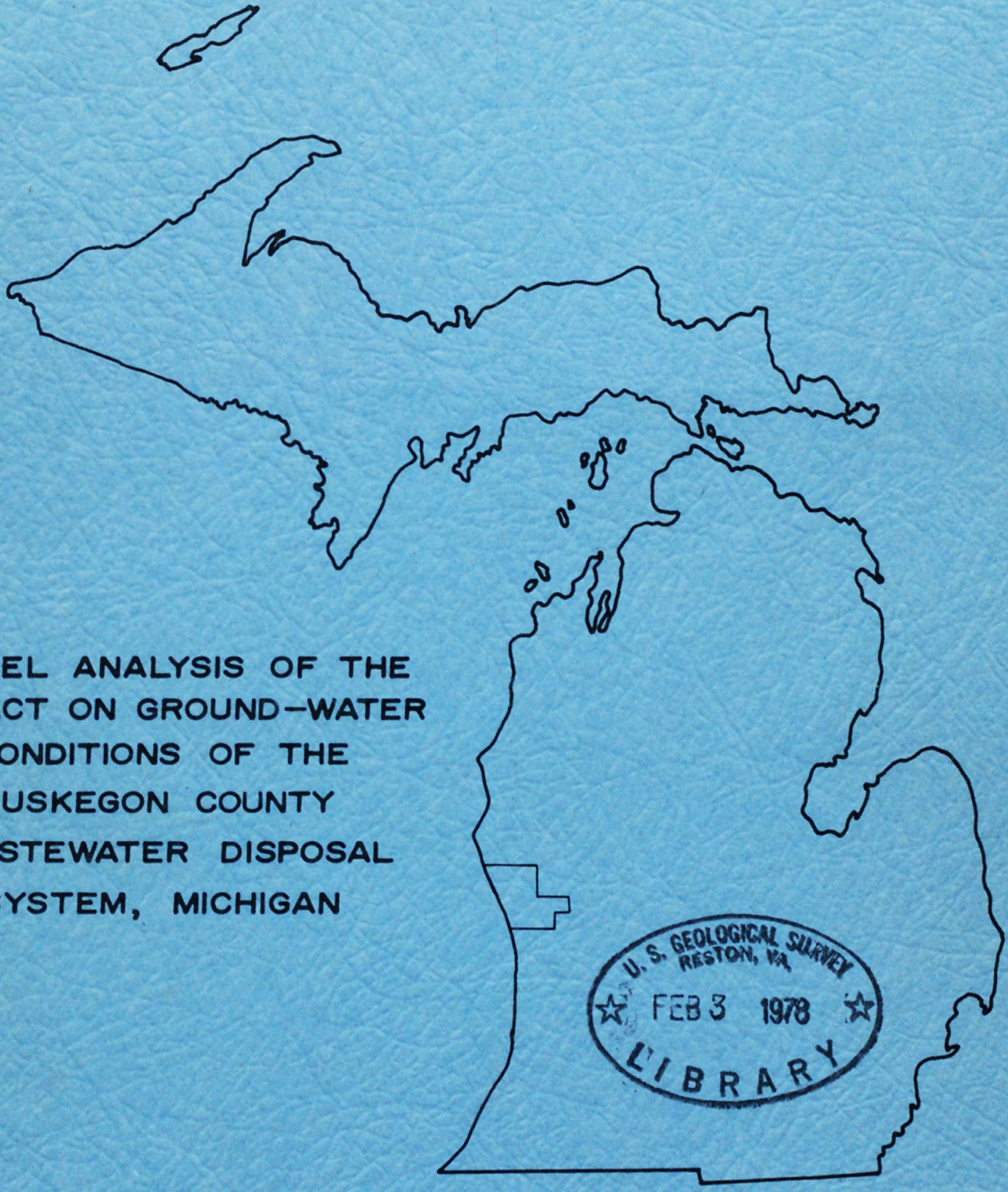
UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY



MODEL ANALYSIS OF THE IMPACT ON GROUND-WATER CONDITIONS OF THE MUSKEGON COUNTY WASTEWATER DISPOSAL SYSTEM, MICHIGAN

Open-file Report 78-99
Prepared in Cooperation with the Geology Division,
Michigan Department of Natural Resources
JANUARY 1978

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ILLUSTRATIONS

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FACTORS FOR CONVERTING ENGLISH UNITS TO INTERNATIONAL

SYSTEM (SI) UNITS

Multiply English Units	By	To Obtain SI Units
inches (in)	2.54	centimeters (cm)
feet (ft)	0.3048	meters (m)
miles (mi)	1.609	kilometers (km)
acres	0.4047	hectares (ha
square miles (mi^2)	2.590	square kilometers (km^2)
cubic feet per second	.02832	cubic meters per second (m^3/s)
gallons per day per square foot ($(gal/d)/ft^2$)	0.0407	meters per day (m/d)
square feet per day (ft^2/d)	0.0929	square meters per day (m^2/d)

Glossary

Aquifer.--A formation, group of formations, or part of a formation that contains sufficient saturated permeable material to yield significant quantities of water to wells and springs.

Artesian water.--Ground water that is under sufficient pressure to rise above the level at which it is encountered by a well, but which does not necessarily rise to or above the surface of the ground.

Base flow.--The discharge entering stream channels as effluent from the ground-water or other delayed sources; sustained or fair weather flow of streams.

Bedrock.--In this report, designates the consolidated rock underlying the glacial deposits.

Confining bed.--A body of relatively impermeable material stratigraphically adjacent to one or more aquifers.

Evapotranspiration.--Water withdrawn from a land area by direct evaporation from water surfaces and moist soil and by plant transpiration, no attempt being made to distinguish between the two.

Head.--The height of the water surface in a cased well at a point in an aquifer. Also called static head.

Hydraulic conductivity.--Ability of a porous mediam to transmit water.

Hydrograph.--A graph showing stage, flow, levels or other property of water with respect to time.

Potentiometric surface.--A surface which represents the levels to which water will rise in tightly cased wells.

Recharge.--Comprises the processes by which water is absorbed and is added to the zone of saturation. Also, the quantity of water added to the zone of saturation.

Specific yield.--The ratio of the volume of water which the saturated medium will yield by gravity to the volume of the porous medium.

Transmissivity.--The ability of aquifer material to transmit water. It is equal to the product of hydraulic conductivity and thickness.

Water table.--The upper surface of the zone of saturation, except where the surface is formed by an impermeable body.

Water-table aquifer.--One in which the upper surface of the body of water is a water table.

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ABSTRACT

A digital model was developed to study the impact on ground-water conditions of the Muskegon County wastewater disposal system. At the disposal site, wastewater is stored in two 850-acre (344-ha) lagoons and then spray-irrigated on crop land. About 70 miles (105 km) of drainage tile, which underlies the irrigated land, has caused the water table to be lowered substantially. The decline in water levels has been partially offset by irrigation and leakage from the lagoons; at some places the water table is higher than it was prior to construction. Predictive simulations by the model were used to study the effects of varying tile drainage, amount of irrigation water applied, lagoon leakage, and natural ground-water recharge. If the effectiveness of the tile to collect drainage is reduced by 75 percent, large areas within the wastewater site would become waterlogged. However, the effect outside of the wastewater site would be negligible.

INTRODUCTION

This report summarizes the results of an investigation of ground-water conditions from 1974 to 1976 at the Muskegon County, Michigan spray-irrigation wastewater disposal facility. The principle purpose of the investigation was to develop a mathematical model that, when used on a digital computer, would simulate the hydrologic system. Figure 1 shows the location and boundaries of the modeled area and the location of the wastewater facility. Geologic data for development and calibration of the model were obtained during the course of the study from a network of observation wells in and surrounding the treatment facility.

As additional information becomes available through the operation of the system, and as data on ground-water fluctuations accumulates, an improvement in the predictive capability of the model will be possible.

COOPERATION

The investigation was undertaken in cooperation with the Geology Division, Michigan Department of Natural Resources. In addition to sharing in the cost of the study, the Geology Division made available well records and other data from their files and provided assistance in field work at the treatment site.

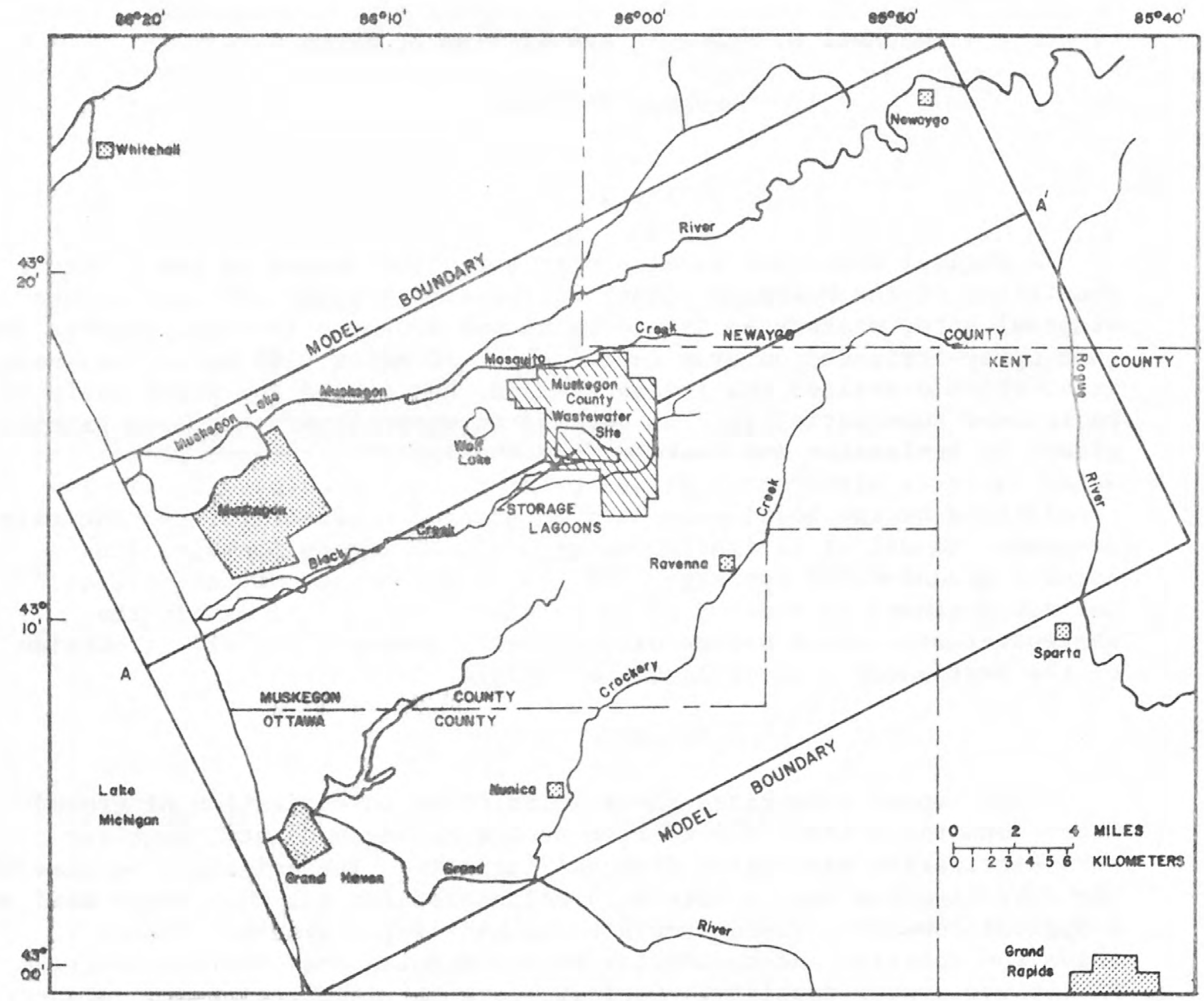

Figure 1. Location of study area. Line A-A' is cross section shown in figure 3.

ACKNOWLEDGEMENTS

The authors are indebted to all individuals who provided assistance in the course of this study, and are especially indebted to Dr. Y. A. Demirjian, Director of the Muskegon County Wastewater Management System, and Gordon D. Bennett, Hydrologist, U.S. Geological Survey. Their cooperation and personal assistance facilitated work at all stages of model development.

DESCRIPTION OF WASTEWATER DISPOSAL SYSTEM

The wastewater system has a design capacity of 42 M gal/d (1.8 m^3/s) (Bauer Engineering, Inc., 1973). Five municipalities and two industries currently pipe 29 M gal/d (1.3 m^3/s) to the site. Wastewater is aerated, chlorinated, and then used to irrigate corn. The treated water is sprayed on the land for 8 months; during the winter it is stored in two large lagoons, each having a surface area of 850 acres (344 ha). The bottoms of the lagoons are about 10 ft (3 m) above the preconstruction altitude of the water table. Leakage from the lagoons is intercepted by ditches that surround about 90 percent of the perimeter of lagoon area. Water in these seepage ditches is either pumped back to the lagoons or to adjacent streams. From the lagoons, water is pumped to center pivot rigs capable of irrigating crops at a rate of 3.5 in (8 cm) per week. There are 54 circles irrigating an area of 5400 acres (2200 ha) (fig. 2). Most circles are drained by corrugated polyethylene tiles having diameters of 6 to 10 in (15 to 25 cm). The tile is perforated with 0.06- by 1.5-in (0.2- by 3.8-cm) slots and is encased in a 0.02 in (0.5 mm) mesh fiberglass fabric. Drainage tile lines are generally set 5 to 8 feet (1.5 to 2.5 m) below land surface and are spaced at 500 ft (150 m) intervals. They are generally just below the water table, except in the northwest corner of the site, where the tile lines are few and above the water. Total length of the tile lines is 70 mi (105 km). Drainage tiles are connected to concrete collector tiles (fig. 2) that discharge to drainage ditches. In addition to tile, there are 30 wells (designated as pumped wells on fig. 2) that are used to control ground-water levels. Seven of the wells along the northwest edge of the lagoons are pumped to reduce ground-water mounding caused by lagoon leakage. The rest of the wells are used to control mounding caused by irrigation. This system of tiles, discharge wells, seepage ditches, and drainage ditches, was designed to lower ground-water levels in the project area.

GEOLOGY

Glacial Deposits

The western half of the modeled area (fig. 1) is underlain by sediments deposited in Pleistocene lakes (fig. 3) (Martin, 1955). The composition of the sediments varies from tight clay to fine gravel. Generally, the upper 20 to 80 ft (6 to 24 m) is well-sorted stratified sand, interlayered with fine gravel and silt. Underlying the sand and gravel are beds of relatively impermeable silt and clay. Topography in the western half is flat and poorly drained; recharge to the ground-water body is high.

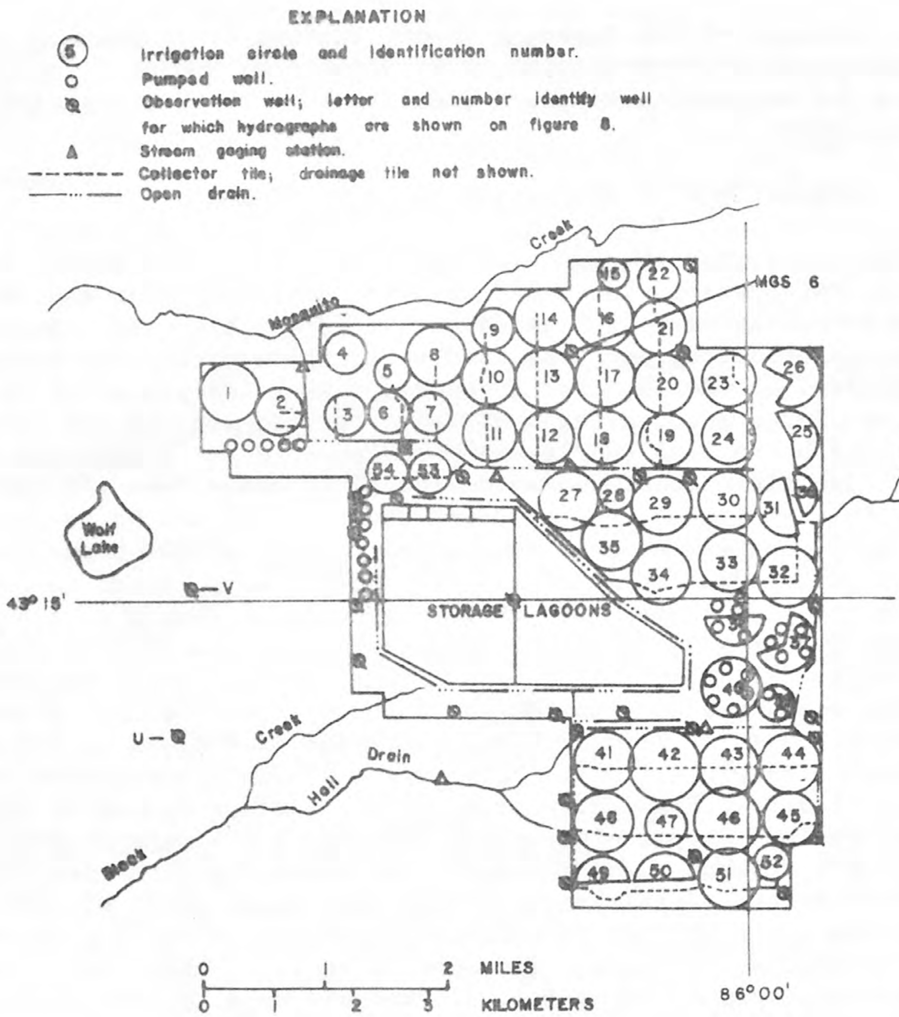

Figure 2. Muskegon County wastewater disposal system.

Most of the eastern part of the area is underlain by morainic deposits, poorly sorted silt and clay containing lenses of sand and gravel. Thin sand and gravel beds occur along some stream valleys. The thickness of the unconsolidated deposits ranges from 100 to 500 ft (30 to 165 m). Under the wastewater site these deposits are approximately 275 ft (85 m) thick. Undulating topography, more extensive stream development, and low recharge to the ground-water body characterize the eastern part.

Bedrock Deposits

Underlying the Pleistocene deposits are consolidated sedimentary rocks of Mississippian age (figs. 3, 4). They include the Bayport Limestone, Michigan Formation, Marshall Formation, and Coldwater Shale (Martin, 1936). The Bayport Limestone is predominantly limestone,

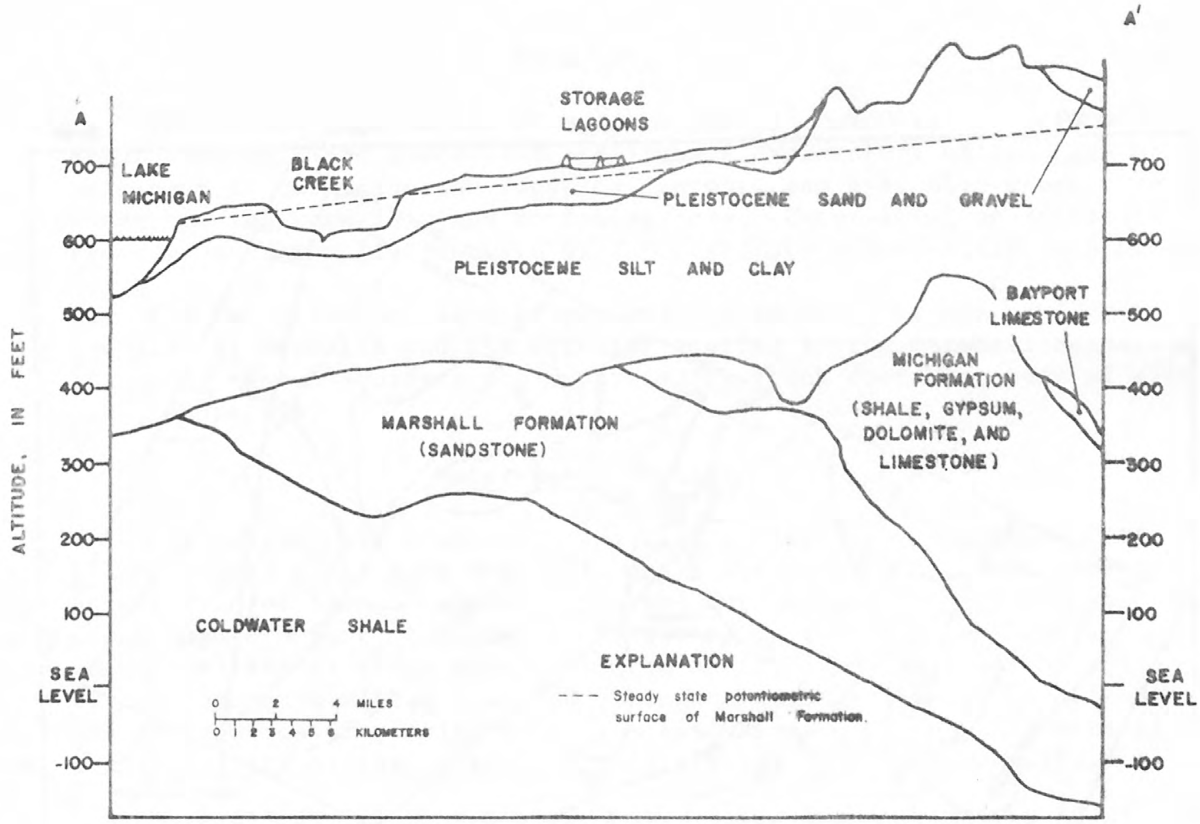

Figure 3. Cross section of study area showing geologic formations. Location of section A-A' shown in figure 1.

