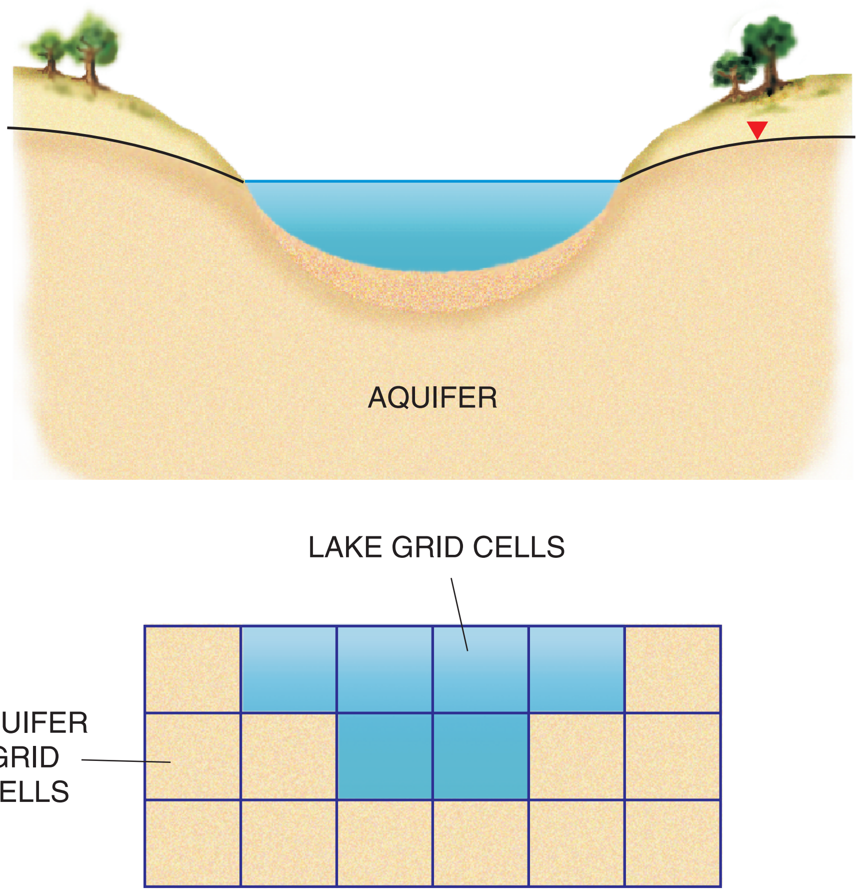
Documentation of a Computer Program to Simulate Lake-Aquifer Interaction Using the MODFLOW Ground-Water Flow Model and the MOC3D Solute-Transport Model

U.S. GEOLOGICAL SURVEY
Water-Resources Investigations Report 00-4167



Prepared in cooperation with the
St. Johns River Water Management District
Southwest Florida Water Management District

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By Michael L. Merritt *and* Leonard F. Konikow

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CONTENTS

Figures

Tables

CONVERSION FACTORS, VERTICAL DATUM, ABBREVIATIONS AND ACRONYMS

Multiply	By	To obtain
	Length	
foot (ft)	0.3048	meter (m)
	Area	
square feet (ft^2)	0.09290	square meter (m^2)
	Volume	
cubic foot (ft^3)	0.028317	cubic meter
	Flow rate	
foot per day (ft/d)	0.3048	meter per day (m/d)
	Hydraulic conductivity	
foot per day (ft/d)	0.3048	meter per day (m/d)
	Hydraulic gradient	
feet per foot (ft/ft)	1.0	meters per meter (m/m)

Temperature in degrees Fahrenheit (°F) may be converted to degrees Celsius (°C) as follows:

°C=(°F-32)/1.8.

Sea level: In this report, “sea level” refers to the National Geodetic Vertical Datum of 1929 (NGVD of 1929)--a geodetic datum derived from a general adjustment of the first-order level nets of both the United States and Canada, formerly called Sea Level Datum of 1929.

Acronyms and Additional Abbreviations

d = day
ET = evapotranspiration
USGS = U.S. Geological Survey

PREFACE

This report presents a computer program for simulating the interaction between lakes and a surficial aquifer in the U.S. Geological Survey (USGS) ground-water models, MODFLOW and MOC3D. The performance of this computer program has been tested in models of hypothetical ground-water flow systems; however, future applications of the programs could reveal errors that were not detected in the test simulations. Users are requested to notify the USGS if errors are found in the report or in the computer program. Correspondence regarding the report or program should be sent to:

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The computer program documented in this report is part of the MODFLOW-96 and MODFLOW-2000 ground-water flow models and the MOC3D solute-transport model. MODFLOW-96, MODFLOW-2000, MOC3D, and other ground-water programs are available from the USGS at the following World Wide Web addresses:

http://water.usgs.gov/software/
http://water.usgs.gov/nrp/gwsoftware/
or by anonymous ftp file transfer from directory **/pub/software/ground_water/modflow** at Internet address: **water.usgs.gov**

Documentation of a Computer Program to Simulate Lake-Aquifer Interaction Using the MODFLOW Ground-Water Flow Model and the MOC3D Solute-Transport Model

By Michael L. Merritt *and* Leonard F. Konikow

Abstract

Heads and flow patterns in surficial aquifers can be strongly influenced by the presence of stationary surface-water bodies (lakes) that are in direct contact, vertically and laterally, with the aquifer. Conversely, lake stages can be significantly affected by the volume of water that seeps through the lakebed that separates the lake from the aquifer. For these reasons, a set of computer subroutines called the Lake Package (LAK3) was developed to represent lake/aquifer interaction in numerical simulations using the U.S. Geological Survey three-dimensional, finite-difference, modular ground-water flow model MODFLOW and the U.S. Geological Survey three-dimensional method-of-characteristics solute-transport model MOC3D.

In the Lake Package described in this report, a lake is represented as a volume of space within the model grid which consists of inactive cells extending downward from the upper surface of the grid. Active model grid cells bordering this space, representing the adjacent aquifer, exchange water with the lake at a rate determined by the relative heads and by conductances that are based on grid cell dimensions, hydraulic conductivities of the aquifer material, and user-specified leakance distributions that represent the resistance to flow through the material of the lakebed. Parts of the lake may become "dry" as upper layers of the model are dewatered, with a concomitant reduction in lake surface area, and may subsequently rewet when aquifer heads rise. An empirical approximation has been encoded to simulate the rewetting of a lake that becomes completely dry.

The variations of lake stages are determined by independent water budgets computed for each lake in the model grid. This lake budget process makes the package a simulator of the response of lake stage to hydraulic stresses applied to the aquifer. Implementation of a lake water budget requires input of parameters including those representing the rate of lake atmospheric recharge and evaporation, overland runoff, and the rate of any direct withdrawal from, or augmentation of, the lake volume. The lake/aquifer interaction may be simulated in both transient and steady-state flow conditions, and the user may specify that lake stages be computed explicitly, semi-implicitly, or fully-implicitly in transient simulations.

The lakes, and all sources of water entering the lakes, may have solute concentrations associated with them for use in solute-transport simulations using MOC3D. The Stream Package of MODFLOW-2000 and MOC3D represents stream connections to lakes, either as inflows or outflows. Because lakes with irregular bathymetry can exist as separate pools of water at lower stages, that coalesce to become a single body of water at higher stages, logic was added to the Lake Package to allow the representation of this process as a user option. If this option is selected, a system of linked pools (sublakes) is identified in each time step and stages are equalized based on current relative sublake surface areas.

INTRODUCTION

In recent years, the simulative capabilities of ground-water flow models have been enhanced by the development of increasingly sophisticated methods of representing the effects of external hydraulic influences on heads and flow patterns in ground-water systems. Heads in surficial aquifers, in particular, can be strongly affected by the hydraulic influence of bodies of surface water and by exchanges of water volumes with the overlying atmosphere. One particular example is the influence of stationary bodies of surface water, such as lakes, that are in direct contact, vertically and laterally, with the surficial aquifer. The magnitudes of significant terms (sources and sinks) in the water budgets of lakes commonly differ from corresponding terms of water budgets of adjacent surficial aquifers, so that varying hydrologic conditions can cause either the lake or the aquifer to affect the head in the other water body. In regions with many lakes or with economically important lakes, it is helpful to have an available technique to describe the hydraulic interaction between a lake and the surrounding aquifer so that the effect of changes in either water body on conditions in the other can be estimated by resource managers.

Methods of representing the hydraulic effect of lakes in ground-water flow models have been available for many years. The many versions of the U.S. Geological Survey (USGS) saturated ground-water flow model MODFLOW (McDonald and Harbaugh, 1988; Harbaugh and McDonald, 1996a,b; Harbaugh and others, 2000) and its precursors have included a “River” Package that could be generalized to represent a lake as a constant-head source or sink of fixed areal extent overlying the aquifer. The implicit assumption of this procedure is that the river or lake stage does not vary as a result of leakage through the lakebed or as a result of other stresses. The River Package concept was extended in the development of the Reservoir Package for use with MODFLOW by Fenske and others (1996). The Reservoir Package allows the stage of the overlying reservoir to vary linearly between user-specified limits during a stress period, and also allows the extent of the reservoir to vary based on a comparison of stage with a user-specified land-surface elevation distribution. Implicit in this approach is the assumption that variations in reservoir (lake) stage can be entered into the simulation as a prior specification by the model user. This implies either that the volume of leakage through the lakebed is small enough that reservoir (lake) stage variations are independent of lakebed leakage or that the specified variation of reservoir (lake) stage accounts for the effect of lakebed leakage. Both the River and Reservoir Packages assume that the surface-water body overlies the upper layer of the model grid. This representation implies that the aquifer is thick compared to the wetted depth of the reservoir and that the amount of horizontal lakebed seepage and the corresponding effects on the flow system in the aquifer surrounding the lake are negligible or unimportant to simulation objectives. This representation can be a good approximation in some applications and has the advantage that it does not require that cells within the model grid be identified as representing the space occupied by the lake (lake-volume grid cells).

Another approach to the simulation of lakes that does not require the use of any modular package is simply to represent parts of the model grid as having the hydraulic characteristics of a lake by specifying a high hydraulic conductivity for lake-volume grid cells, the “high K” technique. A value of 1.0 for the storage coefficient is specified for the surficial lake layer, and a value equal to the compressibility of water is assigned to underlying lake layers. The lake stage is computed for lake-volume grid cells with the same equations used to compute aquifer heads. Because the hydraulic conductivity is high, little or no spatial variation in head (stage) will occur in the lake-volume grid cells. This technique, coupled with a cell rewetting approximation method, was used with good results to represent wetlands in a simulation of flow in a surficial aquifer using a three-dimensional flow and transport model (Merritt, 1997). The technique was also used in a lake simulation using MODFLOW (Lee, 1996), a wetlands/aquifer simulation using MODFLOW (Swain and others, 1996), and in a lake simulation using an analytic element model (Hunt and Krohelski, 1996).

The principal difficulty in using the “high K” technique is that stream-lake connections are difficult to represent accurately. Also, the representation of lakebed leakance requires some effort, and questions of solution stability need to be resolved. Generally, the “high K” technique is most useful for simple application problems. As the application becomes more complex, it becomes easier to use a generic lake package, perhaps coupled with a generic stream package, that is designed to handle many aspects of the application problem.

A different approach to lake/aquifer interaction was developed by Cheng and Anderson (1993). Their Lake Package was also developed for use with MODFLOW and served as the prototype for the Lake Package described herein. The Lake Package presented in this report represents a lake as a volume of space within the model grid composed of inactive cells extending downward from the upper surface of the grid. Active model grid cells bordering this space, representing the adjacent aquifer, exchange water with the lake at a rate determined by the relative heads and by conductances that are based on grid cell dimensions, hydraulic conductivities of the aquifer material, and user-specified leakance distributions that represent the resistance to flow presented by the material of the lakebed. This approach to the representation of lakebed seepage is a refinement of the method developed by Cheng and Anderson (1993), based on the explicit specification of the lakebed top and bottom elevations and lakebed hydraulic conductivity. Cheng and Anderson's (1993) approach, however, did not take into account the resistance to flow within the aquifer, which can be substantial in magnitude compared to the resistance of the lakebed when the lakebed is thin or absent. In the USGS Lake Package described in this report, parts of the lake may become "dry" as upper layers of the model dewater (with a concomitant reduction in lake surface area) and subsequently rewet. In addition, an empirical approximation has been added to the USGS Lake Package logic to permit the entire volume of a lake to become completely dry and subsequently rewet.

Simulated lake stages vary in a manner determined by independent water budgets computed for each lake in the model grid, a technique described by Sacks and others (1992). This lake budget process is crucial in making the model serve as a simulator of the response of lake stage to hydraulic stresses applied to the aquifer, a capability desired by resource managers. Accurately calculating a lake water budget requires the input of parameters describing the rate of lake atmospheric recharge and evaporation, the overland runoff rate after precipitation, and the rate of any direct withdrawal from, or augmentation of, the lake volume. The Stream Package of MODFLOW identifies stream connections to lakes, either as inflows or outflows, and this information is transmitted to the Lake Package. Because lakes with irregular bathymetry can exist as separate pools of water at lower stages, which then coalesce to become a single body of water at higher stages, logic was added to the USGS Lake Package to allow the representation of this process. In each time step, linked sublakes are identified and stages are equalized based on current relative sublake surface areas.

A steady-state option was added to the package that provides for using Newton's method (Press and others, 1989) to compute equilibrium stages in each lake in each MODFLOW iteration in a manner similar to that described by Council (1998). In transient simulations, lake stages may be computed explicitly, semi-implicitly, or fully-implicitly. Though the explicit solution seems to be the most computationally efficient for many applications, some investigators (Nair and Wilsnack, 1998) found that an implicit solution prevents time-wise oscillatory behavior when the aquifer material surrounding the lake is highly permeable, as in the Biscayne aquifer of southern Florida.

The Lake Package was written to be used in conjunction with solute-transport calculations performed using MOC3D (Konikow and others, 1996). MOC3D is not distributed by the USGS as an independent package. Rather, a separate version of MODFLOW adapted to link with and use the MOC3D package has been made available by the USGS. When the Lake Package is used with MOC3D, a solute concentration is assigned to each lake. In addition, sources of water added to the lake also are assigned concentrations, and a solute budgeting process is performed in each time step to update the lake concentrations.

The lake/aquifer interaction package described herein is the product of a cooperative effort of the USGS, the St. Johns River Water Management District, and the Southwest Florida Water Management District. The two latter agencies are responsible for water management in central and northeastern Florida, a karstic region of many large and small lakes with varying recharge and drainage characteristics and regular and irregular bathymetries. Stresses on the surficial aquifer and the consequent effect on lake stages are an important economic concern because many of these lakes are used for recreational purposes with homes constructed nearby. Because of the wide variety of hydrologic conditions occurring in the local area, the Lake Package was developed and tested to have a considerable degree of generality and flexibility. The generalized treatment of lake/aquifer interaction in the Lake Package suggests that it may be applicable, as part of MODFLOW or MOC3D, in a wide range of environments within the United States and elsewhere.

This report documents (1) the basic concepts of the lake/aquifer interaction package; (2) the results of four test simulations; (3) the data input instructions needed to use the package; and (4) the input data sets used for the four test simulations and selected parts of the printed results. It is assumed that the reader is familiar with the MODFLOW model and nomenclature, and with MOC3D concepts if solute transport is to be simulated.

Acknowledgments

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MATHEMATICAL FORMULATION

Quantifying the hydraulic relation between a lake and the adjacent surficial aquifer requires formulation of a method of estimating the amount of water exchanged between the two water bodies by seepage through the materials that separate them. The formulation described herein, an application of Darcy’s Law, is based on a comparison of the head in the aquifer with the stage of the lake. In transient simulations using the Lake Package, the stage of the lake is adjusted at the end of each time step by performing a separate water budget for the lake. This procedure requires that all other components of the lake water budget, such as rainfall recharge, evaporation, overland runoff, surface-water inflows and outflows, and direct withdrawals from the lake or augmentation of the lake volume by anthropogenic means, be known or estimated. In particular, streamflow entering or leaving the lakes must be known or estimated. When MODFLOW is used for steady-state calculations, water fluxes to and from the lake must be known or estimated in performing the Newton’s Method calculations for equilibrium lake stages.

If the lake dries appreciably, then the surface area may decrease, substantially affecting other processes controlling the lake water budget; consequently, model computations must account for changes in the surface area of the lake. In some cases, the drying of a lake having irregular bathymetry may result in its division into two or more bodies, each having a separate water budget and stage; a rise in stage may lead to the coalescence of lakes into a single large lake having a single budget and stage. When the Lake Package is used in conjunction with MOC3D in solute-transport calculations, solute concentrations and fluxes associated with water volumes and fluxes must be estimated or calculated. The mathematical solution and programming procedures formulated to deal with these problems and related issues are described in the following sections of this report.

Seepage Between Lake and Aquifer

The direction and magnitude of seepage between a lake and the adjacent aquifer system depends on the relation between the lake stage and the hydraulic head in the ground-water system, both of which can vary substantially in time and space. Seepage from a lake into the surficial aquifer that surrounds it, where the lake acts as a source of recharge to the aquifer, occurs when and where the lake stage is higher than the altitude of the water table in the adjacent part of the aquifer. Typical situations in which substantial recharge to the aquifer occurs are those where a lake receives surface inflows in excess of outflows, perhaps from a stream discharging into the lake, or where the water level in the aquifer is drawn down by pumpage from wells. Seepage from the surficial aquifer into a lake usually occurs where the water-table altitude is normally higher than that of the lake. Such cases are found in regions with karstic topography where lakes commonly have no substantial surficial inflows or outflows. In these environments, the rate of evaporation from the open lake surface is greater than ground-water evapotranspiration, so more water is removed per unit area from the lake than from the surficial aquifer. Because less water per unit volume is stored in the aquifer than in the lake, periods of rainfall cause the water table to rise higher than the lake stage, thus increasing the rate of seepage from the aquifer into the lake. In this manner, the lake can act as a hydraulic sink for the ground-water system. In still other hydrologic environments, a lake can represent a mixed or “flow-through” condition where, in some areas of the lakebed, seepage is into the lake and in other areas, seepage is out of the lake.

For all of these conceptual cases, quantification of the rate of seepage between the lake and the aquifer is by an application of Darcy’s Law:

$$q = K\frac{h_l - h_a}{\Delta l} , \qquad (1)$$

where

- q is the specific discharge (seepage rate) (L/T);
- K is the hydraulic conductivity (L/T) of materials between the lake and a location within the aquifer below the water table;
- h_l is the stage of the lake (L);
- h_a is the aquifer head (L);
- Δl *is* the distance (L) between the points at which h_l and h_a are measured; and
- L and T denote length and time units.

As written, the seepage rate in equation 1 is positively signed when seepage is from the lake into the aquifer ($h_l > h_a$).

In numerical models, it is convenient to further quantify the transfer of fluid as a volumetric flux Q (L^3/T). This is usually done by integrating the specific discharge over some cross section of area A (L^2) in a plane perpendicular to the direction of flow:

$$Q = qA = \frac{KA}{\Delta l}(h_l - h_a) = c(h_l - h_a) . \qquad (2)$$

The quantity $c = KA/\Delta l$ is termed the conductance (L^2/T). Expressed per unit area, the quantity $K/\Delta l$ is referred to as a leakance (T^{-1}). In numerical models, A is usually the cross-sectional area of a grid-cell face in one of the horizontal (X-Y) or vertical (X-Z or Y-Z) coordinate planes (fig. 1). In the USGS Lake Package, conductances are computed for horizontal lake/aquifer cell interfaces based on parameter input before MODFLOW time steps are performed. Conductances per unit thickness for vertical interfaces are also computed at this stage, and are later multiplied by the current wetted thicknesses of the aquifer cells adjacent to the lake as part of the computation of seepage rates during simulation time steps.

In the Lake Package, either the lake or aquifer occupies the entire volume of a grid cell, and they do not overlap within a grid cell. The lakebed is defined by its assigned leakance value and is not specified to have an explicit dimension within the model grid. In the conceptualization of the Lake Package, vertical or horizontal movement of water from above or next to the lakebed toward a position in the aquifer (or vice versa) is considered to occur through two, probably quite distinct, materials: (1) the lakebed, which could consist of a few inches to several or tens of feet of relatively impermeable sediments; and (2) the aquifer material, which could exhibit a wide range of permeability in different aquifers. It is most convenient to be able to formulate a conductance that accounts for the particular permeability characteristics of each medium. Using a common cross-sectional area, A, the conductance of the lakebed is expressed as $c_b = K_bA/b$, where K_b is the hydraulic conductivity of the lakebed material, and b is the lakebed thickness (fig. 1a). The conductance of the aquifer segment is expressed as $c_a = K_a A/\Delta l$, where K_a is the aquifer hydraulic conductivity, and Δl is the length of the travel path in the aquifer to the point where the aquifer head h_a is measured. The equivalent conductance, c, of the entire path between the points in the lake and aquifer where the heads are measured is found by treating the conductances of the lakebed and aquifer as if they were in series (McDonald and Harbaugh, 1988):

$$\frac{1}{c} = \frac{1}{c_b} + \frac{1}{c_a} \text{, or} \qquad (3)$$

$$c = \frac{A}{\dfrac{b}{K_b} + \dfrac{\Delta l}{K_a}} . \qquad (4)$$

In the numerical modeling context, Δl is half the grid cell dimension in the appropriate coordinate direction (fig. 1b, the distance between the edge of the aquifer grid cell that is the interface with the lakebed and the aquifer grid cell center), A is the cross-sectional area of the grid cell in a plane perpendicular to the travel distance Δl, and K_a is the aquifer hydraulic conductivity in the direction of Δl (either horizontal, K_h, or vertical, K_v). The procedure described above and automated in the Lake Package provides a mathematically correct estimate of the conductance of flow between the lake and the aquifer, the accuracy of which is primarily limited by the accuracy with which the parameters in the formula can be quantified from field data. Either of the terms in the denominator of the right side of equation 4 may or may not dominate quantitatively, depending on the properties of the natural system being investigated. For instance, if the hydraulic conductivity of a 1-foot (ft) thick lakebed were 0.1 foot per day (ft/d), and the hydraulic conductivity of a 100-ft section of aquifer

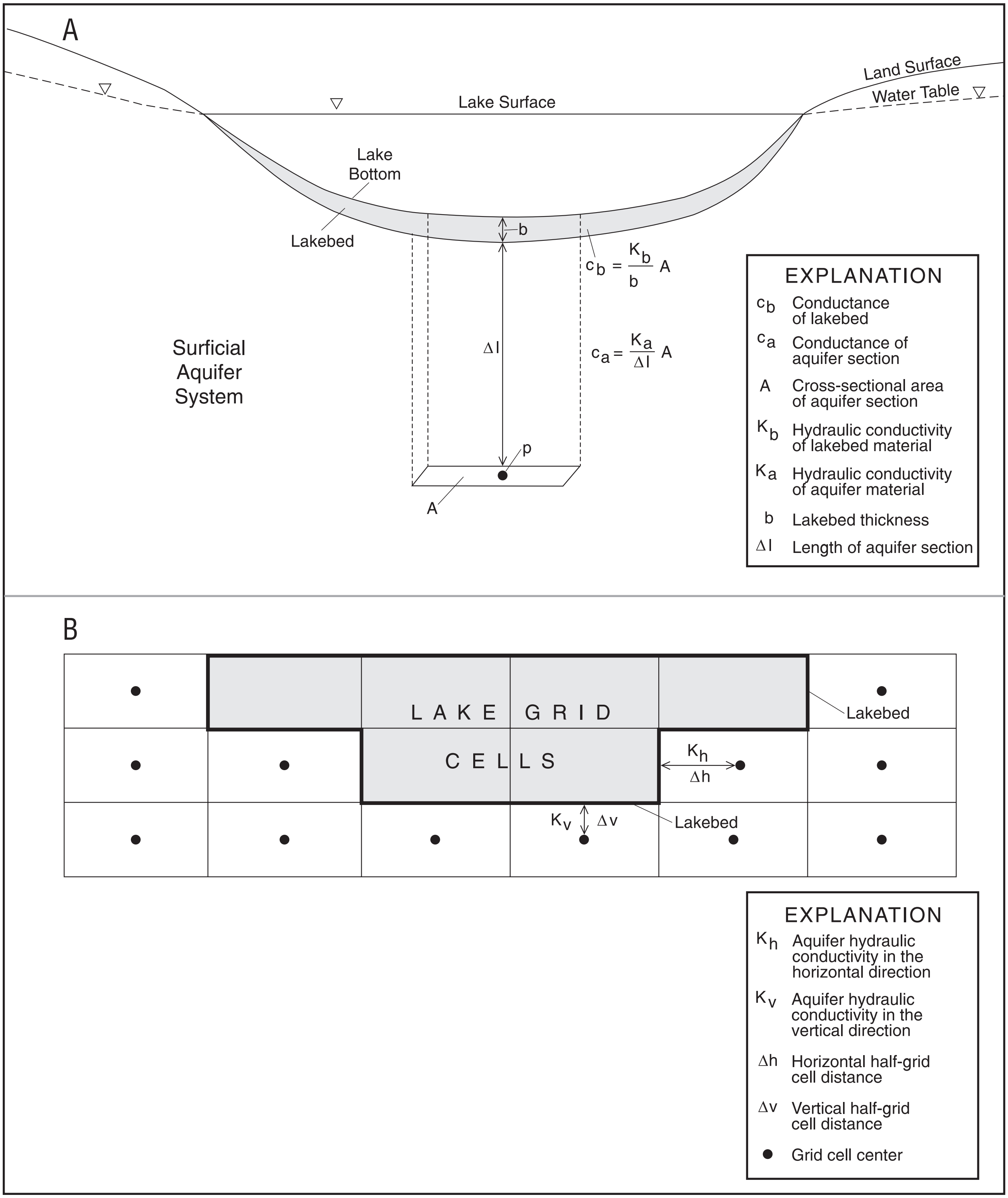


Figure 1. Concepts used in estimating seepage flux between the lake and some point in the surficial aquifer.

(Δl = 100 ft) were 10 ft/d, the two terms in the denominator of equation 4 would be the same. If the lakebed were only 0.1 ft thick and had a hydraulic conductivity of 1 ft/d, the aquifer term would dominate the resulting conductance value. If the aquifer hydraulic conductivity were 1,000 ft/d, the lakebed term would dominate the resulting conductance value.

The implementation of the technique described above is straightforward in MODFLOW when the option of rewetting dry cells is implemented. However, when this option is not implemented, some vertical leakance information is not saved, so the model user must use the lakebed leakance specification to represent the combined leakance of the lakebed and the aquifer.

In computing vertical seepage between the lake and an underlying aquifer grid cell using equation 2, the head in the aquifer below the lake cell is assumed never to fall below the lake bottom elevation, or below the bottom elevation of the layer in which the lake cell occurs. If the head does fall lower than this elevation, then the aquifer between the lake bottom and the water table would be unsaturated. Assuming the aquifer head is no lower than the elevation of the lake bottom means that downward seepage will be limited to that which would result if the head difference were that between the lake stage and the top of the underlying aquifer (lake bottom). This assumption, applied cellwise, is similar to one adopted in analogous circumstances in the River, Stream, and Reservoir Packages developed for use with MODFLOW. The reader is referred to the discussion of McDonald and Harbaugh (1988, p. 6-6 to 6-8).

Seepage rates computed for each interface between a lake cell and a horizontally or vertically adjacent aquifer cell by the Lake Package implementation of equations 1 and 2 are added to the appropriate elements in the *RHS* (right-hand side residual) and *HCOF* (coefficient) matrices (McDonald and Harbaugh, 1988) as follows:

$$RHS_{ijk} = RHS_{ijk} - c_m h_l^{\,n-1} \quad \text{for aquifer head } (h_a) \text{ above lake bottom } (h_{bot}) \text{ in this vertical column} \tag{5a}$$

$$RHS_{ijk} = RHS_{ijk} - c_m(h_l^{\,n-1} - h_{bot}) \quad \text{for } h_a \text{ below } h_{bot}\text{, horizontal interface} \tag{5b}$$

$$RHS_{ijk} = RHS_{ijk} \pm 0 \quad \text{for } h_a \text{ below } h_{bot}\text{, vertical interface} \tag{5c}$$

$$HCOF_{ijk} = HCOF_{ijk} - c_m \quad \text{for } h_a \text{ above } h_{bot} \tag{5d}$$

$$HCOF_{ijk} = HCOF_{ijk} \pm 0 \quad \text{for } h_a \text{ below } h_{bot} \tag{5e}$$

where

ijk designates the particular matrix term,
m denotes a particular cell interface,
c_m is the conductance across that interface, and
n-1 denotes the previous time step.

The *HCOF* and *RHS* matrices are used in the MODFLOW solution for new aquifer heads for the current time step. This procedure constitutes the link between the Lake Package and the MODFLOW solution for aquifer head values. The cell-by-cell seepage rates are integrated over the time step to calculate seepage volumes for the time step. These integrated cell-by-cell seepage volumes are then summed to obtain a total seepage volume for the lake, which is then used for computing the new lake stage.

Lake Water Budget

The interaction between the lake and the surficial aquifer is represented in this Lake Package, as in the Lake Package of Cheng and Anderson (1993), by updating at the end of each time step a water budget for the lake that is independent of the ground-water budget represented by the solution for heads in the aquifer. Implicit in the calculation of a lake water budget is the recomputation of current values of lake volume and stage. The lake stage is crucial in making the estimates of ground-water seepage to and from the lake that are used by MODFLOW. Lake volume is used for MOC3D calculations where a lake is a source or sink of solute.

The reliance upon an independent water budget for the lake is an approach previously used by Sacks and others (1992). The implementation of a separate water budget for the lake that accounts for seepage losses to and seepage gains from the aquifer provides the capability to use the model to make a separate estimate of the stage of the lake and its relation to the water table. Updating a lake water budget also requires that estimates be made of gains and losses of water from the lake other than by seepage, such as (1) gains from rainfall, overland runoff, and inflowing streams, (2) losses to evaporation and outflowing streams, and (3) anthropogenic gains and losses. Examples of the latter include withdrawals for water supply or augmentation with water from another source.

The water budget procedure incorporated in the Lake Package is implied by the equation used to update the lake stage. The explicit form of this equation is:

$$h_l^n = h_l^{n-1} + \Delta t \; \frac{p - e + rnf - w - sp + Q_{si} - Q_{so}}{A_s} \;, \quad (6)$$

where

h_l^n and h_l^{n-1} are the lake stages (L) from the present and previous time steps;

Δt is the time step length (T);

p is the rate of precipitation (L^3/T) on the lake during the time step;

e is the rate of evaporation (L^3/T) from the lake surface during the time step;

rnf is the rate of surface runoff to the lake (L^3/T) during the time step;

w is the rate of water withdrawal from the lake (L^3/T) during the time step (a negative value is used to specify a rate of augmentation);

Q_{si} is the rate of inflow from streams (L^3/T) during the time step;

Q_{so} is the rate of outflow to streams (L^3/T) during the time step;

A_s is the surface area of the lake (L^2) at the beginning of the time step; and

sp is the net rate of seepage between the lake and the aquifer (L^3/T) during the time step (a positive value indicates seepage from the lake into the aquifer), and is computed as the sum of individual seepage terms for all M lake/aquifer cell interfaces:

$$sp = \sum_m^M c_m (h_l - h_{am}) \;,$$

where

h_{am} is the head in the aquifer cell across the m^{th} interface; and

c_m is the conductance across the m^{th} interface.

Source and sink volumes are obtained by integrating computed or user-specified rates over the length of the time step (multiplying the rates denoted in equation 6 by Δt). As presented in equation 6, the calculation of an updated value for lake stage at the end of a time step is explicit in that this calculated stage (h_l) remains a fixed, or explicitly determined, parameter during the following MODFLOW time step in which it is used to calculate seepage fluxes between the lake and aquifer and a new set of aquifer head values. The explicit calculation of lake stage is one of the options available to the user. A limitation imposed by this procedure is that lake stage should not change rapidly with respect to the time step length during a stress period; otherwise, a lake stage computed at the end of a previous time step will not be a good estimator of the lake stage used to compute seepage rates in the current time step.

A related problem concerns solution stability. In some simulations where time step length increases in successive time steps (TSMULT > 1 in MODFLOW BAS package), the computed lake stage begins to oscillate with time, and the magnitude of the oscillations grows in successive time steps. Ultimately, a set of conditions is created that prevents the MODFLOW solution for aquifer heads from converging. When this situation occurs in explicit calculations, it indicates a need to prevent the time step length from increasing beyond some limit that must be determined by trial and error and that depends on the parameters that characterize the specific application problem. Otherwise, the seepage fluxes computed in the large time steps become large with respect to the lake volumes, and errors in the computed lake stage values tend to propagate and grow in successive time steps.

Stability problems in lake/aquifer simulations can also be the result of specifying inappropriate parameter values for use with the wet-dry option of MODFLOW. Though the cause of this difficulty lies outside the scope of the discussion of the lake package, such problems occur with sufficient frequency in lake/aquifer simulations to justify a reference to them.

An alternative to the explicit computation of lake stage at the end of each time step is to consider $\overline{h_l}$, the estimate of lake stage used for seepage calculations during the n^{th} time step, to be a combination of the stage from the previous time step (h_l^{n-1}) and the unknown stage to be computed at the end of the present time step (h_l^n), that is:

$$\overline{h_l} = (1-\theta)h_l^{n-1} + \theta h_l^n \,, \qquad (7)$$

where θ is a user-specified weighting factor, $0 \le \theta \le 1$.

The formulation shown above is the semi-implicit formulation. If $\theta = 0$, this formulation reverts to the explicit case described earlier. If $\theta = 1$, the stage from the previous time step is ignored—this is the fully-implicit case. In each MODFLOW iteration for a computation of aquifer heads, the seepage fluxes across cell interfaces are computed by a variation of equation 2:

$$Q = c(\bar{h}_l - h_a)\ . \tag{8}$$

The compilation of terms in the RHS and HCOF matricesis is done as in equation 5, except that $\bar{h}_l$ replaces h_l^{n-1}.

In the calculation for new lake stage (eq. 6), the computed value of seepage between the lake and the aquifer (*sp*) is replaced by an implicit formulation that depends partly on the new lake stage being computed:

$$h_l^n - h_l^{n-1} = \Delta t \ \frac{p - e + rnf - w + Q_{si} - Q_{so} - \sum_m^M c_m(\bar{h}_l - h_{am})}{A_s}\ , \tag{9}$$

where the summation is of the individual cell-face seepage terms over the entire lake/aquifer interface (*M* cell-face interfaces).

When the definition of $\bar{h}_l$ is inserted into equation 9, a rearrangement of terms yields the expression used to calculate the new lake stage (h_l^n) at the end of the n^{th} time step:

$$h_l^n = \frac{h_l^{n-1} + \Delta t\ \dfrac{p - e + rnf - w + Q_{si} - Q_{so} + \left(\sum_m^M c_m h_{am} - (1-\theta)h_l^{n-1}\sum_m^M c_m\right)}{A_s}}{1 + \dfrac{\theta\Delta t}{A_s}\sum_m^M c_m}\ . \tag{10}$$

When $\theta = 0$ (explicit case), this formula reduces to equation 6.

As currently encoded, equation 10 is used at the end of each iteration within a MODFLOW time step (solution for aquifer head values) to provide an approximate value of current lake stage (h_l^n). In the following iteration, this approximate value of h_l^n is used in equation 7 to compute the value of $\bar{h}_l$ used in the seepage calculations. In the first iteration, the value of h_l^n is set equal to h_l^{n-1} in equation 7, so that the first iteration actually performs an explicit solution for lake stage. After enough MODFLOW iterations have been performed for the aquifer heads to converge to a solution, the lake stage (h_l^n) is recomputed one more time for each lake using equation 10.

Implicit and semi-implicit methods are not implemented in the Lake Package when MODFLOW is run in steady-state mode. Experience with stability issues in using the Lake Package is somewhat limited. As more is learned about stability problems, further refinements to the USGS Lake Package may be made. When applying the Lake Package in transient computations involving lakes interfacing with surficial aquifers of relatively low permeability, the explicit solution method ($\theta = 0$) has proven to be computationally efficient and stable when the time step length was limited to a few days. In these cases, the semi-implicit and fully-implicit solutions ($0 < \theta \le 1$) have provided similar results, but have required more iterations and tighter convergence criteria, and occasionally smaller time step lengths, to remain stable and to keep small the percent discrepancies in the MODFLOW solution for heads in the aquifer.

Investigators simulating the interaction of lakes with aquifers of high permeability, such as the surficial dissolved carbonates of southern Florida, have found an implicit solution approach to be useful as a means of achieving a stable solution. In these hydrologic environments, large volumes of water can be exchanged between a lake and aquifer in a short time. Nair and Wilsnack (1998) found that this situation caused timewise oscillatory behavior, leading to lack of convergence of quarry (lake) stages in their simulation. Although the lake package employed, described by Council (1998), provides for the division of a MODFLOW time step into substeps for lake-stage calculations, Nair and Wilsnack (1998) preferred to encode a fully-implicit solution method, which they claimed resulted in “better convergence of quarry stages” even without subdividing the MODFLOW time step of 1 day.

Drying and Rewetting of Sections of a Lake

Because the elevation of the bottom of a lake is spatially variable and rises to an elevation equivalent to the lake stage at the shoreline, lowering the lake stage can potentially dry sections of the lake having higher bottom elevations. Some lakes have irregular bathymetry and also can vary widely in typical stages, a combination that leads to periodic drying of substantial parts of the lake area. Therefore, the Lake Package was coded to represent the drying and rewetting of sections of a lake and the consequent effects on interchanges of water with the underlying or adjacent aquifer.

The lake is considered to be embedded in the model grid as a volume of inactive cells (zero IBOUND matrix values in input to MODFLOW BAS Package) in upper layers of the model grid that are specified by the user to be either unconfined (LAYCON = 1) or convertible (LAYCON = 3). Therefore, in each vertical column of the model where upper grid cells are inactive cells representing the presence of a lake, the elevation of the bottom of the lowest lake inactive cell is the user-specified bottom elevation of the model layer in which that cell occurs (BOT matrix in input to MODFLOW BCF Package). If the lake stage is lowered below that elevation, all lake volume cells in that vertical column become dry.

In the Lake Package, when all the lake volume cells in a vertical column become dry, the calculated surface area of the lake is reduced by the surface area of the column. The discrete nature of the model grid implies that this will be a stepwise representation of a process that occurs more gradationally in nature. Therefore, the effect of gridding on the computation of lake stage (using equation 6 or 10) could be a discontinuity in the trend of lake stage. This effect can be mitigated by refining the lateral and/or vertical discretization of the grid mesh as much as is feasible. The Lake Package computes and lists stage-volume relations for each lake based on the grid discretization specified by the user.

Another consequence of drying all lake-volume grid cells within a vertical column is that lake recharge and evaporation fluxes will not be applied to the surface area of that column of cells. This means that the column with the newly dry lake cells should be treated as a column of aquifer cells extending to land surface and should receive the amount of recharge and lose the volume of evapotranspiration at the rates that are specified for the aquifer.

Therefore, when the Lake Package is used as part of a MODFLOW simulation, LAK3ST, a module of the Lake Package, is called before and after each use of the computational modules of the Recharge and Evapotranspiration Packages. LAK3ST checks each column of grid cells for overlying lake volume inactive cells, checks whether any are partly saturated, and then makes appropriate temporary changes to the IBOUND matrix to ensure that atmospheric recharge to the aquifer and evapotransporation from the aquifer are simulated in the appropriate columns of grid cells. After the calls to any of the computational modules of the Recharge and Evapotranspiration Packages, a second call to LAK3ST resets the IBOUND array to its former values.

When the lake stage rises, previously dry sections of the lake (entire columns of lake-volume cells void of water) may become part of the lake again when the rising lake stage exceeds the elevation of the bottom of the lowest lake-volume cell in the column. Lake recharge and evaporation, not aquifer recharge and evapotranspiration, are once again applied to the vertical column, and the surface area of the column is used once again in lake stage calculations.

The Lake Package can also represent the rewetting of a lake after total drying (all lake volume cells void of water). After total drying, no lake stage is defined, so the lake water budget cannot be updated. Therefore, an empirical method was needed to determine when rewetting of the lake should occur and to estimate the stage in the previously dry lake. After several methods were tested, a relatively simple method was adopted for use with the Lake Package.

To implement this method, the lowest elevation of the lakebed (defined by the specification of inactive lake-volume grid cells) is saved when the input parameters for the Lake Package are defined (minimum value of BOT for a lake cell). In time steps after the lake dries, heads in aquifer grid cells beneath the deepest part of the lake are averaged and compared with the lowest elevation of the lakebed. If the average head is above the lowest elevation, a new stage equal to the average head is defined for the lake. Lake budget calculations then resume as before. Because no ground-water fluxes into the lake were defined as part of the solution for aquifer heads, it would be inconsistent to change the aquifer water budget to account for water estimated to be part of a wetted lake volume by this rewetting approximation. In subsequent time steps, because the lake contains water, and a lake water budget can be updated, ground-water fluxes into the lake are rigorously defined and accounted for as part of the lake and ground-water budgets.

A possible drawback to this rewetting method is that it may not account for the effect of the lakebed in hydraulically retarding inflow from the aquifer during the physical rewetting process. In addition, stream inflows or inflows by artificial augmentation may occur during the current time step. To account for the latter possibility, the total volume of inflow from these sources is divided by the surface area overlying the deepest part of the lake (the area of grid cells to which the lowest bottom elevation is assigned); the result is assigned to the lake as a wetted stage. This procedure can result in a "perched" lake underlain by an unsaturated zone within the aquifer. However, as noted previously, the lakebed seepage computation method contains a provision for the situation in which the aquifer head is below the bottom of a wetted (non-dry) lake.

An appropriate user control over the time step length during the simulated rewetting event is considered advisable. If the time step length is reasonably small, the initial rewetted volume, estimated empirically without the rigorous control of a water-budgeting process, will be small and will not introduce error into the subsequent water-budgeting process.

Stream-Lake Interconnections

Volumes of water gained from inflowing streams or lost to outflowing streams may be a substantial, if not dominant, part of the lake water budget. At the same time, streams may contribute appreciably to the aquifer water budget by seepage through the streambeds. The mutual interrelation between stream, lake, and aquifer was recognized by Cheng and Anderson (1993), who added coding to the then-current version of the USGS Stream Package (Prudic, 1989) to interface with the Lake Package by providing calculated values of stream inflow and outflow volumes.

The USGS Stream and Lake Packages are coded to identify streamflows at the end of the lowest reaches of stream segments that become lake inflows and to identify lake outflows that become inflows to the uppermost reaches of stream segments. The rate of lake outflow to a stream (Q_{so}) can be computed by the USGS Stream Package (D.E. Prudic and L.F. Konikow, written commun., 2000) in several ways, one of which is a form of the Manning equation:

$$Q_{so} = \frac{C}{n} W \left(\frac{2}{3} D\right)^{\frac{5}{3}} S^{\frac{1}{2}} \quad , \qquad (11)$$

where

C is a constant that determines the units of Q_{so} (1.486 for cubic feet per second);
n is Manning's roughness coefficient (generally in the range of 0.01 to 0.05 for open channels);
W is the width of the stream in feet;
D is the depth of the stream in feet; and
S is the slope of the channel (ft/ft).

At the head of the stream where the stream emerges from the lake, D is computed by the USGS Stream Package as the difference between the lake stage and the top of the streambed. The latter is a standard input to the Stream Package.

Other methods of computing the rate of lake outflow to a stream are available in the current USGS Stream Package (D.E. Prudic and L.F. Konikow, written commun., 2000). These include the eight-point cross-section method, which is based on a method of estimating flow in a channel with varying properties, as for example, a stream channel bordered by a seasonal floodplain (Chow, 1959, p. 138-142).

Steady-State Simulation

In the original version of the Lake Package (Cheng and Anderson, 1993), the initial specified value of lake stage remained invariant in a steady-state simulation of aquifer head values with MODFLOW. A steady-state simulation in which the lake stage varied interactively with the heads in the aquifer was achieved by making a transient run of MODFLOW with time-invariant parameter and stress specifications. The run was allowed to converge to a steady-state condition where the converged lake stage represented an equilibrium between gains and losses of water from the lake by seepage and other sources and sinks of water for the lake.

Nevertheless, it was recognized that to have lake stages converge interactively to values representing an equilibrium between the lake water budget and steady-state heads in the aquifer in one MODFLOW time step (essentially a "steady-state" solution for both aquifer heads and lake stages together) would provide additional ease of use and save computational time. Therefore, the USGS Lake Package has been given this capability. The technique used is one in which, in each iteration of the MODFLOW steady-state solution for heads in the aquifer, a value of stage is computed for each lake that represents a balance between seepage fluxes and other sources and sinks for the lake. The mathematical technique used is Newton's method, or the Newton-Raphson method (Press and others, 1989, p. 254); previous use of the method for the convergence of lake stages in a MODFLOW steady-state simulation was described by Council (1998).

Newton's method is an iterative technique for obtaining a zero of a function $f(x)$ with a continuous derivative $f'(x)$. The form of the equation used for the $n+1^{\text{th}}$ iteration is:

$$x_{n+1} = x_n - \frac{f(x_n)}{f'(x_n)} \ , \qquad (12)$$

where

$f(x)$ and $f'(x)$ are evaluated at the previous estimate x_n.

Newton's method converges rapidly if the initial estimate x_0 is close to the solution value. The method may diverge or converge to a wrong answer if the initial estimate is substantially different from the solution value.

In the application of Newton's method to the problem of computing equilibrium lake stages, the function for which a zero is to be found is the explicit form of the stage correction (eq. 9), expressed as a function of lake stage (h_l):

$$f(h_l) = \frac{\Delta t}{A_s}\left[p - e + rnf - w + Q_{si} - Q_{so}(h_l) - \sum_m^M c_m(h_l - h_{am})\right] . \qquad (13)$$

At the zero values of $f(h_l)$, the inflows to and outflows from the lake will be in balance, that is, the lake stage will be in equilibrium given prevailing hydrologic conditions, including heads in the surrounding aquifer. Assuming that precipitation (p) and evaporation (e) do not change as a result of a change in lake surface area caused by a change in lake stage, then only stream outflow $Q_{so}(h_l)$ and the sum of the seepage terms $c_m(h_l - h_{am})$ have a functional dependence on h_l. Therefore, the derivative of $f(h_l)$ with respect to h_l is:

$$f'(h_l) = \frac{\Delta t}{A_s}\left[-\frac{d}{dh_l}Q_{so}(h_l) - \sum_m^M c_m\right] . \qquad (14)$$

The form of the derivative of $Q_{so}(h_l)$ depends on the type of functional dependence. One way of computing lake-to-stream discharge rates in the USGS Stream Package (D.E. Prudic and L.F. Konikow, written commun., 2000) is by using the Manning formula (eq. 11). In this case, the derivative required by equation 14 is:

$$\frac{d}{dh_l}Q_{so}(h_l) = \frac{d}{dh_l}\left[\frac{C}{n}W\left(\frac{2}{3}[h_l - h_b]\right)^{\frac{5}{3}}S^{\frac{1}{2}}\right] = \frac{5}{3}\frac{Q_{so}(h_l)}{h_l - h_b} = \frac{5}{3}\frac{Q_{so}}{D} , \qquad (15)$$

where

D in equations 11 and 15 is written as the difference between lake stage (h_l) and the streambed elevation (h_b), $D = h_l - h_b$, and other terms are as previously defined.

When other methods are used to compute lake-to-stream discharge rates, the derivative is approximated from the slope of the stage-discharge relation for values of lake stage close to the simulated value.

In the previous equation development, precipitation and evaporation rates were assumed to be independent of lake stage. This assumption is likely to hold true if the initial estimate of lake stage is close to the equilibrium lake stage computed by Newton's method. In the USGS Lake Package, precipitation and evaporation rates depend on the lake stage to the extent that both vary with changes in lake surface area, which can change when the lake stage rises above or falls below the top of a layer of grid cells that defines the bottom of a shallower part of the lake. Because the relation of surface area (and, hence, precipitation and evaporation) to lake stage is a step function in simulations with the Lake Package (that is, the derivative is zero for all values of lake stage except at the discrete values for which the surface area changes, where the derivative is undefined), this functional relation is not suitable for inclusion in the solution for equilibrium lake stage (eqs. 12-14). The consequences for convergence of lake stages as part of a MODFLOW steady-state solution in the case where successive lake-stage estimates are on opposite sides of the boundary between two model layers have not been investigated in detail. The user of the Lake Package for steady-state simulations can avoid this situation by using discretion in specifying initial heads for lakes and the aquifer and the vertical discretization.

To deal with the problem of possible solution divergence in using Newton's method in conjunction with the MODFLOW steady-state solution, a provision has been made for the user to enter maximum and minimum stage values for each lake. If the stage computed by Newton's method falls outside the bounds specified for a lake, the current stage for that lake is re-initialized to be the average of the maximum and minimum values. In some problems, this can lead to a recurring loop, but the lake package will terminate after 10 repetitions for a lake.

The user is also required to set a convergence criteria for the equilibrium lake-stage calculation using Newton's Method. In lake/aquifer systems where a good hydraulic connection exists between the lake and a relatively permeable aquifer, a small number should be used for the convergence criterion because small changes in lake stage can result in substantial water exchanges. The appropriate number (possibly less than 0.001 ft) must be determined by trial and error.

Another restriction on the use of the Lake Package in steady-state MODFLOW simulations is that the coalescence or separation of lakes (to be described in a subsequent section) cannot be simulated. This need not be limiting to the model user. If an initial steady-state simulation shows that lake stage converges to a value above or below the elevation at which pools coalesce, the lake geometry can be redefined in the input to the Lake Package to specify the appropriate lake divisions.

Solute Concentration

If the lake package is active and solute transport in the aquifer is being simulated, then solute transfer between the aquifer and the lakes must be evaluated. Seepage losses from lakes into an adjacent aquifer will affect the solute concentration in the ground-water system. For example, if the concentration in the lake is less than that in the ground water, then seepage losses will dilute the solute in the ground water and reduce its concentration. On the other hand, where a lake is gaining water from the aquifer because of ground-water discharge, the solute concentration in the lake will be affected by the rate and solute content of the ground-water inflow. For example, if a ground-water contaminant plume discharges into a lake, the lake will become contaminated (though most likely at much lower concentration levels than within the ground-water system). If this lake discharges into a stream, traces of the contaminants may be transported over long distances in relatively short time periods.

When a solute-transport package is included in the MODFLOW simulation (Ftype "CONC" exists in the MODFLOW name file), the model will compute the concentration of a solute at every node within the transport domain (which can encompass all or part of the MODFLOW grid). If the ground-water model includes the simulation of solute transport, the lake package includes the capability to account for the exchange of solute between the lake and the aquifer, as well as the flux of water. If a fluid flux exists between the lake and the aquifer in a model cell where concentration is calculated, then the solute flux between the lake and the aquifer can also be computed. Just as lake stage and volume can change over time by accounting for all gains and losses of fluid, the solute concentration in the lake after a given time increment can be computed by accounting for all solute inflows and outflows. The solute concentration also depends on the type of mixing that occurs between the inflows and the water in the lake at the start of a time increment.

In general, the volume of water in a lake is large relative to the flux through the lake, and circulation and flow-through times in a lake are faster than in a ground-water system. Therefore, it is assumed that complete mixing of all water in a lake occurs during a time step for the ground-water model. By assuming (1) complete and instantaneous mixing within the lake volume of all inflows to a lake, (2) that the time scale of changes in the ground-water system is substantially longer than the time scale of changes in surface water, and (3) that there are no reactions in the lake that affect solute concentration, a simple mixing equation can be used to calculate the solute concentration in the lake. This model does not account for flow dynamics within a lake, nor does it simulate spatial variations in water quality in a lake. Thus, if a lake is so large or deep that it remains unmixed or stratified for long periods of time, or for any other reason, the time for complete mixing of water within the lake is much greater than the length of the time step used in the model, then the use of this model may not be appropriate.

Given that the above three assumptions are reasonable, conservation of mass requires that the sum of all solute mass entering the lake minus the sum of all solute mass leaving the lake must equal the change in solute mass stored in the lake during any given time increment. For a solute, this simple mass-balance statement may be expressed as:

$$\sum Q_i(\Delta t)C_i - \sum Q_o(\Delta t)C_o = V_l^n C_l^n - V_l^{n-1} C_l^{n-1}, \quad (16)$$

where

C is the solute concentration, M/L^3;

Q is the rate of fluid flow, L^3/T;

Δt is the length of the n^{th} time increment used to solve the solute-transport equation; the subscript o refers to flow out of the lake; the subscript i refers to flow into the lake; and the subscript l refers to the lake.

Note that each $Q\,\Delta t$ term equals a volume. For clarity, however, equation 16 is written explicitly in terms of flow rates instead of fluid volumes because the length of the transport time increment may be less than the length of the time step used to solve the flow equation. For this same reason we also assume that the lake volume calculated for the flow time step, V_l^n, applies over all transport time increments used during that particular flow time step.

To calculate the new solute concentration in a lake at the end of a time increment, we rearrange equation 16 to solve for C_l^n, yielding:

$$C_l^n = \frac{\sum Q_i(\Delta t)C_i - \sum Q_o(\Delta t)C_o + V_l^{n-1} C_l^{n-1}}{V_l^n} . \quad (17)$$

Expanding terms to account for all individual elements of inflow and outflow yields:

$$C_l^n = \frac{(\Delta t)\left(\sum_{k=1}^{NTRIB}(Q_{si}C_{si})_k - \sum Q_{so}C_{so} + Q_pC_p - Q_eC_e + Q_{rnf}C_{rnf} - Q_wC_w + \sum_m^M (Q_{spi}C_{spi})_m - \sum_m^M (Q_{spo}C_{spo})_m\right) + V_l^{n-1}C_l^{n-1}}{V_l^n} , \quad (18)$$

where

si refers to streamflow into the lake from each tributary stream (indexed by k);

so refers to streamflow out of the reach (all streams leaving a lake would have the same concentration);

spi refers to the flux from the aquifer into the lake across each of M lake/aquifer cell interfaces;

spo refers to the flux from the lake to the aquifer across each of M lake/aquifer cell interfaces;

rnf refers to overland runoff directly into the lake;

p refers to precipitation directly onto the lake;

e refers to evaporation directly out of the lake; and

w refers to withdrawals directly out of the lake or augmentation directly into the lake.

If w represents withdrawal, the concentration in the withdrawn water is equal to the concentration in the lake (that is, $C_w = C_l^n$). If w represents augmentation, C_w must be specified by the user. Where the lake is losing water to the aquifer, the solute concentration in the ground-water recharge is equal to the concentration in the lake. Where the lake is gaining water from ground-water discharge, the solute concentration (C_{spi}) is equal to the concentration in the aquifer at that specific node of the transport subgrid. If a lake is connected to a stream, then the USGS Stream Package (D.E. Prudic and L.F. Konikow, written commun., 2000) must be active in the MODFLOW simulation. The terms Q_{si}, C_{si}, and Q_{so} are all calculated by the Stream Package and transferred to the Lake Package. The term C_{so} is calculated by the Lake Package ($C_{so} = C_l^n$).

Note that for simplicity, it is assumed that the evaporative flux directly out of a lake contains no solute (that is, $C_e = 0.0$) and that evaporation consequently increases the solute concentration in the water left in the lake. Under this assumption, equation 18 reduces to:

$$C_l^n = \frac{(\Delta t)\left(\sum_{k=1}^{NTRIB}(Q_{si}C_{si})_k - \sum Q_{so}C_{so} + Q_pC_p + Q_{rnf}C_{rnf} - Q_wC_w + \sum_m^M (Q_{spi}C_{spi})_m - \sum_m^M (Q_{spo}C_{spo})_m\right) + V_l^{n-1}C_l^{n-1}}{V_l^n} \,. \quad (19)$$

If a lake dries completely, however, no residual solute remains in the lake grid cells. This is consistent with the assumption that the drying was caused primarily by drainage and outflow, rather than by evaporation. Therefore, the solute-transport model does not include a mechanism to represent precipitation of salts as water evaporates and solubility limits are exceeded.

Because the solute-transport equation can be solved only within a subgrid of the primary MODFLOW grid (or domain), a lake cell could be located adjacent to an active grid cell where the aquifer concentration is unknown and undefined. If this occurs, then for parts of a lake that lie outside the transport subgrid, we assume that there is no change in concentration in the lake caused by the influx of ground water. That is, for such cells it is assumed that $(C_{spi} = C_l^n)$. If the lake is losing water at such a location, the loss is accounted for in the lake budget, but the solute concentration in the seepage loss will have no influence on concentration in ground water and will not be accounted for in the ground-water solute budget. Thus, where a lake lies outside the transport subgrid, we can still account for changes in solute concentration in the lake caused by simple dilution (or mixing) effects related to stream inflow, precipitation, evaporation, and runoff. Obviously, if this condition is occurring in an area that is critical to the analysis, the transport subgrid should be expanded to encompass the entire lake area of interest.

Coalescence and Separation of Lakes

In a previous section, it was noted that irregular lake bathymetry, coupled with substantial variations in lake stage, can lead to the drying of sections of a lake and to the subsequent rewetting of those sections. A related problem occurs when the drying section entirely separates two pools that were originally part of a single lake (fig. 2). Until the stage rises again to a sufficient elevation, the two pools will act as separate lakes, each having distinct water budgets, stages, and volumes of water associated with various sources and sinks. When the stage rises sufficiently that both lakes coalesce into a single pool, a single stage, water budget, and set of volume fluxes will again characterize the system. As an example, Lake Brooklyn in north-central Florida (Merritt, 2000) may divide by gradual stages into 10 or more pools and later merge to become a single body of water once again as the stage increases.

The problem that presents itself in terms of representing lakes in a ground-water flow model is how to treat such a system of lakes in a consistent manner in calculations that involve substantial fluctuations in the ground-water table. The solution developed for inclusion in the USGS Lake Package requires the model user to provide time-invariant definitions of the lake geometry and the system of water-budget accounting. The user identifies in advance all important individual pools that can result from the lowest expected stage that could occur in the natural lake system or in scenarios posed for modeling. The individual pools, or "sublakes," are then represented as independent lakes in the input data specifications for the lake simulation. The user also specifies a heirarchy of lake systems, defined as sets of center lakes and surrounding, possibly connected, sublakes. The sublake of a center lake can also be specified to be a center lake of another lake system in a subsequent specification. Associated with each possible connection in a lake system is a sill elevation, defined as the elevation at which the center lake and the sublake are connected and have a common stage and water budget. Sill elevation is usually the elevation of the intervening land surface (when dry, fig. 2b), or shallow lake bottom (when wet, fig. 2a), between the two lakes.

Starting with the center lake of the first specified lake system, the lake and sublake stages and sill elevations are examined to determine the set of sublakes that are currently connected. If a connected sublake is a center lake in a subsequent lake system specification, the stages and sill elevations of the sublakes of that lake system are also examined and the sublakes possibly added to the current connected lake system.

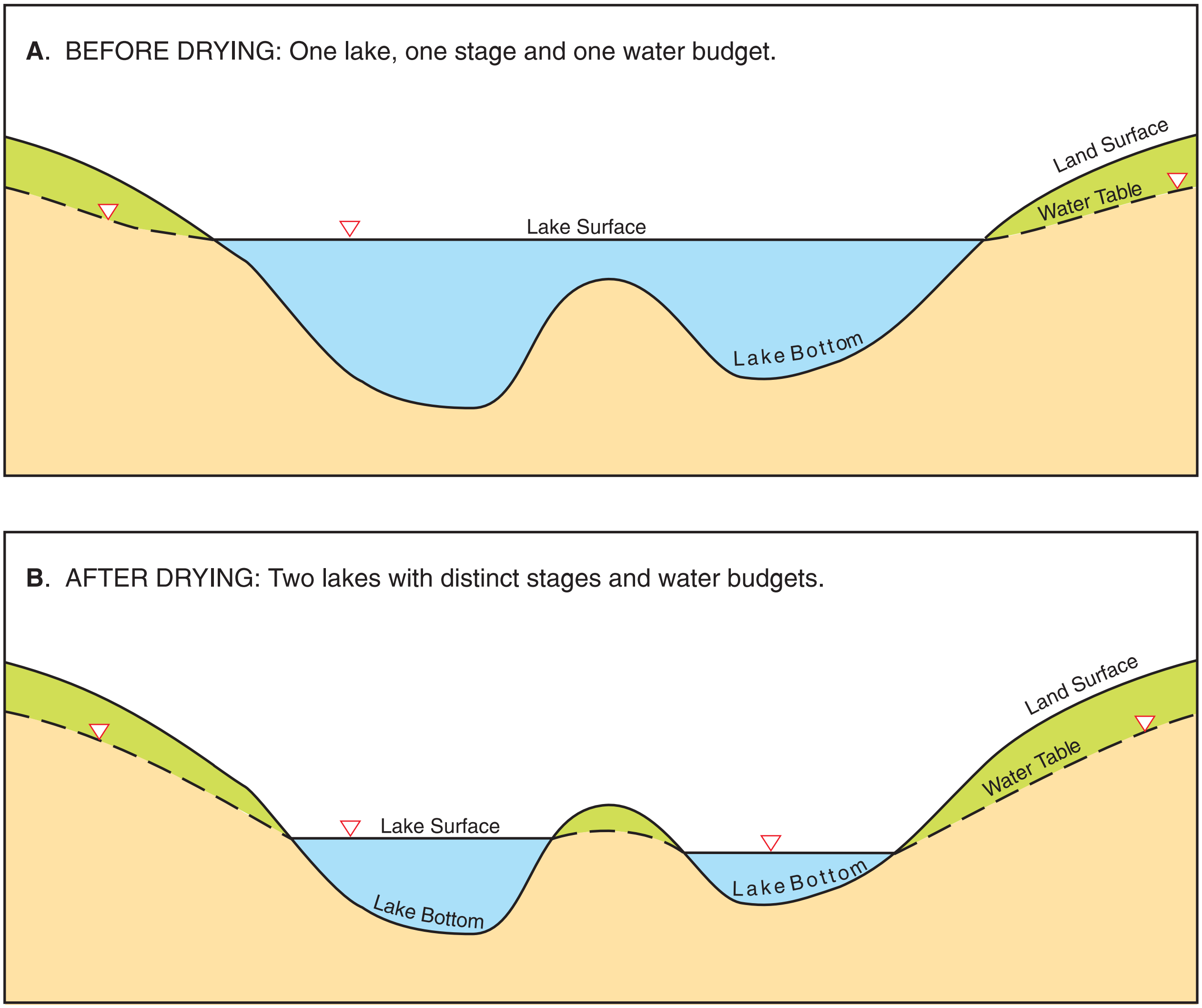


Figure 2. The drying of a lake and its separation into two lakes with distinct stages and water budgets.

