DISCHARGE OF GROUND WATER ALONG THE OZARK ESCARPMENT IN SOUTHEASTERN MISSOURI AND NORTHEASTERN ARKANSAS

By Thomas O. Mesko and Jeffrey L. Imes

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CONVERSION FACTORS, VERTICAL DATUM, AND ABBREVIATIONS

Multiply	*By*	*To obtain*
foot (ft)	0.3048	meter
mile (mi)	1.609	kilometer
square mile (mi^2)	2.590	square kilometer
cubic foot per second (ft^3/s)	0.02832	cubic meter per second

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

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ABSTRACT

Discharge measurements along the Ozark escarpment on the Black and Current Rivers and tributaries in southeastern Missouri and northeastern Arkansas were used to identify and quantify gaining and losing stream segments and to improve understanding of ground- and surface-water interaction between two regional ground-water-flow systems. The measurements indicate the Black and Current Rivers receive substantial discharge from underlying aquifers and the Ozark-St. Francois and McNairy-Nacatoch aquifers contribute a larger portion of water to stream base flow than does the alluvium of the Mississippi embayment. Three major gaining reaches of streams, which receive a total of about 1,220 cubic feet per second of water, were identified during the study. The Current River gains 642 cubic feet per second, of which 492 cubic feet per second is gained after the river enters the Mississippi embayment. The upstream reaches of the main stem of the Black River gain 209 cubic feet per second and the downstream reaches of the Black River gain 370 cubic feet per second. A stream-flow budget indicates a total gain of 1,514 cubic feet per second and total loss of 542 cubic feet per second, for a net gain of 972, or about 1,000 cubic feet per second.

INTRODUCTION

As part of the U.S. Geological Survey's Regional Aquifer-System Analysis (RASA) program, two independent three-dimensional digital computer models were developed to simulate ground-water flow in the Ozark Plateaus and the northern Mississippi embayment areas of the United States (fig. 1). The Ozark Plateaus aquifer-system model (Imes and Emmett,1994) is a subregional study of the Central Midwest Regional Aquifer-System Analysis study (Jorgensen and Signor, 1981). The Mississippi embayment aquifer system in the northern Mississippi embayment (Brahana and Mesko, 1988) was modeled as part of the Gulf Coast Regional Aquifer-System Analysis study (Grubb, 1984). The common boundary between the two RASA study areas extends along about 175 mi of the Ozark escarpment from Poplar Bluff, Missouri, on the northeast to Jacksonport, Arkansas, on the southwest (fig. 2). Hydrologic and geologic data indicate the potential for ground water to move beneath the escarpment into the Ozark-St. Francois aquifer (fig. 2) and to abruptly discharge into overlying geohydrologic units or directly into streams. This concept of flow is consistent with other geohydrologic factors that control flow in the embayment. This paper documents the occurrence and quantity of ground-water discharge to surface-drainage systems along the Ozark escarpment. Results of this study improve the understanding of ground-water flow between the regional aquifer systems and ground- and surface-water interaction along the escarpment.

REGIONAL AQUIFER SYSTEMS AND GROUND-WATER FLOW MODELS

Ozark Plateaus Aquifer System

The Ozark Plateaus aquifer system (Imes, 1990a,b,c, d, Imes and Emmett, 1994) is composed of consolidated sediments of Ordovician and Cambrian age, consisting primarily of dolostone and some sandstone. The Ozark aquifer (Imes, 1990a,d), which ranges in thickness from about 1,500 to more than 4,000 ft, is the surficial unit along the northern edge of the Ozark escarpment. Several large springs discharge from this aquifer near the escarpment in southern Missouri (Beckman and Hinchey, 1944; Vineyard and Feder, 1974). Other units comprising the Ozarks Plateaus aquifer system are the St. Francois confining unit and the St. Francois aquifer (Imes, 1990 a,d). Precambrian igneous and metamorphic rocks form the nearly impermeable Basement confining unit at the base of the Ozark Plateaus aquifer system.