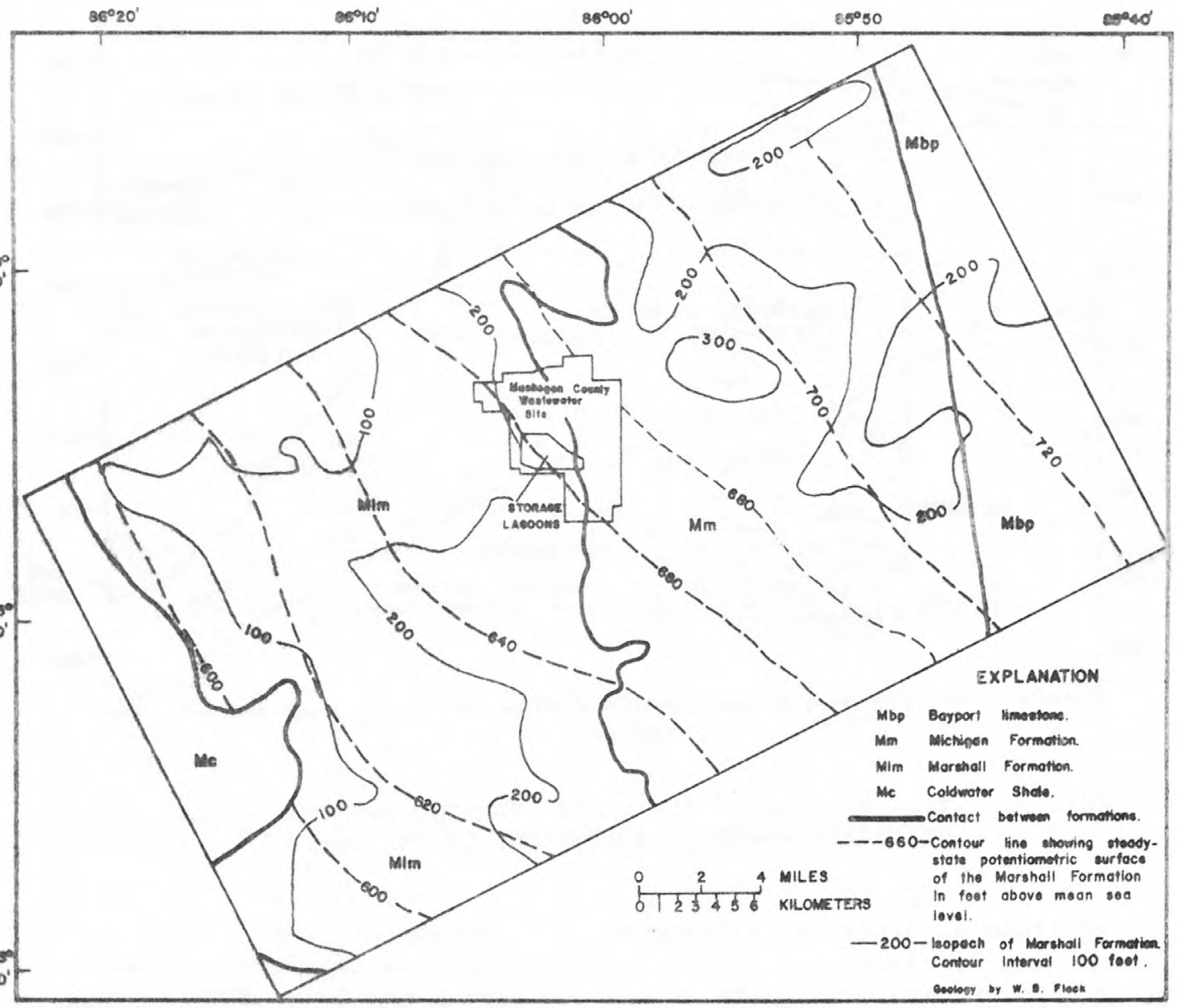

Figure 4. Subcrop formations, thickness, and potentiometric surface of Marshall Formation.

sandstone, and shale. The Michigan Formation is composed of relatively impermeable shale, gypsum, dolomite, and limestone. These two formations and the overlying silt and clay beds range in thickness from 80 ft (24 m) on the west to about 800 ft (245 m) on the east; they form a confining layer over the Marshall Formation. The Marshall is composed of highly permeable gray, pink, and red sandstones (deWitt, 1960, Dorr and Eschman, 1970). This formation ranges in thickness from 0 in the western part of the study area to as much as 300 ft (90 m) in the eastern part. The Coldwater Shale, a thick impermeable shale sequence, underlies and confines the Marshall Formation.

HYDROLOGY

The region studied has an area of 625 mi^2 (1620 km^2). Logs of water wells drilled since 1969 and logs of exploratory oil and gas wells were used to determine the location, extent, and hydraulic properties of water-bearing materials and confining beds. Water-level measurements recorded on the well logs were used to estimate steady-state conditions.

The two principal aquifer systems are the water-table aquifer in the glacial deposits and the artesian aquifer in the Marshall Formation (fig. 3). These aquifers are separated by thick confining beds of silt, clay, and shale.

Water-table Aquifer

The water-table aquifer in the glacial deposits is composed principally of sand containing some silt and gravel. The thickness of the aquifer ranges from 0, where it pinches out against the morainic deposits in the eastern part, to about 80 ft (24 m) in the west. Hydraulic conductivities of these materials were assigned on the basis of well-performance data within the study area and a general knowledge of the characteristics of glacial materials elsewhere. Initial estimates of transmissivity of the aquifer were determined from logs of wells.

Initial transmissivity values were later modified during model calibration. In the model, the water-table aquifer is represented by two layers; values contoured in figure 5 were the sum of the transmissivity values for the two layers.

The regional gradient of the water table is toward Lake Michigan. Water levels range from 820 ft (250 m) above mean sea level on the east side of the study area to 580 ft (177 m) along the shore of Lake Michigan. Water discharges from the aquifer regionally to Lake Michigan and locally to streams. Along the north edge of the wastewater facility, the water table slopes downward about 80 ft/mi (15 m/km) northward toward Mosquito Creek.

Recharge to the water-table aquifer was calculated to be 8 in/yr (20 cm/yr), based on long-term precipitation, streamflow, and ground-water levels. This value agrees well with those of Allen, Miller, and Wood (1972) and Walton (1970) for similar geohydrologic conditions in

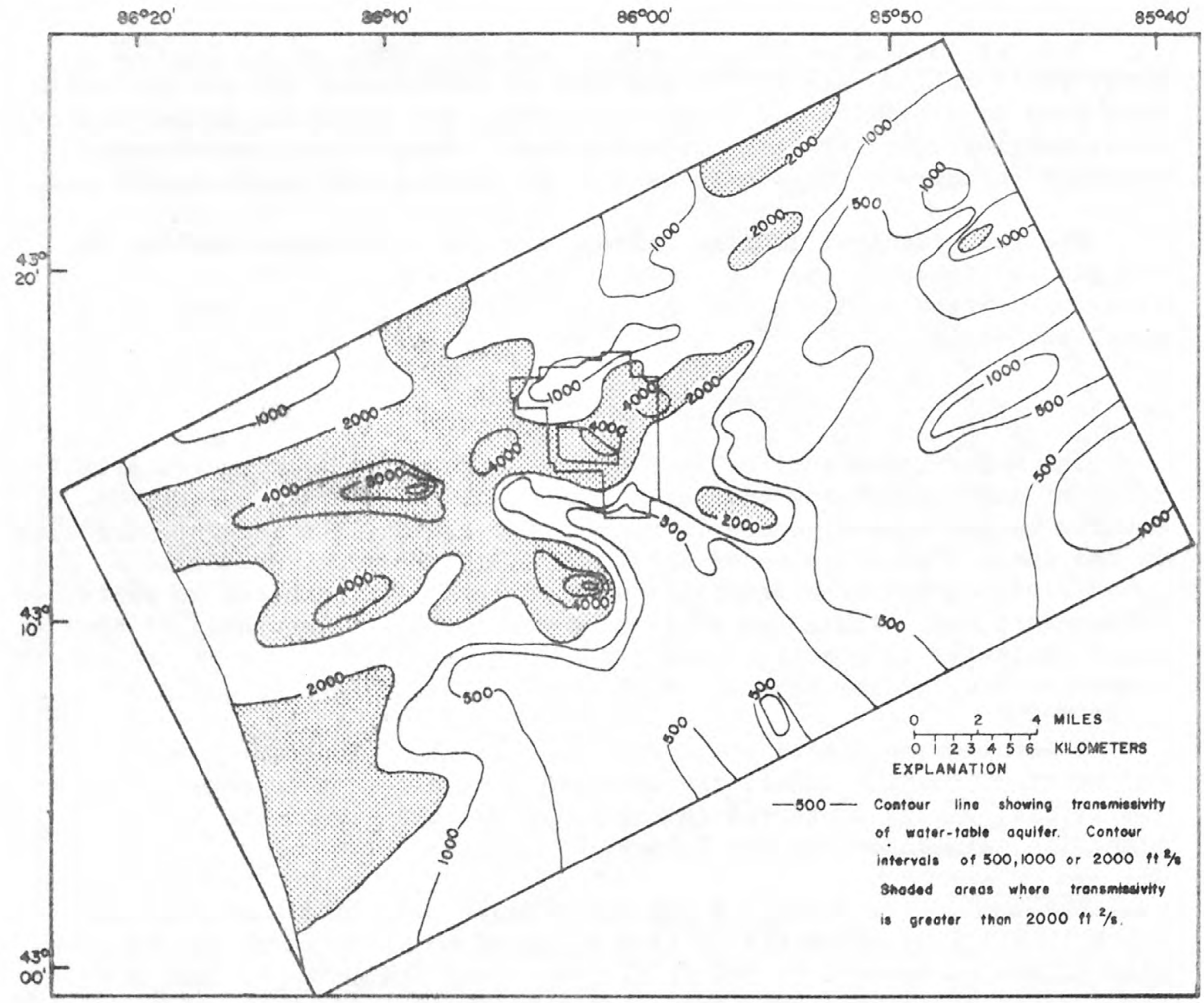

Figure 5. Transmissivity of the water-table aquifer.

southwestern Michigan and Illinois. Precipitation at the wastewater site, and recharge for 1974-75, are shown on table 1. Recharge rates were higher than average in 1974 and 1975 because of intensive storms.

Artesian Aquifer

The Marshall Formation is an artesian aquifer. Hydraulic conductivity values, determined from 7 pumping tests and 33 specific-capacity analyses (Brown and others, 1963, Walton, 1962), ranged from 200 to 20,000 (gal/d)/ft^2 (8 to 800 m/d); the median value was approximately 2000 (gal/d)/ft^2 (80 m/d). The thickness of the Marshall Formation was determined from 750 oil and gas logs. In the eastern half of the study area, where the formation underlies the Michigan Formation, the thickness ranges from 60 to 300 ft (100 m); the average thickness is about 240 ft (73 m). In the western half, the thickness gradually decreases westward from about 230 to 0 (70 m to 0) along the contact with the Coldwater Shale (fig. 3). Transmissivity of the Marshall Formation, determined by multiplying the formation thickness by the median hydraulic conductivity, ranges from 0 along the west border of the study area, where the Coldwater Shale is present, to 86,000 ft^2/d (8000 m^2/d) just east of the wastewater site.

In most of the study area and to the east, the Marshall Formation is recharged by downward flow from the water-table aquifer. Water levels in the artesian aquifer are lower than the overlying water table; at the east edge of the study area, this difference is as much as 100 ft (30 m). Flow within the Marshall Formation is to the west. The slope of the potentiometric surface is 4 to 10 ft/mi (0.8 to 1.9 m/km) (fig. 4). At the shore of Lake Michigan, the potentiometric head of the Marshall Formation is about 590 ft (180 m) above sea level; whereas, the lake level is 580 ft (177 m) above sea level. The vertical flow pattern here changes from downward recharge to upward discharge toward the lake.

Confining Unit

The confining beds of silt, clay, and shale that separate the water-table and artesian aquifers range in thickness from 80 ft (24 m) in the west to about 800 ft (245 m) in the east. Vertical hydraulic conductivity of confining beds, 0.10 (gal/d)/ft^2 (0.004 m/d), was estimated from previous investigations of similar materials in southern Michigan (Allen, Fleck, and Hanson, 1972) and in Ohio (Norris, 1963).

MODEL DESCRIPTION

A ground-water model is a mathematical description of the movement of water in a geologic environment. When converted to a form that permits computer solution of equations containing hydrologic and hydraulic parameters, the response of the ground-water system to stress may be predicted.

Table 1. Monthly precipitation, ground-water discharge to streams, change in ground water in storage and ground-water recharge in inches, in the model area.

Negative values of change in ground water in storage indicate declining water levels. Negative values of ground-water recharge result from losses due to evaportranspiration.

	Precipitation 1/		Ground-water discharge to streams 2/		Change in ground-water storage 3/		Ground-water recharge 4/	
	1974	1975	1974	1975	1974	1975	1974	1975
January	3.5	2.0	0.9	0.8	2.0	1.2	2.9	2.0
February	1.4	2.0	0.9	0.7	-0.5	1.2	0.4	1.9
March	4.3	2.2	1.4	1.1	0.8	1.0	2.2	2.1
April	2.7	2.0	1.6	1.2	1.2	0	2.8	1.2
May	5.8	2.0	1.5	0.9	-0.5	-1.9	1.0	-1.0
June	3.4	4.7	1.0	0.8	-2.5	-0.2	-1.5	0.6
July	1.1	1.6	0.6	0.6	-2.5	-2.2	-1.9	-1.6
August	3.6	9.3	0.5	0.5	-0.2	1.4	0.3	1.9
September	0.5	1.0	0.4	1.2	-0.8	1.2	-0.4	2.4
October	1.2	0.8	0.6	0.8	0.5	-0.2	1.1	0.6
November	2.6	3.6	0.7	1.0	1.5	0.7	2.2	1.7
December	1.3	2.5	0.7	1.4	0.2	1.1	0.9	2.5
TOTAL	31.4	33.7	10.8	11.0	-0.8	3.3	10.0	14.3

1/ Data from rain gage at wastewater disposal site.

2/ Average values calculated from streamflow hydrographs.

3/ Average from seven observation wells using specific yield of 0.2.

4/ Sum of ground-water discharge and change in ground-water storage.

Basic ground-water flow model

The differential equation describing flow in a porous saturated medium is

$$\frac{\partial}{\partial X} K_x \frac{\partial h}{\partial x} + \frac{\partial}{\partial y} K_y \frac{\partial h}{\partial y} + \frac{\partial}{\partial z} K_z \frac{\partial h}{\partial z} = S_s \frac{\partial h}{\partial t} + W(x,y,z,t), \quad (1)$$

where h is the head at time t.

K_x, K_y, *and* K_z are principal components of the hydraulic conductivity tensor alined with the coordinate axes,

S_s is the specific storage.

and W is a source term for inflow or withdrawal per unit volume of an aquifer. In most cases equation *1* cannot be solved analytically. However, it can be replaced with an approximating finite difference equation and thus solved numerically.

The area being modeled is divided into discrete cells by a rectilinear grid. The hydraulic properties of the material in each cell are assumed to be homogeneous, and the potentiometric head is calculated for a node at the center of each cell.

The computer program incorporating the techniques used to approximate a solution to equation 4 was developed by Trescott (1975). Modifications were made by Larson (written commun., March 1976) to simulate tile drainage and river leakage. A typical nonequilibrum simulation with this program will consist of several recharge periods, during each of which recharge to the top layer remains constant. The recharge periods are subdivided into time steps. The length of the time step (Δt in equation 5) affects the accuracy of the approximation to equation 3. As the time steps get shorter, the accuracy of approximation improves, but computation time increases. Similarly, as the cell dimensions become smaller, the accuracy of approximation improves, but again the computation time increases. Thus, the length of the time step and size of the cells must be selected to give acceptable results in a reasonable processing time.

A listing of the computer program with instructions for setting up the data deck is contained in the appendix. More complete documentation is contained in the user's manual by Trescott (1975). The program was written in Fortran for use on IBM 360/370 computer.[1] For this application approximately 600,000 bytes of core storage were required.

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

Drainage Analysis

A separate analysis was made to determine the effects of the drainage tiles. In this analysis, a cross-sectional model, based on simulation techniques described by Prickett and Lonnquist (1971), was utilized. The model simulated flow in a vertical plane perpendicular to a single drainage tile. The vertical depth of the cross section was assumed to be 33 ft (10 m), which is representative of the thickness of the water-table aquifer; the width was taken as half the drain spacing or 250 ft (75 m). To represent the drainage tile, a single node at one side of the mesh was held at a head equal to its elevation. This node was a square, 0.5 ft (0.15 m) on a side; inflow was permitted through one side and through the bottom. The simulation represented half of the flow field to a drain. The hydraulic conductivity of the drain node was reduced to a fraction of that elsewhere to represent the hydraulic resistence of the drain pipe and the surrounding fiberglass net. Also, modifications were made in the model to allow the water-table boundary to move.

During each simulation, the model was set to represent a full saturated rectangular cross section, and recharge was applied to the uppermost node. A nonequilibrium simulation was conducted until steady-state conditions were achieved. As the nodes became dewatered during the simulation process, they were removed from the system by lowering the water-table boundary, and calculations were repeated to achieve a solution corresponding to the new boundary position. Except for the drain node and the recharge nodes, all boundaries were treated as zero-flow boundaries.

Model runs were made using values of lateral hydraulic conductivity that are in the range found at the Muskegon site. Also, several different ratios of lateral to vertical hydraulic conductivity were used. Results showed that the flow into both halves of the drainage tile could be expressed approximately as a function of hydraulic conductivity and average head above the drain by the relation

$$Q=K_L\ (h-V)G \text{ when } h\geq V, \qquad (2)$$

where Q is the flow into a unit length of drainage tile,
h is the average water-table elevation in the area drained by the tile,
V is the elevation of the tile,
K_L is the lateral hydraulic conductivity,
and G is a factor that varies with the anisotropy and with the hydraulic conductivity of the drain node.

When a vertical hydraulic conductivity equal to one-tenth the lateral hydraulic conductivity was used and when the conductivity in the drain node was set at one-tenth of the lateral conductivity elsewhere, G was found to be approximately 0.1. By varying the anisotropy and the conductivity of the drain node, values of G from 0.05 to 0.40 were obtained. These values were subsequently used in checking the sensitivity of the three-dimensional model under various drainage conditions.

The simulated area was divided by a rectilinear grid into 3 water-bearing layers each having 44 rows and 48 columns, as shown in figure 6. Layer 1, the lowermost layer, represents the Marshall Formation. Layer 2 represents all the water-table aquifer except the upper 20 ft (6 m); layer 3 represents the upper 20 ft (6 m). The water-table aquifer was divided into two layers so that drains and streams could be simulated in the uppermost layer as being shallow, rather than deep and affecting the full thickness of the aquifer. The confining unit between the Marshall Formation and the water-table aquifer was not treated as a separate layer; its effect was incorporated into the vertical hydraulic conductivities of layers 1 and 2.

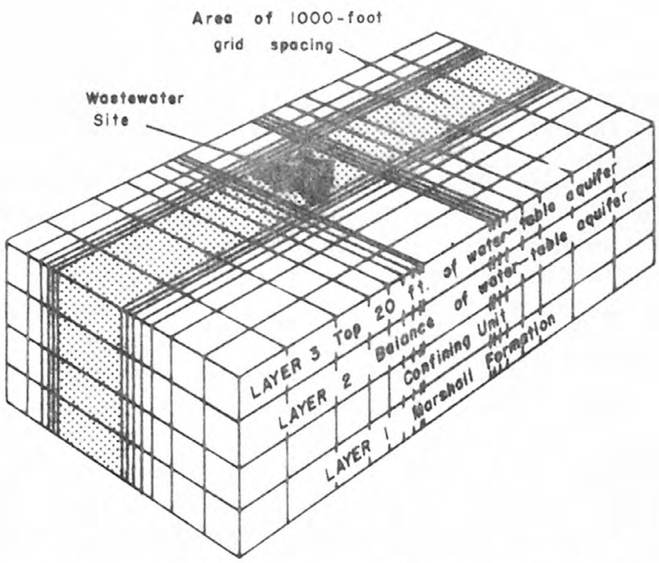

Figure 6. Grid spacing used in finite-difference model. Horizontal spacing ranges from 1,000 ft (305 m) at wastewater site to 15,000 ft (4500 m) at edge of model.

The horizontal grid was designed so that the smallest cells (1000 ft (300 m) on a side) represented the wastewater site (shaded area in figure 6). The grid spacing increased by a factor of 1.5 to the boundaries of the model. Moving the boundaries far beyond the simulated wastewater site greatly diminishes the sensitivity of the model at that site to the effects of the boundaries. All boundaries were treated as being the constant-flow type except the western boundary of the top layer, which was assumed to have a constant head equal to the elevation of Lake Michigan.

Storage effects were simulated only for the uppermost layer. Compressive storage in the unconfined aquifer below the water table was not simulated, nor was artesian storage in the Marshall Sandstone. Compressive storage in the confining unit above the Marshall was also neglected. It was assumed that these compressive effects would be negligible in comparison to the water-table storage in the uppermost layer. Thus, the model grid below the uppermost layer was purely transmissive in character.

The effects of streams on the ground-water system were simulated by the method described by Prickett and Lonnquist (1971, p. 33). The method is based on assumptions that a streambed layer separates the stream from the aquifer and that seepage from the stream to the aquifer becomes constant when the water level in the aquifer falls below the bottom of the streambed. Under these assumptions, the rate of flow through the streambed is expressed by the equation.

$$Q_r = K' A (M-p)/b \qquad (3)$$

where Q_r is the flow between the stream and the aquifer (it is positive when the flow is from the stream to the aquifer),
K' is the hydraulic conductivity,
b is the thickness of the streambed layer,
A is the area of streambed within the model cell,
M is the elevation of the stream surface,
p is the head in the top layer or the elevation of the bottom of the streambed layer, whichever is greater.

In the Muskegon model, K' was taken as one-tenth of the local lateral hydraulic conductivity in layer 3 of the model, and b was taken as 5 ft (1.5 m). Other values of these parameters were also tried during calibration.

Recharge to the water-table aquifer from the lagoons was treated as an evenly distributed constant seepage. In the initial calibrations, the seepage rate through the bottom of the lagoons was assumed to be 21 ft^3/s (0.50 m^3/s). This estimate was based on pumpage records from the seepage ditches around the lagoons. Approximately 23 ft^3/s (0.66 m^3/s) is pumped from these ditches, and it was assumed that 80 percent of this, or 19 ft^3/s (0.53 m^3/s), represents seepage from the lagoons. The balance represents drainage from other sources--that is, from surrounding irrigation circles or from regional ground-water flow. Also, because the seepage ditches do not completely enclose the lagoons, it was assumed that only 90 percent of the seepage from the lagoons was intercepted by the ditches. A total seepage of 21 ft^3/s (0.58 m^3/s) was, therefore, used.

If this estimate of lagoon seepage is accurate, it implies that the vertical hydraulic conductivity beneath the lagoons is considerably lower than that of the streambed or that of the water-table zone. This may reflect the effect of organic matter deposited in the lagoons, even though the system has been operated only since 1974.

The seepage ditches around the lagoons were simulated as streams, using equation 3; the streambed conductivity was assumed to be one-tenth of the local lateral hydraulic conductivity, and the streambed layer thickness was assumed to be 5 ft (1.5 m). Seepage into the ditches in computer simulations was found to be in close agreement with field data.

Data Base

Data required for the model included hydraulic properties of the hydrogeologic units, hydraulic properties of rivers and drainage tiles, and constant recharge and discharge sources. Heads and baseflow calculated by the model were compared with measured water levels and streamflow for calibration.

