STEADY-STATE COMPUTER MODEL OF THE WATER-TABLE AQUIFER IN THE MULLICA RIVER BASIN, THE PINE BARRENS, NEW JERSEY

By Arlen W. Harbaugh and Carol L. Tilley

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WILLIAM P. CLARK, Secretary

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Dallas L. Peck, Director

For additional information,
write to:

District Chief
U.S. Geological Survey
Room 418, Federal Building
402 East State Street
Trenton, New Jersey 08608

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CONVERSION FACTORS AND ABBREVIATIONS

The inch-pound units used in this report can be converted to International System (SI) of metric units as follows:

Multiply inch-pound units	By	To obtain SI units
foot (ft)	0.3048	meter (m)
square mile (mi^2)	2.590	square kilometer (km^2)
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)
foot squared per day (ft^2/d)	1.075×10^{-6}	meter squared per second (m^2/s)

National Geodetic Vertical Datum of 1929 (NGVD of 1929): A geodetic datum derived from a general adjustment of the first-order level nets of both the United States and Canada, formerly called "Mean Sea Level". NGVD of 1929 is referred to as "sea level" in this report.

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ABSTRACT

A two-dimensional steady-state model of the water-table aquifer of the Mullica River basin, New Jersey Pine Barrens, was made as an initial step in developing a predictive model. The purpose of the steady-state model is to evaluate simplfying concepts of the flow system and data required to simulate it. The Mullica River basin covers an area of 570 mi² and is drained by numerous shallow streams. The water-table aquifer consists mainly of sand and gravel intermixed with clay and silt. The computer model is based on the finite-difference method with stream-seepage equations coupled to the ground-water equation. The model was applied to the approximately steady-state conditions of March 1976.

Model-calculated water level and streamflow compare favorably with measured values. Initial estimates of streambed hydraulic conductance and aquifer hydraulic conductivity were adjusted so that model water level matched measured water level within 5 ft for 41 of 42 wells. Also, model streamflow was within 20 percent of measured streamflow at 12 of 15 sites. However, because of uncertainty in the head difference across streambeds, the uncertainty in streambed conductance is large. Additional field measurements of water level beneath the stream and stream stage are required to accurately calibrate streambed conductance. The 5,000-ft grid spacing that was used should also be adequate for the predictive model. The natural flow system is adequately simulated by a two-dimensional model.

INTRODUCTION

The Mullica River basin (570 mi²) is in southern New Jersey and is part of the Pine Barrens region (fig. 1). In 1954, the State acquired the Wharton Tract, now known as the Wharton State Forest, in the Mullica River basin (fig. 1) to conserve and develop its water resources. Development of water resources could affect the ecological balance, use, and management of the area.

To provide quantitative solutions to problems arising from ground-water development, the U.S. Geological Survey, in cooperation with the New Jersey Department of Environmental Protection, Division of Water Resources, and the U.S. Army Corps of Engineers,

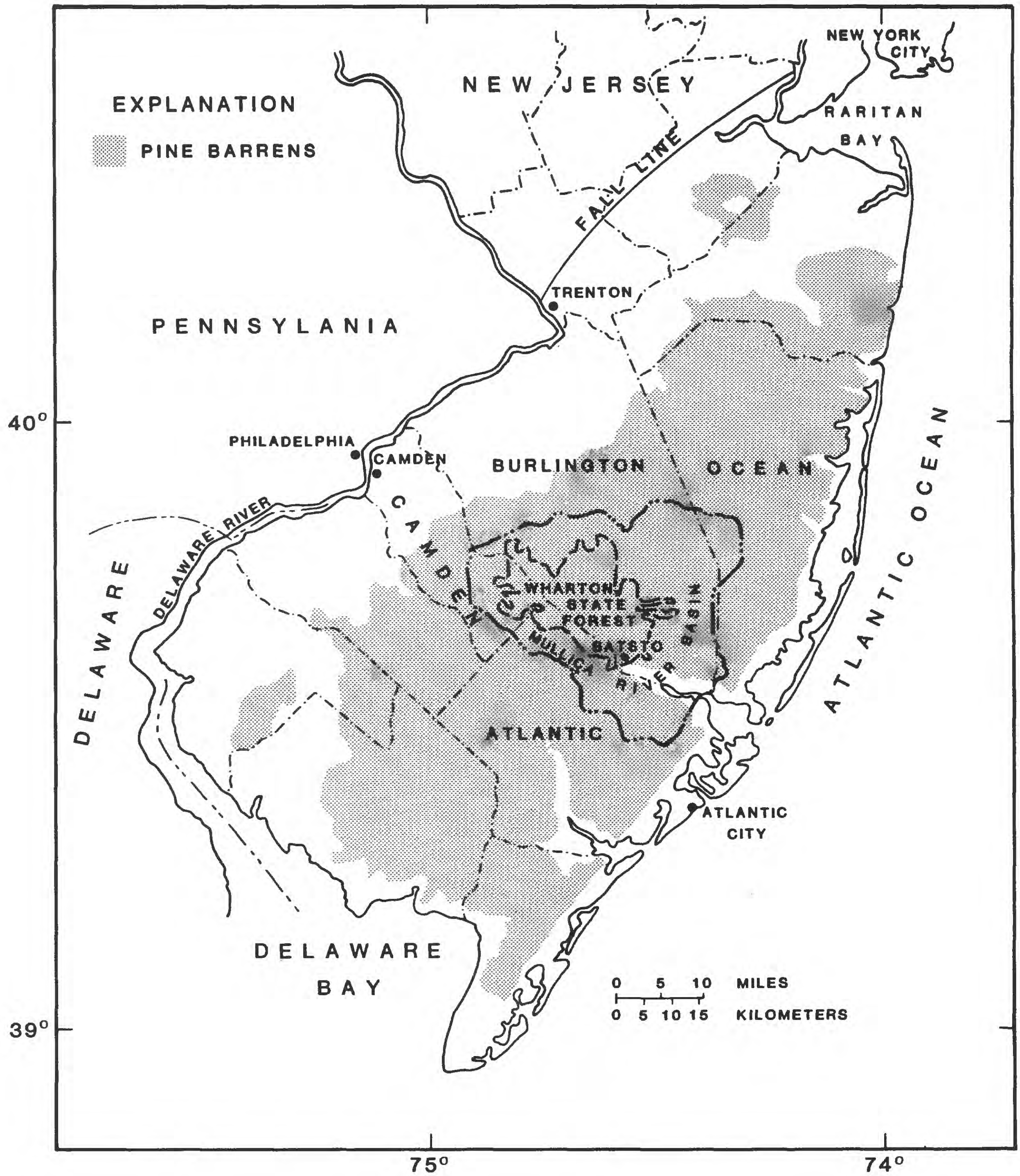


Figure 1.--Location of Mullica River Basin, the Pine Barrens, and the Wharton State Forest. (Modified from McCormick, 1967)

initiated a study of Mullica River basin. The purpose of this report is to present the results of the initial stage of this study, development of a steady-state model of the area.

The steady-state model is a first step toward the final goal of producing a model suitable for use by managers to evaluate alternative water-development schemes. The purpose of the steady-state model is to:

1. Test assumptions about the ground-water flow system.
2. Determine the detail required to simulate the system.
3. Determine data values for use in future models.

This report describes the development of the model, including assumptions made, input data used, and the results of the calibration process. Results are discussed from the point of view of what conceptual changes and additional data are required to test fully and produce a useful, accurate predictive model. The final step remains to develop a model that can simulate ground-water flow under a wide range of conditions.

HYDROGEOLOGY

Physiographic Features

The Mullica River basin drains southeastward to the Atlantic Ocean. The Mullica River has approximately 20 tributaries, including the Batsto and Wading Rivers (fig. 7). These streams cut only slightly into the gentle, undulating topography and are commonly bordered by swamps. Altitudes in the basin rarely exceed 100 ft, and surface slopes of 3 to 10 ft/mi are typical. Swamps, ponds, lakes, and stream channels comprise 23 percent of the drainage basin. Swamps vary from less than 4 percent of headwater areas to as much as 35 percent of downstream areas (Rhodehamel, 1973, p. 7).

The nonswamp upland area of the Mullica River basin is covered with oak and pine trees, which are well adapted to the sandy soils. Low-lying swamps are covered by white cedar and a woody undergrowth, which can tolerate saturated soil.

Geologic Features

The Atlantic Coastal Plain of New Jersey is underlain by a sequence of unconsolidated deposits of gravel, sand, silt, and clay that dip southeastward toward the Atlantic Ocean. The thickness of the deposits ranges from 0 ft along the Delaware River in central and southwestern New Jersey to more than 6,500 ft along the Atlantic Ocean shore in southern New Jersey. Beneath the unconsolidated sediment of the Coastal Plain lie pre-Cretaceous metamorphic rocks.

Table 1 summarizes the uppermost stratigraphic units of the Coastal Plain in the Mullica River basin and lists their hydrologic characteristics. The data are based on information provided by Rhodehamel (1973), Owens and Minard (1979), Farlekas and others (1976), and on unpublished geophysical logs on file at the Trenton office of the U.S. Geological Survey. Figure 2 is a generalized block diagram of these sedimentary deposits. It shows a thick clay bed within the Kirkwood Formation.

The Kirkwood Formation, of middle Miocene age, ranges in thickness from a 0 ft in the west to as much as 780 ft along the southeast coast. It consists of diatomaceous clay, silty sand, feldspathic sand, and clean fine- to medium-grained gravel and sand (Gill, 1962). The diverse minerals and differences in grain size of this formation indicate former advances and retreats of the sea. Many of the lithologic units are not regionally extensive but an extensive diatomaceous clay more than 200 ft thick occurs in the eastern part of the basin. (See fig. 2).

The Kirkwood is unconformably overlain by the Cohansey Sand (Rhodehamel, 1973, p. 21, 26) of Miocene age. The Cohansey is predominantly a quartz sand with some pebbly sand, coarse sand, silty and clayey sand, and interbedded clays. It ranges in thickness from 25 to 200 ft in the Mullica River basin. It is interpreted as resulting from a transitional or mixed depositional environment and includes alluvial, deltaic, estuarine, beach, and other near-shore marine deposits (Rhodehamel, 1973, p. 28).

The Cohansey Sand is overlain by a series of younger deposits that are mostly alluvial in origin. These deposits are not regionally extensive and are typically thin although they may thicken locally to as much as 40 ft.

Hydrology

The top strata of the Kirkwood Formation are hydraulically connected to the overlying Cohansey Sand and younger sediments, forming a single system called the Kirkwood-Cohansey aquifer system (Rhodehamel, 1973, p. 23). The system extends vertically downward from land surface to the thin but regionally extensive clay at the base of the Kirkwood Formation in the western part of the basin (fig. 2). It extends downward only as far as a thick stratigraphically higher clay unit above the lower Kirkwood aquifer or the Atlantic City "800-foot" sand in the eastern part of the basin (Thompson, 1928). The thickness of the sediments in the aquifer system ranges from about 125 to 350 ft. Although the Kirkwood-Cohansey aquifer system is considered a water-table aquifer, its interbedded clays cause local confinement and vertical variation in heads as indicated in some aquifer tests. Also, bog iron occurs at the top of the system in some stream channels and swamps, restricting flow to and from the streams and swamps (Lang and Rhodehamel, 1963).