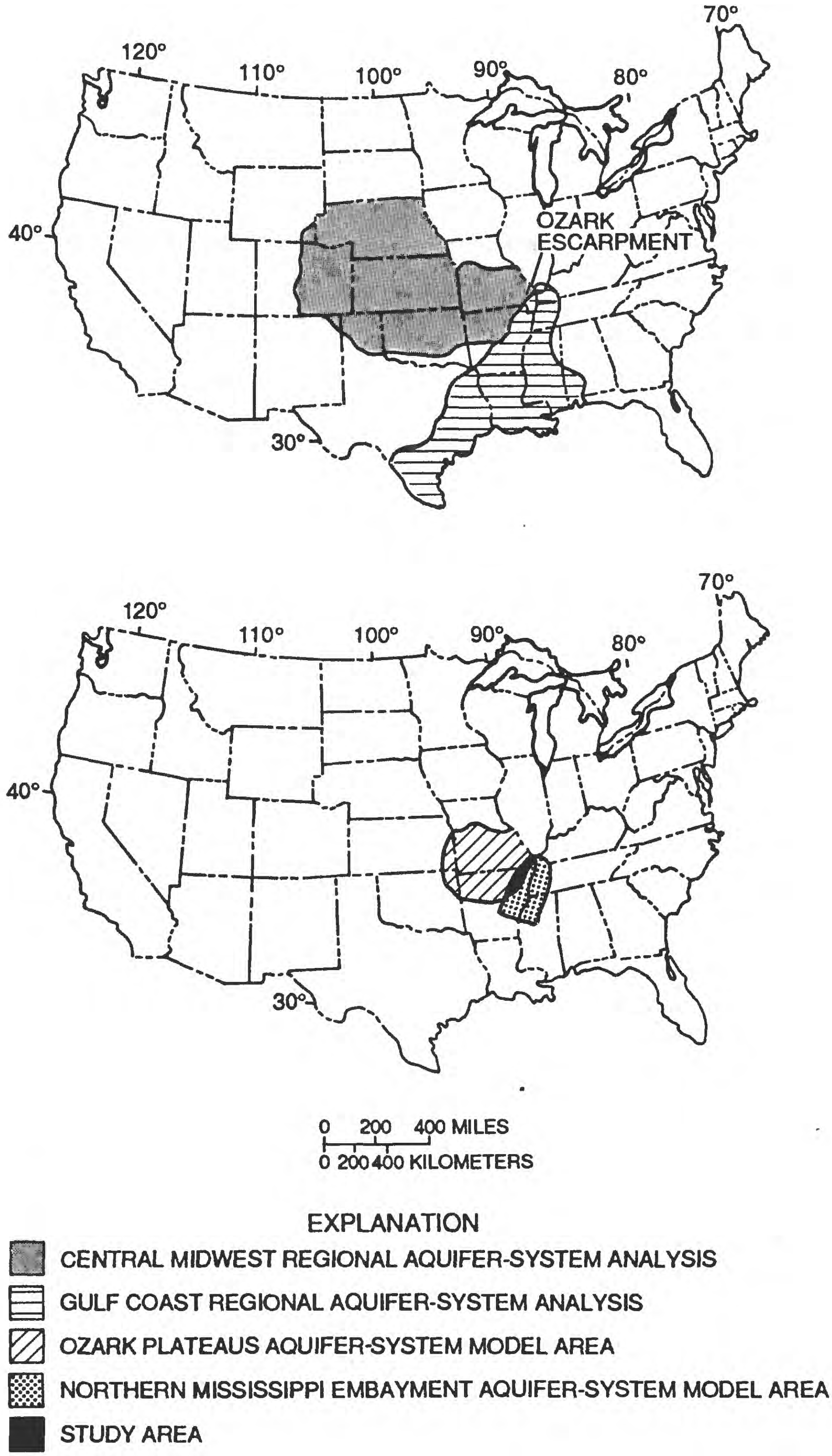
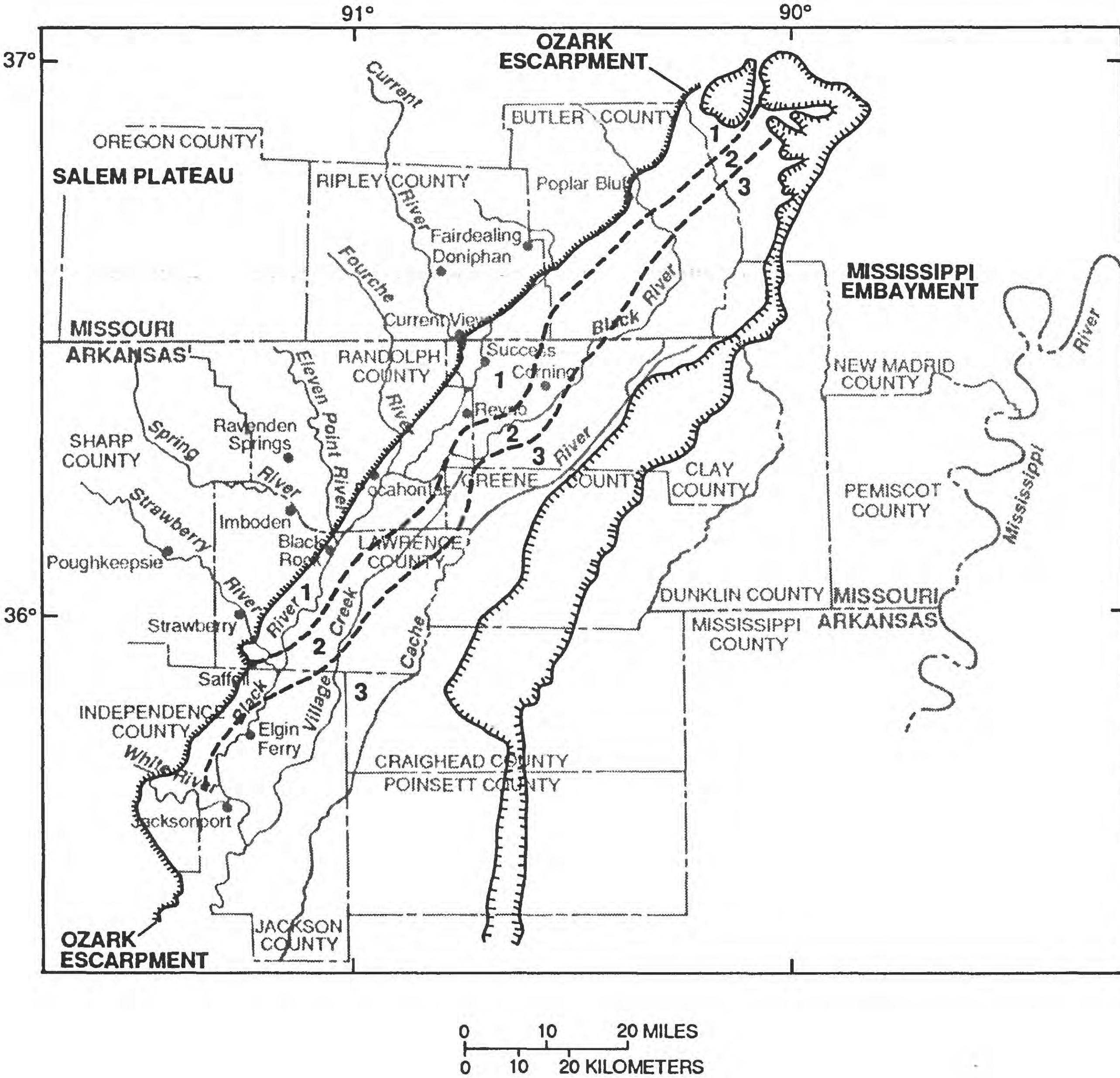