Initial estimates of the transmissivity of each cell in layers 1 and 2, and horizontal hydraulic conductivity of each cell in layer 3 were estimated from lithologic data. Specific yield of layer 3 was set to 0.2. Storage coefficient for layers 1 and 2 was set to 0. The vertical hydraulic conductivity between the bottom two layers at each horizontal grid location was assumed to be equal to the vertical hydraulic conductivity of the confining unit divided by the thickness of the confining unit at the grid location. The vertical hydraulic conductivity between the top two layers at each grid location was initially assumed to be equal to one-tenth of the horizontal hydraulic conductivity of the cell in the top layer at that grid location.

Engineering blueprints were used to estimate length and average elevation of drainage tiles. For each cell, the length and average elevations of all tiles in the cell were used.

The width, length, and elevation of rivers in each cell of the upper layer were determined from topographic maps. Thickness of the streambed layer, as noted previously, was assumed to be 5 ft (1.5 m). The vertical hydraulic conductivity of the streambed in each cell was initially assumed to be one-tenth of the horizontal hydraulic conductivity of the cell. A stream leakage factor was calculated independently of the model program from width, length, hydraulic conductivity, and streambed thickness. The leakage factor and the stream elevation were used in model computations.

In calculating irrigation rates, the design capacities and number of hours of operating time of the irrigation rigs were considered. Total recharge for each cell in the model area was calculated from lagoon leakage, amount of irrigation, and natural recharge.

Water level data from two sources were available. A long-term average water table map was derived from levels reported in driller's well records. Well hydrographs were drawn from records of water levels, which were measured twice a month in 90 observation wells during the study period.

All available geologic and hydrologic data were used. When field data were not available, regional estimates were made, as explained earlier. As more data became available they can be used to refine the model.

Calibration

A model is calibrated by repetitively running the computer program using available hydraulic data. The results of each simulation are then used to refine estimates of hydraulic parameters for subsequent simulations. Developing the Muskegon model involved a steady state calibration and a transient calibration. In each of these calibrations, it was observed that head differences between the upper and middle layers of the grid were negligible - that is, that heads in the upper 20 ft (6 m) of the water-table aquifer were essentially equal to those in the lower part of the aquifer. In presenting each simulation result, therefore, a single map of head in the water-table aquifer or changes in head has been utilized, rather than presenting separate maps for the two model layers representing the unconfined aquifer. Results are not shown for the artesian aquifer, inasmuch as changes in the potentiometric surface were small in all simulations.

During the steady-state calibration a specific yield of 0 was set in all cells of the uppermost layer, thereby eliminating the time dependence in equation 1. The purpose of steady-state calibration was to match the long-term average water table before construction of the wastewater facility with the water table calculated by the model. A uniform recharge of 8 in/yr (20 cm/yr) was used in computations.

A series of steady-state simulations was made to determine the sensitivity of the model to variations in the hydraulic parameters. The simulations indicated that the model was insensitive to changes in vertical hydraulic conductivity or stream leakage. It was, however, very sensitive to changes in horizontal hydraulic conductivity and transmissivity. Best results were obtained when these parameters were reduced to half their initial values. The comparison between computed and measured water-table positions after steady state calibration is shown in figure 7. Along the north edge of the area, steep ground-water gradients caused difficulty in matching water levels.

Transient calibration was used to test assumptions regarding the specific yield and the hydraulic characteristics of the wastewater facility and to further refine other parameters. The period January 1974 to December 1975 was used for transient calibration. This period included the first growing season during which the facility operated at full capacity, as well as some earlier period of operation at part capacity. Twenty-four monthly recharge periods were simulated. Initial heads used in the transient calibration were those calculated in the steady state model.

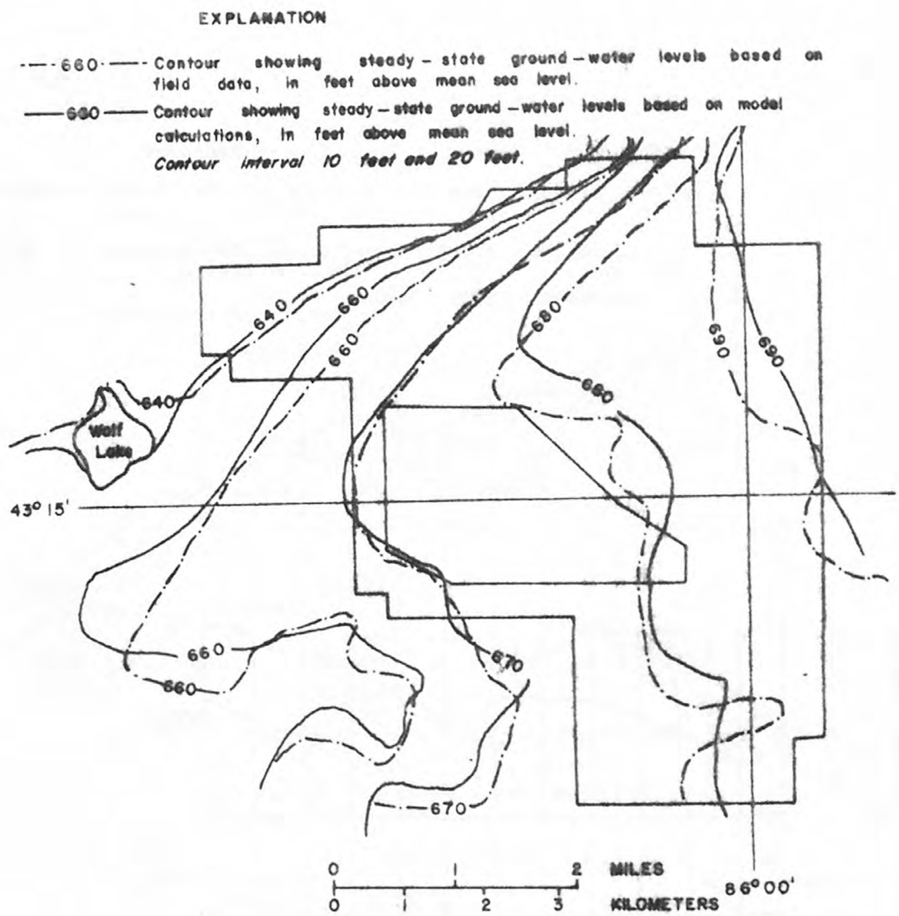

Figure 7. Steady-state water table from field measurements and from model calculations.

Only minor changes were made in hydraulic conductivity and transmissivity during transient calibration. The model was not particularly sensitive to changes in specific yield, and the original value of 0.2 was ultimately retained because it gave the best results. Stream location and stream surface elevation proved to be important factors. For this reason an effort was made to include all streams regardless of size and to establish stream surface elevation as accurately as possible.

Figure 8 shows four representative hydrographs after transient calibration, illustrating the final match between computed and observed water-level trends. Figure 9 compares measured water levels in the water-table aquifer during July 1975 with those calculated by the model during transient calibration. Figure 10 shows the comparison between the amount of observed and computed baseflow from the vicinity of the wastewater site during the period of transient calibration.

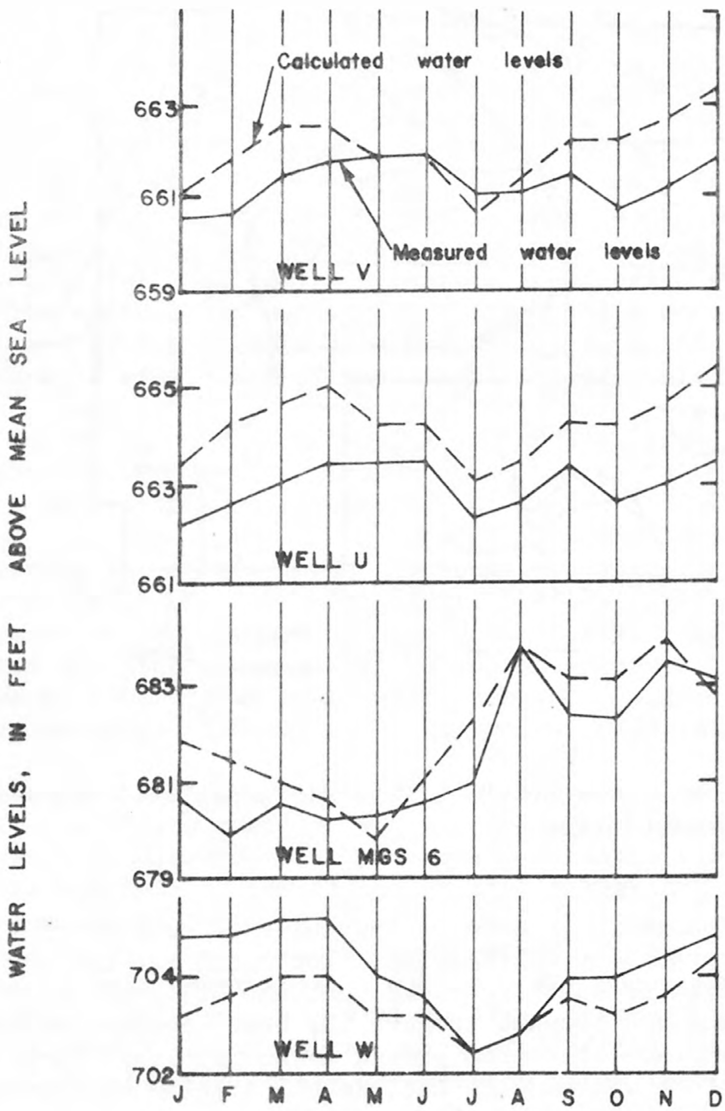

Figure 8. Hydrographs of water levels in selected wells during 1975 (from field measurements and from model calculations). Location of wells shown in figure 2.

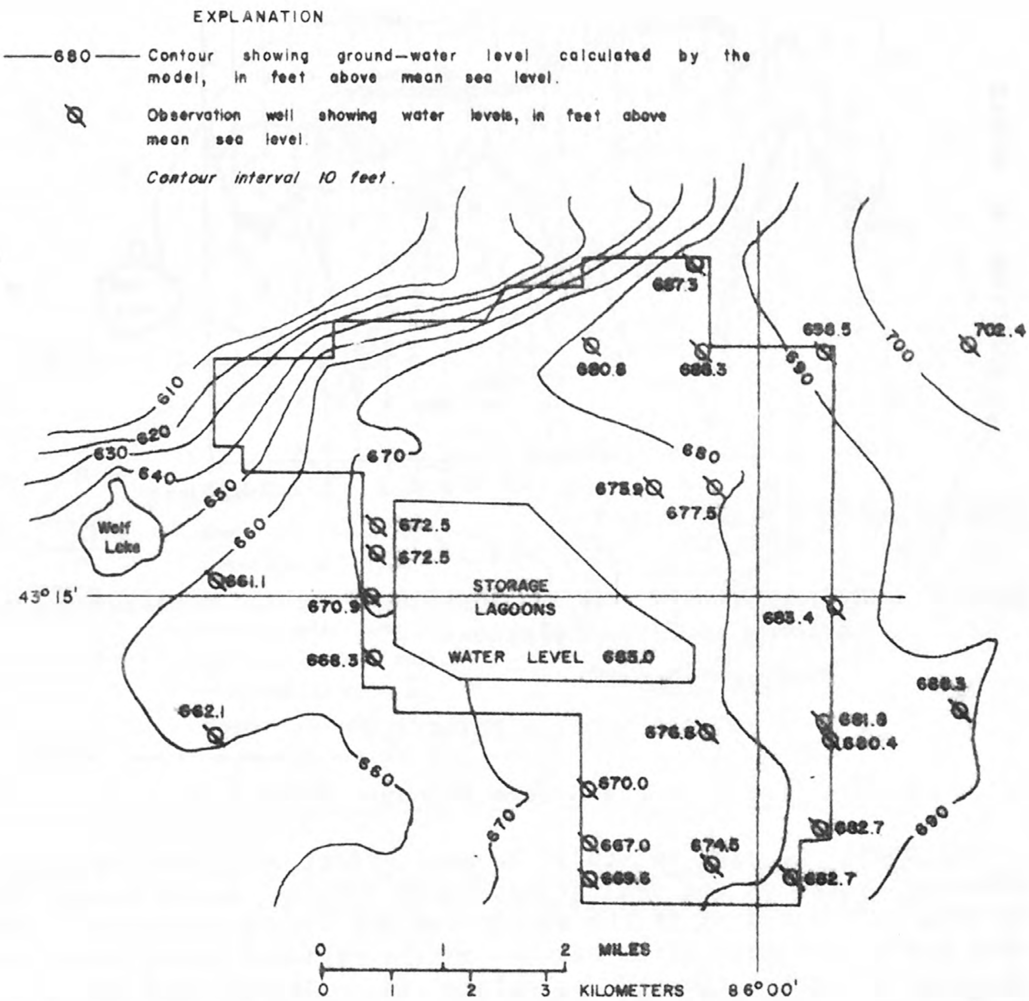

Figure 9. Altitude of water table during July 1975 from field measurements and from model calculations.

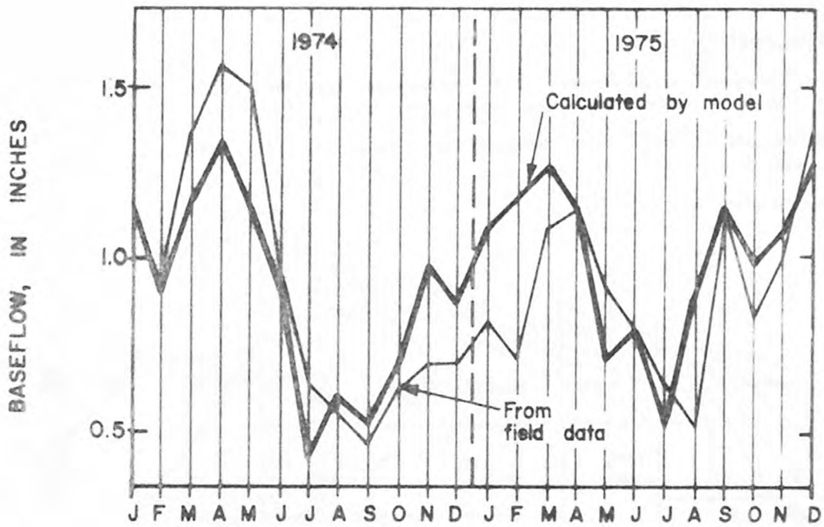

Figure 10. Hydrographs of monthly baseflow from field measurements and from model calculations.

INITIAL MODEL APPLICATIONS

Effects of the System through 1975

The model was used to study the past effect of operating the wastewater system on regional ground-water levels. Water levels for 1975 were calculated as if the system had not been constructed. The impact the wastewater system has had on the regional water table was determined by subtracting the calculated water levels from the actual levels. Figure 11 shows this impact. In most of the site, the effect of the facility has been to lower ground-water levels. However, water levels have risen in the northwestern part of the area, where there are relatively few drains.

Predictive Simulations

Several predictive simulations were made assuming a variety of operational conditions. In the first simulation, it was assumed that irrigation would be maintained at a uniform rate of 1.5 in (4 cm) per week (the average rate for 1975) in all irrigation circles, that lagoons would leak steadily at a rate of 21 ft^3/s (0.58 m^3s), and that drainage-tile performance would again be described by equation 8, with G taken as 0.1. In this and in all subsequent predictive simulations, the December 1975 water-level configuration was used as the starting surface. Steady state was usually attained after 3 or 4 years of operation. The simulations were nevertheless carried for several additional years. The results for 10 years of operation are presented in each case as the steady-state condition.

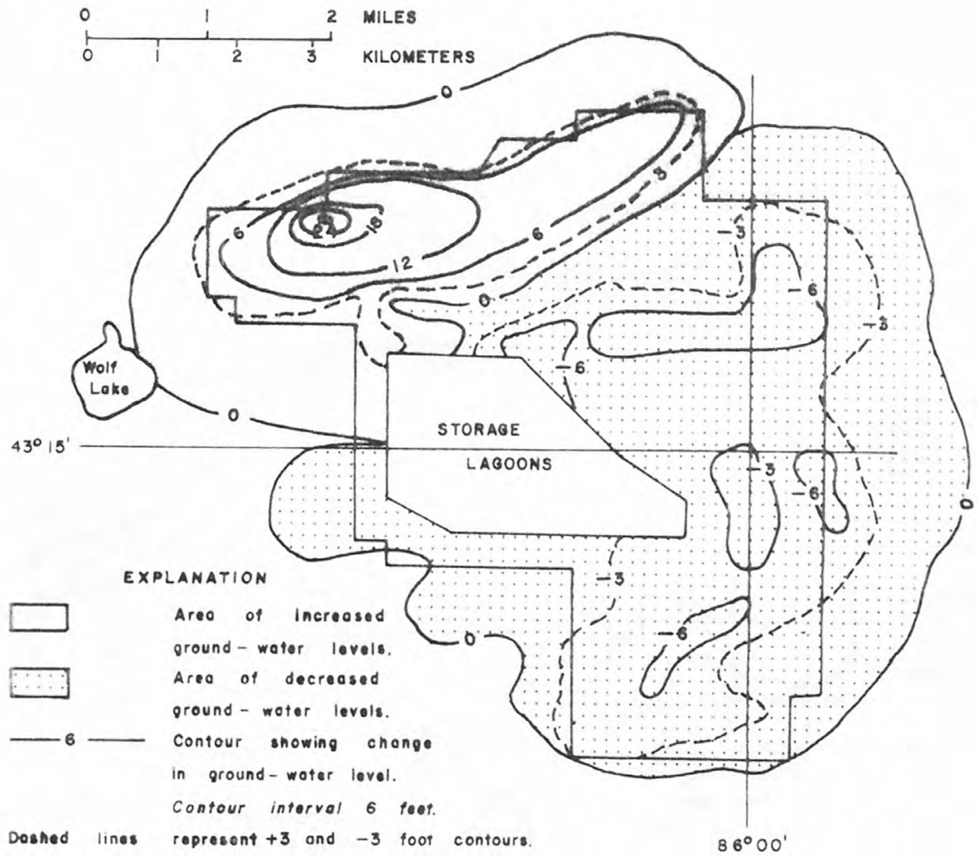

Figure 11. Changes in water level in the water-table aquifer caused by operation of the wastewater system, July 1975.

The results of the initial predictive simulation are shown in figure 12. The effects are primarily at the wastewater site. For a few areas within the site, the computed water levels are above land surface. These areas are shown on figure 12 as being waterlogged; that is, the water table in these areas is approximately at land surface.

The results shown in figure 12 do not imply that waterlogging is a necessary consequence of the waste disposal operation, but, rather, that irrigation at a rate of 1.5 in (4 cm) per week over the entire area would probably cause such problems. In practice, irrigation rates will vary from one part of the system to another and will be managed so as to avoid waterlogging, or alternatively, the number of drainage tiles could be increased to avoid waterlogging.

A second predictive simulation was made in which the irrigation rate was maintained at a uniform rate of 3 in (8 cm) per week (the design irrigation rate). Performance of drainage tiles and the lagoon seepage were the same as in the first predictive simulation. The 1975 water-level surface was again taken as the initial condition, and the

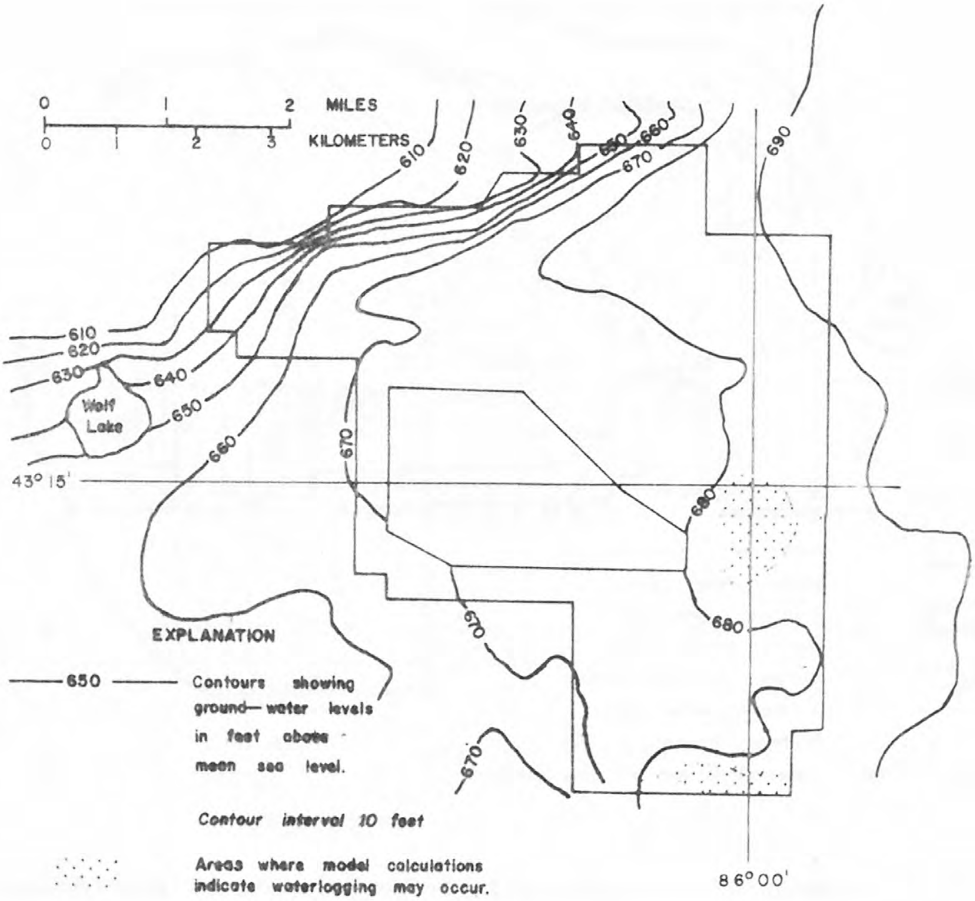

Figure 12. Steady-state water table from model calculations with 1.5 in (4 cm) per week irrigation, normal lagoon leakage, and tile seepage.

simulation was continued to steady state. Figure 13 shows contours of the water-table elevation after steady state was reached. The increase in the irrigation rate from 1.5 to 3.0 in (4 to 8 cm) per week caused the waterlogged area to increase from 350 acres to 1000 acres (150 ha to 400 ha). Figure 14 shows the rise in water level that may be expected with an increase in irrigation rate from 1.5 in (4 cm) per week to 3.0 in (8 cm) per week. The figure shows the difference between water level elevations in figures 12 and 13.

