	10.97 m, NGVD (36.0 ft, NGVD)
Saltwater head at constant head boundary nodes	0.0 m, NGVD (0.0 ft, NGVD)
Bottom elevation of well screen	-260.0 m, NGVD (-853 ft, NGVD)
Length of well screen	221.0 m (724 ft)
Distance from well bottom to the initial interface	178.8 m (587 ft)

Source: Motz (1997)

runs were made with SIMLAS to investigate the steady-state location of the saltwater-freshwater interface in response to pumping. For the parameters in Table 1, saltwater reached the bottom of the well when the pumping rate was Q/4 = 8.54 x 10^4 ft^3/day (28.0 kg/s), which corresponds to a pumping rate of 3.42 x 10^5 ft^3/day (112 kg/s) from the entire aquifer domain (see Figure 2).

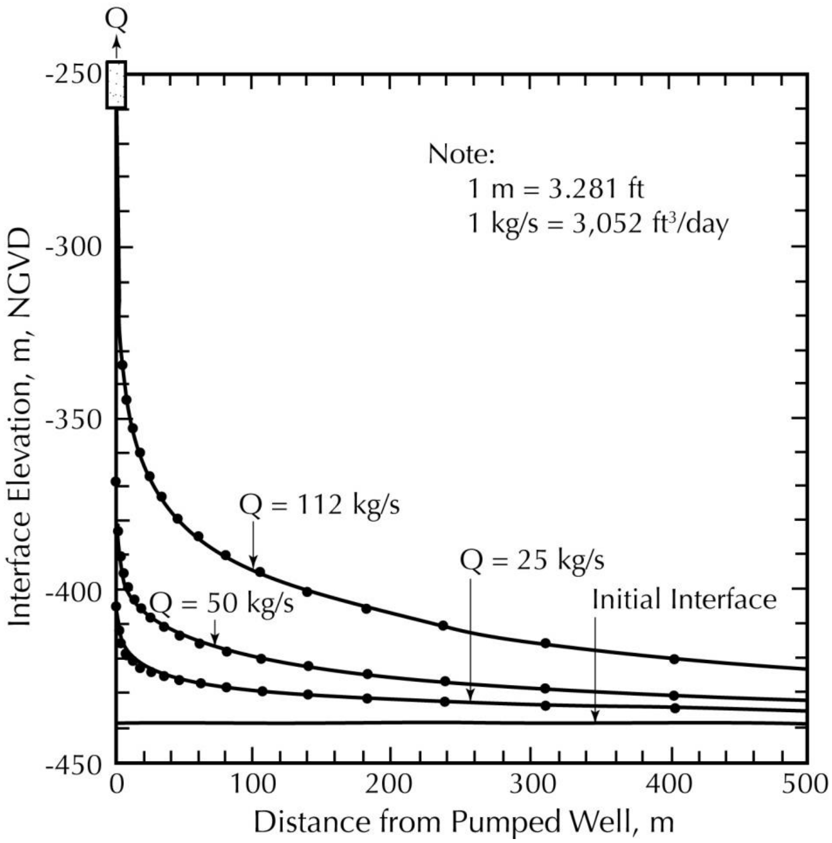

Figure 2. Simulated profiles of the saltwater-interface using SIMLAS [modified from Motz (1997)]

The single-well option in SWUP was used to calculate a critical pumping rate for comparison with SIMLAS. For values of T = 36,800 ft^2/day, K'/b' = 1.20 x 10^{-3} day^{-1}, r_w = 1.00 ft, b = 1,430 ft, d = 119.0 ft, ℓ = 843.0 ft, and K_z/K_r = 1.0, the critical pumping rate is Q_c = 4.23 x 10^5 ft^3/day (138.6 kg/s). As discussed by Motz (1997), this result is in reasonably good agreement with the result obtained using SIMLAS. In the analytical solution, the interface is a streamline, and it is assumed that the saltwater below it is immobile. In SIMLAS, the saltwater can be in motion also, and this may contribute to the greater upconing and smaller critical pumping rate calculated using SIMLAS. Also, in the analytical model it is assumed that the interface rise is small and the transmissivity of the freshwater zone of the aquifer is constant. In SIMLAS, the thickness of the freshwater zone in the vicinity of the pumped well is reduced as upconing occurs, and thus the transmissivity is reduced. This may cause greater drawdowns in the vicinity of the pumped well in SIMLAS and also contribute to the greater upconing and smaller critical pumping rate calculated using SIMLAS.

Files for the analytical solution for the benchmark problem are in Tables 2 through 5. The screen capture for the interactive option is in Table 2, and the output file is in Table 3. The screen capture for the input file option is in Table 4, and the input file for the file option is in Table 5. The input file option writes the same output file as the interactive option (Table 3).

Table 2. Input on screen for interactive input for saltwater upconing benchmark problem

```
****************************************************************************
****************************************************************************
   SWUP: AN INTERACTIVE PROGRAM FOR CALCULATING SALTWATER UPCONING
   IN AN AQUIFER OVERLAIN BY A LEAKY CONFINING UNIT

   PREPARED BY       Louis H. Motz and Ozlem Acar
                     Department of Civil and Coastal Engineering
                     University of Florida
                     Gainesville, Florida
 ****************************************************************************
 ****************************************************************************
 SINGLE OR MULTIPLE WELLS? <s/m>
s
 Do you want to prepare an input FILE or enter data INTERACTIVELY? <f/i>
i
 NAME OF THE PROJECT?: <write in single quotation marks>
'saltwater upconing benchmark problem'
 PLEASE ENTER DATA IN CONSISTENT UNITS
 TRANSMISSIVITY (T) (ft2/day)=?
36800
 LEAKANCE (Kprime/bprime) (1/day)=?
1.20e-3
 RADIUS OF WELL (rw) (ft)=?
1.00
 DISTANCE FROM TOP OF AQUIFER TO SALTWATER-FRESHWATER INTERFACE (b) (ft)=?
1430
 DISTANCE FROM TOP OF AQUIFER TO TOP OF WELL SCREEN (d) (ft)=?
119
 DISTANCE FROM TOP OF AQUIFER TO BOTTOM OF WELL SCREEN (l) (ft)=?
843
 VERT.HYD.CONDUCTIVITY/HORIZ.HYD.CONDUCTIVITY (Kz/Kr)=?
1.0
 ENTER OUTPUT FILE NAME: <filename.out>
swup_1_benchmark.out
 Qc (ft3/day) =  4.23E+05
 PROGRAM COMPLETED
 Do you want to do more calculations? <y/n>
n
```

Table 3. Output file for saltwater upconing benchmark problem

```
  SWUP: AN INTERACTIVE PROGRAM FOR CALCULATING SALTWATER UPCONING
               IN AN AQUIFER OVERLAIN BY A LEAKY CONFINING UNIT

       PREPARED BY       Louis H. Motz and Ozlem Acar
                         Department of Civil and Coastal Engineering
                         University of Florida
                         Gainesville, Florida
----------------------------------------------------------------------------------
----------------------------------------------------------------------------------
saltwater upconing benchmark problem

SALTWATER UPCONING DUE TO SINGLE WELL PUMPING

INPUT DATA
----------
----------
ALL DATA ARE IN CONSISTENT UNITS

TRANSMISSIVITY (T) (ft2/day)                                     : 3.680E+04
LEAKANCE OF CONFINING UNIT (Kprime/bprime) (1/day)               : 1.200E-03
RADIUS OF WELL (rw) (ft)                                         :     1.000
DISTANCE FROM TOP OF AQUIFER TO SW.-FW.INTERFACE (b) (ft)        :  1430.000
DISTANCE FROM TOP OF AQUIFER TO TOP OF WELL SCREEN (d) (ft)      :   119.000
DISTANCE FROM TOP OF AQUIFER TO BOTTOM OF WELL SCREEN (l) (ft)   :   843.000
VERTICAL HYD.CONDUCTIVITY/HORIZONTAL HYD.CONDUCTIVITY (Kz/Kr)    :  1.00E+00

SALTWATER UPCONING RESULTS
OBTAINED BY ANALYTICAL MODEL
----------------------------
----------------------------
REFERENCE: Motz, L.H. 1992. Saltwater Upconing in an Aquifer Overlain by a Leaky Confining Bed.
Journal of Ground Water, 30(2):pp.192-198, March-April.

    *This model uses the Ghyben-Herzberg 40:1 ratio for the saltwater-freshwater
     interface.

      rw/b        Kz/Kr     ((Kz/Kr)^0.5)*(rw/b)    rw/B      (Qc*delta)/(T*b)
     ---------   ---------  --------------------  ---------  ----------------
     6.99E-04    1.00E+00        6.99E-04         1.81E-04       3.22E-01

                                 Qc(ft3/d)
                                 ---------
                                 4.23E+05
```

Table 4. Input on screen for file option for saltwater upconing benchmark problem

```
****************************************************************************
****************************************************************************
 SWUP: AN INTERACTIVE PROGRAM FOR CALCULATING SALTWATER UPCONING

 IN AN AQUIFER OVERLAIN BY A LEAKY CONFINING UNIT

 PREPARED BY        Louis H. Motz and Ozlem Acar
                    Department of Civil and Coastal Engineering
                    University of Florida
                    Gainesville, Florida
 ***************************************************************************
 ***************************************************************************
 SINGLE OR MULTIPLE WELLS? <s/m>
s
 Do you want to prepare an input FILE or enter data INTERACTIVELY? <f/i>
f
 ENTER INPUT FILE NAME: <filename.in>
swup_1_benchmark.in
 NAME OF THE PROJECT: <write in single quotation marks>
'saltwater upconing benchmark problem'
 ENTER OUTPUT FILE NAME: <filename.out>
swup_1_benchmark.out
```

```
 PROGRAM COMPLETED
 Do you want to do more calculations? <y/n>
n
```

Table 5. Input file for file option for saltwater upconing benchmark problem

36800 1.2e-3 1.0 1430.0 119.0 843.0 1.0   Values for T, K'/b', r_w, b, d, ℓ, and K_z/K_r

2.2.4 Example Problem

Similar to the benchmark problem, the aquifer parameters and well geometry in this example are based on aquifer parameters and well geometry representative of the Jay B. Starkey wellfield in Pasco County, Florida (Motz 1992). In this example, T = 36,800 ft^2/day, K'/b' = 1.20 x 10^{-3} day^{-1}, r_w = 1.00 ft, b = 1,430 ft, d = 119.0 ft, and ℓ = 843.0 ft. In this example, a vertical to horizontal hydraulic conductivity ratio of K_z/K_r = 0.1 was used to illustrate the sensitivity of Q_c to K_z/K_r. Using the single-well option in SWUP and these parameters, the critical pumping rate was determined to be Q_c = 8.11 x 10^5 ft^3/day, which is nearly twice as large as the value of Q_c = 4.23 x 10^5 ft^3/day determined using K_z/K_r = 1.0 in the benchmark problem.

Files for the single-well example problem are in Tables 6 through 9. The screen capture for the interactive option is in Table 6, and the output file is in Table 7. The screen capture for the input file option is in Table 8, and the input file for the file option is in Table 9. The input file option writes the same output file as the interactive option (Table 7).

Table 6. Input on screen for interactive input for saltwater upconing single-well example problem

```
***************************************************************************
***************************************************************************
SWUP: AN INTERACTIVE PROGRAM FOR CALCULATING SALTWATER UPCONING
IN AN AQUIFER OVERLAIN BY A LEAKY CONFINING UNIT

PREPARED BY        Louis H. Motz and Ozlem Acar
                   Department of Civil and Coastal Engineering
                   University of Florida
                   Gainesville, Florida
 ***************************************************************************
 ***************************************************************************
 SINGLE OR MULTIPLE WELLS? <s/m>
s
 Do you want to prepare an input FILE or enter data INTERACTIVELY? <f/i>
i
 NAME OF THE PROJECT?: <write in single quotation marks>
'saltwater upconing single well example'
 PLEASE ENTER DATA IN CONSISTENT UNITS
 TRANSMISSIVITY (T) (ft2/day)=?
36800
 LEAKANCE (Kprime/bprime) (1/day)=?
1.20e-3
 RADIUS OF WELL (rw) (ft)=?
1.00
 DISTANCE FROM TOP OF AQUIFER TO SALTWATER-FRESHWATER INTERFACE (b) (ft)=?
1430
 DISTANCE FROM TOP OF AQUIFER TO TOP OF WELL SCREEN (d) (ft)=?
119
 DISTANCE FROM TOP OF AQUIFER TO BOTTOM OF WELL SCREEN (l) (ft)=?
843
 VERT.HYD.CONDUCTIVITY/HORIZ.HYD.CONDUCTIVITY (Kz/Kr)=?
 0.1
 ENTER OUTPUT FILE NAME: <filename.out>
swup_1_example.out
 Qc (ft3/day) =  8.11E+05
 PROGRAM COMPLETED
 Do you want to do more calculations? <y/n>
n
```

Table 7. Output file for saltwater upconing single-well example problem

```
SWUP: AN INTERACTIVE PROGRAM FOR CALCULATING SALTWATER UPCONING
IN AN AQUIFER OVERLAIN BY A LEAKY CONFINING UNIT

PREPARED BY        Louis H. Motz and Ozlem Acar
                   Department of Civil and Coastal Engineering
                   University of Florida
                   Gainesville, Florida
--------------------------------------------------------------------------------------
--------------------------------------------------------------------------------------
saltwater upconing single well example

SALTWATER UPCONING DUE TO SINGLE WELL PUMPING
INPUT DATA
----------
----------
ALL DATA ARE IN CONSISTENT UNITS

TRANSMISSIVITY (T) (ft2/day)                                    : 3.680E+04
LEAKANCE OF CONFINING UNIT (Kprime/bprime) (1/day)              : 1.200E-03
RADIUS OF WELL (rw) (ft)                                        :     1.000
DISTANCE FROM TOP OF AQUIFER TO SW.-FW.INTERFACE (b) (ft)       :  1430.000
DISTANCE FROM TOP OF AQUIFER TO TOP OF WELL SCREEN (d) (ft)     :   119.000
DISTANCE FROM TOP OF AQUIFER TO BOTTOM OF WELL SCREEN (l) (ft)  :   843.000
VERTICAL HYD.CONDUCTIVITY/HORIZONTAL HYD.CONDUCTIVITY (Kz/Kr)   :  1.00E-01

SALTWATER UPCONING RESULTS
OBTAINED BY ANALYTICAL MODEL
----------------------------
----------------------------
REFERENCE: Motz, L.H. 1992. Saltwater Upconing in an Aquifer Overlain by a Leaky Confining Bed.
Journal of Ground Water, 30(2): pp. 192-198, March-April.

    *This model uses the Ghyben-Herzberg 40:1 ratio for the saltwater-freshwater interface.

       rw/b        Kz/Kr     ((Kz/Kr)^0.5)*(rw/b)     rw/B      (Qc*delta)/(T*b)
     ---------   ---------   --------------------   ---------   ----------------
     6.99E-04     1.00E-01        2.21E-04          1.81E-04       6.17E-01

                                  Qc(ft3/d)
                                  ---------
                                  8.11E+05
```

Table 8. Input on screen for file option for saltwater upconing single-well example problem

```
******************************************************************************
******************************************************************************
SWUP: AN INTERACTIVE PROGRAM FOR CALCULATING SALTWATER UPCONING
IN AN AQUIFER OVERLAIN BY A LEAKY CONFINING UNIT

PREPARED BY        Louis H. Motz and Ozlem Acar
                   Department of Civil and Coastal Engineering
                   University of Florida
                   Gainesville, Florida
******************************************************************************
******************************************************************************
 SINGLE OR MULTIPLE WELLS? <s/m>
s
 Do you want to prepare an input FILE or enter data INTERACTIVELY? <f/i>
f
 ENTER INPUT FILE NAME: <filename.in>
swup_1_example.in
 NAME OF THE PROJECT: <write in single quotation marks>
'saltwater upconing single well example'
 ENTER OUTPUT FILE NAME: <filename.out>
swup_1_example.out
 PROGRAM COMPLETED
 Do you want to do more calculations? <y/n>
n
```

Table 9. Input file for file option for saltwater upconing single-well example problem

```
36800  1.2e-3  1.00  1430.0  119.0  843.0   0.1          Values for T, K'/b', r_w, b, d, ℓ, K_z/K_r
```

2.3 Upconing Due to Multiple Wells

2.3.1 Analytical Solution for Multiple Wells

The analytical solution describing the upconing of saltwater beneath multiple wells pumping freshwater from an aquifer overlain by a leaky confining unit is (Motz 1994):

$$Q_c = \frac{2\pi(0.3)T(b-\ell_m)}{\delta\left\{\left[K_0\left(\frac{r_w}{B}\right)+\frac{f_w}{2}\right]+\sum_{m=2}^{m=M}\alpha_m\left[K_0\left(\frac{r_m}{B}\right)+\frac{f_m}{2}\right]\right\}} \tag{5}$$

where m = summation index; M = number of multiple wells; and α_m = pumping rate coefficient = Q_m/Qc. The first bracketed term in the denominator of Equation 5 represents the drawdown effects of pumping from the pumped well under consideration, and the terms in the summation represent the interference effects from the other pumped wells in a wellfield. The coefficients α_m express the ratio of the pumping rate of each of the other pumped wells causing interference to the pumping rate of the pumped well under consideration. Values of α_m are equal to 1.0 if it is specified that all of the wells will be pumped at the same critical pumping rate. If the wells will be pumped at different relative pumping rates, the values for $\alpha_m = Q_m/Q_c$ at each well under consideration would be the relative pumping rates of the other pumped wells causing interference and the well under consideration, i.e., the specified ratios of the pumping rates of the other pumped wells causing interference and the well under consideration.

2.3.2 Multiple-Well Option in SWUP

The multiple-well option in SWUP uses Equations 4 and 5 to calculate the critical pumping rate due to multiple pumped wells. To start the program, the user clicks on the icon for the program and selects the multiple-well option. The program can be run inter-actively with the user inputting the data on the screen, or the user can prepare an input file and select the 'file' option when running the program. If the program is run interactively, the input data and the result for the critical pumping rate are printed to an output file, and the critical pumping rate is also printed on the screen. If the 'file' option is selected, the input data and the critical pumping rate are written to the output file. In the program, δ = 40.0, based on the Ghyben-Herzberg approximation for saltwater (Bear 1979). Also, it is assumed that all of the wells are pumped at the same rate, i.e., the pumping rate coefficient Q_m/Q_c in Equation 5 for each well is $\alpha_m = 1.0$. The Bessel functions in Equations 4 and 5 are calculated by calling the subroutine Bessel.

In the multiple-well option in SWUP, calculations are made at each well to determine the critical pumping rate for the combination of drawdown impacts at the well under consideration and drawdown (or interference) impacts at that well due to pumping the other wells. Each well location in turn is examined in this way, i.e., the drawdown impacts due to the well under consideration and the interference impacts due to the other wells are summed based on Equation 5 to determine the critical pumping rate for each well location. The smallest pumping rate resulting from considering each well location is chosen as the critical pumping rate for the well array under consideration. After the total critical pumping rate for the well array is determined, the total drawdown in each well due to pumping each well at the critical pumping rate and the interference effects of pumping each of the other wells at the same critical pumping rate are calculated using Equations 1 and 2. The average drawdown in a well screened from d to ℓ is determined by calculating the drawdown at the mid-point of the screened (or open-hole) part of each well, i.e., at z = 0.5(ℓ + d), based on Hantush (1964).

2.3.3 Example Problem

In this example, the multiple-well option in SWUP was used to calculate the critical pumping rate for six pumped wells with the same well characteristics. Parameters similar to the parameters used in the single-well example were used, i.e., T = 36,800 ft^2/day, K'/b' = 1.20 x 10^{-3} day^{-1}, b = 1,430 ft, and K_z/K_r = 0.1 were used to characterize the aquifer and confining unit, and r_w = 1.00 ft, d = 119.0 ft, and ℓ = 843.0 ft were specified the same for each well. The wells were located in a rectangular grid consisting of two rows of three wells spaced 1,000 ft apart (see Figure 3). The input and output results for this example, which were run using the file input option, are in Tables 10 through 12. The screen capture for the input file option is in Table 10, and the input file for the file option is in Table 11. As shown in Table 12, the total critical pumping rates determined for well locations 1, 3, 4, and 6 are the same (9.34 x 10^5 ft^3/day), because of the similarity of the well characteristics and symmetry of the grid. Also, the total critical pumping rates determined for well locations 2 and 5 are the same (8.84 x 10^5 ft^3/day) but smaller than the critical pumping rates at well locations 1, 3, 4, and 6, because of their interior location in the grid. Thus, for this example, the smaller critical pumping rates at well locations 2 and 5 are limiting, the total critical pumping rate is 8.84 x 10^5 ft^3/day, and each well is pumped at Q = 1.47 x 10^5 ft^3/ day. The calculated drawdowns at wells 1, 3, 4, and 6 are 15.6 ft, and the calculated drawdowns at wells 2 and 5 are 16.6 ft (Table 12).

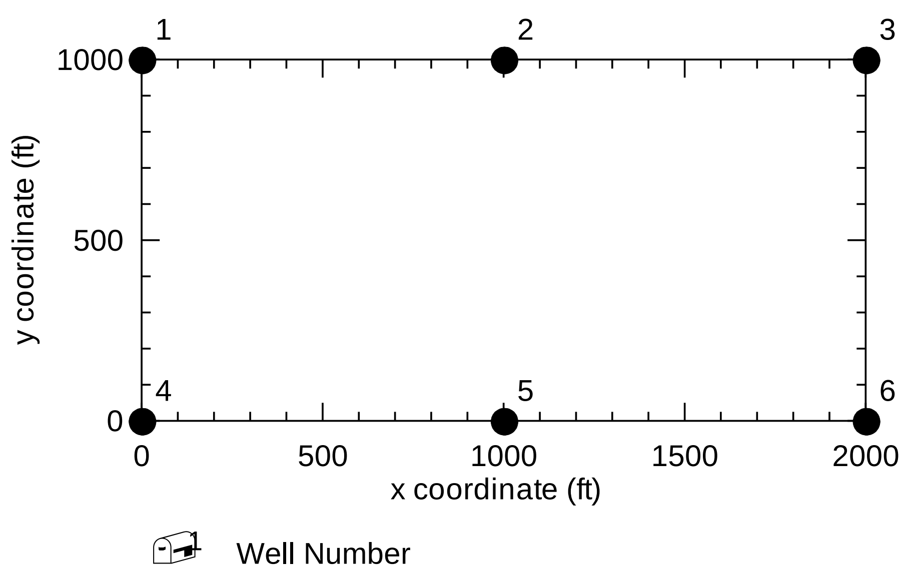

Figure 3. Well array for saltwater multiple-well example problem

Table 10. Input on screen for file option for saltwater upconing multiple-well example problem for 1,000-ft spacing

```
**************************************************************************
**************************************************************************
SWUP: AN INTERACTIVE PROGRAM FOR CALCULATING SALTWATER UPCONING
 IN AN AQUIFER OVERLAIN BY A LEAKY CONFINING UNIT

PREPARED BY        Louis H. Motz and Ozlem Acar
                   Department of Civil and Coastal Engineering
                   University of Florida
                   Gainesville, Florida
**************************************************************************
**************************************************************************
 SINGLE OR MULTIPLE WELLS? <s/m>
m
 Do you want to prepare an input FILE or enter data INTERACTIVELY? <f/i>
f
 ENTER INPUT FILE NAME: <filename.in>
swup_multi_example_1.in
 NAME OF THE PROJECT: <write in single quotation marks>
'saltwater upconing multi-well 1000-ft spacing'
 ENTER OUTPUT FILE NAME: <filename.out>
swup_multi_example_1.out
 PROGRAM COMPLETED
 Do you want to do more calculations? <y/n>
n
```

Table 11. Input file for file option for saltwater upconing multiple-well example problem for 1,000-ft spacing

36800	1.20E-03	1430	0.1			Values for T, K'/b', b, K_z/K_r
6						Number of wells
1	0	1000	1.0	119.0	843.0	Well i.d., x_w, y_w, r_w, d, ℓ
2	1000	1000	1.0	119.0	843.0	Well i.d., x_w, y_w, r_w, d, ℓ
3	2000	1000	1.0	119.0	843.0	Well i.d., x_w, y_w, r_w, d, ℓ
4	0	0	1.0	119.0	843.0	Well i.d., x_w, y_w, r_w, d, ℓ
5	1000	0	1.0	119.0	843.0	Well i.d., x_w, y_w, r_w, d, ℓ
6	2000	0	1.0	119.0	843.0	Well i.d., x_w, y_w, r_w, d, ℓ

Table 12. Output file for saltwater upconing multiple-well example problem for 1,000-ft spacing

```
SWUP: AN INTERACTIVE PROGRAM FOR CALCULATING SALTWATER UPCONING
IN AN AQUIFER OVERLAIN BY A LEAKY CONFINING UNIT

PREPARED BY        Louis H. Motz and Ozlem Acar
                   Department of Civil and Coastal Engineering
                   University of Florida
                   Gainesville, Florida
----------------------------------------------------------------------------------
----------------------------------------------------------------------------------
Saltwater upconing multi-well 1000-ft spacing

SALTWATER UPCONING DUE TO WELLFIELD PUMPING

INPUT DATA
----------
----------
ALL DATA ARE IN CONSISTENT UNITS

TRANSMISSIVITY (T) (ft2/day)                                    : 3.680E+04
LEAKANCE OF CONFINING UNIT (Kprime/bprime) (1/day)              : 1.200E-03
DISTANCE FROM TOP OF AQUIFER TO SW-FW INTERFACE (b) (ft)        :  1430.000
```

```
VERTICAL HYD.CONDUCTIVITY/HORIZONTAL HYD.CONDUCTIVITY (Kz/Kr)      :  1.00E-01

1
X COORDINATE OF WELL (X) (ft)                                      :     0.000
Y COORDINATE OF WELL (Y) (ft)                                      :  1000.000
RADIUS OF WELL (rw) (ft)                                           :     1.000
DISTANCE FROM TOP OF AQUIFER TO TOP OF WELL SCREEN (d) (ft)        :   119.000
DISTANCE FROM TOP OF AQUIFER TO BOTTOM OF WELL SCREEN (l) (ft)     :   843.000

2
X COORDINATE OF WELL (X) (ft)                                      :  1000.000
Y COORDINATE OF WELL (Y) (ft)                                      :  1000.000
RADIUS OF WELL (rw) (ft)                                           :     1.000
DISTANCE FROM TOP OF AQUIFER TO TOP OF WELL SCREEN (d) (ft)        :   119.000
DISTANCE FROM TOP OF AQUIFER TO BOTTOM OF WELL SCREEN (l) (ft)     :   843.000

3
X COORDINATE OF WELL (X) (ft)                                      :  2000.000
Y COORDINATE OF WELL (Y) (ft)                                      :  1000.000
RADIUS OF WELL (rw) (ft)                                           :     1.000
DISTANCE FROM TOP OF AQUIFER TO TOP OF WELL SCREEN (d) (ft)        :   119.000
DISTANCE FROM TOP OF AQUIFER TO BOTTOM OF WELL SCREEN (l) (ft)     :   843.000

4
X COORDINATE OF WELL (X) (ft)                                      :     0.000
Y COORDINATE OF WELL (Y) (ft)                                      :     0.000
RADIUS OF WELL (rw) (ft)                                           :     1.000
DISTANCE FROM TOP OF AQUIFER TO TOP OF WELL SCREEN (d) (ft)        :   119.000
DISTANCE FROM TOP OF AQUIFER TO BOTTOM OF WELL SCREEN (l) (ft)     :   843.000

5
X COORDINATE OF WELL (X) (ft)                                      :  1000.000
Y COORDINATE OF WELL (Y) (ft)                                      :     0.000
RADIUS OF WELL (rw) (ft)                                           :     1.000
DISTANCE FROM TOP OF AQUIFER TO TOP OF WELL SCREEN (d) (ft)        :   119.000
DISTANCE FROM TOP OF AQUIFER TO BOTTOM OF WELL SCREEN (l) (ft)     :   843.000

6
X COORDINATE OF WELL (X) (ft)                                      :  2000.000
Y COORDINATE OF WELL (Y) (ft)                                      :     0.000
RADIUS OF WELL (rw) (ft)                                           :     1.000
DISTANCE FROM TOP OF AQUIFER TO TOP OF WELL SCREEN (d) (ft)        :   119.000
DISTANCE FROM TOP OF AQUIFER TO BOTTOM OF WELL SCREEN (l) (ft)     :   843.000

SALTWATER UPCONING RESULTS
OBTAINED BY ANALYTICAL MODEL
----------------------------
----------------------------

REFERENCE: Motz, L.H. 1994. Predicting Saltwater Upconing Due to Well Field Pumping.
In:Soveri,J., and Suokko,T., Editors. Future Groundwater Resources at Risk. (Proceedings of the
Helsinki Conference, June 1994). International Association of Hydrological Sciences, Publication
No. 222, pp. 55-60.
   * This model uses the Ghyben-Herzberg 40:1 ratio for the saltwater-freshwater
     interface.

Pumped well under consideration       Qc (ft3/day) (critical pumping rate at well under
consideration)
--------------------------------             ------------------------------------------
1                                                  1.56E+05

Other wells causing interference      Qm (ft3/day) (pumping rates at other wells)
--------------------------------             ------------------------------------------
2                                                  1.56E+05
3                                                  1.56E+05
4                                                  1.56E+05
5                                                  1.56E+05
6                                                  1.56E+05
--------------------------------         ------------------------------------------
--------------------------------         ------------------------------------------
TOTAL PUMPING RATE (ft3/day) =                     9.34E+05
```

```
Pumped well under consideration       Qc (ft3/day) (critical pumping rate at well under
consideration)
--------------------------------           ------------------------------------------
2                                                 1.47E+05

Other wells causing interference      Qm (ft3/day) (pumping rates at other wells)
--------------------------------           ------------------------------------------
1                                                 1.47E+05
3                                                 1.47E+05
4                                                 1.47E+05
5                                                 1.47E+05
6                                                 1.47E+05
--------------------------------       ------------------------------------------
--------------------------------       ------------------------------------------
TOTAL PUMPING RATE (ft3/day) =                    8.84E+05

Pumped well under consideration       Qc (ft3/day) (critical pumping rate at well under
consideration)
--------------------------------           ------------------------------------------
3                                                 1.56E+05

Other wells causing interference      Qm (ft3/day) (pumping rates at other wells)
--------------------------------           ------------------------------------------
1                                                 1.56E+05
2                                                 1.56E+05
4                                                 1.56E+05
5                                                 1.56E+05
6                                                 1.56E+05
--------------------------------       ------------------------------------------
--------------------------------       ------------------------------------------
TOTAL PUMPING RATE (ft3/day) =                    9.34E+05

Pumped well under consideration       Qc (ft3/day) (critical pumping rate at well under
consideration)
--------------------------------           ------------------------------------------
4                                                 1.56E+05

Other wells causing interference      Qm (ft3/day) (pumping rates at other wells)
--------------------------------           ------------------------------------------
1                                                 1.56E+05
2                                                 1.56E+05
3                                                 1.56E+05
5                                                 1.56E+05
6                                                 1.56E+05
--------------------------------       ------------------------------------------
--------------------------------       ------------------------------------------
TOTAL PUMPING RATE (ft3/day) =                    9.34E+05

Pumped well under consideration       Qc (ft3/day) (critical pumping rate at well under
consideration)
--------------------------------           ------------------------------------------
5                                                 1.47E+05

Other wells causing interference      Qm (ft3/day) (pumping rates at other wells)
--------------------------------           ------------------------------------------
1                                                 1.47E+05
2                                                 1.47E+05
3                                                 1.47E+05
4                                                 1.47E+05
6                                                 1.47E+05
--------------------------------       ------------------------------------------
--------------------------------       ------------------------------------------
TOTAL PUMPING RATE (ft3/day) =                    8.84E+05

Pumped well under consideration       Qc (ft3/day) (critical pumping rate well under
consideration)
--------------------------------           ------------------------------------------
6                                                 1.56E+05
```

Other wells causing interference	Qm (ft3/day) (pumping rates at other wells)
1	1.56E+05
2	1.56E+05
3	1.56E+05
4	1.56E+05
5	1.56E+05
TOTAL PUMPING RATE (ft3/day) =	9.34E+05

CRITICAL CONDITION OCCURS AT 5
BASED ON WELL PROPERTIES

Well	Q (ft3/day)	Drawdown in well (ft)
1	1.47E+05	15.615
2	1.47E+05	16.575
3	1.47E+05	15.615
4	1.47E+05	15.615
5	1.47E+05	16.575
6	1.47E+05	15.615
CRITICAL PUMPING RATE (ft3/day) =	8.84E+05	

The aquifer parameters and well characteristics used in the saltwater upconing multi-well example problem are the same as the aquifer parameters and well characteristics used in the single-well example. Based on these results, one well could be pumped at a critical rate of Q_c = 8.11 x 10^5 ft^3/day, or six wells spaced 1,000 ft apart could be pumped at individual rates of Q = 1.47 x 10^5 ft^3/day for a total critical pumping rate of Q_c = 8.84 x 10^5 ft^3/day (Table 12). Additional calculations indicate that six wells spaced 2,000 ft apart could be pumped at individual rates of Q = 1.78 × 10^5 ft^3 /day for a total critical pumping rate of Q_c = 1.07 × 10^6 ft^3 / day (see Tables 13 and 14). These results illustrate how the sensitivity of the critical pumping rate to the number and spacing of wells can be investigated.