Figure 1.--Location of Regional Aquifer-System Analysis areas (Central Midwest and Gulf Coast), model areas (Ozark Plateaus and Mississippi Embayment), and study area.



EXPLANATION

3 MIDWAY GROUP SUBCROP--Area where low permeable clay, equivalent to the regional confining unit, directly underlies alluvial sediment

2 UPPER CRETACEOUS SUBCROP--Area where unconsolidated sand, equivalent of the McNairy Nacatoch aquifer, directly underlies alluvial sediment

1 PALEOZOIC SUBCROP--Area where consolidated limestone and dolostone rocks, the equivalent of the Ozark-St. Francois aquifer directly underlies alluvial sediment

CROWLEY'S RIDGE--Area where Tertiary and older units crop out

Figure 2.--Drainage system of part of the Black River basin, subcrop geology, and physiographic features (subcrop geology from Broom and Lyford, 1981, and Mesko, 1990).

The potentiometric surface in the Ozark aquifer near the escarpment (fig. 3) indicates shallow ground-water flow is from upland areas to large streams, springs, and surface-water drainage systems. Deeper, regional ground-water flow leaves the Ozark Plateaus aquifer system and enters the Mississippi embayment aquifer system.

A digital computer model of the Ozark Plateaus aquifer system (Imes and Emmett, 1994) represents three aquifers, two confining units, and one confining system. Using this model, the magnitude of flow discharging from the Ozark Plateaus aquifer system was estimated at 867 ft^3/s. A model of regional ground-water flow in the Central Midwest RASA area (Signor and others, in press) that includes the Ozark Plateaus aquifer system indicates about 827 ft^3/s of water discharges from the system.

