UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

HYDROLOGY OF THE BAYOU BARTHOLOMEW ALLUVIAL AQUIFER-STREAM SYSTEM, ARKANSAS

PROGRESS REPORT

By M. E. Broom and J. E. Reed

Prepared in cooperation with the

ARKANSAS GEOLOGICAL COMMISSION

Open-file report
Little Rock, Arkansas
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ABSTRACT

The study area comprises about 3,200 square miles of the Mississippi Alluvial Plain in southeast Arkansas. About 90 percent of the area drains south to the Ouachita River in Louisiana.

The alluvial aquifer and the streams are hydraulically connected and are studied as an aquifer-stream system. Bayou Bartholomew is a principal stream of the system.

The aquifer is underlain by confining strata of the Jackson Group and Cockfield Formation.

The mean annual surface-water yield of the area that drains to the Ouachita River basin is nearly 2 million acre-feet. Flood-control projects have significantly reduced flooding in the area. Basin boundaries and low-flow characteristics of streams have been altered as a result of the flood-control projects and streamflow diversion for irrigation.

The direction of ground-water flow generally is southward. Bayou Bartholomew functions mostly as a drain for ground-water flow from the west and as a recharge source to the aquifer east

of the bayou. As a result of navigation pools, the Arkansas River is mostly a steady-recharge source to the aquifer.

Pumpage from the aquifer and streams increased from about 20,000 acre-feet in 1941 to 237,000 acre-feet in 1970.

Estimates of flow, derived from analog analysis but lacking field verification, indicate that recharge to the aquifer in 1970 was about 161,000 acre-feet. About 70 percent of the recharge was by capture from streams as a result of ground-water pumpage. Discharge from the aquifer was about 233,000 acre-feet. About 80 percent of the discharge was through wells.

Stream diversion in 1970 from capture and open channel, excluding capture from the Arkansas and Mississippi Rivers, was about 110,000 acre-feet. Return flow to streams from rice irrigation and fishponds was about 60,000 acre-feet.

The chemical quality of streamflows is excellent for irrigation. Water from the aquifer generally ranges from permissible to excellent for irrigation. The use of water from the aquifer in the flood-plain area, exclusive of irrigation, is severely limited unless it is treated to remove the iron and reduce the hardness.

INTRODUCTION

The study area, in the Mississippi Alluvial Plain (fig. 1), comprises about 3,200 square miles in southeast Arkansas. The area is bounded on the east by the Mississippi River, on the north

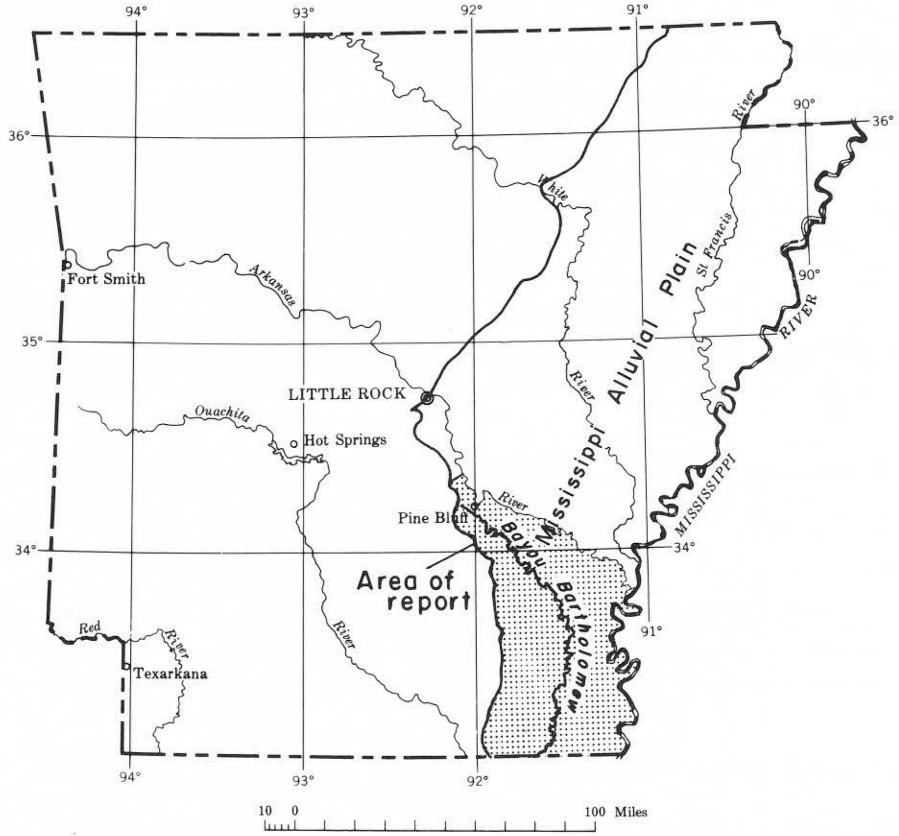

Figure 1.--Location of report area.

by the Arkansas River, on the west by the Ouachita River-Bayou Bartholomew drainage divide, and on the south by the Arkansas-Louisiana State line.

The streams and the alluvial aquifer are hydraulically connected, so that a change in stage or flow in the streams also results, in a change in head or flow in the aquifer; thus, water in either the aquifer or the streams is part of a single integrated aquifer-stream system. This system is termed the Bayou Bartholomew alluvial aquifer-stream system, modified after a classification by Sniegocki and Bedinger (1970). Bayou Bartholomew is a principal stream of the system.

Water-resources and related development affecting the Bayou Bartholomew system have progressed very rapidly in the last 20 years. Present (1972) development includes flood-control levees along the Mississippi and Arkansas Rivers, navigation pools in the Arkansas River, deepened and straightened stream channels, drainage canals, wetlands cleared of forests, and water diverted for irrigation, fish farming, and industry.

Problems associated with water-resources development in the area include (1) local demands for water that exceed the supply; (2) increasing water-lift and conveyance costs; (3) streamflow depletion caused by pumpage from the alluvial aquifer; (4) demands outside the State for water originating in the study area, requiring that potential water yield of the area be known; and

(5) constantly changing requirements for design of the data-control network as stresses of development increase and diversify.

In 1971 the U.S. Geological Survey, in cooperation with the Arkansas Geological Commission, began a study of the Bayou Bartholomew system. The objectives of this study are to (1) analyze cause-effect relations of present water-resources development, (2) project quantitative responses of the system to existing and future stresses of development, and (3) evaluate the data-control network. These objectives will be accomplished by use of electrical-analog or digital-computer models. The models will incorporate fixed and variable flow data so that stresses on the system can be simulated and responses from the models can be measured and scaled in terms of real-system responses.

The purpose of this progress report is to summarize what is now known about the system, so that work priorities can be adjusted to meet the objectives of the study. In addition, the report will be used to disseminate information gained while the study is in progress.

Previous Investigations

Veatch (1906) predicted that large quantities of ground water could be developed from the alluvium. Thirty years later, Branner (1937) reported a few large-capacity wells in the alluvium. In petroleum oriented studies, Spooner (1935) and Caplan

(1954) dealt extensively with the regional structure and stratigraphy of the sedimentary rocks. Fisk (1944, 1947) made extensive investigations of the alluvial geology of the Mississippi River valley.

Accelerated ground-water development in the study area in the 1940's brought about studies by the Geological Survey, in cooperation with the University of Arkansas and the Arkansas Geological and Conservation Commission (Arkansas Geol. Comm.). These studies by Hewitt and others (1949), Klein and others (1950), Onellion and Criner (1955), Onellion (1956), and Bedinger and Reed (1961) provide the data necessary for initial modeling of the boundaries and the character of the alluvial aquifer. Additional data resulted from the Arkansas River navigation studies (Bedinger and Jeffery, 1964; and May and others, 1965a, 1965b).

Acknowledgments

Streamflow data were provided largely by the U.S. Army Corps of Engineers, Vicksburg District. Acreage and crop data were provided by the Agricultural Stablization and Conservation Service and the Statistical Reporting Service, both of which are agencies of the U.S. Department of Agriculture. The cooperation of well drillers and farmers in the study area is appreciated.

PHYSIOGRAPHY

The land surface in the study area is largely a part of the alluvial plain of the Arkansas and Mississippi Rivers (fig. 2). From an altitude of about 200 feet at Pine Bluff, the plain slopes southward at slightly less than 1 foot per mile to an altitude of about 100 feet at the Arkansas-Louisiana State line. Owing to levees along the Arkansas and Mississippi Rivers and the northward merging of the Monticello Ridge and the Arkansas River levee, much of the study area is a closed surface-drainage basin on the north, east, and west. Thus, about 90 percent of the area drains south to the Ouachita River in Louisiana. About 10 percent of the area is on the riverward side of the levees and drains directly to the Arkansas and Mississippi Rivers.

The alluvial plain east of Bayou Bartholomew (fig. 2) is typified by sluggish, meandering streams. Other surface features include abandoned meanders, oxbow lakes, and natural levees. Natural levees along the streams provide local relief of 10-15 feet. The natural-drainage network is inefficient, and flooding is caused by surface backwater during and after periods of heavy rainfall. The backwater areas support lush wetland forests that provide habitats for wildlife. In recent years drainage canals have been dug and streams cleared and straightened through many of the backwater areas to alleviate flooding and to reclaim land for farming.

The alluvial plain west of Bayou Bartholomew rises abruptly 20 feet or more to alluvial terraces (fig. 2). Farther west the alluvial terraces abut outcropping rock of the Jackson Group (fig. 2). The outcropping Jackson forms the Monticello Ridge. Altitudes along the crest of the ridge average about 300 feet but locally rise to slightly more than 400 feet where Pliocene(?) deposits cap the Jackson Group. The alluvial terraces widen southward and overlap the Jackson Group and older rock in most of Ashley County.

GEOLOGY

Rock units that control the flow of water in the Bayou Bartholomew system are summarized in table 1. The areal distribution of the units is shown in figure 2.

The flood-plain and terrace deposits comprise the alluvial aquifer. The Pliocene(?) deposits are not significant to the system. The Jackson Group and the Cockfield Formation generally function as confining strata at the base of the alluvial aquifer. The structure of the Jackson and Cockfield is framed by a basinal downwarp, with the long axis trending northwestward through the study area. Maximum downwarping is in Desha and Lincoln Counties. Thus, from surrounding areas, the Jackson and Cockfield dip toward the center of the study area.

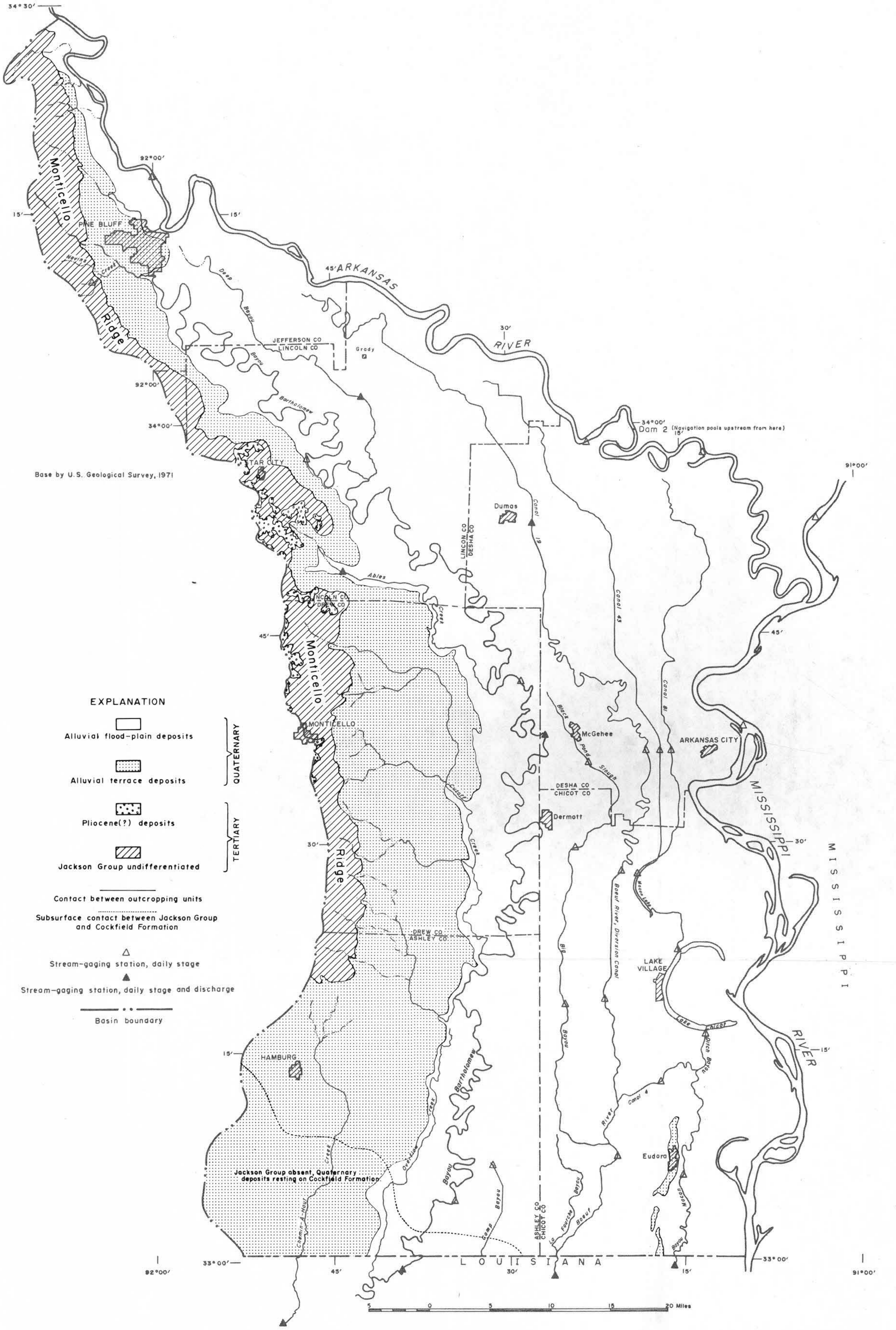

Figure 2.--Geohydrologic map of the Bayou Bartholomew alluvial aquifer-stream system.

Table 1.—*Rock column of the Bayou Bartholomew alluvial aquifer-stream system, Arkansas*

System	Series	Group	Unit	Approximate maximum thickness (feet)	Character of rocks	Water-bearing properties
Quaternary	Holocene and Pleistocene(?)		Alluvial flood-plain deposits	200	Gravel and coarse sand in lower part; fine sand, silt, and clay in upper part.	Yields as much as 3,000 gpm to wells.
	Pleistocene(?)		Alluvial terrace deposits	200	do	Yields as much as 2,000 gpm to wells.
Tertiary	Pliocene(?)		Pliocene(?) deposits	80	Sand and gravel, cemented in part; some silt and clay.	Small areal extent; yields water to springs and domestic wells along the Monticello Ridge.
	Eocene	Jackson		420	Clay; some silt and fine sand.	Generally does not yield water to wells.
		Claiborne	Cockfield	625	Sand, fine- to medium-grained, and clay; lenticularly interbedded. The thicker sand beds generally occur in lower part of for mation. The formation and the sand beds thicken southward.	Yields water in sufficient quantities for domestic supplies in all of the area. In Chicot and Ashley Counties, yields from about 400 to 600 gpm to wells.

