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Estimate of Aquifer Properties By Numerically Simulating Ground-Water/Surface-Water Interactions Fort Wainwright, Alaska

Water-Resources Investigations Report 98-4088

U.S. Department of the Interior
U.S. Geological Survey

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By Allan S. Nakanishi and Michael R. Lilly

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Fairbanks, Alaska
1998

U.S. DEPARTMENT OF THE INTERIOR
BRUCE BABBITT, Secretary

U.S. GEOLOGICAL SURVEY
Thomas J. Casadevall, Acting Director

For additional information:

District Chief
U.S. Geological Survey
4230 University Drive, Suite 201
Anchorage, AK 99508-4664

http://www-water-ak.usgs.gov

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CONVERSION FACTORS AND VERTICAL AND HORIZONTAL DATUMS

Multiply	By	To obtain
foot (ft)	0.3048	meter
mile (mi)	1.609	kilometer
square mile (mi^2)	2.590	square kilometer
foot per day (ft/d)	0.3048	meter per day
foot squared per day (ft^2/d)	0.09290	meter squared per day

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

Horizontal Datum:
The horizontal datum for all locations in this report is the North American Datum of 1927. The U.S. Army typically uses local coordinate systems for each installation. These coordinates were converted to state-plane coordinates and latitude and longitude.

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Abstract

MODFLOW, a finite-difference model of ground-water flow, was used to simulate the flow of water between the aquifer and the Chena River at Fort Wainwright, Alaska. The model was calibrated by comparing simulated ground-water hydrographs to those recorded in wells during periods of fluctuating river levels. The best fit between simulated and observed hydrographs occurred for the following: 20 feet per day for vertical hydraulic conductivity, 400 feet per day for horizontal hydraulic conductivity, 1:20 for anisotropy (vertical to horizontal hydraulic conductivity), and 350 feet^{-1} for riverbed conductance. These values include a 30 percent adjustment for geometry effects. The estimated values for hydraulic conductivities of the alluvium are based on assumed values of 0.25 for specific yield and 1 x 10^{-6} per foot for specific storage of the alluvium; the values assumed for bedrock are 0.1 foot per day horizontal hydraulic conductivity, 0.005 foot per day vertical hydraulic conductivity, and 1 x 10^{-7} per foot for specific storage. The resulting diffusivity for the alluvial aquifer is 1,600 feet per day. The estimated values of these hydraulic properties are nearly proportional to the assumed value of specific yield. These values were not found to be sensitive to the assumed values for bedrock. The hydrologic parameters estimated using the cross-sectional model are only valid when taken in context with the other values (both estimated and assumed) used in this study. The model simulates horizontal and vertical flow directions near the river during periods of varying river stage. This information is useful for interpreting bank-storage effects, including the flow of contaminants in the aquifer near the river.

INTRODUCTION

Background

The U.S. Army Alaska (USARAK), the U.S. Army Corps of Engineers, Alaska District, and the U.S. Geological Survey (USGS) are conducting a cooperative investigation to characterize the geohydrology of the Fort Wainwright, Alaska, area. The project is part of an effort to support activities of USARAK under the Comprehensive Environmental Response, Compensation, and Liability Act. The USGS is collecting ground-water and surface-water data to interpret the geohydrology of the Fort Wainwright area. USGS investigations are coordinated with ongoing technical investigations by the University of Alaska Fairbanks, Water Research Center, and the U.S. Army Cold Regions Research and Engineering Laboratory.

Purpose and Scope

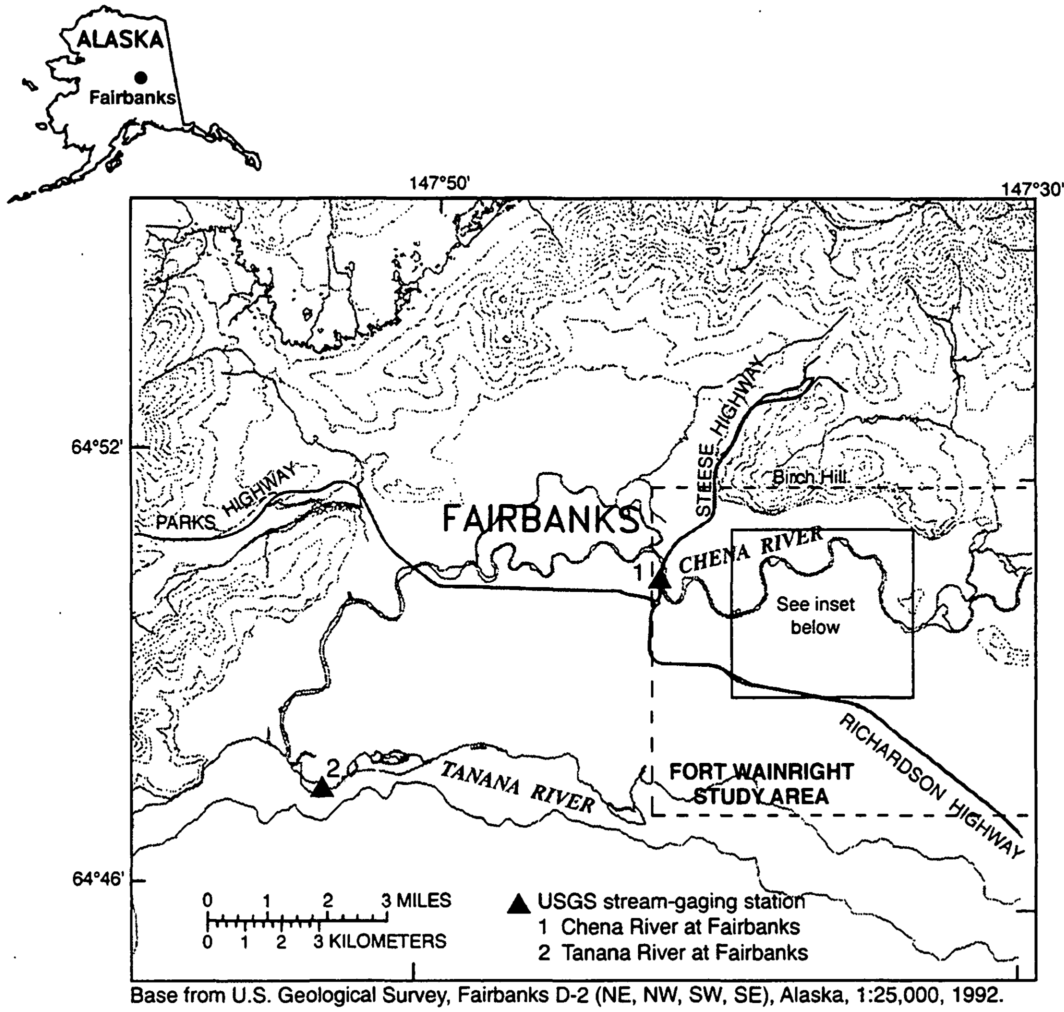
The purpose of this investigation was to estimate the aquifer properties in the study area and to gain insight into the surface-water/ground-water dynamics of the aquifer near the Chena River using a numerical ground-water model. The ground-water modeling approach allows the stress to propagate through the aquifer for many days. This creates a long-term aquifer test that helps describe the aquifer properties over an area that is larger than an area typically tested by an aquifer test. In a single test, this approach helps evaluate multiple aquifer properties, such as horizontal and vertical hydraulic conductivity, riverbed conductance, and aquifer storage. Previous aquifer tests in the Fairbanks area have proven inconclusive in defining aquifer properties (Nelson, 1978).

Continuous water-elevation data were collected from 10 wells screened at various depths and from one station on the Chena River. Data from these 11 stations were used in the numerical model during calibration. The data collected for this model are part of a larger data-collection program throughout much of the alluvial aquifer near Fairbanks. Water elevations throughout this larger network of ground-water and surface-water sites were measured at monthly intervals. In addition, water-elevation data at selected sites were collected at more frequent intervals to document short-term changes in ground-water elevations caused by rapid stage changes of the Chena and Tanana Rivers. A few of the sites were instrumented with continuous-data recorders. All ground-water data are maintained and stored in the USGS Ground-Water Site Inventory (GWSI) data base. Surface-water and continuously recorded ground-water data are in the USGS Automatic Data Acquisition and Processing System (ADAPS) data base. Graphs of the data are presented throughout the report. Although the data are not included in this report, they are available in USGS hydrologic data bases.

Location and Description of Study Area

Fort Wainwright is adjacent to and east of the City of Fairbanks, north of the Tanana River, and south of Birch Hill (fig. 1).The Chena River flows across the fort. This study analyzes aquifer properties by interpreting the hydrologic response of a cross section that is 1 ft wide, 1,032 ft thick, and 9,000 ft long. The cross section runs in a north/south direction starting at the south bank of the Chena River and ending near the Richardson Highway (fig. 1). The section is also referred to as "diffusivity section E" in other reports and data descriptions. Much of the land surface in the study area has been developed since the 1940's and has been cleared of its original vegetation. The Fort Wainwright airfield, roads, parking lots, buildings, and grass fields cover most of the study area.

The location of the cross section was chosen to coincide with ongoing environmental investigations in the study area. It was also chosen because of the geometry of the Chena River in the study area. The section is on an outside meander bend in the river; thus, the shortest distance from the seven wells closest to the river (fig. 1) to the river itself is along the section. This is important for supporting the assumption of ground-water flow only along the modeled section. Some errors are introduced in the analysis of the three most southern wells because other meander bends on the Chena River are closer to the modeled cross section. For example, the shortest distance from the river to well FWM5534 is not along the section (fig. 1).



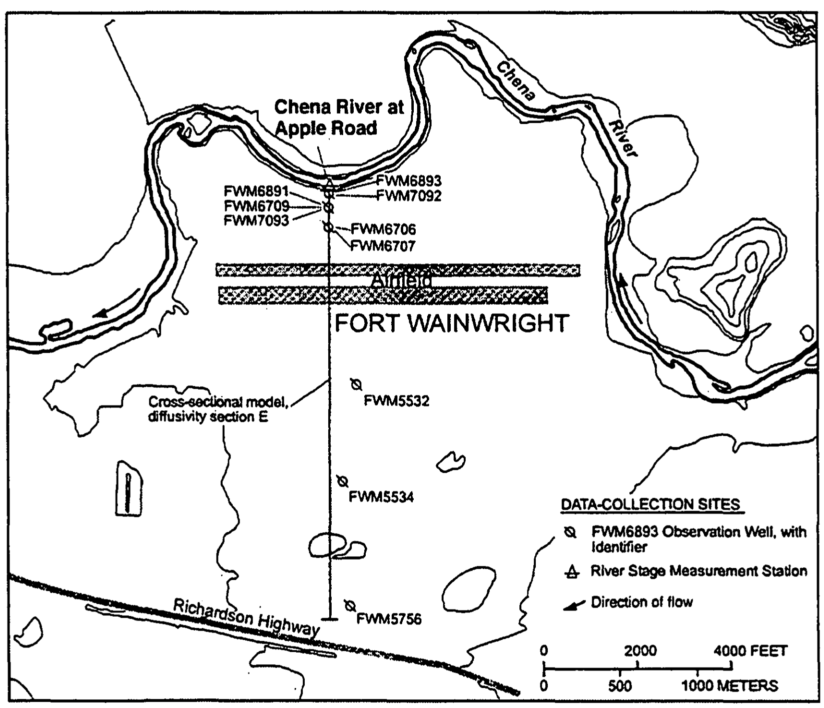


Figure 1. Locations of the study area on Fort Wainwright, Fairbanks, Alaska; the modeled cross sections; and the data-collection sites.

HYDROLOGIC SETTING AND CHARACTERISTICS

The aquifer material underlying the study area and most of the alluvial plain of the surrounding area is composed of alluvial sand and gravel known as the Chena Alluvium, which was deposited by the Tanana River (Péwé and others, 1976). Sediment facies within these deposits are laterally discontinuous as is typical of braided river deposits (Rust, 1978). The thickness of these deposits is generally unknown, but may be in excess of 500 ft beneath the Tanana River (Nelson, 1978). Birch Hill, which is located north of the Chena River and the study area, is part of a metamorphic system that forms the Yukon-Tanana Upland (Anderson, 1970). This metamorphic system almost certainly underlies the study area, though no subsurface geologic investigations to describe the bedrock at depth have been reported. The bedrock system is highly fractured.

The Tanana River has a drainage area of about 20,000 mi^2 and is the main surface-water influence on ground-water levels throughout much of the alluvial aquifer in the general Fairbanks area (Nelson, 1978). The stage of the Tanana River typically rises for one to two weeks during spring because of snowmelt and ice jams, and then declines (fig. 2). The stage rises again for a longer period during the middle of summer in response to glacial runoff from the Alaska Range. The flow decreases and the stage declines during late summer when temperatures drop in the Alaska Range. In winter, the surface of the river is frozen, and stages are not monitored continuously as they are during other parts of the year. Consequently, stages during winter months are not shown in the hydrographs in figure 2. The river stage generally rises after complete ice cover is established across the river as a result of an increase in flow resistance from ice cover. Then the flow decreases and the stage declines throughout the winter because of the continuing reduction of discharge in the rivers.

The Chena River drainage area above the long-term gaging station "Chena River at Fairbanks" (fig. 1) is approximately 2,000 mi^2 in size. Stages rise (fig. 2) and flows increase during spring snowmelt runoff and late-summer rainfall runoff. Local precipitation and runoff have a greater effect on the stages and flows of the Chena River than on those of the Tanana River. Ice covers most of the Chena River during the winter season, although a long reach typically remains ice free as a result of water discharge from the water-distribution and power-plant facilities of the Fairbanks Municipal Utilities System (Kriegler and Lilly, 1995). These facilities are about 5 mi downstream from the Chena River stage measurement site at Apple Road (fig. 1).

In the Fort Wainwright area, the higher elevation of the Tanana River relative to the Chena River, imparts a northerly tilt to the common down-valley slope of the water table. This creates a general water-table gradient to the northwest in the area between the two rivers (Glass and others, 1996). Adjacent to the Chena River, shallow ground water flows into the riverbed and riverbanks as the stage of the river rises above the elevation of the water table. Conversely, as the river stage declines below the water table, ground water flows back into the river. This flow of water into and out of the aquifer in response to changing stage of the river is termed "bank storage effects" (fig. 3) (Linsley and others, 1982). Bank storage effects are attenuated with distance from the river. These effects have been documented at Fort Wainwright as extreme, short-term changes in flow direction in response to rapid stage changes of the Chena River (Taras and Grant, 1995). Hydrographs of ground-water elevations plotted at various distances from the

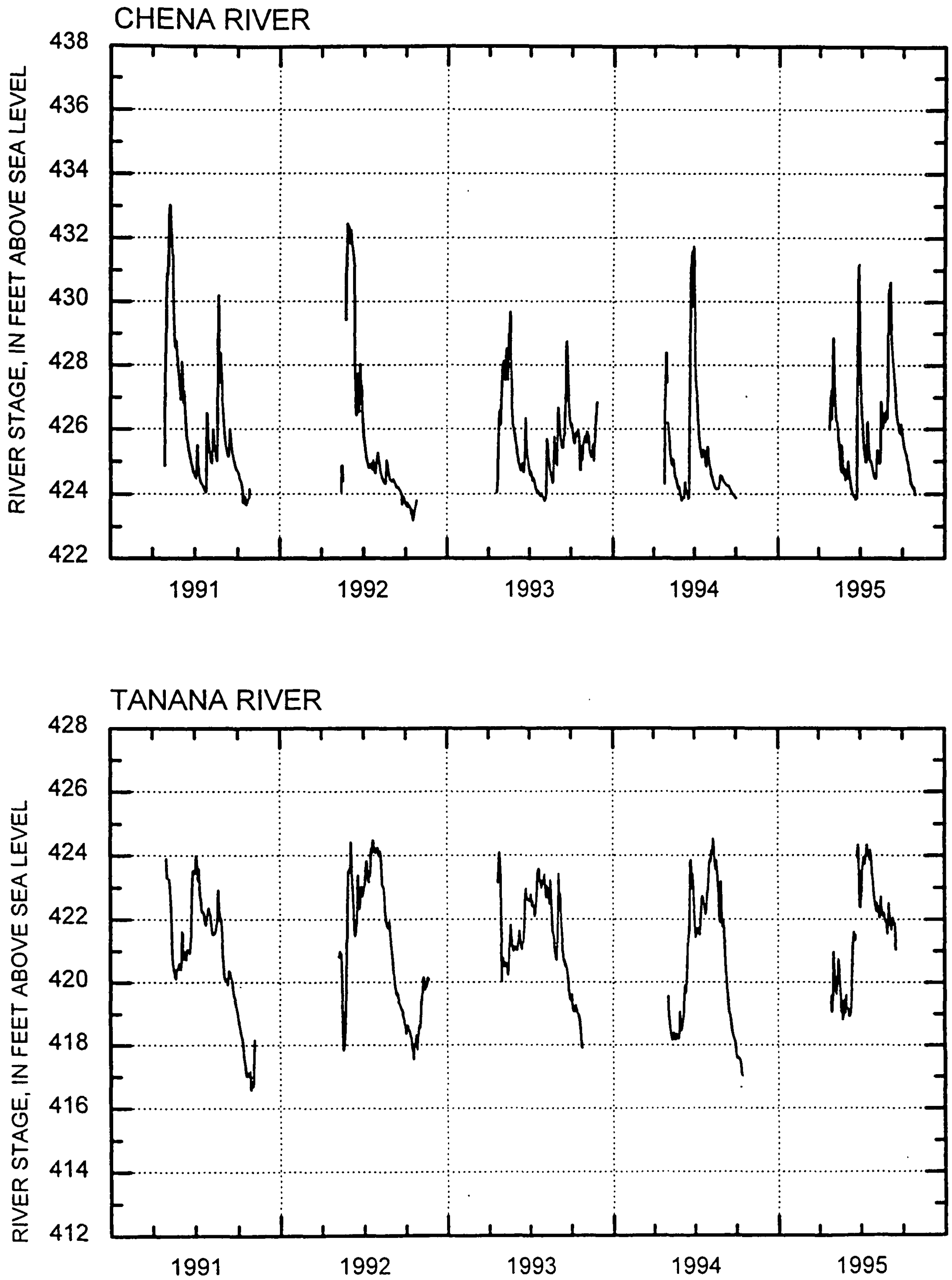


Figure 2. Stage hydrograph of the Chena River at Fairbanks and Tanana River at Fairbanks gaging stations for calendar years 1991 to 1995. Locations of stations are shown on figure 1. [Note: Both gaging stations are downstream from Fort Wainwright. Measured river stages at Fort Wainwright will differ from 5 to 20 feet.]