Mississippi Embayment Aquifer System

The Mississippi embayment aquifer system (Brahana and Mesko, 1988) is composed of unconsolidated sediments of Quaternary, Tertiary, and Late Cretaceous age that overlie consolidated Ordovician and Cambrian rock. The surficial geohydrologic unit in the northern part of the embayment is the Mississippi River valley alluvial aquifer, except where older units crop out on Crowley's Ridge (fig. 2). Thickness of the alluvial aquifer ranges from 0 to more than 250 ft. Other units comprising the Mississippi embayment aquifer system are the Claiborne and Wilcox Groups, Midway Group, and the McNairy-Nacatoch aquifer in the Upper Cretaceous McNairy Sand and Nacatoch Sand (Mesko, 1988 and 1990). A confining unit in Paleozoic and Cretaceous rocks underlies the McNairy-Nacatoch aquifer except near the margins of the embayment or where it has been removed by erosion. The Ozark-St. Francois aquifer underlies the entire region. Broom and Lyford (1981) and Petersen and others (1985) mapped the subcrop of geohydrologic units in eastern Arkansas and Mesko (1988) mapped the subsurface extent of units for southeastern Missouri.

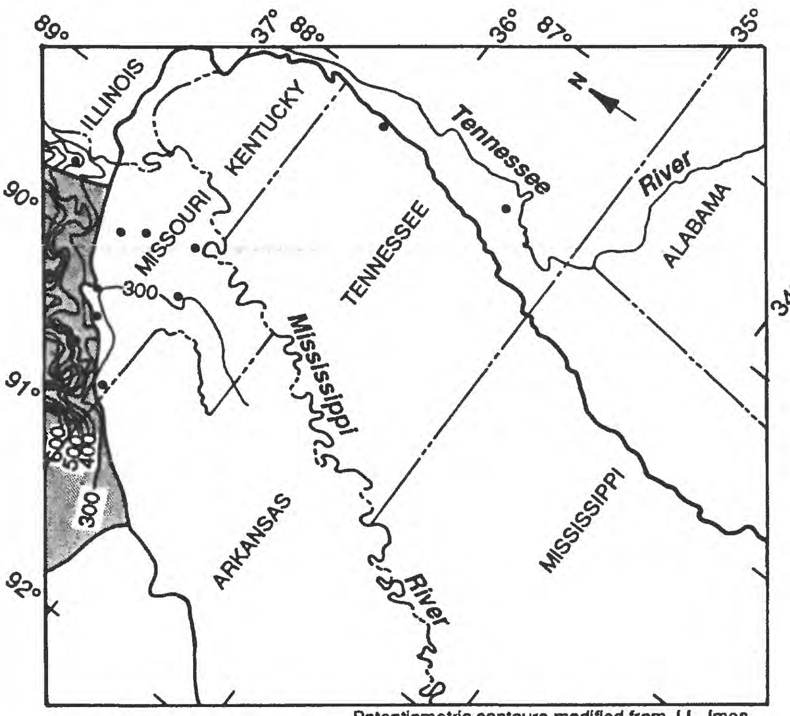
The Current River flows over the outcrop and subcrop of the Ozark-St. Francois aquifer in northeastern Arkansas. The Black River flows over part of the subcrop of the McNairy-Nacatoch aquifer, but as it converges with the Current River near Pocahontas, Arkansas, the Black River also flows over the Ozark-St. Francois aquifer (fig. 2).

Near the margins of the embayment, ground-water is unconfined and, in part, controls recharge and discharge of underlying units. Hydraulic gradients are steep in the Ozark Plateaus aquifer system but are nearly flat in the Mississippi embayment aquifer system.

A digital computer model of ground-water flow in the northern part of the Mississippi embayment aquifer system (Brahana and Mesko, 1988) represents four aquifer layers and three confining units. Preliminary modeling of steady-state conditions indicates that from 50 to 200 ft^3/s of water recharges the Ozark-St. Francois aquifer from the Ozark uplands and flows into the embayment. Near the margin of the embayment, where Upper Cretaceous and Tertiary units are thin or completely absent, water discharges from the Ozark-St. Francois aquifer into the base of the alluvial aquifer.

DISCHARGE OF GROUND WATER ALONG THE OZARK ESCARPMENT

Model simulation of ground-water flow indicated that the quantity of water discharging from the Ozark Plateaus aquifer system southeasterly across the escarpment was much larger than the simulated quantity of water recharging the stratigraphically equivalent Ozark-St. Francois aquifer of the Mississippi embayment. These model results indicated that most of the ground water leaving the Ozark system discharges abruptly along the escarpment (Imes and Emmett, 1994). In order to determine if the ground-water flow differences indicated by the model results could be explained by the interaction of ground water and surface water along the escarpment, a series of low-flow discharge measurements (seepage measurements) were made on the Black and Current Rivers and their major tributaries during August 1987.