A third predictive simulation assumed that the irrigation rate would be maintained at 3.0 in (8 cm) per week and that lagoon leakage would continue at 21 ft^3/s (0.58 m^3s), but that the efficiency of the drainage tiles would be severely reduced by clogging. In the model, the factor G in equation 8 was reduced from 0.1 to 0.025, and thus the flow to the drains, for a given head differential, would be only 25 percent of that in earlier simulations. The 1975 water-table surface was again

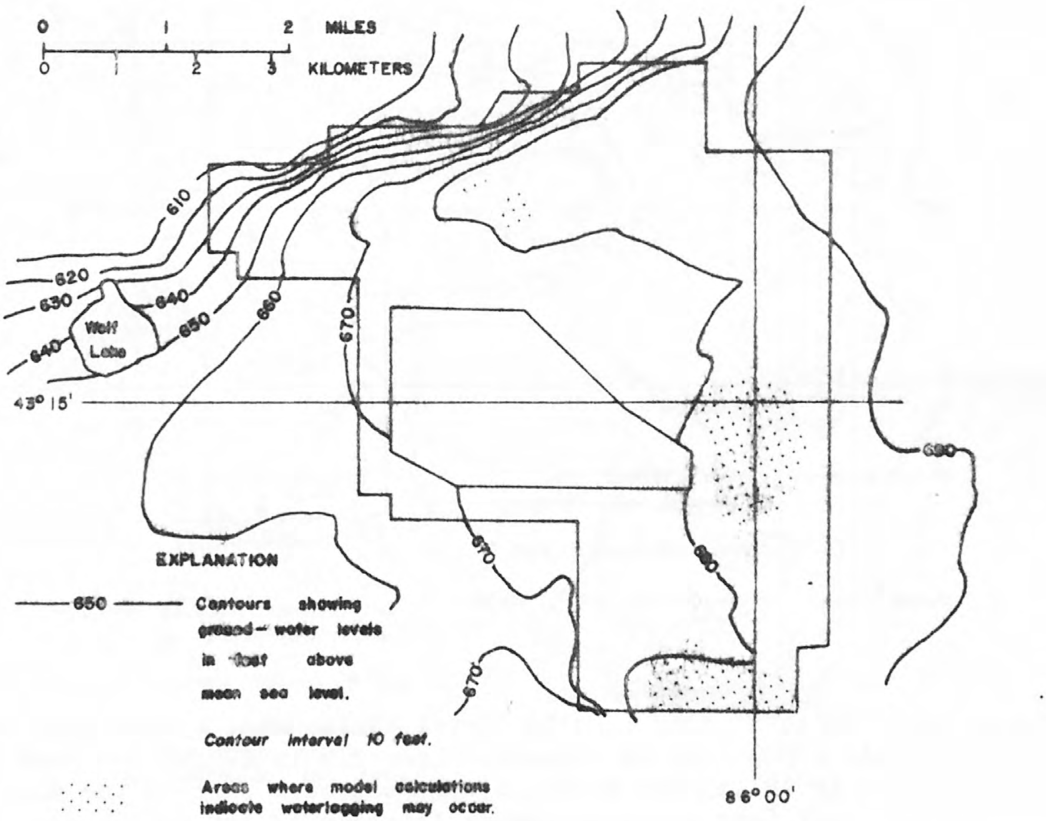

Figure 13. Steady-state water table from model calculations with 3 in (8 cm) per week irrigation, normal lagoon leakage, and tile seepage.

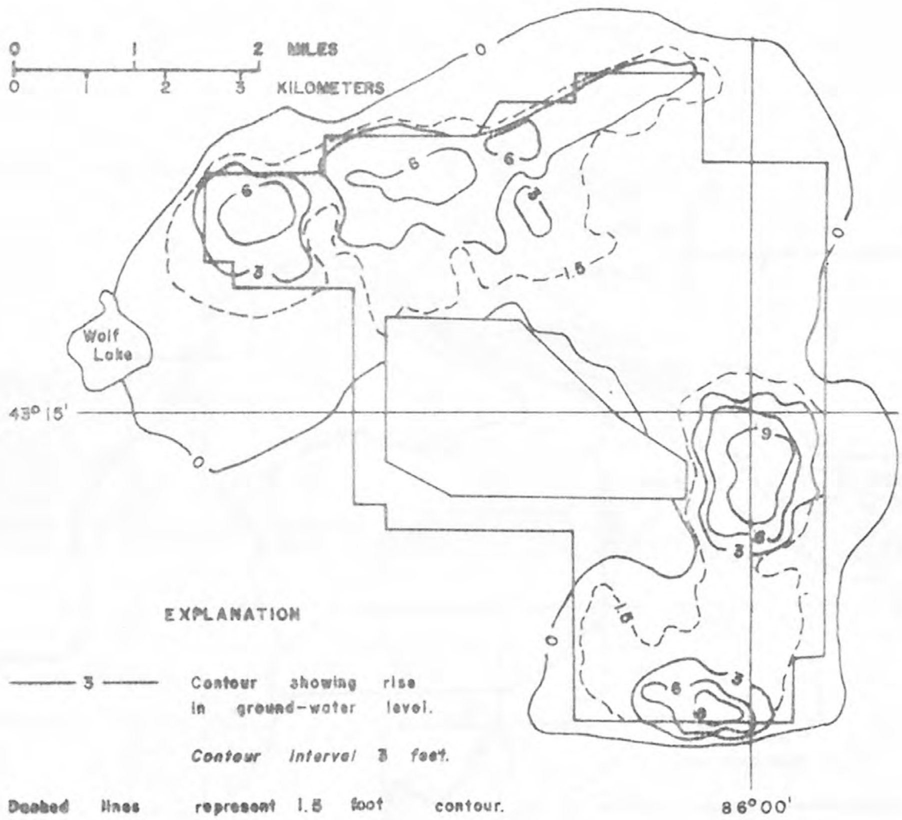

Figure 14. Predicted rise in water level in the water-table aquifer, if irrigation is increased from 1.5 in (4 cm) per week to 3 in (8 cm) per week. In the southern part of the site, the 1.5-in (4-cm)-per-week increase in irrigation rate causes a rise of as much as 9 ft (3 m).

taken as the starting condition, and calculations were continued until steady state was achieved. Figure 15 shows contours of the change in water level that would result from clogging of the drains. The contours represent the rise in water level, above the levels shown in figure 13, that would result if drainage efficiency were reduced but other factors remained as in the previous simulation. Nearly half the irrigated area becomes waterlogged. However, long before waterlogging became extensive, irrigation practices or drainage tiles could be modified.

A fourth predictive simulation was made keeping the rates of lagoon leakage, tile seepage, and irrigation the same as the second predictive simulation. However, the natural recharge was increased from 8 in/yr (20 cm/yr) to 12 in/yr (30 cm/yr). At the end of 10 years this simulation had not achieved steady state. Figure 16 shows the rise in water levels above the levels shown in figure 13 that would result from the increased recharge. The rise is negligible in most of the wastewater site, but as much as 6 ft (2 m) outside the site.

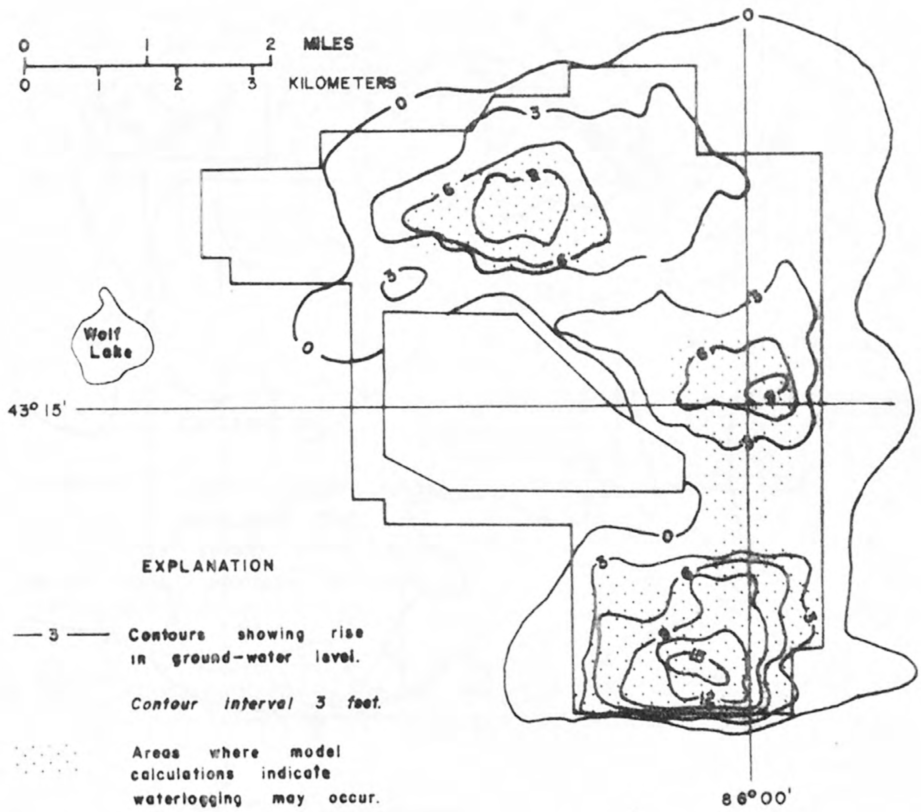

Figure 15. Predicted rise in water level in the water-table aquifer when seepage into drainage tile is reduced by 75 percent.

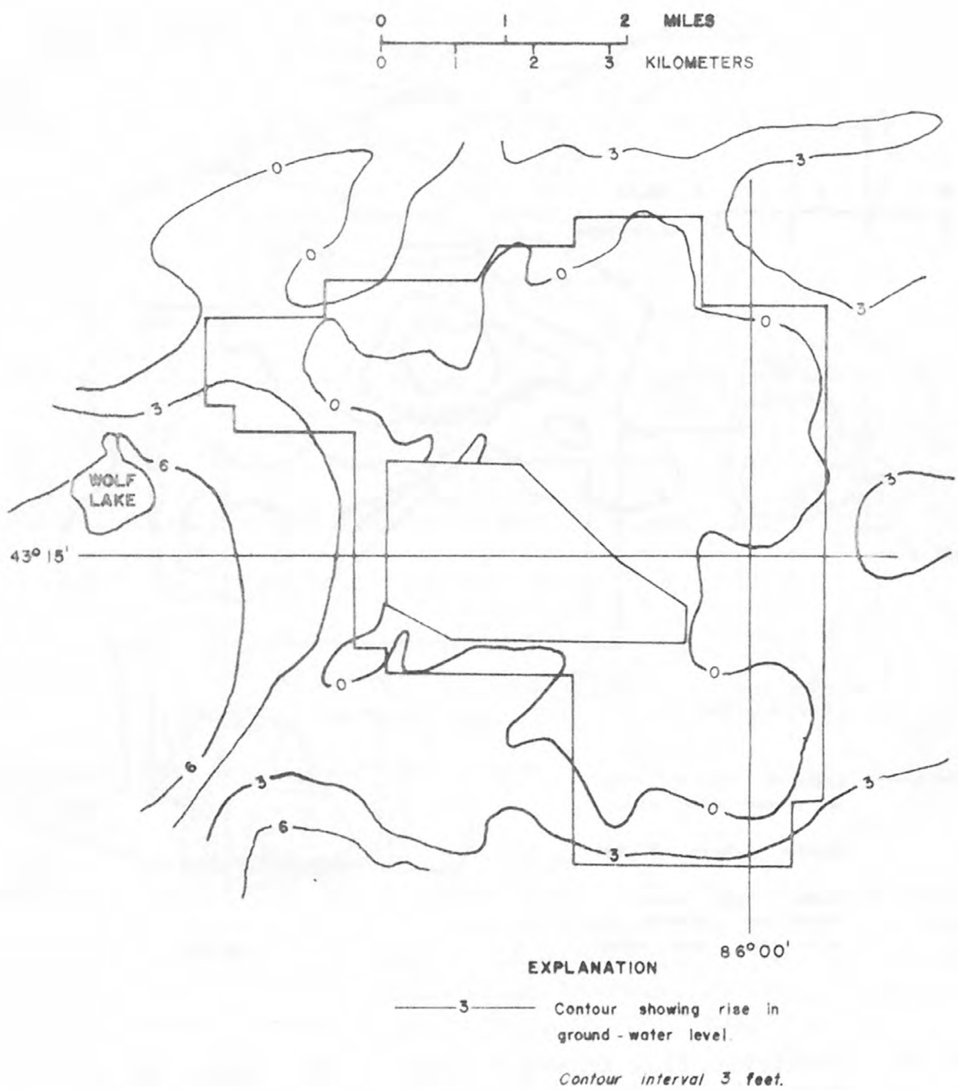

Figure 16. Predicted rise in water level in the water-table aquifer when natural recharge is increased from 8 in/yr (20 cm) to 12 in/yr (30 cm).

In the final predictive simulation, seepage from the lagoons was reduced to zero while the other factors remained unchanged. The purpose of this simulation was to determine the effect on water levels if the bottoms of the lagoons became effectively sealed with organic matter. The 1975 water-table was again taken as the starting condition, and the simulation was continued to steady state. Figure 17 shows contours of the changes in water level that would result from sealing the lagoons; that is, the changes caused by eliminating lagoon seepage while all other factors were maintained as in the second simulation. The changes in water level are relatively minor and are restricted to the immediate vicinity of the lagoons and a small area to the west that extends almost to Wolf Lake. There is virtually no reduction in the waterlogged areas from those shown in figure 13.

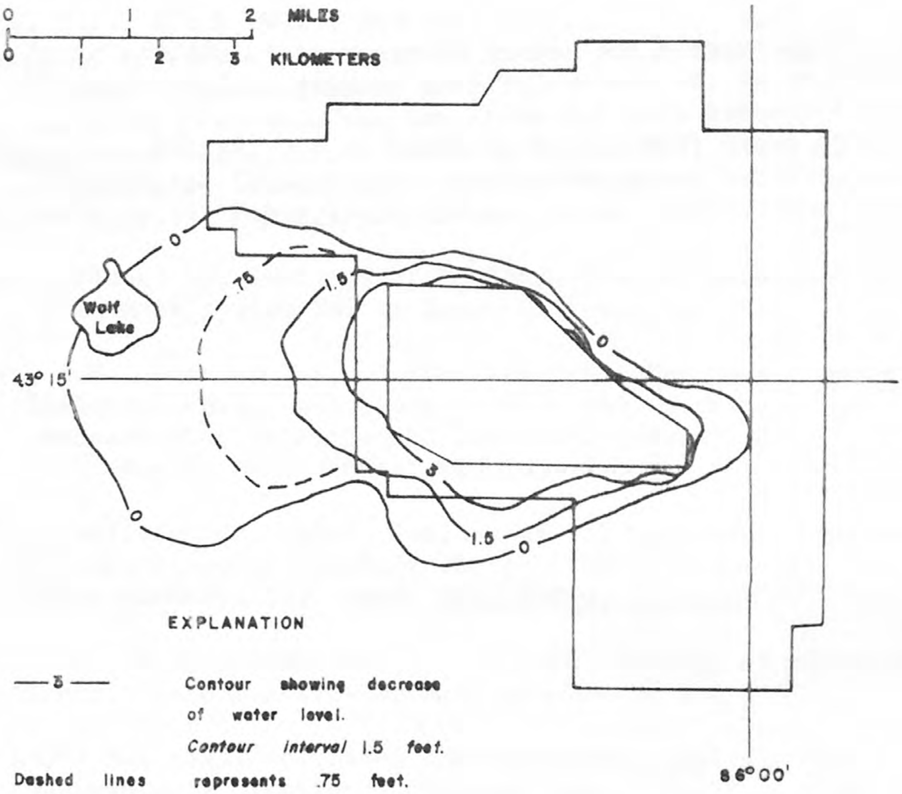

Figure 17. Predicted decline in water level in the water-table aquifer if the bottom of the storage lagoons become sealed.

SUMMARY

The ground-water system at the Muskegon wastewater site was simulated with a three-dimensional finite difference model. The model was calibrated from water-level records from 90 observation wells and from regional estimates of specific yield, recharge, and base flow. Data for simulating the necessary physical aspects of the wastewater system were taken from available engineering blueprints.

The calibrated model showed that, in general, the tile lines are effective in draining ground water from the site and that ground-water levels are lower than they would be under natural conditions. However, in the northwest part of the wastewater site, where tile lines are few and above the water table, water levels are as much as 24 ft (8 m) higher than they are at other locations within the site. Outside the site to the northwest, water levels are as much as 3 ft (1 m) higher than they would be under natural conditions.

Predictive simulations were made to determine the effects that varying operating conditions would have on the ground-water system. The simulations show, for example, that if the drainage tiles lost 75 percent

of their effectiveness the impact of disposal operations on ground-water levels outside of the wastewater site would be small. Also, if irrigation were increased from 1.5 in (4 cm) per week to 3 in (8 cm) per week, almost 1,000 acres (400 ha) of cropland would become waterlogged. Outside the site, the increase in water levels would be negligible, except to the northwest, where levels would rise about 3 ft (1 m).