Table 13. Input file for file option for saltwater upconing multiple-well example problem for 2,000-ft spacing

36800	1.20E-03	1430	0.1			Values for T, K'/b', b, Kz/Kr
6						Number of wells
1	0	2000	1.0	119.0	843.0	Well i.d., x_w, y_w, r_w, d, ℓ
2	2000	2000	1.0	119.0	843.0	Well i.d., x_w, y_w, r_w, d, ℓ
3	4000	2000	1.0	119.0	843.0	Well i.d., x_w, y_w, r_w, d, ℓ
4	0	0	1.0	119.0	843.0	Well i.d., x_w, y_w, r_w, d, ℓ
5	2000	0	1.0	119.0	843.0	Well i.d., x_w, y_w, r_w, d, ℓ
6	4000	0	1.0	119.0	843.0	Well i.d., x_w, y_w, r_w, d, ℓ

Table 14. Output file for saltwater upconing multiple-well example problem for 2,000-ft spacing

```
SWUP:AN INTERACTIVE PROGRAM FOR CALCULATING SALTWATER UPCONING
IN AN AQUIFER OVERLAIN BY A LEAKY CONFINING UNIT

PREPARED BY Louis H.Motz and Ozlem Acar
                            Department of Civil and Coastal Engineering
                            University of Florida
                            Gainesville,Florida
------------------------------------------------------------------------------------
------------------------------------------------------------------------------------
Saltwater upconing multi-well 2000-ft spacing

SALTWATER UPCONING DUE TO WELLFIELD PUMPING

INPUT DATA
----------
----------
ALL DATA ARE IN CONSISTENT UNITS

TRANSMISSIVITY (T) (ft2/day)                                        : 3.680E+04
LEAKANCE OF CONFINING UNIT (Kprime/bprime) (1/day)                  : 1.200E-03
DISTANCE FROM TOP OF AQUIFER TO SW-FW INTERFACE (b) (ft)            :  1430.000
VERTICAL HYD.CONDUCTIVITY/HORIZONTAL HYD.CONDUCTIVITY (Kz/Kr)       :  1.00E-01


1
X COORDINATE OF WELL (X) (ft)                                       :     0.000
Y COORDINATE OF WELL (Y) (ft)                                       :  2000.000
RADIUS OF WELL (rw) (ft)                                            :     1.000
DISTANCE FROM TOP OF AQUIFER TO TOP OF WELL SCREEN (d) (ft)         :   119.000
DISTANCE FROM TOP OF AQUIFER TO BOTTOM OF WELL SCREEN (l) (ft)      :   843.000

2
X COORDINATE OF WELL (X) (ft)                                       :  2000.000
Y COORDINATE OF WELL (Y) (ft)                                       :  2000.000
RADIUS OF WELL (rw) (ft)                                            :     1.000
DISTANCE FROM TOP OF AQUIFER TO TOP OF WELL SCREEN (d) (ft)         :   119.000
DISTANCE FROM TOP OF AQUIFER TO BOTTOM OF WELL SCREEN (l) (ft)      :   843.000
```

```
3
X COORDINATE OF WELL (X) (ft)                                          :  4000.000
Y COORDINATE OF WELL (Y) (ft)                                          :  2000.000
RADIUS OF WELL (rw) (ft)                                               :     1.000
DISTANCE FROM TOP OF AQUIFER TO TOP OF WELL SCREEN (d) (ft)            :   119.000
DISTANCE FROM TOP OF AQUIFER TO BOTTOM OF WELL SCREEN (l) (ft)         :   843.000

4
X COORDINATE OF WELL (X) (ft)                                          :     0.000
Y COORDINATE OF WELL (Y) (ft)                                          :     0.000
RADIUS OF WELL (rw) (ft)                                               :     1.000
DISTANCE FROM TOP OF AQUIFER TO TOP OF WELL SCREEN (d) (ft)            :   119.000
DISTANCE FROM TOP OF AQUIFER TO BOTTOM OF WELL SCREEN (l) (ft)         :   843.000

5
X COORDINATE OF WELL (X) (ft)                                          :  2000.000
Y COORDINATE OF WELL (Y) (ft)                                          :     0.000
RADIUS OF WELL (rw) (ft)                                               :     1.000
DISTANCE FROM TOP OF AQUIFER TO TOP OF WELL SCREEN (d) (ft)            :   119.000
DISTANCE FROM TOP OF AQUIFER TO BOTTOM OF WELL SCREEN (l) (ft)         :   843.000

6
X COORDINATE OF WELL (X) (ft)                                          :  4000.000
Y COORDINATE OF WELL (Y) (ft)                                          :     0.000
RADIUS OF WELL (rw) (ft)                                               :     1.000
DISTANCE FROM TOP OF AQUIFER TO TOP OF WELL SCREEN (d) (ft)            :   119.000
DISTANCE FROM TOP OF AQUIFER TO BOTTOM OF WELL SCREEN (l) (ft)         :   843.000

SALTWATER UPCONING RESULTS
OBTAINED BY ANALYTICAL MODEL
----------------------------
----------------------------

REF: Motz,L.H.1994.Predicting Saltwater Upconing Due to Well Field Pumping.
     In:Soveri,J.,and Suokko,T.,Editors.Future Groundwater Resources at Risk.
     (Proceedings of the Helsinki Conference,June 1994).International Association
     of Hydrological Sciences,Publication No.222,pp.55-60.

   * This model uses the Ghyben-Herzberg 40:1 ratio for the saltwater-freshwater
     interface.

Pumped well under consideration  Qc (ft3/day) (critical pumping rate at well under consideration)
--------------------------------         ------------------------------------------
1                                                  1.99E+05

Other wells causing interference   Qm (ft3/day) (pumping rates at other wells)
--------------------------------         ------------------------------------------
2                                                  1.99E+05
3                                                  1.99E+05
4                                                  1.99E+05
5                                                  1.99E+05
6                                                  1.99E+05
--------------------------------         ------------------------------------------
--------------------------------         ------------------------------------------
TOTAL PUMPING RATE (ft3/day) =                     1.20E+06

Pumped well under consideration  Qc (ft3/day) (critical pumping rate at well under consideration)
--------------------------------         ------------------------------------------
2                                                  1.78E+05

Other wells causing interference    Qm (ft3/day) (pumping rates at other wells)
--------------------------------         ------------------------------------------
1                                                  1.78E+05
3                                                  1.78E+05
4                                                  1.78E+05
5                                                  1.78E+05
6                                                  1.78E+05
--------------------------------         ------------------------------------------
--------------------------------         ------------------------------------------
TOTAL PUMPING RATE (ft3/day) =                     1.07E+06
```

```
Pumped well under consideration  Qc (ft3/day) (critical pumping rate at well under consideration)
--------------------------------        ------------------------------------------
3                                                 1.99E+05

Other wells causing interference    Qm (ft3/day) (pumping rates at other wells)
--------------------------------        ------------------------------------------
1                                                 1.99E+05
2                                                 1.99E+05
4                                                 1.99E+05
5                                                 1.99E+05
6                                                 1.99E+05
--------------------------------        ------------------------------------------
--------------------------------        ------------------------------------------
TOTAL PUMPING RATE (ft3/day) =                    1.20E+06

Pumped well under consideration  Qc (ft3/day) (critical pumping rate at well under consideration)
--------------------------------        ------------------------------------------
4                                                 1.99E+05

Other wells causing interference     Qm (ft3/day) (pumping rates at other wells)
--------------------------------        ------------------------------------------
1                                                 1.99E+05
2                                                 1.99E+05
3                                                 1.99E+05
5                                                 1.99E+05
6                                                 1.99E+05
--------------------------------        ------------------------------------------
--------------------------------        ------------------------------------------
TOTAL PUMPING RATE (ft3/day) =                    1.20E+06

Pumped well under consideration  Qc (ft3/day) (critical pumping rate at well under consideration)
--------------------------------        ------------------------------------------
5                                                 1.78E+05

Other wells causing interference     Qm (ft3/day) (pumping rates at other wells)
--------------------------------        ------------------------------------------
1                                                 1.78E+05
2                                                 1.78E+05
3                                                 1.78E+05
4                                                 1.78E+05
6                                                 1.78E+05
--------------------------------        ------------------------------------------
--------------------------------        ------------------------------------------
TOTAL PUMPING RATE (ft3/day) =                    1.07E+06

Pumped well under consideration  Qc (ft3/day) (critical pumping rate at well under consideration)
--------------------------------        ------------------------------------------
6                                                 1.99E+05

Other wells causing interference     Qm (ft3/day) (pumping rates at other wells)
--------------------------------        ------------------------------------------
1                                                 1.99E+05
2                                                 1.99E+05
3                                                 1.99E+05
4                                                 1.99E+05
5                                                 1.99E+05
--------------------------------        ------------------------------------------
--------------------------------        ------------------------------------------
TOTAL PUMPING RATE (ft3/day) =                    1.20E+06

CRITICAL CONDITION OCCURS AT 5
BASED ON WELL PROPERTIES

Well                      Q (ft3/day)                Drawdown in well (ft)
--------------------      -----------                ---------------------
1                          1.78E+05                      15.755
2                          1.78E+05                      16.573
3                          1.78E+05                      15.755
```

4	1.78E+05	15.755
5	1.78E+05	16.573
6	1.78E+05	15.755
--------------------	-----------	---------------------
--------------------	-----------	---------------------
CRITICAL PUMPING RATE (ft3/day) =	1.07E+06	

3.0 DRAWDOWNS IN A TWO-LAYER AQUIFER SYSTEM

3.1 Drawdowns in Coupled Aquifers

Drawdowns in a water-table aquifer can occur in response to pumping from an underlying confined aquifer (Denis and Motz 1998) (see Figure 4). Water pumped from the underlying aquifer is derived from artesian storage in the pumped aquifer and leakage through the overlying semipermeable confining unit. The leakage in turn is derived from storage in the confining unit and the water-table aquifer and a reduction in evapotranspiration due to a decline in the water table. Drawdowns in the water-table aquifer can also occur in response to pumping from the water-table aquifer itself, and water-table recovery can occur in response to recharging the water-table aquifer. An analytical solution developed by Denis and Motz (1998) to calculate transient and steady-state drawdowns in the water-table and confined aquifers can be used to quantify pumping impacts. In this solution, horizontal flow occurs in both upper and lower aquifers, and vertical flow between the aquifers is represented by leakage through the confining unit. At well locations, pumping can occur from one or both aquifers, and a separate well can be specified for each aquifer being pumped (or recharged). Flow into (or out of) each well occurs only from the aquifer to which the well is open, and it is assumed that the aquifers are not connected hydraulically through the well bore. Evapotranspiration is represented by a coefficient ε, which is a linear representation of the rate at which evapotranspiration is reduced per unit of drawdown in the upper water-table aquifer. It is equivalent to the linear function used in numerical groundwater flow models such as MODFLOW (McDonald and Harbaugh 1988) to describe the reduction in evapotranspiration caused by lowering the water table due to pumping from the uppermost aquifer and/or underlying confined aquifers.

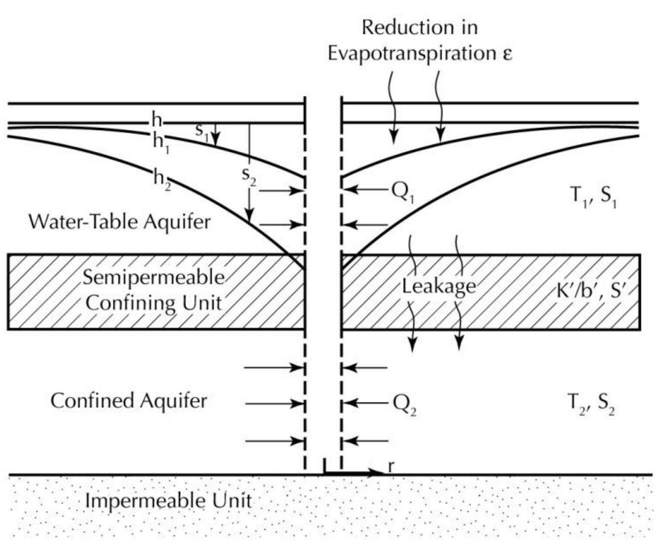

Figure 4. Definition sketch for transient drawdowns in coupled aquifers with confining unit storage and evapotranspiration reduction [from Denis and Motz (1998)]

3.2 Drawdowns Due to Single Well

3.2.1 Analytical Solution for Single Well

The Laplace space solution for the drawdown in aquifer 1 due to pumping from aquifers 1 and 2 at rates Q_1 and Q_2 is (Denis and Motz 1998):

$$\bar{s}_1 = \frac{C_1}{D}\left[\left(A_2-\omega_1^2\right)K_0\left(r\omega_1\right)-\left(A_2-\omega_2^2\right)K_0\left(r\omega_2\right)\right]+\frac{C_2B_1}{D}\left[K_0\left(r\omega_1\right)-K_0\left(r\omega_2\right)\right] \tag{6}$$

The Laplace space solution for the drawdown in aquifer 2 due to pumping from aquifers 1 and 2 at rates Q_1 and Q_2 is:

$$\bar{s}_2 = \frac{C_1B_2}{D}\left[K_0\left(r\omega_1\right)-K_0\left(r\omega_2\right)\right]+\frac{C_2}{D}\left[(A_1-\omega_1^2)K_0\left(r\omega_1\right)-(A_1-\omega_2^2)K_0\left(r\omega_2\right)\right] \tag{7}$$

In Equations 6 and 7, $K_0(\ )$ = modified Bessel function, second kind, zero order; $\bar{s}_{1,2}$ = Laplace transforms of $s_{1,2}$, and:

$$A_1 = \frac{S_1p}{T_1}+\frac{\varepsilon}{T_1}+\frac{1}{T_1}\sqrt{\frac{pK'S'}{b'}}\coth\sqrt{\frac{pS'b'}{K'}} \tag{8}$$

$$A_2 = \frac{S_2p}{T_2}+\frac{1}{T_2}\sqrt{\frac{pK'S'}{b'}}\coth\sqrt{\frac{pS'b'}{K'}} \tag{9}$$

$$B_1 = \frac{1}{T_1}\sqrt{\frac{pK'S'}{b'}}\operatorname{csc}h\sqrt{\frac{pS'b'}{K'}} \tag{10}$$

$$B_2 = \frac{1}{T_2}\sqrt{\frac{pK'S'}{b'}}\operatorname{csc}h\sqrt{\frac{pS'b'}{K'}} \tag{11}$$

$$C_1 = \frac{Q_1}{2\pi T_1 p} \tag{12}$$

$$C_2 = \frac{Q_2}{2\pi T_2 p} \tag{13}$$

$$D = \sqrt{\left(A_1-A_2\right)^2+4B_1B_2} \tag{14}$$

$$\omega_1 = \sqrt{\frac{A_1+A_2-D}{2}} \tag{15}$$

and:

$$\omega_2 = \sqrt{\frac{A_1 + A_2 + D}{2}} \qquad (16)$$

Also:

b'	=	thickness of the confining unit;
$K_0(\ )$	=	modified Bessel function, second kind, zero order;
K'/b'	=	leakance of the confining unit;
p	=	Laplace transform parameter;
$Q_{1,2}$	=	pumping rates from aquifers 1 and 2;
r	=	radial distance from the pumped well;
$S_{1,2}$	=	specific yield and storativity of the confining unit;
$s_{1,2}$	=	drawdowns in aquifers 1 and 2;
$\bar{s}_{1,2}$	=	Laplace transforms of $s_{1,2}$.
S'	=	S_s'b' = storativity of the confining unit.
S_s'	=	specific storage of the confining unit;
$T_{1,2}$	=	transmissivities of aquifers 1 and 2;
t	=	time; and
ε	=	rate at which evapotranspiration is reduced per unit of water-table drawdown.

As described by Denis and Motz (1998), analytical forms for the inverse Laplace transforms for Equations 6 and 7 are not obtained. Instead, drawdowns s_1 and s_2 are obtained by inverting Equations 6 and 7 from Laplace space to the time domain using the Stehfest (1970) numerical algorithm as described by Moench and Ogata (1981, 1984). An important limitation to the coupled aquifer solution represented by Equations 6 through 16 is that the linearized assumptions implicit in Equations 6 and 7 not be exceeded, i.e., predicted drawdowns in layer 1 should be small compared to the initial saturated thickness of layer 1, and layer 2 should remain confined. Also, predicted water levels in layer 1 should not fall below the extinction depth for evapotranspiration in a pumping problem, nor should they rise above the elevation at which evapotranspiration is a maximum in a recharge problem (Denis and Motz 1998).

3.2.2 Single-Well Option in COUAQ

The single-well option in COUAQ uses Equations 6 through 16 and the Stehfest (1970) numerical algorithm to calculate drawdowns for aquifers 1 and 2. To start the program, the user clicks on the icon for the program and selects the single-well option. The program can be run interactively with the user inputting all data on the screen, or the user can prepare an input file and select the 'file' option when running the program. If the program is run interactively, time and drawdown results are printed on the screen, and the user is prompted to enter the names of two output files. One output file (filename.out) echoes the input data and prints the time and drawdown results, and the other file (filename.dat) prints the output results for time and drawdowns in a format that can be readily used in a graphical package such as Grapher™ to plot drawdowns versus time. If the 'file' option is selected, then the user is prompted to enter the input file name (filename.in), the name of the project ('project name'), and the names of the two output files (filename.out and filename.dat), which are the same as the output files written using the interactive option. Interactively on the screen or in the input file, the user inputs the total time of the simulation, the number of time steps, and the time step multiplier. The format of this input is similar to the input format for numerical models such as MODFLOW (McDonald and Harbaugh 1988), but, unlike a numerical model, it is not necessary to discretize the time steps to perform a drawdown calculation. For example, drawdowns can be calculated for one desired time value by inputting the desired time as the total time of the simulation, the number of time steps equal to 1, and a time step multiplier equal to 1.0. Similarly, drawdowns at steady state can be calculated using a large value for time (i.e., 1×10^6 days), one time step, and a time step multiplier equal to 1.0.

Within the program, the first, or outer, loop is for the radial distance from the pumped well to the observation well at which drawdowns are to be calculated. Within this loop, the time interval deltime is calculated if the timestep multiplier is 1.0; otherwise, initial time is calculated. At each step within the time loop, which is the second, or inner, loop, drawdowns are calculated by calling the subroutine Nsscou, which numerically inverts the drawdown equations. Bessel functions in this subroutine are calculated by calling the subroutine Bessel. In the subroutine Nsscou, drawdowns within the range from -1.0×10^{-6} to 1.0×10^{-6} are set equal to 0.0 to avoid problems with underflow. At the end of each time step, time and drawdown results are written to the output file filename.out and also to the screen if the user has selected the interactive option. At the end of the time step loop, control is passed to the radial distance loop if more than one radius has been specified by the user. When calculations for all of the radial distances have been performed, time, radius, and drawdown results are written to the output file filename.dat. At this point, the user is asked if more calculations are to be done.

3.2.3 Benchmark Problem

The single-well option in COUAQ was tested using parameters that are based on representative parameters for the Cypress Creek wellfield in Pasco County in west-central Florida (Denis 1996). In this area, the hydrogeologic system consists of a water-table aquifer, a semipermeable confining unit, and limestone and dolomite formations that make up the upper Floridan aquifer (Miller 1986). Based on values similar to those used by Denis and Motz (1998), values of $Q_1 = 0$ ft^3/day, $T_1 = 270$ ft^2/day, $S_1 = 0.2$, and $\varepsilon = 0.001$ day^{-1} were used for aquifer 1, and $Q_2 = 353{,}000$ ft^3/day, $T_2 = 27{,}000$ ft^2/day, and $S_2 = 0.001$ were used for aquifer 2. Values of $K'/b' = 0.002$ day^{-1} and $S' = 0.01$ were used to represent the confining unit separating aquifers 1 and 2. Drawdowns were calculated at one location 800 ft from the pumped well. The transient simulation was run to 10,000 days in 100 time steps with a time step multiplier = 1.2. The COUAQ solution (see Figure 5) predicts that the maximum drawdowns will be 4.567 ft in the pumped aquifer (aquifer 2) and 2.981 ft in the unpumped aquifer (aquifer 1) and that a steady-state drawdown condition will be reached in approximately 935 days (at a criterion of 0.01 ft).

To verify the COUAQ solution, drawdowns also were calculated for this problem using a five-layer MODFLOW (McDonald and Harbaugh 1988) solution. In the MODFLOW solution, layer 1 was a constant head source bed, and the vertical hydraulic conductivity divided by the thickness in layer 2 represented the evapotranspiration reduction coefficient. Layer 3 represented the unpumped water-table aquifer (aquifer 1), and the vertical hydraulic conductivity

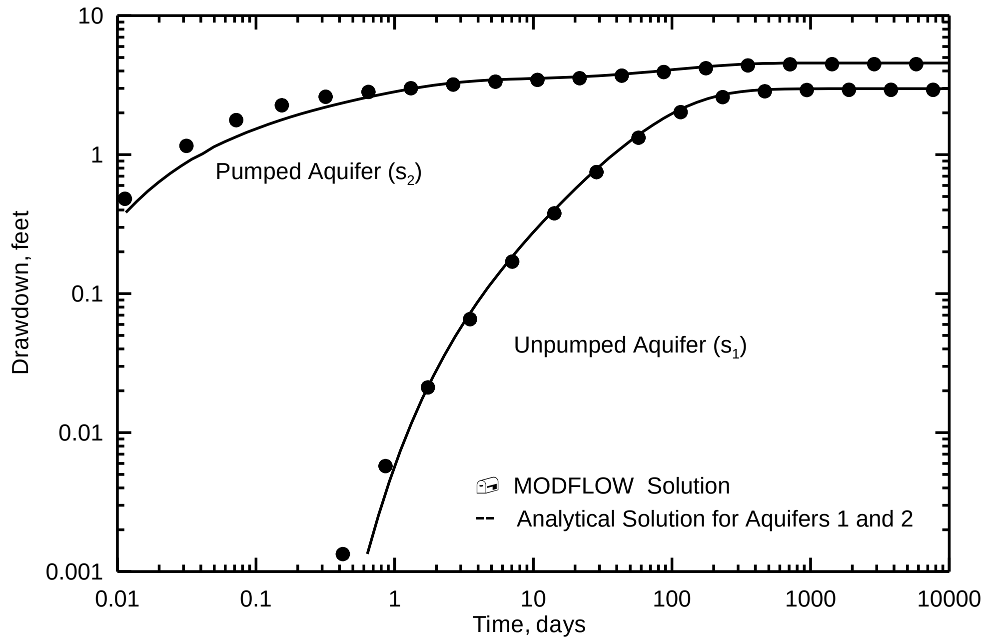

Figure 5. Coupled aquifer benchmark problem: drawdowns versus time for COUAQ and MODFLOW solutions

divided by the thickness of layer 4 represented the leakance of the confining unit overlying the upper Floridan aquifer. Layer 5 represented the underlying upper Floridan aquifer (aquifer 2), which was pumped. All of the layers were specified as confined to match the linearized (i.e., small drawdown) assumptions implicit in Equations 6 and 7. General head boundary conditions were specified around layer 5 to represent the infinite aquifer boundary condition in layer 5. A transient simulation was run with MODFLOW using a data set equivalent to the parameters used in the COUAQ solution to calculate drawdowns due to pumping. At a distance of 800 ft from the pumped well, the MODFLOW solution predicts that the maximum drawdown will be 4.574 ft in the pumped aquifer and 2.985 ft in the unpumped aquifer (Figure 5). Steady-state drawdowns occur in approximately 930 days (at a criterion of 0.01 ft), i.e., approximately the same time as in the COUAQ solution.

Files for the benchmark problem are in Tables 15 through 19. The screen capture for the interactive option is in Table 15, and the output files are in Tables 16 and 17. The screen capture for the input file option is in Table 18, and the input file for the file option is in Table 19. The input file option writes the same output files as the interactive option (Tables 16 and 17).

Table 15. Input on screen for interactive input for coupled aquifer benchmark problem

```
 *********************************************************************
COUAQ: AN INTERACTIVE PROGRAM FOR CALCULATING DRAWDOWNS IN COUPLED AQUIFERS WITH CONFINING UNIT
STORAGE AND ET REDUCTION
PREPARED BY          Louis H. Motz and Ozlem Acar
                     Department of Civil and Coastal Engineering
                     University of Florida
                     Gainesville, Florida
*********************************************************************
 *********************************************************************
 SINGLE OR MULTIPLE WELLS? <s/m>
s
 Do you want to prepare an input FILE or enter data INTERACTIVELY? <f/i>
i
 NAME OF THE PROJECT: <write in single quotation marks>
'coupled aquifer benchmark problem'
 PLEASE ENTER DATA IN CONSISTENT UNITS
 PUMPING RATE FROM AQUIFER 1 (Q1) (ft3/day)=?
0
 TRANSMISSIVITY OF AQUIFER 1 (T1) (ft2/day)=?
270
 SPECIFIC YIELD OF AQUIFER 1 (S1)=?
0.2
 RATE AT WHICH ET IS REDUCED PER UNIT OF WT DRAWDOWN (1/day)=?
0.001
 PUMPING RATE FROM AQUIFER 2 (Q2) (ft3/day)=?
353000
 TRANSMISSIVITY OF AQUIFER 2 (T2) (ft2/day)=?
27000
 STORATIVITY OF AQUIFER 2 (S2)=?
0.001
 LEAKANCE OF CONFINING UNIT (Kprime/bprime) (1/day)=?
0.002
 STORATIVITY OF THE CONFINING UNIT (Sprime)=?
0.01
 NUMBER OF r VALUES FOR WHICH CALCULATIONS ARE CARRIED OUT=?
1
 RADIAL DISTANCE FROM THE PUMPED WELL (r) (ft)=?
800
 TOTAL TIME LENGTH FOR TRANSIENT SIMULATION (t) (days)=?
10000
 NUMBER OF TIME STEPS FOR TRANSIENT SIMULATION=?
100
 TIME STEP MULTIPLIER FOR TRANSIENT SIMULATION=?
1.2

 ENTER OUTPUT FILE NAME: <filename.out>
coupled_1_benchmark.out
 ENTER DATA FILE NAME FOR GRAPHER INPUT: <filename.dat>
coupled_1_benchmark.dat

 r (ft) = 8.000E+02
```

time (days)	drawdown aquifer 1 (ft)	drawdown aquifer 2 (ft)
1.449E-04	0.000E+00	1.000E-20
1.739E-04	0.000E+00	1.000E-20
2.087E-04	0.000E+00	1.000E-20
2.504E-04	0.000E+00	1.000E-20
3.005E-04	0.000E+00	1.000E-20
3.605E-04	0.000E+00	1.000E-20
4.327E-04	0.000E+00	1.000E-20
5.192E-04	0.000E+00	1.000E-20
6.230E-04	0.000E+00	1.207E-05
7.476E-04	0.000E+00	3.701E-05
8.972E-04	0.000E+00	1.321E-04
1.077E-03	0.000E+00	4.542E-04
1.292E-03	0.000E+00	1.344E-03

1.550E-03	0.000E+00	3.401E-03
1.860E-03	0.000E+00	7.509E-03
2.232E-03	0.000E+00	1.480E-02
2.679E-03	0.000E+00	2.656E-02
3.215E-03	0.000E+00	4.406E-02
3.858E-03	0.000E+00	6.843E-02
4.629E-03	0.000E+00	1.005E-01
5.555E-03	0.000E+00	1.409E-01
6.666E-03	0.000E+00	1.896E-01
7.999E-03	0.000E+00	2.467E-01
9.599E-03	0.000E+00	3.115E-01
1.152E-02	0.000E+00	3.836E-01
1.382E-02	0.000E+00	4.623E-01
1.659E-02	0.000E+00	5.466E-01
1.990E-02	0.000E+00	6.359E-01
2.389E-02	0.000E+00	7.295E-01
2.866E-02	0.000E+00	8.253E-01
3.439E-02	0.000E+00	9.275E-01
4.127E-02	0.000E+00	1.016E+00
4.953E-02	0.000E+00	1.138E+00
5.943E-02	0.000E+00	1.240E+00
7.132E-02	0.000E+00	1.340E+00
8.559E-02	0.000E+00	1.445E+00
1.027E-01	0.000E+00	1.550E+00
1.232E-01	0.000E+00	1.656E+00
1.479E-01	0.000E+00	1.761E+00
1.775E-01	0.000E+00	1.866E+00
2.130E-01	3.257E-06	1.970E+00
2.556E-01	1.179E-05	2.074E+00
3.067E-01	3.901E-05	2.178E+00
3.680E-01	1.132E-04	2.281E+00
4.416E-01	2.879E-04	2.383E+00
5.299E-01	6.525E-04	2.484E+00
6.359E-01	1.340E-03	2.585E+00
7.631E-01	2.531E-03	2.686E+00
9.157E-01	4.456E-03	2.785E+00
1.099E+00	7.389E-03	2.883E+00
1.319E+00	1.164E-02	2.978E+00
1.582E+00	1.757E-02	3.069E+00
1.899E+00	2.553E-02	3.153E+00
2.279E+00	3.593E-02	3.230E+00
2.734E+00	4.919E-02	3.297E+00
3.281E+00	6.579E-02	3.353E+00
3.937E+00	8.623E-02	3.400E+00
4.725E+00	1.111E-01	3.437E+00
5.670E+00	1.411E-01	3.467E+00
6.804E+00	1.770E-01	3.491E+00
8.165E+00	2.198E-01	3.511E+00
9.797E+00	2.703E-01	3.530E+00
1.176E+01	3.297E-01	3.550E+00
1.411E+01	3.993E-01	3.571E+00
1.693E+01	4.804E-01	3.595E+00
2.032E+01	5.742E-01	3.623E+00
2.438E+01	6.819E-01	3.656E+00
2.926E+01	8.046E-01	3.693E+00
3.511E+01	9.428E-01	3.735E+00
4.213E+01	1.096E+00	3.783E+00
5.055E+01	1.265E+00	3.837E+00
6.066E+01	1.445E+00	3.896E+00
7.280E+01	1.635E+00	3.959E+00
8.735E+01	1.829E+00	4.027E+00
1.048E+02	2.022E+00	4.098E+00
1.258E+02	2.207E+00	4.169E+00
1.509E+02	2.378E+00	4.239E+00
1.811E+02	2.529E+00	4.306E+00
2.174E+02	2.656E+00	4.367E+00
2.608E+02	2.758E+00	4.421E+00
3.130E+02	2.836E+00	4.465E+00
3.756E+02	2.891E+00	4.500E+00
4.507E+02	2.929E+00	4.526E+00
5.409E+02	2.953E+00	4.544E+00
6.491E+02	2.967E+00	4.555E+00

```
 7.789E+02      2.974E+00      4.562E+00
 9.346E+02      2.978E+00      4.565E+00
 1.122E+03      2.980E+00      4.566E+00
 1.346E+03      2.981E+00      4.567E+00
 1.615E+03      2.981E+00      4.567E+00
 1.938E+03      2.981E+00      4.567E+00
 2.326E+03      2.981E+00      4.567E+00
 2.791E+03      2.981E+00      4.567E+00
 3.349E+03      2.981E+00      4.567E+00
 4.019E+03      2.981E+00      4.567E+00
 4.823E+03      2.981E+00      4.567E+00
 5.787E+03      2.981E+00      4.567E+00
 6.944E+03      2.981E+00      4.567E+00
 8.333E+03      2.981E+00      4.567E+00
 1.000E+04      2.981E+00      4.567E+00

 PROGRAM COMPLETED
 Do you want to do more calculations? <y/n>
n
```

Table 16. Output file for coupled aquifer benchmark problem

```
*********************************************************************************
COUAQ: AN INTERACTIVE PROGRAM FOR CALCULATING DRAWDOWNS IN COUPLED AQUIFERS WITH CONFINING UNIT
STORAGE AND ET REDUCTION
PREPARED BY       Louis H. Motz and Ozlem Acar
                  Department of Civil and Coastal Engineering
                  University of Florida
                  Gainesville, Florida
-----------------------------------------------------------------------------------
-----------------------------------------------------------------------------------
coupled aquifer bench mark problem
DRAWDOWNS DUE TO SINGLE WELL PUMPING
INPUT DATA
----------
----------
ALL DATA ARE IN CONSISTENT UNITS

PUMPING RATE FROM AQUIFER 1 (Q1) (ft3/day)                            :     0.00E+00
TRANSMISSIVITY OF AQUIFER 1 (T1) (ft2/day)                            :     2.70E+02
SPECIFIC YIELD OF AQUIFER 1 (S1)                                      :     2.00E-01
RATE AT WHICH ET IS REDUCED PER UNIT OF WT DRAWDOWN (1/day)           :     1.00E-03
PUMPING RATE FROM AQUIFER 2 (Q2) (ft3/day)                            :     3.53E+05
TRANSMISSIVITY OF AQUIFER 2 (T2) (ft2/day)                            :     2.70E+04
STORATIVITY OF AQUIFER 2 (S2)                                         :     1.00E-03
LEAKANCE OF CONFINING UNIT (Kprime/bprime) (1/day)                    :     2.00E-03
STORATIVITY OF THE CONFINING UNIT (Sprime)                            :     1.00E-02

NUMBER OF R VALUES FOR WHICH CALCULATIONS ARE CARRIED OUT             :            1
RADIAL DISTANCE FROM THE PUMPED WELL (r) (ft)                         :      800.000

TOTAL TIME LENGTH FOR TRANSIENT SIMULATION (t) (days)                 :    10000.000
NUMBER OF TIME STEPS FOR TRANSIENT SIMULATION                         :          100
TIME STEP MULTIPLIER FOR TRANSIENT SIMULATION                         :        1.200

DRAWDOWNS IN COUPLED AQUIFERS
OBTAINED BY ANALYTICAL MODEL
-----------------------------
-----------------------------

REFERENCE: Denis, R.E., and Motz, L.H. 1998. Drawdowns in Coupled Aquifers with Confining Unit
Storage and ET Reduction. J. Ground Water, 36(2), 201-207, March-April.
```

r (ft) = 8.000E+02

time (days)	drawdown aquifer 1 (ft)	drawdown aquifer 2 (ft)
1.449E-04	0.000E+00	1.000E-20
1.739E-04	0.000E+00	1.000E-20
2.087E-04	0.000E+00	1.000E-20
2.504E-04	0.000E+00	1.000E-20
3.005E-04	0.000E+00	1.000E-20
3.605E-04	0.000E+00	1.000E-20
4.327E-04	0.000E+00	1.000E-20
5.192E-04	0.000E+00	1.000E-20
6.230E-04	0.000E+00	1.207E-05
7.476E-04	0.000E+00	3.701E-05
8.972E-04	0.000E+00	1.321E-04
1.077E-03	0.000E+00	4.542E-04
1.292E-03	0.000E+00	1.344E-03
1.550E-03	0.000E+00	3.401E-03
1.860E-03	0.000E+00	7.509E-03
2.232E-03	0.000E+00	1.480E-02
2.679E-03	0.000E+00	2.656E-02
3.215E-03	0.000E+00	4.406E-02
3.858E-03	0.000E+00	6.843E-02
4.629E-03	0.000E+00	1.005E-01
5.555E-03	0.000E+00	1.409E-01
6.666E-03	0.000E+00	1.896E-01
7.999E-03	0.000E+00	2.467E-01
9.599E-03	0.000E+00	3.115E-01
1.152E-02	0.000E+00	3.836E-01
1.382E-02	0.000E+00	4.623E-01
1.659E-02	0.000E+00	5.466E-01
1.990E-02	0.000E+00	6.359E-01
2.389E-02	0.000E+00	7.295E-01
2.866E-02	0.000E+00	8.253E-01
3.439E-02	0.000E+00	9.275E-01
4.127E-02	0.000E+00	1.016E+00
4.953E-02	0.000E+00	1.138E+00
5.943E-02	0.000E+00	1.240E+00
7.132E-02	0.000E+00	1.340E+00
8.559E-02	0.000E+00	1.445E+00
1.027E-01	0.000E+00	1.550E+00
1.232E-01	0.000E+00	1.656E+00
1.479E-01	0.000E+00	1.761E+00
1.775E-01	0.000E+00	1.866E+00
2.130E-01	3.257E-06	1.970E+00
2.556E-01	1.179E-05	2.074E+00
3.067E-01	3.901E-05	2.178E+00
3.680E-01	1.132E-04	2.281E+00
4.416E-01	2.879E-04	2.383E+00
5.299E-01	6.525E-04	2.484E+00
6.359E-01	1.340E-03	2.585E+00
7.631E-01	2.531E-03	2.686E+00
9.157E-01	4.456E-03	2.785E+00
1.099E+00	7.389E-03	2.883E+00
1.319E+00	1.164E-02	2.978E+00
1.582E+00	1.757E-02	3.069E+00
1.899E+00	2.553E-02	3.153E+00
2.279E+00	3.593E-02	3.230E+00
2.734E+00	4.919E-02	3.297E+00
3.281E+00	6.579E-02	3.353E+00
3.937E+00	8.623E-02	3.400E+00
4.725E+00	1.111E-01	3.437E+00
5.670E+00	1.411E-01	3.467E+00
6.804E+00	1.770E-01	3.491E+00
8.165E+00	2.198E-01	3.511E+00
9.797E+00	2.703E-01	3.530E+00
1.176E+01	3.297E-01	3.550E+00
1.411E+01	3.993E-01	3.571E+00
1.693E+01	4.804E-01	3.595E+00

2.032E+01	5.742E-01	3.623E+00
2.438E+01	6.819E-01	3.656E+00
2.926E+01	8.046E-01	3.693E+00
3.511E+01	9.428E-01	3.735E+00
4.213E+01	1.096E+00	3.783E+00
5.055E+01	1.265E+00	3.837E+00
6.066E+01	1.445E+00	3.896E+00
7.280E+01	1.635E+00	3.959E+00
8.735E+01	1.829E+00	4.027E+00
1.048E+02	2.022E+00	4.098E+00
1.258E+02	2.207E+00	4.169E+00
1.509E+02	2.378E+00	4.239E+00
1.811E+02	2.529E+00	4.306E+00
2.174E+02	2.656E+00	4.367E+00
2.608E+02	2.758E+00	4.421E+00
3.130E+02	2.836E+00	4.465E+00
3.756E+02	2.891E+00	4.500E+00
4.507E+02	2.929E+00	4.526E+00
5.409E+02	2.953E+00	4.544E+00
6.491E+02	2.967E+00	4.555E+00
7.789E+02	2.974E+00	4.562E+00
9.346E+02	2.978E+00	4.565E+00
1.122E+03	2.980E+00	4.566E+00
1.346E+03	2.981E+00	4.567E+00
1.615E+03	2.981E+00	4.567E+00
1.938E+03	2.981E+00	4.567E+00
2.326E+03	2.981E+00	4.567E+00
2.791E+03	2.981E+00	4.567E+00
3.349E+03	2.981E+00	4.567E+00
4.019E+03	2.981E+00	4.567E+00
4.823E+03	2.981E+00	4.567E+00
5.787E+03	2.981E+00	4.567E+00
6.944E+03	2.981E+00	4.567E+00
8.333E+03	2.981E+00	4.567E+00
1.000E+04	2.981E+00	4.567E+00

Table 17. Time and drawdown data output file for coupled aquifer benchmark problem

	r = 8.000E+02	
time	s1	s2
1.449E-04	0.000E+00	1.000E-20
1.739E-04	0.000E+00	1.000E-20
2.087E-04	0.000E+00	1.000E-20
2.504E-04	0.000E+00	1.000E-20
3.005E-04	0.000E+00	1.000E-20
3.605E-04	0.000E+00	1.000E-20
4.327E-04	0.000E+00	1.000E-20
5.192E-04	0.000E+00	1.000E-20
6.230E-04	0.000E+00	1.207E-05
7.476E-04	0.000E+00	3.701E-05
8.972E-04	0.000E+00	1.321E-04
1.077E-03	0.000E+00	4.542E-04
1.292E-03	0.000E+00	1.344E-03
1.550E-03	0.000E+00	3.401E-03
1.860E-03	0.000E+00	7.509E-03
2.232E-03	0.000E+00	1.480E-02
2.679E-03	0.000E+00	2.656E-02
3.215E-03	0.000E+00	4.406E-02
3.858E-03	0.000E+00	6.843E-02
4.629E-03	0.000E+00	1.005E-01
5.555E-03	0.000E+00	1.409E-01
6.666E-03	0.000E+00	1.896E-01
7.999E-03	0.000E+00	2.467E-01
9.599E-03	0.000E+00	3.115E-01
1.152E-02	0.000E+00	3.836E-01
1.382E-02	0.000E+00	4.623E-01
1.659E-02	0.000E+00	5.466E-01
1.990E-02	0.000E+00	6.359E-01
2.389E-02	0.000E+00	7.295E-01
2.866E-02	0.000E+00	8.253E-01