EXPLANATION

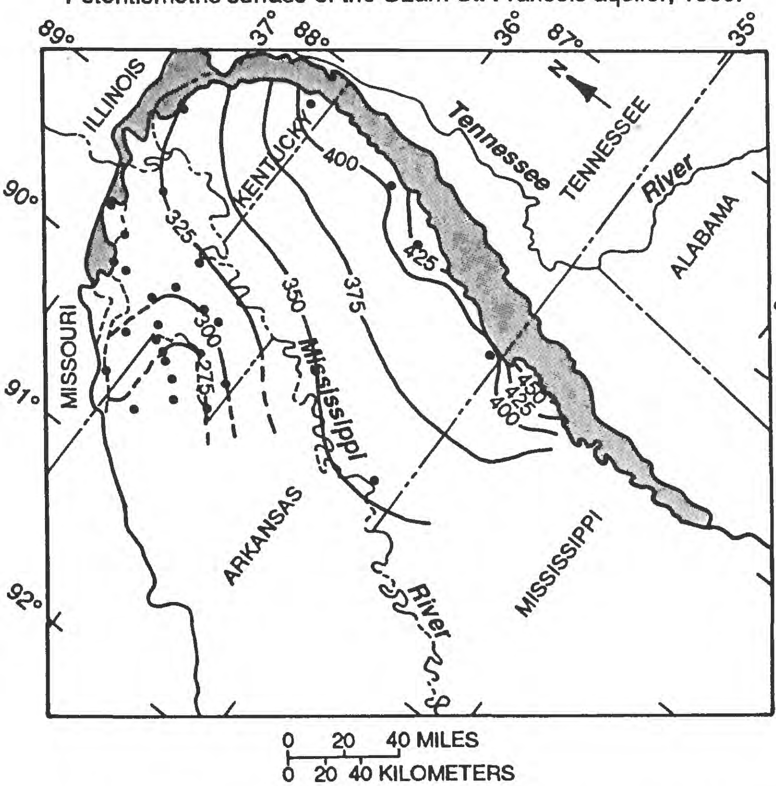
OUTCROP OF OZARK-ST. FRANCOIS AQUIFER

—600— POTENTIOMETRIC CONTOUR--Shows altitude at which water level would have stood in in tightly cased wells. Contour interval 50 feet. Datum is sea level

• DATA POINT

MARGIN OF MISSISSIPPI EMBAYMENT

Potentiometric surface of the Ozark-St. Francois aquifer, 1980.



EXPLANATION

OUTCROP OF McNAIRY-NACATOCH AQUIFER

SUBCROP OF McNAIRY-NACATOCH AQUIFER BENEATH ALLUVIUM

--325— POTENTIOMETRIC CONTOUR--Shows altitude at which water level would have stood in tightly cased wells. Dashed where approximately located. Contour interval 25 feet. Datum is sea level

• DATA POINT

MARGIN OF MISSISSIPPI EMBAYMENT

Potentiometric surface of the McNairy-Nacatoch aquifer, 1988.

Figure 3.--Potentiometric surfaces of the Ozark-St. Francois and McNairy-Nacatoch aquifers, 1980 (modified from Brahana and Mesko, 1988).

Low-Flow Indices

Low-flow indices are useful in comparing discharge between basins that have dissimilar characteristics such as total drainage area or annual low-flows. Low-flow indices are calculated by dividing the annual low flow, in cubic feet per second per square mile [$(ft^3/s)/mi^2$], measured in a stream by the total drainage area upstream of the measuring site, which yields a value of discharge per square mile for a drainage basin. Factors that affect low-flow indices within a basin are: (1) hydraulic characteristics of the stream; (2) depth of penetration of the stream; (3) stream-bed permeability; and; (4) geology within the basin. Speer and others (1966 a,b) reported the main stem of the Black River and its tributaries have large low-flow indices and this flow is principally derived from subsurface springs in Paleozoic rock. In addition, they reported that streams east of the Black River, such as Cache River and Village Creek, have small low-flow indices. Low-flow indices for the Black River and its tributaries range from about 0.10 to more than 0.30 [$(ft^3/s)/mi^2$], while indices for streams draining the alluvium, such as Cache River and Village Creek range from about 0.0001 to 0.10 [$(ft^3/s)/mi^2$]. Additional low flow and duration data for southeastern Missouri and northeastern Arkansas have been reported by Hines (1975), Skelton (1976), Hunrichs (1983), and Hedman and others (1987).