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APPENDIX

Model Program

```
C     ------------------------------------------------------------------
C     FINITE-DIFFERENCE MODEL FOR SIMULATION OF GROUND-WATER FLOW IN
C     THREE DIMENSIONS, SEPTEMBER, 1975 BY P.C. TRESCOTT, U. S. G. S.
C     WITH CONTRIBUTIONS TO MAIN, DATAI AND SOLVE BY S.P. LARSON
C     ------------------------------------------------------------------
C
C     SPECIFICATIONS:
      REAL *8YSTR
C
      COMMON/FILS/ IFIL(14)
      COMMON/IDDC/ IDD(80)
      DIMENSION Y(106000), L(32), HEADNG(33), NAME(42), INFT(2,2), IOFT(
     19,4), DUM(3)
C
      EQUIVALENCE (YSTR,Y(1))
C
      COMMON /INTEGR/ I0,J0,K0,I1,J1,K1,I,J,K,NPER,KTH,ITMAX,LENGTH,KP,N
     1WEL,NUMT,IFINAL,IT,KT,IHEAD,IDRAW,IFLO,IERR,I2,J2,K2,IMAX,ITMX1,NC
     2H,IDK1,IDK2,IWATER,IQRE,IP,JP,IQ,JQ,IK,JK,K5,IPU1,IPU2,ITK
      COMMON /SPARAM/ TMAX,CDLT,DELT,ERR,TEST,SUM,SUMP,QR
      COMMON /RESMUN/ RESMO
      COMMON /SARRAY/ ICHK(13),LEVEL1(9),LEVEL2(9)
C
      DATA NAME/2*4H    ,4H   S,4HTART,4HING ,4HHEAD,4H    ,4H STO,4HRAG
     1E,4H COE,4HFFIC,4HIENT,2*4H    ,4H  TR,4HANSM,4HISSI,4HVITY,5*4H
     2    ,4H  TK,4H  HY,4HDRAU,4HLIC ,4HCOND,4HUCTI,4HVITY,2*4H    ,4HBOT
     3T,4HOM E,4HLEVA,4HTION,2*4H    ,4H   R,4HECHA,4HRGE ,4HRATE/
      DATA INFT/4H(20F,4H4.0),4H(8F1,4H0.4)/
      DATA IOFT/4H(1H0,4H,I2,,4H2X,2,4H0F6.,4H1/(5,4HX,20,4HF6.1,4H))    ,
     14H    ,4H(1H0,4H,I5,,4H14F9,4H.5/(,4H1H ,,4H5X,1,4H4F9.,4H5))  ,4H
     2    ,4H(1H0,4H,I5,,4H10E1,4H2.5/,4H(1H ,4H,5X,,4H10E1,4H2.5),4H)
     3,4H(1H0,4H,I5,,4H10E1,4H1.3/,4H(1H ,4H,5X,,4H10E1,4H1.3),4H)    /
C
      DEFINE FILE 2(14,2112,U,KKK)
C     ..................................................................
C
C     ---READ TITLE, PROGRAM SIZE AND OPTIONS---
      READ (5,200) HEADNG
      WRITE (6,190) HEADNG
      READ(5,197)(IFIL(IRX),IRX=1,14)
197   FORMAT(14I4)
      READ (5,198)(IDD(IBEX),IBEX=1,80)
198   FORMAT(80I1)
      READ (5,497) RESMO
497   FORMAT (F10.0)
      WRITE(6,498) RESMO
498   FORMAT ('ORESMO  ',F10.3)
      WRITE(6,191)
191   FORMAT('OVERSION G 1400 SEP 02 1976')
      READ (5,160) I0,J0,K0,ITMAX,NCH,ND,NRIV
      WRITE (6,180) I0,J0,K0,ITMAX,NCH,ND,NRIV
      READ (5,210) IDRAW,IHEAD,IFLO,IDK1,IDK2,IWATER,IQRE,IPU1,IPU2,ITK
      WRITE (6,220) IDRAW,IHEAD,IFLO,IDK1,IDK2,IWATER,IQRE,IPU1,IPU2,ITK
      IERR=0
C
C     ---COMPUTE DIMENSIONS FOR ARRAYS---
      J1=J0-1
      I1=I0-1
      K1=K0-1
      I2=I0-2
```

```
      J2=J0-2
      K2=K0-2
      IMAX=MAX0(I0,J0)
      NCD=MAX0(1,NCH)
      ITMX1=ITMAX+1
      ISIZ=I0*J0*K0
      IK1=I0*J0
      IK2=MAX0(IK1*K1,1)
      ISUM=2*ISIZ+1
      L(1)=1
      DO 30 I=2,14
      IF (I.NE.8) GO TO 20
      L(8)=ISUM
      ISUM=ISUM+IK2
      IF (IK2.EQ.1) GO TO 10
      IK=I0
      JK=J0
      K5=K1
      GO TO 30
   10 IK=1
      JK=1
      K5=1
      GO TO 30
   20 L(I)=ISUM
      ISUM=ISUM+ISIZ
   30 CONTINUE
      L(15)=ISUM
      ISUM=ISUM+J0
      L(16)=ISUM
      ISUM=ISUM+I0
      L(17)=ISUM
      ISUM=ISUM+K0
      L(18)=ISUM
      ISUM=ISUM+IMAX
      L(19)=ISUM
      ISUM=ISUM+K0*3
      L(20)=ISUM
      ISUM=ISUM+ITMX1
      L(21)=ISUM
      ISUM=ISUM+3*NCD
      L(22)=ISUM
      ISUM=ISUM+NCD
      L(23)=ISUM
      IF (IWATER.NE.ICHK(6)) GO TO 40
      ISUM=ISUM+IK1
      L(24)=ISUM
      ISUM=ISUM+IK1
      IP=I0
      JP=J0
      GO TO 50
   40 ISUM=ISUM+1
      L(24)=ISUM
      ISUM=ISUM+1
      IP=1
      JP=1
   50 L(25)=ISUM
      IF (IQRE.NE.ICHK(7)) GO TO 60
      ISUM=ISUM+IK1
      IQ=I0
      JQ=J0
```

```
      GO TO 70                                                          MAN1080
   60 ISUM=ISUM+1                                                       MAN1090
      IQ=1                                                              MAN1100
      JQ=1                                                              MAN1110
   70  IF(ND.EQ.0) GO TO 75
       L(26)=ISUM
       ISUM=ISUM+IK1
       L(27)=ISUM
       ISUM=ISUM+ND
       L(28)=ISUM
       ISUM=ISUM+ND
       GO TO 76
   75  L(26)=ISUM
       ISUM=ISUM+1
       L(27)=ISUM
       ISUM=ISUM+1
       L(28)=ISUM
       ISUM=ISUM+1
   76 IF(NRIV.EQ.0) GO TO 77
      L(29)=ISUM
      ISUM=ISUM+IK1
      L(30)=ISUM
      ISUM=ISUM+NRIV
      L(31)=ISUM
      ISUM=ISUM+NRIV
      L(32)=ISUM
      ISUM=ISUM+NRIV
      GO TO 78
   77 L(29)=ISUM
      L(30)=ISUM+1
      L(31)=ISUM+2
      L(32)=ISUM+3
      ISUM=ISUM+4
   78 WRITE(6,170) ISUM
C                                                                       MAN1130
C     ---PASS INITIAL ADDRESSES OF ARRAYS TO SUBROUTINES---             MAN1140
      CALL DATAI(Y(L(1)),Y(L(2)),Y(L(3)),Y(L(4)),Y(L(5)),Y(L(6)),Y(L(7))MAN1150
     1,Y(L(8)),Y(L(9)),Y(L(15)),Y(L(16)),Y(L(17)),Y(L(19)),Y(L(23)),Y(L(MAN1160
     224)),Y(L(25)),Y(L(26)),Y(L(27)),Y(L(28)),Y(L(29)),Y(L(30)),
     3 Y(L(31)),Y(L(32)))
      CALL STEP(Y(L(1)),Y(L(2)),Y(L(3)),Y(L(4)),Y(L(5)),Y(L(6)),Y(L(7)),MAN1180
     1Y(L(8)),Y(L(9)),Y(L(15)),Y(L(16)),Y(L(17)),Y(L(19)),Y(L(18)),Y(L(2MAN1190
     20)))                                                              MAN1200
      CALL SOLVE(Y(L(1)),Y(L(2)),Y(L(3)),Y(L(4)),Y(L(5)),Y(L(6)),Y(L(7))MAN1210
     1,Y(L(8)),Y(L(9)),Y(L(15)),Y(L(16)),Y(L(17)),Y(L(19)),Y(L(10)),Y(L(MAN1220
     211)),Y(L(12)),Y(L(13)),Y(L(14)),Y(L(20)),Y(L(25)),Y(L(23)),
     3 Y(L(26)),Y(L(27)),Y(L(28)),Y(L(29)),Y(L(30)),Y(L(31)),Y(L(32)),
     4 ND,NRIV)
      CALL COEF(Y(L(1)),Y(L(2)),Y(L(3)),Y(L(4)),Y(L(5)),Y(L(6)),Y(L(7)),MAN1240
     1Y(L(8)),Y(L(9)),Y(L(15)),Y(L(16)),Y(L(17)),Y(L(19)),Y(L(23)),Y(L(2MAN1250
     24)),Y(L(25)))                                                     MAN1260
      CALL CHECKI(Y(L(1)),Y(L(2)),Y(L(3)),Y(L(4)),Y(L(5)),Y(L(6)),Y(L(7)MAN1270
     1)),Y(L(8)),Y(L(9)),Y(L(15)),Y(L(16)),Y(L(17)),Y(L(19)),Y(L(21)),Y(LMAN1280
     2(22)),Y(L(25)),
     3 Y(L(26)),Y(L(27)),Y(L(28)),Y(L(29)),Y(L(30)),Y(L(31)),Y(L(32)),
     4 ND,NRIV)
      CALL PRNTAI(Y(L(1)),Y(L(2)),Y(L(4)),Y(L(5)),Y(L(9)),Y(L(15)),Y(L(1MAN1300
     16)))                                                              MAN1310
C                                                                       MAN1320
C     ---START COMPUTATIONS---                                          MAN1330
```

```
C     *************************
C     ---READ AND WRITE DATA FOR GROUPS II AND III---
      CALL DATAIN
      IRN=1
      NIJ=I0*J0
      DO 80 K=1,K0
      LOC=L(2)+(K-1)*NIJ
   80 CALL ARRAY(Y(LOC),INFT(1,2),IOFT(1,1),NAME(1),IRN,DUM)
      DO 90 K=1,K0
      LOC=L(5)+(K-1)*NIJ
   90 CALL ARRAY(Y(LOC),INFT(1,1),IOFT(1,2),NAME(7),IRN,DUM)
      DO 100 K=1,K0
      LOC=L(4)+(K-1)*NIJ
      L1=L(19)+K-1
      L2=L(19)+K0+K-1
      L3=L(19)+2*K0+K-1
      CALL ARRAY(Y(LOC),INFT(1,1),IOFT(1,2),NAME(13),IRN,DUM)
      Y(L1)=DUM(1)
      Y(L2)=DUM(2)
      Y(L3)=DUM(3)
  100 WRITE (6,230) K,Y(L1),Y(L2),Y(L3)
      IF (ITK.NE.ICHK(10)) GO TO 120
      DO 110 K=1,K1
      LOC=L(8)+(K-1)*NIJ
  110 CALL ARRAY(Y(LOC),INFT(1,1),IOFT(1,3),NAME(19),IRN,DUM)
  120 K=K0
      IF (IWATER.NE.ICHK(6)) GO TO 130
      CALL ARRAY(Y(L(23)),INFT(1,1),IOFT(1,4),NAME(25),IRN,DUM)
      CALL ARRAY(Y(L(24)),INFT(1,1),IOFT(1,1),NAME(31),IRN,DUM)
  130 IF (IQRE.EQ.ICHK(7)) CALL ARRAY(Y(L(25)),INFT(1,1),IOFT(1,4),NAME(
     137),IRN,DUM)
      CALL MDAT
      IF(ND.NE.0) CALL DDAT(ND)
      IF(NRIV.NE.0) CALL DDAT2(NRIV)
C
C     ---COMPUTE TRANSMISSIVITY FOR UNCONFINED LAYER---
      IF (IWATER.EQ.ICHK(6)) CALL TRANS(1)
C
C     ---COMPUTE T COEFFICIENTS---
      CALL TCOF
C
C     ---COMPUTE ITERATION PARAMETERS---
      CALL ITER
C
C     ---READ TIME PARAMETERS AND PUMPING DATA FOR A NEW PUMPING PERIOD-
  140 CALL NEWPER
C
      KT=0
      IFINAL=0
C
C     ---START NEW TIME STEP COMPUTATIONS---
  150 CALL NEWSTP
C
C     ---START NEW ITERATION IF MAXIMUM NO. ITERATIONS NOT EXCEEDED---
      CALL NEWITA
C
C     ---PRINT OUTPUT AT DESIGNATED TIME STEPS---
      CALL OUTPUT
C
C     ---LAST TIME STEP IN PUMPING PERIOD ?---
```

```
      IF (IFINAL.NE.1) GO TO 150                                        MAN1910
C                                                                       MAN1920
C     ---CHECK FOR NEW PUMPING PERIOD---                                MAN1930
      IF (KP.LT.NPER) GO TO 140                                         MAN1940
C                                                                       MAN1950
      STOP                                                              MAN1960
C                                                                       MAN1970
C     ---FORMATS---                                                     MAN1980
C                                                                       MAN1990
C                                                                       MAN2000
C                                                                       MAN2010
  160 FORMAT (8I10)                                                     MAN2020
  170 FORMAT ('0',54X,'WORDS OF VECTOR Y USED =',I7)                    MAN2030
  180 FORMAT ('0',62X,'NUMBER OF ROWS =',I5/60X,'NUMBER OF COLUMNS =',I5MAN2040
     1/61X,'NUMBER OF LAYERS =',I5//39X,'MAXIMUM PERMITTED NUMBER OF ITEMAN2050
     2RATIONS =',I5//48X,'NUMBER OF CONSTANT HEAD NODES =',I5,
     3 /,56X,'NUMBER OF DRAIN NODES =',I5,
     4 /,56X,'NUMBER OF RIVER NODES =',I5)
  190 FORMAT ('1',33A4)                                                 MAN2070
  200 FORMAT (20A4)                                                     MAN2080
  210 FORMAT (16(A4,1X))                                                MAN2090
  220 FORMAT ('-SIMULATION OPTIONS:  ',11(A4,4X))                       MAN2100
  230 FORMAT (1H0,44X,'DIRECTIONAL TRANSMISSIVITY MULTIPLICATION FACTORSMAN2110
     1 FOR LAYER',I3,/,76X,'X =',G15.7/76X,'Y =',G15.7/76X,'Z =',G15.7) MAN2120
      END                                                               MAN2130-
      SUBROUTINE DATAI(PHI,STRT,OLD,T,S,TR,TC,TK,WELL,DELX,DELY,DELZ,FACDAT0010
     1T,PERM,BOTTOM,QRE,ID,LD,ELD,IDR,RH,RC,RB)
C     ------------------------------------------------------------------DAT0030
C     READ AND WRITE DATA                                               DAT0040
C     ------------------------------------------------------------------DAT0050
C                                                                       DAT0060
C     SPECIFICATIONS:                                                   DAT0070
      REAL *8PHI                                                        DAT0080
      REAL *8XLABEL,YLABEL,TITLE,XN1,MESUR                              DAT0090
      REAL*4 LD
C                                                                       DAT0100
      DIMENSION PHI(I0,J0,K0), STRT(I0,J0,K0), OLD(I0,J0,K0), T(I0,J0,K0DAT0110
     1), S(I0,J0,K0), TR(I0,J0,K0), TC(I0,J0,K0), TK(IK,JK,K5), WELL(I0,DAT0120
     2J0,K0), DELX(J0), DELY(I0), DELZ(K0), FACT(K0,3), PERM(IP,JP), BOTDAT0130
     3TOM(IP,JP), QRE(IQ,JQ), TF(3), A(I0,J0), IN(6), IOFT(9), INFT(2)  DAT0140
     4 ,ID(I0,J0),LD(1),ELD(1)       ,IDR(I0,J0),RH(1),RC(1),RB(1)
C                                                                       DAT0150
      COMMON/FILS/ IFIL(14)
      COMMON /INTEGR/ I0,J0,K0,I1,J1,K1,I,J,K,NPER,KTH,ITMAX,LENGTH,KP,NDAT0160
     1WEL,NUMT,IFINAL,IT,KT,IHEAD,IDRAW,IFLO,IERR,I2,J2,K2,IMAX,ITMX1,NCDAT0170
     2H,IDK1,IDK2,IWATER,IQRE,IP,JP,IQ,JQ,IK,JK,K5,IPU1,IPU2,ITK        DAT0180
      COMMON /SPARAM/ TMAX,CDLT,DELT,ERR,TEST,SUM,SUMP,QR               DAT0190
      COMMON /SARRAY/ ICHK(13),LEVEL1(9),LEVEL2(9)                      DAT0200
      COMMON /CK/ ETFLXT,STORT,QRET,CHST,CHDT,FLUXT,PUMPT,CFLUXT,FLXNT  DAT0210
      COMMON /PR/ XLABEL(3),YLABEL(6),TITLE(6),XN1,MESUR,PRNT(122),BLANKDAT0220
     1(60),DIGIT(122),VF1(6),VF2(6),VF3(7),XSCALE,DINCH,SYM(17),XN(100),DAT0230
     2YN(13),NA(4),N1,N2,N3,YSCALE,FACT1,FACT2                          DAT0240
      RETURN                                                            DAT0250
C     ..................................................................DAT0260
C     ********************                                              DAT0270
      ENTRY DATAIN                                                      DAT0280
C     ********************                                              DAT0290
C                                                                       DAT0300
C     ---READ AND WRITE SCALAR PARAMETERS---                            DAT0310
      READ (5,330) NPER,KTH,ERR,LENGTH                                  DAT0320
```

```
      WRITE (6,340) NPER,KTH,ERR
      READ (5,460) XSCALE,YSCALE,DINCH,FACT1,(LEVEL1(I),I=1,9),FACT2,(LE
     1VEL2(I),I=1,9),MESUR
      IF (XSCALE.NE.0.) WRITE (6,470) XSCALE,YSCALE,MESUR,MESUR,DINCH,FA
     1CT1,LEVEL1,FACT2,LEVEL2
C
C     ---READ CUMULATIVE MASS BALANCE PARAMETERS---
      READ (5,450) SUM,SUMP,PUMPT,CFLUXT,QRET,CHST,CHDT,FLUXT,STORT,ETFL
     1XT,FLXNT
      IF (IDK1.EQ.ICHK(4)) GO TO 20
      IF (IPU1.NE.ICHK(8)) GO TO 50
C
C     ---READ INITIAL HEAD VALUES FROM CARDS---
      DO 10 K=1,K0
      DO 10 I=1,I0
   10 READ (5,360) (PHI(I,J,K),J=1,J0)
      GO TO 30
C
C     ---READ INITIAL HEAD AND MASS BALANCE PARAMETERS FROM DISK---
   20 READ (4) PHI,SUM,SUMP,PUMPT,CFLUXT,QRET,CHST,CHDT,FLUXT,STORT,ETFL
     1XT,FLXNT
      REWIND 4
   30 WRITE (6,430) SUM
      DO 40 K=1,K0
      WRITE (6,440) K
      DO 40 I=1,I0
   40 WRITE (6,350) I,(PHI(I,J,K),J=1,J0)
C
   50 DO 60 K=1,K0
      DO 60 I=1,I0
      DO 60 J=1,J0
      WELL(I,J,K)=0.
      TR(I,J,K)=0.
      TC(I,J,K)=0.
      IF (K.NE.K0) TK(I,J,K)=0.
   60 CONTINUE
      RETURN
C     **********************
      ENTRY ARRAY(A,INFT,IOFT,IN,IRN,TF)
C     **********************
      READ (5,330) FAC,IVAR,IPRN,TF,IRECS,IRECD
      IRLX=IFIL(IRN)
      IC=4*IRECS+2*IVAR+IPRN+1
      GO TO (70,70,90,90,120,120), IC
   70 DO 80 I=1,I0
      DO 80 J=1,J0
   80 A(I,J)=FAC
      WRITE (6,280) IN,FAC,K
      GO TO 140
   90 IF (IC.EQ.3) WRITE (6,290) IN,K
      DO 110 I=1,I0
      READ(IRLX,INFT) (A(I,J),J=1,J0)
      DO 100 J=1,J0
  100 A(I,J)=A(I,J)*FAC
  110 IF (IC.EQ.3) WRITE (6,IOFT) I,(A(I,J),J=1,J0)
      GO TO 140
  120 READ (2*IRN) A
      IF (IC.EQ.6) GO TO 140
      WRITE (6,290) IN,K
      DO 130 I=1,I0
```

```
  130 WRITE (6,IOFT) I,(A(I,J),J=1,J0)
  140 IF (IRECD.EQ.1) WRITE (2'IRN) A
      IRN=IRN+1
      WRITE (13) A
      RETURN
C     **********************
      ENTRY MDAT
C     **********************
      DO 150 K=1,K0
      DO 150 I=1,I0
      DO 150 J=1,J0
      IF (I.EQ.1.OR.I.EQ.I0.OR.J.EQ.1.OR.J.EQ.J0) T(I,J,K)=0.
      IF (IDK1.NE.ICHK(4).AND.IPU1.NE.ICHK(8)) PHI(I,J,K)=STRT(I,J,K)
      IF (K.NE.K0.OR.IWATER.NE.ICHK(6)) GO TO 150
      IF (I.EQ.1.OR.I.EQ.I0.OR.J.EQ.1.OR.J.EQ.J0) PERM(I,J)=0.
  150 CONTINUE
C     ............................. DELX ..............................
      READ (5,330) FAC,IVAR,IPRN
      IF (IVAR.EQ.1) READ (5,330) (DELX(J),J=1,J0)
      DO 170 J=1,J0
      IF (IVAR.NE.1) GO TO 160
      DELX(J)=DELX(J)*FAC
      GO TO 170
  160 DELX(J)=FAC
  170 CONTINUE
      IF (IVAR.EQ.1.AND.IPRN.NE.1) WRITE (6,370) (DELX(J),J=1,J0)
      IF (IVAR.EQ.0) WRITE (6,300) FAC
C     ............................. DELY ..............................
      READ (5,330) FAC,IVAR,IPRN
      IF (IVAR.EQ.1) READ (5,330) (DELY(I),I=1,I0)
      DO 190 I=1,I0
      IF (IVAR.NE.1) GO TO 180
      DELY(I)=DELY(I)*FAC
      GO TO 190
  180 DELY(I)=FAC
  190 CONTINUE
      IF (IVAR.EQ.1.AND.IPRN.NE.1) WRITE (6,380) (DELY(I),I=1,I0)
      IF (IVAR.EQ.0) WRITE (6,310) FAC
C     ............................. DELZ ..............................
      READ (5,330) FAC,IVAR,IPRN
      IF (IVAR.EQ.1) READ (5,330) (DELZ(K),K=1,K0)
      DO 210 K=1,K0
      IF (IVAR.NE.1) GO TO 200
      DELZ(K)=DELZ(K)*FAC
      GO TO 210
  200 DELZ(K)=FAC
  210 CONTINUE
      IF (IVAR.EQ.1.AND.IPRN.NE.1) WRITE (6,390) (DELZ(K),K=1,K0)
      IF (IVAR.EQ.0) WRITE (6,320) FAC
C
C     ---INITIALIZE VARIABLES---
      B=0.
      D=0.
      F=0.
      H=0.
      SU=0.
      Z=0.
      IF (XSCALE.NE.0.) CALL MAP
      RETURN
       ENTRY DDAT(ND)
```

```
      NK=1
      DO 500 I=1,I0
      READ(11,510)(ID(I,J),J=1,J0)
  510 FORMAT (80I1)
      DO 500 J=1,J0
      IF(ID(I,J).EQ.0) GO TO 500
      ID(I,J)=NK
      NK=NK+1
  500 CONTINUE
      NK=NK-1
      IF(NK.EQ.ND) GO TO 520
      PRINT 515,NK,ND
  515 FORMAT (' ERROR****NK.NE.ND   NK=',I5,5X,'ND=',I5)
      STOP
520   READ(11,330)FAC
      READ(11,530)(LD(I),I=1,ND)
  530 FORMAT(40F2.0)
      PRINT 540,(LD(I),I=1,ND)
  540 FORMAT(/,(20(1X,F5.0)))
      DO 550 I=1,I0
      DO 550 J=1,J0
      K=ID(I,J)
      IF(K.EQ.0) GO TO 550
      LD(K)=LD(K)*FAC*T(I,J,K0)/(DELX(J)*DELY(I))
  550 CONTINUE
      READ(11,330)FAC
      READ(11,560)(ELD(I),I=1,ND)
      PRINT 540,(ELD(I),I=1,ND)
  560 FORMAT (20F4.0)
      DO 570 I=1,ND
  570 ELD(I)=ELD(I)*FAC
      RETURN
      ENTRY DDAT2(NRIV)
      NK=1
      DO 580 I=1,I0
      READ(12,510)(IDR(I,J),J=1,J0)
      DO 580 J=1,J0
      IF(IDR(I,J).EQ.0) GO TO 580
      IDR(I,J)=NK
      NK=NK+1
  580 CONTINUE
      NK=NK-1
      IF(NK.EQ.NRIV) GO TO 600
      PRINT 585,NK,NRIV
  585 FORMAT('   ERROR****NK.NE.NRIV    NK=',I5,5X,'NRIV=',I5)
      STOP
600   READ(12,330)FAC
      READ(12,560)(RH(I),I=1,NRIV)
      PRINT 540,(RH(I),I=1,NRIV)
      DO 610 I=1,NRIV
  610 RH(I)=RH(I)*FAC
      READ(12,330)FAC
      READ(12,560)(RB(I),I=1,NRIV)
      PRINT 540,(RB(I),I=1,NRIV)
      DO 620 I=1,NRIV
  620 RB(I)=RB(I)*FAC
      READ(12,330)FAC
      READ(12,625)(RC(I),I=1,NRIV)
  625 FORMAT(10F8.0)
      PRINT 635,(RC(I),I=1,NRIV)
```

```
      DO 630 I=1,NRIV
  630 RC(I)=RC(I)*FAC
  635 FORMAT(/(14(1X,F8.0)))
      RETURN
C     ..................................................................
C     ---READ TIME PARAMETERS AND PUMPING DATA FOR A NEW PUMPING PERIOD-
C     **********************
      ENTRY NEWPER
C     **********************
C
      READ (5,330) KP,KPM1,NWEL,TMAX,NUMT,CDLT,DELT,IRECH
      IF(IRECH.EQ.1) READ(3) QRE
C
C     ---COMPUTE ACTUAL DELT AND NUMT---
      DT=DELT/24.
      TM=0.0
      DO 220 I=1,NUMT
      DT=CDLT*DT
      TM=TM+DT
      IF (TM.GE.TMAX) GO TO 230
  220 CONTINUE
      GO TO 240
  230 DELT=TMAX/TM*DELT
      NUMT=I
  240 WRITE (6,400) KP,TMAX,NUMT,DELT,CDLT
      DELT=DELT*3600.
      TMAX=TMAX*86400.
      SUMP=0.0
C
C     ---READ AND WRITE WELL PUMPING RATES---
      WRITE (6,410) NWEL
      IF (NWEL.EQ.0) GO TO 260
      DO 250 II=1,NWEL
      READ (5,330) K,I,J,WELL(I,J,K)
      WRITE (6,420) K,I,J,WELL(I,J,K)
  250 WELL(I,J,K)=WELL(I,J,K)/(DELX(J)*DELY(I))
  260 RETURN
C
C     ---FORMATS---
C
C
C
  280 FORMAT (1H0,52X,6A4,' =',G15.7,' FOR LAYER',I3)
  290 FORMAT (1H1,45X,6A4,' MATRIX, LAYER',I3/46X,41('-'))
  300 FORMAT ('0',72X,'DELX =',G15.7)
  310 FORMAT ('0',72X,'DELY =',G15.7)
  320 FORMAT ('0',72X,'DELZ =',G15.7)
  330 FORMAT (8G10.0)
  340 FORMAT ('0',51X,'NUMBER OF PUMPING PERIODS =',I5/49X,'TIME STEPS B
     1ETWEEN PRINTOUTS =',I5//51X,'ERROR CRITERIA FOR CLOSURE =',G15.7/)
  350 FORMAT ('0',I2,2X,20F6.1/(5X,20F6.1))
  360 FORMAT (8F10.4)
  370 FORMAT (1H1,46X,40HGRID SPACING IN PROTOTYPE IN X DIRECTION/47X,40
     1('-')//('0',12F10.0))
  380 FORMAT (1H-,46X,40HGRID SPACING IN PROTOTYPE IN Y DIRECTION/47X,40
     1('-')//('0',12F10.0))
  390 FORMAT (1H-,46X,40HGRID SPACING IN PROTOTYPE IN Z DIRECTION/47X,40
     1('-')//('0',12F10.0))
  400 FORMAT ('-',50X,'PUMPING PERIOD NO.',I4,':',F10.2,' DAYS'/51X,38('
     1-')//53X,'NUMBER OF TIME STEPS=',I6//59X,'DELT IN HOURS =',F10.3//
```

```
     253X,'MULTIPLIER FOR DELT =',F10.3)
  410 FORMAT ('-',63X,I4,' WELLS'/65X,9('-')//50X,'K',9X,'I',9X,'J     PU
     1MPING RATE'/)
  420 FORMAT (41X,3I10,2F13.2)
  430 FORMAT ('-',40X,' CONTINUATION - HEAD AFTER ',G20.7,' SEC PUMPING
     1'/42X,58('-'))
  440 FORMAT ('1',55X,'INITIAL  HEAD MATRIX, LAYER',I3/56X,30('-'))
  450 FORMAT (4G20.10)
  460 FORMAT (3G10.0,2(G10.0,9I1,1X),A8)
  470 FORMAT ('0',30X,'ON ALPHAMERIC MAP:'/40X,'MULTIPLICATION FACTOR FO
     1R X DIMENSION =',G15.7/40X,'MULTIPLICATION FACTOR FOR Y DIMENSION
     2=',G15.7/55X,'MAP SCALE IN UNITS OF  ',A11/50X,'NUMBER OF ',A8,' P
     3ER INCH =',G15.7/43X,'MULTIPLICATION FACTOR FOR DRAWDOWN =',G15.7,
     4' PRINTED FOR LAYERS',9I2/47X,'MULTIPLICATION FACTOR FOR HEAD =',G
     515.7,' PRINTED FOR LAYERS',9I2)
      END
      SUBROUTINE CHECKI(PHI,STRT,OLD,T,S,TR,TC,TK,WELL,DELX,DELY,DELZ,FA
     1CT,JFLO,FLOW,QRE,ID,FLD,FLD,IDR,RH,RC,RB,IDRAIN,IRIV)