3.439E-02	0.000E+00	9.275E-01
4.127E-02	0.000E+00	1.016E+00
4.953E-02	0.000E+00	1.138E+00
5.943E-02	0.000E+00	1.240E+00
7.132E-02	0.000E+00	1.340E+00
8.559E-02	0.000E+00	1.445E+00
1.027E-01	0.000E+00	1.550E+00
1.232E-01	0.000E+00	1.656E+00
1.479E-01	0.000E+00	1.761E+00
1.775E-01	0.000E+00	1.866E+00
2.130E-01	3.257E-06	1.970E+00
2.556E-01	1.179E-05	2.074E+00
3.067E-01	3.901E-05	2.178E+00
3.680E-01	1.132E-04	2.281E+00
4.416E-01	2.879E-04	2.383E+00
5.299E-01	6.525E-04	2.484E+00
6.359E-01	1.340E-03	2.585E+00
7.631E-01	2.531E-03	2.686E+00
9.157E-01	4.456E-03	2.785E+00
1.099E+00	7.389E-03	2.883E+00
1.319E+00	1.164E-02	2.978E+00
1.582E+00	1.757E-02	3.069E+00
1.899E+00	2.553E-02	3.153E+00
2.279E+00	3.593E-02	3.230E+00
2.734E+00	4.919E-02	3.297E+00
3.281E+00	6.579E-02	3.353E+00
3.937E+00	8.623E-02	3.400E+00
4.725E+00	1.111E-01	3.437E+00
5.670E+00	1.411E-01	3.467E+00
6.804E+00	1.770E-01	3.491E+00
8.165E+00	2.198E-01	3.511E+00
9.797E+00	2.703E-01	3.530E+00
1.176E+01	3.297E-01	3.550E+00
1.411E+01	3.993E-01	3.571E+00
1.693E+01	4.804E-01	3.595E+00
2.032E+01	5.742E-01	3.623E+00
2.438E+01	6.819E-01	3.656E+00
2.926E+01	8.046E-01	3.693E+00
3.511E+01	9.428E-01	3.735E+00
4.213E+01	1.096E+00	3.783E+00
5.055E+01	1.265E+00	3.837E+00
6.066E+01	1.445E+00	3.896E+00
7.280E+01	1.635E+00	3.959E+00
8.735E+01	1.829E+00	4.027E+00
1.048E+02	2.022E+00	4.098E+00
1.258E+02	2.207E+00	4.169E+00
1.509E+02	2.378E+00	4.239E+00
1.811E+02	2.529E+00	4.306E+00
2.174E+02	2.656E+00	4.367E+00
2.608E+02	2.758E+00	4.421E+00
3.130E+02	2.836E+00	4.465E+00
3.756E+02	2.891E+00	4.500E+00
4.507E+02	2.929E+00	4.526E+00
5.409E+02	2.953E+00	4.544E+00
6.491E+02	2.967E+00	4.555E+00
7.789E+02	2.974E+00	4.562E+00
9.346E+02	2.978E+00	4.565E+00
1.122E+03	2.980E+00	4.566E+00
1.346E+03	2.981E+00	4.567E+00
1.615E+03	2.981E+00	4.567E+00
1.938E+03	2.981E+00	4.567E+00
2.326E+03	2.981E+00	4.567E+00
2.791E+03	2.981E+00	4.567E+00
3.349E+03	2.981E+00	4.567E+00
4.019E+03	2.981E+00	4.567E+00
4.823E+03	2.981E+00	4.567E+00
5.787E+03	2.981E+00	4.567E+00
6.944E+03	2.981E+00	4.567E+00
8.333E+03	2.981E+00	4.567E+00
1.000E+04	2.981E+00	4.567E+00

Table 18. Input on screen for file option for coupled aquifer benchmark problem

```
***************************************************************************
***************************************************************************
COUAQ: AN INTERACTIVE PROGRAM FOR CALCULATING DRAWDOWNS IN COUPLED AQUIFERS WITH CONFINING UNIT
STORAGE AND ET REDUCTION
PREPARED BY       Louis H. Motz and Ozlem Acar
                  Department of Civil and Coastal Engineering
                  University of Florida
                  Gainesville, Florida
 ***************************************************************************
 ***************************************************************************
 SINGLE OR MULTIPLE WELLS? <s/m>
s
 Do you want to prepare an input FILE or enter data INTERACTIVELY? <f/i>
f
 ENTER INPUT FILE NAME: <filename.in>
coupled_1_benchmark.in
 NAME OF THE PROJECT: <write in single quotation marks>
'coupled aquifer benchmark problem'
 ENTER OUTPUT FILE NAME: <filename.out>
coupled_1_benchmark.out
 ENTER DATA FILE NAME FOR GRAPHER INPUT: <filename.dat>
coupled_1_benchmark.dat

 PROGRAM COMPLETED
 Do you want to do more calculations? <y/n>
 n
```

Table 19. Input file for file option for coupled aquifer benchmark problem

0.0 270.0 0.2 0.001 353000. 27000.0 0.001 .002 0.01	Values for Q_1, T_1, S_1, ε, Q_2, T_2, S_2, K'/b', S'
1	Number of observation wells
800	Radial distance from pumped well to observation well
10000 100 1.2	Total time, number of time steps, time-step multiplier

3.2.4 Example Problem

The aquifer parameters used in this example are similar to parameters used in an analysis of the Cross Bar Wellfield in west-central Florida. In that analysis, Motz and Denis (2000) utilized the semianalytical coupled aquifer solution to confirm the results obtained by Stewart and Langevin (1999) using a numerical simulation that approximately 2,500 days were required for the surficial aquifer in the Cross Bar wellfield to reach a new steady-state equilibrium after the start of pumping from the upper Floridan aquifer. When the effects of confining unit storage were included by setting S' = 0.01 [e.g., Denis and Motz (1998)], the initial response of the surficial and upper Floridan aquifers was delayed, and the time to reach steady state increased to approximately 3,000 days (at a criterion of 0.01 ft).

In this example, values of $Q_1 = 0$ ft^3/day, $T_1 = 135$ ft^2/day, $S_1 = 0.2$, and $\varepsilon = 3.42 \times 10^{-4}$ day^{-1} were used for aquifer 1, and $Q_2 = 4.011 \times 10^6$ ft^3/day, $T_2 = 84{,}000$ ft^2/day, and $S_2 = 7.0 \times 10^{-4}$ were used for aquifer 2. A value of $K'/b' = 1.75 \times 10^{-3}$ day^{-1} was used to represent the leakance of the confining unit separating aquifers 1 and 2, and S' = 0.0 was used to represent the storativity of the confining unit, i.e., confining unit storage was not considered. Drawdowns were calculated at two locations, i.e., at radial distances of 12,430 ft and 20,000 ft. Similar to the benchmark problem, a transient simulation was run to 10,000 days in 100 time steps with a time step multiplier = 1.2. At both locations, drawdowns in the upper Floridan aquifer reach an apparent steady-state condition in approximately five days but then increase as the drawdowns in the surficial aquifer become significant (see Figures 6 and 7). The time to reach steady state in the surficial and upper Floridan aquifers is approximately 2,800 days (at a criterion of 0.01 ft). Files for this example problem are in Tables 20 through 24. The screen capture for the interactive option is in Table 20, and the output files are in Tables 21 and 22. The screen capture for the input file option is in Table 23, and the input file for the file option is in Table 24. The input file option writes the same output files as the interactive option (Tables 21 and 22).

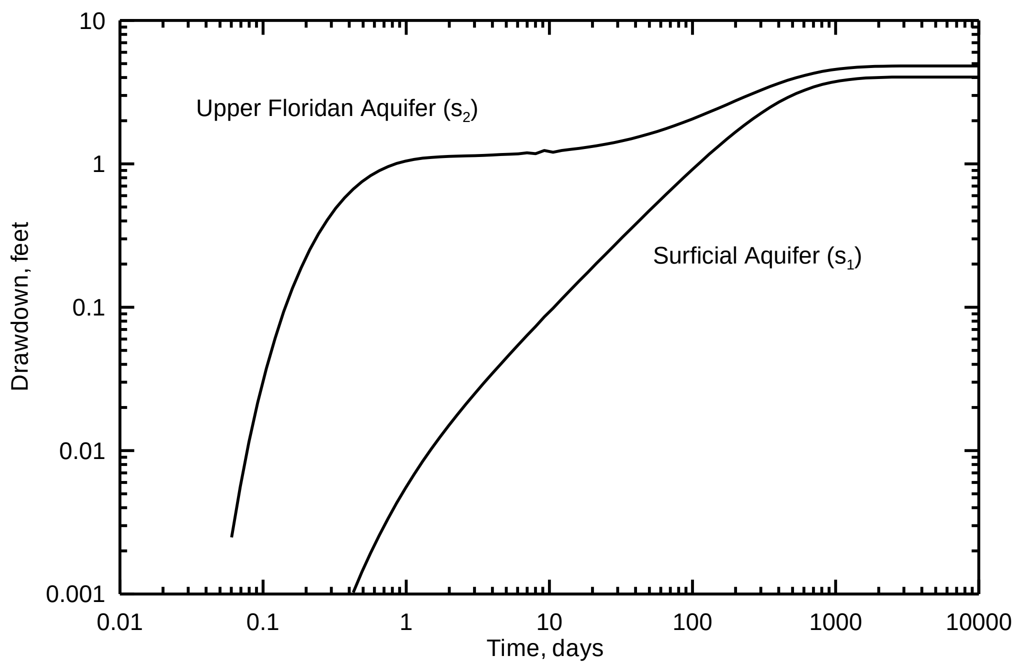

Figure 6. COUAQ single-well example problem: drawdowns versus time in the surficial and upper Floridan aquifers at r = 12,430 ft

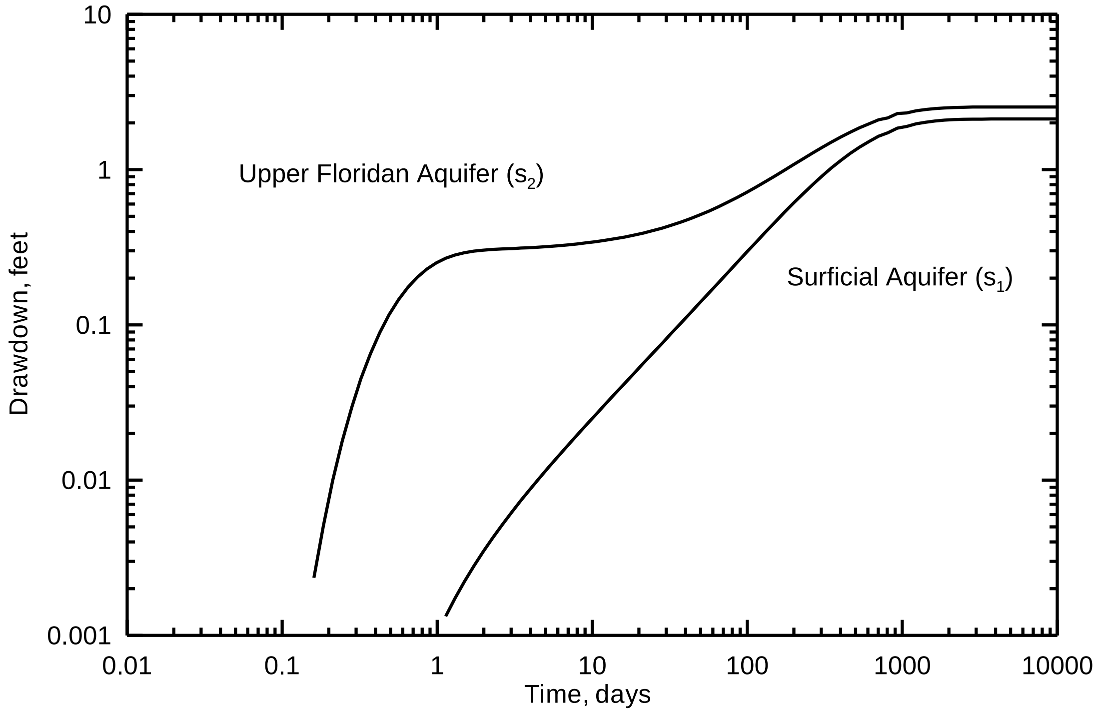

Figure 7. COUAQ single-well example problem: drawdowns versus time in the surficial and upper Floridan aquifers at r = 20,000 ft

Table 20. Input on screen for interactive input for coupled aquifer single-well example problem

```
************************************************************************
************************************************************************
COUAQ: AN INTERACTIVE PROGRAM FOR CALCULATING DRAWDOWNS IN COUPLED AQUIFERS WITH CONFINING UNIT
STORAGE AND ET REDUCTION
PREPARED BY       Louis H. Motz and Ozlem Acar
                  Department of Civil and Coastal Engineering
                  University of Florida
                  Gainesville, Florida
************************************************************************
************************************************************************
 SINGLE OR MULTIPLE WELLS? <s/m>
s
 Do you want to prepare an input FILE or enter data INTERACTIVELY? <f/i>
i
 NAME OF THE PROJECT: <write in single quotation marks>
coupled aquifer single well example
 PLEASE ENTER DATA IN CONSISTENT UNITS
 PUMPING RATE FROM AQUIFER 1 (Q1) (ft3/day)=?
0.0
 TRANSMISSIVITY OF AQUIFER 1 (T1) (ft2/day)=?
135
 SPECIFIC YIELD OF AQUIFER 1 (S1)=?
0.2
 RATE AT WHICH ET IS REDUCED PER UNIT OF WT DRAWDOWN (1/day)=?
3.42e-4
 PUMPING RATE FROM AQUIFER 2 (Q2) (ft3/day)=?
4.011e6
 TRANSMISSIVITY OF AQUIFER 2 (T2) (ft2/day)=?
84000
 STORATIVITY OF AQUIFER 2 (S2)=?
7.0e-4
 LEAKANCE OF CONFINING UNIT (Kprime/bprime) (1/day)=?
```

```
1.75e-3
 STORATIVITY OF THE CONFINING UNIT (Sprime)=?
0.0
 NUMBER OF r VALUES FOR WHICH CALCULATIONS ARE CARRIED OUT=?
2

 RADIAL DISTANCE FROM THE PUMPED WELL (r) (ft)=?
12430
 RADIAL DISTANCE FROM THE PUMPED WELL (r) (ft)=?
20000
 TOTAL TIME LENGTH FOR TRANSIENT SIMULATION (t) (days)=?
10000
 NUMBER OF TIME STEPS FOR TRANSIENT SIMULATION=?
100
 TIME STEP MULTIPLIER FOR TRANSIENT SIMULATION=?
1.2
 ENTER OUTPUT FILE NAME: <filename.out>
coupled_1_example.out
 ENTER DATA FILE NAME FOR GRAPHER INPUT: <filename.dat>
coupled_1_example.dat

 r (ft) = 1.243E+04

   time         drawdown        drawdown
  (days)       aquifer 1 (ft)  aquifer 2 (ft)
 ---------     ----------      -----------
 ---------     ----------      -----------
 1.449E-04     0.000E+00       1.000E-20
 1.739E-04     0.000E+00       1.000E-20
 2.087E-04     0.000E+00       1.000E-20
 2.504E-04     0.000E+00       1.000E-20
 3.005E-04     0.000E+00       1.000E-20
 3.605E-04     0.000E+00       1.000E-20
 4.327E-04     0.000E+00       1.000E-20
 5.192E-04     0.000E+00       1.000E-20
 6.230E-04     0.000E+00       1.000E-20
 7.476E-04     0.000E+00       1.000E-20
 8.972E-04     0.000E+00       1.000E-20
 1.077E-03     0.000E+00       1.000E-20
 1.292E-03     0.000E+00       1.000E-20
 1.550E-03     0.000E+00       1.000E-20
 1.860E-03     0.000E+00       1.000E-20
 2.232E-03     0.000E+00       1.000E-20
 2.679E-03     0.000E+00       1.000E-20
 3.215E-03     0.000E+00       1.000E-20
 3.858E-03     0.000E+00       1.000E-20
 4.629E-03     0.000E+00       1.000E-20
 5.555E-03     0.000E+00       1.000E-20
 6.666E-03     0.000E+00       1.000E-20
 7.999E-03     0.000E+00       1.000E-20
 9.599E-03     0.000E+00       1.000E-20
 1.152E-02     0.000E+00       1.000E-20
 1.382E-02     0.000E+00       1.000E-20
 1.659E-02     0.000E+00       1.000E-20
 1.990E-02     0.000E+00       1.000E-20
 2.389E-02     0.000E+00       1.000E-20
 2.866E-02     0.000E+00       1.000E-20
 3.439E-02     0.000E+00       6.415E-05
 4.127E-02     0.000E+00       1.898E-04
 4.953E-02     0.000E+00       6.762E-04
 5.943E-02     0.000E+00       2.282E-03
 7.132E-02     0.000E+00       6.551E-03
 8.559E-02     1.975E-06       1.598E-02
 1.027E-01     5.607E-06       3.393E-02
 1.232E-01     1.424E-05       6.409E-02
 1.479E-01     3.278E-05       1.098E-01
 1.775E-01     6.918E-05       1.732E-01
 2.130E-01     1.354E-04       2.544E-01
 2.556E-01     2.484E-04       3.515E-01
 3.067E-01     4.302E-04       4.602E-01
 3.680E-01     7.085E-04       5.747E-01
 4.416E-01     1.116E-03       6.885E-01
```

5.299E-01	1.690E-03	7.949E-01
6.359E-01	2.471E-03	8.886E-01
7.631E-01	3.502E-03	9.659E-01
9.157E-01	4.828E-03	1.026E+00
1.099E+00	6.498E-03	1.068E+00
1.319E+00	8.565E-03	1.097E+00
1.582E+00	1.109E-02	1.115E+00
1.899E+00	1.415E-02	1.126E+00
2.279E+00	1.784E-02	1.133E+00
2.734E+00	2.228E-02	1.139E+00
3.281E+00	2.760E-02	1.145E+00
3.937E+00	3.399E-02	1.153E+00
4.725E+00	4.165E-02	1.161E+00
5.670E+00	5.080E-02	1.169E+00
6.804E+00	6.199E-02	1.193E+00
8.165E+00	7.479E-02	1.180E+00
9.797E+00	9.047E-02	1.183E+00
1.176E+01	1.100E-01	1.246E+00
1.411E+01	1.326E-01	1.261E+00
1.693E+01	1.598E-01	1.291E+00
2.032E+01	1.923E-01	1.326E+00
2.438E+01	2.312E-01	1.368E+00
2.926E+01	2.777E-01	1.417E+00
3.511E+01	3.331E-01	1.476E+00
4.213E+01	3.990E-01	1.544E+00
5.055E+01	4.773E-01	1.625E+00
6.066E+01	5.699E-01	1.719E+00
7.280E+01	6.790E-01	1.828E+00
8.735E+01	8.068E-01	1.953E+00
1.048E+02	9.555E-01	2.097E+00
1.258E+02	1.127E+00	2.259E+00
1.509E+02	1.322E+00	2.440E+00
1.811E+02	1.541E+00	2.640E+00
2.174E+02	1.783E+00	2.856E+00
2.608E+02	2.043E+00	3.085E+00
3.130E+02	2.316E+00	3.322E+00
3.756E+02	2.593E+00	3.560E+00
4.507E+02	2.865E+00	3.793E+00
5.409E+02	3.120E+00	4.011E+00
6.491E+02	3.349E+00	4.208E+00
7.789E+02	3.544E+00	4.378E+00
9.346E+02	3.702E+00	4.518E+00
1.122E+03	3.822E+00	4.625E+00
1.346E+03	3.908E+00	4.703E+00
1.615E+03	3.965E+00	4.755E+00
1.938E+03	3.999E+00	4.788E+00
2.326E+03	4.018E+00	4.806E+00
2.791E+03	4.027E+00	4.814E+00
3.349E+03	4.031E+00	4.818E+00
4.019E+03	4.032E+00	4.819E+00
4.823E+03	4.032E+00	4.819E+00
5.787E+03	4.032E+00	4.820E+00
6.944E+03	4.033E+00	4.820E+00
8.333E+03	4.033E+00	4.820E+00
1.000E+04	4.033E+00	4.820E+00

r (ft) = 2.000E+04

time (days)	drawdown aquifer 1 (ft)	drawdown aquifer 2 (ft)
1.449E-04	0.000E+00	1.000E-20
1.739E-04	0.000E+00	1.000E-20
2.087E-04	0.000E+00	1.000E-20
2.504E-04	0.000E+00	1.000E-20
3.005E-04	0.000E+00	1.000E-20
3.605E-04	0.000E+00	1.000E-20
4.327E-04	0.000E+00	1.000E-20
5.192E-04	0.000E+00	1.000E-20
6.230E-04	0.000E+00	1.000E-20
7.476E-04	0.000E+00	1.000E-20

8.972E-04	0.000E+00	1.000E-20
1.077E-03	0.000E+00	1.000E-20
1.292E-03	0.000E+00	1.000E-20
1.550E-03	0.000E+00	1.000E-20
1.860E-03	0.000E+00	1.000E-20
2.232E-03	0.000E+00	1.000E-20
2.679E-03	0.000E+00	1.000E-20
3.215E-03	0.000E+00	1.000E-20
3.858E-03	0.000E+00	1.000E-20
4.629E-03	0.000E+00	1.000E-20
5.555E-03	0.000E+00	1.000E-20
6.666E-03	0.000E+00	1.000E-20
7.999E-03	0.000E+00	1.000E-20
9.599E-03	0.000E+00	1.000E-20
1.152E-02	0.000E+00	1.000E-20
1.382E-02	0.000E+00	1.000E-20
1.659E-02	0.000E+00	1.000E-20
1.990E-02	0.000E+00	1.000E-20
2.389E-02	0.000E+00	1.000E-20
2.866E-02	0.000E+00	1.000E-20
3.439E-02	0.000E+00	1.000E-20
4.127E-02	0.000E+00	1.000E-20
4.953E-02	0.000E+00	1.000E-20
5.943E-02	0.000E+00	1.000E-20
7.132E-02	0.000E+00	1.000E-20
8.559E-02	0.000E+00	4.548E-05
1.027E-01	0.000E+00	1.180E-04
1.232E-01	0.000E+00	4.135E-04
1.479E-01	0.000E+00	1.434E-03
1.775E-01	0.000E+00	4.177E-03
2.130E-01	3.121E-06	1.016E-02
2.556E-01	8.774E-06	2.120E-02
3.067E-01	2.193E-05	3.887E-02
3.680E-01	4.925E-05	6.394E-02
4.416E-01	1.006E-04	9.583E-02
5.299E-01	1.890E-04	1.326E-01
6.359E-01	3.303E-04	1.710E-01
7.631E-01	5.418E-04	2.077E-01
9.157E-01	8.411E-04	2.396E-01
1.099E+00	1.245E-03	2.648E-01
1.319E+00	1.770E-03	2.829E-01
1.582E+00	2.431E-03	2.947E-01
1.899E+00	3.248E-03	3.017E-01
2.279E+00	4.243E-03	3.059E-01
2.734E+00	5.446E-03	3.088E-01
3.281E+00	6.895E-03	3.114E-01
3.937E+00	8.638E-03	3.143E-01
4.725E+00	1.074E-02	3.178E-01
5.670E+00	1.326E-02	3.220E-01
6.804E+00	1.631E-02	3.270E-01
8.165E+00	1.998E-02	3.330E-01
9.797E+00	2.441E-02	3.401E-01
1.176E+01	2.976E-02	3.487E-01
1.411E+01	3.623E-02	3.590E-01
1.693E+01	4.406E-02	3.713E-01
2.032E+01	5.355E-02	3.860E-01
2.438E+01	6.507E-02	4.036E-01
2.926E+01	7.907E-02	4.246E-01
3.511E+01	9.610E-02	4.497E-01
4.213E+01	1.168E-01	4.797E-01
5.055E+01	1.421E-01	5.153E-01
6.066E+01	1.730E-01	5.576E-01
7.280E+01	2.105E-01	6.077E-01
8.735E+01	2.562E-01	6.668E-01
1.048E+02	3.116E-01	7.360E-01
1.258E+02	3.785E-01	8.166E-01
1.509E+02	4.585E-01	9.098E-01
1.811E+02	5.534E-01	1.016E+00
2.174E+02	6.641E-01	1.136E+00
2.608E+02	7.911E-01	1.269E+00
3.130E+02	9.333E-01	1.413E+00
3.756E+02	1.088E+00	1.566E+00

```
 4.507E+02     1.250E+00       1.722E+00
 5.409E+02     1.413E+00       1.876E+00
 6.491E+02     1.571E+00       2.025E+00
 7.789E+02     1.695E+00       2.120E+00
 9.346E+02     1.851E+00       2.298E+00
 1.122E+03     1.942E+00       2.375E+00
 1.346E+03     2.006E+00       2.425E+00
 1.615E+03     2.055E+00       2.472E+00
 1.938E+03     2.087E+00       2.501E+00
 2.326E+03     2.104E+00       2.518E+00
 2.791E+03     2.113E+00       2.526E+00
 3.349E+03     2.116E+00       2.530E+00
 4.019E+03     2.117E+00       2.531E+00
 4.823E+03     2.118E+00       2.531E+00
 5.787E+03     2.118E+00       2.531E+00
 6.944E+03     2.118E+00       2.531E+00
 8.333E+03     2.118E+00       2.531E+00
 1.000E+04     2.118E+00       2.531E+00

 PROGRAM COMPLETED
 Do you want to do more calculations? <y/n>
n
```

Table 21. Output file for coupled aquifer single-well example problem

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            COUAQ: AN INTERACTIVE PROGRAM FOR CALCULATING DRAWDOWNS IN COUPLED
                  AQUIFERS WITH CONFINING UNIT STORAGE AND ET REDUCTION

            PREPARED BY Louis H.Motz and Ozlem Acar
                        Department of Civil and Coastal Engineering
                        University of Florida
                        Gainesville,Florida
-------------------------------------------------------------------------------------
-------------------------------------------------------------------------------------
coupled aquifer single well example

DRAWDOWNS DUE TO SINGLE WELL PUMPING

INPUT DATA
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ALL DATA ARE IN CONSISTENT UNITS

PUMPING RATE FROM AQUIFER 1 (Q1) (ft3/day)                             : 0.000E+00
TRANSMISSIVITY OF AQUIFER 1 (T1) (ft2/day)                             : 1.350E+02
SPECIFIC YIELD OF AQUIFER 1 (S1)                                       : 2.000E-01
RATE AT WHICH ET IS REDUCED PER UNIT OF WT DRAWDOWN (1/day)            : 3.420E-04
PUMPING RATE FROM AQUIFER 2 (Q2) (ft3/day)                             : 4.011E+06
TRANSMISSIVITY OF AQUIFER 2 (T2) (ft2/day)                             : 8.400E+04
STORATIVITY OF AQUIFER 2 (S2)                                          : 7.000E-04
LEAKANCE OF CONFINING UNIT (Kprime/bprime) (1/day)                     : 1.750E-03
STORATIVITY OF THE CONFINING UNIT (Sprime)                             : 0.000E+00

NUMBER OF R VALUES FOR WHICH CALCULATIONS ARE CARRIED OUT              :         2
RADIAL DISTANCE FROM THE PUMPED WELL (r) (ft)                          : 12430.000
RADIAL DISTANCE FROM THE PUMPED WELL (r) (ft)                          : 20000.000


TOTAL TIME LENGTH FOR TRANSIENT SIMULATION (t) (days)                  : 10000.000
NUMBER OF TIME STEPS FOR TRANSIENT SIMULATION                          :       100
TIME STEP MULTIPLIER FOR TRANSIENT SIMULATION                          :     1.200

DRAWDOWNS IN COUPLED AQUIFERS
OBTAINED BY ANALYTICAL MODEL
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REF: Denis,R.E.,and Motz,L.H.1998.Drawdowns in Coupled Aquifers with Confining
     Unit Storage and ET Reduction.J.Ground Water,36(2),201-207,March-April.
 r (ft) = 1.243E+04