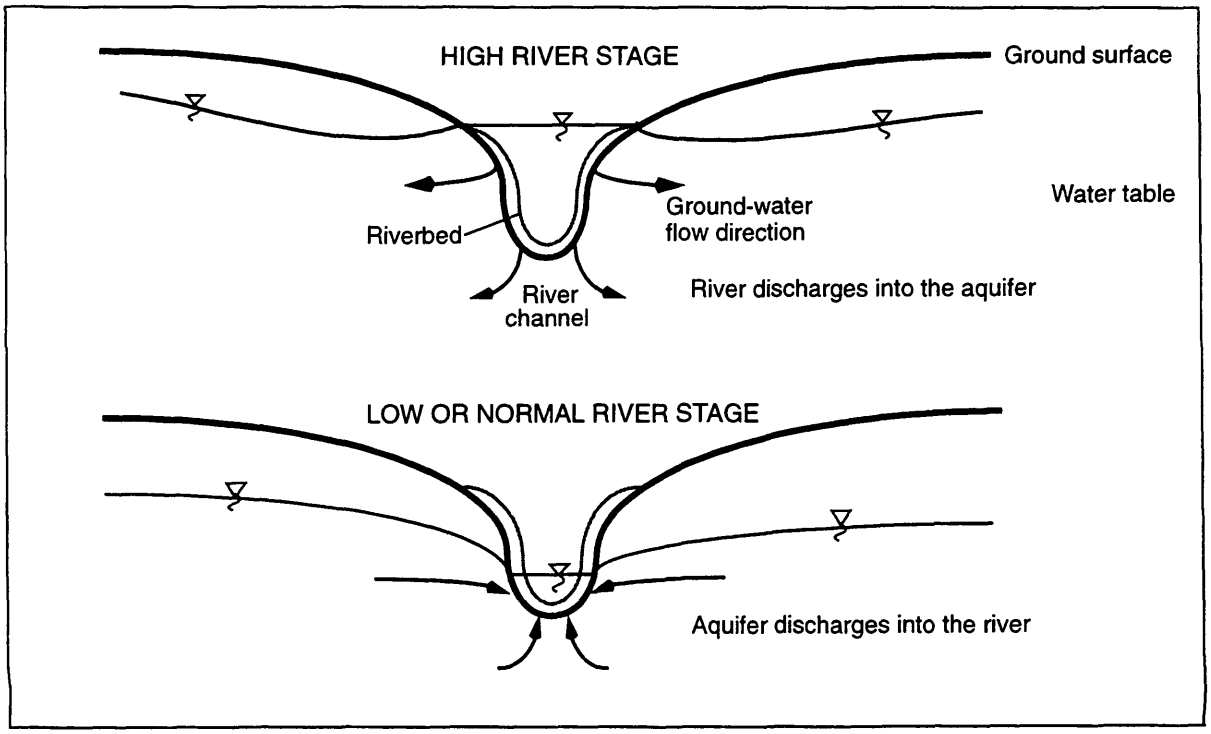


Figure 3. Schematic cross section of river showing effects of river stage on bank storage and near-river ground-water flow directions.

Chena River (fig. 4) illustrate bank storage and its attenuation away from the river. The attenuation of the water-table fluctuation is controlled by the resistance and storage properties of the aquifer. It takes about 2 to 3 days for a peak in the river hydrograph to propagate into the aquifer to wells 1,000 ft from the river. However, the rise in the water levels about 1,000 ft from the riverbank is only about 40 percent of the rise in river stage, and at about 9,000 ft from the river, it is about 10 percent of the river stage (fig. 4).

Hydraulic Conductivity

Horizontal hydraulic conductivities (K_h) of alluvial deposits typically range from 15 to 1,300 ft/d (Freeze and Cherry, 1979). The K_h of the Chena Alluvium along the Tanana River in the Fairbanks area was estimated to range from 500 to 1,200 ft/d on the basis of aquifer tests (Cedergren, 1972; U.S. Army Corps of Engineers, 1974). Analysis of the influence of surface-water fluctuations on ground-water levels along the Chena and Tanana Rivers indicated a K_h ranging from 200 to 2,400 ft/d (Cedergren, 1972). A dye-tracer study done in a thaw channel in discontinuous permafrost at Fort Wainwright between Birch Hill and the Chena River (Johnson and others, 1994) indicated K_h values ranging from 50 to 1,500 ft/d with a mean value of about 425 ft/d. The value of K_h used in a U.S. Army Corps of Engineers (1995) ground-water model for the Chena River Lakes flood control project, about 10 mi southeast of Fort Wainwright, was 400 ft/d for layers simulating alluvium. An aquifer slug- and pumping-test analysis of alluvium at Fort Wainwright estimated a mean K_h of 25.3 ft/d with a range from 8.3 to 41.6 ft/d (CH2M HILL, 1994).

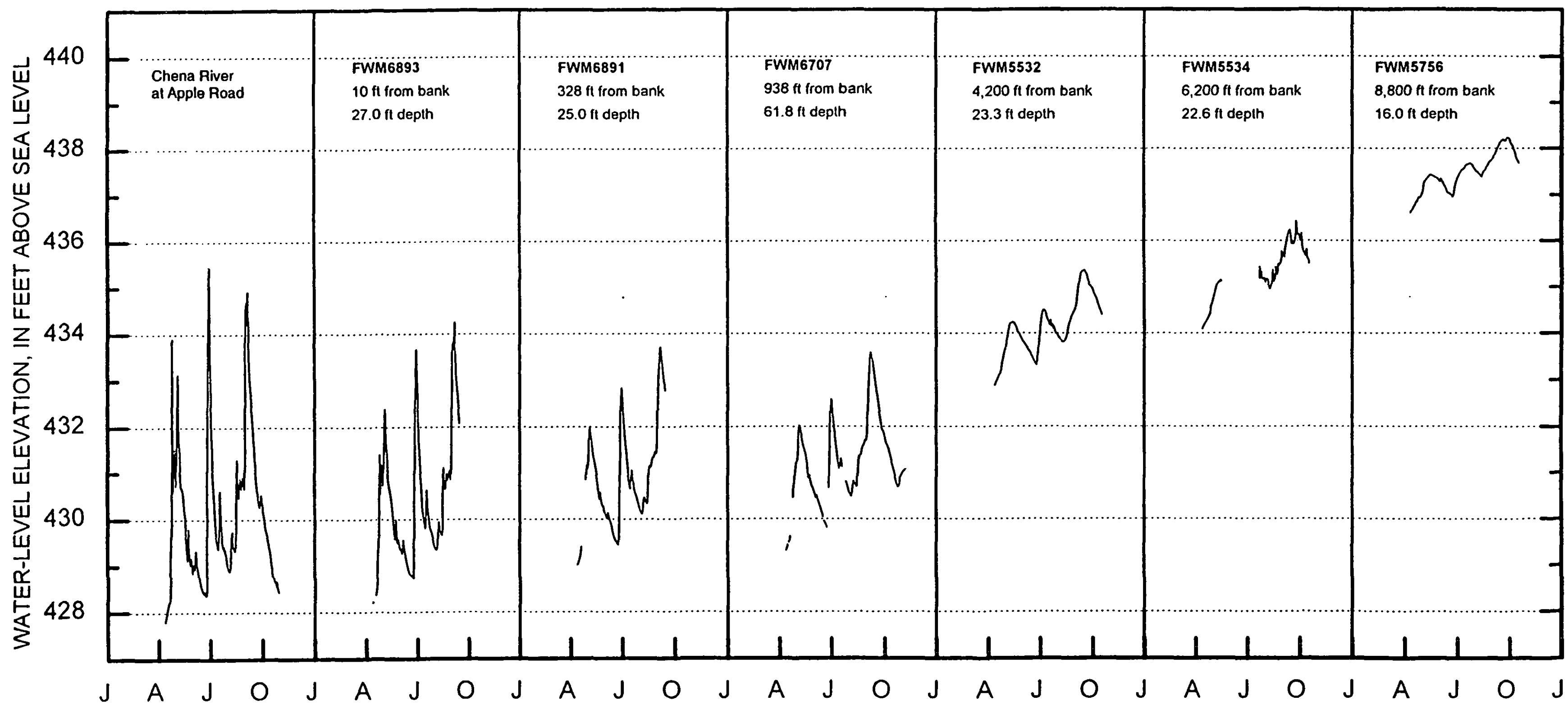


Figure 4. Stages of Chena River and water-level elevations in monitoring wells at various distances from the south bank of the Chena River during 1995

Little information exists about the vertical hydraulic conductivity (K_v) of the Chena Alluvium; however, K_v is generally less than K_h in alluvial aquifers. Layered heterogeneity of alluvial deposits imparts considerable anisotropy (differences in hydraulic conductivity in different directions) on a regional scale (Freeze and Cherry, 1978). Because of the shifting position of river channels and changing depositional velocities, river deposits have a textural variability that causes heterogeneity in the distribution of hydraulic properties.

Storage Properties

The parameter that describes the capacity of an aquifer to transfer water to and from storage is known as the storage coefficient (S), and is related to two other parameters, specific yield (S_y) and specific storage (S_s) by the equation $S = S_y + S_s b$. The variable b is the aquifer thickness. In an unconfined aquifer, the specific yield (S_y) is so much larger than S_s, that the term $S_s b$ is negligible. S is then approximately equal to S_y, which is the quantity of water that drains by gravity from porous materials in response to a decline in the water table. In a confined aquifer, no porous materials are dewatered, so the term S_y is equal to zero. In this case, S is equal to the term $S_s b$. For either the confined or unconfined case, the storage coefficient is the quantity of water released from storage as the head in the aquifer declines.

S_y and S_s can be estimated from aquifer tests; however, these estimates are subject to large errors (Anderson and Woessner, 1992). The typical range of S_y in alluvial-aquifer material is between 0.1 and 0.45 (Freeze and Cherry, 1979; Anderson and Woessner, 1992). Values of S_s for confined aquifers of sandy materials are between 1×10^{-4} ft^{-1} and 1×10^{-6} ft^{-1} for alluvium and between 1×10^{-5} ft^{-1} and 1×10^{-7} ft^{-1} for bedrock.

NUMERICAL ANALYSIS OF THE GROUND-WATER FLOW SYSTEM

Conceptual Model of the Flow System

The Chena River is both a source and a sink at the northern end of the simulated cross section. Bank recharge occurs as the Chena River stage rises, and bank discharge occurs as stage declines. The conceptual model assumes that no ground water flows under the Chena River, treating the river as a ground-water divide. Although this is not true, the error introduced by this assumption is not significant for the purpose of analyzing aquifer properties. The Tanana River and the aquifer system are a source of water along the southern end of the cross section. The Chena Alluvium forms the unconfined alluvial aquifer system. The alluvial aquifer is treated as a homogeneous and anisotropic system, whereas the underlying bedrock system is treated as homogeneous and isotropic.

Flow between the ground-water system and the river is treated as two dimensional. This results in the flow pathlines always being parallel to the plane of the model. Recharge and evapotranspiration are assumed to be negligible and are not incorporated into the conceptual model.

Numerical Model Construction

A numerical model of ground-water flow simulates water levels, as well as the directions and fluxes of water moving through an aquifer system. This is done by numerically solving partial differential equations that represent the physical processes of ground-water flow. The aquifer system is discretized (subdivided into small blocks) by a three-dimensional rectangular grid. Each cell, which is labeled by row, column, and layer represents a volume of permeable material in which the hydraulic properties are assumed to be uniform. The cross section was simulated using the computer program MODFLOW (McDonald and Harbaugh, 1988). Although MODFLOW is three dimensional, only two dimensions were used in this simulation.

Transient simulations that are needed to analyze time-dependent problems typically begin with steady-state initial conditions. These initial conditions giving the head distribution (starting heads) in the aquifer at the beginning of the transient simulation were calculated by running a steady-state numerical model simulating the end of winter recession, which is a relatively stable period. Large water-level fluctuations of short duration generally do not occur during this time and the water-table profile is relatively steady (fig. 5).

The northern boundary condition of the numerical model is defined by the stages of the Chena River. The stage is recorded 3 mi downstream, however, so a correction must be applied. The correction is based on regression analysis. Stage data from the continuous recorder at the Chena River at Fairbanks gaging station (fig. 1) were regressed against periodic measurements at the Chena River at Apple Road (fig. 6). The Chena River at Apple Road measuring station is located at the riverbank end of the cross section (fig. 1).

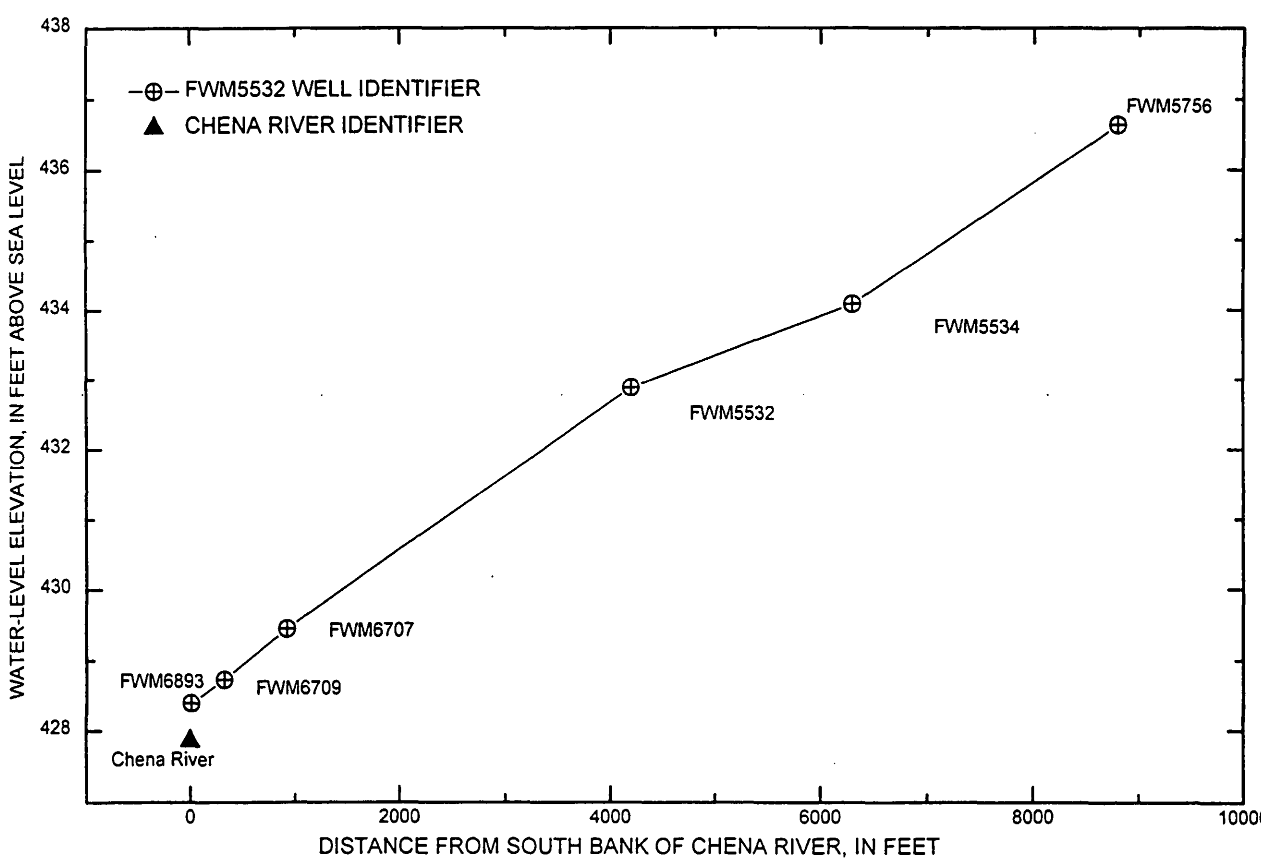


Figure 5. Water-level elevations during late winter recession (start of numerical model simulation) and changes with distance from the south bank of the Chena River.