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	Pleistocene(?)		Alluvial terrace deposits	200	do	Yields as much as 2,000 gpm to wells.
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		Claiborne	Cockfield	625	Sand, fine- to medium-grained, and clay; lenticularly interbedded. The thicker sand beds generally occur in lower part of formation. The formation and the sand beds thicken southward.	Yields water in sufficient quantities for domestic supplies in all of the area. In Chicot and Ashley Counties, yields from about 400 to 600 gpm to wells.

Jackson Group and Cockfield Formation

The Jackson Group is a relatively homogeneous clay, sandy and silty in part. Along the Monticello Ridge, where Pliocene(?) deposits may have protected the Jackson from erosion, the unit is a least 400 feet thick. In most of the area, the Jackson is 100-300 feet thick, but in a few places along the Mississippi River and along the Arkansas-Louisiana State line in Chicot County the unit was thinned by erosion to only a few feet. In the southwestern corner of the area (fig. 2), the Jackson was completely removed by erosion and, here, alluvial deposits directly overlie the Cockfield Formation.

The Cockfield Formation is composed chiefly of lenticularly interbedded, fine- to medium-quartz sand and lignitic clay; the basal part of the formation is sandier. The thickness of the formation generally increases southward from about 300 feet, in Jefferson County, to as much as 625 feet, in Chicot County. In the southwestern corner of the area, the Cockfield was thinned by erosion to about 200 feet.

The sandy basal part of the Cockfield Formation yields sufficient water to be termed an aquifer. The Cockfield aquifer provides sufficient yield for domestic needs in all the area. In Ashley and Chicot Counties, the Cockfield aquifer yields 400-600 gpm (gallons per minute) of water to wells.

Because of the impervious character of the Jackson Group and the upper part of the Cockfield Formation, they function as confining strata. Thus, the alluvial aquifer and the Cockfield aquifer generally are not hydraulically connected. Some hydraulic connection may exist between the two aquifers in the southwestern part of the area where the Jackson Group and the upper part of the Cockfield have been removed by erosion. In this area further investigation is required to determine if the hydraulic connection is significant.

Alluvial Flood-Plain and Terrace Deposits

The flood-plain deposits (fig. 2) generally grade from gravel and coarse sand, in the lower part, to silt and clay, in the upper part. The composition and order of texture in the terrace deposits are much the same as the flood-plain deposits (Bedinger and Reed, 1961, p. 19). In the following, the flood-plain and terrace deposits together are termed alluvium.

The alluvium underlying the flood plain generally ranges from about 100 to 150 feet in thickness, but in places it is as thin as 50 feet or as thick as 200 feet. As the surface of the flood plain is relatively flat, the thickness variation is caused largely by the irregular Jackson surface on which the alluvium was deposited. Beneath the terraces, the Jackson bedrock gradually rises westward and the alluvium thins to a few feet against the Jackson outcrop (fig. 2). Where the Jackson Group is overlapped by the alluvium, in the vicinity of Hamburg and southward, the maximum thickness of the alluvium is about 150 feet.

Although grading upwards from coarse to fine, the sand and gravel are lenticularly interbedded and the beds differ considerably in thickness over short distances. The gravel commonly is angular to subangular, pea-sized, and is composed of chert, quartz, and pebbles of sandstone and igneous rock. Cobbles and boulders commonly occur at the base of the alluvium.

The gravel and coarse sand of the alluvium store and transmit large quantities of water. The alluvial aquifer yields as much as 3,000 gpm to wells in the flood-plain area and as much as 2,000 gpm to wells in the terrace area.

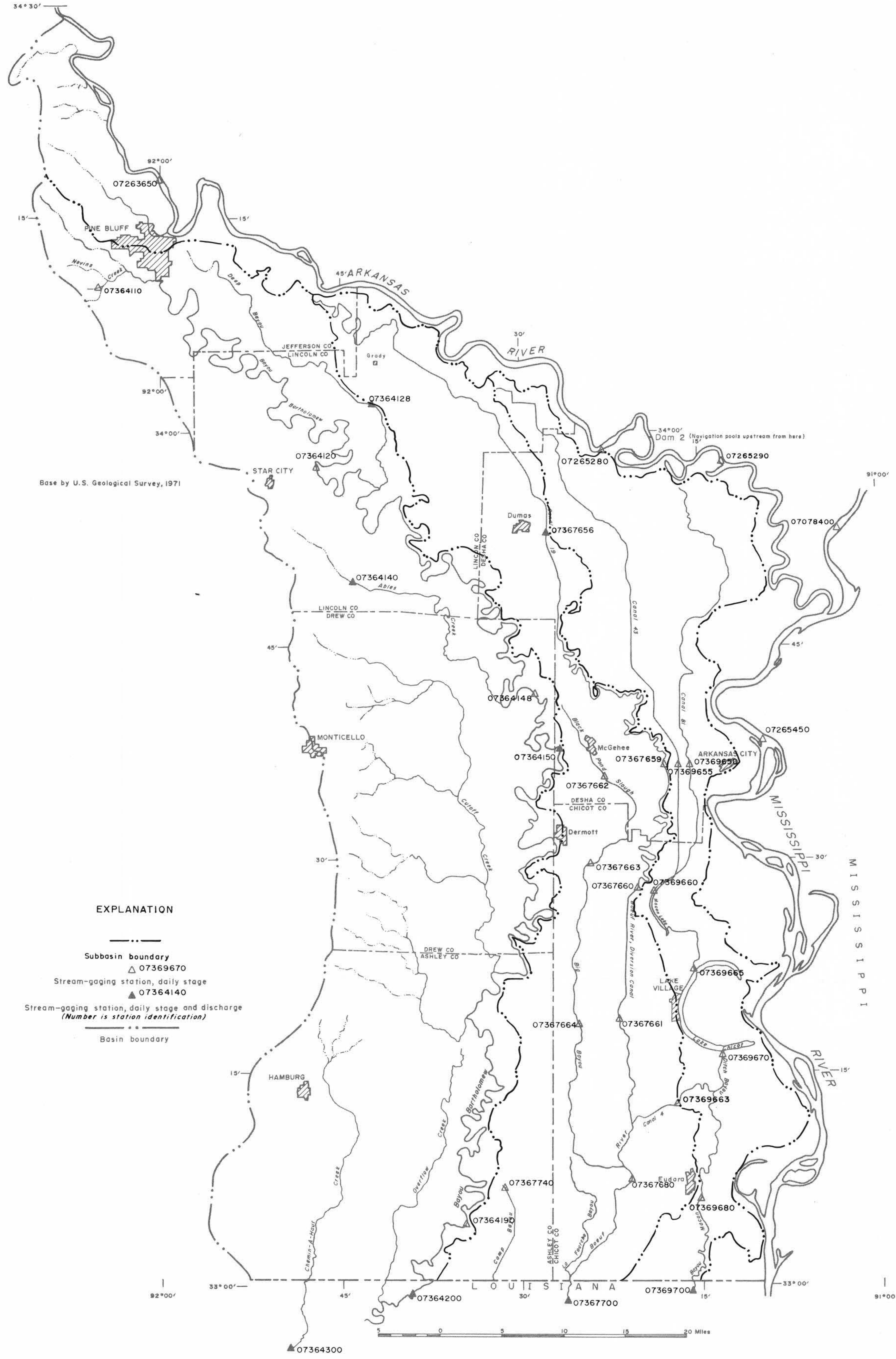
The fine-grained material in the upper 25-50 feet of the alluvium generally functions as a semiconfining bed over the alluvial aquifer.

HYDROLOGY

Streams

Basin Characteristics

Surface drainage in the project area is to three principal subbasins: (1) Bayou Bartholomew, (2) Boeuf River, and (3) Bayou Macon. The subbasin boundaries, main channels, large tributaries, and the locations of stream-gaging stations are shown in figure 3. The subbasin characteristics and precipitation at selected stream



Base by U.S. Geological Survey, 1971

Figure 3.--Subbasin boundaries and gaging-station locations.

sites are summarized in table 2. Precipitation values were derived from National Weather Service records. The project is not concerned with the surface drainage on the riverward side of the levees along the Arkansas and Mississippi Rivers.

The Bayou Bartholomew basin, the largest of the subbasins, has a drainage area of about 1,480 square miles above the Arkansas-Louisiana State line. The length of the greatly meandering main channel from the head to the State line is 279 miles. The channel slope in this reach averages about 0.5 foot per mile, as determined from altitudes at points 10 percent and 85 percent of the distance along the channel from the gaging station to the divide.

The Boeuf River basin has a drainage area of about 780 square miles above the Arkansas-Louisiana State line. As measured along Boeuf River, the Boeuf River Diversion Canal, and Canal 19, the length of the main channel to the State line is 145 miles. The slope of the main channel along this reach averages about 0.8 foot per mile.

The Bayou Macon basin has a drainage area of about 500 square miles above the Arkansas-Louisiana State line. The length of the main channel to the State line is 101 miles, as measured along Bayou Macon, Ditch Bayou, Lake Chicot, Macon Lake, and Canal 43. The slope of the channel along this reach averages about 1 foot per mile.

Table 2.—*Basin characteristics and mean precipitation for selected streams*

Station		Basin characteristics					Mean precipitation (inches)												
Number	Name	Drainage area (sq mi)	Main channel		Forest cover (percent)	Mean basin elevation (feet)	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
			Slope (feet per mile)	Length (miles)															
07364120	Bayou Bartholomew near Star City.	215	0.59	81.7	50	220	5.35	4.65	5.10	5.00	4.65	3.35	4.00	2.90	2.95	2.85	4.40	4.80	50
07364128	Deep Bayou near Grady-----------	102	1.5	23	41	190	5.35	4.65	5.10	5.00	4.65	3.35	4.00	2.90	2.95	2.90	4.40	4.75	50
07364150	Bayou Bartholomew near McGehee--	592	.53	167	54	190	5.40	4.65	5.20	4.95	4.50	3.20	4.20	2.90	2.95	2.75	4.40	4.90	50
07367656	Canal 19 near Dumas-------------	162	.85	45.4	38	169	5.40	4.70	5.30	4.85	4.45	3.25	4.20	2.95	2.95	2.75	4.30	4.90	50
07367659	Canal 19 near Arkansas City-----	255	1.04	70.7	39	165	5.51	4.74	5.36	5.00	4.44	3.32	4.34	3.03	3.01	2.81	4.39	5.05	51
07367660	Diversion Canal, Boeuf River at Macon Lake.	303	.61	104.4	40	161	5.55	4.74	5.45	4.95	4.44	3.26	4.39	3.01	3.01	2.81	4.39	5.00	51
07367661	Boeuf River near Lake Village--	355	.59	115.7	43	156	5.61	4.79	5.50	4.95	4.34	3.26	4.39	3.01	3.01	2.75	4.39	5.00	51
07367662	Black Pond Slough near McGehee--	11	1.65	6.5	38	141	5.65	4.74	5.46	4.91	4.28	3.27	4.59	3.06	2.96	2.75	4.28	5.05	51
07367663	Big Bayou near Dermott----------	60	1.30	18.4	26	136	5.66	4.74	5.46	4.90	4.34	3.26	4.59	3.01	2.96	2.75	4.28	5.05	51
07367664	Big Bayou near Lake Village-----	102	1.2	33.5	47	130	5.71	4.74	5.51	4.90	4.28	3.22	4.54	3.01	2.96	2.75	4.28	5.10	51
07369650	Canal 81 near Arkansas City-----	157	.86	32.6	52	142	5.60	4.80	5.50	4.90	4.40	3.30	4.60	3.00	3.00	2.70	4.20	5.00	51
07369660	Canal 43 near Arkansas City-----	138	1.15	42.0	54	149	5.41	4.78	5.36	4.94	4.44	3.26	4.34	3.01	3.06	2.86	4.49	5.05	51
07369670	Ditch Bayou near Lake Village---	404	1.00	70.5	51	137	5.56	4.79	5.51	4.90	4.34	3.26	4.44	3.01	3.01	2.75	4.43	5.00	51

Precipitation, almost entirely rain, varies little in distribution between the subbasins (table 2). In all the subbasins, the mean annual precipitation increases southward from 50 to 51 inches; the mean monthly precipitation ranges from about 5-1/2 inches, in January, to about 2-3/4 inches, in October.

As estimated from gaged flow at the stations along the Arkansas-Louisiana State line (fig. 3) and from some ungaged flow, the combined mean annual discharge from the subbasins—Bayou Bartholomew, Boeuf River, and Bayou Macon—is about 3,000 cfs, or 2,200,000 acre-feet.

The flow regimen of the Bayou Bartholomew subbasin has been little altered by surface-water development. However, in the Boeuf River and Bayou Macon subbasins, an extensive network of canals was developed by the U.S. Army Corps of Engineers to alleviate flooding. The flood-control projects, begun in the 1940's, included chiefly the construction of Canals 19, 43, 81, and the Boeuf River Diversion Canal (fig. 3).

Before completion of the major flood-control projects, the upper half of the present-day Boeuf River subbasin was a part of the Bayou Macon subbasin. Canal 19 and the Boeuf River Diversion Canal largely altered the natural-drainage scheme. Also, the constructions placed part of the south half of the Bayou Macon subbasin in the Boeuf River subbasin. However, prior to construction, high flows always caused considerable shift of natural-drainage boundaries and exchange of flows between the two subbasins. To a less extent, there is still exchange of floodflows between all the subbasins.

Another condition that intensifies the problem of defining subbasin boundaries is the interaction of streamflow and ground-water, flow, and the fact that the subbasin boundaries or surface divides seldom function as ground-water divides (figs, 5, 6). Thus, there is considerable interbasin transfer of flows resulting from ground-water movement regardless of the nature of the surface divides.

Streamflow Characteristics

The periods of record of stage, discharge, and rainfall at stream-gaging stations in the project area are summarized in table 3. The mean monthly and annual discharges at selected gaging stations in the project area are given in table 4.

The streams throughout the subbasins generally are gaining streams, but most have intermittently losing reaches. A seepage study in the Bayou Bartholomew basin (U.S. Geol. Survey, 1969, p. 168-169) in October 1967 shows the main channel gaining from zero flow, near Pine Bluff, to 45.5 cfs, at the Arkansas-Louisiana State line. However, about 75 percent of the gain occurred in the reach downstream from McGehee (fig. 3).

Table 3.—*Periods of record of stage, discharge, and rainfall at stream-gaging stations*

Number: National downstream-order number.
Rainfall: Dual-digital stage and rainfall recorder.

Collecting agency: CE, U.S. Army Corps of Engineers; GS, U.S. Geological Survey.