C     ------------------------------------------------------------------
C     COMPUTE A VOLUMETRIC BALANCE
C     ------------------------------------------------------------------
C
C     SPECIFICATIONS:
      REAL *8PHI
C
      DIMENSION PHI(I0,J0,K0), STRT(I0,J0,K0), OLD(I0,J0,K0), T(I0,J0,K0
     1), S(I0,J0,K0), TR(I0,J0,K0), TC(I0,J0,K0), TK(IK,JK,K5), WELL(I0,
     2J0,K0), DELX(J0), DELY(I0), DELZ(K0), FACT(K0,3), JFLO(NCH,3), FLO
     3W(NCH), QRE(I0,J0)
     4,ID(I0,J0),FLD(1),FLD(1),IDR(I0,J0),RH(1),RC(1),RB(1)
C
      COMMON /INTEGR/ I0,J0,K0,I1,J1,K1,I,J,K,NPER,KTH,ITMAX,LENGTH,KP,N
     1WEL,NUMT,IFINAL,IT,KT,IHEAD,IDRAW,IFLO,IERR,I2,J2,K2,IMAX,ITMX1,NC
     2H,IDK1,IDK2,IWATER,IQRE,IP,JP,IQ,JQ,IK,JK,K5,IPU1,IPU2,ITK
      COMMON /SPARAM/ TMAX,CDLT,DELT,ERR,TEST,SUM,SUMP,QR
      COMMON /SARRAY/ ICHK(13),LEVEL1(9),LEVEL2(9)
      COMMON /CK/ ETFLXT,STORT,QRET,CHST,CHDT,FLUXT,PUMPT,CFLUXT,FLXNT
      RETURN
C     ..................................................................
C     ********************
      ENTRY CHECK
C     ********************
C     ---INITIALIZE VARIABLES---
      PUMP=0.
      STOR=0.
      FLUXS=0.0
      CHD1=0.0
      CHD2=0.0
      QREFLX=0.
      CFLUX=0.
      FLUX=0.
      ETFLUX=0.
      FLXN=0.0
      II=0
C     ..................................................................
C
C     ---COMPUTE RATES,STORAGE AND PUMPAGE FOR THIS STEP---
      DO 220 K=1,K0
      DO 220 I=2,I1
      DO 220 J=2,J1
```

```
      IF (T(I,J,K).EQ.0.) GO TO 220
      AREA=DELX(J)*DELY(I)
      IF (S(I,J,K).GE.0.) GO TO 180
C
C     ---COMPUTE FLOW RATES TO AND FROM CONSTANT HEAD BOUNDARIES---
      II=II+1
      FLOW(II)=0.
      JFLO(II,1)=K
      JFLO(II,2)=I
      JFLO(II,3)=J
      IF (S(I,J-1,K).LT.0..OR.T(I,J-1,K).EQ.0.) GO TO 30
      X=(PHI(I,J,K)-PHI(I,J-1,K))*TR(I,J-1,K)*DELY(I)
      FLOW(II)=FLOW(II)+X
      IF (X) 10,30,20
   10 CHD1=CHD1+X
      GO TO 30
   20 CHD2=CHD2+X
   30 IF (S(I,J+1,K).LT.0..OR.T(I,J+1,K).EQ.0.) GO TO 60
      X=(PHI(I,J,K)-PHI(I,J+1,K))*DELY(I)*TR(I,J,K)
      FLOW(II)=FLOW(II)+X
      IF (X) 40,60,50
   40 CHD1=CHD1+X
      GO TO 60
   50 CHD2=CHD2+X
   60 IF (K.EQ.1) GO TO 90
      IF (S(I,J,K-1).LT.0..OR.T(I,J,K-1).EQ.0.) GO TO 90
      X=(PHI(I,J,K)-PHI(I,J,K-1))*TK(I,J,K-1)*AREA*2./(DELZ(K)+DELZ(K-1)
     1)
      FLOW(II)=FLOW(II)+X
      IF (X) 70,90,80
   70 CHD1=CHD1+X
      GO TO 90
   80 CHD2=CHD2+X
   90 IF (K.EQ.KO) GO TO 120
      IF (S(I,J,K+1).LT.0..OR.T(I,J,K+1).EQ.0.) GO TO 120
      X=(PHI(I,J,K)-PHI(I,J,K+1))*TK(I,J,K)*AREA*2./(DELZ(K)+DELZ(K+1))
      FLOW(II)=FLOW(II)+X
      IF (X) 100,120,110
  100 CHD1=CHD1+X
      GO TO 120
  110 CHD2=CHD2+X
  120 IF (S(I-1,J,K).LT.0..OR.T(I-1,J,K).EQ.0.) GO TO 150
      X=(PHI(I,J,K)-PHI(I-1,J,K))*TC(I-1,J,K)*DELX(J)
      FLOW(II)=FLOW(II)+X
      IF (X) 130,150,140
  130 CHD1=CHD1+X
      GO TO 150
  140 CHD2=CHD2+X
  150 IF (S(I+1,J,K).LT.0..OR.T(I+1,J,K).EQ.0.) GO TO 220
      X=(PHI(I,J,K)-PHI(I+1,J,K))*TC(I,J,K)*DELX(J)
      FLOW(II)=FLOW(II)+X
      IF (X) 160,220,170
  160 CHD1=CHD1+X
      GO TO 220
  170 CHD2=CHD2+X
      GO TO 220
C
C     ---RECHARGE AND WELLS---
  180 IF (K.EQ.KO.AND.IQRE.EQ.ICHK(7)) QREFLX=QREFLX+QRE(I,J)*AREA
      IF (WELL(I,J,K)) 190,210,200
```

```
  190 PUMP=PUMP+WELL(I,J,K)*AREA                                       CHK1040
      GO TO 210                                                        CHK1050
  200 CFLUX=CFLUX+WELL(I,J,K)*AREA                                     CHK1060
C                                                                      CHK1070
C     ---COMPUTE VOLUME FROM STORAGE---                                CHK1080
  210 STOR=STOR+S(I,J,K)*(OLD(I,J,K)-PHI(I,J,K))*AREA                  CHK1090
       IF(K.NE.K0.OR.IRIV.LE.0) GO TO 212
C    COMPUTE LEAKAGE TO RIVER
      ND=IDR(I,J)
      IF(ND.EQ.0) GO TO 212
      IF(PHI(I,J,K).GT.RB(ND)) GO TO 211
      ETFLUX=RC(ND)*(RH(ND)-RB(ND))*AREA+ETFLUX
      GO TO 212
  211 ETFLUX=RC(ND)*(RH(ND)-PHI(I,J,K))*AREA+ETFLUX
  212  IF(K.NE.K0.OR.IDRAIN.LE.0) GO TO 220
C      COMPUTE LEAKAGE TO DRAIN
       ND=ID(I,J)
       IF(ND.EQ.0) GO TO 220
       IF(ELD(ND).GT.PHI(I,J,K)) GO TO 220
       FLUX=FLUX+FLD(ND)*AREA*(ELD(ND)-STRT(I,J,K))
       FLXN=FLXN+FLD(ND)*AREA*(ELD(ND)-PHI(I,J,K))
      FLUXS=FLXN
  220 CONTINUE                                                         CHK1100
C     ..............................................................CHK1110
C                                                                      CHK1120
C     ---COMPUTE CUMULATIVE VOLUMES, TOTALS, AND DIFFERENCES---        CHK1130
      FLXPT=0.0                                                        CHK1140
      FLXNT=FLXNT-FLXN*DELT
      ETFLXT=ETFLXT-ETFLUX*DELT
      STORT=STORT+STOR                                                 CHK1150
      STOR=STOR/DELT                                                   CHK1160
      QRET=QRET+QREFLX*DELT                                            CHK1170
      CHDT=CHDT-CHD1*DELT                                              CHK1180
      CHST=CHST+CHD2*DELT                                              CHK1190
      PUMPT=PUMPT-PUMP*DELT                                            CHK1200
      TOTL1=STORT+QRET+CFLUXT+CHST+FLXPT                               CHK1220
      CFLUXT=CFLUXT+CFLUX*DELT                                         CHK1210
      TOTL2=CHDT+PUMPT+ETFLXT+FLXNT                                    CHK1230
      SUMR=QREFLX+CFLUX+CHD2+CHD1+PUMP+ETFLUX+FLUXS+STOR               CHK1240
      DIFF=TOTL2-TOTL1                                                 CHK1250
      PERCNT=0.0                                                       CHK1260
      IF (TOTL2.EQ.0.) GO TO 230                                       CHK1270
      PERCNT=DIFF/TOTL2*100.                                           CHK1280
  230 RETURN                                                           CHK1290
C     ..............................................................CHK1300
C                                                                      CHK1310
C     ---PRINT RESULTS---                                              CHK1320
C     ************************                                         CHK1330
      ENTRY CWRITE                                                     CHK1340
C     ************************                                         CHK1350
C                                                                      CHK1360
      WRITE (6,260) STOR,QREFLX,STORT,CFLUX,QRET,PUMP,CFLUXT,ETFLUX,CHSTCHK1370
     1,FLXPT,CHD2,TOTL1,CHD1,FLUX,FLUXS,ETFLXT,CHDT,SUMR,PUMPT,FLXNT,TOTCHK1380
     2L2,DIFF,PERCNT                                                   CHK1390
      IF (NCH.EQ.0) GO TO 240                                          CHK1400
      WRITE (6,270)                                                    CHK1410
      WRITE (6,280) ((JFLO(I,J),J=1,3),FLOW(I),I=1,NCH)                CHK1420
C                                                                      CHK1430
C     ---COMPUTE VERTICAL FLOW---                                      CHK1440
  240 X=0.                                                             CHK1450
```

```
      Y=0.
      IF (KO.EQ.1) RETURN
      DO 250 I=2,I1
      DO 250 J=2,J1
      X=X+(PHI(I,J,1)-PHI(I,J,2))*TK(I,J,1)*DELX(J)*DELY(I)*2./(DELZ(1)+
     1DELZ(2))
  250 Y=Y+(PHI(I,J,K1)-PHI(I,J,K0))*TK(I,J,K1)*DELX(J)*DELY(I)*2./(DELZ(
     1K1)+DELZ(K0))
      WRITE (6,290) Y,X
      RETURN
C
C     ---FORMATS---
C
C     ------------------------------------------------------------------
C
C
C
  260 FORMAT ('0',10X,'CUMULATIVE MASS BALANCE:',16X,'L**3',23X,'RATES F
     1OR THIS TIME STEP:',16X,'L**3/T'/11X,24('-'),43X,25('-')//20X,'SOU
     2RCES:',69X,'STORAGE =',F20.4/20X,8('-'),68X,'RECHARGE =',F20.4/27X
     3,'STORAGE =',F20.2,35X,'CONSTANT FLUX =',F20.4/26X,'RECHARGE =',F2
     40.2,41X,'PUMPING =',F20.4/21X,'CONSTANT FLUX =',F20.2,30X,'      RI
     5VER LEAKAGE =',F20.4/21X,'CONSTANT HEAD =',F20.2,34X,'CONSTANT HEA
     6D:'/27X,'LEAKAGE =',F20.2,46X,'IN =',F20.4/21X,'TOTAL SOURCES =',F
     720.2,45X,'OUT =',F20.4/96X,'LEAKAGE:'/20X,'DISCHARGES:',45X,'FROM 
     8PREVIOUS PUMPING PERIOD =',F20.4/20X,11('-'),68X,'TOTAL =',F20.4/1
     96X,'      RIVER LEAKAGE =',F20.2/21X,'CONSTANT HEAD =',F20.2,36X,'S
     $UM OF RATES =',F20.4/19X'QUANTITY PUMPED =',F20.2/27X,'LEAKAGE =',
     $F20.2/19X,'TOTAL DISCHARGE =',F20.2//17X,'DISCHARGE-SOURCES =',F20
     $.2/15X,'PER CENT DIFFERENCE =',F20.2//)
  270 FORMAT ('0FLOW RATES TO CONSTANT HEAD NODES:'/' ',34('-')//' ',3(9
     1X,'K',4X,'I',4X,'J',5X,'RATE (L**3/T)')/' ',3(9X,'-',4X,'-',4X,'-'
     2,5X,13('-'))/)
  280 FORMAT (/(1X,3(I10,2I5,G18.7)))
  290 FORMAT ('0FLOW TO TOP LAYER =',G15.7,'   FLOW TO BOTTOM LAYER =',G
     115.7,'       POSITIVE UPWARD')
      END
      SUBROUTINE STEP(PHI,STRT,OLD,T,S,TR,TC,TK,WELL,DELX,DELY,DELZ,FACT
     1,DDN,TEST3)
C     ------------------------------------------------------------------
C     INITIALIZE DATA FOR A NEW TIME STEP AND PRINT RESULTS
C     ------------------------------------------------------------------
C
C     SPECIFICATIONS:
      REAL *8PHI
      REAL *8XLABEL,YLABEL,TITLE,XN1,MESUR
C
      DIMENSION PHI(I0,J0,K0), STRT(I0,J0,K0), OLD(I0,J0,K0), T(I0,J0,K0
     1), S(I0,J0,K0), TR(I0,J0,K0), TC(I0,J0,K0), TK(IK,JK,K5), WELL(I0,
     2J0,K0), DELX(J0), DELY(I0), DELZ(K0), FACT(K0,3), DDN(IMAX), TEST3
     3(ITMX1), ITTO(50)
C
      COMMON/IDDC/ IDD(80)
      COMMON /INTEGR/ I0,J0,K0,I1,J1,K1,I,J,K,NPER,KTH,ITMAX,LENGTH,KP,N
     1WEL,NUMT,IFINAL,IT,KT,IHEAD,IDRAW,IFLO,IERR,I2,J2,K2,IMAX,ITMX1,NC
     2H,IDK1,IDK2,IWATER,IQRE,IP,JP,IQ,JQ,IK,JK,K5,IPU1,IPU2,ITK
      COMMON /SPARAM/ TMAX,CDLT,DELT,ERR,TEST,SUM,SUMP,QR
      COMMON /SARRAY/ ICHK(13),LEVEL1(9),LEVEL2(9)
      COMMON /CK/ FTFLXT,STORT,QRET,CHST,CHDT,FLUXT,PUMPT,CFLUXT,FLXNT
      COMMON /PR/ XLABEL(3),YLABEL(6),TITLE(6),XN1,MESUR,PRNT(122),BLANK
```

```
     1(60),DIGIT(122),VF1(6),VF2(6),VF3(7),XSCALE,DINCH,SYM(17),XN(100),STP 230
     2YN(13),NA(4),N1,N2,N3,YSCALE,FACT1,FACT2                          STP 240
      RETURN                                                            STP 250
C     ..................................................................STP 260
C     ********************                                              STP 270
      ENTRY NEWSTP                                                      STP 280
C     ********************                                              STP 290
      KT=KT+1                                                           STP 300
      IT=0                                                              STP 310
      DO 10 K=1,K0                                                      STP 320
      DO 10 I=1,I0                                                      STP 330
      DO 10 J=1,J0                                                      STP 340
   10 OLD(I,J,K)=PHI(I,J,K)                                             STP 350
      DELT=CDLT*DELT                                                    STP 360
      SUM=SUM+DELT                                                      STP 370
      SUMP=SUMP+DELT                                                    STP 380
      DAYSP=SUMP/86400.                                                 STP 390
      YRSP=DAYSP/365.                                                   STP 400
      HRS=SUM/3600.                                                     STP 410
      SMIN=HRS*60.                                                      STP 420
      DAYS=HRS/24.                                                      STP 430
      YRS=DAYS/365.                                                     STP 440
      RETURN                                                            STP 450
C                                                                       STP 460
C     ---PRINT OUTPUT AT DESIGNATED TIME STEPS---                       STP 470
C     *********************                                             STP 480
      ENTRY OUTPUT                                                      STP 490
C     *********************                                             STP 500
      IF (KT.EQ.NUMT) IFINAL=1                                          STP 510
      ITTO(KT)=IT                                                       STP 520
      IF (IT.LE.ITMAX) GO TO 20                                         STP 530
      IT=IT-1                                                           STP 540
      ITTO(KT)=IT                                                       STP 550
      IERR=2                                                            STP 560
C                                                                       STP 570
C     ---IF MAXIMUM ITERATIONS EXCEEDED,WRITE RESULTS ON DISK OR CARDS--STP 580
      IF (IDK2.EQ.ICHK(5)) WRITE (4) PHI,SUM,SUMP,PUMPT,CFLUXT,QRET,CHSTSTP 590
     1,CHDT,FLUXT,STORT,ETFLXT,FLXNT                                    STP 600
      IF (IPU2.EQ.ICHK(9)) WRITE (7,230) SUM,SUMP,PUMPT,CFLUXT,QRET,CHSTSTP 610
     1,CHDT,FLUXT,STORT,ETFLXT,FLXNT                                    STP 620
C                                                                       STP 630
   20 IF (IFLO.EQ.ICHK(3)) CALL CHECK                                   STP 640
      IF (IERR.EQ.2) GO TO 30                                           STP 650
      IF (MOD(KT,KTH).NE.0.AND.IFINAL.NE.1) RETURN                      STP 660
   30 WRITE (6,210) KT,DELT,SUM,SMIN,HRS,DAYS,YRS,DAYSP,YRSP            STP 670
      IF (IFLO.EQ.ICHK(3)) CALL CWRITE                                  STP 680
      IT=IT+1                                                           STP 690
      WRITE (6,180) (TEST3(J),J=1,IT)                                   STP 700
      I3=1                                                              STP 701
      I5=0                                                              STP 702
  352 I5=I5+40                                                          STP 703
      I4=MIN0(KT,I5)                                                    STP 704
      WRITE (6,240) (I,I=I3,I4)                                         STP 710
      WRITE (6,260)                                                     STP 720
      WRITE (6,250) (ITTO(I),I=I3,I4)                                   STP 730
      WRITE (6,260)                                                     STP 740
      IF(KT.LE.I5) GO TO 353                                            STP 741
      I3=I3+40                                                          STP 742
      GO TO 352                                                         STP 743
C                                                                       STP 750
```

```
C     ---PRINT MAPS---
  353 IF (XSCALE.EQ.0.) GO TO 70
      IF (IDD(KP).EQ.0) GO TO 70
      IF (FACT1.EQ.0.) GO TO 50
      DO 40 IA=1,9
      II=LEVEL1(IA)
      IF (II.EQ.0) GO TO 50
   40 CALL PRNTA(1,II)
   50 IF (FACT2.EQ.0.) GO TO 70
      DO 60 IA=1,9
      II=LEVEL2(IA)
      IF (II.EQ.0) GO TO 70
   60 CALL PRNTA(2,II)
   70 IF (IDRAW.NE.ICHK(1)) GO TO 100
C
C     ---PRINT DRAWDOWN---
      DO 90 K=1,K0
      WRITE (6,200) K
      DO 90 I=1,I0
      DO 80 J=1,J0
   80 DDN(J)=STRT(I,J,K)-PHI(I,J,K)
   90 WRITE (6,170) I,(DDN(J),J=1,J0)
100   CONTINUE
      DO 103 K=1,K0
103   WRITE (15) ((PHI(I,J,K),J=1,J0),I=1,I0)
      IF (IHEAD.NE.ICHK(2)) GO TO 120
C
C     ---PRINT HEAD MATRIX---
      IF (IDD(KP).EQ.0) GO TO 120
      NKDKL=4-IDD(KP)
      DO 110 K=NKDKL,K0
      WRITE (6,190) K
      DO 110 I=1,I0
  110 WRITE (6,170) I,(PHI(I,J,K),J=1,J0)
C
C     ---WRITE ON DISK---
  120 IF (IERR.EQ.2) GO TO 130
      IF (KP.LT.NPER.OR.IFINAL.NE.1) RETURN
      IF (IDK2.EQ.ICHK(5)) WRITE (44) PHI,SUM,SUMP,PUMPT,CFLUXT,QRET,CHS
     1T,CHDT,FLUXT,STORT,ETFLXT,FLXNT
C
C     ---PUNCHED OUTPUT---
  130 IF (IPU2.NE.ICHK(9)) GO TO 160
      IF (IERR.EQ.2) GO TO 140
      WRITE (7,230) SUM,SUMP,PUMPT,CFLUXT,QRET,CHST,CHDT,FLUXT,STORT,ETF
     1LXT,FLXNT
  140 DO 150 K=1,K0
      DO 150 I=1,I0
  150 WRITE (7,220)  (PHI(I,J,K),J=1,J0)
  160 IF (IERR.EQ.2) STOP
      RETURN
C
C     ---FORMATS---
C
C
C
  170 FORMAT ('0',I4,18F7.2/(5X,18F7.2))
  180 FORMAT ('0MAXIMUM HEAD CHANGE FOR EACH ITERATION:'/' ',39('-')/('0
     1',10F12.4))
  190 FORMAT ('1',55X,'HEAD MATRIX, LAYER',I3/56X,21('-'))
```

```
  200 FORMAT ('1',55X,'   DRAWDOWN, LAYER',I3/59X,18('-'))
  210 FORMAT (1H1,44X,57('-')/45X,'I',14X,'TIME STEP NUMBER =',I9,14X,'I
     1'/45X,57('-')//50X,29HSIZE OF TIME STEP IN SECONDS=,F14.2//55X,'TO
     2TAL SIMULATION TIME IN SECONDS=',F14.2/80X,8HMINUTES=,F14.2/82X,6H
     3HOURS=,F14.2/83X,5HDAYS=,F14.2/82X,'YEARS=',F14.2///45X,'DURATION
     4OF CURRENT PUMPING PERIOD IN DAYS=',F14.2/82X,'YEARS=',F14.2//)
  220 FORMAT (10F8.2)
  230 FORMAT (4G20.10)
  240 FORMAT ('0TIME STEP :',40I3)
  250 FORMAT ('0ITERATIONS:',40I3)
  260 FORMAT (' ',10('-'))
      END
      SUBROUTINE SOLVE(PHI,STRT,OLD,T,S,TR,TC,TK,WELL,DELX,DELY,DELZ,FAC
     1T,EL,FL,GL,V,XI,TEST3,QRE,PERM,ID,FLD,ELD,IDR,RH,RC,RB,IDRAIN,
     2 IRIV)
C     ------------------------------------------------------------------
C     SOLUTION BY THE STRONGLY IMPLICIT PROCEDURE
C     ------------------------------------------------------------------
C
C     SPECIFICATIONS:
      REAL *8PHI,RHO,B,D,F,H,Z,SU,RHOP,W,WMIN,RHO1,RHO2,RHO3,XPART,YPART
      REAL*8 UX,UXR
     1,ZPART,DMIN1,WMAX,XT,YT,ZT,DABS,DMAX1,DEN,TXM,TYM,TZM
      REAL *8E,AL,BL,CL,A,C,G,WU,TU,U,DL,RES,SUPH,GLXI,ZPHI
C
      DIMENSION PHI(1), STRT(1), OLD(1), T(1), S(1), TR(1), TC(1), TK(1)
     1, WELL(1), DELX(1), DELY(1), DELZ(1), FACT(K0,3), RHOP(20), TEST3(
     21), EL(1), FL(1), GL(1), V(1), XI(1), QRE(1)
     3,ID(1),FLD(1),ELD(1),PERM(1),IDR(1),RH(1),RC(1),RB(1)
C
      COMMON /INTEGR/ I0,J0,K0,I1,J1,K1,I,J,K,NPER,KTH,ITMAX,LENGTH,KP,N
     1WEL,NUMT,IFINAL,IT,KT,IHEAD,IDRAW,IFLO,IERR,I2,J2,K2,IMAX,ITMX1,NC
     2H,IDK1,IDK2,IWATER,IQRE,IP,JP,IQ,JQ,IK,JK,K5,IPU1,IPU2,ITK
      COMMON /SPARAM/ TMAX,CDLT,DELT,ERR,TEST,SUM,SUMP,QR
      COMMON /RESMUN/ RESMO
      COMMON /SARRAY/ ICHK(13),LEVEL1(9),LEVEL2(9)
      RETURN
C     ..................................................................
C     ********************
      ENTRY ITER
C     ********************
C     ---COMPUTE AND PRINT ITERATION PARAMETERS---
      WRITE (6,240)
      P2=LENGTH-1
      NT=I0*J0*K0
      NIJ=I0*J0
      PJ=-1.
      READ(5,250) WMAX
  250 FORMAT(F10.0)
      DO 50 I=1,LENGTH
      PJ=PJ+1.
   50 RHOP(I)=1.D0-(1.D0-WMAX)**(PJ/P2)
      WRITE (6,230) LENGTH,(RHOP(J),J=1,LENGTH)
      RETURN
C     ..................................................................
C
C     ---INITIALIZE DATA FOR A NEW ITERATION---
   60 IT=IT+1
      IF (IT.LE.ITMAX) GO TO 70
      WRITE (6,220)
```

```
      CALL OUTPUT                                                       SP3 900
   70 IF (MOD(IT,LENGTH)) 80,80,90                                      SP3 910
C     **********************                                            SP3 920
C     NTH=0                                                             SP3 950
      ENTRY NEWITA                                                      SP3 930
C     **********************                                            SP3 940
   90 NTH=NTH+1                                                         SP3 960
      W=RHOP(NTH)                                                       SP3 970
      TEST3(IT+1)=0.                                                    SP3 980
      TEST=0.0                                                          SP3 990
      BIG=0.                                                            SP31000
      DO 100 I=1,NT                                                     SP31010
      EL(I)=0.                                                          SP31020
      FL(I)=0.                                                          SP31030
      GL(I)=0.                                                          SP31040
      G=CL*FL(NJB)
      WU=CL*GL(NJB)
      U=BL*GL(NIB)
      IF (K.EQ.1) GO TO 140
      AL=Z/(1.+W*(EL(NKB)+FL(NKB)))
      A=AL*EL(NKB)                                                      SP31540
      TU=AL*FL(NKB)                                                     SP31550
      DL=E+W*(A+C+G+WU+TU+U)-CL*EL(NJB)-BL*FL(NIB)-AL*GL(NKB)           SP31560
      EL(N)=(F-W*(A+C))/DL                                              SP31570