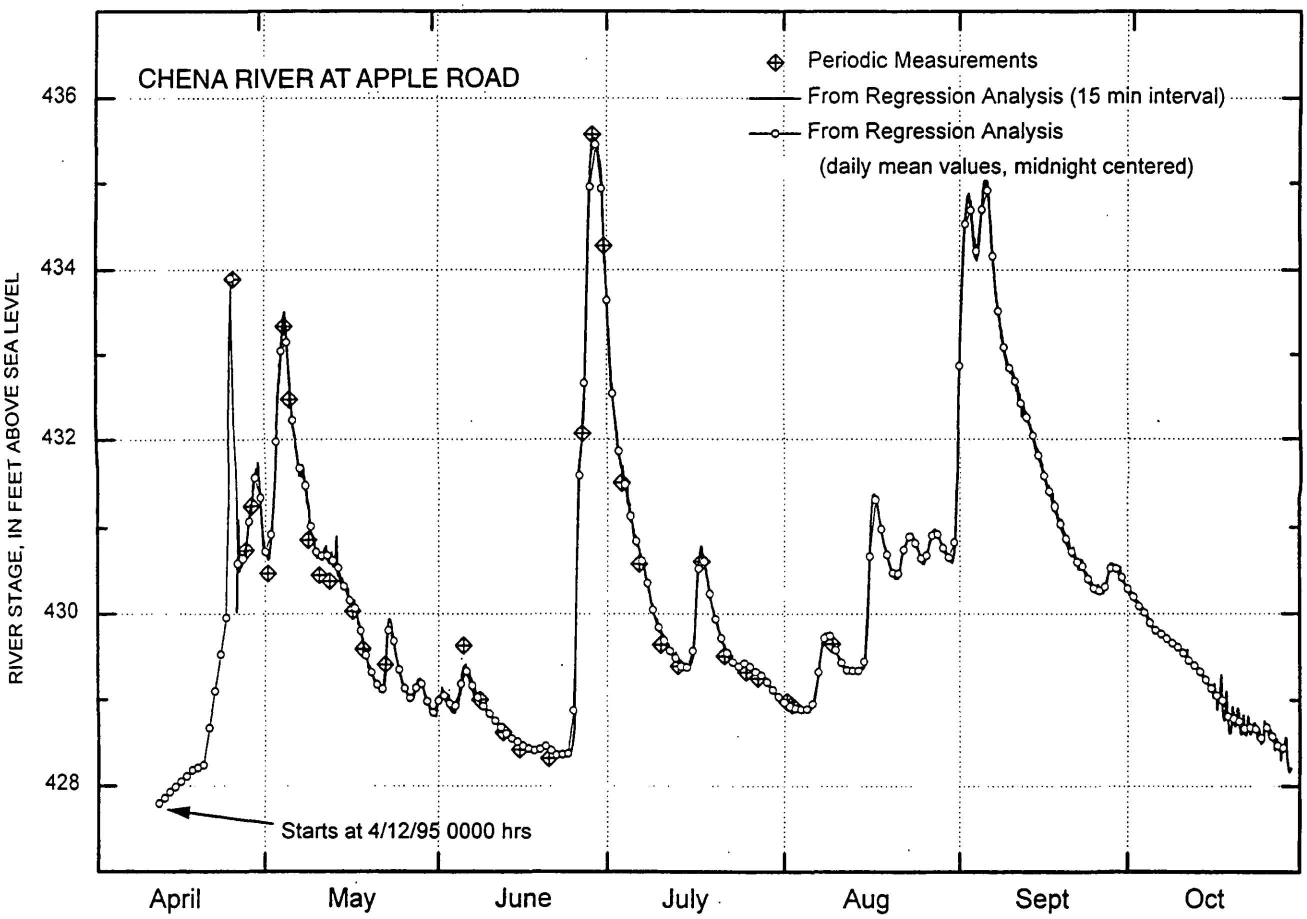


Figure 6. Stage of the Chena River at Apple Road from April 12 to October 30, 1995.

The southern boundary condition of the model is defined by the water-level elevations measured at monitoring well FWM5756 (fig. 1). The daily mean values, midnight centered, were calculated from the measured data set and used to specify heads at all depths at the southern end of the model. The lower boundary of the model was treated as a no-flow boundary at a specified elevation of -600 ft. No recharge is applied to the top of the numerical model.

Numerical Model Grid

The aquifer is treated as being confined between two vertically parallel planes, one foot apart (fig. 7). The numerical model grid contains 45 columns, 1 row, and 11 layers for a total of 495 cells. Column widths and layer thicknesses were chosen to accommodate both the cross-sectional profile of the Chena River and the screened interval of the monitoring

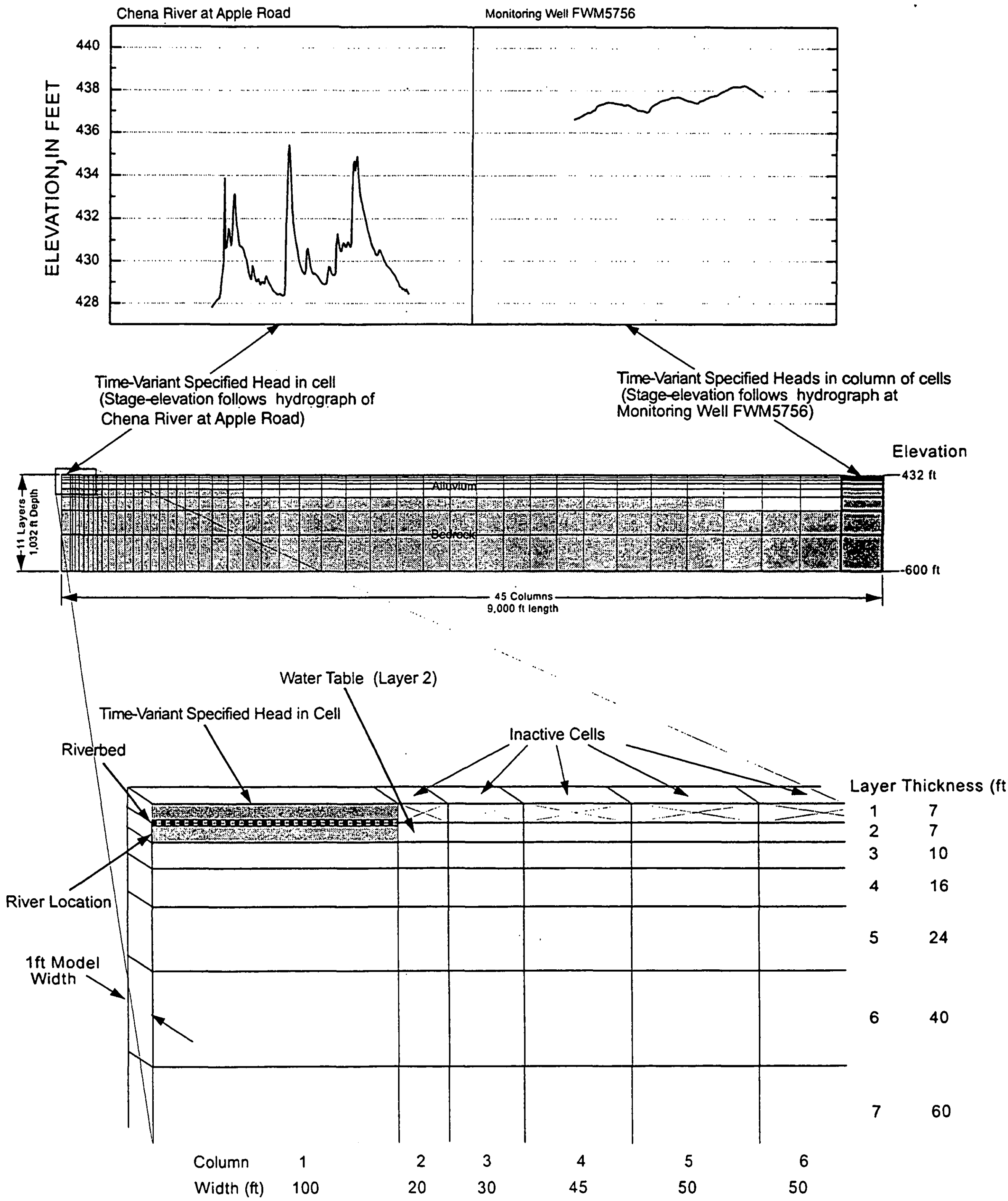


Figure 7. Cross-sectional numerical-model grid, Fort Wainwright, Alaska.

wells (table 1; fig. 8). The center of a cell in the numerical model grid corresponds to the approximate midpoint of each well screen. The widths of the columns increase with distance from the river. No column was more than 1.5 times the width of an adjacent column. A factor of 1.5 is a generally accepted maximum for maintaining numerical stability. The increase in column width away from the river reflects that not as much detail is needed to simulate the smaller changes in water levels. The narrower column widths near the river reflect the more finely detailed discretization needed to describe the greater changes in water levels in this area.

The head in the cell in column 1 of layer 1 is specified using the Time-Variant Specified-Head package for MODFLOW (Leake and Prudic, 1991). Midnight-centered daily mean stages of the Chena River are specified. Riverbed conductance (R_c) is the area (1 ft x 100 ft) of the riverbed, divided by the thickness (1 ft) of the riverbed material, multiplied by its vertical hydraulic conductivity. Movement of water into and out of the river was controlled by both the riverbed conductance and the vertical conductance term between layers 1 and 2 (fig. 9).

Vertical Discretization

Eleven layers in the numerical model simulate a total aquifer thickness of 1,032 ft. River simulation effects, vertical locations of screened intervals, and aquifer geometry were used to determine the necessary numbers of layers. Each grouping of similar layers is described in the sections below.

Layer 1: Most of this layer is not an active part of the numerical model, but it was used to specify the river stage in column 1 (fig. 7). The cells at columns 2 to 45 are inactive. The cell in column 1 uses specified heads as previously described. Conceptually, it might be visualized as the area above the water table, the unsaturated zone.

Table 1. Ground-water data-collection sites and corresponding numerical-model grid-cell indexes
[FWM numbers are interchangeable with AP identification numbers used on Fort Wainwright]

Well ID (fig. 1)	Coordinate		Distance from south bank of Chena River (feet)	Well depth (feet below land surface)	Elevation (feet above sea level)				Grid-cell index	
	Northing	Easting			Land surface	Measuring point	Top of screen	Bottom of screen	Column	Layer
FWM6893	3965662	247553	10	27.0	444.4	447.1	433.4	419.3	2	2
FWM7092	3965659	247559	10	66.2	444.4	446.8	388.4	377.9	2	5
FWM6891	3965339	247532	328	25.0	447.2	450.1	435.2	420.0	9	2
FWM7093	3965342	247538	328	61.8	447.3	449.7	390.5	385.5	9	5
FWM6709	3965347	247546	328	102.4	447.6	450.7	353.3	348.3	9	6
FWM6706	3964732	247462	928	26.6	444.1	446.4	425.5	420.5	16	3
FWM6707	3964741	247454	928	61.8	444.1	447.7	391.5	386.5	16	5
FWM5532	3961547	248752	4,200	23.3	447.5	450.3	435.2	424.2	32	3
FWM5534	3959425	248108	6,300	22.6	448.7	451.4	436.1	426.1	38	3
FWM5756	3956539	248247	8,800	16.0	448.9	451.4	442.9	432.9	45	2

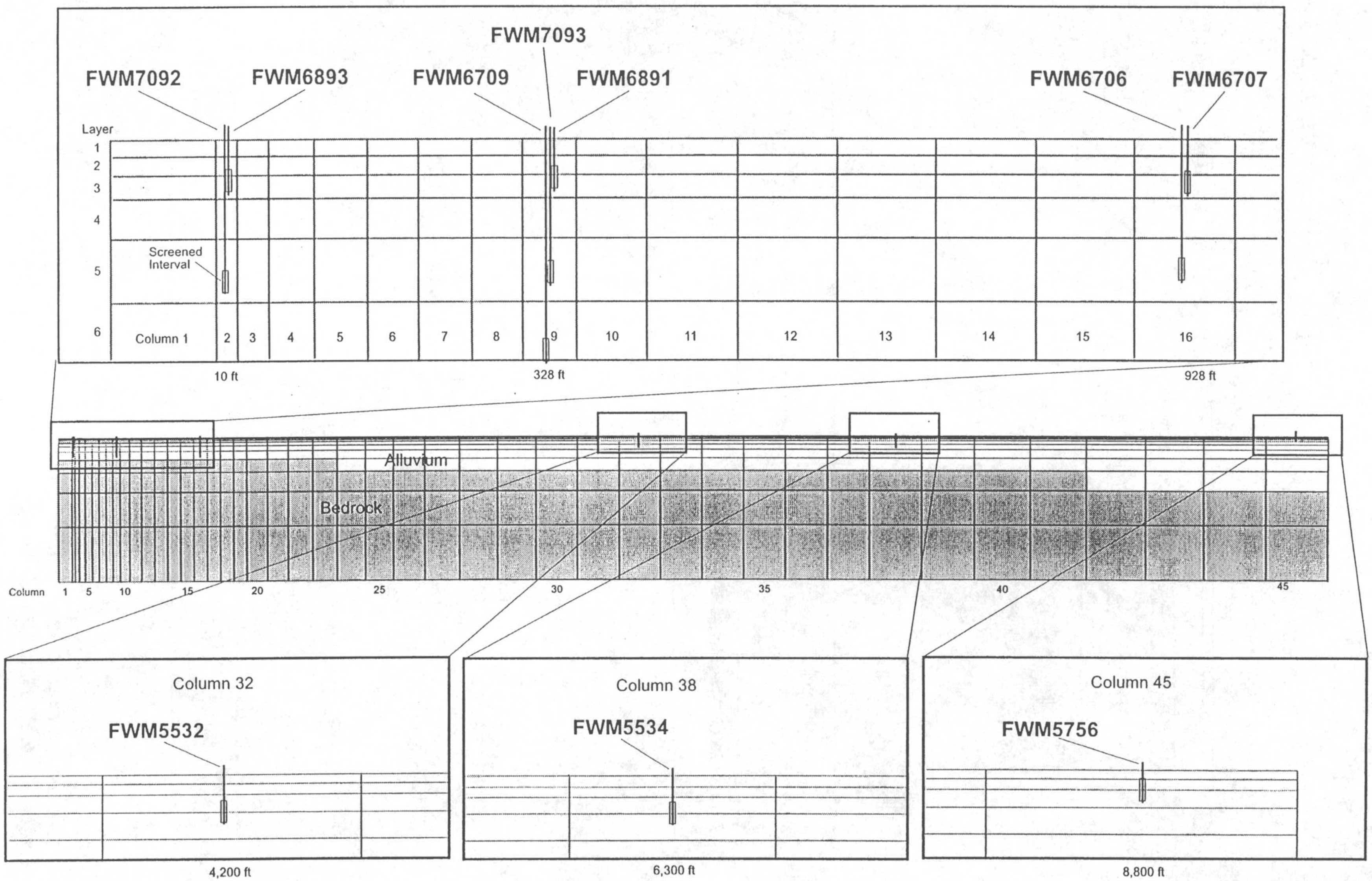


Figure 8. Well locations relative to numerical-model columns and layers, Fort Wainwright, Alaska.