   time      drawdown          drawdown
  (days)     aquifer 1 (ft)   aquifer 2 (ft)
 ---------   --------------   --------------
 ---------   --------------   --------------
```

1.449E-04	0.000E+00	1.000E-20
1.739E-04	0.000E+00	1.000E-20
2.087E-04	0.000E+00	1.000E-20
2.504E-04	0.000E+00	1.000E-20
3.005E-04	0.000E+00	1.000E-20
3.605E-04	0.000E+00	1.000E-20
4.327E-04	0.000E+00	1.000E-20
5.192E-04	0.000E+00	1.000E-20
6.230E-04	0.000E+00	1.000E-20
7.476E-04	0.000E+00	1.000E-20
8.972E-04	0.000E+00	1.000E-20
1.077E-03	0.000E+00	1.000E-20
1.292E-03	0.000E+00	1.000E-20
1.550E-03	0.000E+00	1.000E-20
1.860E-03	0.000E+00	1.000E-20
2.232E-03	0.000E+00	1.000E-20
2.679E-03	0.000E+00	1.000E-20
3.215E-03	0.000E+00	1.000E-20
3.858E-03	0.000E+00	1.000E-20
4.629E-03	0.000E+00	1.000E-20
5.555E-03	0.000E+00	1.000E-20
6.666E-03	0.000E+00	1.000E-20
7.999E-03	0.000E+00	1.000E-20
9.599E-03	0.000E+00	1.000E-20
1.152E-02	0.000E+00	1.000E-20
1.382E-02	0.000E+00	1.000E-20
1.659E-02	0.000E+00	1.000E-20
1.990E-02	0.000E+00	1.000E-20
2.389E-02	0.000E+00	1.000E-20
2.866E-02	0.000E+00	1.000E-20
3.439E-02	0.000E+00	6.415E-05
4.127E-02	0.000E+00	1.898E-04
4.953E-02	0.000E+00	6.762E-04
5.943E-02	0.000E+00	2.282E-03
7.132E-02	0.000E+00	6.551E-03
8.559E-02	1.975E-06	1.598E-02
1.027E-01	5.607E-06	3.393E-02
1.232E-01	1.424E-05	6.409E-02
1.479E-01	3.278E-05	1.098E-01
1.775E-01	6.918E-05	1.732E-01
2.130E-01	1.354E-04	2.544E-01
2.556E-01	2.484E-04	3.515E-01
3.067E-01	4.302E-04	4.602E-01
3.680E-01	7.085E-04	5.747E-01
4.416E-01	1.116E-03	6.885E-01
5.299E-01	1.690E-03	7.949E-01
6.359E-01	2.471E-03	8.886E-01
7.631E-01	3.502E-03	9.659E-01
9.157E-01	4.828E-03	1.026E+00
1.099E+00	6.498E-03	1.068E+00
1.319E+00	8.565E-03	1.097E+00
1.582E+00	1.109E-02	1.115E+00
1.899E+00	1.415E-02	1.126E+00
2.279E+00	1.784E-02	1.133E+00
2.734E+00	2.228E-02	1.139E+00
3.281E+00	2.760E-02	1.145E+00
3.937E+00	3.399E-02	1.153E+00
4.725E+00	4.165E-02	1.161E+00
5.670E+00	5.080E-02	1.169E+00
6.804E+00	6.199E-02	1.193E+00
8.165E+00	7.479E-02	1.180E+00
9.797E+00	9.047E-02	1.183E+00
1.176E+01	1.100E-01	1.246E+00
1.411E+01	1.326E-01	1.261E+00
1.693E+01	1.598E-01	1.291E+00
2.032E+01	1.923E-01	1.326E+00
2.438E+01	2.312E-01	1.368E+00
2.926E+01	2.777E-01	1.417E+00
3.511E+01	3.331E-01	1.476E+00
4.213E+01	3.990E-01	1.544E+00
5.055E+01	4.773E-01	1.625E+00
6.066E+01	5.699E-01	1.719E+00
7.280E+01	6.790E-01	1.828E+00
8.735E+01	8.068E-01	1.953E+00
1.048E+02	9.555E-01	2.097E+00
1.258E+02	1.127E+00	2.259E+00
1.509E+02	1.322E+00	2.440E+00
1.811E+02	1.541E+00	2.640E+00
2.174E+02	1.783E+00	2.856E+00
2.608E+02	2.043E+00	3.085E+00
3.130E+02	2.316E+00	3.322E+00

3.756E+02	2.593E+00	3.560E+00
4.507E+02	2.865E+00	3.793E+00
5.409E+02	3.120E+00	4.011E+00
6.491E+02	3.349E+00	4.208E+00
7.789E+02	3.544E+00	4.378E+00
9.346E+02	3.702E+00	4.518E+00
1.122E+03	3.822E+00	4.625E+00
1.346E+03	3.908E+00	4.703E+00
1.615E+03	3.965E+00	4.755E+00
1.938E+03	3.999E+00	4.788E+00
2.326E+03	4.018E+00	4.806E+00
2.791E+03	4.027E+00	4.814E+00
3.349E+03	4.031E+00	4.818E+00
4.019E+03	4.032E+00	4.819E+00
4.823E+03	4.032E+00	4.819E+00
5.787E+03	4.032E+00	4.820E+00
6.944E+03	4.033E+00	4.820E+00
8.333E+03	4.033E+00	4.820E+00
1.000E+04	4.033E+00	4.820E+00

r (ft) = 2.000E+04

time (days)	drawdown aquifer 1 (ft)	drawdown aquifer 2 (ft)
1.449E-04	0.000E+00	1.000E-20
1.739E-04	0.000E+00	1.000E-20
2.087E-04	0.000E+00	1.000E-20
2.504E-04	0.000E+00	1.000E-20
3.005E-04	0.000E+00	1.000E-20
3.605E-04	0.000E+00	1.000E-20
4.327E-04	0.000E+00	1.000E-20
5.192E-04	0.000E+00	1.000E-20
6.230E-04	0.000E+00	1.000E-20
7.476E-04	0.000E+00	1.000E-20
8.972E-04	0.000E+00	1.000E-20
1.077E-03	0.000E+00	1.000E-20
1.292E-03	0.000E+00	1.000E-20
1.550E-03	0.000E+00	1.000E-20
1.860E-03	0.000E+00	1.000E-20
2.232E-03	0.000E+00	1.000E-20
2.679E-03	0.000E+00	1.000E-20
3.215E-03	0.000E+00	1.000E-20
3.858E-03	0.000E+00	1.000E-20
4.629E-03	0.000E+00	1.000E-20
5.555E-03	0.000E+00	1.000E-20
6.666E-03	0.000E+00	1.000E-20
7.999E-03	0.000E+00	1.000E-20
9.599E-03	0.000E+00	1.000E-20
1.152E-02	0.000E+00	1.000E-20
1.382E-02	0.000E+00	1.000E-20
1.659E-02	0.000E+00	1.000E-20
1.990E-02	0.000E+00	1.000E-20
2.389E-02	0.000E+00	1.000E-20
2.866E-02	0.000E+00	1.000E-20
3.439E-02	0.000E+00	1.000E-20
4.127E-02	0.000E+00	1.000E-20
4.953E-02	0.000E+00	1.000E-20
5.943E-02	0.000E+00	1.000E-20
7.132E-02	0.000E+00	1.000E-20
8.559E-02	0.000E+00	4.548E-05
1.027E-01	0.000E+00	1.180E-04
1.232E-01	0.000E+00	4.135E-04
1.479E-01	0.000E+00	1.434E-03
1.775E-01	0.000E+00	4.177E-03
2.130E-01	3.121E-06	1.016E-02
2.556E-01	8.774E-06	2.120E-02
3.067E-01	2.193E-05	3.887E-02
3.680E-01	4.925E-05	6.394E-02
4.416E-01	1.006E-04	9.583E-02
5.299E-01	1.890E-04	1.326E-01
6.359E-01	3.303E-04	1.710E-01
7.631E-01	5.418E-04	2.077E-01
9.157E-01	8.411E-04	2.396E-01
1.099E+00	1.245E-03	2.648E-01
1.319E+00	1.770E-03	2.829E-01
1.582E+00	2.431E-03	2.947E-01
1.899E+00	3.248E-03	3.017E-01
2.279E+00	4.243E-03	3.059E-01

2.734E+00	5.446E-03	3.088E-01
3.281E+00	6.895E-03	3.114E-01
3.937E+00	8.638E-03	3.143E-01
4.725E+00	1.074E-02	3.178E-01
5.670E+00	1.326E-02	3.220E-01
6.804E+00	1.631E-02	3.270E-01
8.165E+00	1.998E-02	3.330E-01
9.797E+00	2.441E-02	3.401E-01
1.176E+01	2.976E-02	3.487E-01
1.411E+01	3.623E-02	3.590E-01
1.693E+01	4.406E-02	3.713E-01
2.032E+01	5.355E-02	3.860E-01
2.438E+01	6.507E-02	4.036E-01
2.926E+01	7.907E-02	4.246E-01
3.511E+01	9.610E-02	4.497E-01
4.213E+01	1.168E-01	4.797E-01
5.055E+01	1.421E-01	5.153E-01
6.066E+01	1.730E-01	5.576E-01
7.280E+01	2.105E-01	6.077E-01
8.735E+01	2.562E-01	6.668E-01
1.048E+02	3.116E-01	7.360E-01
1.258E+02	3.785E-01	8.166E-01
1.509E+02	4.585E-01	9.098E-01
1.811E+02	5.534E-01	1.016E+00
2.174E+02	6.641E-01	1.136E+00
2.608E+02	7.911E-01	1.269E+00
3.130E+02	9.333E-01	1.413E+00
3.756E+02	1.088E+00	1.566E+00
4.507E+02	1.250E+00	1.722E+00
5.409E+02	1.413E+00	1.876E+00
6.491E+02	1.571E+00	2.025E+00
7.789E+02	1.695E+00	2.120E+00
9.346E+02	1.851E+00	2.298E+00
1.122E+03	1.942E+00	2.375E+00
1.346E+03	2.006E+00	2.425E+00
1.615E+03	2.055E+00	2.472E+00
1.938E+03	2.087E+00	2.501E+00
2.326E+03	2.104E+00	2.518E+00
2.791E+03	2.113E+00	2.526E+00
3.349E+03	2.116E+00	2.530E+00
4.019E+03	2.117E+00	2.531E+00
4.823E+03	2.118E+00	2.531E+00
5.787E+03	2.118E+00	2.531E+00
6.944E+03	2.118E+00	2.531E+00
8.333E+03	2.118E+00	2.531E+00
1.000E+04	2.118E+00	2.531E+00

Table 22. Time and drawdown data output file for coupled aquifer single-well example problem

	r = 1.243E+04		r = 2.000E+04	
time	s1	s2	s1	s2
1.449E-04	0.000E+00	1.000E-20	0.000E+00	1.000E-20
1.739E-04	0.000E+00	1.000E-20	0.000E+00	1.000E-20
2.087E-04	0.000E+00	1.000E-20	0.000E+00	1.000E-20
2.504E-04	0.000E+00	1.000E-20	0.000E+00	1.000E-20
3.005E-04	0.000E+00	1.000E-20	0.000E+00	1.000E-20
3.605E-04	0.000E+00	1.000E-20	0.000E+00	1.000E-20
4.327E-04	0.000E+00	1.000E-20	0.000E+00	1.000E-20
5.192E-04	0.000E+00	1.000E-20	0.000E+00	1.000E-20
6.230E-04	0.000E+00	1.000E-20	0.000E+00	1.000E-20
7.476E-04	0.000E+00	1.000E-20	0.000E+00	1.000E-20
8.972E-04	0.000E+00	1.000E-20	0.000E+00	1.000E-20
1.077E-03	0.000E+00	1.000E-20	0.000E+00	1.000E-20
1.292E-03	0.000E+00	1.000E-20	0.000E+00	1.000E-20
1.550E-03	0.000E+00	1.000E-20	0.000E+00	1.000E-20
1.860E-03	0.000E+00	1.000E-20	0.000E+00	1.000E-20
2.232E-03	0.000E+00	1.000E-20	0.000E+00	1.000E-20
2.679E-03	0.000E+00	1.000E-20	0.000E+00	1.000E-20
3.215E-03	0.000E+00	1.000E-20	0.000E+00	1.000E-20
3.858E-03	0.000E+00	1.000E-20	0.000E+00	1.000E-20
4.629E-03	0.000E+00	1.000E-20	0.000E+00	1.000E-20
5.555E-03	0.000E+00	1.000E-20	0.000E+00	1.000E-20
6.666E-03	0.000E+00	1.000E-20	0.000E+00	1.000E-20
7.999E-03	0.000E+00	1.000E-20	0.000E+00	1.000E-20
9.599E-03	0.000E+00	1.000E-20	0.000E+00	1.000E-20
1.152E-02	0.000E+00	1.000E-20	0.000E+00	1.000E-20
1.382E-02	0.000E+00	1.000E-20	0.000E+00	1.000E-20

1.659E-02	0.000E+00	1.000E-20	0.000E+00	1.000E-20
1.990E-02	0.000E+00	1.000E-20	0.000E+00	1.000E-20
2.389E-02	0.000E+00	1.000E-20	0.000E+00	1.000E-20
2.866E-02	0.000E+00	1.000E-20	0.000E+00	1.000E-20
3.439E-02	0.000E+00	6.415E-05	0.000E+00	1.000E-20
4.127E-02	0.000E+00	1.898E-04	0.000E+00	1.000E-20
4.953E-02	0.000E+00	6.762E-04	0.000E+00	1.000E-20
5.943E-02	0.000E+00	2.282E-03	0.000E+00	1.000E-20
7.132E-02	0.000E+00	6.551E-03	0.000E+00	1.000E-20
8.559E-02	1.975E-06	1.598E-02	0.000E+00	4.548E-05
1.027E-01	5.607E-06	3.393E-02	0.000E+00	1.180E-04
1.232E-01	1.424E-05	6.409E-02	0.000E+00	4.135E-04
1.479E-01	3.278E-05	1.098E-01	0.000E+00	1.434E-03
1.775E-01	6.918E-05	1.732E-01	0.000E+00	4.177E-03
2.130E-01	1.354E-04	2.544E-01	3.121E-06	1.016E-02
2.556E-01	2.484E-04	3.515E-01	8.774E-06	2.120E-02
3.067E-01	4.302E-04	4.602E-01	2.193E-05	3.887E-02
3.680E-01	7.085E-04	5.747E-01	4.925E-05	6.394E-02
4.416E-01	1.116E-03	6.885E-01	1.006E-04	9.583E-02
5.299E-01	1.690E-03	7.949E-01	1.890E-04	1.326E-01
6.359E-01	2.471E-03	8.886E-01	3.303E-04	1.710E-01
7.631E-01	3.502E-03	9.659E-01	5.418E-04	2.077E-01
9.157E-01	4.828E-03	1.026E+00	8.411E-04	2.396E-01
1.099E+00	6.498E-03	1.068E+00	1.245E-03	2.648E-01
1.319E+00	8.565E-03	1.097E+00	1.770E-03	2.829E-01
1.582E+00	1.109E-02	1.115E+00	2.431E-03	2.947E-01
1.899E+00	1.415E-02	1.126E+00	3.248E-03	3.017E-01
2.279E+00	1.784E-02	1.133E+00	4.243E-03	3.059E-01
2.734E+00	2.228E-02	1.139E+00	5.446E-03	3.088E-01
3.281E+00	2.760E-02	1.145E+00	6.895E-03	3.114E-01
3.937E+00	3.399E-02	1.153E+00	8.638E-03	3.143E-01
4.725E+00	4.165E-02	1.161E+00	1.074E-02	3.178E-01
5.670E+00	5.080E-02	1.169E+00	1.326E-02	3.220E-01
6.804E+00	6.199E-02	1.193E+00	1.631E-02	3.270E-01
8.165E+00	7.479E-02	1.180E+00	1.998E-02	3.330E-01
9.797E+00	9.047E-02	1.183E+00	2.441E-02	3.401E-01
1.176E+01	1.100E-01	1.246E+00	2.976E-02	3.487E-01
1.411E+01	1.326E-01	1.261E+00	3.623E-02	3.590E-01
1.693E+01	1.598E-01	1.291E+00	4.406E-02	3.713E-01
2.032E+01	1.923E-01	1.326E+00	5.355E-02	3.860E-01
2.438E+01	2.312E-01	1.368E+00	6.507E-02	4.036E-01
2.926E+01	2.777E-01	1.417E+00	7.907E-02	4.246E-01
3.511E+01	3.331E-01	1.476E+00	9.610E-02	4.497E-01
4.213E+01	3.990E-01	1.544E+00	1.168E-01	4.797E-01
5.055E+01	4.773E-01	1.625E+00	1.421E-01	5.153E-01
6.066E+01	5.699E-01	1.719E+00	1.730E-01	5.576E-01
7.280E+01	6.790E-01	1.828E+00	2.105E-01	6.077E-01
8.735E+01	8.068E-01	1.953E+00	2.562E-01	6.668E-01
1.048E+02	9.555E-01	2.097E+00	3.116E-01	7.360E-01
1.258E+02	1.127E+00	2.259E+00	3.785E-01	8.166E-01
1.509E+02	1.322E+00	2.440E+00	4.585E-01	9.098E-01
1.811E+02	1.541E+00	2.640E+00	5.534E-01	1.016E+00
2.174E+02	1.783E+00	2.856E+00	6.641E-01	1.136E+00
2.608E+02	2.043E+00	3.085E+00	7.911E-01	1.269E+00
3.130E+02	2.316E+00	3.322E+00	9.333E-01	1.413E+00
3.756E+02	2.593E+00	3.560E+00	1.088E+00	1.566E+00
4.507E+02	2.865E+00	3.793E+00	1.250E+00	1.722E+00
5.409E+02	3.120E+00	4.011E+00	1.413E+00	1.876E+00
6.491E+02	3.349E+00	4.208E+00	1.571E+00	2.025E+00
7.789E+02	3.544E+00	4.378E+00	1.695E+00	2.120E+00
9.346E+02	3.702E+00	4.518E+00	1.851E+00	2.298E+00
1.122E+03	3.822E+00	4.625E+00	1.942E+00	2.375E+00
1.346E+03	3.908E+00	4.703E+00	2.006E+00	2.425E+00
1.615E+03	3.965E+00	4.755E+00	2.055E+00	2.472E+00
1.938E+03	3.999E+00	4.788E+00	2.087E+00	2.501E+00
2.326E+03	4.018E+00	4.806E+00	2.104E+00	2.518E+00
2.791E+03	4.027E+00	4.814E+00	2.113E+00	2.526E+00
3.349E+03	4.031E+00	4.818E+00	2.116E+00	2.530E+00
4.019E+03	4.032E+00	4.819E+00	2.117E+00	2.531E+00
4.823E+03	4.032E+00	4.819E+00	2.118E+00	2.531E+00
5.787E+03	4.032E+00	4.820E+00	2.118E+00	2.531E+00
6.944E+03	4.033E+00	4.820E+00	2.118E+00	2.531E+00

8.333E+03	4.033E+00	4.820E+00	2.118E+00	2.531E+00
1.000E+04	4.033E+00	4.820E+00	2.118E+00	2.531E+00

Table 23. Input on screen for file option for coupled aquifer single-well example problem

****
****
COUAQ: AN INTERACTIVE PROGRAM FOR CALCULATING DRAWDOWNS IN COUPLED AQUIFERS WITH CONFINING UNIT STORAGE AND ET REDUCTION
PREPARED BY Louis H. Motz and Ozlem Acar
Department of Civil and Coastal Engineering
University of Florida
Gainesville, Florida
****
****
SINGLE OR MULTIPLE WELLS? <s/m>
s
Do you want to prepare an input FILE or enter data INTERACTIVELY? <f/i>
f
ENTER INPUT FILE NAME: <filename.in>
coupled_1_example.in
NAME OF THE PROJECT: <write in single quotation marks>
'coupled aquifer single well example'
ENTER OUTPUT FILE NAME: <filename.out>
coupled_1_example.out
ENTER DATA FILE NAME FOR GRAPHER INPUT: <filename.dat>
coupled_1_example.dat

PROGRAM COMPLETED
Do you want to do more calculations? <y/n>
n

Table 24. Input file for file option for coupled aquifer single-well example problem

0.0 135.0 0.2 3.42e-4 4.011e6 84000.0 7.0e-4 1.75e-3 0.0	Values for Q1, T1, S1, ε, Q2, T2, S2, K'/b', S'
2	Number of observation wells
12430	Distance from pumped well to first observation well
20000	Distance from pumped well to second observation well
10000 100 1.20	Total time, number of time steps, time-step multiplier

3.3 Drawdowns Due to Multiple Wells

3.3.1 Analytical Solution for Multiple Wells

Based on the principle of superposition (Bear 1979), individual solutions for hydraulic head or drawdown can be added together if the underlying differential equations and boundary conditions are linear. In a wellfield, the total drawdown at a given location is the sum of the drawdowns due to each individual well as if each well were acting alone. The differential equations and boundary conditions on which the single-well solution in Equations 6 through 16 is based are linear (Denis and Motz 1998). Thus, multiple well impacts can be determined by superimposing drawdowns due to individual wells at different spatial locations using Equations 6 through 16, provided that the underlying assumptions in these equations are still met, i.e., drawdowns in layer 1 are small compared to the initial saturated thickness, layer 2 remains confined, and the evapotranspiration reduction process remains linearly related to the drawdown in layer 1.

3.3.2 Multiple-Well Option in COUAQ

Similar to the single-well option, the multiple-well option in COUAQ uses Equations 6 through 16 and the Stehfest (1970) numerical algorithm to calculate drawdowns for aquifers 1 and 2. To start the program, the user clicks on the icon for the program and selects the multi-well option. The program can be run interactively with the user inputting all data on the screen, or the user can prepare input files and select the 'file' option when running the program. If the program is run interactively, time and drawdown results are printed on the screen, and the user is prompted to enter the names of two output files. One output file (filename.out) echoes the input data and prints the time and drawdown results, and the other file (filename.dat) prints the output results for time and drawdowns in a format that can be readily used in a graphical package such as Grapher™ to plot drawdowns versus time. If the 'file' option is selected, then the user is prompted to enter the names of three input files, the name of the project ('project name'), and the names of the two output files. Aquifer parameters are entered in the first input file (e.g., parameters.in), time and well data are entered in the second input file (e.g., time_well.in), and grid data are entered in third input file (e.g., grid_data.in). Similar to the interactive option, two output files are written, i.e., one output file (filename.out) echoes the input data and prints the time and drawdown results, and the other file (filename.dat) prints the output results for time and drawdowns in a format that can be readily used in a graphical package such as Grapher™ to plot drawdowns versus time. Interactively on the screen or in the input file, the user inputs the total time of the simulation, the number of time steps, and the time step multiplier. Similar to the single-well option in COUAQ, drawdowns can be calculated in the multi-well option for one desired time value by inputting the desired time as the total time of the simulation, the number of time steps equal to 1, and a time step multiplier equal to 1.0. Similarly, drawdowns at steady state can be calculated using a large value for time (i.e., 1×10^6 days), one time step, and a time step multiplier equal to 1.0.

In the program, a time step loop is the outer loop. Within the time step loop, drawdowns are calculated at the grid locations and then separately at the well locations. It is permissible, but not necessary, for a well to be location at a grid intersection. At the beginning of the time step loop, the time interval deltime is calculated if the time step multiplier is 1.0; otherwise, the initial time is calculated. Next, drawdowns are calculated at all of the grid locations in a grid loop. Within the grid loop, radial distances from each grid location to the pumped well locations are calculated in a well loop, and the subroutine Nsscou is used to calculate drawdowns at each grid location. If any radial distance from a grid location to a well location is less than the well radius at that location, then the radial distance at that location is set equal to the well radius. At the end of the well loop, the drawdown results (x and y grid locations, x and y well locations, radiuses, time, and drawdowns in layers 1 and 2) are written to the output file filename.out for each grid location. After drawdowns due to each well at each grid location have been calculated, a sum of drawdowns loop is used to calculate the sum of the drawdowns at each grid location due to all of the wells.

Similar to the calculations for drawdowns at each grid location, drawdowns are calculated separately at each well location. At each well location, the radius of the pumped well under consideration and the radial distances from each of the other wells to the pumped well under consideration are used in the subroutine Nsscou to calculate drawdowns. For each well, the drawdown results (well i.d., x and y well locations, radiuses, time, and drawdowns due to each well in layers 1 and 2) are written to the output file filename.out. After drawdowns at each well have been calculated, a sum of drawdowns loop is used to calculate the sum of the drawdowns at each well location due to all of the wells. When calculations for all of the time steps have been performed and the time step loop has been completed, the user is asked if more calculations are to be performed.

3.3.3 Example Problems

Two example problems were run using the multi-well option in COUAQ. The first example, which was run using the interactive option, illustrates how drawdown values can be plotted for one pumped well for a rectangular grid. In this example, values of T_1 = 335 ft^2/day, S_1 = 0.2, and ε = 1.50 x 10^{-4} day^{-1} were used for aquifer 1, and T_2 = 36,800 ft^2/day and S_2 = 2.85 x 10^{-4} were used for aquifer 2. A value of K'/b' = 1.2 x 10^{-3} day^{-1} was used to represent the leakance of the confining unit separating aquifers 1 and 2, and S' = 0.0 was used for the storativity of the confining unit. The values for T_1, ε, T_2, S_2, and K'/b' are based on values obtained for the Jay B. Starkey wellfield in Pasco County (Motz 1981), and the values used for S_1 and S' are considered representative values of the storage coefficients of the water-table aquifer and confining unit, respectively. A steady-state simulation was run by specifying time = 1.0 x 10^6 days, one time step, and a time step multiplier = 1.0. One well was located at (x,y) = (0.0, 0.0) and assigned a radius = 1.0 ft. This well was specified to pump only from layer 2 by inputting Q_1 = 0.0 and Q_2 = 192,500 ft^3/day for the well. Drawdowns were calculated in layers 1 and 2 in a grid that ranged from x, y = (-10,000; -10,000 ft) to x, y = (10,000; 10,000 ft) at 1,681 evenly-spaced locations that were 500 ft apart in both the x and y directions (see Figures 8 and 9).

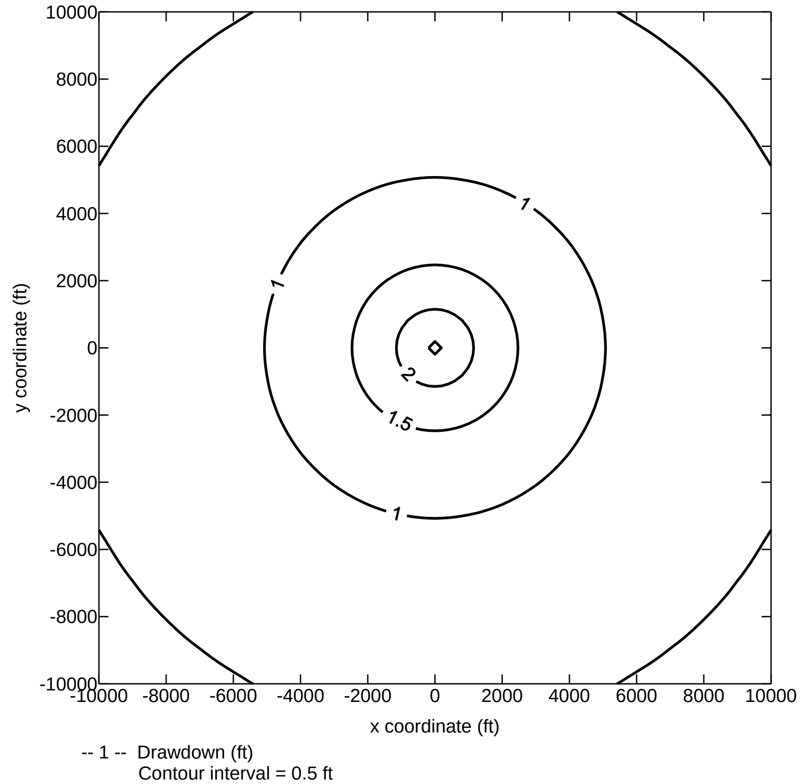

Figure 8. COUAQ multiple-well example one: drawdowns in the surficial aquifer at steady-state due to pumping one well in the upper Floridan aquifer

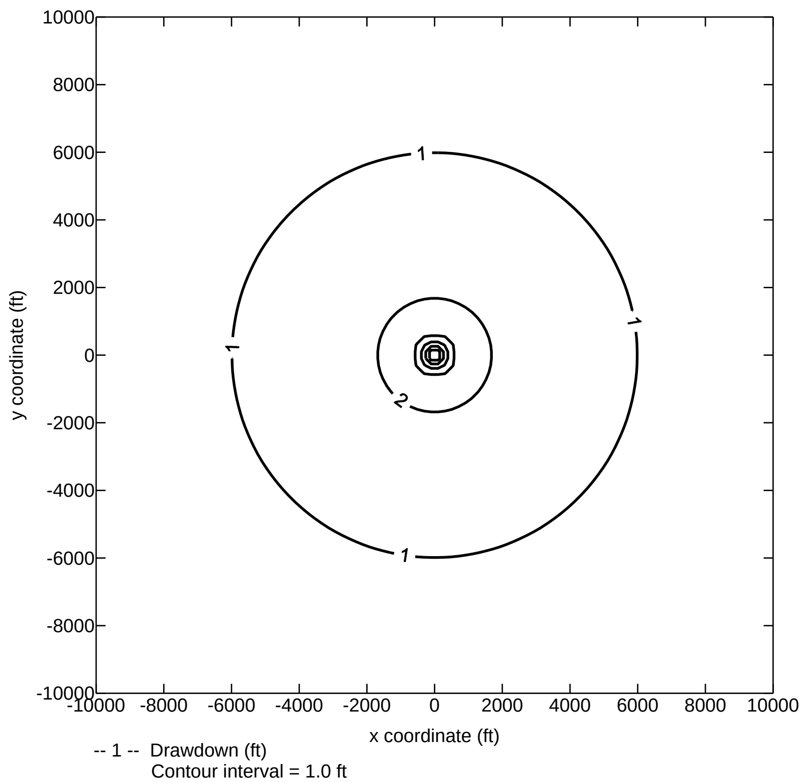

Figure 9. COUAQ multiple-well example one: drawdowns in the upper Floridan aquifer at steady-state due to pumping one well in the upper Floridan aquifer

Files for example one are in Tables 25 through 27. The screen input for this example using the interactive option is in Table 25, and the output files are in Tables 26 and 27. Drawdown results for both layers are printed for every grid location in the output files. As a result, these files are quite large, and only parts of these files are printed in Tables 26 and 27.

Table 25. Input on screen for interactive input for coupled aquifer multiple-well example one

```
******************************************************************************
******************************************************************************
COUAQ: AN INTERACTIVE PROGRAM FOR CALCULATING DRAWDOWNS IN COUPLED AQUIFERS WITH CONFINING UNIT
STORAGE AND ET REDUCTION
PREPARED BY       Louis H. Motz and Ozlem Acar
                  Department of Civil and Coastal Engineering
                  University of Florida
                  Gainesville, Florida
******************************************************************************
******************************************************************************
 SINGLE OR MULTIPLE WELLS? <s/m>
m
 Do you want to prepare an input FILE or enter data INTERACTIVELY? <f/i>
i
 NAME OF THE PROJECT: <write in single quotation marks>
'coupled aquifer multi-well example 1'
 PLEASE ENTER DATA IN CONSISTENT UNITS
 TRANSMISSIVITY OF AQUIFER 1 (T1) (ft2/day)=?
335
 SPECIFIC YIELD OF AQUIFER 1 (S1)=?
0.2
 RATE AT WHICH ET IS REDUCED PER UNIT OF WT DRAWDOWN (1/day)=?
1.50e-4
 TRANSMISSIVITY OF AQUIFER 2 (T2) (ft2/day)=?
36800
 STORATIVITY OF AQUIFER 2 (S2)=?
2.85e-4
 LEAKANCE OF CONFINING UNIT (Kprime/bprime) (1/day)=?
1.2e-3
 STORATIVITY OF THE CONFINING UNIT (Sprime)=?
0.0
 TOTAL TIME LENGTH FOR TRANSIENT SIMULATION (t) (days)=?
1e6
 NUMBER OF TIME STEPS FOR TRANSIENT SIMULATION=?
1
 TIME STEP MULTIPLIER FOR TRANSIENT SIMULATION=?
1.0
 NUMBER OF WELLS=?
1
 WELL NUMBER OR NAME: <write in single quotation marks>
'Well 1'
 X COORDINATE OF WELL (ft)=?
0.0
 Y COORDINATE OF WELL (ft)=?
0.0
 RADIUS OF WELL (rw) (ft)=?
1.0
 PUMPING RATE FROM AQUIFER 1 (Q1) (ft3/day)=?
0.0
 PUMPING RATE FROM AQUIFER 2 (Q2) (ft3/day)=?
192500
 ENTER X COORDINATE FOR LOWER LEFT CORNER OF GRID
-10000
 ENTER Y COORDINATE FOR LOWER LEFT CORNER OF GRID
-10000
 ENTER X COORDINATE FOR UPPER RIGHT CORNER OF GRID
10000
 ENTER Y COORDINATE FOR UPPER RIGHT CORNER OF GRID
10000
 ENTER DELTA X SPACING FOR THE GRID
500
 ENTER DELTA Y SPACING FOR THE GRID
```

```
500
 ENTER OUTPUT FILE NAME: <filename.out>
coupled_multi_example_1.out
 ENTER DATA FILE NAME FOR SUM OF DRAWDOWNS: <filename.dat>
coupled_multi_example_1.dat
 …
 (Note: output on screen is not printed.)
 PROGRAM COMPLETED
 Do you want to do more calculations? <y/n>
n
```

Table 26. Output file for coupled aquifer multiple-well example one

```
COUAQ: AN INTERACTIVE PROGRAM FOR CALCULATING DRAWDOWNS IN COUPLED AQUIFERS WITH CONFINING UNIT
STORAGE AND ET REDUCTION
PREPARED BY       Louis H. Motz and Ozlem Acar
                  Department of Civil and Coastal Engineering
                  University of Florida
                  Gainesville, Florida
----------------------------------------------------------------------------------
----------------------------------------------------------------------------------
coupled aquifer multi-well example 1
DRAWDOWNS DUE TO WELLFIELD PUMPING
INPUT DATA
----------
----------
ALL DATA ARE IN CONSISTENT UNITS
TRANSMISSIVITY OF AQUIFER 1 (T1) (ft2/day)                          : 3.350E+02
SPECIFIC YIELD OF AQUIFER 1 (S1)                                    : 2.000E-01
RATE AT WHICH ET IS REDUCED PER UNIT OF WT DRAWDOWN (1/day)         : 1.500E-04
TRANSMISSIVITY OF AQUIFER 2 (T2) (ft2/day)                          : 3.680E+04
STORATIVITY OF AQUIFER 2 (S2)                                       : 2.850E-04
LEAKANCE OF CONFINING UNIT (Kprime/bprime) (1/day)                  : 1.200E-03
STORATIVITY OF THE CONFINING UNIT (Sprime)                          : 0.000E+00

TOTAL TIME LENGTH FOR TRANSIENT SIMULATION (t) (days)               : 1.000E+06
NUMBER OF TIME STEPS FOR TRANSIENT SIMULATION                       :   1
TIME STEP MULTIPLIER FOR TRANSIENT SIMULATION                       :  1.000


NUMBER OF PUMPED WELLS                                              :   1

Well 1
X COORDINATE OF WELL (ft)                                           :  0.000
Y COORDINATE OF WELL (ft)                                           :  0.000
RADIUS OF WELL (rw) (ft)                                            :  1.000
PUMPING RATE FROM AQUIFER 1 (Q1) (ft3/day)                          : 0.000E+00
PUMPING RATE FROM AQUIFER 2 (Q2) (ft3/day)                          : 1.925E+05

NUMBER OF GRIDS WHERE DRAWDOWNS ARE TO BE CALCULATED                :   1681

GRID LOCATION : 1
X COORDINATE OF LOCATION WHERE DRAWDOWNS ARE TO BE CALCULATED (ft)  :-10000.000
Y COORDINATE OF LOCATION WHERE DRAWDOWNS ARE TO BE CALCULATED (ft)  :-10000.000

GRID LOCATION : 2
X COORDINATE OF LOCATION WHERE DRAWDOWNS ARE TO BE CALCULATED (ft)  : -9500.000
Y COORDINATE OF LOCATION WHERE DRAWDOWNS ARE TO BE CALCULATED (ft)  :-10000.000

GRID LOCATION : 3
X COORDINATE OF LOCATION WHERE DRAWDOWNS ARE TO BE CALCULATED (ft)  : -9000.000
Y COORDINATE OF LOCATION WHERE DRAWDOWNS ARE TO BE CALCULATED (ft)  :-10000.000

(Note: x- and y-coordinates for grid locations 4 - 1678 are not printed.)


GRID LOCATION : 1679
X COORDINATE OF LOCATION WHERE DRAWDOWNS ARE TO BE CALCULATED (ft)  :  9000.000
Y COORDINATE OF LOCATION WHERE DRAWDOWNS ARE TO BE CALCULATED (ft)  : 10000.000
```

```
GRID LOCATION : 1680
X COORDINATE OF LOCATION WHERE DRAWDOWNS ARE TO BE CALCULATED (ft)   :  9500.000
Y COORDINATE OF LOCATION WHERE DRAWDOWNS ARE TO BE CALCULATED (ft)   : 10000.000

GRID LOCATION : 1681
X COORDINATE OF LOCATION WHERE DRAWDOWNS ARE TO BE CALCULATED (ft)   : 10000.000
Y COORDINATE OF LOCATION WHERE DRAWDOWNS ARE TO BE CALCULATED (ft)   : 10000.000

DRAWDOWNS IN COUPLED AQUIFERS
OBTAINED BY ANALYTICAL MODEL
-----------------------------
-----------------------------

REFERENCE: Denis, R.E., and Motz, L.H. 1998. Drawdowns in Coupled Aquifers with Confining Unit
Storage and ET Reduction. J. Ground Water, 36(2), 201-207, March-April.

  Grid location =   1

  xgrid       ygrid         xwell    ywell   rad.dist.      time         dd1      dd2
 --------    --------      -------  -------  ---------    ---------     -------  -------
-10000.000   -10000.000    0.000    0.000    14142.136    1.000E+06     0.387    0.434

  Grid location =   2

  xgrid       ygrid         xwell    ywell   rad.dist.     time          dd1      dd2
 --------    --------      -------  -------  ---------    ---------     -------  -------
 -9500.000   -10000.000    0.000    0.000    13793.114    1.000E+06     0.399    0.448

  Grid location =   3

  xgrid       ygrid         xwell    ywell   rad.dist.     time          dd1      dd2
 --------    --------      -------  -------  ---------    ---------     -------  -------
 -9000.000   -10000.000    0.000    0.000    13453.624    1.000E+06     0.411    0.462

(Note: output for grid locations 4 – 1678 is not printed.)

  Grid location =1679

  xgrid       ygrid         xwell   ywell    rad.dist.     time          dd1      dd2
 --------    --------      -------  -------  ---------    ---------     -------  -------
  9000.000   10000.000     0.000    0.000    13453.624    1.000E+06     0.411    0.462

  Grid location =1680

  xgrid       ygrid         xwell   ywell    rad.dist.     time          dd1      dd2
 --------    --------      -------  -------  ---------    ---------     -------  -------
  9500.000   10000.000     0.000    0.000    13793.114    1.000E+06     0.399    0.448

  Grid location =1681

  xgrid       ygrid         xwell   ywell    rad.dist.     time          dd1      dd2
 --------    --------      -------  -------  ---------    ---------     -------  -------
 10000.000   10000.000     0.000    0.000    14142.136    1.000E+06     0.387    0.434

  Grid location     xgrid       ygrid          time        sum of dd1    sum of dd2
  -------------    -------     -------       ---------     ----------    ----------
  -------------    -------     -------       ---------     ----------    ----------
     1          -10000.000   -10000.000     1.000E+06      0.387         0.434
     2           -9500.000   -10000.000     1.000E+06      0.399         0.448
     3           -9000.000   -10000.000     1.000E+06      0.411         0.462

(Note: output for grid locations 4 – 1678 is not printed.)

  1679             9000.000    10000.000     1.000E+06      0.411         0.462
  1680             9500.000    10000.000     1.000E+06      0.399         0.448
  1681            10000.000    10000.000     1.000E+06      0.387         0.434



  Well location = Well 1
```

Well id	xwell	ywell	rad.dist.	time	dd1	dd2
Well 1	0.000	0.000	1.000	1.000E+06	2.584	8.169

Well id	xwell	ywell	rwell	time	sum of dd1	sum of dd2
-------	-------	-------	---------	---------	----------	----------
Well 1	0.000	0.000	1.000	1.000E+06	2.584	8.169

Table 27. Time and drawdown data output file for coupled aquifer multiple-well example one

Grid/well	x	y	time	sum1	sum2
1	-10000.00	-10000.00	1.000E+06	0.387	0.434
2	-9500.00	-10000.00	1.000E+06	0.399	0.448
3	-9000.00	-10000.00	1.000E+06	0.411	0.462

(Note: grid location, time, and drawdowns are not printed for grid locations 4 – 1678.)

1679	9000.00	10000.00	1.000E+06	0.411	0.462
1680	9500.00	10000.00	1.000E+06	0.399	0.448
1681	10000.00	10000.00	1.000E+06	0.387	0.434
Well 1	0.000	0.000	1.000E+06	2.584	8.169

The second example, which was run using the file input option, illustrates the use of multiple wells in aquifers 1 and 2 and illustrates how recharge wells can be specified in layer 1. In this example, similar to the first example described above, values of $T_1 = 335$ ft^2/day, $S_1 = 0.2$, and $\varepsilon = 1.50 \times 10^{-4}$ day^{-1} were used for aquifer 1, and $T_2 = 36{,}800$ ft^2/day and $S_2 = 2.85 \times 10^{-4}$ were used for aquifer 2. A value of $K'/b' = 1.2 \times 10^{-3}$ day^{-1} was used to represent the leakance of the confining unit separating aquifers 1 and 2, and $S' = 0.0$ was used for the storativity of the confining unit. The values for T_1, ε, T_2, S_2, and K'/b' are based on values obtained for the Jay B. Starkey wellfield in Pasco County (Motz 1981), and the values used for S_1 and S' are considered representative values of the storage coefficients of the water-table aquifer and confining unit, respectively. A steady-state simulation was run by specifying time = 1.0×10^6 days, one time step, and a time step multiplier = 1.0. Six wells were specified at x and y locations. Three wells were considered Floridan aquifer deep wells and assigned radiuses = 1.0 ft. These wells were specified to pump only from layer 2 by inputting $Q_1 = 0.0$ and $Q_2 = 192{,}500$ ft^3/day for each well. The other three wells were considered surficial aquifer wells, and each of these wells was located at the same x-y location as a deep Floridan well. These wells were assigned radiuses = 0.5 ft and were specified to pump only from layer 1 by inputting $Q_1 = -1{,}925$ ft^3/day and $Q_2 = 0.0$ for each well. The negative values for Q_1 for these wells were used to represent these wells as recharge, or injection, wells. Drawdowns were calculated in a grid that ranged from x, y = (-10,000, -10,000 ft) to x, y = (10,000, 10,000 ft). Drawdowns were calculated at 1,681 evenly-spaced locations that were 500 ft apart in both the x and y directions (see Figures 10 and 11).

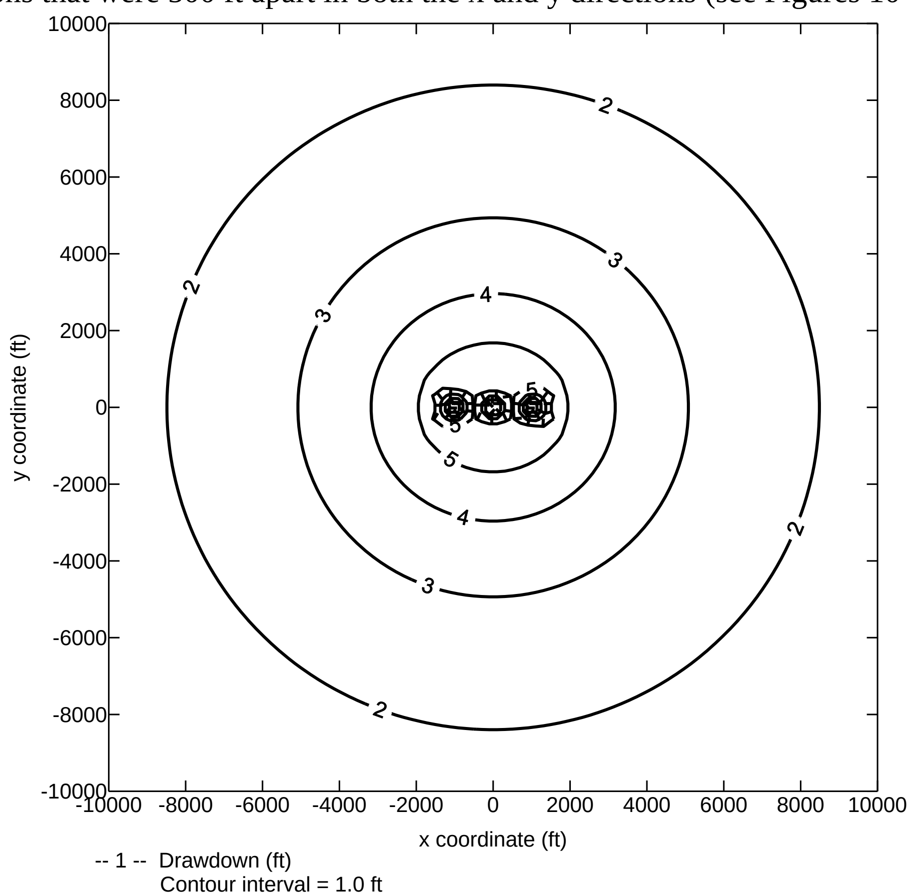

Figure 10. COUAQ multiple-well example two: drawdowns in the surficial aquifer at steady-state due to three pumped wells in the upper Floridan aquifer and three recharge wells in the surficial aquifer

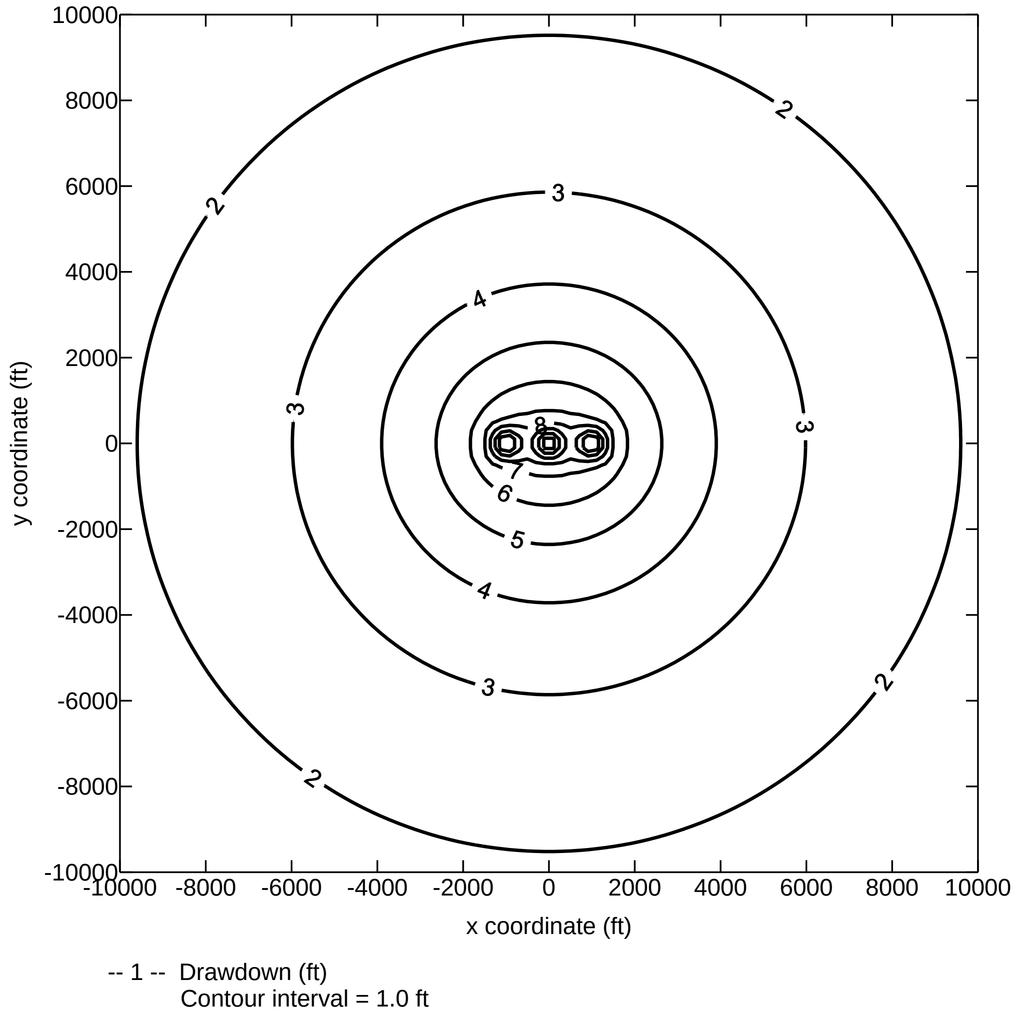

Figure 11. COUAQ multiple-well example two: drawdowns in the upper Floridan aquifer at steady-state due to three pumped wells in the upper Floridan aquifer and three recharge wells in the surficial aquifer

Files for example two are in Tables 28 through 31. The screen input for this example using the input file option is in Table 28. Aquifer parameters and time, well, and grid data are entered in the input file in Table 29. Only parts of the output files are printed (Tables 30 and 31), because of the large size of these files.

Table 28. Input on screen for file option for coupled aquifer multiple-well example two