Table 1.--Summary of the uppermost stratigraphic section in the Mullica River basin

System	Series	Formation	Thickness	Lithology	Hydrologic Characteristics
Quaternary	Holocene	Undifferentiated deposits in stream channels, marshes, estuaries, and bays	0-10	Clay, silt, sand, bog iron, and peat	Too thin to be tapped for water.
	Pleistocene	Cape May Formation	0-15[1]	Clay, silt, sand and gravel	Highly permeable, hydraulically connected to underlying formations.
		Bridgeton Formation	0-20	Clayey, feldspathic sand.	Commonly connected hydraulically with underlying aquifers.
		Beacon Hill Gravel	0-40	Interbeded sand and gravel.	Commonly connected hydraulically with underlying aquifers.
Tertiary	Miocene	Cohansey Sand	25-200	Coarse-grained sand and sandy silt, thin beds of clay.	Excellent capacity to store and ability to yield water.
		Kirkwood Formation	100-600	Very fine to coarse-grained sand, gravel and clay.	Excellent to poor ability to yield water. Upper part of formation hydraulically connected to the Cohansey Sand.
	Eocene	Manasquan Formation	0-200[2]	Clayey, fine-grained glauconitic, quartz sand.	Confining unit and minor aquifer.

[1] Maximum thickness exceeds 15 ft in tidal reaches of some streams.
[2] Thickness range is approximate.

EXPLANATION

Tch Cohansey Sand

Tkw Kirkwood Formation

Tmq Manasquan Formation

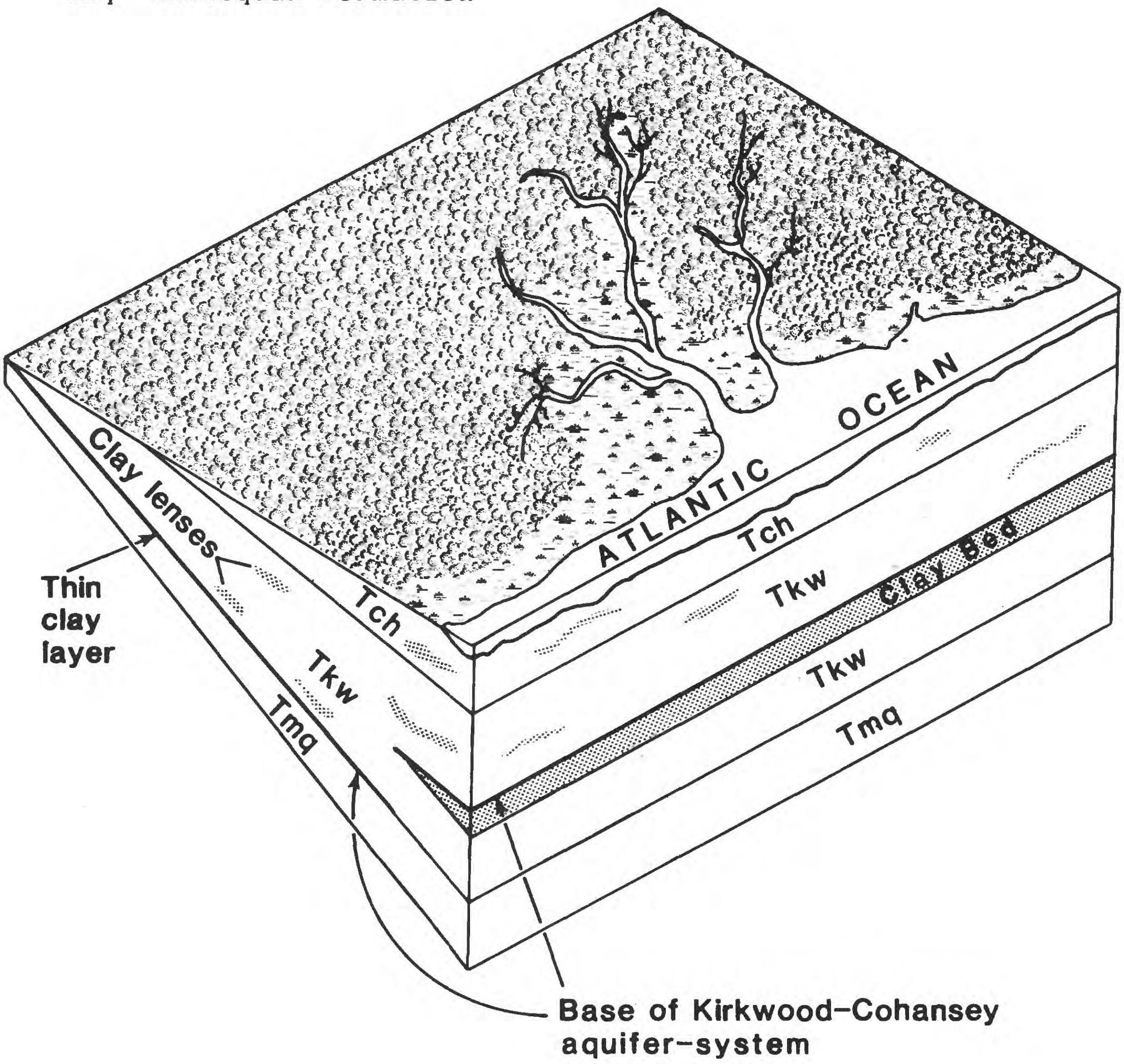


Figure 2.--Block diagram of the uppermost Coastal Plain sediments

The hydraulic conductivity of the Kirkwood Formation is considered to be lower than that of the Cohansey Sand. However, hydraulic conductivity values for each unit are not readily available because aquifer tests are believed to have produced values representative of the entire Kirkwood-Cohansey aquifer system. An aquifer test adjacent to the Mullica River, 2.5 miles south of Batsto (Lang and Rhodehamel, 1963) indicated an average transmissivity of 20,000 ft^2/d (feet squared per day). Rhodehamel (1973, p. 30) considered that this value is representative of the entire saturated thickness of the Kirkwood-Cohansey aquifer system despite some local confinement in the area. Based on an analysis of geophysical logs at the Trenton office of the U.S. Geological Survey, saturated aquifer thickness at the aquifer test site is 230 ft, and average hydraulic conductivity (transmissivity divided by saturated thickness) is 87 ft/d (feet per day).

The average value of 87 ft/d is consistent with knowledge of hydraulic conductivity for the various sediments. Rhodehamel (1973, p. 30) used 130 to 150 ft/d for the hydraulic conductivity of sand deposits in the aquifer system, but significant beds of finer sediments, such as clay and silt, have much lower hydraulic conductivity. Geophysical logs show that as much as 25 percent of the thickness of the Kirkwood-Cohansey aquifer system in parts of the Mullica River basin is clay. Accordingly, the average hydraulic conductivity of all sediments combined is believed to be significantly less than 150 ft/d, depending on the proportion of sediments finer than sand.

Hydrologic Cycle

Figure 3 is a schematic diagram of the hydrologic cycle in the Mullica River basin. The source of water in the basin is precipitation. The temperate climate, the forested interdivide, and the swampy riparian lands all promote a significant amount of evapotranspiration annually. Overland flow is a small fraction of the total hydrologic budget (Rhodehamel, 1970, p. 7). The remainder of the precipitation infiltrates the predominantely sandy soil of the basin and percolates through the ground to the water-table aquifer. Ground water moves laterally to nearby streams, adjacent swampy areas, or to deeper areas from which it is discharged to larger streams or bays.

STEADY-STATE MODEL DEVELOPMENT

The computer model program used in this study is documented by McDonald and Harbaugh (1984). The program solves the ground-water flow equations in three dimensions by use of finite difference approximations. However, for this study the program was set up to simulate only two-dimensional horizontal flow. The program calculates seepage to streams and also calculates ground-water levels.

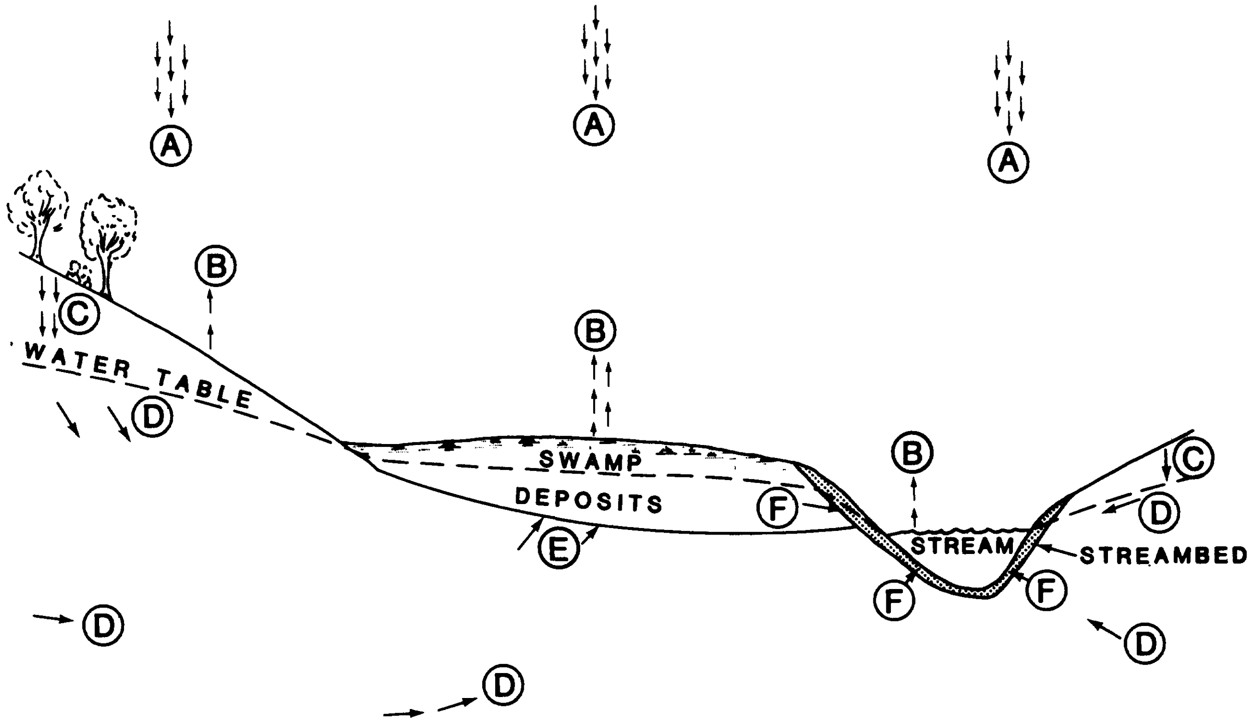


Figure 3.--Hydrologic cycle of the Mullica River basin
(A) precipitation, (B) evapotranspiration
(C) percolation, (D) ground-water flow
(E) seepage to swamp, (F) seepage to stream

To construct a model, certain geologic and hydrologic data for the study area must be entered into the model program. The accuracy of a model is customarily tested by comparing model generated streamflow and water levels to measured values.

Steady-state conditions prevail in an aquifer when water levels remain constant for some time. This occurs when inflow to the system is equal to outflow so that the volume of water in storage does not change. Transient conditions prevail while water levels and storage are changing in response to a changes in stress (for example, changes in pumping and evapotranspiration rates).

A steady-state model cannot simulate aquifer response to changes in stress. The advantage of constructing a steady-state model is its relative simplicity. Fewer input parameters are required for a steady-state model, and limiting the number of input parameters facilitates model calibration. In addition, the steady-state model is useful for testing the modeler's concept of how the aquifer system functions and whether the assumptions used to build the model are valid. A further advantage is that a completed steady-state model can be used to develop a transient model. Many of the parameters established in the steady-state model may be used without change in the transient model.