Seepage Measurements

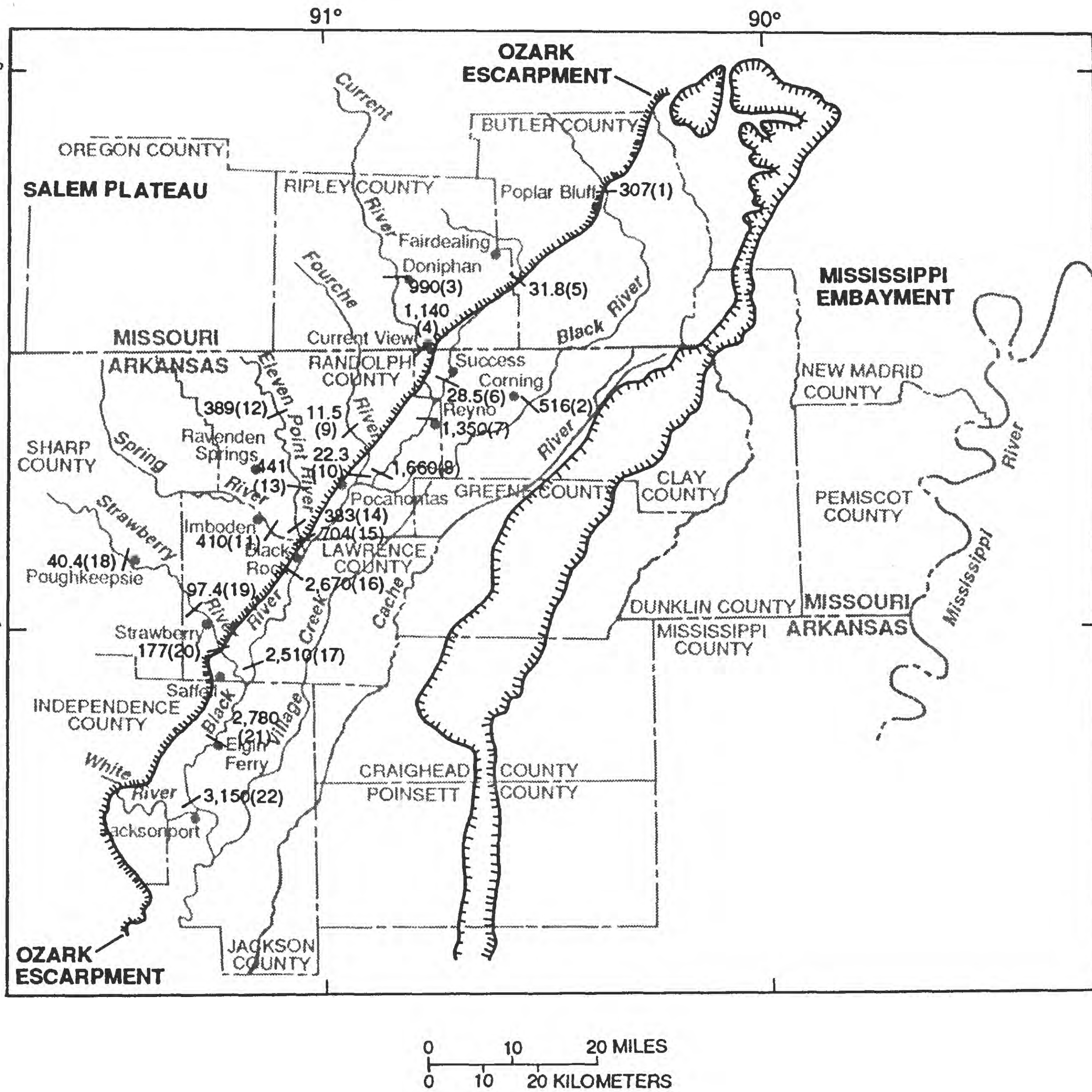
Stream discharge was measured at 16 sites and gage height was recorded at 6 sites during August 24-26, 1987, for streams and tributaries in the Black River basin (fig. 4). Minimal or no precipitation had occurred in the region for at least 2 weeks before the seepage study, and gage-height data from continuous recorders indicated that the Black River main stem, Current River, Eleven Point River, Spring River, and Strawberry River (fig. 4) were all in moderate recession during the seepage study. Results of the seepage study are presented in table 1 with site-location data. Generally, each discharge measurement is subject to a plus or minus (+ or -) 5-percent uncertainty, indicating that actual discharge can range from 5 percent less than to 5 percent greater than the measured discharge. Measurements that differ by more that 5 percent are considered to reflect actual changes in discharge rather than measurement error. The quantity and percentage change of discharge between selected sites and the gain or loss in flows per mile of river are presented in table 2. Where streams converge, the discharges of the streams were added and compared to the discharge at the next downstream measurement site.