Station		Period of record (calendar years)				
Number	Name	Daily stage	Daily discharge	Intermittent discharge measurements	Rainfall	Collecting agency
07263650	Arkansas River near Pine Bluff	1948-	1949-53	1938-	--------	CE
07265280	Arkansas River at Pendleton	1951-53, 1959	-----------	------------	--------	CE
07265290	Arkansas River at Yancopin	1906-	-----------	1937, 1948-50	--------	CE
07078400	Mississippi River near Rosedale, Miss	1871-	-----------	------------	--------	CE
07265450	Mississippi River at Arkansas City	1879-	1928-	1884-	--------	CE
07364110	Nevins Creek tributary near Pine Bluff	1968-	-----------	1961-	1968-	GS
07364120	Bayou Bartholomew near Star City	1941-	-----------	1939-	--------	CE,GS
07364128	Deep Bayou near Grady	1947-	1969-	1948-	1969-	CE,GS
07364140	Ables Creek near Tyro	1969-	1969-	1969-	1969-	GS
07364148	Bayou Bartholomew near Tillar	1969-	-----------	------------	1969-	GS
07364150	Bayou Bartholomew near McGehee	1938-	1938-41, 1956-	1938-	--------	CE,GS
07364190	Bayou Bartholomew at Wilmot	1925-	-----------	1939,1946-	--------	CE
07364200	Bayou Bartholomew near Jones, La	1957-	1957-	1957-	--------	GS
07364300	Chemin-a-Haut Bayou (Creek) near Beekman, La.	1955-	1955-	1955-	--------	GS
07367656	Canal 19 near Dumas	1959-	1969-	1958-	--------	CE,GS
07367659	Canal 19 near Arkansas City	1946-	1969-	1945-	--------	CE,GS
07367660	Diversion Canal, Boeuf River at Macon Lake.	1938-	1939-40	1938-	--------	CE,GS
07367661	Boeuf River near Lake Village	1946-	-----------	1945-	--------	CE,GS
07367662	Black Pond Slough near McGehee	1950-	-----------	1948-	--------	CE,GS
07367663	Big Bayou near Dermott	1950-	-----------	1949-	--------	CE
07367664	Big Bayou near Lake Village	1946-	-----------	1945-	--------	CE,GS
07367680	Boeuf River near Eudora	1938-	1938-39	1938-	--------	CE
07367700	Boeuf River near Arkansas-Louisiana State line.	1946-	1957-68	1968-	--------	CE,GS
07367740	Camp Bayou near Parkdale	1969-	-----------	1963-	1969-	GS
07369650	Canal 81 near Arkansas City	1946-	-----------	1945-	--------	CE,GS
07369655	Canal 43 near Arkansas City	1946-	1969-	1945-	--------	CE,GS
07369660	Macon Lake near Macon Lake	1949-	-----------	1949-	--------	CE,GS
07369663	Canal 4 near Chicot	1938-	1938-39	1938-	--------	CE
07369665	Connerly Bayou near Lake Village	1938-46, 1949-	-----------	------------	--------	CE
07369670	Ditch Bayou near Lake Village	1938-	1938-39	1938-	--------	CE,GS
07369680	Bayou Macon at Eudora	1938-	-----------	1938-	--------	CE
07369700	Bayou Macon near Kilbourne, La	1957-	1957-68	1951-	--------	CE,GS

Table 4.—*Flow characteristics of selected streams*

Station		Drainage area (sq mi)	Years used for computation	Mean monthly and mean annual discharge (cubic feet per second)												
Number	Name			Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
07364120	Bayou Bartholomew near Star City.	215	1945-68	424	588	527	502	561	116	46.4	26.8	52.2	79.3	131	199	264
07364128	Deep Bayou near Grady--------	102	1948-68	174	212	163	135	202	44.9	31.1	28.9	54.4	23.1	55.4	93.2	102
07364150	Bayou Bartholomew near McGehee.	592	1939-42, 1946-60	917	1,508	1,371	1,262	1,206	395	191	101	158	181	260	500	664
07364200	Bayou Bartholomew near Jones, La.	1,187	1958-70	1,605	1,912	2,466	2,202	1,917	1,043	342	258	315	493	487	1,257	1,187
07364300	Chemin-a-Haut Bayou near Beekman, La.	271	1956-70	273	528	429	531	381	131	48.1	32.5	145	23.2	173	259	244
07367656	Canal 19 near Dumas----------	162	1960-68	302	366	385	345	333	146	116	107	123	75.7	95.9	331	227
07367659	Canal 19 near Arkansas City--	255	1947-68	487	701	508	472	484	146	104	81.0	164	96.0	178	311	311
07367660	Diversion Canal, Boeuf River at Macon Lake.	303	1947-68	373	544	423	367	400	89.5	72.7	46.3	122	56.8	171	264	242
07367661	Boeuf River near Lake Village.	355	1947-68	529	748	576	484	464	130	108	65.3	177	79.1	194	308	319
07367662	Black Pond Slough near McGehee.	11	1952-68	25.3	41.3	25.0	19.9	20.6	8.50	7.60	6.80	9.10	5.70	18.6	19.0	17.1
07367663	Big Bayou near Dermott-------	60	1952-68	134	204	136	98.5	123	26.2	20.6	16.0	48.3	11.3	64.9	95.8	80.8
07367664	Big Bayou near Lake Village--	102	1947-68	237	333	222	165	180	60.1	50.2	23.0	89.4	22.1	77.8	115	130
07367700	Boeuf River near Arkansas-Louisiana State line.	785	1958-68	1,429	1,919	1,513	1,340	1,474	415	338	187	687	228	813	1,118	949
07369650	Canal 81 near Arkansas City--	157	1947-68	371	537	397	339	352	188	210	181	189	109	191	241	274
07369660	Canal 43 near Arkansas City--	138	1947-68	339	497	414	259	377	76.5	60.1	35.9	97.8	53.1	116	163	209
07369670	Ditch Bayou near Lake Village.	404	1946-68	920	1,471	1,247	1,111	1,053	547	399	217	241	204	279	484	671
07369700	Bayou Macon near Kilbourne, La.	504	1958-68	683	879	832	745	833	357	242	183	274	216	317	555	508

A frequently used index of the dry-weather yield of streams is the 7-day 2-year low flow; that is, the minimum annual 7-day average flow that has a probability of occurring on the average of once in 2 years. The 7-day 2-year low flow determined by Patterson (written commun., 1972) at five gaging stations in or just downstream from the study area are listed below:

Station		7-day 2-year low flow (cubic feet per second)
Number	Name	
07364150	Bayou Bartholomew near McGehee----------	26
07364200	Bayou Bartholomew near Jones, La--------	92
07364300	Chemin-a-Haut Bayou (Creek) near Beekman, La--------------------------	.4
07367700	Boeuf River near Arkansas-Louisiana State line---------------------------	36
07369700	Bayou Macon near Kilbourne, La----------	52

The percentage of time during which specified discharges were equaled or exceeded during a given period can be shown by flow-duration curves or tables. Flow duration for the five gaging stations for which low-flow data are listed above are shown in table 5. Discharge values are listed using all daily mean discharge data for the period of record and using daily mean discharge only for the normal irrigation season, May through September.

Using discharge records for Bayou Bartholomew near McGehee for 1958-70, table 5 shows that for 50 percent of the time daily mean discharge equaled or exceeded 210 cfs; whereas, using only

Table 5.—*Duration of daily flow at selected gaging stations*

[Flow: Upper figure is seasonal, May 1 to Sept. 30, duration value; lower figure is period-of-record duration value]

Station		Period of record	Flow, in cubic feet per second, which was equaled or exceeded for indicated percentage of time													
Number	Name		99	95	90	80	70	60	50	40	30	20	10	5	1	0.5
07364150	Bayou Bartholomew near McGehee.	1958-70	17	25	32	47	64	86	120	165	250	440	980	2,500	5,000	6,000
			15	25	35	58	88	135	210	370	660	1,050	1,800	2,600	4,600	5,600
07364200	Bayou Bartholomew near Jones, La.	1958-70	44	62	80	110	160	220	290	410	560	900	2,400	3,700	5,400	5,800
			44	64	84	140	200	290	470	780	1,400	2,300	3,500	4,500	6,000	6,200
07364300	Chemin-a-Haut Bayou (Creek) near Beekman, La.	1956-65, 1967-69	.1	.78	1.5	3.6	6.4	10	15	24	42	88	380	760	2,800	3,700
			.09	.6	1.1	3.7	7.6	14	26	50	100	270	740	1,100	3,400	4,400
07367700	Boeuf River near Arkansas-Louisiana State line.	1958-68	4	32	48	70	88	110	140	180	250	440	1,200	2,500	11,000	-----
			18	43	54	72	94	130	180	280	500	1,000	2,400	4,500	13,000	-----
07369700	Bayou Macon near Kilbourne, La.	1959-65, 1968	17	42	56	76	94	120	150	190	290	500	920	1,600	3,800	4,100
			24	40	56	84	110	150	210	320	600	900	1,400	2,000	3,500	4,000

records for the normal irrigation season, May through September, for the same period, the table shows that for 50 percent of the time daily mean discharge equaled or exceeded only 120 cfs.

The stage-discharge relation at many gaging stations in the project area cannot be adequately defined to compute the low-flow discharges necessary for low-flow frequency and duration studies. Also, upstream channel improvement during the period of record at some stations has been accompanied by substantial changes in the low flow of the channels.

Ranges in annual peak stages and discharges at selected gaging stations are given in table 6. The maximum flow may occur during any time of the year but occurs most frequently from January through May, and according to Patterson (1971, p. 3) generally is caused by storms moving northeastward from the west gulf region.

A comparison of bankfull gage height with maximum and minimum peak gage heights at a given station in table 6 gives an idea of the frequency of flooding at the station. For example, at station 07364120, on Bayou Bartholomew near Star City (fig. 3), the 26-year record shows no flooding; station 07364150, on Bayou Bartholomew near McGehee, shows intermittent flooding during the 31-year record; and station 07364200, on Bayou Bartholomew near Jones, La., shows flooding every year throughout the 11-year record.

Table 6.—*Ranges in annual peak stages and discharges at selected gaging stations*

[Period of record after channel improvements shown separately]

Station		Period of record (water years)	Bankfull gage height (feet)	Maximum annual peak		Minimum annual peak	
Number	Name			Gage height (feet)	Discharge (cfs)	Gage height (feet)	Discharge (cfs)
07364120	Bayou Bartholomew near Star City--	1942-68	28.00	26.29	4,000	15.4	740
07364128	Deep Bayou near Grady-------------	1948-61	13.00	17.60	4,050	13.9	724
		1962-69		15.50	1,280	6.3	250
07364150	Bayou Bartholomew near McGehee----	1930,1932, 1939-68	20.00	24.49	6,870	11.1	1,350
07364190	Bayou Bartholomew at Wilmot-------	1926-68	25.00	26.30	[a]7,100	8.18	910
07364200	Bayou Bartholomew near Jones, La--	1958-69	8.00	28.24	[a]6,100	8.86	885
07364300	Chemin-a-Haut Bayou (Creek) near Beekman, La.	1956-68	16.00	28.21	29,500	16.80	480
07367656	Canal 19 near Dumas---------------	1960-68	(b)	29.10	4,050	19.60	1,140
07367659	Canal 19 near Arkansas City-------	1947-56	22.00	26.41	2,260	22.90	1,120
		1957-70		26.30	5,050	16.10	1,400
07367660	Diversion Canal, Boeuf River at Macon Lake.	1947-56	(b)	17.90	1,780	9.90	646
		1957-68		17.40	7,420	9.60	2,630
07367661	Boeuf River near Lake Village-----	1947-56	24.00	22.50	2,800	17.00	1,600
		1957-68		18.50	8,280	7.10	1,750
07367663	Big Bayou near Dermott------------	1952-56	13.40	15.60	982	12.80	635
		1957-68		15.00	3,330	5.00	830
07367664	Big Bayou near Lake Village-------	1947-55	19.0	16.4	1,670	14.5	1,350
		1956-68		16.7	3,280	8.1	1,180
07367680	Boeuf River near Eudora-----------	1939-55	21.0	21.52	9,830	16.8	4,080
		1956-70		20.15	15,300	6.34	2,600
07367700	Boeuf River near Arkansas-Louisiana State line.	1947-55	25.0	22.8	---------	21.5	---------
		1956-68		22.64	16,500	7.21	3,180
07369650	Canal 81 near Arkansas City-------	1947-58	28.0	29.50	1,730	24.80	952
		1959-68		27.10	3,600	18.10	1,070
07369655	Canal 43 near Arkansas City-------	1947-56	26.0	25.9	2,970	19.3	1,260
		1957-69		24.4	3,120	16.1	2,120
07369670	Ditch Bayou near Lake Village-----	1946-68	27.0	25.5	6,000	14.5	1,020
07369680	Bayou Macon at Eudora-------------	1932, 1938-64	18.0	27.43	5,100	13.96	1,200
		1965-68		22.08	---------	10.36	---------
07369700	Bayou Macon near Kilbourne, La----	1958-68	19.0	26.35	4,740	11.93	1,310

[a] During extreme flood, considerable flow bypasses station.

[b] Not defined; bankfull stage never reached during period of record.

Table 6 also shows the effect of channel improvement on peak stages and discharges of the streams. Channel improvement speeds drainage, resulting in a shorter time required to drain a given volume of water. This condition generally is reflected by a lowering of peak stages and an increasing of peak discharges after channel improvement (table 6). However, the increase in peak discharge may be partly due to greater rainfall after channel improvement.

Patterson (1971) shows peak-discharge recurrences at several stations in the Bayou Bartholomew basin. Peak-discharge recurrences at selected stations determined by Patterson (1971, and written commun., 1972) are given in table 7. Where channel improvements have been made upstream from the station, the recurrences of peak discharges were determined for the periods of record after channel improvements.

Regression Analysis

Regression analysis using procedures described by Benson (1962) and Patterson (1969) is a method of regionalizing data. The method involves relating streamflow and basin characteristics in gaged basins by multiple-regression techniques, then applying this relation as a mathematical or a regression model, to ungaged basins that have similar basin characteristics, to obtain estimates of streamflow characteristics.

Table 7.—*Peak-discharge recurrence at selected gaging stations*

Station		Bankfull discharge (cfs)	Peak discharge, in cubic feet per second, for indicated recurrence interval, in years				
Number	Name		2	5	10	25	50
07364120	Bayou Bartholomew near Star City-------	(a)	1,690	2,360	2,770	3,260	3,600
07364150	Bayou Bartholomew near McGehee---------	4,500	3,280	4,600	5,240	6,100	6,800
07364190	Bayou Bartholomew at Wilmot------------	6,100	4,930	6,340	6,800	7,200	7,700
07364200	Bayou Bartholomew near Jones, La-------	700	4,400	-------	-------	-------	-----
07364300	Chemin-a-Haut Bayou (Creek) near Beekman, La.	300	4,500	-------	-------	-------	------
07367680	Boeuf River near Eudora----------------	(a)	10,000	-------	-------	-------	------
07367700	Boeuf River near Arkansas-Louisiana State line.	(a)	13,000	-------	-------	-------	------
07369700	Bayou Macon near Kilbourne, La---------	2,440	3,000	-------	-------	-------	------

a Not defined.

In addition, a regionally applicable regression model can be an effective tool for evaluating a data-collection network in a relatively complex drainage system. For example, a significant difference in modeled flow and measured flow at a gaging station may indicate upstream problems, including poorly defined drainage-basin boundaries and interbasin-flow exchanges. Also, the model may indicate undetected sites of diversion or return flows upstream from the gaging station.

Briefly, the development of the model is based on stepwise regression. The regression program considers streamflow characteristics as dependent variables and basin and climatic characteristics as independent variables. The digital computer calculates least-square regression equations for the desired flow characteristics, the standard error of estimate for the equations, and the percentage level of significance of each independent variable. The final product is a model that includes all statistically significant parameters for each streamflow characteristic. The model has the form

$$Y=aA^{b_1}S^{b_2}P^{b_3} \ . \ . \ . \ ,$$

where Y is a statistical streamflow characteristic; A, S, and P are topographic or climatic characteristics; a is the regression constant, and b_1, b_2, and b_3 are coefficients obtained by regression. The model is shown in table 8. In the regression equations, Q is mean annual discharge; q_1, q_2 . . . are mean monthly discharges, beginning with January.

Table 8.—*Regression model*

[Model is $Y=aA^{b_1}L^{b_2}F^{b_3}I^{b_4}S^{b_5}E^{b_6}$; Y=mean annual Q, or mean monthly q_1, q_2, . . .]