The steady-state model was developed for the Mullica River basin based on conditions in March 1976 when approximately steady-state conditions prevailed. An absolutely steady state is never attained in the basin because aquifer recharge and evapotranspiration vary from day to day and from place to place because of differences in climate. Nevertheless, an approximately steady state prevails toward the end of a typical winter. At this time, water levels generally are near their seasonal peak levels after recovering from summer lows resulting from high evapotranspiration. Ground-water withdrawals are small, especially in the winter when irrigation is nil, therefore they were not simulated in the model. Water-level measurements show that monthly changes in head during late winter, 1976, were small compared to normal seasonal changes. Ground-water levels measured at 47 observation wells tapping the Kirkwood-Cohansey aquifer system in the Mullica River basin showed an average change of only 0.93 ft from February to March 1976.

Model Design

Streams and Swamps

The computer model simulates the interaction of streams with the water-table aquifer. Fluxes between stream and aquifer are modeled as a function of stream and aquifer heads.

In order to model swamps as separate entities, data quantifying their interaction with the ground-water flow system are required. Such data were not available, hence, simplified assumptions were necessary. The assumptions were based on the following hydrologic observations:

1. A major function of swamps during high ground-water levels is to drain ground water.

2. Water draining from swamps flows into nearby stream channels.

It was assumed that ground-water seepage to swamps could be adequately accounted for in the model by seepage directly into adjacent stream reaches; accordingly, swamps are not modeled separately from streams. Therefore, modeled seepage through a streambed, represents both actual ground-water seepage through the streambed and seepage into swamps that drain into the stream. Also, precipitation on a swampy area that would ordinarily run off to an adjacent stream channel is modeled as recharge to the ground-water system and subsequent seepage through the streambed. Although these assumptions are considered valid for the steady-state conditions being modeled, they are not valid for transient conditions.

Grid Design

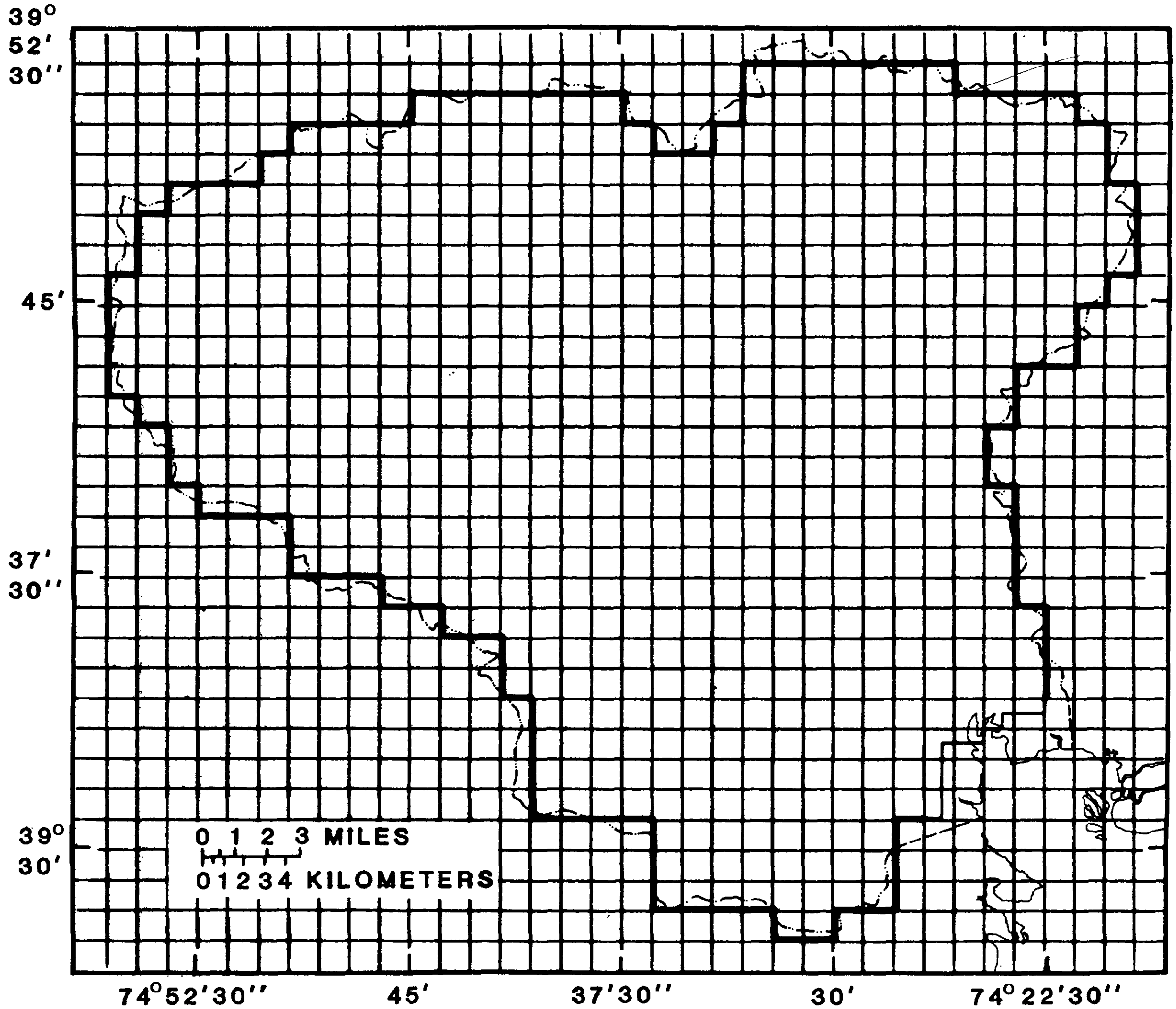
The aquifer system of the Mullica River basin was discretized by use of a 31x36 finite-difference grid with a uniform spacing of 5,000 ft (fig. 4). Nodes are located at the center of each square. The spacing was made as large as possible with the constraint that most of the streams had to be separately represented. The grid orientation minimizes the number of unused nodes and parallels the latitudinal and longitudinal axes.

Boundary Conditions

Both no-flow boundaries and constant head boundaries are used in the model. The base of the Kirkwood-Cohansey aquifer system and the ground-water divide of the Mullica River basin are simulated as impermeable (no-flow) boundaries. The base, defined by the highest regionally extensive silt-clay horizon within the Kirkwood Formation, is simulated as an impermeable boundary. This boundary delineates the vertical extent of the aquifer system modeled.

The ground-water divide is assumed to coincide with the topographic divide and is simulated as a no-flow boundary (fig. 4). The boundary is modeled by assigning a zero hydraulic conductivity to the nodes outside of the divide. In a transient situation, the ground-water divide would move as stresses changed and could not be simulated as a no-flow boundary.

The marshes bordering the tidal basin (fig. 2) correspond to a known constant-head boundary in the model (fig. 4). The shoreline marshes are assumed to be hydraulically connected with the bay. The maximum landward extent of the marshes approximates the maximum onshore encroachment of saltwater in the subsurface. An initial head of 2 ft was input for these constant head nodes; this is the freshwater equivalent of head at one-half the depth of



EXPLANATION

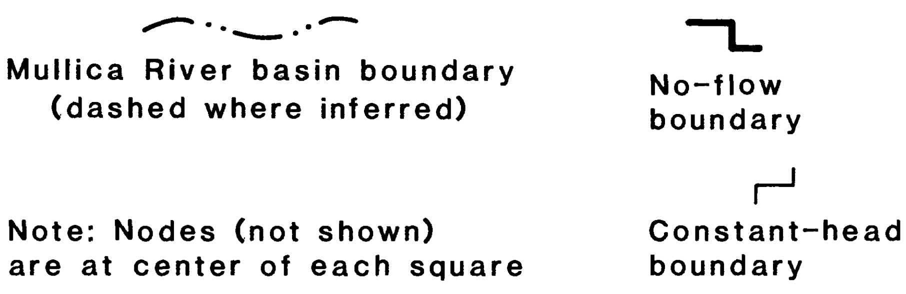


Figure 4.--Model grid and boundaries.

the aquifer. Tidal fluctuations were ignored because their effects are small.

Model Input Data

Aquifer Data

The aquifer was simulated as a water-table aquifer. Characteristics required for the aquifer at each node are altitude of the base of the aquifer, initial values for water level, and hydraulic conductivity.

The altitude of the base of the aquifer system is defined as the first regionally extensive confining bed within the Kirkwood Formation. Twenty-six geophysical logs within the basin were used to construct a contour map of the base of the unconfined aquifer system. Figure 5 shows the discretized version of this contour map and represents model input for the altitude of the aquifer bottom.

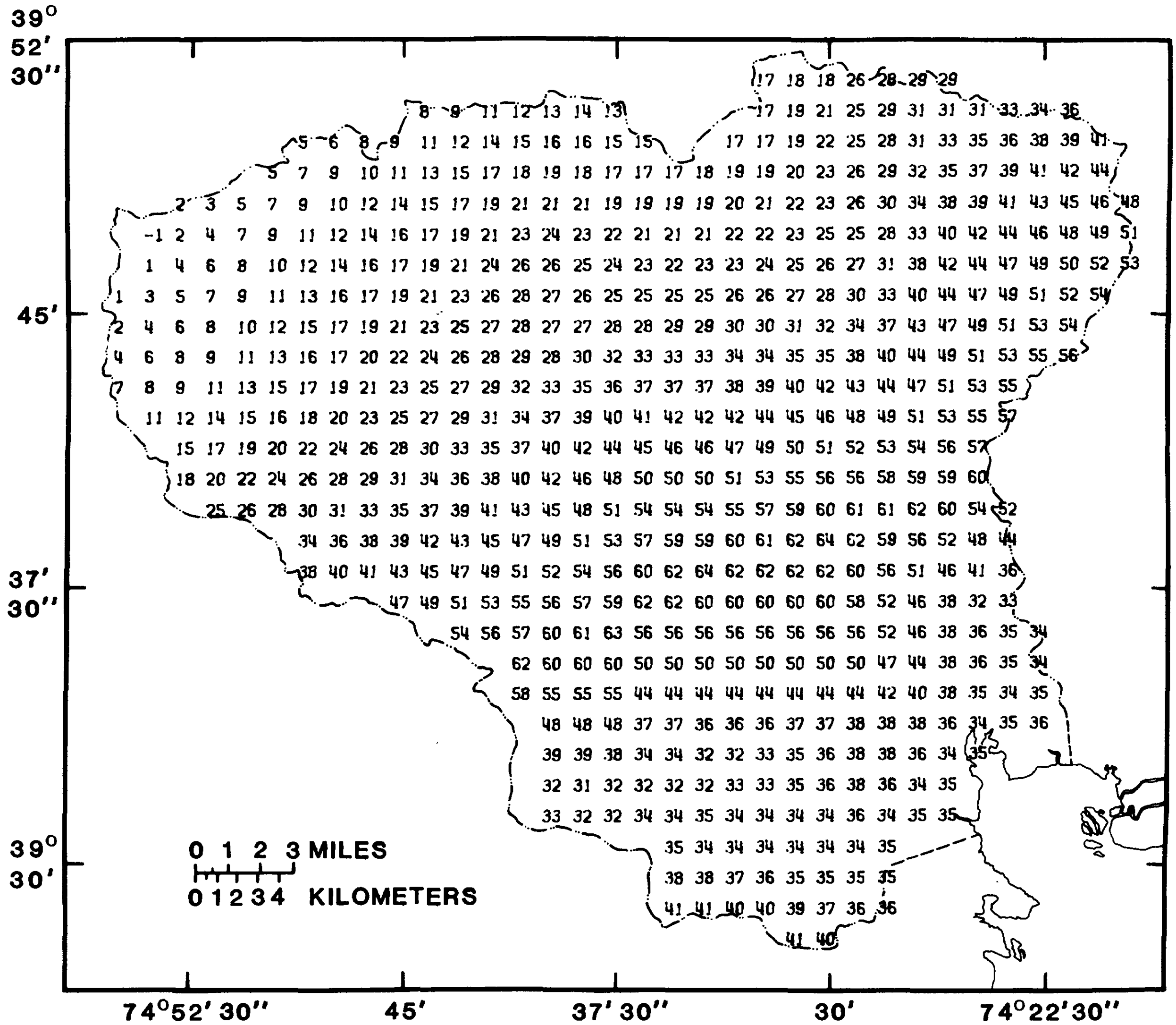
Although the model solves for steady-state water levels, specification of initial water levels is necessary. If the initial values are accurate, then computation time is saved. A water-table map of the Mullica River basin, based primarily on surface topography and altitude of surface waters (Rhodehamel, 1973, p. 19), was adapted for this purpose. The 47 water-level measurements made within the Wharton State Forest during March 1976 were incorporated in the water-table map. The well locations, and the water-level measurements are presented in figure 7 and table 3. The resulting contour map is shown in figure 8.

