STATE OF LOUISIANA
DEPARTMENT OF TRANSPORTATION AND DEVELOPMENT
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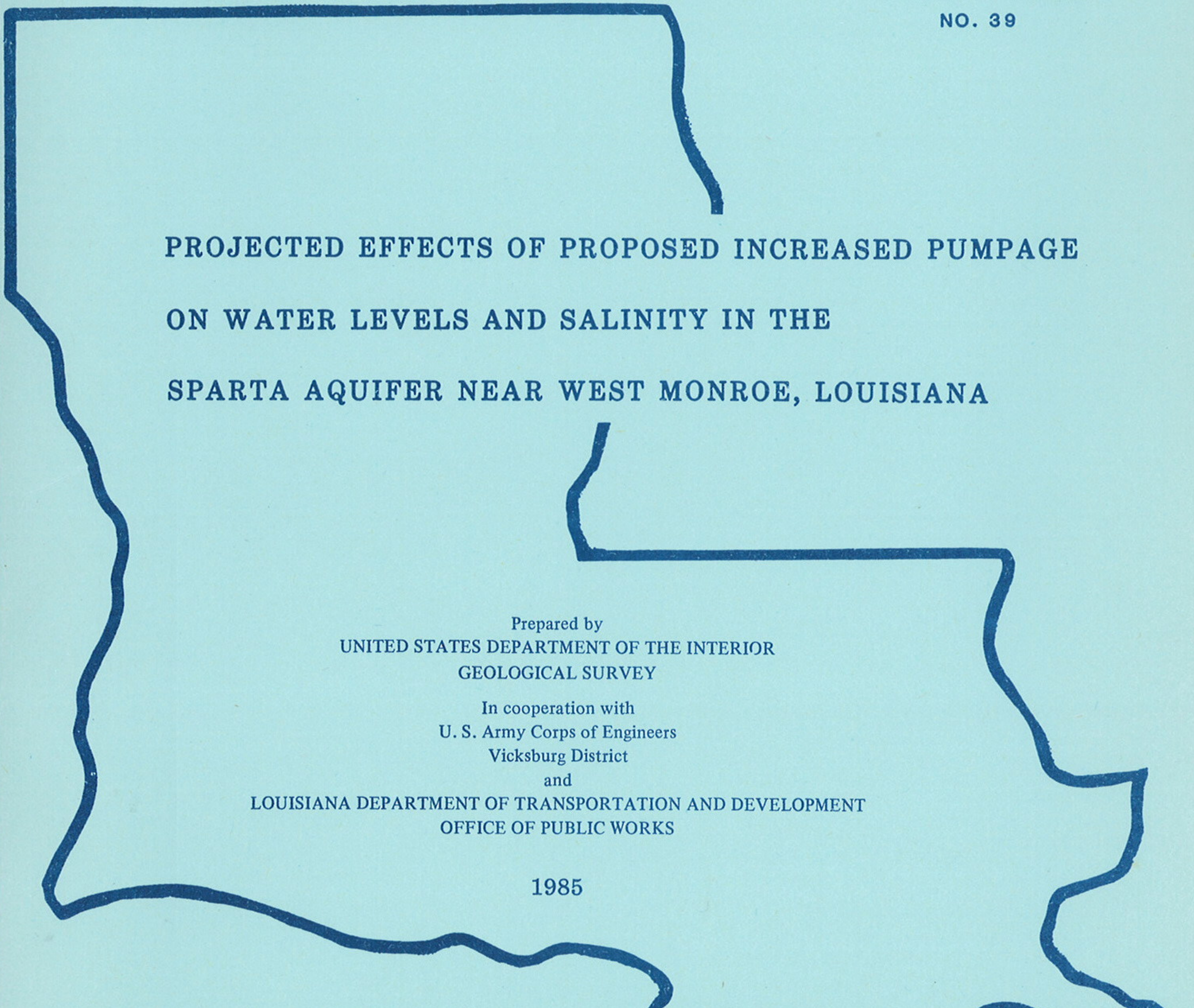
WATER RESOURCES
TECHNICAL REPORT
NO. 39



PROJECTED EFFECTS OF PROPOSED INCREASED PUMPAGE ON WATER LEVELS AND SALINITY IN THE SPARTA AQUIFER NEAR WEST MONROE, LOUISIANA

Prepared by
UNITED STATES DEPARTMENT OF THE INTERIOR
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FACTORS FOR CONVERTING INCH-POUND UNITS TO INTERNATIONAL SYSTEM (SI) OF UNITS

Multiply	By	To obtain
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)
foot (ft)	0.3048	meter (m)
foot per day (ft/d)	0.3048	meter per day (m/d)
foot per year (ft/year)	0.3048	meter per year (m/year)
square foot per day (ft^2/d)	0.9290	square meter per day (m^2/d)
mile (mi)	1.609	kilometer (km)
square mile (mi^2)	2.590	square kilometer (km^2)

FACTOR FOR CONVERTING CUBIC FEET PER SECOND TO MILLION GALLONS PER DAY

cubic foot per second (ft^3/s)	0.6463	million gallons per day (Mgal/d)

PROJECTED EFFECTS OF PROPOSED INCREASED PUMPAGE ON WATER LEVELS AND SALINITY IN THE SPARTA AQUIFER NEAR WEST MONROE, LOUISIANA

By Douglas A. Trudeau and Anthony Buono

ABSTRACT

A ground-water model of the Sparta aquifer was developed to evaluate the effects on water levels and salinity of proposed increased pumping to meet projected water-supply requirements for the Monroe-West Monroe area, La. Estimates of projected water-supply requirements were made by the U.S. Army Corps of Engineers. The area of study centered on West Monroe and encompassed the area of occurrence of the Sparta sand from its western outcrop area in Louisiana and southern Arkansas to its eastern outcrop in Mississippi, an area of approximately 66,000 square miles. A detailed three-dimensional model of the aquifer and overlying and underlying confining layers and aquifers was prepared and calibrated for the period 1900-1964, using parameter-estimation techniques and the observed change in water levels in wells in the Sparta aquifer. The model indicates that 45 percent of the total water pumped from the Sparta aquifer between 1900 and 1980 was derived from leakage through confining layers, 38 percent from recharge in the outcrop-subcrop area, and 17 percent was released from storage in the aquifer.

Eight alternate pumping plans proposed by the Corps of Engineers for the period 1980-2040 were evaluated using the developed model. These plans projected additional pumpage from the Sparta aquifer ranging from 10 to 226 cubic feet per second. Water-level declines simulated by the model indicate that water levels in wells in the Sparta aquifer will eventually drop below the top of the aquifer near West Monroe with all plans. The maximum projected water-level decline for the various plans ranges from 51 to 296 feet. Evaluation of the effects of the various pumping plans on the rate of movement of downdip saltwater towards West Monroe indicates that the rate would increase 34 to 74 percent from the 1980 projected rate of about 30 to 100 feet per year; however, this would not result in a significant change in water quality at West Monroe for at least 200 years. Pumping plan A, which calls for an increase in pumpage of 10.58 cubic feet per second through 2040, would minimize the areal extent of excessive drawdown. In addition, it would produce the slowest rate of water movement from the saltwater front towards West Monroe.

INTRODUCTION

Background and Location of the Study Area

The Sparta Sand is the most important aquifer in northern Louisiana and is also an important source of water in southern Arkansas and western Mississippi. Potentiometric levels of the Sparta aquifer have been declining significantly since 1920 in response to the development of major pumping centers in Arkansas and Louisiana. Major pumping centers currently are located near West Monroe, Jonesboro-Hodge, and Bastrop, La.; near Magnolia and El Dorado, Ark.; and near Jackson, Miss. Water-level declines caused by these pumping centers have formed overlapping cones of depression. The cone of depression at West Monroe in northeastern Louisiana is the center of interest for this study. To evaluate this cone, the area of study encompassed the area underlain by the Sparta Sand from its western outcrop in Louisiana and southern Arkansas to its eastern outcrop in Mississippi. This area is 210 mi wide by more than 315 mi long. (See fig. 1.)

Purpose

The U.S. Army Corps of Engineers, as part of a study of the Ouachita River basin, has projected the water use for the Monroe-West Monroe area in Ouachita Parish, La., for the period 1980-2040. The purpose of this study was to estimate the effects on water levels and salinity of the Sparta aquifer if the projected pumpage were obtained from the Sparta. Proposed well fields would be installed near West Monroe.

Approach

A ground-water model of the aquifer and related confining beds and underlying and overlying aquifers was developed to determine the impact of the proposed pumpage from the Sparta aquifer near West Monroe. Development of the model involved first determining whether the aquifer could be treated as a single hydrologic unit, as in earlier modeling studies, or as one of a series of hydraulically connected aquifers. To determine whether the Sparta aquifer is hydraulically connected to other aquifers, preliminary two- and three-dimensional models were prepared before developing the detailed model. Data to define the hydrogeologic properties of confining layers and aquifers for the detailed model were gathered from the literature. The model was prepared to simulate historical declines in water levels and was calibrated against records of the decline from 1900 through 1964. This calibration was confirmed by model simulations of water-level declines from 1964 through 1979. The model was then used to project the impact of the proposed increased pumpage near West Monroe on water levels, 1980-2040.

Increased pumpage from the Sparta aquifer will possibly increase the rate of movement of a saltwater front in the aquifer that is moving slowly towards West Monroe. To determine if the proposed increased pumpage will cause changes in the water quality at West Monroe, water levels projected by the model were used to estimate the change in rate of movement of the front.

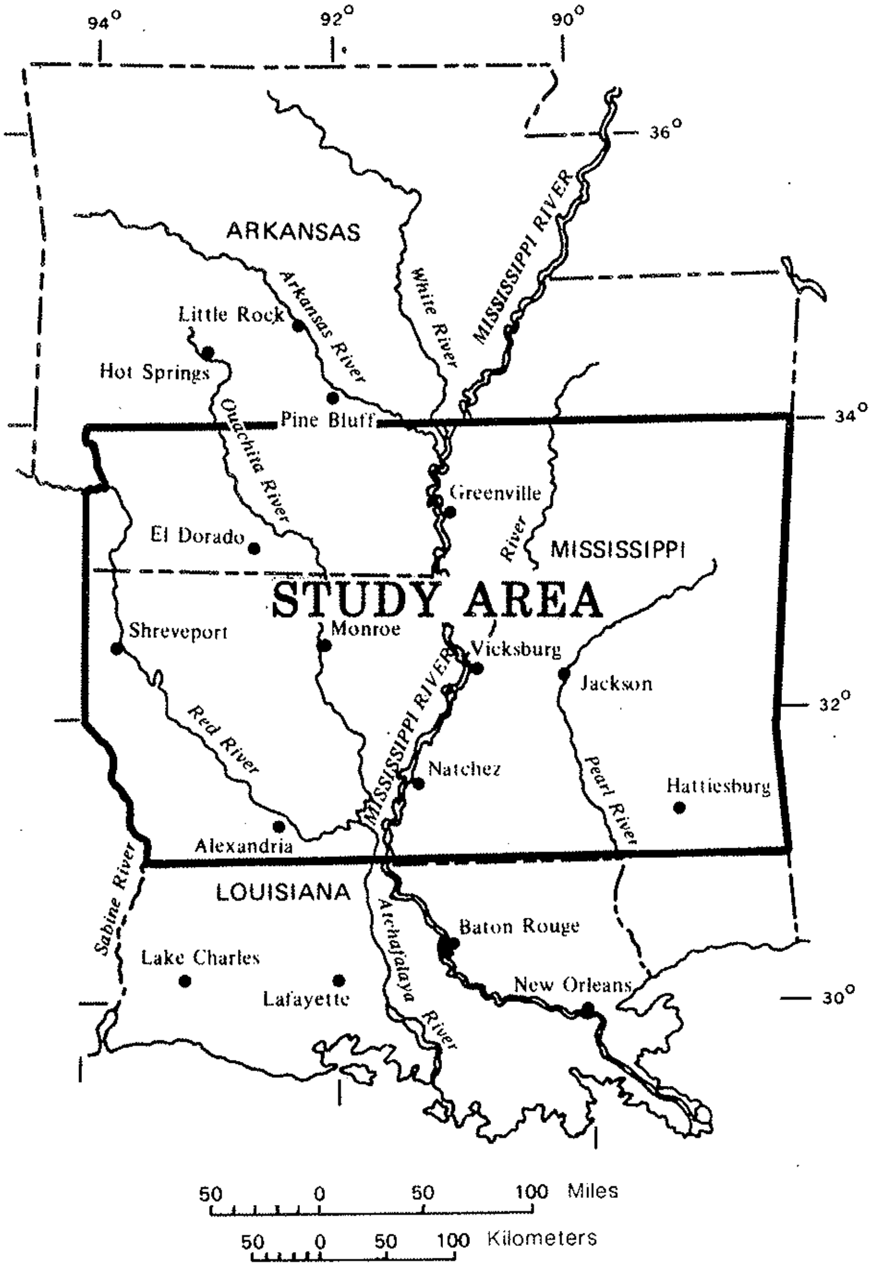


Figure 1.--Location of the study area.

Previous Investigations

Data from the reports of Payne (1968, 1970, 1972, and 1975), Hosman and others (1968), Ryals (1980a, 1980b, 1982, and 1984), and Rogers and others (1972) were used to help define the aquifer systems for modeling. Hydrologic data for the Cockfield Formation, Sparta Sand, Cane River Formation, and Carrizo Sand in the study area were obtained from the reports of Payne (1968, 1970, 1972, and 1975). Additional data for the

Tertiary aquifers in the Mississippi embayment were obtained from a report by Hosman and others (1968). Data from reports by Ryals (1983a, 1983b, and 1984) were used to describe the thickness of the Cook Mountain Formation and Carrizo-Wilcox aquifer and the hydraulic characteristics of the Carrizo-Wilcox aquifer. Data on the ground-water resources in the Monroe-West Monroe area were obtained from a report on Ouachita Parish by Rogers and others (1972).

Previous efforts to model the Sparta aquifer include an analog model of the Sparta in the Mississippi embayment by Reed (1972) and digital modeling of the Sparta in the Ruston area by Sanford (1973). Information from these models was used in preliminary modeling and in development of the detailed three-dimensional model.

Well-Numbering System

In Louisiana, the U.S. Geological Survey assigns water wells a number in approximate order of inventory; a two letter prefix represents the parish in which the well is located. For example, Ou-1 is the first well inventoried in Ouachita Parish. Where more than one test well has been developed consecutively in the same test hole, the different wells are indicated by a letter suffix. For example, wells Ou-71A and Ou-71B are test wells installed in test hole Ou-71.

GEOHYDROLOGY

General Geohydrologic Framework

Geologic units at West Monroe and in the study area were classified as aquifers or confining layers for preparing a ground-water model. The discussion of the general geohydrologic framework in the study area and around West Monroe as it relates to modeling the Sparta aquifer follows.

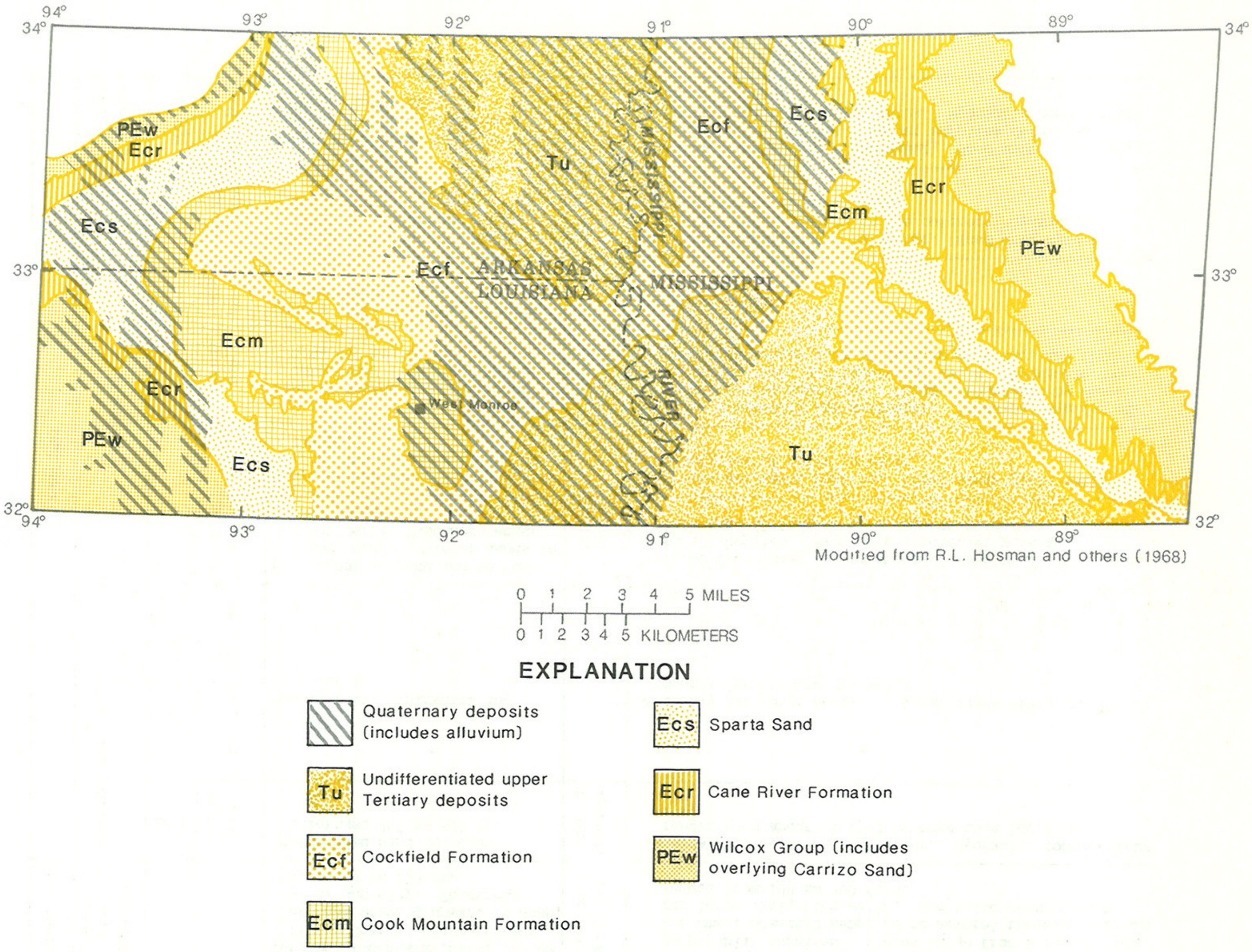
The West Monroe area is on the western limb, of the Mississippi embayment, "...a geosyncline plunging gently to the south, the axis of which roughly follows the present course of the Mississippi River." (Cushing and others, 1970, p. A1). The stratigraphic units of interest as aquifers or confining layers (table 1) are from oldest to youngest: the Wilcox group, the Carrizo Sand, the Cane River Formation, the Sparta Sand, the Cook Mountain Formation, the Cockfield Formation and undifferentiated upper Tertiary deposits. The general outcrop and sub-surface configuration of the units are shown in figures 2 and 3, respectively. They show the general nature of the Mississippi embayment in the study area with units cropping out on both sides of the axis of the embayment and thickening toward the center of the embayment.

The following paragraphs give a general description of the aquifers and confining layers. For a more detailed description of the aquifers and confining layers in the study area, refer to the reports mentioned in the Previous Investigations section of this report.

Table 1.--Generalized description of aquifers in northern Louisiana

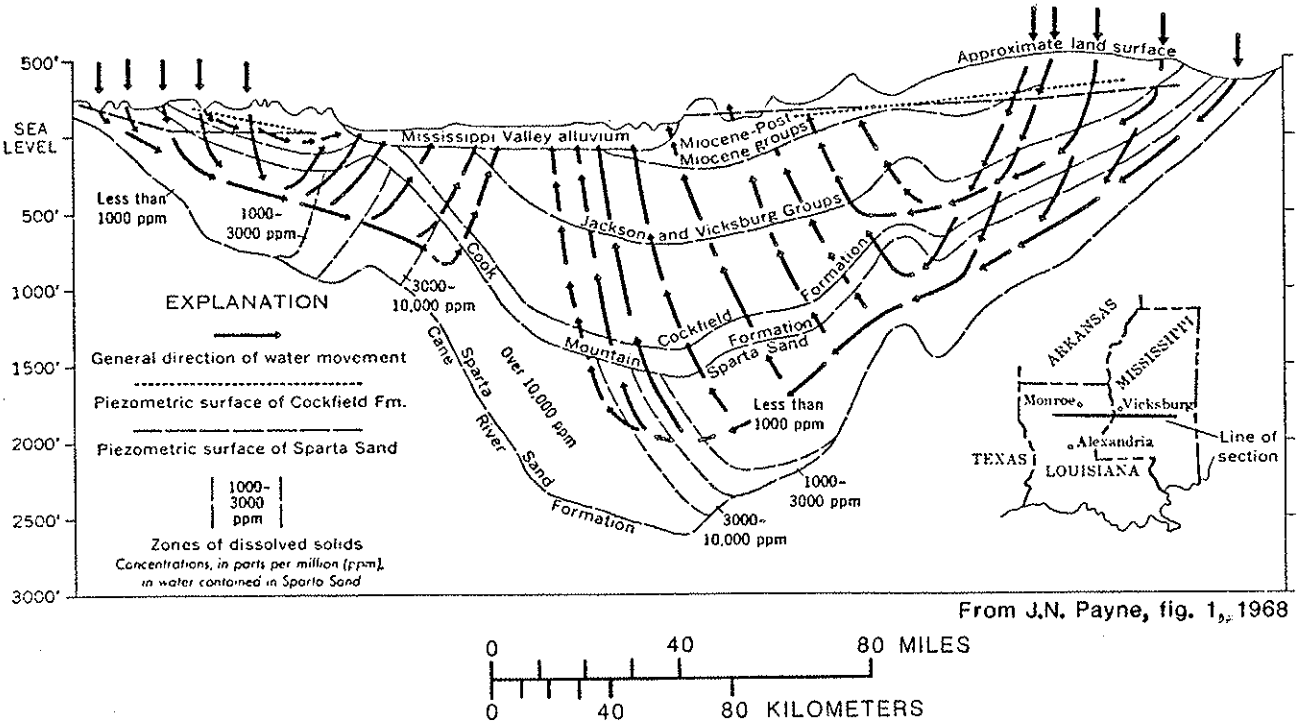
[Feet, ft; feet per day, ft/d; gallons per minute, gal/min]

Era	System	Series	Group	Formation	Description	Aquifer	Hydrologic characteristics
Cenzoic	Quaternary	Holocene and Pleistocene			Terrace remnants alluvial valley fill. Coarse, graveliferous at base grading upward to sand, silt, and clay. Thickness about 50 to 150 ft.	Quaternary aquifers	Contains freshwater. Used locally for rural supplies and some public supplies. Yields range from a few gal/min for small domestic supplies to several thousand gal/min for large irrigation wells. Hydraulic conductivity ranges from 100 to 300 ft/d.
	Tertiary	Miocene	Undivided	Undivided	Interbedded sand and clay. Thickness 400 to 800 ft.	Miocene aquifers	Contains freshwater and saltwater. Hydraulic conductivity ranges from about 25 ft/d to more than 100 ft/d.
		Oligocene	Vicksburg	Undivided	Mostly clay. Thickness 400 to 700 ft.		Generally not water bearing. Local sands yield small quantities of water to wells.
		Eocene	Jackson	Undivided			
			Claiborne	Cockfield Formation	Fine lignitic sand and carbonaceous clay. Thicker sands in lower part. Thickness about 500 to 600 ft.	Cockfield aquifer	Contains freshwater and saltwater. Used mostly for small rural supplies. Hydraulic conductivity ranges from less than 15 ft/d to more than 40 ft/d.
				Cook Mountain Fm.	Clay, partly sandy and glauconitic. Thickness about 100 to 200 ft.		Generally not water bearing. Local sands yield small quantities of water to wells.
				Sparta Sand	Fine to medium sand with clay interbeds; lignitic. Thickness 500 to 700 ft.	Sparta aquifer	Contains freshwater and saltwater. Principal aquifer of north-central Louisiana. Large withdrawals by domestic, municipal, and industrial wells. Hydraulic conductivity ranges from 30 ft/d to more than 100 ft/d.
				Cane River Fm.	Mostly clay; some marl. Thickness 200 to 300 ft.		Not water bearing.
				Carrizo Sand	Fine to medium sand; discontinuous. Thickness 0 to 150 ft.	Carrizo-Wilcox aquifer	Contains freshwater and saltwater. Used only by a few shallow wells, mostly in the outcrop. Hydraulic conductivity about 25 ft/d.
		Paleocene	Wilcox	Undivided	Interbedded sand, clay, and silt; lignitic. Thickness 500 to 1,500 ft.		Contains freshwater and saltwater. Used mostly by small-yielding rural wells. Larger supplies developed locally where sands are thick. Hydraulic conductivity about 15 ft/d.