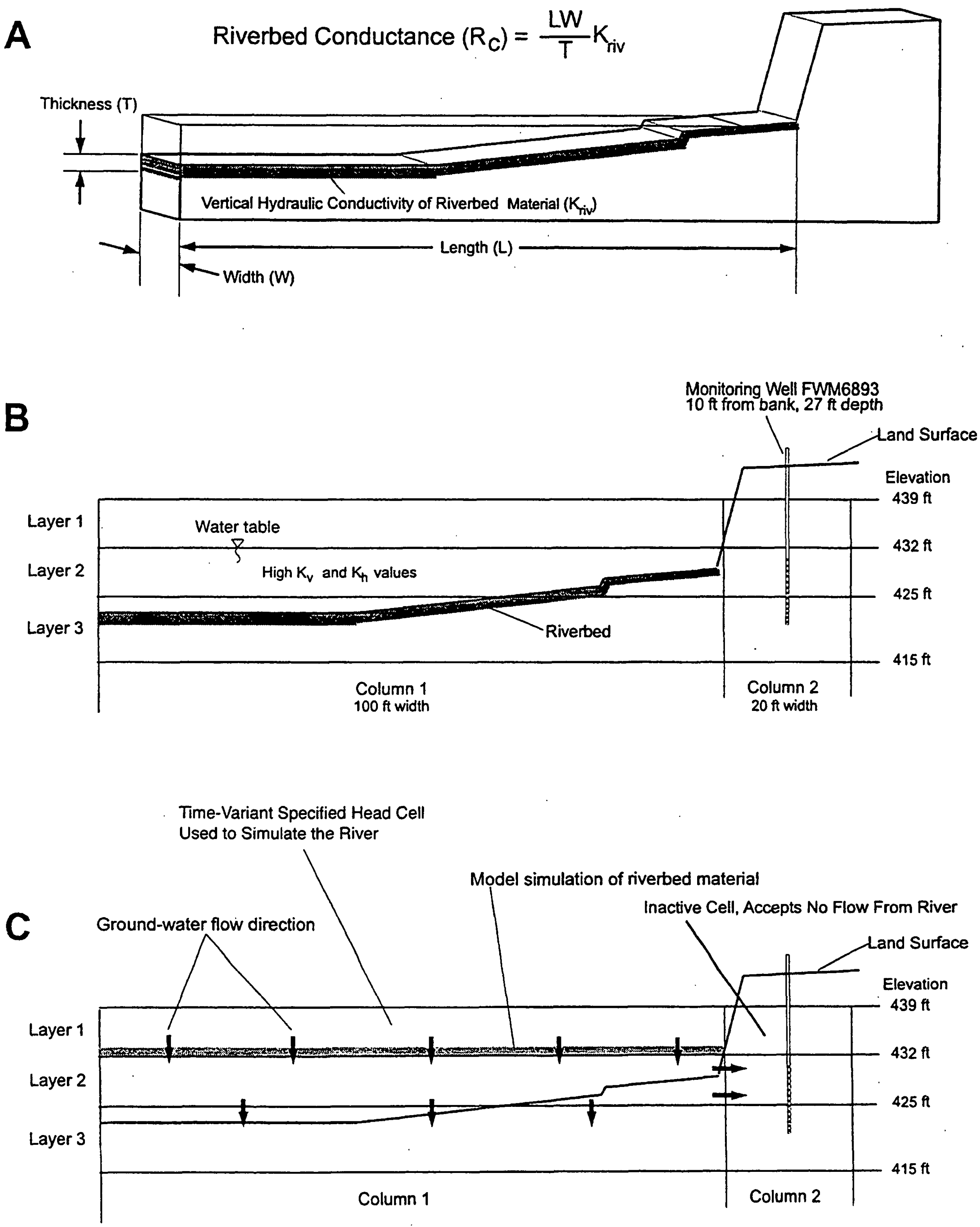


Figure 9. Simulation of river and riverbed in the numerical model, Fort Wainwright, Alaska. A. Calculation of riverbed conductance. B. Relation of actual riverbed profile to model layers. C. Simulated location of riverbed.

Layer 2: Simulated heads in this layer represent the elevation of the water table. Although the changes in thickness of the saturated zone caused by the rising and falling of the water table change the transmissivity in this layer, the transmissivity was modeled as being constant. A test of simulating changes of transmissivity over time did not significantly affect the simulated head values. A specific yield value of 0.25 for alluvial material was used as the storage property for this layer. The thickness of this layer, approximately 7 ft, is the mathematical difference between the average river stage elevation (432 ft) and the average riverbed elevation (425 ft).

Layers 3 to 11: These layers represent the continuously saturated part of the aquifer. A specific storage value of 1×10^{-6} ft^{-1} was used for the storage term for cells representing alluvium in these layers. Layer thicknesses were designed so that the center of the layers matched the center of the screened interval of the monitoring wells. Layers 8 to 11 contain cells representing bedrock (figs. 7 and 8). The bedrock surface was simulated as grading from north (275 ft elevation, beneath the Chena River) to south (40 ft elevation, beneath well FWM5756). The bedrock aquifer is not a no-flow boundary, but actively transmits ground water both horizontally and vertically. Horizontal hydraulic conductivity and specific storage for bedrock cells were constant for all simulations at values of 0.10 ft/d and 1×10^{-7} ft^{-1}, respectively.

Horizontal Discretization

Column 1: The width of this column is 100 ft, which is approximately one-half the width of the Chena River. This width is based on the assumption that the effects of stage changes of the Chena River on the surrounding ground-water system are symmetrical. That is, the south half of the river exchanges water to the south; the north half of the river exchanges water with the aquifer north of the river.

Columns 2 to 45: Widths of these columns range from 20 to 450 ft, and were chosen so that monitoring wells are at the centers of columns. Column 45 is the southern boundary along the modeled cross section.

Geometry Error

It was assumed that the modeled cross section was perpendicular to the Chena River and that the river was straight and infinitely long. However, the cross section is on the outside of a river bend approximately 1 mi in length and on the inside of two larger river bends approximately 2 mi in length (fig. 1). A simple one-layer areal ground-water model of the airfield area at Fort Wainwright was constructed in order to investigate the effects of river geometry on the cross-sectional model. The model's eastern and western boundaries were near the eastern and western boundaries of the inset map in figure 1. The northern boundary was the Chena River and the southern boundary was an east-to-west line that passed through the southern boundary of the cross-sectional model (near monitoring well FWM5756). This numerical simulation indicated that use of the cross-sectional model causes the horizontal hydraulic conductivity and other aquifer properties to be overestimated by about 30 percent. Consequently, a 30 percent correction was applied to the estimates obtained with the modeled cross section.

Calibration Techniques

The calibration techniques used in this report follow a systematic progression of testing boundary conditions for the model, initial head conditions, time discretization, and aquifer properties. The calibration target and goals focused on matching particular ground-water observations and simulated heads for specific parts of the hydrographs in question and for specific combinations of observation wells and associated simulated heads.

The first series of simulations consisted of varying the vertical and horizontal extent of the model to appropriate locations for the model's southern and bottom boundaries. Steady-state conditions were defined by using ground-water measurements for April 12, 1995 (fig. 6). This time period is directly before ice breakup: it is the time of year when ground-water elevations and surface-water stages are changing the least and thus best represent an idealized steady-state condition. The output heads from steady-state conditions were then used as starting heads for the succeeding transient-state runs. Time discretization was also varied to determine the appropriate time steps for the model. Simulated heads were compared to measured ground-water elevations using an iterative method of independently varying R_c, K_v, and K_h while keeping all other parameters constant. The "best fit" between simulated and measured ground-water hydrographs was determined primarily on a qualitative basis by observing the timing and amplitude of the peaks.

Extent of the Model

The southern boundary of the modeled cross section should be sufficiently distant so that it has negligible effect on the simulated head values in the area of primary calibration, which is the northern 1,000 ft of the model. Outputs from steady-state models having total horizontal lengths of 4,000, 6,000, 8,000, 9,000, and 10,000 ft were compared with one another. The maximum calibration goal between each run was 0.02 ft for heads 10 to 1,000 ft from the bank. Transient model results were compared with the results of the next lower length run to observe changes in heads within the first 1,000 ft of the model. The 9,000-foot length was chosen for the numerical model because it was the shortest horizontal extent having head differences less than the maximum calibration goal (0.02 ft). The vertical extent of the model was set at 1,032 ft, which includes all of the alluvium and several hundred feet or more of bedrock.

Analysis of Time Discretization

The time discretization was calibrated after the geometry of the numerical model was determined. A time step that is too large produces more of a step change in a simulated head and delays the effect of the response of the modeled system to the changes. A time step that is too small adds computational time to the overall modeling effort. The Time-Variant Specified-Head Package interpolates head values between stress periods. For the purposes of this numerical model, stress periods are equal to one day. Time steps are subdivisions of stress periods, and the number of time steps per stress period affects calibration. The results of the numerical model using 1, 2, 4, 6, and 24 time steps per stress period were compared (appendix, fig. A). The numerical model output of 24 time steps per stress period had a maximum difference of <0.01 ft when compared with the numerical model output of 12 time-steps per stress period. The 24 time steps per stress period was chosen for the final simulations.

Analysis of Riverbed Conductance

The width, length, and thickness of the riverbed were kept constant for calibration of the riverbed conductance (R_c). Calculated ground-water level elevations from transient simulations were compared at layer 2/column 2 with water-level elevations observed in well FWM6893 (10 ft from bank, 27.0 ft depth) (appendix, fig. B). The best R_c value was chosen by matching the amplitude between simulated and measured ground-water elevation data. Values of K_v, K_h, S_y and S_s were kept constant for all runs.

Analysis of Vertical Hydraulic Conductivity

Using the best R_c value from the analysis of riverbed conductance, the difference in heads between layer 2/column 2 and layer

2/column 5, and the difference in ground-water elevations between wells FWM6893 (10 ft from bank, 27.0 ft depth) and FWM7092 (10 ft from bank, 66.2 ft depth) were compared for all stress periods for varying values of K_v. The best K_v value was chosen for subsequent simulations by matching the closest amplitude between the measured and simulated head differences (appendix, fig. C). For all these simulations, the values of R_c, K_h, S_y and S_s were kept constant.

Analysis of Horizontal Hydraulic Conductivity

A series of simulations were run, varying K_h about a center value (the K_h value used in the analysis). R_c and K_v were multiplied by the same factor by which K_h is increased or decreased about the center value. The simulated head data from the corresponding cells were compared with measured ground-water elevations from wells FWM6893, FWM6709, FWM6707, and FWM5532 for all stress periods. The best K_h value was chosen from the best overall amplitude and timing match for those four wells (appendix, fig. D).

ESTIMATED AQUIFER PARAMETERS AND SIMULATED GROUND-WATER/SURFACE-WATER INTERACTION

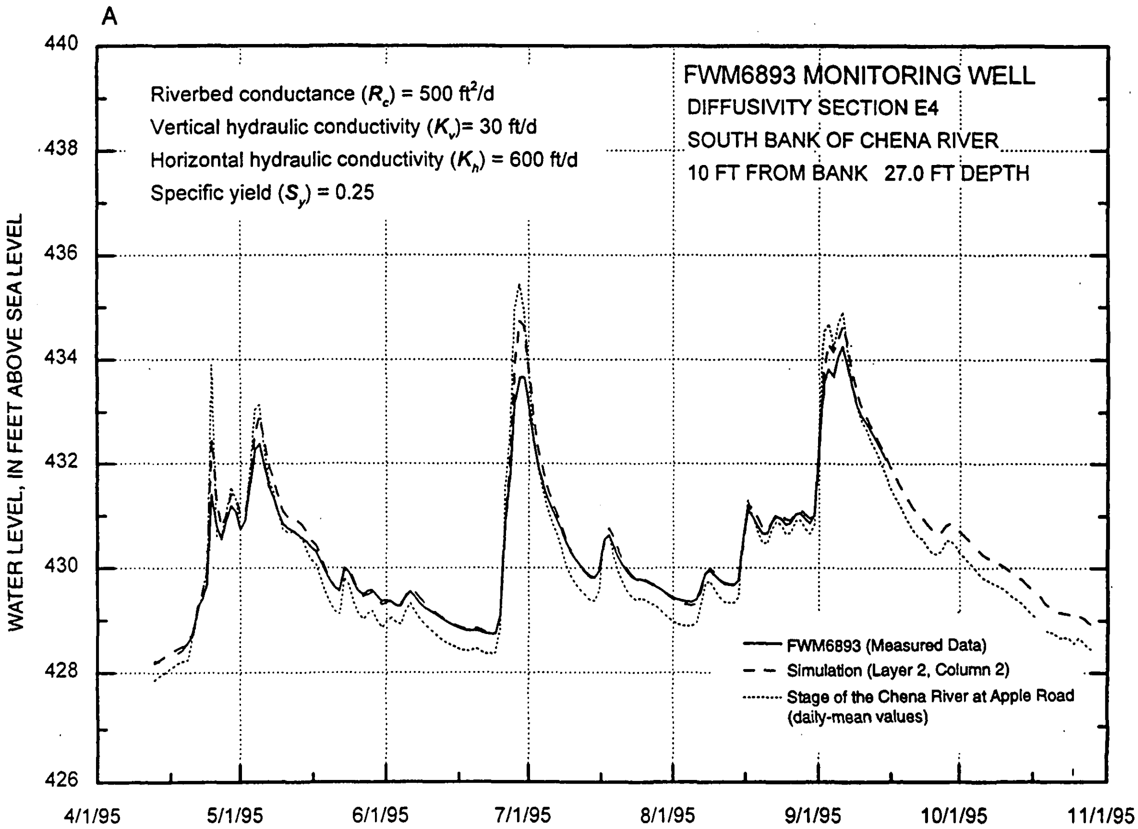
Comparison of Simulated and Measured Ground-Water Elevations

The estimated aquifer parameters after calibration are plotted on figure 10. These plots compare the simulated and measured ground-water elevations for each well with the stage of the Chena River at Apple Road. The plots are shown in order of increasing distance from the Chena River. Comparisons of the simulated heads with measured heads illustrate how the numerical model matched the hydrologic response of the stage changes in the river. The best values obtained from the final numerical model simulation are shown in table 2. Because the cross-sectional model does not account for the effect of the meander bends of the Chena River, a river geometry correction factor was applied to the estimated K_h based on the river geometry test using a single-layer areal model.