Flow characteristic, *Y*	Regression constant, *a*	Exponent of basin characteristic						Standard error of estimate (percent)
		Drainage area, *A*	Main channel length, *L*	Forest cover, *F*	Soil index, *I*	Main channel slope, *S*	Mean basin elevation, *E*	
Q	1.75	1.17	-0.31	----------	----------	----------	----------	16
q_1	3.28	1.24	-.44	----------	----------	----------	----------	20
q_2	4.19	.93	----------	----------	----------	----------	----------	19
q_3	3.44	1.26	-.37	-0.43	----------	----------	----------	17
q_4	.12	1.09	----------	----------	----------	----------	----------	21
q_5	229	.96	----------	----------	-1.70	----------	----------	22
q_6	.39	1.09	----------	----------	----------	----------	----------	39
q_7	57.8	1.84	-1.46	----------	----------	-0.99	-0.70	43
q_8	.80	1.61	-1.06	----------	----------	----------	----------	43
q_9	227	1.38	-.73	----------	----------	----------	-1.01	27
q_{10}	1.27	1.49	-1.02	----------	----------	-.95	----------	34
q_{11}	2.77	1.13	-.51	----------	----------	----------	----------	22
q_{12}	2.65	1.23	-.51	----------	----------	----------	----------	21

Patterson (1969, 1971) developed a regression model for statewide use in Arkansas. This model, with some adjustment for changes in topographic and climatic characteristics, has been refined for use in the Coastal Plain in Arkansas, including the Bayou Bartholomew study area. In developing the Coastal Plain model, it was found that drainage area is a much more significant variable than any of the other variables. Rainfall is uniform throughout the study area and hence it did not prove to be significant in the regression model. In fact, the use of independent variables other than drainage area and main-channel length will improve the standard error of estimate by less than 2 percent.

The Coastal Plain model was tested in the project area, where, as previously stated, there are complex drainage features such as ill-defined basin boundaries, interbasin transfer of flows, substantial withdrawals of surface and ground water, and returns of this water to streams. So, the test of the model is largely a test of its utility for indicating these problem features. However, the model does not specifically indicate what the problem is; it only indicates that flow at a given point in a stream is greater or less than the model estimate. And, as each regression equation (table 8) has a standard error of estimate, only flows that exceed the standard error of estimate are considered significant indications of upstream problem features.

Table 9 shows a comparison of measured flow and model estimates of flow at gaging stations on selected streams in the project area. For an example of the test, significant differences are indicated in modeled mean monthly flow and measured mean monthly flow in Bayou Bartholomew near Star City (first station in table 9) in April and July. In April, the measured flow is 22 percent greater than the modeled flow, and in July, 48 percent less than the modeled flow. Upstream conditions that might explain these differences in measured and modeled flow are extensive draining of rice areas in April for spring planting and extensive diverting of streamflow in July for irrigation.

The consistently large excesses of streamflow in the Bayou Macon subbasin and the large deficiencies of streamflow in the Boeuf River subbasin (table 9) might result from ill-defined subbasin boundaries or interbasin transfer of flow. As previously indicated, both of these problem features are established by the potentiometric-surface maps.

The test in the Bayou Bartholomew area showed that the Coastal Plain model has statistical validity and may be useful elsewhere.

Alluvial Aquifer

Transmissivity and Storage Coefficient

The transmissivity (T) and the storage coefficient (S) of an aquifer are indices of the aquifer's capacity to transmit and store water. T is the rate at which the aquifer will transmit

Table 9.—*Results of regression analysis*

Station		Difference, in percent, between measured mean flow and model mean flow												
Number	Name	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Ann.
07364120	Bayou Bartholomew near Star City.	18	-3	17	*22	-21	-16	*-48	-38	-21	14	-2	-3	10
07364128	Deep Bayou near Grady.	*-31	*-23	*-36	*-27	4	-27	-38	-42	-21	-33	*-48	*-41	*-31
07364150	Bayou Bartholomew near McGehee.	0	-2	7	2	2	-6	-20	-3	-15	8	8	1	5
07367656	Canal 19 near Dumas.	-8	*-21	11	14	10	*44	10	*109	*37	28	*-24	*69	10
07367659	Canal 19 near Arkansas City.	3	-1	-4	-5	4	-13	25	21	0	*58	6	14	1
07367660	Boeuf River Diversion Canal at Macon Lake.	*-24	*-34	*-26	*-39	*-27	-1	*-50	-21	0	*-35	2	-5	*-27
07367661	Boeuf River near Lake Village.	-8	*-22	-17	*-32	*-28	*-46	-36	-3	22	-32	2	-4	*-18
07367662	Black Pond Slough near McGehee.	-10	7	6	*22	-10	*58	31	29	-16	*37	15	2	5
07367663	Big Bayou near Dermott.	-7	10	16	-5	5	-24	*-46	-41	-12	*-50	0	5	-6
07367664	Big Bayou near Lake Village.	12	10	-6	-10	-7	-2	7	-32	16	-24	-11	-11	-2
07369650	Canal 81 near Arkansas City.	1	19	-8	16	20	*92	24	*161	*45	*38	*32	8	*24
07369660	Canal 43 near Arkansas City.	*21	*24	*22	17	*45	-10	7	-17	14	*41	6	-3	*18
07369670	Ditch Bayou near Lake Village.	10	*36	*18	*36	*45	*98	*74	*54	-15	*62	-2	1	*28

*Difference exceeds standard error of estimate shown in table 8.
-Measured mean flow less than model mean flow.

water through a vertical strip of a unit width of the aquifer under a unit hydraulic gradient. It may be expressed in units of feet squared per day (ft^2/day), or cubic feet of water per day per foot. S is the volume of water an aquifer releases from or takes into storage per unit surface area of the aquifer per unit change in head. S is a dimensionless value ordinarily expressed as a decimal fraction. T and S values are used conjunctively for arriving at quantitative estimates of the response of the aquifer to stress, that is, the decline in water level in response to pumping and the change in water level in response to changes in river stage.

T values of the aquifer were mapped, as shown in figure 4, by using 14 aquifer tests, 65 specific-capacity tests, and 56 lithologic logs. The aquifer tests were analyzed by the Theis nonequilibrium method, as modified by Cooper and Jacob (1946), and by the Theis recovery method (Wenzel, 1942). The aquifer-test results were used as a basis for estimating T values from the specific-capacity tests (Bedinger and Emmett, 1963). Laboratory determinations of the relation of permeability to grain size were used in estimating T values from the lithologic logs (Bedinger, 1961).

The T values of the aquifer (fig. 4) range from about 13,000 to 40,000 ft^2/day. The highest T values of the aquifer are along Bayou Bartholomew. Westward from Bayou Bartholomew, the T values

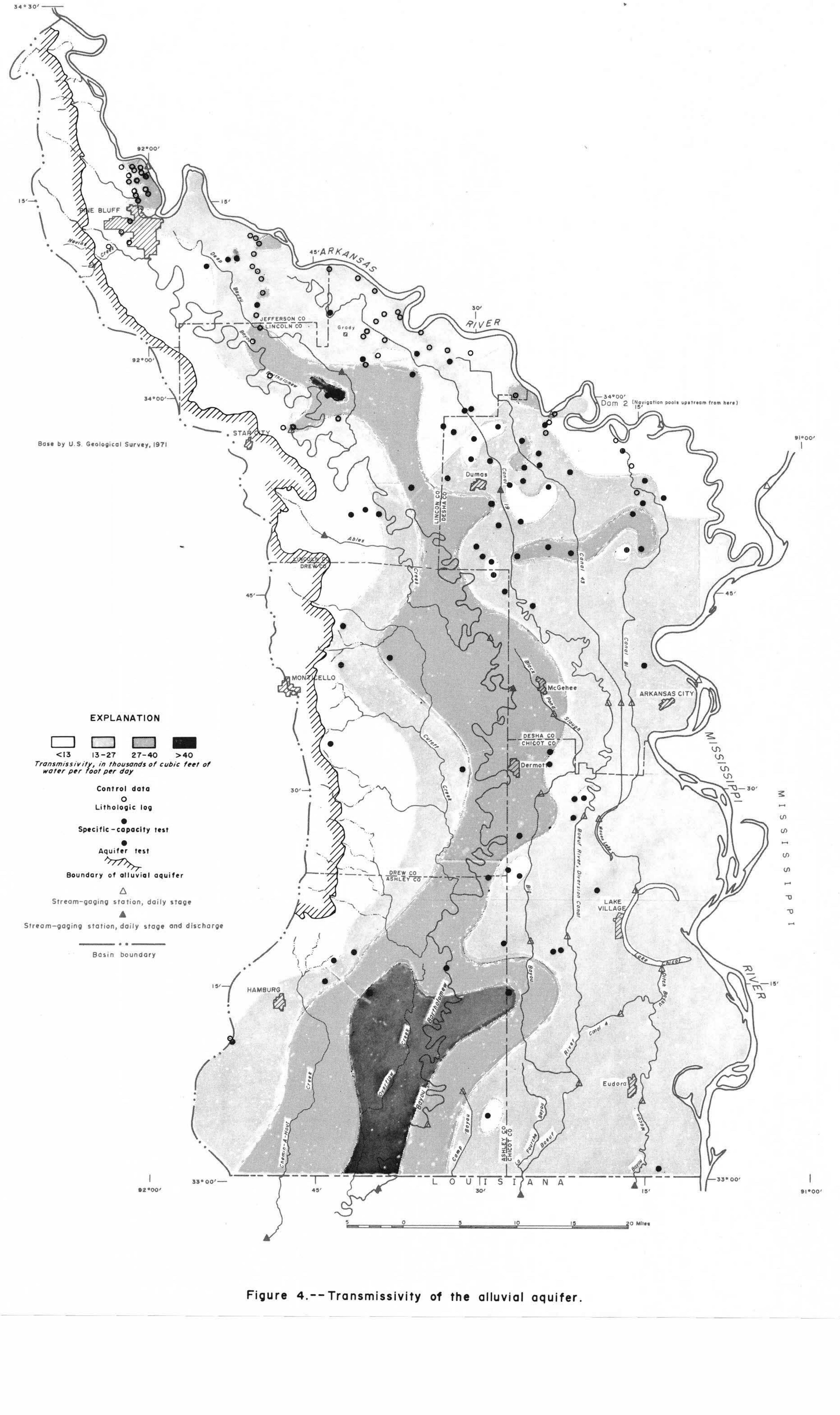


Figure 4.--Transmissivity of the alluvial aquifer.

generally are less as a result of aquifer thinning. Eastward from Bayou Bartholomew, the full range of T values occur locally due to differences in both the thickness and the permeability of the aquifer, but here the T values generally range from 13,000 to 27,000 ft^2/day.

S values, as determined from nine aquifer tests, ranged from 5.1×10^{-4} to 2.0×10^{-2} and averaged about 2.0×10^{-3}. All of these S values fall in the range of artesian conditions. That is, the water table or potentiometric surface is higher than the top of the aquifer. However, water-table conditions exist in areas where the aquifer is in good hydraulic connection with streams and in areas where the surficial alluvial deposits are permeable. Also, heavy pumpage locally creates water-table conditions; that is, the potentiometric surface drops to or below the top of the aquifer in response to the pumpage.

Flow Boundaries

Flow boundaries of an aquifer are boundaries at which the aquifer takes in or releases significant quantities of water in either liquid or vapor form. Flows across the boundaries are termed recharge when entering the aquifer and discharge when leaving the aquifer. Flow boundaries of the aquifer in this study include streams, the top surface of the aquifer, and discharging wells. Another boundary, arbitrarily designated, is the Arkansas-Louisiana State line.

In addition to Bayou Bartholomew, significant stream boundaries include the Arkansas, Mississippi, and Boeuf Rivers, Bayou Macon, and Canal 19. Water moves in the direction of decreasing head; thus, the direction of flow across the stream boundaries is controlled by the head distribution in the aquifer and the stage of the streams. As a consequence, flow may alternate from the stream to the aquifer or from the aquifer to the stream.

The top surface of the aquifer is the boundary at which the aquifer is recharged by infiltrating water from rainfall, irrigation, and surface storage, and where the aquifer discharges or loses water to evaporation and plants (evapotranspiration).

The discharging well is the boundary at which the aquifer is discharged by pumping. Because the head in the aquifer is always lowered in the vicinity of a discharging well, the direction of flow is always locally toward the well.

Head Distribution and Lateral Flow

The head distribution in the aquifer is represented by potentiometric-surface maps for the spring and fall of 1970 (figs. 5, 6). Data for the maps consist of water levels in wells, supplemented in some areas by stages on streams. The water levels were measured shortly before and after the seasonal irrigation pumping, which usually starts in May and ends in September. The