Modified from R.L. Hosman and others (1968)

Figure 2.--Generalized geologic map showing the geologic units of interest in the study area.



From J.N. Payne, fig. 1, 1968

Figure 3.--Geohydrologic section from western outcrop to eastern outcrop of the Sparta Sand.

The Wilcox Group and the Carrizo Sand are treated as a single hydrologic unit, the Carrizo-Wilcox aquifer, because the Wilcox has been shown by Ryals (1982) to be hydraulically connected to the overlying Carrizo. The Carrizo-Wilcox consists of fine to medium sand and interbedded clay and silt ranging from 400 to 1,500 ft thick.

The Cane River Formation is the confining layer that overlies the Carrizo-Wilcox aquifer and separates the Carrizo-Wilcox from the Sparta Sand. The formation consists mainly of clay and silty clay and ranges in thickness from 200 to more than 300 ft.

The Sparta aquifer, the principal aquifer in the study, consists of interbedded sand, silt, and clay ranging from 500 to 700 ft in thickness. Regionally, the sands are hydraulically connected from top to bottom and respond as one unit. In Ouachita Parish, the area of specific interest, the base of the unit ranges from 650 to 850 ft below sea level and ranges from 600 to 700 ft in thickness. The top of the Sparta is less than 100 ft below sea level in the western part of the parish and about 200 ft below sea level in the eastern part of the parish.

Overlying the Sparta aquifer is the Cook Mountain Formation, a confining bed. Although the unit is predominantly clay, thin sands make it a local source of freshwater. The Cook Mountain crops out in the northwestern part of the parish and ranges from less than 100 to more than 200 ft in thickness.

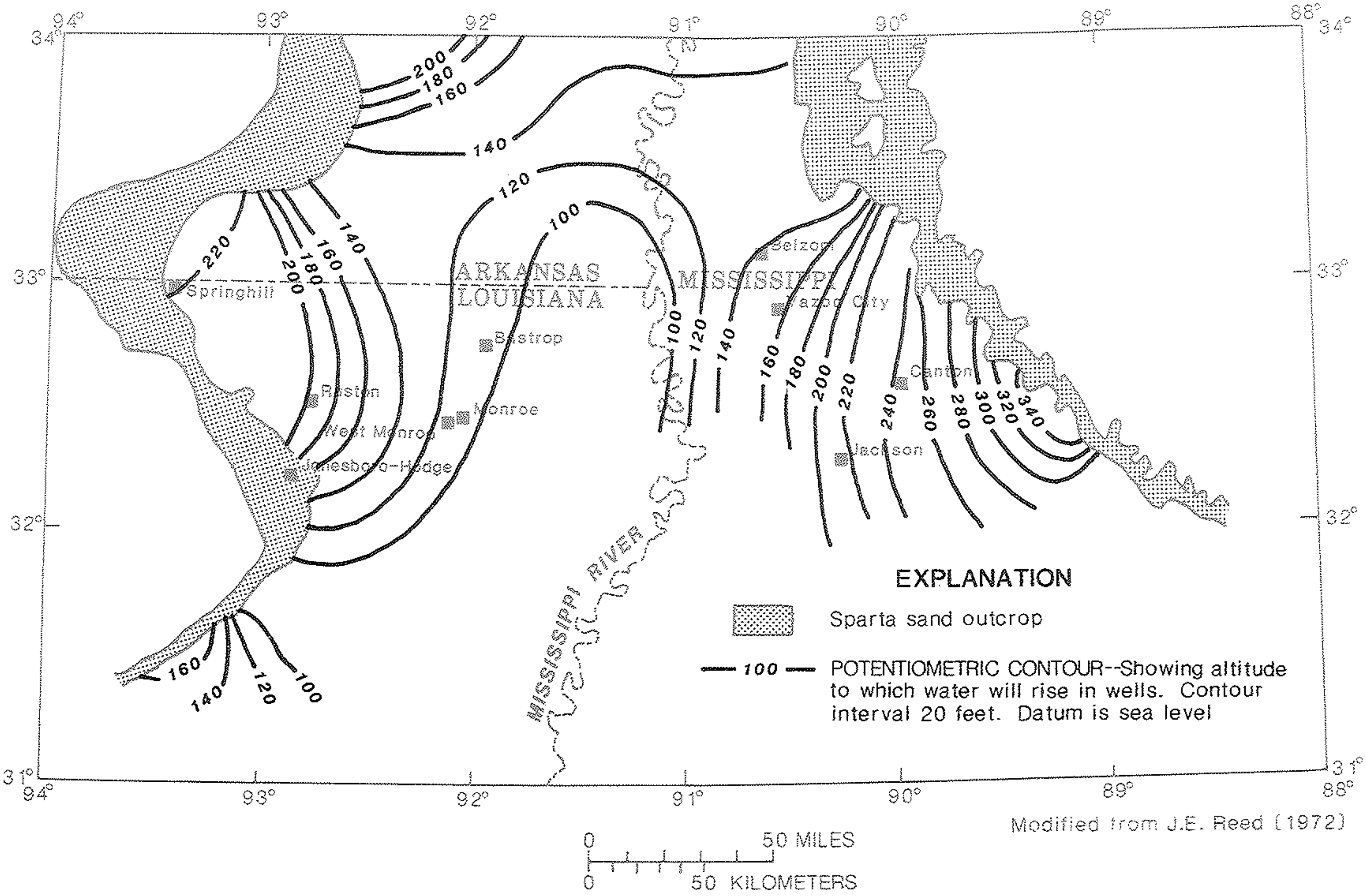
The Cockfield Formation, the uppermost geologic unit considered an aquifer in this system of aquifers, consists of interbedded sand and clay. The aquifer is missing in the Ouachita River valley (fig. 2) because of erosion by the ancestral Ouachita River and has been replaced by alluvial sands and gravel. In the Mississippi River valley, the Cockfield is overlain by Mississippi River alluvium. The Cockfield and the alluvium are hydraulically connected and act as a single hydrologic unit (fig. 3).

Overlying the Cockfield Formation in parts of the embayment (fig. 2) are undifferentiated deposits (predominantly clay) of Tertiary age that range from 400 to 700 ft in thickness and act as a confining zone.

The relations of recharge, discharge, and regional flow in the unstressed, natural-flow system to the geology are shown in figure 3. Figure 3 does not show the Cane River Formation or Carrizo-Wilcox aquifer. The relations of recharge, discharge, and regional flow for these units are believed to be similar to those shown in figure 3 for the other units. The Sparta Sand and the other aquifers in this study are recharged in their outcrop areas directly by infiltration of rainfall and indirectly in the subcrop area by downward percolation through surficial materials. A large part of the water that infiltrates to the aquifers is returned as base flow to the streams in the outcrop area. Only a small part of the water that infiltrates enters the deep percolation system of the aquifers. Water that enters the Cockfield, Sparta, and Carrizo-Wilcox aquifers as recharge is confined a short distance downdip by clay beds within the respective formations or by overlying clay. Discharges of this water are primarily to the Mississippi River alluvial valley by upward leakage through overlying aquifers and confining beds (fig. 3). Development of the aquifers for water supplies has materially altered the natural-flow system shown in figure 3.

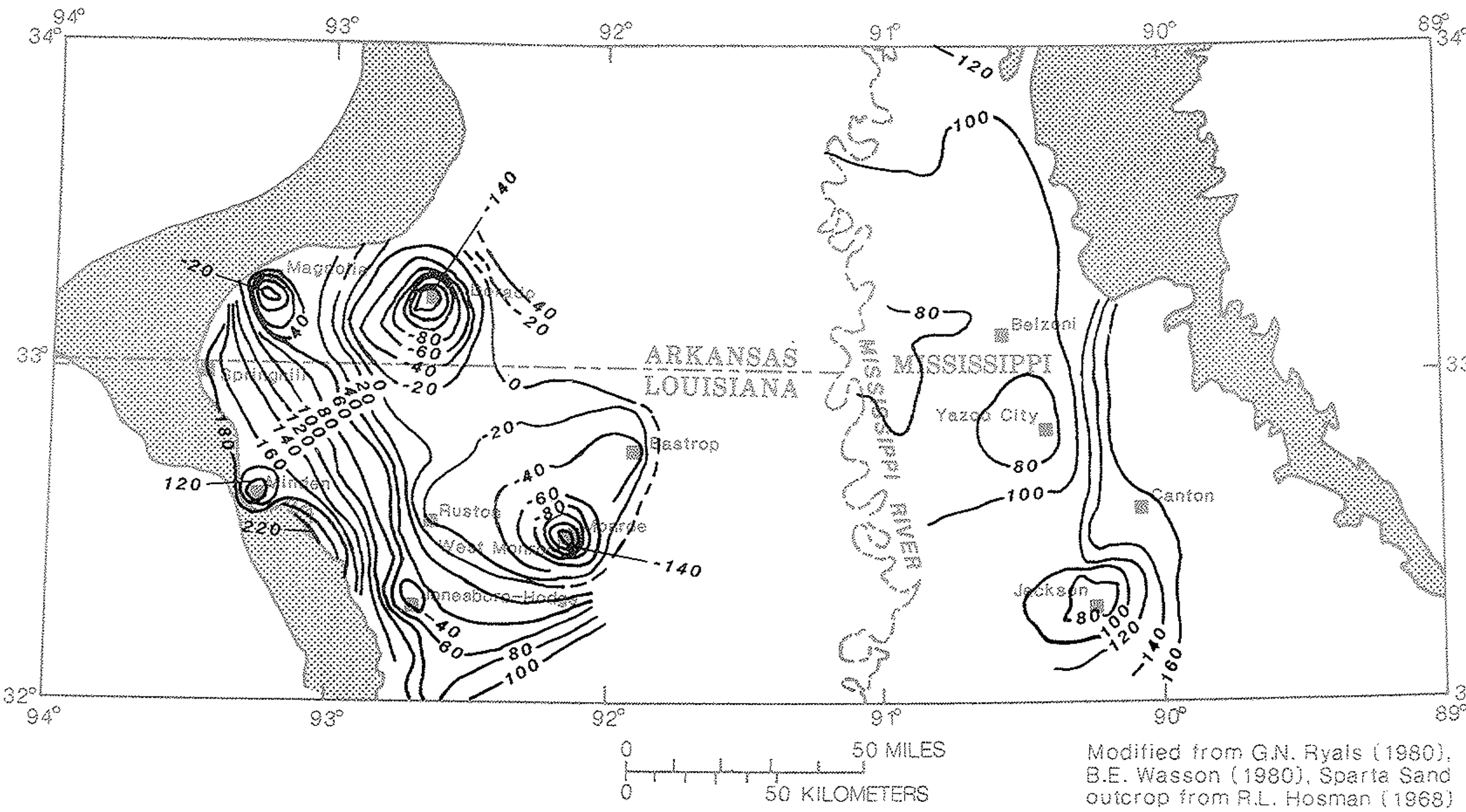
Pumpage and Decline in Potentiometric Level

A comparison of potentiometric maps of the Sparta aquifer for 1886 (fig. 4), prior to extensive develpoment of the aquifer, and for 1980 (fig. 5) shows that several major pumping depressions have formed in the potentiometric surface of the aquifer. These depressions have developed in response to major pumping centers that are located near Bastrop, Jonesboro-Hodge, and West Monroe, La.; El Dorado and Magnolia, Ark.; and Jackson, Miss. In addition, another major pumping depression has developed in the vicinity of Pine Bluff, Ark., located just north of the study area.



Modified from J.E. Reed (1972)

Figure 4.--Potentiometric surface of the Sparta Sand, 1886.



Modified from G.N. Ryals (1980), B.E. Wasson (1980), Sparta Sand outcrop from R.L. Hosman (1968)

EXPLANATION

▨ Sparta Sand outcrop

—100— — POTENTIOMETRIC CONTOUR--Showing altitude to which water will rise in wells. Contour interval 20 feet. Dashed where approximate. Datum is sea level

Figure 5.--Potentiometric surface of the Sparta Sand, 1980.

Records of water use from the Sparta aquifer prior to 1960 are intermittent to nonexistant. Sanford (1973) reported an average pumping rate from the major pumping centers in Arkansas and Louisiana for the period 1925-65. Sanford concluded that, although development of the aquifer began around 1900, significant water-level declines began to occur only after 1920. Since 1960, the U.S. Geological Survey has been gathering data on water use, and more complete records are available. Table 2 shows the pumpage rates at major centers of water use in Arkansas, Louisiana, and Mississippi. Pumpage from the Sparta aquifer at the major pumping centers during 1975 was 201 ft^3/s; total pumpage was 239 ft^3/s.

Few data are available on the impact of pumpage on potentiometric levels of the Cockfield and Carrizo-Wilcox aquifers in the study area. Data are available only for areas where the aquifers contain freshwater, which are near the outcrop areas of these formations and represent only a small part of the modeled area.

As shown in figure 2, the Cockfield underlies shallow Quaternary deposits in much of the study area. Water use in the study area from the Cockfield during 1975 totaled about 45 ft^3/s. No significant pumping depressions occur in the Cockfield in Arkansas and Louisiana because there are no major pumping centers. In Mississippi, however, several significant pumping depressions occur associated with the large pumping centers (Wasson, 1981b).

Table 2.--Pumpage at major pumping centers from the Sparta aquifer, 1925-80

[Data for Arkansas, 1965-80, from unpublished data furnished by Arkansas District, U.S. Geological Survey. Data for Louisiana, 1965-80, from unpublished data on file in Louisiana District, U.S. Geological Survey. In cubic feet per second]

	1925-65	1965	1970	1975	1980
Pine Bluff, Ark-------------	[a]20.39	63.85	90.08	71.01	-----
Magnolia, Ark---------------	[b]4.64	1.89	5.75	4.93	-----
El Dorado, Ark--------------	[b]24.75	27.00	24.05	18.43	-----
Bastrop, La-----------------	[b]15.47	18.24	17.43	18.46	16.49
Hodge, La-------------------	[b]15.47	20.50	20.50	21.74	20.87
Monroe, La------------------	[b]20.11	22.97	15.80	20.57	22.95
Ruston, La------------------	[b]2.48	5.11	4.81	6.28	7.37
Springhill, La--------------	[b]10.51	16.70	9.90	7.78	.90
Yazoo City area, Miss-------	--------	--------	-----	[c]14.07	-----
Belzoni, Miss---------------	--------	--------	-----	[c]1.67	-----
Jackson area, Miss----------	[d]6.68	[e]15.56	-----	[c]12.99	-----
Canton, Miss----------------	--------	[e]1.16	-----	[c]3.09	-----

[a] From Bedinger and others (1960).
[b] From Sanford (1973).
[c] From Newcome (1976).
[d] From Harvey and others (1964).
[e] From Shattles and others (1967).

Water use from the Carrizo-Wilcox aquifer in Arkansas and Louisiana and its equivalents in Mississippi, during 1975, totaled about 65 ft^3/s. The aquifer has not been extensively developed in Arkansas and Louisiana; therefore, no significant pumping depressions occur. In Mississippi, there are several cones of depression associated with major pumping centers (Wasson, 1980).

Evidence to show hydraulic connection between the Carrizo-Wilcox, the Sparta, and the Cockfield aquifers in areas where the Sparta is heavily pumped is sparse. Water levels in sands in the Cook Mountain Formation, overlying the Sparta, have declined from 5 ft to as much as 40 ft near Ruston and near Monroe, La. (Sanford, 1973; Rogers and others, 1972) in response to heavy pumping from the Sparta. This suggests hydraulic connection between the Cook Mountain confining clay and the Sparta, but no downward trend in water levels in wells in the Cockfield aquifer has been observed. Information on gradients from the Carrizo-Wilcox aquifer and Cane River confining clay to the Sparta near large pumping centers could not be obtained.

The approach used to determine the effects of proposed increased pumpage near West Monroe on water levels was to use a model that simulated historic declines in water level in wells in the Sparta aquifer.

Water Quality

The dissolved-solids concentration of ground water as an indication of salinity is the only water-quality parameter used in this study. The existing patterns of water salinity must be considered in evaluating effects of the proposed increased pumpage from the Sparta aquifer on water quality at West Monroe. As the Sparta may be hydraulically connected to aquifers above and below it, the potential effects of influx of water from these aquifers must also be considered.

Plate 1 (after Payne, 1968, 1970, and 1975) shows the downdip limit of freshwater in the Cockfield Formation, Sparta Sand, Carrizo Sand, and equivalents. For mapping purposes, Payne defined freshwater as water having a dissolved-solids concentration of 1,000 mg/L or less. Plate 1 indicates that near West Monroe, the Cockfield and the Sparta contain freshwater, but the water becomes saline to the southeast, and the Carrizo-Wilcox contains saline water. Because water in the Cockfield is fresh near West Monroe, inflow of water from that aquifer poses no water-quality problem to the Sparta aquifer at West Monroe. Potentiometric contours in figure 5 indicate that ground-water movement in the Sparta is from the saline front, which lies to the south towards West Monroe. The proposed pumpage increases near West Monroe would affect the movement of the saline water towards West Monroe by lowering potentiometric levels and increasing the northward gradient. The underlying Carrizo-Wilcox aquifer contains saline water at West Monroe and by leaking upward, also may pose a threat to the water quality of the Sparta. However, because of the lack of data on water levels in the Carrizo-Wilcox aquifer, no reasonable estimate of water-movement rates can be made.

DEVELOPMENT OF A THREE-DIMENSIONAL MODEL

To determine the impact on water levels of the Sparta aquifer that might be caused by proposed increases in pumpage near West Monroe, a digital model of the Sparta aquifer was prepared. The approach used in modeling the aquifer system was to develop a model that could simulate changes in water level (drawdown) from 1900 through 1964. It was assumed that in 1900 water levels were stable because there was little or no pumping. The model of the aquifer system was used to generate the stable (steady-state) water-level map of 1900. The steady-state water-level map then was used in combination with the computed change in water levels to prepare computed water-level maps. The model was further tested on how well it could simulate change in water levels between 1965 and 1979. Once the model passed this final testing, it was used to analyze the effects on water levels of projected increased pumpage from the Sparta aquifer.

Finite-difference models developed by Trescott and others (1976) and by McDonald and Harbaugh (1984) were used during this study. The Trescott model was used to simulate ground-water flow in two directions and to simulate vertical leakage from a river. The McDonald-Harbaugh model was used to simulate ground-water flow in three directions. The basic equations governing ground-water flow that these models solve by the finite-difference method are documented in the above-mentioned references. The strongly-implicit procedure was used to solve the equations of ground-water flow. (See above references.)

Preliminary two- and three-dimensional models of the Sparta aquifer system were prepared to determine whether the Sparta was the only aquifer to be included in the model. Both the Trescott and others (1976) and McDonald and Harbaugh (1984) models were used for these early studies. On the basis of concepts developed from the preliminary two- and three-dimensional models, a detailed three-dimensional model was made of the aquifer system using the McDonald model. The modeled system is composed of (from top to bottom) the Cockfield aquifer, the Cook Mountain confining layer, the Sparta aquifer, the Cane River confining layer, and the Carrizo-Wilcox aquifer. Preliminary modeling of the aquifer system indicated that the undifferentiated upper Tertiary deposits did not need to be included in the model to simulate changes in the water level of the Sparta aquifer. The geohydrologic units of which the aquifer system is comprised and the way they were treated in the model are graphically illustrated in figure 6. Basically, each aquifer was modeled from outcrop area to outcrop area and treated as a confined aquifer. Each confining layer was treated as a zone through which vertical flow occurs.