Initially a uniform value of hydraulic conductivity was assumed. Adjustment of its value and distribution was required during model calibration. See Model Calibration section.

Stream Data

For simulation of streams, model nodes representing streams were chosen, and routing (interconnection) was defined. The major streams and tributaries of the Mullica River basin were discretized and routed as indicated in figure 6. The model calculates seepage between the aquifer and stream, and the routing data were used to calculate total streamflow at each node. Streamflow is accumulated outside the model program because the program calculates the amount of seepage into the stream at each node, not the total of this seepage along the stream.

For each stream node, streambed conductance, altitude of the bottom of the streambed, and stream stage need to entered into the model. Streambed conductance is calculated as the product of streambed hydraulic conductivity, width, and length within the node, divided by bed thickness. Stream stage is based on topographic maps of the U.S. Geological Survey (Scale 1:24,000). Altitude of the bottom of the streambed is set 10 ft below the



EXPLANATION

Mullica River basin boundary (dashed where inferred)

27
Altitude in feet below sea level multiplied by 5

Figure 5.--Simulated altitude of base of Kirkwood-Cohansey aquifer system.

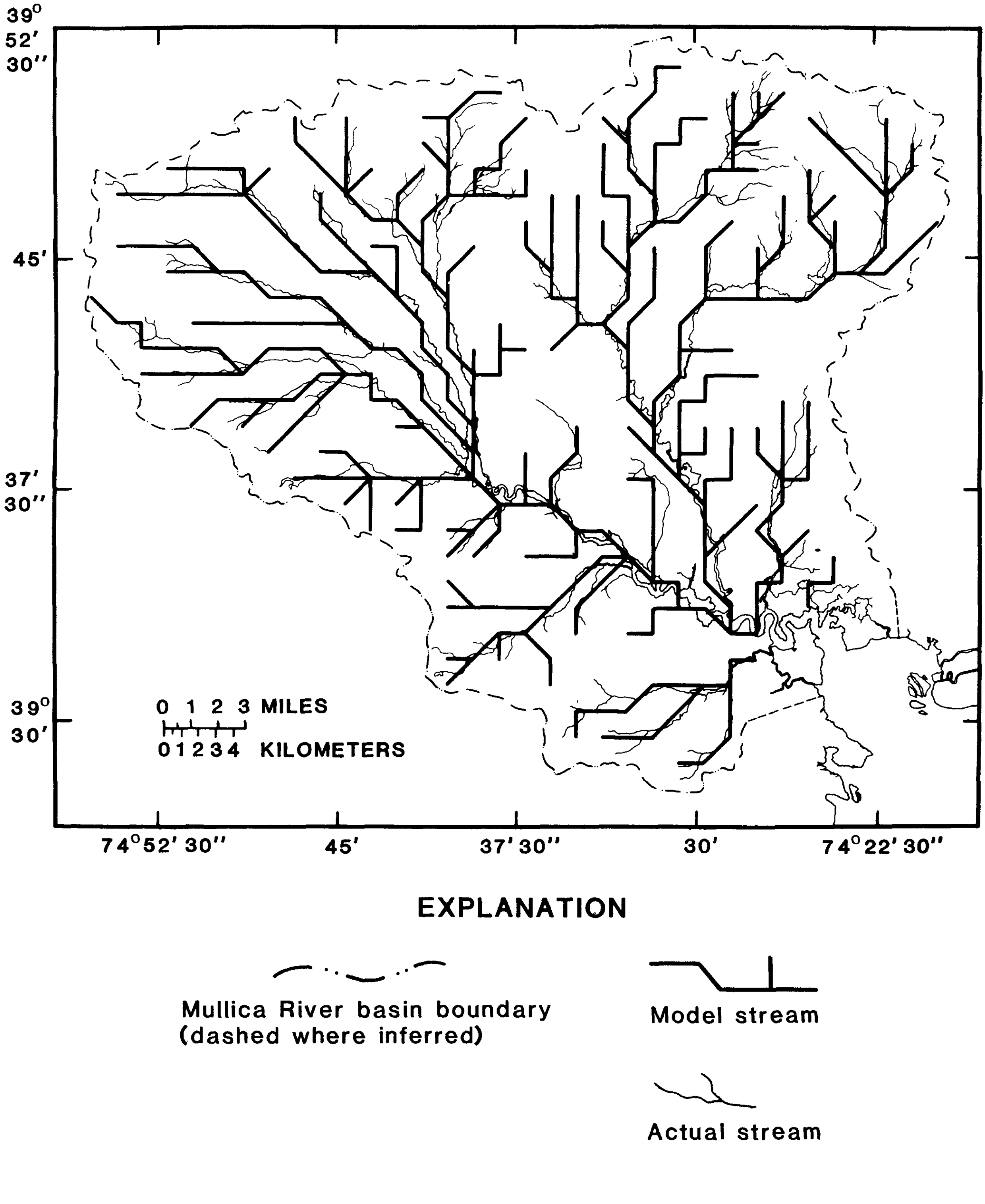


Figure 6.--Model stream-routing scheme.

stream stage. Although this value is required model input, it is not meaningful in this simulation. It is significant if the aquifer water level drops below the bottom of the streambed (McDonald and Harbaugh, 1984), which does not occur under the conditions modeled.

To make the initial estimate of streambed conductance, streambed hydraulic conductivity was assigned a constant value of 0.2 ft/d at all stream nodes. Thickness of the streambed was arbitrarily assigned as 2.5 ft at all stream nodes. Stream width at each stream node was estimated using topographic maps and experience of field personnel. During model calibration, values of streambed conductance were adjusted in order to make simulated streamflow match measured streamflow. See Model Calibration Section.

Stress Data

Stresses incorporated in the model program are aquifer recharge and evapotranspiration. Aquifer recharge consists of that part of the precipitation that reaches the water table. In the model, runoff is assumed to be zero because most of it comes from swampy areas, and it is modeled as seepage into the streams. The value of net aquifer recharge (precipitation minus evapotranspiration) can be determined relatively simply under steady-state conditions where inflow is equal to outflow. In the Mullica River basin, the only outflow is seepage to streams and flow to constant-head nodes. Flow to constant head nodes is negligible compared to streamflow. Therefore, the value of aquifer recharge was set to the estimated streamflow of the entire Mullica River basin in March 1976, approximately 922 ft^3/s. Because this amount already includes evapotranspiration losses, model evapotranspiration values were set to zero.

Recharge was divided equally among the 618 active model nodes because total precipitation was nearly equivalent at four weather stations in and near the basin for the period January through March 1976. However, on a day-to-day and week-to-week basis, there were significant differences among stations. The average rate of precipitation throughout the modeled area was 1,600 ft^3/s for the period January through March 1976.

Model Calibration

Performance Criteria

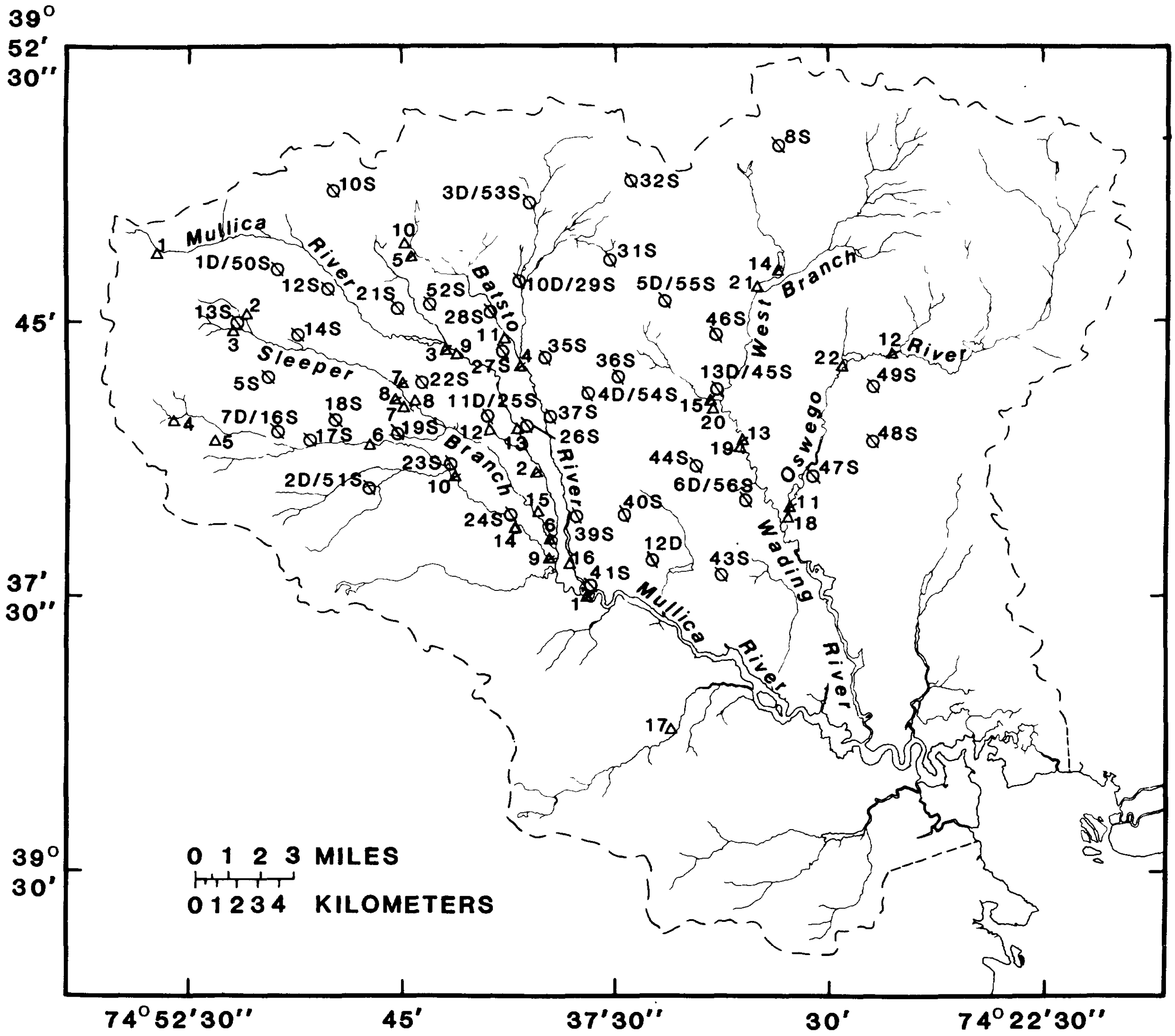
The major performance criteria for the steady-state model of the Mullica River basin are that its ground-water levels and streamflow match with reasonable closeness corresponding ground-water levels and streamflow measured in March 1976. A water-table map was constructed from measurements made in March 1976 at 52 observation wells and from stream altitudes taken from topographic maps of the U.S. Geological Survey.