      FL(N)=(H-W*(G+TU))/DL                                             SP31580
      GL(N)=(SU-W*(WU+U))/DL                                            SP31590
      SUPH=0.D0                                                         SP31600
      IF (K.NE.K0) SUPH=SU*PHI(NKA)                                     SP31610
      RES=-B*PHI(NIB)-D*PHI(NJB)-E*PHI(N)-F*PHI(NJA)-H*PHI(NIA)-SUPH-Z*PSP31620
     1HI(NKB)-WELL(N)-RHO*OLD(N)-QR                                     SP31630
      RES=RES*RESMO
      V(N)=(RES-AL*V(NKB)-BL*V(NIB)-CL*V(NJB))/DL                       SP31640
      GO TO 150                                                         SP31650
  140 DL=E+W*(C+G+WU+U)-CL*EL(NJB)-BL*FL(NIB)                           SP31660
      EL(N)=(F-W*C)/DL                                                  SP31670
      FL(N)=(H-W*G)/DL                                                  SP31680
      GL(N)=(SU-W*(WU+U))/DL                                            SP31690
      SUPH=0.D0                                                         SP31700
      IF (K.NE.K0) SUPH=SU*PHI(NKA)                                     SP31710
      RES=-B*PHI(NIB)-D*PHI(NJB)-E*PHI(N)-F*PHI(NJA)-H*PHI(NIA)-SUPH-WELSP31720
     1L(N)-RHO*OLD(N)-QR                                                SP31730
      RES=RES*RESMO
      V(N)=(RES-BL*V(NIB)-CL*V(NJB))/DL                                 SP31740
  150 CONTINUE                                                          SP31750
C                                                                       SP31760
C     ---BACK SUBSTITUTE FOR VECTOR XI---                               SP31770
      DO 160 K=1,K0                                                     SP31780
      K3=K0-K+1                                                         SP31790
      DO 160 I=1,I2                                                     SP31800
      I3=I0-I                                                           SP31810
      DO 160 J=1,J2                                                     SP31820
      J3=J0-J                                                           SP31830
      N=I3+(J3-1)*I0+(K3-1)*NIJ+I-I                                     SP31840
      IF (T(N).EQ.0..OR.S(N).LT.0.) GO TO 160                           SP31850
      GLXI=0.D0                                                         SP31860
      IF (K3.NE.K0) GLXI=GL(N)*XI(N+NIJ)                                SP31870
      XI(N)=V(N)-EL(N)*XI(N+I0)-FL(N)*XI(N+1)-GLXI                      SP31880
C                                                                       SP31890
C     ---COMPARE MAGNITUDE OF CHANGE WITH CLOSURE CRITERIA---           SP31900
      TCHK=ABS(XI(N))                                                   SP31910
```

```
      IF (TCHK.GT.BIG) BIG=TCHK                                         SP31920
      PHI(N)=PHI(N)+XI(N)                                               SP31930
  160 CONTINUE                                                          SP31940
      IF (BIG.GT.ERR) TEST=1.                                           SP31950
      TEST3(IT+1)=BIG                                                   SP31960
      IF (TEST.EQ.0.) RETURN                                            SP31970
      GO TO 60                                                          SP31980
C     ..................................................................SP31990
  170 DO 200 KK=1,K0                                                    SP32000
      K=K0-KK+1                                                         SP32010
      DO 200 II=1,I2                                                    SP32020
      I=I0-II                                                           SP32030
      DO 200 J=2,J1                                                     SP32040
      N=I+(J-1)*I0+(K-1)*NIJ                                            SP32050
      NIA=N+1                                                           SP32060
      NIB=N-1                                                           SP32070
      NJA=N+I0                                                          SP32080
      NJB=N-I0                                                          SP32090
      NKA=N+NIJ                                                         SP32100
      NKB=N-NIJ                                                         SP32110
C                                                                       SP32120
C     ---SKIP COMPUTATIONS IF NODE OUTSIDE AQUIFER---                   SP32130
      IF (T(N).EQ.0..OR.S(N).LT.0.) GO TO 200                           SP32140
C                                                                       SP32150
C     ---COMPUTE COEFFICIENTS---                                        SP32160
      D=TR(NJB)/DELX(J)                                                 SP32170
      F=TR(N)/DELX(J)                                                   SP32180
      B=TC(NIB)/DELY(I)                                                 SP32190
      H=TC(N)/DELY(I)                                                   SP32200
      SU=0.D0                                                           SP32210
      Z=0.D0                                                            SP32220
      IF (K.NE.1) Z=TK(NKB)/DELZ(K)                                     SP32230
      IF (K.NE.K0) SU=TK(N)/DELZ(K)                                     SP32240
      RHO=S(N)/DELT                                                     SP32250
      QR=0.                                                             SP32260
      UXR=0.
      UX=0.
      IF (K.NE.K0) GO TO 180                                            SP32270
      IF (IQRE.EQ.ICHK(7)) QR=QRE(I+(J-1)*I0)                           SP32280
      IF(IRIV.LE.0) GO TO 175
      ND=IDR(I+(J-1)*I0)
      IF(ND.EQ.0) GO TO 175
      IF(PHI(N).GT.RB(ND)) GO TO 174
      QR=QR+RC(ND)*(RH(ND)-RB(ND))
      GO TO 175
  174 UXR=RC(ND)
      QR=QR+RC(ND)*RH(ND)
  175  IF(IDRAIN.LE.0) GO TO 180
      ND=ID(I+(J-1)*I0)
       IF(ND.EQ.0) GO TO 180
       IF(FLD(ND).GT.PHI(N)) GO TO 180
       UX=FLD(ND)
       QR=QR+FLD(ND)*ELD(ND)
C                                                                       SP32290
C     ---SIP REVERSE ALGORITHM---                                       SP32300
C     ---FORWARD SUBSTITUTE, COMPUTING INTERMEDIATE VECTOR V---         SP32310
  180  E=-B-H-D-F-SU-Z-RHO-UX-UXR
      BL=H/(1.+W*(EL(NIA)+GL(NIA)))                                     SP32330
      CL=D/(1.+W*(FL(NJB)+GL(NJB)))                                     SP32340
      C=BL*EL(NIA)                                                      SP32350
```

```
      G=CL*FL(NJB)
      WU=CL*GL(NJB)
      U=BL*GL(NIA)
      IF (K.EQ.K0) GO TO 190
      AL=SU/(1.+W*(EL(NKA)+FL(NKA)))
      A=AL*EL(NKA)
      TU=AL*FL(NKA)
      DL=E+W*(C+G+A+WU+TU+U)-AL*GL(NKA)-BL*FL(NIA)-CL*EL(NJB)
      FL(N)=(F-W*(C+A))/DL
      FL(N)=(B-W*(G+TU))/DL
      GL(N)=(Z-W*(WU+U))/DL
      ZPHI=0.D0
      IF (K.NE.1) ZPHI=Z*PHI(NKB)
      RES=-B*PHI(NIB)-D*PHI(NJB)-E*PHI(N)-F*PHI(NJA)-H*PHI(NIA)-SU*PHI(N
     1KA)-ZPHI-WELL(N)-RHO*OLD(N)-QR
      RES=RES*RESMO
      V(N)=(RES-AL*V(NKA)-BL*V(NIA)-CL*V(NJB))/DL
      GO TO 200
  190 DL=E+W*(C+G+WU+U)-BL*FL(NIA)-CL*EL(NJB)
      FL(N)=(F-W*C)/DL
      FL(N)=(B-W*G)/DL
      GL(N)=(Z-W*(WU+U))/DL
      ZPHI=0.D0
      IF (K.NE.1) ZPHI=Z*PHI(NKB)
      RES=-B*PHI(NIB)-D*PHI(NJB)-E*PHI(N)-F*PHI(NJA)-H*PHI(NIA)-ZPHI-WEL
     1L(N)-RHO*OLD(N)-QR
      RES=RES*RESMO
      V(N)=(RES-BL*V(NIA)-CL*V(NJB))/DL
  200 CONTINUE
C
C     ---BACK SUBSTITUTE FOR VECTOR XI---
      DO 210 K=1,K0
      DO 210 I=2,I1
      DO 210 J=1,J2
      J3=J0-J
      N=I+(J3-1)*I0+(K-1)*NIJ
      IF (T(N).EQ.0..OR.S(N).LT.0.) GO TO 210
      GLXI=0.D0
      IF (K.NE.1) GLXI=GL(N)*XI(N-NIJ)
      XI(N)=V(N)-EL(N)*XI(N+I0)-FL(N)*XI(N-1)-GLXI
C
C     ---COMPARE MAGNITUDE OF CHANGE WITH CLOSURE CRITERIA---
      TCHK=ABS(XI(N))
      IF (TCHK.GT.BIG) BIG=TCHK
      PHI(N)=PHI(N)+XI(N)
  210 CONTINUE
      IF (BIG.GT.ERR) TEST=1.
      TEST3(IT+1)=BIG
      IF (TEST.EQ.0.) RETURN
      GO TO 60
C     ..................................................................
C
C     ---FORMATS---
C
C
C
  220 FORMAT ('0EXCEEDED PERMITTED NUMBER OF ITERATIONS'/' ',39('*'))
  230 FORMAT (///1H0,I5,22H ITERATION PARAMETERS:,6E15.7/(28X,6E15.7/))
  240 FORMAT ('-',44X,'SOLUTION BY THE STRONGLY IMPLICIT PROCEDURE'/45X,
     143('_'))
```

```
      END
      SUBROUTINE COEF(PHI,STRT,OLD,T,S,TR,TC,TK,WELL,DELX,DELY,DELZ,FACT
     1,PERM,BOTTOM,QRE)
C     ------------------------------------------------------------------
C     COMPUTE COEFFICIENTS
C     ------------------------------------------------------------------
C
C     SPECIFICATIONS:
      REAL *8PHI
C
      DIMENSION PHI(I0,J0,K0), STRT(I0,J0,K0), OLD(I0,J0,K0), T(I0,J0,K0
     1), S(I0,J0,K0), TR(I0,J0,K0), TC(I0,J0,K0), TK(IK,JK,K5), WELL(I0,
     2J0,K0), DELX(J0), DELY(I0), DELZ(K0), FACT(K0,3), PERM(IP,JP), BOT
     3TOM(IP,JP), QRE(IQ,JQ)
C
      COMMON /INTEGR/ I0,J0,K0,I1,J1,K1,I,J,K,NPER,KTH,ITMAX,LENGTH,KP,NC
     1WEL,NUMT,IFINAL,IT,KT,IHEAD,IDRAW,IFLO,IERR,I2,J2,K2,IMAX,ITMX1,NC
     2H,IDK1,IDK2,IWATER,IGRE,IP,JP,IQ,JQ,IK,JK,K5,IPU1,IPU2,ITK
      COMMON /SPARAM/ TMAX,CDLT,DELT,ERR,TEST,SUM,SUMP,QR
      COMMON /SARRAY/ ICHK(13),LEVEL1(9),LEVEL2(9)
      RETURN
C     ..................................................................
C     ---COMPUTE TRANSMISSIVITY FOR UPPER HYDROLOGIC UNIT WHEN
C     IT IS UNCONFINED---
C     *********************
      ENTRY TRANS(N3)
C     *********************
      DO 10 I=2,I1
      DO 10 J=2,J1
      IF (PERM(I,J).EQ.0.) GO TO 10
      T(I,J,K0)=PERM(I,J)*(PHI(I,J,K0)-BOTTOM(I,J))
      IF (T(I,J,K0).GT.0.) GO TO 10
      IF (WELL(I,J,K0).LT.0.) WRITE (6,60) I,J,K0
      IF (WELL(I,J,K0).GE.0.) WRITE (6,70) I,J,K0
      WRITE (6,180) KT,PERM(I,J),PHI(I,J,K0),BOTTOM(I,J)
  180 FORMAT ('-',I5,E15.5,E15.7,E15.7)
      PERM(I,J)=0.
      T(I,J,K0)=0.
      TR(I,J-1,K0)=0.
      TR(I,J,K0)=0.
      TC(I,J,K0)=0.
      TC(I-1,J,K0)=0.
      IF (K0.NE.1) TK(I,J,K1)=0.
      PHI(I,J,K0)=1.D30
   10 CONTINUE
      IF (N3.EQ.1) RETURN
      N1=K0
      N2=K0
      N4=K1
      GO TO 20
C     ---COMPUTE T COEFFICIENTS---
C     *********************
      ENTRY TCOF
C     *********************
      N1=1
      N2=K0
      N4=1
   20 DO 40 K=N1,N2
      DO 40 I=1,I1
      DO 40 J=1,J1
```

```
      IF (T(I,J,K).EQ.0.) GO TO 40
      IF (T(I,J+1,K).EQ.0.) GO TO 30
      TR(I,J,K)=(2.*T(I,J+1,K)*T(I,J,K))/(T(I,J,K)*DELX(J+1)+T(I,J+1,K)*
     1DELX(J))*FACT(K,1)
   30 IF (T(I+1,J,K).EQ.0.) GO TO 40
      TC(I,J,K)=(2.*T(I+1,J,K)*T(I,J,K))/(T(I,J,K)*DELY(I+1)+T(I+1,J,K)*
     1DELY(I))*FACT(K,2)
   40 CONTINUE
      IF (K0.EQ.1.OR.ITK.EQ.ICHK(10)) RETURN
      DO 50 K=N4,K1
      DO 50 I=2,I1
      DO 50 J=2,J1
      IF (T(I,J,K+1).EQ.0.) GO TO 50
      T1=T(I,J,K)*FACT(K,3)
      T2=T(I,J,K+1)*FACT(K+1,3)
      TK(I,J,K)=(2.*T2*T1)/(T1*DELZ(K+1)+T2*DELZ(K))
   50 CONTINUE
      RETURN
C
C
   60 FORMAT ('-',20('*'),'WELL',2I3,' IN LAYER',I3,' GOES DRY',20('*'))
   70 FORMAT ('-',20('*'),'NODE',2I3,' IN LAYER',I3,' GOES DRY',20('*'))
      END
      SUBROUTINE PRNTAI(PHI,STRT,T,S,WELL,DELX,DELY)
C     ------------------------------------------------------------------
C     PRINT MAPS OF DRAWDOWN AND HYDRAULIC HEAD
C     ------------------------------------------------------------------
C
C     SPECIFICATIONS:
      REAL *8PHI,Z,XLABEL,YLABEL,TITLE,XN1,MESUR
      REAL *4K
C
      DIMENSION PHI(I0,J0,K0), STRT(I0,J0,K0), S(I0,J0,K0), WELL(I0,J0,K
     10), DELX(J0), DELY(I0), T(I0,J0,K0)
      DIMENSION SYM2(10)
C
      COMMON /INTEGR/ I0,J0,K0,I1,J1,K1,I,J,K,NPER,KTH,ITMAX,LENGTH,KP,N
     1WEL,NUMT,IFINAL,IT,KT,IHEAD,IDRAW,IFLO,IERR,I2,J2,K2,IMAX,ITMX1,NC
     2H,IDK1,IDK2,IWATER,IQRE,IP,JP,IQ,JQ,IK,JK,K5,IPU1,IPU2,ITK
      COMMON /PR/ XLABEL(3),YLABEL(6),TITLE(6),XN1,MESUR,PRNT(122),BLANK
     1(60),DIGIT(122),VF1(6),VF2(6),VF3(7),XSCALE,DINCH,SYM(17),XN(100),
     2YN(13),NA(4),N1,N2,N3,YSCALE,FACT1,FACT2
      DATA SYM2/'A','B','C','D','E','F','G','H','I','J'/
      RETURN
C     ..................................................................
C
C     ---INITIALIZE VARIABLES FOR PLOT---
C     ********************
      ENTRY MAP
C     ********************
      YDIM=0.
      WIDTH=0.
      DO 10 J=2,J1
   10 WIDTH=WIDTH+DELX(J)
      DO 20 I=2,I1
   20 YDIM=YDIM+DELY(I)
   30 XSF=DINCH*XSCALE
      YSF=DINCH*YSCALE
      NYD=YDIM/YSF
      IF (NYD*YSF.LE.YDIM-DELY(I1)/2.) NYD=NYD+1
```

```
      IF (NYD.LE.12) GO TO 40
      DINCH=YDIM/(12.*YSCALE)
      WRITE (6,330) DINCH
      IF (YSCALE.LT.1.0) WRITE (6,340)
      GO TO 30
   40 NXD=WIDTH/XSF
      IF (NXD*XSF.LE.WIDTH-DELX(J1)/2.) NXD=NXD+1
      N4=NXD*N1+1
      N5=NXD+1
      N6=NYD+1
      N8=N2*NYD+1
      NA(1)=N4/2-1
      NA(2)=N4/2
      NA(3)=N4/2+3
      NC=(N3-N8-10)/2
      ND=NC+N8
      NE=MAX0(N5,N6)
      VF1(3)=DIGIT(ND)
      VF2(3)=DIGIT(ND)
      VF3(3)=DIGIT(NC)
      XLABEL(3)=MESUR
      YLABEL(6)=MESUR
      DO 60 I=1,NE
      NNX=N5-I
      NNY=I-1
      IF (NNY.GE.N6) GO TO 50
      YN(I)=YSF*NNY/YSCALE
   50 IF (NNX.LT.0) GO TO 60
      XN(I)=XSF*NNX/YSCALE
   60 CONTINUE
      RETURN
C     .................................................................
C
C     ********************
      ENTRY PRNTA(NG,LA)
C     ********************
C     ---VARIABLES INITIALIZED EACH TIME A PLOT IS REQUESTED---
      DIST=WIDTH-DELX(J1)/2.
      JJ=J1
      LL=1
      Z=NXD*XSF
      IF (NG.EQ.1) WRITE (6,300) (TITLE(I),I=1,3),LA
      IF (NG.EQ.2) WRITE (6,300) (TITLE(I),I=4,6),LA
      DO 290 I=1,N4
C
C     ---LOCATE X AXES---
      IF (I.EQ.1.OR.I.EQ.N4) GO TO 70
      PRNT(1)=SYM(12)
      PRNT(N8)=SYM(12)
      IF ((I-1)/N1*N1.NE.I-1) GO TO 90
      PRNT(1)=SYM(14)
      PRNT(N8)=SYM(14)
      GO TO 90
C
C     ---LOCATE Y AXES---
   70 DO 80 J=1,N8
      IF ((J-1)/N2*N2.EQ.J-1) PRNT(J)=SYM(14)
   80 IF ((J-1)/N2*N2.NE.J-1) PRNT(J)=SYM(13)
C
C     ---COMPUTE LOCATION OF NODES AND DETERMINE APPROPRIATE SYMBOL---
```

```
   90 IF (DIST.LT.0..OR.DIST.LT.Z-XN1*XSF) GO TO 240                    PRN 960
      YLEN=DELY(2)/2.                                                   PRN 970
      DO 220 L=2,I1                                                     PRN 980
      J=YLEN*N2/YSF+1.5                                                 PRN 990
      IF (T(L,JJ,LA).EQ.0.) GO TO 160                                   PRN1000
      IF (S(L,JJ,LA).LT.0.) GO TO 210                                   PRN1010
      INDX3=0                                                           PRN1020
      GO TO (100,110), NG                                               PRN1030
  100 K=(STRT(L,JJ,LA)-PHI(L,JJ,LA))*FACT1                              PRN1040
C     -TO CYCLE SYMBOLS FOR DRAWDOWN, REMOVE C FROM COL. 1 OF NEXT CARD-PRN1050
C     K=AMOD(K,10.)                                                     PRN1060
      GO TO 120                                                         PRN1070
  110 K=PHI(L,JJ,LA)*FACT2                                              PRN1080
  120 IF (K) 130,160,140                                                PRN1090
  130 N=-K
      N=MOD(N,10)+1
      PRNT(J)=SYM2(N)
      GO TO 220
  140 N=K
      N=MOD(N,10)+1
      PRNT(J)=SYM(N)
      GO TO 220
  160 PRNT(J)=SYM(15)
      IF(T(L,JJ,LA).EQ.0.) PRNT(J)=SYM(14)
      GO TO 220
  210 IF (S(L,JJ,LA).LT.0.) PRNT(J)=SYM(16)                             PRN1370
  220 YLEN=YLEN+(DELY(L)+DELY(L+1))/2.                                  PRN1380
  230 DIST=DIST-(DELX(JJ)+DELX(JJ-1))/2.                                PRN1390
      JJ=JJ-1                                                           PRN1400
      IF (JJ.EQ.0) GO TO 240                                            PRN1410
      IF (DIST.GT.Z-XN1*XSF) GO TO 230                                  PRN1420
  240 CONTINUE                                                          PRN1430
C                                                                       PRN1440
C     ---PRINT AXES,LABELS, AND SYMBOLS---                              PRN1450
      IF (I-NA(LL).EQ.0) GO TO 260                                      PRN1460
      IF ((I-1)/N1*N1-(I-1)) 270,250,270                                PRN1470
  250 WRITE (6,VF1) (BLANK(J),J=1,NC),(PRNT(J),J=1,N8),XN(1+(I-1)/6)    PRN1480
      GO TO 280                                                         PRN1490
  260 WRITE (6,VF2) (BLANK(J),J=1,NC),(PRNT(J),J=1,N8),XLABEL(LL)       PRN1500
      LL=LL+1                                                           PRN1510
      GO TO 280                                                         PRN1520
  270 WRITE (6,VF2) (BLANK(J),J=1,NC),(PRNT(J),J=1,N8)                  PRN1530
C                                                                       PRN1540
C     ---COMPUTE NEW VALUE FOR Z AND INITIALIZE PRNT---                 PRN1550
  280 Z=Z-2.*XN1*XSF                                                    PRN1560
      DO 290 J=1,N8                                                     PRN1570
  290 PRNT(J)=SYM(15)                                                   PRN1580
C                                                                       PRN1590
C     ---NUMBER AND LABEL Y AXIS AND PRINT LEGEND---                    PRN1600
      WRITE (6,VF3) (BLANK(J),J=1,NC),(YN(I),I=1,N6)                    PRN1610
      WRITE (6,320) (YLABEL(I),I=1,6)                                   PRN1620
      IF (NG.EQ.1) WRITE (6,310) FACT1                                  PRN1630
      IF (NG.EQ.2) WRITE (6,310) FACT2                                  PRN1640
      RETURN                                                            PRN1650
C                                                                       PRN1660
C     ---FORMATS---                                                     PRN1670
C                                                                       PRN1680
C     ------------------------------------------------------------------PRN1690
C                                                                       PRN1700
C                                                                       PRN1710
```

```
  300 FORMAT ('1',49X,3A8,'LAYER',I4//)
  310 FORMAT ('0EXPLANATION'/' ',11('-')//' R = CONSTANT HEAD BOUNDARY'/
     1' *** = VALUE EXCEEDED 3 FIGURES'/' MULTIPLICATION FACTOR =',F8.3)
  320 FORMAT ('0',39X,6A8)
  330 FORMAT ('0',25X,10('*'),' TO FIT MAP WITHIN 12 INCHES, DINCH REVIS
     1ED TO',G15.7,1X,10('*'))
  340 FORMAT ('0',45X,'NOTE: GENERALLY SCALE SHOULD BE > OR = 1.0')
      END
      BLOCK DATA
C     ----------
C
C     SPECIFICATIONS:
      REAL *8XLABEL,YLABEL,TITLE,XN1,MFSUR
C
      COMMON /SARRAY/ ICHK(13),LEVEL1(9),LEVEL2(9)
      COMMON /PR/ XLABEL(3),YLABEL(6),TITLE(6),XN1,MESUR,PRNT(122),BLANK
     1(60),DIGIT(122),VF1(6),VF2(6),VF3(7),XSCALE,DINCH,SYM(17),XN(100),
     2YN(13),NA(4),N1,N2,N3,YSCALE,FACT1,FACT2
C     *****************************************************************
C
      DATA ICHK/'DRAW','HEAD','MASS','DK1','DK2','WATE','RECH','PUN1','P
     1UN2','ITKR',3*0/
      DATA SYM/'1','2','3','4','5','6','7','8','9','0','*','|','-','+','
     1 ','R','W'/
      DATA PRNT/122*' '/,N1,N2,N3,XN1/6,10,133,.833333333D-1/,BLANK/60*'
     1 '/,NA(4)/1000/
      DATA XLABEL/' X DIS- ','TANCE IN','  MILES '/,YLABEL/'DISTANCE',' 
     1FROM OR','IGIN IN ','Y DIRECT','ION, IN ','MILES   '/,TITLE/'PLOT 
     2OF ','DRAWDOWN',' ','PLOT OF ','HYDRAULI','C HEAD'/
      DATA DIGIT/'1','2','3','4','5','6','7','8','9','10','11','12','13'
     1,'14','15','16','17','18','19','20','21','22','23','24','25','26',
     2'27','28','29','30','31','32','33','34','35','36','37','38','39','
     340','41','42','43','44','45','46','47','48','49','50','51','52','5
     43','54','55','56','57','58','59','60','61','62','63','64','65','66
     5','67','68','69','70','71','72','73','74','75','76','77','78',' 79
     6','80','81','82','83','84','85','86','87','88','89','90','91','92'
     7,'93','94','95','96','97','98','99','100','101','102','103',' 104'
     8,'105','106','107','108','109','110','111','112','113','114','115'
     9,'116','117','118','119','120','121','122'/
      DATA VF1/'(1H ',',',' ','A1,F','10.2',')'/
      DATA VF2/'(1H ',',',' ','A1,1','X,A8',')'/
      DATA VF3/'(1H0',',',' ','A1,F','3.1,','12F1','0.2)'/
C     *****************************************************************
      END
```