Table 2. Estimated values of geohydrologic parameters obtained by calibrating cross-sectional model
[ft/d, foot per day; ft^2/d, foot squared per day; --. correction not applied]

Parameter	Estimated value: Cross-sectional model	Estimated value: Corrected for river geometry effects
Riverbed conductance (R_c)	500 ft^2/d	350 ft^2/d
Alluvium		
Vertical hydraulic conductivity (K_v)	30 ft/d	20 ft/d
Horizontal hydraulic conductivity (K_h)	600 ft/d	400 ft/d
Anisotropy (K_v/K_h)	1:20	1:20
Specific yield (S_y)	[a]0.25	--
Specific storage (S_s)	[a]1×10^{-6}	[a]1×10^{-6}
Diffusivity (K_h/S_y)	2,400 ft/d	--
Bedrock		
Vertical hydraulic conductivity (K_v)	[a]0.005 ft/d	--
Horizontal hydraulic conductivity (K_h)	[a]0.10 ft/d	--
Specific storage (S_s)	[a]1×10^{-7}	--

[a] Assumed value, not estimated by calibration



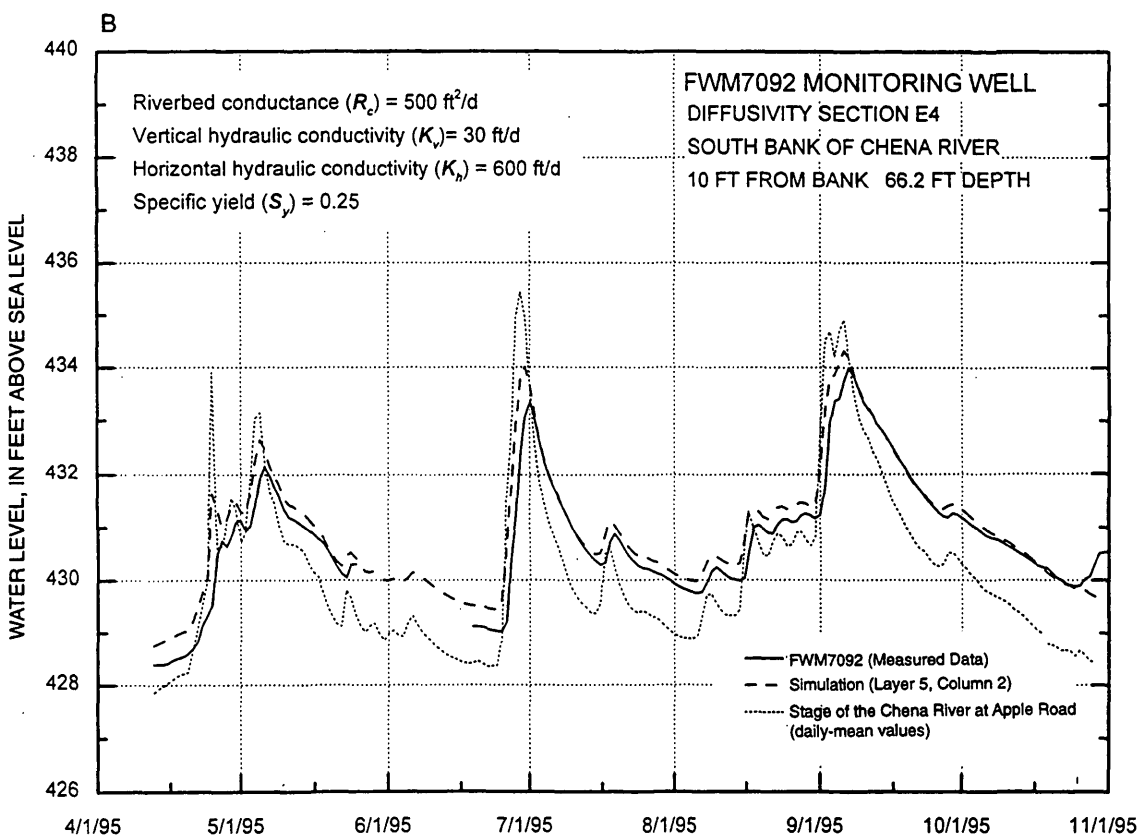
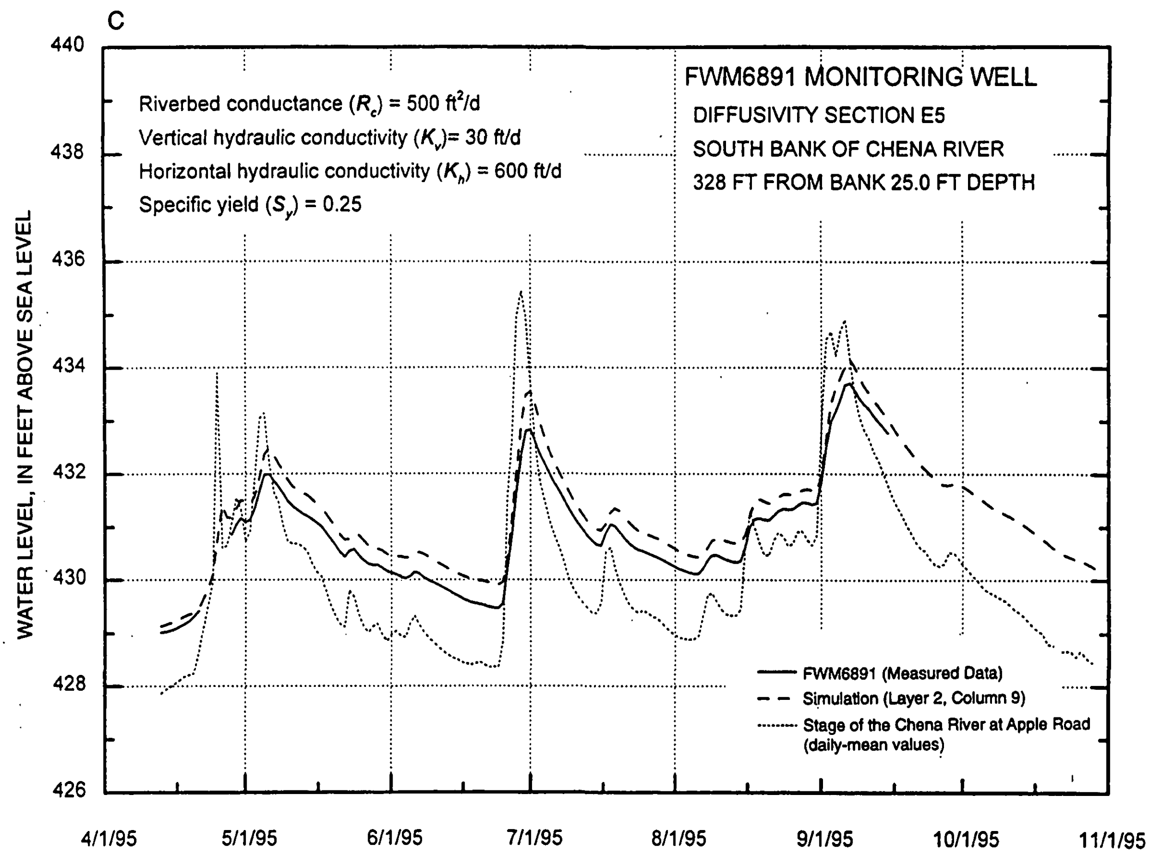


Figure 10. Comparison of simulated to measured data.



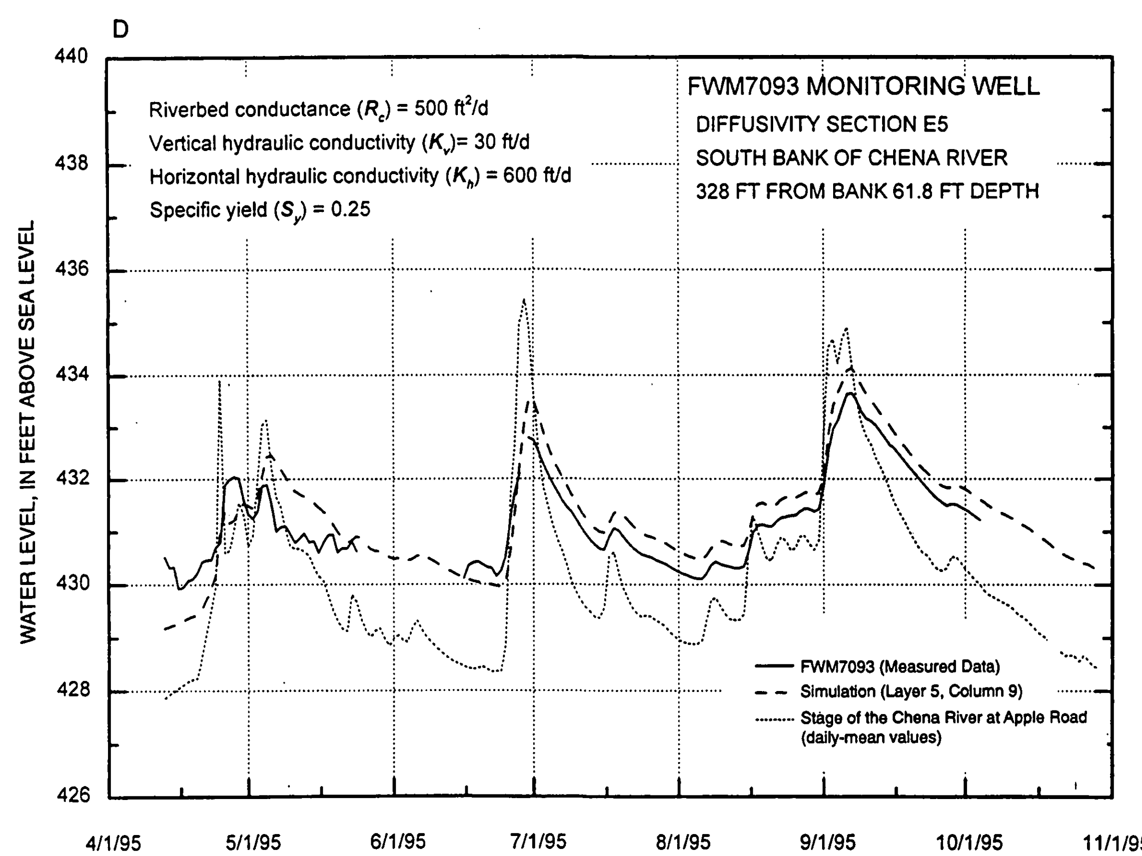
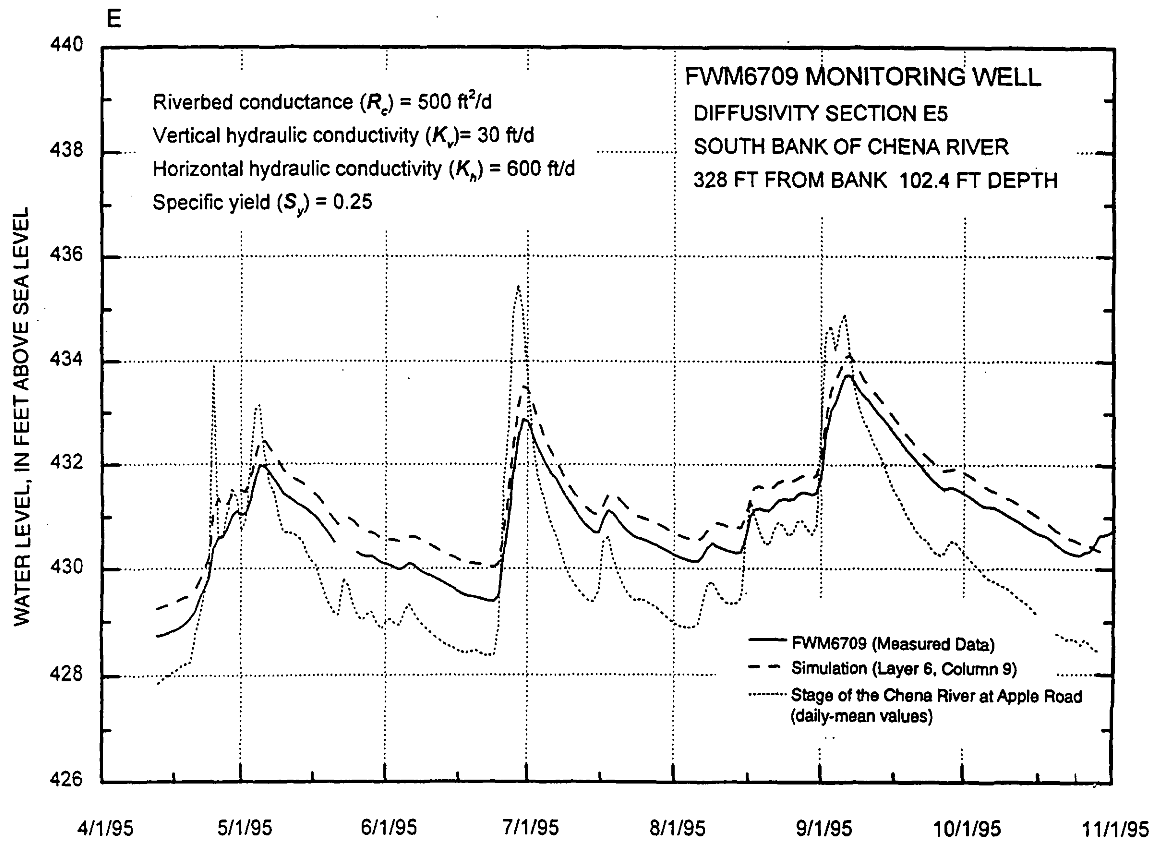
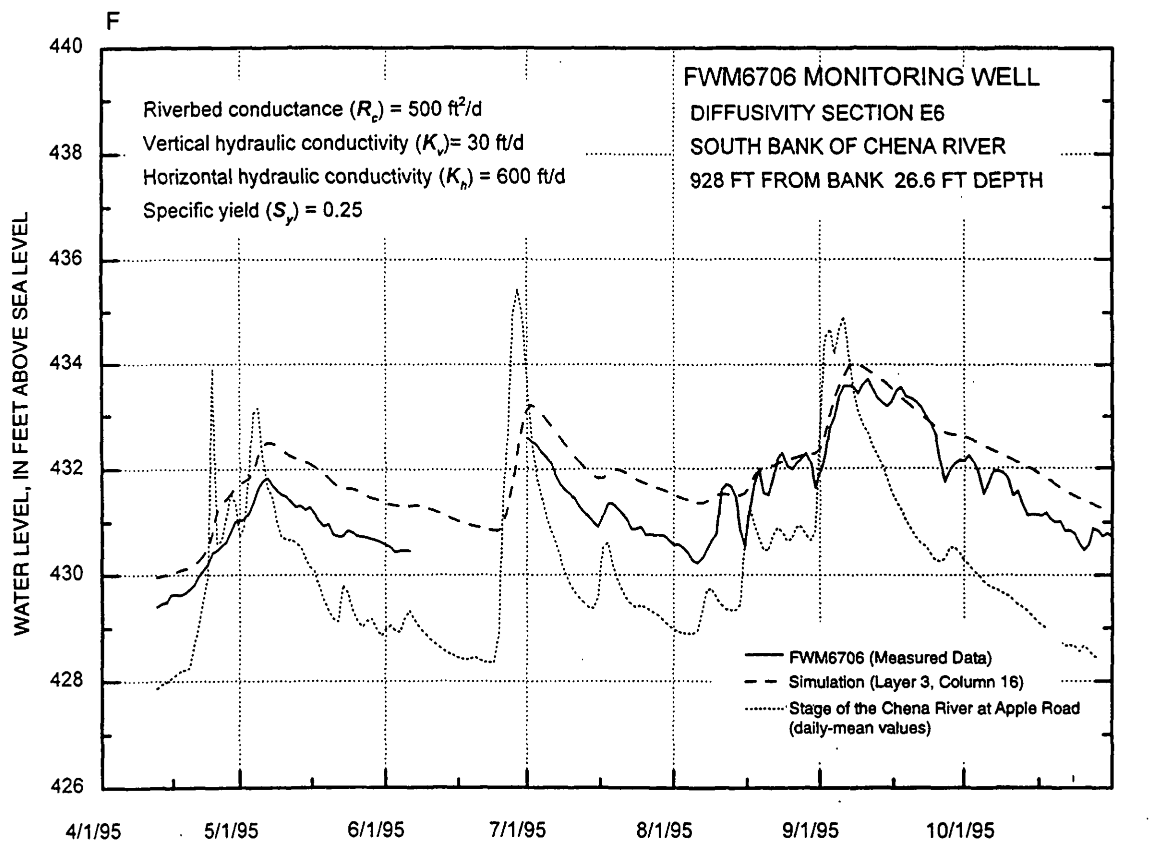


Figure 10. Continued.