The water-table altitude was assumed to be nearly equal to stream altitude along stream channels. This assumption is generally accepted in situations where the streambed is highly conductive, but is not so certain in areas where bog iron occurs. The hydraulic conductivity of bog iron is much lower than that of sand. Bog iron occurs along the Mullica River where aquifer head was reported to be only 2 to 3 ft higher than stream surface (Lang and Rhodehamel, 1963). Although the main stream-bed was clogged here, ground water was discharging to swampy areas flanking the stream. These swampy areas extend along most streams in the basin. So there is likely an error of 2 to 3 ft in the water-table map near streams whose beds contain bog iron.

For areas where wells are sparse, the generalized water-table map by Rhodehamel (1973, p. 19) was used. This map is largely based on stream altitudes and generally matches the water levels measured in March 1976. Accuracy of model water level was judged both by subjective appraisal of the regional match of model water levels to the measured water-table map and by a well-by-well comparison of model levels and measured levels at the 52 observation wells. The selected water-level calibration criterion is that model-calculated water level should match measured water level within 5 ft. Location of the observation wells is shown in figure 7. Although water levels measured at the wells are accurate to less than 0.1 ft, the 5-ft error criterion is considered reasonable because the accuracy of the simulation is limited by its scale, the assumptions used to simulate stream and swamps, and uncertainty in input data.

For streamflow comparisons, actual streamflow records for 22 continual and partial-record sites were analyzed (fig. 7). Table 2 identifies the sites and gives average March 1976 streamflow. Several miscellaneous measurements were also made. Low-flow correlation curves were used for the partial-record sites to calculate the average March 1976 flows. From these records, average March 1976 streamflow was estimated for each model stream node. Streamflow at ungaged points along each stream was estimated by use of stream-discharge profiles based on actual measurements combined with drainage-area correlations. Discrepancies in the comparison flow drainage area showed that gaging all water is difficult in many areas because of dense plant growth and multiple shallow channels. Also, some channels may split into two, diverting water from one subbasin to another. Some of these are artificial diversions for cranberry farming.

Although measured streamflow was estimated at each model stream node, a match of streamflow at each node was not justified. The sparsity of measured data and the insensitivity of the model to the amount of seepage at any single node would make such comparisons meaningless. Fifteen sites (fig. 7) near streamflow-measuring sites were chosen for streamflow calibration. The adopted streamflow-calibration criterion specifies that model flow at the calibration sites should match measured flow within 20 percent.



EXPLANATION

Mullica River basin boundary (dashed where inferred)

17S

Observation well. Alphanumeric characters identify well in table 3

2

Streamflow-gaging station or partial-record station. Number identifies station in table 2

7

Streamflow calibration site. Number identifies site in table 4

Figure 7.--Location of observation wells, streamflow sites, and stream-calibration sites.

Table 2.--Average streamflow in March 1976

Site identifier in figure 7	Station number	Station name	Station type[1]	Streamflow (ft^3/s)
1	01409375	Mullica River near Atco, NJ	PR	10.1
2	01409402	Hays Mill Creek near Chesilhurst, NJ	PR	28.6
3	01409403	Wildcat Branch at Chesilhurst, NJ	PR	1.57
4	01409407	Pump Branch near Blue Anchor, NJ	PR	8.64
5	01409409	Blue Anchor Brook near Blue Anchor, NJ	PR	3.40
6	01409410	Albertson Brook near Hammonton, NJ	PR	34.0
7	01409405	Clark Branch near Atsion, NJ	PR	26.6
8	01409404	Sleeper Branch near Atsion, NJ	PR	5.50
9	01409390	Mullica River at Atsion, NJ	PR	56.4
10	01409450	Springers Brook near Indian Mills, NJ	PR	22.3
11	01409460	Springers Brook near Atsion, NJ	PR	24.9
12	01409395	Mullica River tributary near Atsion, NJ	PR	28.3
13	01409400	Mullica River near Batsto, NJ	CG	130
14	01409411	Nescochague Creek at Pleasant Mills, NJ	PR	71.5
15	01409406	Sleeper Branch at Batsto, NJ	PR	9.26
16	01409500	Batsto River at Batsto, NJ	CG	116
17	01409575	Landing Creek at Philadelphia Avenue at Egg Harbor City, NJ	PR	13.2
18	01410000	Oswego River at Harrisville, NJ	CG	84.0
19	01409810	West Branch Wading River near Jenkins, NJ	CG	168
20	01409780	Tulpehocken Creek near Jenkins, NJ	PR	26.0
21	01409730	West Branch Wading River near Chatsworth, NJ	PR	44.1
22	01409970	Oswego River at Oswego Lake, NJ	PR	71.2

[1] PR indicates low-flow partial-record station and CG indicates continuous-record gaging station.

Besides meeting water-level and streamflow-performance criteria, the model input data must not require adjustment beyond reasonable limits in order to meet these criteria. Only two values were adjusted during the calibration process: hydraulic conductivity of the aquifer, and the conductance of the streambed. Establishing the range of uncertainty of these characteristics is important in order to insure realistic results.

Aquifer hydraulic conductivity should be within 15 to 150 ft/d. The maximum is based on Rhodehamel's (1973, p. 30) estimates of hydraulic conductivity of the Cohansey Sand. The minimum chosen was an order of magnitude lower to account for the possibility of a high percentage of lower conductivity materials. Also, the value of hydraulic conductivity was not adjusted node by node but by groups of nine or more nodes (with one exception described below). A large variation in average hydraulic conductivity within small areas is considered unreasonable because the water-bearing deposits are widespread and generally uniform in character (Rhodehamel, 1973, p. 30).

No limits were placed on the streambed conductance because most of the values controlling this property are unknown. A wide variation in the streambed conductance was expected. As previously indicated, bog iron deposits are thought to significantly limit seepage in some stream channels. Seepage from swamps, which is being modeled as part of stream seepage, would cause the streambed conductance to be large. All stream nodes were required to gain water except two nodes in a swampy area where one stream is known to lose water.

The stream that loses water is Sleeper Branch. Measurements show it loses water near its junction with the Mullica River (See fig. 7). The path of this "short-circuited" water could not be directly traced because the interstream area is swampy. There are two possible paths for this "cross flow", either on the surface or through the ground. Surface flow could move through high-conductivity swamp deposits that are isolated from the aquifer or, through a network of small channels throughout the swamp. Areal photographs show no large channel through the area. In the model the cross flow was simulated as flow through the ground. Hydraulic conductivity at the four nodes between the streams was raised to allow the cross flow.

Results

Results of the calibration are satisfactory. Water-level comparisons are shown in figure 8 and table 3. Figure 8 shows a generally close regional match between measured and simulated water levels. The disparity between the measured and simulated values near streams is expected because of the 5,000-ft node spacing and because of uncertainly of the measured water levels near streams where iron occurs. Significant discrepancies also mark the northeastern and east-central parts of the basin. Because there are no wells in these areas, the accuracy of the

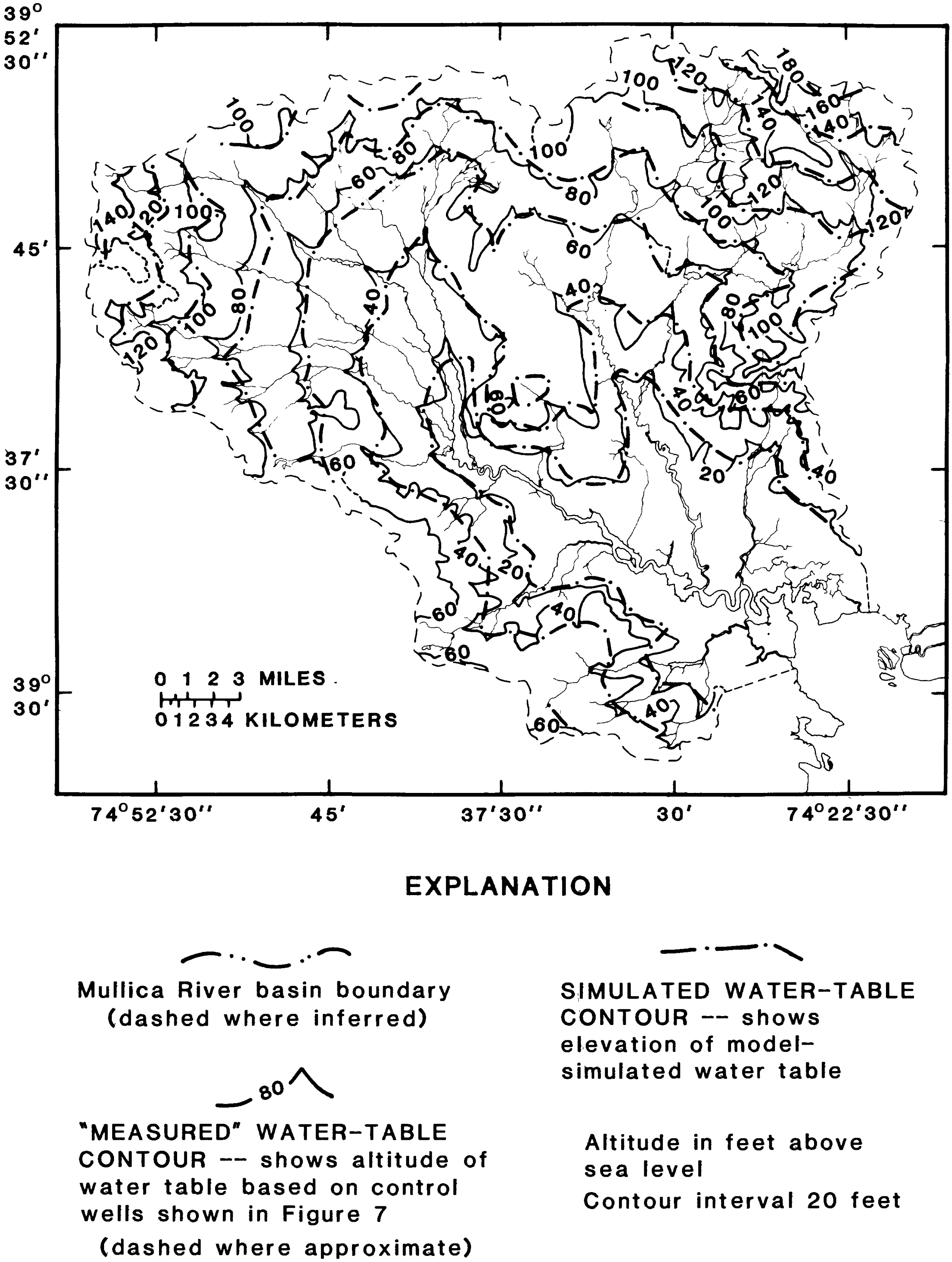


Figure 8.--Comparison of "measured" and model-simulated water levels, March 1976.

measured-water-level map is not known, and no attempt was made to adjust hydraulic conductivity locally.

Table 3 indicates that the model-calculated water levels match measured ones. To construct the table, model-simulated values at actual well locations were calculated from weighted values of the nearest surrounding model nodes. Weighting was based on the inverse of distance to the well location. The difference between measured and simulated water level is consistently less than 5 feet, except at well 39S. A perched water table may underlie this area. For all other wells, the average of the absolute value of water-level difference is 2.2 ft.