```
****************************************************************************
****************************************************************************
          COUAQ:AN INTERACTIVE PROGRAM FOR CALCULATING DRAWDOWNS IN COUPLED
                AQUIFERS WITH CONFINING UNIT STORAGE AND ET REDUCTION

          PREPARED BY Louis H.Motz and Ozlem Acar
                      Department of Civil and Coastal Engineering
                      University of Florida
                      Gainesville,Florida
 ****************************************************************************
 ****************************************************************************
 SINGLE OR MULTIPLE WELLS? <s/m>
m
 Do you want to prepare an input FILE or enter data INTERACTIVELY? <f/i>
f
 ENTER INPUT FILE NAME: <filename.in>
coupled_multi_example_2.in
 NAME OF THE PROJECT: <write in single quotation marks>
'coupled aquifer multi-well example 2'
 ENTER OUTPUT FILE NAME: <filename.out>
coupled_multi_example_2.out
 ENTER DATA FILE NAME FOR SUM OF DRAWDOWNS: <filename.dat>
coupled_multi_example_2.dat


 PROGRAM COMPLETED
 Do you want to do more calculations? <y/n>
n
```

Table 29. Input file for coupled aquifer multiple-well example two

335.0 0.2 1.50e-4 36800. 2.85e-4 1.20e-3 0.0	Values for T1, S1, epsilon, T2, S2, K'/b', S'
1.0e6 1 1.0	Total time, number of time steps, time-step multiplier
6	Number of pumped wells
Well_1_Deep 0.0 0.0 1.0 0.0 192500.0	Well i.d., x_w, y_w, well radius, Q1, Q2
Well_2_Deep 1000.0 0.0 1.0 0.0 192500.0	Well i.d., x_w, y_w, well radius, Q1, Q2
Well_3_Deep -1000.0 0.0 1.0 0.0 192500.0	Well i.d., x_w, y_w, well radius, Q1, Q2
Well_1_Shallow 0.0 0.0 0.50 -1925.0 0.0	Well i.d., x_w, y_w, well radius Q1, Q2
Well_2_Shallow 1000.0 0.0 0.50 -1925.0 0.0	Well i.d., x_w, y_w, well radius, Q1, Q2
Well_3_Shallow -1000.0 0.0 0.50 -1925.0 0.0	Well i.d., x_w, y_w, well radius, Q1, Q2
-10000 -10000	Beginning x and y coordinates (at lower left corner)
10000 10000	Ending x and y coordinates (at upper right corner)
500 500	Spacing in x direction, spacing in y direction

Table 30. Output file for coupled aquifer multiple-well example two

```
COUAQ: AN INTERACTIVE PROGRAM FOR CALCULATING DRAWDOWNS IN COUPLED AQUIFERS WITH CONFINING UNIT
STORAGE AND ET REDUCTION
PREPARED BY       Louis H. Motz and Ozlem Acar
                  Department of Civil and Coastal Engineering
                  University of Florida
                  Gainesville, Florida
-------------------------------------------------------------------------------------
-------------------------------------------------------------------------------------
coupled aquifer multiple-well example 2

DRAWDOWNS DUE TO WELLFIELD PUMPING

INPUT DATA
----------
----------
ALL DATA ARE IN CONSISTENT UNITS

TRANSMISSIVITY OF AQUIFER 1 (T1) (ft2/day)                          :  3.350E+02
SPECIFIC YIELD OF AQUIFER 1 (S1)                                    :  2.000E-01
RATE AT WHICH ET IS REDUCED PER UNIT OF WT DRAWDOWN (1/day)         :  1.500E-04
TRANSMISSIVITY OF AQUIFER 2 (T2) (ft2/day)                          :  3.680E+04
STORATIVITY OF AQUIFER 2 (S2)                                       :  2.850E-04
LEAKANCE OF CONFINING UNIT (Kprime/bprime) (1/day)                  :  1.200E-03
STORATIVITY OF THE CONFINING UNIT (Sprime)                          :  0.000E+00

TOTAL TIME LENGTH FOR TRANSIENT SIMULATION (t) (days)               :  1.000E+06
NUMBER OF TIME STEPS FOR TRANSIENT SIMULATION                       :          1
TIME STEP MULTIPLIER FOR TRANSIENT SIMULATION                       :      1.000

NUMBER OF PUMPED WELLS                                              :          6

Well_1_Deep
X COORDINATE OF WELL (ft)                                           :      0.000
Y COORDINATE OF WELL (ft)                                           :      0.000
RADIUS OF WELL (rw) (ft)                                            :      1.000
PUMPING RATE FROM AQUIFER 1 (Q1) (ft3/day)                          :  0.000E+00
PUMPING RATE FROM AQUIFER 2 (Q2) (ft3/day)                          :  1.925E+05

Well_2_Deep
X COORDINATE OF WELL (ft)                                           :   1000.000
Y COORDINATE OF WELL (ft)                                           :      0.000
RADIUS OF WELL (rw) (ft)                                            :      1.000
PUMPING RATE FROM AQUIFER 1 (Q1) (ft3/day)                          :  0.000E+00
PUMPING RATE FROM AQUIFER 2 (Q2) (ft3/day)                          :  1.925E+05

Well_3_Deep
X COORDINATE OF WELL (ft)                                           :  -1000.000
Y COORDINATE OF WELL (ft)                                           :      0.000
RADIUS OF WELL (rw) (ft)                                            :      1.000
PUMPING RATE FROM AQUIFER 1 (Q1) (ft3/day)                          :  0.000E+00
PUMPING RATE FROM AQUIFER 2 (Q2) (ft3/day)                          :  1.925E+05

Well_1_Shallow
X COORDINATE OF WELL (ft)                                           :      0.000
Y COORDINATE OF WELL (ft)                                           :      0.000
RADIUS OF WELL (rw) (ft)                                            :      0.500
PUMPING RATE FROM AQUIFER 1 (Q1) (ft3/day)                          : -1.925E+03
PUMPING RATE FROM AQUIFER 2 (Q2) (ft3/day)                          :  0.000E+00

Well_2_Shallow
X COORDINATE OF WELL (ft)                                           :   1000.000
Y COORDINATE OF WELL (ft)                                           :      0.000
RADIUS OF WELL (rw) (ft)                                            :      0.500
PUMPING RATE FROM AQUIFER 1 (Q1) (ft3/day)                          : -1.925E+03
PUMPING RATE FROM AQUIFER 2 (Q2) (ft3/day)                          :  0.000E+00

Well_3_Shallow
X COORDINATE OF WELL (ft)                                           :  -1000.000
Y COORDINATE OF WELL (ft)                                           :      0.000
RADIUS OF WELL (rw) (ft)                                            :      0.500
PUMPING RATE FROM AQUIFER 1 (Q1) (ft3/day)                          : -1.925E+03
PUMPING RATE FROM AQUIFER 2 (Q2) (ft3/day)                          :  0.000E+00
```

NUMBER OF GRIDS WHERE DRAWDOWNS ARE TO BE CALCULATED : 1681

GRID LOCATION : 1
X COORDINATE OF LOCATION WHERE DRAWDOWNS ARE TO BE CALCULATED (ft) : -10000.000
Y COORDINATE OF LOCATION WHERE DRAWDOWNS ARE TO BE CALCULATED (ft) : -10000.000

GRID LOCATION : 2
X COORDINATE OF LOCATION WHERE DRAWDOWNS ARE TO BE CALCULATED (ft) : -9500.000
Y COORDINATE OF LOCATION WHERE DRAWDOWNS ARE TO BE CALCULATED (ft) : -10000.000

GRID LOCATION : 3
X COORDINATE OF LOCATION WHERE DRAWDOWNS ARE TO BE CALCULATED (ft) : -9000.000
Y COORDINATE OF LOCATION WHERE DRAWDOWNS ARE TO BE CALCULATED (ft) : -10000.000
…
(Note: x- and y-coordinates for grid locations 4 – 1678 are not printed.)

GRID LOCATION : 1679
X COORDINATE OF LOCATION WHERE DRAWDOWNS ARE TO BE CALCULATED (ft) : 9000.000
Y COORDINATE OF LOCATION WHERE DRAWDOWNS ARE TO BE CALCULATED (ft) : 10000.000

GRID LOCATION : 1680
X COORDINATE OF LOCATION WHERE DRAWDOWNS ARE TO BE CALCULATED (ft) : 9500.000
Y COORDINATE OF LOCATION WHERE DRAWDOWNS ARE TO BE CALCULATED (ft) : 10000.000

GRID LOCATION : 1681
X COORDINATE OF LOCATION WHERE DRAWDOWNS ARE TO BE CALCULATED (ft) : 10000.000
Y COORDINATE OF LOCATION WHERE DRAWDOWNS ARE TO BE CALCULATED (ft) : 10000.000

DRAWDOWNS IN COUPLED AQUIFERS
OBTAINED BY ANALYTICAL MODEL

REF: Denis, R.E., and Motz, L.H. 1998. Drawdowns in Coupled Aquifers with Confining Unit Storage and ET Reduction. J. Ground Water, 36(2), 201-207, March-April.

Grid location = 1

xgrid	ygrid	xwell	ywell	rad.dist.	time	dd1	dd2
-10000.000	-10000.000	0.000	0.000	14142.136	1.000E+06	0.387	0.434
-10000.000	-10000.000	1000.000	0.000	14866.069	1.000E+06	0.362	0.407
-10000.000	-10000.000	-1000.000	0.000	13453.624	1.000E+06	0.411	0.462
-10000.000	-10000.000	0.000	0.000	14142.136	1.000E+06	-0.003	-0.004
-10000.000	-10000.000	1000.000	0.000	14866.069	1.000E+06	-0.003	-0.004
-10000.000	-10000.000	-1000.000	0.000	13453.624	1.000E+06	-0.004	-0.004

Grid location = 2

xgrid	ygrid	xwell	ywell	rad.dist.	time	dd1	dd2
-9500.000	-10000.000	0.000	0.000	13793.114	1.000E+06	0.399	0.448
-9500.000	-10000.000	1000.000	0.000	14500.000	1.000E+06	0.374	0.421
-9500.000	-10000.000	-1000.000	0.000	13124.405	1.000E+06	0.424	0.477
-9500.000	-10000.000	0.000	0.000	13793.114	1.000E+06	-0.004	-0.004
-9500.000	-10000.000	1000.000	0.000	14500.000	1.000E+06	-0.003	-0.004
-9500.000	-10000.000	-1000.000	0.000	13124.405	1.000E+06	-0.004	-0.004

Grid location = 3

xgrid	ygrid	xwell	ywell	rad.dist.	time	dd1	dd2
-9000.000	-10000.000	0.000	0.000	13453.624	1.000E+06	0.411	0.462
-9000.000	-10000.000	1000.000	0.000	14142.136	1.000E+06	0.387	0.434
-9000.000	-10000.000	-1000.000	0.000	12806.248	1.000E+06	0.437	0.491
-9000.000	-10000.000	0.000	0.000	13453.624	1.000E+06	-0.004	-0.004
-9000.000	-10000.000	1000.000	0.000	14142.136	1.000E+06	-0.003	-0.004
-9000.000	-10000.000	-1000.000	0.000	12806.248	1.000E+06	-0.004	-0.004

(Note: output for grid locations 4 – 1678 is not printed.)

Grid location =1679

xgrid	ygrid	xwell	ywell	rad.dist.	time	dd1	dd2

9000.000	10000.000	0.000	0.000	13453.624	1.000E+06	0.411	0.462
9000.000	10000.000	1000.000	0.000	12806.248	1.000E+06	0.437	0.491
9000.000	10000.000	-1000.000	0.000	14142.136	1.000E+06	0.387	0.434
9000.000	10000.000	0.000	0.000	13453.624	1.000E+06	-0.004	-0.004
9000.000	10000.000	1000.000	0.000	12806.248	1.000E+06	-0.004	-0.004
9000.000	10000.000	-1000.000	0.000	14142.136	1.000E+06	-0.003	-0.004

Grid location =1680

xgrid	ygrid	xwell	ywell	rad.dist.	time	dd1	dd2
9500.000	10000.000	0.000	0.000	13793.114	1.000E+06	0.399	0.448
9500.000	10000.000	1000.000	0.000	13124.405	1.000E+06	0.424	0.477
9500.000	10000.000	-1000.000	0.000	14500.000	1.000E+06	0.374	0.421
9500.000	10000.000	0.000	0.000	13793.114	1.000E+06	-0.004	-0.004
9500.000	10000.000	1000.000	0.000	13124.405	1.000E+06	-0.004	-0.004
9500.000	10000.000	-1000.000	0.000	14500.000	1.000E+06	-0.003	-0.004

Grid location =1681

xgrid	ygrid	xwell	ywell	rad.dist.	time	dd1	dd2
10000.000	10000.000	0.000	0.000	14142.136	1.000E+06	0.387	0.434
10000.000	10000.000	1000.000	0.000	13453.624	1.000E+06	0.411	0.462
10000.000	10000.000	-1000.000	0.000	14866.069	1.000E+06	0.362	0.407
10000.000	10000.000	0.000	0.000	14142.136	1.000E+06	-0.003	-0.004
10000.000	10000.000	1000.000	0.000	13453.624	1.000E+06	-0.004	-0.004
10000.000	10000.000	-1000.000	0.000	14866.069	1.000E+06	-0.003	-0.004

Grid location	xgrid	ygrid	time	sum of dd1	sum of dd2
1	-10000.000	-10000.000	1.000E+06	1.150	1.293
2	-9500.000	-10000.000	1.000E+06	1.187	1.334
3	-9000.000	-10000.000	1.000E+06	1.224	1.375

(Note: drawdown sums for grid locations 4 – 1678 are not printed.)

1679	9000.000	10000.000	1.000E+06	1.224	1.375
1680	9500.000	10000.000	1.000E+06	1.187	1.334
1681	10000.000	10000.000	1.000E+06	1.150	1.293

Well location = Well_1_Deep

well id	xwell	ywell	rad.dist.	time	dd1	dd2
Well_1_D	0.000	0.000	1.000	1.000E+06	2.584	8.169
Well_2_D	1000.000	0.000	1000.000	1.000E+06	2.075	2.425
Well_3_D	-1000.000	0.000	1000.000	1.000E+06	2.075	2.425
Well_1_S	0.000	0.000	0.500	1.000E+06	-6.440	-0.026
Well_2_S	1000.000	0.000	1000.000	1.000E+06	-0.121	-0.021
Well_3_S	-1000.000	0.000	1000.000	1.000E+06	-0.121	-0.021

Well location = Well_2_Deep

well id	xwell	ywell	rad.dist.	time	dd1	dd2
Well_1_D	0.000	0.000	1000.000	1.000E+06	2.075	2.425
Well_2_D	1000.000	0.000	1.000	1.000E+06	2.584	8.169
Well_3_D	-1000.000	0.000	2000.000	1.000E+06	1.645	1.858
Well_1_S	0.000	0.000	1000.000	1.000E+06	-0.121	-0.021
Well_2_S	1000.000	0.000	0.500	1.000E+06	-6.440	-0.026
Well_3_S	-1000.000	0.000	2000.000	1.000E+06	-0.025	-0.016

Well location = Well_3_Deep

well id	xwell	ywell	rad.dist.	time	dd1	dd2

```
 ---------    -------     -------  ---------    ---------     -------    -------
 Well_1_D       0.000     0.000    1000.000     1.000E+06      2.075      2.425
 Well_2_D    1000.000     0.000    2000.000     1.000E+06      1.645      1.858
 Well_3_D   -1000.000     0.000       1.000     1.000E+06      2.584      8.169
 Well_1_S       0.000     0.000    1000.000     1.000E+06     -0.121     -0.021
 Well_2_S    1000.000     0.000    2000.000     1.000E+06     -0.025     -0.016
 Well_3_S   -1000.000     0.000       0.500     1.000E+06     -6.440     -0.026

 Well location = Well_1_Shallow
  well id      xwell       ywell   rad.dist.     time          dd1        dd2
 ---------    -------     -------  ---------    ---------     -------    -------
 Well_1_D       0.000     0.000       1.000     1.000E+06      2.584      8.169
 Well_2_D    1000.000     0.000    1000.000     1.000E+06      2.075      2.425
 Well_3_D   -1000.000     0.000    1000.000     1.000E+06      2.075      2.425
 Well_1_S       0.000     0.000       0.500     1.000E+06     -6.440     -0.026
 Well_2_S    1000.000     0.000    1000.000     1.000E+06     -0.121     -0.021
 Well_3_S   -1000.000     0.000    1000.000     1.000E+06     -0.121     -0.021

 Well location = Well_2_Shallow
  well id      xwell       ywell   rad.dist.      time         dd1        dd2
  ---------   -------     -------  ---------     ---------    -------    -------
 Well_1_D       0.000     0.000    1000.000     1.000E+06      2.075      2.425
 Well_2_D    1000.000     0.000       1.000     1.000E+06      2.584      8.169
 Well_3_D   -1000.000     0.000    2000.000     1.000E+06      1.645      1.858
 Well_1_S       0.000     0.000    1000.000     1.000E+06     -0.121     -0.021
 Well_2_S    1000.000     0.000       0.500     1.000E+06     -6.440     -0.026
 Well_3_S   -1000.000     0.000    2000.000     1.000E+06     -0.025     -0.016

 Well location = Well_3_Shallow
  well id      xwell      ywell    rad.dist.      time         dd1        dd2
  ---------   -------    -------   ---------     ---------    -------    -------
 Well_1_D       0.000     0.000    1000.000     1.000E+06      2.075      2.425
 Well_2_D    1000.000     0.000    2000.000     1.000E+06      1.645      1.858
 Well_3_D   -1000.000     0.000       1.000     1.000E+06      2.584      8.169
 Well_1_S       0.000     0.000    1000.000     1.000E+06     -0.121     -0.021
 Well_2_S    1000.000     0.000    2000.000     1.000E+06     -0.025     -0.016
 Well_3_S   -1000.000     0.000       0.500     1.000E+06     -6.440     -0.026

  well id     xwell        ywell    rwell      time          sum of dd1    sum of dd2
  -------    -------      -------  ---------  ---------      ----------    ----------
  -------    -------      -------  ---------  ---------      ----------    ----------
 Well_1_D       0.000     0.000    1.000      1.000E+06        0.053       12.952
 Well_2_D    1000.000     0.000    1.000      1.000E+06       -0.281       12.390
 Well_3_D   -1000.000     0.000    1.000      1.000E+06       -0.281       12.390
 Well_1_S       0.000     0.000    0.500      1.000E+06        0.053       12.952
 Well_2_S    1000.000     0.000    0.500      1.000E+06       -0.281       12.390
 Well_3_S   -1000.000     0.000    0.500      1.000E+06       -0.281       12.390
```

Table 31. Time and drawdown data output file for coupled aquifer multiple-well example two

```
  Grid/well      x           y             time         sum1        sum2
      1      -10000.00    -10000.00      1.000E+06      1.150       1.293
      2       -9500.00    -10000.00      1.000E+06      1.187       1.334
      3       -9000.00    -10000.00      1.000E+06      1.224       1.375
(Note: grid locations, time, and drawdowns are not printed for grid locations 4 – 1678.)

    1679       9000.00     10000.00      1.000E+06      1.224       1.375
    1680       9500.00     10000.00      1.000E+06      1.187       1.334
    1681      10000.00     10000.00      1.000E+06      1.150       1.293
 Well_1_D        0.000        0.000      1.000E+06      0.053      12.952
 Well_2_D     1000.000        0.000      1.000E+06     -0.281      12.390
 Well_3_D    -1000.000        0.000      1.000E+06     -0.281      12.390
 Well_1_S        0.000        0.000      1.000E+06      0.053      12.952
 Well_2_S     1000.000        0.000      1.000E+06     -0.281      12.390
 Well_3_S    -1000.000        0.000      1.000E+06     -0.281      12.390
```

4.0 DOCUMENTATION

The source codes for SWUP and COUAQ, which are listed in Appendices A and B, were written in Fortran 90 programming language using Compaq Visual Fortran Version 6.6. The executable codes for these programs, which were compiled in the Microsoft Visual C++™ development environment (also known as Microsoft Developer Studio), are compatible with the Microsoft Windows 2000, Windows NT, Windows me, Windows 95, and Windows 98 operating systems. The source codes can be run from the Microsoft Developer Studio environment, or the executable codes can be run from the command console. The executable codes, which should be copied to selected subdirectories, can be started using the command prompt from the Windows desktop by specifying the complete path of the selected executable code. Alternately, a selected code can be started from the command console by typing and entering the name of the program in the appropriate subdirectory or by double clicking on the program icon of the executable file using a program such as Windows Explorer. Input files, which are required if the file input option is selected, can be prepared and modified using a text editor such as Wordpad. Output files also can be read and printed using a text editor. Opening output files using Microsoft Word and changing the font to Courier regular 8-point font has been found to yield a reasonably good match to the format in the FORTRAN input and output files. Graphical user interfaces (GUI's) could be prepared so that the programs could be run directly from a Windows-based environment. It is recommended that the preparation of such GUI's, which was beyond the scope of the present investigation, be considered by the District.

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APPENDIX A

Source Code for SWUP

```
!***********************************************************************************************
! SWUP:AN INTERACTIVE PROGRAM FOR CALCULATING SALTWATER UPCONING
! IN AN AQUIFER OVERLAIN BY A LEAKY CONFINING UNIT
! PREPARED BY Louis H.Motz and Ozlem Acar
!             Department of Civil and Coastal Engineering
!             University of Florida
!             Gainesville,Florida
!***********************************************************************************************
!***********************************************************************************************
! SWUP.F90
!***********************************************************************************************
!***********************************************************************************************

! THIS PROGRAM HAS MAINLY TWO PARTS:ONE PART IS FOR THE SINGLE WELL OPTION AND
! THE SECOND PART IS FOR THE MULTIPLE WELLS OPTION

!***********************************************************************************************

! BOTH OPTIONS:
! CALCULATE NONDIMENSIONAL AND DIMENSIONAL CRITICAL PUMPING RATES
! DUE TO VERTICAL UPCONING OF SALTWATER (MOTZ,1992)
! INPUT EITHER INTERACTIVE OR FROM FILENAME.IN,OUTPUT TO FILENAME.OUT

!***********************************************************************************************

! TRANS    = TRANSMISSIVITY [L2/T]
! K'       = VERTICAL HYDRAULIC CONDUCTIVITY OF CONFINING UNIT [L/T]
! b'       = THICKNESS OF CONFINING UNIT [L]
! LEAK     = K'/b',LEAKANCE OF CONFINING UNIT [1/T]
! BTHICK   = DISTANCE FROM TOP OF AQUIFER TO INTERFACE [L]
! RWDIVBTH = RADIUS OF WELL/THICKNESS OF AQUIFER [dimensionless]
! LS       = DISTANCE FROM TOP OF AQUIFER TO BOTTOM OF WELL SCREEN (FOR SINGLE WELL) [L]
! DS       = DISTANCE FROM TOP OF AQUIFER TO TOP OF WELL SCREEN (FOR SINGLE WELL) [L]
! L        = DISTANCE FROM TOP OF AQUIFER TO BOTTOM OF WELL SCREEN (FOR MULTIPLE WELLS) [L]
! D        = DISTANCE FROM TOP OF AQUIFER TO TOP OF WELL SCREEN (FOR MULTIPLE WELLS) [L]
! LDIVBTH  = DISTANCE FROM TOP OF AQUIFER TO BOTTOM OF WELL SCREEN/THICKNESS OF AQUIFER
! DDIVBTH  = DISTANCE FROM TOP OF AQUIFER TO TOP OF WELL SCREEN/THICKNESS OF AQUIFER
! 1/CAPB   = (sqrt(LEAKANCE/TRANSMISSIVITY) [1/L]
! RDIVCAPB = (sqrt(LEAKANCE/TRANSMISSIVITY))*(RAD.OF WELL)
! Kz       = VERTICAL HYDRAULIC CONDUCTIVITY OF AQUIFER [L/T]
! Kr       = HORIZONTAL HYDRAULIC CONDUCTIVITY OF AQUIFER [L/T]
! KZDIVKR  = Kz/Kr (VERT.HYD.CONDUCTIVITY OF AQUIFER/HORIZ.HYD.CONDUCTIVITY OF AQUIFER)
! KKRBTH   = (sqrt(Kz/Kr))*(RAD.OF WELL/THICKNESS OF AQUIFER)
! LCDELTA  = DENSITY OF FRESHWATER/(DENSITY OF SALTWATER-DENSITY OF FRESHWATER)

! *********   THIS PROGRAM USES LCDELTA=40.0 BY DEFAULT,WHICH IS BASED ON THE   ******************
! *********  GHYBEN-HERZBERG 40:1 RATIO FOR THE SALTWATER-FRESHWATER INTERFACE. ******************

! X        = ARGUMENT FOR WHICH BESSEL FUNCTION Ko IS CALCULATED
! BESL     = Ko:MODIFIED BESSEL FUNCTION OF THE SECOND KIND,ZERO ORDER
! QCRITS   = CRITICAL PUMPING RATE OF WELL (FOR SINGLE WELL) [L3/T]
! QCRIT    = CRITICAL PUMPING RATE OF WELL (FOR MULTIPLE WELLS) [L3/T]
! RWELL    = RADIUS OF WELL (FOR SINGLE WELL) [L]
! RW       = RADIUS OF WELL (FOR MULTIPLE WELLS) [L]
! NOWELL   = NUMBER OF WELLS
! XC       = X COORDINATE OF EACH WELL [L]
! YC       = Y COORDINATE OF EACH WELL [L]
! R        = DISTANCE BETWEEN TWO WELLS [L]
! ALPHA    = PUMPING RATE COEFFICIENT (ASSUMED AS 1.0 FOR ALL WELLS)
! Qm(:)    = ARRAY FOR PUMPING RATES AT OTHER WELLS CAUSING INTERFERENCE,BASED ON ALPHA VALUES
! QTOTAL   = TOTAL PUMPING RATE AT ALL WELLS
! MINQTOTAL= CRITICAL PUMPING RATE BASED ON WELL PROPERTIES & ASSIGNED RELATIVE UNIT PUMPING RATES
! SS       = DRAWDOWN AT EACH WELL FOR THE CRITICAL CASE [L]



!***********************************************************************************************

! INPUT AND OUTPUT UNITS ARE IN FT AND DAY UNITS,i.e.,ft2/day,1/day,ft3/day.

!***********************************************************************************************

DOUBLE PRECISION PI,TRANS,LEAK,RWELL,BTHICK,RWDIVBTH,KKRBTH,RDIVCAPB
DOUBLE PRECISION DS,LS
DOUBLE PRECISION LDIVBTH,DDIVBTH,KZDIVKR,LCDELTA
DOUBLE PRECISION SUM,A1,A2,F1,A3,A4,F2,X,BESL,FI,DENOM,NUMER
DOUBLE PRECISION SUMDENOM,TOTALS
DOUBLE PRECISION QCRITS,QCRITSTB,QmSUMM,MINQTOTAL
DOUBLE PRECISION:: XC(1:100),YC(1:100)
```

```
DOUBLE PRECISION:: RW(1:100),R(1:100)
DOUBLE PRECISION:: D(1:100),L(1:100)
DOUBLE PRECISION:: ALPHA(1:100,1:100),Qm(1:100,1:100),QCRIT(1:100)
DOUBLE PRECISION:: QmSUM(1:100),QTOTAL(1:100),SS(1:100,1:100),SUMSS(1:100)
DIMENSION:: WELLID(1:100)
INTEGER N,I,J,K,NOWELL,MINI
CHARACTER* 50 PRNAME
CHARACTER* 1 SUBRTYPE
CHARACTER* 11 DATAENTRY
CHARACTER* 50 INPUTUNIT
CHARACTER* 50 OUTPUTUNIT
CHARACTER* 3 ENDDECISION
CHARACTER* 25 WELLID

PRINT *,'**************************************************************************'
PRINT *,'**************************************************************************'
PRINT *,'         SWUP:AN INTERACTIVE PROGRAM FOR CALCULATING SALTWATER UPCONING '
PRINT *,'              IN AN AQUIFER OVERLAIN BY A LEAKY CONFINING UNIT'
PRINT *,'                                                                          '
PRINT *,'         PREPARED BY Louis H.Motz and Ozlem Acar'
PRINT *,'                     Department of Civil and Coastal Engineering'
PRINT *,'                     University of Florida'
PRINT *,'                     Gainesville,Florida'
PRINT *,'**************************************************************************'
PRINT *,'**************************************************************************'

!ASK SINGLE OR MULTIPLE WELLS
1 PRINT *,'SINGLE OR MULTIPLE WELLS? <s/m>'
READ *,SUBRTYPE
IF (SUBRTYPE(1:1).EQ.'s'.OR.SUBRTYPE(1:1).EQ.'S') THEN
CALL SWUP_1(SUBRTYPE,TRANS,LEAK,RWELL,BTHICK,DS,LS,KZDIVKR)
ELSE
CALL SWUP_M(SUBRTYPE,TRANS,LEAK,BTHICK,KZDIVKR,NOWELL)
END IF

!END THE PROGRAM
PRINT *,'PROGRAM COMPLETED'
PRINT *,'Do you want to do more calculations? <y/n>'
READ *,ENDDECISION
IF (ENDDECISION.EQ.'y'.OR.ENDDECISION.EQ.'Y') THEN
      GO TO 1
   ELSE
      GO TO 999
END IF

999 STOP
END
```

```
!*******************************************************************************************
!*******************************************************************************************
!SUBROUTINE SWUP_1(SUBRTYPE,TRANS,LEAK,RWELL,BTHICK,DS,LS,KZDIVKR)
!*******************************************************************************************
!*******************************************************************************************
SUBROUTINE SWUP_1(SUBRTYPE,TRANS,LEAK,RWELL,BTHICK,DS,LS,KZDIVKR)
DOUBLE PRECISION PI,TRANS,LEAK,RWELL,BTHICK,RWDIVBTH,KKRBTH,RDIVCAPB
DOUBLE PRECISION DS,LS
DOUBLE PRECISION LDIVBTH,DDIVBTH,KZDIVKR,LCDELTA
DOUBLE PRECISION SUM,A1,A2,F1,A3,X,BESL,FI,DENOM,NUMER
DOUBLE PRECISION QCRITSTB,QCRITS
INTEGER N
CHARACTER* 50 PRNAME
CHARACTER* 1 SUBRTYPE
CHARACTER* 11 DATAENTRY
CHARACTER* 50 INPUTUNIT
CHARACTER* 50 OUTPUTUNIT

!ASK HOW TO ENTER DATA
PRINT *,'Do you want to prepare an input FILE or enter data INTERACTIVELY? <f/i>'
READ *,DATAENTRY

!READ VALUES OF T,K'/b',rw,b,d,l,Kz/Kr AND ENTER THESE VALUES INTO OUTPUT FILE
IF (DATAENTRY(1:1).EQ.'f'.OR.DATAENTRY(1:1).EQ.'F') THEN
   !READ DATA FROM INPUT FILE
   PRINT *,'ENTER INPUT FILE NAME: <filename.in>'
   READ *,INPUTUNIT
   OPEN (10,FILE=INPUTUNIT)
   PRINT *,'NAME OF THE PROJECT: <write in single quotation marks>'
   READ *,PRNAME
   READ (10,*) TRANS,LEAK,RWELL,BTHICK,DS,LS,KZDIVKR
   !WRITE INPUT DATA INTO OUTPUT FILE
   PRINT *,'ENTER OUTPUT FILE NAME: <filename.out>'
   READ *,OUTPUTUNIT
   OPEN (12,FILE=OUTPUTUNIT)
   WRITE (12,11)
   11 FORMAT(//,13X,'SWUP:AN INTERACTIVE PROGRAM FOR CALCULATING SALTWATER UPCONING',/,18X,'IN AN&
   & AQUIFER OVERLAIN BY A LEAKY CONFINING UNIT',/,/,13X,'PREPARED BY Louis H.Motz and Ozlem Acar&
   &',/,25X,'Department of Civil and Coastal Engineering',/,25X,'University of Florida',/,25X,'Ga&
   &inesville,Florida',/,'----------------------------------------------------------------------&
   &-------------',/,'------------------------------------------------------------------------&
   &---------',/)
   WRITE (12,12) PRNAME
   12 FORMAT(A,/)
   IF (SUBRTYPE.EQ.'s'.OR.SUBRTYPE.EQ.'S') THEN
      WRITE (12,13)
      13 FORMAT('SALTWATER UPCONING DUE TO SINGLE WELL PUMPING',/)
   ELSE
      WRITE (12,14)
      14 FORMAT('SALTWATER UPCONING DUE TO WELLFIELD PUMPING',/)
   END IF
   WRITE (12,15)
   15 FORMAT('INPUT DATA',/,'----------',/,'----------',/)
   WRITE (12,16)
   16 FORMAT('ALL DATA ARE IN CONSISTENT UNITS',/)
   WRITE (12,17) TRANS,LEAK,RWELL,BTHICK,DS,LS
   17 FORMAT('TRANSMISSIVITY (T) (ft2/day)',40X,':',ES10.3,/,'LEAKANCE OF CONFINING UNIT (Kprime/&
  &bprime) (1/day)',18X,':',ES10.3,/,'RADIUS OF WELL (rw) (ft)',44X,':',F10.3,/,'DISTANCE FROM T&
  &OP OF AQUIFER TO SW.-FW.INTERFACE (b) (ft)',11X,':',F10.3,/,'DISTANCE FROM TOP OF AQUIFER TO &
  &TOP OF WELL SCREEN (d) (ft)',9X,':',F10.3,/,'DISTANCE FROM TOP OF AQUIFER TO BOTTOM OF WELL S&
   &CREEN (l) (ft)',6X,':',F10.3)
   WRITE (12,18) KZDIVKR
   18 FORMAT('VERTICAL HYD.CONDUCTIVITY/HORIZONTAL HYD.CONDUCTIVITY (Kz/Kr)',7X,':',ES10.2,/,/,/,/,&
   &/)
ELSE
   !READ DATA INTERACTIVELY
   PRINT *,'NAME OF THE PROJECT?: <write in single quotation marks>'
   READ *,PRNAME
   PRINT *,'PLEASE ENTER DATA IN CONSISTENT UNITS'
   PRINT *,'TRANSMISSIVITY (T) (ft2/day)=?'
   READ *,TRANS
   PRINT *,'LEAKANCE (Kprime/bprime) (1/day)=?'
   READ *,LEAK
   PRINT *,'RADIUS OF WELL (rw) (ft)=?'
   READ *,RWELL
   PRINT *,'DISTANCE FROM TOP OF AQUIFER TO SALTWATER-FRESHWATER INTERFACE (b) (ft)=?'
   READ *,BTHICK
   PRINT *,'DISTANCE FROM TOP OF AQUIFER TO TOP OF WELL SCREEN (d) (ft)=?'
   READ *,DS
   PRINT *,'DISTANCE FROM TOP OF AQUIFER TO BOTTOM OF WELL SCREEN (l) (ft)=?'
   READ *,LS
```