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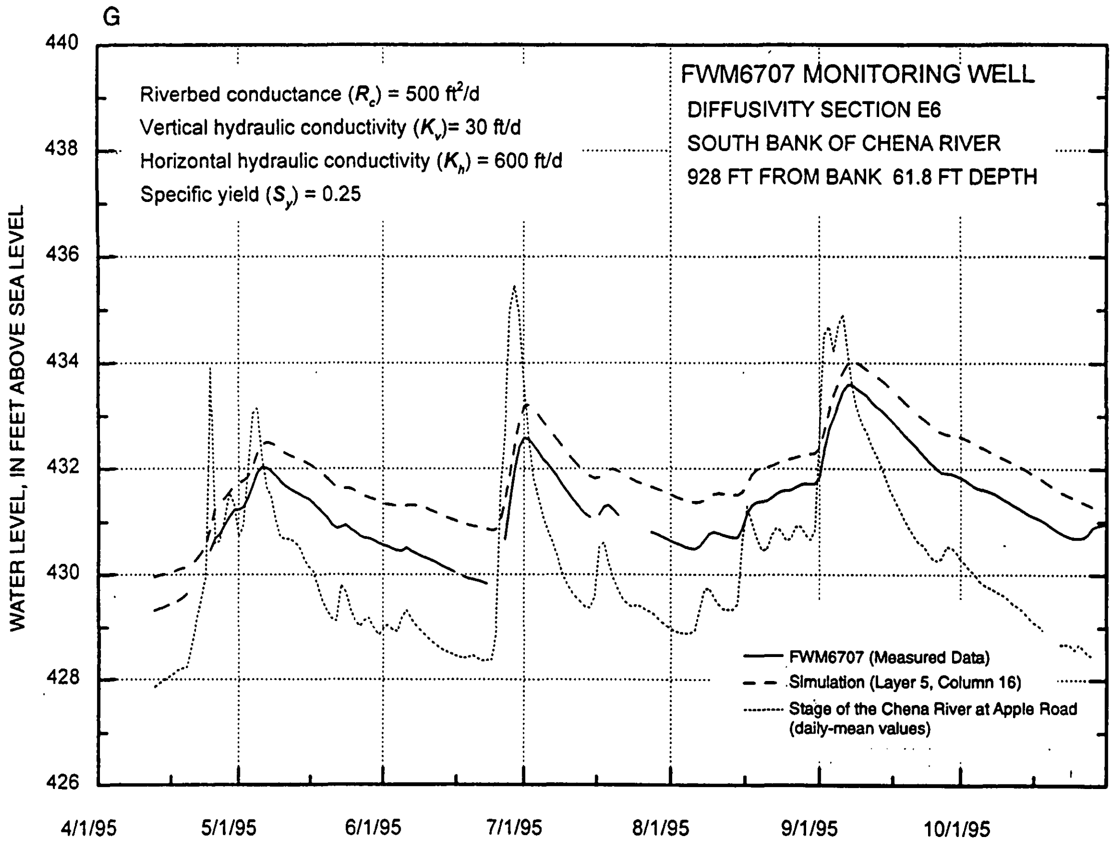


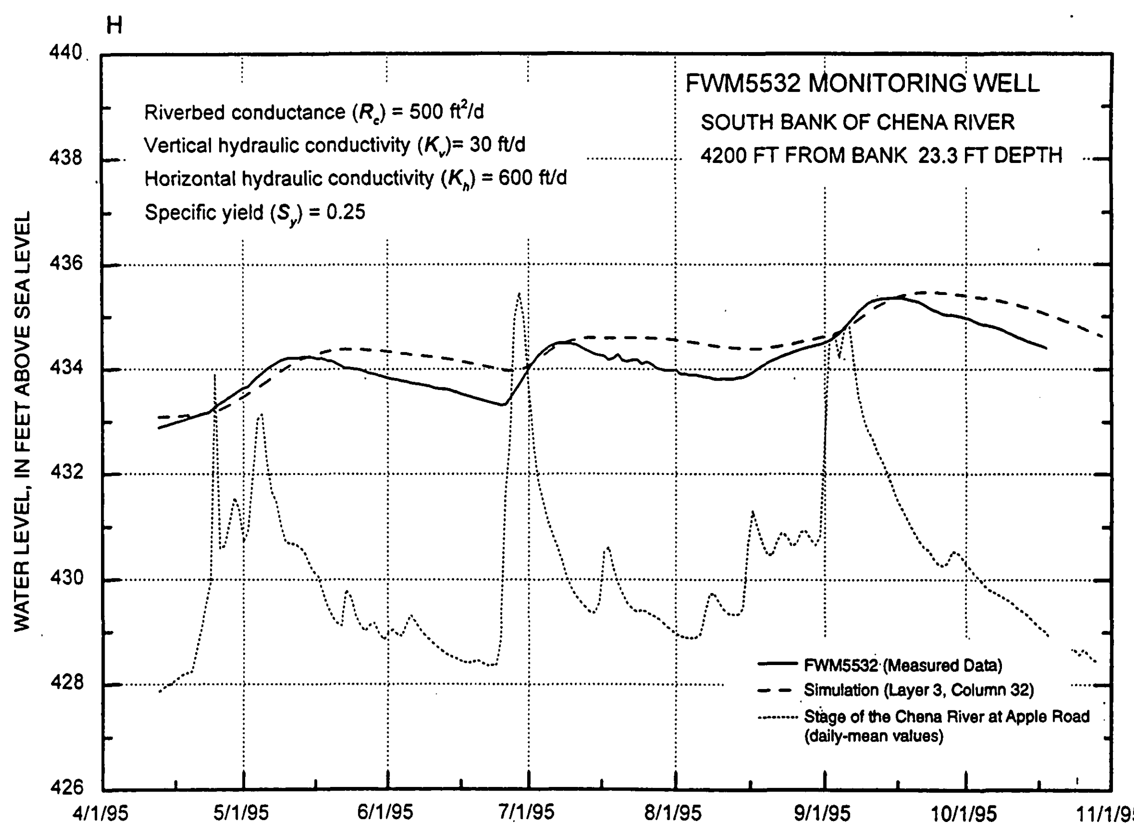


Figure 10. Continued.

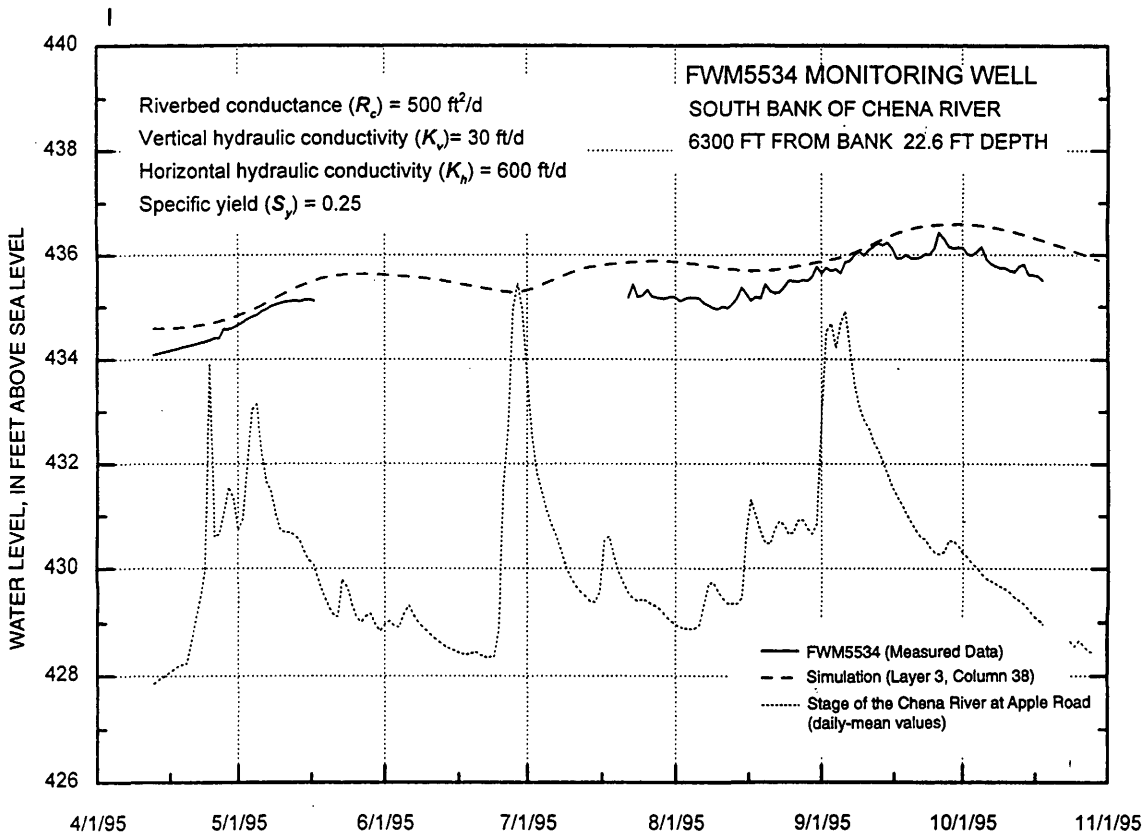


Figure 10. Continued.

Although it is not certain how the river geometry affects the estimates of R_c and K_v, the correction was applied to these parameters also.

The estimated geohydrologic parameters are non-unique, meaning that other combinations of geohydrologic parameters in the numerical model will produce similar results. It is important to note however, that the ratios R_c/K_v, R_c/K_h, and K_h/S_y are constrained for the non-unique solution. The estimated values of the parameters in table 2 are sensitive to the value of S_y. They are not sensitive to the other assumed aquifer parameters. The hydrologic parameters estimated using this cross-sectional model are only valid when taken in context with the other values (both estimated and assumed) used in this study. By gathering and analyzing additional field data, it may be possible to further constrain the number or range of variables to obtain a more accurate set of estimated aquifer parameters.

Simulated Water-Table Profiles During a Storm Peak

The highest recorded storm peak of the Chena River during 1995 occurred between June 24 and July 9. Water-level elevations for the top layer (layer 2) of the model during this time period were extracted from the numerical-model output and plotted as a function of distance from the south bank of the Chena River (fig. 11a-c). This series of plots illustrates the transient effects of bank storage of the aquifer near the Chena River. Between June 24 and 29, during a 6-day rise of river stage of approxi-

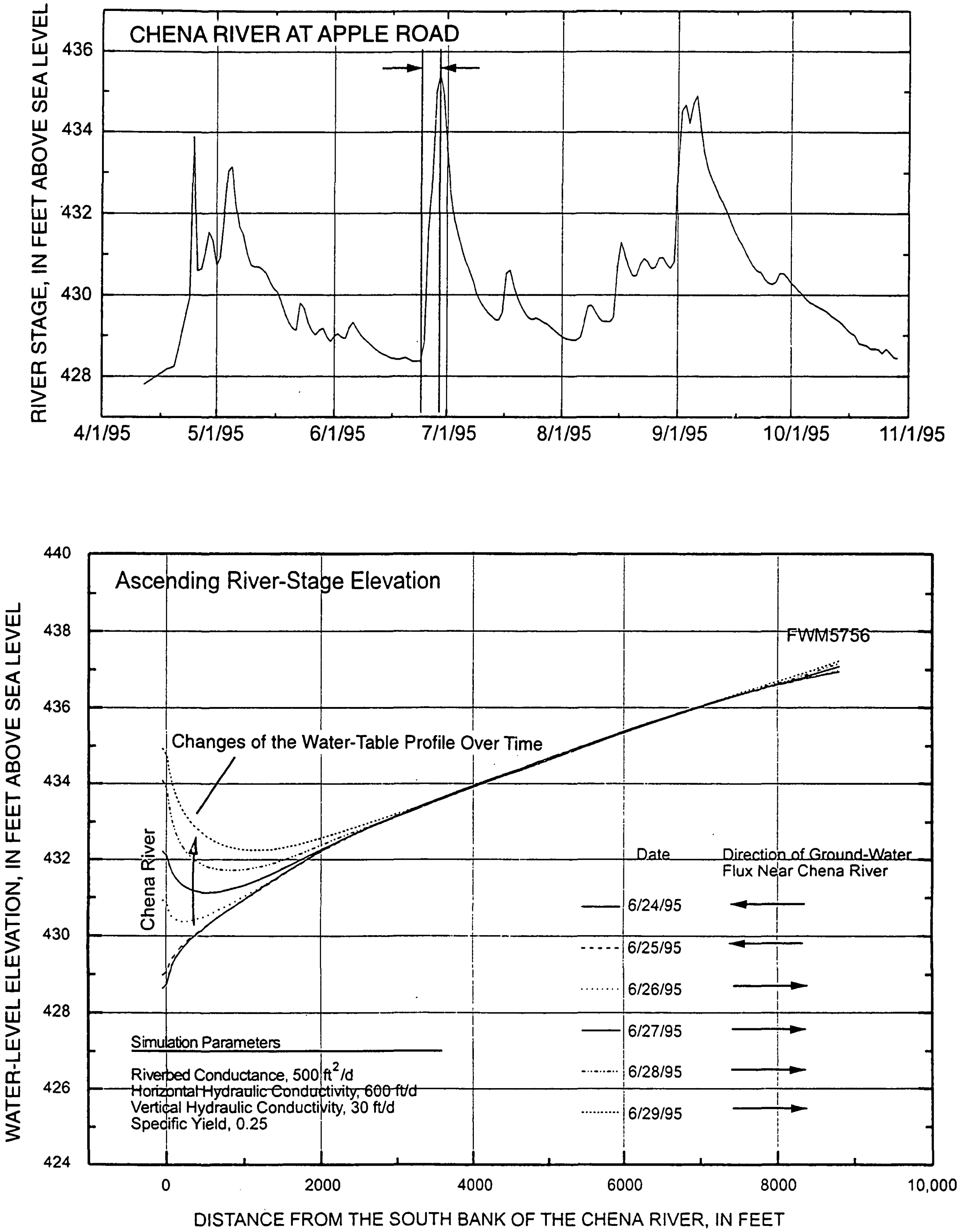


Figure 11a. Simulated water-table profiles for June 24 to 29, 1995, Fort Wainwright, Alaska.

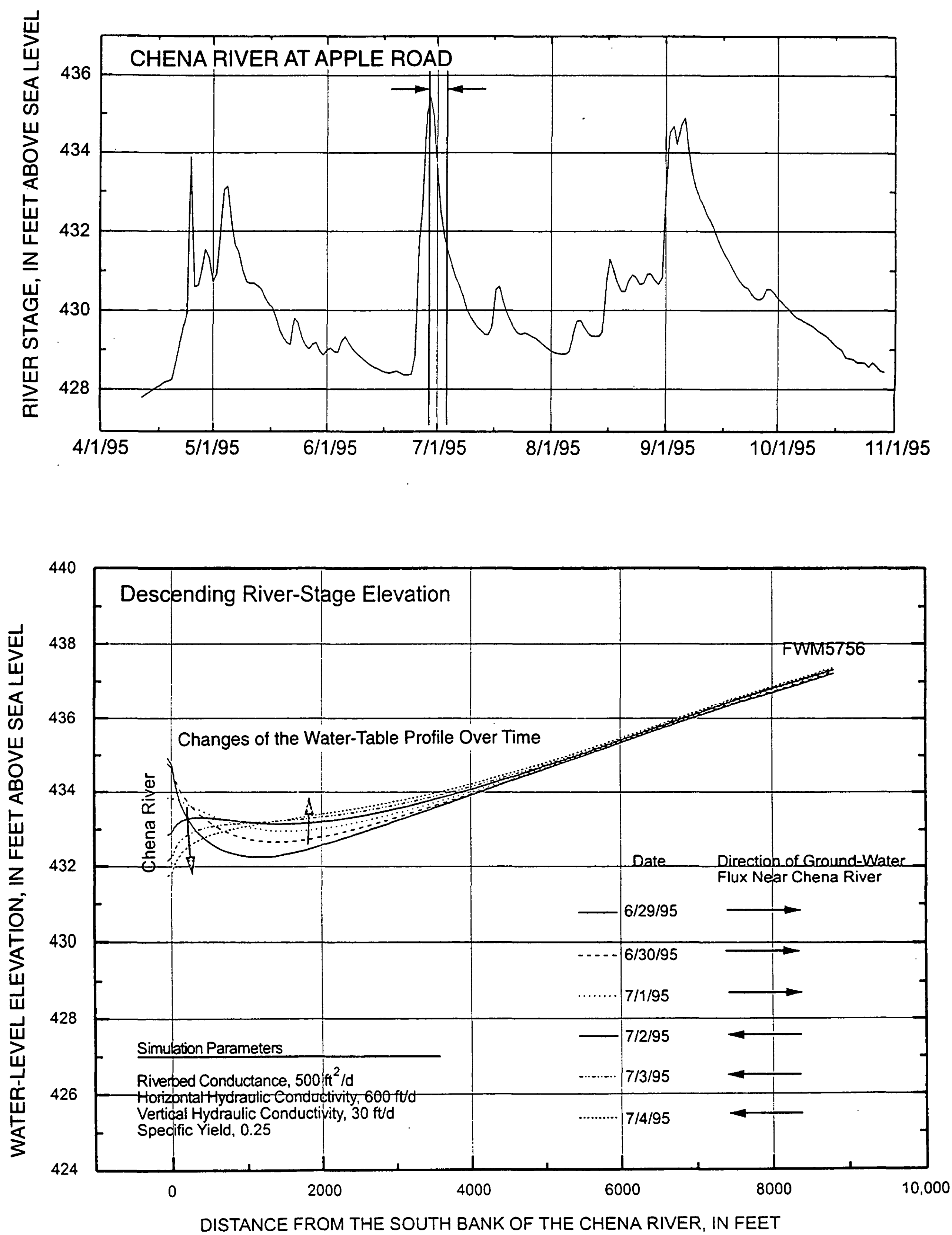
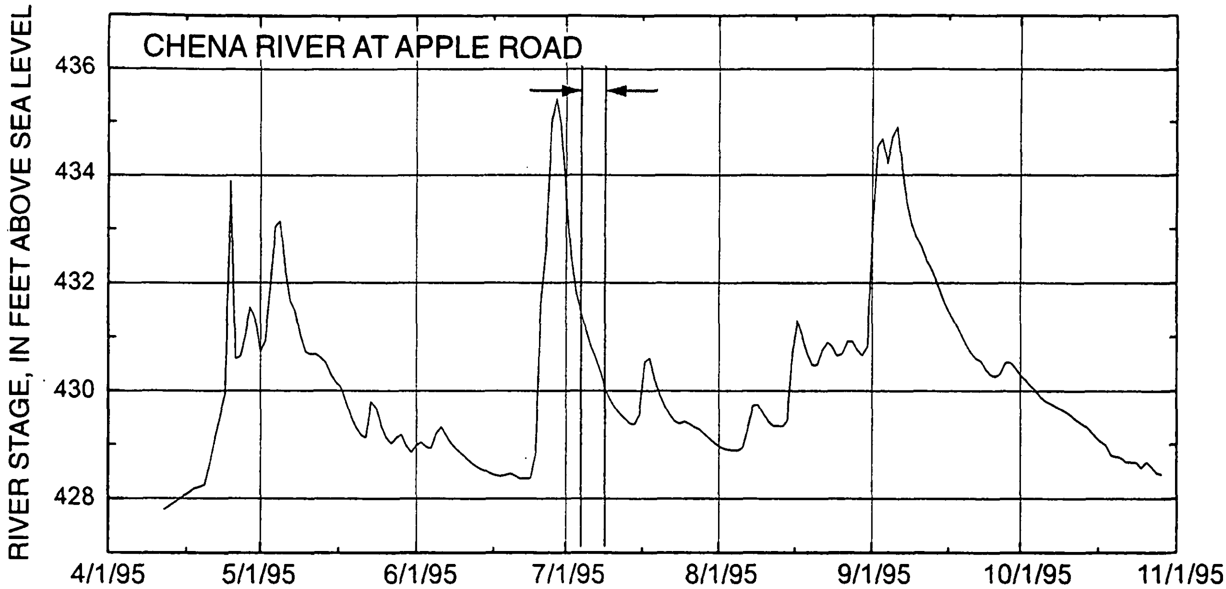


Figure 11b. Simulated water-table profiles for June 24 to 29, 1995, Fort Wainwright, Alaska.