Streamflow comparisons are shown in table 4. Except at calibration sites 11-13, model values are within 20 percent of measured ones. At sites 11 and 12, measured streamflow is less than the drainage area would indicate and accordingly, model-calculated streamflow is greater than measured flow. At site 13, measured streamflow is greater than the drainage area would indicate. A possible explanation is that the ground-water divide between the West Branch and Oswego River basins in the northeastern part of the Mullica River basin (fig. 7) may not coincide with the surface-water divide. A shift in this ground-water divide toward Oswego River would cause more water to seep into the West Branch and less to seep into Oswego River. The lack of observation wells in this area precludes evaluation of this hypothesis, therefore, no adjustments were made in the model to shift water from the Oswego basin to the West Branch basin.

The final values for horizontal hydraulic conductivity of the aquifer system are shown in figure 9. Other combinations of hydraulic conductivity having the same regional pattern would produce similar results because the model is insensitive to the value of hydraulic conductivity at a single node. Except for the four nodes that were assigned high values to simulate the cross flow between 2 streams, the values are within or close to the acceptable range.

The hydraulic conductivity required to simulate the previously mentioned cross flow between streams is unrealistically high. It is likely that the aquifer is not the path for this water. Presumably, then, there is a surface path through the swampy area that carries the water between streams. The dense vegetation is assumed to hide this path from view.

A small area near the center was assigned a value of 10 ft/d, which is lower than the assumed minimum of 15 ft/d. The small deviation is probably not unreasonable because the minimum is arbitrary. However, it is also possible that the low value may be incorrect because of a misinterpreted water level measured in the area. Well 39S, which is within the low-conductivity area, is not considered representative of the regional water table. This well is only 1,500 ft from the Batsto River, but its water level is 35 ft higher than the river stage. This results in a ground-

Table 3.--Comparison of measured and model-simulated water levels for March 1976

[Water level in feet above sea level]

Well identification[1]	New Jersey unique well number[2]	Water level: Measured[3]	Water level: Model-simulated	Water level: Difference
10S	05-0422	101.61	99.04	2.57
1D/50S	07-0451/07-0452	94.01	91.60	2.41
12S	07-0444	70.97	72.61	-1.64
21S	05-0399	59.59	55.69	3.90
52S	05-0415	52.16	52.14	0.02
28S	05-0414	45.72	42.03	3.69
10D/29S	05-0417/05-0418	43.66	47.17	-3.51
3D/53S	05-0454/05-0455	59.06	61.67	-2.61
31S	05-0453	66.13	64.36	1.77
32S	05-0457	90.42	86.17	4.25
5D/55S	05-0451/05-0452	58.19	54.31	3.88
8S	05-0678	97.68	100.04	-2.36
13S	07-0442	93.58	95.08	-1.50
15S	07-0440	90.65	90.80	-0.15
14S	07-0441	80.93	82.69	-1.76
7D/16S	07-0430/07-0431	81.02	80.06	0.96
17S	07-0429	70.06	73.25	-3.19
18S	07-0432	67.21	65.75	1.46
19S	01-0352	49.94	51.85	-1.91
2D/51S	01-0349/01-0350	55.94	59.23	-3.29
22S	01-0348	47.80	49.01	-1.21
27S	05-0404	36.91	35.97	0.94
35S	05-0625	40.50	40.84	-0.34
11D/25S	05-0598/05-0599	31.76	29.29	2.47
26S	05-0592	22.72	23.97	-1.25
37S	05-0600	24.93	29.44	-4.51
4D/54S	05-0608/05-0609	44.17	45.93	-1.76
23S	01-0351	35.85	34.59	1.26
24S	01-0419	20.25	19.85	0.40
39S	05-0503	47.27	27.20	20.07
41S	05-0477	3.92	5.74	-1.82
36S	05-0618	48.16	51.48	-3.32
46S	05-0627	54.38	53.33	1.05
13D/45S	05-0612/05-0613	37.41	36.77	0.64
44S	05-0568	47.83	49.45	-1.62
40S	05-0502	60.54	58.07	2.47
6D/56S	05-0511	32.05	28.59	3.46
47S	05-0019	26.79	23.57	3.22
12D	05-0485	31.61	27.68	3.93
43S	05-0482	33.51	33.49	0.02
49S	05-0034	61.65	59.08	2.57
48S	05-0024	56.59	60.11	-3.52

[1] If two wells are at one site, a slash (/) separates the two well identifiers. D indicates a deep well (those in the table range in depth from 100 to 272 ft); S indicates a shallow well (those in the table range in depth from 15 to 60 ft). See figure 7 for location.

[2] This is a number assigned to all wells in the data bank of the U.S. Geological Survey Ground Water Site Inventory. It enables one to access information about a well that is stored in the bank.

[3] For sites with two wells, measured water level is the average of the two water levels.

Table 4.--Comparison of measured streamflow and model-simulated streamflow for March 1976

[Streamflow in cubic feet per second]

Streamflow calibration site (see figure 7 for location)	Streamflow		Difference	
	Measured	Model	Flow	Percent
1	366	370	-4	-1
2	130	112	18	14
3	58	53	5	9
4	84	84	0	0
5	22	23	-1	-5
6	9	9	0	0
7	29	32	-3	-10
8	9	9	0	0
9	72	82	-10	-14
10	64	66	-2	-3
11	84	119	-35	-42
12	56	86	-30	-54
13	165	129	36	22
14	34	32	2	6
15	26	31	-5	-19

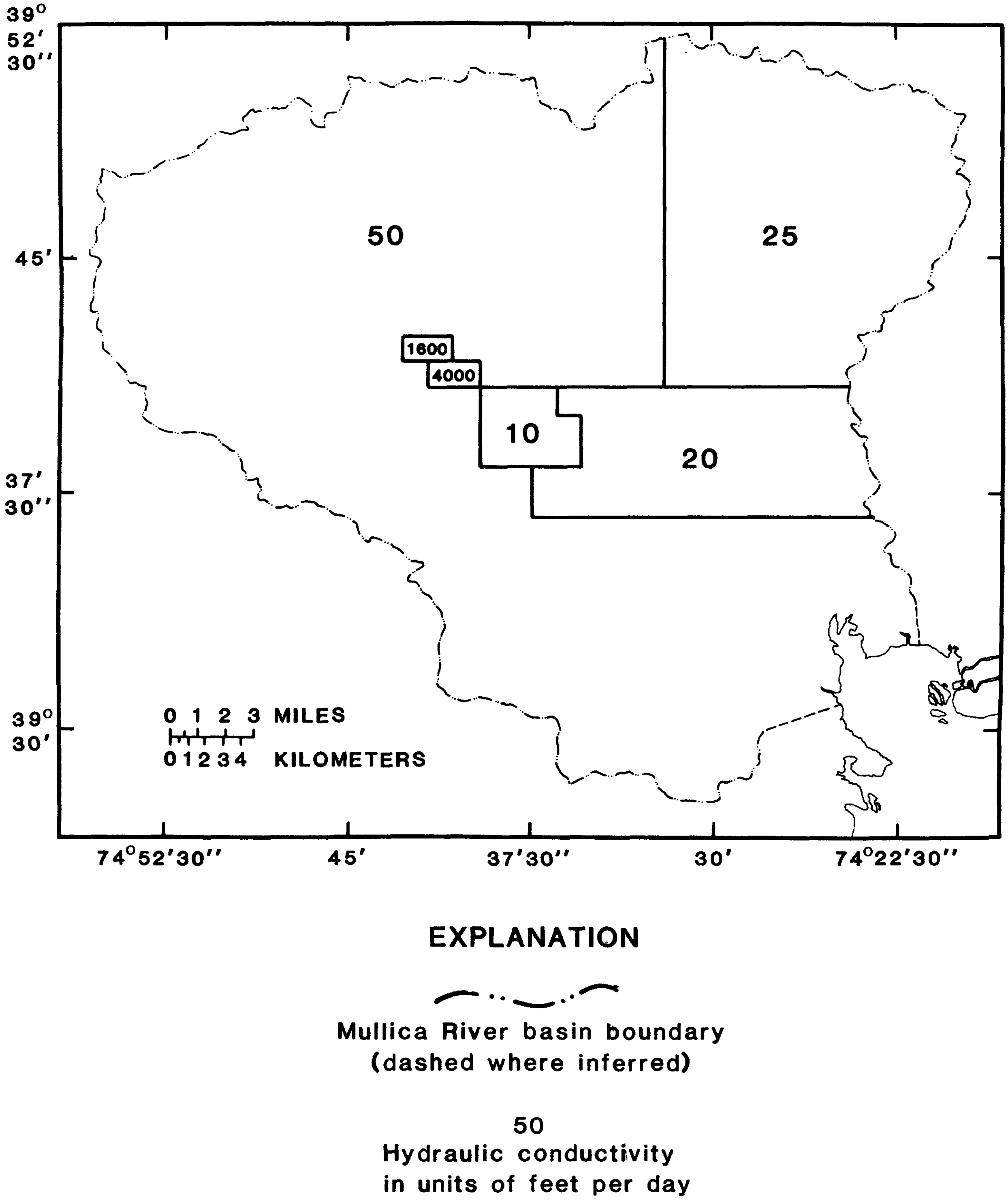


Figure 9.--Hydraulic conductivity of the Kirkwood Cohansey aquifer system used in the calibrated model.

water-level gradient in the area of more than 100 ft/mi, which is unrealistically high for the aquifer. So it is likely that either the well is not freely connected to the aquifer or the local water table is perched. Thus, the 10 ft/d value of hydraulic conductivity may not be representative of the regional aquifer.

During calibration the model was insensitive to the distribution of seepage among neighboring nodes along a stream reach. If it is assumed that a total of 9 ft^3/s was seeping from a section of a stream consisting of 3 nodes, the same generalized water level would be obtained if each of the nodes contributed an equal amount of seepage, 3 ft^3/s, and also if seepage were unequally divided, for example, 4, 3, and 2 ft^3/s. This means that average seepage in an area of the model, rather than individual node values, may be considered correct. For this reason, the seepage calculated at each node in the model is not included in this report. Only the streamflow, which is the cumulative seepage, is shown for the selected stream-calibration sites in table 4.

Moreover, the individual values for streambed conductance at stream nodes are not considered reliable because the model is insensitive to these values. During calibration, streambed conductance in the model was adjusted to obtain correct streamflow. Seepage to a stream is calculated as streambed conductance times the difference between the aquifer water level and stream stage. Because simulated water level and stream stage are considered accurate only within 5 ft, the possible error in their difference is 10 ft. Such an error could cause a large error in streambed conductance. For example, consider the instance where the difference between the water level and the stream stage at a node is 1 ft and the stream-bed conductance is C. If the water level is in error by only 2 ft, making the real difference between water level and stream stage 3 ft, then the streambed conductance should actually be C/3 to obtain the same seepage. Therefore, there could be large errors in streambed conductance even though streamflow and water-level calibration criteria are met. In spite of the potential for large errors, values of streambed hydraulic conductance are listed in the appendix for those who wish to duplicate model results or make other models. Model users are cautioned against using the values for detailed analysis.

SUMMARY AND CONCLUSIONS

A steady-state computer model of the water-table aquifer system in the Mullica River basin was made based on approximately equilibrium conditions prevailing in March 1976. The aquifer system was discretized by use of a 31x36 finite-difference grid having uniform spacing of 5,000 ft. Most streams in the basin could be represented at this scale. Because swamps drain water from the aquifer, much as streams do, and they are close to streams, they were included with the streams in the simulation. This would not be possible in a transient simulation owing to the different dynamic behavior of swamps and streams. Data defining the aquifer and streams were entered into the model, and it was run to compare results with measured ground-water levels and streamflow.

The model was run repeatedly with different values for streambed conductance and aquifer hydraulic conductivity until simulated ground-water levels and streamflow matched measured values within closely established limits. For ground-water levels, model-simulated values matched measured values within 5 ft in 41 of 42 wells. For streamflow, the model matched measured flow within 20 percent at 12 of 15 sites.