```
   PRINT *,'VERT.HYD.CONDUCTIVITY/HORIZ.HYD.CONDUCTIVITY (Kz/Kr)=?'
   PRINT *,'SUGGESTED RATIO IS 1.0'
   READ *,KZDIVKR
   !WRITE INPUT DATA INTO OUTPUT FILE
   PRINT *,'ENTER OUTPUT FILE NAME: <filename.out>'
   READ *,OUTPUTUNIT
   OPEN (12,FILE=OUTPUTUNIT)
   WRITE (12,21)
   21 FORMAT(//,13X,'SWUP:AN INTERACTIVE PROGRAM FOR CALCULATING SALTWATER UPCONING',/,18X,'IN AN&
   & AQUIFER OVERLAIN BY A LEAKY CONFINING UNIT',/,/,13X,'PREPARED BY Louis H.Motz and Ozlem Acar&
   &',/,25X,'Department of Civil and Coastal Engineering',/,25X,'University of Florida',/,25X,'Ga&
   &inesville,Florida',/,'------------------------------------------------------------------&
   &-------------',/,'--------------------------------------------------------------------------&
   &---------',/)
   WRITE (12,22) PRNAME
   22 FORMAT(A,/)
   IF (SUBRTYPE.EQ.'s'.OR.SUBRTYPE.EQ.'S') THEN
      WRITE (12,23)
      23 FORMAT('SALTWATER UPCONING DUE TO SINGLE WELL PUMPING',/)
   ELSE
      WRITE (12,24)
      24 FORMAT('SALTWATER UPCONING DUE TO WELLFIELD PUMPING',/)
   END IF
   WRITE (12,25)
   25 FORMAT('INPUT DATA',/,'----------',/,'----------',/)
   WRITE (12,26)
   26 FORMAT('ALL DATA ARE IN CONSISTENT UNITS',/)
   WRITE (12,27) TRANS,LEAK,RWELL,BTHICK,DS,LS
   27 FORMAT('TRANSMISSIVITY (T) (ft2/day)',40X,':',ES10.3,/,'LEAKANCE OF CONFINING UNIT (Kprime/&
   &bprime) (1/day)',18X,':',ES10.3,/,'RADIUS OF WELL (rw) (ft)',44X,':',F10.3,/,'DISTANCE FROM T&
   &OP OF AQUIFER TO SW.-FW.INTERFACE (b) (ft)',11X,':',F10.3,/,'DISTANCE FROM TOP OF AQUIFER TO &
   &TOP OF WELL SCREEN (d) (ft)',9X,':',F10.3,/,'DISTANCE FROM TOP OF AQUIFER TO BOTTOM OF WELL S&
   &CREEN (l) (ft)',6X,':',F10.3)
   WRITE (12,28) KZDIVKR
   28 FORMAT('VERTICAL HYD.CONDUCTIVITY/HORIZONTAL HYD.CONDUCTIVITY (Kz/Kr)',7X,':',ES10.2,/,/,/,&
   &/)
END IF

!CALCULATE rw/b,l/b,d/b,(Kz/Kr)^0.5*(rw/b),rw/B
PI=4.0d0*datan(1.0d0)
RWDIVBTH=RWELL/BTHICK
LDIVBTH=LS/BTHICK
DDIVBTH=DS/BTHICK
!print *,ldivbth,ddivbth
KKRBTH=DSQRT(KZDIVKR)*RWDIVBTH
RDIVCAPB=DSQRT(LEAK/TRANS)*RWELL
LCDELTA=40.0d0
SUM=0.0d0
    DO N=1,5000
       A1=N*PI*LDIVBTH
     A2=N*PI*DDIVBTH
     F1=DSIN(A1)-DSIN(A2)
     A3=KKRBTH*N*PI
     X=A3
       !CALL SUBROUTINE BESSEL TO CALCULATE Ko(A3)
       CALL BESSEL(X,BESL)
     !print *,'bessel insidefi',besl
     SUM=(((-1)**N)*F1*BESL/N)+SUM
    END DO
    !print *,'sum',sum
FI=4.0d0*SUM/(PI*(LDIVBTH-DDIVBTH))
!print *,'fi',fi
X=RDIVCAPB
!CALL SUBROUTINE BESSEL TO CALCULATE Ko(r/B)
CALL BESSEL(X,BESL)
!print *,'besl',besl
DENOM=BESL+(FI/2.0d0)
!print *,'denom',denom
IF (DENOM.LT.0) DENOM=1.0E-10
NUMER=2.0d0*PI*.3d0*(1.0d0-LDIVBTH)
!print *,'numer',numer
QCRITSTB=NUMER/DENOM
QCRITS=TRANS*BTHICK*NUMER/(DENOM*LCDELTA)

!WRITE THE RESULTS TO OUTPUT FILE
WRITE (12,31)
31 FORMAT('SALTWATER UPCONING RESULTS',/,'OBTAINED BY ANALYTICAL MODEL',/,'----------------------&
   &------',/,'----------------------------',/,/,'REF: Motz,L.H.1992. Saltwater Upconing in an Aqui&
   &fer Overlain by a Leaky Confining',/,5X,'Bed. Journal of Ground Water,30(2):pp.192-198,March-&
   &April.',/,/)
WRITE (12,33)
```

```
33 FORMAT(4X,'*This model uses the Ghyben-Herzberg 40:1 ratio for the saltwater-freshwater',/,5X,&
   &'interface.',/,/)
WRITE (12,34)
34 FORMAT(7X,'rw/b',9X,'Kz/Kr',5X,'((Kz/Kr)^0.5)*(rw/b)',5X,'rw/B',6X,'(Qc*delta)/(T*b)')
WRITE (12,35)
35 FORMAT(5X,'---------',4X,'---------',3X,'-------------------',3X,'---------',3X,'------------&
   &----')
WRITE (12,36) RWDIVBTH,KZDIVKR,KKRBTH,RDIVCAPB,QCRITSTB
36 FORMAT(3X,ES10.2,3X,ES10.2,7X,ES10.2,8X,ES10.2,5X,ES10.2,/,/)
WRITE (12,37)
37 FORMAT(35X,'Qc(ft3/d)')
WRITE (12,38)
38 FORMAT(35X,'---------')
WRITE (12,39) QCRITS
39 FORMAT(33X,ES10.2)

!FOR INTERACTIVE,WRITE Qc TO SCREEN
IF (DATAENTRY(1:1).EQ.'i'.OR.DATAENTRY(1:1).EQ.'I') THEN
   WRITE (*,'(A,ES10.2)') ' Qc (ft3/day) =',QCRITS
END IF

RETURN
END
```

```
!*************************************************************************************
!*************************************************************************************
!SUBROUTINE SWUP_M(SUBRTYPE,TRANS,LEAK,BTHICK,KZDIVKR,NOWELL)
!*************************************************************************************
!*************************************************************************************
SUBROUTINE SWUP_M(SUBRTYPE,TRANS,LEAK,BTHICK,KZDIVKR,NOWELL)
DOUBLE PRECISION PI,TRANS,LEAK,RWELL,BTHICK,RWDIVBTH,KKRBTH,RDIVCAPB
DOUBLE PRECISION LDIVBTH,DDIVBTH,KZDIVKR,LCDELTA
DOUBLE PRECISION SUM,A1,A2,F1,A3,A4,F2,X,BESL,FI,DENOM,NUMER
DOUBLE PRECISION SUMDENOM,TOTALS
DOUBLE PRECISION QCRITSTB,QmSUMM,MINQTOTAL
DOUBLE PRECISION:: XC(1:100),YC(1:100)
DOUBLE PRECISION:: RW(1:100),R(1:100)
DOUBLE PRECISION:: D(1:100),L(1:100)
DOUBLE PRECISION:: ALPHA(1:100,1:100),Qm(1:100,1:100),QCRIT(1:100)
DOUBLE PRECISION:: QmSUM(1:100),QTOTAL(1:100),SS(1:100,1:100),SUMSS(1:100)
DIMENSION:: WELLID(1:100)
INTEGER N,I,J,K,NOWELL,MINI
CHARACTER* 50 PRNAME
CHARACTER* 1 SUBRTYPE
CHARACTER* 11 DATAENTRY
CHARACTER* 50 INPUTUNIT
CHARACTER* 50 OUTPUTUNIT
CHARACTER* 25 WELLID

!ASK HOW TO ENTER DATA
PRINT *,'Do you want to prepare an input FILE or enter data INTERACTIVELY? <f/i>'
READ *,DATAENTRY

!READ VALUES OF T,K'/b',b,Kz/Kr,rw,d,l,alpha AND ENTER THESE VALUES INTO OUTPUT FILE
IF (DATAENTRY(1:1).EQ.'f'.OR.DATAENTRY(1:1).EQ.'F') THEN
   !READ DATA FROM INPUT FILE
   PRINT *,'ENTER INPUT FILE NAME: <filename.in>'
   READ *,INPUTUNIT
   OPEN (10,FILE=INPUTUNIT)
   PRINT *,'NAME OF THE PROJECT: <write in single quotation marks>'
   READ *,PRNAME
   READ (10,*) TRANS,LEAK,BTHICK,KZDIVKR
   READ (10,*) NOWELL
   DO I=1,NOWELL
      READ (10,*) WELLID(I),XC(I),YC(I),RW(I),D(I),L(I)
   END DO
   !WRITE INPUT DATA INTO OUTPUT FILE
   PRINT *,'ENTER OUTPUT FILE NAME: <filename.out>'
   READ *,OUTPUTUNIT
   OPEN (12,FILE=OUTPUTUNIT)
   WRITE (12,11)
   11 FORMAT(//,13X,'SWUP:AN INTERACTIVE PROGRAM FOR CALCULATING SALTWATER UPCONING',/,18X,'IN AN&
   & AQUIFER OVERLAIN BY A LEAKY CONFINING UNIT',/,/,13X,'PREPARED BY Louis H.Motz and Ozlem Acar&
   &',/,25X,'Department of Civil and Coastal Engineering',/,25X,'University of Florida',/,25X,'Ga&
   &inesville,Florida',/,'-----------------------------------------------------------------------&
   &-------------',/,'---------------------------------------------------------------------------&
   &---------',/)
   WRITE (12,12) PRNAME
   12 FORMAT(A,/)
   IF (SUBRTYPE.EQ.'s'.OR.SUBRTYPE.EQ.'S') THEN
      WRITE (12,13)
      13 FORMAT('SALTWATER UPCONING DUE TO SINGLE WELL PUMPING',/)
   ELSE
      WRITE (12,14)
      14 FORMAT('SALTWATER UPCONING DUE TO WELLFIELD PUMPING',/)
   END IF
   WRITE (12,15)
   15 FORMAT('INPUT DATA',/,'----------',/,'----------',/)
   WRITE (12,16)
   16 FORMAT('ALL DATA ARE IN CONSISTENT UNITS',/)
   WRITE (12,17) TRANS,LEAK,BTHICK,KZDIVKR
   17 FORMAT('TRANSMISSIVITY (T) (ft2/day)',43X,':',ES10.3,/,'LEAKANCE OF CONFINING UNIT (Kprime/&
   &bprime) (1/day)',21X,':',ES10.3,/,'DISTANCE FROM TOP OF AQUIFER TO SW-FW INTERFACE (b) (ft)',&
   &15X,':',F10.3,/,'VERTICAL HYD.CONDUCTIVITY/HORIZONTAL HYD.CONDUCTIVITY (Kz/Kr)',10X,':',ES10.&
   &2,/,/)
   DO I=1,NOWELL
      WRITE (12,193) WELLID(I),XC(I),YC(I),RW(I),D(I),L(I)
      193 FORMAT(A,/,'X COORDINATE OF WELL (X) (ft)',42X,':',F10.3,/,'Y COORDINATE OF WELL (Y) (f&
    &t)',42X,':',F10.3,/,'RADIUS OF WELL (rw) (ft)',47X,':',F10.3,/,'DISTANCE FROM TOP OF AQUIF&
    &ER TO TOP OF WELL SCREEN (d) (ft)',12X,':',F10.3,/,'DISTANCE FROM TOP OF AQUIFER TO BOTTOM&
    & OF WELL SCREEN (l) (ft)',9X,':',F10.3,/)
   END DO
   WRITE (12,194)
   194 FORMAT(/,/,/)
ELSE
```

```
   !READ DATA INTERACTIVELY
   PRINT *,'NAME OF THE PROJECT: <write in single quotation marks>'
   READ *,PRNAME
   PRINT *,'PLEASE ENTER DATA IN CONSISTENT UNITS'
   PRINT *,'TRANSMISSIVITY (T) (ft2/day)=?'
   READ *,TRANS
   PRINT *,'LEAKANCE (Kprime/bprime) (1/day)=?'
   READ *,LEAK
   PRINT *,'DISTANCE FROM TOP OF AQUIFER TO SALTWATER-FRESHWATER INTERFACE (b) (ft)=?'
   READ *,BTHICK
   PRINT *,'VERT.HYD.CONDUCTIVITY/HORIZ.HYD.CONDUCTIVITY (Kz/Kr)=?'
   PRINT *,'SUGGESTED RATIO IS 1.0'
   READ *,KZDIVKR
   PRINT *,'ENTER NUMBER OF WELLS:'
   READ *,NOWELL
   DO I=1,NOWELL
      PRINT *,'WELL NUMBER OR NAME: <write in single quotation marks>'
    READ *,WELLID(I)
    PRINT *,'X COORDINATE OF WELL (X) (ft)=?'
    READ *,XC(I)
      PRINT *,'Y COORDINATE OF WELL (Y) (ft)=?'
    READ *,YC(I)
    PRINT *,'RADIUS OF WELL (rw) (ft)=?'
      READ *,RW(I)
    PRINT *,'DISTANCE FROM TOP OF AQUIFER TO TOP OF WELL SCREEN (d) (ft)=?'
      READ *,D(I)
      PRINT *,'DISTANCE FROM TOP OF AQUIFER TO BOTTOM OF WELL SCREEN (l) (ft)=?'
      READ *,L(I)
   END DO
   !WRITE INPUT DATA INTO OUTPUT FILE
   PRINT *,'ENTER OUTPUT FILE NAME: <filename.out>'
   READ *,OUTPUTUNIT
   OPEN (12,FILE=OUTPUTUNIT)
   WRITE (12,21)
   21 FORMAT(//,13X,'SWUP:AN INTERACTIVE PROGRAM FOR CALCULATING SALTWATER UPCONING',/,18X,'IN AN&
   & AQUIFER OVERLAIN BY A LEAKY CONFINING UNIT',/,/,13X,'PREPARED BY Louis H.Motz and Ozlem Acar&
   &',/,25X,'Department of Civil and Coastal Engineering',/,25X,'University of Florida',/,25X,'Ga&
   &inesville,Florida',/,'---------------------------------------------------------------------&
   &-------------',/,'-----------------------------------------------------------------------&
   &---------',/)
   WRITE (12,22) PRNAME
   22 FORMAT(A,/)
   IF (SUBRTYPE.EQ.'s'.OR.SUBRTYPE.EQ.'S') THEN
      WRITE (12,23)
      23 FORMAT('SALTWATER UPCONING DUE TO SINGLE WELL PUMPING',/)
   ELSE
      WRITE (12,24)
      24 FORMAT('SALTWATER UPCONING DUE TO WELLFIELD PUMPING',/)
   END IF
   WRITE (12,25)
   25 FORMAT('INPUT DATA',/,'----------',/,'----------',/)
   WRITE (12,26)
   26 FORMAT('ALL DATA ARE IN CONSISTENT UNITS',/)
   WRITE (12,27) TRANS,LEAK,BTHICK,KZDIVKR
   27 FORMAT('TRANSMISSIVITY (T) (ft2/day)',43X,':',ES10.3,/,'LEAKANCE OF CONFINING UNIT (Kprime/&
   &bprime) (1/day)',21X,':',ES10.3,/,'DISTANCE FROM TOP OF AQUIFER TO SW-FW INTERFACE (b) (ft)',&
   &15X,':',F10.3,/,'VERTICAL HYD.CONDUCTIVITY/HORIZONTAL HYD.CONDUCTIVITY (Kz/Kr)',10X,':',ES10.&
   &2,/,/)
   DO I=1,NOWELL
      WRITE (12,293) WELLID(I),XC(I),YC(I),RW(I),D(I),L(I)
      293 FORMAT(A,/,'X COORDINATE OF WELL (X) (ft)',42X,':',F10.3,/,'Y COORDINATE OF WELL (Y) (f&
    &t)',42X,':',F10.3,/,'RADIUS OF WELL (rw) (ft)',47X,':',F10.3,/,'DISTANCE FROM TOP OF AQUIF&
    &ER TO TOP OF WELL SCREEN (d) (ft)',12X,':',F10.3,/,'DISTANCE FROM TOP OF AQUIFER TO BOTTOM&
    & OF WELL SCREEN (l) (ft)',9X,':',F10.3,/)
   END DO
   WRITE (12,294)
   294 FORMAT(/,/,/)
END IF

PI=4.0d0*datan(1.0d0)
LCDELTA=40.0d0
!BEGINNING OF THE LOOP FOR THE MAIN PUMPING WELL
DO I=1,NOWELL
   SUMDENOM=0.0d0
   DO J=1,NOWELL
      ALPHA(I,J)=1.0d0
      !print *,'alpha(i,j)',alpha(i,j)
   END DO
   !CALCULATE rw/b,l/b,d/b,(Kz/Kr)^0.5*(rw/b),rw/B
   RWDIVBTH=RW(I)/BTHICK
   LDIVBTH=L(I)/BTHICK
```

```
DDIVBTH=D(I)/BTHICK
KKRBTH=DSQRT(KZDIVKR)*RWDIVBTH
RDIVCAPB=DSQRT(LEAK/TRANS)*RW(I)
SUM=0.0d0
    DO N=1,5000
    A1=N*PI*LDIVBTH
  A2=N*PI*DDIVBTH
  F1=DSIN(A1)-DSIN(A2)
  A3=KKRBTH*N*PI
  X=A3
    !CALL SUBROUTINE BESSEL TO CALCULATE Ko(A3)
    CALL BESSEL(X,BESL)
  SUM=(((-1)**N)*F1*BESL/N)+SUM
    END DO
!print *,'mainwellsum',sum
FI=4.0d0*SUM/(PI*(LDIVBTH-DDIVBTH))
!print *,'mainwellfi',fi
X=RDIVCAPB
!CALL SUBROUTINE BESSEL TO CALCULATE Ko(r/B)
CALL BESSEL(X,BESL)
!print *,'mainwellbesl',besl
DENOM=ALPHA(I,I)*(BESL+(FI/2.0d0))
!print *,'mainwelldenom',denom
IF (DENOM.LT.0) DENOM=1.0E-10
!print *,'mainwellifdenom',denom
SUMDENOM=DENOM+SUMDENOM
!print *,'mainwellsumdenom',sumdenom
!BEGINNING OF THE LOOP FOR THE OTHER WELLS
DO K=1,NOWELL
   IF(K.EQ.I) THEN
     GO TO 66
 ELSE
     !CALCULATE THE DISTANCE BETWEEN THE MAIN PUMPED WELL AND THE OTHER WELL
        !THIS DISTANCE WILL BE USED AS R IN CALCULATIONS
        R(K)=DSQRT(((XC(K)-XC(I))**2.0d0)+((YC(K)-YC(I))**2.0d0))
     !CALCULATE rw/b,l/b,d/b,(Kz/Kr)^0.5*(rw/b),rw/B
        RWDIVBTH=R(K)/BTHICK
       LDIVBTH=L(K)/BTHICK
       DDIVBTH=D(K)/BTHICK
       KKRBTH=DSQRT(KZDIVKR)*RWDIVBTH
       RDIVCAPB=DSQRT(LEAK/TRANS)*R(K)
       SUM=0.0d0
           DO N=1,5000
           A1=N*PI*LDIVBTH
         A2=N*PI*DDIVBTH
         F1=DSIN(A1)-DSIN(A2)
         A3=KKRBTH*N*PI
         X=A3
           !CALL SUBROUTINE BESSEL TO CALCULATE Ko(A3)
           CALL BESSEL(X,BESL)
         SUM=(((-1)**N)*F1*BESL/N)+SUM
           END DO
       !print *,'otherwellsum',sum
        FI=4.0d0*SUM/(PI*(LDIVBTH-DDIVBTH))
       !print *,'otherwellfi',fi
        X=RDIVCAPB
       !CALL SUBROUTINE BESSEL TO CALCULATE Ko(r/B)
       CALL BESSEL(X,BESL)
       !print *,'otherwellbesl',besl
        DENOM=ALPHA(I,K)*(BESL+(FI/2.0d0))
     !print *,'otherwelldenom',denom
        IF (DENOM.LT.0) DENOM=1.0E-10
       !print *,'otherwellifdenom',denom
        SUMDENOM=DENOM+SUMDENOM
        END IF
       !print *,'otherwellsumdenom',sumdenom
!END OF THE LOOP FOR THE OTHER WELLS
66 END DO
!CALCULATE Qc AT PUMPED WELL UNDER CONSIDERATION
NUMER=2.0d0*PI*.3d0*(1.d0-(L(I)/BTHICK))
QCRITSTB=NUMER/SUMDENOM
QCRIT(I)=TRANS*BTHICK*NUMER/(SUMDENOM*LCDELTA)
!CALCULATE PUMPING RATES (Qm) AT OTHER WELLS CAUSING INTERFERENCE
!FINALLY,CALCULATE TOTAL PUMPING RATE FOR THIS WELL UNDER CONSIDERATION
QmSUMM=0.0
DO M=1,NOWELL
   IF(M.EQ.I) GO TO 77
 Qm(I,M)=ALPHA(I,M)*QCRIT(I)
   !print *,Qm(M)
 QmSUMM=QmSUMM+Qm(I,M)
 QmSUM(I)=QmSUMM
```

```
   77 END DO
   QTOTAL(I)=QCRIT(I)+QmSUM(I)
!END OF THE LOOP FOR THE MAIN PUMPING WELL
END DO

!CHOOSE THE MINIMUM TOTAL PUMPING RATE AS THE MOST CRITICAL CASE
     MINQTOTAL=QTOTAL(1)
     DO I=1,NOWELL
     IF(QTOTAL(I).LE.MINQTOTAL) THEN
  MINQTOTAL=QTOTAL(I)
  MINI=I
  END IF
  END DO
     !print *,minqtotal,mini

!CALCULATE DRAWDOWN AT z=0.5(l+d) FOR THE CRITICAL CASE
!BEGINNING OF THE LOOP FOR THE MAIN WELL
DO I=1,NOWELL
TOTALS=0.0d0
!CALCULATE rw/b,l/b,d/b,(Kz/Kr)^0.5*(rw/b),rw/B
RWDIVBTH=RW(I)/BTHICK
LDIVBTH=L(I)/BTHICK
DDIVBTH=D(I)/BTHICK
KKRBTH=DSQRT(KZDIVKR)*RWDIVBTH
RDIVCAPB=DSQRT(LEAK/TRANS)*RW(I)
SUM=0.0d0
   DO N=1,5000
      A1=N*PI*LDIVBTH
      A2=N*PI*DDIVBTH
      F1=DSIN(A1)-DSIN(A2)
      A4=N*PI*0.5d0*((L(I)+D(I))/BTHICK)
      F2=DCOS(A4)
      A3=KKRBTH*N*PI
      X=A3
      !CALL SUBROUTINE BESSEL TO CALCULATE Ko(A3)
      CALL BESSEL(X,BESL)
      SUM=(F1*F2*BESL/N)+SUM
   END DO
FI=4.0d0*SUM/(PI*(LDIVBTH-DDIVBTH))
X=RDIVCAPB
!CALL SUBROUTINE BESSEL TO CALCULATE Ko(r/B)
CALL BESSEL(X,BESL)
SS(I,I)=ALPHA(MINI,I)*QCRIT(MINI)*(BESL+(FI/2.0d0))/(2.0d0*PI*TRANS)
!print *,'alpha(mini,i)',alpha(mini,i),'qcrit(mini)',qcrit(mini)
!print *,'ss(i,i)',ss(i,i)
TOTALS=TOTALS+SS(I,I)
   !BEGINNING OF THE LOOP FOR THE OTHER WELLS
   DO J=1,NOWELL
      IF(J.EQ.I) THEN
      GO TO 666
      ELSE
      !CALCULATE THE DISTANCE BETWEEN THE MAIN PUMPED WELL AND THE OTHER WELL
    !THIS DISTANCE WILL BE USED AS R IN CALCULATIONS
    R(J)=DSQRT(((XC(J)-XC(I))**2.0d0)+((YC(J)-YC(I))**2.0d0))
      !CALCULATE rw/b,l/b,d/b,(Kz/Kr)^0.5*(rw/b),rw/B
    RWDIVBTH=R(J)/BTHICK
      LDIVBTH=L(J)/BTHICK
      DDIVBTH=D(J)/BTHICK
      KKRBTH=DSQRT(KZDIVKR)*RWDIVBTH
      RDIVCAPB=DSQRT(LEAK/TRANS)*R(J)
      SUM=0.0d0
      DO N=1,5000
         A1=N*PI*LDIVBTH
         A2=N*PI*DDIVBTH
         F1=DSIN(A1)-DSIN(A2)
         A4=N*PI*0.5d0*((L(I)+D(I))/BTHICK)
         F2=DCOS(A4)
         A3=KKRBTH*N*PI
         X=A3
         !CALL SUBROUTINE BESSEL TO CALCULATE Ko(A3)
         CALL BESSEL(X,BESL)
         SUM=(F1*F2*BESL/N)+SUM
      END DO
      FI=4.0d0*SUM/(PI*(LDIVBTH-DDIVBTH))
      X=RDIVCAPB
      !CALL SUBROUTINE BESSEL TO CALCULATE Ko(r/B)
      CALL BESSEL(X,BESL)
    SS(I,J)=ALPHA(MINI,J)*QCRIT(MINI)*(BESL+(FI/2.0d0))/(2.0d0*PI*TRANS)
      !print *,'alpha(mini,j)',alpha(mini,j),'alpha(mini,i)',alpha(mini,i)
    !print *,'ss(i,j)',ss(i,j)
    TOTALS=TOTALS+SS(I,J)
```

```
      END IF
   !END OF THE LOOP FOR THE OTHER WELLS
   666 END DO
SUMSS(I)=TOTALS
!END OF THE LOOP FOR THE MAIN WELL
END DO

!WRITE THE RESULTS TO OUTPUT FILE
WRITE (12,31)
31 FORMAT('SALTWATER UPCONING RESULTS',/,'OBTAINED BY ANALYTICAL MODEL',/,'---------------------&
   &------',/,'----------------------------',/)
WRITE (12,32)
32 FORMAT('REF: Motz,L.H.1994.Predicting Saltwater Upconing Due to Well Field Pumping.',/,5X,'In:&
   &Soveri,J.,and Suokko,T.,Editors.Future Groundwater Resources at Risk.',/,5X,'(Proceedings of &
   &the Helsinki Conference,June 1994).International Association',/,5X,'of Hydrological Sciences,&
   &Publication No.222,pp.55-60.',/)
WRITE (12,33)
33 FORMAT(3X,'* This model uses the Ghyben-Herzberg 40:1 ratio for the saltwater-freshwater',/,5X&
   &,'interface.',/,/)
DO I=1,NOWELL
   WRITE (12,34)
   34 FORMAT('Pumped well under consideration',10X,'Qc (ft3/day) (critical pumping rate')
   WRITE (12,35)
   35 FORMAT(55X,'at well under consideration)')
   WRITE (12,36)
   36 FORMAT('---------------------------------',9X,'------------------------------------------')
   WRITE (12,37) WELLID(I),QCRIT(I)
   37 FORMAT(A,25X,ES10.2,/)
   WRITE (12,38)
   38 FORMAT('Other wells causing interference',9X,'Qm (ft3/day) (pumping rates at other')
   WRITE (12,39)
   39 FORMAT(55X,'wells)')
   WRITE (12,40)
   40 FORMAT('---------------------------------',9X,'------------------------------------------')
      DO J=1,NOWELL
         IF(J.EQ.I) GO TO 88
       WRITE (12,41) WELLID(J),Qm(I,J)
         41 FORMAT(A,25X,ES10.2)
   88 END DO
   WRITE (12,42)
   42 FORMAT('---------------------------------',9X,'------------------------------------------')
   WRITE (12,43)
   43 FORMAT('---------------------------------',9X,'------------------------------------------')
   WRITE (12,44) QTOTAL(I)
   44 FORMAT('TOTAL PUMPING RATE (ft3/day) =',20X,ES10.2,/,/,/)
END DO
WRITE (12,45) WELLID(MINI)
45 FORMAT(/,'CRITICAL CONDITION OCCURS AT ',A)
WRITE (12,451)
451 FORMAT('BASED ON WELL PROPERTIES',/)
WRITE (12,46)
46 FORMAT('Well',22X,'Q (ft3/day)',17X,'Drawdown in well (ft)')
WRITE (12,47)
47 FORMAT('--------------------',6X,'-----------',17X,'---------------------')
DO K=1,NOWELL
   IF(K.EQ.MINI) THEN
   WRITE (12,48) WELLID(K),QCRIT(MINI),SUMSS(K)
   48 FORMAT(A,ES10.2,19X,F10.3)
   ELSE
   WRITE (12,49) WELLID(K),Qm(MINI,K),SUMSS(K)
   49 FORMAT(A,ES10.2,19X,F10.3)
   END IF
END DO
WRITE (12,50)
50 FORMAT('--------------------',6X,'-----------',17X,'---------------------')
WRITE (12,51)
51 FORMAT('--------------------',6X,'-----------',17X,'---------------------')
WRITE (12,52)
52 FORMAT('CRITICAL PUMPING')
WRITE (12,53) MINQTOTAL
53 FORMAT('RATE  (ft3/day)  =',7X,ES10.2)

!FOR INTERACTIVE,WRITE Qc,Qm,QTOTAL TO SCREEN
IF (DATAENTRY(1:1).EQ.'i'.OR.DATAENTRY(1:1).EQ.'I') THEN
  DO I=1,NOWELL
   WRITE (*,'(/,A,5X,A)') ' Pumped well under consideration','Qc (ft3/day) (critical pumping rate'
   WRITE (*,'(51X,A)') 'at well under consideration)'
   WRITE (*,'(1X,A,4X,A)') '---------------------------------','-----------------------------------&
   &--------'
   WRITE (*,'(1X,A,20X,ES10.2)') WELLID(I),QCRIT(I)
   WRITE (*,'(/,A,4X,A)') ' Other wells causing interference','Qm (ft3/day) (pumping rates at oth&
```

```
    &er'
    WRITE (*,'(51X,A)') 'wells)'
    WRITE (*,'(1X,A,4X,A)') '--------------------------------','-----------------------------------&
    &--------'
       DO J=1,NOWELL
          IF(J.EQ.I) GO TO 99
        WRITE (*,'(1X,A,20X,ES10.2)') WELLID(J),Qm(I,J)
    99 END DO
    WRITE (*,'(1X,A,4X,A)') '---------------------------------','----------------------------------&
    &--------'
    WRITE (*,'(1X,A,4X,A)') '---------------------------------','----------------------------------&
    &--------'
    WRITE (*,'(A,15X,ES10.2,/,/)') ' TOTAL PUMPING RATE (ft3/day) =',QTOTAL(I)
   END DO
    WRITE (*,'(/,A,A)') ' CRITICAL CONDITION OCCURS AT ',WELLID(MINI)
    WRITE (*,'(A)') ' BASED ON WELL PROPERTIES'
    WRITE (*,'(/,A,22X,A,20X,A)') ' Well','Q (ft3/day)','Drawdown in well (ft)'
    WRITE (*,'(A,6X,A,20X,A)') ' ---------------------','-----------','----------------------'
    DO K=1,NOWELL
       IF(K.EQ.MINI) THEN
       WRITE (*,'(1X,A,ES10.2,22X,F10.3)') WELLID(K),QCRIT(MINI),SUMSS(MINI)
       ELSE
       WRITE (*,'(1X,A,ES10.2,22X,F10.3)') WELLID(K),Qm(MINI,K),SUMSS(K)
       END IF
    END DO
    WRITE (*,'(A,6X,A,20X,A)') ' ---------------------','-----------','----------------------'
    WRITE (*,'(A,6X,A,20X,A)') ' ---------------------','-----------','----------------------'
    WRITE (*,'(A)') ' CRITICAL PUMPING'
    WRITE (*,'(A,7X,ES10.2,/)') ' RATE  (ft3/day)  =',MINQTOTAL
END IF

RETURN
END

!*************************************************************************************************
!*************************************************************************************************
! SUBROUTINE BESSEL CALCULATES Ko(X)
! REFERENCE:ABRAMOWITZ,M. and I.A.STEGUN,Handbook of Mathematical Functions,
! Dover,New York,1965.
!*************************************************************************************************
!*************************************************************************************************
SUBROUTINE BESSEL(X,BESL)
DOUBLE PRECISION X,BESL,T,T2,T4,T6,T8,T10,T12
DOUBLE PRECISION IO,Y,Y2,Y4,Y6,Y8,Y10,Y12,COKO,COEF
IF (X.GT.50) GO TO 1140
IF (X.GT.2) GO TO 1090
T=X/3.75d0
T2=T**2
T4=T2**2
T6=T2*T4
T8=T4*T4
T10=T4*T6
T12=T6*T6
IO=1.0d0+3.5156229d0*T2+3.0899424d0*T4+1.2067492d0*T6+0.2659732d0*T8+0.0360768d0*T10+0.0045813d0*&
&T12
Y=X/2.0d0
Y2=Y**2
Y4=Y2**2
Y6=Y2*Y4
Y8=Y4*Y4
Y10=Y4*Y6
Y12=Y6*Y6
BESL=-DLOG(Y)*IO-0.57721566d0+0.4227842d0*Y2+0.23069756d0*Y4+0.0348859d0*Y6+2.62698E-03*Y8+0.0001&
&075d0*Y10+0.0000074d0*Y12
GO TO 1150
1090 Y=2.0d0/X
     Y2=Y**2
  Y3=Y**3
  Y4=Y**4
  Y5=Y**5
  Y6=Y**6
  COKO=1.25331414d0-7.832358E-02*Y+2.189568E-02*Y2-1.062446E-02*Y3+5.87872E-03*Y4-0.0025154*Y5&
  &+5.3208E-04*Y6
  COEF=DSQRT(X)*DEXP(X)
  BESL=COKO/COEF
  GO TO 1150
1140 BESL=0.0
     GO TO 1150
1150 RETURN
     END
```

!**

APPENDIX B

Source Code for COUAQ

```
!*************************************************************************************************
! COUAQ:AN INTERACTIVE PROGRAM FOR CALCULATING DRAWDOWNS IN COUPLED AQUIFERS
! WITH CONFINING UNIT STORAGE AND ET REDUCTION
! PREPARED BY Louis H.Motz and Ozlem Acar
!            Department of Civil and Coastal Engineering
!            University of Florida
!            Gainesville,Florida
!*************************************************************************************************
!*************************************************************************************************
! COUAQ.F90
!*************************************************************************************************
!*************************************************************************************************

! THIS PROGRAM HAS MAINLY TWO PARTS:ONE PART IS FOR THE SINGLE WELL OPTION AND
! THE SECOND PART IS FOR THE MULTIPLE WELLS OPTION

!*************************************************************************************************