When the complete connected lake system is determined, the solution to a system of simultaneous equations is applied to equalize stages in all of the connected lakes. In these equations, individual lake stages are weighted according to their current surface area. The first equation of the set of simultaneous equations, representing the principal of mass conservation, equates the change in volume ($A_1\Delta h_1$) resulting from the stage correction to the main center lake (Δh_1) to the negative sum of the changes in volume of the remaining lakes ($A_i\Delta h_i$) in the system of n connected lakes:

$$A_1\Delta h_1 = -\sum_{i=2}^{n} A_i\Delta h_i \ , \qquad (20)$$

where

A_i is the current surface area of lake i.

The remaining n-1 equations state that all connected lakes have the same stage:

$$\bar{h} = h_1^{\ 0} + \Delta h_1 = h_j^{\ 0} + \Delta h_j \qquad (1 < j \leq n) \ , \quad (21)$$

where

$\bar{h}$ is the corrected stage common to all the lakes, and

h_j^0 is the simulated stage in lake j before the correction Δh_j is applied.

The solution is a series of n equations (i = 1,...,n) of the form:

$$\Delta h_i = \frac{\sum\limits_{j=1, j \neq i}^{n} A_j (h_j^0 - h_i^0)}{\sum\limits_{j=1}^{n} A_j} \quad . \qquad (22)$$

The Δh_i values are used to compute interchange volumes and the common stage $\bar{h}$.

In some trial simulations using this method, the stages of one or more smaller lakes determined to be part of the connected lake system received corrections that lowered their stages below their respective sill elevations. The scenario considered to be physically more realistic is that the smaller lakes with sill elevations that were intermediate between their simulated independent stages and the common stage computed by equation 22 would spill into the connected lake system until the stage of the smaller lake dropped to the sill elevation, at which time, the interchange of water would cease and the stage of the smaller lake would remain fixed at the sill elevation. Mathematically, this scenario places a constraint on the possible range of variation of the stage of some of the lakes in a connected lake system, and the solution developed above needed to be modified to take these constraints into account.

A logical check performed after equalizing the stages of a connected lake system determines if the stages of any sublakes have been drawn down below their sill elevations. If so, and these sublakes are denoted by indices j_m+1 to n, then the system of simultaneous equations (eqs. 20 and 21) is replaced by the following system of equations:

$$A_1 \Delta h_1 = -\sum_{i=2}^{j_m} A_i \Delta h_i - \sum_{i=j_m+1}^{n} A_i \left(h_{s_i} - h_i^0 \right) , \qquad (23)$$

where

h_{s_i} is the sill elevation for lake i, and:

$$\bar{h} = h_1^0 + \Delta h_1 = h_j^0 + \Delta h_j \qquad (1 < j \leq j_m) \quad . \qquad (24)$$

The solution to this set of j_m equations is a set of j_m equations (i = 1,...,j_m) of the form:

$$\Delta h_i = \frac{\sum\limits_{j=1, j \neq i}^{j_m} A_j (h_j^0 - h_i^0) - \sum\limits_{j=j_m+1}^{n} A_j \left(h_{s_j} - h_j^0 \right)}{\sum\limits_{j=1}^{j_m} A_j} \quad . \qquad (25)$$

The stages of lakes denoted by indices j_m+1 to n are set equal to their sill elevations h_{si}. After equations 22 or 25 have been applied to equalize the stages within a connected lake system, the logic proceeds down the list of specified lake systems of center lakes and sublakes. If a center lake is found that has not been defined as part of a previous connected lake system, the steps above are repeated in an effort to define another connected lake system and to equalize stages. The logic proceeds in this way until the list of lake systems is exhausted.

The process of lake coalescence and stage equalization can be visualized with the help of an illustration (fig. 3). Figure 3a shows three sublakes, labeled 1, 2, and 3, of different surface area. Sublake 2 is considered to be the center lake and has the largest surface area. Sublake 1 has the smallest surface area. The sublakes are divided by land areas of low elevation, labeled A and B. Sublakes 1 and 2 are connected if the stage of each exceeds the elevation of land area A. Sublakes 2 and 3 are connected if their stages exceed the elevation of land area B. In figure 3a, all lake stages are below the elevations of land areas A and B (referred to previously as “sill elevations”). Therefore, the three lakes are separate and have independent water budgets and distinct stages that reflect local hydrologic conditions.

In figure 3b, the stages of the three sublakes have increased as a result of ground-water seepage influx, atmospheric recharge, anthropogenic augmentation, or some combination of those factors. Still treated as independent lakes by the logic of the Lake Package, the sublake stages exceed the “sill elevations” of the land areas A and B that divide them. The stage of the smallest sublake (1) is the highest of the three because, if all hydraulic properties and processes affect the sublakes equally and seepage inflow is considered to be proportional to the circumference of the lake, the stage of the sublake with the smallest surface area will increase the most. Because sublake stages exceed the respective sill elevations, equation 22 is applied three times to compute the stage corrections to give the sublakes a common stage, which is illustrated by figure 3c.

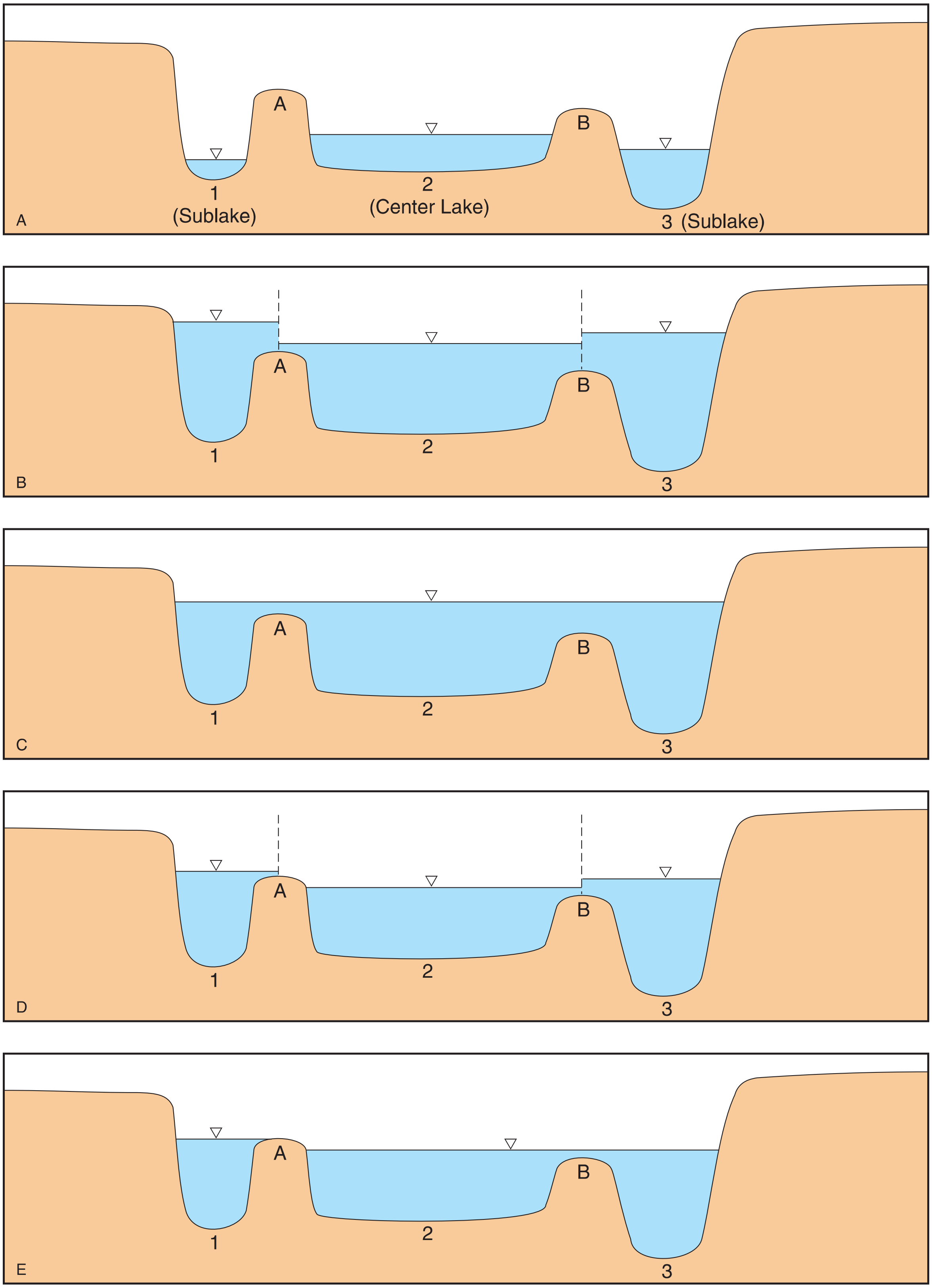


Figure 3. The process of sublake coalescence and stage equalization, as simulated by the Lake Package.

In figure 3d, the three sublake stages have increased because of inflows, as before, but the stage increases are not as great as in the case shown in figure 3b. Because the stages of sublakes 1 and 3 exceed the respective sill elevations, all three sublakes are considered connected, but when the stages are equalized using equation 22, the common stage falls below sill elevation A. To obtain a more realistic result (fig. 3e), the stage of lake 1 is set at its sill elevation (A) and sublakes 2 and 3 have their stages equalized by equation 25, which takes into account the limited volume of water contributed by sublake 1.

The model user should note that, although the logic described above has been tested and modified to be as robust as possible, nature can present a wide variety of unexpected scenarios that may defeat even the best-designed logical system. This is especially true for a system of logic designed to deal with the complex problem of coalescing and separating lakes. The model user should be prepared to modify and generalize the way the application problem is presented for modeling purposes to make the solution work with maximum effectiveness.

The situation in which a center lake is drawn down below the sill elevation of a large sublake by the equalization procedure has been investigated by the first author. This situation can occur when a center lake of a system of disconnected sublakes is simulated as receiving large surface-water inflows. Eventually, the stage of the center lake exceeds the sill elevation of one or more sublakes. Equalization of the stages may lead to the unrealistic result of the center lake being lowered below the sill elevation of the sublakes. A few time steps later, as the center lake continues to fill, the situation may recur. Eventually, the sublakes are filled and all lakes remain connected.

Unfortunately, because there may be many sublakes with differing sill elevations, the task of formulating a logical approach with sufficient generality to deal with all possible aspects of this situation has proved daunting. However, the lake coalescence logic has been formulated to ensure that the overall volume of water in the lake system is conserved, so there will be no error in the cumulative water budget, even when computed stages of the center lake oscillate in time. Possibly, this condition could be avoided by reposing the problem, perhaps by redefining the connected sublake network. Such a redefinition would involve primarily the appropriate selection of which sublake should be considered the center lake of the network.

As previously noted, the lake coalescense and division procedure cannot be used when MODFLOW is used in steady-state mode (one time step). However, preliminary runs can indicate the degree of subdivision that will occur at the approximate steady-state lake stage, and a final steady-state solution can be made with the correct subdivision specified as the lake-geometry definition.

Assumptions and Limitations

Many of the assumptions and limitations inherent in the design and implementation of the Lake Package have been discussed in previous sections of this report. Following is a summary of major considerations for the model user.

- It is assumed that the position and spatial extent of the lake volume is defined by the specification of a volume of inactive cells within a three-dimensional model grid. Because the model grid is used to define the lake volume, the lateral and vertical grid dimensions must be appropriately chosen so that the spatial extent and bathymetry of the lake are defined with the necessary accuracy. In some cases this may require a finer horizontal discretization in the vicinity of the lake and a finer vertical discretization than would be necessary to simulate heads in the aquifer.
- Layers containing lakes must be specified as either unconfined or convertible (LAYCON = 1 or 3), so that top and bottom elevations of layers can be conveniently defined.
- IBOUND matrix entries corresponding to grid cells that are identified as part of a lake should be set equal to zero.
- When the option of rewetting dry cells is not implemented, the model user must use the lakebed leakance specification to represent the combined leakance of the lakebed and the aquifer in the vertical direction.
- If the head in the aquifer drops below the bottom of a lake still containing water, the seepage rate from the lake is limited to that which would occur if the aquifer head were the same as the elevation of the bottom of the lake.
- In using the explicit method of updating lake stages, the time step length should be small enough that lake stages from the previous time step provide good estimates of lakebed seepage in the current time step.
- In using the explicit method of updating lake stages, there will be a limitation on time step size that must be observed to prevent timewise oscillations in lake stage. The size of this limit depends on the parameters of the application problem.

- Compared to the explicit method of updating lake stage, the semi-implicit and fully-implicit methods require more iterations, more run time, and tighter convergence criteria to minimize the percent discrepancy in the aquifer water budget.
- Lake-aquifer simulations may experience stability problems if inappropriate parameter values are specified in the input data for the setup of the wet-dry option.
- During a computational time period in which a dry lake rewets, the use of relatively small time steps will help to avoid substantial inaccuracies in the lake and aquifer water budgets.
- The method for rewetting a dry lake does not take into account the possible retarding effect of the lakebed.
- Only the explicit method of updating lake stage can be used when the Lake Package is used as part of a MODFLOW steady-state simulation.
- The method used for computing lake stages as part of a MODFLOW steady-state solution can fail if the initial estimate is substantially different from the solution value, so the user should choose an initial value that is as close as possible to the anticipated solution value.
- The method used for computing lake stages as part of a MODFLOW steady-state solution works better if the initial estimate and solution value are not on opposite sides of a layer boundary where a change in the lake surface area occurs.
- When the Lake Package is used as part of a MODFLOW steady-state solution, the option for simulating coalescing and dividing lakes will not work, and its use should not be attempted.
- The Lake Package is not suitable for simulating tilted aquifer systems having a tilted grid because the package assumes that lake stage is uniform across the entire surface area of the lake.
- The logic for simulating coalescing and dividing lakes is an attempt to generalize a set of conditions that can manifest a wide variety of characteristics. The user should be prepared to critically evaluate model results, repose the problem, and simulate it in alternative ways if initial attempts do not work well.
- If the Lake Package is used in conjunction with a MOC3D solute-transport simulation, the user should check that it is reasonable to assume complete mixing in the lake within the length of the time step in the model.

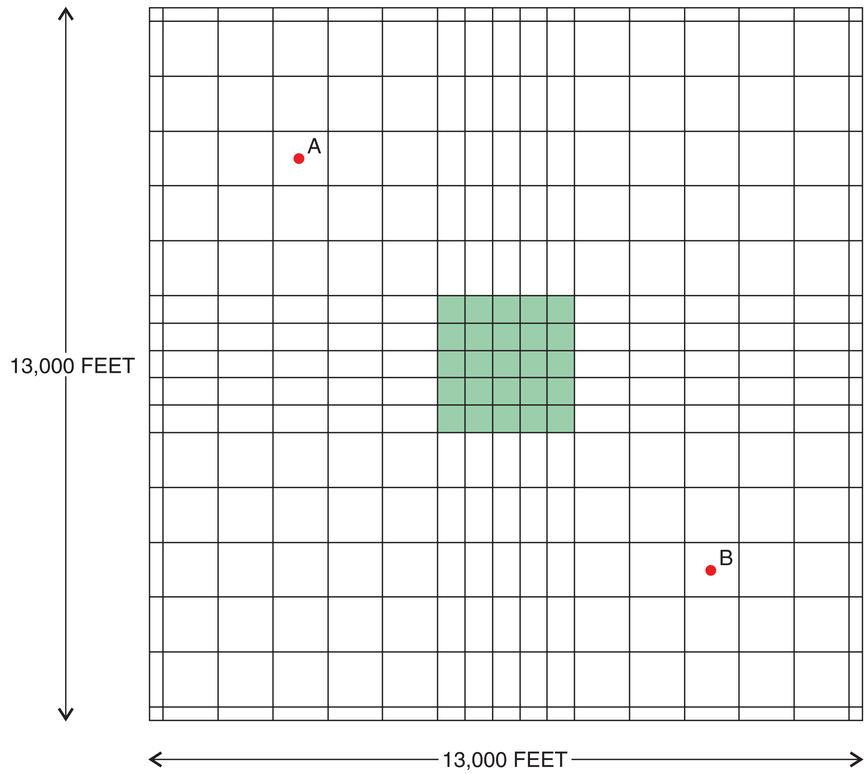
TEST SIMULATIONS

Four test simulations were run to develop examples that illustrate various features of the Lake Package. The general instructions for setting up and inputting data to run the Lake Package are presented in appendix 1. The first test simulation (app. 2) illustrates the interaction of a lake and aquifer as each reaches equilibrium under time-invariant conditions. This problem is solved using MODFLOW in transient and steady-state modes. A special case of this test simulation illustrates the operation of the Lake Package as the lake and aquifer undergo a substantial degree of drying that causes desaturation of lake volume nodes and aquifer nodes. As part of this special case, the entire lake dries before the process is reversed and rewetting occurs. The second test simulation (app. 3) illustrates the operation of the Lake Package when two lakes have, and are interconnected by, inflowing and outflowing streams. The third test simulation (app. 4) illustrates the operation of the Lake Package in simulating the separation and coalescence of a group of lakes separated by land areas of low elevation, or, alternatively, a lake with several deep pools separated by areas of shallow-bottom elevation. The final test simulation (app. 5) illustrates the updating of a lake solute budget as the Lake Package is used in conjunction with MOC3D. Test simulations 1, 3, and 4 were performed using MODFLOW96. Test simulation 2 was performed using MODFLOW2000 so that it would be possible to link with the new USGS Stream Package (D.E. Prudic and L.F. Konikow, written commun., 2000), available only in MODFLOW2000.

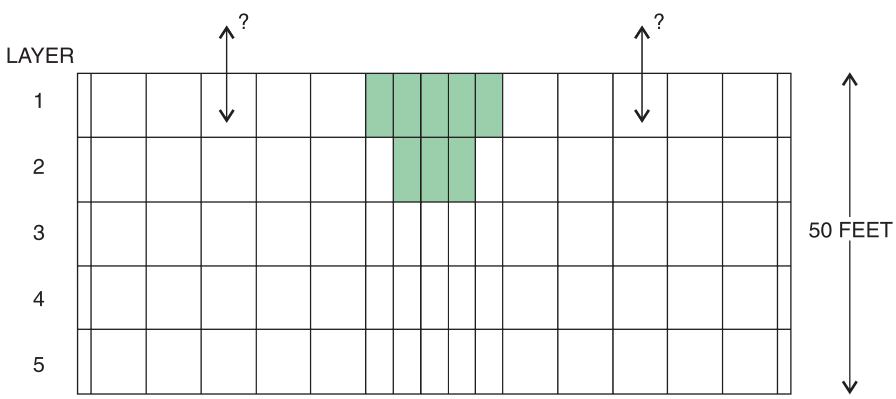
Test Simulation 1: Lake-Aquifer Equilibrium Simulation

Test simulation 1 (app. 2) represents a lake surrounded by a surficial aquifer. In a transient MODFLOW simulation, the heads and lake stage are allowed to respond interactively to time-invariant conditions until an equilibrium interactive state is reached. The same conditions are specified for a MODFLOW steady-state simulation in one computational time step. In both simulations, the initial conditions for head in the aquifer and the stage of the lake are artificially set at values appreciably different from the equilibrium values to more clearly illustrate the convergence process.

The aquifer segment is discretized laterally and symmetrically into 17 rows and 17 columns, as shown in figure 4a. The aquifer is discretized vertically into 5 layers that adjoin each other vertically (fig. 4b). The top layer is surficial (LAYCON = 1, as shown in the input data for the Block-Centered Flow Package in app. 2). In the transient simulation, the top layer is assigned a storage coefficient equal to the estimated specific yield of 0.20. The storage coefficient specification is omitted in the steady-state simulation. Layers 2 through 5 are considered convertible (LAYCON = 3)



A. Plan view -- Shaded area is the surface extent of lake cells in layer 1. Interior grid dimensions are 500 and 1,000 ft. Border row/column cells are 250 ft. thick. A and B denote the locations of hypothetical observation wells.



B. Cross-sectional view -- Shaded area is the cross section of the lake. Although a nominal 10 ft. thickness is shown for layer 1, the upper surface of layer 1 is not actually specified, and lake stages and aquifer water-table altitudes may rise higher than the nominal surface shown above.

Figure 4. The lateral and vertical grid discretization for test simulation 1.

between confined and unconfined states; in the transient simulation, layers 2 through 5 are assigned primary storage coefficients of 0.0003 (confined) and secondary storage coefficients of 0.20 (if they convert to unconfined). The Lake Package requires that layers 2 and 3 be considered convertible so that top and bottom elevations will be specified in the input to the Block-Centered Flow Package. In test simulation 1, layers 2 through 5 are each considered to be 10 ft thick. The input logic of MODFLOW does not require a top elevation to be specified for layer 1. Formally, there is no upper limit on computed heads or lake stages in layer 1. The assigned bottom elevations for layers 1 through 5 in the simulation are 107, 97, 87, 77, and 67 ft, respectively. A uniform and horizontally isotropic hydraulic conductivity of 30 ft/d is assigned to all layers of the model grid, and represents flow in a semi-permeable surficial aquifer composed of silty sands. The vertical hydraulic conductivity is also 30 ft/d, resulting in a vertical leakance value of 3 d^{-1} between each successive pair of layers and assuming a nominal thickness of 10 ft for layer 1.

The grid cells that correspond to the lake volume must be assigned a zero inactive cell code (IBOUND = 0) in the input to the Basic Package (app. 2). It is also necessary to specify a wet-dry value of zero for these cells in input to the Block-Centered Flow Package if the wetting capability of MODFLOW is enabled. The lake volume cells are shown as shaded areas in the planar and cross-sectional view of the model grid in figures 4a and 4b. These same cells are assigned an identification number of 1 (to associate them with lake "number 1") in the matrices in the input to the Lake Package (app. 2).

Further input to the Lake Package designates that a lakebed leakance of 0.1 d^{-1} be assigned to all lake/aquifer cell interfaces in each layer, and that 110 ft be the initial lake stage. The last input line to the Lake Package specifies recharge and evaporation rates for the lake of 0.0116 ft/d (the average rainfall rate) and 0.0103 ft/d, respectively. Recharge to the aquifer, which is specified by the input to the Recharge Package (app. 2), also is equal to the average rainfall rate of 0.0116 ft/d. The Evapotranspiration Package (app. 2) specifies the "evapotranspiration surface," the elevation in the aquifer below which evapotranspiration (ET) is assumed to decline linearly. This elevation is represented as sloping from 160 ft in the west to 140 ft in the east, except in the lake area, where the elevation is specified as 3 ft below the lakebed (this means that in the possible case of lake drying, land-surface ET from the water table under the dry lakebed is at the maximum rate if the water table is not deeper than 3 ft below the lakebed). Away from the lake, the ET surface is an implicit representation of land surface, since the latter is normally equal to or slightly above the ET surface. The extinction depth is specified to be 15 ft, and the maximum potential evapotranspiration rate is specified to be 0.0141 ft/d.

The initial head in each model layer is set equal to 115 ft by the Basic Package. The Flow and Head Boundary Package (Leake and Lilly, 1997) is used to set boundary conditions (160 ft on the western boundary, 140 ft on the eastern boundary, and varying linearly between these values along the northern and southern boundaries), which are specified as constant in time.

A list of selected sections of output from the transient run of test simulation 1 follows the listing of input in appendix 2. This application of the Lake Package used 24,602 elements of the "X array." Following a list of lakebed leakance values is a list of cell interfaces between the aquifer and the lake volume that are identified by the Lake Package based on the input data. In this list, there may be two or more cell interfaces associated with each aquifer grid cell, depending on the lake geometry. Together with the cell location are a code (ITYPE) that identifies the plane in which the cell interface lies, and the assigned lakebed leakance value. (ITYPE = 0 for a cell interface in a horizontal plane across which vertical flow between adjacent model layers occurs, ITYPE = 1 or 2, respectively, for a lateral-flow cell interface in a vertical plane in the *x* or *y* coordinate directions, respectively.) The subsequent list of "interface conductances for lakes" associates conductance values (in the last column) with each of the lake/aquifer cell interfaces. The two previous columns are the conductances associated with the lakebed and the aquifer, respectively. If the "wet-dry" option were not used (IWTFLG = 0), only the lakebed leakance would be listed, and its value would be considered to include the aquifer leakance. When the conductances are in the lateral direction (column 5, ITYPE = 1 or 2), they are expressed as values per unit thickness. Vertical conductances (column 5, ITYPE = 0) are for the entire lake/aquifer cell interface. Following the conductance table is a table presenting the stage-volume relation for the lake as represented in the model grid.

The results of the transient run are shown in figure 5 and in additional output included in appendix 2 following the stage-volume table. Both water-table altitudes and the lake stage converge asymptotically to

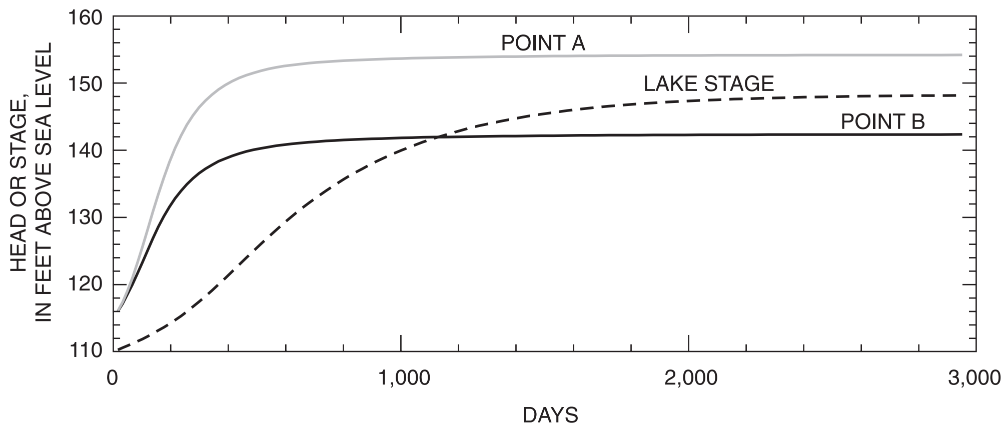


Figure 5. Selected heads in the aquifer and the lake stage computed by test simulation 1 - transient run to equilibrium. Locations of points A and B are shown in figure 4.

equilibrium values (fig. 5). The water-table altitudes approximately converge in about 1,000 days and the lake stage in about 2,000 days of simulation time. The list of selected model output shows results for time step 10 after about 175 days (d) and at the end of the run (after 5,000 d). The hydrologic budget summary for the lake at time step 10 shows that only inflow to the lake occurs through the lakebed. The stage is still quite low (113.6 ft). The MODFLOW volumetric budget for the aquifer also shows zero cumulative lake seepage under the "IN" heading (into the aquifer from the lake), and over $2x10^7$ cubic feet (ft^3) under the "OUT" heading (out of the aquifer into the lake). The percent discrepancy is small, a desirable result indicating a good solution in which the various water fluxes balance each other. The MODFLOW solution using the SIP solver required 8 iterations to converge in time step 10.

The hydrologic budget summary for the lake at the end of the transient run shows that both inflows to the lake and outflows from the lake occur through the lakebed; the lake outflows exceed the lake inflows by almost 50 percent for the final 113.7-day time step. The volumetric budget for the aquifer (rates for the time step) shows the same ratio of inflowing (to the aquifer) and outflowing (from the aquifer) lake seepage rates for the time step. The cumulative percent discrepancy in the MODFLOW solution is small, indicating a good balance of computed water fluxes. The lake stage has increased to over 148 ft. An examination of additional output indicates that inflows to the lake from the aquifer occur in columns 8 and 9 of the grid, and outflows from the lake to the aquifer occur in columns 10, 11, and 12, which is consistent with the model design that specifies boundary head values that slope downward toward the east.

Semi-implicit and fully implicit lake stage calculations

When a semi-implicit calculation for lake stages was specified in the Lake Package input (THETA = 0.50 on the second line of input shown in app. 2), the simulated lake stage differed from that simulated by the explicit method (THETA = 0.0) by 0.01 ft, and the cumulative percent discrepancy was 0.02 percent, an acceptable value. Time step 10 took 12 iterations to converge. When lake stage was calculated fully implicitly (THETA = 1.0), the simulated lake stage differed from that simulated by the explicit method by 0.03 ft and the cumulative percent discrepancy was 0.03 percent, still an acceptable value. Time step 10 took 26 iterations to converge.

Steady-state solution

The transient MODFLOW run (explicit case) was converted to a steady-state run by making minor changes to the input data sets for the Basic Package (BAS), the Block-Centered Flow Package (BCF), and the Lake Package (LAK), appendix 2, as follows.

1. The last record of the input to the BAS was modified to make PERLEN = 1.0 and NSTP = 1 (stress period length a nominal 1 day and 1 time step in the stress period).
2. The first entry on the first line of input to the BCF was changed from 0 to 1 (steady-state input flag) and all lines of input for "storage coefficient," "primary storage coefficient," and "secondary storage coefficient" were deleted.
3. The second and third lines of input to the LAK were modified as shown in appendix 2. The two new parameters added to the list on the second line are the maximum number of iterations (50) of the

Newton's method solution for equilibrium lake stage in each MODFLOW iteration and the convergence criterion (0.001 ft). The two new parameters added to the list on the third line (100.0 and 170.0 ft) are the minimum and maximum allowable values for lake stage.

Selected sections of the output from this run are included in appendix 2. The Newton's method solution for lake stage convergence required two iterations at the start of the 472 MODFLOW iterations, but only required one iteration near the end. The solution for lake stage converged to a listed value of 148.28 ft, about 0.01 ft different from the listed stage value from the transient run, an acceptable result. (The actual difference was 0.0030 ft.) The percent discrepancy in the MODFLOW solution was small. Specifications of THETA = 0.50 and 1.00 had no effect on computed results, which was to be expected as implicit solution weighting factors have significance only in transient calculations.

Drying and rewetting

As a final test of the transient model based on the simple case of a single lake without stream connections, the lake was allowed to dry under idealized and extreme simulated drought conditions before the conditions specified for the previous transient and steady-state simulations were reestablished. This was done by specifying two 5,000-d stress periods instead of one, the first representing a drying scenario, and the second a return to previous environmental conditions. This goal was accomplished by making minor changes to the transient-run input data sets (app. 2) for the Basic Package (BAS), the Evapotranspiration Package (EVT), the Recharge Package (RCH), and the Lake Package (LAK), as follows.

1. The fourth field of the first record of input to the BAS, specifying the number of stress periods, was changed from 1 to 2. The last record of input was repeated for a second stress period. In addition, the initial heads in the aquifer, first five of the last six lines, were changed from 115 ft to 145 ft to enhance and better illustrate the results of the simulation.
2. The value for maximum ET rate (0.0141 ft/d) used previously in the transient and steady-state equilibrium runs was increased to 0.0412 ft/d in the first stress period. This value is larger than would be reasonable in nature, but serves the purpose of this exercise by enhancing the simulated drying of the aquifer. A record with three fields was added at the end of the input data set for the EVT to indicate that a new value for the maximum ET rate was to be read for the second stress period. Then a value of 0.0141 ft/d, the previous maximum ET rate, was entered on an additional line.
3. The last two records of the input data set for the RCH were repeated for a second stress period with a recharge rate specified to be the same (0.0116 ft/d) as for the transient and steady-state equilibrium runs described previously. The recharge rate for stress period 1 was changed from 0.0116 ft/d to 0.0 to represent drying conditions.
4. The input data set for the LAK was modified as shown in appendix 2. One change was the first entry in the third record (initial lake stage). The value was changed from 110 ft to 140 ft to enhance and better illustrate the results of the simulation. Two more records were added at the end of the input data set for a second stress period with environmental parameters having the same values as for the transient and steady-state equilibrium runs described previously. In the record for the first stress period, the lake recharge (rainfall) rate was changed to 0 ft/d, and the evaporation rate was quadrupled to 0.0412 ft/d. This rate is not realistic but serves the purpose of this exercise by causing the simulated lake to go dry.

In addition to these changes, the number of records in the output control (OC) input data set are doubled to provide for twice the number of time steps as required for the transient equilibrium run described previously. The sequence of drying and rewetting is shown in figure 6, and abbreviated output for various time steps is shown in appendix 2. In time step 30, the drying is well underway but the stage (124.77 ft) is still above the bottom of the uppermost layer of grid cells (fig. 6). The surface area of the lake is listed as 6,250,000 square feet (ft^2), which is the combined area of the twenty-five 500-ft x 500-ft lake cells as indicated by the input to the Lake Package for layer 1. In time step 70, drying has progressed to the point that the lake surface (at 102.61 ft) is between the top and bottom of layer 2. The lake surface area is now listed to be 2,250,000 ft^2, which is the combined area of the nine 500-ft x 500-ft lake cells shown in the input to the Lake Package for layer 2. In time step 76, the stage

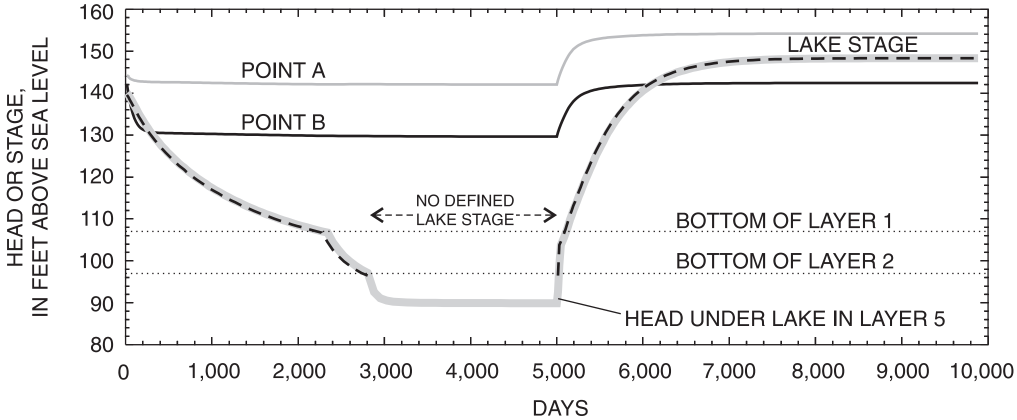


Figure 6. Selected heads in the aquifer and the lake stage computed by test simulation 1 - drying and rewetting case. Locations of points A and B are shown in figure 4.

goes below 97 ft (the bottom of layer 2) and the Lake Package recognizes that the lake has gone dry. In time steps 77-100, the lake remains dry, the last computed value for stage remains unchanged, and the surface area is listed as zero. All atmospheric and other fluxes to and from the lake are listed as zero.

When atmospheric recharge to the lake and aquifer begin in stress period 2, and lake evaporation is reduced to 25 percent of the value for the first stress period, heads in the aquifer beneath the lake recover quickly, as shown in figure 6 and by comparing values listed for step 2, period 2, with values listed previously for step 70, period 1 (app. 2). In time step 2, stress period 2, the logical test for rewetting a lake is satisfied, and the lake is assigned a stage of 103.77 ft. Aquifer heads and the lake stage continue to recover quickly, and by the end of the second stress period, time step 100, the lake stage has converged to the value, 148.29 ft, previously computed in the transient and steady-state equilibrium simulations.

Test Simulation 2: Stream-Lake Interconnections

In test simulation 2 (app. 3), a stream passes through two lakes (fig. 7). Thus, both lakes have inflowing and outflowing streams, and the outflowing stream for the upper lake is the inflowing stream for the lower lake. This test simulation specifies lake and aquifer characteristics and stresses similar to those of test simulation 1, which makes possible an evaluation of the influence of inflowing and outflowing streams on lake stages, given the described aquifer conditions. Results provide a striking contrast with the results of conditions specified in test simulation 1, where an isolated lake interacted solely with the surrounding aquifer. The test simulation is first performed using transient calculations, and is then performed again using steady-state calculations. Lake stage was computed explicitly (THETA = 0.0).

As shown in the input data for the Basic, Block-Centered Flow, and Discretization Packages (app. 3), the grid of test simulation 1 has been enlarged with the addition of 10 additional rows. The coding of the matrix input to these three packages and the Lake Package (app. 3) shows that there are now two lakes identical in dimension and configuration to the single lake of test simulation 1 and separated by 5 rows representing an intervening distance of 5,000 ft (fig. 7). The two lakes are given identification numbers 1 and 2 in the input to the Lake Package (app. 3). Aquifer hydraulic conductivity, leakance, and storage coefficients are as for test simulation 1. The hydraulic conductivity of the lakebed (0.10 ft/d) is the same as in test simulation 1. The initial aquifer head is 115 ft in all layers and the initial stages in the upper and lower lakes are each 130 ft. Recharge, evaporation, and evapotranspiration (ET) coefficients are the same as for test simulation 1, although the ET surface has been expanded and revised to show the presence of two lakes (app. 3). Boundary head values are as in test simulation 1, and are input using the Flow and Head Boundary Package (FHB).

As shown by the input data (app. 3) to the Stream Package (D.E. Prudic and L.F. Konikow, written commun., 2000), an arbitrary inflow amount of 6.9×10^5 ft^3/d is assigned to the uppermost reach in the system (reach 1 of stream segment 1). The length

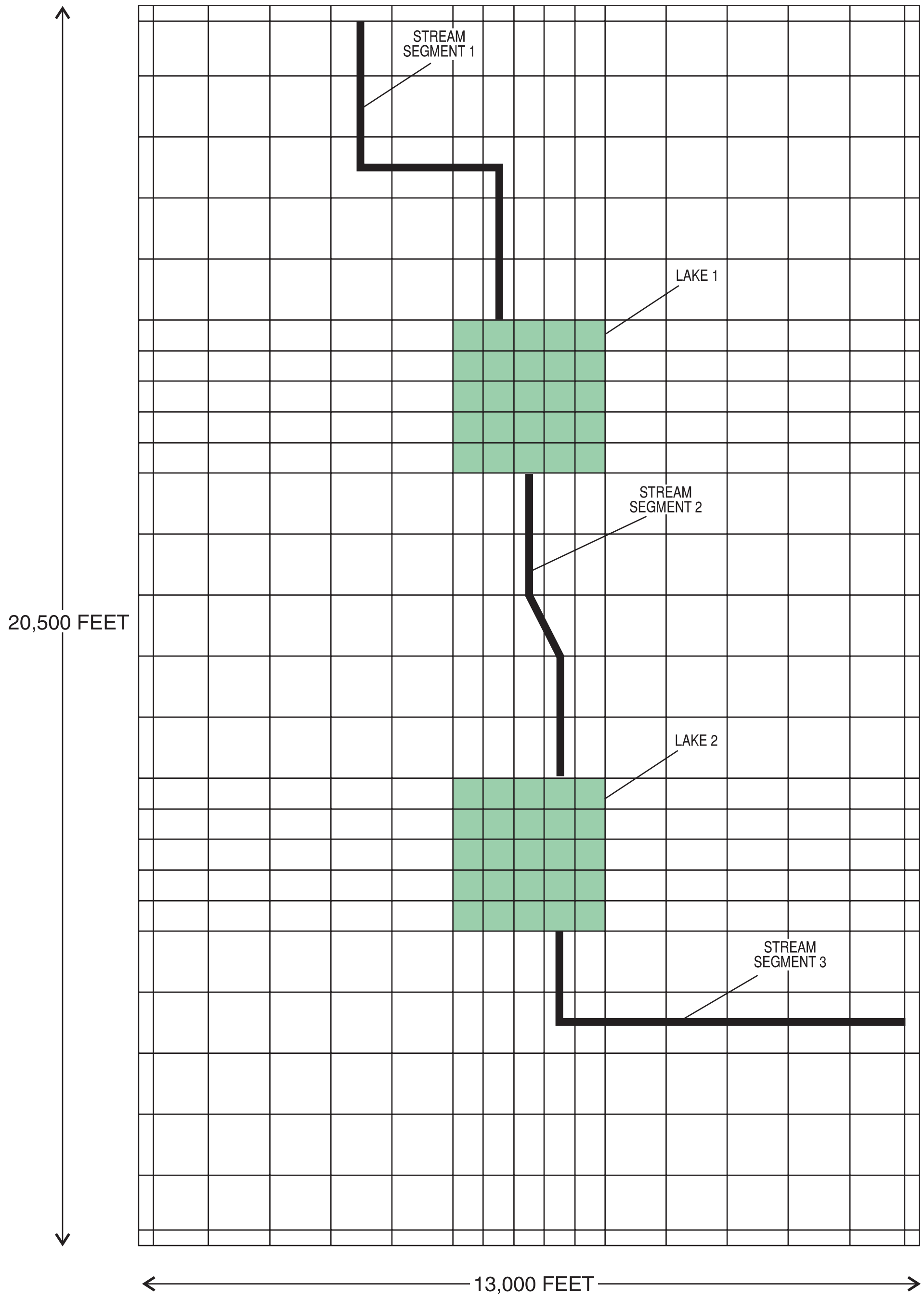


Figure 7. Relation of streams and lakes to the model grid used for test simulation 2.

of each individual reach is obtained from the dimensions of the model grid (fig. 7). Most reaches are specified to be 1,000 ft in length and all are at least 500 ft in length. Stream segment 1 has 8 reaches and flows into lake 1. The elevation of the top of the streambed drops from 124 to 117 ft between the centers of the upper and lower reaches. (The specified streambed elevations are for the upstream and downstream ends of the segment.) Stream segment 2 has 6 reaches and flows out of lake 1 and into lake 2. The elevation of the top of the streambed at the reach centers drops from 114.5 to 111 ft in the segment. Stream segment 3 flows out of lake 2 and has 8 reaches. The top of the streambed at the reach centers drops from 109 to 103 ft in the segment. The streambed is assumed to be 0.5 ft thick everywhere, and arbitrary uniform values are assigned for streambed hydraulic conductivity (0.5 ft/d), stream width (5 ft), and roughness coefficient (0.05). Stream stage is calculated by Manning's formula (ICALC = 1) and not prespecified. The streambed hydraulic conductivity value is sufficiently high to allow small exchanges of water with the surficial aquifer. In this example, it is assumed that there is no precipitation on the stream surface, evaporation from the stream surface, or overland runoff to the stream.

Because of the stream connections, lake stages remain well below the stage computed for the isolated lake in test simulation 1. By time step 200, at the end of the 1,500-d simulation, aquifer heads in the interior part of the grid have greatly increased except in the immediate vicinity of the lakes, as shown in selected pages of the output file for the simulation. With an outflow elevation to a stream segment of 114.85 ft, the stage of lake 1 converges to 118.1 ft, and with a stream outflow elevation of 109.4 ft, the stage of lake 2 converges to 113.2 ft. These stages are 25-30 ft below the equilibrium stage of the isolated lake of test simulation 1.

The hydrologic budget for the lake shows that, while the inflow to the upper stream segment remains fixed as a model parameter, ground-water and surface-water inflows to each lake are balanced by water that discharges to its downstream stream segment. As a result, the stream system, as described in the input to test simulation 2, acts as a highly effective drain for the lake/aquifer system. The depth of flow in stream segment 2 is about 2.5 ft and the depth of flow in stream segment 3 generally is about 2.5-3 ft. The volume of water leaking from the aquifer to the stream generally is about 2 to 3 percent of the flow of each reach.

In this test simulation, the time step length did not exceed 12 d. This restriction was made necessary by the tendency of flows in the stream/lake system to become unstable and oscillate in successive time steps when the time-step length became greater than about 20 d. The tendency for oscillatory behavior is likely related to the relative rapidity of streamflow in relation to ground-water flow and the resulting large surface-water fluxes that are computed. When time steps are large, minor approximation errors can produce large errors in the surface-water terms that are part of the water budgets for the lakes.

The steady-state run was prepared using the same techniques described for test simulation 1. In addition, initial stages in the upper and lower lakes were specified to be 120 ft and 115 ft, respectively. Minimum and maximum allowable stage ranges were specified as 97 ft (the lake bottom) and 130 ft, respectively. The solution for each lake stage in each MODFLOW iteration was expected to satisfy a closure criterion of 0.001 ft in no more than 50 iterations.

Results (app. 2) show that MODFLOW required 30 iterations to achieve a steady-state solution, far less than the 472 required in test simulation 1. In early iterations, the steady-state solution for equilibrium lake stage took as many as 17 iterations, far more than the maximum of 2 iterations per time step required in test simulation 1.

The test problem was rerun with the width of the stream segments increased to 7 ft. However, the steady-state MODFLOW run could not be made to converge, even by the use of initial values close to the known solution. The exact cause of the instabilities was not determined. Further work is needed to develop techniques for obtaining stable steady-state solutions when large surface-water fluxes characterize a stream-lake system. When the stream segments widths were specified to be 6.5 ft, convergence of the solution was achieved in 75 MODFLOW iterations, in each of which as many as 21 iterations were required for convergence of lake stages to equilibrium.

Test Simulation 3: Sublake Separation and Coalescence

The hypothetical lake of test simulation 3 (app. 4) has four pools sufficiently deep that they do not dry in the simulated drying scenario. The pools are separated by shallow areas that do become dry during the simulated drying scenario, but are inundated during simulated periods of normal recharge and drying. A situation is thus posed for analysis using the Lake Package in which a single lake (fig. 8) dries and separates into several isolated pools, each having its own stage and water budget, during periods of extended drying with little recharge. Then, during periods of normal recharge and drying, the pools coalesce back into a single lake having a single stage and water budget.

It was noted previously that the Lake Package can represent this situation if the potentially separate pools are treated consistently as separate lakes. Specifications are entered as part of the input data to indicate that groups of these pools (sublakes) coalesce into a single lake when the stages of one or more exceed specified "sill elevations." These specifications entail the identification of sets of lakes where one is considered a center lake and the others as potentially connected sublakes. The specifications are heirarchical in that a sublake of one specification can be a center lake for a subsequent specification of a set of lakes. The program logic considers all sets of center lakes and sublakes in each time step to develop the largest possible set of connected sublakes. Then, stages of all the sublakes in the identified connected lake system are equalized, subject to the restriction that no sublake can be drawn down below its sill elevation.

The first line of the Lake Package input specifies that there are four lakes in the simulation. The matrix input of the Basic, Block-Centered Flow, and Lake Packages (app. 4) show the grid cells occupied by the sublakes, with the Lake Package input identifying the individual sublakes by number. The lakes are

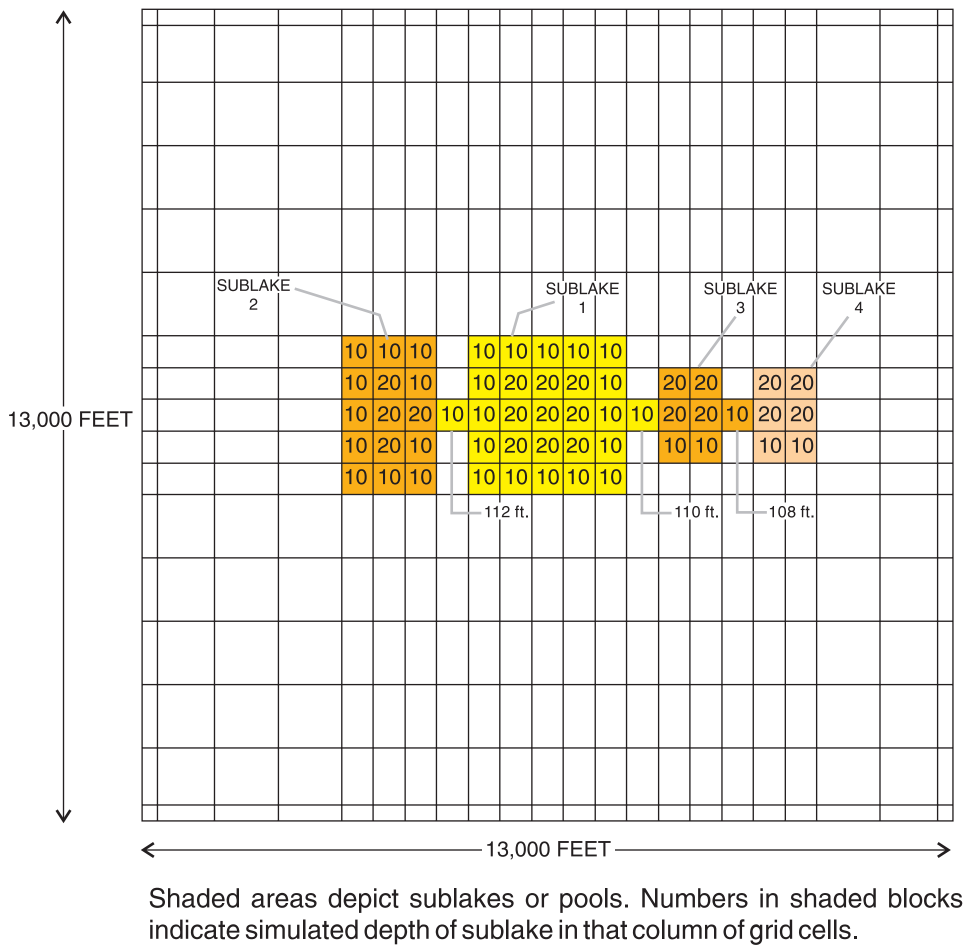


Figure 8. Model grid representing a lake that is subdivided into separate pools as the stage decreases and is connected by shallow areas when the stage increases in test simulation 3.

described as occurring in the uppermost two layers of the five-layer grid. The grid of test simulation 1 has been enlarged laterally by the addition of five columns to accommodate the four-lake system (app. 4, input for the BCF package), although the overall dimension remains the same. Lines near the end of the Lake Package input that appear before the specification of recharge and evapotranspiration rates specify that there are two connected lake systems and specify the sublakes and their sill elevations. The first specification identifies sublake 1 as a center lake and sublakes 2 and 3 as potentially connected to sublake 1 at sill elevations of 112 and 110 ft, respectively. The next specification identifies sublake 3 as a center lake and sublake 4 as potentially connected to sublake 3 at a sill elevation of 108 ft. At each time step, the program logic attempts to identify the largest possible set of connected sublakes, possibly all four sublakes.

Aquifer hydraulic conductivity, leakance, hydraulic conductivity of the lakebed, and storage coefficients are the same as for test simulation 1 (app. 4, input data for the Block-Centered Flow and Lake Packages), although the grid has changed. The initial head in the aquifer and initial lake stage are 115 ft (app. 4, input data for the Basic and Lake Packages). Boundary head values are specified by the Flow and Head Boundary Package (app. 4) to slope linearly from 160 ft on the western boundary to 140 ft on the eastern boundary, as in all previous test simulations, and do not vary with time. In the first of two 400-day stress periods, which is the drying period, aquifer and lake recharge are zero, but the lake evaporation rate is high (0.0412 ft/d) (app. 4, input data for the Lake and Recharge Packages). The specified rate of maximum potential aquifer ET for the first stress period also is high (0.0412 ft/d). This rate is the same as for the drying/rewetting scenario of test simulation 1. The ET surface has been expanded and revised to show the presence of the four-lake system (app. 4, input data for the Evapotranspiration Package). In the second of the two stress periods, representing normal recharge and drying conditions, aquifer and lake recharge rates are 0.0116 ft/d, and the lake evaporation rate is 0.0103 ft/d. The specified rate of maximum potential ET for the aquifer is 0.0141 ft/d.

The sublakes are connected in the beginning of the test simulation. The output from time step 15 (simulation time 66 d) (app. 4, selected pages from printed results) shows that slightly different stages, ranging from 112.39 to 112.46 ft, are computed for the four sublakes by individual sublake water-budget equations, and the stages are then equalized to 112.40 ft after the program logic determines that all four sublakes are connected. The output lists the volume corrections associated with the slight stage corrections. These values are listed again as “connected lake influxes” in the lake budget summary. By time step 20 (simulation time 95 d), the stages in sublakes 1 and 2 have dropped below the sill elevation of 112 ft. Lakes 1, 3, and 4 are still connected and their stages are equalized at 111.36 ft. The stage in lake 2 is computed by the normal water-budget procedure to be 111.41 ft. By time step 30, only sublakes 3 and 4 are connected, at a stage of 109.34 ft. In time step 40, the water-budget stage (before equalization with other connected lakes) of smaller sublake 4 is still above the sill elevation, but the stage adjustment lowers the stage below the sill elevation, which is considered to be physically unrealistic. A program check activates an additional logical process to set the stage of sublake 4 at 108 ft and to put the remaining excess water in sublake 3, raising the stage of sublake 3 slightly by 0.01 ft to 107.08 ft. All of the stage adjustments described thus far and in the following paragraphs preserve the overall volume of water in the lakes. By time step 50 (simulation time 400 d), none of the sublakes are connected, and each has a stage and water budget independent of the others.

After normal recharge and drying rates are reestablished in stress period 2, aquifer heads and sublake stages begin to rise. By time step 25 (simulation time 529 d), the water-budget stage of sublake 3 has reached 110.15 ft, above the sill elevation of 110 ft, although the water-budget stage of the larger sublake 1 is only 102.96 ft. Sublake 3 is connected to sublake 4, which has a water-budget stage of 110.53 ft, because the intervening sill elevation is only 108 ft. The stage equalization process recomputes a common stage below 110 ft, because of the greater surface area of sublake 1. However, such a stage reduction for sublakes 3 and 4 is considered unrealistic because it should not be possible to lower the stages of sublake 3 or sublake 4, which connects to sublake 1 through sublake 3, below the sill elevation of 110 ft. The logic checks in the Lake Package detect these inconsistencies, and the stages of lakes 3 and 4 are set at the sublake 3 sill elevation of 110 ft. The stage of sublake 1 is then recomputed to be 103.35 ft, only slightly greater than that computed by its independent water-budget equation.

In time step 30 (simulation time 569 d), the stages of all three sublakes are computed by their independent water budgets to be above the respective sill elevations for each sublake (112 ft for sublake 2, 110 ft for sublake 3, and 108 ft for sublake 4), and the stage of center lake is computed to be 108.33 ft. But, the equalization calculation lowers the three sublakes below the 110-ft sill elevation. Therefore, the stages of sublakes 2, 3, and 4 are set at the appropriate sill elevations (112 ft and 110 ft). The corrected stage of center lake is then computed to be 108.83 ft.

By time step 40 (simulation time 667 d), the four computed water-budget stages range from 114.03 to 114.62 ft, all sublakes are connected, and the equalized stage is 114.24 ft. The MODFLOW cumulative-volume water budget for the aquifer at the end of time step 40 estimates the percent discrepancy to be zero to two decimal places, indicating a good balance among computed influxes and effluxes. Beneath the sublakes, aquifer heads are above 113 ft and range substantially higher elsewhere.

Test Simulation 4: Simulation of Solute Concentrations

This test case is designed to illustrate the solute-transport capabilities of the Lake Package (app. 5). The test case is inspired by a sewage plume in a sand and gravel aquifer in Cape Cod, Massachusetts, as documented by LeBlanc (1984). At the Cape Cod site, effluent from a sewage treatment plant was the source of a plume of contaminated water. One edge of the plume appeared to intersect and (or) pass under part of Ashumet Pond. The test case is a highly simplified and idealized abstraction of the field conditions at the Cape Cod site. Although parameter values and boundary conditions were selected on the basis of reported field conditions, this example analysis is not intended to yield an accurate simulation of the actual flow field or observed plume in Cape Cod.

Table 1. Parameters and properties used in test simulation 4

[ft/d, foot per day; ft, foot; d, day; µg/L, micrograms per liter]

Parameter/property	Value
Horizontal hydraulic conductivity	250 ft/d
Vertical hydraulic conductivity	125 ft/d
Thickness	120 ft
Porosity	0.30
Lakebed leakance	10.0 d^{-1}
Recharge rate	4.79 x 10^{-3} ft/d
Longitudinal dispersivity	20.0 ft
Horizontal transverse dispersivity	2.0 ft
Vertical transverse dispersivity	0.2 ft
Diffusion coefficient	0.0 ft^2/d
Initial concentration	0.0 µg/L
Source concentration	500 µg/L

In the test case, the aquifer is moderately permeable and is assumed to have homogeneous properties and uniform thickness (table 1). The boundary conditions, which are illustrated in figure 9, were designed to produce flow that is generally from north to south.

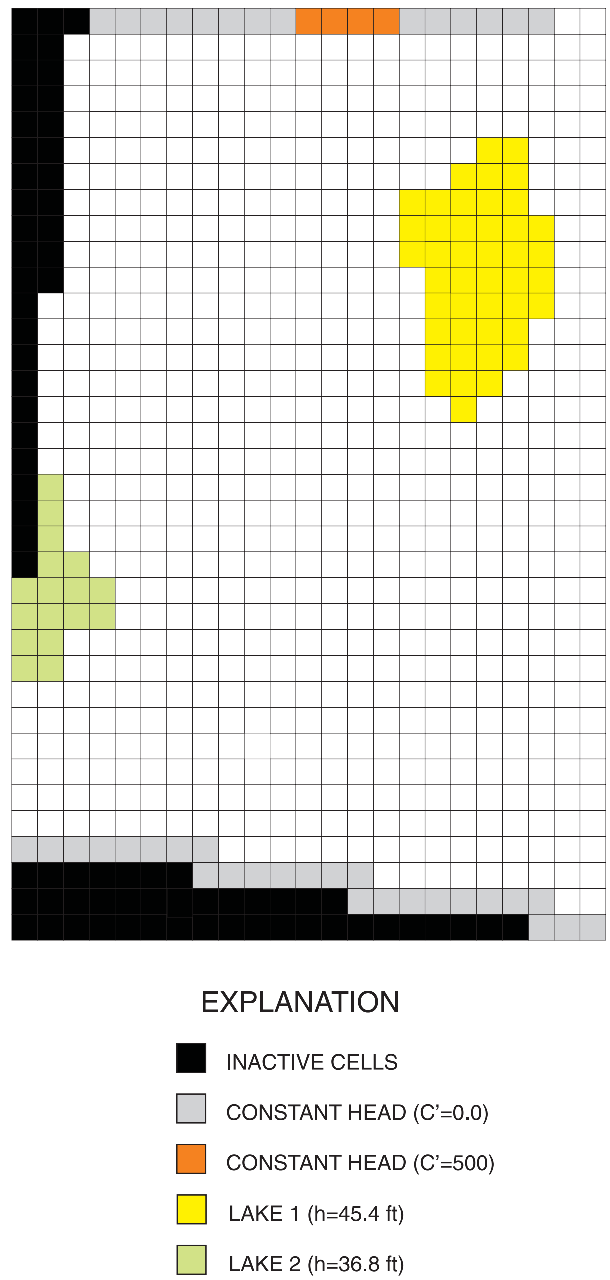


Figure 9. Boundary conditions and areal grid for test simulation 4.

Constant-head conditions were specified along the northern and southern edges of the model domain, and no-flow boundaries set along the east and west edges. Constant-head elevations were specified as 50.0 ft along the north boundary, except at the nodes representing the inflow from the sewage treatment effluent where the fixed heads were 50.15 ft in the two middle nodes and 50.10 in the two outer nodes. The constant-head elevations were set at 28.0 ft along the southern boundary. Two lakes are located within the model domain, although the lakes are not connected to each other or to any streams. Uniform recharge is applied to the top model layer. It is assumed that the average flow field could be adequately represented by a steady-state head distribution.