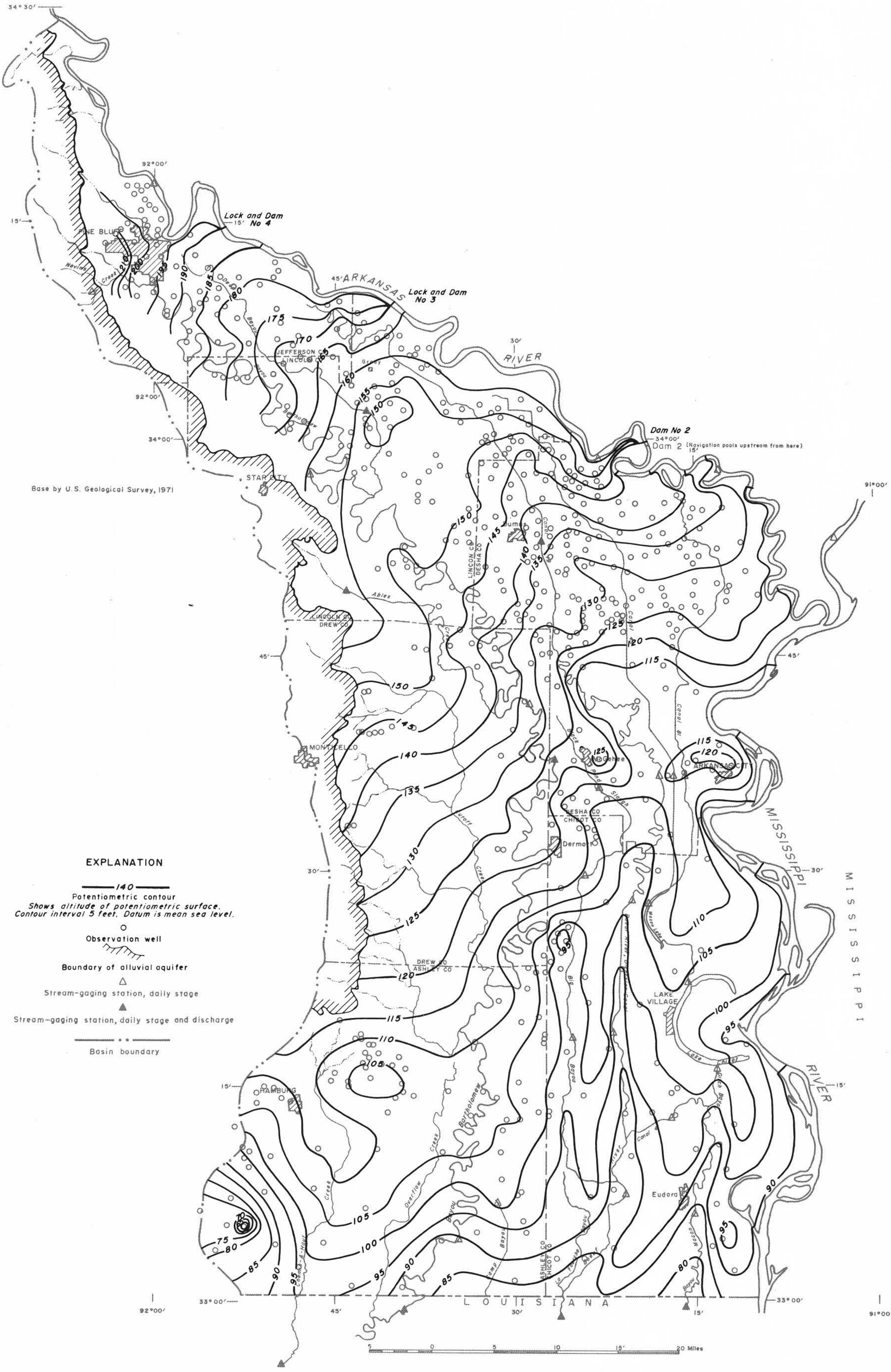
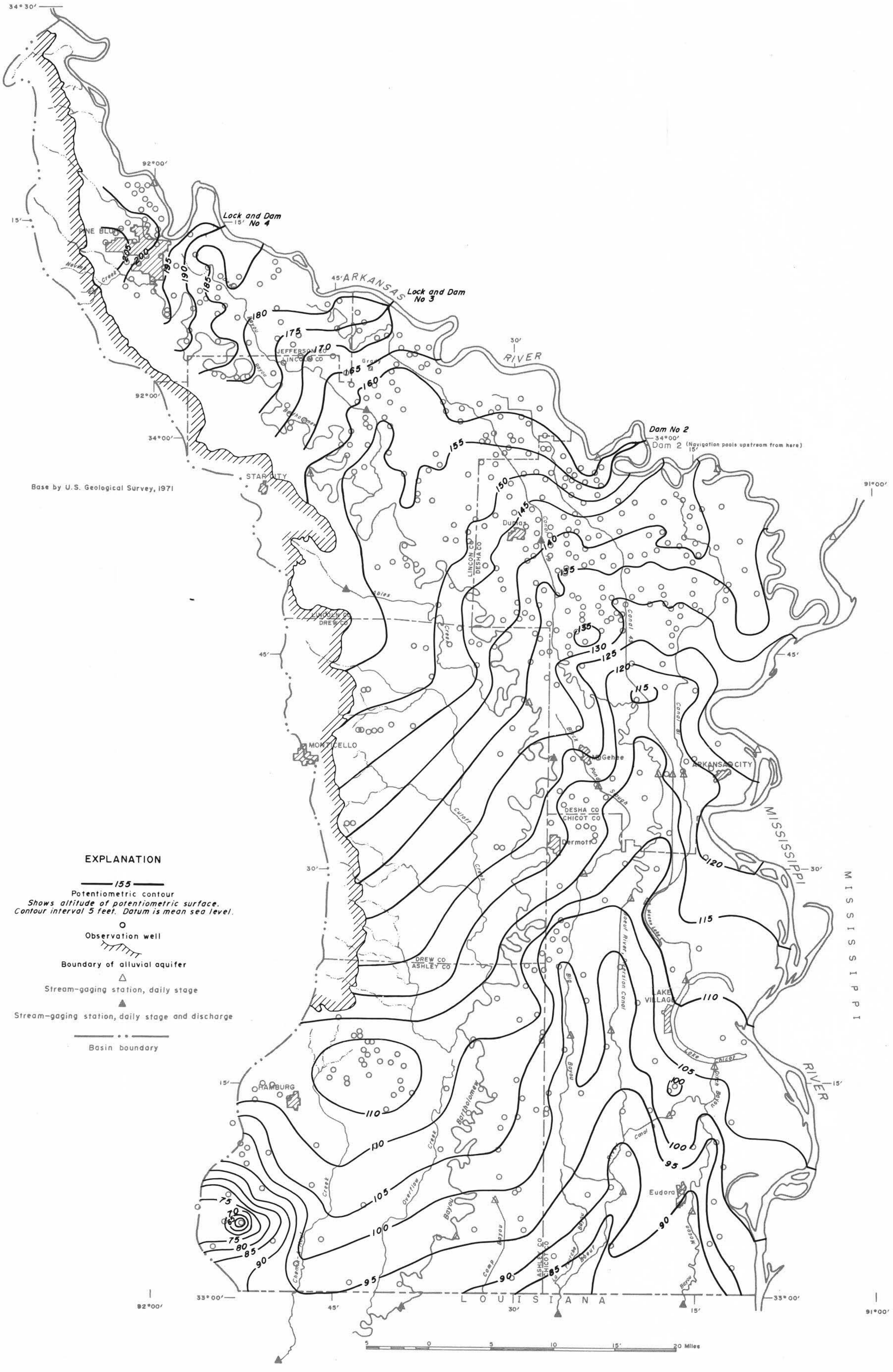


Figure 6.--Potentiometric surface of the alluvial aquifer, fall of 1970.



Base by U.S. Geological Survey, 1971

Figure 5.--Potentiometric surface of the alluvial aquifer, spring of 1970.

only significant pumping at the time the measurements were made was local, and consisted almost entirely of pumping at an industrial well field of the Georgia-Pacific Paper Co., south-southwest of Hamburg.

The depth to water below land surface in wells on the flood plain generally ranged from about 10 feet, in the south half of the project area, to 20 feet, in the north half; the depth to water in wells on the terrace generally ranged from about 50 feet, near Monticello, to 60 feet, near Hamburg. All water levels were lower in the fall, and the differences in levels in the spring and in the fall ranged from about 10 feet in heavily pumped areas to about 2 feet elsewhere. As indicated by the density of control points (figs. 5, 6), the most heavily pumped area extends northwestward from Desha County and lies between Bayou Bartholomew and the Arkansas River.

Average stream stages during selected periods in the spring and fall of 1970 were used for supplemental data for the potentiometric-surface maps. The Arkansas River upstream from Dam 2 showed insignificant change in the spring and fall stages because of navigation pools. Fall stages on the Arkansas River downstream from Dam 2 and on the Mississippi River were about 10 to 16 feet lower than spring stages. Fall stages on Bayou Bartholomew and other larger streams in this area were about 5 to 10 feet lower than spring stages.

The general slope of the potentiometric surface is to the south (figs. 5, 6). The direction of ground-water flow, which is reflected by the local slope of the potentiometric surface, is commonly either southeastward or southwestward. The potentiometric maps for the spring and for the fall indicate that Bayou Bartholomew is mostly a drain for ground-water flow from the west and a recharge source for the aquifer east of the bayou. The Arkansas River upstream from Dam 2 is a recharge source. Boeuf River and the smaller streams in the southeastern part of the area are drains most of the time.

The potentiometric map for the spring indicates that at high stage the Mississippi River and the Arkansas River upstream to Dam 2 are recharge sources. But the potentiometric map for the fall indicates that at low stage the Mississippi River and the Arkansas River upstream to Dam 2 are drains.

A conspicuous troughlike potentiometric depression, which is closed in the fall, has been created between Bayou Bartholomew and the Arkansas River as a result of heavy pumpage. Also, local closed depressions have been created east and south-southwest of Hamburg. The depression south-southwest of Hamburg is more conspicuous because it is affected by continuous industrial pumpage.

Water Use

Use of water from the aquifer and streams for industrial, municipal, and domestic purposes in the project area dates back many years, but pumpage for municipal and domestic purposes has never been large. Timber and paper industries have used the aquifer since the early 1900's. Most industrial pumpage is localized in the Hamburg area and now consists of pumpage at the Georgia-Pacific Paper Co. (Crossett Division) for supplemental process waters. The principal water supply for Georgia-Pacific is the Saline River west of the project area.

Figure 7 reflects the history of water use from the aquifer (ground water) and from streams (surface water). Significant pumpage in the area, which increased from 14,000 acre-ft (acre-feet) in 1945 to 180,000 acre-ft in 1953, began with irrigation for rice farming. During the same period, pumpage from streams, mostly those draining the aquifer in Chicot County, increased from less than 2,000 to about 50,000 acre-ft.

Rice-acreage controls went into effect in 1953, and since that time pumpage has fluctuated mostly according to the size of annual rice-acreage allotments. From 1953 to 1957, rice acreage steadily decreased and pumpage from the aquifer and from streams in 1957 was 110,000 and 33,000 acre-ft, respectively. Since 1957, rice acreage and pumpage for rice have increased, with some fluctuation, to near the high of 1953. Although the use of surface

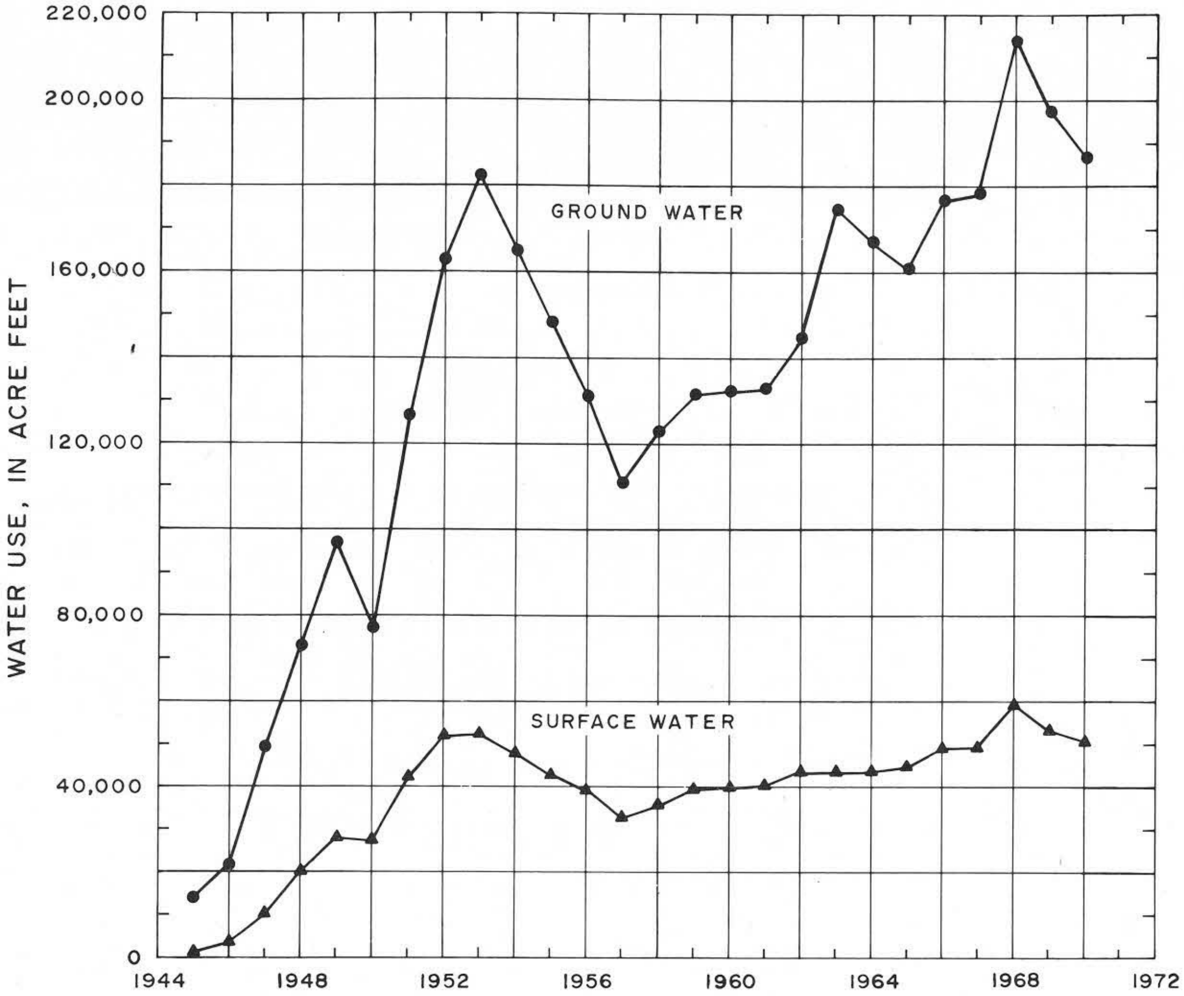


Figure 7.--Use of water from the alluvial aquifer and from streams.

water has remained almost entirely limited to rice irrigation, the use of water from the aquifer was expanded in the 1950's to include row-crop irrigation, and in the 1960's was expanded to include pumpage for fish farming. Although pumpage for row-crop irrigation is periodically significant, rainfall is sufficiently well distributed during some growing seasons so that irrigation of row crops is unnecessary.

Pumpage for fish farming is locally significant. In 1970 there were slightly more than 3,000 acres of fish farms in the area, largely in Desha and Lincoln Counties. A small amount of water from the aquifer and from streams is used for flooding a few forested and flood-prone areas for duck hunting during dry spells in the fall.

Table 10 gives the distribution of pumpage in 1970 by counties in the project area. Municipal pumpage from the aquifer, which was very small and was restricted to Ashley County, was combined with industrial pumpage because some wells supplied both.

Estimates of pumpage for rice irrigation were obtained by measuring the application of water on rice at 51 sites and applying median values of the application rates to the total rice acreage. Estimates of pumpage for fishponds were similarly obtained. The median application rate on rice was 28 inches per acre on the terrace and 54 inches per acre on the flood plain. The application rate to fishponds was about 60 inches per acre.

Table 10.—*Use of water from the alluvial aquifer and streams, in acre-feet, 1970*

County	Rice irrigation		Fish farms		Municipal and industrial		Total	
	Alluvial aquifer	Streams	Alluvial aquifer	Streams	Alluvial aquifer	Streams	Alluvial aquifer	Streams
Ashley-------	17,000	1,500	900	---------	11,300	---------	29,200	1,500
Chicot-------	20,200	27,800	2,000	---------	-----------	---------	22,200	27,800
Desha--------	49,800	13,200	4,300	---------	-----------	---------	54,100	13,200
Drew---------	14,500	3,000	400	---------	-----------	---------	14,900	3,000
Jefferson----	11,000	800	100	---------	-----------	---------	11,100	800
Lincoln------	47,300	3,800	7,700	---------	-----------	---------	55,000	3,800
Subtotal---	159,800	50,100	15,400	---------	11,300	---------	186,500	50,100

The large difference in application rate to rice on the terrace and to rice on the flood plain may be attributed largely to one or both of two conditions: (1) efficiency of application and (2) infiltration characteristics of the soil. Both of these conditions require further study.

Estimates of return water to streams from applied irrigation water, based on open-channel measurements at five ricefields, were about 25 percent of the applied water. The percentage of return to streams from fishponds was about the same. So, about 75 percent of the water applied to rice and to fishponds was consumed through evapotranspiration or entered ground-water storage through infiltration. Separate estimates of evapotranspiration and infiltration were not made. However, because the ricefields and fishponds are normally located on clayey subsoil to minimize infiltration losses, evapotranspiration losses probably are as high as 50 percent or more of the applied water.

Electrical-Analog Model

Analog models of aquifers are based on the analogy between the physical laws governing flow and storage of ground water and the physical laws governing flow and storage of electricity. This analogy, as described by Skibitzke (1960), permits the construction of small-scale models for the analysis of aquifers. The electrical-analog models are related to the aquifers by scale factors (Bedinger and others, 1970, p. 10) so that voltage and current in the analog models can be converted into ground-water head and ground-water flow.