! SINGLE WELL OPTION:
! CALCULATES DRAWDOWN VERSUS TIME AND DISTANCE USING DENIS AND MOTZ (1998)
! NONSTEADY LEAKY COUPLED AQUIFER EQUATION WITH ET REDUCTION AND CONFINING BED STORAGE.
! INVERSE FUNCTIONS FOR s1 and s2 CALCULATED USING STEHFEST (1970) NUMERICAL
! INVERSION ALGORITHM AS CORRECTED BY MOENCH AND OGATA (1981)
! INPUT READ FROM INPUTFILENAME.IN, OUTPUT WRITTEN TO OUTPUTFILENAME.OUT and to
! DATAFILENAME.DAT (IN FORMAT SUITABLE FOR GRAPHER INPUT)

!*************************************************************************************************

! MULTIPLE WELLS OPTION:
! CALCULATES DRAWDOWNS DUE TO MULTIPLE WELLS AT MULTIPLE GRID LOCATIONS AT SPECIFIED TIMES
! USING DENIS AND MOTZ (1998) NONSTEADY LEAKY COUPLED AQUIFER EQUATION
! WITH ET REDUCTION AND CONFINING BED STORAGE
! INVERSE FUNCTIONS FOR S1 AND S2 ARE CALCULATED USING STEHFEST (1970)
! NUMERICAL INVERSION ALGORITHM AS CORRECTED BY MOENCH AND OGATA (1981)

!*************************************************************************************************

! NWELLS       = NUMBER OF WELLS
! XWELL        = X COORDINATE OF WELL [L]
! YWELL        = Y COORDINATE OF WELL [L]
! RWELL        = RADIUS OF WELL [L]
! X1GRID       = X COORDINATE FOR LOWER LEFT CORNER OF GRID [L]
! Y1GRID       = Y COORDINATE FOR LOWER LEFT CORNER OF GRID [L]
! X2GRID       = X COORDINATE FOR UPPER RIGHT CORNER OF GRID [L]
! Y2GRID       = Y COORDINATE FOR UPPER RIGHT CORNER OF GRID [L]
! DELX         = DELTA X FOR THE GRID [L]
! DELY         = DELTA Y FOR THE GRID [L]
! NOXREPEAT    = NUMBER OF DIFFERENT REPEATING X COORDINATES IN THE GRID
! NOYREPEAT    = NUMBER OF DIFFERENT REPEATING Y COORDINATES IN THE GRID
! XGRIDREPEAT  = REPEATING X COORDINATES IN THE GRID [L]
! YGRIDREPEAT  = REPEATING Y COORDINATES IN THE GRID [L]
! NGRIDS       = NUMBER OF LOCATIONS (GRIDS) WHERE DRAWDOWNS ARE TO BE CALCULATED
! XGRID        = X COORDINATE OF LOCATION WHERE DRAWDOWNS ARE TO BE CALCULATED [L]
! YGRID        = Y COORDINATE OF LOCATION WHERE DRAWDOWNS ARE TO BE CALCULATED [L]
! RADIUS       = RADIAL DISTANCE FROM EACH GRID LOCATION TO PUMPED WELLS [L]
! R            = RADIAL DISTANCE FROM THE PUMPED WELL [L] (USED FOR SINGLE WELL)
! NR           = NUMBER OF R VALUES FOR WHICH CALCULATIONS ARE CARRIED OUT (USED FOR SINGLE WELL)
! Q1           = PUMPING RATE FROM AQUIFER 1 [L3/T]
! T1           = TRANSMISSIVITY OF AQUIFER 1 [L2/T]
! STO1         = SPECIFIC YIELD OF AQUIFER 1
! EP           = RATE AT WHICH EVAPOTRANSPIRATION IS REDUCED PER UNIT OF WT DRAWDOWN [1/T]
! Q2           = PUMPING RATE FROM AQUIFER 2 [L3/T]
! T2           = TRANSMISSIVITY OF AQUIFER 2 [L2/T]
! STO2         = STORATIVITY OF AQUIFER 2
! K'           = VERTICAL HYDRAULIC CONDUCTIVITY OF CONFINING UNIT [L/T]
! b'           = THICKNESS OF CONFINING UNIT [L]
! LEAK         = K'/b',LEAKANCE OF CONFINING UNIT [1/T]
! STOPRIME     = STORATIVITY OF THE CONFINING UNIT
! z            = VERTICAL DISTANCE FROM THE BOTTOM OF THE CONFINING UNIT [L]
! DD1S         = DRAWDOWN IN AQUIFER 1 (FOR SINGLE WELL)[L]
! DD2S         = DRAWDOWN IN AQUIFER 2 (FOR SINGLE WELL)[L]
! DD3S         = DRAWDOWN IN CONFINING UNIT AT z/b'=0.2 (FOR SINGLE WELL)[L]
! DD4S         = DRAWDOWN IN CONFINING UNIT AT z/b'=0.5 (FOR SINGLE WELL)[L]
! DD5S         = DRAWDOWN IN CONFINING UNIT AT z/b'=0.8 (FOR SINGLE WELL)[L]
! DD1          = DRAWDOWN IN AQUIFER 1 (AT A GRID LOCATION FOR MULTIPLE WELLS)[L]
! DD2          = DRAWDOWN IN AQUIFER 2 (AT A GRID LOCATION FOR MULTIPLE WELLS)[L]
! DD3          = DRAWDOWN IN CONFINING UNIT AT z/b'=0.2 (AT A GRID LOCATION FOR MULTIPLE WELLS)[L]
! DD4          = DRAWDOWN IN CONFINING UNIT AT z/b'=0.5 (AT A GRID LOCATION FOR MULTIPLE WELLS)[L]
! DD5          = DRAWDOWN IN CONFINING UNIT AT z/b'=0.8 (AT A GRID LOCATION FOR MULTIPLE WELLS)[L]
! DDW1         = DRAWDOWN IN AQUIFER 1 (AT A WELL LOCATION FOR MULTIPLE WELLS)[L]
! DDW2         = DRAWDOWN IN AQUIFER 2 (AT A WELL LOCATION FOR MULTIPLE WELLS)[L]
```

```
! S            = LAPLACE TRANSFORM PARAMETER
! X            = ARGUMENT FOR WHICH BESSEL FUNCTION Ko IS CALCULATED
! BESL         = Ko:MODIFIED BESSEL FUNCTION OF THE SECOND KIND,ZERO ORDER
! TIME         = TIME FOR TRANSIENT SIMULATION [T]
! PERIOD       = TOTAL TIME LENGTH FOR TRANSIENT SIMULATION [T]
! NTIMESTEPS   = NUMBER OF TIME STEPS FOR TRANSIENT SIMULATION
! TIMESTEPMULT = TIME STEP MULTIPLIER FOR TRANSIENT SIMULATION

!**********************************************************************************************

DOUBLE PRECISION X1GRID,Y1GRID,X2GRID,Y2GRID,DELX,DELY
DOUBLE PRECISION XGRIDREPEAT(1000),YGRIDREPEAT(1000)
DOUBLE PRECISION XWELL(100),YWELL(100),RWELL(100),XGRID(2650),YGRID(2650)
DOUBLE PRECISION RADIUS(2650,2650),DD1(2650,2650),DD2(2650,2650)
DOUBLE PRECISION DDW1(100,100),DDW2(100,100)
DOUBLE PRECISION QQ1(100),TRANS1,STO1,EP,QQ2(100),TRANS2,STO2
DOUBLE PRECISION LEAK,STOPRIME,TOTALQ1,TOTALQ2
DOUBLE PRECISION SUM1,SUM2,SUMW1,SUMW2
DOUBLE PRECISION TIMEINI,DELTIME,TIME
DOUBLE PRECISION PERIOD,TIMESTEPMULT
DOUBLE PRECISION PI,MINRADIUS
DOUBLE PRECISION R,Q1,Q2,T1,T2
DOUBLE PRECISION U1,U2,DF1,DF2
DOUBLE PRECISION DD3,DD4,DD5,DF3,DF4,DF5
DOUBLE PRECISION RADIUSS(1000)
DOUBLE PRECISION DD1S,DD2S,DD3S,DD4S,DD5S
DOUBLE PRECISION TIMEARRAY(1000),DDARRAY(2,1000,1000)
INTEGER NR,NWELLS,NGRIDS,NTIMESTEPS
INTEGER NOXREPEAT,NOYREPEAT
DIMENSION:: WELLID(1:100)
CHARACTER* 50 PRNAME
CHARACTER* 1 SUBRTYPE
CHARACTER* 50 INPUTUNIT
CHARACTER* 11 DATAENTRY
CHARACTER* 50 OUTPUTUNIT
CHARACTER* 50 DATUNIT
CHARACTER* 3 ENDDECISION
CHARACTER* 25 WELLID
CHARACTER* 50 GRAPHERINUNIT

PRINT *,'************************************************************************'
PRINT *,'************************************************************************'
PRINT *,'         COUAQ:AN INTERACTIVE PROGRAM FOR CALCULATING DRAWDOWNS IN COUPLED'
PRINT *,'               AQUIFERS WITH CONFINING UNIT STORAGE AND ET REDUCTION'
PRINT *,'                                                                       '
PRINT *,'         PREPARED BY Louis H.Motz and Ozlem Acar'
PRINT *,'                     Department of Civil and Coastal Engineering'
PRINT *,'                     University of Florida'
PRINT *,'                     Gainesville,Florida'
PRINT *,'************************************************************************'
PRINT *,'************************************************************************'

!ASK SINGLE OR MULTIPLE WELLS
1 PRINT *,'SINGLE OR MULTIPLE WELLS? <s/m>'
READ *,SUBRTYPE
IF (SUBRTYPE(1:1).EQ.'s'.OR.SUBRTYPE(1:1).EQ.'S') THEN
CALL COUAQ_1(SUBRTYPE,Q1,T1,STO1,EP,Q2,T2,STO2,LEAK,STOPRIME,NR,RADIUSS,PERIOD,NTIMESTEPS,TIMESTE&
&PMULT)
ELSE
CALL COUAQ_M(SUBRTYPE,TRANS1,STO1,EP,TRANS2,STO2,LEAK,STOPRIME,PERIOD,NTIMESTEPS,TIMESTEPMU&
&LT,NWELLS,WELLID,XWELL,YWELL,RWELL,QQ1,QQ2,NGRIDS,XGRID,YGRID)
END IF

!END THE PROGRAM
WRITE(*,'(/)')
PRINT *,'PROGRAM COMPLETED'
PRINT *,'Do you want to do more calculations? <y/n>'
READ *,ENDDECISION
IF (ENDDECISION.EQ.'y'.OR.ENDDECISION.EQ.'Y') THEN
      GO TO 1
   ELSE
      GO TO 999
END IF

999 STOP
END


!**********************************************************************************************
!**********************************************************************************************
!SUBROUTINE COUAQ_1(SUBRTYPE,Q1,T1,STO1,EP,Q2,T2,STO2,LEAK,STOPRIME,NR,RADIUSS,PERIOD,NTIMESTEPS,&
```

```
!&TIMESTEPMULT)
!*******************************************************************************************
!*******************************************************************************************
SUBROUTINE COUAQ_1(SUBRTYPE,Q1,T1,STO1,EP,Q2,T2,STO2,LEAK,STOPRIME,NR,RADIUSS,PERIOD,NTIMESTEPS,T&
&IMESTEPMULT)
DOUBLE PRECISION Q1,Q2,T1,T2,STO1,STO2,STOPRIME,EP,LEAK
DOUBLE PRECISION RADIUSS(1000),R
DOUBLE PRECISION TIMEINI,DELTIME,TIME
DOUBLE PRECISION PERIOD,TIMESTEPMULT
DOUBLE PRECISION PI,U2
DOUBLE PRECISION DF1,DF2,DF3,DF4,DF5
DOUBLE PRECISION DD1S,DD2S,DD3S,DD4S,DD5S
DOUBLE PRECISION TIMEARRAY(1000),DDARRAY(2,1000,1000)
INTEGER NR,NTIMESTEPS
CHARACTER* 50 PRNAME
CHARACTER* 1 SUBRTYPE
CHARACTER* 11 DATAENTRY
CHARACTER* 50 INPUTUNIT
CHARACTER* 50 OUTPUTUNIT
CHARACTER* 50 GRAPHERINUNIT

!ASK HOW TO ENTER DATA
PRINT *,'Do you want to prepare an input FILE or enter data INTERACTIVELY? <f/i>'
READ *,DATAENTRY

!READ VALUES OF Q1,T1,STO1,EP,Q2,T2,STO2,LEAK,STOPRIME FROM INPUT FILE
IF (DATAENTRY(1:1).EQ.'f'.OR.DATAENTRY(1:1).EQ.'F') THEN
   !READ DATA FROM INPUT FILE
   PRINT *,'ENTER INPUT FILE NAME: <filename.in>'
   READ *,INPUTUNIT
   OPEN (UNIT=5,FILE=INPUTUNIT)
   PRINT *,'NAME OF THE PROJECT: <write in single quotation marks>'
   READ *,PRNAME
   READ(5,*) Q1,T1,STO1,EP,Q2,T2,STO2,LEAK,STOPRIME
   READ(5,*) NR
   DO I=1,NR
      READ(5,*) RADIUSS(I)
      IF(RADIUSS(I).LE.0.0) THEN
        PRINT *,'r HAS TO BE GREATER THAN 0.0'
        GO TO 50
      END IF
   END DO
   READ(5,*) PERIOD,NTIMESTEPS,TIMESTEPMULT
   !WRITE INPUT DATA INTO OUTPUT FILE
   PRINT *,'ENTER OUTPUT FILE NAME: <filename.out>'
   READ *,OUTPUTUNIT
   OPEN (UNIT=6,FILE=OUTPUTUNIT)
   PRINT *,'ENTER DATA FILE NAME FOR GRAPHER INPUT: <filename.dat>'
   READ *,GRAPHERINUNIT
   OPEN(UNIT=8,FILE=GRAPHERINUNIT)
   WRITE (6,11)
   11 FORMAT(//,12X,'COUAQ:AN INTERACTIVE PROGRAM FOR CALCULATING DRAWDOWNS IN COUPLED',/,18X,'AQ&
   &UIFERS WITH CONFINING UNIT STORAGE AND ET REDUCTION',/,/,12X,'PREPARED BY Louis H.Motz and Oz&
   &lem Acar',/,24X,'Department of Civil and Coastal Engineering',/,24X,'University of Florida',/&
   &,24X,'Gainesville,Florida',/,'-----------------------------------------------------------------&
   &---------------------',/,'-----------------------------------------------------------------&
   &-----------------',/)
   WRITE (6,12) PRNAME
   12 FORMAT(A,/)
   IF (SUBRTYPE.EQ.'s'.OR.SUBRTYPE.EQ.'S') THEN
      WRITE (6,13)
      13 FORMAT('DRAWDOWNS DUE TO SINGLE WELL PUMPING',/)
   ELSE
      WRITE (6,14)
      14 FORMAT('DRAWDOWNS DUE TO WELLFIELD PUMPING',/)
   END IF
   WRITE (6,15)
   15 FORMAT('INPUT DATA',/,'----------',/,'----------',/)
   WRITE (6,16)
   16 FORMAT('ALL DATA ARE IN CONSISTENT UNITS',/)
   WRITE (6,17) Q1,T1,STO1,EP
   17 FORMAT('PUMPING RATE FROM AQUIFER 1 (Q1) (ft3/day)',29X,':',ES10.3,/,'TRANSMISSIVITY OF AQU&
   &IFER 1 (T1) (ft2/day)',29X,':',ES10.3,/,'SPECIFIC YIELD OF AQUIFER 1 (S1)',39X,':',ES10.3,/,'&
   &RATE AT WHICH ET IS REDUCED PER UNIT OF WT DRAWDOWN (1/day)',12X,':',ES10.3)
   WRITE (6,18) Q2,T2,STO2,LEAK
   18 FORMAT('PUMPING RATE FROM AQUIFER 2 (Q2) (ft3/day)',29X,':',ES10.3,/,'TRANSMISSIVITY OF AQU&
   &IFER 2 (T2) (ft2/day)',29X,':',ES10.3,/,'STORATIVITY OF AQUIFER 2 (S2)',42X,':',ES10.3,/,'LEA&
   &KANCE OF CONFINING UNIT (Kprime/bprime) (1/day)',21X,':',ES10.3)
   WRITE (6,19) STOPRIME
   19 FORMAT('STORATIVITY OF THE CONFINING UNIT (Sprime)',29X,':',ES10.3,/)
   WRITE (6,191) NR
```

```
    191 FORMAT('NUMBER OF R VALUES FOR WHICH CALCULATIONS ARE CARRIED OUT',14X,':',I10)
    DO I=1,NR
       WRITE (6,192) RADIUSS(I)
       192 FORMAT('RADIAL DISTANCE FROM THE PUMPED WELL (r) (ft)',26X,':',F10.3)
    END DO
    WRITE (6,193)
    193 FORMAT(/)
    WRITE (6,194) PERIOD
    194 FORMAT('TOTAL TIME LENGTH FOR TRANSIENT SIMULATION (t) (days)',18X,':',F10.3)
    WRITE (6,195) NTIMESTEPS
    195 FORMAT('NUMBER OF TIME STEPS FOR TRANSIENT SIMULATION',26X,':',I10)
    WRITE (6,196) TIMESTEPMULT
    196 FORMAT('TIME STEP MULTIPLIER FOR TRANSIENT SIMULATION',26X,':',F10.3)
    WRITE (6,197)
    197 FORMAT(/,/)
 ELSE
    !READ DATA INTERACTIVELY
    PRINT *,'NAME OF THE PROJECT: <write in single quotation marks>'
    READ *,PRNAME
    PRINT *,'PLEASE ENTER DATA IN CONSISTENT UNITS'
    PRINT *,'PUMPING RATE FROM AQUIFER 1 (Q1) (ft3/day)=?'
    READ *,Q1
    PRINT *,'TRANSMISSIVITY OF AQUIFER 1 (T1) (ft2/day)=?'
    READ *,T1
    PRINT *,'SPECIFIC YIELD OF AQUIFER 1 (S1)=?'
    READ *,STO1
    PRINT *,'RATE AT WHICH ET IS REDUCED PER UNIT OF WT DRAWDOWN (1/day)=?'
    READ *,EP
    PRINT *,'PUMPING RATE FROM AQUIFER 2 (Q2) (ft3/day)=?'
    READ *,Q2
    PRINT *,'TRANSMISSIVITY OF AQUIFER 2 (T2) (ft2/day)=?'
    READ *,T2
    PRINT *,'STORATIVITY OF AQUIFER 2 (S2)=?'
    READ *,STO2
    PRINT *,'LEAKANCE OF CONFINING UNIT (Kprime/bprime) (1/day)=?'
    READ *,LEAK
    PRINT *,'STORATIVITY OF THE CONFINING UNIT (Sprime)=?'
    READ *,STOPRIME
    PRINT *,'NUMBER OF r VALUES FOR WHICH CALCULATIONS ARE CARRIED OUT=?'
    READ *,NR
    DO I=1,NR
       PRINT *,'RADIAL DISTANCE FROM THE PUMPED WELL (r) (ft)=?'
       READ *,RADIUSS(I)
       IF(RADIUSS(I).LE.0.0) THEN
         PRINT *,'r HAS TO BE GREATER THAN 0.0'
         GO TO 50
       END IF
    END DO
    PRINT *,'TOTAL TIME LENGTH FOR TRANSIENT SIMULATION (t) (days)=?'
    READ *,PERIOD
    PRINT *,'NUMBER OF TIME STEPS FOR TRANSIENT SIMULATION=?'
    READ *,NTIMESTEPS
    PRINT *,'TIME STEP MULTIPLIER FOR TRANSIENT SIMULATION=?'
    READ *,TIMESTEPMULT
    !WRITE INPUT DATA INTO OUTPUT FILE
    PRINT *,'ENTER OUTPUT FILE NAME: <filename.out>'
    READ *,OUTPUTUNIT
    OPEN (UNIT=6,FILE=OUTPUTUNIT)
    PRINT *,'ENTER DATA FILE NAME FOR GRAPHER INPUT: <filename.dat>'
    READ *,GRAPHERINUNIT
    OPEN(UNIT=8,FILE=GRAPHERINUNIT)
    WRITE (6,21)
    21 FORMAT(//,12X,'COUAQ:AN INTERACTIVE PROGRAM FOR CALCULATING DRAWDOWNS IN COUPLED',/,18X,'AQ&
    &UIFERS WITH CONFINING UNIT STORAGE AND ET REDUCTION',/,/,12X,'PREPARED BY Louis H.Motz and Oz&
    &lem Acar',/,24X,'Department of Civil and Coastal Engineering',/,24X,'University of Florida',/&
    &,24X,'Gainesville,Florida',/,'-----------------------------------------------------------------&
    &---------------------',/,'-----------------------------------------------------------------&
    &-----------------',/)
    WRITE (6,22) PRNAME
    22 FORMAT(A,/)
    IF (SUBRTYPE.EQ.'s'.OR.SUBRTYPE.EQ.'S') THEN
       WRITE (6,23)
       23 FORMAT('DRAWDOWNS DUE TO SINGLE WELL PUMPING',/)
    ELSE
       WRITE (6,24)
       24 FORMAT('DRAWDOWNS DUE TO WELLFIELD PUMPING',/)
    END IF
    WRITE (6,25)
    25 FORMAT('INPUT DATA',/,'----------',/,'----------',/)
    WRITE (6,26)
    26 FORMAT('ALL DATA ARE IN CONSISTENT UNITS',/)
```

```
   WRITE (6,27) Q1,T1,STO1,EP
   27 FORMAT('PUMPING RATE FROM AQUIFER 1 (Q1) (ft3/day)',29X,':',ES10.3,/,'TRANSMISSIVITY OF AQU&
   &IFER 1 (T1) (ft2/day)',29X,':',ES10.3,/,'SPECIFIC YIELD OF AQUIFER 1 (S1)',39X,':',ES10.3,/,'&
   &RATE AT WHICH ET IS REDUCED PER UNIT OF WT DRAWDOWN (1/day)',12X,':',ES10.3)
   WRITE (6,28) Q2,T2,STO2,LEAK
   28 FORMAT('PUMPING RATE FROM AQUIFER 2 (Q2) (ft3/day)',29X,':',ES10.3,/,'TRANSMISSIVITY OF AQU&
   &IFER 2 (T2) (ft2/day)',29X,':',ES10.3,/,'STORATIVITY OF AQUIFER 2 (S2)',42X,':',ES10.3,/,'LEA&
   &KANCE OF CONFINING UNIT (Kprime/bprime) (1/day)',21X,':',ES10.3)
   WRITE (6,29) STOPRIME
   29 FORMAT('STORATIVITY OF THE CONFINING UNIT (Sprime)',29X,':',ES10.3,/)
   WRITE (6,291) NR
   291 FORMAT('NUMBER OF R VALUES FOR WHICH CALCULATIONS ARE CARRIED OUT',14X,':',I10)
   DO I=1,NR
      WRITE (6,292) RADIUSS(I)
      292 FORMAT('RADIAL DISTANCE FROM THE PUMPED WELL (r) (ft)',26X,':',F10.3)
   END DO
   WRITE (6,293)
   293 FORMAT(/)
   WRITE (6,294) PERIOD
   294 FORMAT('TOTAL TIME LENGTH FOR TRANSIENT SIMULATION (t) (days)',18X,':',F10.3)
   WRITE (6,295) NTIMESTEPS
   295 FORMAT('NUMBER OF TIME STEPS FOR TRANSIENT SIMULATION',26X,':',I10)
   WRITE (6,296) TIMESTEPMULT
   296 FORMAT('TIME STEP MULTIPLIER FOR TRANSIENT SIMULATION',26X,':',F10.3)
   WRITE (6,297)
   297 FORMAT(/,/)
END IF

IF (LEAK.EQ.0) LEAK=1.0d-38
PI=4.0d0*datan(1.0d0)

!WRITE OUTPUT HEADLINES TO OUTPUT FILE
WRITE (6,31)
31 FORMAT('DRAWDOWNS IN COUPLED AQUIFERS',/,'OBTAINED BY ANALYTICAL MODEL',/,'------------------&
   &----------',/,'-----------------------------',/)
WRITE (6,32)
32 FORMAT('REF: Denis,R.E.,and Motz,L.H.1998.Drawdowns in Coupled Aquifers with Confining',/,5X,'&
   &Unit Storage and ET Reduction.J.Ground Water,36(2),201-207,March-April.',/,/)

!CALCULATE DRAWDOWNS USING STEHFEST ALGORITHM
!BEGINNING OF LOOP FOR DIFFERENT RADII
DO I=1,NR
   R=RADIUSS(I)
   !CALCULATE DELTIME IF TIMESTEPMULTIPLIER IS 1.0,ELSE CALCULATE INITIAL TIME
   !THESE WILL BE USED TO FIND TIME IN TIME LOOP
   IF(TIMESTEPMULT.EQ.1) THEN
     DELTIME=PERIOD/NTIMESTEPS
   ELSE
     TIMEINI=PERIOD/(TIMESTEPMULT**(NTIMESTEPS-1.0))
   END IF
   !FOR INTERACTIVE,WRITE HEADLINES TO SCREEN
   IF (DATAENTRY(1:1).EQ.'i'.OR.DATAENTRY(1:1).EQ.'I') THEN
      !WRITE (*,'(/,4X,A,8X,A,6X,A,4X,A)') 'r','time','drawdown','drawdown'
      !WRITE (*,'(3X,A,6X,A,4X,A,3X,A)') '(ft)','(days)','aquifer 1','aquifer 2'
      !WRITE (*,'(25X,A,8X,A)') '(ft)','(ft)'
      !WRITE (*,'(A,2X,A,3X,A,3X,A)') '---------','---------','---------','---------'
      !WRITE (*,'(A,2X,A,3X,A,3X,A)') '---------','---------','---------','---------'
      WRITE (*,'(/,A,ES10.3)') ' r (ft) =',R
    WRITE (*,'(/,3X,A,6X,A,4X,A)') 'time','drawdown','drawdown'
      WRITE (*,'(2X,A,5X,A,3X,A)') '(days)','aquifer 1','aquifer 2'
      WRITE (*,'(15X,A,8X,A)') '(ft)','(ft)'
      WRITE (*,'(1X,A,3X,A,3X,A)') '---------','---------','---------'
      WRITE (*,'(1X,A,3X,A,3X,A)') '---------','---------','---------'
   END IF
   !WRITE HEADLINES TO OUTPUT FILE
   WRITE (6,33) R
   33 FORMAT(' r (ft) =',ES10.3,/)
   !WRITE (6,33)
   !33 FORMAT(5X,'r',9X,'time',6X,'drawdown',4X,'drawdown')
   WRITE (6,331)
   331 FORMAT(3X,'time',6X,'drawdown',9X,'drawdown')
   !WRITE (6,34)
   !34 FORMAT(4X,'(ft)',7X,'(days)',4X,'aquifer 1',3X,'aquifer 2')
   WRITE (6,34)
   34 FORMAT(2X,'(days)',5X,'aquifer 1 (ft)',3X,'aquifer 2 (ft)')
   !WRITE (6,35)
   !35 FORMAT(27X,'(ft)',8X,'(ft)')
   !WRITE (6,35)
   !35 FORMAT(15X,'(ft)',8X,'(ft)')
   !WRITE (6,37)
   !37 FORMAT(1X,'---------',3X,'---------',3X,'---------',3X,'---------')
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```
   !WRITE (6,38)
   !38 FORMAT(1X,'---------',3X,'---------',3X,'---------',3X,'---------')
   WRITE (6,37)
   37 FORMAT(1X,'---------',3X,'--------------',3X,'--------------')
   WRITE (6,38)
   38 FORMAT(1X,'---------',3X,'--------------',3X,'--------------')
   !BEGINNING OF TIME LOOP
   DO J=1,NTIMESTEPS
      IF(TIMESTEPMULT.EQ.1) THEN
     TIME=J*DELTIME
    ELSE
     TIME=TIMEINI*(TIMESTEPMULT**(J-1.0))
      END IF
    CALL NUNSCOU(Q1,T1,STO1,EP,Q2,T2,STO2,LEAK,STOPRIME,R,DF1,DF2,DF3,DF4,DF5,TIME)
      DD1S=DF1
      DD2S=DF2
      DD3S=DF3
      DD4S=DF4
      DD5S=DF5
      !IF (DD1S.LE.0) DD1S=1E-20
      !IF (DD2S.LE.0) DD2S=1E-20
      !IF (DD3S.LE.0) DD3S=1E-20
      !IF (DD4S.LE.0) DD4S=1E-20
      !IF (DD5S.LE.0) DD5S=1E-20
      IF (DD1S.LT.1E-06.AND.DD1S.GT.-1E-06) DD1S=0.0d0
    IF (DD2S.LT.1E-06.AND.DD2S.GT.-1E-06) DD2S=0.0d0
    IF (DD3S.LT.1E-06.AND.DD3S.GT.-1E-06) DD3S=0.0d0
    IF (DD4S.LT.1E-06.AND.DD4S.GT.-1E-06) DD4S=0.0d0
    IF (DD5S.LT.1E-06.AND.DD5S.GT.-1E-06) DD5S=0.0d0
    U2=(R*R*STO2)/(4.0D0*T2*TIME)
      IF (U2.GT.10) DD2S=1E-20
      !WRITE R,TIME,DD1S,DD2S TO OUTPUT FILE
    !WRITE(6,39) R,TIME,DD1S,DD2S
      !39 FORMAT(ES10.3,2X,ES10.3,2X,ES10.3,2X,ES10.3)
      WRITE(6,39) TIME,DD1S,DD2S
      39 FORMAT(ES10.3,5X,ES10.3,7X,ES10.3)
    !FOR INTERACTIVE;WRITE R,TIME,DD1S,DD2S TO SCREEN
      !IF (DATAENTRY(1:1).EQ.'i'.OR.DATAENTRY(1:1).EQ.'I') THEN
      !    WRITE(*,'(ES9.3,1X,ES10.3,2X,ES10.3,2X,ES10.3)') R,TIME,DD1S,DD2S
      !END IF
      IF (DATAENTRY(1:1).EQ.'i'.OR.DATAENTRY(1:1).EQ.'I') THEN
         WRITE(*,'(ES10.3,2X,ES10.3,2X,ES10.3)') TIME,DD1S,DD2S
      END IF
    !WRITE TIME,DD1S,DD2S IN GRAPHER FORMAT
      !WRITE (8,391) TIME,DD1S,DD2S
      !391 FORMAT(3E12.4)
      !PUT TIME,DD1S AND DD2S INTO ARRAYS TO SAVE FOR GRAPHER FORMAT
    TIMEARRAY(J)=TIME
    DDARRAY(1,I,J)=DD1S
    DDARRAY(2,I,J)=DD2S
      !print *,timearray(j)
    !print *,ddarray(1,i,j)
    !print *,ddarray(2,i,j)
   !END OF TIME LOOP
   END DO
   WRITE (6,392)
   392 FORMAT(/)
   IF (DATAENTRY(1:1).EQ.'i'.OR.DATAENTRY(1:1).EQ.'I') THEN
      WRITE(*,'(/)')
   END IF
!END OF LOOP FOR DIFFERENT RADII
END DO

!WRITE TIME,DD1S,DD2S IN GRAPHER FORMAT
WRITE (8,39100) (RADIUSS(I),i=1,NR)
39100 FORMAT(7X,<nr>(12x,'r=',ES10.3))
WRITE (8,3910)
3910 FORMAT(5X,'time',<nr>(10X,'s1',10X,'s2'))
DO J=1,NTIMESTEPS
   WRITE (8,391) TIMEARRAY(J),(DDARRAY(1,I,J),DDARRAY(2,I,J),I=1,NR)
   391 FORMAT(ES12.4,<nr>(2es12.4))
END DO

RETURN
50 END


!*************************************************************************************************
!*************************************************************************************************
!SUBROUTINE NUNSCOU(Q1,T1,STO1,EP,Q2,T2,STO2,LEAK,STOPRIME,R,DF1,DF2,DF3,DF4,DF5,TIME)
!PROGRAMMED 7/2/96 BY L.H.MOTZ
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!NUMERICAL INVERSION FOR COUPLED AQUIFER EQN (DENIS AND MOTZ 1998) USING
!STEHFEST (1970) ALGORITHM AS CORRECTED BY MOENCH AND OGATA (1981)
!*********************************************************************************************
!*********************************************************************************************
SUBROUTINE NUNSCOU(Q1,T1,STO1,EP,Q2,T2,STO2,LEAK,STOPRIME,R,DF1,DF2,DF3,DF4,DF5,TIME)
DOUBLE PRECISION T1,STO1,EP,T2,STO2,LEAK,R,TIME,DF1,DF2
DOUBLE PRECISION DF3,DF4,DF5
DOUBLE PRECISION Q1,Q2,STOPRIME
INTEGER N,NH,I,K,MINIMUM
DOUBLE PRECISION FAC(0:30),VSUM(30),V(30),NUM,DEN,S,X
DOUBLE PRECISION BESL1,BESL2,C1,C2,P1,P2,P3,P4,P5
DOUBLE PRECISION SUM1,SUM2,SUM3,SUM4,SUM5,FA1,FA2,FA3,FA4,FA5
DOUBLE PRECISION BESL
DOUBLE PRECISION A1,A2,B1,B2,D,PI,W1,W2,OVER

PI=4.0d0*datan(1.0d0)
N=12
NH=N/2

!COMPUTE FACTORIALS
FAC(0)=1.0d0
DO 10 I=1,N
      FAC(I)=DFLOAT(I)*FAC(I-1)
10 CONTINUE

!CALCULATE VSUM(I)
DO 30 I=1,N
      IF (I.LE.NH) THEN
         MINIMUM=I
      ELSE
         MINIMUM=NH
      END IF
      VSUM(I)=0.0
      DO 20 K=INT((I+1)/2),MINIMUM
            NUM=(DFLOAT(K)**NH)*FAC(2*K)
            DEN=FAC(NH-K)*FAC(K)*FAC(K-1)*FAC(I-K)*FAC(2*K-I)
            VSUM(I)=VSUM(I)+NUM/DEN
      20 CONTINUE
      V(I)=((-1)**(NH+I))*VSUM(I)
30 CONTINUE

!FIND LAPLACE TRANSFORMS AND SUMMATIONS FOR V(I)P TERMS
SUM1=0.0d0
SUM2=0.0d0
SUM3=0.0d0
SUM4=0.0d0
SUM5=0.0d0
DO 40 I=1,N
      S=DLOG(2.0D0)*DFLOAT(I)/TIME
      IF (STOPRIME.LT.1.d-38) STOPRIME=1.d-38
      IF (S*LEAK*STOPRIME.GT.10000.) THEN
          A1=(STO1*S/T1)+(EP/T1)+(1.0d0/T1)*DSQRT(S*LEAK*STOPRIME)
          A2=(STO2*S/T2)+(1.0d0/T2)*DSQRT(S*LEAK*STOPRIME)
      ELSE
          A1=(STO1*S/T1)+(EP/T1)+(1.0d0/T1)*DSQRT(S*LEAK*STOPRIME)/DTANH(DSQRT(S*STOPRIME/LEAK))
          A2=(STO2*S/T2)+(1.0d0/T2)*DSQRT(S*LEAK*STOPRIME)/DTANH(DSQRT(S*STOPRIME/LEAK))
      END IF
      OVER=DSQRT(S*STOPRIME/LEAK)
      IF (OVER.GT.89.4) THEN
          B1=(1/T1)*DSQRT(S*LEAK*STOPRIME)/3.35d38
          B2=(1/T2)*DSQRT(S*LEAK*STOPRIME)/3.35d38
      ELSE
          B1=(1/T1)*DSQRT(S*LEAK*STOPRIME)/DSINH(DSQRT(S*STOPRIME/LEAK))
          B2=(1/T2)*DSQRT(S*LEAK*STOPRIME)/DSINH(DSQRT(S*STOPRIME/LEAK))
      END IF
      C1=Q1/(2.d0*PI*T1*S)
      C2=Q2/(2.d0*PI*T2*S)
      D=DSQRT((A1-A2)*(A1-A2)+4.d0*B1*B2)
      W1=DSQRT((A1+A2-D)/2.d0)
      W2=DSQRT((A1+A2+D)/2.d0)
      X=R*W1
      CALL BESSEL(X,BESL)
      BESL1=BESL
      X=R*W2
      CALL BESSEL(X,BESL)
      BESL2=BESL
      !FIRST FUNCTION TO BE INVERTED (SBAR1)
      P1=(C1/D)*((A2-W1*W1)*BESL1-(A2-W2*W2)*BESL2)+(C2*B1/D)*(BESL1-BESL2)
      SUM1=SUM1+V(I)*P1
      !SECOND FUNCTION TO BE INVERTED (SBAR2)
      P2=(C1*B2/D)*(BESL1-BESL2)+(C2/D)*((A1-W1*W1)*BESL1-(A1-W2*W2)*BESL2)
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      SUM2=SUM2+V(I)*P2
      !THIRD FUNCTION TO BE INVERTED (SPRIMEBAR AT 0.2)
      IF (OVER.GT.89.4) THEN
         P3=0.0
      ELSE
         P3=(P1*DSINH(.2*DSQRT(S*STOPRIME/LEAK))+P2*DSINH(.8*DSQRT(S*STOPRIME/LEAK)))/DSINH(DSQRT&
             &(S*STOPRIME/LEAK))
      END IF
      SUM3=SUM3+V(I)*P3
      !FOURTH FUNCTION TO BE INVERTED (SPRIMEBAR AT 0.5)
      IF (OVER.GT.89.4) THEN
         P4=0.0
      ELSE
         P4=(P1*DSINH(.5*DSQRT(S*STOPRIME/LEAK))+P2*DSINH(.5*DSQRT(S*STOPRIME/LEAK)))/DSINH(DSQRT&
             &(S*STOPRIME/LEAK))
      END IF
      SUM4=SUM4+V(I)*P4
      !FIFTH FUNCTION TO BE INVERTED (SPRIMEBAR AT 0.8)
      IF (OVER.GT.89.4) THEN
         P5=0.0
      ELSE
         P5=(P1*DSINH(.8*DSQRT(S*STOPRIME/LEAK))+P2*DSINH(.2*DSQRT(S*STOPRIME/LEAK)))/DSINH(DSQRT&
             &(S*STOPRIME/LEAK))
      END IF
      SUM5=SUM5+V(I)*P5
40 CONTINUE