It was decided to model each aquifer as a confined aquifer because this closely approximated the natural system and also minimized the model input requirements; the latter was important because of the short time allotted to this investigation. The assumption that the aquifers behave as confined aquifers is valid as long as dewatering (water levels declining below the bottom of the overlying confining layer) does not occur. Dewatering of the Sparta was not anticipated to be a major problem, considering the initial values of pumpage projected by the U.S. Army Corps of Engineers.

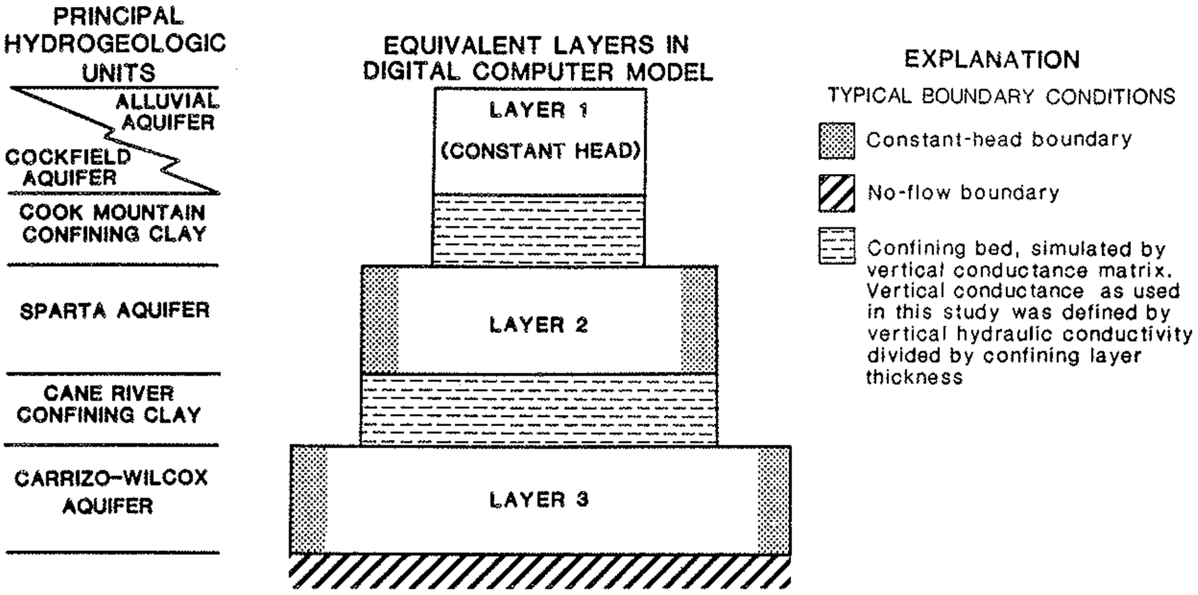


Figure 6.--Principal hydrogeologic units and equivalent layers in digital-computer model.

Model Construction

Finite-Difference Grid and Hydrogeologic Parameters

The principal area of interest was the area around West Monroe, where the proposed increased pumpage is to occur. The size of grid blocks around West Monroe, in Ouachita Parish, was chosen so that pumping centers and observation wells would be near grid nodes and to facilitate the analysis of the proposed pumping. Grid blocks in Ouachita Parish were 2 mi by 2 mi. The finite-difference grid used in the detailed model was oriented in a north-south, east-west direction to incorporate the major north to northeast axis of transmissivity reported by Payne (1968, p. A8) for the western limb of the Mississippi embayment. Although Ouachita Parish is the principal area of interest, the Sparta aquifer is strongly affected by pumpage in other areas. Accordingly, the grid was gradually expanded to cover the study area. The model grid, which consists of 26 rows and 35 columns, represents an area about 210 mi wide and about 315 mi long as shown on plate 2. The way in which the Sparta aquifer was modeled--the model grid, the location and the type of model boundaries used, and the location of pumping centers, are also shown on plate 2.

The hydrogeologic parameters required as input to the detailed three-dimensional model in order to define each modeled layer (fig. 6) consisted of the following: transmissivity, storage coefficient, and vertical conductance of confining beds between layers. Note that the vertical conductance is defined as the vertical hydraulic conductivity divided by the thickness of the confining bed. Data on aquifer and confining-layer properties for the detailed three-dimensional model were obtained from previous investigations of the Tertiary aquifers in the Mississippi embayment (Hosman and others, 1968; Payne, 1968, 1970, 1972, and 1975) or were calculated during the preliminary modeling stage of this study. The values used to describe the geohydrologic units in the model are summarized in table 3.

Generally, input to the detailed model was obtained by overlaying the finite-difference grid on maps of hydrogeologic properties and interpolating the values for each node. The transmissivity of the Sparta and the thickness of confining layers were input to the model in this manner. Input to the model for the storage coefficient of the Sparta aquifer was obtained by plotting published data for storage coefficient on the model grid and estimating values over the rest of the grid. Input to the model for some hydrogeologic parameters were average values, which were assumed constant over the entire grid. Average values were used for the transmissivity and storage coefficient of both the Cockfield and Carrizo-Wilcox aquifers. Values of vertical hydraulic conductivity for determination of vertical conductance of confining layers were estimated values obtained from preliminary modeling.

Boundary Conditions

Model boundaries were chosen to closely approximate the natural hydrologic boundaries. The boundary conditions specified for the Sparta aquifer were no-flow on the northern and southern boundaries and constant-head on the western and eastern boundaries. The boundary conditions for the Carrizo-Wilcox aquifer were the same as those specified for the Sparta. The Cockfield aquifer was treated as a constant head layer. Justification for these boundary specifications follows.

The southern boundary of the Sparta aquifer also was treated as a no-flow boundary. The Sparta aquifer thins to the south and gradually grades to clay, producing a natural no-flow boundary. The exact location where the aquifer becomes no-flow is unknown. The southern boundary of the model was set at 31 degrees north latitude based on preliminary modeling results which showed no difference between the use of a no-flow or constant-head boundary at this location.

The northern boundary of the Sparta aquifer was treated as a no-flow boundary. Potentiometric-contours of the Sparta in the Mississippi embayment (Reed, 1972) show that a ground-water divide has developed between the El Dorado and Pine Bluff, Ark., pumping centers. The divide occurs approximately at 34 degrees north latitude. This ground-water divide acts as a no-flow boundary.

Table 3.--Hydrogeologic parameters used in the detailed three-dimensional model

Aquifer parameters		
Aquifer	Transmissivity (square foot per second)	Storage coefficient
Cockfield	[a]0.068	[b]0.1
Sparta	[c]0.02-0.25	[d]0.1-0.0001
Carrizo-Wilcox	[d]0.065	0.1 in outcrop 0.001 elsewhere

Confining-layer parameters		
Confining layer	Vertical hydraulic conductivity (foot per second)	Thickness (feet)
Cook Mountain	[e]1.46×10^{-10}	[f]50-650
Cane River	[e]6.08×10^{-11}	[g]25-600

[a] Average of values reported by Hosman and others (1968).

[b] Assumed.

[c] Initial values from Payne (1972), plate 7, were adjusted during modeling to the range shown.

[d] From Hosman and others (1968) and assumed values for water-table conditions.

[e] Initial value, 1×10^{-11} foot per second, varied during modeling to value shown.

[f] From Ryals (1983a); Spiers (1977); Payne (1970), plates 2 and 3; and Payne (1968), plates 3 and 4.

[g] Payne (1972), plate 1.

The western boundary of the Sparta aquifer is the western limit of the outcrop-subcrop area. The aquifer outcrop-subcrop area was treated as a constant head boundary to simulate additional recharge water available to pumping centers. Streams in the outcrop area are perennial with base flow sustained by discharging ground water. Until such time as sufficient water is captured by the drawdown cones so that streams dry up in the outcrop-subcrop area, use of constant-head nodes seems justified. The potentiometric surface of the Sparta aquifer (fig. 5) indicates that a drawdown cone is now capturing water in the outcrop-subcrop area (Ryals, 1980). To accommodate the drawdown within the outcrop-subcrop area of the Sparta aquifer, the westernmost limit (nodes) of the outcrop-subcrop area was treated as constant head (pl. 2). The remainder of the outcrop-subcrop area was included as active nodes to accommodate the drawdown.

The eastern boundary of the model was selected as the eastern limit of the Sparta outcrop-subcrop area. The eastern boundary, like the western boundary of the Sparta, was treated as a constant-head boundary.

The boundaries of the Carrizo-Wilcox aquifer were treated the same as the Sparta aquifer. The location of constant-head nodes was slightly different to correspond to the difference in location of the outcrop-subcrop area. The justification for the way boundaries were treated for the Carrizo-Wilcox was basically the same as was mentioned for the Sparta. Different boundary conditions could be used in the Carrizo-Wilcox without materially affecting the model because the model was only calibrated on water levels for the Sparta aquifer.

The Cockfield Formation crops out over much of the study area (fig. 2), and where it does not crop out, it is overlain by alluvial deposits, or it has been removed by erosion and replaced by alluvium. The Cockfield aquifer was treated as a constant-head layer because it is in direct hydrologic connection with rivers and streams in large parts of the area. Preliminary modeling of the aquifer system showed that there was little difference between simulating the Cockfield as a constant-head layer or simulating the aquifer with the following: constant-head nodes in the outcrop area and simulating leakage into the Mississippi River alluvium or undifferentiated upper Tertiary deposits by use of the river package (McDonald, 1984). To simplify input requirements, the constant-head layer was used. The location of eastern and western boundaries of the Cockfield were selected to correspond with the eastern and western limits of its outcrop area, while the northern and southern boundaries were located the same as for the other aquifers.

Initial Potentiometric Conditions

The initial potentiometric levels used in the model for the Sparta aquifer were taken from a potentiometric map (fig. 4) of the Sparta Sand for 1886 (Reed, 1972; fig. 2), which depicts water levels prior to extensive development of the aquifer. Information on prepumping potentiometric levels for the Carrizo-Wilcox and Cockfield aquifers are not sufficient for preparing a pre-development potentiometric map; however, because the two aquifers have not had extensive development, more recent maps of potentiometric levels in these aquifers were used. Initial potentiometric levels of the Cockfield aquifer and of the alluvial aquifer, where the Cockfield has been eroded, were obtained from the following sources: in Louisiana, from unpublished data in the files of the U.S. Geological Survey; in Arkansas, from Terry and others (1979); and in Mississippi, from Wasson (1980). Potentiometric levels of the Carrizo-Wilcox aquifer and equivalent geohydrologic units were taken from the following sources: in Louisiana, from Ryals (1980c) and from unpublished data in the files of the U.S. Geological Survey; in Arkansas, from Terry and others (1979); and in Mississippi, from Wasson (1980).

Pumpage

The geographical and temporal distribution of ground-water pumpage from the Sparta aquifer was the only pumpage input to the detailed model. Pumpage from the Cockfield aquifer was not included because that aquifer is treated as a constant-head layer. Pumpage from the Carrizo-Wilcox aquifer was not included because of (1) the lack of long-term data on pumpage and potentiometric levels that could be used to calibrate the model and (2) the insignificant amount of pumpage in the principal area of interest in the study area.

In the detailed model, pumpage for all individual pumping centers where pumpage from the Sparta was greater than 0.15 ft^3/s were simulated by individual wells. All other pumpage was totaled by parish and was assumed to occur at one or two nodes within each parish.

Pumpage was divided into 11 periods (table 4) based on variations in pumpage and water levels observed at West Monroe. Grid blocks used to simulate pumpage are indicated on plate 2. No pumpage is shown occurring from the Sparta aquifer prior to 1900; whereas, an estimated 248 ft^3/s was pumped in 1980.

Calibration of Model, 1900 Through 1964

The approach used in calibrating the model was to simulate the period 1900 through the end of 1964, making reasonable adjustments in model parameters to obtain a match between model-generated change in water levels for the simulation period and the observed change in water levels. Data used in calibrating the model were water levels in wells in the Sparta aquifer and drawdown information from maps of drawdown. Drawdown is defined as the change in potentiometric level from one time to another. For the calibration process of the detailed model, drawdown was defined as the change in potentiometric level between 1900 and 1964. Generally, maps of drawdown for 1965 were used to determine drawdown at major pumping centers outside the principal area of study in Louisiana. At most sites in Louisiana, drawdown was determined at wells. As Ouachita Parish was the principal area of interest, more wells from Ouachita Parish were used in calibrating the model than for any other area. A scattering of other wells were used in the calibration process to provide good representation of the rest of the aquifer system. Initial water levels at observation wells were estimated from maps of intial head. The potentiometric levels in wells in early 1965 were then compared to the initial head to get the drawdown in the well. Although maps of drawdown have been published for the Sparta aquifer for 1965, the period during 1965 that they represent is not known. Because a significant reduction in pumpage from the Sparta aquifer at West Monroe occurred in 1965, these published maps were not used for Louisiana. If maps of drawdown had been used to determine observed nodal values of drawdown for the calibration process, then a better calibration may have been obtained. However, the relative merit of using point values of drawdown versus nodal values of drawdown was not investigated in this study.

Table 4.--Temporal distribution of pumpage for the detailed three-dimensional model

Pumping period	Historical period simulated	Length of simulation (years)	Pumping rates from the Sparta aquifer (cubic feet per second)
1	1900-09	10	1
2	1910-19	10	2
3	1920-29	10	13
4	1930-39	10	40
5	1940-49	10	121
6	1950-59	10	152
7	1960-64	5	201
8	1965-69	5	215
9	1970-74	5	228
10	1975-79	5	239
11	1980	1	248

Initially in the calibration process, trial-and-error adjustments were made in hydrogeologic parameters (such as transmissivity and storage coefficient) in the model to match the observed potentiometric level of the Sparta aquifer at the end of 1964 and model generated potentiometric values. Because a desirable match was not made within a reasonable number of simulations, parameter estimation as described by Cooley (1977) was used to calibrate the model on the drawdown in potentiometric levels for the period 1900-1964. Parameter estimation shows the sensitivity of the model to changes in hydrogeologic parameters and, thus, aids in the calibration process. The sensitivity of the model is gaged by the change in model-generated drawdown caused by a change in hydrogeologic parameters.

Calibration of the model was based on pumping data from 1900 through the end of 1964, the first seven pumping periods shown in table 4. The ending year, 1964, was selected for calibration because of the available potentiometric data gathered for the Sparta aquifer and because of a change in pumping rate at West Monroe after 1964. During the calibration of the model, pumpage from the Sparta was not one of the parameters varied when using the parameter-estimation technique because good estimates of water use were not available for Ouachita Parish and surrounding parishes for the period 1900-1960. Prior to 1960, pumpage data were collected intermittently at some pumping centers (table 2), but for the most part, individual well data did not exist. Since 1960, records are more complete for most of the major pumping centers.

Parameter Estimation

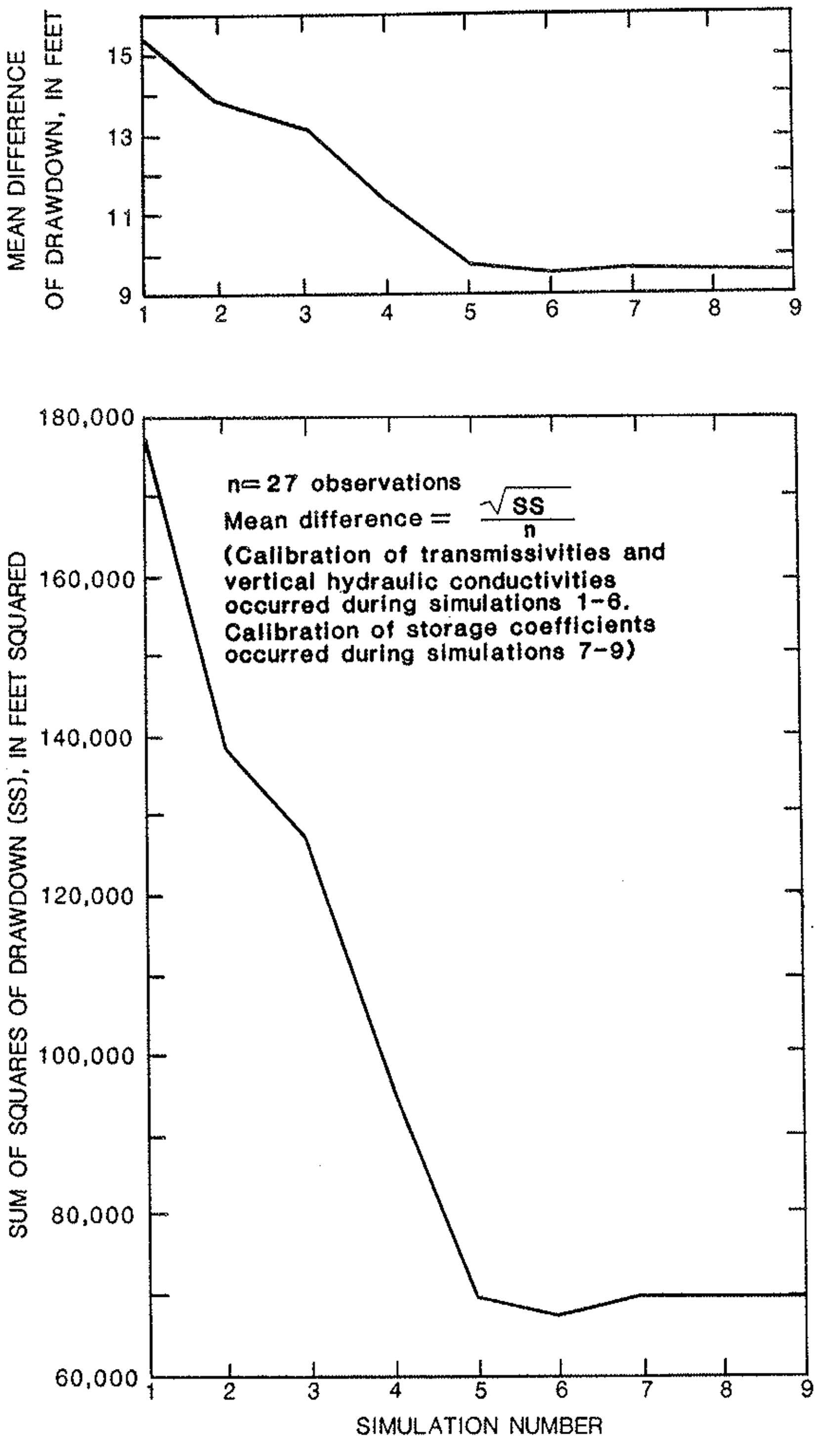
A program written for a hand-held programmable calculator was used to determine the change in hydrogeologic parameters required to achieve a better match between observed and calculated drawdown. The program is a modified version of one documented by Torak and Whiteman (1982, appendix V). Modifications to the program documented by Torak involved eliminating some statistical calculations and the solver subroutine. Elimination of the solver subroutine necessitated the manual solution of the governing equations. The program uses drawdown from a number of observation wells to calculate the change required in three hydrogeologic parameters to calibrate the model. Initially, 13 observation wells were used. The validity of using only 13 observation wells was later tested by adding an additional 14 observation wells. The results from all 27 observation wells are discussed below.

Transmissivity of the Sparta Sand and vertical hydraulic conductivity of the two confining layers were the first three parameters tested using the parameter-estimation technique because the model was found to be most sensitive to these parameters during the trial-and-error stage of modeling. A "base run" of the model simulating the 65 years of pumping was executed using a preliminary set of parameter values. On successive "perturbation runs" one parameter value was changed. Each perturbation run represented the effects on the aquifer system of changing one parameter.

Input to the parameter-estimation program consisted of observed drawdowns at wells and the corresponding model-generated drawdown at nodes from base and perturbation runs. The "sensistivity" or change in drawdown caused by the change in hydrogeologic parameter was computed by the program using results of base and perturbation runs. A sum of squares was then computed from the differences between observed drawdowns and those obtained from the base run. The sum of squares was used as an indicator of how close the model-generated value of drawdown was to the observed value. The lower the sum of squares the closer the match between observed and model-generated drawdown.

Values for transmissivity and vertical hydraulic conductivity were allowed to vary within plausible limits as dictated by the output of the parameter-estimation program. Parameters were changed by adjusting a multiplier value for each matrix. All elements of the matrix that defined a parameter were multiplied by this value. Additionally, trial-and-error adjustments were made within the matrices in areas where a poor match was obtained between observed and computed head.

After five sets of base and perturbation simulations, accompanied by changing of parameters as indicated by the parameter-estimation program, the sum of squares for computed and observed drawdowns were reduced by more than half of the original value. The mean difference (fig. 7) between observed and computed drawdowns decreased 5.7 ft (from 15.5 to 9.8 ft) after five simulations. Several additional simulations were made using the parameter-estimation technique. However, the change in parameters produced no appreciable change in the results as indicated by figure 7, which shows the sum of squares of drawdown and mean difference plotted versus the simulation number. After the seventh calibration simulation, the model was considered calibrated with respect to the transmissivity of the Sparta aquifer and the vertical hydraulic conductivity of the confining layers. To complete the calibration procedure, storage coefficients of the aquifers were evaluated by the parameter-estimation program. Three simulations were made, but no significant change in the sum of squares



n= 27 observations

Mean difference = $\frac{\sqrt{SS}}{n}$

(Calibration of transmissivities and vertical hydraulic conductivities occurred during simulations 1-6. Calibration of storage coefficients occurred during simulations 7-9)

Figure 7.--Mean difference and sum of squares of drawdowns versus simulation number for calibration simulations.

occurred. After the ninth calibration run, the model was considered calibrated. Table 5 shows how the final simulation compared with the observed data. The mean difference from run nine, 9.6 ft, represents a 7 percent difference from the average observed drawdown.

During the calibration procedure, the factor that multiplies the transmissivity matrix of the Sparta aquifer was changed by 35 percent from 1.0×10^{-4} to 6.5×10^{-5}. The values of transmissivity that were input to the model were coded from a map of the transmissivity of the Sparta prepared by Payne (1968). The 35-percent variation in transmissivity from the initial estimate was considered acceptable. Additionally, the matrix values were adjusted in recharge areas in Ouachita Parish and at Magnolia, Ark. Plate 3 is included to show the areal distribution in transmissivity of the Sparta that was used in the model.