Three stream reaches were found to have the largest gains, the Black River between Poplar Bluff (site 1) and Corning (site 2), the Current River between Doniphan (site 3) and Pocahontas (site 8), and the Black River between Elgin Ferry (site 21) and Jacksonport (site 22). These three gaining reaches contributed about 1,220 ft^3/s of flow to the Black River. A streamflow budget based on the available data (table 2) indicates total gains of 1,514 ft^3/s, total losses of 542 ft^3/s, and thus a net gain of 972 ft^3/s. An average gain of 2.6 [$(ft^3/s)/mi$] was calculated for the entire river system.

The model-estimated ground-water flow beneath the Ozark escarpment ranged from 650 to 800 ft^3/s, which is slightly less than the 972 ft^3/s measured discharging to area streams. Sources of this additional flow may be from shallower, post-Paleozoic and Cretaceous rocks, Quaternary alluvium (which probably are not a substantial source), or local flow systems originating in upland areas adjacent to the escarpment.

SUMMARY

Comparison of simulations from two regional ground-water flow models, one of the Ozark Plateaus aquifer system and the other of the Mississippi embayment aquifer system, indicated a large difference (650 to 800 ft^3/s) in the quantity of ground water flowing southeast beneath the Ozark escarpment into the Mississippi embayment. Discharge measurements on the Black and Current Rivers and their tributaries in southeastern Missouri and northeastern Arkansas were made to determine if difference in simulation results could be attributed to the discharge of ground water near the common boundary between the models. Analysis of discharge data indicates that ground- and surface-water interaction does occur along the escarpment and can be used to explain differences in water budgets calculated by the two models. Three stream reaches were identified as having the largest gains in flow. One on the Black River and two on the Current River. A streamflow budget indicated a total gain of 1,514 ft^3/s, a total loss of 542 ft^3/s, and thus a net gain of 972 ft^3/s. An average gain of 2.6 [$(ft^3/s)/mi$] was calculated for the entire river system.



EXPLANATION

177(20)╲ DISCHARGE MEASUREMENT SITE--Number is discharge in cubic feet per second. Number in parentheses is site number from tables 1 and 2

CROWLEY'S RIDGE--Area where Tertiary and older units crop out

Figure 4.--Location of discharge measurement sites and measured or calculated discharge, August 24-26, 1987.

Table 1.—Discharge at sites in the Black River Basin, southeastern Missouri and northeastern Arkansas, August 24-26, 1987

[NW1/4 sec.2, T.24N. R.6E., Township, range, section location; --, no data; *, discharge from field measurement, otherwise discharge was calculated from gage height and rating curve]

Site number (figure 4)	Station number	Station name	Station location	Date	Gage height, in feet	Discharge, in cubic feet per second	Continuous record available
1	07063000	Black River at Poplar Bluff, MO	NW1/4 sec.2, T.24N. R.6E., Butler County, 1,500 feet upstream from bridge on U.S. Highway 60 and at river mile 211.2.	8-24-87 8-26-87	0.40 --	310 *307	Yes Yes
2	07064000	Black River near Corning, AR	NE1/4 sec.4, T.20N. R.5E., Clay County, 2.2 miles east of Corning and at river mile 152.2.	8-25-87	1.96	516	Yes
3	07068000	Current River at Doniphan, MO	NW1/4 sec.27, T.23N. R.2E., Ripley County, 0.5 mile upstream from U.S. Highway 160, 1 mile west of Doniphan at river mile 51.3.	8-24-87	.73	990	Yes
4	--	Current River near Currentview, MO	NW1/4 sec.5, T.21N. R.2E., Clay County, AR, 500 feet downstream from State line.	8-24-87	--	*1,140	No
5	07068510	Little Black River below Fairdealing, MO	NE1/4 sec.24, T.23N. R.4E., Butler County, 3.1 miles southeast of Fairdealing, MO.	8-24-87	--	*31.8	Yes
6	07068600	Little Black River at Success, AR	NW1/4 sec.23, T.21N. R.3E., Clay County, at bridge on State Highway 211 at the northwest corner of Success.	8-24-87	--	*28.5	Yes
7	--	Current River near Reyno, AR	NW1/4 sec.20,T.20N. R.3E., Randolph County, at bridge on State Highway 328, 1.3 miles west of Reyno.	8-25-87	--	*1,350	No

Table 1.—Discharge at sites in the Black River Basin, southeastern Missouri and northeastern Arkansas, August 24-*26, 1987*—Continued