!COMPUTE INVERSE OF LAPLACE TRANSFORMS
FA1=(DLOG(2.0d0)/TIME)*SUM1
DF1=FA1
FA2=(DLOG(2.0d0)/TIME)*SUM2
DF2=FA2
FA3=(DLOG(2.0d0)/TIME)*SUM3
DF3=FA3
FA4=(DLOG(2.0d0)/TIME)*SUM4
DF4=FA4
FA5=(DLOG(2.0d0)/TIME)*SUM5
DF5=FA5
RETURN
END




!*************************************************************************************************
!*************************************************************************************************
!SUBROUTINE BESSEL(X,BESL)
!PROGRAMMED 3/16/94 BY L.H.MOTZ
!CALCULATES MODIFIED BESSEL FUNCTION Ko(X)
!REFERENCE: ABRAMOWITZ AND STEGUN, PP.378-379, 417-421
!*************************************************************************************************
!*************************************************************************************************
SUBROUTINE BESSEL(X,BESL)
DOUBLE PRECISION X,BESL
DOUBLE PRECISION C,C1,C2,C3,C4,C5,C6,C8,C10,C12,COKO,COEFF
DOUBLE PRECISION Y,T,I2,I4,I6,I8,I10,I12,IO,FIRST,SECOND,y6
IF (X.GT.50.) THEN
    BESL=0.0d0
ELSE IF (X.GT.2.) THEN
    Y=2.0d0/X
    C=1.25331414d0
    C1=0.07832358d0
    C2=0.02189568d0
    C3=0.01062446d0
    C4=0.00587872d0
    C5=0.00251540d0
    C6=0.00053208d0
    y6=y**6
    COKO=C-C1*Y+C2*(Y**2)-C3*(Y**3)+C4*(Y**4)-C5*(Y**5)+C6*Y6
    COEFF=DSQRT(X)*DEXP(X)
    BESL=COKO/COEFF
ELSE
    T=X/3.75d0
    I2=3.5156229d0
    I4=3.0899424d0
    I6=1.2067492d0
    I8=0.2659732d0
```

```
    I10=0.0360768d0
    I12=0.0045813d0
    IO=1.+I2*T**2+I4*T**4+I6*T**6+I8*T**8+I10*T**10+I12*T**12
    Y=X/2.0d0
    C=0.57721566d0
    C2=0.4227842d0
    C4=0.23069756d0
    C6=0.0348859d0
    C8=0.00262698d0
    C10=0.0001075d0
    C12=0.0000074d0
    FIRST=-DLOG(Y)*IO-C+C2*Y**2+C4*Y**4
    SECOND=C6*Y**6+C8*Y**8+C10*Y**10+C12*Y**12
    BESL=FIRST+SECOND
END IF
CONTINUE
RETURN
END


!*****************************************************************************************
!*****************************************************************************************
! SUBROUTINE COUAQ_M(SUBRTYPE,TRANS1,STO1,EP,TRANS2,STO2,LEAK,STOPRIME,PERIOD,NTIMESTEPS,TIMESTEP&
!&MULT,NWELLS,WELLID,XWELL,YWELL,RWELL,QQ1,QQ2,NGRIDS,XGRID,YGRID)
!*****************************************************************************************
!*****************************************************************************************
SUBROUTINE COUAQ_M(SUBRTYPE,TRANS1,STO1,EP,TRANS2,STO2,LEAK,STOPRIME,PERIOD,NTIMESTEPS,TIMESTEPMU&
&LT,NWELLS,WELLID,XWELL,YWELL,RWELL,QQ1,QQ2,NGRIDS,XGRID,YGRID)
DOUBLE PRECISION X1GRID,Y1GRID,X2GRID,Y2GRID,DELX,DELY
DOUBLE PRECISION XGRIDREPEAT(1000),YGRIDREPEAT(1000)
DOUBLE PRECISION XWELL(100),YWELL(100),RWELL(100),XGRID(2650),YGRID(2650)
DOUBLE PRECISION RADIUS(2650,2650),DD1(2650,2650),DD2(2650,2650)
DOUBLE PRECISION DDW1(100,100),DDW2(100,100)
DOUBLE PRECISION QQ1(100),TRANS1,STO1,EP,QQ2(100),TRANS2,STO2
DOUBLE PRECISION LEAK,STOPRIME,TOTALQ1,TOTALQ2
DOUBLE PRECISION SUM1,SUM2,SUMW1,SUMW2
DOUBLE PRECISION TIMEINI,DELTIME,TIME
DOUBLE PRECISION PERIOD,TIMESTEPMULT
DOUBLE PRECISION PI,MINRADIUS
DOUBLE PRECISION R,Q1,Q2,T1,T2
DOUBLE PRECISION U1,U2,DF1,DF2
DOUBLE PRECISION DD3,DD4,DD5,DF3,DF4,DF5
INTEGER NWELLS,NGRIDS,NTIMESTEPS
INTEGER NOXREPEAT,NOYREPEAT
DIMENSION:: WELLID(1:100)
CHARACTER* 50 PRNAME
CHARACTER* 1 SUBRTYPE
CHARACTER* 50 INPUTUNIT
CHARACTER* 11 DATAENTRY
CHARACTER* 50 OUTPUTUNIT
CHARACTER* 50 DATUNIT
CHARACTER* 25 WELLID

!ASK HOW TO ENTER DATA
PRINT *,'Do you want to prepare an input FILE or enter data INTERACTIVELY? <f/i>'
READ *,DATAENTRY

!OPEN(unit=16,file='drawdowns.txt')

PI=4.0d0*datan(1.0d0)
!MINRADIUS=1.0d0

!READ VALUES OF AQUIFER PARAMETERS,TIME,PUMPED WELL DATA AND GRID LOCATIONS
IF (DATAENTRY(1:1).EQ.'f'.OR.DATAENTRY(1:1).EQ.'F') THEN
   !READ DATA FROM INPUT FILES
   PRINT *,'ENTER INPUT FILE NAME: <filename.in>'
   READ *,INPUTUNIT
   OPEN (UNIT=3,FILE=INPUTUNIT)
   READ(3,*) TRANS1,STO1,EP,TRANS2,STO2,LEAK,STOPRIME
   READ(3,*) PERIOD,NTIMESTEPS,TIMESTEPMULT
   READ(3,*) NWELLS
       DO I=1,NWELLS
          READ(3,*) WELLID(I),XWELL(I),YWELL(I),RWELL(I),QQ1(I),QQ2(I)
       END DO
   !CALL GRIDLOCATIONS SUBROUTINE TO CALCULATE GRID LOCATIONS FROM GRID DATA INPUT
   CALL GRIDLOCATIONS(XGRID,YGRID,NGRIDS)
   OPEN (UNIT=6,FILE='GRIDLOCATIONS.IN')
   READ(6,*) NGRIDS
       DO I=1,NGRIDS
          READ(6,*) XGRID(I),YGRID(I)
       END DO
```

```
   PRINT *,'NAME OF THE PROJECT: <write in single quotation marks>'
   READ *,PRNAME
ELSE
   !READ DATA INTERACTIVELY
   PRINT *,'NAME OF THE PROJECT: <write in single quotation marks>'
   READ *,PRNAME
   PRINT *,'PLEASE ENTER DATA IN CONSISTENT UNITS'
   PRINT *,'TRANSMISSIVITY OF AQUIFER 1 (T1) (ft2/day)=?'
   READ *,TRANS1
   PRINT *,'SPECIFIC YIELD OF AQUIFER 1 (S1)=?'
   READ *,STO1
   PRINT *,'RATE AT WHICH ET IS REDUCED PER UNIT OF WT DRAWDOWN (1/day)=?'
   READ *,EP
   PRINT *,'TRANSMISSIVITY OF AQUIFER 2 (T2) (ft2/day)=?'
   READ *,TRANS2
   PRINT *,'STORATIVITY OF AQUIFER 2 (S2)=?'
   READ *,STO2
   PRINT *,'LEAKANCE OF CONFINING UNIT (Kprime/bprime) (1/day)=?'
   READ *,LEAK
   PRINT *,'STORATIVITY OF THE CONFINING UNIT (Sprime)=?'
   READ *,STOPRIME
   PRINT *,'TOTAL TIME LENGTH FOR TRANSIENT SIMULATION (t) (days)=?'
   READ *,PERIOD
   PRINT *,'NUMBER OF TIME STEPS FOR TRANSIENT SIMULATION=?'
   READ *,NTIMESTEPS
   PRINT *,'TIME STEP MULTIPLIER FOR TRANSIENT SIMULATION=?'
   READ *,TIMESTEPMULT
   PRINT *,'NUMBER OF WELLS=?'
   READ *,NWELLS
       DO I=1,NWELLS
        PRINT *,'WELL NUMBER OR NAME: <write in single quotation marks>'
           READ *,WELLID(I)
           PRINT *,'X COORDINATE OF WELL (ft)=?'
           READ *,XWELL(I)
          PRINT *,'Y COORDINATE OF WELL (ft)=?'
           READ *,YWELL(I)
           PRINT *,'RADIUS OF WELL (rw) (ft)=?'
           READ *,RWELL(I)
          PRINT *,'PUMPING RATE FROM AQUIFER 1 (Q1) (ft3/day)=?'
          READ *,QQ1(I)
          PRINT *,'PUMPING RATE FROM AQUIFER 2 (Q2) (ft3/day)=?'
          READ *,QQ2(I)
       END DO
   PRINT *,'ENTER X COORDINATE FOR LOWER LEFT CORNER OF GRID'
   READ *,X1GRID
   PRINT *,'ENTER Y COORDINATE FOR LOWER LEFT CORNER OF GRID'
   READ *,Y1GRID
   PRINT *,'ENTER X COORDINATE FOR UPPER RIGHT CORNER OF GRID'
   READ *,X2GRID
   PRINT *,'ENTER Y COORDINATE FOR UPPER RIGHT CORNER OF GRID'
   READ *,Y2GRID
   PRINT *,'ENTER DELTA X SPACING FOR THE GRID'
   READ *,DELX
   PRINT *,'ENTER DELTA Y SPACING FOR THE GRID'
   READ *,DELY
   !CALL GRIDLOCATIONSINT SUBROUTINE TO CALCULATE GRID LOCATIONS FROM GRID DATA INPUT
   CALL GRIDLOCATIONSINT(XGRID,YGRID,NGRIDS,X1GRID,Y1GRID,X2GRID,Y2GRID,DELX,DELY)
   OPEN (UNIT=6,FILE='GRIDLOCATIONS.IN')
   READ(6,*) NGRIDS
       DO I=1,NGRIDS
          READ(6,*) XGRID(I),YGRID(I)
       END DO
END IF

IF (LEAK.EQ.0) LEAK=1.0d-38

!CALCULATE TOTAL PUMPAGE
!TOTALQ1=0.0d0
!TOTALQ2=0.0d0
!DO I=1,NWELLS
!   TOTALQ1=TOTALQ1+QQ1(I)
!   TOTALQ2=TOTALQ2+QQ2(I)
!END DO

!CALCULATE RADIAL DISTANCES FROM EACH GRID LOCATION TO PUMPED WELLS
!I=GRID LOCATIONS,J=PUMPED WELLS
!DO I=1,NGRIDS
!   DO J=1,NWELLS
!      RADIUS(I,J) =((XWELL(J)-XGRID(I))**2.+(YWELL(J)-YGRID(I))**2.)**.5
!   END DO
!END DO
```

```
!WRITE INPUT DATA INTO OUTPUT FILE
   PRINT *,'ENTER OUTPUT FILE NAME: <filename.out>'
   READ *,OUTPUTUNIT
   OPEN (UNIT=15,FILE=OUTPUTUNIT)
   PRINT *,'ENTER DATA FILE NAME FOR SUM OF DRAWDOWNS: <filename.dat>'
   READ *,DATUNIT
   OPEN (UNIT=16,FILE=DATUNIT)
   WRITE (16,1111)
   1111 FORMAT('Grid/well',8X,'x',11X,'y',11X,'time',10X,'sum1',8X,'sum2')
   WRITE (15,11)
   11 FORMAT(//,12X,'COUAQ:AN INTERACTIVE PROGRAM FOR CALCULATING DRAWDOWNS IN COUPLED',/,18X,'AQ&
   &UIFERS WITH CONFINING UNIT STORAGE AND ET REDUCTION',/,/,12X,'PREPARED BY Louis H.Motz and Oz&
   &lem Acar',/,24X,'Department of Civil and Coastal Engineering',/,24X,'University of Florida',/&
   &,24X,'Gainesville,Florida',/,'--------------------------------------------------------------&
   &---------------------',/,'------------------------------------------------------------------&
   &-----------------',/)
   WRITE (15,12) PRNAME
   12 FORMAT(A,/)
   IF (SUBRTYPE.EQ.'s'.OR.SUBRTYPE.EQ.'S') THEN
      WRITE (15,13)
      13 FORMAT('DRAWDOWNS DUE TO SINGLE WELL PUMPING',/)
   ELSE
      WRITE (15,14)
      14 FORMAT('DRAWDOWNS DUE TO WELLFIELD PUMPING',/)
   END IF
   WRITE (15,15)
   15 FORMAT('INPUT DATA',/,'----------',/,'----------',/)
   WRITE (15,16)
   16 FORMAT('ALL DATA ARE IN CONSISTENT UNITS',/)
   WRITE (15,17) TRANS1,STO1,EP
   17 FORMAT('TRANSMISSIVITY OF AQUIFER 1 (T1) (ft2/day)',29X,':',ES10.3,/,'SPECIFIC YIELD OF AQU&
   &IFER 1 (S1)',39X,':',ES10.3,/,'RATE AT WHICH ET IS REDUCED PER UNIT OF WT DRAWDOWN (1/day)',1&
   &2X,':',ES10.3)
   WRITE (15,18) TRANS2,STO2,LEAK
   18 FORMAT('TRANSMISSIVITY OF AQUIFER 2 (T2) (ft2/day)',29X,':',ES10.3,/,'STORATIVITY OF AQUIFE&
   &R 2 (S2)',42X,':',ES10.3,/,'LEAKANCE OF CONFINING UNIT (Kprime/bprime) (1/day)',21X,':',ES10.&
   &3)
   WRITE (15,19) STOPRIME
   19 FORMAT('STORATIVITY OF THE CONFINING UNIT (Sprime)',29X,':',ES10.3,/)
   WRITE (15,194) PERIOD
   194 FORMAT('TOTAL TIME LENGTH FOR TRANSIENT SIMULATION (t) (days)',18X,':',ES10.3)
   WRITE (15,195) NTIMESTEPS
   195 FORMAT('NUMBER OF TIME STEPS FOR TRANSIENT SIMULATION',26X,':',I10)
   WRITE (15,196) TIMESTEPMULT
   196 FORMAT('TIME STEP MULTIPLIER FOR TRANSIENT SIMULATION',26X,':',F10.3)
   WRITE (15,22)
   22 FORMAT(/)
   WRITE (15,23) NWELLS
   23 FORMAT('NUMBER OF PUMPED WELLS',49X,':',I10,/)
        DO I=1,NWELLS
      WRITE (15,231) WELLID(I),XWELL(I),YWELL(I),RWELL(I),QQ1(I),QQ2(I)
      231 FORMAT(A,/,'X COORDINATE OF WELL (ft)',46X,':',F10.3,/,'Y COORDINATE OF WELL (ft)',46X,&
   &':',F10.3,/,'RADIUS OF WELL (rw) (ft)',47X,':',F10.3,/,'PUMPING RATE FROM AQUIFER 1 (Q1) (&
   &ft3/day)',29X,':',ES10.3,/,'PUMPING RATE FROM AQUIFER 2 (Q2) (ft3/day)',29X,':',ES10.3,/)
      END DO
   WRITE (15,24) NGRIDS
   24 FORMAT('NUMBER OF GRIDS WHERE DRAWDOWNS ARE TO BE CALCULATED',19X,':',I10,/)
      DO I=1,NGRIDS
       WRITE (15,240) I
          240 FORMAT('GRID LOCATION :',I5)
          WRITE (15,241) XGRID(I),YGRID(I)
         241 FORMAT('X COORDINATE OF LOCATION WHERE DRAWDOWNS ARE TO BE CALCULATED (ft)',5X,':',F&
          &10.3,/,'Y COORDINATE OF LOCATION WHERE DRAWDOWNS ARE TO BE CALCULATED ft)',5X,':',F10.&
          &3,/)
    END DO
   WRITE (15,25)
   25 FORMAT(/,/)

!WRITE REFERENCE TO OUTPUT FILE
WRITE (15,31)
31 FORMAT('DRAWDOWNS IN COUPLED AQUIFERS',/,'OBTAINED BY ANALYTICAL MODEL',/,'------------------&
   &----------',/,'------------------------------',/)

WRITE (15,32)
32 FORMAT('REF: Denis,R.E.,and Motz,L.H.1998.Drawdowns in Coupled Aquifers with Confining',/,5X,'&
   &Unit Storage and ET Reduction.J.Ground Water,36(2),201-207,March-April.',/)

!DRAWDOWN CALCULATIONS
!CALCULATE DELTIME IF TIMESTEPMULTIPLIER IS 1.0,ELSE CALCULATE INITIAL TIME
!THESE WILL BE USED TO FIND TIME IN TIME LOOP
```

```
IF(TIMESTEPMULT.EQ.1) THEN
  DELTIME=PERIOD/NTIMESTEPS
ELSE
  TIMEINI=PERIOD/(TIMESTEPMULT**(NTIMESTEPS-1.0))
END IF
!BEGINNING OF TIME LOOP
DO K=1,NTIMESTEPS
   IF(TIMESTEPMULT.EQ.1) THEN
   TIME=K*DELTIME
   ELSE
   TIME=TIMEINI*(TIMESTEPMULT**(K-1))
   END IF
   !**********FIRST ROUND OF CALCULATIONS FOR GRID LOCATIONS**************************************
   !BEGINNING OF GRID LOCATIONS LOOP
   DO I=1,NGRIDS
    !WRITE HEADLINES OF RESULTS TO OUTPUT FILE
    WRITE(15,321)
    321 FORMAT(/)
    WRITE(15,33)'      Grid location =',I
    33 FORMAT(A,I4,/)
    WRITE(15,34)
    34 FORMAT(5X,'xgrid',7X,'ygrid',5X,'xwell',5X,'ywell',2X,'rad.dist.',6X,'time',7X,'dd1',7X,&
    &'dd2')
    WRITE(15,35)
    35 FORMAT(2X,'---------',4X,'---------',3X,'--------',3X,'--------',2X,'----------',2X,'---------&
    &-',3X,'-------',3X,'-------')
    !WRITE HEADLINES OF RESULTS TO SCREEN FOR INTERACTIVE
    IF (DATAENTRY(1:1).EQ.'i'.OR.DATAENTRY(1:1).EQ.'I') THEN
       WRITE(*,'(/,A,I4,/)')'      Grid location = ',I
       WRITE(*,'(5X,A,5X,A,5X,A,5X,A,2X,A,5X,A,7X,A,6X,A)')'xgrid','ygrid','xwell','ywell','rad&
           &.dist.','time','dd1','dd2'
       WRITE(*,'(2X,A,2X,A,3X,A,3X,A,2X,A,1X,A,2X,A,2X,A)')'---------','---------','--------','---&
           &----','----------','-----------','--------','--------'
    END IF
    !BEGINNING OF LOOP FOR WELLS
    DO J=1,NWELLS
          !CALCULATE RADIAL DISTANCES FROM EACH GRID LOCATION TO PUMPED WELLS
         !SET MINIMUM RADII AND CALCULATE DRAWDOWNS
         !I=GRID LOCATIONS,J=PUMPED WELLS
          RADIUS(I,J)=((XWELL(J)-XGRID(I))**2.+(YWELL(J)-YGRID(I))**2.)**.5
          !IF (RADIUS(I,J).LE.MINRADIUS) RADIUS(I,J)=MINRADIUS
          IF (RADIUS(I,J).LE.RWELL(J)) RADIUS(I,J)=RWELL(J)
          R=RADIUS(I,J)
          Q1=QQ1(J)
          Q2=QQ2(J)
          T1=TRANS1
          T2=TRANS2
          U1=(R*R*STO1)/(4.0d0*TRANS1*TIME)
          U2=(R*R*STO2)/(4.0d0*TRANS2*TIME)
         !CALCULATE DF1 AND DF2 USING STEHFEST ALGORITHM
          CALL NUNSCOU(Q1,T1,STO1,EP,Q2,T2,STO2,LEAK,STOPRIME,R,DF1,DF2,DF3,DF4,DF5,TIME)
         !IF (DF1.LE.0) DF1=1.0e-20
         !IF (DF2.LE.0) DF2=1.0e-20
          IF (DF1.LT.1E-06.AND.DF1.GT.-1E-06) DF1=0.0d0
      IF (DF2.LT.1E-06.AND.DF2.GT.-1E-06) DF2=0.0d0
          DD1(I,J)=DF1
          DD2(I,J)=DF2
          !WRITE RESULTS TO OUTPUT FILE
          WRITE(15,120) XGRID(I),YGRID(I),XWELL(J),YWELL(J),RADIUS(I,J),TIME,DD1(I,J),DD2(I,J)
         120 FORMAT(F10.3,2X,4F10.3,2X,ES10.3,2F10.3)
              !WRITE RESULTS TO SCREEN FOR INTERACTIVE
          IF (DATAENTRY(1:1).EQ.'i'.OR.DATAENTRY(1:1).EQ.'I') THEN
            WRITE(*,'(F10.2,3F10.2,F10.3,1X,ES9.2,2F10.3)') XGRID(I),YGRID(I),XWELL(J),YWELL(J),R&
                 &ADIUS(I,J),TIME,DD1(I,J),DD2(I,J)
         END IF
    !END OF LOOP FOR WELLS
    END DO
   !END OF GRID LOCATIONS LOOP
   END DO
   !WRITE HEADLINES FOR SUM OF DRAWDOWNS TO OUTPUT FILE
   WRITE(15,544)
   544 FORMAT(/)
   WRITE(15,55)
   55 FORMAT(5X,'Grid location',7X,'xgrid',7X,'ygrid',7X,'time',4X,'sum of dd1',3X,'sum of dd2')
   WRITE(15,551)
   551 FORMAT(5X,'-------------',5X,'--------',5X,'--------',3X,'----------',3X,'-----------',3X,'---&
   &-------')
   WRITE(15,552)
   552 FORMAT(5X,'-------------',5X,'--------',5X,'--------',3X,'----------',3X,'-----------',3X,'---&
   &-------')
   !WRITE HEADLINES FOR SUM OF DRAWDOWNS TO SCREEN FOR INTERACTIVE
```

```
IF (DATAENTRY(1:1).EQ.'i'.OR.DATAENTRY(1:1).EQ.'I') THEN
   WRITE(*,'(/)')
   WRITE(*,'(A,7X,A,7X,A,7X,A,4X,A,3X,A)')'Grid location','xgrid','ygrid','time','sum of dd1',&
 &'sum of dd2'
   WRITE(*,'(A,5X,A,5X,A,3X,A,3X,A,3X,A)')'------------','-------','-------','---------','---&
 &-------','----------'
   WRITE(*,'(A,5X,A,5X,A,3X,A,3X,A,3X,A)')'------------','-------','-------','---------','---&
 &-------','----------'
END IF
!CALCULATE SUM OF DRAWDOWNS AT EACH GRID LOCATION
!I=GRID LOCATIONS,J=PUMPED WELLS
!BEGINNING OF SUM OF DRAWDOWNS LOOP
DO I=1,NGRIDS
 SUM1=0.0d0
 SUM2=0.0d0
 DO J=1,NWELLS
       SUM1=SUM1+DD1(I,J)
       SUM2=SUM2+DD2(I,J)
 END DO
 !WRITE RESULTS TO OUTPUT FILE
 WRITE(15,110) I,XGRID(I),YGRID(I),TIME,SUM1,SUM2
 110 FORMAT(5X,I7,6X,2F12.3,ES12.3,2F12.3)
 !WRITE RESULTS TO .DAT FILE
 WRITE(16,115) I,XGRID(I),YGRID(I),TIME,SUM1,SUM2
   115 FORMAT(I8,2F12.2,1ES15.3,2F12.3)
   !WRITE RESULTS TO SCREEN FOR INTERACTIVE
 IF (DATAENTRY(1:1).EQ.'i'.OR.DATAENTRY(1:1).EQ.'I') THEN
      WRITE(*,'(I7,6X,2F12.2,ES12.3,2F12.3)') I,XGRID(I),YGRID(I),TIME,SUM1,SUM2
   END IF
!END OF SUM OF DRAWDOWNS LOOP
END DO
WRITE(15,111)
111 FORMAT(/)
IF (DATAENTRY(1:1).EQ.'i'.OR.DATAENTRY(1:1).EQ.'I') THEN
   WRITE(*,'(/)')
END IF
!**********SECOND ROUND OF CALCULATIONS FOR WELLS*********************************************
!BEGINNING OF OUTER LOOP FOR WELL LOCATIONS
DO I=1,NWELLS
 !WRITE HEADLINES OF RESULTS TO OUTPUT FILE
 WRITE(15,421)
 421 FORMAT(/)
 WRITE(15,43)'     Well location =',WELLID(I)
 43 FORMAT(A,1X,A,/)
 WRITE(15,44)
 44 FORMAT(5X,'well id',6X,'xwell',5X,'ywell',2X,'rad.dist.',6X,'time',7X,'dd1',7X,'dd2')
 WRITE(15,45)
 45 FORMAT(3X,'---------',4X,'-------',3X,'-------',2X,'---------',2X,'---------',3X,'------&
 &-',3X,'-------')
 !WRITE HEADLINES OF RESULTS TO SCREEN FOR INTERACTIVE
 IF (DATAENTRY(1:1).EQ.'i'.OR.DATAENTRY(1:1).EQ.'I') THEN
    WRITE(*,'(/,A,1X,A,/)')'     Well location =',WELLID(I)
    WRITE(*,'(A,6X,A,5X,A,2X,A,6X,A,7X,A,7X,A)')'well id','xwell','ywell','rad.dist.','time'&
       &,'dd1','dd2'
    WRITE(*,'(A,2X,A,3X,A,2X,A,2X,A,3X,A,3X,A)')'---------','-------','-------','---------',&
       &'---------','-------','-------'
 END IF
 !BEGINNING OF INNER LOOP FOR WELLS
 DO J=1,NWELLS
       !CALCULATE RADIAL DISTANCES FROM EACH WELL LOCATION TO PUMPED WELLS
      !SET MINIMUM RADII AND CALCULATE DRAWDOWNS
      !I=OBSERVED WELL LOCATION,J=OTHER PUMPED WELLS
       RADIUS(I,J)=((XWELL(J)-XWELL(I))**2.+(YWELL(J)-YWELL(I))**2.)**.5
       IF (RADIUS(I,J).LE.0) RADIUS(I,J)=RWELL(J)
       R=RADIUS(I,J)
       Q1=QQ1(J)
       Q2=QQ2(J)
       T1=TRANS1
       T2=TRANS2
       U1=(R*R*STO1)/(4.0d0*TRANS1*TIME)
       U2=(R*R*STO2)/(4.0d0*TRANS2*TIME)
      !CALCULATE DF1 AND DF2 USING STEHFEST ALGORITHM
       CALL NUNSCOU(Q1,T1,STO1,EP,Q2,T2,STO2,LEAK,STOPRIME,R,DF1,DF2,DF3,DF4,DF5,TIME)
      !IF (DF1.LE.0) DF1=1.0e-20
      !IF (DF2.LE.0) DF2=1.0e-20
       IF (DF1.LT.1E-06.AND.DF1.GT.-1E-06) DF1=0.0d0
    IF (DF2.LT.1E-06.AND.DF2.GT.-1E-06) DF2=0.0d0
       DDW1(I,J)=DF1
       DDW2(I,J)=DF2
       !WRITE RESULTS TO OUTPUT FILE
       WRITE(15,220) WELLID(J),XWELL(J),YWELL(J),RADIUS(I,J),TIME,DDW1(I,J),DDW2(I,J)
```

```
        220 FORMAT(5X,A8,3F10.3,2X,ES10.3,2F10.3)
            !WRITE RESULTS TO SCREEN FOR INTERACTIVE
         IF (DATAENTRY(1:1).EQ.'i'.OR.DATAENTRY(1:1).EQ.'I') THEN
           WRITE(*,'(A8,3F10.3,2X,ES10.3,2F10.3)') WELLID(J),XWELL(J),YWELL(J),RADIUS(I,J),TIME,&
                &DDW1(I,J),DDW2(I,J)
        END IF
   !END OF INNER LOOP FOR WELLS
   END DO
  !END OF OUTER LOOP FOR WELL LOCATIONS
  END DO
  !WRITE HEADLINES FOR SUM OF DRAWDOWNS TO OUTPUT FILE
  WRITE(15,644)
  644 FORMAT(/)
  WRITE(15,65)
  65 FORMAT(5X,'Well id',6X,'xwell',5X,'ywell',5X,'rwell',7X,'time',4X,'sum of dd1',2X,'sum of d&
  &d2')
  WRITE(15,651)
  651 FORMAT(5X,'-------',4X,'-------',3X,'-------',2X,'---------',2X,'---------',3X,'---------&
  &',2X,'----------')
  WRITE(15,652)
  652 FORMAT(5X,'-------',4X,'-------',3X,'-------',2X,'---------',2X,'---------',3X,'---------&
  &',2X,'----------')
  !WRITE HEADLINES FOR SUM OF DRAWDOWNS TO SCREEN FOR INTERACTIVE
  IF (DATAENTRY(1:1).EQ.'i'.OR.DATAENTRY(1:1).EQ.'I') THEN
     WRITE(*,'(/)')
     WRITE(*,'(A,7X,A,6X,A,7X,A,7X,A,2X,A,2X,A)')'Well id','xwell','ywell','rwell','time','sum o&
   &f dd1','sum of dd2'
     WRITE(*,'(A,5X,A,4X,A,3X,A,2X,A,2X,A,3X,A)')'------','-------','-------','---------','----&
   &-----','----------','----------'
     WRITE(*,'(A,5X,A,4X,A,3X,A,2X,A,2X,A,3X,A)')'------','-------','-------','---------','----&
   &-----','----------','----------'
  END IF
  !CALCULATE SUM OF DRAWDOWNS AT EACH WELL LOCATION
  !I=OBSERVED WELL LOCATION,J=OTHER PUMPED WELLS
  !BEGINNING OF SUM OF DRAWDOWNS LOOP
  DO I=1,NWELLS
   SUMW1=0.0d0
   SUMW2=0.0d0
   DO J=1,NWELLS
         SUMW1=SUMW1+DDW1(I,J)
         SUMW2=SUMW2+DDW2(I,J)
   END DO
   !WRITE RESULTS TO OUTPUT FILE
   WRITE(15,210) WELLID(I),XWELL(I),YWELL(I),RWELL(I),TIME,SUMW1,SUMW2
     210 FORMAT(5X,A8,F10.3,F10.3,ES12.3,1X,F10.3,1X,F10.3)
     !WRITE RESULTS TO .DAT FILE
     WRITE(16,215) WELLID(I),XWELL(I),YWELL(I),TIME,SUMW1,SUMW2
     215 FORMAT(A8,2F12.3,1ES15.3,2F12.3)
     !WRITE RESULTS TO SCREEN FOR INTERACTIVE
     IF (DATAENTRY(1:1).EQ.'i'.OR.DATAENTRY(1:1).EQ.'I') THEN
     WRITE(*,'(A8,F10.3,2X,F10.3,1X,F10.3,ES12.3,1X,F10.3,2X,F10.3)') WELLID(I),XWELL(I),YWELL(I&
   &),RWELL(I),TIME,SUMW1,SUMW2
     END IF
  !END OF SUM OF DRAWDOWNS LOOP AT EACH WELL LOCATION
  END DO
  !END OF SECOND ROUND OF CALCULATIONS FOR WELLS
  WRITE(15,211)
  211 FORMAT(/)
  IF (DATAENTRY(1:1).EQ.'i'.OR.DATAENTRY(1:1).EQ.'I') THEN
     WRITE(*,'(/)')
  END IF
!END OF TIME LOOP
END DO

!WRITE SUM OF DRAWDOWNS TO.DAT FILE FOR THE LAST TIME STEP
!DO I=1,NGRIDS
!   WRITE(16,115) I,XGRID(I),YGRID(I),TIME,SUM1,SUM2
!   115 FORMAT(I8,2F12.2,1E15.3,2F12.3)
!END DO

RETURN
END


!*************************************************************************************************
!*************************************************************************************************
!SUBROUTINE GRIDLOCATIONS(XGRID,YGRID,NGRIDS)
!CALCULATES GRID LOCATIONS FROM INPUT GRID DATA AND GIVES THE RESULT AS GRIDLOCATIONS.IN FILE
!WHICH IS AN INPUT FILE FOR THE MAIN PROGRAM
!*************************************************************************************************
!*************************************************************************************************
```

```
SUBROUTINE GRIDLOCATIONS(XGRID,YGRID,NGRIDS)
DOUBLE PRECISION XGRID(2650),YGRID(2650)
DOUBLE PRECISION XGRIDREPEAT(1000),YGRIDREPEAT(1000)
DOUBLE PRECISION X1GRID,Y1GRID,X2GRID,Y2GRID,DELX,DELY
INTEGER NOXREPEAT,NOYREPEAT,NGRIDS
OPEN (UNIT=6,FILE='GRIDLOCATIONS.IN')
READ (3,*) X1GRID,Y1GRID
READ (3,*) X2GRID,Y2GRID
READ (3,*) DELX,DELY
NOYREPEAT=(Y2GRID-Y1GRID)/DELY
NOXREPEAT=(X2GRID-X1GRID)/DELX
NGRIDS=(NOYREPEAT+1)*(NOXREPEAT+1)
WRITE (6,*) NGRIDS
DO J=1,NOYREPEAT+1
   YGRIDREPEAT(J)=(J-1)*DELY+Y1GRID
   DO I=1,NOXREPEAT+1
      XGRIDREPEAT(I)=(I-1)*DELX+X1GRID
      WRITE (6,*) XGRIDREPEAT(I),YGRIDREPEAT(J)
   END DO
END DO
CLOSE(6)
RETURN
END


!***************************************************************************************************
!***************************************************************************************************
!SUBROUTINE GRIDLOCATIONSINT(XGRID,YGRID,NGRIDS,X1GRID,Y1GRID,X2GRID,Y2GRID,DELX,DELY)
!(FOR INTERACTIVE PART OF THE PROGRAM)
!CALCULATES GRID LOCATIONS FROM INPUT GRID DATA AND GIVES THE RESULT AS GRIDLOCATIONS.IN FILE
!WHICH IS AN INPUT FILE FOR THE MAIN PROGRAM
!***************************************************************************************************
!***************************************************************************************************
SUBROUTINE GRIDLOCATIONSINT(XGRID,YGRID,NGRIDS,X1GRID,Y1GRID,X2GRID,Y2GRID,DELX,DELY)
DOUBLE PRECISION XGRID(2650),YGRID(2650)
DOUBLE PRECISION XGRIDREPEAT(1000),YGRIDREPEAT(1000)
DOUBLE PRECISION X1GRID,Y1GRID,X2GRID,Y2GRID,DELX,DELY
INTEGER NOXREPEAT,NOYREPEAT,NGRIDS
OPEN (UNIT=6,FILE='GRIDLOCATIONS.IN')
NOYREPEAT=(Y2GRID-Y1GRID)/DELY
NOXREPEAT=(X2GRID-X1GRID)/DELX
NGRIDS=(NOYREPEAT+1)*(NOXREPEAT+1)
WRITE (6,*) NGRIDS
DO J=1,NOYREPEAT+1
   YGRIDREPEAT(J)=(J-1)*DELY+Y1GRID
   DO I=1,NOXREPEAT+1
      XGRIDREPEAT(I)=(I-1)*DELX+X1GRID
      WRITE (6,*) XGRIDREPEAT(I),YGRIDREPEAT(J)
   END DO
END DO
CLOSE(6)
RETURN
END

!***************************************************************************************************
```