Because boron-concentration data were available for both the plume and the sewage effluent, boron was selected as the analog for the Cape Cod test case. For this test simulation, it was assumed that boron is a nonreactive constituent. It was further assumed that molecular diffusion is negligible in contributing to solute spreading at the field scale. As a result, hydrodynamic dispersion could be related solely to mechanical dispersion, which is computed in MOC3D as a function of the specified dispersivity of the medium and the velocity of the flow field. Initial concentrations of boron in the aquifer and in the lakes were assumed to be zero, whereas the concentration in the sewage effluent was assumed to be 500 µg/L at all times. The solute-transport model was run for a stress period of 25 years.

For the numerical model, the aquifer was discretized into 8 layers (each 15 ft thick), 36 rows (at equal spacing of 405.7 ft), and 23 columns (at equal spacing of 403.7 ft). The constant-head boundaries were placed in all 8 layers at the map locations shown in figure 9. The contaminant source, however, was introduced only into the upper two model layers (that is, in a total of 8 cells altogether). The lakes were assumed to penetrate only the first model layer. Selected parts of the input data files are shown in appendix 5; the complete set of input data files will be available for downloading over the internet at the same site where the code is available.

Selected output for this test problem is also shown in appendix 5. The strongly implicit procedure was used to solve the flow equation. A total of 752 iterations were required to converge to a solution.

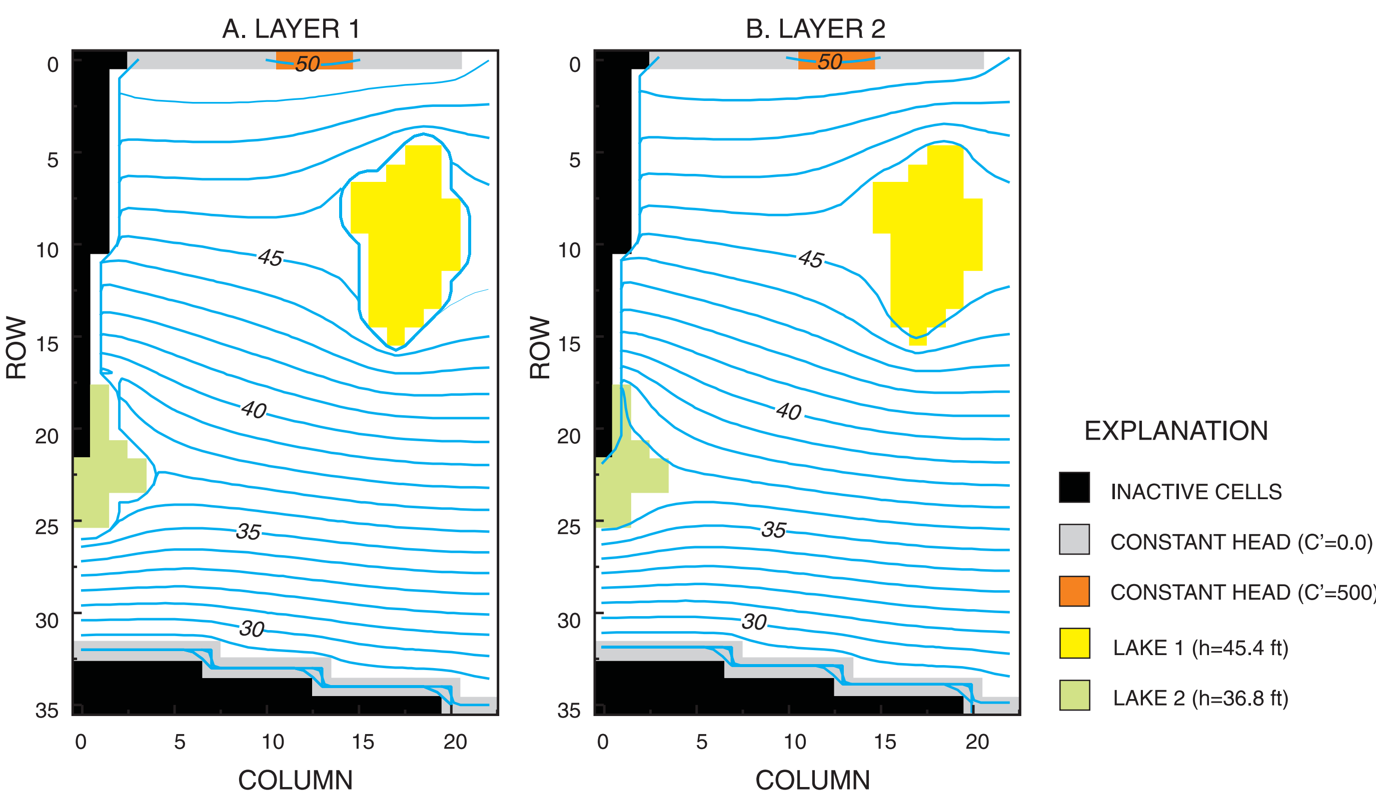


Figure 10. Calculated steady-state heads in (A) layer 1 and (B) layer 2.

The simulation required 36 min 23 sec of central processing unit (CPU) time on a Silicon Graphics Unix workstation. The calculated steady-state head distributions in layers 1 and 2 are shown in figure 10. The heads in layers 3 through 8 are almost identical to the heads shown for layer 2 (fig. 10b). As expected, the flow is generally from north to south, and the impact of the lakes on the flow field is substantial. In layer 1 (fig. 10a), the position of the lake corresponds with inactive aquifer cells; in layer 2, the good hydraulic connection with the lakebed results in nearly a flat horizontal hydraulic gradient in head under the lake. The northern part of the lake gains water through ground-water discharge to the lake, whereas the southern part of the lake loses water through ground-water recharge to the aquifer. As listed in the main MODFLOW output file (app. 5), the model calculated the steady-state stage in lake 1 to equal 45.4 ft and in lake 2 to equal 36.8 ft. Because of recharge over the entire surface, there is a slight vertically downward flow in most areas. Overall, the heads show a good qualitative agreement with the observed water-table map for the area of the sewage plume on Cape Cod (LeBlanc, 1984, p. 8). Lake 1 in the model is the analogue for Ashumet Pond.

The MOC3D solute-transport model required 1,128 time increments to solve the transport equation for a 25-year stress period. The solution used the implicit dispersion solver, 27 particles per cell, and a value of CELDIS = 0.75. The calculated boron concentration in lake 1 during the 25-year simulation period is shown in figure 11. (This plot was constructed from the output file from the GAGE package—*testcase.gs1* in this case—after converting the output units of time in days to time in years.) The leading edge of the plume reaches the upstream edge of lake 1 after about 4 years, at which time, the concentration in the lake begins to increase rapidly. After about 23 years, the part of the plume close to the source and near the lake has stabilized and the concentration in the lake reaches an equilibrium concentration of about 31 μg/L.

As the lake concentration increases, the lake acts as a source of contamination to the aquifer in the areas where the aquifer is gaining water (or being recharged) by seepage losses out of the lake. Although the lake substantially dilutes the contaminants entering from the aquifer, in effect, the lake provides a short circuit for the transmission of low levels of the contaminant. This is evident in figure 12, which shows the computed solute distributions in layers 1, 3, and 5 after 25 years. The low-concentration part of the plume emanating from the downgradient side of lake 1 has advanced farther, and is wider, than the main plume that emanated directly from the source at the northern edge of the model. A comparison of concentration levels at different depths in the system indicates that in the southern half of the area, concentrations generally increase with depth. In contrast, in the northern half of the area, but downgradient from the source, the highest concentrations occur in layer 3. These various patterns result from the dilution effect of recharge of uncontaminated water at the water table coupled with the consequent downward component of flow, which causes the solute to sink slowly as it migrates to the south.

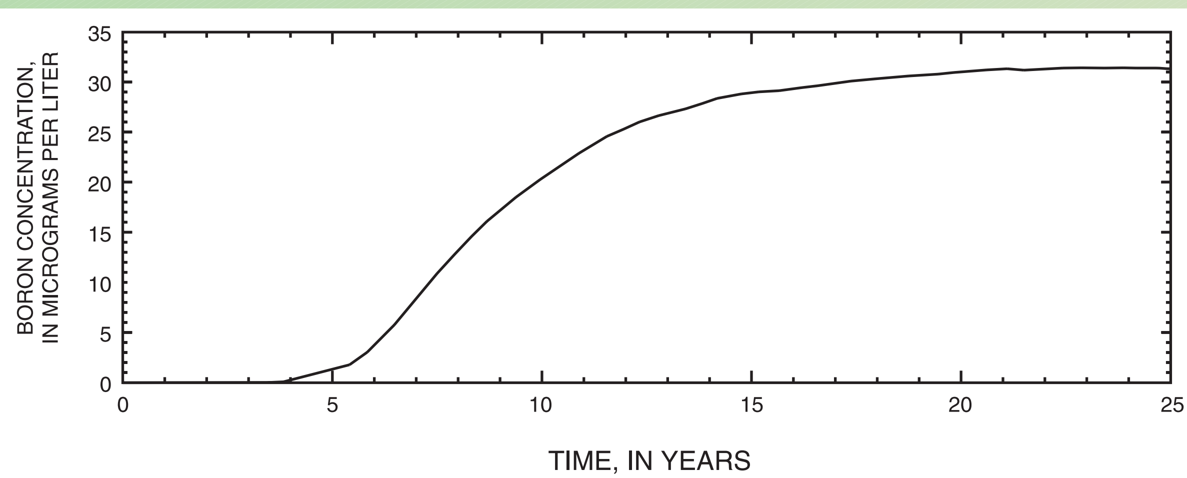


Figure 11. Plot showing calculated boron concentration in lake 1 for 25-year simulation period.

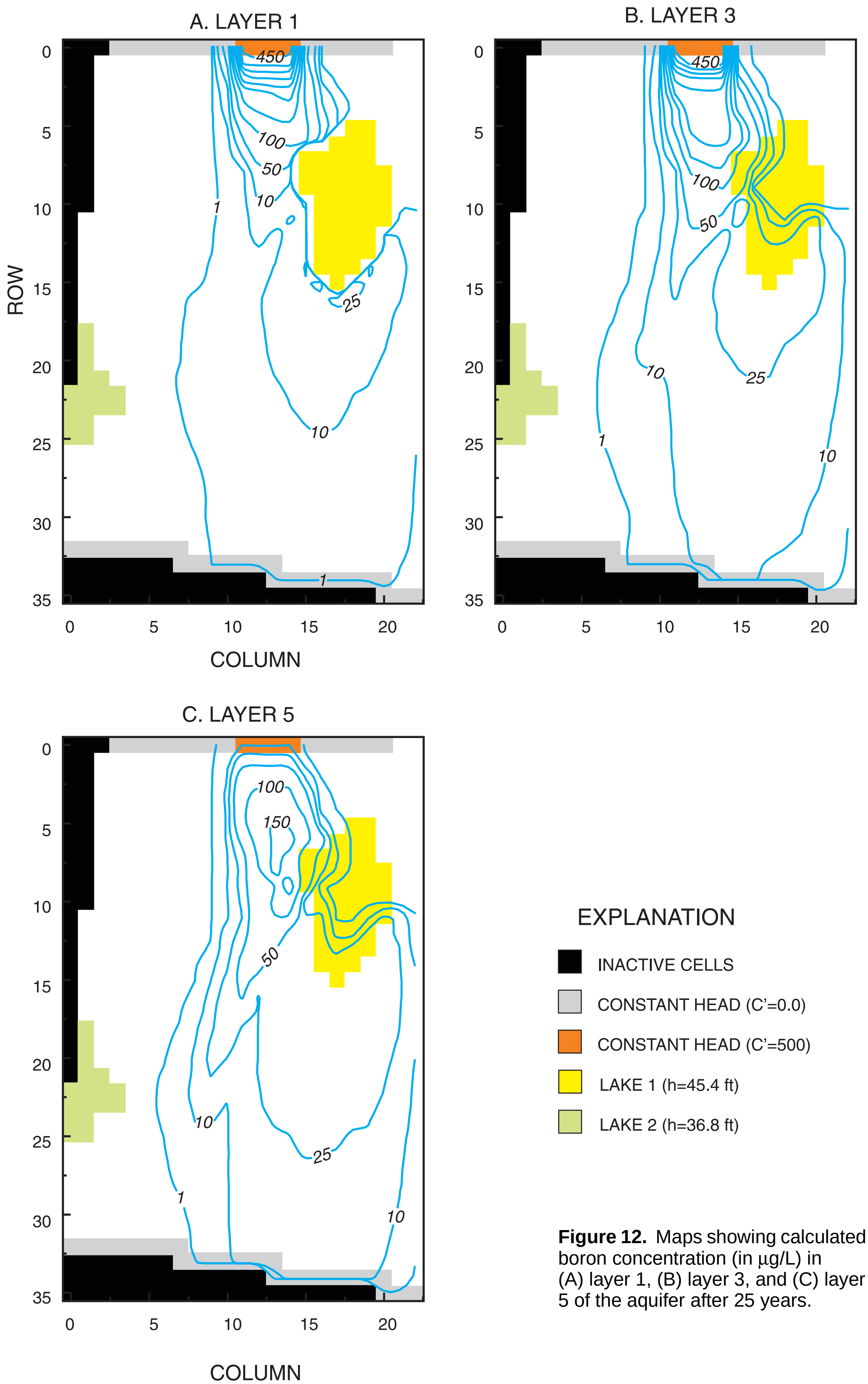


Figure 12. Maps showing calculated boron concentration (in µg/L) in (A) layer 1, (B) layer 3, and (C) layer 5 of the aquifer after 25 years.

The length of the transport time increment in this example is about 8.1 days. It is assumed that complete mixing occurs within the lake in this time or less. But even if it took two to three times longer for lake water to effectively mix completely, it probably would not induce any meaningful errors in the solution. If this were the case, the increase in lake concentration at the southern side of the lake (farthest from the inflow seepage area) might lag that shown in fig. 11 by an equivalent period of time (shifting the curve to the right by an amount that is insignificant relative to the 25-year time scale). Similarly, the inflow of contaminants from the lake to the aquifer near the downgradient side of the lake may lag by a few weeks relative to what was computed here, which also would have an insignificant effect on the position of the plume shown in fig. 12.

Calculating the lake concentration directly would not have been possible if the lakes in this system had been represented using other available MODFLOW packages or options, such as general-head boundaries or constant-head boundaries. Similarly, it would not have been possible to simulate the impact of the time-varying solute concentration in the lake on the downgradient ground-water system. This test case demonstrates that these effects can be important. The inclusion in the Lake Package of the ability to calculate lake concentrations will enhance its applicability to a broader range of field problems.

IMPLEMENTATION OF THE LAKE-AQUIFER INTERACTION PACKAGE IN THE GROUND-WATER FLOW MODEL

The Lake-Aquifer Interaction Package (LAK3), also referred to simply as the Lake Package, is designed for incorporation into the USGS three-dimensional finite-difference modular ground-water flow model (MODFLOW), which was documented by McDonald and Harbaugh (1988). LAK3 was specifically designed for incorporation into MODFLOW-96 (Harbaugh and McDonald, 1996a,b) but has also been revised for use with MODFLOW-2000 (Harbaugh and others, 2000). LAK1 is the designation of the Lake Package developed by Cheng and Anderson (1993), and LAK2 is used to designate the Lake Package prepared by the first author for the earlier (1988) version of MODFLOW. The version of the Lake Package reported by Council (1998) also received the LAK2 designation.

LAK3 consists mainly of six FORTRAN subroutines (modules) that are called by the MAIN program of MODFLOW: LAK3AL, LAK3RP, LAK3AD, LAK3ST, LAK3FM, and LAK3BD. The first three characters identify the modules as being part of the Lake Package; the next character identifies the version number of the module, and the last two characters identify the type of procedures performed by the module according to conventions used in common with other MODFLOW packages. The division of procedures among the various modules is also consistent with other MODFLOW packages. LAK3AL allocates memory to arrays used by the rest of the package; LAK3RP reads input data and prepares coefficient arrays for use in computations; LAK3AD advances the lake budget to the next time step; LAK3ST sets the IBOUND array for recharge and ET calculations; LAK3FM formulates the aquifer leakage terms added to the ground-water solution matrices; and LAK3BD computes the water budget for each lake. Subsequent sections provide expanded descriptions of these six modules. In addition, a seventh module (LSN3RP) is called internally within the LAK3RP module (MODFLOW-96) or from MAIN (MODFLOW-2000) to retrieve stream/lake interface parameters. Revisions to the MAIN program include adding the alpha code LAK in position 22 of the CUNIT data statement. Using the alpha code LAK in the first field of a line in the input list of input file unit designations tells the model that the Lake Package will be used in the current MODFLOW run.

In many potential applications of MODFLOW and the Lake Package, cells that are either part of the aquifer or those designated as lake volume cells could become dry as a result of applied stresses that would lower the water table or lake stage. Module LAK3ST was developed to scan vertical columns of grid cells to determine whether lake volume grid cells were present in the vertical columns, and if so, whether these cells were dry. The result, in the case of recharge and ET applied to the uppermost wetted cell in a grid column, was to determine whether or not aquifer recharge and ET fluxes should be applied in a given vertical column of grid cells. Depending on results of the scan, entries in the IBOUND array of MODFLOW were temporarily modified (given negative values) so that aquifer recharge and ET would be applied to the correct vertical columns of the model grid. A subsequent call to LAK3ST resets the IBOUND array elements to their previous values. LAK3ST is called before and after MODFLOW calls to RCH5FM, RCH5BD, EVT6FM, and EVT6BD.

The ET Package was modified as part of a recent USGS study using the Lake Package (Merritt, 2000) to apply ET fluxes to the uppermost wetted cell (option NEVTOP = 3) and renamed EVT6. (The capability to choose the uppermost wetted cell for recharge was available in previous versions of the Recharge Package). The present Lake Package is fully compatible with both EVT6 and the previously available ET package (EVT5), and with any choice of a value for NEVTOP acceptable to the package used, as the argument lists are the same. However, the appropriate module names have to be used in the call statements in the MAIN package.

Module LAK3AL

A generalized flow chart for module LAK3AL is shown in figure 13. Operations are carried out in the following order.

1. Print message identifying the package.
2. Read the number of lakes (NLAKES) and the cell-by-cell storage flag (ILKCB). Read the degree of implicitness (THETA) and, if a MODFLOW steady-state solution is specified (ISS > 0), the maximum number of iterations and convergence criterion for lake stage computation by Newton's method.
3. Allocate storage for the arrays (table 2) used by the Lake Package for aquifer head/lake stage simulation with MODFLOW. Other arrays used for solute transport simulation with MOC3D are listed separately in a subsequent section.
4. Calculate and print the amount of space used by LAK3.
5. Return.

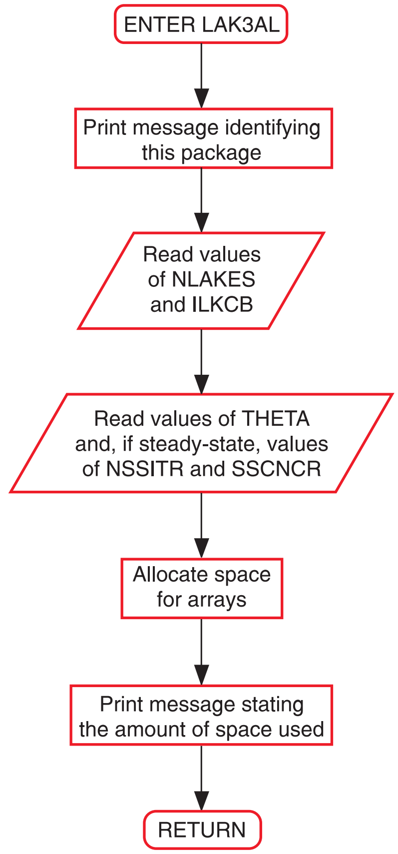


Figure 13. Generalized flow chart of the module LAK3AL.

Module LAK3RP

A generalized flow chart for module LAK3RP is shown in figure 14. Operations are carried out in the following order.

1. Read initial lake stages. If steady-state run, also read maximum and minimum allowable lake stages.
2. If MOC3D is to be used for solute transport calculations, read initial solute concentrations for all lakes.
3. Read array for each layer showing location of lakes in that layer of the grid. Read array for each layer specifying lakebed leakances for each grid cell in the layer.
4. Search lake location matrix, column by column, to identify aquifer cells that border lake volume grid cells. For each lake/aquifer interface, store cell location, interface orientation, the associated lake identification number, and the lakebed leakance. Set LKNODE equal to the number of interfaces detected and print table of interface information. (LKNODE should be less than the default value of MXLKND, which is two times NODES, where NODES is the total number of cells in the MODFLOW grid. If the number of interfaces detected exceeds MXLKND, the MODFLOW run terminates with an error message.)

Table 2. Arrays used by the Lake Package for aquifer head/lake stage simulation

[Dimensions: MXLKND, maximum allowable number of lake/aquifer cell interfaces; NLAKES, number of lakes; NSS, number of stream segments; NODES, total number of cells in model grid; NCOL, NROW, and NLAY, the number of columns, rows, and layers, respectively, in the MODFLOW grid; NCLS, number of connected lake systems, ICMAX, maximum number of sublakes in a connected-lake system]

Variable name (Dimensions)	Location in X-Array	Definition
BEDLAK(MXLKND)	LCCOND	Lakebed leakances at lake/aquifer cell faces
CNDFCT(MXLKND)	LCCNDF	Lake/aquifer conductances or unit depth conductances across lake/aquifer cell faces
ILAKE(5,MXLKND)	ICLAKE	Grid location, orientation, and lake ID of lake/aquifer cell interface
STAGES(NLAKES)	LCSTAG	Lake initial stages
PRCPLK(NLAKES)	LCLKPR	Lake precipitation rates
EVAPLK(NLAKES)	LCLKEV	Lake evaporation rates
WTHDRW(NLAKES)	LCWTDR	Lake artificial withdrawal rates
RNF(NLAKES)	LCRNF	Overland runoff rates for lakes
ITRB(NLAKES,NSS)	INTRB	ID’s of stream segments flowing into lakes
IDIV(NLAKES,NSS)	INDV	ID’s of stream segments flowing out of lakes
STGOLD(NLAKES)	ISTGLD	Lake stages at the end of the previous time step
STGNEW(NLAKES)	ISTGNW	Lake stages computed in the current time step
ICS(NLAKES)	IICS	Number of sublakes in each multiple-sublake system
ISUB(NLAKES,NLAKES)	IISUB	Lake ID’s of sublakes in multiple-sublake systems
SILLVT(NLAKES,NLAKES)	ISILL	Sill elevations between sublakes in multiple-lake systems
MSUB(NLAKES,NLAKES)	IMSUB	Identifiers of lakes in connected set
MSUB1(NLAKES)	IMSUB1	Number of connected lake sets determined by lake package
LKARR(NODES)	IBNLK	Location of lakes in grid
LKARR1(NROW,NCOL,NLAY)	IBNLK	Location of lakes in grid
BDLKNC(NODES)	ILKBL	Lakebed leakance values
BDLKN1(NROW,NCOL,NLAY)	ILKBL	Lakebed leakance values
EVAP(NLAKES)	LKACC1	Evaporation flux for each lake during the current time step
PRECIP(NLAKES)	LKACC2	Recharge flux for each lake during the current time step
SEEP(NLAKES)	LKACC3	Ground-water seepage flux for each lake during the current time step
SURFA(NLAKES)	LKACC4	Current surface area for each lake
SURFIN(NLAKES)	LKACC5	Sum of stream inflows for each lake during the current time step
SURFOT(NLAKES)	LKACC6	Sum of stream outflows for each lake during the current time step
VOL(NLAKES)	LKACC7	Current total volume of each lake
GWIN(NLAKES)	LKACC8	Ground-water seepage influx to each lake during the current time step
GWOUT(NLAKES)	LKACC9	Ground-water seepage efflux from each lake during the current time step
DELH(NLAKES)	LKACC10	Computed lake stage change for each lake during the current time step
TDELH(NLAKES)	LKACC11	Cumulative lake stage change for each lake from the beginning of the run
NCNT(NLAKES)	LKNCNT	Temporary array of counters used in connected-lake logic
KSUB(NLAKES)	LKKSUB	Temporary array of lake numbers used in connected-lake logic
STGADJ(NLAKES)	LKSADJ	Stage adjustments for connected lakes
FLXINL(NLAKES)	LKFLXI	Connected-lake interchange fluxes
NCNST(NLAKES)	LKNCNS	Temporary array of counters used in connected-lake logic
SVT(NLAKES)	LKSVT	Temporary array of sill elevations used in connected-lake logic
JCLS(NCLS,ICMX)	LKJCLS	Temporary array of counters used in connected-lake logic
LDRY(NODES)	LKDRY	Indices of lake cells that are dry in the current time step
BOTTMS(NLAKES)	IBTMS	Bottom elevations of lakes
BGAREA(NLAKES)	IAREN	Surface areas of lakes in uppermost layer
NCNCVR(NLAKES)	LKNCN	Counters used to indicate convergence of lake stages in steady-state simulation
DSRFOT(NLAKES)	LKDSR	Sums of stage-flow derivatives used in steady-state solution for lake stages
SSMN(NLAKES)	LKSSMN	Minimum lake stages allowed in steady-state solution
SSMX(NLAKES)	LKSSMX	Maximum lake stages allowed in steady-state solution
SUMCNN(NLAKES)	LKCNN	Sums of conductances used in lake seepage calculations
SUMCHN(NLAKES)	LKCHN	Sums of conductances times heads used in lake seepage calculations

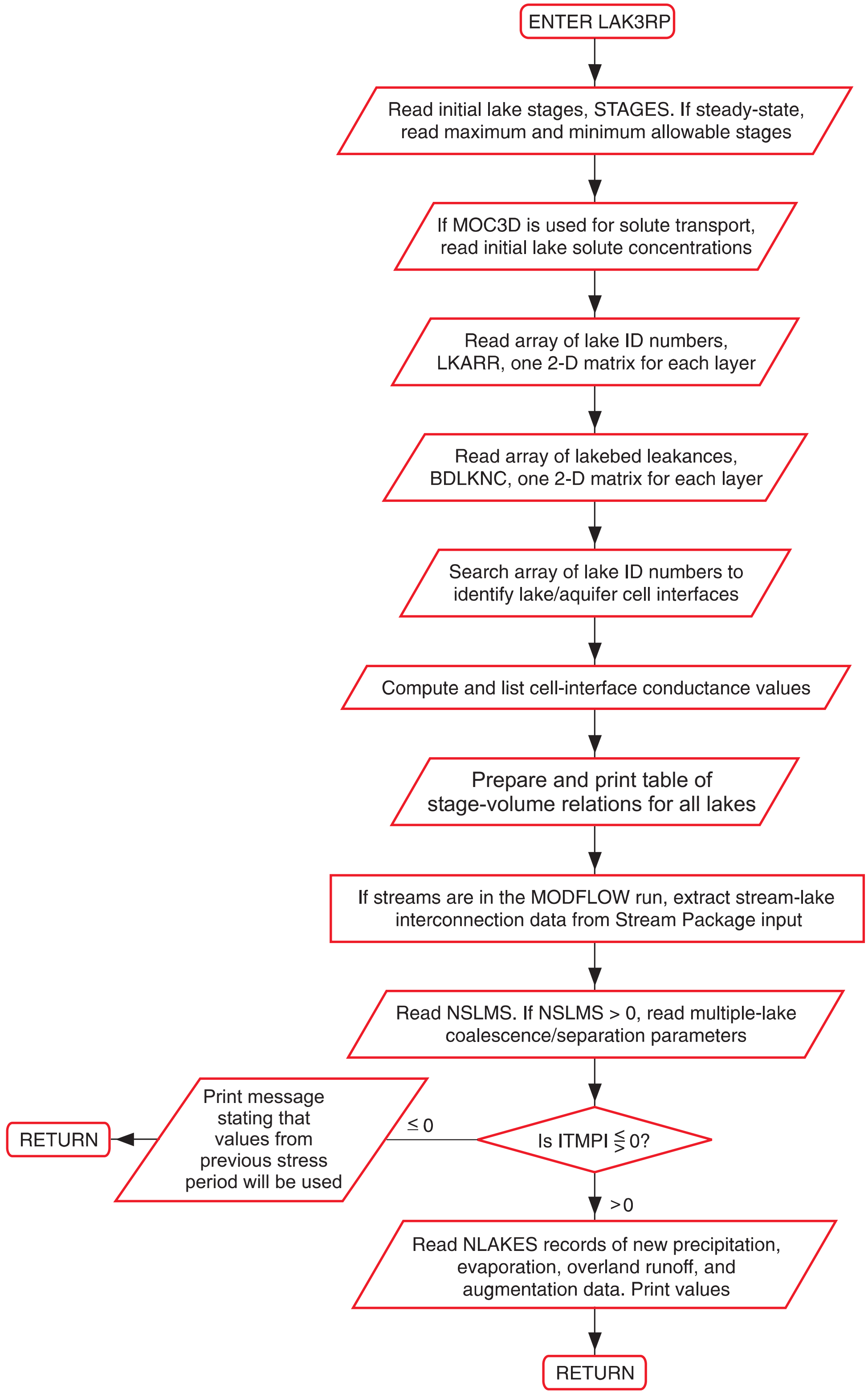


Figure 14. Generalized flow chart of the module LAK3RP.

5. Compute lake/aquifer cell-interface conductances (CNDFCT) based on lakebed leakances and the aquifer hydraulic conductivity. Values for lateral cell-interface conductances (across vertical interfaces) are computed as unit depth quantities. Values for vertical cell-interface conductances are absolute quantities. Both lateral cell-interface conductance/depth values and vertical cell-interface conductances are computed by determining the conductance of fluid movement through a distance of half a grid cell of aquifer material (either CNDFC2 or CVWD/2), computing the lakebed conductance (CNDFC1) based on the input leakance values, and combining the two values harmonically. If the "wet-dry" option of MODFLOW is not used (IWTFLG = 0), vertical cell-interface conductances are based solely on the specified input lakebed leakance values (CNDFCT = CNDFC1). If lateral anisotropy exists, aquifer material conductances in the lateral column direction are multiplied by the specified factor (TRPY). For each lake, the lowest elevation of the lake bottom is detected and saved in the array BOTTMS. A table of cell-interface conductances is printed.
6. Prepare tables of stage/volume relations for all lakes, and print in a format that is readily conducive to graphical display. Each table has 150 values that range from the bottom of the lake to an arbitrary elevation above the bottom of the uppermost model layer.
7. If streams are in the MODFLOW run, call module LSN3RP to extract stream-lake interconnection data from input to the Stream Package. Inflowing and outflowing stream segment numbers are stored in arrays ITRB and IDIV, respectively, and the maximum numbers of inflowing and outflowing streams for all the lakes are stored as variables NTRB and NDV, respectively.
8. Read NSLMS, the number of multiple-lake systems. If NSLMS is greater than zero, read NSLMS pairs of records, the first of which identifies lakes as sublakes of multiple-sublake systems that can coalesce into a connected lake or divide into separate lakes. The second record of each pair gives the sill elevations at which the center lake and the sublakes are connected. Print a table of input specifications.
9. Check the value of ITMP1. If it is less than or equal to zero, previously specified values of lake recharge, evaporation, overland runoff, and withdrawal rates will be used in the current stress period. If ITMP1 is greater than zero, new values for lake recharge, evaporation, overland runoff, and withdrawal rates will be read for use in the current stress period. Print table of values input in this step.
10. Return.

Module LSN3RP

A generalized flow chart for module LSN3RP is shown in figure 15. Operations are carried out in the following order.

1. Loop through array of stream segments used by the Stream Package. If the stream segment flows into a lake (the value of IOTSG associated with the stream segment < 0), save segment number in array ITRB used by the Lake Package. If stream segment originates in a lake (the value of IDIVAR associated with the stream segment < 0), save segment number in array IDIV used by the Lake Package.

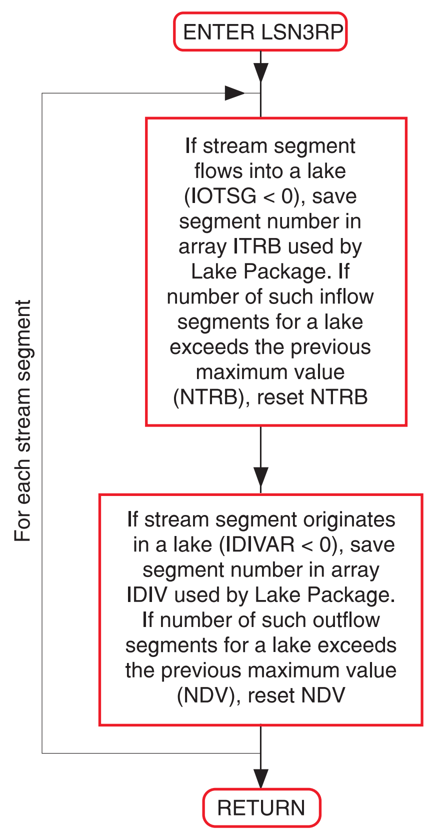


Figure 15. Generalized flow chart of the module LSN3RP.

2. Compute the maximum number of streams inflowing into any lake and store as variable NTRB used by the Lake Package. Compute the maximum number of streams originating in any lake and store as variable NDV used by the Lake Package.
3. Return.

Module LAK3AD

A generalized flow chart for module LAK3AD is shown in figure 16. Operations are carried out in the following order.

1. If this is the first time step of the simulation, set the values of the array STGOLD equal to the values of the array STAGES that contains the initial stages of all lakes in the simulation.
2. If this is not the first time step of the first stress period, reset the values of STGOLD to the values of STGNEW, values of lake stage that were computed in the just-completed previous time step.
3. If solute transport is being simulated with MOC3D, initialize matrix of cell-by-cell flow terms, FLOB, to zero.
4. Return.

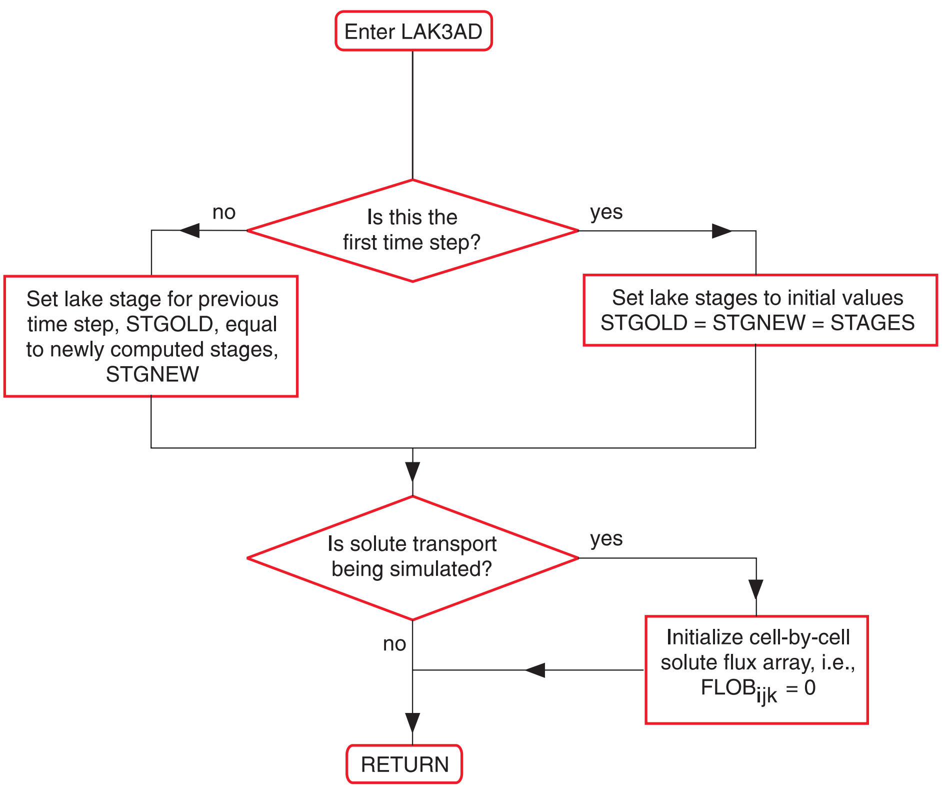


Figure 16. Generalized flow chart of the module LAK3AD.

Module LAK3ST

Module LAK3ST is called once before each of the MODFLOW calls to RCH5FM, EVT6FM, RCH5BD, and EVT6BD with the parameter NFLG set equal to 0. The module is called again after each of those MODFLOW calls with the parameter NFLG set equal to 1. A generalized flow chart for module LAK3ST is shown in figure 17. Operations are carried out in the following order.

1. Loop through the array of lake/aquifer cell interfaces. For interfaces in the vertical direction only (ITYPE = 0), if NFLG = 0, set the IBOUND value of the overlying lake cell equal to -7, but only if the lake stage is sufficiently high that the cell contains water. If the overlying cell does not contain water, the IBOUND value is set equal to 0 (actually, the value should already be 0). If NFLG = 1, the IBOUND value of the overlying lake cell is reset to 0.
2. Return.

Module LAK3FM

A generalized flow chart for module LAK3FM is shown in figure 18. Operations are carried out in the following order.

1. Sum stream inflows into each lake and stream outflows from each lake. If the MODFLOW solution is steady-state, sum the stream outflow/stage derivative values computed by the Stream Package.
2. If the MODFLOW solution is transient, skip to step 3. If the MODFLOW solution is steady-state, then perform a maximum of NSSITR iterations of the Newton's method solution for equilibrium lake stages, or until the solution converges (maximum lake stage <SSCNCR). In each Newton's method iteration, compute and sum seepage rates (FLOBOT) for all lake/aquifer cell interfaces, compute and sum recharge and evaporation fluxes for

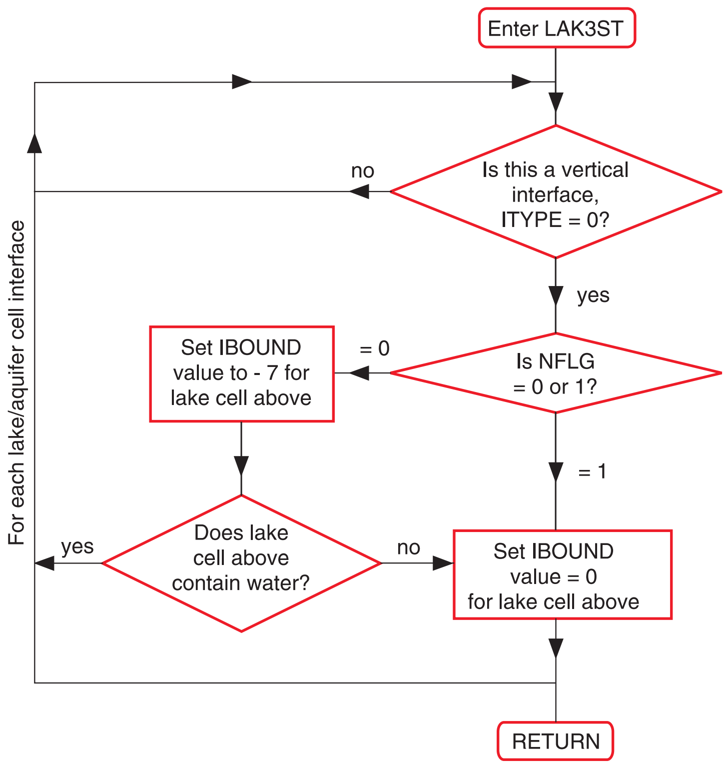


Figure 17. Generalized flow chart of the module LAK3ST.

the lake surface, and then apply the Newton's method formula to update the equilibrium stage estimate for each lake.

3. Compute and sum seepage rates (FLOBOT) for all lake/aquifer cell interfaces, while incrementally adjusting the MODFLOW solution matrices RHS and HCOF for the cell seepage rates and summing recharge and evaporation fluxes for the lake surface. The calculation of cell face seepage is slightly different for lateral interfaces than for vertical interfaces because the conductance values stored for lateral interfaces are for a unit thickness and must be adjusted for the saturated thicknesses of the surficial or convertible (LAYCON =1 or 3) grid cells. For a vertical interface, the values used to increment the RHS matrix element and whether or not the HCOF matrix element is incremented depend on whether the aquifer head is above or below the bottom of the lake cell. Values of sums for evaporation (EVAP), precipitation (PRECIP), and lake surface area (SURFA) are incremented only for vertical interfaces and when the overlying lake volume cell is at least partly saturated.

4. Apply the water-budget equation to recompute the stage (STGNEW) of each lake. The recomputed stage is used only if the cell seepage estimates are partly implicit and the MODFLOW solution is transient and requires more than one iteration.

5. Return.

Module LAK3BD

A generalized flow chart for module LAK3BD is shown in figure 19. Because of the complexity of the logic for analyzing multiple-lake systems for connectedness, an additional flow chart is included (fig. 20) to present these procedures in greater detail than can be shown in figure 19.

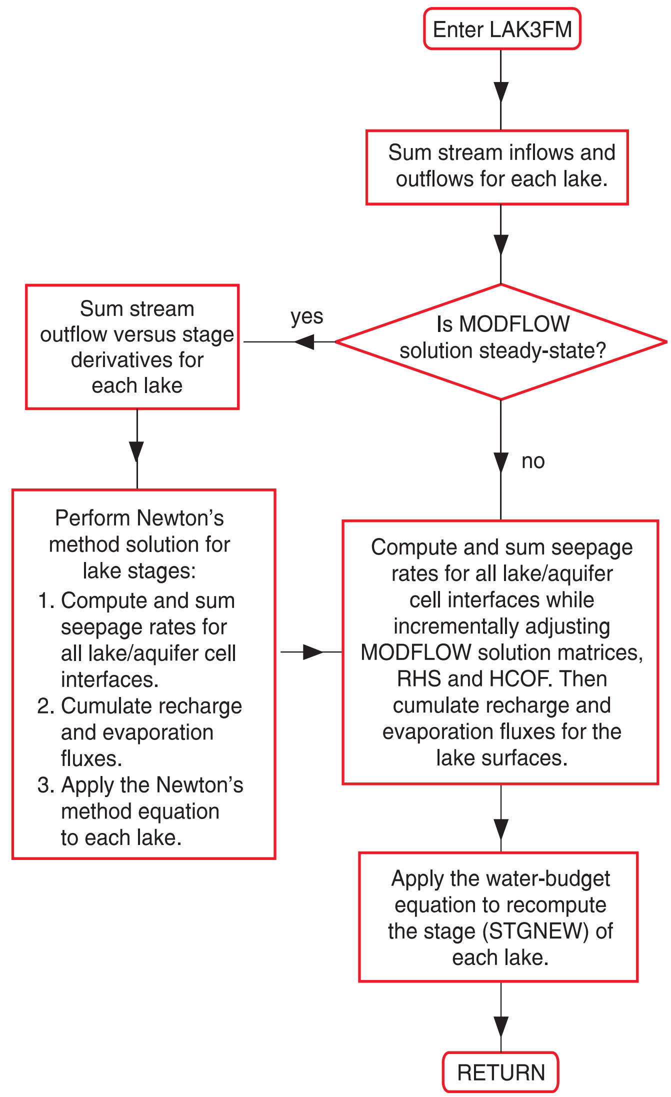


Figure 18. Generalized flow chart of the module LAK3FM.

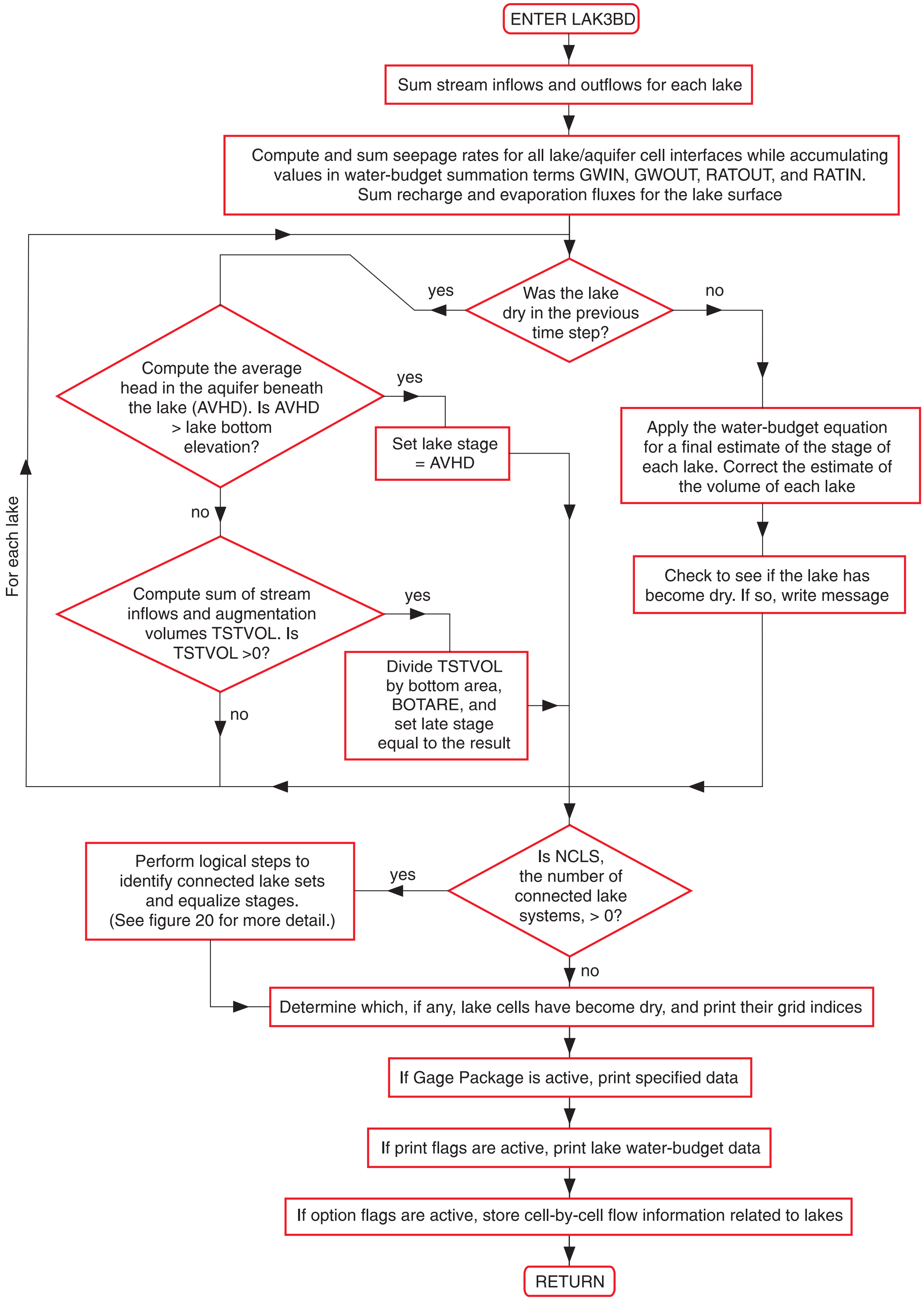
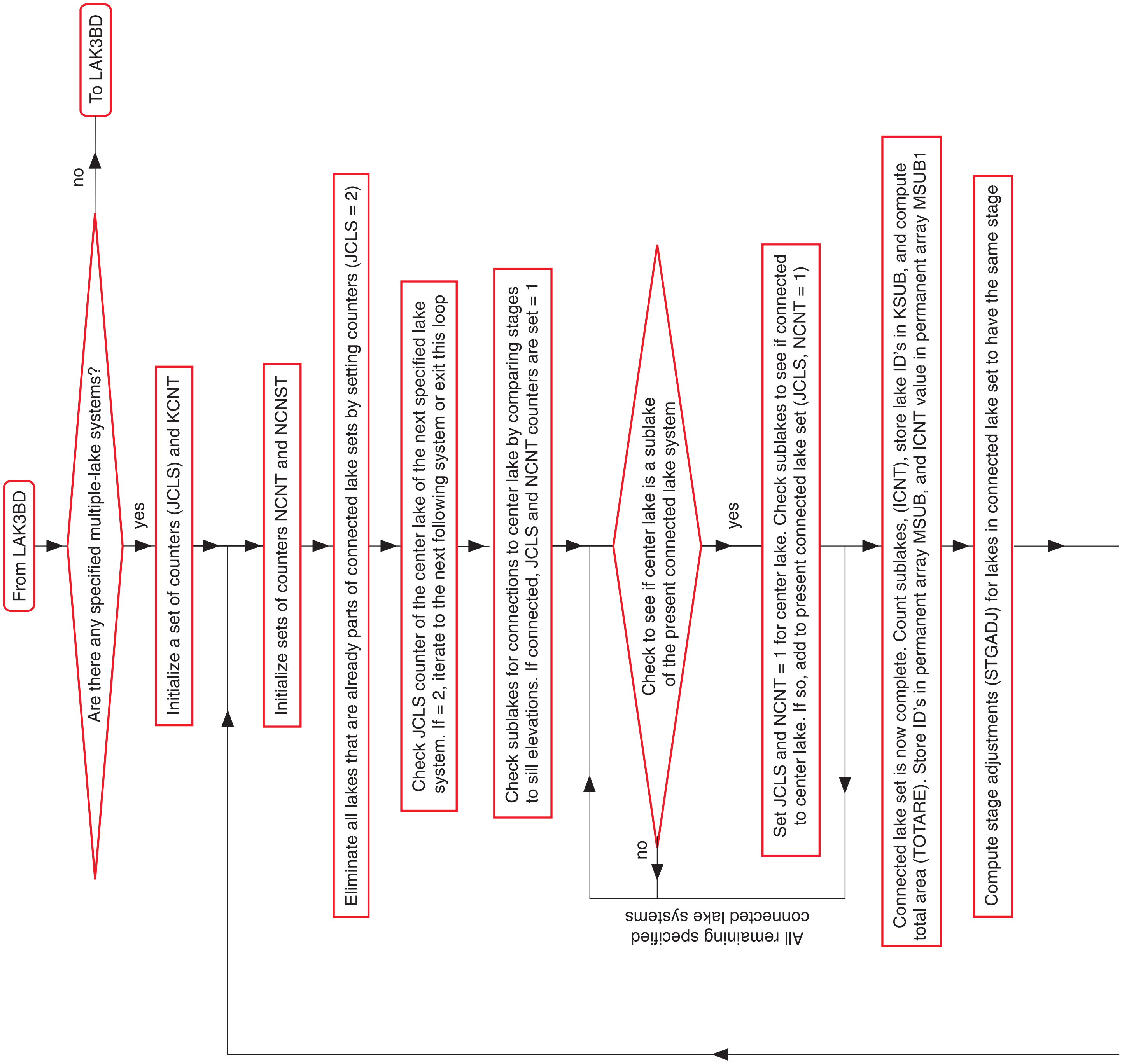


Figure 19. Generalized flow chart of the module LAK3BD.


From LAK3BD
Are there any specified multiple-lake systems?
no
To LAK3BD
yes
Initialize a set of counters (JCLS) and KCNT
Initialize sets of counters NCNT and NCNST
Eliminate all lakes that are already parts of connected lake sets by setting counters (JCLS = 2)
Check JCLS counter of the center lake of the next specified lake system. If = 2, iterate to the next following system or exit this loop
Check sublakes for connections to center lake by comparing stages to sill elevations. If connected, JCLS and NCNT counters are set = 1
Check to see if center lake is a sublake of the present connected lake system
no
yes
Set JCLS and NCNT = 1 for center lake. Check sublakes to see if connected to center lake. If so, add to present connected lake set (JCLS, NCNT = 1)
All remaining specified connected lake systems
Connected lake set is now complete. Count sublakes, (ICNT), store lake ID's in KSUB, and compute total area (TOTARE). Store ID's in permanent array MSUB, and ICNT value in permanent array MSUB1
Compute stage adjustments (STGADJ) for lakes in connected lake set to have the same stage

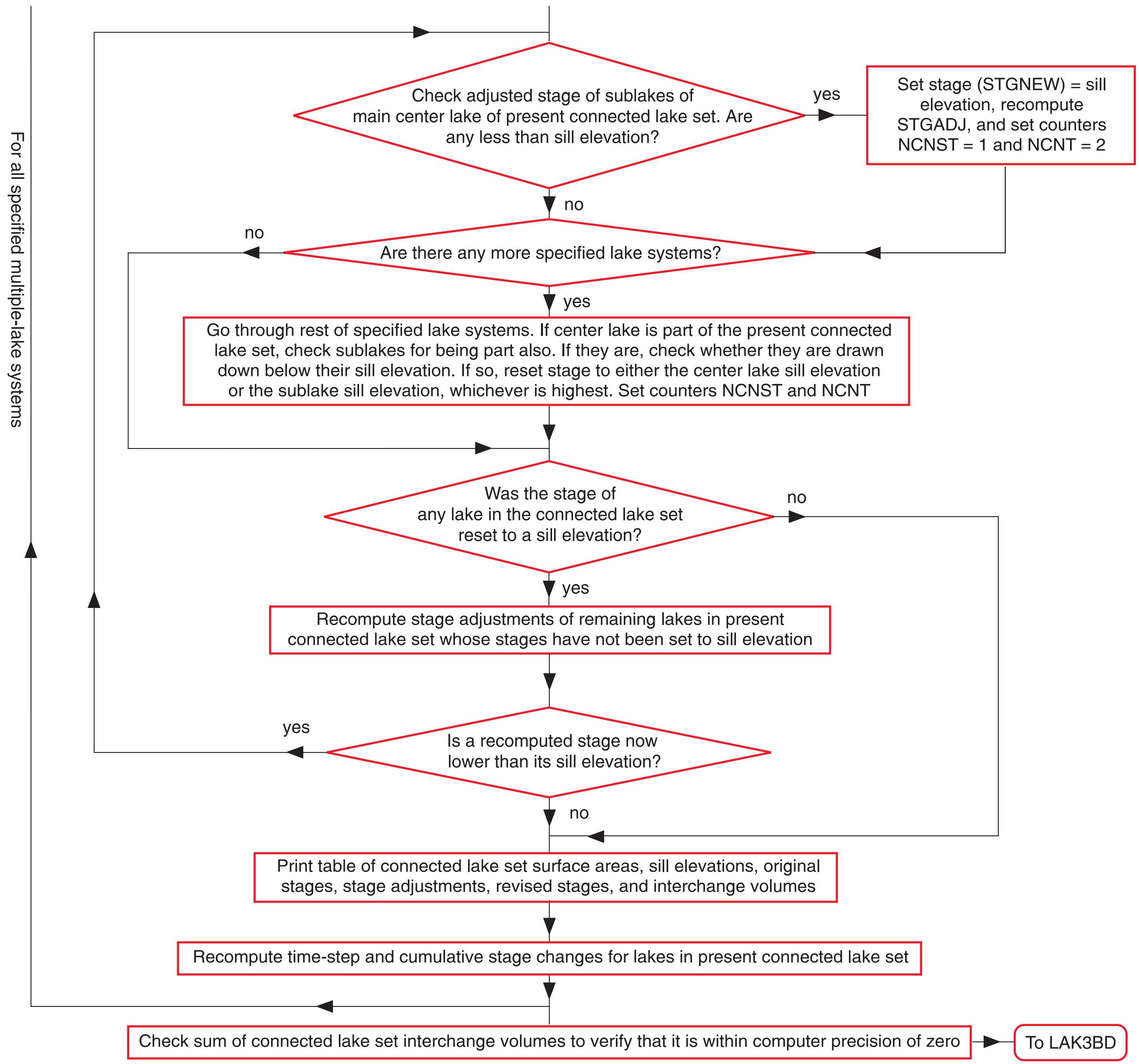


Figure 20. Generalized flow chart of the procedure for analyzing multiple-lake systems in module LAK3BD.

Operations are carried out in the following order.

1. Sum stream inflows into each lake and stream outflows from each lake. Individual streamflow quantities were previously computed and stored by the Stream Package of MODFLOW.
2. A final set of calculations to determine the rates of seepage (FLOBOT) through the lake/aquifer cell interfaces is performed. The calculations for lateral and vertical interfaces are similar to those described in module LAK3FM. Recharge (PRECIP) and evaporation (EVAP) fluxes for each lake are summed for vertical interfaces and when the overlying lake volume cell is at least partly saturated, as are lake surface areas (SURFA) and volumes (VOL). Values are integrated over the time step before summation.
3. After each calculation of a value of seepage through a lake/aquifer cell interface, values are accumulated in the water-budget summation terms. Depending on a user input specification, all seepage terms are printed or stored in cell-by-cell flow terms. All seepage inflows to lakes for each lake (GWIN) and for all lakes (RATOUT) are summed. All seepage outflows from lakes for each lake (GWOUT) and for all lakes (RATIN) are summed. Individual lake seepage sums are to be used for printouts of individual lake budgets, and totals for all lakes are to be used for printouts and analysis of the aquifer water budget.
4. If the volume of water in a lake from the previous time step is positive (lake is not dry), the water-budget equation is used for a final estimate of the stage and volume of each lake. This step is omitted in MODFLOW steady-state runs. A check is performed to determine whether the new volume of the lake is less than zero (if the lake has become dry).
5. If the lake volume from the previous time step was less than zero (the lake was dry), the average head in aquifer grid cells beneath the deepest part of the lake is computed and compared with the bottom elevation of the lake. If the average head value exceeds the bottom elevation of the lake, reset the lake stage to the average head value. This rewets the previously dry lake. If the lake remains dry, sum stream inflows and artificial augmentation inflows. If this sum is positive, divide by the bottom surface area and set the rewetted lake stage equal to the result.
6. If multiple-sublake systems are specified in the simulation (NCLS > 0), the list of multiple-sublake systems is processed to determine sets of connected lakes. After the current stages of sublakes of a center lake are checked against sill elevations to determine whether they are connected to the center lake, center lakes of other sublake systems are checked to determine if they are connected sublakes of the original system. If they are connected sublakes, sublakes of the other systems are checked to determine if they are also part of the connected system. When the complete set of connected sublakes is determined, stages are equalized in all sublakes of the connected system based on current lake surface areas.
   A subsequent check determines whether any sublakes have been lowered below their sill elevations by this procedure. If so, those sublake stages are fixed at the appropriate sill elevation and the equalization procedure is performed again, subject to the constraints on the volume of water contributed by lakes with stages set equal to their sill elevations. All lakes previously identified as part of connected lake systems are excluded from further consideration as the logic proceeds in the loop to subsequent specifications of center lake/sublake systems. Time-step and cumulative stage changes are recomputed for all lakes that are part of connected lake systems.
   A check on the sum of connected lake interchange volumes is performed. The procedures for analyzing multiple-lake systems for connectedness are presented in figure 20.
7. A check is made for lake volume cells that have become dry. The total number of such cells and their grid indices are printed.
8. If the Gage Package is being used and solute transport is not being computed, ASCII-formatted records of the current simulation time and the newly computed lake stage and volume are written to the chosen file.
9. If print flags have the right values, Lake Package summary tables with time-step information, lake budget information, new stages, stage changes, lake volumes, and surface areas are printed.
10. If option flags have the right values, seepage rates and fluxes are entered into cell-by-cell flow storage locations.
11. Return.

INTEGRATION WITH SOLUTE-TRANSPORT PACKAGE

The solute-transport package of MODFLOW (Konikow and others, 1996; Kipp and others, 1998) has been modified to ensure compatibility with the Lake Package, which is documented in this report, and with the Stream Package (D.E. Prudic and L.F. Konikow, written commun., 2000). The new code allows the model to calculate the concentration of a single solute in a lake or series of lakes based on a mass-balance approach that accounts for all inflows and outflows of both water and solute. Thus, the model allows solute to be routed through a stream network that may connect to a lake and accounts for inputs from (and seepage losses to) heterogeneous ground-water systems, in which the solute concentration may vary greatly in space and time.

The major steps in the calculation procedure of the integrated package are illustrated in figure 21. Solute concentrations in lakes are determined by calculations in four separate modules (subroutines). Several important steps, however, have been integrated directly into the Lake Package subroutines, which have been programmed to recognize whether or not solute transport is being simulated simultaneously with use of the Lake Package. Thus, allocation of space for variable arrays used in calculating lake solute concentrations are made in the LAK3AL subroutine and required input data are read by the LAK3AL and LAK3RP subroutines. For the benefit of those users who may want to examine or modify the Fortran source code, the new variables introduced to the code to enable calculation of lake concentrations are defined in table 3, which also shows the dimensions of arrays and their location within the main X-array of MODFLOW.