Site number (figure 4)	Station number	Station name	Station location	Date	Gage height, in feet	Discharge, in cubic feet per second	Continuous record available
8	07068850	Current River near Pocahontas, AR	SW1/4 sec.10, T19N. R.2E., Randolph County, at bridge on U.S. Highway 67, 5.5 miles northeast of Pocahontas.	8-24-87	--	*1,660	No
9	--	Forche River above Pocahontas	NW1/4 sec.35, T20N. R.1E., Randolph County, at bridge on State Highway 115, 5.6 miles north of Pocahontas and at river mile 112.	8-25-87	--	*11.5	No
10	--	Forche River near Pocahontas	NW1/4 sec.24, T.19N. R.1E., Randolph County, at bridge on U.S. Highway 67, east of Pocahontas.	8-24-87	--	*22.3	No
11	07069500	Spring River at Imboden, AR	NE1/4,sec.15, T.18N. R.2W., Randolph County, at bridge on U.S. Highway 62 at Imboden, 8.2 miles upstream from Eleven Point River and at river mile 12.1.	8-25-87	2.72	410	Yes
12	07072000	Eleven Point River near Ravenden Springs, AR	SE1/4 sec.30, T.20N. R.1W., Randolph County, at bridge on State Highway 90, 6.6 miles northeast of Ravenden Springs and at river mile 21.2.	8-25-87	2.82	389	Yes
13	--	Eleven Point River Pocahontas	SE1/4 sec.33, T.19N. R.1W., Randolph near County, at bridge on U.S. Highway 62, 6.0 miles west of Pocahontas.	8-25-87	--	*441	No
14	--	Eleven Point River near Black Rock, AR	NE1/4 sec.4, T.17N. R.1W., Randolph County, 200 feet upstream from the mouth.	8-25-87	--	*383	No

Table 1—Discharge at sites in the Black River Basin, southeastern Missouri and northeastern Arkansas, August 24-26, 1987—Continued

Site number (figure 4)	Station number	Station name	Station location	Date	Gage height, in feet	Discharge, in cubic feet per second	Continuous record available
15	--	Spring River near Black Rock	NW1/4 sec.15, T.17N. R.1W., Lawrence County, 1,500 feet upstream from junction with the Black River.	8-25-87	--	*704	No
16	07072500	Black River at Black Rock	NW1/4 sec.21, T.17N. R.1W., Lawrence County, 3.7 miles downstream from Spring River and at river mile 69.3.	8-25-87	1.11	2,670	Yes
17	--	Black River near Saffell, AR	NE1/4 sec 4, T.14N. R.2W., Independence County, 0.8 mile upstream from the mouth of the Strawberry River.	8-25-87	--	*2,510	No
18	07074000	Strawberry River near Poughkeepsie, AR	NW1/4 sec.19, T.17N. R.4W., Sharp County, 250 feet upstream from bridge on State Highway 58, 2.5 miles northeast of Poughkeepsie and at river mile 35.9.	8-25-87	1.51	48.4	Yes
19	--	Strawberry River near Strawberry, AR	NE1/4 sec.34, T.16N. R.3W., Lawrence County, 1,000 feet upstream from bridge on State Highway 25.	8-25-87	--	*97.4	No
20	--	Strawberry River near Saffell, AR	NW1/4 sec.30, T.15N. R.2W., Lawrence County, at bridge on State Highway 361.	8-25-87	--	*177	No
21	--	Black River at Elgin Ferry, AR	NW1/4 sec.15, T.13N. R.3W., Jackson County, at bridge on State Highway 37.	8-26-87	--	*2,780	No
22	--	Black River near Jacksonport, AR	SE1/4 sec.29, T.12N. R.3W., Jackson County, at bridge on State Highway 69.	8-26-87	--	*3,150	No

Table 2.—Quantity and percent of discharge between selected sites
[+, plus; -, minus]

Site number(s) to site number (figure 4)	Change in discharge between sites, in cubic feet per second	Distance between sites, in river miles	Gain or loss in discharge per mile, in cubic feet per second	Percentage of change in discharge between sites
1 to 2	+209	59	3.5	+68
3 to 4	+150	13	12	+15
5 to 6	-3.3	30	-0.11	-10
(4 and 6) to 7	+182	22	8.3	+16
7 to 8	+310	11	28	+23
9 to 10	+11	9.1	1.2	+94
12 to 13	+52	11	4.7	+13
13 to 14	-58	9.8	-5.9	-13
(11 and 14) to 15	-89	12	-7.4	-11
(2 and 8; 10 and 15) to 16	-232	93	-2.5	-8
16 to 17	-160	33	-4.8	-6
18 to 19	+57	23	2.5	+141
19 to 20	+80	7.2	11	+82
(17 and 20) to 21	+93	24	3.9	+3
21 to 22	+370	15	25	+13
Net change in discharge (1 to 22)	+972			

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