The aquifer of the Bayou Bartholomew system was simulated by a single-layer resistance-capacitance network with a node spacing of 1 inch on the model = 7,040 feet across the aquifer. The resistance network represented the transmissivity of the aquifer (fig. 4). Initially, the capacitance network represented the storage coefficient of the aquifer obtained from aquifer tests. However, simulated pumpage for 1970 caused water-level declines in the model to be several times greater than actual water-level declines in the aquifer in 1970. This condition indicated that the storage coefficient obtained from short-duration pumping tests was not representative of the aquifer during the pumping season. The storage coefficient in the model then was increased until declines in the model were about the same as the actual declines in the aquifer. The result was a storage coefficient that ranged from 0.03 to 0.24, depending on location in the model.

The final values of the resistance-capacitance network and aquifer constants were as follows:

Transmissivity (ft /day)	Resistance (ohms)
<13,000	120,000
13,000-27,000	39,000
27,000-40,000	27,000
>40,000	18,000

Storage coefficient	Capacitance (microfarads)
0.24	0.04
.18	.03
.12	.02
.06	.01
.03	.005

The scale relating real time to model time is:

$1\text{X}10^{-4}$ sec (model) = 1 year (real time).

Several scales relating feet to volts and ft^3/day to amperes were used, ranging from 10 ft/volt and $8.36\text{X}10^3$ ft^3/day per ampere to 2.5 ft/volt and $2.09\text{X}10^9$ ft^3/day per ampere.

Stream boundaries were simulated on the analog model by connecting their boundary points to a voltage source whose output was scaled in proportion to the head in the streams. If the stream had good hydraulic connection with the aquifer, the voltage source was connected directly to the resistance-capacitance network. If the stream had poor connection with the aquifer, the voltage source was connected to the model through a resistor. The Mississippi, Arkansas, and Boeuf Rivers were modeled as having good connection with the aquifer. Bayou Bartholomew, Bayou Macon, and Canal 19 were modeled as having poor connection with the aquifer. Other streams of the system were not modeled. The stream boundaries, although continuous in reality, were necessarily represented as discrete segments on the analog model. The locations of lateral boundary segments are shown in figure 8.

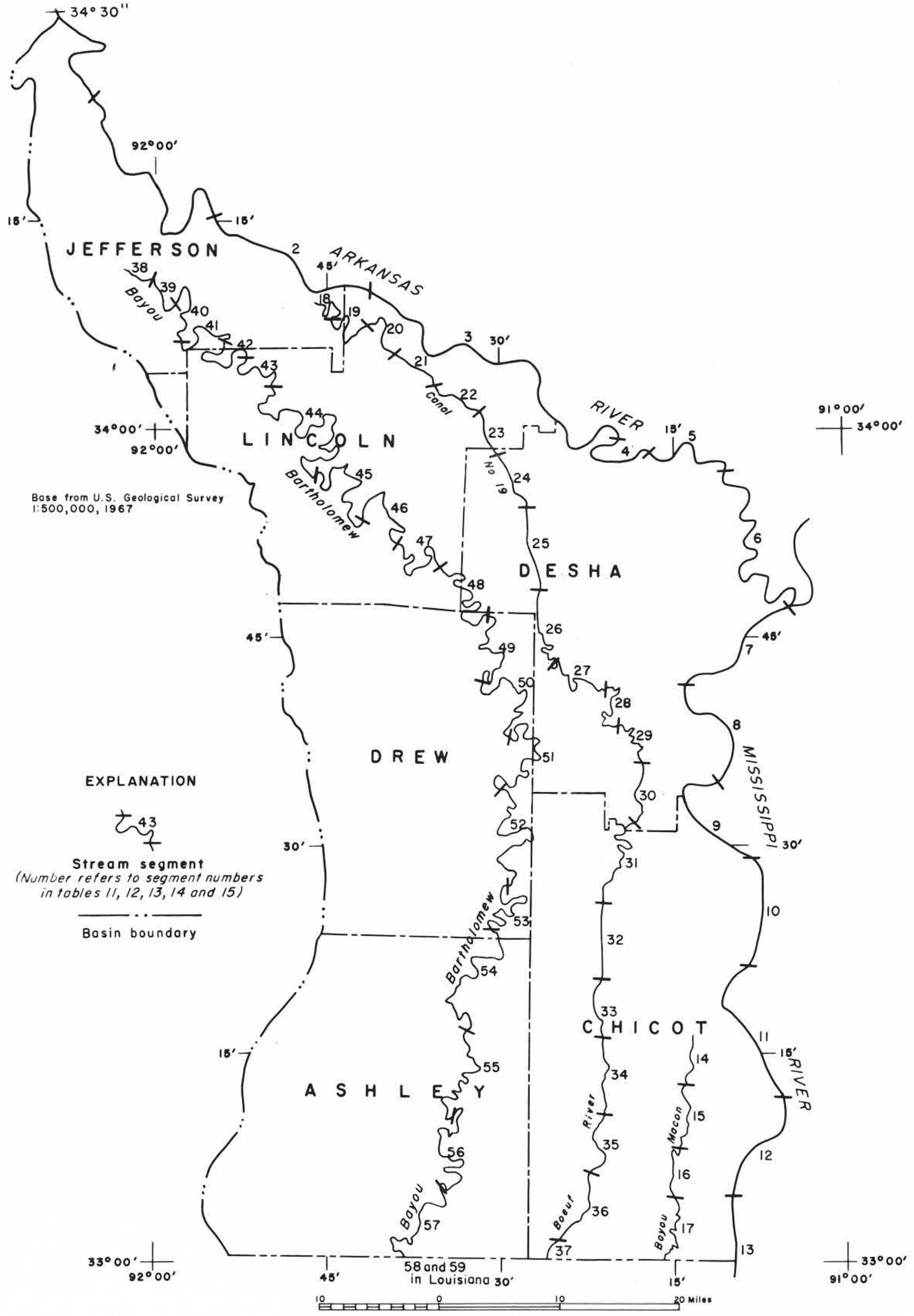


Figure 8.--Analog representation of streams.

The analog model was used to estimate aquifer-stream interflow in the spring and fall of 1970, before and after seasonal pumping. Spring was the period of maximum inflow from the streams to the aquifer, and fall was the period of maximum outflow from the aquifer to the streams. The values for the extremes of inflow and outflow at the stream boundaries provided an estimate of average aquifer recharge and discharge at the stream boundaries in 1970, under natural and steady-state conditions. How good this estimate is of aquifer recharge and discharge at the stream boundaries depends on the distribution of the inflow and outflow rates between the extreme rates of inflow and outflow. In addition, the estimate of aquifer recharge and discharge at the stream boundaries depends on the accuracy of the transmissivity distribution of the aquifer (fig. 4). Transmissivity data are reasonably sufficient in the principal areas of ground-water pumpage but are scant elsewhere, particularly in the lower reaches of the study area.

The method consisted of two separate model setups in which voltages were adjusted to average stream stages in the spring and fall, and then the voltages were applied along stream boundaries of the model. Current fed into the model network was adjusted until the voltage distribution in the model was equivalent to the head distribution in the aquifer, as shown by the potentiometric maps (figs. 5, 6). The potentiometric maps reflect not only the effects of natural conditions acting upon the aquifer, but also reflect the change in water level (drawdown) resulting from approximately 20 years of pumping. After the potentiometric head was simulated in the model, current was measured along the modeled stream boundaries. The current measurements were then converted to water equivalents to arrive at the flow between the streams and the aquifer (tables 11-14).

At low stage in the fall of 1970 the Mississippi River was draining the aquifer; at high stage in the spring of 1970 it was recharging the aquifer (table 11). The Arkansas River was chiefly recharging the aquifer in both the spring and fall because of the navigation pools along its course (table 11).

As indicated by table 12, Bayou Macon was a source of recharge in the spring and fall. However, the potentiometric-surface maps (figs. 5, 6) indicate that Bayou Macon was a drain in the spring and fall. This discrepancy between the maps and the model could not be resolved with the data. The data show ground-water levels lower than Bayou Macon stages along the modeled reach of the stream. Not conforming to ground-water levels, the Bayou Macon stages were not used for control in the potentiometric-surface maps. The stages were used for control in the model.

Canal 19 and the aquifer show little exchange of flow in the spring or fall (table 13) because of poor aquifer-stream connection and little difference in aquifer-stream head. Boeuf River

Table 11.—*Model estimates of flow to the aquifer from the Arkansas and Mississippi Rivers*

[Sign is minus if flow is from aquifer to stream]

Segment (fig. 7)	Flow, in acre-feet per year	
	Spring 1970	Fall 1970
Arkansas River		
1	6,100	5,200
2	-2,000	300
3	3,500	6,800
4	-900	-2,600
5	-600	-500
6	900	-2,400
Total	7,000	6,800
Mississippi River		
7	-1,200	-7,000
8	500	-8,300
9	1,000	-11,100
10	-800	-6,600
11	1,300	-3,900
12	1,300	-5,700
13	1,000	-4,400
Total	3,100	-47,000

Table 12.—*Model estimates of flow to the aquifer from Bayou Macon*

[Sign is minus if flow is from the aquifer to Bayou Macon]

Segment (fig. 7)	Flow, in acre-feet per year	
	Spring 1970	Fall 1970
14	1,000	3,600
15	200	-200
16	0	-100
17	100	-200
Total	1,300	3,100

Table 13.—*Model estimates of flow to the aquifer from Canal 19 and Boeuf River*

[Sign is minus if flow is from aquifer to stream]

Segment (fig. 7)	Flow, in acre-feet per year	
	Spring 1970	Fall 1970
Canal 19		
18	0	-100
19	0	0
20	0	-100
21	0	0
22	0	-100
23	-100	-100
24	-100	-100
25	-100	-100
26	100	100
27	100	100
28	100	100
29	100	100
30	0	100
Total	100	-100
Boeuf River		
31	-1,700	900
32	-1,900	-4,600
33	-1,300	-3,000
34	-2,300	-2,200
35	-2,400	-4,200
36	-4,500	-4,800
37	-4,900	-5,100
Total	-19,000	-23,000

was a drain in both the spring and fall (table 13). The aquifer discharged more water to Boeuf River than to any other stream in the system in 1970.

Bayou Bartholomew was a source of recharge to the aquifer in the spring of 1970 and was a drain in the fall (table 14). Because Bayou Bartholomew contributes more recharge to the aquifer at high stage than it later removes or drains at low stage, on the average, Bayou Bartholomew is a source of recharge to the aquifer.

Although Bayou Bartholomew originates in the area, it is apparent from table 14 that in the spring the stream losses to aquifer recharge are greater than stream gains from aquifer discharge. This condition is possible because in the spring the greatest part of the streamflow in Bayou Bartholomew, as well as the other streams originating in the area, is derived from rainfall runoff.

The total of the algebraic sums of aquifer recharge and discharge at the stream boundaries (tables 11-14) gives a net aquifer recharge of about 26,000 acre-ft in the spring and a net aquifer discharge of about 79,000 acre-ft in the fall. The average of the spring and fall values gives about 27,000 acre-ft of aquifer discharge. This value was used as an estimate of aquifer discharge to streams in 1970.

Table 14.—*Model estimates of flow to the aquifer from Bayou Bartholomew*

[Sign is minus if flow is from the aquifer to Bayou Bartholomew]

Segment (fig. 7)	Flow, in acre-feet per year	
	Spring 1970	Fall 1970
38	100	-300
39	0	-100
40	0	-100
41	100	-100
42	0	-200
43	100	-100
44	1,500	800
45	200	100
46	200	100
47	1,400	-900
48	2,600	400
49	600	100
50	600	-400
51	1,000	-200
52	1,700	-600
53	800	100
54	600	700
55	3,700	-3,500
56	4,100	-7,000
57	7,800	-4,000
58	6,100	-500
59	800	-3,300
Total	34,000	-19,000

Ground-water flow across the Arkansas-Louisiana State boundary, an item of aquifer discharge, was also estimated from the spring and fall analyses. The average value of this underflow was 20,000 acre-ft.

A separate analysis was made of the effects of 20 years of pumping on the water levels in the aquifer and the flow in the streams. Holding the current pumping rate constant, the model was pulsed to simulate seasonal pumping for each year dating back to 1950. This analysis showed how much the streamflow was reduced as a result of salvaged discharge or induced recharge caused by pumping from the aquifer. The decrease in natural discharge plus the increase in recharge of a developed aquifer is termed "capture" (Lohman and others, 1972, p. 3).

The total capture from all streams in the area was 114,500 acre-ft in 1970 (table 15). The excess of discharge over recharge at stream boundaries (tables 11-14) after 20 years of pumping indicates that most of the capture from the streams was salvaged discharge.

The capture from the Mississippi River was not large; it was about 12,000 acre-ft in 1970, or 10 percent of the total of all streams. This small amount of capture was because there was little ground-water withdrawal near the Mississippi River. The capture from the Arkansas River, caused by large ground-water withdrawals near the river, was about one-third of the total capture.

Table 15.—*Model estimates of change in flow, or capture, at stream boundaries caused by 20 years of pumping*

Stream	Segment (fig. 7)	Capture after 20 years of pumping (acre-ft per year)
Arkansas River----------	1- 3	33,000
	4- 5	3,100
	6	3,900
Total--------------	----------------	40,000
Mississippi River-------	7-11	10,800
	12	300
	13	900
Total--------------	----------------	12,000
Bayou Macon-------------	14	500
	15	800
	16	0
	17	0
Total--------------	----------------	1,300
Canal 19----------------	18-30	6,500
Boeuf River-------------	31	3,000
	32	2,400
	33	2,600
	34	900
	35-37	1,800
Total--------------	----------------	10,700
Bayou Bartholomew-------	38-44	4,900
	45-46	2,100
	47-48	15,200
	49-50	5,000
	51-52	5,800
	53-54	2,300
	55-56	5,100
	57-59	3,600
Total--------------	----------------	44,000
Total, all streams-	----------------	114,500

The capture from Bayou Macon was small, because only small withdrawals were made near it and the stream has poor connection with the aquifer. Canal 19 also has poor connection with the aquifer, but the capture from it was significant due to large withdrawals of ground water near the canal. The capture from Boeuf River, though significant, was only a small percentage of the total capture. This condition was caused by the relatively small ground-water withdrawals near Boeuf River. The capture from Bayou Bartholomew was large; it amounted to nearly 40 percent of the total.

With the current annual ground-water pumpage at 186,000 acre-ft, the annual capture is about 60 percent of the pumpage. Therefore, aquifer storage is declining. Even if pumpage continues at the current rate, streamflow will continue to be depleted as a result of capture until the capture is about equal to the pumpage.

The analog analyses provided an approximate water balance for the aquifer in 1970. The water balance, in acre-feet, is shown below:

Discharge:	
To streams	27,000
Underflow to Louisiana	20,000
Pumpage	186,000
Total	233,000

Recharge:

Capture plus recharge from rainfall and infiltration of irrigation water------------------------------ 161,000

Change in aquifer storage:

Recharge minus discharge------------- 72,000

Pumpage, estimated from field inventory, was 186,000 acre-ft, or nearly 80 percent of the total discharge. Discharge to streams and discharge as underflow to Louisiana were 27,000 and 20,000 acre-ft. These two items of discharge were estimated from the spring and fall steady-state analyses (p. 53, 55).

Recharge, totaling 161,000 acre-ft, included capture plus recharge from rainfall and infiltration of irrigation water. Capture (salvaged discharge plus induced recharge) was estimated to be about 114,000 acre-ft (table 15). However, the model allowed the other items of recharge to be treated only as the algebraic sum of vertical flow. This vertical flow also included aquifer discharge to evapotranspiration, which was cancelled by the summation of vertical flow.