To obtain a solution to the ground-water solute-transport equation where a lake is losing water to the aquifer, it is also necessary to use the lake package to define $C'_{j,i,k}$, where $C'_{j,i,k}$ is the concentration in a fluid source to cell j,i,k (see Konikow and others, 1996, eq. 55). Therefore, equation 19 is solved at the beginning of each time increment used to solve the transport equation, but after a solution to the ground-water flow equation has been obtained. This allows us to define the value of $C'_{j,i,k}$ at grid locations where the seepage flux across a lake/aquifer cell interface is into the aquifer, as required to solve the solute-transport equation for the next time

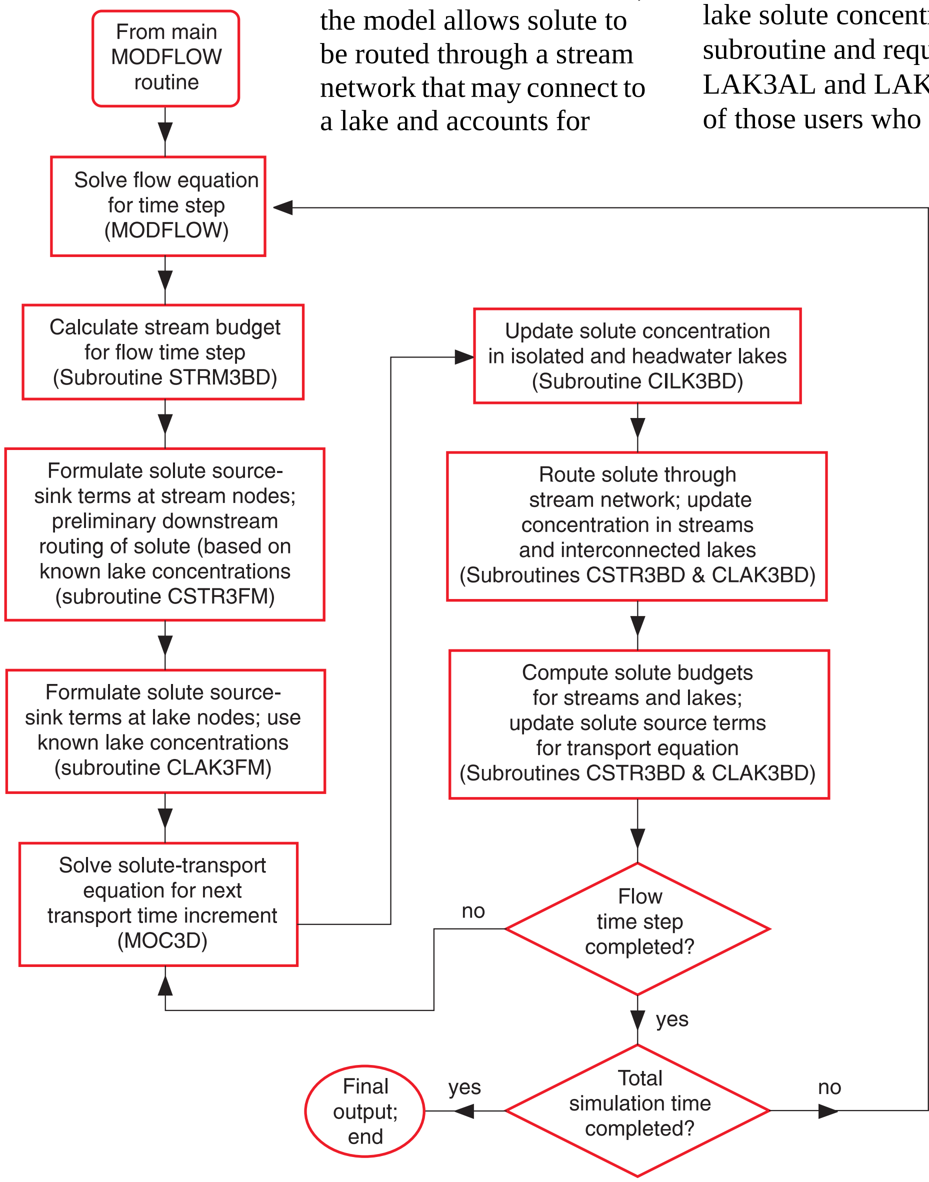


Figure 21. Flow chart illustrating major calculation steps in integrated lake, stream, and solute-transport packages, starting with solution to flow equation by MODFLOW solver package.

Table 3. List of new Lake Package variables related to solute concentration

[Dimensions: NLAKES, number of lakes; NSOL, number of solute species; NCOL, NROW, and NLAY, the number of columns, rows, and layers, respectively, in the MODFLOW grid; and LKNODE, the number of interfaces between lake cells and active aquifer cells]

Array name (Dimensions)	Location in X-Array	Definition
CLAKE(NLAKES,NSOL)	LSLAKE	Concentration in lake (initial values specified in input data; updated in code)
CPPT(NLAKES,NSOL)	LSPPT	Solute concentration in precipitation on each lake (input data)
CAUG(NLAKES,NSOL)	LSAUG	Concentration in specified augmentation to a lake (a negative withdrawal) (input data)
CRUNF(NLAKES,NSOL)	LSRNF	Concentration in overland runoff into lake (input data)
CGWL(NSOL)	LSCGWL	Concentration in fluid flux between ground water and lake (intermediate variable used during summation calculations)
CSLAKE(NLAKES,NSOL)	LSSLAK	Solute mass in lake during time increment based on concentration at end of previous time increment
CSWIN(NLAKES,NSOL)	LSSWIN	Total solute mass entering lake in streamflow from tributary streams
CSWOUT(NLAKES,NSOL)	LSSWOT	Total solute mass out of a lake into streams draining lake
SOLPPT(NLAKES,NSOL)	LSSPPT	Solute mass entering lake in precipitation
CWDRAW(NLAKES,NSOL)	LSCDRW	Solute mass entering or leaving a lake in specified withdrawals
CSRUN(NLAKES,NSOL)	LSSRUN	Solute mass entering lake in overland runoff
CGWIN(NLAKES,NSOL)	LSGWIN	Solute mass entering lake from ground-water discharge
CGWOUT(NLAKES,NSOL)	LSGWOT	Solute mass leaving lake in seepage loss to ground water
VOL(NLAKES)	LKACC7	Volume of water in each lake
VOLOLD(NLAKES)	LSOVOL	Volume of water in lake at end of previous time step
LKDONE(NLAKES)	LSDONE	Flag indicating that concentrations have been updated for this lake (if LKDONE>0)
KLK(NLAKES)	LSKLK	Flag indicating that lake has tributary inflow (if KLK>0)
CLKSUM(NSOL)	LSLKSM	Summation term for solute mass in lakes that comprise a multiple lake system
FLOB(LKNODE)	LSFLOB	Flux between lake and aquifer by cell (L^3/T)
RATECO(LKNODE,NSOL)	LSRTCO	Solute mass flux between aquifer cell and lake cell during previous transport time increment
ALKIN(NSOL)	LSALKI	Cumulative solute mass into aquifer by seepage out of all lakes within transport subgrid during one time increment
ALKOUT(NSOL)	LSALKO	Cumulative solute mass out of aquifer by seepage into all lakes within transport subgrid during one time increment
IGENLK(NCOL,NROW,NLAY)	LSIGLK	Flag indicating whether a lake node is gaining or losing water to a lake; affects particle movement routine in MOC3D

increment, as $C'_{j,i,k} = C_l^{n-1}$. This means that ground-water recharge from a lake during a transport time increment carries with it the solute concentration in the lake at the start of that time increment. Similarly, in solving equation 19 at the start of a transport time increment, it is also assumed that the concentration in water entering the lake from the ground-water system, C_{si}, equals the concentration in the aquifer at that cell at the end of the previous transport time increment.

To solve the ground-water solute-transport equation accurately, it is common for transport time increments to be smaller than the length of the time step used to solve the ground-water flow equation. In such cases, the fluid fluxes between the lake and the aquifer calculated for the flow time step are applied (at the same rate) to every transport time increment during that flow time step, but the concentrations in the lake and in the aquifer are updated more frequently.

In the mass-balance calculations for the solute-transport model, for a lake/aquifer interface across which the lake is gaining water from the aquifer during a given time increment, the solute mass flux between the aquifer and the lake is assumed to equal the flow rate times the average concentration at the aquifer node between the start and end of the time increment; that is, $m = q(\Delta t)[(C_{j,i,k}^{n-1} + C_{j,i,k}^{n})/2]$.

If the solute-transport equation is solved using one of the particle tracking algorithms (F-type MOC or MOCIMP in the transport name file), then special attention must be given to the specification of fluid sources or sinks as either “strong” or “weak.” This information is specified in Data Set 13 of the input data file for MOC3D (Kipp and others, 1998, or Konikow and others, 1996). As discussed, a “strong” source (or sink) cell is one in which all flow leaving (or entering) the cell is associated with the specified flux boundary condition, and there is no cell-to-cell flow into a strong source cell (or out of a strong sink cell). These conditions affect the particle movement and the particle regeneration-removal schemes inherent in the MOC3D transport model. Although some trial and error adjustments may be required, in many cases, it would be a reasonable first approximation to assume that all lake cells represent strong fluid sources or sinks. This would require setting IGENPT = 1 at all nodes corresponding to lake cells.

The lake package includes a number of output control parameters. These control the frequency and type of output written to the MODFLOW listing file or to separate output files. These parameters also control the frequency of writing output related to the solute calculations. Output related to solute transport, however, is written to the MOC3D listing file (FTYPE = CLST). Solute output from the lake package is also constrained by the MOC3D output control parameter NPNTCL, which is a flag for frequency of printing concentration data. Also, if the Gage Package is implemented simultaneously with solute transport and the Lake Package, the solute concentration at the location of the “gage” will be recorded (in addition to other parameters) at the end of every transport time increment.

Module CLAK3FM

The purpose of this subroutine is to formulate the solute source/sink terms for the solution to the solute-transport equation. The code checks all lake cells, and wherever the lake/aquifer interaction induces flow into the aquifer, the solute mass flux for that cell of the transport subgrid is stored. The source concentration is assumed to be the concentration in the lake at the end of the previous time flow time step (or at the start of the present time step). The fluid flux is determined from the implicitly calculated heads and the updated lake stages for the end of the present flow time step. The fluid and solute mass fluxes into the aquifer for the next transport time increment are then accumulated in the SRCFLO and SRCSOL arrays, respectively, for use later in solving the transport equation. Where the lake is gaining water from the aquifer (a fluid sink in terms of aquifer flux), the fluid flux to the lake is added to any other sink terms for that cell.

Module CILK3BD

This subroutine is called after the solute-transport equation has been solved for a transport time increment. The purpose of this subroutine is to calculate solute budget terms for all lakes for the present transport time increment. Because solute has not yet been routed through the stream network, the lake solute budgets cannot be completed for any lake that has inflow from a stream. Therefore, the solute budgets can be completed and the solute concentrations updated for only lakes that are isolated or lakes that are headwater lakes (that is, they have stream outflows, but not stream inflows).

After computations for all individual lakes are finished, the subroutine checks to see if any of the lakes for which new solute concentrations were calculated are part of a set of connected lakes. If they are, then a new uniform average concentration for all lakes in the lake set is calculated on the basis of complete mixing of water and solute in all lakes that compose a lake set.

The updated concentrations in headwater lakes are then passed to the Stream Package to allow the routing of solute through the stream network.

Module CLAK3BD

In a stream network, a lake can serve as the source of inflow to a stream segment or as the receiver of ouflow from a stream segment. As the Stream Package progresses in routing solute downstream, it determines whether the solute concentration in a lake that provides inflow to a stream has been updated. If not, the reason is that the lake also had streamflow entering it. However, by the time such a lake is evaluated by the Stream Package, the computation of stream inflow would have already been completed because the lake receives inflow from streams higher in the network. At this point, subroutine CLAK3BD is called to complete the solute budget terms for the lake that has not yet been updated. The purpose of subroutine CLAK3BD is thus to update the concentration in such a lake for the present transport time increment.

As before in subroutine CILK3BD, this routine also checks to see if the lake is part of a set of connected lakes. If so, then a new uniform average concentration for all lakes in that lake set is calculated on the basis of complete mixing of water and solute in all lakes that compose a lake set.

After the updating of the concentration in this lake or lake set is completed, the routing of solute through the stream network can continue.

Module CLAK3AD

After the solute routing through the stream network has been completed, and the concentrations in all lakes have been updated, subroutine CLAK3AD is called to advance the calculations to the next transport time increment. To accomplish this, the solute budgets for all lakes are computed and updated. The lake solute budgets and concentrations are then available for output, if indicated. If the Gage Package is active, then lake concentrations are written to the appropriate separate output file for each lake where a gaging station is located.

This subroutine also updates the solute source term for lake/aquifer interface cells where the aquifer is gaining water from the lake. The SRCSOL array is updated to account for the new lake concentration. The fluid flow terms for both sources and sinks are not updated until a new flow time step is completed (because that is when ground-water heads are recalculated).

SUMMARY

The Lake Package documented in this report enhances the capabilities of MODFLOW, the U.S. Geological Survey's three-dimensional, finite-difference, modular, ground-water model. This package allows for development of more realistic simulations of aquifers that interact with lakes than could be implemented previously.

The Lake Package computes water fluxes between grid cells designated as part of a lake and adjacent grid cells representing the aquifer. Lake budgets account for atmospheric, surface, water, and subsurface fluxes into and out of each lake; the model computes new lake stages and lake volumes that are consistent with a balanced water budget. The Lake Package has been designed to interface with the U.S. Geological Survey's Stream Package, so that a complex stream-lake system can be accurately represented.

The surface area of a lake may expand or contract, depending on changes in stage and the specified lake geometry. At one extreme, with declining lake stages, lakes may dry up partially or completely, and may subsequently rewet if conditions change over time. With rising lake stages, adjacent lakes may coalesce to form a larger lake having a uniform water level over the joint area. With falling lake stages, and depending on the bathymetry of the lake bottom, a large lake may divide into separate sublakes, each having a distinct water level.

If MODFLOW is implemented with the MOC3D package activated to simulate solute transport in the aquifer, then the new Lake Package will also compute a solute budget for the lakes. Just as both specified and calculated fluid fluxes provide the basis for the water budget and calculations of stage changes over time, tracking all solute fluxes into and out of a lake allows for the calculation of changes in solute concentration in the lake. Also, where a lake is recharging the aquifer, the solute in the recharge water may create a solute "plume" in the aquifer. At present, the model assumes that the solute is nonreactive.

Four test cases were documented to demonstrate the accuracy of the lake calculations and to illustrate the range of conditions for which the package is applicable. The Lake Package is applicable to a wide range of hydrogeological problems involving lake/aquifer systems.

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Appendixes

APPENDIX 1: DATA INPUT INSTRUCTIONS FOR LAKE PACKAGE

MODFLOW Name File

The simulation of the interaction of lakes with the aquifer is activated by including a record in the MODFLOW name file using the file type (Ftype) “LAK” to indicate that such calculations are to be made in the model and to specify the related input data file. The user can optionally specify that lake stages are to be written using the Gage Package by including a record in the MODFLOW name file using the file type (Ftype) “GAGE” that specifies the selected input data file identifying the lakes.

Lake Package Input Data

Input for the Lake Package is read from the unit specified in the MODFLOW name file. The input consists of nine separate data sets, each consisting of one or more records, as described in detail below. These data are used to specify information about the physical geometry of the lakes, hydraulic properties of the lakebeds, and the degree of hydraulic stress originating from atmospheric and anthropogenic sources, as well as specifying certain output control parameters. Spatial and temporal units of input data specifications should be consistent with other data input for the MODFLOW run.

In the following section, parameters are indicated as being optional by their enclosure in brackets. All input variables are read using free formats, unless specifically indicated otherwise. In free format, variables are separated by one or more spaces, or by a comma and, optionally, one or more spaces. It is important to note that, in free format, blank spaces are not read as zeroes and a blank field cannot be used to set a parameter value to zero.

For Each Simulation:

These data are read by module LAK3AL.

Record 1. Data: NLAKES ILKCB

NLAKES Number of separate lakes.

ILKCB Whether or not to write cell-by-cell flows (yes if ILKCB> 0, no otherwise). If ILKCB< 0 and ICBCFL is not equal to 0, the cell-by-cell flows will be printed in the standard output file.

Notes:

1. Sublakes of multiple-lake systems are considered separate lakes for input purposes. The variable NLAKES is used, with certain internal assumptions and approximations, to dimension arrays for the simulation.

2. If data are being read using the fixed format mode, then each field should be entered using I10 format.

3. ICBCFL is specified in the input to the Output Control Package of MODFLOW.

Record 2. Data: THETA {NSSITR SSCNCR}

THETA Explicit (THETA = 0.0), semi-implicit (0.0 < THETA < 1.0), or implicit (THETA = 1.0) solution for lake stages.

NSSITR Maximum number of iterations for Newton's method solution for equilibrium lake stages in each MODFLOW iteration for steady-state aquifer head solution. Only read if ISS (option flag input to BCF Package of MODFLOW indicating steady-state solution) is not zero.

SSCNCR Convergence criterion for equilibrium lake stage solution by Newton's method. Only read if ISS is not zero.

Notes:

1. NSSITR and SSCNCR are not needed for a transient solution (ISS = 0) and should be omitted when the solution is transient.

2. If data are being read using the fixed format mode, then the data should be entered using format (F10.4,I10,F10.4).

3. THETA should be set equal to zero if a steady-state solution is to be performed.

For the First Stress Period Only:

These data are read by module LAK3RP.

Record 3. Data: STAGES {SSMN SSMX} {CLAKE(1)..........CLAKE(NSOL)}

STAGES The initial stage of each lake at the beginning of the run.

SSMN Minimum stage allowed for each lake in steady-state solution.

SSMX Maximum stage allowed for each lake in steady-state solution.

CLAKE The initial concentrations in each lake at the beginning of the model run. Values are entered for NSOL constituents. The value of NSOL is passed from MOC3D. CLAKE values are ignored if entered in MODFLOW runs.

Notes:

1. This data set should consist of one line for each lake, where line 1 includes data for lake 1, and line *n* includes data for lake *n*. There must be exactly NLAKES lines of data.

2. SSMN and SSMX are not needed for a transient run and must be omitted when the solution is transient.

3. CLAKE is an optional parameter, and is only read if solute transport is being simulated. In that case, if more than one solute is being simulated, then there should be a string of NSOL values of CLAKE (where NSOL is the number of solutes) on one line. The default value of NSOL is NSOL = 1.

4. If data are being read using the fixed format mode, then each field should be entered using F10.4 format.

For Each Stress Period:

These data are read by module LAK3RP.

Record 4. Data: ITMP ITMP1 LWRT

ITMP > 0, read lake definition data (records 5-7, and, optionally, records 8 and 9);
= 0, no lake calculations this stress period;
< 0, use lake definition data from last stress period.

ITMP1 > 0 or = 0, read new recharge, evaporation, runoff, and withdrawal data for each lake, and associated concentrations if needed for MOC3D runs;
< 0, use recharge, evaporation, runoff, and withdrawal data, and concentrations, if needed, from last stress period.

LWRT > 0, suppresses printout from the lake package.

Notes:

1. ICBCFL < 0 or = 0 also suppresses printout from the lake package. ICBCFL is specified in the input to the Output Control Package of MODFLOW.

2. If data are being read using the fixed format mode, then each field should be entered using I10 format.

3. Lake definition data are restricted to cells for which IBOUND and WETDRY values have been set to zero.

If ITMP > 0:

Record 5. Data: LKARR(NCOL,NROW)

A NCOL by NROW array is read for each layer in the grid by MODFLOW module U2DINT.

LKARR A value is read in for every grid cell. If LKARR(I,J,K) = 0, the grid cell is not a lake volume cell. If LKARR(I,J,K) > 0, its value is the identification number of the lake occupying the grid cell. LKARR(I,J,K) must not exceed the value NLAKES. If it does, or if LKARR(I,J,K) < 0, LKARR(I,J,K) is set to zero.

Notes:

1. Lake cells cannot be overlain by non-lake cells in a higher layer.

Record 6. Data: BDLKNC(NCOL,NROW)

A NCOL by NROW array is read for each layer in the grid by MODFLOW module U2DREL.

BDLKNC A value is read in for every grid cell. The value is the lakebed leakance that will be assigned to lake/aquifer interfaces that occur in the corresponding grid cell.

Notes:

1. If the wet-dry option flag (IWTFLG) is not active (cells cannot rewet if they become dry), then the BDLKNC values are assumed to represent the combined leakances of the lakebed material and the aquifer material between the lake and the centers of the underlying grid cells, i. e., the vertical conductance values (CV) will not be used in the computation of conductances across lake/aquifer boundary faces in the vertical direction.

2. IBOUND in the input to the Basic Package of MODFLOW and, if the IWTFLG option is active, WETDRY in the input to the BCF or other flow package of MODFLOW, should be set to zero for every cell for which LKARR is not equal to zero.

If ITMP > 0:

Record 7. Data: NSLMS

NSLMS — The number of sublake systems if coalescing/dividing lakes are to be simulated (only in transient runs). Enter 0 if no sublake systems are to be simulated.

Notes:

1. If data are being read using the fixed format mode, then NSLMS should be entered using format I5.

If ITMP > 0 and NSLMS > 0:

Record 8a. Data: IC ISUB(1) ISUB(2) .... ISUB(IC)

Record 8b. Data: SILLVT(2) .... SILLVT(IC)

IC — The number of sublakes, including the center lake, in the sublake system being described in this record.

ISUB — The identification numbers of the sublakes in the sublake system being described in this record. The center lake number is listed first.

SILLVT — Sill elevation that determines whether the center lake is connected with a given sublake. One value is entered in this record for each sublake in the order the sublakes are listed in the previous record.

Notes:

1. A pair of records (records 8a and 8b) is read for each multiple-lake system, i.e., NSLMS pairs of records. However, IC = 0 will terminate the input.

2. If data are being read using the fixed format mode, then each field of Record 8a should be entered using I5 format and each field of Record 8b should be entered using F10.4 format.

If ITMP1 > 0 or = 0.

Record 9a. Data: PRCPLK EVAPLK RNF WTHDRW

PRCPLK — The rate of precipitation per unit area at the surface of a lake (L/T).

EVAPLK — The rate of evaporation per unit area from the surface of a lake (L/T).

RNF Overland runoff from an adjacent watershed entering the lake. If RNF > 0, it is specified directly as a volumetric rate, or flux (L^3/T). If RNF < 0, its absolute value is used as a dimensionless multiplier applied to the product of the lake precipitation rate per unit area (PRCPLK) and the surface area of the lake at its full stage (occupying all layer 1 lake cells).

WTHDRW The volumetric rate, or flux (L^3/T), of water removal from a lake by means other than rainfall, evaporation, surface outflow, or ground-water seepage. A negative value indicates augmentation. Normally, this would be used to specify the rate of artificial withdrawal from a lake for human water use, or if negative, artificial augmentation of a lake volume for esthetic or recreational purposes.

Notes:

1. When RNF is entered as a dimensionless multiplier (RNF < 0), it is considered to be the product of two proportionality factors. The first is the ratio of the area of the basin contributing runoff to the surface area of the lake when it is at full stage. The second is the fraction of the current rainfall rate that becomes runoff to the lake. This procedure provides a means for the automated computation of runoff rate from a watershed to a lake as a function of varying rainfall rate. For example, if the basin area is 10 times greater than the surface area of the lake, and 20 percent of the precipitation on the basin becomes overland runoff directly into the lake, then set RNF = -2.0.

If solute transport is also being simulated (Ftype “CONC” exists), then for each solute the following data are read:

Record 9b. Data: CPPT(NSOL) CRNF(NSOL) {CAUG(NSOL)}

CPPT The concentration of solute in precipitation onto the lake surface.
CRNF The concentration of solute in overland runoff directly into the lake.
CAUG The concentration of solute in water used to augment the lake volume.

Notes:

1. At least one of the above records will be read for each lake; i.e., NLAKES records, or sets of records, will be read. If MODFLOW is being run, only the first record is read. If MOC3D is being run, a set of two or more records will be read for each lake (see note 2).

2. If record 9b is included because solute transport is being simulated, then 9b should consist of one record (line) for each solute; each record must contain two or three values; and there must be as many records as the number of solutes being simulated (NSOL). The order of records must be that all necessary lines for 9b are listed for a given lake before line 9a for the next lake. For example, if the Lake Package is representing three lakes and the solute transport package is representing two solutes, then the order of data for Record 9 would be 9a, 9b, 9b, 9a, 9b, 9b, 9a, 9b, and 9b.

3. CAUG is an optional parameter, and is only read if the value of WTHDRW in 9a is negative (no value should be specified for CAUG if WTHDRW in 9a is positive, indicating withdrawal of water from the lake).

4. It is implicitly assumed that no solute is present in water evaporated from the lake surface.

5. If data are being read using the fixed format mode, then each field should be entered using F10.4 format.

Gaging (Monitoring) Station File (GAGE)

Lakes can be designated as having gaging stations located on them. For each such designated lake, the time and stage of that lake (and if solute transport is being simulated, the concentration of each solute) after each time step (and each transport time increment) will be written to a separate output file to facilitate graphical postprocessing of the calculated data. The input file for specifying gaging station locations is read if the file type (Ftype) “GAGE” is included in the MODFLOW name file.

For each simulation, if GAGE Package is used:

Record 1: Data: NUMGAGE

NUMGAGE Number of gaging stations

For each gaging station:

Record 2: Data: LAKE UNIT

LAKE Negative value of the lake number of the lake where the gage is located.
UNIT Unit number for output file.

<u>Notes</u>:

1. The user should specify a unique unit number for each gaging station and match those unit numbers to DATA file types and file names in the MODFLOW name file (Harbaugh and McDonald, 1996b).

2. The Gage Package can also be used in conjunction with the Stream Package to specify the location of a gaging station on a stream. Therefore, to guarantee that the code can distinguish between input for lakes and that for stream locations, lake numbers are specified as their negative value.

3. Data Set 2 must include exactly NUMGAGE lines (or records) of data. If NUMGAGE > 1, it is permissible to interleaf in Data Set 2 records for stream gaging stations (according to the format specified in the documentation for the Stream Package) with records for gages on lakes (according to the format described above). Data lines (records) within Data Set 2 can be listed in any arbitrary order.

APPENDIX 2

INPUT DATA SETS AND PRINTED RESULTS FOR TEST SIMULATION 1

This simulation demonstrates the capability of MODFLOW with the lake package to portray convergence to an equilibrium state in which the water budget of a lake is in balance with that of an aquifer having a regional hydraulic gradient. The first set of input data sets shown below are for a transient run to equilibrium. Additional input data sets for the Lake Package and partial output data sets are shown for a steady-state simulation and for the case where an equilibrium simulation is preceded by complete drying of the lake.

Listing of Input Data Sets for Test Simulation 1 - Transient Case

The input data set names and the unit numbers that they are associated with are identified in the namefile, the name of which is entered from the console at execution time. The following namefile data set was used for Test Simulation 1. The three entries on each line are an alpha character identification of the MODFLOW package, the logical unit number for the corresponding input data set, and the input data set name, and are separated by spaces.

`LIST  6 unit6dn.96`	← Designates main output file for MODFLOW
`BAS   5 unit5dn`	← Basic input data for MODFLOW
`BCF  10 unit10dn`	← Input for Block-Centered Flow Package
`EVT  11 unit11dn`	← Input for Evapotranspiration Package
`RCH  12 unit12b`	← Input for Recharge Package
`SIP  13 unit13a`	← Input parameters for strongly-implicit procedure
`FHB  21 unit21dn`	← Input data for Flow and Head Boundary Package
`LAK  16 unit16dn`	← Input data for Lake Package
`OC   17 unit17d1`	← Output control data specifications
`GAGE 33 unit33dn`	← Specifications for output gage locations
`DATA 37 daunit37`	← Output unit for GAGE data

↑ ↑ ↑

1 2 3

1 Ftype (that is, the type of file)

2 Unit number (arbitrarily selected)

3 File name (name chosen to reflect contents of file)

Listing of Input Data for Basic Package

Input for the Basic Package (BAS) follows the column headings below. The input consists of 102 records (lines). Input for the package is read from the FORTRAN unit number specified in the MAIN program.

```
                                        Column Numbers
         1         2         3         4         5         6         7         8
12345678901234567890123456789012345678901234567890123456789012345678901234567890
______________________________________________________________________________
Shows convergence to equilibrium in transient mode.          ; begin BAS Input
      NLAY      NROW      NCOL      NPER    ITMUNI           ; second comment line
         5        17        17         1         4
                                                             ; options line (blank)
         0         0                                         ; IAPART, ISTRT
         5         1(24I3)                       3           ; IBOUND, 1st layer
 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1
 -1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1 -1
 -1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1 -1
 -1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1 -1
 -1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1 -1
 -1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1 -1
 -1  1  1  1  1  1  0  0  0  0  0  1  1  1  1  1 -1
 -1  1  1  1  1  1  0  0  0  0  0  1  1  1  1  1 -1
 -1  1  1  1  1  1  0  0  0  0  0  1  1  1  1  1 -1
 -1  1  1  1  1  1  0  0  0  0  0  1  1  1  1  1 -1
 -1  1  1  1  1  1  0  0  0  0  0  1  1  1  1  1 -1
 -1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1 -1
 -1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1 -1
 -1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1 -1
 -1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1 -1
 -1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1 -1
 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1
         5         1(24I3)                       3           ; IBOUND, 2nd layer
 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1
 -1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1 -1
 -1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1 -1
 -1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1 -1
 -1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1 -1
 -1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1 -1
 -1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1 -1
 -1  1  1  1  1  1  1  0  0  0  1  1  1  1  1  1 -1
 -1  1  1  1  1  1  1  0  0  0  1  1  1  1  1  1 -1
 -1  1  1  1  1  1  1  0  0  0  1  1  1  1  1  1 -1
 -1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1 -1
 -1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1 -1
 -1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1 -1
 -1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1 -1
 -1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1 -1
 -1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1 -1
 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1
         5         1(24I3)                       3           ; IBOUND, 3rd layer
 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1
 -1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1 -1
 -1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1 -1
 -1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1 -1
 -1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1 -1
 -1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1 -1
 -1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1 -1
 -1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1 -1
```

```
-1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1 -1
-1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1 -1
-1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1 -1
-1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1 -1
-1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1 -1
-1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1 -1
-1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1 -1
-1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1 -1
-1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1
        5         1(24I3)                     3             ; IBOUND, 4th layer
-1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1
-1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1 -1
-1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1 -1
-1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1 -1
-1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1 -1
-1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1 -1
-1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1 -1
-1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1 -1
-1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1 -1
-1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1 -1
-1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1 -1
-1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1 -1
-1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1 -1
-1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1 -1
-1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1 -1
-1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1 -1
-1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1
        5         1(24I3)                     3             ; IBOUND, 5th layer
-1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1
-1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1 -1
-1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1 -1
-1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1 -1
-1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1 -1
-1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1 -1
-1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1 -1
-1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1 -1
-1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1 -1
-1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1 -1
-1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1 -1
-1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1 -1
-1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1 -1
-1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1 -1
-1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1 -1
-1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1 -1
-1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1
    -999.                                                   ; HNOFLO
        0      115.                                         ; Initial head, layer 1
        0      115.                                         ; Initial head, layer 2
        0      115.                                         ; Initial head, layer 3
        0      115.                                         ; Initial head, layer 4
        0      115.                                         ; Initial head, layer 5
    5000.       100       1.02                              ; PERLEN, NSTP,TSMULT
```

Listing of Input Data for Block-Centered Flow Package

Input for the Block-Centered Flow Package (BCF) follows the column headings below. The input consists of 128 records (lines). Input for the package is read from FORTRAN unit number 10, as specified in the namefile.

```
                                       Column Numbers
         1         2         3         4         5         6         7         8
12345678901234567890123456789012345678901234567890123456789012345678901234567890
________________________________________________________________________________
         0         0       0.0         1       1.0         1         0 ; BCF input
 1 3 3 3 3                                                               ; LAYCON
         0       1.0                                                      ; TRPY
        10       1.0(7F10.0)                   0                          ; DELR
      250.     1000.     1000.     1000.     1000.     1000.      500.
      500.      500.      500.      500.     1000.     1000.     1000.
     1000.     1000.      250.
        10       1.0(7F10.0)                   0                          ; DELC
      250.     1000.     1000.     1000.     1000.     1000.      500.
      500.      500.      500.      500.     1000.     1000.     1000.
     1000.     1000.      250.
         0      0.20                                      ; storage coefficient, layer 1
         0       30.                                      ; hydraulic conductivity, layer 1
         0      107.                                      ; bottom elevation, layer 1
         0        3.                                      ; vertical leakance, layers 1 and 2
        10      -0.2(24F3.0)                   8          ; wet-dry, layer 1
  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
  0  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  0
  0  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  0
  0  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  0
  0  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  0
  0  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  0
  0  1  1  1  1  1  0  0  0  0  0  1  1  1  1  1  0
  0  1  1  1  1  1  0  0  0  0  0  1  1  1  1  1  0
  0  1  1  1  1  1  0  0  0  0  0  1  1  1  1  1  0
  0  1  1  1  1  1  0  0  0  0  0  1  1  1  1  1  0
  0  1  1  1  1  1  0  0  0  0  0  1  1  1  1  1  0
  0  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  0
  0  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  0
  0  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  0
  0  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  0
  0  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  0
  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
         0    0.0003                                   ; primary storage coefficient, layer 2
         0       30.                                   ; hydraulic conductivity, layer 2
         0       97.                                   ; bottom elevation, layer 2
         0        3.                                   ; vertical leakance, layers 2 and 3
         0       0.2                                   ; secondary storage coefficient, layer 2
         0      107.                                   ; top elevation, layer 2
        10      -0.2(24F3.0)                   8       ; wet-dry, layer 2
  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
  0  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  0
  0  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  0
  0  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  0
  0  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  0
  0  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  0
  0  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  0
  0  1  1  1  1  1  1  0  0  0  1  1  1  1  1  1  0
  0  1  1  1  1  1  1  0  0  0  1  1  1  1  1  1  0
  0  1  1  1  1  1  1  0  0  0  1  1  1  1  1  1  0
  0  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  0
  0  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  0
  0  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  0
  0  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  0
  0  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  0
  0  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  0
  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
         0    0.0003                                   ; primary storage coefficient, layer 3
         0       30.                                   ; hydraulic conductivity, layer 3
         0       87.                                   ; bottom elevation, layer 3
         0        3.                                   ; vertical leakance, layers 3 and 4
```

```
       0       0.2                                            ; secondary storage coefficient, layer 3
       0       97.                                            ; top elevation, layer 3
      10      -0.2(24F3.0)                          8         ; wet-dry, layer 3
0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
0  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  0
0  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  0
0  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  0
0  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  0
0  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  0
0  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  0
0  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  0
0  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  0
0  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  0
0  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  0
0  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  0
0  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  0
0  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  0
0  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  0
0  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  0
0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
       0    0.0003                                            ; primary storage coefficient, layer 4
       0       30.                                            ; hydraulic conductivity, layer 4
       0       77.                                            ; bottom elevation, layer 4
       0        3.                                            ; vertical leakance, layers 4 and 5
       0       0.2                                            ; secondary storage coefficient, layer 4
       0       87.                                            ; top elevation, layer 4
      10      -0.2(24F3.0)                          8         ; wet-dry, layer 4
0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
0  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  0
0  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  0
0  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  0
0  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  0
0  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  0
0  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  0
0  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  0
0  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  0
0  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  0
0  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  0
0  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  0
0  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  0
0  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  0
0  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  0
0  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  0
0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
       0    0.0003                                            ; primary storage coefficient, layer 5
       0       30.                                            ; hydraulic conductivity, layer 5
       0       67.                                            ; bottom elevation, layer 5
       0       0.2                                            ; secondary storage coefficient, layer 5
       0       77.                                            ; top elevation, layer 5
      10      -0.2(24F3.0)                          8         ; wet-dry, layer 5
0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
0  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  0
0  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  0
0  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  0
0  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  0
0  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  0
0  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  0
0  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  0
0  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  0
0  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  0
0  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  0
0  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  0
0  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  0
0  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  0
0  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  0
0  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  0
0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
```

Listing of Input Data for Evapotranspiration Package

Input for the Evapotranspiration Package (EVT) follows the column headings below. The input consists of 22 records (lines). Input for the package is read from FORTRAN unit number 11, as specified in the namefile.

```
                                           Column Numbers
         1         2         3         4         5         6         7         8         9        10        11
12345678901234567890123456789012345678901234567890123456789012345678901234567890123456789012345678901234567890
______________________________________________________________________________________________________________

         3         0                                         ; EVT input - NEVTOP, IEVTCB
         1         1         1         0                     ; input options INSURF,INEVTR,INEXDP,INIEVT
        11       1.0(19F6.1)                   8             ; ET surface
 160.0 159.0 157.4 155.9 154.3 152.7 151.6 150.8 150.0 149.2 148.4 147.3 145.7 144.1 142.6 141.0 140.0
 160.0 159.0 157.4 155.9 154.3 152.7 151.6 150.8 150.0 149.2 148.4 147.3 145.7 144.1 142.6 141.0 140.0
 160.0 159.0 157.4 155.9 154.3 152.7 151.6 150.8 150.0 149.2 148.4 147.3 145.7 144.1 142.6 141.0 140.0
 160.0 159.0 157.4 155.9 154.3 152.7 151.6 150.8 150.0 149.2 148.4 147.3 145.7 144.1 142.6 141.0 140.0
 160.0 159.0 157.4 155.9 154.3 152.7 151.6 150.8 150.0 149.2 148.4 147.3 145.7 144.1 142.6 141.0 140.0
 160.0 159.0 157.4 155.9 154.3 152.7 151.6 150.8 150.0 149.2 148.4 147.3 145.7 144.1 142.6 141.0 140.0
 160.0 159.0 157.4 155.9 154.3 152.7 105.0 105.0 105.0 105.0 105.0 147.3 145.7 144.1 142.6 141.0 140.0
 160.0 159.0 157.4 155.9 154.3 152.7 105.0  95.0  95.0  95.0 105.0 147.3 145.7 144.1 142.6 141.0 140.0
 160.0 159.0 157.4 155.9 154.3 152.7 105.0  95.0  95.0  95.0 105.0 147.3 145.7 144.1 142.6 141.0 140.0
 160.0 159.0 157.4 155.9 154.3 152.7 105.0  95.0  95.0  95.0 105.0 147.3 145.7 144.1 142.6 141.0 140.0
 160.0 159.0 157.4 155.9 154.3 152.7 105.0 105.0 105.0 105.0 105.0 147.3 145.7 144.1 142.6 141.0 140.0
 160.0 159.0 157.4 155.9 154.3 152.7 151.6 150.8 150.0 149.2 148.4 147.3 145.7 144.1 142.6 141.0 140.0
 160.0 159.0 157.4 155.9 154.3 152.7 151.6 150.8 150.0 149.2 148.4 147.3 145.7 144.1 142.6 141.0 140.0
 160.0 159.0 157.4 155.9 154.3 152.7 151.6 150.8 150.0 149.2 148.4 147.3 145.7 144.1 142.6 141.0 140.0
 160.0 159.0 157.4 155.9 154.3 152.7 151.6 150.8 150.0 149.2 148.4 147.3 145.7 144.1 142.6 141.0 140.0
 160.0 159.0 157.4 155.9 154.3 152.7 151.6 150.8 150.0 149.2 148.4 147.3 145.7 144.1 142.6 141.0 140.0
 160.0 159.0 157.4 155.9 154.3 152.7 151.6 150.8 150.0 149.2 148.4 147.3 145.7 144.1 142.6 141.0 140.0
         0    0.0141                                         ; maximum ET rate
         0       15.                                         ; extinction depth
______________________________________________________________________________________________________________
```

Listing of Input Data for Recharge Package

Input for the Recharge Package (RCH) follows the column headings below. The input consists of 3 records (lines). Input for the package is read from FORTRAN unit number 12, as specified in the namefile.

```
                                 Column Numbers
         1         2         3         4         5         6         7         8
12345678901234567890123456789012345678901234567890123456789012345678901234567890
________________________________________________________________________________________
         3         0                                     ; RCH input - NRCHOP,IRCHCB
         1         0                                     ; input options INRECH,INIRCH
         0    0.0116                                     ; recharge rate
________________________________________________________________________________________
```

Listing of Input Data for Strongly-Implicit Procedure Package

Input for the Strongly-Implicit Procedure Package (SIP) follows the column headings below. The input consists of 2 records (lines). Input for the package is read from FORTRAN unit number 13, as specified in the namefile.

```
                                 Column Numbers
         1         2         3         4         5         6         7         8
12345678901234567890123456789012345678901234567890123456789012345678901234567890
________________________________________________________________________________________
       500         5                                      ; SIP input - MXITER,NPARM
       0.0    0.0001         1       0.0         1        ; SIP parameter specifications
________________________________________________________________________________________
```

Listing of Input Data for the Flow and Head Boundary Package

Input for the Flow and Head Boundary Package (FHB) follows the column headings below. The input consists of 324 records (lines). Input for the package is read from FORTRAN unit number 21, as specified in the namefile. The fourth column is not used by MODFLOW but may be used by MOC3D.

```
                                               Column Numbers
         1         2         3         4         5         6         7         8
12345678901234567890123456789012345678901234567890123456789012345678901234567890
____________________________________________________________________________________
         1         0       320         0         0         0         0 ; FHB input
        21       1.0         1                                 ; simulation times for input
       0.0
        21       1.0         1                                 ; boundary head values
         1         1         1       160    160.00
         1         2         1       160    160.00
         1         3         1       160    160.00
         1         4         1       160    160.00
(162 records have been omitted assigning heads in all layers on the west and east boundaries
to 160 and 140 feet, respectively.)
         5        14        17       140    140.00
         5        15        17       140    140.00
         5        16        17       140    140.00
         5        17        17       140    140.00
         1         1         2       150    158.85
         1         1         3       150    157.31
         1         1         4       150    155.77
         1         1         5       150    154.23
(142 records have been omitted assigning specified heads across the northern and southern
boundaries in all layers by linear interpolation between 160 and 140 feet.)
         5        17        13       140    145.77
         5        17        14       144    144.23
         5        17        15       140    142.69
         5        17        16       140    141.15
____________________________________________________________________________________
```

Listing of Input Data for the Lake Package

Input for the Lake Package (LAK) follows the column headings below. The input consists of 50 records (lines). Input for the package is read from FORTRAN unit number 16, as specified in the namefile.

```
                                               Column Numbers
         1         2         3         4         5         6         7         8
12345678901234567890123456789012345678901234567890123456789012345678901234567890
____________________________________________________________________________
         1         0                                        ; LAK input - NLAKES,ILKCB
      0.00                                                  ; THETA
     110.0                                                  ; initial stage
         1         0         0                              ; input/output options
        16         1(24I3)                            3     ; lake position array, layer 1
  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
  0  0  0  0  0  0  1  1  1  1  1  0  0  0  0  0  0
  0  0  0  0  0  0  1  1  1  1  1  0  0  0  0  0  0
  0  0  0  0  0  0  1  1  1  1  1  0  0  0  0  0  0
  0  0  0  0  0  0  1  1  1  1  1  0  0  0  0  0  0
  0  0  0  0  0  0  1  1  1  1  1  0  0  0  0  0  0
  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
        16         1(24I3)                            3     ; lake position array, layer 2
  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
```

```
  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
  0  0  0  0  0  0  0  1  1  1  0  0  0  0  0  0  0
  0  0  0  0  0  0  0  1  1  1  0  0  0  0  0  0  0
  0  0  0  0  0  0  0  1  1  1  0  0  0  0  0  0  0
  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
         0         0                                    ; lake position array, layer 3
         0         0                                    ; lake position array, layer 4
         0         0                                    ; lake position array, layer 5
         0      0.10                                    ; lakebed leakance array, layer 1
         0      0.10                                    ; lakebed leakance array, layer 2
         0      0.10                                    ; lakebed leakance array, layer 3
         0      0.10                                    ; lakebed leakance array, layer 4
         0      0.10                                    ; lakebed leakance array, layer 5
         0                                              ; number of coalescing lake systems
    0.0116    0.0103       0.0       0.0                ; recharge,ET,runoff,withdrawal rates
```

Listing of Input Data for the Output-Control Package

Input for the Output-Control Package (OC) follows the column headings below. The input consists of 241 records (lines). Input for the package is read from FORTRAN unit number 17, as specified in the namefile.

```
                                        Column Numbers
         1         2         3         4         5         6         7         8
12345678901234567890123456789012345678901234567890123456789012345678901234567890

       -14         9        18        19          ; formatting and file unit options
         0         0         0         1    1     ; output options, time step 1
         0         0         0         0          ; head-drawdown print/file options, time step 1
         0         0         0         1    2     ; time step 2
         0         0         0         0
         0         0         0         1    3     ; time step 3
         0         0         0         0
         0         0         0         1    4     ; time step 4
         0         0         0         0
         0         0         0         1    5     ; time step 5
         0         0         0         0
         0         0         0         1    6     ; time step 6
         0         0         0         0
         0         0         0         1    7     ; time step 7
         0         0         0         0
         0         0         0         1    8     ; time step 8
         0         0         0         0
         0         0         0         1    9     ; time step 9
         0         0         0         0
         1         1         1         1   10     ; time step 10
         0         0         0         0
         0         0         0         0
         0         0         0         0
         0         0         0         0
         1         0         0         0
(The previous 24 lines are repeated 9 more times.)
```

Listing of Input Data for the Gage Package

Input for the Gage Package (GAGE) follows the column headings below. The input consists of 2 records (lines). Input for the package is read from FORTRAN unit number 33, as specified in the namefile.

```
                                                Column Numbers
         1         2         3         4         5         6         7         8
12345678901234567890123456789012345678901234567890123456789012345678901234567890
```

```
    1                     ; number of gages
   -1   37                ; lake or stream segment number and output unit number
```

Selected Pages from Printed Results for Test Simulation 1 - Transient Case

(Title lines and beginning of input data)

```
1                                  MODFLOW
      U.S. GEOLOGICAL SURVEY MODULAR FINITE-DIFFERENCE GROUND-WATER FLOW MODEL

 Hypothetical simulator of lake and surficial aquifer interaction. -------------
 Shows convergence to equilibrium in transient mode.
    5 LAYERS        17 ROWS        17 COLUMNS
   1 STRESS PERIOD(S) IN SIMULATION
 MODEL TIME UNIT IS DAYS
```

(Output from LAK3AL module of Lake Package)

```
 LAK3 -- LAKE PACKAGE, VERSION 3, 6/28/99 INPUT READ FROM UNIT 16
 SPACE ALLOCATION FOR 2890 GRID CELL FACES ADJACENT TO LAKES
 MAXIMUM NUMBER OF LAKES IS  1 FOR THIS SIMULATION
 CELL-BY-CELL SEEPAGES WILL NOT BE PRINTED OR SAVED

 THETA =       .00  METHOD FOR UPDATING LAKE STAGES IN ITERATIONS OF THE SOLUTION FOR AQUIFER
HEADS.
                    0.0 IS EXPLICIT, 0.5 IS CENTERED, AND 1.0 IS FULLY IMPLICIT.
    24602 ELEMENTS IN X ARRAY ARE USED BY THE LAKE PACKAGE
```

(Output from LAK3RP module of Lake Package)

```
 INITIAL LAKE STAGE:  LAKE    STAGE

                        1   110.000

                      LAKE ID ARRAY FOR LAYER   1
 READING ON UNIT  16 WITH FORMAT: (24I3)

        1   2   3   4   5   6   7   8   9  10  11  12  13  14  15  16  17
 ........................................................................
   1    0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0
   2    0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0
   3    0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0
   4    0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0
   5    0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0
   6    0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0
   7    0   0   0   0   0   0   1   1   1   1   1   0   0   0   0   0   0
   8    0   0   0   0   0   0   1   1   1   1   1   0   0   0   0   0   0
   9    0   0   0   0   0   0   1   1   1   1   1   0   0   0   0   0   0
  10    0   0   0   0   0   0   1   1   1   1   1   0   0   0   0   0   0
  11    0   0   0   0   0   0   1   1   1   1   1   0   0   0   0   0   0
  12    0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0
  13    0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0
  14    0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0
  15    0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0
  16    0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0
  17    0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0
                      LAKE ID ARRAY FOR LAYER   2
```

```
 READING ON UNIT  16 WITH FORMAT: (24I3)

        1   2   3   4   5   6   7   8   9  10  11  12  13  14  15  16  17
 ..........................................................................
   1    0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0
   2    0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0
   3    0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0
   4    0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0
   5    0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0
   6    0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0
   7    0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0
   8    0   0   0   0   0   0   0   1   1   1   0   0   0   0   0   0   0
   9    0   0   0   0   0   0   0   1   1   1   0   0   0   0   0   0   0
  10    0   0   0   0   0   0   0   1   1   1   0   0   0   0   0   0   0
  11    0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0
  12    0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0
  13    0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0
  14    0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0
  15    0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0
  16    0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0
  17    0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0

            LAKE ID ARRAY =              0 FOR LAYER   3

            LAKE ID ARRAY =              0 FOR LAYER   4

            LAKE ID ARRAY =              0 FOR LAYER   5

   LAKEBED LEAKANCE ARRAY =   .1000000     FOR LAYER   1

   LAKEBED LEAKANCE ARRAY =   .1000000     FOR LAYER   2

   LAKEBED LEAKANCE ARRAY =   .1000000     FOR LAYER   3

   LAKEBED LEAKANCE ARRAY =   .1000000     FOR LAYER   4

   LAKEBED LEAKANCE ARRAY =   .1000000     FOR LAYER   5
```

(Output from LAK3RP - List of Cell Interfaces Determined by Code)

```
     LOCATIONS,LAKE #, INTERFACE TYPE FOR GRID CELLS ADJACENT TO LAKES
     ---------------------------------------------------------
     LAYER #     ROW #     COLUMN #    LAKE #  INTERFACE TYPE  LAKEBED LEAKANCE
         1         7          6          1          1              .10000
         1         8          6          1          1              .10000
         1         9          6          1          1              .10000
         1        10          6          1          1              .10000
         1        11          6          1          1              .10000
         1         6          7          1          2              .10000
         2         7          7          1          0              .10000
         2         8          7          1          0              .10000
         2         8          7          1          1              .10000
         2         9          7          1          0              .10000
         2         9          7          1          1              .10000
         2        10          7          1          0              .10000
         2        10          7          1          1              .10000
         2        11          7          1          0              .10000
         1        12          7          1          2              .10000
         1         6          8          1          2              .10000
         2         7          8          1          0              .10000
```

2	7	8	1	2	.10000
3	8	8	1	0	.10000
3	9	8	1	0	.10000
3	10	8	1	0	.10000
2	11	8	1	0	.10000
2	11	8	1	2	.10000
1	12	8	1	2	.10000
1	6	9	1	2	.10000
2	7	9	1	0	.10000
2	7	9	1	2	.10000
3	8	9	1	0	.10000
3	9	9	1	0	.10000
3	10	9	1	0	.10000
2	11	9	1	0	.10000
2	11	9	1	2	.10000
1	12	9	1	2	.10000
1	6	10	1	2	.10000
2	7	10	1	0	.10000
2	7	10	1	2	.10000
3	8	10	1	0	.10000
3	9	10	1	0	.10000
3	10	10	1	0	.10000
2	11	10	1	0	.10000
2	11	10	1	2	.10000
1	12	10	1	2	.10000
1	6	11	1	2	.10000
2	7	11	1	0	.10000
2	8	11	1	0	.10000
2	8	11	1	1	.10000
2	9	11	1	0	.10000
2	9	11	1	1	.10000
2	10	11	1	0	.10000
2	10	11	1	1	.10000
2	11	11	1	0	.10000
1	12	11	1	2	.10000
1	7	12	1	1	.10000
1	8	12	1	1	.10000
1	9	12	1	1	.10000
1	10	12	1	1	.10000
1	11	12	1	1	.10000

NUMBER OF LAKE-AQUIFER CELL INTERFACES = 57

(Output from LAK3RP - List of Cell Interface Conductance Values)

INTERFACE CONDUCTANCES FOR LAKES

(IF TYPE = 1 OR 2, CONDUCTANCES ARE PER UNIT THICKNESS.)

LAYER	ROW	COLUMN	LAKE	TYPE	DELTA Y	DELTA X	LAKEBED LEAKANCE	CONDUCTANCES LAKEBED	CONDUCTANCES AQUIFER	CONDUCTANCES COMBINED
1	7	6	1	1	5.00E+02	1.00E+03	1.00E-01	5.00E+01	3.00E+01	1.88E+01
1	8	6	1	1	5.00E+02	1.00E+03	1.00E-01	5.00E+01	3.00E+01	1.88E+01
1	9	6	1	1	5.00E+02	1.00E+03	1.00E-01	5.00E+01	3.00E+01	1.88E+01
1	10	6	1	1	5.00E+02	1.00E+03	1.00E-01	5.00E+01	3.00E+01	1.88E+01
1	11	6	1	1	5.00E+02	1.00E+03	1.00E-01	5.00E+01	3.00E+01	1.88E+01
1	6	7	1	2	1.00E+03	5.00E+02	1.00E-01	5.00E+01	3.00E+01	1.88E+01
2	7	7	1	0	5.00E+02	5.00E+02	1.00E-01	2.50E+04	7.50E+05	2.46E+04

2	8	7	1	0	5.00E+02	5.00E+02	1.00E-01	2.50E+04	7.50E+05	2.46E+04
2	8	7	1	1	5.00E+02	5.00E+02	1.00E-01	5.00E+01	6.00E+01	2.73E+01
2	9	7	1	0	5.00E+02	5.00E+02	1.00E-01	2.50E+04	7.50E+05	2.46E+04
2	9	7	1	1	5.00E+02	5.00E+02	1.00E-01	5.00E+01	6.00E+01	2.73E+01
2	10	7	1	0	5.00E+02	5.00E+02	1.00E-01	2.50E+04	7.50E+05	2.46E+04
2	10	7	1	1	5.00E+02	5.00E+02	1.00E-01	5.00E+01	6.00E+01	2.73E+01
2	11	7	1	0	5.00E+02	5.00E+02	1.00E-01	2.50E+04	7.50E+05	2.46E+04
1	12	7	1	2	1.00E+03	5.00E+02	1.00E-01	5.00E+01	3.00E+01	1.88E+01
1	6	8	1	2	1.00E+03	5.00E+02	1.00E-01	5.00E+01	3.00E+01	1.88E+01
2	7	8	1	0	5.00E+02	5.00E+02	1.00E-01	2.50E+04	7.50E+05	2.46E+04
2	7	8	1	2	5.00E+02	5.00E+02	1.00E-01	5.00E+01	6.00E+01	2.73E+01
3	8	8	1	0	5.00E+02	5.00E+02	1.00E-01	2.50E+04	7.50E+05	2.46E+04
3	9	8	1	0	5.00E+02	5.00E+02	1.00E-01	2.50E+04	7.50E+05	2.46E+04
3	10	8	1	0	5.00E+02	5.00E+02	1.00E-01	2.50E+04	7.50E+05	2.46E+04
2	11	8	1	0	5.00E+02	5.00E+02	1.00E-01	2.50E+04	7.50E+05	2.46E+04
2	11	8	1	2	5.00E+02	5.00E+02	1.00E-01	5.00E+01	6.00E+01	2.73E+01
1	12	8	1	2	1.00E+03	5.00E+02	1.00E-01	5.00E+01	3.00E+01	1.88E+01
1	6	9	1	2	1.00E+03	5.00E+02	1.00E-01	5.00E+01	3.00E+01	1.88E+01
2	7	9	1	0	5.00E+02	5.00E+02	1.00E-01	2.50E+04	7.50E+05	2.46E+04
2	7	9	1	2	5.00E+02	5.00E+02	1.00E-01	5.00E+01	6.00E+01	2.73E+01
3	8	9	1	0	5.00E+02	5.00E+02	1.00E-01	2.50E+04	7.50E+05	2.46E+04
3	9	9	1	0	5.00E+02	5.00E+02	1.00E-01	2.50E+04	7.50E+05	2.46E+04
3	10	9	1	0	5.00E+02	5.00E+02	1.00E-01	2.50E+04	7.50E+05	2.46E+04
2	11	9	1	0	5.00E+02	5.00E+02	1.00E-01	2.50E+04	7.50E+05	2.46E+04
2	11	9	1	2	5.00E+02	5.00E+02	1.00E-01	5.00E+01	6.00E+01	2.73E+01
1	12	9	1	2	1.00E+03	5.00E+02	1.00E-01	5.00E+01	3.00E+01	1.88E+01
1	6	10	1	2	1.00E+03	5.00E+02	1.00E-01	5.00E+01	3.00E+01	1.88E+01
2	7	10	1	0	5.00E+02	5.00E+02	1.00E-01	2.50E+04	7.50E+05	2.46E+04
2	7	10	1	2	5.00E+02	5.00E+02	1.00E-01	5.00E+01	6.00E+01	2.73E+01
3	8	10	1	0	5.00E+02	5.00E+02	1.00E-01	2.50E+04	7.50E+05	2.46E+04
3	9	10	1	0	5.00E+02	5.00E+02	1.00E-01	2.50E+04	7.50E+05	2.46E+04
3	10	10	1	0	5.00E+02	5.00E+02	1.00E-01	2.50E+04	7.50E+05	2.46E+04
2	11	10	1	0	5.00E+02	5.00E+02	1.00E-01	2.50E+04	7.50E+05	2.46E+04
2	11	10	1	2	5.00E+02	5.00E+02	1.00E-01	5.00E+01	6.00E+01	2.73E+01
1	12	10	1	2	1.00E+03	5.00E+02	1.00E-01	5.00E+01	3.00E+01	1.88E+01
1	6	11	1	2	1.00E+03	5.00E+02	1.00E-01	5.00E+01	3.00E+01	1.88E+01
2	7	11	1	0	5.00E+02	5.00E+02	1.00E-01	2.50E+04	7.50E+05	2.46E+04
2	8	11	1	0	5.00E+02	5.00E+02	1.00E-01	2.50E+04	7.50E+05	2.46E+04
2	8	11	1	1	5.00E+02	5.00E+02	1.00E-01	5.00E+01	6.00E+01	2.73E+01
2	9	11	1	0	5.00E+02	5.00E+02	1.00E-01	2.50E+04	7.50E+05	2.46E+04
2	9	11	1	1	5.00E+02	5.00E+02	1.00E-01	5.00E+01	6.00E+01	2.73E+01
2	10	11	1	0	5.00E+02	5.00E+02	1.00E-01	2.50E+04	7.50E+05	2.46E+04
2	10	11	1	1	5.00E+02	5.00E+02	1.00E-01	5.00E+01	6.00E+01	2.73E+01
2	11	11	1	0	5.00E+02	5.00E+02	1.00E-01	2.50E+04	7.50E+05	2.46E+04
1	12	11	1	2	1.00E+03	5.00E+02	1.00E-01	5.00E+01	3.00E+01	1.88E+01
1	7	12	1	1	5.00E+02	1.00E+03	1.00E-01	5.00E+01	3.00E+01	1.88E+01
1	8	12	1	1	5.00E+02	1.00E+03	1.00E-01	5.00E+01	3.00E+01	1.88E+01
1	9	12	1	1	5.00E+02	1.00E+03	1.00E-01	5.00E+01	3.00E+01	1.88E+01
1	10	12	1	1	5.00E+02	1.00E+03	1.00E-01	5.00E+01	3.00E+01	1.88E+01
1	11	12	1	1	5.00E+02	1.00E+03	1.00E-01	5.00E+01	3.00E+01	1.88E+01

(Output from LAK3RP - Computed stage/volume relation)

```
 STAGE/VOLUME RELATION FOR LAKE  1

   STAGE     VOLUME
   97.0000  0.000E+00
   97.2000  4.500E+05
   97.4000  9.000E+05
   97.6000  1.350E+06
   97.8000  1.800E+06
   98.0000  2.250E+06
   98.2000  2.700E+06
   98.4000  3.150E+06
   98.6000  3.600E+06
   98.8000  4.050E+06
   99.0000  4.500E+06
   99.2000  4.950E+06
   99.4000  5.400E+06
   99.6000  5.850E+06
   99.8000  6.300E+06
  100.0000  6.750E+06
```

(110 similar lines omitted)

```
  122.1996  1.175E+08
  122.3996  1.187E+08
  122.5996  1.200E+08
  122.7996  1.212E+08
  122.9996  1.225E+08
  123.1996  1.237E+08
  123.3996  1.250E+08
  123.5996  1.262E+08
  123.7996  1.275E+08
  123.9996  1.287E+08
  124.1996  1.300E+08
  124.3996  1.312E+08
  124.5996  1.325E+08
  124.7996  1.337E+08
  124.9996  1.350E+08
  125.1996  1.362E+08
  125.3996  1.375E+08
  125.5996  1.387E+08
  125.7996  1.400E+08
  125.9996  1.412E+08
  126.1996  1.425E+08
  126.3996  1.437E+08
  126.5995  1.450E+08
  126.7995  1.462E+08
  126.9995  1.475E+08
```

(Remaining Output from LAK3RP)

```
 NUMBER OF CONNECTED LAKE SYSTEMS IN SIMULATION IS   0

 LAKE       PRECIP      EVAP    RUNOFF    WITHDRAW   BOTTOM     AREA
-----------------------------------------------------------------------
   1         .0116     .0103 0.000E+00   0.000E+00 9.700E+01 6.250E+06
```

