Hydrogeology and Water Quality of the Mississippi River Alluvium Near Muscatine, Iowa, June 1992 Through June 1994

By KEITH J. LUCEY, RONALD L. KUZNIAR, and
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PLATE

[Plate is in pocket]

FIGURES

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TABLES

CONVERSION FACTORS, ABBREVIATIONS, AND VERTICAL DATUM

Multiply	By	To obtain
inch (in.)	25.4	millimeter
foot (ft)	0.3048	meter
mile (mi)	1.609	kilometer
square mile (mi^2)	2.590	square kilometer
gallon (gal)	3.785	liter
million gallons (Mgal)	3,785	cubic meter
billion gallons (Bgal)	0.003785	cubic kilometer
billion gallons per year (Bgal/yr)	0.003785	cubic kilometer per year
gallon per minute (gal/min)	0.631	liter per second
gallon per minute per foot [(gal/min)/ft]	0.2070	liter per second per meter
inch per year (in/yr)	25.4	millimeter per year
foot per day (ft/d)	0.3048	meter per day
foot per year (ft/yr)	0.3048	meter per year
foot per mile (ft/mi)	0.1894	meter per kilometer
foot squared per day (ft^2/d)	0.0929	meter squared per day
cubic foot (ft^3)	28.32	liter
cubic foot per second (ft^3/s)	0.02832	cubic meter per second
cubic foot per day (ft^3/d)	0.02832	cubic meter per day

Temperature in degrees Fahrenheit (°F) can be converted to degrees Celsius (°C) as follows:

$$°C = (°F-32)/1.8.$$

Abbreviated water-quality units used in this report: Chemical concentrations are given in metric units. Chemical concentration is given in milligrams per liter (mg/L) or micrograms per liter (µg/L). Milligrams per liter and micrograms per liter are units expressing the concentration of chemical constituents in solution as weight (milligrams or micrograms) of solute per unit volume (liter) of water. For concentrations less than 7,000 mg/L, the numerical value of milligrams per liter is the same as for concentrations in parts per million. The numerical value of micrograms per liter is the same as for concentrations in parts per billion.

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

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Abstract

A study of the Mississippi River alluvium near Muscatine, Iowa, was conducted to evaluate ground-water flow and water quality using data collected from June 1992 through June 1994. The study area included approximately 80 square miles in parts of Muscatine and Louisa Counties in Iowa and Rock Island and Mercer Counties in Illinois.

A steady-state, ground-water flow model was constructed using February 1993 hydrologic conditions. Model results indicate that drawdown in the lower alluvium caused by the pumping centers in Iowa extends beneath the Muscatine Slough in the northwest part of the study area and beneath the Mississippi River in the central and northern parts of the area. The primary sources of ground water in the alluvium are recharge from precipitation, leakage from the Mississippi River, and infiltration of upland runoff. The bedrock is not a major contributor of ground water to the alluvium.

The areal distribution of selected water-quality properties and constituents in ground water results from several factors. Localized large chloride and nitrite-plus-nitrate nitrogen concentrations could be indicative of contamination from human activity. Specific conductance and calcium, magnesium, and sulfate concentrations are larger in ground water near the boundary between the river valley and upland area and could result from infiltration of upland runoff or lithologic differences in the alluvium. Large iron or manganese concentrations occur in the ground water near the Mississippi River and Muscatine Slough that result from microbial processes and the presence of dissolved organic carbon.

Temporal variations of concentrations for selected water-quality constituents in ground-water samples attest to the dynamic nature of the ground-water system as it responds to natural and human-induced changes in water quality. Leakage from the Mississippi River affects ground-water quality in the alluvium adjacent to the river. Temporal variations in water quality of the Mississippi River can be caused by seasonality, amount of discharge, or upstream human activities.

The quality of ground water induced from discrete zones of the alluvium by the pumping centers in Iowa has implications for the entire ground-water resource. The ground-water flow model calculated that 10 percent of the water that enters the zone of active pumping on the Iowa side of the Mississippi River originates from the zone west and north of Muscatine Slough, and that 5.2 percent originates from the zone on the Illinois side of the Mississippi River east of the center of the river channel.