The values of vertical hydraulic conductivity for the Cook Mountain and Cane River confining layers were changed during model calibration from an initial value of 1×10^{-11} ft/s for both units to 1.46×10^{-10} ft/s and 6.08×10^{-11} ft/s, respectively. Whiteman (1980) reports a value of vertical hydraulic conductivity for a confining layer in the Baton Rouge, La., area of 1×10^{-10} ft/s. The variation in vertical hydraulic conductivity used to calibrate the model seemed reasonable, based on preliminary modeling results and the one available reported value. Changes also were made in the matrix values of the reciprocal of thickness for the Cook Mountain Formation at Magnolia, Ark. and in Ouachita Parish.

Storage-coefficient factors, which multiply matrices of values, were varied over several orders of magnitude in the last few calibration simulations with little change in computed sum of squares of drawdown. The initial factors used to multiply the matrices of storage coefficient were equivalent to storage coefficients of 0.1 for the Cockfield Formation, and 1×10^{-4} for the Sparta and Carrizo-Wilcox aquifers. Because of the lack of sensitivity, the initial values were used for the additional model calibration. Matrix values of the storage coefficient near recharge areas of the Sparta aquifer and in Ouachita Parish also were adjusted during the calibration. Generally, the lack of model sensitivity to changes in storage coefficient was (1) because of the way that sensitivity was determined and (2) because of large differences between observed and computed drawdowns in some of the wells used in the determination.

The difference between the computed and observed drawdown values in table 5 is 44 ft or more in several areas. The areas where this occurs are near pumping centers (Ruston, well L-25; West Monroe, well Ou-77; Springhill; El Dorado; and Magnolia), near the recharge area of the Sparta aquifer (well sites Sa-389 and Sa-390), and in Ouachita Parish (wells Ou-88, Ou-403, and Ou-404). Significant differences are expected when comparing point-drawdown data at or near a pumping well with the drawdown in a model-grid block because the model averages drawdown over the area; therefore, the grid-block drawdown should be less than the observed drawdown. This occurs at most of the pumping centers except for Springhill, La., which is next to the recharge area. The large difference between

Table 5.--Observed and computed drawdowns at selected nodes used to calibrate the detailed three-dimensional model

Well No.[1] and location	Node		Observed drawdown to 1965 (feet)	Computed[2] drawdown to 1965 (feet)	Difference	
	Row	Column			(feet)	(percent)
Bi-1-------------------	16	7	52	32	20	38
Bi-4-------------------	16	9	83	84	-1	1
Cl-9, Haynesville, La--	5	7	110	88	22	20
Cl-58------------------	7	8	75	82	-7	-9
Ja-49------------------	21	11	157	126	31	20
L-25-------------------	12	11	162	118	44	27
Mo-5, Bastrop, La------	6	26	170	190	-20	-12
Ou-24, Ouachita Parish-	8	23	140	159	-19	-14
Ou-77, West Monroe, La-	14	20	294	229	65	22
Ou-87, Ouachita Parish-	14	21	203	186	17	8
Ou-88, Ouachita Parish-	15	21	126	175	-49	-39
Ou-96, Ouachita Parish-	13	22	149	166	-17	-11
Ou-401A----------------	17	23	112	136	-24	-21
Ou-403-----------------	20	22	82	115	-33	-40
Ou-404-----------------	13	26	83	134	-51	-61
Ou-406-----------------	16	21	159	162	-3	-2
Sa-389-----------------	26	3	56	4	52	93
Sa-390-----------------	26	4	95	5	90	95
Un-26------------------	7	20	149	153	-4	3
W-16-------------------	24	12	55	61	-6	11
Wb-3, Springhill, La---	5	4	60	102	-42	70
Wb-96------------------	6	5	26	62	-36	138
El Dorado, Ark.[3]-------	3	11	300	234	66	22
Magnolia, Ark.[3]--------	3	7	220	41	179	81
Hodge, La.[4]------------	20	11	160	155	5	3
Ruston, La.[4]-----------	12	12	153	133	20	13
Jackson, Miss.[3]--------	19	33	62	87	-25	-40

[1] See description of well-numbering system in the Introduction.
[2] Final simulation.
[3] Based on map of drawdown (Reed, 1972).
[4] From Sanford, 1973.

computed and observed drawdown at Springhill is believed to result from the difficulty of selecting appropriate transmissivity values for the varying grid-block sizes at the recharge boundary. At Magnolia, Ark., which also is near the recharge area, large differences between observed and computed drawdown occur. Reasonable adjustments in aquifer and confining-layer parameters were made, but they produced no significant improvement between observed and calculated drawdown. Because Magnolia was not an area of concern, nothing further was done to rectify differences there.

In Ouachita Parish, the difference of 50 ft or more between observed and computed drawdown is thought to be the result of two factors. The gradients in Ouachita Parish are fairly steep because of pumping at West Monroe. The steep gradients could account for significant differences between observed and computed drawdown when comparing the point values of drawdown at a well to the average drawdown of the grid block in which the well is located. Another possible reason for the significant difference between observed and computed drawdown is that the Sparta aquifer is assumed to behave as a single hydrologic unit. Rogers and others (1972, p. 28) stated, "In parts of the area some of the upper sands of the Sparta, which are poorly connected with the lower sands in some places, had a piezometric surface higher than that of the deeper sands. This results from a lag in pressure adjustment to the withdrawals of water from the lower, more heavily pumped sands." Examination of the wells used for parameter estimation shows that most of them (Ou-87, Ou-88, Ou-96, Ou-401A, and Ou-403) are completed in the upper half of the Sparta Sand.

Overall, the model-computed drawdowns are considered to represent an acceptable match with observed drawdown. Given the time frame of this study, the model was considered to be adequately calibrated for the purpose of estimating the effects on water levels and salinity of the Sparta aquifer of projected increased pumpage from the Sparta near West Monroe.

Sensitivity Analysis

The sensitivity of the developed model to the various hydrologic parameters used in the model was determined through a formalized sensitivity analysis. Simulations were made in which values of a parameter were allowed to vary over a reasonable range. The mean difference of each simulation for each change in parameter was plotted versus the ratio of the varied parameter to the value of that parameter used during the final calibration simulation.

The model was found to be insensitive to changes in (1) the storage coefficient of all aquifers and (2) the transmissivity of the Carrizo-Wilcox aquifer. Large variations in these parameters would cause only a slight change in the calculated mean difference.

Figure 8A shows that the model is highly sensitive to the value of the transmissivity of the Sparta aquifer. A small change in transmissivity of the Sparta aquifer would produce a significant change in the mean difference. Figure 8C shows that the model is not as sensitive to the value of vertical conductance of the Cane River confining layer as it is to the corresponding value for the Cook Mountain confining layer, shown in figure 8B. Large changes in the vertical conductance for the Cane River confining layer produced only a negligible change in the mean difference; whereas, only a small change in the vertical conductance for the Cook Mountain confining layer produced a significant change in the mean difference.

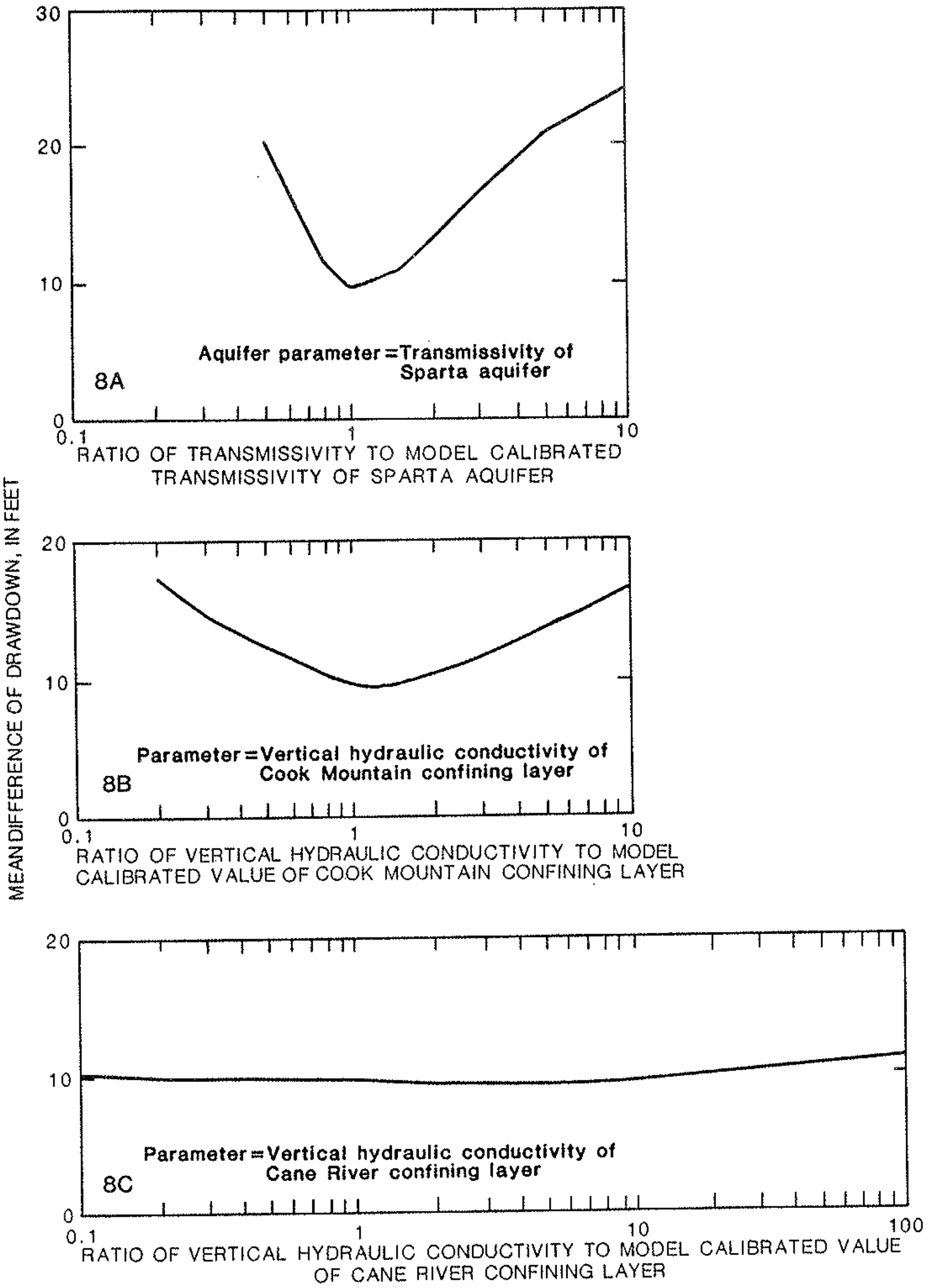


Figure 8.--Mean difference of drawdown versus ratio of range of aquifer parameter to model calibrated parameter.

To investigate the areal sensitivity of the model to the parameters used, plate 4 (maps A, B, and C) was prepared. Because the model seems to be most sensitive to transmissivity of the Sparta aquifer and vertical conductance of the Cook Mountain confining layer, the areal sensitivity of the model to these parameters was analyzed. An indicator of sensitivity is the difference between observed and computed drawdown. Plate 4A shows the areal variation between observed and computed drawdown for the Sparta aquifer for the calibration simulation through 1964. Plate 4B shows the areal variation between observed and computed drawdown for the Sparta using a value for transmissivity of the Sparta aquifer of 1.5 times the calibrated value. Plate 4C shows the areal variation between observed and computed drawdown using a value for vertical conductance of the Cook Mountain confining layer of 1.5 times the calibrated value. By comparing plate 4B and 4C to plate 4A, the sensitivity of the model to areal changes in parameters can be inferred. Vertical conductance is defined as the vertical hydraulic conductivity of the confining layer divided by the thickness of the layer.

Plate 4A shows a fairly random distribution of positive and negative drawdown differences between the observed and computed drawdown. The one exception to the random distribution is in Ouachita Parish, where mainly negative differences occur. During the parameter-estimation simulations, matrix values of vertical conductance for the Cook Mountain confining layer and the matrix values for transmissivity in the Sparta aquifer in Ouachita Parish were increased as much as 50 percent. The modification of the nodal values of transmissivity and vertical conductance resulted in some decrease in the difference between the observed and computed head. Areal variations beyond 50 percent in aquifer parameters were not considered reasonable.

From plate 4B and 4C, it appears that the model was areally sensitive to increases in the vertical conductance of the Cook Mountain confining layer and transmissivity of the Sparta aquifer. Comparison of plate 4B and 4C with 4A shows that in Ouachita Parish increases in the two parameters would result in a decrease in the difference between observed and computed drawdown. Elsewhere, either no significant change occurs, or the difference between observed and computed drawdown increases. The sensitivity analysis indicates that a decrease in the difference in observed and computed drawdown could have been obtained with further areal adjustment of parameters in Ouachita Parish. However, additional areal adjustment was not made in the two parameters under consideration because the areal distribution of parameters used for the calibration through 1964 was considered reasonable. More importantly, further areal adjustments were not made in the parameters because the change in drawdown would not have significantly improved the accuracy of the model as measured by the mean difference. Computed drawdown from the calibration simulation through 1964 was already within the error range for the observed drawdown.

The sensitivity analysis indicated the adequacy of the aquifer parameters used in the model. The model could be refined if better estimates of the magnitude and areal distribution of transmissivity of the Sparta aquifer and leakance of the Cook Mountain confining layer were available.

Steady-State Model Simulation

The calibrated model was used with the initial potentiometric conditions, discussed previously, to generate a steady-state surface of initial potentiometric levels of the Sparta aquifer. The computed initial potentiometric levels shown on plate 5 are roughly comparable to the observed potentiometric levels shown in figure 4. Near West Monroe, the computed potentiometric levels are higher by 20 to 30 ft than the observed initial potentiometric levels. Generally, the computed steady-state potentiometric surface ranges from 0 to 40 ft higher than the observed potentiometric surface. Because of the lack of control for the observed potentiometric surface, this degree of difference was deemed acceptable. Drawdown computed during additional model simulations were superimposed on this steady-state potentiometric surface to generate potentiometric surface maps for other time periods.

Acceptance Testing of the Model, 1965 through 1979

To further test the developed model to determine its accuracy for analyzing the results of increased pumpage near West Monroe, the model was further checked against the decline in water levels in the Sparta aquifer from 1965-79. This acceptance testing involved determining if the model could match recorded changes in water level using pumpage from a period of time different than that used to initially calibrate the model. Pumpage was divided into four pumping periods, the last four pumping periods shown in table 4. The periods were divided so that drawdown data from the end of 1979 could be compared with observed data from early 1980. Simulations used to test the model were a continuation of the last calibration simulation. Drawdown at the end of 1964 was input to the simulation as starting head. Except for the change in pumping rates, the two simulations were identical but were independent of each other.

Table 6 shows the computed versus observed drawdown for the acceptance testing simulation for 21 observation wells. The sum of squares and mean difference of the simulation were 6,148 ft^2 and 3.7 ft, respectively. The mean difference is significantly less than that calculated during the earlier calibration. Table 6 shows that more than 50 percent (3,844 ft^2) of the total sum of the squares of the difference between the observed and computed drawdown is a result of data for well Ja-49, which is near the pumping center at Hodge, La. Records of pumpage near well Ja-49 show that pumpage increased significantly after 1960, from 16 ft^3/s to 20-22 ft^3/s and then remained fairly constant through 1980. On the basis of the pumping rates, an increase in drawdown would be expected from 1965-80; yet, decreasing drawdown (rising water level) occurred in well Ja-49. The apparent anomaly is believed to be the result of a shift in pumpage among wells within the grid block. Eliminating the values for well Ja-49 results in a mean difference of 2.4 ft for the remaining wells in table 6.

Table 6.--Observed and computed drawdown at selected nodes (1965-79) used during second calibration of the detailed three-dimensional model

[Sum of squares = 6,148 feet and mean difference = 3.7 feet]

Well No.	Node		Observed drawdown 1965-80 (feet)	Computed drawdown 1965-80 (feet)	Difference	
	Row	Column			(feet)	(percent)
Mo-5	6	26	0	24	-24	-----
Ou-24	8	23	13	19	-6	46
Ou-77	14	20	[a]-1	10	-11	1,100
Ou-88	15	21	10	20	-10	100
Ou-96	13	22	30	22	8	27
Wb-27	5	4	[a]-33	-26	-7	21
Cl-9	5	7	16	15	1	6
Bi-1	16	7	18	16	2	11
Bi-4	16	9	41	30	11	28
Cl-58	7	8	12	26	-14	117
Ja-49	21	11	[a]-21	41	-62	295
L-25	12	11	19	41	-22	115
Ou-401A	17	23	24	21	3	13
Ou-403	20	22	11	21	-10	91
Ou-404	13	26	15	21	-6	40
Ou-406	16	21	14	21	-7	50
Sa-389	26	3	[a]-3	1	-4	133
Sa-390	26	4	0	2	-2	-----
Un-26	7	20	14	23	-9	64
Wb-96	6	5	[a]-4	-5	1	25
W-16	24	12	7	23	-16	228

[a] Water-level rise.

Comparison of observed versus computed drawdown in wells in Ouachita Parish, listed in table 6, shows a sum of squares of 515 ft^2 and a mean difference of 2.8 ft for the eight wells. The mean difference represents a 19-percent difference from the observed average drawdown of 14.5 ft in the eight observation wells. The largest differences between computed and observed drawdown in Ouachita Parish are in wells Ou-77, Ou-88, and Ou-403. As stated earlier, Ou-88 and Ou-403 are wells screened in the upper part of the Sparta Sand; whereas, most of the pumpage is from the lower part of the Sparta. The large difference between observed and computed drawdown in these wells may result from a time lag in response to pumping if upper sands of the Sparta are poorly connected to the lower sands. The poor match between computed and observed drawdown in well Ou-77 is probably because the comparison is between the average drawdown in the grid block and the point drawdown at the actual well.

During the model simulation period, pumping was reduced at several of the major pumping centers. At Springhill, pumpage was reduced from 16.70 ft^3/s in 1965 to 0.90 ft^3/s in 1980. In the Monroe-West Monroe area, pumpage decreased from 22.97 ft^3/s in 1965 to 15.80 ft^3/s in 1970. Then from 1970 to 1980, pumpage at Monroe-West Monroe increased to 22.95 ft^3/s. The observed water-level rise for the period 1965-80 was 33 ft at Springhill and 1 ft at West Monroe. The model computed a 26-foot rise at Springhill and 10-foot decline at West Monroe.

Plate 6 shows the computed potentiometric level of the Sparta aquifer at the beginning of 1980. Drawdown data through the end of 1979 were combined with the computed steady-state water level to prepare plate 6. Comparison of plate 6 with figure 5 shows how well the computed potentiometric levels agree with the observed. The computed potentiometric level does not show a cone of depression around Magnolia, Ark. As noted previously, values of aquifer and confining-layer parameters around Magnolia were varied in the modeling effort within plausible limits; yet, a drawdown cone similar to the observed cone could not be produced. The shape of the drawdown cones around the other pumping centers indicated by the computed potentiometric-contour map are similar to those observed. The calibrated model, when tested for an additional time period, reasonably reproduced drawdowns for that period and is deemed acceptable for evaluating various pumping alternatives proposed by the Corps of Engineers.

Figure 9 shows the computed versus observed drawdown at wells Ou-77, Ou-87, and Ou-96. The hydrographs show how well the model reproduced the trends in water levels in selected wells in the principal area of interest in Ouachita Parish. Well Ou-77 is located in the center of the major pumping cone at West Monroe. Close agreement between observed and computed drawdown at well Ou-77 was not expected because the comparison is between the point value of drawdown in a well in a pumping field versus the average value of drawdown over an area of the node, which is 4 mi^2. Figure 9 shows that for well Ou-77 for early time (1940-60), when only scanty data on pumpage were available, the difference between the computed and observed drawdown was greater than in later time (1960-80). Beginning in 1960 when records of pumpage improved, the computed and observed drawdown trends are very similar although there is a water-level difference of about 40 ft. The observed versus computed drawdown at well Ou-87 also shows a poor match between observed and computed drawdown for the early data and a better match from 1960 to 1980. It appears that the results of the ground-water model would be improved by better definition of pumpage during earlier time periods (1900-1960). Well Ou-96, which is farther out on the cone of depression surrounding West Monroe than either well Ou-77 or Ou-87, has shown a steady drawdown of about 2 to 3 ft/yr during the period of record. The model-computed drawdown for well Ou-96 closely approximates the observed drawdown.