The amount of capture resulting from decreased evapotranspiration is not known but it was assumed to be small.

Aquifer storage was reduced by 72,000 acre-ft, as indicated by model analysis. This change in storage was compared with change in storage computed from change in observed ground-water levels in the spring of 1970 and in the spring of 1971. Change in storage in the real aquifer was less, but was within 10 percent of the change in storage indicated by the model analysis.

Streamflow diversion and return flow in the subbasins in 1970 are shown in table 16. The amount of streamflow diversion was determined from an inventory of open-channel diversion plus capture, arrived at by analog analysis. Capture from outside the subbasins was largely from the Arkansas and Mississippi Rivers.

Water Quality

The quality and suitability for use of water in the aquifer have been described in detail in ground-water resources reports cited in this report. Most of the sampling for laboratory determinations was done between 1945 and 1958. In connection with this study, supplementary field determinations were made in 1970. The period of record for stream sampling is given in table 17.

Quality as Related to Water Use

Concentrations of dissolved solids, chloride, hardness, and iron pose the chief water-quality problems in the study area.

Dissolved solids

Dissolved-solids concentration is sometimes cited as the limiting chemical factor on the potability of water. The U.S. Public Health Service (1962) recommends that water containing

Table 16.—*Streamflow diversion and return flow in 1970*

Subbasin	(1) Diversion from streams in the subbasin (acre-ft)	(2) Total water use (acre-ft)	(3) Water from aquifer storage and capture from outside the subbasin (acre-ft) Column 2 minus 1	Return flow from irrigation and fishponds (acre-ft)	Net loss to streamflow in subbasin (acre-ft)
Bayou Bartholomew------	55,400	74,600	19,200	18,700	36,700
Boeuf River------------	32,900	92,800	59,900	23,200	9,700
Bayou Macon------------	24,300	69,200	44,900	17,300	7,000
Total-------------	112,600	236,600	124,000	59,200	53,400

Table 17.—*Streamflow water-quality records*

[Number: Only 8-digit numbers are national downstream-order numbers. Collecting agency: AR, Arkansas Department of Pollution Control and Ecology; EP, Environmental Protection Agency (Federal); GS, U.S. Geological Survey]

Station		Period of record (calendar years)				
Number	Name	Daily	Weekly	Monthly	Periodic	Collecting agency
07263650	Arkansas River near Pine Bluff---------------	--------	--------	1962-63	--------	GS
07263720	Arkansas River near Altheimer----------------	1953-55	--------	----------	--------	GS
07265280	Arkansas River at Pendleton------------------	--------	1969-	1962-63	--------	GS,EP
040000	Arkansas River at Yancopin-------------------	--------	--------	----------	1965-67	GS
07364150	Bayou Bartholomew near McGehee---------------	1959-63	--------	1964-	--------	GS
07364190	Bayou Bartholomew near Wilmot----------------	1952-53	--------	----------	1947	GS
07364200	Bayou Bartholomew near Jones, La-------------	--------	--------	----------	1964-	GS,AR
07364210	Overflow Creek near Jones, La----------------	--------	--------	----------	1966	GS
07364250	Chemin-a-Haut Creek (Bayou) near Berlin------	--------	--------	----------	1960,1962	
07364300	Chemin-a-Haut Bayou (Creek) near Beekman, La--	--------	--------	----------	1966-	GS
AR-14	La Fourche Bayou near Arkansas-Louisiana State line.	--------	--------	----------	1968-	AR
AR-15	Boeuf River near Arkansas-Louisiana State line.	--------	--------	----------	1968-	AR
07367700	Boeuf River near Arkansas-Louisiana State line.	--------	--------	----------	1966-	GS
AR-16	Bayou Macon near Eudora----------------------	--------	--------	----------	1968-	AR
07369700	Bayou Macon Near Kilbourne, La---------------	--------	--------	----------	1965-	GS

more than 500 mg/l (milligrams per liter) of dissolved solids not be used if less mineralized water is available. A concentration of about 1,000 mg/l of dissolved solids is an upper limit of acceptability for many industrial uses.

In terms of sodium and electrical conductivity (Wilcox, 1948, p. 26), irrigation water from the aquifer containing less than 500 mg/l of dissolved solids would be classified excellent to good; 500-1,000 mg/l, good to permissible; 1,000-1,500 mg/l, permissible to doubtful; and more than 1,500 mg/l, doubtful to unsuitable.

As indicated in figure 9, the aquifer in practically all the area draining to Bayou Bartholomew yields water that contains less than 500 mg/l of dissolved solids. West of Bayou Bartholomew, the water is less mineralized; and near its western edge, the aquifer yields water containing less than 100 mg/l of dissolved solids. Also, the aquifer yields water that contains less than 500 mg/l of dissolved solids in areas bordering the Arkansas and Mississippi Rivers (fig. 9).

The aquifer in a large part of the Boeuf River basin and a part of the upper half of the Bayou Macon basin yields a more-mineralized water. This water, generally containing from 500 to 1,000 mg/l of dissolved solids, occurs in a nearly continuous zone that extends southward from the upper reach of the Boeuf River basin near the Arkansas River, remaining centered mostly in the Boeuf River basin, and crosses the State line. A small extension of this zone occurs west of Grady (fig. 9).

Within the zone of water containing more than 500 mg/l of dissolved solids, concentrations of 1,000-1,500 mg/l occur in small areas east of Dumas and west of Lake Village. The greatest concentrations of dissolved solids (as high as 3,720 mg/l) were found in a small area west of Eudora (fig. 9). Water from the aquifer in this small area killed rice (Onellion and Criner, 1955, p. 32).

As in the aquifer, the concentration of dissolved solids in the streams (table 18) is higher in the Boeuf River subbasin, reaching maximum concentrations of about 450 mg/l at low flows. The low flows represent mostly drainage from the aquifer. When the contribution of surface runoff is greater to Boeuf River and the streamflow is more than about 1,000 cfs, the concentration of dissolved solids will decrease to about 50 mg/l. Table 18 can be used with table 5 (flow duration) to relate time with the different ranges of concentration of dissolved solids and other constituents in the streams. For example, table 5 indicates that flow in the Boeuf River near the Arkansas-Louisiana State line exceeds 110 cfs about 60 percent of the time. Thus, the flow will be less than 110 cfs about 40 percent of the time. Table 18 shows that when the flow in Boeuf River is less than 100 cfs (about 40 percent of the time) the dissolved-solids content will be 160-450 mg/l.

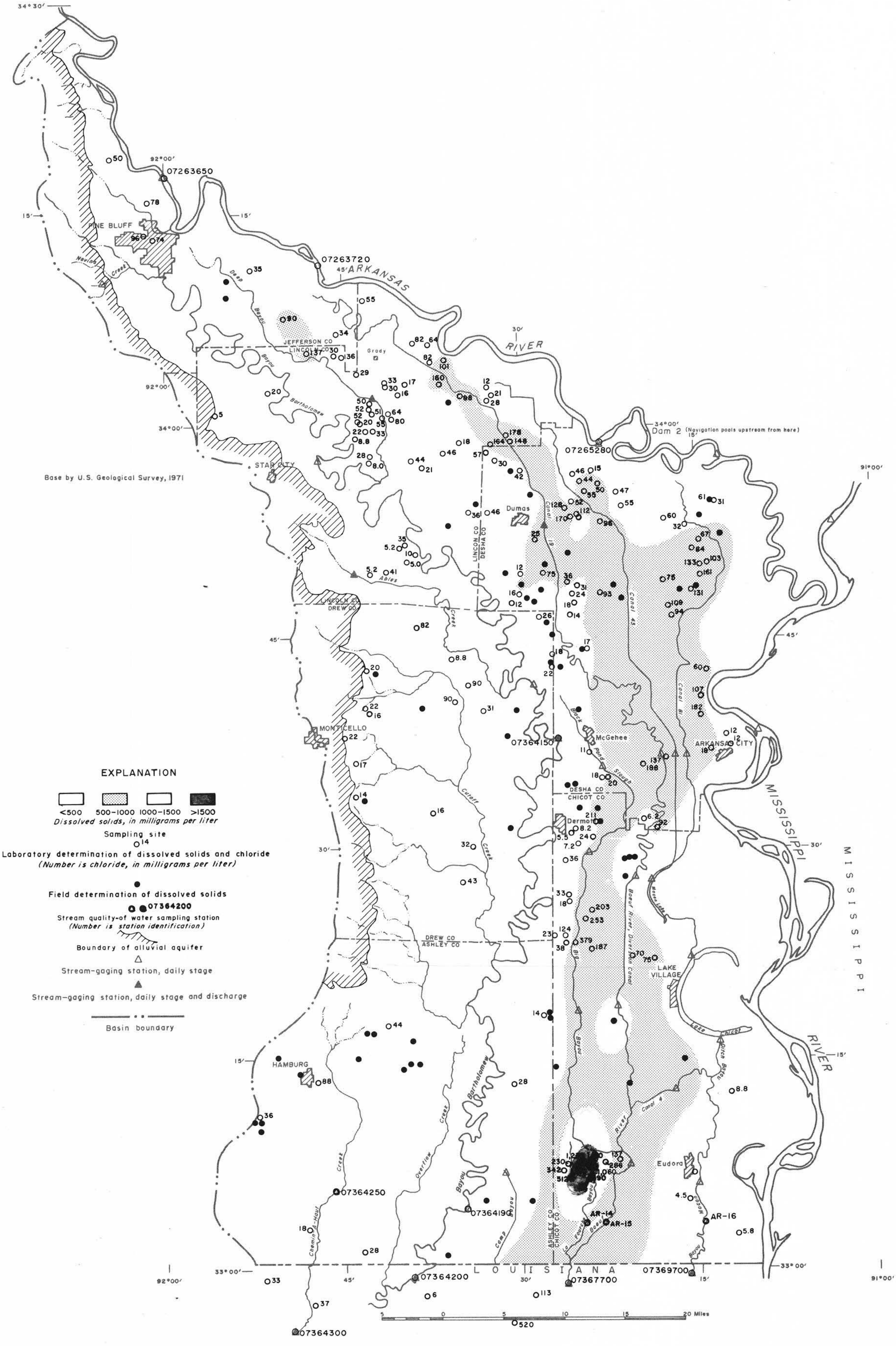


Figure 9.--Dissolved solids and chloride in the alluvial aquifer.

Table 18.—*Water quality as related to streamflow at selected gaging stations*

Station		Period of record	Ranges in concentration of indicated constituents, in milligrams per liter, for streamflows of less than 100, 100-1,000, and more than 1,000 cubic feet per second								
Number	Name		<100	100-1,000	>1,000	<100	100-1,000	>1,000	<100	100-1,000	>1,000
			Dissolved solids			Hardness			Chloride		
07364150	Bayou Bartholomew near McGehee.	1964-70	90-250	40-200	30-140	40-150	20-130	10-30	5- 40	3-30	2- 5
07364200	Bayou Bartholomew near Jones, La.	1966-71	140-200	50-190	40- 70	80-120	20-110	10-30	15- 25	5-25	1- 5
07364300	Chemin-a-Haut Bayou (Creek) near Beekman, La.	1958, 1966-68	90-190	30- 60	10- 30	40-130	10- 30	5-20	10- 40	5-10	1- 5
07367700	Boeuf River near Arkansas-Louisiana State line.	1966-71	160-450	90-430	50-170	80-290	40-240	30-90	20-100	5-80	2-30
07369700	Bayou Macon near Kilbourne, La.	1966-71	190-320	100-240	100-180	140-240	50-170	50-80	10- 30	5-25	5-15

Chloride

More than 250 mg/l of chloride in combination with sodium gives water a salty taste. The U.S. Public Health Service (1962) recommends that water containing more than 250 mg/l of chloride not be used for drinking purposes if other more suitable supplies are available.

Chloride concentrations of water in the aquifer generally vary directly with the dissolved solids. As shown in figure 9, in localities where the concentration of dissolved solids is less than 500 mg/l, the chloride is seldom more than 50 mg/l; and where the dissolved solids is more than 500 mg/l, chloride generally ranges from about 50 to 200 mg/l. Locally, concentrations of chloride in the aquifer are considerably higher. Along Big Bayou, west of Lake Village, chloride concentration is as high as about 400 mg/l. West of Eudora, chloride concentration is as high as about 1,500 mg/l. As shown in table 18, chloride in streams is never more than about 40 mg/l except in Boeuf River. In Boeuf River, during flows of less than 100 cfs, chloride concentration is as high as about 100 mg/l.

Hardness and iron

Hardness in a domestic water supply increases soap consumption, and a very hard water may leave insoluble deposits on articles washed with soap. Also, hardness contributes to the formation of scale in boilers, water heaters, and pipes. A standard of classification of water for hardness by Doll and others (1963) is as follows:

Hardness (mg/l)	Classification
Less than 60	Soft
61-120	Moderately hard
121-180	Hard
More than 180	Very hard

Public water supplies should not contain more than 0.3 mg/l of iron (U.S. Public Health Service, 1962). More than about 0.3 mg/l of iron in water may cause unpleasant taste and contribute to growth of iron bacteria. Also, more than 0.3 mg/l of iron will stain laundry and porcelain fixtures and will be objectionable in water used for manufacturing textiles, paper, beverages, and other products.

The concentrations of hardness and iron in the aquifer are shown in figure 10. In the area that drains to Bayou Bartholomew from the west, or largely from the alluvial terrace, hardness in the aquifer generally is less than 100 mg/l and commonly is less than 60 mg/l. An exception is in the Hamburg area where a zone of very hard water, more than 200 mg/l, extends across the terrace through an area of irrigation pumpage from the aquifer. Dissolved iron in the water here and elsewhere, from the aquifer in the terrace area, is commonly less than a few tenths of a milligram per liter. Locally, iron concentration may be 2 mg/l or more.

The aquifer yields moderately to very hard water (more than 100 mg/l) in practically all the area east of Bayou Bartholomew (fig. 10). In that part of the area draining mostly to Boeuf River, the hardness concentration is commonly higher than 400 mg/l, and locally is as high as 600 mg/l. Also, east of Bayou Bartholomew, dissolved iron in the aquifer is generally more than 5 mg/l and locally is more than 40 mg/l.

Hardness values in the low flow of the streams (table 18) correspond to the hardness values in the ground water in the drainage area of the streams (fig. 10). When the flows are sustained almost entirely by ground-water discharge, maximum hardness in the streamflows is about 290 mg/l in Boeuf River, 240 mg/l in Bayou Macon, 150 mg/l in Bayou Bartholomew, and 130 mg/l in Chemin-a-Haut Bayou.

Dissolved iron in the streams is generally very low and is not a problem even though the connected aquifer is largely iron bearing. At times, however, dissolved iron of significance (maximum, about 3 mg/l) has been measured in Bayou Bartholomew. This iron probably represents either colloidal particulate iron or iron that is combined with organic matter in a soluble complex (Hem, written commun., 1972). Also, at times the water in Bayou Bartholomew is colored owing to the solution of organic debris.

Quality as Related to Hydrochemical Controls

The lower dissolved-solids content of water in the aquifer in the area that drains to Bayou Bartholomew (fig. 9) reflects dilution by recharge that has a relatively rapid movement to discharge points. This process continued through a long period has removed the more readily attacked material from the soil and subsoil in this part of the study area. Controlling hydrologic factors, some interrelated, include the proximity to recharge areas, the steep hydraulic gradient from the west imposed on the aquifer, the function of Bayou Bartholomew as a significant recharge source and drain, and the comparatively high transmissivity of the aquifer along the course of Bayou Bartholomew (fig. 4). Water in the aquifer is also diluted by recharge in areas that border the Arkansas and Mississippi Rivers (fig. 9).