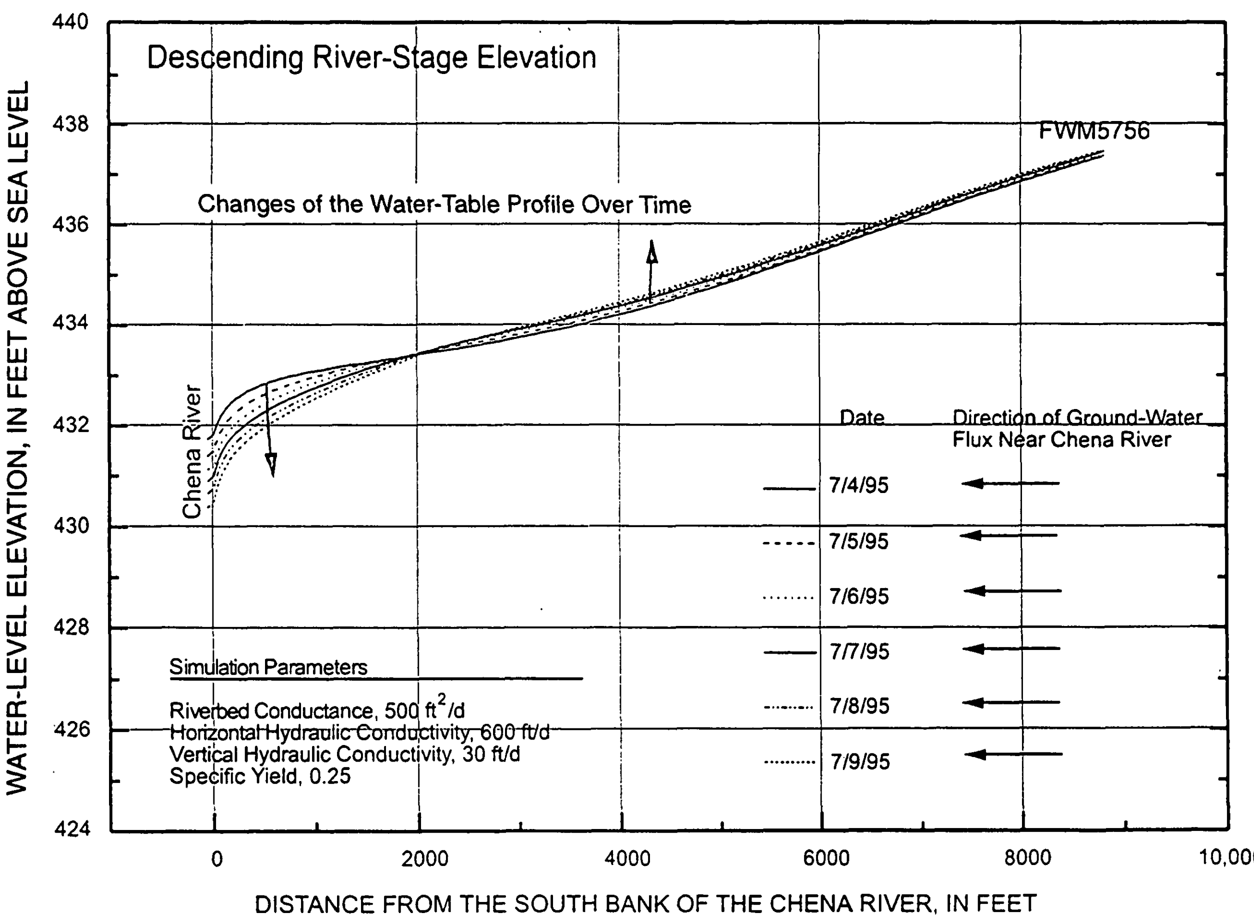


Figure 11c. Simulated water-table profiles for June 24 to 29, 1995, Fort Wainwright, Alaska.

mately 6 ft, the water-table elevation rose about 0.5 ft at a distance of 2,000 ft from the bank (fig. 11a). Water flowed from the river into the aquifer because the elevation of the river stage was higher than the elevation of the water table. During the rapid decline in river stage between June 29 and July 9, the flow direction changed and water flowed from the aquifer to the river when the elevation of the Chena River fell below that of the water table (figs. 11b and 11c). Away from the near-bank aquifer, the water table steadily rose as the aquifer continued its delayed response to the flood peak. Eventually, as water continued to flow from the aquifer to the river, water introduced to the ground-water system by the Chena River flowed back into its source.

SUMMARY

The alluvial-plain aquifer in the Fairbanks, Alaska, area is affected by transient stage changes of the Chena and Tanana Rivers. Adjacent to the river, water flows into or out of the riverbed and riverbanks depending on the elevation of water in the river relative to the water table. The water table rises and falls in response to these river fluctuations and the response is attenuated with distance from the river. A numerical simulation of the interactions between the ground water and the Chena River at Fort Wainwright near Fairbanks was used to estimate the vertical and horizontal hydraulic conductivity, anisotropy, and riverbed conductance of the aquifer.

Continuous water-elevation data from 10 wells, screened at various depths, and one surface-water site were used for numerical-model data input, numerical-model grid design, and calibration analysis. After the initial development of the numerical model, a series of simulations was made to test potential error sources caused by vertical and horizontal discretization, and time discretization. The simulated data were then calibrated to measured data using an iterative method of independently varying riverbed conductance, vertical hydraulic conductivity, and horizontal hydraulic conductivity, while keeping all other parameters constant. The "best fit" between simulated and measured data was judged primarily on a qualitative basis from the graphical output of simulated and measured data. Using this method of qualitative analysis, the timing of the peaks and the amplitude between the highest and lowest values for each simulation were matched.

The best estimate of aquifer properties of the alluvium was based on the closest match of simulated to measured data and corrected for river geometry effects. The estimated values are 20 ft/d for vertical hydraulic conductivity, 400 ft/d for horizontal hydraulic conductivity, 1:20 for vertical anisotropy, and 350 ft^2/d for riverbed conductance. The estimated values of aquifer properties are based on assumed values of 0.25 for specific yield and 1×10^{-6} ft^{-1} for specific storage of alluvium. The resulting diffusivity is 1,600 ft/d for the alluvial aquifer. The values assumed for bedrock include 1×10^{-7} ft^{-1} for specific storage, 0.005 ft/d for vertical hydraulic conductivity, and 0.10 ft/d for horizontal hydraulic conductivity.

The estimated properties are sensitive to S_y. However, the ratios R_c/K_v, R_c/K_h, and K_h/S_y are constrained by the numerical analysis. The estimated geohydrologic properties are less sensitive to the other assumed parameters in the numerical model. The estimated and assumed values also agree with those commonly found reported for the described aquifer materials.

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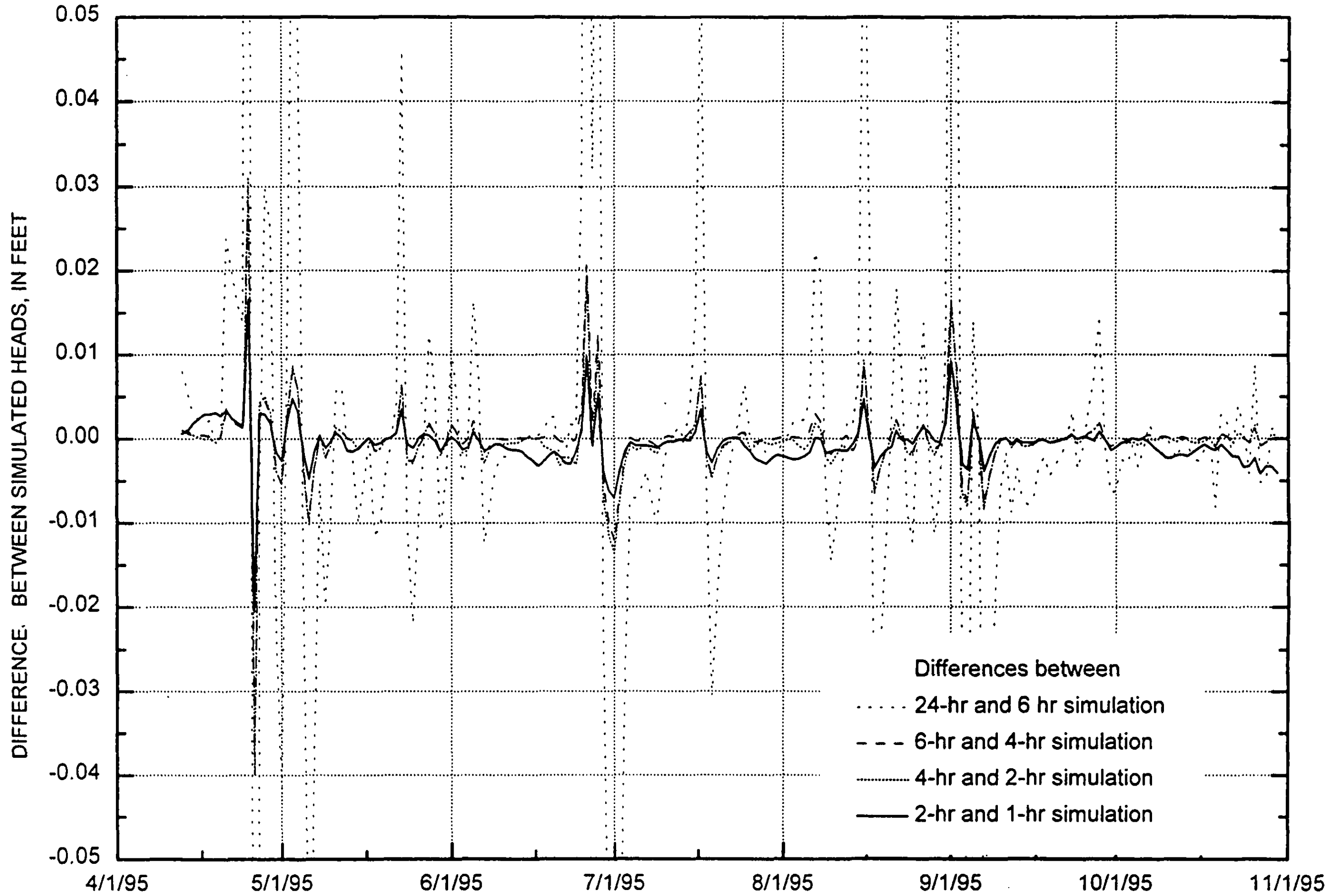
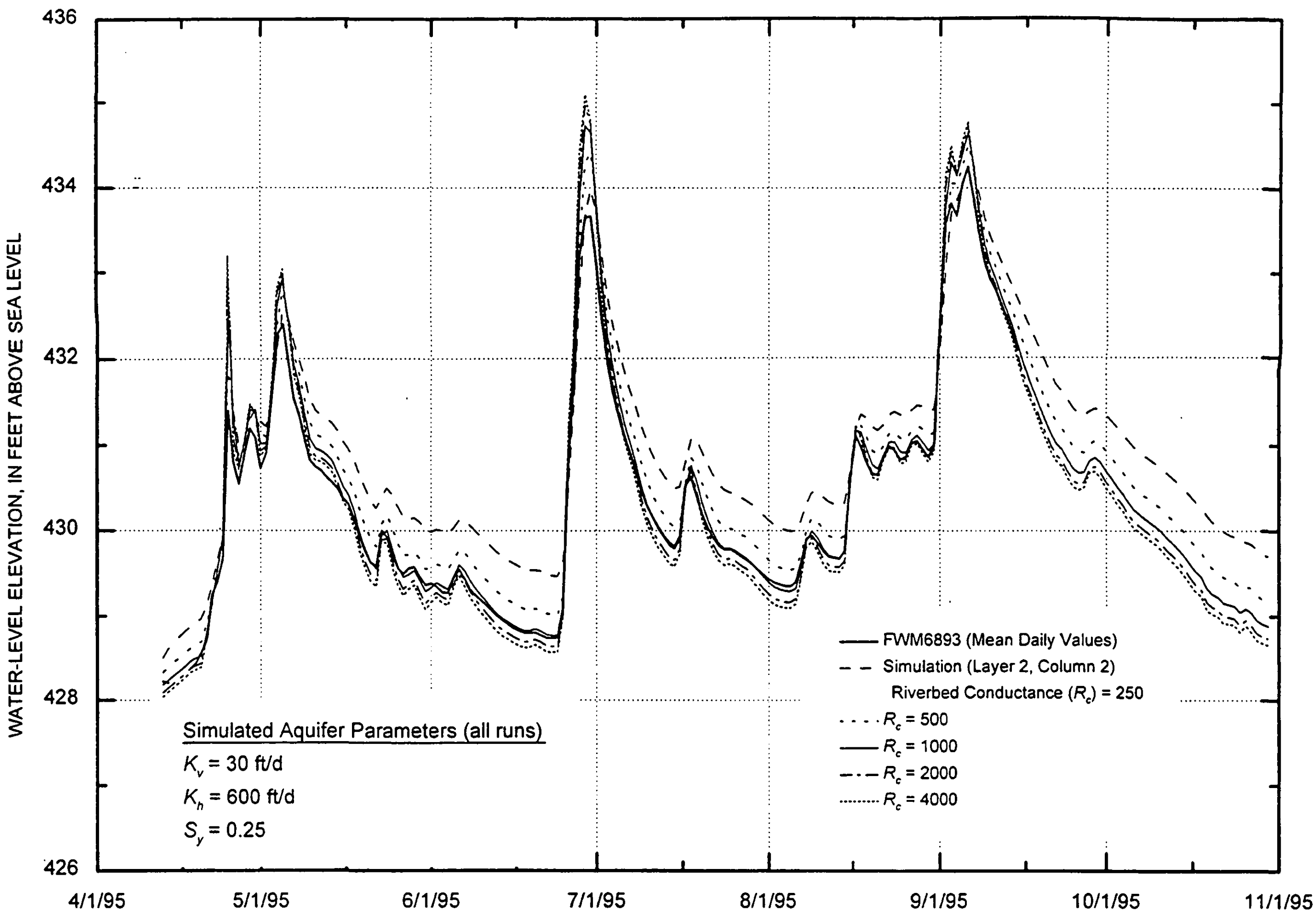
APPENDIX