The drawdown computed from the last calibration simulation was sufficiently close to the observed drawdown that no additional adjustments were necessary. The total mean difference from the combined calibration simulations is 9.6 ft, which is less than 10 percent of the average drawdown for the 1900-1980 period. The calibration and acceptance testing simulations indicate the model satisfactorily reproduces drawdown within

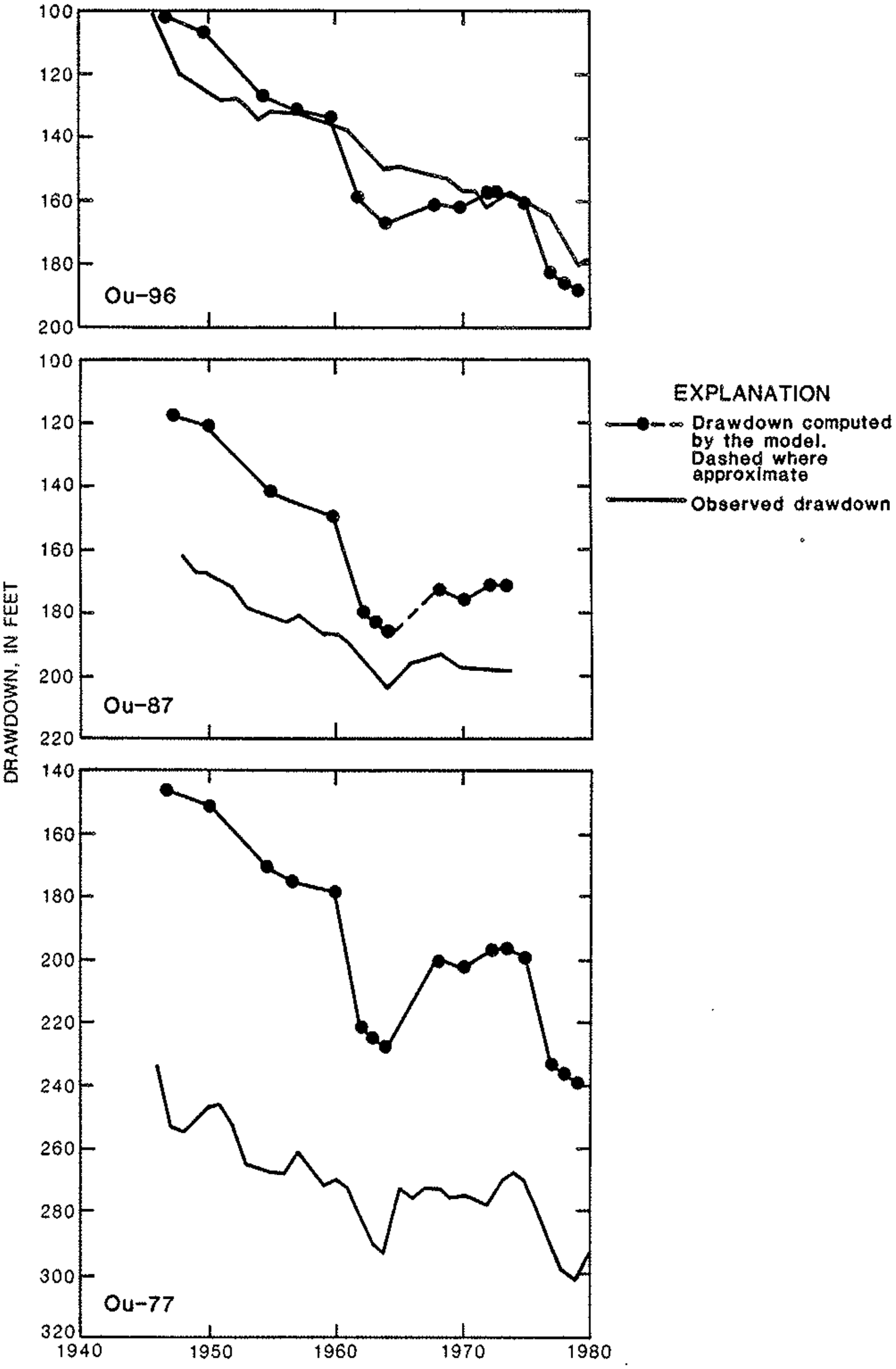


Figure 9.--Observed drawdown versus computed drawdown for selected observation wells near West Monroe, Louisiana.

the Sparta and is, therefore, suitable to analyze the drawdown effects of projected increased pumpage. The water budget was examined to further evaluate the validity of the model and the impact of drawdown within the Sparta outcrop areas capturing ground water discharge to streams.

Evaluation of Components of the Flow System

In 1980, 247.8 ft^3/s was pumped from the Sparta aquifer (table 7). Of this amount, 40 percent was derived from the outcrop-subcrop area of the Sparta; 44 percent was derived from leakage into the Sparta from the Cockfield aquifer through the overlying Cook Mountain confining layer; 5 percent was derived from leakage from the Carrizo-Wilcox aquifer through the underlying Cane River confining layer; and 11 percent was derived from release of water from storage in the Sparta aquifer. The 40 percent of pumped water that was derived from the Sparta outcrop-subcrop area in 1980 represents a "captured-recharge" rate of 0.3 in/yr. The water is captured recharge because this represents water that formerly was discharged to streams in the recharge area. Although this captured-recharge rate cannot be verified, it is not unreasonable in terms of 50 to 60 in/yr of rainfall. Because the model was not calibrated on water levels in either the Carrizo-Wilcox aquifer or Cockfield aquifer, the percentages of leakage from the individual layers are somewhat suspect.

Cumulative pumpage from the Sparta aquifer for the period 1900-1980 was 2.51×10^{11} ft^3 (table 7). Of this amount, 38 percent was derived from the recharge area of the Sparta; 40 percent was derived from leakage into the aquifer through the Cook Mountain confining bed; 5 percent of the water was derived from leakage through the Cane River confining bed; and 17 percent was derived from release of water from storage in the Sparta. The total leakage (45 percent) is considered a valid number. Reed (1972), using an analog model of the entire Sparta Sand, found that in 1965, with a pumpage of 539 ft^3/s, 60 percent of the water was derived from leakage, 20 percent from captured recharge, and 20 percent was released from storage in the Sparta. The value from the current study compares well with Reed's analog-model results for the entire Mississippi embayment. Based on the simulations and on the evaluation of the water budget, the model was considered suitable for analyzing the effects of increased pumpage.

SIMULATED AQUIFER RESPONSE TO ALTERNATIVE PUMPING PLANS

Projected Pumpage

The U.S. Army Corps of Engineers initially requested that the effects of obtaining approximately 20 ft^3/s from three well fields west of West Monroe be analyzed. The model described in the previous section was designed to analyze the effects of this pumpage. After review of the results of the initially proposed pumping plans, the Corps of Engineers requested that the effects of eight alternative pumping plans on water levels and water quality of the Sparta aquifer be analyzed. Table 8 shows the additional ground-water requirements in the West Monroe area projected

Table 7.--Volumetric budget for the Sparta aquifer

Inflow	1980 (cubic feet per second)	Cumulative 1900-1980 (cubic feet)
Storage	26.9	4.38×10^{10}
Constant-head leakage	98.9	9.42×10^{10}
Leakage through the Cook Mountain Formation	109.6	1.00×10^{11}
Leakage through the Cane River Formation	13.6	1.33×10^{10}
Total	249.1	2.51×10^{11}
Outflow	**1980 (cubic feet per second)**	**Cumulative 1900-1980 (cubic feet)**
Storage	0.8	9.96×10^{7}
Leakage through the Cane River Formation	.4	3.61×10^{8}
Pumpage from wells	247.8	2.51×10^{11}
Total	249.0	2.51×10^{11}
Percentage of error	.0	.0

by the Corps of Engineers. The table shows six groups of wells (A through F), the location of wells by model-node location (row, column) within each group, and the projected pumpage at each node with time. Plate 7 shows the location in Ouachita Parish of the wells listed in table 8. Groups A, B, and C represent existing pumpage (1980), and the pumpage from these wells was the same as was used in the simulation for 1980. Groups D and F represent new pumpage in 1980 and, therefore, were not applied except during simulation of the alternative plans. For the eight alternative model simulations, projected pumpage was based on eight different combinations of the well groups shown in table 8 and described below.

Alternative A.--Pumping would consist of groups A, B, and C from table 8. Groups A, B, and C show an increase in pumpage from 12.03 ft^3/s in 1980 to 22.61 ft^3/s in 2040, an 88-percent increase.

Alternative B.--Pumping would consist of groups A, B, C, and D in table 8. Group D would involve a large increase in pumpage from no pumpage in 1980 to 23.47 ft^3/s in 2040. The total increase in pumpage from the 1980 value is 34.05 ft^3/s.

Alternative C.--Pumping would consist of groups A, B, C, and E in table 8. Group E would involve an increase in pumpage of 8.54 ft^3/s in 2040. The total increase in pumpage from the 1980 value is 19.12 ft^3/s.

Table 8.--Temporal distribution of projected pumpage for simulating alternative plans

Model row	Model column	Rate of pumping (cubic feet per second) per period interval (years)												
		1980	1981-85	1986-90	1991-95	1996-2000	2001-05	2006-10	2011-15	2016-20	2021-25	2026-30	2031-35	2036-40
							Group A							
11	19	0.00	0.00	0.00	0.14	0.24	0.34	0.44	0.54	0.64	0.74	0.84	0.94	0.94
11	20	.00	.00	.00	.14	.24	.34	.44	.54	.64	.74	.84	.94	.94
12	16	.00	.00	.00	.00	.05	.01	.00	.00	.05	.17	.39	.61	.94
12	17	.00	.34	.44	.54	.64	.74	.84	.91	.94	.94	.94	.94	.94
12	18	1.08	1.08	1.08	1.08	1.08	1.08	1.08	1.08	1.08	1.08	1.08	1.08	1.08
13	16	.00	.00	.00	.00	.04	.02	.01	.01	.05	.17	.39	.62	.94
13	17	.00	.34	.44	.54	.64	.74	.84	.91	.94	.94	.94	.94	.94
13	18	1.08	1.08	1.08	1.08	1.08	1.08	1.08	1.08	1.08	1.08	1.08	1.08	1.08
14	19	3.26	3.26	3.26	3.26	3.26	3.26	3.26	3.26	3.26	3.25	3.26	3.26	3.26
[a]14	20	.00	.00	.24	.34	.44	.54	.64	.74	.84	.95	.95	.95	.95
15	19	.00	.00	.24	.34	.44	.54	.64	.74	.85	.94	.94	.94	.94
							Group B							
12	19	0.93	0.97	1.01	1.06	1.09	1.13	1.16	1.19	1.22	1.30	1.38	1.46	1.54
12	20	.93	.98	1.02	1.06	1.10	1.13	1.16	1.19	1.22	1.30	1.38	1.46	1.54
13	19	.93	.97	1.02	1.06	1.10	1.13	1.16	1.19	1.22	1.30	1.38	1.46	1.54
13	20	.94	.98	1.02	1.06	1.10	1.13	1.16	1.20	1.23	1.31	1.38	1.47	1.54

[a] An additional 17.86 cubic feet per second of pumpage was included at model row 14, column 20, to account for water use by the papermill at West Monroe.

Table 8.--Temporal distribution of projected pumpage for simulating alternative plans--Continued

Model row	Model column	Rate of pumping (cubic feet per second) per period interval (years)												
		1980	1981-85	1986-90	1991-95	1996-2000	2001-05	2006-10	2011-15	2016-20	2021-25	2026-30	2031-35	2036-40
Group C														
11	22	0.96	1.00	1.01	1.02	1.03	1.04	1.05	1.06	1.07	1.05	1.02	0.99	0.96
11	24	.00	.00	.11	.12	.13	.14	.15	.16	.17	.18	.19	.20	.21
11	25	.00	.00	.00	.04	.08	.08	.08	.09	.10	.11	.12	.13	.14
12	23	.96	1.00	1.01	1.02	1.03	1.04	1.05	1.06	1.07	1.04	1.01	.98	.96
15	22	.96	1.00	1.01	1.02	1.03	1.04	1.05	1.06	1.07	1.04	1.01	.98	.95
15	23	.00	.00	.00	.03	.06	.07	.08	.09	.10	.11	.12	.13	.14
17	23	.00	.00	.00	.03	.06	.07	.08	.09	.10	.11	.12	.13	.14
Group D														
11	18	14.93	15.60	16.27	16.94	17.62	18.23	18.83	19.43	20.04	20.89	21.75	22.61	23.47
Group E														
11	18	0.00	0.67	1.34	2.01	2.69	3.30	3.90	4.50	5.11	5.96	6.82	7.68	8.54
Group F														
11	15	14.93	15.60	16.27	16.94	17.62	18.23	18.83	19.43	20.04	20.89	21.75	22.61	23.47

Alternative D.--Pumping would consist of groups A, B, C, and F in table 8. Group F would involve an increase in pumpage of 23.47 ft^3/s. The total increase in pumpage from the 1980 value with this alternative plan is 34.05 ft^3/s.

Alternatives A1, B1, C1, and D1.--Pumping would be the same as for alternatives A-D, except that the pumpage would increase at all other pumping centers from the Sparta aquifer, assuming that the growth rate for those centers was the same as for alternative A.

Groups A, B, and C represent existing pumping centers in Ouachita Parish in 1980. Projections by the Corps of Engineers indicate that from 1980 to 2040 pumpage for alternative A (groups A, B, and C) will increase 88 percent. Therefore, for alternatives A1 through D1 to include growth outside Ouachita Parish, background pumpage was increased by 88 percent from 1980-2040. The pumpage from the Sparta aquifer outside Ouachita Parish in 1980 was 218 ft^3/s. This background pumpage in 2040 for alternatives A1 through D1 will increase to about 410 ft^3/s.

Analysis of Impact on Potentiometric Levels

Simulations of alternative pumping plans were made using the eight pumping schemes described previously. The drawdown from 1900 to 1980 was input to these simulations. The output of the simulations was drawdown from 1980 to 2040. This output was superimposed on the prepumping water level of the Sparta aquifer (obtained from the steady-state analysis) to obtain the potentiometric level in 2040.

Alternatives B and B1 produced the most severe impact on the potentiometric levels of the Sparta aquifer. The results of the model simulations for these alternatives in the area of interest, Ouachita Parish, are shown on plates 8 and 9. These alternatives caused a severe impact because of the magnitude of the pumpage and the location of a new major pumping center (group D, table 8) adjacent to the existing major center at West Monroe. The most severe impact of these two alternatives was caused by B1 because a projected increase in regional pumpage also was included.

For alternative B, the drawdown cone at West Monroe is projected to decline to 236 ft below sea level at the end of 2040, from the model-generated level of 96 ft below sea level at the beginning of 1980. Additionally, a new drawdown cone is projected to develop around pumping center group D (table 8, pl. 7), northwest of West Monroe. The water level at this new drawdown cone would be 250 ft below sea level at the end of 2040, a decline of 211 ft from early 1980. For alternative B1, the water levels at West Monroe would deline to 327 ft below sea level at the end of 2040. The water level at the group D well field would decline to 350 ft below sea level by 2040, which represents a 311-foot decline from 1980.

The top of the Sparta aquifer in Ouachita Parish ranges from less than 100 ft below sea level to more than 200 ft below sea level. Alternative B and B1 are projected to cause the potentiometric level of the Sparta aquifer in Ouachita Parish to drop below the top of the aquifer. For alternative B, the potentiometric level in Ouachita Parish will drop below the top of the aquifer in the area within the -150 ft contour line (pl. 8). For alternative B1, large water-level declines would occur, and the potentiometric level would drop below the top of the aquifer in large areas of the model, including most of Ouachita Parish (pl. 8). With plan B1, dewatering in the upper part of the aquifer probably will occur. Dewatering occurs when the potentiometric level of an aquifer drops below the top of the aquifer and the aquifer changes from a confined system to a water table, or unconfined, aquifer. Problems associated with large water-level declines are land subsidence and possible well failure as a result of the subsidence and changes in the aquifer properties within the areas where dewatering occurs, such as lowered aquifer transmissivity, higher storage coefficient, and lower well yield.

Plates 8 and 9 also show the projected potentiometric surface of the Sparta aquifer for the year 2040 in Ouachita Parish for the remaining six alternative pumping plans. All of the alternatives are projected to result in potentiometric levels in the Sparta aquifer dropping below the top of the aquifer in Ouachita Parish. The conditions projected by plans A1 through D1 will have a greater impact than plans A through D. For plans A1 through D1, the potentiometric level will drop below the top of the aquifer in larger areas. For plans A-D, plans B and D are projected to cause the most severe areal drawdown and plans A and C would result in the least. Alternative A minimizes the areal extent of drawdown below the top of the aquifer.

The ground-water flow model used in this study was not set up to treat the local change from a confined to unconfined aquifer, as occurred with the eight alternative pumping plans. To determine when the potentiometric level drops below the top of the aquifer, elevations of the base of the Cook Mountain confining layer (Ryals, 1984) were compared with potentiometric levels. The model did not treat the change in storage coefficient that occurs when the level declines below the top of the aquifer. This change would be from the model value of about 1×10^{-4} to a value between 0.1 to 0.3. Drawdown associated with the change in storage coefficient likely would be an order of magnitude smaller because water would begin to be released from storage. The model results, thus, represent a "worst-case" condition. At West Monroe, most of the pumpage from the Sparta is from the lower part of the aquifer. As pointed out during the discussion of calibration, the uppermost sands typically are poorly connected to the lower sands. This resulted in model simulated drawdown being greater than the observed drawdown. Because the model was not designed to treat the poor connection between upper and lower sands that occurs in some areas, the model-projected drawdown in these areas also would represent a worst-case condition. Despite these limitations, the results discussed above provide a means for evaluating the relative effects of each of the alternative pumping plans.

Analysis of Movement of Saline Water

The pumping alternatives projected by the Corps of Engineers will have an adverse impact on the rate of movement of saline water within the Sparta aquifer toward West Monroe. Presently (1983), saline water occurs in most of the Sparta about 6 mi southeast of West Monroe. The rate of movement of the saline water toward West Monroe was estimated to be about 150 ft/yr during a previous investigation (Rogers and others, 1972, p. 31). However, based on information from this model, different projected rates of movement have been made for 1980 and for each of the pumping alternatives. Rates of water movement were estimated using Darcy's law, hydraulic parameters used in the model, projected potentiometric levels along a flow path across the saltwater front (model nodes row 14, column 20 and row 17, column 23), and an assumed effective porosity of 0.10 and 0.30. The form of Darcy's Law used in these calculations is

$$V = \frac{(3.1356 \times 10^7)T}{N_e b} \frac{dh}{dl}$$

where V = average velocity of ground-water movement in feet per year

N_e = effective porosity of the aquifer as a decimal fraction (dimensionless)

dh/dl = the hydraulic gradient of the aquifer along a flow path across the saltwater front (dimensionless)

T = the transmissivity of the aquifer along the flow path in square feet per second.

b = thickness of the aquifer (feet)

3.1356×10^7 = conversion factor from feet per second to feet per year.

Using an effective porosity of 0.1 (lower limit of probable range) results in a faster rate of water movement; whereas, using an effective porosity of 0.3 (upper limit of probable range) results in a slower rate. In the following discussion of the effects of pumpage on the rate of water movement, the rate using an effective porosity of 0.1 is given first, followed in parentheses by the rate using an effective porosity of 0.3.

The rate of saline-water movement toward West Monroe for 1980 is estimated to have been 96(32) ft/yr. For 2040, the maximum rates of movement toward West Monroe were obtained for pumping alternatives B and B1. For alternative B, the rate in 2040 is projected to be 156(52) ft/yr; for alternative B1, 167(56) ft/yr. Alternative A produced the slowest rate of movement (129(43) ft/yr). Based on these data, the rate of movement of saline water toward West Monroe will increase between 34 and 74 percent from the 1980 rate. However, no adverse effects on the water quality in West Monroe from the saltwater body to the southeast is anticipated for at least 200 years. Wells closer to the saline water would be affected sooner. For more accurate predictions of the movement of saline water toward West Monroe, a solute-transport model, which is beyond the scope of this investigation, would be needed.

SUMMARY AND CONCLUSIONS

A conceptual model of the Sparta aquifer was developed using preliminary two- and three-dimensional finite-difference ground-water models. The preliminary modeling indicated that the Sparta aquifer does not behave as an isolated hydrogeologic unit when pumped because significant amounts of water are derived from underlying and overlying aquifers as leakage through intervening confining layers.

A detailed three-dimensional finite-difference ground-water model was developed to simulate flow in the system that included the Sparta and underlying and overlying confining layers and aquifers. The area modeled extended from the eastern outcrop area of the Sparta aquifer in Mississippi, across northern Louisiana to its western outcrop. The model was calibrated for the period 1900-1964, using parameter-estimation techniques. The developed model was found to be most sensitive to the transmissivity of the Sparta aquifer and the vertical hydraulic conductivity of the Cook Mountain confining layer. The model was further tested for water-level response to pumpage for the period 1965-79. A water budget of the Sparta aquifer, based on results from the model for the period 1900-1980, indicates that about 45 percent of the water pumped from the aquifer is derived from leakage through overlying and underlying confining layers. Of the remaining 55 percent of water pumped from the aquifer, 38 percent originates from the outcrop-subcrop areas and 17 percent originates from release of water from storage in the Sparta aquifer. The major source of leakage to the Sparta aquifer is from the Cockfield aquifer, which is the source of 40 percent of the water pumped from the aquifer.

The U.S. Army Corps of Engineers has projected increased pumpage from the Sparta to meet water-supply requirements for West Monroe. The model was used to determine the effects of these increases on water levels and water quality. Eight alternative pumping plans were evaluated using the model. The additional pumpage for the period 1980-2040 projected for the eight plans ranged from 10.58 ft^3/s for plan A to 226 ft^3/s for plan B1. In all instances, potentiometric levels of the Sparta aquifer were projected to decline below the top of the aquifer within parts of Ouachita Parish. The maximum decline in water level, for the period 1980-2040 associated with the eight pumping plans, ranged from 51 ft (plan A) to 296 ft (plan B1). These projected drawdowns represent the worst-case conditions because the model did not treat the change from confined to water-table conditions or the local poor connection within sands of the Sparta aquifer.

Water levels projected by the model were used to calculate the rate of movement toward West Monroe of saline water in an area 6 mi southeast of West Monroe. To bracket the potential rate, effective porosities of 0.1 and 0.3 were assumed in the calculations. In the following discussion the rate determined by using a value of 0.1 is given first, followed in parentheses by the rate using 0.3. The 1980 rate of movement was 96(32) ft/yr. The rate of water movement for 2040 for the eight plans ranged from 129(43) ft/yr for plan A to 167(56) ft/yr for plan B1. The projected pumpage is not expected to cause adverse water-salinity problems at West Monroe for at least 200 years. Of the eight plans evaluated, plan A is preferable because it produced the least drawdown, minimized the areal extent of drawdown, and produced the slowest rate of movement of saline water towards West Monroe.

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APPENDIX A

Listing for Sparta Sand, Calibration Run 9

Data are input to the McDonald (1983) modular model through the various modules in the program. Input for each module used during the final calibration simulation are listed on the following pages.

A1. Basic Package Input Listing

A2. Block-Centered Flow Package Input Listing

A3. Well Package Input Listing

A4. Strongly Impicit Procedure Package Input Listing

A5. Output Control Listing.