(Output for time step 10)

```
     8 ITERATIONS FOR TIME STEP  10 IN STRESS PERIOD  1

 MAXIMUM HEAD CHANGE FOR EACH ITERATION:

    HEAD CHANGE   HEAD CHANGE   HEAD CHANGE   HEAD CHANGE   HEAD CHANGE
  LAYER,ROW,COL LAYER,ROW,COL LAYER,ROW,COL LAYER,ROW,COL LAYER,ROW,COL
 ----------------------------------------------------------------------
      1.591         .8838         .3710         .5573E-01     .7130E-02
  (  1, 14,  4) (  5, 11,  3) (  5,  8,  4) (  4, 11,  4) (  5, 10,  4)
     -.6893E-03    -.2124E-03    -.7416E-04
  (  2,  7,  3) (  5,  8,  3) (  4,  9,  3)


 HEAD/DRAWDOWN PRINTOUT FLAG = 1     TOTAL BUDGET PRINTOUT FLAG = 1
 CELL-BY-CELL FLOW TERM FLAG = 1

 OUTPUT FLAGS FOR EACH LAYER:
          HEAD    DRAWDOWN  HEAD  DRAWDOWN
 LAYER  PRINTOUT  PRINTOUT  SAVE    SAVE
 -----------------------------------------
    1       0         0       0       0
    2       0         0       0       0
    3       0         0       0       0
    4       0         0       0       0
    5       1         0       0       0
     0  LAKE CELLS ARE DRY.

 PERIOD     1     TIME STEP    10     TIME STEP LENGTH  1.9138E+01
 PERIOD TIME  1.7535E+02     TOTAL SIMULATION TIME  1.7535E+02
```

(Output for time step 10 - Water budget for lake)

```
     HYDROLOGIC BUDGET SUMMARIES FOR SIMULATED LAKES
     -----------------------------------------------
 LAKE  STAGE     PRECIP       EVAP       RUNOFF
   1  113.60  .13875E+07  .12320E+07  .00000

          GROUND WATER           SURFACE WATER
 LAKE    INFLOW     OUTFLOW      INFLOW     OUTFLOW
   1  .28758E+07  .00000      .00000      .00000

       WATER    CONNECTED LAKE   UPDATED     TIME-STEP          STAGE CHANGE
 LAKE     USE         INFLUX        VOLUME    SURFACE AREA   TIME STEP  CUMULATIVE
   1    .00000       .00000       .63765E+08   .62500E+07   .48502       3.6023
 --------------------------------------------------------------------------------
```

(Output for time step 10 - Table of aquifer heads in layer 5)

HEAD IN LAYER 5 AT END OF TIME STEP 10 IN STRESS PERIOD 1

	1	2	3	4	5	6	7	8	9	10
1	160.0	159.1	157.5	155.9	154.4	152.8	151.6	150.8	150.0	149.2
2	160.0	157.0	153.0	150.0	147.8	146.2	145.1	144.5	143.8	143.1
3	160.0	154.6	147.1	141.8	138.7	137.0	136.1	135.7	135.3	134.9
4	160.0	153.0	143.2	135.9	132.0	130.2	129.5	129.1	128.9	128.8
5	160.0	152.3	141.1	132.9	128.5	126.3	125.4	125.0	124.8	124.8
6	160.0	152.0	140.3	131.6	126.7	123.5	121.0	120.3	120.1	120.2
7	160.0	151.9	140.0	131.1	125.9	121.1	113.6	113.4	113.3	113.4
8	160.0	151.9	139.9	131.0	125.6	120.4	113.4	113.1	113.1	113.1
9	160.0	151.9	139.9	130.9	125.5	120.2	113.3	113.1	113.1	113.1
10	160.0	151.9	139.9	131.0	125.6	120.4	113.4	113.1	113.1	113.1
11	160.0	151.9	140.0	131.1	125.9	121.1	113.6	113.4	113.3	113.4
12	160.0	152.0	140.3	131.6	126.7	123.5	121.0	120.3	120.1	120.2
13	160.0	152.3	141.1	132.9	128.5	126.3	125.4	125.0	124.8	124.8
14	160.0	153.0	143.2	135.9	132.0	130.2	129.5	129.1	128.9	128.8
15	160.0	154.6	147.1	141.8	138.7	137.0	136.1	135.7	135.3	134.9
16	160.0	157.0	153.0	150.0	147.8	146.2	145.1	144.5	143.8	143.1
17	160.0	159.1	157.5	155.9	154.4	152.8	151.6	150.8	150.0	149.2

1

HEAD IN LAYER 5 AT END OF TIME STEP 10 IN STRESS PERIOD 1

	11	12	13	14	15	16	17
1	148.4	147.2	145.6	144.1	142.5	140.9	140.0
2	142.5	141.6	140.4	139.4	139.0	139.2	140.0
3	134.5	134.1	133.6	133.7	134.8	137.4	140.0
4	128.7	128.8	129.1	130.1	132.4	136.4	140.0
5	125.0	125.6	126.7	128.4	131.3	136.0	140.0
6	120.9	123.1	125.3	127.5	130.9	135.9	140.0
7	113.6	120.8	124.5	127.2	130.7	135.8	140.0
8	113.3	120.1	124.3	127.1	130.7	135.8	140.0
9	113.3	119.9	124.2	127.1	130.7	135.8	140.0
10	113.3	120.1	124.3	127.1	130.7	135.8	140.0
11	113.6	120.8	124.5	127.2	130.7	135.8	140.0
12	120.9	123.1	125.3	127.5	130.9	135.9	140.0
13	125.0	125.6	126.7	128.4	131.3	136.0	140.0
14	128.7	128.8	129.1	130.1	132.4	136.4	140.0
15	134.5	134.1	133.6	133.7	134.8	137.4	140.0
16	142.5	141.6	140.4	139.4	139.0	139.2	140.0
17	148.4	147.2	145.6	144.1	142.5	140.9	140.0

(Output for time step 10 - Water budget for aquifer showing lake seepage)

```
  VOLUMETRIC BUDGET FOR ENTIRE MODEL AT END OF TIME STEP 10 IN STRESS PERIOD  1
  -----------------------------------------------------------------------------

     CUMULATIVE VOLUMES      L**3       RATES FOR THIS TIME STEP      L**3/T
     ------------------                 ------------------------

           IN:                                     IN:
           ---                                     ---
             STORAGE =       33100.9000              STORAGE =             .0000
       CONSTANT HEAD =   353151900.0000        CONSTANT HEAD =       949361.6000
                  ET =            .0000                   ET =             .0000
            RECHARGE =   305103300.0000             RECHARGE =      1740000.0000
     SPECIFIED FLOWS =            .0000      SPECIFIED FLOWS =             .0000
       LAKE  SEEPAGE =            .0000        LAKE  SEEPAGE =             .0000

            TOTAL IN =   658288300.0000             TOTAL IN =      2689362.0000

          OUT:                                    OUT:
          ----                                    ----
             STORAGE =   598187800.0000              STORAGE =      2038967.0000
       CONSTANT HEAD =            .0000        CONSTANT HEAD =             .0000
                  ET =    39010640.0000                   ET =       500132.4000
            RECHARGE =            .0000             RECHARGE =             .0000
     SPECIFIED FLOWS =            .0000      SPECIFIED FLOWS =             .0000
       LAKE  SEEPAGE =    21090200.0000        LAKE  SEEPAGE =       150266.0000

           TOTAL OUT =   658288600.0000            TOTAL OUT =      2689365.0000

            IN - OUT =        -320.0000             IN - OUT =           -3.5000

 PERCENT DISCREPANCY =              .00     PERCENT DISCREPANCY =            .00
```

(Output for time step 10 - Time summary)

```
         TIME SUMMARY AT END OF TIME STEP 10 IN STRESS PERIOD  1
                   SECONDS     MINUTES      HOURS       DAYS        YEARS
                   -----------------------------------------------------------
  TIME STEP LENGTH 1.65352E+06  27559.      459.31      19.138     5.23969E-02
 STRESS PERIOD TIME 1.51500E+07 2.52499E+05  4208.3      175.35      .48007
        TOTAL TIME 1.51500E+07 2.52499E+05  4208.3      175.35      .48007
```

(Output for time step 100)

```
     4 ITERATIONS FOR TIME STEP 100 IN STRESS PERIOD  1

 MAXIMUM HEAD CHANGE FOR EACH ITERATION:

    HEAD CHANGE   HEAD CHANGE   HEAD CHANGE   HEAD CHANGE   HEAD CHANGE
  LAYER,ROW,COL LAYER,ROW,COL LAYER,ROW,COL LAYER,ROW,COL LAYER,ROW,COL
 ----------------------------------------------------------------------
      .8170E-03     .2127E-03     .1263E-03     .6686E-04
  (  3,  9,  9) (  5,  6,  8) (  5,  8,  6) (  3, 10, 13)


 HEAD/DRAWDOWN PRINTOUT FLAG = 1     TOTAL BUDGET PRINTOUT FLAG = 1
 CELL-BY-CELL FLOW TERM FLAG = 1
```

```
 OUTPUT FLAGS FOR EACH LAYER:
          HEAD    DRAWDOWN  HEAD  DRAWDOWN
 LAYER  PRINTOUT  PRINTOUT  SAVE    SAVE
 -----------------------------------------
    1       0         0       0       0
    2       0         0       0       0
    3       0         0       0       0
    4       0         0       0       0
    5       1         0       0       0
     0  LAKE CELLS ARE DRY.

 PERIOD     1     TIME STEP   100     TIME STEP LENGTH  1.1374E+02
 PERIOD TIME  5.0000E+03     TOTAL SIMULATION TIME  5.0000E+03
```

(Output for time step 100 - Water budget for lake)

```
     HYDROLOGIC BUDGET SUMMARIES FOR SIMULATED LAKES
     -----------------------------------------------
 LAKE  STAGE     PRECIP       EVAP       RUNOFF
   1  148.29  .82461E+07  .73220E+07  .00000

           GROUND WATER            SURFACE WATER
 LAKE    INFLOW     OUTFLOW      INFLOW     OUTFLOW
   1  .19181E+07  .28415E+07  .00000      .00000

        WATER    CONNECTED LAKE   UPDATED     TIME-STEP          STAGE CHANGE
 LAKE     USE        INFLUX        VOLUME    SURFACE AREA   TIME STEP  CUMULATIVE
   1    .00000       .00000       .28055E+09   .62500E+07  -.13733E-03   38.287


 --------------------------------------------------------------------------------
```

(Output for time step 100 - Table of aquifer heads in layer 5)

```
             HEAD IN LAYER  5 AT END OF TIME STEP100 IN STRESS PERIOD  1
  -----------------------------------------------------------------------

        1      2      3      4      5      6      7      8      9     10
 ........................................................................
   1   160.0  159.1  157.5  155.9  154.4  152.8  151.6  150.8  150.0  149.2
   2   160.0  158.7  156.9  155.2  153.5  151.9  150.7  149.9  149.1  148.4
   3   160.0  158.4  156.3  154.5  152.8  151.2  150.0  149.2  148.4  147.6
   4   160.0  158.3  156.1  154.2  152.4  150.8  149.6  148.8  148.1  147.3
   5   160.0  158.2  156.0  154.0  152.2  150.5  149.4  148.6  147.9  147.2
   6   160.0  158.2  155.9  153.9  152.1  150.3  149.1  148.5  148.0  147.5
   7   160.0  158.2  155.9  153.9  152.0  150.1  148.4  148.3  148.3  148.3
   8   160.0  158.2  155.9  153.8  151.9  150.0  148.3  148.3  148.3  148.3
   9   160.0  158.2  155.8  153.8  151.9  150.0  148.3  148.3  148.3  148.3
  10   160.0  158.2  155.9  153.8  151.9  150.0  148.3  148.3  148.3  148.3
  11   160.0  158.2  155.9  153.9  152.0  150.1  148.4  148.3  148.3  148.3
  12   160.0  158.2  155.9  153.9  152.1  150.3  149.1  148.5  148.0  147.5
  13   160.0  158.2  156.0  154.0  152.2  150.5  149.4  148.6  147.9  147.2
  14   160.0  158.3  156.1  154.2  152.4  150.8  149.6  148.8  148.1  147.3
  15   160.0  158.4  156.3  154.5  152.8  151.2  150.0  149.2  148.4  147.6
  16   160.0  158.7  156.9  155.2  153.5  151.9  150.7  149.9  149.1  148.4
  17   160.0  159.1  157.5  155.9  154.4  152.8  151.6  150.8  150.0  149.2
1
```

```
             HEAD IN LAYER  5 AT END OF TIME STEP100 IN STRESS PERIOD  1
 -----------------------------------------------------------------------

       11     12     13     14     15     16     17
 ....................................................
  1   148.4  147.2  145.6  144.1  142.5  140.9  140.0
  2   147.6  146.4  144.8  143.3  141.8  140.5  140.0
  3   146.9  145.7  144.1  142.7  141.3  140.2  140.0
  4   146.5  145.4  143.8  142.4  141.1  140.1  140.0
  5   146.5  145.3  143.7  142.3  141.0  140.1  140.0
  6   146.8  145.5  143.8  142.2  141.0  140.1  140.0
  7   148.2  145.9  143.9  142.3  141.0  140.1  140.0
  8   148.2  146.0  143.9  142.3  141.0  140.1  140.0
  9   148.2  146.0  143.9  142.3  141.0  140.1  140.0
 10   148.2  146.0  143.9  142.3  141.0  140.1  140.0
 11   148.2  145.9  143.9  142.3  141.0  140.1  140.0
 12   146.8  145.5  143.8  142.2  141.0  140.1  140.0
 13   146.5  145.3  143.7  142.3  141.0  140.1  140.0
 14   146.5  145.4  143.8  142.4  141.1  140.1  140.0
 15   146.9  145.7  144.1  142.7  141.3  140.2  140.0
 16   147.6  146.4  144.8  143.3  141.8  140.5  140.0
 17   148.4  147.2  145.6  144.1  142.5  140.9  140.0
```

(Output for time step 100 - Water budget for aquifer showing lake seepage)

```
 VOLUMETRIC BUDGET FOR ENTIRE MODEL AT END OF TIME STEP100 IN STRESS PERIOD  1
 -----------------------------------------------------------------------------

    CUMULATIVE VOLUMES      L**3       RATES FOR THIS TIME STEP      L**3/T
    ------------------                 ------------------------

          IN:                                   IN:
          ---                                   ---
            STORAGE =       33131.2700              STORAGE =       5.6178E-02
      CONSTANT HEAD =  1290829000.0000        CONSTANT HEAD =      166880.8000
                 ET =            .0000                   ET =            .0000
           RECHARGE =  8700039000.0000             RECHARGE =     1740000.0000
    SPECIFIED FLOWS =            .0000      SPECIFIED FLOWS =            .0000
      LAKE  SEEPAGE =    79640080.0000        LAKE  SEEPAGE =       24982.8800

           TOTAL IN = 10070540000.0000             TOTAL IN =     1931864.0000

         OUT:                                  OUT:
         ----                                  ----
            STORAGE =  1011716000.0000              STORAGE =          23.8247
      CONSTANT HEAD =    38468440.0000        CONSTANT HEAD =        9491.0120
                 ET =  8742021000.0000                   ET =     1905485.0000
           RECHARGE =            .0000             RECHARGE =            .0000
    SPECIFIED FLOWS =            .0000      SPECIFIED FLOWS =            .0000
      LAKE  SEEPAGE =   278344400.0000        LAKE  SEEPAGE =       16863.9500

          TOTAL OUT = 10070550000.0000            TOTAL OUT =     1931864.0000

           IN - OUT =       -7168.0000             IN - OUT =            .1250

 PERCENT DISCREPANCY =            .00     PERCENT DISCREPANCY =            .00
```

(Output for time step 100 - Time summary)

```
         TIME SUMMARY AT END OF TIME STEP100 IN STRESS PERIOD  1
                   SECONDS     MINUTES      HOURS       DAYS        YEARS
                   -----------------------------------------------------------
  TIME STEP LENGTH 9.82708E+06 1.63785E+05  2729.7      113.74      .31140
STRESS PERIOD TIME 4.32002E+08 7.20003E+06 1.20001E+05  5000.0      13.689
        TOTAL TIME 4.32002E+08 7.20003E+06 1.20001E+05  5000.0      13.689
```

Listing of Input Data Sets for Test Simulation 1 - Steady-State Case

Listing of Input Data for the Lake Package

Input for the Lake Package (LAK) follows the column headings below. The input consists of 50 records (lines). Input for the package is read from FORTRAN unit number 16, as specified in the namefile.

```
                                                Column Numbers
         1         2         3         4         5         6         7         8
12345678901234567890123456789012345678901234567890123456789012345678901234567890
_____________________________________________________________________________
         1         0                                            ; LAK input - NLAKES,ILKCB
      0.00        50      0.001                                 ; THETA,NSSITR,SSCNCR
     110.0     100.0      170.0                                 ; initial, minimum, maximum stages
         1         0          0                                 ; input/output options
        16          1(24I3)                     3               ; lake position array, layer 1
  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
  0  0  0  0  0  0  1  1  1  1  1  0  0  0  0  0  0
  0  0  0  0  0  0  1  1  1  1  1  0  0  0  0  0  0
  0  0  0  0  0  0  1  1  1  1  1  0  0  0  0  0  0
  0  0  0  0  0  0  1  1  1  1  1  0  0  0  0  0  0
  0  0  0  0  0  0  1  1  1  1  1  0  0  0  0  0  0
  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
        16          1(24I3)                     3               ; lake position array, layer 2
  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
  0  0  0  0  0  0  0  1  1  1  0  0  0  0  0  0  0
  0  0  0  0  0  0  0  1  1  1  0  0  0  0  0  0  0
  0  0  0  0  0  0  0  1  1  1  0  0  0  0  0  0  0
  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
         0         0                                            ; lake position array, layer 3
         0         0                                            ; lake position array, layer 4
         0         0                                            ; lake position array, layer 5
         0      0.10                                            ; lakebed leakance array, layer 1
         0      0.10                                            ; lakebed leakance array, layer 2
         0      0.10                                            ; lakebed leakance array, layer 3
         0      0.10                                            ; lakebed leakance array, layer 4
         0      0.10                                            ; lakebed leakance array, layer 5
         0                                                      ; number of coalescing lake systems
    0.0116    0.0103        0.0       0.0                       ; recharge,ET,runoff,withdrawal rates
_____________________________________________________________________________
```

Selected Pages from Printed Results for Test Simulation 1 - Steady-State Case

Steady-State Simulation

(Title lines and beginning of input data)

```
 INITIAL LAKE STAGE:  LAKE    STAGE     SS MIN    SS MAX

                        1   110.000   100.000   170.000
```

(Lake ID and leakance arrays omitted - they are the same as for the transient run)
(Interface and conductance tables omitted - they are the same as for the transient run)

```
 NUMBER OF CONNECTED LAKE SYSTEMS IN SIMULATION IS   0

 LAKE       PRECIP      EVAP    RUNOFF    WITHDRAW   BOTTOM     AREA
--------------------------------------------------------------------------------
   1         .0116     .0103 0.000E+00   0.000E+00 9.700E+01 6.250E+06
 ALL LAKES CONVERGED TO STEADY-STATE AFTER   2  ITERATIONS

 AVERAGE SEED =  .00000194
 MINIMUM SEED =  .00000137

     5 ITERATION PARAMETERS CALCULATED FROM AVERAGE SEED:

   .000000E+00  .962690E+00  .998608E+00  .999948E+00  .999998E+00
 ALL LAKES CONVERGED TO STEADY-STATE AFTER   2  ITERATIONS
 ALL LAKES CONVERGED TO STEADY-STATE AFTER   2  ITERATIONS
 ALL LAKES CONVERGED TO STEADY-STATE AFTER   2  ITERATIONS
 ALL LAKES CONVERGED TO STEADY-STATE AFTER   2  ITERATIONS
 ALL LAKES CONVERGED TO STEADY-STATE AFTER   2  ITERATIONS
 ALL LAKES CONVERGED TO STEADY-STATE AFTER   2  ITERATIONS
```

(459 similar records omitted - no more than one lake iteration after 281 MODFLOW iterations)

```
 ALL LAKES CONVERGED TO STEADY-STATE AFTER   1  ITERATIONS
 ALL LAKES CONVERGED TO STEADY-STATE AFTER   1  ITERATIONS
 ALL LAKES CONVERGED TO STEADY-STATE AFTER   1  ITERATIONS
 ALL LAKES CONVERGED TO STEADY-STATE AFTER   1  ITERATIONS
 ALL LAKES CONVERGED TO STEADY-STATE AFTER   1  ITERATIONS
 ALL LAKES CONVERGED TO STEADY-STATE AFTER   1  ITERATIONS

   472 ITERATIONS FOR TIME STEP   1 IN STRESS PERIOD  1

 MAXIMUM HEAD CHANGE FOR EACH ITERATION:

    HEAD CHANGE   HEAD CHANGE   HEAD CHANGE   HEAD CHANGE   HEAD CHANGE
  LAYER,ROW,COL LAYER,ROW,COL LAYER,ROW,COL LAYER,ROW,COL LAYER,ROW,COL
 ----------------------------------------------------------------------

      30.76         17.73         14.37         27.25         7.574
  (  1,  2,  2) (  1,  3,  3) (  5, 14,  3) (  1,  8,  4) (  5, 12,  6)
      1.055         .8803         1.145         .9846         .6372
  (  1, 13,  3) (  5,  6,  8) (  1,  6,  9) (  5,  6, 10) (  2,  8, 11)
      .8307         .5908         .7517         .5902         .8456
  (  2, 11,  7) (  5,  9,  9) (  5, 10,  8) (  3,  8, 10) (  3, 10,  8)
      .5684         .5713         .5453         .8003         .5541
  (  2,  7,  7) (  5, 10,  8) (  3,  8, 10) (  3, 10,  8) (  2,  8, 11)
```

(174 similar lines omitted)

```
     .1458E-03     .1548E-03     .1326E-03     .2007E-03     .1304E-03
  (  2,  7,  7) (  5, 10,  8) (  3,  8, 10) (  3, 10,  8) (  3,  8, 10)
     .1792E-03     .1277E-03     .1648E-03     .1292E-03     .1813E-03
  (  2,  7,  7) (  5,  9,  9) (  5, 10,  8) (  2,  9, 11) (  2, 11,  9)
     .1158E-03     .1116E-03     .1116E-03     .1615E-03     .1204E-03
  (  2,  7,  7) (  5, 10,  8) (  3,  8, 10) (  3, 10,  8) (  3,  8, 10)
     .1511E-03     .9660E-04
  (  2,  7,  7) (  5,  9,  9)
```

(Lake budget data)

```
    0  LAKE CELLS ARE DRY.

 PERIOD     1     TIME STEP     1     TIME STEP LENGTH  1.0000E+00
 PERIOD TIME  1.0000E+00     TOTAL SIMULATION TIME  1.0000E+00

    HYDROLOGIC BUDGET SUMMARIES FOR SIMULATED LAKES
    -----------------------------------------------
 LAKE  STAGE     PRECIP       EVAP       RUNOFF
   1  148.28  72500.      64375.      .00000

          GROUND WATER           SURFACE WATER
 LAKE    INFLOW     OUTFLOW      INFLOW     OUTFLOW
   1  16884.      24955.      .00000      .00000

        WATER    CONNECTED LAKE   UPDATED     TIME-STEP         STAGE CHANGE
 LAKE     USE         INFLUX        VOLUME    SURFACE AREA   TIME STEP  CUMULATIVE
   1    .00000       .00000       .28052E+09   .62500E+07   .00000       38.284
 --------------------------------------------------------------------------------

1
            HEAD IN LAYER  5 AT END OF TIME STEP  1 IN STRESS PERIOD  1
  ----------------------------------------------------------------------

         1      2      3      4      5      6      7      8      9     10
 ..........................................................................
   1   160.0  158.9  157.3  155.8  154.2  152.7  151.5  150.8  150.0  149.2
   2   160.0  158.6  156.7  155.1  153.4  151.9  150.7  149.9  149.1  148.4
   3   160.0  158.4  156.3  154.5  152.8  151.1  150.0  149.2  148.4  147.6
   4   160.0  158.3  156.1  154.2  152.4  150.8  149.6  148.8  148.1  147.3
   5   160.0  158.2  155.9  154.0  152.2  150.5  149.4  148.6  147.9  147.2
   6   160.0  158.2  155.9  153.9  152.1  150.3  149.1  148.5  148.0  147.5
   7   160.0  158.2  155.9  153.8  152.0  150.1  148.4  148.3  148.3  148.3
   8   160.0  158.2  155.8  153.8  151.9  150.0  148.3  148.3  148.3  148.3
   9   160.0  158.2  155.8  153.8  151.9  150.0  148.3  148.3  148.3  148.3
  10   160.0  158.2  155.8  153.8  151.9  150.0  148.3  148.3  148.3  148.3
  11   160.0  158.2  155.9  153.8  152.0  150.1  148.4  148.3  148.3  148.3
  12   160.0  158.2  155.9  153.9  152.1  150.3  149.1  148.5  148.0  147.5
  13   160.0  158.2  155.9  154.0  152.2  150.5  149.4  148.6  147.9  147.2
  14   160.0  158.3  156.1  154.2  152.4  150.8  149.6  148.8  148.1  147.3
  15   160.0  158.4  156.3  154.5  152.8  151.1  150.0  149.2  148.4  147.6
  16   160.0  158.6  156.7  155.1  153.4  151.9  150.7  149.9  149.1  148.4
  17   160.0  158.9  157.3  155.8  154.2  152.7  151.5  150.8  150.0  149.2
1
```

```
            HEAD IN LAYER  5 AT END OF TIME STEP  1 IN STRESS PERIOD  1
  -----------------------------------------------------------------------
       11     12     13     14     15     16     17
 ....................................................
   1   148.5  147.3  145.8  144.2  142.7  141.1  140.0
   2   147.6  146.4  144.9  143.4  141.9  140.6  140.0
   3   146.9  145.7  144.2  142.7  141.4  140.3  140.0
   4   146.5  145.4  143.8  142.4  141.1  140.2  140.0
   5   146.5  145.3  143.7  142.3  141.0  140.1  140.0
   6   146.8  145.5  143.8  142.2  141.0  140.1  140.0
   7   148.2  145.9  143.9  142.3  141.0  140.1  140.0
   8   148.2  146.0  143.9  142.3  141.0  140.1  140.0
   9   148.2  146.0  143.9  142.3  141.0  140.1  140.0
  10   148.2  146.0  143.9  142.3  141.0  140.1  140.0
  11   148.2  145.9  143.9  142.3  141.0  140.1  140.0
  12   146.8  145.5  143.8  142.2  141.0  140.1  140.0
  13   146.5  145.3  143.7  142.3  141.0  140.1  140.0
  14   146.5  145.4  143.8  142.4  141.1  140.2  140.0
  15   146.9  145.7  144.2  142.7  141.4  140.3  140.0
  16   147.6  146.4  144.9  143.4  141.9  140.6  140.0
  17   148.5  147.3  145.8  144.2  142.7  141.1  140.0
1
  VOLUMETRIC BUDGET FOR ENTIRE MODEL AT END OF TIME STEP  1 IN STRESS PERIOD  1
  -----------------------------------------------------------------------------

     CUMULATIVE VOLUMES      L**3       RATES FOR THIS TIME STEP      L**3/T
     ------------------                 ------------------------

           IN:                                      IN:
           ---                                      ---
       CONSTANT HEAD =      166883.1000         CONSTANT HEAD =      166883.1000
                  ET =           .0000                     ET =           .0000
            RECHARGE =     1740000.0000              RECHARGE =     1740000.0000
     SPECIFIED FLOWS =           .0000        SPECIFIED FLOWS =           .0000
       LAKE  SEEPAGE =       24954.6300         LAKE  SEEPAGE =       24954.6300

            TOTAL IN =     1931838.0000              TOTAL IN =     1931838.0000

          OUT:                                     OUT:
          ----                                     ----
       CONSTANT HEAD =        9490.4130         CONSTANT HEAD =        9490.4130
                  ET =     1905448.0000                    ET =     1905448.0000
            RECHARGE =           .0000               RECHARGE =           .0000
     SPECIFIED FLOWS =           .0000        SPECIFIED FLOWS =           .0000
       LAKE  SEEPAGE =       16884.4900         LAKE  SEEPAGE =       16884.4900

           TOTAL OUT =     1931823.0000             TOTAL OUT =     1931823.0000

            IN - OUT =         14.5000               IN - OUT =         14.5000

 PERCENT DISCREPANCY =           .00     PERCENT DISCREPANCY =           .00


          TIME SUMMARY AT END OF TIME STEP  1 IN STRESS PERIOD  1
                    SECONDS     MINUTES      HOURS       DAYS        YEARS
                    -----------------------------------------------------------
   TIME STEP LENGTH  86400.      1440.0      24.000      1.0000     2.73785E-03
 STRESS PERIOD TIME  86400.      1440.0      24.000      1.0000     2.73785E-03
         TOTAL TIME  86400.      1440.0      24.000      1.0000     2.73785E-03
```

Listing of Input Data Sets for Test Simulation 1 - Drying-Rewetting Case

Listing of Input Data for the Lake Package

Input for the Lake Package (LAK) follows the column headings below. The input consists of 52 records (lines). Input for the package is read from FORTRAN unit number 16, as specified in the namefile.

```
                                       Column Numbers
         1         2         3         4         5         6         7         8
12345678901234567890123456789012345678901234567890123456789012345678901234567890
________________________________________________________________________________
         1         0                                  ; LAK input - NLAKES,ILKCB
      0.00                                            ; THETA
     140.0                                            ; initial stage
         1         0         0                        ; input/output options, stress period 1
        16         1(24I3)                       3    ; lake position array, layer 1
  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
  0  0  0  0  0  0  1  1  1  1  1  0  0  0  0  0  0
  0  0  0  0  0  0  1  1  1  1  1  0  0  0  0  0  0
  0  0  0  0  0  0  1  1  1  1  1  0  0  0  0  0  0
  0  0  0  0  0  0  1  1  1  1  1  0  0  0  0  0  0
  0  0  0  0  0  0  1  1  1  1  1  0  0  0  0  0  0
  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
        16         1(24I3)                       3    ; lake position array, layer 2
  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
  0  0  0  0  0  0  0  1  1  1  0  0  0  0  0  0  0
  0  0  0  0  0  0  0  1  1  1  0  0  0  0  0  0  0
  0  0  0  0  0  0  0  1  1  1  0  0  0  0  0  0  0
  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
         0         0                                  ; lake position array, layer 3
         0         0                                  ; lake position array, layer 4
         0         0                                  ; lake position array, layer 5
         0      0.10                                  ; lakebed leakance array, layer 1
         0      0.10                                  ; lakebed leakance array, layer 2
         0      0.10                                  ; lakebed leakance array, layer 3
         0      0.10                                  ; lakebed leakance array, layer 4
         0      0.10                                  ; lakebed leakance array, layer 5
         0                                            ; number of coalescing lake systems
    0.0000    0.0412       0.0       0.0          ; recharge,ET,runoff,withdrawal rates,period 1
        -1         0         0                        ; input/output options, stress period 2
    0.0116    0.0103       0.0       0.0          ; recharge,ET,runoff,withdrawal rates,period 2
________________________________________________________________________________
```

Selected Pages from Printed Results for Test Simulation 1 - Drying-Rewetting Case

(Period 1, time step 30 - early in drying period, all lake cells still contain water)

```
     7 ITERATIONS FOR TIME STEP  30 IN STRESS PERIOD  1

 MAXIMUM HEAD CHANGE FOR EACH ITERATION:

    HEAD CHANGE   HEAD CHANGE   HEAD CHANGE   HEAD CHANGE   HEAD CHANGE
  LAYER,ROW,COL LAYER,ROW,COL LAYER,ROW,COL LAYER,ROW,COL LAYER,ROW,COL
 ----------------------------------------------------------------------
     -.4701        -.1470        -.6899E-01    -.1345E-01    -.2106E-02
  (  3,  9,  9) (  5,  6,  8) (  5, 12,  9) (  4, 11, 12) (  5, 12,  7)
      .2704E-03     .5349E-04
  (  1,  7,  6) (  5,  8,  5)

     0  LAKE CELLS ARE DRY.

 PERIOD     1     TIME STEP    30     TIME STEP LENGTH  2.8438E+01
 PERIOD TIME  6.4965E+02     TOTAL SIMULATION TIME  6.4965E+02


     HYDROLOGIC BUDGET SUMMARIES FOR SIMULATED LAKES
     -----------------------------------------------
 LAKE  STAGE     PRECIP       EVAP       RUNOFF
   1  122.17  .00000      .73228E+07  .00000

            GROUND WATER            SURFACE WATER
 LAKE    INFLOW     OUTFLOW      INFLOW     OUTFLOW
   1  .41411E+07  .00000      .00000      .00000

        WATER    CONNECTED LAKE   UPDATED     TIME-STEP          STAGE CHANGE
 LAKE     USE        INFLUX        VOLUME    SURFACE AREA   TIME STEP  CUMULATIVE
   1    .00000       .00000      .11730E+09   .62500E+07  -.50906      -17.831
 --------------------------------------------------------------------------------

1
               HEAD IN LAYER  5 AT END OF TIME STEP 30 IN STRESS PERIOD  1
  -----------------------------------------------------------------------

         1      2      3      4      5      6      7      8      9     10
 ........................................................................
   1   160.0  158.9  157.3  155.8  154.2  152.7  151.5  150.8  150.0  149.2
   2   160.0  154.3  150.6  148.3  146.5  144.8  143.6  142.8  142.0  141.2
   3   160.0  152.3  146.9  144.1  142.0  140.2  138.9  138.1  137.3  136.5
   4   160.0  151.7  145.7  142.5  140.2  138.2  136.8  135.9  135.1  134.4
   5   160.0  151.5  145.3  141.9  139.2  136.4  134.5  133.4  132.6  132.0
   6   160.0  151.4  145.1  141.4  138.0  133.8  130.4  129.1  128.4  128.1
   7   160.0  151.4  145.0  141.2  137.2  131.3  123.2  122.9  122.9  122.9
   8   160.0  151.4  145.0  141.1  136.8  130.5  122.9  122.7  122.7  122.7
   9   160.0  151.4  145.0  141.1  136.7  130.3  122.9  122.7  122.7  122.7
  10   160.0  151.4  145.0  141.1  136.8  130.5  122.9  122.7  122.7  122.7
  11   160.0  151.4  145.0  141.2  137.2  131.3  123.2  122.9  122.9  122.9
  12   160.0  151.4  145.1  141.4  138.0  133.8  130.4  129.1  128.4  128.1
  13   160.0  151.5  145.3  141.9  139.2  136.4  134.5  133.4  132.6  132.0
  14   160.0  151.7  145.7  142.5  140.2  138.2  136.8  135.9  135.1  134.4
  15   160.0  152.3  146.9  144.1  142.0  140.2  138.9  138.1  137.3  136.5
  16   160.0  154.3  150.6  148.3  146.5  144.8  143.6  142.8  142.0  141.2
  17   160.0  158.9  157.3  155.8  154.2  152.7  151.5  150.8  150.0  149.2
1
```

```
             HEAD IN LAYER  5 AT END OF TIME STEP 30 IN STRESS PERIOD  1
  -----------------------------------------------------------------------
         11     12     13     14     15     16     17
 ..............................................................
   1   148.5  147.3  145.8  144.2  142.7  141.1  140.0
   2   140.4  139.2  137.7  136.2  135.2  135.7  140.0
   3   135.7  134.6  133.1  131.8  131.4  133.5  140.0
   4   133.7  132.7  131.5  130.4  130.2  132.8  140.0
   5   131.6  131.2  130.6  129.8  129.8  132.7  140.0
   6   128.2  129.1  129.6  129.5  129.6  132.6  140.0
   7   123.0  127.2  128.9  129.3  129.6  132.6  140.0
   8   122.8  126.7  128.7  129.2  129.6  132.6  140.0
   9   122.8  126.5  128.6  129.2  129.6  132.6  140.0
  10   122.8  126.7  128.7  129.2  129.6  132.6  140.0
  11   123.0  127.2  128.9  129.3  129.6  132.6  140.0
  12   128.2  129.1  129.6  129.5  129.6  132.6  140.0
  13   131.6  131.2  130.6  129.8  129.8  132.7  140.0
  14   133.7  132.7  131.5  130.4  130.2  132.8  140.0
  15   135.7  134.6  133.1  131.8  131.4  133.5  140.0
  16   140.4  139.2  137.7  136.2  135.2  135.7  140.0
  17   148.5  147.3  145.8  144.2  142.7  141.1  140.0
```

(Period 1, time step 70 - lake cells in layer 1 are dry)

```
    14 ITERATIONS FOR TIME STEP  70 IN STRESS PERIOD  1

 MAXIMUM HEAD CHANGE FOR EACH ITERATION:

    HEAD CHANGE   HEAD CHANGE   HEAD CHANGE   HEAD CHANGE   HEAD CHANGE
  LAYER,ROW,COL LAYER,ROW,COL LAYER,ROW,COL LAYER,ROW,COL LAYER,ROW,COL
 ----------------------------------------------------------------------
     -2.084        -.4908        -.3403        -.3947E-01    -.8158E-01
  (  3,  9,  9) (  4,  9, 11) (  2,  9,  7) (  4,  8, 11) (  2, 11, 11)
     -.2963E-01    -.1132E-01     .2173E-02    -.3151E-02    -.2217E-03
  (  2,  8,  7) (  4,  7,  7) (  3, 12,  8) (  2,  9,  7) (  5,  6,  8)
     -.1292E-02    -.2815E-03    -.4937E-03    -.5458E-04
  (  2,  8,  7) (  5,  7,  7) (  2,  7,  7) (  4,  9,  6)

     SECTIONS OF THE LAKE BOTTOM HAVE BECOME DRY.  THE DRY SECTIONS
     LIE ABOVE THE FOLLOWING 16 AQUIFER CELLS (LAYER,ROW,COLUMN):
     (  2,  7,  7)  (  2,  8,  7)  (  2,  9,  7)  (  2, 10,  7)  (  2, 11,  7)
     (  2,  7,  8)  (  2, 11,  8)  (  2,  7,  9)  (  2, 11,  9)  (  2,  7, 10)
     (  2, 11, 10)  (  2,  7, 11)  (  2,  8, 11)  (  2,  9, 11)  (  2, 10, 11)
     (  2, 11, 11)  (

 PERIOD     1     TIME STEP    70     TIME STEP LENGTH  6.2792E+01
 PERIOD TIME  2.4017E+03     TOTAL SIMULATION TIME  2.4017E+03


     HYDROLOGIC BUDGET SUMMARIES FOR SIMULATED LAKES
     ---------------------------------------------
 LAKE  STAGE     PRECIP       EVAP       RUNOFF
   1  102.61  .00000      .58208E+07  .00000

              GROUND WATER            SURFACE WATER
 LAKE    INFLOW     OUTFLOW      INFLOW     OUTFLOW
   1  .17359E+07  .00000      .00000      .00000

         WATER    CONNECTED LAKE   UPDATED     TIME-STEP          STAGE CHANGE
 LAKE     USE         INFLUX        VOLUME    SURFACE AREA   TIME STEP  CUMULATIVE
   1    .00000       .00000       .12613E+08   .22500E+07  -1.8155      -37.394
 ------------------------------------------------------------------------------

1
```

```
            HEAD IN LAYER  5 AT END OF TIME STEP 70 IN STRESS PERIOD  1
  ----------------------------------------------------------------------

        1      2      3      4      5      6      7      8      9     10
 ........................................................................
   1   160.0  158.9  157.3  155.8  154.2  152.7  151.5  150.8  150.0  149.2
   2   160.0  154.3  150.6  148.3  146.4  144.7  143.4  142.6  141.8  141.0
   3   160.0  152.2  146.9  143.9  141.6  139.5  138.1  137.2  136.4  135.6
   4   160.0  151.6  145.5  142.0  139.1  136.2  134.2  133.1  132.2  131.4
   5   160.0  151.4  144.9  140.8  136.6  132.2  129.3  127.8  126.7  126.1
   6   160.0  151.2  144.5  139.5  133.9  127.3  122.3  119.8  118.4  118.1
   7   160.0  151.2  144.3  138.8  132.3  123.7  111.2  107.2  106.1  106.2
   8   160.0  151.2  144.2  138.5  131.6  122.0  107.9  104.6  104.5  104.5
   9   160.0  151.2  144.1  138.4  131.4  121.5  107.1  104.5  104.4  104.4
  10   160.0  151.2  144.2  138.5  131.6  122.0  107.9  104.6  104.5  104.5
  11   160.0  151.2  144.3  138.8  132.3  123.7  111.2  107.2  106.1  106.2
  12   160.0  151.2  144.5  139.5  133.9  127.3  122.3  119.8  118.4  118.1
  13   160.0  151.4  144.9  140.8  136.6  132.2  129.3  127.8  126.7  126.1
  14   160.0  151.6  145.5  142.0  139.1  136.2  134.2  133.1  132.2  131.4
  15   160.0  152.2  146.9  143.9  141.6  139.5  138.1  137.2  136.4  135.6
  16   160.0  154.3  150.6  148.3  146.4  144.7  143.4  142.6  141.8  141.0
  17   160.0  158.9  157.3  155.8  154.2  152.7  151.5  150.8  150.0  149.2
1
            HEAD IN LAYER  5 AT END OF TIME STEP 70 IN STRESS PERIOD  1
  ----------------------------------------------------------------------

       11     12     13     14     15     16     17
 ..................................................
   1   148.5  147.3  145.8  144.2  142.7  141.1  140.0
   2   140.2  139.0  137.5  136.1  135.1  135.7  140.0
   3   134.9  133.9  132.7  131.6  131.3  133.4  140.0
   4   130.9  130.4  130.1  129.8  130.0  132.8  140.0
   5   126.0  126.4  127.4  128.4  129.3  132.6  140.0
   6   118.9  121.4  124.6  127.0  128.9  132.4  140.0
   7   108.3  117.6  123.0  126.3  128.7  132.4  140.0
   8   105.5  115.9  122.2  126.0  128.6  132.4  140.0
   9   104.9  115.4  122.0  125.9  128.6  132.4  140.0
  10   105.5  115.9  122.2  126.0  128.6  132.4  140.0
  11   108.3  117.6  123.0  126.3  128.7  132.4  140.0
  12   118.9  121.4  124.6  127.0  128.9  132.4  140.0
  13   126.0  126.4  127.4  128.4  129.3  132.6  140.0
  14   130.9  130.4  130.1  129.8  130.0  132.8  140.0
  15   134.9  133.9  132.7  131.6  131.3  133.4  140.0
  16   140.2  139.0  137.5  136.1  135.1  135.7  140.0
  17   148.5  147.3  145.8  144.2  142.7  141.1  140.0
```

(Period 1, time step 76 - lake goes dry)

```
    10 ITERATIONS FOR TIME STEP  76 IN STRESS PERIOD  1

 MAXIMUM HEAD CHANGE FOR EACH ITERATION:

    HEAD CHANGE   HEAD CHANGE   HEAD CHANGE   HEAD CHANGE   HEAD CHANGE
  LAYER,ROW,COL LAYER,ROW,COL LAYER,ROW,COL LAYER,ROW,COL LAYER,ROW,COL
 ----------------------------------------------------------------------
     -.7090        -.1726        -.1550        -.3713E-01    -.4401E-01
  (  3,  9,  9) (  4,  9, 11) (  2, 11,  7) (  4, 10, 12) (  2, 11,  7)
     -.9137E-02    -.1972E-02     .6732E-03     .3563E-03     .4822E-04
  (  2,  7,  7) (  5,  7,  8) (  3, 12,  9) (  5, 12, 10) (  2,  6,  7)
```

```
..........LAKE  1 HAS JUST GONE DRY..........

    SECTIONS OF THE LAKE BOTTOM HAVE BECOME DRY.  THE DRY SECTIONS
    LIE ABOVE THE FOLLOWING 25 AQUIFER CELLS (LAYER,ROW,COLUMN):
    (  2,  7,  7)  (  2,  8,  7)  (  2,  9,  7)  (  2, 10,  7)  (  2, 11,  7)
    (  2,  7,  8)  (  3,  8,  8)  (  3,  9,  8)  (  3, 10,  8)  (  2, 11,  8)
    (  2,  7,  9)  (  3,  8,  9)  (  3,  9,  9)  (  3, 10,  9)  (  2, 11,  9)
    (  2,  7, 10)  (  3,  8, 10)  (  3,  9, 10)  (  3, 10, 10)  (  2, 11, 10)
    (  2,  7, 11)  (  2,  8, 11)  (  2,  9, 11)  (  2, 10, 11)  (  2, 11, 11)

PERIOD     1     TIME STEP    76     TIME STEP LENGTH  7.0714E+01
PERIOD TIME  2.8057E+03     TOTAL SIMULATION TIME  2.8057E+03

    HYDROLOGIC BUDGET SUMMARIES FOR SIMULATED LAKES
    ------------------------------------------------
LAKE  STAGE     PRECIP       EVAP       RUNOFF
  1   96.44  .00000      .65552E+07  .00000

           GROUND WATER            SURFACE WATER
LAKE    INFLOW     OUTFLOW      INFLOW     OUTFLOW
  1  .50630E+07  .00000      .00000      .00000

        WATER    CONNECTED LAKE   UPDATED     TIME-STEP         STAGE CHANGE
LAKE     USE         INFLUX        VOLUME    SURFACE AREA   TIME STEP  CUMULATIVE
  1    .00000       .00000      -.12506E+07   .22500E+07  -.66309      -43.556
--------------------------------------------------------------------------------
```

(Period 1, time step 77 - lake remains dry, stage set at lake bottom altitude)

```
   14 ITERATIONS FOR TIME STEP  77 IN STRESS PERIOD  1

MAXIMUM HEAD CHANGE FOR EACH ITERATION:

   HEAD CHANGE   HEAD CHANGE   HEAD CHANGE   HEAD CHANGE   HEAD CHANGE
 LAYER,ROW,COL LAYER,ROW,COL LAYER,ROW,COL LAYER,ROW,COL LAYER,ROW,COL
----------------------------------------------------------------------
    -3.311        -.6755        -.7784        -.1022        -.2501
 (  3,  9,  9) (  5,  8, 10) (  3, 10,  9) (  4,  8, 11) (  3, 10, 10)
    -.3939E-01    -.1033E-01     .2828E-02     .3859E-02     .3465E-03
 (  3, 10, 10) (  5,  9, 10) (  2,  9,  6) (  2,  8,  7) (  4, 10,  6)
     .1018E-02     .2560E-03     .2969E-03     .3105E-04
 (  2,  7,  7) (  4,  7,  8) (  2,  7,  7) (  4,  6,  9)

..........LAKE  1 IS DRY..........

    SECTIONS OF THE LAKE BOTTOM HAVE BECOME DRY.  THE DRY SECTIONS
    LIE ABOVE THE FOLLOWING 25 AQUIFER CELLS (LAYER,ROW,COLUMN):
    (  2,  7,  7)  (  2,  8,  7)  (  2,  9,  7)  (  2, 10,  7)  (  2, 11,  7)
    (  2,  7,  8)  (  3,  8,  8)  (  3,  9,  8)  (  3, 10,  8)  (  2, 11,  8)
    (  2,  7,  9)  (  3,  8,  9)  (  3,  9,  9)  (  3, 10,  9)  (  2, 11,  9)
    (  2,  7, 10)  (  3,  8, 10)  (  3,  9, 10)  (  3, 10, 10)  (  2, 11, 10)
    (  2,  7, 11)  (  2,  8, 11)  (  2,  9, 11)  (  2, 10, 11)  (  2, 11, 11)

PERIOD     1     TIME STEP    77     TIME STEP LENGTH  7.2129E+01
PERIOD TIME  2.8779E+03     TOTAL SIMULATION TIME  2.8779E+03

    HYDROLOGIC BUDGET SUMMARIES FOR SIMULATED LAKES
    ------------------------------------------------
LAKE  STAGE     PRECIP       EVAP       RUNOFF
  1   96.44  .00000      .00000      .00000
```

```
          GROUND WATER           SURFACE WATER
LAKE    INFLOW     OUTFLOW      INFLOW     OUTFLOW
  1  .00000      .00000      .00000      .00000

        WATER    CONNECTED LAKE   UPDATED     TIME-STEP         STAGE CHANGE
LAKE     USE         INFLUX        VOLUME    SURFACE AREA   TIME STEP  CUMULATIVE
  1    .00000       .00000       .00000       .00000      -.66309      -43.556
--------------------------------------------------------------------------------
```

(Period 2, time step 2 - lake rewets from ground-water seepage)

```
   18 ITERATIONS FOR TIME STEP   2 IN STRESS PERIOD  2

MAXIMUM HEAD CHANGE FOR EACH ITERATION:

   HEAD CHANGE   HEAD CHANGE   HEAD CHANGE   HEAD CHANGE   HEAD CHANGE
 LAYER,ROW,COL LAYER,ROW,COL LAYER,ROW,COL LAYER,ROW,COL LAYER,ROW,COL
----------------------------------------------------------------------
     2.194         2.143         4.150         .4381         3.423
 (  3, 10,  8) (  3,  8, 10) (  3,  9,  8) (  4,  7, 11) (  3, 10,  8)
   -.7305        -.2272        -.2616E-01     .1076        -.7365E-02
 (  3, 11,  9) (  3, 10,  9) (  4, 12,  9) (  3,  9,  8) (  4,  8, 11)
   -.4435E-01    -.7903E-02    -.1246E-01    -.5120E-03    -.3862E-02
 (  3, 10, 10) (  5,  9, 10) (  3, 10,  9) (  5,  8, 11) (  3, 10, 10)
   -.1883E-02    -.8944E-03    -.8789E-04
 (  3, 10,  9) (  5,  9,  9) (  5,  8, 10)

..........LAKE  1 IS DRY..........

AQUIFER HEAD UNDERNEATH BOTTOM OF LAKE IS HIGHER THAN LAKE BOTTOM ELEVATION

LAKE  1 HAS REWET.  SET STAGE OF LAKE TO    103.77  FT


    SECTIONS OF THE LAKE BOTTOM HAVE BECOME DRY.  THE DRY SECTIONS
    LIE ABOVE THE FOLLOWING 16 AQUIFER CELLS (LAYER,ROW,COLUMN):
    (  2,  7,  7)  (  2,  8,  7)  (  2,  9,  7)  (  2, 10,  7)  (  2, 11,  7)
    (  2,  7,  8)  (  2, 11,  8)  (  2,  7,  9)  (  2, 11,  9)  (  2,  7, 10)
    (  2, 11, 10)  (  2,  7, 11)  (  2,  8, 11)  (  2,  9, 11)  (  2, 10, 11)
    (  2, 11, 11)  (

PERIOD     2     TIME STEP     2     TIME STEP LENGTH  1.6334E+01
PERIOD TIME  3.2348E+01     TOTAL SIMULATION TIME  5.0324E+03


    HYDROLOGIC BUDGET SUMMARIES FOR SIMULATED LAKES
    ----------------------------------------------
LAKE  STAGE     PRECIP       EVAP       RUNOFF
  1  103.77  .00000      .00000      .00000

          GROUND WATER           SURFACE WATER
LAKE    INFLOW     OUTFLOW      INFLOW     OUTFLOW
  1  .00000      .00000      .00000      .00000

        WATER    CONNECTED LAKE   UPDATED     TIME-STEP         STAGE CHANGE
LAKE     USE         INFLUX        VOLUME    SURFACE AREA   TIME STEP  CUMULATIVE
  1    .00000       .00000      .15224E+08   .22500E+07  -.66309      -43.556
--------------------------------------------------------------------------------
```

(Period 2, time step 100 - lake stage has converged to equilibrium, all lake cells contain water)

```
     2 ITERATIONS FOR TIME STEP 100 IN STRESS PERIOD  2

 MAXIMUM HEAD CHANGE FOR EACH ITERATION:

    HEAD CHANGE   HEAD CHANGE   HEAD CHANGE   HEAD CHANGE   HEAD CHANGE
  LAYER,ROW,COL LAYER,ROW,COL LAYER,ROW,COL LAYER,ROW,COL LAYER,ROW,COL
 ----------------------------------------------------------------------
     -.1602E-03     .3897E-04
  (  2, 11,  7) (  2, 11, 13)

     0  LAKE CELLS ARE DRY.

 PERIOD     2     TIME STEP   100     TIME STEP LENGTH  1.1374E+02
 PERIOD TIME  5.0000E+03     TOTAL SIMULATION TIME  1.0000E+04


     HYDROLOGIC BUDGET SUMMARIES FOR SIMULATED LAKES
     -----------------------------------------------
 LAKE  STAGE     PRECIP       EVAP       RUNOFF
   1  148.29  .82461E+07  .73220E+07  .00000

            GROUND WATER           SURFACE WATER
 LAKE    INFLOW     OUTFLOW      INFLOW     OUTFLOW
   1  .19187E+07  .28406E+07  .00000      .00000

        WATER    CONNECTED LAKE   UPDATED     TIME-STEP         STAGE CHANGE
 LAKE     USE         INFLUX        VOLUME    SURFACE AREA   TIME STEP  CUMULATIVE
   1    .00000       .00000      .28054E+09   .62500E+07  -.15259E-03   8.2868
 --------------------------------------------------------------------------------

1
             HEAD IN LAYER  5 AT END OF TIME STEP100 IN STRESS PERIOD  2
  -----------------------------------------------------------------------
```

	1	2	3	4	5	6	7	8	9	10
1	160.0	158.9	157.3	155.8	154.2	152.7	151.5	150.8	150.0	149.2
2	160.0	158.6	156.7	155.1	153.4	151.9	150.7	149.9	149.1	148.4
3	160.0	158.4	156.3	154.5	152.8	151.1	150.0	149.2	148.4	147.6
4	160.0	158.3	156.1	154.2	152.4	150.8	149.6	148.8	148.1	147.3
5	160.0	158.2	155.9	154.0	152.2	150.5	149.4	148.6	147.9	147.2
6	160.0	158.2	155.9	153.9	152.1	150.3	149.1	148.5	148.0	147.5
7	160.0	158.2	155.9	153.8	152.0	150.1	148.4	148.3	148.3	148.3
8	160.0	158.2	155.8	153.8	151.9	150.0	148.3	148.3	148.3	148.3
9	160.0	158.2	155.8	153.8	151.9	150.0	148.3	148.3	148.3	148.3
10	160.0	158.2	155.8	153.8	151.9	150.0	148.3	148.3	148.3	148.3
11	160.0	158.2	155.9	153.8	152.0	150.1	148.4	148.3	148.3	148.3
12	160.0	158.2	155.9	153.9	152.1	150.3	149.1	148.5	148.0	147.5
13	160.0	158.2	155.9	154.0	152.2	150.5	149.4	148.6	147.9	147.2
14	160.0	158.3	156.1	154.2	152.4	150.8	149.6	148.8	148.1	147.3
15	160.0	158.4	156.3	154.5	152.8	151.1	150.0	149.2	148.4	147.6
16	160.0	158.6	156.7	155.1	153.4	151.9	150.7	149.9	149.1	148.4
17	160.0	158.9	157.3	155.8	154.2	152.7	151.5	150.8	150.0	149.2

1

```
            HEAD IN LAYER  5 AT END OF TIME STEP100 IN STRESS PERIOD  2
  -----------------------------------------------------------------------

        11      12      13      14      15      16      17
 ..........................................................
   1   148.5   147.3   145.8   144.2   142.7   141.1   140.0
   2   147.6   146.4   144.9   143.4   141.9   140.6   140.0
   3   146.9   145.7   144.2   142.7   141.4   140.3   140.0
   4   146.5   145.4   143.8   142.4   141.1   140.2   140.0
   5   146.5   145.3   143.7   142.3   141.0   140.1   140.0
   6   146.9   145.5   143.8   142.2   141.0   140.1   140.0
   7   148.2   145.9   143.9   142.3   141.0   140.1   140.0
   8   148.2   146.0   143.9   142.3   141.0   140.1   140.0
   9   148.2   146.0   143.9   142.3   141.0   140.1   140.0
  10   148.2   146.0   143.9   142.3   141.0   140.1   140.0
  11   148.2   145.9   143.9   142.3   141.0   140.1   140.0
  12   146.9   145.5   143.8   142.2   141.0   140.1   140.0
  13   146.5   145.3   143.7   142.3   141.0   140.1   140.0
  14   146.5   145.4   143.8   142.4   141.1   140.2   140.0
  15   146.9   145.7   144.2   142.7   141.4   140.3   140.0
  16   147.6   146.4   144.9   143.4   141.9   140.6   140.0
  17   148.5   147.3   145.8   144.2   142.7   141.1   140.0
1
  VOLUMETRIC BUDGET FOR ENTIRE MODEL AT END OF TIME STEP100 IN STRESS PERIOD  2
  -----------------------------------------------------------------------------

     CUMULATIVE VOLUMES      L**3       RATES FOR THIS TIME STEP      L**3/T
     ------------------                 ------------------------

           IN:                                      IN:
           ---                                      ---
             STORAGE =   336612000.0000             STORAGE =           .1864
       CONSTANT HEAD =  7795152000.0000       CONSTANT HEAD =     166881.0000
                  ET =            .0000                  ET =           .0000
            RECHARGE =  8705571000.0000            RECHARGE =    1740000.0000
     SPECIFIED FLOWS =            .0000     SPECIFIED FLOWS =           .0000
       LAKE  SEEPAGE =    82209530.0000       LAKE  SEEPAGE =      24975.0200

            TOTAL IN = 16919540000.0000            TOTAL IN =    1931856.0000

          OUT:                                     OUT:
          ----                                     ----
             STORAGE =   442690000.0000             STORAGE =          5.9153
       CONSTANT HEAD =    40544060.0000       CONSTANT HEAD =       9490.9420
                  ET = 15726370000.0000                  ET =    1905483.0000
            RECHARGE =            .0000            RECHARGE =           .0000
     SPECIFIED FLOWS =            .0000     SPECIFIED FLOWS =           .0000
       LAKE  SEEPAGE =   709938900.0000       LAKE  SEEPAGE =      16869.5300

           TOTAL OUT = 16919550000.0000           TOTAL OUT =    1931849.0000

            IN - OUT =       -2048.0000            IN - OUT =          7.0000

 PERCENT DISCREPANCY =            .00     PERCENT DISCREPANCY =           .00

          TIME SUMMARY AT END OF TIME STEP100 IN STRESS PERIOD  2
                    SECONDS     MINUTES      HOURS       DAYS        YEARS
                    -----------------------------------------------------------
   TIME STEP LENGTH 9.82708E+06 1.63785E+05  2729.7      113.74      .31140
 STRESS PERIOD TIME 4.32002E+08 7.20003E+06 1.20001E+05  5000.0      13.689
         TOTAL TIME 8.64004E+08 1.44001E+07 2.40001E+05  10000.      27.379
```

APPENDIX 3

INPUT DATA SETS AND PRINTED RESULTS FOR TEST SIMULATION 2

This simulation demonstrates the capability of MODFLOW with the Lake Package to portray convergence to an equilibrium state in a scenario that includes two lakes with inflowing and outflowing streams, one of which connects the two lakes. The simulation was performed with transient and steady-state calculations. The input items shown below are for the transient calculations. Because the revised Stream Package (SFR1) is only available for MODFLOW2000, the following input items are coded for MODFLOW2000. Conversion to the input items for steady-state calculations is as indicated for the input items in Appendix 1. Selected sections of output data are shown for both simulations.

Listing of Input Items for Test Simulation 2

The input item names and the unit numbers that they are associated with are identified in the namefile, the name of which is entered from the console at execution time. The following namefile data set was used for Test Simulation 2. The three entries on each line are an alpha character identification of the MODFLOW package, the logical unit number for the corresponding input item, and the input item name, and are separated by spaces.