Data Preparation

Basic model operation requires four input files.

1. The basic data deck describes the finite difference grid, input and output options, the hydraulic properties of the aquifers, initial conditions and pumpage rates.

2. The recharge file contains recharge rates for each node in the top layer of the model for each recharge period. This file is read at the beginning of each recharge period for which there is a "1" punched in column 80 of the recharge period card.

3. The river data deck contains arrays indicating the nodes on the top layer which have rivers and specifying the leakage factor, elevation of streambed and elevation of the bottom of the streambed layer.

4. The drainage tile deck contains arrays indicating the nodes in the top layer which have drainage tiles and specifying the length and elevation of tile in each node.

Basic Data Deck Instructions

These instructions have been copied, with minor modifications from model documentation by Trescott (1975).

Group I: Title, Simulation Options and Problem Dimensions.--This group of cards, which is read by the main program, contains data required to dimension the model. To specify an option on card 7 punch the characters underlined in the definition. For an option not used, that section of the card 7 can be left blank.

Note: Default typing of variables applies for all data input.

CARD	COLUMNS	FORMAT	VARIABLE	DEFINITION
1	1-80	20A4	HEADING	Any title the user wishes to print on one line at the start of output.
2	1-52	13A4	"	
3	1-56	14I4	IFIL	Symbolic unit numbers of file from which arrays normally part of the Basic Data file are to be read. Normally set to 5.
4	1-80	80I1	IDD	Number of layers (starting from the top) for which the potentiometric heads are to

CARD	COLUMNS	FORMAT	VARIABLE	DEFINITION
				be printed. The column number in which the number is punched corresponds to the recharge period for which heads will be printed.
5	1-10	F10.0	RESMO	Multiplier for "RES" field in subroutine SOLVE.
6	1-10	I10	IO	Number of rows
	11-20	I10	JO	Number of columns
	21-30	I10	KO	Number of layers
	31-40	I10	ITMAX	Maximum number of iterations per time step
	41-50	I10	NCH	Number of constant head nodes
	51-60	I10	ND	Number of nodes containing a drain
	61-70	I10	NRIV	Number of nodes containing a river
7	1-4	A4	IDRAW	DRAW to print drawdown
	6-9	A4	IHEAD	HEAD to print hydraulic head
	11-14	A4	IFLOW	MASS to compute a mass balance
	16-18	A3	IDK1	DK1 to read initial head, elapsed time, and mass balance parameters from unit 4 on disk
	21-23	A3	IDK2	DK2 to write computed head, elapsed time, and mass balance parameters on unit 44 (disk)
	26-29	A4	IWATER	WATE if the upper hydrologic unit is unconfined
	31-34	A4	IQRE	RECH for a constant recharge that may be a function of space
	36-39	A4	IPU1	PUN1 to read initial head, elapsed time, and mass balance parameters from cards

CARD	COLUMNS	FORMAT	VARIABLE	DEFINITION
	41-44	A4	IPU2	PUN2 to punch computed head, elapsed time, and mass balance parameters on cards
	46-49	A4	ITK	ITKR to read the value of TK(I,J,K) for simulations in which confining layers are not represented by layers of nodes (TK (I,J,K)) = K_{zz}/b

Group II: Scalar parameters.--The parameters required in every problem are underlined. The other parameters are required as noted; when not required, their location on the card can be left blank. The G format is used to read E, F and I format data. Minimize mistakes by always right-justifying data in the field. If F format data do not contain significant figures to the right of the decimal point, the decimal point can be omitted.

CARD	COLUMNS	FORMAT	VARIABLE	DEFINITION
1	1-10	G10.0	NPER	Number of recharge periods for the simulation
	11-20	G10.0	KTH	Number of time steps between printouts

Note: To print only the results for the final time step in a pumping period, make KTH greater than the expected number of time steps. The program always prints the results for the final time step.

CARD	COLUMNS	FORMAT	VARIABLE	DEFINITION
	21-30	G10.0	ERR	Error criteria for closure (L)

Note: When the head change at all nodes on subsequent iterations is less than this value (for example, 0.01 foot), the program has converged to a solution for the time step.

CARD	COLUMNS	FORMAT	VARIABLE	DEFINITION
	31-40	G10.0	LENGTH	Number of iteration parameters
	1-10	G10.0	XSCALE	Factor to convert model length unit to unit in X direction on maps (e.g. to convert from feet to miles, XSCALE - 5280). For no maps, card 2 is blank

CARD	COLUMN	FORMAT	VARIABLE	DEFINITION
	11-20	G10.0	YSCALE	Factor to convert model length unit to unit used in Y direction on maps.
	21-30	G10.0	DINCH	Number of map units per inch
	31-40	G10.0	FACT1	Factor to adjust value of drawdown printed*
	41-49	9I1	LEVEL(I)	Layers for which drawdown maps are to be printed. List the layers starting in column 41; the first zero entry terminates the printing of drawdown maps.
2	51-60	G10.0	FACT2	Factor to adjust value of head printed*
	61-69	9I1	LEVEL2(I)	Layers for which head maps are to be printed. List layers starting in column 61; the first zero entry terminates the printing of head maps.
	71-78	A8	MESUR	Name of map length unit.
3	1-20	G20.10	SUM	
	21-40	G20.10	SUMP	
	41-60	G20.10	PUMPT	Parameters in which elapsed times and cumulative volumes for mass balance are stored. For the start of a simulation insert three blank cards. <u>For continuation</u> of a previous run using cards as input, replace the three blank cards with the first three cards of punched output from the previous run. Using data from disk for input, leave the three blank cards in the data deck.
	61-80	G20.10	CFLUXT	
4	1-20	G20.10	QRET	
	21-40	G20.10	CHST	
	41-60	G20.10	CHDT	
	61-80	G20.10	FLUXT	
5	1-20	G20.10	STORT	
	21-40	G20.10	ETFLXT	
	41-60	G20.10	FLXNT	

*Value of drawdown or head	FACT 1 or FACT 2	Printed value
0.01	1	
	0.1	5
52.57	1.0	53
	10.0	526
	100.0	***

Group III: Array Data.--Each of the following data sets (except data set 1) consists of a parameter card and, if the data set contains variable data, a set of data cards for each layer in the model. Each parameter card contains at least five variables:

CARD	COLUMNS	FORMAT	VARIABLE	DEFINITION
Every Parameter Card	1-10	G10.0	FAC	If IVAR = 0, FAC is the value assigned to every element of the matrix for this layer. If IVAR = 1, FAC is the multiplication factor for the following set of data cards for this layer.
	11-20	G10.0	IVAR	= 0 if no data cards are to be read for this year. = 1 if data cards for this layer follow.
	21-30	G10.0	IPRN	= 0 if input data for this layer are to be printed; = 1 if input data for the layer are not to be printed.
Trans-missivity Parameter cards also have these Variables	31-40	G10.0	FACT(K,1)	multiplication factor for transmissivity in x direction
	41-50	G10.0	FACT(K,2)	multiplication factor for transmissivity in the y direction

CARD	COLUMNS	FORMAT	VARIABLE	DEFINITION
	51-60	G10.0	FACT(K,3)	multiplication factor for hydraulic conductivity in the z direction. (Not used when confining bed nodes are eliminated and TK values are read)
Every Parameter Card	61-70	G10.0	IRECS	= 0 if the matrix is being read from cards or if each element is being set equal to FAC. = 1 if the matrix is to be read from disk (unit 2)
	71-80	G10.0	IRECD	= 0 if the matrix is not to be stored on disk. = 1 if the matrix being read from cards or set equal to FAC is to be stored on disk (unit 2) for later retrieval.

DATA SET	COLUMNS	FORMAT	VARIABLE	DEFINITION
1	1-80	8F 10.4	PHI(I,J,K)	Head values for continuation of a previous run (L)

Note: For a new simulation this data set is omitted. Do not include a parameter card with this data set.

DATA SET	COLUMNS	FORMAT	VARIABLE	DEFINITION
2	1-80	8F 10.4	STRT(I,J,K)	Starting head matrix (L)
3	1-80	20F 4.0	S (I,J,K)	Storage coefficient (dimensionless)

Note: This matrix is also used to locate constant head boundaries by coding a negative number at constant head nodes. At these nodes T must be greater than zero.

DATA SET	COLUMNS	FORMAT	VARIABLE	DEFINITION
4	1-80	20F 4.0	T(I,J,K)	Transmissivity (L^2/t)

Note 1) Zero values are required around the perimeter of the T matrix for each layer for reasons inherent in the computational scheme. This is done automatically by the program.

2) See the previous page for the additional requirements on the parameter cards for this data set.

DATA SET	COLUMNS	FORMAT	VARIABLE	DEFINITION

Note 3) If the upper active layer is unconfined and PERM and BOTTOM are to be read for this layer, insert a parameter card for this layer with only the values for FACT on it.

DATA SET	COLUMNS	FORMAT	VARIABLE	DEFINITION
5	1-80	20F 4.0	TK(I,J,K)	K_{zz}/b

Note: This data set is read only if specified in the options. The number of layers of TK values = K'=1. See the discussion of the treatment of confining layers.

DATA SET	COLUMNS	FORMAT	VARIABLE	DEFINITION
6	1-80	20F 4.0	PERM(I,J)	Hydraulic conductivity (L/T) (see note 1 for data set 4)
7	1-80	20F 4.0	BOTTOM(I,J)	Elevation of bottom of water-table unit (L)

Note: Data sets 6 and 7 are required only for simulating unconfined conditions in the upper hydrologic unit.

DATA SET	COLUMNS	FORMAT	VARIABLE	DEFINITION
8	1-80	20F 4.0	QRE(I,J)	Recharge rate (L/T) If recharge rate is read for each recharge period then this card is ignored and recharge rate is read from the Recharge File

Note: Omit if not used.

DATA SET	COLUMNS	FORMAT	VARIABLE	DEFINITION
9	1-80	8G10.0	DELX(J)	Grid spacing in x direction (L)
10	1-80	8G10.0	DELY(I)	Grid spacing in y direction (L)
11	1-80	8G10.0	DELZ(K)	Grid spacing in z direction (L)

Group IV: Parameters that change with the recharge period.--The Program has two options for the simulation period:

1. To simulate a given number of time steps, set TMAX to a value larger than the expected simulation period. The program will use NUMT, CDLT, and DELT as coded.

2. To simulate a given recharge period, set NUMT larger than the number required for the simulation period (for example, 100). The program will compute the exact DELT (which will be ≤ DELT coded) and NUMT to arrive exactly at TMAX on the last time step.

CARD	COLUMNS	FORMAT	VARIABLE	DEFINITION
1	1-10	G10.0	KP	Number of the recharge period
	11-20	G10.0	KPM1	Number of the previous recharge period
	Note: KPM1 is currently not used.			
	21-30	G10.0	NWEL	Number of wells for this recharge period
	31-40	G10.0	TMAX	Number of days in this recharge period
	41-50	G10.0	NUMT	Number of time steps
	51-60	G10.0	CDLT	Multiplying factor for DELT
	Note: 1.5 is commonly used			
	61-70	G10.0	DELT	Initial time step in hours
	71-80	G10.0		Flag to indicate that recharge to the top layer is to be read from recharge file for each recharge period.

If NWEL: 0 the following set of cards is omitted

DATA SET 1 (NEWL cards)

COLUMNS	FORMAT	VARIABLE	DEFINITION
1-10	G10.0	K	Layer in which well is located
11-20	G10.0	I	Row location of well
21-30	G10.0	J	Column location of well
31-40	G10.0	WELL(I,J,K)	Pumping rate (L^3/t), negative for a pumping well.

For each recharge period only wells pumping at a different rate than the previous recharge period need to be entered.

Recharge File Instructions

The recharge file contains one record for each recharge period in the simulation. Each record contains a recharge rate per unit area for each node in the top layer of the grid. The values are in internal floating point notation in column major order.

River Data Deck

The river data deck consists of four arrays and three parameter cards.

ARRAY	COLUMNS	FORMAT	DEFINITION
IDR(I,J)	1-80	80I1	Indicator array for cells containing a river, 1 for river 0 for no river.
RH(NRIV)	1-80	20F4.0	River water level for each of the NRIV cells containing a river. Entered in row major order.
RB(NRIV)	1-80	20F4.0	Bottom of streambed layer in each of the NRIV cells containing a river. Entered in row major order.
RC(NRIV)	1-80	10F8.0	Leakage factor for each of the NRIV cells containing a river. The factor for each cell is the percent area of the cell occupied by the hydraulic conductivity of the river bed and directed by the thickness of the river bed.

The RH, RB and RC arrays must each be preceded by a parameter card similar to those described for array data in the basic data deck.

Drainage Tile Deck

This file consists of three arrays and two parameter cards.

ARRAY	COLUMNS	FORMAT	DEFINITION
ID(I,J)	1-80	80I1	Indicator array for cells containing drainage tile, 1 for tile, 0 for no tile.

ARRAY	COLUMNS	FORMAT	DEFINITION
LD(ND)	1-80	40F2.0	Length of drainage tile (in hundreds of feet) in the ND cells containing tile. Entered in row major order.

The LD and ELD arrays must each be preceded by a parameter card similar to those described for array data in the basic data deck.

Several additional files are available for data input. They are described in detail in the model program documentation (Trescott 1975).