A1. BASIC PACKAGE INPUT LISTING

```
 SPARTA SAND,CALIBRAT BASE RUN 9 S1=.1    ,S2=1E-6 ,S3=5E-4            8
10-10  BY  DOUG TRUDEAU
         3        26        35         7         1         1
11 31                    29       30
         0         1
         5         1              (35I2)        -3
 0 0 0 0 0 0 0 0 0 0 0-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1 0
 0 0 0 0 0 0 0 0 0 0 0-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1 0
 0 0 0 0 0 0-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1 0
 0 0 0 0 0 0-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1 0
 0 0 0 0 0 0 0 0-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1 0
 0 0 0 0 0 0 0 0-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1 0
               0-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1 0
               0-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1 0
               0-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1 0
               0-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1 0
               0-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1 0
               0-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1 0
               0-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1 0
               0 0 0 0-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1 0
                     0-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1 0
                     0-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1 0
                     0-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1 0
                     0-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1 0
                     0-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1 0
                     0-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1 0
                     0-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1 0
                     0-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1 0
                   0 0-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1
                   0-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1
               0-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1
     0-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1
         5         1              (35I2)        -3
               0-1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1-1 0
         0-1-1-1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1-1 0
   0-1-1-1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1-1 0
-1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1-1 0
 0-1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1-1 0
   0-1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1-1 0
     0-1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1-1 0
       0-1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1-1 0
       0-1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1-1
       0-1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1-1
       0-1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1-1
         0-1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1-1
         0-1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1-1
         0-1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1-1
         0-1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1-1
         0-1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1-1
         0-1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1-1
         0-1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1-1
           0-1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1-1
           0-1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1-1
           0-1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1-1
             0-1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1-1
             0-1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1-1
             0-1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1-1
   0-1-1-1-1-1-1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1-1
-1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1-1
         5         1              (35I2)        -3
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 0 0 0 0-1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1-1
 0-1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1-1
-1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1-1
-1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1-1
-1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1-1
 0 0-1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1-1
 0 0 0-1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1-1
 0 0 0 0-1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1-1
 0 0 0 0-1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1-1
 0 0 0 0-1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1-1
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 0 0 0 0 0-1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1-1
 0 0 0 0 0-1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1-1
 0 0 0 0 0-1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1-1
 0 0 0 0 0-1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1-1
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 0 0 0 0 0-1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1-1
         0-1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1-1
         0-1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1-1
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         0-1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1-1
 0 0 0 0 0-1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1-1
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-1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1-1
-1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1-1
9999999999
         0       0.0
         0       0.0
         0       0.0
 3.1536E08        17       1.5
 3.1536E08        17       1.5
 3.1536E08        17       1.5
 3.1536E08        17       1.5
 3.1536E08        17       1.5
 3.1536E08        17       1.5
 1.5768E08        15       1.5
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A2. BLOCK-CENTERED FLOW PACKAGE INPUT LISTING

```
         0        41
0 0 0
         0       1.0
        11      5280.           (8F10.2)
     10.00      6.75      6.75      6.75      6.75      6.75      6.75      6.75
      6.75      6.75      6.75      6.75      6.75      4.50      3.00      2.00
      2.00      2.00      2.00      2.00      2.00      2.00      2.00      2.00
      2.00      3.00      4.50      6.75     10.00     15.00     22.50     33.75
     33.75     33.75     33.75
        11      5280.           (8F10.2)
     22.50     15.00     15.00     15.00     10.00      6.75      4.50      3.00
      2.00      2.00      2.00      2.00      2.00      2.00      2.00      2.00
      2.00      2.00      2.00      3.00      4.50      6.75     10.00     15.00
     22.50     33.75
         0        .1
         0   6.50E-2
        11  1.46E-10            (10F8.7)           2
                                                                        0.00
0.00    1.00E-2 1.00E-2 1.00E-2 1.00E-2 1.00E-2 1.00E-2 1.00E-2 1.00E-2 1.00E-2
1.00E-2 1.00E-2 1.00E-2 1.00E-2 1.00E-2 1.00E-2 1.00E-2 1.00E-2 1.00E-2 1.00E-2
1.00E-2 4.35E-2
                                                                        0.00
0.00    1.00E-2 1.00E-2 1.00E-2 1.00E-2 1.00E-2 1.00E-2 1.00E-2 1.00E-2 1.00E-2
1.00E-2 1.00E-2 1.00E-2 1.00E-2 1.00E-2 1.00E-2 1.00E-2 1.00E-2 1.00E-2 1.00E-2
1.00E-2 3.70E-3
                                                6.67E-3 6.67E-3 6.67E-3 6.67E-3
6.67E-3 6.67E-3 6.67E-3 6.06E-3 5.71E-3 5.71E-3 5.88E-3 6.25E-3 6.06E-3 5.88E-3
5.71E-3 5.56E-3 5.40E-3 5.26E-3 5.40E-3 5.56E-3 6.25E-3 6.67E-3 6.25E-3 1.00E-2
1.00E-2 1.00E-2
                                                6.67E-3 6.67E-3 6.67E-3 6.67E-3
6.67E-3 6.67E-3 5.26E-3 5.00E-3 5.71E-3 5.83E-3 6.06E-3 6.45E-3 6.67E-3 6.67E-3
7.14E-3 6.90E-3 6.67E-3 6.67E-3 6.67E-3 6.90E-3 7.14E-3 6.67E-3 6.67E-3 1.00E-2
1.00E-2 1.00E-2
                                                                6.67E-3 6.67E-3
6.67E-3 6.67E-3 4.76E-3 6.25E-3 7.14E-3 6.90E-3 6.67E-3 6.67E-3 6.67E-3 6.45E-3
6.45E-3 6.25E-3 6.25E-3 6.67E-3 6.45E-3 6.25E-3 5.71E-3 5.00E-3 5.88E-3 6.67E-3
5.71E-3 5.00E-3 2.00E-2
                                                                6.67E-3 6.67E-3
6.67E-3 6.25E-3 5.56E-3 5.00E-3 5.00E-3 5.00E-3 5.26E-3 5.71E-3 7.14E-3 8.00E-3
8.00E-3 7.69E-3 7.69E-3 7.41E-3 7.14E-3 6.67E-3 5.88E-3 5.00E-3 5.40E-3 6.67E-3
5.71E-3 6.67E-3 1.00E-2
                                                                6.67E-3 6.67E-3
6.67E-3 5.88E-3 5.88E-3 6.67E-3 7.41E-3 8.00E-3 9.52E-3 1.00E-2 1.11E-2 1.11E-2
1.00E-2 1.00E-2 1.00E-2 9.90E-3 9.90E-3 8.85E-3 7.23E-3 5.00E-3 5.56E-3 5.88E-3
4.76E-3 3.45E-3 1.00E-2
                                                                6.67E-3 6.67E-3
6.25E-3 5.56E-3 7.14E-3 7.41E-3 7.69E-3 8.70E-3 1.11E-2 1.11E-2 1.11E-2 1.11E-2
9.90E-3 9.90E-3 9.50E-3 9.30E-3 8.80E-3 7.50E-3 6.25E-3 5.56E-3 5.71E-3 6.67E-3
6.25E-3 3.08E-3 1.00E-2
                                                                6.67E-3 6.67E-3
5.88E-3 5.26E-3 7.69E-3 7.69E-3 8.00E-3 7.69E-3 8.33E-3 8.69E-3 8.69E-3 9.90E-3
9.90E-3 9.90E-3 9.50E-3 8.90E-3 8.50E-3 7.41E-3 6.67E-3 5.88E-3 5.88E-3 6.67E-3
4.44E-3 3.33E-3 1.33E-2
                                                                6.67E-3 6.67E-3
5.88E-3 5.00E-3 8.33E-3 7.41E-3 7.14E-3 6.67E-3 7.14E-3 8.00E-3 8.20E-3 9.90E-3
9.90E-3 9.90E-3 9.89E-3 9.50E-3 8.90E-3 7.41E-3 6.90E-3 6.25E-3 6.06E-3 8.00E-3
1.00E-2 3.64E-3 8.00E-3
                                                                8.00E-3 8.00E-3
5.71E-3 4.76E-3 8.00E-3 7.14E-3 6.67E-3 5.71E-3 6.67E-3 7.14E-3 9.90E-3 9.90E-3
9.90E-3 9.90E-3 9.90E-3 9.90E-3 9.30E-3 8.90E-3 7.41E-3 6.67E-3 6.25E-3 8.00E-3
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5.71E-3 3.57E-3 8.70E-3 2.00E-2
                                                                6.90E-3 6.90E-3
6.45E-3 6.45E-3 7.14E-3 6.67E-3 5.56E-3 5.00E-3 5.71E-3 7.90E-3 9.50E-3 9.90E-3
9.90E-3 9.90E-3 9.90E-3 9.90E-3 9.90E-3 8.90E-3 8.00E-3 7.14E-3 6.45E-3 8.00E-3
6.67E-3 3.85E-3 7.69E-3 1.33E-2
                                                                6.90E-3 6.90E-3
1.45E-3 6.67E-3 7.14E-3 6.06E-3 5.00E-3 5.00E-3 6.71E-3 8.50E-3 9.90E-3 9.90E-3
9.90E-3 9.90E-3 9.90E-3 9.90E-3 9.90E-3 8.90E-3 8.00E-3 7.41E-3 6.67E-3 8.00E-3
8.00E-3 4.54E-3 4.26E-3 1.00E-2

        7.14E-3 6.67E-3 5.71E-3 5.40E-3 5.40E-3 6.91E-3 8.90E-3 9.90E-3 9.90E-3
9.90E-3 9.90E-3 9.90E-3 9.50E-3 9.50E-3 8.26E-3 8.13E-3 8.00E-3 6.90E-3 6.67E-3
5.71E-3 4.08E-3 8.00E-3 1.18E-2

        6.67E-3 6.45E-3 5.71E-3 5.71E-3 5.71E-3 5.88E-3 7.91E-3 9.50E-3 9.90E-3
9.90E-3 9.90E-3 9.90E-3 9.90E-3 9.90E-3 8.90E-3 8.13E-3 8.00E-3 7.14E-3 8.00E-3
6.67E-3 4.26E-3 6.06E-3 2.00E-2

        6.45E-3 6.25E-3 5.88E-3 5.88E-3 5.71E-3 5.88E-3 7.91E-3 9.50E-3 9.90E-3
9.90E-3 9.90E-3 9.90E-3 9.90E-3 9.90E-3 9.90E-3 8.53E-3 7.41E-3 7.41E-3 5.71E-3
5.56E-3 4.08E-3 7.70E-3 2.00E-2

        5.88E-3 6.06E-3 6.06E-3 5.88E-3 5.81E-3 5.88E-3 7.28E-3 9.34E-3 9.90E-3
9.90E-3 9.90E-3 9.90E-3 9.90E-3 9.90E-3 8.26E-3 8.13E-3 8.00E-3 7.14E-3 5.00E-3
7.41E-3 5.13E-3 6.90E-3 2.00E-2

        7.50E-3 9.34E-3 9.90E-3 6.25E-3 5.88E-3 6.06E-3 7.50E-3 9.34E-3 9.90E-3
9.90E-3 9.90E-3 9.90E-3 9.90E-3 8.90E-3 8.33E-3 8.33E-3 8.33E-3 7.41E-3 4.44E-3
4.88E-3 4.35E-3 9.09E-3 1.54E-3

        6.06E-3 6.25E-3 6.90E-3 6.45E-3 6.25E-3 6.06E-3 7.90E-3 9.90E-3 9.90E-3
9.90E-3 9.90E-3 9.90E-3 8.33E-3 8.33E-3 8.26E-3 8.33E-3 8.33E-3 8.00E-3 5.00E-3
5.40E-3 4.88E-3 9.09E-3 1.00E-2

        6.25E-3 6.45E-3 6.90E-3 6.45E-3 6.45E-3 6.67E-3 6.45E-3 6.45E-3 6.67E-3
7.25E-3 8.00E-3 8.70E-3 8.70E-3 8.33E-3 8.20E-3 8.13E-3 8.00E-3 7.69E-3 8.00E-3
8.00E-3 4.88E-3 8.00E-3 5.71E-3

        6.45E-3 6.90E-3 6.67E-3 6.40E-3 6.45E-3 6.67E-3 6.45E-3 7.14E-3 7.69E-3
8.33E-3 1.00E-2 1.00E-2 9.09E-3 8.70E-3 8.00E-3 8.00E-3 7.41E-3 7.41E-3 8.00E-3
1.11E-2 5.26E-3 6.45E-3 4.44E-3
                                                                        0.00
        7.69E-3 7.69E-3 7.14E-3 6.25E-3 5.71E-3 6.06E-3 7.14E-3 7.14E-3 6.67E-3
6.67E-3 7.14E-3 8.00E-3 7.14E-3 6.67E-3 6.67E-3 5.71E-3 6.67E-3 6.67E-3 1.33E-2
1.54E-3 5.56E-3 5.00E-3 3.64E-3
                                                                        0.00
        7.69E-3 7.69E-3 8.00E-3 7.69E-3 7.69E-3 8.33E-3 9.52E-3 1.00E-2 1.05E-2
9.52E-3 8.69E-3 8.00E-3 7.41E-3 6.90E-3 6.45E-3 5.88E-3 5.71E-3 5.56E-3 1.00E-2
5.00E-3 3.92E-3 5.71E-3 4.76E-3 4.44E-3
                                                                        0.00
8.00E-3 6.67E-3 8.00E-3 8.33E-3 8.00E-3 8.00E-3 8.00E-3 9.09E-3 1.00E-2 1.00E-2
9.09E-3 8.33E-3 8.00E-3 6.67E-3 6.67E-3 6.25E-3 5.88E-3 5.56E-3 5.26E-3 1.33E-2
5.00E-3 5.71E-3 4.00E-3 3.08E-3 1.33E-2
                                                                5.88E-3 5.71E-3
5.00E-3 5.40E-3 5.71E-3 5.71E-3 6.67E-3 7.41E-3 7.69E-3 7.41E-3 6.90E-3 6.67E-3
6.90E-3 6.25E-3 6.25E-3 6.06E-3 5.88E-3 5.88E-3 6.06E-3 5.71E-3 5.40E-3 4.44E-3
5.00E-3 6.67E-3 6.67E-3 4.00E-3 3.08E-3
                        2.67E-3 4.44E-3 3.85E-3 9.09E-3 7.14E-3 8.00E-3 2.94E-3
1.82E-3 3.64E-3 6.67E-3 5.71E-3 1.74E-3 3.85E-3 3.23E-3 3.08E-3 3.33E-3 2.86E-3
2.56E-3 2.30E-3 2.33E-3 2.50E-3 2.60E-3 2.86E-3 2.86E-3 2.74E-3 2.22E-3 3.70E-3
```

A2. BLOCK-CENTERED FLOW PACKAGE INPUT LISTING--CONTINUED

```
 5.71E-3 6.67E-3 1.32E-3 5.00E-3 3.64E-3
        11    1.0E-5            (20F4.0)         0
                                1E 4  40  40  40  40  40  75  75  75  75  75  75
  75  75  75  75 120 120 120 120 120 240  50  401E04
                    1E041E041E04  52  52  52  52  52  52  85  85  85  85  85  85
  85  85  85 120 120 120 120 120 120  50  50  301E04
        1E041E041E041E04  40  40  40  40  40  40  40  40  85  85  85  85  85  85
  85  85  85  85  50  50  50  50  50  50  50  301E04
1E04  80  80  80  80  80  80  80  40  40  40  40  40  40  40  40  40  40  40  50
  40  40  40  40  40  40  40  40  40  40  40  20  201E04
    1E041E04  10  10  10  25  25  25  25  40  40  40  40  40  40  40  40  40  40
  40  10  10  10  10  10  10  10  10  10  20  30  101E04
        1E041E04  10  25  25  25  25  25  25  25  25  25  25  25  25  25  25  25
  10  10  10  10  10  10  10  10  10  10  20  30  101E04
            1E04  25  25  25  25  25  40  40  40  20  20  20  20  20  20  20  20
  10  10  10  10  10  10  10  10  10  10  20  30  101E04
                1E04  25  25  25  25  40  40  40  40  20  20  20  20  20  20  20
  10  10  10  10  10  10  10  10  10  10  10  30  101E04
                1E04  25  25  25  25  40  40  40  40  20  20  20  20  20  10  10
  10  10  10  10  10  10  10  10  10  10  10  30  10  101E04
                1E04  25  25  25  25  40  40  40  40  20  20  20  20  10  10  10
  10  10  10  10  10  10  10  10  10  10  10  30  10  101E04
                1E04 120 120 120 120  40  40  40  40  10  10  10  10  10  10  10
  10  10  10  10  10  10  10  30  30  10  30  45  10  101E04
                    1E04 120 120 120  40  40  40  40  10  10  10  10  10  10  10
  10  10  10  10  10  10  30  30  30  30  40  45  10  101E04
                    1E04 120 120 120  40  40  40  40  10  10  10  10  10  10  10
  10  10  10  10  10  10  30  30  30  40  40  45  10  101E04
                    1E04 120 120 120  80  80  50  50  10  10  10  10  10  10  10
  10  10  10  10  10  30  30  30  30  40  40  45  10  101E04
                    1E04 120 120 120 120  50  50  50  10  10  10  10  10  10  10
  10  10  10  10  10  30  30  30  30  40  40  45  10  101E04
                    1E04 120 120 120 120  50  50  50  10  10  10  10  10  10  10
  10  10  10  10  30  30  30  30  30  40  40  45  10  101E04
                    1E04 120 120 120 120  50  50  50  10  10  10  10  10  10  10
  10  10  10  30  30  30  30  30  25  40  40  45  10  101E04
                    1E04 120 120 120 120  50  50  50  50  10  10  10  10  10  10
  10  10  10  30  30  30  30  30  25  40  40  45  10  101E04
                        1E04 120 120 120  50  50  50  50  10  10  10  10  10  10
  10  10  10  30  30  30  30  30  25  40  40  40  10  101E04
                        1E04 120 120 120  50  50  50  10  10  10  10  10  10  10
  10  10  30  30  30  30  30  25  25  40  40  40  10  101E04
                        1E04 120 120 120  50  50  50  50  10  10  10  10  10  10
  10  10  10  30  30  30  30  25  25  40  40  40  10  101E04
                            1E04  50  50  50  50  50  50  10  10  10  10  10  10
  10  10  10  10  10  10  25  25  25  40  40  40  10  101E04
                            1E04  10  10  10  10  10  10  10  10  10  10  10  10
  10  10  10  10  10  10  25  25  25  40  50  40  20  101E04
                            1E04  10  10  10  10  10  10  30  30  30  30  30  30
  30  30  30  40  40  40  40  40  40  40  50  40  20  101E04
        1E041E041E041E041E041E04  20  20  20  20  20  20  30  30  30  30  30  30
  30  30  30  40  40  40  40  40  50  50  50  30  10  101E04
1E04  20  20  20  20  20  20  20  20  40  40  40  40  40  40  40  40  40  40  40
  40  40  40  40  40  40  40  40  50  50  50  20  10  101E04
        11   0.65E-4            (8F10.5)         2
     0.0       0.0       0.0       0.0       0.0       0.0       0.0           0
   330.000  1000.000  1000.000  1006.000  1238.000  1470.000  1702.000  1895.000
  1934.000  2011.000  2707.000  2784.000  2784.000  2784.000  2359.000  2243.000
  2073.000  2436.000  3481.000  3363.000  3094.000  3094.000  2707.000  1933.000
   396.000     0.0       0.0
```