`LIST   6 l2a2k.lst`	← Designates main output file for MODFLOW
`BAS6   5 l2a2k.ba6`	← Basic input data for MODFLOW
`BCF6  10 l2a2k.bc6`	← Input for Block-Centered Flow Package
`EVT   11 l2.evt`	← Input for Evapotranspiration Package
`RCH   12 l2.rch`	← Input for Recharge Package
`SIP   13 l2.sip`	← Input parameters for strongly-implicit procedure
`SFR   14 l2.sfr`	← Input data for Stream Package
`FHB   21 l2.fhb`	← Input data for Flow and Head Boundary Package
`LAK   16 l2a.lak`	← Input data for Lake Package
`OC    17 l2a.oc`	← Output control data specifications
`DIS   15 l2a2k.dis`	← Input for Discretization Package

↑ ↑ ↑

1 2 3

1 Ftype (that is, the type of file)

2 Unit number (arbitrarily selected)

3 File name (name chosen to reflect contents of file)

Listing of Input Data for Basic Package

Input for the MODFLOW2000 Basic Package (BAS6) follows the column headings below. The input consists of 149 records (lines). Input for the package is read from the FORTRAN unit number specified in the MAIN program.

```
                                                  Column Numbers
         1         2         3         4         5         6         7         8
12345678901234567890123456789012345678901234567890123456789012345678901234567890
________________________________________________________________________________
# Shows convergence to equilibrium in transient mode.    ; begin BAS Input
# Tests interaction of two lakes and three streams                        ; second comment line
NO OPTIONS                                                  ; options line
INTERNAL           1 (20I4)    3  IBOUND layer   1
  -1  -1  -1  -1  -1  -1  -1  -1  -1  -1  -1  -1  -1  -1  -1  -1  -1
  -1   1   1   1   1   1   1   1   1   1   1   1   1   1   1   1  -1
  -1   1   1   1   1   1   1   1   1   1   1   1   1   1   1   1  -1
  -1   1   1   1   1   1   1   1   1   1   1   1   1   1   1   1  -1
  -1   1   1   1   1   1   1   1   1   1   1   1   1   1   1   1  -1
  -1   1   1   1   1   1   1   1   1   1   1   1   1   1   1   1  -1
  -1   1   1   1   1   1   0   0   0   0   0   1   1   1   1   1  -1
  -1   1   1   1   1   1   0   0   0   0   0   1   1   1   1   1  -1
  -1   1   1   1   1   1   0   0   0   0   0   1   1   1   1   1  -1
  -1   1   1   1   1   1   0   0   0   0   0   1   1   1   1   1  -1
  -1   1   1   1   1   1   0   0   0   0   0   1   1   1   1   1  -1
  -1   1   1   1   1   1   1   1   1   1   1   1   1   1   1   1  -1
  -1   1   1   1   1   1   1   1   1   1   1   1   1   1   1   1  -1
  -1   1   1   1   1   1   1   1   1   1   1   1   1   1   1   1  -1
  -1   1   1   1   1   1   1   1   1   1   1   1   1   1   1   1  -1
  -1   1   1   1   1   1   1   1   1   1   1   1   1   1   1   1  -1
  -1   1   1   1   1   1   0   0   0   0   0   1   1   1   1   1  -1
  -1   1   1   1   1   1   0   0   0   0   0   1   1   1   1   1  -1
  -1   1   1   1   1   1   0   0   0   0   0   1   1   1   1   1  -1
  -1   1   1   1   1   1   0   0   0   0   0   1   1   1   1   1  -1
  -1   1   1   1   1   1   0   0   0   0   0   1   1   1   1   1  -1
  -1   1   1   1   1   1   1   1   1   1   1   1   1   1   1   1  -1
  -1   1   1   1   1   1   1   1   1   1   1   1   1   1   1   1  -1
  -1   1   1   1   1   1   1   1   1   1   1   1   1   1   1   1  -1
  -1   1   1   1   1   1   1   1   1   1   1   1   1   1   1   1  -1
  -1   1   1   1   1   1   1   1   1   1   1   1   1   1   1   1  -1
  -1  -1  -1  -1  -1  -1  -1  -1  -1  -1  -1  -1  -1  -1  -1  -1  -1
INTERNAL           1 (20I4)    3  IBOUND layer   2
  -1  -1  -1  -1  -1  -1  -1  -1  -1  -1  -1  -1  -1  -1  -1  -1  -1
  -1   1   1   1   1   1   1   1   1   1   1   1   1   1   1   1  -1
  -1   1   1   1   1   1   1   1   1   1   1   1   1   1   1   1  -1
  -1   1   1   1   1   1   1   1   1   1   1   1   1   1   1   1  -1
  -1   1   1   1   1   1   1   1   1   1   1   1   1   1   1   1  -1
  -1   1   1   1   1   1   1   1   1   1   1   1   1   1   1   1  -1
  -1   1   1   1   1   1   1   1   1   1   1   1   1   1   1   1  -1
  -1   1   1   1   1   1   1   0   0   0   1   1   1   1   1   1  -1
  -1   1   1   1   1   1   1   0   0   0   1   1   1   1   1   1  -1
  -1   1   1   1   1   1   1   0   0   0   1   1   1   1   1   1  -1
  -1   1   1   1   1   1   1   1   1   1   1   1   1   1   1   1  -1
  -1   1   1   1   1   1   1   1   1   1   1   1   1   1   1   1  -1
  -1   1   1   1   1   1   1   1   1   1   1   1   1   1   1   1  -1
  -1   1   1   1   1   1   1   1   1   1   1   1   1   1   1   1  -1
  -1   1   1   1   1   1   1   1   1   1   1   1   1   1   1   1  -1
  -1   1   1   1   1   1   1   1   1   1   1   1   1   1   1   1  -1
  -1   1   1   1   1   1   1   1   1   1   1   1   1   1   1   1  -1
```

```
  -1   1   1   1   1   1   1   0   0   0   1   1   1   1   1   1  -1
  -1   1   1   1   1   1   1   0   0   0   1   1   1   1   1   1  -1
  -1   1   1   1   1   1   1   0   0   0   1   1   1   1   1   1  -1
  -1   1   1   1   1   1   1   1   1   1   1   1   1   1   1   1  -1
  -1   1   1   1   1   1   1   1   1   1   1   1   1   1   1   1  -1
  -1   1   1   1   1   1   1   1   1   1   1   1   1   1   1   1  -1
  -1   1   1   1   1   1   1   1   1   1   1   1   1   1   1   1  -1
  -1   1   1   1   1   1   1   1   1   1   1   1   1   1   1   1  -1
  -1   1   1   1   1   1   1   1   1   1   1   1   1   1   1   1  -1
  -1  -1  -1  -1  -1  -1  -1  -1  -1  -1  -1  -1  -1  -1  -1  -1  -1
INTERNAL             1 (20I4)     3  IBOUND layer   3
  -1  -1  -1  -1  -1  -1  -1  -1  -1  -1  -1  -1  -1  -1  -1  -1  -1
  -1   1   1   1   1   1   1   1   1   1   1   1   1   1   1   1  -1
  -1   1   1   1   1   1   1   1   1   1   1   1   1   1   1   1  -1
  -1   1   1   1   1   1   1   1   1   1   1   1   1   1   1   1  -1
  -1   1   1   1   1   1   1   1   1   1   1   1   1   1   1   1  -1
  -1   1   1   1   1   1   1   1   1   1   1   1   1   1   1   1  -1
  -1   1   1   1   1   1   1   1   1   1   1   1   1   1   1   1  -1
  -1   1   1   1   1   1   1   1   1   1   1   1   1   1   1   1  -1
  -1   1   1   1   1   1   1   1   1   1   1   1   1   1   1   1  -1
  -1   1   1   1   1   1   1   1   1   1   1   1   1   1   1   1  -1
  -1   1   1   1   1   1   1   1   1   1   1   1   1   1   1   1  -1
  -1   1   1   1   1   1   1   1   1   1   1   1   1   1   1   1  -1
  -1   1   1   1   1   1   1   1   1   1   1   1   1   1   1   1  -1
  -1   1   1   1   1   1   1   1   1   1   1   1   1   1   1   1  -1
  -1   1   1   1   1   1   1   1   1   1   1   1   1   1   1   1  -1
  -1   1   1   1   1   1   1   1   1   1   1   1   1   1   1   1  -1
  -1   1   1   1   1   1   1   1   1   1   1   1   1   1   1   1  -1
  -1   1   1   1   1   1   1   1   1   1   1   1   1   1   1   1  -1
  -1   1   1   1   1   1   1   1   1   1   1   1   1   1   1   1  -1
  -1   1   1   1   1   1   1   1   1   1   1   1   1   1   1   1  -1
  -1   1   1   1   1   1   1   1   1   1   1   1   1   1   1   1  -1
  -1   1   1   1   1   1   1   1   1   1   1   1   1   1   1   1  -1
  -1   1   1   1   1   1   1   1   1   1   1   1   1   1   1   1  -1
  -1   1   1   1   1   1   1   1   1   1   1   1   1   1   1   1  -1
  -1   1   1   1   1   1   1   1   1   1   1   1   1   1   1   1  -1
  -1   1   1   1   1   1   1   1   1   1   1   1   1   1   1   1  -1
  -1  -1  -1  -1  -1  -1  -1  -1  -1  -1  -1  -1  -1  -1  -1  -1  -1
INTERNAL             1 (20I4)     3  IBOUND layer   4
  -1  -1  -1  -1  -1  -1  -1  -1  -1  -1  -1  -1  -1  -1  -1  -1  -1
  -1   1   1   1   1   1   1   1   1   1   1   1   1   1   1   1  -1
  -1   1   1   1   1   1   1   1   1   1   1   1   1   1   1   1  -1
  -1   1   1   1   1   1   1   1   1   1   1   1   1   1   1   1  -1
  -1   1   1   1   1   1   1   1   1   1   1   1   1   1   1   1  -1
  -1   1   1   1   1   1   1   1   1   1   1   1   1   1   1   1  -1
  -1   1   1   1   1   1   1   1   1   1   1   1   1   1   1   1  -1
  -1   1   1   1   1   1   1   1   1   1   1   1   1   1   1   1  -1
  -1   1   1   1   1   1   1   1   1   1   1   1   1   1   1   1  -1
  -1   1   1   1   1   1   1   1   1   1   1   1   1   1   1   1  -1
  -1   1   1   1   1   1   1   1   1   1   1   1   1   1   1   1  -1
  -1   1   1   1   1   1   1   1   1   1   1   1   1   1   1   1  -1
  -1   1   1   1   1   1   1   1   1   1   1   1   1   1   1   1  -1
  -1   1   1   1   1   1   1   1   1   1   1   1   1   1   1   1  -1
  -1   1   1   1   1   1   1   1   1   1   1   1   1   1   1   1  -1
  -1   1   1   1   1   1   1   1   1   1   1   1   1   1   1   1  -1
  -1   1   1   1   1   1   1   1   1   1   1   1   1   1   1   1  -1
  -1   1   1   1   1   1   1   1   1   1   1   1   1   1   1   1  -1
  -1   1   1   1   1   1   1   1   1   1   1   1   1   1   1   1  -1
  -1   1   1   1   1   1   1   1   1   1   1   1   1   1   1   1  -1
```

```
  -1   1   1   1   1   1   1   1   1   1   1   1   1   1   1   1  -1
  -1   1   1   1   1   1   1   1   1   1   1   1   1   1   1   1  -1
  -1   1   1   1   1   1   1   1   1   1   1   1   1   1   1   1  -1
  -1   1   1   1   1   1   1   1   1   1   1   1   1   1   1   1  -1
  -1   1   1   1   1   1   1   1   1   1   1   1   1   1   1   1  -1
  -1  -1  -1  -1  -1  -1  -1  -1  -1  -1  -1  -1  -1  -1  -1  -1  -1
INTERNAL          1 (20I4)    3  IBOUND layer   5
  -1  -1  -1  -1  -1  -1  -1  -1  -1  -1  -1  -1  -1  -1  -1  -1  -1
  -1   1   1   1   1   1   1   1   1   1   1   1   1   1   1   1  -1
  -1   1   1   1   1   1   1   1   1   1   1   1   1   1   1   1  -1
  -1   1   1   1   1   1   1   1   1   1   1   1   1   1   1   1  -1
  -1   1   1   1   1   1   1   1   1   1   1   1   1   1   1   1  -1
  -1   1   1   1   1   1   1   1   1   1   1   1   1   1   1   1  -1
  -1   1   1   1   1   1   1   1   1   1   1   1   1   1   1   1  -1
  -1   1   1   1   1   1   1   1   1   1   1   1   1   1   1   1  -1
  -1   1   1   1   1   1   1   1   1   1   1   1   1   1   1   1  -1
  -1   1   1   1   1   1   1   1   1   1   1   1   1   1   1   1  -1
  -1   1   1   1   1   1   1   1   1   1   1   1   1   1   1   1  -1
  -1   1   1   1   1   1   1   1   1   1   1   1   1   1   1   1  -1
  -1   1   1   1   1   1   1   1   1   1   1   1   1   1   1   1  -1
  -1   1   1   1   1   1   1   1   1   1   1   1   1   1   1   1  -1
  -1   1   1   1   1   1   1   1   1   1   1   1   1   1   1   1  -1
  -1   1   1   1   1   1   1   1   1   1   1   1   1   1   1   1  -1
  -1   1   1   1   1   1   1   1   1   1   1   1   1   1   1   1  -1
  -1   1   1   1   1   1   1   1   1   1   1   1   1   1   1   1  -1
  -1   1   1   1   1   1   1   1   1   1   1   1   1   1   1   1  -1
  -1   1   1   1   1   1   1   1   1   1   1   1   1   1   1   1  -1
  -1   1   1   1   1   1   1   1   1   1   1   1   1   1   1   1  -1
  -1   1   1   1   1   1   1   1   1   1   1   1   1   1   1   1  -1
  -1   1   1   1   1   1   1   1   1   1   1   1   1   1   1   1  -1
  -1   1   1   1   1   1   1   1   1   1   1   1   1   1   1   1  -1
  -1   1   1   1   1   1   1   1   1   1   1   1   1   1   1   1  -1
  -1  -1  -1  -1  -1  -1  -1  -1  -1  -1  -1  -1  -1  -1  -1  -1  -1
   -999.00  HNOFLO
CONSTANT   1.150000E+02  Initial Head layer   1
CONSTANT   1.150000E+02  Initial Head layer   2
CONSTANT   1.150000E+02  Initial Head layer   3
CONSTANT   1.150000E+02  Initial Head layer   4
CONSTANT   1.150000E+02  Initial Head layer   5
```

Listing of Input Data for Block-Centered Flow Package

Input for the MODFLOW2000 Block-Centered Flow Package (BCF6) follows the column headings below. The input consists of 161 records (lines). Input for the package is read from FORTRAN unit number 10, as specified in the namefile.

```
                                       Column Numbers
         1         2         3         4         5         6         7         8
12345678901234567890123456789012345678901234567890123456789012345678901234567890
```

```
         0  0.00E+00         1  1.00E+00         1         0  ;options
 1 3 3 3 3                                                                ; LAYCON
CONSTANT   1.000000E+00  TRPY
CONSTANT   2.000000E-01  SF1 layer   1
CONSTANT   3.000000E+01  HY layer   1
CONSTANT   3.000000E+00  VCONT layer   1
```

```
INTERNAL  -2.000000E-01 (20F4.0)    0  WETDRY layer   1
 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0
 0.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 0.0
 0.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 0.0
 0.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 0.0
 0.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 0.0
 0.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 0.0
 0.0 1.0 1.0 1.0 1.0 1.0 0.0 0.0 0.0 0.0 0.0 1.0 1.0 1.0 1.0 1.0 0.0
 0.0 1.0 1.0 1.0 1.0 1.0 0.0 0.0 0.0 0.0 0.0 1.0 1.0 1.0 1.0 1.0 0.0
 0.0 1.0 1.0 1.0 1.0 1.0 0.0 0.0 0.0 0.0 0.0 1.0 1.0 1.0 1.0 1.0 0.0
 0.0 1.0 1.0 1.0 1.0 1.0 0.0 0.0 0.0 0.0 0.0 1.0 1.0 1.0 1.0 1.0 0.0
 0.0 1.0 1.0 1.0 1.0 1.0 0.0 0.0 0.0 0.0 0.0 1.0 1.0 1.0 1.0 1.0 0.0
 0.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 0.0
 0.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 0.0
 0.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 0.0
 0.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 0.0
 0.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 0.0
 0.0 1.0 1.0 1.0 1.0 1.0 0.0 0.0 0.0 0.0 0.0 1.0 1.0 1.0 1.0 1.0 0.0
 0.0 1.0 1.0 1.0 1.0 1.0 0.0 0.0 0.0 0.0 0.0 1.0 1.0 1.0 1.0 1.0 0.0
 0.0 1.0 1.0 1.0 1.0 1.0 0.0 0.0 0.0 0.0 0.0 1.0 1.0 1.0 1.0 1.0 0.0
 0.0 1.0 1.0 1.0 1.0 1.0 0.0 0.0 0.0 0.0 0.0 1.0 1.0 1.0 1.0 1.0 0.0
 0.0 1.0 1.0 1.0 1.0 1.0 0.0 0.0 0.0 0.0 0.0 1.0 1.0 1.0 1.0 1.0 0.0
 0.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 0.0
 0.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 0.0
 0.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 0.0
 0.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 0.0
 0.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 0.0
 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0
CONSTANT   3.000000E-04  SF1 layer   2
CONSTANT   3.000000E+01  HY layer   2
CONSTANT   3.000000E+00  VCONT layer   2
CONSTANT   2.000000E-01  SF2 layer   2
INTERNAL  -2.000000E-01 (20F4.0)    0  WETDRY layer   2
 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0
 0.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 0.0
 0.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 0.0
 0.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 0.0
 0.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 0.0
 0.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 0.0
 0.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 0.0
 0.0 1.0 1.0 1.0 1.0 1.0 1.0 0.0 0.0 0.0 1.0 1.0 1.0 1.0 1.0 1.0 0.0
 0.0 1.0 1.0 1.0 1.0 1.0 1.0 0.0 0.0 0.0 1.0 1.0 1.0 1.0 1.0 1.0 0.0
 0.0 1.0 1.0 1.0 1.0 1.0 1.0 0.0 0.0 0.0 1.0 1.0 1.0 1.0 1.0 1.0 0.0
 0.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 0.0
 0.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 0.0
 0.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 0.0
 0.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 0.0
 0.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 0.0
 0.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 0.0
 0.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 0.0
 0.0 1.0 1.0 1.0 1.0 1.0 1.0 0.0 0.0 0.0 1.0 1.0 1.0 1.0 1.0 1.0 0.0
 0.0 1.0 1.0 1.0 1.0 1.0 1.0 0.0 0.0 0.0 1.0 1.0 1.0 1.0 1.0 1.0 0.0
 0.0 1.0 1.0 1.0 1.0 1.0 1.0 0.0 0.0 0.0 1.0 1.0 1.0 1.0 1.0 1.0 0.0
 0.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 0.0
 0.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 0.0
```

```
 0.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 0.0
 0.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 0.0
 0.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 0.0
 0.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 0.0
 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0
CONSTANT    3.000000E-04  SF1 layer   3
CONSTANT    3.000000E+01  HY layer   3
CONSTANT    3.000000E+00  VCONT layer   3
CONSTANT    2.000000E-01  SF2 layer   3
INTERNAL  -2.000000E-01 (20F4.0)    0  WETDRY layer   3
 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0
 0.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 0.0
 0.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 0.0
 0.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 0.0
 0.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 0.0
 0.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 0.0
 0.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 0.0
 0.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 0.0
 0.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 0.0
 0.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 0.0
 0.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 0.0
 0.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 0.0
 0.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 0.0
 0.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 0.0
 0.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 0.0
 0.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 0.0
 0.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 0.0
 0.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 0.0
 0.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 0.0
 0.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 0.0
 0.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 0.0
 0.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 0.0
 0.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 0.0
 0.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 0.0
 0.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 0.0
 0.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 0.0
 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0
CONSTANT    3.000000E-04  SF1 layer   4
CONSTANT    3.000000E+01  HY layer   4
CONSTANT    3.000000E+00  VCONT layer   4
CONSTANT    2.000000E-01  SF2 layer   4
INTERNAL  -2.000000E-01 (20F4.0)    0  WETDRY layer   4
 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0
 0.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 0.0
 0.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 0.0
 0.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 0.0
 0.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 0.0
 0.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 0.0
 0.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 0.0
 0.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 0.0
 0.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 0.0
 0.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 0.0
 0.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 0.0
 0.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 0.0
 0.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 0.0
```

```
 0.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 0.0
 0.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 0.0
 0.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 0.0
 0.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 0.0
 0.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 0.0
 0.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 0.0
 0.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 0.0
 0.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 0.0
 0.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 0.0
 0.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 0.0
 0.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 0.0
 0.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 0.0
 0.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 0.0
 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0
CONSTANT   3.000000E-04  SF1 layer   5
CONSTANT   3.000000E+01  HY layer   5
CONSTANT   2.000000E-01  SF2 layer   5
INTERNAL  -2.000000E-01 (20F4.0)    0  WETDRY layer   5
 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0
 0.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 0.0
 0.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 0.0
 0.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 0.0
 0.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 0.0
 0.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 0.0
 0.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 0.0
 0.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 0.0
 0.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 0.0
 0.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 0.0
 0.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 0.0
 0.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 0.0
 0.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 0.0
 0.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 0.0
 0.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 0.0
 0.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 0.0
 0.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 0.0
 0.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 0.0
 0.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 0.0
 0.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 0.0
 0.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 0.0
 0.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 0.0
 0.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 0.0
 0.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 0.0
 0.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 0.0
 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0
```

Listing of Input Data for Discretization Package

Input for the MODFLOW2000 Discretization Package (DIS) follows the column headings below. The input consists of 16 records (lines). Input for the package is read from FORTRAN unit number 15, as specified in the namefile.

```
                                        Column Numbers
         1         2         3         4         5         6         7         8
12345678901234567890123456789012345678901234567890123456789012345678901234567890
_______________________________________________________________________________
    5   27   17    1    4    0  NLAY,NROW,NCOL,NPER,ITMUNI,LENUNI
 0 0 0 0 0
INTERNAL   1.000000E+00 (10F8.0)    0  DELR
 2.5E+02 1.0E+03 1.0E+03 1.0E+03 1.0E+03 1.0E+03 5.0E+02 5.0E+02 5.0E+02 5.0E+02
 5.0E+02 1.0E+03 1.0E+03 1.0E+03 1.0E+03 1.0E+03 2.5E+02
INTERNAL   1.000000E+00 (10F8.0)    0  DELC
 2.5E+02 1.0E+03 1.0E+03 1.0E+03 1.0E+03 1.0E+03 5.0E+02 5.0E+02 5.0E+02 5.0E+02
 5.0E+02 1.0E+03 1.0E+03 1.0E+03 1.0E+03 1.0E+03 5.0E+02 5.0E+02 5.0E+02 5.0E+02
 5.0E+02 1.0E+03 1.0E+03 1.0E+03 1.0E+03 1.0E+03 2.5E+02
CONSTANT   2.000000E+02  TOP of system
CONSTANT   1.070000E+02  Layer BOTM layer   1
CONSTANT   9.700000E+01  Layer BOTM layer   2
CONSTANT   8.700000E+01  Layer BOTM layer   3
CONSTANT   7.700000E+01  Layer BOTM layer   4
CONSTANT   6.700000E+01  Layer BOTM layer   5
 1.500E+03       200 1.005E+00  TR  PERLEN,NSTP,TSMULT,Ss/tr
_______________________________________________________________________________
```

Listing of Input Data for Evapotranspiration Package

Input for the Evapotranspiration Package (EVT) follows the column headings below. The input consists of 32 records (lines). Input for the package is read from FORTRAN unit number 11, as specified in the namefile.

```
                                        Column Numbers
         1         2         3         4         5         6         7         8         9        10        11
12345678901234567890123456789012345678901234567890123456789012345678901234567890123456789012345678901234567890
______________________________________________________________________________________________________________

         1         0                                                    ; EVT input - NEVTOP, IEVTCB
         1         1         1         0                                ; input options INSURF,INEVTR,INEXDP,INIEVT
        11       1.0(19F6.1)                     8                      ; ET surface
 160.0 159.0 157.4 155.9 154.3 152.7 151.6 150.8 150.0 149.2 148.4 147.3 145.7 144.1 142.6 141.0 140.0
 160.0 159.0 157.4 155.9 154.3 152.7 151.6 150.8 150.0 149.2 148.4 147.3 145.7 144.1 142.6 141.0 140.0
 160.0 159.0 157.4 155.9 154.3 152.7 151.6 150.8 150.0 149.2 148.4 147.3 145.7 144.1 142.6 141.0 140.0
 160.0 159.0 157.4 155.9 154.3 152.7 151.6 150.8 150.0 149.2 148.4 147.3 145.7 144.1 142.6 141.0 140.0
 160.0 159.0 157.4 155.9 154.3 152.7 151.6 150.8 150.0 149.2 148.4 147.3 145.7 144.1 142.6 141.0 140.0
 160.0 159.0 157.4 155.9 154.3 152.7 151.6 150.8 150.0 149.2 148.4 147.3 145.7 144.1 142.6 141.0 140.0
 160.0 159.0 157.4 155.9 154.3 152.7 105.0 105.0 105.0 105.0 105.0 147.3 145.7 144.1 142.6 141.0 140.0
 160.0 159.0 157.4 155.9 154.3 152.7 105.0  95.0  95.0  95.0 105.0 147.3 145.7 144.1 142.6 141.0 140.0
 160.0 159.0 157.4 155.9 154.3 152.7 105.0  95.0  95.0  95.0 105.0 147.3 145.7 144.1 142.6 141.0 140.0
 160.0 159.0 157.4 155.9 154.3 152.7 105.0  95.0  95.0  95.0 105.0 147.3 145.7 144.1 142.6 141.0 140.0
 160.0 159.0 157.4 155.9 154.3 152.7 105.0 105.0 105.0 105.0 105.0 147.3 145.7 144.1 142.6 141.0 140.0
 160.0 159.0 157.4 155.9 154.3 152.7 151.6 150.8 150.0 149.2 148.4 147.3 145.7 144.1 142.6 141.0 140.0
 160.0 159.0 157.4 155.9 154.3 152.7 151.6 150.8 150.0 149.2 148.4 147.3 145.7 144.1 142.6 141.0 140.0
 160.0 159.0 157.4 155.9 154.3 152.7 151.6 150.8 150.0 149.2 148.4 147.3 145.7 144.1 142.6 141.0 140.0
 160.0 159.0 157.4 155.9 154.3 152.7 151.6 150.8 150.0 149.2 148.4 147.3 145.7 144.1 142.6 141.0 140.0
 160.0 159.0 157.4 155.9 154.3 152.7 151.6 150.8 150.0 149.2 148.4 147.3 145.7 144.1 142.6 141.0 140.0
 160.0 159.0 157.4 155.9 154.3 152.7 105.0 105.0 105.0 105.0 105.0 147.3 145.7 144.1 142.6 141.0 140.0
 160.0 159.0 157.4 155.9 154.3 152.7 105.0  95.0  95.0  95.0 105.0 147.3 145.7 144.1 142.6 141.0 140.0
 160.0 159.0 157.4 155.9 154.3 152.7 105.0  95.0  85.0  95.0 105.0 147.3 145.7 144.1 142.6 141.0 140.0
 160.0 159.0 157.4 155.9 154.3 152.7 105.0  95.0  95.0  95.0 105.0 147.3 145.7 144.1 142.6 141.0 140.0
 160.0 159.0 157.4 155.9 154.3 152.7 105.0 105.0 105.0 105.0 105.0 147.3 145.7 144.1 142.6 141.0 140.0
```

```
 160.0 159.0 157.4 155.9 154.3 152.7 151.6 150.8 150.0 149.2 148.4 147.3 145.7 144.1 142.6 141.0 140.0
 160.0 159.0 157.4 155.9 154.3 152.7 151.6 150.8 150.0 149.2 148.4 147.3 145.7 144.1 142.6 141.0 140.0
 160.0 159.0 157.4 155.9 154.3 152.7 151.6 150.8 150.0 149.2 148.4 147.3 145.7 144.1 142.6 141.0 140.0
 160.0 159.0 157.4 155.9 154.3 152.7 151.6 150.8 150.0 149.2 148.4 147.3 145.7 144.1 142.6 141.0 140.0
 160.0 159.0 157.4 155.9 154.3 152.7 151.6 150.8 150.0 149.2 148.4 147.3 145.7 144.1 142.6 141.0 140.0
 160.0 159.0 157.4 155.9 154.3 152.7 151.6 150.8 150.0 149.2 148.4 147.3 145.7 144.1 142.6 141.0 140.0
         0    0.0141                                                 ; maximum ET rate
         0       15.                                                 ; extinction depth
```

Listing of Input Data for Recharge Package

Input for the Recharge Package (RCH) follows the column headings below. The input consists of 3 records (lines). Input for the package is read from FORTRAN unit number 12, as specified in the namefile.

```
                                       Column Numbers
         1         2         3         4         5         6         7         8
12345678901234567890123456789012345678901234567890123456789012345678901234567890
_________________________________________________________________________________
         3         0                                        ; RCH input - NRCHOP,IRCHCB
         1         0                                        ; input options INRECH,INIRCH
         0    0.0116                                        ; recharge rate
_________________________________________________________________________________
```

Listing of Input Data for Strongly-Implicit Procedure Package

Input for the Strongly-Implicit Procedure Package (SIP) follows the column headings below. The input consists of 2 records (lines). Input for the package is read from FORTRAN unit number 13, as specified in the namefile.

```
                                       Column Numbers
         1         2         3         4         5         6         7         8
12345678901234567890123456789012345678901234567890123456789012345678901234567890
_________________________________________________________________________________
       500         5                                    ; SIP input - MXITER,NPARM
       0.0    0.0001         1       0.0         1      ; SIP parameter specifications
_________________________________________________________________________________
```

Listing of Input Data for the Flow and Head Boundary Package

Input for the Flow and Head Boundary Package (FHB) follows the column headings below. The input consists of 424 records (lines). Input for the package is read from FORTRAN unit number 21, as specified in the namefile. The fourth data column is not used by MODFLOW but may be used by MOC3D.

```
                                       Column Numbers
         1         2         3         4         5         6         7         8
12345678901234567890123456789012345678901234567890123456789012345678901234567890
_________________________________________________________________________________
         1         0       420         0         0         0         0 ; FHB input
        21       1.0         1                                   ; simulation times for input
       0.0
        21       1.0         1                                   ; boundary head values
         1         1         1    64    160.00
         1         2         1    64    160.00
         1         3         1    64    160.00
         1         4         1    64    160.00
(262 records have been omitted assigning heads in all layers on the west and east boundaries
to 160 and 140 feet, respectively.)
```

```
        5        24        17      64    140.00
        5        25        17      64    140.00
        5        26        17      64    140.00
        5        27        17      64    140.00
        1         1         2      64    158.85
        1         1         3      64    157.31
        1         1         4      64    155.77
        1         1         5      64    154.23
(142 records have been omitted assigning specified heads across the northern and southern
boundaries in all layers by linear interpolation between 160 and 140 feet.)
        5        17        13      64    145.77
        5        17        14      64    144.23
        5        17        15      64    142.69
        5        17        16      64    141.15
```

Listing of Input Data for the Stream Package

Input for the Streamflow Routing Package (SFR) is entered in free format. There is no provision for input in fixed-field format. The input consists of 33 records (lines). Input for the package is read from FORTRAN unit number 14, as specified in the namefile.

```
                                   Column Numbers
        1         2         3         4         5         6         7         8
12345678901234567890123456789012345678901234567890123456789012345678901234567890

22,3,0,0,128390.4,.0001,-1,0        ; SFR options
1,2,5,1,1,1000.                     ; segment and reach identification and reach length
1,3,5,1,2,1000.
1,4,5,1,3,1000.
1,4,6,1,4,1000.
1,4,7,1,5,500.
1,4,8,1,6,750.
1,5,8,1,7,1000.
1,6,8,1,8,1000.
1,12,9,2,1,1000.
1,13,9,2,2,1000.
1,14,9,2,3,559.
1,14,10,2,4,559.
1,15,10,2,5,1000.
1,16,10,2,6,1000.
1,22,10,3,1,1000.
1,23,10,3,2,750.
1,23,11,3,3,500.
1,23,12,3,4,1000.
1,23,13,3,5,1000.
1,23,14,3,6,1000.
1,23,15,3,7,1000.
1,23,16,3,8,1000.
3,0,0                                                ; stream data read and print flags
1  1  -1  0     691200. 0.   0.   0.    0.05         ; flow and environmental data for segment 1
0.50,0.5,124.5,5.                                    ; upstream stream channel information for segment 1
0.50,0.5,116.5,5.                                   ; downstream stream channel information for segment 1
2  1  -2 -1          0. 0.   0.   0.    0.05         ;flow and environmental data for segment 2
0.50,0.5,114.85,5.                                   ; upstream stream channel information for segment 2
0.50,0.5,110.65,5.                                  ; downstream stream channel information for segment 2
3  1   0 -2          0. 0.   0.   0.    0.05         ;flow and environmental data for segment 3
0.50,0.5,109.4286,5.                                 ; upstream stream channel information for segment 3
0.50,0.5,102.5714,5.                                ; downstream stream channel information for segment 3
```

Listing of Input Data for the Lake Package

Input for the Lake Package (LAK) follows the column headings below. The input consists of 72 records (lines). Input for the package is read from FORTRAN unit number 16, as specified in the namefile.

```
                                       Column Numbers
         1         2         3         4         5         6         7         8
12345678901234567890123456789012345678901234567890123456789012345678901234567890
______________________________________________________________________________
         2         0                                  ; LAK input - NLAKES,ILKCB
      0.00                                            ; THETA
     130.0                                            ; initial stage, lake 1
     130.0                                            ; initial stage, lake 2
         1         0         0                        ; input/output options
        16         1(24I3)                       3    ; lake position array, layer 1
  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
  0  0  0  0  0  0  1  1  1  1  1  0  0  0  0  0  0
  0  0  0  0  0  0  1  1  1  1  1  0  0  0  0  0  0
  0  0  0  0  0  0  1  1  1  1  1  0  0  0  0  0  0
  0  0  0  0  0  0  1  1  1  1  1  0  0  0  0  0  0
  0  0  0  0  0  0  1  1  1  1  1  0  0  0  0  0  0
  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
  0  0  0  0  0  0  2  2  2  2  2  0  0  0  0  0  0
  0  0  0  0  0  0  2  2  2  2  2  0  0  0  0  0  0
  0  0  0  0  0  0  2  2  2  2  2  0  0  0  0  0  0
  0  0  0  0  0  0  2  2  2  2  2  0  0  0  0  0  0
  0  0  0  0  0  0  2  2  2  2  2  0  0  0  0  0  0
  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
        16         1(24I3)                       3    ; lake position array, layer 2
  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
  0  0  0  0  0  0  0  1  1  1  0  0  0  0  0  0  0
  0  0  0  0  0  0  0  1  1  1  0  0  0  0  0  0  0
  0  0  0  0  0  0  0  1  1  1  0  0  0  0  0  0  0
  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
  0  0  0  0  0  0  0  2  2  2  0  0  0  0  0  0  0
  0  0  0  0  0  0  0  2  2  2  0  0  0  0  0  0  0
```

```
  0  0  0  0  0  0  0  2  2  2  0  0  0  0  0  0  0
  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
         0         0                                  ; lake position array, layer 3
         0         0                                  ; lake position array, layer 4
         0         0                                  ; lake position array, layer 5
         0      0.10                                  ; lakebed leakance array, layer 1
         0      0.10                                  ; lakebed leakance array, layer 2
         0      0.10                                  ; lakebed leakance array, layer 3
         0      0.10                                  ; lakebed leakance array, layer 4
         0      0.10                                  ; lakebed leakance array, layer 5
    0                                                 ; number of coalescing lake systems
    0.0116    0.0103       0.0       0.0          ; recharge,ET,runoff,withdrawal rates, lake 1
    0.0116    0.0103       0.0       0.0          ; recharge,ET,runoff,withdrawal rates, lake 2
```

Listing of Input Data for the Output-Control Package

Input for the Output-Control Package (OC) follows the column headings below. The input consists of 481 records (lines). Input for the package is read from FORTRAN unit number 17, as specified in the namefile.

```
                                        Column Numbers
         1         2         3         4         5         6         7         8
12345678901234567890123456789012345678901234567890123456789012345678901234567890
________________________________________________________________________________
       -14         9        18        19          ; formatting and file unit options
         0         0         0         1    1     ; output options, time step 1
         0         0         0         0          ; head-drawdown print/file options, time step 1
         0         0         0         1    2     ; time step 2
         0         0         0         0
         0         0         0         1    3     ; time step 3
         0         0         0         0
         0         0         0         1    4     ; time step 4
         0         0         0         0
         0         0         0         1    5     ; time step 5
         0         0         0         0
         0         0         0         1    6     ; time step 6
         0         0         0         0
         0         0         0         1    7     ; time step 7
         0         0         0         0
         0         0         0         1    8     ; time step 8
         0         0         0         0
         0         0         0         1    9     ; time step 9
         0         0         0         0
         1         1         1         1   10     ; time step 10
         0         0         0         0
         0         0         0         0
         0         0         0         0
         0         0         0         0
         1         0         0         0
(The previous 24 lines are repeated 19 more times.)
```

Selected Pages from Printed Results for Test Simulation 2 - Transient Case

(Output for time step 200)

```
     2 ITERATIONS FOR TIME STEP 200 IN STRESS PERIOD  1

 MAXIMUM HEAD CHANGE FOR EACH ITERATION:

    HEAD CHANGE   HEAD CHANGE   HEAD CHANGE   HEAD CHANGE   HEAD CHANGE
  LAYER,ROW,COL LAYER,ROW,COL LAYER,ROW,COL LAYER,ROW,COL LAYER,ROW,COL
 ----------------------------------------------------------------------
     0.1415E-03    0.6857E-04
  (  1, 14,  6) (  5, 15,  7)
```

(Output for time step 200 - Water budget for stream reaches)

```
   STREAM LEAKAGE   PERIOD  1   STEP200

  LAYER    ROW  COLUMN  STREAM   REACH    FLOW INTO    FLOW INTO    FLOW OUT OF    OVERLAND
DIRECT       STREAM     STREAM      STREAM      STREAM     STREAMBED
                      NUMBER  NUMBER  STREAM REACH    AQUIFER    STREAM REACH     RUNOFF
PRECIP          ET        HEAD        DEPTH       WIDTH    CONDUCTANCE

     1      2      5      1      1     6.9120E+05   -8.004E+04    7.7124E+05     0.000E+00
0.000E+00   0.000E+00   1.253E+02   1.382E+00   5.000E+00   5.000E+03
     1      3      5      1      2     7.7124E+05   -5.640E+04    8.2764E+05     0.000E+00
0.000E+00   0.000E+00   1.243E+02   1.458E+00   5.000E+00   5.000E+03
     1      4      5      1      3     8.2764E+05   -5.347E+04    8.8111E+05     0.000E+00
0.000E+00   0.000E+00   1.233E+02   1.517E+00   5.000E+00   5.000E+03
     1      4      6      1      4     8.8111E+05   -4.379E+04    9.2489E+05     0.000E+00
0.000E+00   0.000E+00   1.222E+02   1.568E+00   5.000E+00   5.000E+03
     1      4      7      1      5     9.2489E+05   -2.132E+04    9.4622E+05     0.000E+00
0.000E+00   0.000E+00   1.214E+02   1.602E+00   5.000E+00   2.500E+03
     1      4      8      1      6     9.4622E+05   -3.501E+04    9.8123E+05     0.000E+00
0.000E+00   0.000E+00   1.208E+02   1.631E+00   5.000E+00   3.750E+03
     1      5      8      1      7     9.8123E+05   -3.734E+04    1.0186E+06     0.000E+00
0.000E+00   0.000E+00   1.198E+02   1.667E+00   5.000E+00   5.000E+03
     1      6      8      1      8     1.0186E+06   -2.694E+04    1.0455E+06     0.000E+00
0.000E+00   0.000E+00   1.188E+02   1.699E+00   5.000E+00   5.000E+03
     1     12      9      2      1     1.3376E+06   -2.859E+04    1.3662E+06     0.000E+00
0.000E+00   0.000E+00   1.166E+02   2.184E+00   5.000E+00   5.000E+03
     1     13      9      2      2     1.3662E+06   -4.160E+04    1.4078E+06     0.000E+00
0.000E+00   0.000E+00   1.158E+02   2.218E+00   5.000E+00   5.000E+03
     1     14      9      2      3     1.4078E+06   -2.825E+04    1.4360E+06     0.000E+00
0.000E+00   0.000E+00   1.152E+02   2.251E+00   5.000E+00   2.795E+03
     1     14     10      2      4     1.4360E+06   -2.765E+04    1.4637E+06     0.000E+00
0.000E+00   0.000E+00   1.148E+02   2.277E+00   5.000E+00   2.795E+03
     1     15     10      2      5     1.4637E+06   -4.106E+04    1.5047E+06     0.000E+00
0.000E+00   0.000E+00   1.142E+02   2.310E+00   5.000E+00   5.000E+03
     1     16     10      2      6     1.5047E+06   -2.892E+04    1.5337E+06     0.000E+00
0.000E+00   0.000E+00   1.134E+02   2.342E+00   5.000E+00   5.000E+03
     1     22     10      3      1     1.8505E+06   -2.959E+04    1.8801E+06     0.000E+00
0.000E+00   0.000E+00   1.115E+02   2.539E+00   5.000E+00   5.000E+03
     1     23     10      3      2     1.8801E+06   -4.053E+04    1.9206E+06     0.000E+00
0.000E+00   0.000E+00   1.107E+02   2.567E+00   5.000E+00   3.750E+03
     1     23     11      3      3     1.9206E+06   -2.402E+04    1.9447E+06     0.000E+00
0.000E+00   0.000E+00   1.101E+02   2.593E+00   5.000E+00   2.500E+03
     1     23     12      3      4     1.9447E+06   -4.757E+04    1.9922E+06     0.000E+00
0.000E+00   0.000E+00   1.094E+02   2.622E+00   5.000E+00   5.000E+03
```

```
    1     23     13      3      5     1.9922E+06   -5.104E+04    2.0433E+06     0.000E+00
0.000E+00   0.000E+00   1.085E+02   2.661E+00   5.000E+00   5.000E+03
    1     23     14      3      6     2.0433E+06   -5.464E+04    2.0979E+06     0.000E+00
0.000E+00   0.000E+00   1.076E+02   2.703E+00   5.000E+00   5.000E+03
    1     23     15      3      7     2.0979E+06   -6.192E+04    2.1598E+06     0.000E+00
0.000E+00   0.000E+00   1.067E+02   2.748E+00   5.000E+00   5.000E+03
    1     23     16      3      8     2.1598E+06   -9.006E+04    2.2499E+06     0.000E+00
0.000E+00   0.000E+00   1.059E+02   2.807E+00   5.000E+00   5.000E+03
```

(Output for time step 200 - Water budget for lake)

```
     0  LAKE CELLS ARE DRY.

 PERIOD     1     TIME STEP   200     TIME STEP LENGTH  1.1823E+01
 PERIOD TIME  1.5000E+03     TOTAL SIMULATION TIME  1.5000E+03
     HYDROLOGIC BUDGET SUMMARIES FOR SIMULATED LAKES
     ---------------------------------------------
 LAKE  STAGE     PRECIP       EVAP       RUNOFF
   1   118.10  8.5716E+05  7.6110E+05  0.0000E+00
   2   113.22  8.5716E+05  7.6110E+05  0.0000E+00

              GROUND WATER            SURFACE WATER
 LAKE    INFLOW     OUTFLOW      INFLOW     OUTFLOW
   1  3.3573E+06  0.0000E+00  1.2361E+07  1.5814E+07
   2  3.6500E+06  0.0000E+00  1.8132E+07  2.1879E+07

        WATER    CONNECTED LAKE   UPDATED     TIME-STEP          STAGE CHANGE
 LAKE     USE        INFLUX        VOLUME    SURFACE AREA   TIME STEP  CUMULATIVE
   1   0.0000E+00   0.0000E+00   9.1905E+07    6.2500E+06   0.0000E+00 -1.1895E+01
   2   0.0000E+00   0.0000E+00   6.1364E+07    6.2500E+06  -4.5776E-05 -1.6782E+01

 --------------------------------------------------------------------------------
```

(Output for time step 200 - Table of aquifer heads in layer 5)

```
             HEAD IN LAYER  5 AT END OF TIME STEP200 IN STRESS PERIOD  1
  -----------------------------------------------------------------------

         1      2      3      4      5      6      7      8      9     10
 ..........................................................................
   1   160.0  158.9  157.3  155.8  154.2  152.7  151.5  150.8  150.0  149.2
   2   160.0  158.2  155.3  151.1  141.4  146.7  147.2  147.2  147.0  146.7
   3   160.0  157.6  153.6  147.6  135.6  139.9  140.8  141.3  142.2  142.8
   4   160.0  157.3  153.0  146.7  134.0  131.0  130.0  130.1  135.4  138.3
   5   160.0  157.3  153.3  148.4  141.9  136.3  131.4  127.3  131.7  134.7
   6   160.0  157.4  153.6  149.3  143.9  136.5  128.8  124.2  126.6  128.7
   7   160.0  157.5  153.8  149.6  143.9  134.1  118.9  118.3  118.4  118.5
   8   160.0  157.5  153.9  149.7  143.9  133.4  118.6  118.1  118.1  118.1
   9   160.0  157.5  153.9  149.9  144.0  133.4  118.6  118.1  118.1  118.1
  10   160.0  157.6  154.0  150.0  144.4  133.9  118.6  118.1  118.1  118.1
  11   160.0  157.6  154.1  150.3  144.9  135.1  119.0  118.4  118.3  118.4
  12   160.0  157.7  154.3  150.7  145.9  138.9  131.1  126.8  122.4  125.4
  13   160.0  157.7  154.4  151.1  147.0  141.4  135.6  130.6  124.2  127.9
  14   160.0  157.7  154.5  151.2  147.3  142.1  136.7  131.9  125.4  124.7
  15   160.0  157.7  154.4  151.0  146.8  141.3  135.9  131.8  127.3  122.4
  16   160.0  157.7  154.3  150.5  145.6  138.0  129.8  125.9  122.6  119.2
  17   160.0  157.6  154.2  150.2  144.4  133.2  114.3  113.6  113.5  113.4
  18   160.0  157.6  154.1  150.0  143.9  131.7  113.8  113.3  113.2  113.2
```

```
 19   160.0  157.6  154.1  150.0  143.8  131.4  113.8  113.2  113.2  113.2
 20   160.0  157.6  154.2  150.2  144.1  131.9  113.8  113.3  113.2  113.2
 21   160.0  157.7  154.3  150.4  144.8  133.7  114.4  113.7  113.5  113.4
 22   160.0  157.8  154.5  151.0  146.3  139.0  130.8  126.7  122.6  117.4
 23   160.0  157.9  155.0  152.0  148.4  143.7  139.0  135.3  130.0  121.5
 24   160.0  158.0  155.4  152.9  150.1  146.9  144.0  141.9  139.6  137.3
 25   160.0  158.2  155.9  153.7  151.5  149.2  147.3  145.9  144.6  143.3
 26   160.0  158.5  156.6  154.8  153.0  151.2  149.8  148.9  147.9  147.0
 27   160.0  158.9  157.3  155.8  154.2  152.7  151.5  150.8  150.0  149.2
            HEAD IN LAYER  5 AT END OF TIME STEP200 IN STRESS PERIOD  1
 ----------------------------------------------------------------------

        11     12     13     14     15     16     17
 ..................................................
  1   148.5  147.3  145.8  144.2  142.7  141.1  140.0
  2   146.3  145.6  144.4  143.1  141.8  140.5  140.0
  3   143.2  143.3  142.8  141.9  141.0  140.2  140.0
  4   139.9  141.1  141.5  141.1  140.5  139.9  140.0
  5   136.7  138.8  140.1  140.3  140.1  139.8  140.0
  6   130.9  135.5  138.6  139.6  139.7  139.7  140.0
  7   118.9  131.8  137.4  139.1  139.5  139.6  140.0
  8   118.5  130.5  136.8  138.9  139.4  139.6  140.0
  9   118.5  130.1  136.6  138.8  139.4  139.6  140.0
 10   118.5  130.2  136.6  138.7  139.3  139.6  140.0
 11   118.8  131.0  136.8  138.8  139.3  139.6  140.0
 12   128.4  133.7  137.5  138.9  139.4  139.6  140.0
 13   131.3  135.3  138.0  139.1  139.4  139.6  140.0
 14   129.9  135.0  137.9  139.0  139.3  139.5  140.0
 15   127.9  133.7  137.3  138.7  139.2  139.5  140.0
 16   124.0  131.2  136.0  138.0  138.8  139.3  140.0
 17   114.0  127.7  134.8  137.3  138.3  139.1  140.0
 18   113.6  126.3  134.0  136.7  137.9  138.9  140.0
 19   113.6  125.5  133.2  136.0  137.3  138.6  140.0
 20   113.6  125.0  132.2  135.0  136.4  138.1  140.0
 21   113.8  124.6  131.0  133.5  135.0  137.2  140.0
 22   120.1  124.5  128.2  130.0  131.5  134.9  140.0
 23   119.8  119.0  118.8  118.6  119.2  123.9  140.0
 24   135.8  134.1  132.9  132.2  132.5  135.2  140.0
 25   142.2  140.8  139.4  138.3  137.8  138.5  140.0
 26   146.1  144.9  143.4  142.0  140.9  140.1  140.0
 27   148.5  147.3  145.8  144.2  142.7  141.1  140.0
```

(Output for time step 200 - Water budget for aquifer showing lake seepage and stream leakage)

```
 VOLUMETRIC BUDGET FOR ENTIRE MODEL AT END OF TIME STEP200 IN STRESS PERIOD  1
 ----------------------------------------------------------------------------

    CUMULATIVE VOLUMES      L**3       RATES FOR THIS TIME STEP      L**3/T
    ------------------                 ------------------------

          IN:                                     IN:
          ---                                     ---
            STORAGE =     3372379.5000              STORAGE =          0.0000
      CONSTANT HEAD =  1305823230.0000        CONSTANT HEAD =     538796.7500
                 ET =           0.0000                   ET =          0.0000
           RECHARGE =  4132498430.0000             RECHARGE =    2755000.0000
    SPECIFIED FLOWS =           0.0000      SPECIFIED FLOWS =          0.0000
     STREAM LEAKAGE =     4195993.0000       STREAM LEAKAGE =          0.0000
      LAKE  SEEPAGE =     3023173.7500        LAKE  SEEPAGE =          0.0000

           TOTAL IN =  5448913410.0000             TOTAL IN =    3293796.7500
```

```
        OUT:                                        OUT:
        ----                                        ----
           STORAGE =  1276113790.0000                  STORAGE =         253.9300
     CONSTANT HEAD =     2974152.5000            CONSTANT HEAD =        2790.2576
                ET =  2159329020.0000                       ET =     1748317.2500
          RECHARGE =           0.0000                 RECHARGE =           0.0000
   SPECIFIED FLOWS =           0.0000          SPECIFIED FLOWS =           0.0000
    STREAM LEAKAGE =  1270447360.0000           STREAM LEAKAGE =      949726.9380
     LAKE  SEEPAGE =   740047744.0000            LAKE  SEEPAGE =      592688.8750

         TOTAL OUT =  5448911870.0000                TOTAL OUT =     3293777.5000

          IN - OUT =        1536.0000                 IN - OUT =          19.2500

PERCENT DISCREPANCY =           0.00     PERCENT DISCREPANCY =           0.00
```

(Output for time step 200 - Time summary)

```
         TIME SUMMARY AT END OF TIME STEP200 IN STRESS PERIOD  1
                   SECONDS     MINUTES      HOURS       DAYS        YEARS
                   -----------------------------------------------------------
  TIME STEP LENGTH 1.02150E+06  17025.      283.75      11.823     3.23695E-02
STRESS PERIOD TIME 1.29600E+08 2.16000E+06  36000.      1500.0      4.1068
        TOTAL TIME 1.29600E+08 2.16000E+06  36000.      1500.0      4.1068
```

Selected Pages from Printed Results for Test Simulation 2 - Steady-State Case

(Output for single steady-state time step)

```
ALL LAKES CONVERGED TO STEADY-STATE AFTER  17  ITERATIONS

AVERAGE SEED =  .00000109
MINIMUM SEED =  .00000054

    5 ITERATION PARAMETERS CALCULATED FROM AVERAGE SEED:

  .000000E+00  .967686E+00  .998956E+00  .999966E+00  .999999E+00
ALL LAKES CONVERGED TO STEADY-STATE AFTER  16  ITERATIONS
ALL LAKES CONVERGED TO STEADY-STATE AFTER   7  ITERATIONS
ALL LAKES CONVERGED TO STEADY-STATE AFTER   7  ITERATIONS
ALL LAKES CONVERGED TO STEADY-STATE AFTER   7  ITERATIONS
ALL LAKES CONVERGED TO STEADY-STATE AFTER   9  ITERATIONS
ALL LAKES CONVERGED TO STEADY-STATE AFTER  11  ITERATIONS
ALL LAKES CONVERGED TO STEADY-STATE AFTER  10  ITERATIONS
ALL LAKES CONVERGED TO STEADY-STATE AFTER  10  ITERATIONS
ALL LAKES CONVERGED TO STEADY-STATE AFTER  10  ITERATIONS
ALL LAKES CONVERGED TO STEADY-STATE AFTER  10  ITERATIONS
ALL LAKES CONVERGED TO STEADY-STATE AFTER  11  ITERATIONS
ALL LAKES CONVERGED TO STEADY-STATE AFTER  10  ITERATIONS
ALL LAKES CONVERGED TO STEADY-STATE AFTER   9  ITERATIONS
ALL LAKES CONVERGED TO STEADY-STATE AFTER   9  ITERATIONS
ALL LAKES CONVERGED TO STEADY-STATE AFTER   9  ITERATIONS
ALL LAKES CONVERGED TO STEADY-STATE AFTER   7  ITERATIONS
ALL LAKES CONVERGED TO STEADY-STATE AFTER   6  ITERATIONS
ALL LAKES CONVERGED TO STEADY-STATE AFTER   6  ITERATIONS
ALL LAKES CONVERGED TO STEADY-STATE AFTER   5  ITERATIONS
ALL LAKES CONVERGED TO STEADY-STATE AFTER   5  ITERATIONS
ALL LAKES CONVERGED TO STEADY-STATE AFTER   5  ITERATIONS
ALL LAKES CONVERGED TO STEADY-STATE AFTER   3  ITERATIONS
ALL LAKES CONVERGED TO STEADY-STATE AFTER   2  ITERATIONS
ALL LAKES CONVERGED TO STEADY-STATE AFTER   1  ITERATIONS
```

```
 ALL LAKES CONVERGED TO STEADY-STATE AFTER   1  ITERATIONS
 ALL LAKES CONVERGED TO STEADY-STATE AFTER   1  ITERATIONS
 ALL LAKES CONVERGED TO STEADY-STATE AFTER   1  ITERATIONS
 ALL LAKES CONVERGED TO STEADY-STATE AFTER   1  ITERATIONS
 ALL LAKES CONVERGED TO STEADY-STATE AFTER   1  ITERATIONS

    30 ITERATIONS FOR TIME STEP   1 IN STRESS PERIOD  1

 MAXIMUM HEAD CHANGE FOR EACH ITERATION:
    HEAD CHANGE   HEAD CHANGE   HEAD CHANGE   HEAD CHANGE   HEAD CHANGE
  LAYER,ROW,COL LAYER,ROW,COL LAYER,ROW,COL LAYER,ROW,COL LAYER,ROW,COL
 ----------------------------------------------------------------------
      30.76         17.75         15.04         27.54        -7.316
  (  1,  2,  2) (  1,  3,  3) (  5, 24,  3) (  1, 18,  4) (  1, 24,  4)
     1.410         1.280        0.8736        0.7275       -0.2860
  (  1, 23,  3) (  5, 20,  9) (  1, 16,  8) (  5, 15,  8) (  2, 18, 11)
    0.3127       -0.3322        0.2311       -0.1497        0.1423
  (  3, 18, 10) (  3, 19,  9) (  3, 18, 10) (  3, 18, 10) (  3, 18, 10)
   -0.1256        0.4617E-01   -0.2880E-01    0.2175E-01   -0.1931E-01
  (  2, 17,  7) (  2, 17,  7) (  3, 18, 10) (  3, 18, 10) (  2, 18, 11)
    0.1512E-01   -0.1434E-01   -0.5708E-02   -0.2164E-02   -0.2089E-02
  (  2, 17, 11) (  3, 19,  9) (  1, 22, 10) (  3, 18, 10) (  3, 23, 10)
   -0.4180E-03   -0.1777E-03   -0.1560E-03   -0.1555E-03    0.3303E-04
  (  2, 17,  7) (  5, 20,  8) (  1, 21, 12) (  5, 19, 13) (  1, 17, 12)
```

(Output for steady-state time step - Water budget for stream reaches)

```
   STREAM LEAKAGE   PERIOD  1   STEP  1

  LAYER    ROW  COLUMN  STREAM   REACH    FLOW INTO    FLOW INTO    FLOW OUT OF    OVERLAND
DIRECT       STREAM     STREAM      STREAM      STREAM     STREAMBED
                       NUMBER  NUMBER  STREAM REACH    AQUIFER    STREAM REACH     RUNOFF
PRECIP         ET        HEAD         DEPTH        WIDTH    CONDUCTANCE

     1      2     5       1      1     6.9120E+05   -8.004E+04    7.7124E+05     0.000E+00
0.000E+00   0.000E+00   1.253E+02   1.382E+00   5.000E+00   5.000E+03
     1      3     5       1      2     7.7124E+05   -5.640E+04    8.2764E+05     0.000E+00
0.000E+00   0.000E+00   1.243E+02   1.458E+00   5.000E+00   5.000E+03
     1      4     5       1      3     8.2764E+05   -5.347E+04    8.8111E+05     0.000E+00
0.000E+00   0.000E+00   1.233E+02   1.517E+00   5.000E+00   5.000E+03
     1      4     6       1      4     8.8111E+05   -4.379E+04    9.2490E+05     0.000E+00
0.000E+00   0.000E+00   1.222E+02   1.568E+00   5.000E+00   5.000E+03
     1      4     7       1      5     9.2490E+05   -2.132E+04    9.4622E+05     0.000E+00
0.000E+00   0.000E+00   1.214E+02   1.602E+00   5.000E+00   2.500E+03
     1      4     8       1      6     9.4622E+05   -3.501E+04    9.8123E+05     0.000E+00
0.000E+00   0.000E+00   1.208E+02   1.631E+00   5.000E+00   3.750E+03
     1      5     8       1      7     9.8123E+05   -3.734E+04    1.0186E+06     0.000E+00
0.000E+00   0.000E+00   1.198E+02   1.667E+00   5.000E+00   5.000E+03
     1      6     8       1      8     1.0186E+06   -2.694E+04    1.0455E+06     0.000E+00
0.000E+00   0.000E+00   1.188E+02   1.699E+00   5.000E+00   5.000E+03
     1     12     9       2      1     1.3376E+06   -2.859E+04    1.3662E+06     0.000E+00
0.000E+00   0.000E+00   1.166E+02   2.184E+00   5.000E+00   5.000E+03
     1     13     9       2      2     1.3662E+06   -4.160E+04    1.4078E+06     0.000E+00
0.000E+00   0.000E+00   1.158E+02   2.218E+00   5.000E+00   5.000E+03
     1     14     9       2      3     1.4078E+06   -2.825E+04    1.4361E+06     0.000E+00
0.000E+00   0.000E+00   1.152E+02   2.251E+00   5.000E+00   2.795E+03
     1     14    10       2      4     1.4361E+06   -2.765E+04    1.4637E+06     0.000E+00
0.000E+00   0.000E+00   1.148E+02   2.277E+00   5.000E+00   2.795E+03
     1     15    10       2      5     1.4637E+06   -4.106E+04    1.5048E+06     0.000E+00
0.000E+00   0.000E+00   1.142E+02   2.310E+00   5.000E+00   5.000E+03
     1     16    10       2      6     1.5048E+06   -2.893E+04    1.5337E+06     0.000E+00
0.000E+00   0.000E+00   1.134E+02   2.342E+00   5.000E+00   5.000E+03
     1     22    10       3      1     1.8506E+06   -2.959E+04    1.8802E+06     0.000E+00
0.000E+00   0.000E+00   1.115E+02   2.539E+00   5.000E+00   5.000E+03
     1     23    10       3      2     1.8802E+06   -4.053E+04    1.9207E+06     0.000E+00
0.000E+00   0.000E+00   1.107E+02   2.567E+00   5.000E+00   3.750E+03
```

```
    1     23     11      3      3     1.9207E+06   -2.402E+04    1.9447E+06     0.000E+00
0.000E+00  0.000E+00  1.101E+02  2.593E+00  5.000E+00  2.500E+03
    1     23     12      3      4     1.9447E+06   -4.757E+04    1.9923E+06     0.000E+00
0.000E+00  0.000E+00  1.094E+02  2.622E+00  5.000E+00  5.000E+03
    1     23     13      3      5     1.9923E+06   -5.104E+04    2.0434E+06     0.000E+00
0.000E+00  0.000E+00  1.085E+02  2.661E+00  5.000E+00  5.000E+03
    1     23     14      3      6     2.0434E+06   -5.464E+04    2.0980E+06     0.000E+00
0.000E+00  0.000E+00  1.076E+02  2.703E+00  5.000E+00  5.000E+03
    1     23     15      3      7     2.0980E+06   -6.192E+04    2.1599E+06     0.000E+00
0.000E+00  0.000E+00  1.067E+02  2.748E+00  5.000E+00  5.000E+03
    1     23     16      3      8     2.1599E+06   -9.006E+04    2.2500E+06     0.000E+00
0.000E+00  0.000E+00  1.059E+02  2.807E+00  5.000E+00  5.000E+03
```

(Output for steady-state time step - Water budget for lake)

```
     0  LAKE CELLS ARE DRY.

 PERIOD     1     TIME STEP     1     TIME STEP LENGTH  1.0000E+00
 PERIOD TIME  1.0000E+00     TOTAL SIMULATION TIME  1.0000E+00


     HYDROLOGIC BUDGET SUMMARIES FOR SIMULATED LAKES
     -----------------------------------------------
 LAKE  STAGE     PRECIP       EVAP       RUNOFF
   1   118.10  7.2500E+04  6.4375E+04  0.0000E+00
   2   113.22  7.2500E+04  6.4375E+04  0.0000E+00

            GROUND WATER           SURFACE WATER
 LAKE    INFLOW     OUTFLOW      INFLOW     OUTFLOW
   1  2.8399E+05  0.0000E+00  1.0455E+06  1.3376E+06
   2  3.0876E+05  0.0000E+00  1.5337E+06  1.8506E+06

         WATER    CONNECTED LAKE   UPDATED     TIME-STEP         STAGE CHANGE
 LAKE     USE         INFLUX        VOLUME    SURFACE AREA   TIME STEP  CUMULATIVE
   1   0.0000E+00   0.0000E+00   9.1905E+07    6.2500E+06   0.0000E+00 -1.8952E+00
   2   0.0000E+00   0.0000E+00   6.1365E+07    6.2500E+06   0.0000E+00 -1.7816E+00

 -------------------------------------------------------------------------------
```

(Output for steady-state time step - Table of aquifer heads in layer 5)

```
              HEAD IN LAYER  5 AT END OF TIME STEP  1 IN STRESS PERIOD  1
  ----------------------------------------------------------------------

          1      2      3      4      5      6      7      8      9     10
 ........................................................................
   1   160.0  158.9  157.3  155.8  154.2  152.7  151.5  150.8  150.0  149.2
   2   160.0  158.2  155.3  151.1  141.4  146.7  147.2  147.2  147.0  146.7
   3   160.0  157.6  153.6  147.6  135.6  139.9  140.8  141.3  142.2  142.8
   4   160.0  157.3  153.0  146.7  134.0  131.0  130.0  130.1  135.4  138.3
   5   160.0  157.3  153.3  148.4  141.9  136.3  131.4  127.3  131.7  134.7
   6   160.0  157.4  153.6  149.3  143.9  136.5  128.8  124.2  126.6  128.7
   7   160.0  157.5  153.8  149.6  143.9  134.1  118.9  118.3  118.4  118.5
   8   160.0  157.5  153.9  149.7  143.9  133.4  118.6  118.1  118.1  118.1
   9   160.0  157.5  153.9  149.9  144.0  133.4  118.6  118.1  118.1  118.1
  10   160.0  157.6  154.0  150.0  144.4  133.9  118.6  118.1  118.1  118.1
  11   160.0  157.6  154.1  150.3  144.9  135.1  119.0  118.4  118.3  118.4
  12   160.0  157.7  154.3  150.7  145.9  138.9  131.1  126.8  122.4  125.4
  13   160.0  157.7  154.4  151.1  147.0  141.4  135.6  130.6  124.2  127.9
  14   160.0  157.7  154.5  151.2  147.3  142.1  136.7  131.9  125.4  124.7
```

15	160.0	157.7	154.4	151.0	146.9	141.3	135.9	131.8	127.3	122.4
16	160.0	157.7	154.3	150.5	145.6	138.0	129.8	125.9	122.6	119.2
17	160.0	157.6	154.2	150.2	144.4	133.2	114.3	113.6	113.5	113.4
18	160.0	157.6	154.1	150.1	143.9	131.7	113.8	113.3	113.2	113.2
19	160.0	157.6	154.1	150.0	143.8	131.4	113.8	113.2	113.2	113.2
20	160.0	157.6	154.2	150.2	144.1	131.9	113.8	113.3	113.2	113.2
21	160.0	157.7	154.3	150.4	144.8	133.7	114.4	113.7	113.5	113.4
22	160.0	157.8	154.5	151.0	146.3	139.0	130.8	126.7	122.6	117.4
23	160.0	157.9	155.0	152.0	148.4	143.7	139.1	135.3	130.0	121.5
24	160.0	158.0	155.4	152.9	150.1	146.9	144.0	141.9	139.6	137.3
25	160.0	158.2	155.9	153.7	151.5	149.2	147.3	145.9	144.6	143.3
26	160.0	158.5	156.6	154.8	153.0	151.2	149.8	148.9	147.9	147.0
27	160.0	158.9	157.3	155.8	154.2	152.7	151.5	150.8	150.0	149.2

1

HEAD IN LAYER 5 AT END OF TIME STEP 1 IN STRESS PERIOD 1

	11	12	13	14	15	16	17
1	148.5	147.3	145.8	144.2	142.7	141.1	140.0
2	146.3	145.6	144.4	143.1	141.8	140.5	140.0
3	143.2	143.3	142.8	142.0	141.0	140.2	140.0
4	139.9	141.2	141.5	141.1	140.5	139.9	140.0
5	136.7	138.8	140.1	140.3	140.1	139.8	140.0
6	130.9	135.5	138.6	139.6	139.7	139.7	140.0
7	118.9	131.8	137.4	139.1	139.5	139.6	140.0
8	118.5	130.5	136.8	138.9	139.4	139.6	140.0
9	118.5	130.1	136.6	138.8	139.4	139.6	140.0
10	118.5	130.2	136.6	138.7	139.3	139.6	140.0
11	118.8	131.0	136.8	138.8	139.3	139.6	140.0
12	128.4	133.7	137.5	138.9	139.4	139.6	140.0
13	131.3	135.3	138.0	139.1	139.4	139.6	140.0
14	129.9	135.0	137.9	139.0	139.3	139.5	140.0
15	127.9	133.7	137.3	138.7	139.2	139.5	140.0
16	124.0	131.2	136.0	138.0	138.8	139.3	140.0
17	114.0	127.7	134.8	137.3	138.3	139.1	140.0
18	113.6	126.3	134.0	136.7	137.9	138.9	140.0
19	113.6	125.5	133.2	136.0	137.3	138.6	140.0
20	113.6	125.0	132.2	135.0	136.4	138.1	140.0
21	113.8	124.6	131.0	133.5	135.0	137.2	140.0
22	120.1	124.5	128.2	130.0	131.5	134.9	140.0
23	119.8	119.0	118.8	118.6	119.2	123.9	140.0
24	135.8	134.1	132.9	132.2	132.5	135.2	140.0
25	142.2	140.8	139.4	138.3	137.8	138.5	140.0
26	146.1	144.9	143.4	142.0	140.9	140.1	140.0
27	148.5	147.3	145.8	144.2	142.7	141.1	140.0

(Output for steady-state time step - Water budget for aquifer showing lake seepage and stream leakage)

```
  VOLUMETRIC BUDGET FOR ENTIRE MODEL AT END OF TIME STEP  1 IN STRESS PERIOD  1
  -----------------------------------------------------------------------------

     CUMULATIVE VOLUMES      L**3       RATES FOR THIS TIME STEP      L**3/T
     ------------------                 ------------------------

           STORAGE =           0.0000            STORAGE =           0.0000
     CONSTANT HEAD =      538745.1250      CONSTANT HEAD =      538745.1250
                ET =           0.0000                 ET =           0.0000
          RECHARGE =     2755000.0000           RECHARGE =     2755000.0000
   SPECIFIED FLOWS =           0.0000    SPECIFIED FLOWS =           0.0000
    STREAM LEAKAGE =           0.0000     STREAM LEAKAGE =           0.0000
     LAKE  SEEPAGE =           0.0000      LAKE  SEEPAGE =           0.0000

          TOTAL IN =     3293745.0000           TOTAL IN =     3293745.0000

         OUT:                                OUT:
         ----                                ----
           STORAGE =           0.0000            STORAGE =           0.0000
     CONSTANT HEAD =        2790.8638      CONSTANT HEAD =        2790.8638
                ET =     1748452.5000                 ET =     1748452.5000
          RECHARGE =           0.0000           RECHARGE =           0.0000
   SPECIFIED FLOWS =           0.0000    SPECIFIED FLOWS =           0.0000
    STREAM LEAKAGE =      949765.5000     STREAM LEAKAGE =      949765.5000
     LAKE  SEEPAGE =      592749.3130      LAKE  SEEPAGE =      592749.3130

         TOTAL OUT =     3293758.2500          TOTAL OUT =     3293758.2500

          IN - OUT =         -13.2500           IN - OUT =         -13.2500

 PERCENT DISCREPANCY =           0.00     PERCENT DISCREPANCY =           0.00
```

(Output for time step 200 - Time summary)

```
         TIME SUMMARY AT END OF TIME STEP  1 IN STRESS PERIOD  1
                   SECONDS     MINUTES      HOURS       DAYS        YEARS
                   -----------------------------------------------------------
   TIME STEP LENGTH  86400.      1440.0      24.000      1.0000     2.73785E-03
 STRESS PERIOD TIME  86400.      1440.0      24.000      1.0000     2.73785E-03
         TOTAL TIME  86400.      1440.0      24.000      1.0000     2.73785E-03
```

APPENDIX 4

INPUT DATA SETS AND PRINTED RESULTS FOR TEST SIMULATION 3

This simulation demonstrates the capability of MODFLOW with the Lake Package to portray the division of a lake with shallow areas into separate pools (sublakes) during a period of drying and the subsequent coalescence of the pools into one lake during a period of normal rainfall. The simulation of this scenario with the Lake Package requires that the pools be treated formally as separate lakes in the input data sets. Also, the separation/coalescence process can only be simulated with transient calculations.