The high dissolved-solids content of water in the aquifer in the area draining to Boeuf River may be related to hydrologic controls that substantially inhibit the rate of movement or freshening of the ground water by recharge. Land-surface altitudes generally are lower in this area, and the water table is nearer the land surface. These factors may favor local discharge through evapotranspiration, because the water table in this area is largely within the root zone of plants. High rates of evapotranspiration increase mineralization of residual ground water.

The moderately high concentrations (100-200 mg/l) of chloride in the ground water in the Boeuf River drainage area, noted by Bedinger and Reed (1961, p. 50) in Lincoln and Desha Counties, seemingly are the result of controls within the aquifer-stream system. The variations in chloride concentrations may be related to the variations in the transmissivity of the aquifer (fig. 4), as well as other factors, including evapotranspiration. The much higher concentration of chloride in the aquifer west of Eudora (fig. 9) might come from water moving upward from formations underlying the aquifer (Onellion and Criner, 1955, p. 24). However, the Cockfield Formation, the youngest Tertiary aquifer in the area, yields satisfactory domestic and public water supplies.

The abundance of calcium and bicarbonate in the aquifer east of Bayou Bartholomew suggests that carbonate minerals are available in the soil and subsoil and are attacked by percolating water that contains carbon dioxide. This gas probably is abundantly available because of plant-root respiration and decay of organic matter. The general tendency for the dissolved-solids content of water in this part of the aquifer to be higher may be related to the aquifer's having served as an area of natural discharge through a long period, but many complicating factors might modify this interpretation. The alluvium probably also contains iron-bearing minerals that yield soluble iron by chemical-reduction processes in organic-rich soil and sediment (Hem, written commun., 1972).

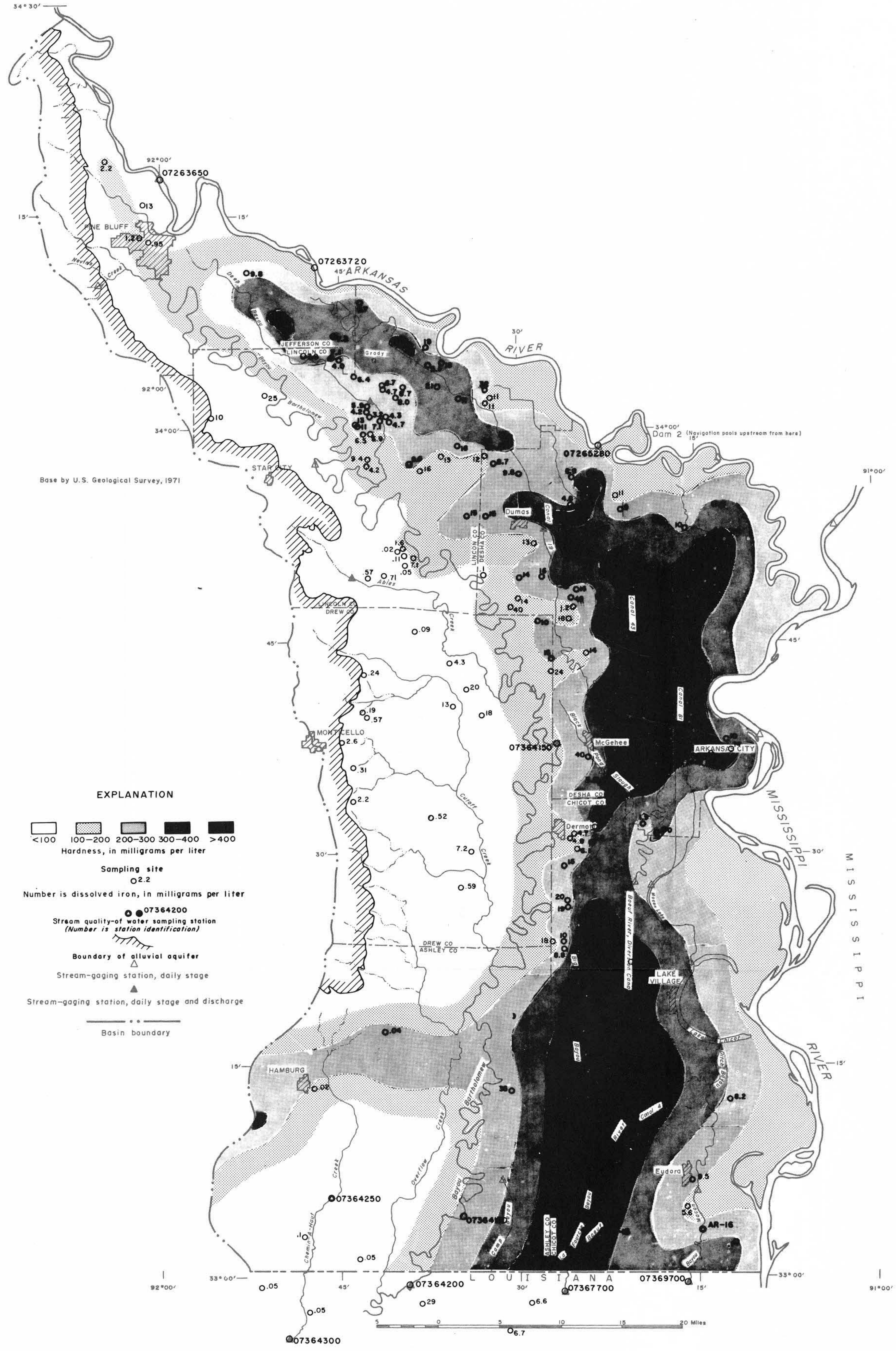


Figure 10.--Hardness and dissolved iron in the alluvial aquifer.

The chemical characteristics of ground water in the terrace area are significantly different from the ground water in the low area to the east. In the terrace area, the water generally is a sodium bicarbonate rather than a calcium bicarbonate type, and is considerably lower in dissolved solids, hardness, and iron (figs. 9, 10). The higher altitude on the terrace allows a deeper water table (40 ft or more below the land surface) and a steeper hydraulic gradient. The features favor local recharge, a faster rate of water movement, and a more-oxidized environment. Both the water type and the pH (as low as about 5.0) are indications that the terrace soil is relatively deficient in lime or hardness-contributing minerals, which probably have been removed by circulating water. Because of the oxidizing conditions, iron solubility is very low in this water. Significant concentrations of iron in solution might occur near the base of the aquifer, where reducing and acid conditions would be possible.

The zone of very hard water extending from the area of Bayou Bartholomew through Hamburg (fig. 10) is an exception to the general quality of ground water in the terrace area. Also, this water approaches 500 mg/l of dissolved solids. This more-mineralized water is probably related to the development of ground water. The aquifer is heavily pumped here for rice irrigation, as illustrated by the depressed potentiometric surface on figure 6. The source of the mineralization could be (1) recharge from irrigation water, or (2) movement of ground water into this area from the east, caused by local reversal of the hydraulic gradient during the pumping season.

To what extent the quality of water in the Arkansas River affects the quality of water in the aquifer is not known. Prior to the navigation pools established in 1968, the Arkansas River at potentially recharging stages contained on the average about 400 mg/l of dissolved solids and 100 mg/l of chloride. At draining stages, the river contained on the average about 5,000 mg/l of dissolved solids and 200 mg/l of chloride. So, historically, the natural head-stage relation between the aquifer and the river has substantially aided in preserving good water quality in the aquifer.

A short period of chemical records from station 07265280 (fig. 9) indicate that the navigation-pool water of the Arkansas River throughout the entire year averages about 300 mg/l of dissolved solids and about 100 mg/l of chloride. During the summer and fall, dissolved solids and chloride contents average about 400 mg/l and 125 mg/l, respectively. But, periodically, when very low discharge rates occur in the late summer and fall, dissolved solids and chloride are as high as about 700 mg/l and 300 mg/l. If any changes are occurring in the chemical regimen of the aquifer, as a result of the navigation pools, they probably will be slow and difficult to observe.

The Mississippi River water, as shown from sampling stations at Memphis, Tenn., and Vicksburg, Miss., averages about 250 mg/l of dissolved solids, seldom changing more than 50 mg/l throughout the full range of flow. The water is uniformly low in chloride content—less than 20 mg/l. Recharge from the Mississippi River, at any stage, would have a significant diluting effect on the aquifer.

PROGRESS AND PLANS FOR FURTHER STUDY

The study thus far has been concerned with the first phase of work as outlined in the project planning; that is, basically, to compile and analyze the data at hand, with a minimum of additional data collection.

The analyses of surface-water data produced useful statistical estimates of mean monthly and annual stream discharges, as well as statistical estimates of fair-weather flow and floodflows. Also, the analyses pointed at changes caused by the flood-control projects. In addition to a significant reduction in the frequency of flooding in the lower reaches of the Boeuf River and the Bayou Macon subbasins, the canalization and channel improvements have caused an increase in base flow or ground-water discharge to open-channel flow where the potentiometric surface of the aquifer is near the land surface.

Finally, the streamflow analyses showed a very complex surface-water regimen, resulting from irregular ponding and diversion of flows for irrigation, interbasin transfer of flows, indefinite subbasin boundaries, and unrated backwater-flow conditions. The test of the regression model might indicate the general extent of these conditions and the potentiometric-surface maps definitely reflect the indefinite subbasin boundaries and the interbasin transfer of flow. At this point, it seems the development of a streamflow model, although desirable, would require manpower and funding not now available. An alternate plan being considered is to select less complex segments of the area for streamflow modeling.

The analog model of the aquifer is calibrated as far as data permit for 1970. A close agreement (within 10 percent) between the change in aquifer storage derived from model analysis and the change in storage derived from change in ground-water levels indicates good correspondence between the field data and the model. However, the model lacks verification until some estimates of flow in the water balance are derived independently of the model. Plans for additional data collection and study are, therefore, directed primarily toward obtaining independent estimates of flow, or model verification.

Low-flow measurements in the modeled streams, with the exception of the Arkansas and Mississippi Rivers, will be given the highest priority in the additional data collection,for the purpose of making independent estimates of flow exchange at the stream boundaries. The great difference in the magnitude of flows between open-channel flow and flow across the stream boundaries makes this effort impractical for the Arkansas and Mississippi Rivers. Ground-water level measurements will be continued for additional checks on change in aquifer storage. A lower priority will be given to the collection of evapotranspiration (ET) and irrigation seepage data, but , hopefully, more of those data will become available from other sources. ET and seepage could be used for refinement of model estimates. For increased versatility in interpreting data, making additional model estimates, and projecting estimates, a digital-computer model will be used.

The time required for a reasonable model verification is indefinite. Because the primary method selected for independent flow estimates requires low-flow data, fair-weather flow conditions before and after seasonal pumping periods are essential for a reasonable degree of success. Although optimum low-flow conditions are not rare events, they did not exist in the spring and fall of 1970, or in the spring of 1973.

The flow estimates derived from analog analysis should be of some use even though the estimates are subject to revision until model verfication.

The most significant results of the model analysis are the estimates of streamflow capture, particularly the capture from Bayou Bartholomew. Estimated capture from the bayou was 44,000 acre-ft, or 75 percent of the total diversion from the bayou. At the current rate of ground-water pumpage, the bayou will cease to be a perennial stream in the upper reaches. The scant flow in the bayou along the reach of greatest ground-water pumpage supports this estimate.

The zone of high concentration of chemical constituents in the aquifer indicates that the Boeuf River subbasin historically is an area of a very shallow water table and high rates of ground-water discharge to evapotranspiration. With extensive forest clearing and ground-water development through the past 30 years, both of which have trended southward, the water table has lowered and evapotranspiration has decreased. However, the high concentration of chemical constituents, a residual effect of the evapotranspiration, will decrease slowly throughout the subbasin.

Deterioration of water quality in the aquifer as a result of ground-water development is indicated on the terrace near Hamburg. The sediment load in streams is assumed to be increasing throughout the study area, owing to the conversion of forested lands to farming.

Chemical sampling of ground water and sediment sampling of streamflows will be expanded in additional phases of work. Modeling of sediment loads in some reaches is being considered, but the feasibility of this is questionable.

CONCLUSIONS

The combined mean annual surface-water yield of the Bayou Bartholomew, Boeuf River, and Bayou Macon subbasins near the Arkansas-Louisiana State line is about 3,000 cfs, or about 2.2 million acre-ft.

Flood control projects, consisting of canals and channel improvement, have reduced flooding in the area. Some change in the drainage boundaries of the streams has resulted from the flood-control projects. Also, channel improvement and streamflow diversions have altered the low-flow characteristics of some streams.

The direction of flow in the aquifer generally is southward. Local patterns of flow are significantly affected by the large streams. Bayou Bartholomew is mostly a ground-water drain for that part of the aquifer west of the bayou and is a recharge source for that part of the aquifer east of the bayou. The Arkansas River in the navigation pool area is a steady-recharge source to the aquifer. The Arkansas River downstream from the navigation pool area and the Mississippi River are recharge sources during high stage and are drains at low stage. Streams in the southern half of the Boeuf River and Bayou Macon subbasins are mostly drains.

Estimates of flow, derived from analog analysis but lacking field verification, indicate that recharge to the aquifer in 1970 was about 161,00 acre-ft. About 70 percent, or 114,000 acre-ft, of the recharge was by capture from streams caused by groundwater pumpage. Capture from streams, in acre-feet, was as follows: Bayou Bartholomew, 44,000; Arkansas River, 40,000; Boeuf River and Canal 19, 17,200; Mississippi River, 12,000; and Bayou Macon, 1,300. The rest of the recharge (47,000 acre-ft) was from rainfall and irrigation seepage.

Discharge from the aquifer in 1970 was about 233,000 acre-ft. About 80 percent, or 186,000 acre-ft, was discharged through wells. Natural discharge to streams was about 27,000 acre-ft, and discharge as underflow to Louisiana was about 20,000 acre-ft.

Storage in the aquifer in 1970 was reduced by about 72,000 acre-ft.

In 1970 streamflow diversion from the subbasins, consisting of open-channel diversion and capture, was 112,600 acre-ft. By subbasin, in acre-feet, the streamflow diversions were 55,400 from Bayou Bartholomew, 32,900 from Boeuf River, and 24,300 from Bayou Macon. Return flows, in acre-feet, to the subbasins, were 18,700 to Bayou Bartholomew, 23,700 to Boeuf River, and 17,300 to Bayou Macon.

The chemical quality of streamflows is excellent for irrigation. Except during summer low-flow periods and with precaution during periodic draining of ricefields and fishponds, the streamflows should be suitable in quality for most other uses.

The chemical quality of water from the aquifer generally ranges from permissible to excellent for irrigation. The only area of the aquifer proved unsuitable for irrigation is a small area west of Eudora, where water from the aquifer contains excessive chloride.

The use of water from the aquifer in the flood-plain area for household, municipal, and industrial purposes is severely limited unless the water is treated to remove the iron and reduce the hardness. However, water from the aquifer in the terrace area should be suitable for general use with little treatment.

Significant responses to water-resources development of the system include (1) reduced base flow in Bayou Bartholomew, resulting from capture by irrigation wells; (2) steady-state recharge of the aquifer along the Arkansas River, resulting from the navigation pools; and (3) changes in basin boundaries and low-flow characteristics of streams, resulting from flood-control projects and streamflow diversion.

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