```
     0.0         0.0         0.0     000.000     000.000     100.000     600.000    1140.000
  1140.000    1140.000    1147.000    1315.000    1933.000    1470.000    1392.000    1392.000
  1663.000    1663.000    1392.000    1160.000     928.000     774.000     928.000    1547.000
  1856.000    2320.000    2475.000    1856.000    2707.000    2707.000    1933.000    1160.000
   396.000       0.0         0.0
     0.0     000.000     100.000     600.000     600.000     600.000     600.000     600.000
   600.000     600.000     600.000     600.000     735.000    1006.000     928.000    1083.000
  1083.000    1160.000    1392.000    1470.000    1547.000    1702.000    1934.000    2320.000
  2475.000    2552.000    2320.000    2591.000    3094.000    3094.000    1547.000    1547.000
   396.000       0.0         0.0
   100.000     600.000     600.000     600.000     600.000     600.000     600.000    1006.000
  1238.000    1392.000    2011.000    1702.000    1392.000    1160.000    1006.000    1160.000
  1160.000    1238.000    1314.000    1431.000    1692.000    1832.000    1933.000    2397.000
  2475.000    2552.000    2320.000    2939.000    2320.000    2707.000    1547.000    2475.000
  1160.000     374.000       0.0
     0.0    1220.000    1200.000    1200.000    1938.000    1934.000    1934.000    1702.000
  1702.000    1934.000    1934.000    1315.000    1160.000    1160.000    1314.000    1547.000
  1547.000    1547.000    1547.000    1702.000    1392.000    1470.000    2166.000    2475.000
  2320.000    2088.000    2392.000    2784.000    1934.000    1934.000    2320.000    2707.000
  1933.000     300.000       0.0
     0.0         0.0     360.000    1100.000    1114.000    1392.000    1934.000    1547.000
  1702.000    1702.000    1470.000    1470.000    1547.000    1547.000    1702.000    1934.000
  2321.000    1547.000    1392.000    1392.000    1547.000    2321.000    3094.000    2707.000
  1934.000    2000.000    2100.000    2320.000    2320.000    1702.000    1934.000    2935.000
  2320.000     396.000       0.0
     0.0         0.0         0.0     380.000    1300.000    1392.000    2011.000    1702.000
  1160.000    1702.000    1470.000    1470.000    1624.000    1547.000    1702.000    1780.000
  2011.000    2000.000    2000.000    1900.000    1702.000    2707.000    1470.000    1470.000
  1470.000    1547.000    1547.000    2320.000    1779.000    1934.000    2320.000    2320.000
  2320.000     396.000       0.0
     0.0         0.0         0.0         0.0     426.000    1547.000    1934.000    1547.000
  1500.000    1779.000    1470.000    1470.000    1392.000    1392.000    1470.000    1702.000
  2088.000    2398.000    1547.000    1392.000    1392.000    2475.000    2475.000    1392.000
  1392.000    1470.000    1934.000    2475.000    1547.000    1934.000    2320.000    2169.000
  2320.000    1160.000     346.000
     0.0         0.0         0.0         0.0     420.000    1547.000    1753.000    1547.000
  1547.000    1779.000    1470.000    1624.000    1392.000    1470.000    1500.000    1856.000
  2166.000    2398.000    1934.000    1392.000    1392.000    1779.000    2050.000    1470.000
  1392.000    1470.000    2320.000    1934.000    1699.000    1934.000    2320.000    2574.000
  2320.000    1160.000     346.000
     0.0         0.0         0.0         0.0     420.000    1547.000    1572.000    1547.000
  1547.000    1779.000    1470.000    1933.000    1392.000    1779.000    1934.000    1934.000
  2320.000    2475.000    1934.000    1392.000    1392.000    1516.000    2475.000    1934.000
  1779.000    2011.000    2398.000    1856.000    1602.000    2118.000    2320.000    2830.000
  2320.000    1160.000     346.000
     0.0         0.0         0.0         0.0     404.000    1340.000    1392.000    1547.000
  1547.000    1702.000    1470.000    1933.000    1470.000    1934.000    2290.000    2398.000
  2398.000    2320.000    1624.000    1392.000    1392.000    1702.000    2475.000    2398.000
  2398.000    2475.000    2320.000    1934.000    1516.000    2118.000    2320.000    3287.000
  2320.000    1160.000     346.000
     0.0         0.0         0.0         0.0     000.000     435.000    1392.000    1547.000
  1547.000    1624.000    1470.000    2166.000    1470.000    2011.000    2398.000    2398.000
  2398.000    1934.000    1470.000    1392.000    1624.000    2320.000    2398.000    2398.000
  2475.000    2398.000    2166.000    1934.000    1392.000    1962.000    2320.000    3481.000
  2127.000    1160.000     446.000
     0.0         0.0         0.0         0.0         0.0     475.000    1148.000    1470.000
  1516.000    1934.000    1470.000    2397.000    1470.000    1933.000    2398.000    2475.000
  2320.000    1779.000    1470.000    1547.000    2243.000    2398.000    2475.000    2475.000
  2398.000    2320.000    2166.000    2243.000    1602.000    1895.000    2528.000    3713.000
  1933.000    1160.000     446.000
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A2. BLOCK-CENTERED FLOW PACKAGE INPUT LISTING--CONTINUED

```
     0.0       0.0       0.0       0.0       0.0     404.000  1340.000  1392.000
  1469.000  2166.000  1470.000  2397.000  1448.000  1933.000  2475.000  2475.000
  2320.000  1856.000  1856.000  1356.000  2398.000  2475.000  2475.000  2398.000
  2320.000  1702.000  1933.000  2320.000  1895.000  2166.000  3353.000  3481.000
  1547.000  1160.000   493.000
     0.0       0.0       0.0       0.0       0.0     404.000  1350.000  1392.000
  1430.000  2320.000  1470.000  2475.000  1545.000  1856.000  2398.000  2475.000
  2398.000  2398.000  2398.000  2398.000  2245.000  1934.000  1895.000  1702.000
  1407.000  1547.000  2011.000  2475.000  2127.000  2088.000  2448.000  2346.000
  1663.000  1160.000   496.000
     0.0       0.0       0.0       0.0       0.0     460.000  1100.000  1100.000
  1392.000  2166.000  1702.000  2475.000  1470.000  1938.000  2398.000  2475.000
  2475.000  2398.000  2320.000  1780.000  1470.000  1392.000  1392.000  1470.000
  1470.000  1779.000  2320.000  2320.000  1933.000  2514.000  2320.000  2268.000
  1802.000  1160.000   496.000
     0.0       0.0       0.0       0.0       0.0     439.000  1065.000  1065.000
  1392.000  2166.000  1780.000  2397.000  1470.000  2011.000  2475.000  2475.000
  2398.000  1934.000  1547.000  1470.000  1392.000  1392.000  1470.000  1702.000
  1856.000  2166.000  2475.000  2702.000  2127.000  2417.000  2320.000  2374.000
  1906.000  1160.000   687.000
     0.0       0.0       0.0       0.0       0.0     496.000  1160.000  1160.000
  1392.000  2166.000  1856.000  2346.000  1470.000  2397.000  2475.000  2475.000
  2243.000  1547.000  1470.000  1392.000  1392.000  1392.000  1470.000  1702.000
  1856.000  2243.000  2475.000  2166.000  2320.000  2425.000  2398.000  2514.000
  2047.000  1160.000   711.000
     0.0       0.0       0.0       0.0       0.0     000.000   404.000  1340.000
  1676.000  2166.000  1856.000  2296.000  1470.000  2398.000  2475.000  2398.000
  1779.000  1470.000  1470.000  1392.000  1392.000  1392.000  1392.000  1470.000
  1780.000  2011.000  2475.000  1934.000  2320.000  2320.000  2011.000  2785.000
  2047.000  1360.000   837.000
     0.0       0.0       0.0       0.0       0.0       0.0     404.000  1344.000
  1650.000  2166.000  1933.000  2296.000  1702.000  2398.000  2475.000  2320.000
  1470.000  1470.000  1547.000  1392.000  1392.000  1392.000  1392.000  1392.000
  1470.000  1547.000  2088.000  1934.000  1856.000  2042.000  2320.000  2735.000
  2093.000  1160.000   711.000
     0.0       0.0       0.0       0.0       0.0       0.0     460.000  1100.000
  1152.000  1547.000  1933.000  2346.000  2088.000  2475.000  2475.000  2244.000
  1933.000  1675.000  1470.000  1392.000  1392.000  1932.000  1932.000  1932.000
  1932.000  1932.000  1470.000  2320.000  1702.000  2127.000  2475.000  2127.000
  1707.000  1160.000   461.000
     0.0       0.0       0.0       0.0       0.0       0.0       0.0     411.000
  1075.000  1466.000  1856.000  2475.000  2398.000  2165.000  1856.000  2011.000
  1547.000  1392.000  1392.000  1392.000  1392.000  1470.000  1547.000  1934.000
  2320.000  2320.000  2166.000  2320.000  2320.000  2707.000  3094.000  1934.000
  1702.000  1160.000   411.000
     0.0       0.0       0.0       0.0       0.0       0.0       0.0     351.000
  1171.000  1096.000  1547.000  2320.000  1934.000  1547.000  1934.000  1934.000
  2166.000  1934.000  1934.000  1856.000  1779.000  1702.000  1547.000  1624.000
  1856.000  2011.000  2166.000  2320.000  1699.000  2320.000  2320.000  2514.000
  1547.000  1392.000   432.000
     0.0       0.0       0.0       0.0       0.0       0.0       0.0     354.000
  1392.000  1547.000  1547.000  2011.000  1470.000  1238.000  1903.000  1852.000
  1686.000  2135.000  2015.000  1753.000  1392.000  1392.000  1392.000  1392.000
  1547.000  1932.000  1699.000  1699.000  1699.000  1547.000  1547.000  2707.000
  1470.000  1160.000   351.000
     0.0       0.0     380.000   800.000   800.000   800.000   850.000   948.000
  1547.000  1934.000  1906.000  1315.000  2088.000  1934.000  1470.000  1934.000
  1934.000  1547.000  1547.000  2320.000  2224.000  2224.000  2320.000  1702.000
  1702.000  1934.000  1699.000  1699.000  1699.000  1547.000  1547.000  2011.000
  1300.000  1300.000   437.000
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A2. BLOCK-CENTERED FLOW PACKAGE INPUT LISTING--CONTINUED

```
   360.000  1200.000  1250.000  1300.000  1320.000  1330.000  1340.000  1350.000
  1547.000  1934.000  1906.000  1315.000  2088.000  1934.000  1470.000  1934.000
  1934.000  1547.000  1547.000  2320.000  2224.000  2224.000  2320.000  1702.000
  1702.000  1934.000  1699.000  1699.000  1699.000  1547.000  1547.000  2011.000
  1300.000  1300.000   487.000
        11  6.08E-11            (10F8.7)           2
                                                                6.67E-3 5.00E-3
3.64E-3 2.86E-3 2.35E-3 2.22E-3 2.22E-3 2.22E-3 2.00E-3 2.00E-3 2.00E-3 2.00E-3
2.00E-3 1.96E-3 1.90E-3 1.90E-3 1.90E-3 1.90E-3 1.90E-3 1.74E-3 1.74E-3 1.64E-3
1.64E-3 1.74E-3 2.50E-3
                                        6.67E-3 5.00E-3 5.00E-3 4.00E-3 3.08E-3
2.86E-3 2.67E-3 2.44E-3 2.78E-3 2.94E-3 2.94E-3 2.90E-3 2.63E-3 2.35E-3 2.17E-3
2.10E-3 2.00E-3 2.10E-3 2.22E-3 2.35E-3 2.35E-3 2.17E-3 1.90E-3 2.08E-3 1.96E-3
1.82E-3 1.74E-3 2.50E-3
                4.00E-3 4.44E-3 4.44E-3 3.64E-3 4.00E-3 3.85E-3 3.64E-3 3.45E-3
3.33E-3 3.08E-3 3.08E-3 3.33E-3 3.33E-3 3.33E-3 3.33E-3 3.08E-3 2.94E-3 2.78E-3
2.86E-3 2.78E-3 2.67E-3 2.60E-3 2.50E-3 2.44E-3 2.50E-3 2.50E-3 2.67E-3 2.35E-3
2.00E-3 1.82E-3
4.44E-3 3.64E-3 3.64E-3 3.17E-3 3.08E-3 3.08E-3 3.08E-3 3.08E-3 3.08E-3 3.33E-3
3.64E-3 3.57E-3 3.33E-3 3.64E-3 3.51E-3 3.33E-3 3.33E-3 3.33E-3 3.51E-3 3.45E-3
3.33E-3 3.22E-3 3.17E-3 3.12E-3 3.12E-3 3.12E-3 3.12E-3 3.08E-3 3.51E-3 2.60E-3
2.50E-3 2.22E-3 2.10E-3 6.67E-3
        5.00E-3 4.44E-3 3.85E-3 4.00E-3 4.17E-3 3.85E-3 3.64E-3 3.51E-3 3.64E-3
3.85E-3 4.00E-3 3.85E-3 3.57E-3 3.64E-3 3.85E-3 3.85E-3 3.85E-3 3.77E-3 3.33E-3
3.17E-3 3.22E-3 3.33E-3 3.28E-3 3.17E-3 3.08E-3 3.08E-3 2.78E-3 3.08E-3 2.67E-3
2.86E-3 2.35E-3 2.10E-3 3.64E-3
                5.00E-3 4.00E-3 3.85E-3 3.85E-3 4.00E-3 4.00E-3 4.08E-3 4.08E-3
4.17E-3 4.00E-3 4.00E-3 3.64E-3 3.85E-3 3.77E-3 3.64E-3 3.33E-3 3.45E-3 3.22E-3
3.03E-3 3.08E-3 3.03E-3 3.03E-3 2.98E-3 2.94E-3 2.90E-3 2.94E-3 3.08E-3 2.98E-3
3.08E-3 2.22E-3 2.22E-3 3.33E-3
                        5.00E-3 3.64E-3 3.57E-3 4.00E-3 4.17E-3 4.17E-3 4.17E-3
4.08E-3 3.85E-3 4.17E-3 4.55E-3 4.17E-3 3.85E-3 4.17E-3 3.85E-3 3.70E-3 3.57E-3
3.45E-3 3.33E-3 3.22E-3 3.17E-3 3.08E-3 3.22E-3 3.45E-3 3.12E-3 3.08E-3 3.17E-3
3.08E-3 2.35E-3 2.35E-3 3.33E-3
                                4.00E-3 3.08E-3 3.08E-3 4.00E-3 4.26E-3 4.26E-3
4.17E-3 4.00E-3 4.00E-3 5.00E-3 4.35E-3 4.08E-3 4.17E-3 4.08E-3 3.85E-3 3.70E-3
3.57E-3 3.45E-3 3.17E-3 3.08E-3 3.12E-3 3.17E-3 3.45E-3 3.08E-3 3.12E-3 3.33E-3
2.86E-3 2.10E-3 2.50E-3 3.22E-3
                                4.17E-3 2.94E-3 3.08E-3 4.00E-3 4.17E-3 4.17E-3
4.17E-3 4.00E-3 3.92E-3 4.54E-3 4.54E-3 4.17E-3 4.17E-3 4.17E-3 4.08E-3 3.78E-3
3.64E-3 3.45E-3 3.22E-3 3.17E-3 3.22E-3 3.22E-3 3.40E-3 3.12E-3 3.17E-3 3.33E-3
2.78E-3 2.06E-3 2.35E-3 3.08E-3 4.00E-2
                                6.67E-3 3.08E-3 3.64E-3 4.00E-3 4.08E-3 4.17E-3
4.17E-3 4.00E-3 3.85E-3 4.26E-3 4.35E-3 4.26E-3 4.17E-3 4.08E-3 4.08E-3 3.77E-3
3.64E-3 3.45E-3 3.22E-3 3.22E-3 3.33E-3 3.33E-3 3.39E-3 3.33E-3 3.22E-3 3.33E-3
2.70E-3 2.00E-3 2.35E-3 2.94E-3 4.00E-2
                                1.00E-2 3.64E-3 4.00E-3 3.85E-3 4.00E-3 4.08E-3
4.00E-3 3.92E-3 3.85E-3 4.17E-3 4.17E-3 4.17E-3 4.08E-3 4.00E-3 4.00E-3 3.77E-3
3.64E-3 3.45E-3 3.28E-3 3.39E-3 3.45E-3 3.45E-3 3.39E-3 3.45E-3 3.33E-3 3.33E-3
2.56E-3 1.96E-3 2.50E-3 2.94E-3 4.00E-2
                                        4.25E-3 4.17E-3 3.85E-3 4.08E-3 4.08E-3
3.77E-3 3.85E-3 3.77E-3 4.08E-3 4.08E-3 4.00E-3 3.92E-3 3.85E-3 3.70E-3 3.85E-3
3.85E-3 3.64E-3 3.51E-3 3.57E-3 3.64E-3 3.64E-3 3.45E-3 3.64E-3 3.22E-3 3.39E-3
2.50E-3 1.90E-3 2.50E-3 2.86E-3 4.00E-2
                                        5.00E-3 4.26E-3 4.00E-3 4.17E-3 4.17E-3
3.85E-3 3.78E-3 3.70E-3 4.00E-3 3.92E-3 3.85E-3 3.77E-3 3.70E-3 3.85E-3 4.00E-3
4.00E-3 3.85E-3 3.70E-3 3.70E-3 3.85E-3 3.92E-3 3.57E-3 4.00E-3 3.33E-3 3.45E-3
2.50E-3 1.82E-3 2.67E-3 2.86E-3 2.00E-2
                                        6.67E-3 4.55E-3 4.08E-3 4.26E-3 4.17E-3
3.92E-3 3.70E-3 3.64E-3 3.64E-3 3.64E-3 3.64E-3 3.70E-3 3.77E-3 3.92E-3 4.08E-3
```

```
  4.08E-3 4.08E-3 3.85E-3 3.70E-3 4.00E-3 4.54E-3 3.85E-3 4.00E-3 3.33E-3 3.39E-3
  2.50E-3 1.82E-3 2.67E-3 2.86E-3 1.33E-2
                                          8.00E-3 4.76E-3 4.44E-3 4.44E-3 4.26E-3
  4.00E-3 3.77E-3 3.51E-3 3.33E-3 3.39E-3 3.57E-3 3.64E-3 3.77E-3 3.85E-3 4.08E-3
  4.17E-3 4.17E-3 4.00E-3 3.85E-3 4.00E-3 5.13E-3 4.17E-3 4.17E-3 3.39E-3 3.33E-3
  2.50E-3 1.82E-3 2.86E-3 2.86E-3 1.00E-2
                                          1.00E-2 5.71E-3 3.85E-3 4.54E-3 4.26E-3
  4.00E-3 3.70E-3 3.45E-3 3.22E-3 3.45E-3 3.57E-3 3.64E-3 3.70E-3 3.85E-3 4.08E-3
  4.17E-3 4.17E-3 4.00E-3 3.85E-3 4.17E-3 5.13E-3 4.44E-3 4.00E-3 3.51E-3 3.08E-3
  2.50E-3 1.82E-3 2.86E-3 3.08E-3 8.00E-3
                                          1.33E-2 5.71E-3 3.85E-3 4.00E-3 4.54E-3
  3.85E-3 3.64E-3 3.39E-3 3.45E-3 3.51E-3 3.57E-3 3.64E-3 3.77E-3 3.85E-3 4.00E-3
  4.17E-3 4.17E-3 3.92E-3 4.00E-3 4.44E-3 5.13E-3 5.00E-3 4.17E-3 3.39E-3 2.67E-3
  2.35E-3 1.82E-3 2.86E-3 3.08E-3 6.67E-3
                                          2.00E-2 5.71E-3 4.44E-3 4.76E-3 4.44E-3
  3.85E-3 3.64E-3 3.45E-3 3.51E-3 3.57E-3 3.57E-3 3.57E-3 3.57E-3 3.77E-3 3.85E-3
  4.08E-3 4.17E-3 4.17E-3 4.44E-3 4.88E-3 5.71E-3 5.71E-3 5.00E-3 3.33E-3 2.60E-3
  2.22E-3 1.74E-3 2.67E-3 2.86E-3 5.00E-3
                                                  6.67E-3 5.71E-3 5.00E-3 4.08E-3
  3.85E-3 3.70E-3 3.64E-3 3.64E-3 3.64E-3 3.57E-3 3.51E-3 3.51E-3 3.64E-3 3.77E-3
  3.92E-3 4.17E-3 4.44E-3 4.76E-3 5.40E-3 6.45E-3 6.67E-3 5.26E-3 3.45E-3 2.60E-3
  2.10E-3 1.74E-3 2.67E-3 2.78E-3 4.44E-3
                                                  6.67E-3 6.67E-3 5.00E-3 3.85E-3
  3.85E-3 3.77E-3 3.85E-3 3.77E-3 3.64E-3 3.51E-3 3.39E-3 3.39E-3 3.57E-3 3.70E-3
  3.85E-3 4.00E-3 4.54E-3 5.13E-3 5.71E-3 6.25E-3 6.90E-3 5.26E-3 3.64E-3 2.60E-3
  2.00E-3 1.74E-3 2.67E-3 2.67E-3 4.00E-3
                                                  1.00E-2 7.14E-3 5.00E-3 3.85E-3
  3.85E-3 3.85E-3 4.00E-3 3.85E-3 3.85E-3 3.64E-3 3.64E-3 4.00E-3 3.85E-3 3.70E-3
  3.85E-3 4.00E-3 4.76E-3 5.26E-3 5.71E-3 6.25E-3 6.67E-3 4.44E-3 3.33E-3 2.50E-3
  2.00E-3 1.74E-3 2.67E-3 2.35E-3 3.33E-3
                                                          8.00E-3 5.71E-3 4.76E-3
  4.44E-3 3.85E-3 3.85E-3 4.00E-3 4.17E-3 4.17E-3 4.08E-3 4.00E-3 3.85E-3 3.70E-3
  3.51E-3 3.64E-3 4.00E-3 4.26E-3 4.44E-3 4.44E-3 4.00E-3 3.33E-3 3.08E-3 2.50E-3
  1.82E-3 1.74E-3 2.27E-3 2.50E-3 3.08E-3
                                                          1.33E-2 8.00E-3 5.71E-3
  4.44E-3 4.44E-3 4.44E-3 4.00E-3 3.85E-3 3.85E-3 3.85E-3 3.85E-3 4.00E-3 4.00E-3
  4.00E-3 3.85E-3 3.64E-3 3.64E-3 3.64E-3 3.57E-3 3.33E-3 2.94E-3 2.67E-3 2.22E-3
  1.85E-3 1.67E-3 2.22E-3 2.50E-3 3.03E-3
                                                          4.00E-2 8.00E-3 5.71E-3
  5.00E-3 5.00E-3 4.44E-3 4.26E-3 4.17E-3 4.17E-3 4.44E-3 4.76E-3 5.26E-3 5.13E-3
  5.00E-3 4.54E-3 4.17E-3 3.85E-3 4.00E-3 3.64E-3 3.33E-3 3.64E-3 2.56E-3 2.35E-3
  2.10E-3 1.82E-3 1.82E-3 2.10E-3 2.86E-3
                  4.00E-2 2.00E-2 1.00E-2 6.67E-3 4.44E-3 4.44E-3 3.64E-3 3.64E-3
  4.44E-3 4.00E-3 4.00E-3 5.00E-3 5.00E-3 6.67E-3 6.67E-3 8.00E-3 8.00E-3 8.00E-3
  6.67E-3 6.67E-3 5.71E-3 5.00E-3 4.00E-3 3.64E-3 3.39E-3 3.08E-3 2.67E-3 2.50E-3
  2.35E-3 2.10E-3 2.00E-3 2.35E-3 2.50E-3
  3.64E-3 4.00E-3 4.00E-3 3.64E-3 3.64E-3 3.08E-3 2.67E-3 2.67E-3 2.86E-3 2.74E-3
  2.67E-3 2.86E-3 3.08E-3 3.22E-3 3.08E-3 3.08E-3 3.33E-3 3.33E-3 3.64E-3 3.64E-3
  3.64E-3 3.64E-3 3.64E-3 3.64E-3 3.78E-3 3.39E-3 3.33E-3 2.86E-3 2.50E-3 2.86E-3
  3.08E-3 2.86E-3 2.67E-3 3.33E-3 3.08E-3
        11   1.00E-4            (20F4.3)         2
   0   0   0   01000  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.
  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.1000   0
   01000  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.
  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.1000   0
1000  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.
  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.1000
1000  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.
  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.1000
1000  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.
```

A2. BLOCK-CENTERED FLOW PACKAGE INPUT LISTING--CONTINUED