Listing of Input Data Sets for Test Simulation 3

The input data set names and the unit numbers that they are associated with are identified in the namefile, the name of which is entered from the console at execution time. The following namefile data set was used for Test Simulation 3. The three entries on each line are an alpha character identification of the MODFLOW package, the logical unit number for the corresponding input data set, and the input data set name, and are separated by spaces.

```
LIST  6 unit6dnc.96
BAS   5 unit5dnc
BCF  10 unit10dnc
EVT  11 unit11dnc
RCH  12 unit12bdw
SIP  13 unit13a
FHB  21 unit21dnc
LAK  16 unit16dnc
OC   17 unit17d1
```

← Designates main output file for MODFLOW
← Basic input data for MODFLOW
← Input for Block-Centered Flow Package
← Input for Evapotranspiration Package
← Input for Recharge Package
← Input parameters for strongly-implicit procedure
← Input data for Flow and Head Boundary Package
← Input data for Lake Package
← Output control data specifications

↑ ↑ ↑
1 2 3

1 Ftype (that is, the type of file)

2 Unit number (arbitrarily selected)

3 File name (name chosen to reflect contents of file)

Listing of Input Data for Basic Package

Input for the Basic Package (BAS) follows the column headings below. The input consists of 103 records (lines). Input for the package is read from the FORTRAN unit number specified in the MAIN program.

```
                                                     Column Numbers
         1         2         3         4         5         6         7         8
12345678901234567890123456789012345678901234567890123456789012345678901234567890
______________________________________________________________________________
Separation and coalescence in a multiple-lake system.       ; begin BAS Input
      NLAY      NROW      NCOL      NPER    ITMUNI          ; second comment line
         5        17        22         2         4
                                                            ; options line (blank)
         0         0                                        ; IAPART, ISTRT
         5         1(24I3)                       3          ; IBOUND, 1st layer
 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1
 -1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1 -1
 -1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1 -1
 -1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1 -1
 -1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1 -1
 -1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1 -1
 -1  1  1  1  0  0  0  1  0  0  0  0  0  1  1  1  1  1  1  1  1 -1
 -1  1  1  1  0  0  0  1  0  0  0  0  0  1  0  0  1  0  0  1  1 -1
 -1  1  1  1  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  1  1 -1
 -1  1  1  1  0  0  0  1  0  0  0  0  0  1  0  0  1  0  0  1  1 -1
 -1  1  1  1  0  0  0  1  0  0  0  0  0  1  1  1  1  1  1  1  1 -1
 -1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1 -1
 -1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1 -1
 -1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1 -1
 -1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1 -1
 -1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1 -1
 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1
         5         1(24I3)                       3          ; IBOUND, 2nd layer
 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1
 -1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1 -1
 -1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1 -1
 -1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1 -1
 -1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1 -1
 -1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1 -1
 -1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1 -1
 -1  1  1  1  1  0  1  1  1  0  0  0  1  1  0  0  1  0  0  1  1 -1
 -1  1  1  1  1  0  0  1  0  0  0  0  0  1  0  0  1  0  0  1  1 -1
 -1  1  1  1  1  0  1  1  1  0  0  0  1  1  1  1  1  1  1  1  1 -1
 -1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1 -1
 -1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1 -1
 -1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1 -1
 -1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1 -1
 -1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1 -1
 -1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1 -1
 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1
         5         1(24I3)                       3          ; IBOUND, 3rd layer
 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1
 -1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1 -1
 -1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1 -1
 -1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1 -1
 -1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1 -1
 -1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1 -1
 -1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1 -1
```

```
 -1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1 -1
 -1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1 -1
 -1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1 -1
 -1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1 -1
 -1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1 -1
 -1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1 -1
 -1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1 -1
 -1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1 -1
 -1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1 -1
 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1
         5         1(24I3)                             3            ; IBOUND, 4th layer
 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1
 -1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1 -1
 -1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1 -1
 -1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1 -1
 -1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1 -1
 -1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1 -1
 -1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1 -1
 -1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1 -1
 -1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1 -1
 -1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1 -1
 -1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1 -1
 -1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1 -1
 -1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1 -1
 -1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1 -1
 -1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1 -1
 -1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1 -1
 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1
         5         1(24I3)                             3            ; IBOUND, 5th layer
 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1
 -1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1 -1
 -1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1 -1
 -1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1 -1
 -1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1 -1
 -1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1 -1
 -1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1 -1
 -1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1 -1
 -1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1 -1
 -1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1 -1
 -1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1 -1
 -1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1 -1
 -1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1 -1
 -1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1 -1
 -1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1 -1
 -1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1 -1
 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1
     -999.                                                         ; HNOFLO
         0       115.                                              ; Initial head, layer 1
         0       115.                                              ; Initial head, layer 2
         0       115.                                              ; Initial head, layer 3
         0       115.                                              ; Initial head, layer 4
         0       115.                                              ; Initial head, layer 5
      400.         50       1.03                      ; PERLEN, NSTP,TSMULT, stress period 1
      400.         50       1.03                      ; PERLEN, NSTP,TSMULT, stress period 2
```

Listing of Input Data for Block-Centered Flow Package

Input for the Block-Centered Flow Package (BCF) follows the column headings below. The input consists of 129 records (lines). Input for the package is read from FORTRAN unit number 10, as specified in the namefile.

```
                                Column Numbers
         1         2         3         4         5         6         7         8
12345678901234567890123456789012345678901234567890123456789012345678901234567890
________________________________________________________________________________
         0         0       0.0         1       1.0         1         0 ; BCF input
 1 3 3 3 3                                                               ; LAYCON
         0       1.0                                                     ; TRPY
        10       1.0(7F10.0)                     0                       ; DELR
      250.     1000.     1000.     1000.      500.      500.      500.
      500.      500.      500.      500.      500.      500.      500.
      500.      500.      500.      500.      500.     1000.     1000.
      250.
        10       1.0(7F10.0)                     0                       ; DELC
      250.     1000.     1000.     1000.     1000.     1000.      500.
      500.      500.      500.      500.     1000.     1000.     1000.
     1000.     1000.      250.
         0      0.20                                   ; storage coefficient, layer 1
         0       30.                                   ; hydraulic conductivity, layer 1
         0      107.                                   ; bottom elevation, layer 1
         0        3.                                   ; vertical leakance, layers 1 and 2
        10      -0.2(24F3.0)                     7     ; wet-dry, layer 1
 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1
 -1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1 -1
 -1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1 -1
 -1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1 -1
 -1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1 -1
 -1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1 -1
 -1  1  1  1  0  0  0  1  0  0  0  0  0  1  1  1  1  1  1  1  1 -1
 -1  1  1  1  0  0  0  1  0  0  0  0  0  1  0  0  1  0  0  1  1 -1
 -1  1  1  1  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  1  1 -1
 -1  1  1  1  0  0  0  1  0  0  0  0  0  1  0  0  1  0  0  1  1 -1
 -1  1  1  1  0  0  0  1  0  0  0  0  0  1  1  1  1  1  1  1  1 -1
 -1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1 -1
 -1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1 -1
 -1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1 -1
 -1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1 -1
 -1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1 -1
 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1
         0    0.0003                              ; primary storage coefficient, layer 2
         0       30.                              ; hydraulic conductivity, layer 2
         0       97.                              ; bottom elevation, layer 2
         0        3.                              ; vertical leakance, layers 2 and 3
         0       0.2                              ; secondary storage coefficient, layer 2
         0      107.                              ; top elevation, layer 2
        10      -0.2(24F3.0)                     7; wet-dry, layer 2
 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1
 -1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1 -1
 -1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1 -1
 -1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1 -1
 -1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1 -1
 -1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1 -1
 -1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1 -1
 -1  1  1  1  1  0  1  1  1  0  0  0  1  1  0  0  1  0  0  1  1 -1
 -1  1  1  1  1  0  0  1  0  0  0  0  0  1  0  0  1  0  0  1  1 -1
```

```
-1  1  1  1  1  0  1  1  1  0  0  0  1  1  1  1  1  1  1  1  1 -1
-1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1 -1
-1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1 -1
-1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1 -1
-1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1 -1
-1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1 -1
-1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1 -1
-1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1
         0    0.0003                                       ; primary storage coefficient, layer 3
         0       30.                                       ; hydraulic conductivity, layer 3
         0       87.                                       ; bottom elevation, layer 3
         0        3.                                       ; vertical leakance, layers 3 and 4
         0       0.2                                       ; secondary storage coefficient, layer 3
         0       97.                                       ; top elevation, layer 3
        10      -0.2(24F3.0)                         7     ; wet-dry, layer 3
-1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1
-1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1 -1
-1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1 -1
-1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1 -1
-1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1 -1
-1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1 -1
-1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1 -1
-1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1 -1
-1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1 -1
-1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1 -1
-1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1 -1
-1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1 -1
-1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1 -1
-1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1 -1
-1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1 -1
-1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1 -1
-1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1
         0    0.0003                                       ; primary storage coefficient, layer 4
         0       30.                                       ; hydraulic conductivity, layer 4
         0       77.                                       ; bottom elevation, layer 4
         0        3.                                       ; vertical leakance, layers 4 and 5
         0       0.2                                       ; secondary storage coefficient, layer 4
         0       87.                                       ; top elevation, layer 4
        10      -0.2(24F3.0)                         7     ; wet-dry, layer 4
-1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1
-1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1 -1
-1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1 -1
-1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1 -1
-1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1 -1
-1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1 -1
-1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1 -1
-1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1 -1
-1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1 -1
-1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1 -1
-1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1 -1
-1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1 -1
-1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1 -1
-1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1 -1
-1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1 -1
-1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1 -1
-1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1
         0    0.0003                                       ; primary storage coefficient, layer 5
         0       30.                                       ; hydraulic conductivity, layer 5
         0       67.                                       ; bottom elevation, layer 5
         0       0.2                                       ; secondary storage coefficient, layer 5
```

```
          0        77.                                                    ; top elevation, layer 5
         10       -0.2(24F3.0)                                  7         ; wet-dry, layer 5
 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1
 -1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1 -1
 -1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1 -1
 -1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1 -1
 -1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1 -1
 -1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1 -1
 -1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1 -1
 -1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1 -1
 -1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1 -1
 -1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1 -1
 -1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1 -1
 -1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1 -1
 -1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1 -1
 -1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1 -1
 -1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1 -1
 -1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1 -1
 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1
```

Listing of Input Data for Evapotranspiration Package

Input for the Evapotranspiration Package (EVT) follows the column headings below. The input consists of 24 records (lines). Input for the package is read from FORTRAN unit number 11, as specified in the namefile.

Column Numbers

```
         1         2         3         4         5         6         7         8         9        10        11        12        13
1234567890123456789012345678901234567890123456789012345678901234567890123456789012345678901234567890123456789012345678901234567890

         3         0                                       ; EVT input - NEVTOP, IEVTCB
         1         1         1         0    ; input options INSURF,INEVTR,INEXDP,INIEVT, stress period 1
        11       1.0(24F6.1)                         8     ; ET surface
 160.0 159.0 157.4 155.9 154.7 153.9 153.1 152.3 151.6 150.8 150.0 149.2 148.4 147.7 146.9 146.1 145.3 144.5 143.8 142.6 141.0 140.0
 160.0 159.0 157.4 155.9 154.7 153.9 153.1 152.3 151.6 150.8 150.0 149.2 148.4 147.7 146.9 146.1 145.3 144.5 143.8 142.6 141.0 140.0
 160.0 159.0 157.4 155.9 154.7 153.9 153.1 152.3 151.6 150.8 150.0 149.2 148.4 147.7 146.9 146.1 145.3 144.5 143.8 142.6 141.0 140.0
 160.0 159.0 157.4 155.9 154.7 153.9 153.1 152.3 151.6 150.8 150.0 149.2 148.4 147.7 146.9 146.1 145.3 144.5 143.8 142.6 141.0 140.0
 160.0 159.0 157.4 155.9 154.7 153.9 153.1 152.3 151.6 150.8 150.0 149.2 148.4 147.7 146.9 146.1 145.3 144.5 143.8 142.6 141.0 140.0
 160.0 159.0 157.4 155.9 154.7 153.9 153.1 152.3 151.6 150.8 150.0 149.2 148.4 147.7 146.9 146.1 145.3 144.5 143.8 142.6 141.0 140.0
 160.0 159.0 157.4 155.9 105.0 105.0 105.0 125.0 105.0 105.0 105.0 105.0 105.0 147.7 146.9 146.1 145.3 144.5 143.8 142.6 141.0 140.0
 160.0 159.0 157.4 155.9 105.0  95.0 105.0 120.0 105.0  95.0  95.0  95.0 105.0 120.0  95.0  95.0 120.0  95.0  95.0 142.6 141.0 140.0
 160.0 159.0 157.4 155.9 105.0  95.0  95.0 105.0  95.0  95.0  95.0  95.0  95.0 105.0  95.0  95.0 105.0  95.0  95.0 142.6 141.0 140.0
 160.0 159.0 157.4 155.9 105.0  95.0 105.0 120.0 105.0  95.0  95.0  95.0 105.0 120.0 105.0 105.0 120.0 105.0 105.0 142.6 141.0 140.0
 160.0 159.0 157.4 155.9 105.0 105.0 105.0 125.0 105.0 105.0 105.0 105.0 105.0 147.7 146.9 146.1 145.3 144.5 143.8 142.6 141.0 140.0
 160.0 159.0 157.4 155.9 154.7 153.9 153.1 152.3 151.6 150.8 150.0 149.2 148.4 147.7 146.9 146.1 145.3 144.5 143.8 142.6 141.0 140.0
 160.0 159.0 157.4 155.9 154.7 153.9 153.1 152.3 151.6 150.8 150.0 149.2 148.4 147.7 146.9 146.1 145.3 144.5 143.8 142.6 141.0 140.0
 160.0 159.0 157.4 155.9 154.7 153.9 153.1 152.3 151.6 150.8 150.0 149.2 148.4 147.7 146.9 146.1 145.3 144.5 143.8 142.6 141.0 140.0
 160.0 159.0 157.4 155.9 154.7 153.9 153.1 152.3 151.6 150.8 150.0 149.2 148.4 147.7 146.9 146.1 145.3 144.5 143.8 142.6 141.0 140.0
 160.0 159.0 157.4 155.9 154.7 153.9 153.1 152.3 151.6 150.8 150.0 149.2 148.4 147.7 146.9 146.1 145.3 144.5 143.8 142.6 141.0 140.0
 160.0 159.0 157.4 155.9 154.7 153.9 153.1 152.3 151.6 150.8 150.0 149.2 148.4 147.7 146.9 146.1 145.3 144.5 143.8 142.6 141.0 140.0
         0    0.0412                                       ; maximum ET rate, stress period 1
         0       15.                                       ; extinction depth
        -1         1        -1         0    ; input options INSURF,INEVTR,INEXDP,INIEVT, stress period 2
         0    0.0141                                       ; maximum ET rate, stress period 2
```

Listing of Input Data for Recharge Package

Input for the Recharge Package (RCH) follows the column headings below. The input consists of 5 records (lines). Input for the package is read from FORTRAN unit number 12, as specified in the namefile.

```
                                       Column Numbers
         1         2         3         4         5         6         7         8
12345678901234567890123456789012345678901234567890123456789012345678901234567890
____________________________________________________________________________________
         3         0                                 ; RCH input - NRCHOP,IRCHCB
         1         0                                 ; input options INRECH,INIRCH, stress period 1
         0    0.0000                                 ; recharge rate, stress period 1
         1         0                                 ; input options INRECH,INIRCH, stress period 2
         0    0.0116                                 ; recharge rate, stress period 2
____________________________________________________________________________________
```

Listing of Input Data for Strongly-Implicit Procedure Package

Input for the Strongly-Implicit Procedure Package (SIP) follows the column headings below. The input consists of 2 records (lines). Input for the package is read from FORTRAN unit number 13, as specified in the namefile.

```
                                       Column Numbers
         1         2         3         4         5         6         7         8
12345678901234567890123456789012345678901234567890123456789012345678901234567890
____________________________________________________________________________________
       500         5                                           ; SIP input - MXITER,NPARM
       0.0    0.0001         1       0.0         1             ; SIP parameter specifications
____________________________________________________________________________________
```

Listing of Input Data for the Flow and Head Boundary Package

Input for the Flow and Head Boundary Package (FHB) follows the column headings below. The input consists of 374 records (lines). Input for the package is read from FORTRAN unit number 21, as specified in the namefile. The fourth column in the list of boundary head values is not used by MODFLOW but may be used by MOC3D.

```
                                       Column Numbers
         1         2         3         4         5         6         7         8
12345678901234567890123456789012345678901234567890123456789012345678901234567890
____________________________________________________________________________________
         1         0       370         0         0         0         0 ; FHB input
        21       1.0         1                                  ; simulation times for input
       0.0
        21       1.0         1                                     ; boundary head values
         1         1         1        64    160.00
         1         2         1        64    160.00
         1         3         1        64    160.00
         1         4         1        64    160.00
(162 records have been omitted assigning heads in all layers on the west and east boundaries
to 160 and 140 feet, respectively.)
         5        14        22        64    140.00
         5        15        22        64    140.00
         5        16        22        64    140.00
         5        17        22        64    140.00
         1         1         2        64    158.85
         1         1         3        64    157.31
```

```
         1         1         4        64    155.77
         1         1         5        64    154.62
(192 records have been omitted assigning specified heads across the northern and southern
boundaries in all layers by linear interpolation between 160 and 140 feet.)
         5        17        18        64    144.62
         5        17        19        64    143.85
         5        17        20        64    142.69
         5        17        21        64    141.15
```

Listing of Input Data for the Lake Package

Input for the Lake Package (LAK) follows the column headings below. The input consists of 65 records (lines). Input for the package is read from FORTRAN unit number 16, as specified in the namefile.

```
                                         Column Numbers
         1         2         3         4         5         6         7         8
12345678901234567890123456789012345678901234567890123456789012345678901234567890
```

```
         4         0                                  ; LAK input - NLAKES,ILKCB
      0.00                                            ; THETA
     115.0                                            ; initial stage, sublake 1
     115.0                                            ; initial stage, sublake 2
     115.0                                            ; initial stage, sublake 3
     115.0                                            ; initial stage, sublake 4
         1         0         0                        ; input/output options for stress period 1
        16         1(22I3)                       3    ; lake position array, layer 1
  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
  0  0  0  0  2  2  2  0  1  1  1  1  1  0  0  0  0  0  0  0  0  0
  0  0  0  0  2  2  2  0  1  1  1  1  1  0  3  3  0  4  4  0  0  0
  0  0  0  0  2  2  2  1  1  1  1  1  1  1  3  3  3  4  4  0  0  0
  0  0  0  0  2  2  2  0  1  1  1  1  1  0  3  3  0  4  4  0  0  0
  0  0  0  0  2  2  2  0  1  1  1  1  1  0  0  0  0  0  0  0  0  0
  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
        16         1(24I3)                       3     ; lake position array, layer 2
  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
  0  0  0  0  0  2  0  0  0  1  1  1  0  0  3  3  0  4  4  0  0  0
  0  0  0  0  0  2  2  0  1  1  1  1  1  0  3  3  0  4  4  0  0  0
  0  0  0  0  0  2  0  0  0  1  1  1  0  0  0  0  0  0  0  0  0  0
  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
```

```
   0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
   0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
   0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
   0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
         0         0                                       ; lake position array, layer 3
         0         0                                       ; lake position array, layer 4
         0         0                                       ; lake position array, layer 5
         0      0.10                                       ; lakebed leakance array, layer 1
         0      0.10                                       ; lakebed leakance array, layer 2
         0      0.10                                       ; lakebed leakance array, layer 3
         0      0.10                                       ; lakebed leakance array, layer 4
         0      0.10                                       ; lakebed leakance array, layer 5
         2                                                 ; number of coalescing lake systems
    3    1    2    3                                       ; sublakes 1, 2  and 3 in lake system 1
      112.      110.                                       ; sill elevations for sublakes 2 and 3
    2    3    4                                            ; sublakes 3, 4 in lake system 2
      108.                                                 ; sill elevation for sublake 4
    0.0000    0.0412       0.0       0.0             ; recharge,ET,runoff,withdrawal rates, sublake 1
    0.0000    0.0412       0.0       0.0             ; recharge,ET,runoff,withdrawal rates, sublake 2
    0.0000    0.0412       0.0       0.0             ; recharge,ET,runoff,withdrawal rates, sublake 3
    0.0000    0.0412       0.0       0.0             ; recharge,ET,runoff,withdrawal rates, sublake 4
        -1         0         0                          ; input/output options for stress period 2
    0.0116    0.0103       0.0       0.0             ; recharge,ET,runoff,withdrawal rates, sublake 1
    0.0116    0.0103       0.0       0.0             ; recharge,ET,runoff,withdrawal rates, sublake 2
    0.0116    0.0103       0.0       0.0             ; recharge,ET,runoff,withdrawal rates, sublake 3
    0.0116    0.0103       0.0       0.0             ; recharge,ET,runoff,withdrawal rates, sublake 4
```

Listing of Input Data for the Output-Control Package

Input for the Output-Control Package (OC) follows the column headings below. The input consists of 241 records (lines). Input for the package is read from FORTRAN unit number 17, as specified in the namefile.

```
                                       Column Numbers
         1         2         3         4         5         6         7         8
12345678901234567890123456789012345678901234567890123456789012345678901234567890

       -14         9        18        19            ; formatting and file unit options
         0         0         0         1    1       ; output options, time step 1
         0         0         0         0            ; head-drawdown print/file options, time step 1
         0         0         0         1    2       ; time step 2
         0         0         0         0
         0         0         0         1    3       ; time step 3
         0         0         0         0
         0         0         0         1    4       ; time step 4
         0         0         0         0
         0         0         0         1    5       ; time step 5
         0         0         0         0
         0         0         0         1    6       ; time step 6
         0         0         0         0
         0         0         0         1    7       ; time step 7
         0         0         0         0
         0         0         0         1    8       ; time step 8
         0         0         0         0
         0         0         0         1    9       ; time step 9
         0         0         0         0
         1         1         1         1   10       ; time step 10
         0         0         0         0
         0         0         0         0
```

```
        0         0         0         0
        0         0         0         0
        1         0         0         0
(The previous 24 lines are repeated 9 more times.)
```

Selected Pages from Printed Results for Test Simulation 3

(Sublake definition output from LAK3RP)

```
 NUMBER OF CONNECTED LAKE SYSTEMS IN SIMULATION IS   2

          SYSTEM  1

  NUMBER OF LAKES IN SYSTEM    3  CENTER LAKE NUMBER    1

 SUBLAKE NUMBER   SILL ELEVATION

        2            112.00
        3            110.00

          SYSTEM  2

  NUMBER OF LAKES IN SYSTEM    2  CENTER LAKE NUMBER    3

 SUBLAKE NUMBER   SILL ELEVATION

        4            108.00

 READ DATA FOR    2 LAKE SYSTEMS


 LAKE        PRECIP      EVAP   RUNOFF     WITHDRAW    BOTTOM    AREA
--------------------------------------------------------------------------------
   1         .0000     .0412       .00         .00     97.00  6750000.
   2         .0000     .0412       .00         .00     97.00  3750000.
   3         .0000     .0412       .00         .00     97.00  1750000.
   4         .0000     .0412       .00         .00     97.00  1500000.
```

(Output for time step 15, stress period 1 - all 4 sublakes are connected)

```
     6 ITERATIONS FOR TIME STEP  15 IN STRESS PERIOD  1

 MAXIMUM HEAD CHANGE FOR EACH ITERATION:

    HEAD CHANGE   HEAD CHANGE   HEAD CHANGE   HEAD CHANGE   HEAD CHANGE
  LAYER,ROW,COL LAYER,ROW,COL LAYER,ROW,COL LAYER,ROW,COL LAYER,ROW,COL
 ----------------------------------------------------------------------
      1.155         .2868          .3765E-01     .1988E-02     .1752E-03
  (  1,  3,  2) (  5, 10,  2) (  5,  9,  2) (  4, 11,  2) (  4, 11,  3)
     -.2413E-04
  (  1, 10,  8)

 ------------------------------------------------------------------------------
 TIME STEP  15     NUMBER OF CONNECTED LAKES IS  4     TOTAL AREA =   .137500000D+08
```

```
          SURFACE       SILL   WATER BUDGET  STAGE  CORRECTED   LAKE VOLUME
 LAKE       AREA      ELEVATION   STAGE   CORRECTION  STAGE     CORRECTION
  1      .67500E+07 -99999.00    112.39       .01    112.40     86448.
  2      .37500E+07    112.00    112.41      -.01    112.40    -27962.
  3      .17500E+07    110.00    112.39       .01    112.40     21318.
  4      .15000E+07    108.00    112.46      -.05    112.40    -79804.
--------------------------------------------------------------------------------

    0  LAKE CELLS ARE DRY.

PERIOD     1     TIME STEP    15     TIME STEP LENGTH  5.3639E+00
PERIOD TIME  6.5955E+01     TOTAL SIMULATION TIME  6.5955E+01
```

(Output for time step 15, stress period 1 - Water budget for lakes)

```
    HYDROLOGIC BUDGET SUMMARIES FOR SIMULATED LAKES
    -----------------------------------------------
LAKE  STAGE     PRECIP       EVAP       RUNOFF
  1  112.40  .00000      .14917E+07  .00000
  2  112.40  .00000      .82873E+06  .00000
  3  112.40  .00000      .38674E+06  .00000
  4  112.40  .00000      .33149E+06  .00000

           GROUND WATER           SURFACE WATER
LAKE    INFLOW     OUTFLOW      INFLOW     OUTFLOW
  1  .10318E+06  23630.      .00000      .00000
  2  .12709E+06  7073.2      .00000      .00000
  3  27798.      6138.4      .00000      .00000
  4  .11765E+06  1017.5      .00000      .00000

        WATER    CONNECTED LAKE   UPDATED     TIME-STEP         STAGE CHANGE
LAKE     USE         INFLUX       VOLUME    SURFACE AREA   TIME STEP  CUMULATIVE
  1    .00000       86448.      .63963E+08   .67500E+07  -.19643      -2.5980
  2    .00000      -27962.      .30257E+08   .37500E+07  -.19643      -2.5980
  3    .00000       21318.      .19453E+08   .17500E+07  -.19643      -2.5980
  4    .00000      -79804.      .18103E+08   .15000E+07  -.19643      -2.5980
--------------------------------------------------------------------------------

  1 CONNECTED LAKE SETS

  4 LAKES:    1  2  3  4
```

(Output for time step 20, stress period 1 - sublakes 1, 3, and 4 are connected)

```
    6 ITERATIONS FOR TIME STEP  20 IN STRESS PERIOD  1

MAXIMUM HEAD CHANGE FOR EACH ITERATION:

   HEAD CHANGE   HEAD CHANGE   HEAD CHANGE   HEAD CHANGE   HEAD CHANGE
 LAYER,ROW,COL LAYER,ROW,COL LAYER,ROW,COL LAYER,ROW,COL LAYER,ROW,COL
----------------------------------------------------------------------
     1.009         .2279         .3725E-01     .1931E-02     .2388E-03
 (  1,  3,  3) (  5, 10,  2) (  5,  9,  3) (  4, 11,  2) (  4, 11,  3)
     .2314E-04
 (  1, 10, 14)

--------------------------------------------------------------------------------
TIME STEP  20     NUMBER OF CONNECTED LAKES IS  3     TOTAL AREA =   .100000000D+08
```

```
         SURFACE       SILL   WATER BUDGET  STAGE  CORRECTED   LAKE VOLUME
 LAKE      AREA      ELEVATION   STAGE   CORRECTION  STAGE     CORRECTION
  1      .67500E+07 -99999.00    111.34       .02    111.36     .12179E+06
  3      .17500E+07    110.00    111.35       .01    111.36     23564.
  4      .15000E+07    108.00    111.46      -.10    111.36    -.14535E+06
--------------------------------------------------------------------------------

    0  LAKE CELLS ARE DRY.

PERIOD     1     TIME STEP    20     TIME STEP LENGTH  6.2183E+00
PERIOD TIME  9.5288E+01     TOTAL SIMULATION TIME  9.5288E+01
```

(Output for time step 20, stress period 1 - Water budget for lakes)

```
    HYDROLOGIC BUDGET SUMMARIES FOR SIMULATED LAKES
    ------------------------------------------------
LAKE  STAGE     PRECIP       EVAP       RUNOFF
  1  111.36  .00000      .17293E+07  .00000
  2  111.41  .00000      .96072E+06  .00000
  3  111.36  .00000      .44834E+06  .00000
  4  111.36  .00000      .38429E+06  .00000

           GROUND WATER           SURFACE WATER
LAKE    INFLOW     OUTFLOW      INFLOW     OUTFLOW
  1  .16096E+06  16361.       .00000      .00000
  2  .22600E+06  5882.1       .00000      .00000
  3  47923.      2402.0       .00000      .00000
  4  .20490E+06  348.49       .00000      .00000

        WATER    CONNECTED LAKE   UPDATED     TIME-STEP         STAGE CHANGE
LAKE     USE         INFLUX        VOLUME    SURFACE AREA   TIME STEP  CUMULATIVE
  1    .00000       .12179E+06   .56930E+08   .67500E+07  -.21674      -3.6401
  2    .00000       .00000       .26544E+08   .37500E+07  -.19747      -3.5882
  3    .00000       23564.       .17630E+08   .17500E+07  -.21674      -3.6401
  4    .00000      -.14535E+06   .16540E+08   .15000E+07  -.21674      -3.6401
--------------------------------------------------------------------------------

  1 CONNECTED LAKE SETS

  3 LAKES:    1  3  4
```

(Output for time step 30, stress period 1 - only sublakes 3 and 4 are connected)

```
    6 ITERATIONS FOR TIME STEP  30 IN STRESS PERIOD  1

MAXIMUM HEAD CHANGE FOR EACH ITERATION:

   HEAD CHANGE   HEAD CHANGE   HEAD CHANGE   HEAD CHANGE   HEAD CHANGE
 LAYER,ROW,COL LAYER,ROW,COL LAYER,ROW,COL LAYER,ROW,COL LAYER,ROW,COL
----------------------------------------------------------------------
     .6385         .1952         .4259E-01     .1994E-02     .2830E-03
 (  1,  4,  3) (  5, 15,  5) (  5,  3,  6) (  4, 11,  3) (  3,  4,  7)
    -.1745E-04
 (  2,  3,  6)

--------------------------------------------------------------------------------
TIME STEP  30     NUMBER OF CONNECTED LAKES IS  2     TOTAL AREA =   .325000000D+07
```

```
          SURFACE       SILL   WATER BUDGET  STAGE  CORRECTED   LAKE VOLUME
 LAKE       AREA      ELEVATION   STAGE   CORRECTION  STAGE     CORRECTION
   3      .17500E+07 -99999.00    109.23       .11    109.34     .19335E+06
   4      .15000E+07    108.00    109.47      -.13    109.34    -.19335E+06
--------------------------------------------------------------------------------

    0  LAKE CELLS ARE DRY.

PERIOD     1     TIME STEP    30     TIME STEP LENGTH  8.3568E+00
PERIOD TIME  1.6871E+02     TOTAL SIMULATION TIME  1.6871E+02
```

(Output for time step 30, stress period 1 - Water budget for lakes)

```
    HYDROLOGIC BUDGET SUMMARIES FOR SIMULATED LAKES
    -----------------------------------------------
LAKE  STAGE     PRECIP       EVAP       RUNOFF
  1  108.83  .00000      .23240E+07  .00000
  2  109.44  .00000      .12911E+07  .00000
  3  109.34  .00000      .60253E+06  .00000
  4  109.34  .00000      .51645E+06  .00000

           GROUND WATER           SURFACE WATER
LAKE    INFLOW     OUTFLOW      INFLOW     OUTFLOW
  1  .37453E+06  .00000      .00000      .00000
  2  .58648E+06  8988.2      .00000      .00000
  3  .10058E+06  2634.7      .00000      .00000
  4  .44297E+06  .00000      .00000      .00000

        WATER    CONNECTED LAKE   UPDATED     TIME-STEP          STAGE CHANGE
LAKE     USE         INFLUX        VOLUME    SURFACE AREA   TIME STEP  CUMULATIVE
  1    .00000       .00000       .39855E+08   .67500E+07  -.28882      -6.1697
  2    .00000       .00000       .19165E+08   .37500E+07  -.19028      -5.5560
  3    .00000       .19335E+06   .14102E+08   .17500E+07  -.17788      -5.6560
  4    .00000      -.19335E+06   .13516E+08   .15000E+07  -.17788      -5.6560
--------------------------------------------------------------------------------

  1 CONNECTED LAKE SETS

  2 LAKES:    3  4
```

(Output for time step 40, stress period 1 - sublakes 3 and 4 are partly connected , lake 4 stage has to be readjusted to the sill elevation between lakes 3 and 4.)

```
    7 ITERATIONS FOR TIME STEP  40 IN STRESS PERIOD  1

MAXIMUM HEAD CHANGE FOR EACH ITERATION:

   HEAD CHANGE   HEAD CHANGE   HEAD CHANGE   HEAD CHANGE   HEAD CHANGE
 LAYER,ROW,COL LAYER,ROW,COL LAYER,ROW,COL LAYER,ROW,COL LAYER,ROW,COL
----------------------------------------------------------------------
    -.4934         .1979        -.8212E-01     .3879E-02    -.4572E-02
 (  3,  9, 11) (  5,  4,  5) (  2, 11,  9) (  4,  4,  8) (  2, 11,  9)
     .1989E-03     .2758E-04
 (  5, 11, 14) (  5, 11, 15)

--------------------------------------------------------------------------------
TIME STEP  40     NUMBER OF CONNECTED LAKES IS  2     TOTAL AREA =   .325000000D+07

READJUST STAGE OF LAKE   4 TO LAKE   4 SILL ELEVATION BY  -.02 TO  108.00
```

```
         SURFACE       SILL   WATER BUDGET  STAGE  CORRECTED   LAKE VOLUME
 LAKE      AREA      ELEVATION   STAGE   CORRECTION  STAGE     CORRECTION
  3      .17500E+07 -99999.00    107.07       .02    107.08     32684.
  4      .15000E+07    108.00    108.02      -.02    108.00    -32684.
 --------------------------------------------------------------------------------

     SECTIONS OF THE LAKE BOTTOM HAVE BECOME DRY.  THE DRY SECTIONS
     LIE ABOVE THE FOLLOWING 16 AQUIFER CELLS (LAYER,ROW,COLUMN):
     (  2,  9,  8)  (  2,  7,  9)  (  2,  8,  9)  (  2, 10,  9)  (  2, 11,  9)
     (  2,  7, 10)  (  2, 11, 10)  (  2,  7, 11)  (  2, 11, 11)  (  2,  7, 12)
     (  2, 11, 12)  (  2,  7, 13)  (  2,  8, 13)  (  2, 10, 13)  (  2, 11, 13)
     (  2,  9, 14)  (

 PERIOD     1     TIME STEP    40     TIME STEP LENGTH  1.1231E+01
 PERIOD TIME  2.6739E+02     TOTAL SIMULATION TIME  2.6739E+02
```

(Output for time step 40, stress period 1 - Water budget for lakes)

```
     HYDROLOGIC BUDGET SUMMARIES FOR SIMULATED LAKES
     -----------------------------------------------
 LAKE  STAGE     PRECIP       EVAP       RUNOFF
   1  104.90  .00000      .12725E+07  .00000
   2  107.73  .00000      .17352E+07  .00000
   3  107.08  .00000      .80975E+06  .00000
   4  108.00  .00000      .69407E+06  .00000

           GROUND WATER           SURFACE WATER
 LAKE    INFLOW     OUTFLOW      INFLOW     OUTFLOW
   1  .00000      .25022E+06  .00000      .00000
   2  .12194E+07  72561.      .00000      .00000
   3  .18414E+06  33960.      .00000      .00000
   4  .72816E+06  1395.0      .00000      .00000

        WATER    CONNECTED LAKE   UPDATED     TIME-STEP          STAGE CHANGE
 LAKE     USE         INFLUX        VOLUME    SURFACE AREA   TIME STEP  CUMULATIVE
   1    .00000       .00000      .21715E+08   .27500E+07  -.55373      -10.103
   2    .00000       .00000      .12737E+08   .37500E+07  -.15687      -7.2700
   3    .00000       32684.      .10148E+08   .17500E+07  -.35822      -7.9153
   4    .00000      -32684.      .11500E+08   .15000E+07   .00000      -7.0000
 --------------------------------------------------------------------------------

   1 CONNECTED LAKE SETS

   2 LAKES:    3  4
```

(Output for time step 50, stress period 1 - no sublakes are connected)

```
    10 ITERATIONS FOR TIME STEP  50 IN STRESS PERIOD  1

 MAXIMUM HEAD CHANGE FOR EACH ITERATION:

    HEAD CHANGE   HEAD CHANGE   HEAD CHANGE   HEAD CHANGE   HEAD CHANGE
  LAYER,ROW,COL LAYER,ROW,COL LAYER,ROW,COL LAYER,ROW,COL LAYER,ROW,COL
 ----------------------------------------------------------------------
     -.5516         .1684         .8048E-01     .6869E-02     .2036E-01
  (  3,  9,  6) (  5, 10,  4) (  2, 11,  5) (  4,  5,  8) (  2,  7,  5)
      .5936E-02    -.1302E-02    -.1050E-03    -.2227E-03     .8573E-05
  (  2, 11,  5) (  4,  7,  5) (  4, 12,  7) (  2,  8,  5) (  5,  8,  7)
```

```
    SECTIONS OF THE LAKE BOTTOM HAVE BECOME DRY.  THE DRY SECTIONS
    LIE ABOVE THE FOLLOWING 30 AQUIFER CELLS (LAYER,ROW,COLUMN):
    (  2,  7,  5)  (  2,  8,  5)  (  2,  9,  5)  (  2, 10,  5)  (  2, 11,  5)
    (  2,  7,  6)  (  2, 11,  6)  (  2,  7,  7)  (  2,  8,  7)  (  2, 10,  7)
    (  2, 11,  7)  (  2,  9,  8)  (  2,  7,  9)  (  2,  8,  9)  (  2, 10,  9)
    (  2, 11,  9)  (  2,  7, 10)  (  2, 11, 10)  (  2,  7, 11)  (  2, 11, 11)
    (  2,  7, 12)  (  2, 11, 12)  (  2,  7, 13)  (  2,  8, 13)  (  2, 10, 13)
    (  2, 11, 13)  (  2,  9, 14)  (  2, 10, 15)  (  2, 10, 16)  (  2,  9, 17)

PERIOD     1     TIME STEP    50     TIME STEP LENGTH  1.5093E+01
PERIOD TIME  4.0000E+02     TOTAL SIMULATION TIME  4.0000E+02
```

(Output for time step 50, stress period 1 - Water budget for lakes)

```
    HYDROLOGIC BUDGET SUMMARIES FOR SIMULATED LAKES
    -----------------------------------------------
LAKE  STAGE     PRECIP       EVAP       RUNOFF
  1   99.17  .00000      .17101E+07  .00000
  2  104.46  .00000      .62185E+06  .00000
  3  102.61  .00000      .62185E+06  .00000
  4  107.88  .00000      .93277E+06  .00000

           GROUND WATER           SURFACE WATER
LAKE    INFLOW     OUTFLOW      INFLOW     OUTFLOW
  1  .12830E+06  385.60      .00000      .00000
  2  .17282E+06  .13012E+06  .00000      .00000
  3  .23574E+06  43814.      .00000      .00000
  4  .95637E+06  57487.      .00000      .00000

        WATER    CONNECTED LAKE   UPDATED     TIME-STEP         STAGE CHANGE
LAKE     USE         INFLUX        VOLUME    SURFACE AREA   TIME STEP  CUMULATIVE
  1    .00000       .00000       .59777E+07   .27500E+07  -.57531      -15.826
  2    .00000       .00000       .74552E+07   .10000E+07  -.57912      -10.545
  3    .00000       .00000       .56118E+07   .10000E+07  -.42994      -12.388
  4    .00000       .00000       .11317E+08   .15000E+07  -.22591E-01  -7.1223
--------------------------------------------------------------------------------
```

(Output for time step 50, stress period 1 - Table of aquifer heads in layer 5)

```
             HEAD IN LAYER  5 AT END OF TIME STEP 50 IN STRESS PERIOD  1
 ----------------------------------------------------------------------
        1      2      3      4      5      6      7      8      9     10
........................................................................
  1   160.0  158.9  157.3  155.8  154.6  153.9  153.1  152.3  151.5  150.8
  2   160.0  154.2  150.3  147.7  146.2  145.2  144.2  143.4  142.5  141.7
  3   160.0  151.9  145.9  142.0  139.7  138.2  136.9  135.7  134.8  133.9
  4   160.0  151.0  143.5  137.3  133.6  131.4  129.6  128.2  127.1  126.3
  5   160.0  150.4  141.5  132.9  127.7  124.8  122.6  121.0  119.8  119.0
  6   160.0  149.9  139.5  128.5  121.2  117.3  114.7  113.1  111.6  110.8
  7   160.0  149.7  138.4  125.6  111.5  106.7  104.6  105.3  102.0  101.0
  8   160.0  149.6  138.0  124.3  108.9  105.1  102.7  102.6   99.7   99.8
  9   160.0  149.6  137.8  123.8  108.2  105.1  104.8  101.0   99.8   99.8
 10   160.0  149.6  138.0  124.3  108.9  105.1  102.7  102.6   99.7   99.8
 11   160.0  149.7  138.4  125.6  111.5  106.7  104.6  105.3  102.0  101.0
 12   160.0  149.9  139.5  128.5  121.2  117.3  114.7  113.1  111.6  110.8
 13   160.0  150.4  141.5  132.9  127.7  124.8  122.6  121.0  119.8  119.0
 14   160.0  151.0  143.5  137.3  133.6  131.4  129.6  128.2  127.1  126.3
 15   160.0  151.9  145.9  142.0  139.7  138.2  136.9  135.7  134.8  133.9
 16   160.0  154.2  150.3  147.7  146.2  145.2  144.2  143.4  142.5  141.7
 17   160.0  158.9  157.3  155.8  154.6  153.9  153.1  152.3  151.5  150.8
```

```
           HEAD IN LAYER  5 AT END OF TIME STEP 50 IN STRESS PERIOD  1
 ----------------------------------------------------------------------

       11     12     13     14     15     16     17     18     19     20
 ........................................................................
   1   150.0  149.2  148.5  147.7  146.9  146.1  145.4  144.6  143.9  142.7
   2   140.9  140.2  139.4  138.7  138.1  137.4  136.7  136.1  135.6  135.0
   3   133.2  132.6  132.1  131.7  131.4  131.1  130.8  130.6  130.5  130.7
   4   125.6  125.2  125.0  124.9  125.0  125.2  125.7  126.3  127.1  128.7
   5   118.5  118.3  118.4  118.7  119.2  119.9  120.9  122.2  123.9  126.9
   6   110.4  110.5  111.1  112.2  113.3  114.4  115.9  117.7  120.0  124.5
   7   100.8  101.0  102.1  105.9  107.6  108.8  110.7  112.5  114.9  122.1
   8    99.8   99.8   99.7  102.7  103.2  103.3  106.4  108.0  108.4  120.4
   9    99.8   99.8   99.8  100.5  102.9  103.1  103.9  107.8  108.2  119.9
  10    99.8   99.8   99.6  102.3  102.2  103.3  106.4  108.1  108.6  120.4
  11   100.8  101.0  102.0  105.6  107.2  108.6  110.6  112.5  114.9  122.1
  12   110.4  110.5  111.0  112.1  113.2  114.3  115.8  117.7  120.0  124.5
  13   118.5  118.3  118.3  118.7  119.2  119.9  120.9  122.2  123.9  126.9
  14   125.6  125.2  125.0  124.9  125.0  125.2  125.7  126.3  127.1  128.7
  15   133.2  132.6  132.1  131.7  131.4  131.1  130.8  130.6  130.5  130.7
  16   140.9  140.2  139.4  138.7  138.1  137.4  136.7  136.1  135.6  135.0
  17   150.0  149.2  148.5  147.7  146.9  146.1  145.4  144.6  143.9  142.7

           HEAD IN LAYER  5 AT END OF TIME STEP 50 IN STRESS PERIOD  1
 ----------------------------------------------------------------------

       21     22
 .................
   1   141.1  140.0
   2   135.7  140.0
   3   133.2  140.0
   4   132.4  140.0
   5   131.9  140.0
   6   131.3  140.0
   7   130.9  140.0
   8   130.6  140.0
   9   130.6  140.0
  10   130.6  140.0
  11   130.9  140.0
  12   131.3  140.0
  13   131.9  140.0
  14   132.4  140.0
  15   133.2  140.0
  16   135.7  140.0
  17   141.1  140.0
```

(Output for time step 50, stress period 1 - Water budget for aquifer showing lake seepage)

```
 VOLUMETRIC BUDGET FOR ENTIRE MODEL AT END OF TIME STEP 50 IN STRESS PERIOD  1
 ----------------------------------------------------------------------------

    CUMULATIVE VOLUMES      L**3       RATES FOR THIS TIME STEP      L**3/T
    ------------------                 ------------------------

          IN:                                   IN:
          ---                                   ---
            STORAGE =    19953360.0000            STORAGE =       43148.3100
      CONSTANT HEAD =   785145400.0000      CONSTANT HEAD =     1477687.0000
                 ET =            .0000                 ET =            .0000
           RECHARGE =            .0000           RECHARGE =            .0000
```

```
    SPECIFIED FLOWS =           .0000      SPECIFIED FLOWS =          .0000
      LAKE  SEEPAGE =    5259858.0000        LAKE  SEEPAGE =     15358.1200

           TOTAL IN =  810358600.0000             TOTAL IN =   1536193.0000

          OUT:                                 OUT:
          ----                                 ----
            STORAGE =  478363700.0000              STORAGE =    272927.2000
      CONSTANT HEAD =           .0000        CONSTANT HEAD =          .0000
                 ET =  276949500.0000                   ET =   1164335.0000
           RECHARGE =           .0000             RECHARGE =          .0000
    SPECIFIED FLOWS =           .0000      SPECIFIED FLOWS =          .0000
      LAKE  SEEPAGE =   55048350.0000        LAKE  SEEPAGE =     98932.7300

          TOTAL OUT =  810361600.0000            TOTAL OUT =   1536195.0000

           IN - OUT =      -3008.0000             IN - OUT =        -2.1250

PERCENT DISCREPANCY =           .00     PERCENT DISCREPANCY =          .00
```

(Output for time step 50, stress period 1 - Time summary)

```
          TIME SUMMARY AT END OF TIME STEP 50 IN STRESS PERIOD  1
                    SECONDS     MINUTES      HOURS       DAYS        YEARS
                    -----------------------------------------------------------
  TIME STEP LENGTH 1.30407E+06  21734.      362.24      15.093     4.13234E-02
STRESS PERIOD TIME 3.45599E+07 5.75999E+05  9600.0      400.00      1.0951
        TOTAL TIME 3.45599E+07 5.75999E+05  9600.0      400.00      1.0951
```

(Output for time step 25, stress period 2 - sublakes 1, 3, and 4 are partly connected, stages of sublakes 3 and 4 have to be readjusted to the sill elevation between center lake 1 and sub-lake 3)

```
   10 ITERATIONS FOR TIME STEP  25 IN STRESS PERIOD  2

 MAXIMUM HEAD CHANGE FOR EACH ITERATION:

   HEAD CHANGE   HEAD CHANGE   HEAD CHANGE   HEAD CHANGE   HEAD CHANGE
 LAYER,ROW,COL LAYER,ROW,COL LAYER,ROW,COL LAYER,ROW,COL LAYER,ROW,COL
----------------------------------------------------------------------
      .5420         .2772         .2791         .2264E-01     .5256E-01
 (  3,  9, 11) (  5,  7, 11) (  2, 11, 10) (  2,  7, 13) (  2, 11, 12)
    -.8954E-02    -.1920E-02    -.3010E-03    -.2183E-03     .3262E-04
 (  3, 11, 14) (  2, 11, 13) (  2,  7, 12) (  2,  7, 10) (  4,  7, 13)

 HEAD/DRAWDOWN PRINTOUT FLAG = 0     TOTAL BUDGET PRINTOUT FLAG = 0
 CELL-BY-CELL FLOW TERM FLAG = 1

 OUTPUT FLAGS FOR ALL LAYERS ARE THE SAME:
   HEAD    DRAWDOWN  HEAD  DRAWDOWN
 PRINTOUT  PRINTOUT  SAVE    SAVE
 ----------------------------------
     0         0       0       0

 --------------------------------------------------------------------------------
 TIME STEP  25     NUMBER OF CONNECTED LAKES IS  3     TOTAL AREA =   .600000000D+07

 READJUST STAGE OF LAKE   3 TO LAKE   3 SILL ELEVATION BY  -.15 TO  110.00
 READJUST STAGE OF LAKE   4 TO LAKE   3 SILL ELEVATION BY  -.53 TO  110.00
```

```
          SURFACE       SILL   WATER BUDGET  STAGE  CORRECTED   LAKE VOLUME
 LAKE       AREA      ELEVATION   STAGE   CORRECTION  STAGE     CORRECTION
   1      .27500E+07 -99999.00    102.96       .39    103.35     .10618E+07
   3      .17500E+07    110.00    110.15      -.15    110.00    -.26405E+06
   4      .15000E+07    108.00    110.53      -.53    110.00    -.79770E+06
--------------------------------------------------------------------------------

    SECTIONS OF THE LAKE BOTTOM HAVE BECOME DRY.  THE DRY SECTIONS
    LIE ABOVE THE FOLLOWING 16 AQUIFER CELLS (LAYER,ROW,COLUMN):
    (  2,  9,  8)  (  2,  7,  9)  (  2,  8,  9)  (  2, 10,  9)  (  2, 11,  9)
    (  2,  7, 10)  (  2, 11, 10)  (  2,  7, 11)  (  2, 11, 11)  (  2,  7, 12)
    (  2, 11, 12)  (  2,  7, 13)  (  2,  8, 13)  (  2, 10, 13)  (  2, 11, 13)
    (  2,  9, 14)  (

PERIOD     2     TIME STEP    25     TIME STEP LENGTH  7.2087E+00
PERIOD TIME  1.2929E+02     TOTAL SIMULATION TIME  5.2929E+02
```

(Output for time step 25, stress period 2 - Water budget for lakes)

```
    HYDROLOGIC BUDGET SUMMARIES FOR SIMULATED LAKES
    -----------------------------------------------
LAKE  STAGE     PRECIP       EVAP       RUNOFF
  1  103.35  .22996E+06  .20419E+06  .00000
  2  111.57  .31358E+06  .27844E+06  .00000
  3  110.00  .14634E+06  .12994E+06  .00000
  4  110.00  .12543E+06  .11137E+06  .00000

           GROUND WATER           SURFACE WATER
LAKE    INFLOW     OUTFLOW      INFLOW     OUTFLOW
  1  .63164E+06  .00000      .00000      .00000
  2  .15617E+07  45042.      .00000      .00000
  3  .26358E+06  15925.      .00000      .00000
  4  .78366E+06  .00000      .00000      .00000

        WATER    CONNECTED LAKE   UPDATED     TIME-STEP         STAGE CHANGE
LAKE     USE         INFLUX        VOLUME    SURFACE AREA   TIME STEP  CUMULATIVE
  1    .00000      .10618E+07   .17451E+08   .27500E+07   .62516      -11.654
  2    .00000      .00000       .27151E+08   .37500E+07   .41383      -3.4264
  3    .00000     -.26405E+06   .15250E+08   .17500E+07   .00000      -5.0000
  4    .00000     -.79770E+06   .14500E+08   .15000E+07   .00000      -5.0000
--------------------------------------------------------------------------------

  1 CONNECTED LAKE SETS

  3 LAKES:    1  3  4
```