Possible causes for water level and streamflow discrepancies are summarized below.

1. The model is a simplified representation of the stream-aquifer system.

2. The ground-water divide for the Mullica River basin may not coincide with the surface-water divide.

3. Some surface water may bypass gaging stations.

4. Partial-record station correlations may be incorrect.

5. Regional water-level contours may be inaccurately drawn because of lack of water-level data or because of perched-water-table conditions.

6. Recharge may not be uniformly distributed as assumed because of variation in precipitation or evapotranspiration.

A few conclusions that relate to construction of a predictive model of the Mullica River basin can be made. These are summarized below and are followed by a discussion of each point:

1. The model grid spacing of 5,000 ft is appropriate for a transient model.

2. A two-dimensional model can simulate the dynamics of the natural flow system.

3. Precise measurements of stream stage and aquifer head beneath streams are required to effectively calibrate streambed conductance.

4. The interpretation of water levels using stream altitudes taken from topographic maps does not provide data accurate enough for calibration.

The model grid spacing of 5,000 ft was small enough to enable simulation of the streams and the ground-water flow system, and large enough to be economical. A smaller grid size would necessitate significantly greater data-management and collection costs. A larger grid size would cause multiple streams to be simulated as single streams. Under transient conditions, distinct simulation of each stream would be crucial. The dynamics of streams drying up could not be accurately simulated if several streams were simulated as one.

The steady-state model simulates the essential characteristics of the flow system even though it is a two-dimensional approximation of a three-dimensional system. For the transient model, a three-dimensional model might be desirable, depending on how extreme the artificial stresses that will be imposed are. For example, vertical flow might become important if a large well is screened below a local clay bed within the Kirkwood-Cohansey aquifer system. Also, vertical flow from other deeper aquifers could become significant.

Calibration of streambed conductance is dependent upon accurate knowledge of head gradient across the streambed. Although the steady-state model is not sensitive to the values of streambed conductance, a transient model might be more sensitive. A significant field effort would be required to measure the head gradient across streambeds throughout the modeled area.

Water-level data interpreted from topographic maps were useful, but inadequate to serve as the only calibration data. The well measurements in the Wharton State Forest area showed that the interpreted data were not always correct. In some areas where no wells are available, measured and simulated water level do not match, and part of the assumed cause is that extrapolation of the measured water level is incorrect.

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APPENDIX

Data listed below are provided for those who wish to reproduce model results or make other models of the same area. Data are located by the indicated rows and columns from the model grid. Row one starts at the top, and column one starts at the left. A blank water level value at a grid point indicates the point is outside the model boundary. A blank stream value at a grid point indicates no stream at that point. Refer to the Results section for qualifications on streambed conductance. Note also that streambed conductance includes conductance of swamp deposits as explained in the section titled Streams and Swamps.

Model stream stage, in feet above sea level

	COL 1	COL 2	COL 3	COL 4	COL 5	COL 6	COL 7	COL 8	COL 9	COL 10	COL 11	COL 12
ROW 1												
ROW 2												
ROW 3												
ROW 4										98.5		85.0
ROW 5										94.0		78.0
ROW 6					101.0	92.0	84.0	84.0	91.0		81.0	74.0
ROW 7			136.5	122.5	111.5	96.5	85.5	81.5			71.0	62.0
ROW 8									68.5		65.8	
ROW 9			126.0	117.0	105.5	95.8				61.5		49.0
ROW 10					105.5	96.0	85.0	81.0			51.5	48.5
ROW 11		128.0							69.0	63.0	54.0	
ROW 12			117.5	111.5		95.5	88.5	80.8	70.8	62.0	54.0	46.3
ROW 13				106.2	97.0	87.0	81.2		66.0	60.2	53.8	
ROW 14				111.0	95.0	88.0	79.0	73.5			54.0	44.0
ROW 15							86.0	78.0	69.0	61.0	54.0	
ROW 16						98.0		80.0		63.0		
ROW 17									76.0		58.5	52.0
ROW 18										69.0	59.0	50.0
ROW 19												56.0
ROW 20												
ROW 21												
ROW 22												
ROW 23												
ROW 24												
ROW 25												
ROW 26												
ROW 27												
ROW 28												
ROW 29												
ROW 30												
ROW 31												

Model stream stage, in feet above sea level--Continued

	COL 13	COL 14	COL 15	COL 16	COL 17	COL 18	COL 19	COL 20	COL 21	COL 22	COL 23	COL 24
ROW 1												
ROW 2												110.5
ROW 3					83.5	89.5						99.8
ROW 4			80.0	72.5			89.5			92.5	91.8	
ROW 5			70.0	62.5		71.0				89.5	85.0	83.0
ROW 6	74.0		61.5	55.0	58.0	67.0	76.5			83.5	78.0	74.0
ROW 7		54.0		47.0	57.0	62.0	66.5	72.8	77.8	76.0	72.0	67.0
ROW 8	53.0	48.0	43.0				61.0	60.8	64.0	68.5	63.5	61.0
ROW 9	47.0	46.0	39.0		53.0		49.0	48.8	53.0	58.0	52.5	55.0
ROW 10	43.0	40.0	34.5	41.5				46.0	47.0		46.5	53.0
ROW 11		33.0		28.5				42.0	42.0		46.5	45.0
ROW 12			24.5	26.0		43.5			38.5	30.0	37.0	
ROW 13	36.5	32.5	21.5	21.0	31.0	37.8	41.8	50.0			25.0	
ROW 14	35.0		23.5	20.0	18.0	32.8					20.0	
ROW 15	34.0	28.5	23.0	13.5	14.5						18.0	15.0
ROW 16		30.0	19.5	13.8	11.0				34.8		24.0	8.5
ROW 17				11.0	10.5		30.0		29.0			8.0
ROW 18	38.0	32.0	24.0	14.0	3.8		12.0	12.0			25.0	9.0
ROW 19	48.5	38.8	33.8			3.5	3.2	3.0				6.0
ROW 20	52.0	48.5	45.8	40.0	30.8	23.0			3.0	3.0		4.0
ROW 21				48.7	40.5		14.5	9.0	5.0	4.0	3.0	3.0
ROW 22				53.0					5.5	5.5		2.5
ROW 23				54.0	46.0	37.0	22.0	13.0	14.0			3.0
ROW 24						35.0	21.0		30.8		25.8	11.8
ROW 25				50.8	41.0	36.0		36.0				
ROW 26				57.0				45.6				22.0
ROW 27									47.8	44.0	31.0	
ROW 28									50.8	44.5	38.8	28.0
ROW 29												
ROW 30												
ROW 31												

Model stream stage, in feet above sea level--Continued

	COL 25	COL 26	COL 27	COL 28	COL 29	COL 30	COL 31	COL 32	COL 33	COL 34	COL 35	COL 36
ROW 1												
ROW 2	116.5											
ROW 3			119.5	125.5	136.5							
ROW 4	96.5	104.5	109.5	115.0		140.0			143.5			
ROW 5	84.0		98.0	112.0			136.5		136.0	135.5		
ROW 6		88.0	94.0	108.0		119.5		127.0	122.0	125.8		
ROW 7		84.0			107.5	110.5	110.5		111.0			
ROW 8	73.0		85.5		99.5	97.8	100.5		105.0		119.5	
ROW 9		69.0		84.5	85.8		94.0		97.0	104.5		
ROW 10		61.0		66.0			87.0	87.0	98.0			
ROW 11		48.5	56.0	62.0	69.0	76.0						
ROW 12	40.5											
ROW 13	29.5	41.0	59.5									
ROW 14	23.0	39.5	59.5	74.5								
ROW 15	23.0	39.8			59.5	59.5						
ROW 16	17.0	26.5	39.5	39.5	40.5	40.5						
ROW 17	8.5	18.5	25.5	25.5	26.5	26.0						
ROW 18	5.5	12.5	16.5		14.0	24.0						
ROW 19		5.0		9.5	9.0							
ROW 20		4.0	5.0	6.0		10.0						
ROW 21		4.0			6.0		5.0					
ROW 22	2.5	3.0		5.0	5.0	2.0	2.0					
ROW 23	2.5	2.0	3.0	4.0		2.0						
ROW 24			2.0	2.0								
ROW 25			6.0	2.0								
ROW 26	11.0	8.0	6.0									
ROW 27	16.0		7.0									
ROW 28			16.0									
ROW 29	36.0	26.0										
ROW 30												
ROW 31												

Streambed conductance, in millions of square feet per day.

	COL 1	COL 2	COL 3	COL 4	COL 5	COL 6	COL 7	COL 8	COL 9	COL 10	COL 11	COL 12
ROW 1												
ROW 2												
ROW 3												
ROW 4										0.2398		0.4031
ROW 5										0.2556		0.3245
ROW 6					0.2519	0.1630	0.3029	0.3197	0.1971		0.1863	0.1331
ROW 7			0.0683	0.1978	0.1092	0.1987	0.2633	0.2616			0.2031	0.2833
ROW 8									0.5032		0.1877	
ROW 9			0.3307	0.2538	0.2309	0.2735				0.3905		0.2786
ROW 10					0.2721	0.1969	0.3350	0.2605			0.3081	0.1509
ROW 11		0.2921							0.2865	0.1464	0.1747	
ROW 12			0.3235	0.2259		0.1714	0.1288	0.1585	0.0917	0.1326	0.1206	0.2637
ROW 13				0.2205	0.2013	0.2352	0.1999		0.2655	0.1804	0.1503	
ROW 14				0.0490	0.3155	0.2135	0.2004	0.2468			0.1528	0.2354
ROW 15							0.1774	0.1229	0.2290	0.2006	0.2379	
ROW 16						0.2265		0.2205		0.2786		
ROW 17									0.2453		0.2179	0.1621
ROW 18										0.1827	0.1918	0.2142
ROW 19												0.0227
ROW 20												
ROW 21												
ROW 22												
ROW 23												
ROW 24												
ROW 25												
ROW 26												
ROW 27												
ROW 28												
ROW 29												
ROW 30												
ROW 31												

Streambed conductance, in millions of square feet per day--Continued.

	COL 13	COL 14	COL 15	COL 16	COL 17	COL 18	COL 19	COL 20	COL 21	COL 22	COL 23	COL 24
ROW 1												
ROW 2												0.1678
ROW 3					0.2347	0.0893						0.3074
ROW 4			0.3084	0.3199			0.1217			0.1046	0.2714	
ROW 5			0.2249	0.2652		0.3427				0.1442	0.1520	0.1769
ROW 6	0.2056		0.1941	0.1922	0.2652	0.1332	0.1734			0.1408	0.1593	0.2233
ROW 7		0.2956		0.3694	0.1461	0.1871	0.1744	0.1622	0.0799	0.1099	0.1159	0.2344
ROW 8	0.1915	0.1604	0.3175				0.1250	0.1456	0.1604	0.0438	0.1385	0.1896
ROW 9	0.1522	0.0619	0.2692		0.2741		0.3697	0.2234	0.1723	0.1006	0.2016	0.2131
ROW 10	0.2125	0.1060	0.2521	0.1713				0.2188	0.1628		0.2671	0.1383
ROW 11		0.3321		0.3850				0.3379	0.1798		0.0437	0.2323
ROW 12			0.2763	0.2274		0.2407			0.2740	0.5040	0.0920	
ROW 13	0.2137	2.2690	2.1908	0.2562	0.0820	0.1175	0.3326	0.0809			0.4267	
ROW 14	0.2051		1.1232	1.5647	0.4207	0.2747					0.4658	
ROW 15	0.2099	0.1847	0.0597	0.3277	0.2168						0.4203	0.1800
ROW 16		0.2462	0.2451	0.1471	0.2436				0.3505		0.0897	0.3368
ROW 17				0.3499	0.1512		0.1887		0.2451			0.2829
ROW 18	0.3827	0.2570	0.2449	0.3028	0.5547		0.1286	0.2391			0.0594	0.1780
ROW 19	0.0043	0.2352	0.1931			0.6596	0.3793	0.5123				0.2430
ROW 20	0.0047	0.0577	0.0651	0.0165	0.1447	0.0504			0.3863	0.3585		0.2427
ROW 21				0.0688	0.0952		0.3745	0.2604	0.1440	0.1422	0.2916	0.1853
ROW 22				0.0370					0.2948	0.3128		0.2344
ROW 23				0.0143	0.1621	0.1048	0.2519	0.3752	0.2510			0.2821
ROW 24						0.1778	0.4216		0.1412		0.1508	0.3360
ROW 25				0.1586	0.3399	0.3416		0.2717				
ROW 26				0.0639				0.2490				0.2837
ROW 27									0.2334	0.1187	0.3181	
ROW 28									0.3088	0.2616	0.1745	0.4141
ROW 29												
ROW 30												
ROW 31												

Streambed conductance, in millions of square feet per day--Continued.