```
  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.1000
   0   01000  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.
  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.1000
   0   0   01000  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.
  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.1000
   0   0   0   01000  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.
  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.1000
   0   0   0   01000  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.
  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.1000
   0   0   0   01000  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.
  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.1000
   0   0   0   01000  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.
  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.1000
   0   0   0   0   01000  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.
  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.1000
   0   0   0   0   01000  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.
  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.1000
   0   0   0   0   01000  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.
  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.1000
   0   0   0   0   01000  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.
  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.1000
   0   0   0   0   01000  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.
  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.1000
   0   0   0   0   01000  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.
  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.1000
   0   0   0   0   01000  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.
  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.1000
   0   0   0   0   01000  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.
  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.1000
   0   0   0   0   01000  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.
  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.1000
   0   0   0   0   01000  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.
  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.1000
   0   0   0   0   01000  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.
  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.1000
   0   0   0   0   01000  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.
  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.1000
1000  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.
  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.1000
1000  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.
  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.1000
1000  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.
  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.1000
        11   6.80E-2           (20F4.3)          2
   0   0   0   0  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.
  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.   0
   0  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.
  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.   0
  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.
  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.
  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.
  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.
  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.
  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.
   0   0  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.
  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.
   0   0   0  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.
  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.
   0   0   0   0  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.
  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.  1.
```

A2. BLOCK-CENTERED FLOW PACKAGE INPUT LISTING--CONTINUED

```
    0    0    0    0   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.
   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.
    0    0    0    0   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.
   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.
    0    0    0    0   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.
   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.
    0    0    0    0    0   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.
   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.
    0    0    0    0    0   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.
   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.
    0    0    0    0    0   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.
   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.
    0    0    0    0    0   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.
   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.
    0    0    0    0    0   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.
   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.
    0    0    0    0    0   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.
   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.
    0    0    0    0    0   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.
   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.
    0    0    0    0    0   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.
   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.
    0    0    0    0    0   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.
   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.
    0    0    0    0    0   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.
   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.
    0    0    0    0    0   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.
   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.
    0    0    0    0    0   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.
   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.
   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.
   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.
   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.
   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.
   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.
   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.
```

A3. WELL PACKAGE INPUT LISTING

```
85          41
 5           1
 2           8          21       -0.31
 2          11           9       -0.10
 2          12           9       -0.10
 2          12          12       -0.15
 2          13          19       -0.31
 8
 2           8          21       -0.54
 2          10           6       -0.15
 2          11           9       -0.12
 2          12           9       -0.12
 2          12          12       -0.46
 2          13          19       -0.54
 2           5          32       -0.20
 2          19          33       -0.30
17
 2           1          24       -0.25
 2           1          26       -0.25
 2           3           7       -0.10
 2           3          11       -2.05
 2           5           5       -0.07
 2           6           7       -0.09
 2           6           8       -0.09
 2           6          26       -3.09
 2           8          21       -0.54
 2          10           6       -0.54
 2          11           9       -0.18
 2          12           9       -0.18
 2          12          12       -0.46
 2          13          19       -0.54
 2          20          11       -0.15
 2           5          32       -2.00
 2          19          33       -2.30
26
 2           1          24       -0.50
 2           1          26       -0.50
 2           2          22       -0.20
 2           3           7       -0.54
 2           3          11       -5.66
 2           5           5       -0.15
 2           5           7       -0.15
 2           6           7       -0.19
 2           6           8       -0.19
 2           6          26      -10.83
 2           7          11       -0.08
 2           7          24       -2.32
 2           7          27       -0.08
 2           8          21       -1.24
 2           9           6       -0.15
 2          10           6       -0.62
 2          11           9       -0.27
 2          12           9       -0.27
 2          12          12       -0.70
 2          13          19       -0.62
 2          20          11       -3.28
 2          24          11       -0.08
 2           1          32       -0.50
 2           5          32       -4.50
 2          19          33       -5.40
```

A3. WELL PACKAGE INPUT LISTING--CONTINUED

```
   2        20        33     -0.50
  37
   2         1        24     -2.60
   2         1        26     -3.24
   2         1        28     -0.19
   2         2        22     -0.50
   2         3         7     -0.54
   2         3        11    -13.13
   2         3        12     -0.75
   2         5         4    -31.18
   2         5         5     -0.23
   2         5         7     -0.19
   2         6         7     -0.19
   2         6         8     -0.47
   2         6        11     -0.15
   2         6        14     -0.19
   2         6        26    -13.92
   2         7        11     -0.23
   2         7        24     -2.32
   2         7        27     -0.15
   2         8        21     -1.24
   2         9         6     -0.31
   2        10         6     -1.16
   2        11         9     -0.48
   2        12         9     -0.32
   2        12        11     -0.15
   2        12        12     -1.15
   2        13        19     -0.93
   2        14        20    -15.47
   2        20        11     -7.97
   2        21        11     -0.23
   2        24         9     -0.46
   2        24        11     -0.08
   2         1        32     -2.00
   2         5        32     -9.00
   2         8        33     -0.20
   2        18        33     -0.40
   2        19        33     -9.60
   2        20        33     -0.30
  45
   2         1        12     -0.50
   2         1        23     -0.77
   2         1        24     -2.90
   2         1        25     -4.14
   2         1        26     -1.23
   2         1        28     -0.30
   2         2        10     -0.50
   2         2        22     -1.00
   2         3         7     -1.00
   2         3        11    -17.00
   2         3        12     -1.50
   2         5         4    -19.02
   2         5         5     -0.23
   2         5         7     -0.31
   2         6         7     -0.19
   2         6         8     -0.63
   2         6        11     -0.31
   2         6        14     -0.31
   2         6        26    -18.56
   2         7        11     -0.70
```

A3. WELL PACKAGE INPUT LISTING--CONTINUED

```
 2           7         22     -0.31
 2           7         24     -2.32
 2           7         27     -0.23
 2           8         21     -1.70
 2           9          6     -0.46
 2           9         12     -0.15
 2          10          6     -1.73
 2          11          9     -0.57
 2          11         19     -0.31
 2          12          7     -0.15
 2          12          9     -0.29
 2          12         12     -1.99
 2          13         19     -1.24
 2          14         20    -15.47
 2          20         11    -15.70
 2          21         11     -0.25
 2          24          9     -1.04
 2          24         11     -0.39
 2          24         12     -0.67
 2           1         32     -5.00
 2           5         32    -13.90
 2           8         33     -0.50
 2          18         33     -0.50
 2          19         33    -15.77
 2          20         33     -0.50
56
 2           1         12     -0.50
 2           1         23     -3.85
 2           1         24     -3.44
 2           1         25    -20.73
 2           1         26     -1.15
 2           1         28     -0.50
 2           2         10     -2.00
 2           2         22     -1.00
 2           3          7     -1.50
 2           3         11    -20.00
 2           3         12     -3.00
 2           5          4    -16.56
 2           5          5     -0.37
 2           5          7     -2.09
 2           6          5     -2.30
 2           6          6     -0.22
 2           6          7     -0.60
 2           6          8     -1.38
 2           6         10     -0.28
 2           6         11     -0.42
 2           6         14     -0.39
 2           6         26    -18.80
 2           6         28     -0.18
 2           7         11     -1.31
 2           7         22     -0.46
 2           7         24     -2.63
 2           7         27     -0.34
 2           8         11     -0.77
 2           8         21     -2.01
 2           8         23     -0.15
 2           9          6     -0.54
 2           9         12     -0.53
 2          10          6     -2.80
 2          11          9     -1.18
```

A3. WELL PACKAGE INPUT LISTING--CONTINUED

```
2         11        19       -0.31
2         12         7       -0.22
2         12         9       -0.56
2         12        12       -3.10
2         12        23       -0.15
2         13        11       -0.12
2         13        19       -1.86
2         14        19       -0.46
2         14        20      -20.61
2         20        11      -16.46
2         21        11       -0.62
2         24         9       -1.31
2         24        11       -0.90
2         24        12       -1.08
2          1        32       -6.00
2          3        32       -0.20
2          5        32      -13.90
2          8        33       -1.16
2         18        33       -1.00
2         19        33      -16.00
2         20        33       -1.00
2         19        34       -0.20
```

A4. STRONGLY IMPLICIT PROCEDURE PACKAGE INPUT LISTING

```
100         5
  1.      1.E-3         0        4.E-5          0
```

A5. OUTPUT CONTROL LISTING

```
          -7        -7        40         0
           0         0         0         0
 0
 0
 0
 0
 0
 0
 0
 0
 0
 0
 0
 0
 0
 0
 0
 0
           0         0         0         0
           0         0         0         0
           0         0         0
           0
           0
           0
           0
           0
           0
           0
           0
           0
           0
           0
           0         0         0         0
           1       100         0         1
           0         0         0         0
           0        -3         0         0
           0         0         0         0
           0         0         0         0   THIS IS NEXT STRESS P
 0
 0
 0
 0
 0
 0
 0
 0
 0
 0
 0
 0
 0
 0
 0
 0
           0
           0
           0
           0
           0
           0
```

A5. OUTPUT CONTROL LISTING--CONTINUED

```
         0
         0
         0
         0
         0
         0
         0
         0
         0
         1        100         0         1
         0          0         0         0
         0         -3         0         0
         0          0         0         0
         0          0         0         0   THIS IS NEXT STRESS P
0
0
0
0
0
0
0
0
0
0
0
0
0
0
0
0
         0
         0
         0
         0
         0
         0
         0
         0
         0
         0
         0
         0
         0
         0
         0
         1       100       100         1
         0         0         0         0
         0        -3         0         0
         0         0         0         0
         0                                   THIS IS A NEXT STRESS P
0
0
0
0
0
0
0
0
0
0
```

A5. OUTPUT CONTROL LISTING--CONTINUED

```
0
0
0
0
0
0
         0
         0
         0
         0
         0
         0
         0
         0
         0
         0
         0
         0
         0
         0
         0
         1        100       100         1
         0          0         0         0
         0         -3         0         0
         0          0         0         0
         0                                  THIS IS NEXT STRESS P
0
0
0
0
0
0
0
0
0
0
0
0
0
0
0
0
         0
         0
         0
         0
         0
         0
         0
         0
         0
         0
         0
         0          1
         0          1
         0          1
         0          1
         1        100       100         1
         0          0         0         0
         0         -3         0         0
```

A5. OUTPUT CONTROL LISTING--CONTINUED

```
         0         0         0         0
         0                                 THIS IS NEXT STRESS P
0
0
0
0
0
0
0
0
0
0
0
0
0
0
0
0
         0
         0
         0
         0
         0
         0
         0
         0
         0
         0
         0
         0         1
         0         1
         0         1
         0         1
         1       100       100         1
         0         0         0         0
         0        -3         0         0
         0         0         0         0
         0                                THIS IS NEXT STRESS P
0
0
0
0
0
0
0
0
0
0
0
0
0
0
0
0
         0
         0
         0
         0
         0
         0
```

A5. OUTPUT CONTROL LISTING--CONTINUED

```
0
0           1
0           1
0           1
0           1
1         100        100          1
3           3         11          0
3          -3         11          0
3           3         11          0
```

APPENDIX B

Listing for Sparta Sand, Steady-State Simulation

Data input for the steady-state model simulations were the same as for the last calibration simulation except for:

B1. Basic Package Input Listing

B2. Output Control Listing (No well package is used.)

B1. BASIC PACKAGE INPUT LISTING

```
 SPARTA SAND,STEADY STATE RUN S1=.1    ,S2=1E-6 ,S3=5E-4           8
10-10  BY  DOUG TRUDEAU
         3        26        35         1         1         1
11  0                   29      30
         0         1
         5         1                   (35I2)              -3
 0 0 0 0 0 0 0 0 0 0 0-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1 0
 0 0 0 0 0 0 0 0 0 0 0-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1 0
 0 0 0 0 0 0-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1 0
 0 0 0 0 0 0-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1 0
 0 0 0 0 0 0 0 0-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1 0
 0 0 0 0 0 0 0 0-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1 0
               0-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1 0
               0-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1 0
               0-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1 0
               0-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1 0
               0-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1 0
               0-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1 0
               0-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1 0
               0 0 0 0-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1 0
                     0-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1 0
                     0-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1 0
                     0-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1 0
                     0-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1 0
                     0-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1 0
                     0-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1 0
                     0-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1 0
                     0-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1 0
                   0 0-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1
                   0-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1
               0-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1
     0-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1
         5         1                   (35I2)              -3
               0-1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1-1 0
         0-1-1-1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1-1 0
   0-1-1-1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1-1 0
-1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1-1 0
 0-1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1-1 0
   0-1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1-1 0
     0-1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1-1 0
       0-1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1-1 0
       0-1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1-1
       0-1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1-1
       0-1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1-1
         0-1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1-1
         0-1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1-1
         0-1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1-1
         0-1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1-1
         0-1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1-1
         0-1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1-1
         0-1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1-1
           0-1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1-1
           0-1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1-1
           0-1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1-1
             0-1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1-1
             0-1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1-1
             0-1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1-1
   0-1-1-1-1-1-1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1-1
-1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1-1
         5         1                   (35I2)              -3
```

```
 0 0 0 0-1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1-1
 0-1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1-1
-1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1-1
-1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1-1
-1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1-1
 0 0-1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1-1
 0 0 0-1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1-1
 0 0 0 0-1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1-1
 0 0 0 0-1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1-1
 0 0 0 0-1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1-1
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 0 0 0 0 0-1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1-1
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-1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1-1
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9999999999
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 140 130 120 110 110 110 110 100  90  90 100 130
                                             220 220 175 150 175 200 250 250 225
 175 125 125 100  90  90  90 110 110  90  90 105
                         325 275 250 225 250 150 150  90  75  75  80  85  80  90
  80  75  70  70  70  85  90 101 100  90  95  93
                         290 225 200 200 190 175 160 200 210 200 150 100  85  80
  75  74  74  74  73  74  75  87 100 100  90  86
                                 180 170 170 120 120 145 170 170 160 140 120  90
  70  69  69  70  71  72  73  75  79  85  90  85 220
                                 180 155 145 105  80 100 129 130 123 112 100  85
  70  60  59  60  69  70  72  74  72  80  85  85 220
                                 220 190 175 160 110  79  77  80  82  85  85  80
  65  59  58  59  63  68  72  72  70  76  84  85 220
                                 230 230 200 180 160 120 100  85  79  75  70  69
  60  54  54  58  60  65  71  71  69  70  83  90 220
                                 250 260 220 200 190 130 119 100  91  80  75  66
  56  50  51  55  60  64  69  71  70  69  83  90 210
                                 260 280 240 200 190 137 120 110 100  95  81  65
  54  49  51  55  60  64  68  70  70  69  82  90 200
                                 270 300 250 210 190 137 120 110 100  90  80  63
  52  48  51  55  59  62  65  68  70  68  82  90 130 380
                                 270 300 250 220 190 138 120 110  99  90  78  60
  50  48  52  55  56  60  62  65  71  67  82  90 180 380
                                 270 300 260 224 190 140 120 110  94  85  75  60
  49  47  52  53  55  58  60  64  70  66  80  90 130 380
                                             225 190 150 120 110  95  84  71  58
  47  47  52  53  55  56  60  63  68  65  79  90 180 380
                                             230 200 153 120 110  99  84  70  55
  46  46  51  52  53  55  60  63  65  64  78  90 180 380
                                             230 200 153 125 110 100  80  65  55
  46  46  51  51  52  54  60  63  63  63  77  90 180 380
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                                             230 190 155 130 108 100  80  65  55
  45  45  49  49  50  53  59  62  61  63  76  90 180 375
                                             220 190 155 143 115 100  80  65  53
  44  44  47  47  50  53  58  61  60  62  75  90 180 370
                                             200 190 155 145 118 100  80  65  50
  43  43  44  44  47  53  55  59  61  61  73  90 175 365
                                             210 190 155 148 125 100  80  65  50
  39  39  42  40  43  50  53  55  60  60  71  90 170 360
                                             205 190 160 150 130 105  80  65  50
  39  38  36  37  39  44  50  53  59  60  70  90 168 300
                                             180 180 170 150 120 100  80  65  55
  45  39  38  38  38  39  40  48  55  60  62 100 165 290
                                             160 160 140 110  90  80  75  70  65
  60  55  45  39  38  38  39  42  49  55  48 110 160 240 290
                                         110 100 100 100 100 100 110 110 110 110
 110 100  90  80  70  60  50  40  40  42  43  69 120 180 210
                                  90  80  90 140 140 100 100 100 120 130 130 130
 130 110  90  60  50  40  35  33  33  33  35  60 110 140 150
             220 219 218 218 200 180 150 110  80  70  60  58  55  50  48  45  40
  40  40  39  38  35  34  33  30  29  29  30  59 100 130 140
        5       1.0             (20F4.0)
                                 155 150 150 150 150 150 150 150 150 150 150 150
 150 150 150 150 150 148 146 145 143 138 137 138 200
                     224 210 205 200 160 140 140 140 140 140 140 140 140 140 140
 140 140 140 140 140 137 133 130 125 125 127 137 200
         239 237 233 228 222 210 185 160 145 138 135 132 130 129 128 127 126 125
 124 123 122 121 119 117 113 108 103 100 115 135 220
 245 240 238 235 234 228 215 210 205 190 170 150 139 136 133 130 128 126 124 121
 119 117 115 113 111 110 106 100  99  98 105 150 220 310
     240 238 235 234 228 212 210 205 200 180 165 150 139 135 133 130 127 124 122
 118 116 114 112 110 107 104  99  98  97 105 155 230 315
         237 235 234 215 212 210 207 205 186 168 153 143 136 132 129 126 123 120
 118 116 114 112 109 106 103  99  98  97 105 160 237 315
             235 232 213 213 212 210 205 188 171 155 143 138 135 131 127 124 122
 118 115 112 110 107 105 100  99  98  96 105 165 240 315
                 232 215 214 213 212 205 189 173 156 143 138 134 130 127 124 122
 118 116 113 110 107 104 100  98  97  96 105 165 240 315
                 232 218 216 214 212 205 189 173 155 143 138 134 130 127 124 123
 118 116 113 110 103 106  99  98  97  96 105 165 240 310 350
                 232 218 216 214 212 207 188 173 156 143 138 134 130 127 124 123
 118 116 113 110 107 105  99  98  97  96 105 165 240 310 350
                 232 227 225 223 221 207 188 173 156 143 138 134 130 127 124 122
 118 116 113 110 107 104  98  97  97  96 105 165 240 310 345
                     232 225 223 222 207 187 173 156 143 138 134 130 127 124 122
 118 116 113 110 107 103  98  97  96  96 107 165 240 310 345
                     232 225 223 222 206 186 172 156 143 138 134 130 127 124 121
 117 114 111 109 106 102  98  97  96  96 107 170 240 307 340
                     232 225 223 222 205 185 170 155 143 137 133 130 127 123 120
 117 113 110 107 105 100  98  97  96  96 107 170 240 307 330
                     232 224 223 222 200 183 170 154 142 137 133 129 125 122 119
 116 113 110 107 104 100  98  97  96  96 107 170 240 305 320
                     232 223 222 221 195 180 168 153 140 135 132 127 124 121 117
 115 111 108 106 103  99  97  96  96  96 107 165 240 305 310
                     232 222 221 220 192 178 165 152 140 133 130 126 122 118 116
 113 110 107 103 100  98  97  96  95  96 107 165 240 300 300
                     232 221 220 200 190 175 162 150 138 132 128 124 120 117 115
 112 108 106 102  99  98  96  95  94  95 107 165 240 300 295
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 109 107 105 100  99  98  96  95  94  95 105 165 237 295 290
                         195 195 190 175 165 152 140 133 125 120 118 115 112 110
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 107 104 101  99  98  97  96  95  94  95 105 165 237 290 285
                         210 175 170 165 155 145 135 126 120 118 115 111 109 107
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  99  98  98  97  96  95  95  94  93  95 105 155 235 270 270
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  98  97  97  96  95  95  94  93  92  93 102 155 230 253 250
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  95  95  94  94  93  93  92  92  91  92  99 150 215 235 230
         170 165 160 155 135 115 100  99  98  98  97  97  96  96  95  95  94  94
  93  93  92  92  91  91  91  90  90  91  96 130 175 205 190
 180 175 170 165 160 155 135 125 115 107 100  99  98  96  95  94  93  92  91  91
  90  90  90  89  89  89  88  88  89  90  92 105 140 170 140
           5     1.0            (20F4.0)
                 270 260 250 200 155 150 150 150 150 150 150 150 150 150 150 150
 150 150 150 150 150 148 146 145 143 138 137 138 200 280
     270 260 250 250 225 210 205 200 160 140 140 140 140 140 140 140 140 140 140
 140 140 140 140 140 137 133 130 125 125 127 137 200 320
 225 225 200 200 180 160 150 149 148 147 146 138 135 132 130 129 128 127 126 125
 124 123 122 121 119 117 113 108 103 100 115 135 220 380 400
 200 160 160 149 148 147 146 145 143 142 141 140 139 136 133 130 128 126 124 121
 119 117 115 113 111 110 106 100  99  98 105 150 230 360 400
 200 195 175 160 150 147 146 145 143 142 141 141 140 139 135 133 130 127 124 122
 118 116 114 112 110 107 104  99  98  97 105 155 230 330 400
         200 190 180 160 150 149 148 147 146 145 144 143 136 132 129 126 123 120
 118 116 114 112 109 106 103  99  98  97 105 160 237 330 400
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 118 115 112 110 107 105 100  99  98  96 105 165 240 315 400
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 118 116 113 110 107 104  98  97  97  96 105 165 240 310 360
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 116 113 110 107 104 100  98  97  96  96 107 170 240 270 290
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  99  98  98  97  96  95  95  94  93  95 105 155 235 270 270
                     150 140 130 130 130 127 124 115 110 105 102 100  99  98  98
  98  97  97  96  95  95  94  93  92  93 102 155 230 253 270
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B1. BASIC PACKAGE INPUT LISTING--CONTINUED

```
  220  215  210  200  150  105  100  100  100  100  102  102  100   98   98   98   97   97   96   96
   95   95   94   94   93   93   92   92   91   92   99  150  215  235  260
  220  215  210  200  165  175  135  115  100   99   93   98   97   97   96   96   95   95   94   94
   93   93   92   92   91   91   91   90   90   91   96  130  175  167  190
  200  183  167  150  145  140  135  125  115  107  100   99   98   96   95   94   93   92   91   91
   90   90   90   89   89   89   88   88   89   90   92  105  140  140  140
8.6400E04              2            1.5
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B2. OUTPUT CONTROL LISTING

```
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         0         1
         0         1
         1       100       100         1
         3         3        11         0
         3        -3        11         0
         3         3        11         0
```