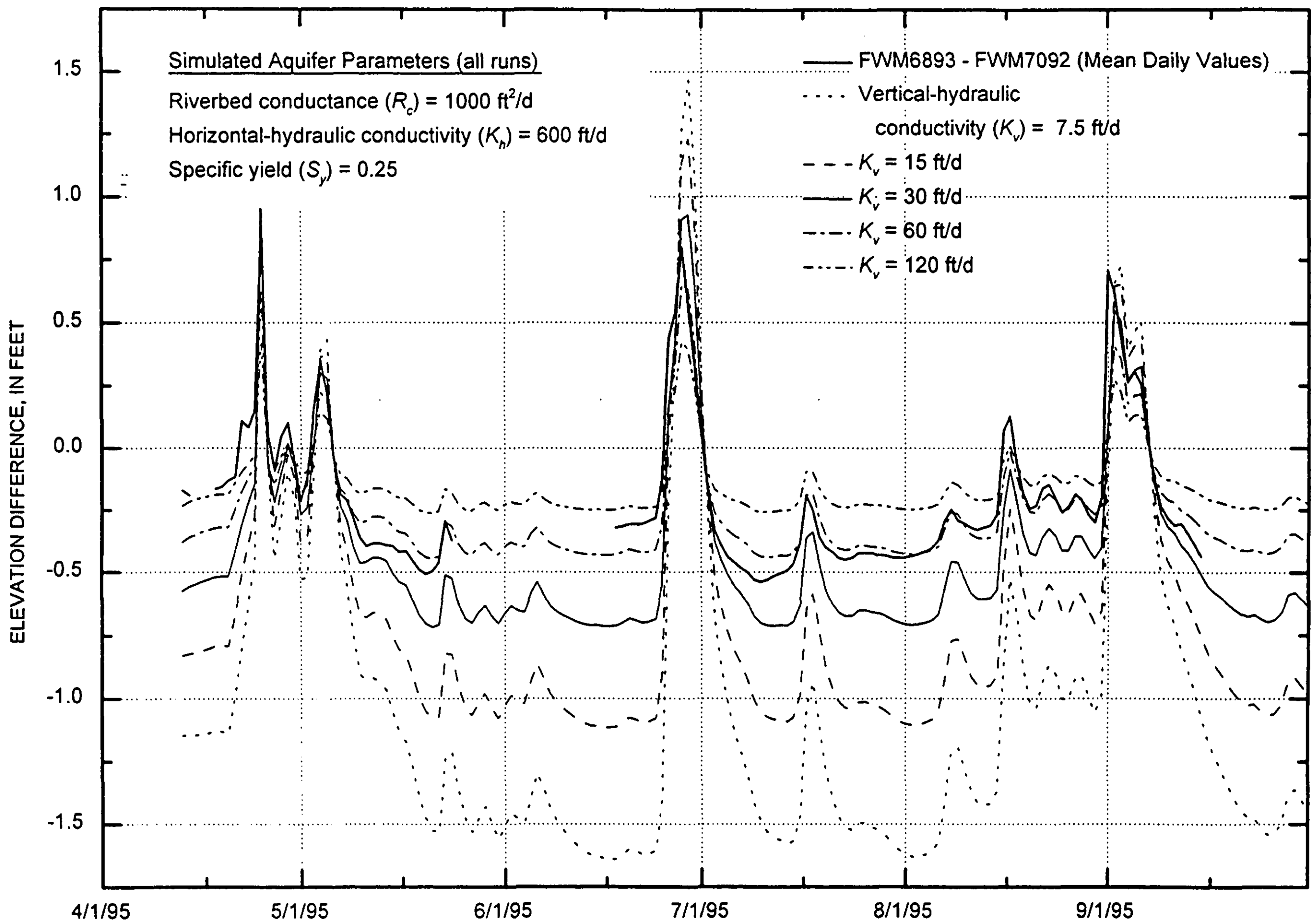
Analysis results of time discretization, riverbed conductance, vertical hydraulic conductivity, and horizontal hydraulic conductivity



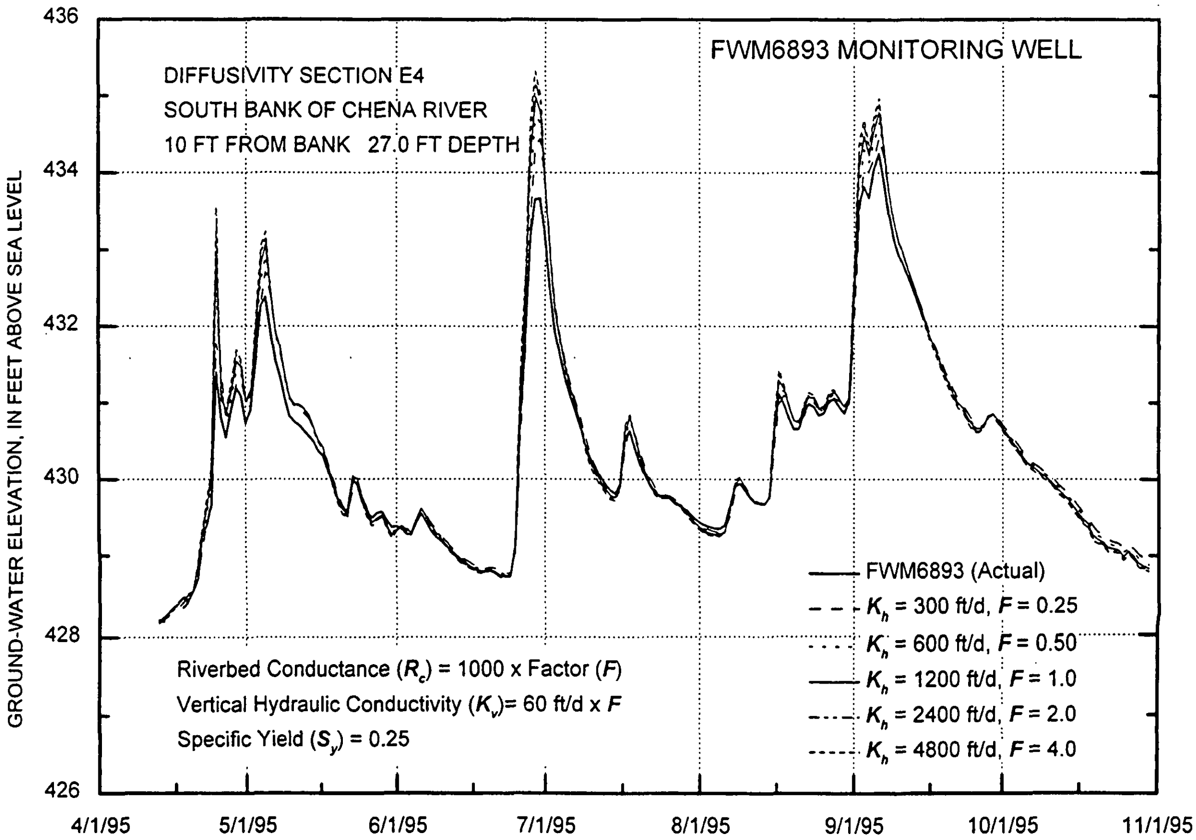
Appendix A. Time-discretization test analysis. Comparison of differences between simulations with varied time discretization in numerical-model grid layer 2, column 2.

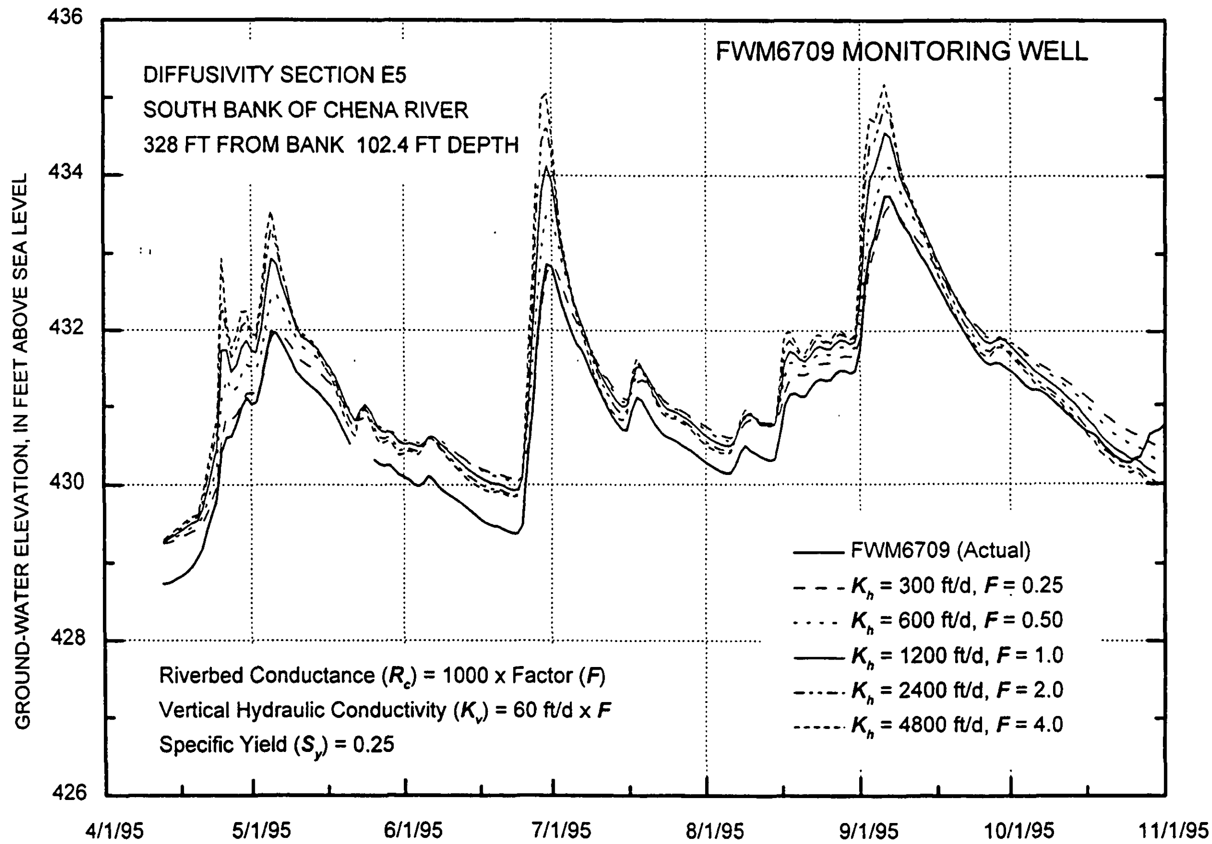


Appendix B. Riverbed-conductance analysis results. Comparison of measured data from monitoring well FWM6893 to numerical-model grid layer 2, column 2.

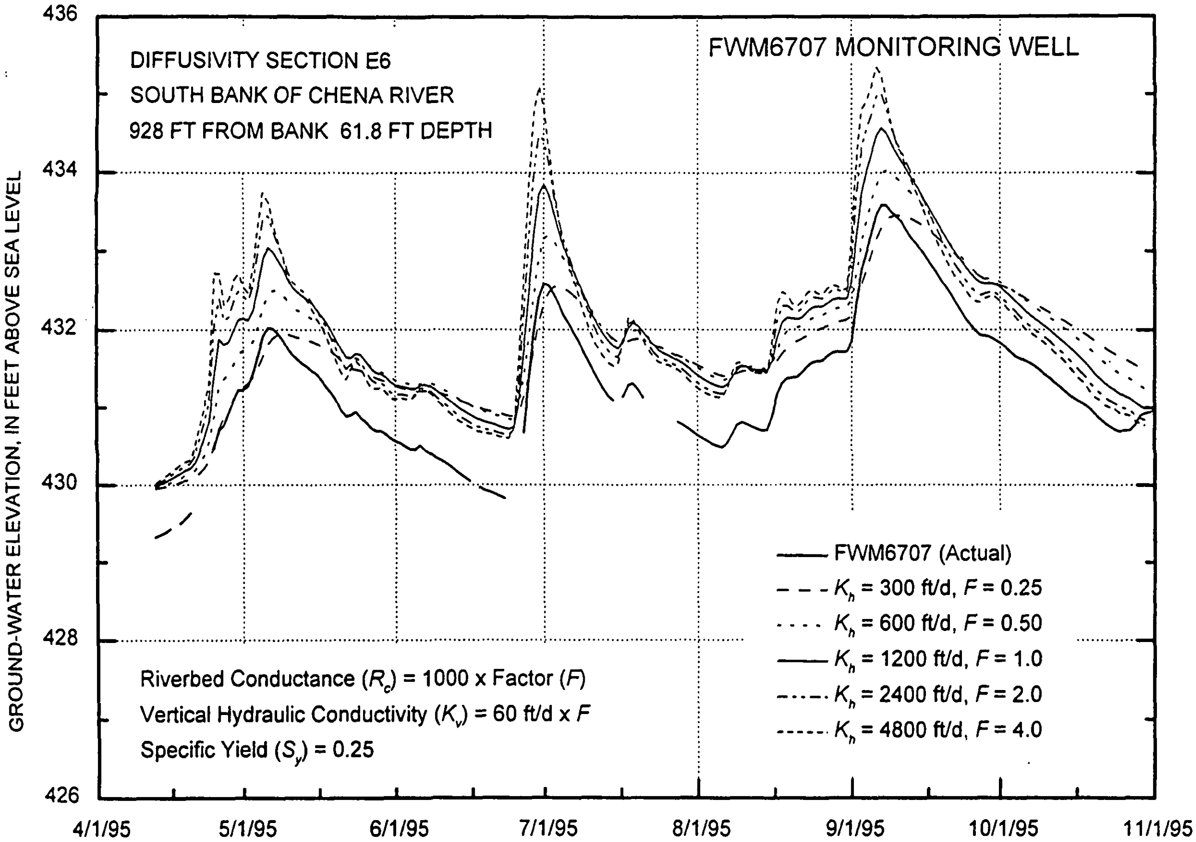


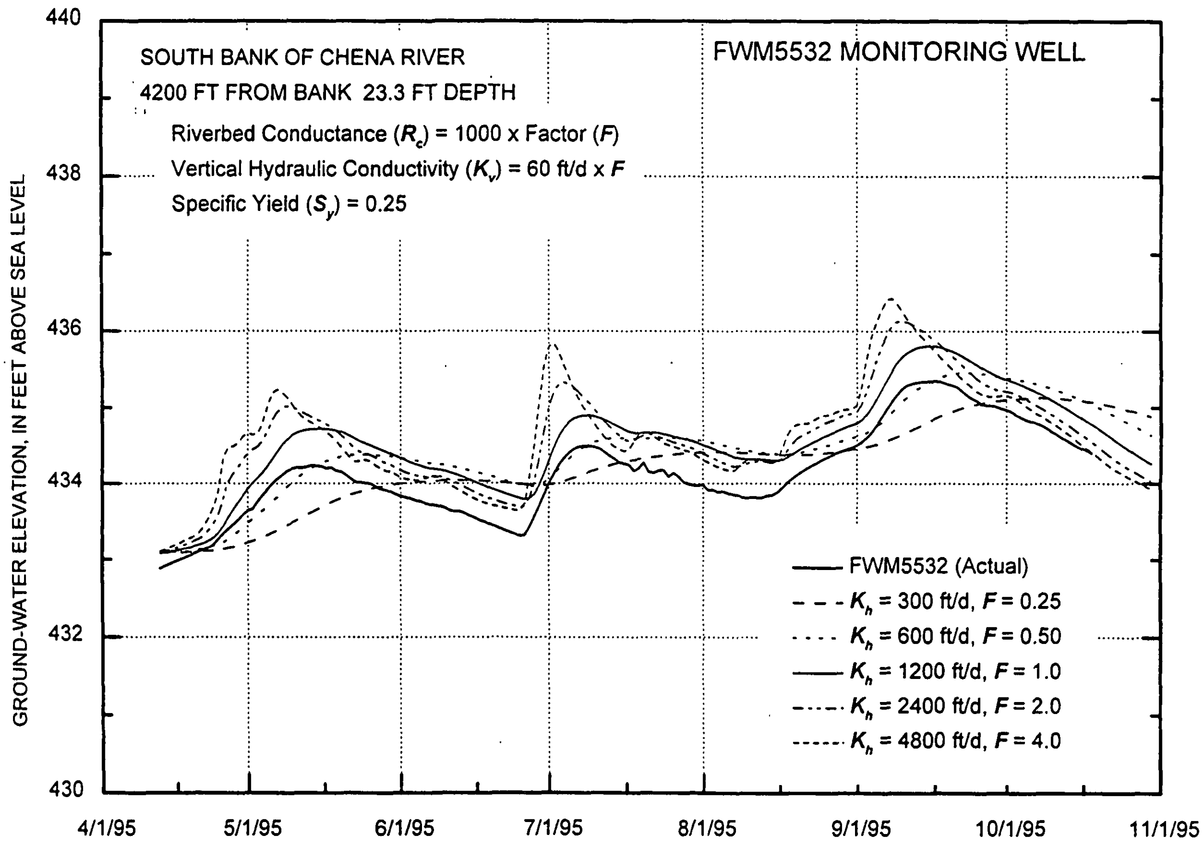
Appendix C. Vertical-hydraulic conductivity analysis results.





Appendix D. Horizontal-hydraulic conductivity analysis results for wells FWM6893, FWM6709, FWM6707, and FWM5532.





Appendix D. Continued.