	COL 25	COL 26	COL 27	COL 28	COL 29	COL 30	COL 31	COL 32	COL 33	COL 34	COL 35	COL 36
ROW 1												
ROW 2	0.2109											
ROW 3			0.2755	0.2354	0.2741							
ROW 4	0.2244	0.2054	0.1341	0.2615		0.2871			0.3650			
ROW 5	0.2770		0.2528	0.1762			0.2544		0.1356	0.1625		
ROW 6		0.2134	0.2284	0.1845		0.2468		0.1753	0.2166	0.2659		
ROW 7		0.2462			0.1780	0.1091	0.2270		0.3368			
ROW 8	0.2011		0.2515		0.1116	0.2467	0.2157		0.2621		0.2312	
ROW 9		0.2620		0.1893	0.2754		0.2423		0.2905	0.1739		
ROW 10		0.2176		0.2617			0.2977	0.4674	0.1439			
ROW 11		0.3015	0.3197	0.3196	0.2997	0.3685						
ROW 12	0.2688											
ROW 13	0.2576	0.2386	0.2584									
ROW 14	0.2705	0.1877	0.0752	0.0709								
ROW 15	0.1736	0.0448			0.2039	0.2392						
ROW 16	0.1250	0.1882	0.0555	0.1763	0.1865	0.2503						
ROW 17	0.2170	0.1229	0.1331	0.1996	0.1495	0.3557						
ROW 18	0.2640	0.1132	0.1588		0.2710	0.2339						
ROW 19		0.2624		0.2025	0.2443							
ROW 20		0.2231	0.2448	0.2435		0.3510						
ROW 21		0.2279			0.2376		0.4519					
ROW 22	0.1786	0.1812		0.2005	0.1440	0.2011	0.2262					
ROW 23	0.2486	0.2469	0.1793	0.1414		0.1597						
ROW 24			0.2492	0.1443								
ROW 25			0.1517	0.2135								
ROW 26	0.2969	0.2969	0.1814									
ROW 27	0.3366		0.2708									
ROW 28			0.2582									
ROW 29	0.2780	0.2379										
ROW 30												
ROW 31												

Model-simulated water level in March 1976, in feet above sea level

	COL 1	COL 2	COL 3	COL 4	COL 5	COL 6	COL 7	COL 8	COL 9	COL 10	COL 11	COL 12
ROW 1												
ROW 2												
ROW 3												107.3
ROW 4								121.9	115.6	99.4	98.8	86.1
ROW 5							108.2	110.5	107.6	94.9	93.0	79.0
ROW 6				123.2	102.1	93.0	85.1	85.0	91.9	92.9	81.9	74.9
ROW 7			137.1	123.4	112.3	97.5	86.5	82.5	87.0	86.1	72.0	63.1
ROW 8			136.9	128.6	118.3	107.8	100.2	90.6	69.6	75.6	66.7	62.6
ROW 9		143.3	127.0	118.0	106.5	96.8	98.0	91.8	80.2	62.5	62.1	50.1
ROW 10		141.6	135.6	125.7	106.5	96.9	86.0	82.0	79.2	68.7	52.6	49.5
ROW 11		128.9	131.1	125.3	115.9	105.4	95.9	86.4	70.0	63.9	55.0	53.7
ROW 12		131.7	118.4	112.5	109.6	96.6	89.4	81.7	71.7	63.0	55.1	47.3
ROW 13			120.4	107.3	98.0	88.0	82.2	80.1	67.1	61.2	54.8	49.6
ROW 14				111.1	96.1	89.0	80.2	74.5	72.8	66.1	54.9	45.0
ROW 15				116.2	108.5	99.1	87.0	78.8	70.0	62.0	55.0	50.7
ROW 16					109.2	98.8	92.8	81.1	75.9	64.0	61.2	55.0
ROW 17								85.5	76.8	70.1	59.5	52.8
ROW 18								88.2	81.5	69.9	59.9	50.9
ROW 19											62.8	56.9
ROW 20												
ROW 21												
ROW 22												
ROW 23												
ROW 24												
ROW 25												
ROW 26												
ROW 27												
ROW 28												
ROW 29												
ROW 30												
ROW 31												

Model-simulated water level in March 1976, in feet above sea level--Continued

	COL 13	COL 14	COL 15	COL 16	COL 17	COL 18	COL 19	COL 20	COL 21	COL 22	COL 23	COL 24
ROW 1												
ROW 2											118.1	111.4
ROW 3	110.5	107.6	98.8	91.2	84.4	90.3					109.7	100.8
ROW 4	100.1	97.8	80.9	73.5	84.0	88.2	90.3			93.4	92.8	100.0
ROW 5	89.3	86.8	70.9	63.6	73.7	72.1	87.8	95.7	96.8	90.3	86.0	84.0
ROW 6	74.8	73.8	62.5	56.0	59.1	68.0	77.4	88.0	90.4	84.4	79.0	75.1
ROW 7	65.8	55.1	56.2	48.1	57.9	63.0	67.5	73.7	78.5	76.9	73.0	68.1
ROW 8	54.0	49.0	44.1	54.9	61.5	65.3	61.9	61.9	65.0	69.1	64.5	62.1
ROW 9	48.0	46.8	40.1	51.4	53.9	60.8	50.0	49.9	54.0	58.8	53.7	56.0
ROW 10	44.0	40.9	35.6	42.4	54.7	59.8	56.1	47.0	48.1	53.4	47.6	53.9
ROW 11	48.1	34.0	34.8	29.6	48.6	54.6	53.9	43.0	43.0	46.5	47.0	46.0
ROW 12	45.9	36.6	25.5	27.0	41.0	44.4	50.2	48.7	39.5	31.1	37.8	45.1
ROW 13	37.4	31.5	22.7	22.1	31.8	38.7	42.8	50.5	48.0	39.4	26.1	36.6
ROW 14	35.9	31.0	22.6	20.9	19.1	33.9	49.2	55.1	51.7	41.2	21.1	28.8
ROW 15	35.6	29.4	23.6	14.6	15.5	50.5	63.8	62.4	53.6	44.0	18.8	16.3
ROW 16	44.7	30.9	20.7	14.8	12.1	51.1	61.1	58.2	35.7	41.0	25.3	9.4
ROW 17	45.7	36.4	26.1	12.1	11.6	34.3	31.0	39.9	30.0	38.4	29.7	9.0
ROW 18	39.2	33.0	25.1	15.0	4.9	13.0	13.1	13.2	28.8	33.8	26.1	10.0
ROW 19	49.4	39.8	34.7	30.3	20.4	4.7	4.0	3.7	18.6	22.6	20.5	7.0
ROW 20	53.0	48.7	46.2	41.0	31.7	23.4	17.4	11.9	4.0	4.1	9.7	5.1
ROW 21			53.2	48.9	41.0	31.9	15.7	10.0	6.0	5.0	4.0	4.0
ROW 22			57.1	53.5	46.9	38.1	26.5	17.1	6.6	6.5	10.9	3.5
ROW 23				54.5	46.8	37.7	23.0	14.1	15.0	21.6	19.0	4.2
ROW 24				54.9	47.8	35.9	22.2	29.4	31.5	34.2	26.5	12.8
ROW 25				51.6	42.1	37.0	40.0	36.9	43.8	43.8	37.1	26.8
ROW 26				57.5	54.6	51.5	50.1	46.5	49.5	47.1	38.1	23.0
ROW 27								56.3	48.7	44.7	32.1	28.7
ROW 28								61.8	51.7	45.5	39.6	29.1
ROW 29								66.6	61.7	56.3	51.0	45.8
ROW 30												53.4
ROW 31												

Model-simulated water level in March 1976, in feet above sea level--Continued

	COL 25	COL 26	COL 27	COL 28	COL 29	COL 30	COL 31	COL 32	COL 33	COL 34	COL 35	COL 36
ROW 1												
ROW 2	117.4	134.7	139.7	144.8	149.9							
ROW 3	116.5	124.8	120.5	126.5	137.4	152.5	162.1	164.9	162.2			
ROW 4	97.5	105.5	110.5	116.1	136.0	140.9	152.8	155.0	144.4	147.8		
ROW 5	85.1	100.6	99.1	112.9	131.3	136.6	137.4	143.1	136.9	136.4		
ROW 6	90.2	89.0	95.0	108.9	121.6	120.5	128.3	127.8	123.1	126.8	136.4	
ROW 7	85.8	85.0	99.7	109.1	108.6	111.3	111.6	119.3	112.1	125.8	132.0	
ROW 8	73.9	84.9	86.6	100.0	100.2	98.8	101.5	110.8	106.0	117.9	120.4	
ROW 9	73.0	70.0	83.9	85.1	86.8	96.6	94.8	101.6	98.1	105.5		
ROW 10	67.1	61.9	72.6	67.4	83.0	90.2	88.0	88.0	98.7			
ROW 11	56.5	49.6	56.9	62.9	70.3	77.4	97.4	102.4	107.4			
ROW 12	41.5	55.3	67.9	79.7	88.8	97.0	106.0					
ROW 13	30.6	42.1	60.3	80.9	91.9	99.9	109.7					
ROW 14	24.2	40.5	60.4	75.0	82.8	86.8						
ROW 15	23.9	40.7	56.0	62.9	60.4	60.4						
ROW 16	18.0	27.5	40.5	40.6	41.4	41.6	57.7					
ROW 17	9.5	19.5	26.4	26.5	27.5	27.0	53.0					
ROW 18	6.5	13.4	17.6	23.6	15.0	24.9	49.6					
ROW 19	12.2	6.0	15.0	10.5	10.0	28.6	42.1					
ROW 20	9.6	5.0	6.0	7.0	12.1	11.0	23.6	28.8				
ROW 21	8.2	5.0	10.2	10.5	7.0	10.2	6.0	20.8				
ROW 22	3.6	4.0	9.1	6.0	5.9	3.1	3.1	13.4				
ROW 23	3.5	3.0	4.0	5.0	7.5	3.0	2.0	2.0				
ROW 24	15.9	12.7	3.1	3.0	2.0	2.0						
ROW 25	21.0	15.7	6.9	3.0	2.0							
ROW 26	12.1	9.0	7.0	8.8	2.0							
ROW 27	17.0	18.8	8.1									
ROW 28	30.8	26.7	17.0									
ROW 29	36.8	27.0	28.5									
ROW 30	50.7											
ROW 31												