(Output for time step 30, stress period 2 - sublakes 1, 2, 3, and 4 are partly connected, stages of sublakes 3 and 4 have to be readjusted to the sill elevation between center lake 1 and sublake 3, and the stage of sublake 2 has to be readjusted to the sill elevation between center lake 1 and sublake 2)

```
    6 ITERATIONS FOR TIME STEP  30 IN STRESS PERIOD  2
```

```
MAXIMUM HEAD CHANGE FOR EACH ITERATION:

   HEAD CHANGE   HEAD CHANGE   HEAD CHANGE   HEAD CHANGE   HEAD CHANGE
 LAYER,ROW,COL LAYER,ROW,COL LAYER,ROW,COL LAYER,ROW,COL LAYER,ROW,COL
----------------------------------------------------------------------
    -5.184        -.3926        -.7625E-01     .3845E-02     .7010E-03
 (  2,  7,  9) (  5, 11,  8) (  5, 11,  9) (  4,  6,  8) (  3,  7,  9)
    -.6898E-04
 (  3,  7, 16)
TIME STEP  30     NUMBER OF CONNECTED LAKES IS  4     TOTAL AREA =   .137500000D+08

READJUST STAGE OF LAKE   2 TO LAKE   2 SILL ELEVATION BY  -.52 TO  112.00
READJUST STAGE OF LAKE   3 TO LAKE   3 SILL ELEVATION BY  -.24 TO  110.00
READJUST STAGE OF LAKE   4 TO LAKE   3 SILL ELEVATION BY  -.68 TO  110.00

          SURFACE       SILL   WATER BUDGET  STAGE  CORRECTED   LAKE VOLUME
 LAKE       AREA      ELEVATION   STAGE   CORRECTION  STAGE     CORRECTION
  1      .67500E+07 -99999.00    108.33       .50    108.83     .33819E+07
  2      .37500E+07    112.00    112.52      -.52    112.00    -.19323E+07
  3      .17500E+07    110.00    110.24      -.24    110.00    -.42673E+06
  4      .15000E+07    108.00    110.68      -.68    110.00    -.10228E+07
--------------------------------------------------------------------------------

    0  LAKE CELLS ARE DRY.

PERIOD     2     TIME STEP    30     TIME STEP LENGTH  8.3568E+00
PERIOD TIME  1.6871E+02     TOTAL SIMULATION TIME  5.6871E+02
```

(Output for time step 30, stress period 2 - Water budget for lakes)

```
    HYDROLOGIC BUDGET SUMMARIES FOR SIMULATED LAKES
    -----------------------------------------------
LAKE  STAGE     PRECIP       EVAP       RUNOFF
  1  108.83  .65434E+06  .58101E+06  .00000
  2  112.00  .36352E+06  .32278E+06  .00000
  3  110.00  .16964E+06  .15063E+06  .00000
  4  110.00  .14541E+06  .12911E+06  .00000

           GROUND WATER            SURFACE WATER
LAKE    INFLOW     OUTFLOW      INFLOW     OUTFLOW
  1  .17654E+07  88.820      .00000      .00000
  2  .19307E+07  39088.      .00000      .00000
  3  .41820E+06  10482.      .00000      .00000
  4  .10065E+07  .00000      .00000      .00000

        WATER    CONNECTED LAKE   UPDATED     TIME-STEP         STAGE CHANGE
LAKE     USE         INFLUX        VOLUME    SURFACE AREA   TIME STEP  CUMULATIVE
  1    .00000       .33819E+07   .39856E+08   .67500E+07   .77341      -6.1695
  2    .00000      -.19323E+07   .28750E+08   .37500E+07   .00000      -3.0000
  3    .00000      -.42673E+06   .15250E+08   .17500E+07   .00000      -5.0000
  4    .00000      -.10228E+07   .14500E+08   .15000E+07   .00000      -5.0000
--------------------------------------------------------------------------------

  1 CONNECTED LAKE SETS

  4 LAKES:    1  2  3  4
```

(Output for time step 40, stress period 2 - all sublakes are connected once again)

```
    6 ITERATIONS FOR TIME STEP  40 IN STRESS PERIOD  2

 MAXIMUM HEAD CHANGE FOR EACH ITERATION:

   HEAD CHANGE   HEAD CHANGE   HEAD CHANGE   HEAD CHANGE   HEAD CHANGE
 LAYER,ROW,COL LAYER,ROW,COL LAYER,ROW,COL LAYER,ROW,COL LAYER,ROW,COL
 ----------------------------------------------------------------------
     .4256         .1648         .5494E-01     .3326E-02    -.3975E-03
 (  3,  9, 19) (  5,  7, 14) (  5, 11, 15) (  4, 12, 17) (  4, 10, 15)
     .8518E-04
 (  2,  7, 18)
   5       1         0       0       0

 TIME STEP  40     NUMBER OF CONNECTED LAKES IS  4     TOTAL AREA =   .137500000D+08

          SURFACE       SILL   WATER BUDGET  STAGE  CORRECTED   LAKE VOLUME
 LAKE       AREA      ELEVATION   STAGE   CORRECTION  STAGE     CORRECTION
  1      .67500E+07 -99999.00    114.03       .21    114.24     .14093E+07
  2      .37500E+07    112.00    114.54      -.29    114.24    -.11010E+07
  3      .17500E+07    110.00    114.10       .15    114.24     .25621E+06
  4      .15000E+07    108.00    114.62      -.38    114.24    -.56449E+06
 --------------------------------------------------------------------------------

    0  LAKE CELLS ARE DRY.

 PERIOD     2     TIME STEP    40     TIME STEP LENGTH  1.1231E+01
 PERIOD TIME  2.6739E+02     TOTAL SIMULATION TIME  6.6739E+02
```

(Output for time step 40, stress period 2 - Water budget for lakes)

```
    HYDROLOGIC BUDGET SUMMARIES FOR SIMULATED LAKES
    -----------------------------------------------
 LAKE  STAGE     PRECIP       EVAP       RUNOFF
   1  114.24  .87938E+06  .78083E+06  .00000
   2  114.24  .48854E+06  .43379E+06  .00000
   3  114.24  .22799E+06  .20244E+06  .00000
   4  114.24  .19542E+06  .17352E+06  .00000

           GROUND WATER           SURFACE WATER
 LAKE    INFLOW     OUTFLOW      INFLOW     OUTFLOW
   1  .17149E+07  .00000      .00000      .00000
   2  .28363E+07  .00000      .00000      .00000
   3  .55373E+06  .00000      .00000      .00000
   4  .12587E+07  .00000      .00000      .00000

        WATER    CONNECTED LAKE   UPDATED     TIME-STEP          STAGE CHANGE
 LAKE     USE        INFLUX        VOLUME    SURFACE AREA   TIME STEP  CUMULATIVE
   1    .00000      .14093E+07   .76384E+08   .67500E+07   .47741      -.75799
   2    .00000     -.11010E+07   .37158E+08   .37500E+07   .47741      -.75799
   3    .00000      .25621E+06   .22674E+08   .17500E+07   .47741      -.75799
   4    .00000     -.56449E+06   .20863E+08   .15000E+07   .47741      -.75799
 --------------------------------------------------------------------------------

   1 CONNECTED LAKE SETS

   4 LAKES:    1  2  3  4
```

(Output for time step 40, stress period 2 - Table of aquifer heads in layer 5)

```
            HEAD IN LAYER  5 AT END OF TIME STEP 40 IN STRESS PERIOD  2
 ----------------------------------------------------------------------

        1      2      3      4      5      6      7      8      9     10
........................................................................
  1   160.0  158.9  157.3  155.8  154.6  153.9  153.1  152.3  151.5  150.8
  2   160.0  158.3  156.1  154.1  152.7  151.7  150.8  150.0  149.1  148.3
  3   160.0  157.7  154.6  151.8  149.9  148.7  147.6  146.6  145.7  144.8
  4   160.0  157.2  153.2  149.4  146.9  145.3  143.9  142.7  141.7  140.8
  5   160.0  156.6  151.5  146.2  142.3  140.2  138.5  137.1  135.9  135.1
  6   160.0  156.0  149.4  140.9  132.8  129.6  127.8  126.9  125.7  125.0
  7   160.0  155.6  147.8  134.9  115.0  114.3  114.3  116.7  114.3  114.1
  8   160.0  155.4  147.2  133.0  114.4  113.8  113.8  114.3  113.8  113.8
  9   160.0  155.4  146.9  132.5  114.4  113.8  113.8  113.8  113.8  113.8
 10   160.0  155.4  147.2  133.0  114.4  113.8  113.8  114.3  113.8  113.8
 11   160.0  155.6  147.8  134.9  115.0  114.3  114.3  116.7  114.3  114.1
 12   160.0  156.0  149.4  140.9  132.8  129.6  127.8  126.9  125.7  125.0
 13   160.0  156.6  151.5  146.2  142.3  140.2  138.5  137.1  135.9  135.1
 14   160.0  157.2  153.2  149.4  146.9  145.3  143.9  142.7  141.7  140.8
 15   160.0  157.7  154.6  151.8  149.9  148.7  147.6  146.6  145.7  144.8
 16   160.0  158.3  156.1  154.1  152.7  151.7  150.8  150.0  149.1  148.3
 17   160.0  158.9  157.3  155.8  154.6  153.9  153.1  152.3  151.5  150.8

            HEAD IN LAYER  5 AT END OF TIME STEP 40 IN STRESS PERIOD  2
 ----------------------------------------------------------------------

       11     12     13     14     15     16     17     18     19     20
........................................................................
  1   150.0  149.2  148.5  147.7  146.9  146.1  145.4  144.6  143.9  142.7
  2   147.6  146.8  146.1  145.4  144.7  144.0  143.3  142.7  142.1  141.3
  3   144.0  143.3  142.7  142.1  141.5  141.1  140.6  140.3  140.0  139.7
  4   140.1  139.4  138.9  138.6  138.3  138.0  137.9  137.9  137.9  138.2
  5   134.4  134.0  133.9  133.9  134.0  134.2  134.4  134.8  135.4  136.5
  6   124.7  124.6  125.0  126.1  127.0  127.9  128.8  129.8  131.1  133.9
  7   114.1  114.1  114.3  118.3  119.6  120.4  121.4  122.0  123.8  130.8
  8   113.8  113.8  113.8  114.8  114.0  114.1  115.7  114.1  114.4  128.5
  9   113.8  113.8  113.8  113.9  113.8  113.8  113.9  113.8  114.1  127.9
 10   113.8  113.8  113.8  114.8  114.1  114.1  115.7  114.2  114.7  128.5
 11   114.1  114.1  114.3  118.3  119.6  120.4  121.5  122.0  123.8  130.8
 12   124.7  124.6  125.0  126.1  127.0  127.9  128.8  129.8  131.1  133.9
 13   134.4  134.0  133.9  133.9  134.0  134.2  134.4  134.8  135.4  136.5
 14   140.1  139.4  138.9  138.6  138.3  138.0  137.9  137.9  137.9  138.2
 15   144.0  143.3  142.7  142.1  141.5  141.1  140.6  140.3  140.0  139.7
 16   147.6  146.8  146.1  145.4  144.7  144.0  143.3  142.7  142.1  141.3
 17   150.0  149.2  148.5  147.7  146.9  146.1  145.4  144.6  143.9  142.7

            HEAD IN LAYER  5 AT END OF TIME STEP 40 IN STRESS PERIOD  2
 ----------------------------------------------------------------------

       21     22
.................
  1   141.1  140.0
  2   140.3  140.0
  3   139.6  140.0
  4   139.0  140.0
  5   138.4  140.0
  6   137.6  140.0
  7   136.8  140.0
```

```
  8   136.4  140.0
  9   136.2  140.0
 10   136.4  140.0
 11   136.8  140.0
 12   137.6  140.0
 13   138.4  140.0
 14   139.0  140.0
 15   139.6  140.0
 16   140.3  140.0
 17   141.1  140.0
```

(Output for time step 40, stress period 2 - Water budget for aquifer showing lake seepage)

```
  VOLUMETRIC BUDGET FOR ENTIRE MODEL AT END OF TIME STEP 40 IN STRESS PERIOD  2
  ------------------------------------------------------------------------------

     CUMULATIVE VOLUMES      L**3       RATES FOR THIS TIME STEP      L**3/T
     ------------------                 ------------------------

           IN:                                       IN:
           ---                                       ---
             STORAGE =    20724880.0000             STORAGE =            .0000
       CONSTANT HEAD =   962339900.0000       CONSTANT HEAD =      410543.6000
                  ET =            .0000                  ET =            .0000
            RECHARGE =   451636400.0000            RECHARGE =     1653000.0000
     SPECIFIED FLOWS =            .0000     SPECIFIED FLOWS =            .0000
       LAKE  SEEPAGE =     6545937.0000       LAKE  SEEPAGE =            .0000

            TOTAL IN =  1441247000.0000            TOTAL IN =     2063544.0000

          OUT:                                      OUT:
          ----                                      ----
             STORAGE =   773427300.0000             STORAGE =      462025.8000
       CONSTANT HEAD =      202126.3000       CONSTANT HEAD =        2385.7580
                  ET =   493016800.0000                  ET =     1032517.0000
            RECHARGE =            .0000            RECHARGE =            .0000
     SPECIFIED FLOWS =            .0000     SPECIFIED FLOWS =            .0000
       LAKE  SEEPAGE =   174604600.0000       LAKE  SEEPAGE =      566621.4000

           TOTAL OUT =  1441251000.0000           TOTAL OUT =     2063550.0000

            IN - OUT =       -3840.0000            IN - OUT =          -6.5000

 PERCENT DISCREPANCY =              .00     PERCENT DISCREPANCY =              .00
```

(Output for time step 40, stress period 2 - Time summary)

```
          TIME SUMMARY AT END OF TIME STEP 40 IN STRESS PERIOD  2
                    SECONDS     MINUTES      HOURS       DAYS        YEARS
                    -----------------------------------------------------------
   TIME STEP LENGTH 9.70348E+05  16172.      269.54      11.231     3.07485E-02
 STRESS PERIOD TIME 2.31023E+07 3.85038E+05  6417.3      267.39      .73207
         TOTAL TIME 5.76622E+07 9.61037E+05  16017.      667.39      1.8272
```

APPENDIX 5

INPUT DATA SETS AND PRINTED RESULTS FOR TEST SIMULATION 4

This simulation demonstrates the capability of MODFLOW/MOC3D with the Lake Package to simulate solute transport into and out of a lake, as well as to calculate changes in the solute concentration in the lake over time. The simulation was performed for steady-state flow and transient transport calculations. Selected sections of several key input and output data files are shown below; gaps in the listings are indicated by an ellipsis. A complete set of these files will be made available for distribution over the internet. Contents of some files are enclosed in a border and explanations are noted outside of the border; for other files, explanations are included as comments following a semi-colon on the line being explained. Font sizes in the following listings are sometimes reduced so that lines will fit within page margins.

Listing of Input Data Sets for Test Simulation 4

```
LIST 10 testcase.lst      <-- Designates main output file for MODFLOW
BAS  11 testcase.bas      <-- Basic input data for MODFLOW
OC    12 testcase.oc      <-- Output control data specifications
BCF   13 testcase.bcf     <-- Input for Block-Centered Flow Package
RCH   14 testcase.rch     <-- Input for Recharge Package
LAK   19 testcase.lak     <-- Input data for Lake Package
GAGE  22 testcase.gge     <-- Input data for Gage Package
SIP   34 testcase.sip     <-- Input parameters for strongly-implicit procedure
CONC  70 testcase.mcn     <-- Solute-transport name file
DATA  23 testcase.fhd     <-- Output file for calculated heads
DATA  26 testcase.gs1     <-- Output file for gaging station 1 records
DATA  27 testcase.gs2     <-- Output file for gaging station 2 records
 ↑     ↑     ↑
 1     2     3
```

1 Ftype (that is, the type of file)

2 Unit number (arbitrarily selected)

3 File name (name chosen to reflect contents of file)

Following is a listing of input data for the basic package (file name: *testcase.bas*).

Several arrays are read using standard MODFLOW array reading utilities, which open and close separate files for the particular array, as indicated. A representative example follows immediately after the listing for the basic package.

```
                                         Column Numbers
         1         2         3         4         5         6         7         8
12345678901234567890123456789012345678901234567890123456789012345678901234567890

Simplified model of Cape Cod sewage plume--lake package test case ; begin BAS Input
                                                                ; second comment line
    8   36   23    1    4                                       ; NLAY NROW NCOL NPER ITMUNI
FREE, CHTOCH                                                    ; options line
    0    1                                                      ; IAPART, ISTRT
OPEN/CLOSE testcase.i2 1 (FREE)    5                            ; IBOUND, 1st layer
OPEN/CLOSE testcase.i0 1 (FREE)    5                            ; IBOUND, 2nd layer
OPEN/CLOSE testcase.i1 1 (FREE)    5                            ; IBOUND, 3rd layer
OPEN/CLOSE testcase.i1 1 (FREE)    5                            ; IBOUND, 4th layer
OPEN/CLOSE testcase.i1 1 (FREE)    5                            ; IBOUND, 5th layer
OPEN/CLOSE testcase.i1 1 (FREE)    5                            ; IBOUND, 6th layer
OPEN/CLOSE testcase.i1 1 (FREE)    5                            ; IBOUND, 7th layer
OPEN/CLOSE testcase.i1 1 (FREE)    5                            ; IBOUND, 8th layer
999999                                                          ; HNOFLO
OPEN/CLOSE testcase.h0 1.0 (FREE)    2                          ; Initial head, layer 1
OPEN/CLOSE testcase.h0 1.0 (FREE)    2                          ; Initial head, layer 2
OPEN/CLOSE testcase.h1 1.0 (FREE)    2                          ; Initial head, layer 3
OPEN/CLOSE testcase.h1 1.0 (FREE)    2                          ; Initial head, layer 4
OPEN/CLOSE testcase.h1 1.0 (FREE)    2                          ; Initial head, layer 5
OPEN/CLOSE testcase.h1 1.0 (FREE)    2                          ; Initial head, layer 6
OPEN/CLOSE testcase.h1 1.0 (FREE)    2                          ; Initial head, layer 7
OPEN/CLOSE testcase.h1 1.0 (FREE)    2                          ; Initial head, layer 8
9131.     1 1.                                                  ; PERLEN, NSTP, TSMULT
```

Following is a listing of input data for the IBOUND array for Layer 1 (file name: *testcase.i2*)**.**

```
                                                     Column Numbers
         1         2         3         4         5         6         7         8         9         0         1         2         3
1234567890123456789012345678901234567890123456789012345678901234567890123456789012345678901234567890123456789012345678901234567890

    0    0    0   -1   -1   -1   -1   -1   -1   -1   -1   -2   -2   -2   -2   -1   -1   -1   -1   -1   -1    1    1
    0    0    1    1    1    1    1    1    1    1    1    1    1    1    1    1    1    1    1    1    1    1    1
    0    0    1    1    1    1    1    1    1    1    1    1    1    1    1    1    1    1    1    1    1    1    1
    0    0    1    1    1    1    1    1    1    1    1    1    1    1    1    1    1    1    1    1    1    1    1
    0    0    1    1    1    1    1    1    1    1    1    1    1    1    1    1    1    1    1    1    1    1    1
    0    0    1    1    1    1    1    1    1    1    1    1    1    1    1    1    1    1   00   00    1    1    1
    0    0    1    1    1    1    1    1    1    1    1    1    1    1    1    1    1   00   00   00    1    1    1
    0    0    1    1    1    1    1    1    1    1    1    1    1    1    1   00   00   00   00   00    1    1    1
    0    0    1    1    1    1    1    1    1    1    1    1    1    1    1   00   00   00   00   00   00    1    1
    0    0    1    1    1    1    1    1    1    1    1    1    1    1    1   00   00   00   00   00   00    1    1
    0    0    1    1    1    1    1    1    1    1    1    1    1    1    1    1   00   00   00   00   00    1    1
    0    1    1    1    1    1    1    1    1    1    1    1    1    1    1    1   00   00   00   00   00    1    1
    0    1    1    1    1    1    1    1    1    1    1    1    1    1    1    1   00   00   00   00    1    1    1
    0    1    1    1    1    1    1    1    1    1    1    1    1    1    1    1   00   00   00   00    1    1    1
    0    1    1    1    1    1    1    1    1    1    1    1    1    1    1    1   00   00   00    1    1    1    1
    0    1    1    1    1    1    1    1    1    1    1    1    1    1    1    1    1   00    1    1    1    1    1
    0    1    1    1    1    1    1    1    1    1    1    1    1    1    1    1    1    1    1    1    1    1    1
    0    1    1    1    1    1    1    1    1    1    1    1    1    1    1    1    1    1    1    1    1    1    1
    0   00    1    1    1    1    1    1    1    1    1    1    1    1    1    1    1    1    1    1    1    1    1
    0   00    1    1    1    1    1    1    1    1    1    1    1    1    1    1    1    1    1    1    1    1    1
    0   00    1    1    1    1    1    1    1    1    1    1    1    1    1    1    1    1    1    1    1    1    1
    0   00   00    1    1    1    1    1    1    1    1    1    1    1    1    1    1    1    1    1    1    1    1
   00   00   00   00    1    1    1    1    1    1    1    1    1    1    1    1    1    1    1    1    1    1    1
   00   00   00   00    1    1    1    1    1    1    1    1    1    1    1    1    1    1    1    1    1    1    1
   00   00    1    1    1    1    1    1    1    1    1    1    1    1    1    1    1    1    1    1    1    1    1
   00   00    1    1    1    1    1    1    1    1    1    1    1    1    1    1    1    1    1    1    1    1    1
    1    1    1    1    1    1    1    1    1    1    1    1    1    1    1    1    1    1    1    1    1    1    1
    1    1    1    1    1    1    1    1    1    1    1    1    1    1    1    1    1    1    1    1    1    1    1
    1    1    1    1    1    1    1    1    1    1    1    1    1    1    1    1    1    1    1    1    1    1    1
    1    1    1    1    1    1    1    1    1    1    1    1    1    1    1    1    1    1    1    1    1    1    1
    1    1    1    1    1    1    1    1    1    1    1    1    1    1    1    1    1    1    1    1    1    1    1
    1    1    1    1    1    1    1    1    1    1    1    1    1    1    1    1    1    1    1    1    1    1    1
   -1   -1   -1   -1   -1   -1   -1   -1    1    1    1    1    1    1    1    1    1    1    1    1    1    1    1
    0    0    0    0    0    0    0   -1   -1   -1   -1   -1   -1   -1    1    1    1    1    1    1    1    1    1
    0    0    0    0    0    0    0    0    0    0    0    0    0   -1   -1   -1   -1   -1   -1   -1   -1    1    1
    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0   -1   -1   -1
```

Listing of Input Data for Block-Centered Flow Package (file name: *testcase.bcf*)

```
                                       Column Numbers
         1         2         3         4         5         6         7         8
12345678901234567890123456789012345678901234567890123456789012345678901234567890

    1   33 -9.99999e+05    0  5.00000e-01    1    1       ; BCF input
01                                                        ; LAYCON
03
00
00
00
00
00
00
INTERNAL 1.0 (FREE)    1                                  ; TRPY
  1.00000e+00
  1.00000e+00
  1.00000e+00
  1.00000e+00
  1.00000e+00
  1.00000e+00
  1.00000e+00
  1.00000e+00
INTERNAL 1.0 (FREE)    1                                  ; DELR
  4.05665e+02
  4.05665e+02
   ...
  4.05665e+02
  4.05665e+02
INTERNAL 1.0 (FREE)    1                                  ; DELC
  4.03717e+02
  4.03717e+02
   ...
  4.03717e+02
  4.03717e+02
OPEN/CLOSE testcase.k0 1.0 (FREE)   12                    ; hydraulic conductivity, layer 1
INTERNAL 1.0 (FREE)   12                                  ; bottom elevation, layer 1
   ...
OPEN/CLOSE testcase.z0 1.0 (FREE)   12                    ; vertical leakance, layers 1 and 2
OPEN/CLOSE testcase.k0 1.0 (FREE)   12                    ; hydraulic conductivity, layer 2
INTERNAL 1.0 (FREE)   12                                  ; bottom elevation, layer 2
   ...
INTERNAL 1.0 (FREE)   12                                  ; vertical leakance, layers 2 and 3
   ...
INTERNAL 1.0 (FREE)   12                                  ; top elevation, layer 2
   ...
OPEN/CLOSE testcase.k1 1.0 (FREE)   12                    ; transmissivity, layer 3
OPEN/CLOSE testcase.z1 1.0 (FREE)   12                    ; vertical leakance, layers 3 and 4
OPEN/CLOSE testcase.k1 1.0 (FREE)   12                    ; transmissivity, layer 4
OPEN/CLOSE testcase.z1 1.0 (FREE)   12                    ; vertical leakance, layers 4 and 5
OPEN/CLOSE testcase.k1 1.0 (FREE)   12                    ; transmissivity, layer 5
OPEN/CLOSE testcase.z1 1.0 (FREE)   12                    ; vertical leakance, layers 5 and 6
OPEN/CLOSE testcase.k1 1.0 (FREE)   12                    ; transmissivity, layer 6
OPEN/CLOSE testcase.z1 1.0 (FREE)   12                    ; vertical leakance, layers 6 and 7
OPEN/CLOSE testcase.k1 1.0 (FREE)   12                    ; transmissivity, layer 7
OPEN/CLOSE testcase.z1 1.0 (FREE)   12                    ; vertical leakance, layers 7 and 8
OPEN/CLOSE testcase.k1 1.0 (FREE)   12                    ; transmissivity, layer 8
```

Listing of Input Data for Recharge Package (file name: *testcase.rch*)

```
                                       Column Numbers
         1         2         3         4         5         6         7         8
12345678901234567890123456789012345678901234567890123456789012345678901234567890

    1   33                                       ; RCH input - NRCHOP, IRCHCB
    1   -1                                       ; input options INRECH, INIRCH
INTERNAL 1.0  (FREE)    2                        ; recharge rate (cell by cell array follows)
0.00479 ...
...  0.00479
```

Listing of Input Data for Strongly-Implicit Procedure Package (file name: *testcase.sip*)

```
                                       Column Numbers
         1         2         3         4         5         6         7         8
12345678901234567890123456789012345678901234567890123456789012345678901234567890

      1000         7                                    ; SIP input - MXITER,NPARM
      1.05     0.001         1         2        10      ; SIP parameter specifications
```

Listing of Input Data for the Lake Package (file name: *testcase.lak*)

```
                                       Column Numbers
         1         2         3         4         5         6         7         8
12345678901234567890123456789012345678901234567890123456789012345678901234567890

   2  -1                                    ; LAK input - NLAKES, ILKCB
  0.0   200   0.00001                       ; THETA, NSSITR, SSCNCR
   44.0   40.0   48.0   0.0                 ; LAKE 1: STAGES, SSMN, SSMX, CLAKE
   35.2   31.2   39.2   0.0                 ; LAKE 2: STAGES, SSMN, SSMX, CLAKE
  1  1  0                                   ; ITMP, ITMP1, LWRT
OPEN/CLOSE testcase.lk1 1 (FREE)    5       ; lake position array, layer 1
OPEN/CLOSE testcase.lk0 1 (FREE)    5       ; lake position array, layer 2
OPEN/CLOSE testcase.lk0 1 (FREE)    5       ; lake position array, layer 3
OPEN/CLOSE testcase.lk0 1 (FREE)    5       ; lake position array, layer 4
OPEN/CLOSE testcase.lk0 1 (FREE)    5       ; lake position array, layer 5
OPEN/CLOSE testcase.lk0 1 (FREE)    5       ; lake position array, layer 6
OPEN/CLOSE testcase.lk0 1 (FREE)    5       ; lake position array, layer 7
OPEN/CLOSE testcase.lk0 1 (FREE)    5       ; lake position array, layer 8
CONSTANT  10.0                              ; lakebed leakance array, layer 1
CONSTANT  10.0                              ; lakebed leakance array, layer 2
CONSTANT  10.0                              ; lakebed leakance array, layer 3
CONSTANT  10.0                              ; lakebed leakance array, layer 4
CONSTANT  10.0                              ; lakebed leakance array, layer 5
CONSTANT  10.0                              ; lakebed leakance array, layer 6
CONSTANT  10.0                              ; lakebed leakance array, layer 7
CONSTANT  10.0                              ; lakebed leakance array, layer 8
0                                           ; NSLMS
  0.0  0.0  0.0  0.0                        ; Lake 1: PRCPLK, EVAPLK, RNF, WTHDRW
  0.0  0.0  0.0                             ; Lake 1: CPPT, CRNF, CAUG
  0.0  0.0  0.0  0.0                        ; Lake 2: PRCPLK, EVAPLK, RNF, WTHDRW
  0.0  0.0  0.0                             ; Lake 2: CPPT, CRNF, CAUG
```

Listing of Input Data for the Output-Control Package (file name: *testcase.oc*)

Input for the Output-Control Package was constructed in the optional style using words.

```
                                        Column Numbers
         1         2         3         4         5         6         7         8
12345678901234567890123456789012345678901234567890123456789012345678901234567890

HEAD PRINT FORMAT   -12
DRAWDOWN PRINT FORMAT   -12
HEAD SAVE FORMAT (8E13.5) LABEL
HEAD SAVE UNIT 23
PERIOD        1   STEP        1
PRINT HEAD
PRINT BUDGET
SAVE HEAD
SAVE BUDGET
```

Following are the contents of the MOC3D solute-transport name file (file name: *testcase.nam*)**:**

```
CLST   71 testcase.out   <— Designates main output file for MOC3D
MOCIMP 72 testcase.moc   <— Basic input data for MOC3D
CRCH   73 testcase.crc   <— Input for Recharge Concentration Package
CNCA   74 testcase.cna   <— Output file for calculated concentrations
VELA   76 testcase.vla   <— Output file for calculated velocities
```

Listing of Input Data for the MOC3D (Implicit) Package (file name: *testcase.moc*)

```
                                        Column Numbers
         1         2         3         4         5         6         7         8
12345678901234567890123456789012345678901234567890123456789012345678901234567890

Otis sewage plume--lake package                  ; 1st comment line
                                                 ; 2nd comment line
    1    8    1   36    1   23                   ; Transport subgrid descriptors
    0  0.00000e+00  0.00000e+00                  ; NODISP, DECAY, DIFFUS
    0   27                                       ; NPMAX, NPTPND
  0.75000e-00  5.00000e-02    1                  ; CELDIS, FZERO, INTRPL
  1.00000e+00    2    1  1.00000e-05  100        ; FDTMTH, NCXIT, IDIREC, EPSSLV, MAXIT
   300    0   -1    0    0    0    0             ; Flags for output control
 -9.99900e+02                                    ; CNOFLO
INTERNAL 1 (FREE)    0                ; Initial concentration in layer 1; this block is repeated for other 7 layers
  0.00000e+00  ...
    ...  0.00000e+00
   2                                             ; NZONES
   -1  0.00000e+00                               ; Layer 1: IZONE, ZONCON
   -2  5.00000e+02                               ; Layer 2: IZONE, ZONCON
INTERNAL 1 (FREE)    7                ; IGENPT array for Layer 1; this block is repeated for other 7 layers
   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0
   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0
   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0
   0   0   0   0   0   1   1   1   1   1   1   1   1   1   1   1   1   0   0   0   0   0   0
   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0
   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0
   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0
```

```
    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0
    0    0    1    1    1    1    1    1    1    1    1    1    1    1    0    0    0    0    0    0    0    0    0
    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0
    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0
    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0
    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0
    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0
    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0
    0    0    1    1    1    1    1    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0
    0    0    0    0    0    0    1    1    1    1    1    1    1    1    1    1    1    1    0    0    0    0    0
    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    1    1    1    1    1    1
    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0
    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0
    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0
    0    0    0    0    0    0    1    1    1    1    1    0    0    0    0    0    0    0    0    0    0    0    0
    0    0    0    0    0    0    0    0    0    0    1    1    1    1    1    1    1    1    1    0    0    0    0
    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    1    1    1    1    1
    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0
    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0
    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0
    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0
    1    1    1    1    1    1    1    1    1    1    1    1    1    1    1    1    1    1    1    1    1    1    1
    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0
    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0
    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0
    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0
    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0
    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0
    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0
  ...
INTERNAL 1.0 (FREE)     1                               ; Longitudinal dispersivity in each layer
  2.00000e+01  2.00000e+01  2.00000e+01  2.00000e+01  2.00000e+01  2.00000e+01  2.00000e+01  2.00000e+01
INTERNAL 1.0 (FREE)     1                               ; Horizontal transverse dispersivity in each layer
  2.00000e+00  2.00000e+00  2.00000e+00  2.00000e+00  2.00000e+00  2.00000e+00  2.00000e+00  2.00000e+00
INTERNAL 1.0 (FREE)     1                               ; Vertical transverse dispersivity in each layer
  2.00000e-01  2.00000e-01  2.00000e-01  2.00000e-01  2.00000e-01  2.00000e-01  2.00000e-01  2.00000e-01
INTERNAL 1.0 (FREE)     1                               ; Retardation factor in each layer
  1.00000e+00  1.00000e+00  1.00000e+00  1.00000e+00  1.00000e+00  1.00000e+00  1.00000e+00  1.00000e+00
INTERNAL 1 (FREE)    0                                  ; Thickness of layer 1
  1.50000e+01  ...
INTERNAL 1 (FREE)    5                                  ; Porosity of layer 1
  3.00000e-01  ...

  ...                                  ; For each successive layer, the thickness & porosity are listed here
```

Listing of Input Data for Source Concentration in Recharge Package (file name: *testcase.crc*)

```
                                        Column Numbers
         1         2         3         4         5         6         7         8
12345678901234567890123456789012345678901234567890123456789012345678901234567890

    0                                   ; INCRCH
INTERNAL 1.0  (FREE)    0               ; Read source concentration in recharge as column-row array
  0.00000e+00  ...
...  0.00000e+00
```

Listing of Gaging Station file for GAGE Package (file name: *testcase.gge*)

```
                                        Column Numbers
         1         2         3         4         5         6         7         8
12345678901234567890123456789012345678901234567890123456789012345678901234567890

 2                                   ; NUMGAGE (number of gaging stations)
-1   26                              ; LAKE (lake number); Unit number for output file--Gage 1
-2   27                              ; LAKE (lake number); Unit number for output file--Gage 2
```

Selected Output from Results for Test Simulation 4 - Solute Transport

1. MODFLOW results **(file name: *testcase.lst*)**

```
                                       Column Numbers
         1         2         3         4         5         6         7         8
12345678901234567890123456789012345678901234567890123456789012345678901234567890

LISTING FILE: testcase.lst
                         UNIT  10

 OPENING testcase.bas
 FILE TYPE:BAS   UNIT  11

 OPENING testcase.oc
 FILE TYPE:OC   UNIT  12

 OPENING testcase.bcf
 FILE TYPE:BCF   UNIT  13

 OPENING testcase.rch
 FILE TYPE:RCH   UNIT  14

 OPENING testcase.lak
 FILE TYPE:LAK   UNIT  19

 OPENING testcase.gge
 FILE TYPE:GAGE   UNIT  22

 OPENING testcase.sip
 FILE TYPE:SIP   UNIT  34

 OPENING testcase.mcn
 FILE TYPE:CONC   UNIT  70

 OPENING testcase.fhd
 FILE TYPE:DATA   UNIT  23

 OPENING testcase.gs1
 FILE TYPE:DATA   UNIT  26

 OPENING testcase.gs2
 FILE TYPE:DATA   UNIT  27
1                                 MODFLOW
      U.S. GEOLOGICAL SURVEY MODULAR FINITE-DIFFERENCE GROUND-WATER FLOW MODEL

 Simplified model of Cape Cod sewage plume--lake package test case

 THE FREE FORMAT OPTION HAS BEEN SELECTED
    8 LAYERS        36 ROWS        23 COLUMNS
   1 STRESS PERIOD(S) IN SIMULATION
 MODEL TIME UNIT IS DAYS
 CALCULATE FLOW BETWEEN ADJACENT CONSTANT-HEAD CELLS


              U.S. GEOLOGICAL SURVEY
 METHOD-OF-CHARACTERISTICS SOLUTE-TRANSPORT MODEL
           MOC3D (Version 3.1) 10/15/1999
```

```
 MOC BASIC INPUT READ FROM UNIT  72

 MOC OUTPUT ON FILE UNIT IOUTS=   71

 BAS5 -- BASIC MODEL PACKAGE, VERSION 5, 1/1/95 INPUT READ FROM UNIT 11
 ARRAYS RHS AND BUFF WILL SHARE MEMORY
 INITIAL HEAD WILL BE KEPT THROUGHOUT THE SIMULATION
      65503 ELEMENTS IN X ARRAY ARE USED BY BAS
      65503 ELEMENTS OF X ARRAY USED OUT OF   14043727

 BCF5 -- BLOCK-CENTERED FLOW PACKAGE, VERSION 5, 9/1/93 INPUT READ FROM UNIT 13
 STEADY-STATE SIMULATION
 CELL-BY-CELL FLOWS WILL BE SAVED ON UNIT 33
 HEAD AT CELLS THAT CONVERT TO DRY= -0.10000E+07
 WETTING CAPABILITY IS NOT ACTIVE
      LAYER  LAYER-TYPE CODE     INTERBLOCK T
      --------------------------------------------
         1            1          0 -- HARMONIC
         2            3          0 -- HARMONIC
         3            0          0 -- HARMONIC
         4            0          0 -- HARMONIC
         5            0          0 -- HARMONIC
         6            0          0 -- HARMONIC
         7            0          0 -- HARMONIC
         8            0          0 -- HARMONIC
       4148 ELEMENTS IN X ARRAY ARE USED BY BCF
      69651 ELEMENTS OF X ARRAY USED OUT OF   14043727

 RCH5 -- RECHARGE PACKAGE, VERSION 5, 6/1/95 INPUT READ FROM UNIT 14
 OPTION 1 -- RECHARGE TO TOP LAYER
 CELL-BY-CELL FLOWS WILL BE SAVED ON UNIT 33
        828 ELEMENTS IN X ARRAY ARE USED BY RCH
      70479 ELEMENTS OF X ARRAY USED OUT OF   14043727

 SIP5 -- STRONGLY IMPLICIT PROCEDURE SOLUTION PACKAGE
                    VERSION 5, 9/1/93 INPUT READ FROM UNIT 34
 MAXIMUM OF1000 ITERATIONS ALLOWED FOR CLOSURE
  7 ITERATION PARAMETERS
      30503 ELEMENTS IN X ARRAY ARE USED BY SIP
     100982 ELEMENTS OF X ARRAY USED OUT OF   14043727

 LAK3 -- LAKE PACKAGE, VERSION 3, 6/28/99 INPUT READ FROM UNIT 19
 SPACE ALLOCATION FOR  13248 GRID CELL FACES ADJACENT TO LAKES
 MAXIMUM NUMBER OF LAKES IS  2 FOR THIS SIMULATION
 CELL-BY-CELL SEEPAGES WILL NOT BE PRINTED OR SAVED

 THETA =       0.00  METHOD FOR UPDATING LAKE STAGES IN ITERATIONS OF THE SOLUTION FOR AQUIFER HEADS.
                    0.0 IS EXPLICIT, 0.5 IS CENTERED, AND 1.0 IS FULLY IMPLICIT.

 STEADY-STATE SOLUTION FOR LAKES.  MAXIMUM NUMBER OF ITERTIONS =   200   CONVERGENCE CRITERION =     0.0000
    119352 ELEMENTS IN X ARRAY ARE USED BY THE LAKE PACKAGE
    220336 ELEMENTS OF X ARRAY USED OUT OF   14043727
         6 ELEMENTS IN X ARRAY ARE USED BY GAGE
    220342 ELEMENTS OF X ARRAY USED OUT OF  14043727
   2321228 ELEMENTS IN X ARRAY ARE USED BY MOC
   2541570 ELEMENTS OF X ARRAY USED OUT OF14043727
       828 ELEMENTS IN X ARRAY ARE USED BY RCH
   2542398 ELEMENTS OF X ARRAY USED OUT OF14043727
1
 Simplified model of Cape Cod sewage plume--lake package test case
```

```
...                                        ; print out of input data arrays is skipped here

          SOLUTION BY THE STRONGLY IMPLICIT PROCEDURE
          -------------------------------------------
 MAXIMUM ITERATIONS ALLOWED FOR CLOSURE =     1000
                 ACCELERATION PARAMETER =     1.0500
      HEAD CHANGE CRITERION FOR CLOSURE =    0.10000E-02
      SIP HEAD CHANGE PRINTOUT INTERVAL =       10

     CALCULATE ITERATION PARAMETERS FROM MODEL CALCULATED WSEED

   2 GAGING STATIONS WERE SPECIFIED.
     RECORDS WILL BE WRITTEN TO SEPARATE OUTPUT FILES REPRESENTED BY FOLLOWING UNIT NUMBERS:
     (Neg. Segment No. Indicates Lake Number)

  GAGE #   SEGMENT   REACH   UNIT
       1      -1              26
       2      -2              27

                              STRESS PERIOD NO.   1, LENGTH =   9131.000
                              ----------------------------------------------

                                NUMBER OF TIME STEPS =     1

                                 MULTIPLIER FOR DELT =     1.000

                              INITIAL TIME STEP SIZE =   9131.000

...                                     ; listing of recharge data is skipped

 INITIAL LAKE STAGE:  LAKE    STAGE    SS MIN    SS MAX

                        1    44.000    40.000    48.000
                        2    35.200    31.200    39.200

 OPENING FILE ON UNIT  99:
 testcase.lk1

                       LAKE ID ARRAY FOR LAYER   1
 READING ON UNIT  99 WITH FORMAT: (FREE)

...                                     ; listing of lake array for each layer is skipped

   LAKEBED LEAKANCE ARRAY =   10.00000     FOR LAYER   1
...
   LAKEBED LEAKANCE ARRAY =   10.00000     FOR LAYER   8

       LOCATIONS, LAKE #, INTERFACE TYPE FOR GRID CELLS ADJACENT TO LAKES:
     ----------------------------------------------------------------------
     LAYER #    ROW #    COLUMN #   LAKE #  INTERFACE TYPE  LAKEBED LEAKANCE
         1       19         1         2         1            10.00000
         1       20         1         2         1            10.00000
         1       21         1         2         1            10.00000
         1       22         1         2         1            10.00000
         1       22         1         2         2            10.00000
         2       23         1         2         0            10.00000
...
         1        9        22         1         1            10.00000
         1       10        22         1         1            10.00000
         1       11        22         1         1            10.00000
         1       12        22         1         1            10.00000
```

```
     NUMBER OF LAKE-AQUIFER CELL INTERFACES =   115

         C                INTERFACE CONDUCTANCES FOR LAKES
   L     O
   A     L  L  T      (IF TYPE = 1 OR 2, CONDUCTANCES ARE PER UNIT THICKNESS.)
   Y  R  U  A  Y
   E  O  M  K  P                          LAKEBED     C O N D U C T A N C E S
   R  W  N  E  E     DELTA Y   DELTA X  LEAKANCE   LAKEBED   AQUIFER  COMBINED
 ______________________________________________________________________________
   1 19  1  2  1    4.04E+02  4.06E+02  1.00E+01  4.04E+03  4.98E+02  4.43E+02
   1 20  1  2  1    4.04E+02  4.06E+02  1.00E+01  4.04E+03  4.98E+02  4.43E+02
   1 21  1  2  1    4.04E+02  4.06E+02  1.00E+01  4.04E+03  4.98E+02  4.43E+02
   1 22  1  2  1    4.04E+02  4.06E+02  1.00E+01  4.04E+03  4.98E+02  4.43E+02
   1 22  1  2  2    4.04E+02  4.06E+02  1.00E+01  4.06E+03  5.02E+02  4.47E+02
   2 23  1  2  0    4.04E+02  4.06E+02  1.00E+01  1.64E+06            1.64E+06
...
   1  9 22  1  1    4.04E+02  4.06E+02  1.00E+01  4.04E+03  4.98E+02  4.43E+02
   1 10 22  1  1    4.04E+02  4.06E+02  1.00E+01  4.04E+03  4.98E+02  4.43E+02
   1 11 22  1  1    4.04E+02  4.06E+02  1.00E+01  4.04E+03  4.98E+02  4.43E+02
   1 12 22  1  1    4.04E+02  4.06E+02  1.00E+01  4.04E+03  4.98E+02  4.43E+02

 STAGE/VOLUME RELATION FOR LAKE  1

   STAGE    VOLUME

   29.7000  0.000E+00
   29.8546  9.648E+05
   30.0092  2.978E+06
   30.1638  6.079E+06
...
   52.5800  1.225E+10
   52.7346  1.241E+10
   52.8892  1.258E+10
...

 NUMBER OF CONNECTED LAKE SYSTEMS IN SIMULATION IS   0

 LAKE       PRECIP      EVAP    RUNOFF    WITHDRAW   BOTTOM     AREA
-----------------------------------------------------------------------
   1        0.0000    0.0000 0.000E+00   0.000E+00 2.970E+01 7.206E+06
   2        0.0000    0.0000 0.000E+00   0.000E+00 2.020E+01 2.784E+06

 ALL LAKES CONVERGED TO STEADY-STATE AFTER   2  ITERATIONS
 ...
     7 ITERATION PARAMETERS CALCULATED FROM AVERAGE SEED:

  0.000000E+00 0.852134E+00 0.978136E+00 0.996767E+00 0.999522E+00
  0.999929E+00 0.999990E+00
 ALL LAKES CONVERGED TO STEADY-STATE AFTER   2  ITERATIONS
...
 ALL LAKES CONVERGED TO STEADY-STATE AFTER   2  ITERATIONS

   752 ITERATIONS FOR TIME STEP   1 IN STRESS PERIOD  1

...

    LAKE  SEEPAGE   PERIOD  1   STEP  1   NODE   6   LAYER  2   ROW  23   COL   1   RATE  -58.64398
    LAKE  SEEPAGE   PERIOD  1   STEP  1   NODE   7   LAYER  2   ROW  24   COL   1   RATE   67.35971
    LAKE  SEEPAGE   PERIOD  1   STEP  1   NODE   8   LAYER  2   ROW  25   COL   1   RATE   1765.802
    LAKE  SEEPAGE   PERIOD  1   STEP  1   NODE   9   LAYER  2   ROW  26   COL   1   RATE   32231.54
```

```
   LAKE  SEEPAGE   PERIOD  1   STEP  1   NODE  10   LAYER  1   ROW  27   COL   1   RATE   8900.507
   LAKE  SEEPAGE   PERIOD  1   STEP  1   NODE  11   LAYER  1   ROW  18   COL   2   RATE  -14247.68
...
   LAKE  SEEPAGE   PERIOD  1   STEP  1   NODE 112   LAYER  1   ROW   9   COL  22   RATE  -1461.709
   LAKE  SEEPAGE   PERIOD  1   STEP  1   NODE 113   LAYER  1   ROW  10   COL  22   RATE  -704.8510
   LAKE  SEEPAGE   PERIOD  1   STEP  1   NODE 114   LAYER  1   ROW  11   COL  22   RATE  -147.3909
   LAKE  SEEPAGE   PERIOD  1   STEP  1   NODE 115   LAYER  1   ROW  12   COL  22   RATE   508.4921

     0  LAKE CELLS ARE DRY.

 PERIOD     1     TIME STEP     1     TIME STEP LENGTH  9.1310E+03
 PERIOD TIME  9.1310E+03     TOTAL SIMULATION TIME  9.1310E+03


     HYDROLOGIC BUDGET SUMMARIES FOR SIMULATED LAKES
     -----------------------------------------------
 LAKE   STAGE     PRECIP       EVAP       RUNOFF
   1    45.41  0.0000E+00  0.0000E+00  0.0000E+00
   2    36.82  0.0000E+00  0.0000E+00  0.0000E+00

            GROUND WATER           SURFACE WATER
 LAKE    INFLOW     OUTFLOW      INFLOW     OUTFLOW
   1  2.3587E+09  1.9332E+09  0.0000E+00  0.0000E+00
   2  1.6176E+09  1.3717E+09  0.0000E+00  0.0000E+00

         WATER    CONNECTED LAKE   UPDATED     TIME-STEP         STAGE CHANGE
 LAKE     USE         INFLUX        VOLUME    SURFACE AREA   TIME STEP  CUMULATIVE
   1   0.0000E+00   0.0000E+00   1.1298E+08    7.2061E+06   0.0000E+00  1.4120E+00
   2   0.0000E+00   0.0000E+00   4.6274E+07    2.7842E+06   0.0000E+00  1.6207E+00
```

```
1
              HEAD IN LAYER  1 AT END OF TIME STEP  1 IN STRESS PERIOD  1
  ---------------------------------------------------------------------

...                                ; calculated heads not shown

  VOLUMETRIC BUDGET FOR ENTIRE MODEL AT END OF TIME STEP  1 IN STRESS PERIOD  1
  ------------------------------------------------------------------------------

     CUMULATIVE VOLUMES      L**3       RATES FOR THIS TIME STEP      L**3/T
     ------------------                 ------------------------

           IN:                                      IN:
           ---                                      ---
       CONSTANT HEAD =  5548110848.0000         CONSTANT HEAD =      607612.6250
            RECHARGE =  4648824832.0000              RECHARGE =      509125.5000
       LAKE  SEEPAGE =  3304954368.0000         LAKE  SEEPAGE =      361948.7813

            TOTAL IN = 13501890560.0000              TOTAL IN =     1478686.8750

          OUT:                                     OUT:
          ----                                     ----
       CONSTANT HEAD =  9525641216.0000         CONSTANT HEAD =     1043219.9375
            RECHARGE =            0.0000              RECHARGE =           0.0000
       LAKE  SEEPAGE =  3976272128.0000         LAKE  SEEPAGE =      435469.5313

           TOTAL OUT = 13501913088.0000             TOTAL OUT =     1478689.5000
```

```
           IN - OUT =      -22528.0000              IN - OUT =          -2.6250

 PERCENT DISCREPANCY =           0.00     PERCENT DISCREPANCY =           0.00


         TIME SUMMARY AT END OF TIME STEP  1 IN STRESS PERIOD  1
                   SECONDS     MINUTES      HOURS       DAYS        YEARS
                   -----------------------------------------------------------
   TIME STEP LENGTH 7.88918E+08 1.31486E+07 2.19144E+05  9131.0      24.999
 STRESS PERIOD TIME 7.88918E+08 1.31486E+07 2.19144E+05  9131.0      24.999
         TOTAL TIME 7.88918E+08 1.31486E+07 2.19144E+05  9131.0      24.999
```

2. MOC3D results **(file name: *testcase.out*)**

```
                                        Column Numbers
         1         2         3         4         5         6         7         8
12345678901234567890123456789012345678901234567890123456789012345678901234567890

              U.S. GEOLOGICAL SURVEY
 METHOD-OF-CHARACTERISTICS SOLUTE-TRANSPORT MODEL
           MOC3D (Version 3.1) 1999/10/15

 MOC BASIC INPUT READ FROM UNIT
 LISTING FILE: testcase.out   UNIT  71

 OPENING testcase.moc
 FILE TYPE: MOCIMP   UNIT  72

 OPENING testcase.crc
 FILE TYPE: CRCH   UNIT  73

 OPENING testcase.cna
 FILE TYPE: CNCA   UNIT  74

 OPENING testcase.vla
 FILE TYPE: VELA   UNIT  76

 MOC BASIC INPUT READ FROM UNIT  72

 Otis sewage plume--lake package

      MAPPING OF SOLUTE-TRANSPORT SUBGRID IN FLOW GRID:
 FIRST LAYER FOR SOLUTE TRANSPORT =   1      LAST LAYER FOR SOLUTE TRANSPORT  =   8
 FIRST ROW FOR SOLUTE TRANSPORT   =   1      LAST ROW FOR SOLUTE TRANSPORT    =  36
 FIRST COLUMN FOR SOLUTE TRANSPORT=   1      LAST COLUMN FOR SOLUTE TRANSPORT =  23

 UNIFORM DELCOL AND DELROW IN SUBGRID FOR SOLUTE TRANSPORT

 NO. OF LAYERS =    8   NO. OF ROWS =   36   NO. OF COLUMNS =   23
 NO SOLUTE DECAY
 NO MOLECULAR DIFFUSION
 MAXIMUM NUMBER OF PARTICLES (NPMAX) =   357696
  2321228 ELEMENTS IN X ARRAY ARE USED BY MOC

CRCH5  --  CONCENTRATIONS IN RECHARGE INPUT READ FROM UNIT  73
      828 ELEMENTS IN X ARRAY ARE USED BY RCH

 NUMBER OF PARTICLES INITIALLY IN EACH ACTIVE CELL (NPTPND) =  27
```

```
...                       ; particle locations not shown

 CELDIS=     0.750
 FZERO =     0.050

INTRPL= 1:  LINEAR INTERPOLATION SCHEME

 NUMERICAL PARAMETERS FOR IMPLICIT SOLVER:
 FDTMTH =     1.00
 NCXIT  =      2
 IDIREC =      1
 EPSSLV =  1.0000E-05
 MAXIT  =    100

...

CONCENTRATION WILL BE SET TO -999.90     AT ALL NO-FLOW NODES (IBOUND=0).

              INITIAL CONCENTRATION FOR LAYER   1
 READING ON UNIT  72 WITH FORMAT: (FREE)
...           ; initial conc. = 0.0 everywhere; not shown in this listing

VALUES OF C' REQUIRED FOR SUBGRID BOUNDARY ARRAY =    0

 NUMBER OF ZONES FOR CONCENTRATIONS AT FIXED HEAD CELLS =    2

 ZONE FLAG =   -1     INFLOW CONCENTRATION =   0.0000E+00
FIXED HEAD INFLOW CONCENTRATION SET TO        0.000  FOR NODE AT         4         1         1
...
 ZONE FLAG =   -2     INFLOW CONCENTRATION =   5.0000E+02
FIXED HEAD INFLOW CONCENTRATION SET TO      500.000  FOR NODE AT        12         1         1
...
FIXED HEAD INFLOW CONCENTRATION SET TO      500.000  FOR NODE AT        15         1         2

                   SINK-SOURCE FLAG FOR LAYER   1
...

  *** NOTE ***  LAKE PACKAGE ACTIVE;
  ALL ACTIVE TRANSPORT SUBGRID CELLS ADJACENT TO LAKES FLAGGED AS STRONG SOURCE/SINK CELLS.

           LONGITUDNL. DISPERSIVITY
 READING ON UNIT  72 WITH FORMAT: (FREE)
   20.000       20.000       20.000       20.000       20.000
   20.000       20.000       20.000

            HORIZ. TRANSVERSE DISP.
 READING ON UNIT  72 WITH FORMAT: (FREE)
   2.0000       2.0000       2.0000       2.0000       2.0000
   2.0000       2.0000       2.0000

             VERT. TRANSVERSE DISP.
 READING ON UNIT  72 WITH FORMAT: (FREE)
  0.20000      0.20000      0.20000      0.20000      0.20000
  0.20000      0.20000      0.20000

                 RETARDATION FACTOR
 READING ON UNIT  72 WITH FORMAT: (FREE)
   1.0000       1.0000       1.0000       1.0000       1.0000
   1.0000       1.0000       1.0000
```

```
                  INITIAL THICKNESS FOR LAYER   1
 READING ON UNIT  72 WITH FORMAT: (FREE)
...
                   INITIAL POROSITY FOR LAYER   1
 READING ON UNIT  72 WITH FORMAT: (FREE)
...
...                              ; print out of thickness and porosity for 8 layers not shown

CONCENTRATION DATA WILL BE SAVED ON UNIT  74 IN MATRIX FORMAT

 INITIAL LAKE CONCENTRATIONS:  LAKE   CONCENTRATION (NSOL =  1)

                                 1      0.000E+00
                                 2      0.000E+00

 LAKE    SOLUTE      CPPT      CRNF      CAUG

   1        1       0.00E+00  0.00E+00

   2        1       0.00E+00  0.00E+00

...
                  CONC. IN RECHARGE
 READING ON UNIT  73 WITH FORMAT: (FREE)
...                       ; source conc. = 0.0, not shown in listing

          STABILITY CRITERIA --- M.O.C.
...
 NUMBER OF MOVES FOR ALL STABILITY CRITERIA:
    CELDIS   INJECTION
      1128         439

 CELDIS IS LIMITING
...
          NO. OF PARTICLE MOVES REQUIRED TO COMPLETE THIS TIME STEP  = 1128
            MOVE TIME STEP (TIMV)=  8.094858169556E+00


  NP       =   161217 AT START OF MOVE          IMOV     =            1
  No. of solver iterations =    1 Relative residual =   1.9700E-08
  NP       =   161217 AT START OF MOVE          IMOV     =            2
  No. of solver iterations =    1 Relative residual =   6.5369E-08
...                                     ; routine printout for intermediate transport time increments not shown
  NP       =   267560 AT START OF MOVE          IMOV     =         1128
     NUMBER OF CELLS WITH ZERO PARTICLES  =   123
  No. of solver iterations =    1 Relative residual =   1.6997E-07


 SOLUTE BUDGETS FOR LAKES FOR THIS TIME INCREMENT:
 Lake   Lake   Solute  Concen-     Ppt.    Stream    Stream  Withdrawal  Runoff      GW        GW    Solute Mass
  No.  Volume    No.   tration   Mass In   Mass In  Mass Out  Net Mass   Mass In   Mass In  Mass Out   in Lake

   1  1.13E+08    1    3.13E+01  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  5.32E+07  5.37E+07  3.54E+09
   2  4.63E+07    1    1.80E-03  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  2.74E+03  2.18E+03  8.29E+04

           SOLUTE BUDGET AND MASS BALANCE FOR TRANSPORT SUBGRID

      VALUES CALCULATED AT END OF:
               STRESS PERIOD    1  OUT OF    1
              FLOW TIME STEP    1  OUT OF    1
    TRANSPORT TIME INCREMENT 1128  OUT OF 1128
```

```
 ELAPSED TIME =  9.1310E+03

 CHEMICAL MASS IN STORAGE:
     INITIAL:   MASS DISSOLVED =  0.0000E+00     MASS SORBED =  0.0000E+00
     PRESENT:   MASS DISSOLVED =  7.2719E+10     MASS SORBED =  0.0000E+00

           CHANGE IN MASS STORED = -7.2719E+10

CUMULATIVE SOLUTE MASS  (L**3)(M/VOL)
----------------------

     IN:
     ---
               DECAY =  0.0000E+00
        CONSTANT HEAD =  1.3335E+12
     SUBGRID BOUNDARY =  0.0000E+00
             RECHARGE =  0.0000E+00
                WELLS =  0.0000E+00
               RIVERS =  0.0000E+00
               DRAINS =  0.0000E+00
GENL. HEAD-DEP. BDYS. =  0.0000E+00
   EVAPOTRANSPIRATION =  0.0000E+00
 SPECIFIED FLOW (FHB) =  0.0000E+00
    LOSING LAKE CELLS =  3.7787E+10

             TOTAL IN =  1.3712E+12

    OUT:
    ----
               DECAY =  0.0000E+00
        CONSTANT HEAD = -1.1977E+12
     SUBGRID BOUNDARY =  0.0000E+00
             RECHARGE =  0.0000E+00
                WELLS =  0.0000E+00
               RIVERS =  0.0000E+00
               DRAINS =  0.0000E+00
GENL. HEAD-DEP. BDYS. =  0.0000E+00
   EVAPOTRANSPIRATION =  0.0000E+00
 SPECIFIED FLOW (FHB) =  0.0000E+00
   GAINING LAKE CELLS = -4.1326E+10

            TOTAL OUT = -1.2390E+12

    SOURCE-TERM DECAY =  0.0000E+00


             RESIDUAL =  5.9494E+10

  PERCENT DISCREPANCY =  4.3387E+00 RELATIVE TO MASS FLUX IN
```

3. GAGE results--records for Gaging Station 1 **(file name: *testcase.gs1*)**

```
                                       Column Numbers
         1         2         3         4         5         6         7         8
12345678901234567890123456789012345678901234567890123456789012345678901234567890

 "GAGE No.  1:  Lake No. =   1 "                                  ; first header line
 "DATA:  Time        Stage     Volume   Concentration"            ; second header line
      0.000E+00  4.400E+01  1.028E+08   0.000E+00
      8.095E+00  4.541E+01  1.130E+08   1.029E-20
      1.619E+01  4.541E+01  1.130E+08   3.351E-19
      2.428E+01  4.541E+01  1.130E+08   8.910E-18
      3.238E+01  4.541E+01  1.130E+08   1.081E-16
      4.047E+01  4.541E+01  1.130E+08   1.434E-15
      4.857E+01  4.541E+01  1.130E+08   5.667E-15
      5.666E+01  4.541E+01  1.130E+08   3.026E-14
      6.476E+01  4.541E+01  1.130E+08   8.549E-14
      7.285E+01  4.541E+01  1.130E+08   1.630E-13
      8.095E+01  4.541E+01  1.130E+08   3.842E-13
      8.904E+01  4.541E+01  1.130E+08   7.027E-13
...
      9.042E+03  4.541E+01  1.130E+08   3.139E+01
      9.050E+03  4.541E+01  1.130E+08   3.138E+01
      9.058E+03  4.541E+01  1.130E+08   3.139E+01
      9.066E+03  4.541E+01  1.130E+08   3.138E+01
      9.074E+03  4.541E+01  1.130E+08   3.137E+01
      9.082E+03  4.541E+01  1.130E+08   3.136E+01
      9.090E+03  4.541E+01  1.130E+08   3.134E+01
      9.099E+03  4.541E+01  1.130E+08   3.133E+01
      9.107E+03  4.541E+01  1.130E+08   3.134E+01
      9.115E+03  4.541E+01  1.130E+08   3.133E+01
      9.123E+03  4.541E+01  1.130E+08   3.132E+01
      9.131E+03  4.541E+01  1.130E+08   3.132E+01
```