INTRODUCTION

For several decades, the sand and gravel deposits of the Mississippi River alluvium in Muscatine and Louisa Counties, Iowa, have been a dependable source of large quantities of ground water that generally is suitable for municipal, industrial, and agricultural uses. During the 1960's, continued municipal and industrial development of the ground-water resource resulted in well-interference problems in the pumping centers. Areas of water-table draw-down concerned irrigation users that were dependent on shallow centrifugal (suction-lift) pumps. Increased hardness and concentrations of iron and manganese have caused a deterioration of the quality of water from some wells.

The last comprehensive study of the ground-water resource in the Muscatine, Iowa, area was conducted using data collected during the 1960's and early 1970's (Hansen and Steinhilber, 1977). The study focused on approximately 30 mi^2 of the alluvium in Muscatine County and described geology, seasonal water levels, aquifer hydraulic properties, water use, and water quality. Induced infiltration from the Mississippi River was estimated to provide 80 to 85 percent of the water withdrawn at pumping centers located near the river. Annual recharge to the alluvium from precipitation was estimated to average 6 in. Seepage from the bedrock was interpreted to cause local noticeable increases in hardness and iron content in the alluvial aquifer.

Annual ground-water withdrawals in Muscatine and Louisa Counties have increased from approximately 13.5 Bgal in 1970 to approximately 17.7 Bgal in 1990 (table 1). This trend of increasing withdrawals has renewed concerns about water-table declines and potential deterioration of water quality. There is a need to define the sources of water recharging the alluvium and to understand the current distribution of selected water-quality constituents in the ground-water flow system. Water managers need the ability to assess the effects of additional water withdrawals on the ground-water resource and to locate additional pumping centers in areas that would minimize any negative effects. To address these concerns, the U.S. Geological Survey (USGS), in cooperation with Muscatine Power and Water (MPW), Muscatine, Iowa, conducted a hydrogeologic study of the Mississippi River alluvium. Because alluvial aquifers commonly are used as a source of water for municipal, irrigation, and industrial use, it is important to develop an improved understanding of ground-water flow, the interaction between the river and the ground water, and the effects of different recharge sources on ground-water quality in alluvial systems.

Table 1. Estimated ground-water withdrawals in Muscatine and Louisa Counties, Iowa, 1970 and 1990

[Bgal/yr, billion gallons per year; 1970 data from Hansen and Steinhilber (1977); 1990 data from water-use permits, Iowa Department of Natural Resources, Des Moines, Iowa]

Pumpage category	1970 (Bgal/yr)	1990 (Bgal/yr)
Municipal	5.0	8.1
Industrial	8.2	8.6
Irrigation	.3	1.0
Total	**13.5**	**17.7**

Purpose and Scope

The purposes of the report include: (1) evaluation of the ground-water flow system and identification of the sources of water recharging the Mississippi River alluvium under current (1993) pumping conditions, (2) documentation of the areal distribution and temporal variation of water quality, and (3) evaluation of the quality of water recharging the alluvium under current (1993) pumping conditions. The report includes a discussion of the hydrogeology of the alluvium, a description of a computer model used to simulate ground-water flow, results of the model simulation of ground-water flow identifying and quantifying sources of recharge to the system, and a discussion of the temporal variation and areal distribution of selected water-quality constituents and differences in water types that occur in the alluvium. Hydrologic and geologic data used in this study were collected from June 1992 through June 1994.

Description of Study Area

The study area covers approximately 80 mi^2 in southeast Iowa and northwest Illinois and includes parts of Muscatine and Louisa Counties in Iowa and Rock Island and Mercer Counties in Illinois (fig. 1). The topography of the relatively flat alluvial plain of the Mississippi River Valley generally has an altitude of 535 to 550 ft above sea level and gradually rises to 590 ft at the base of the bluffs on either side of the valley. These steep bluffs separate the valley from the upland areas that rise to 750 ft.

Climate is temperate continental with warm, wet summers and cold, dry winters (Rudloff, 1981). Mean annual precipitation at Muscatine, based on data

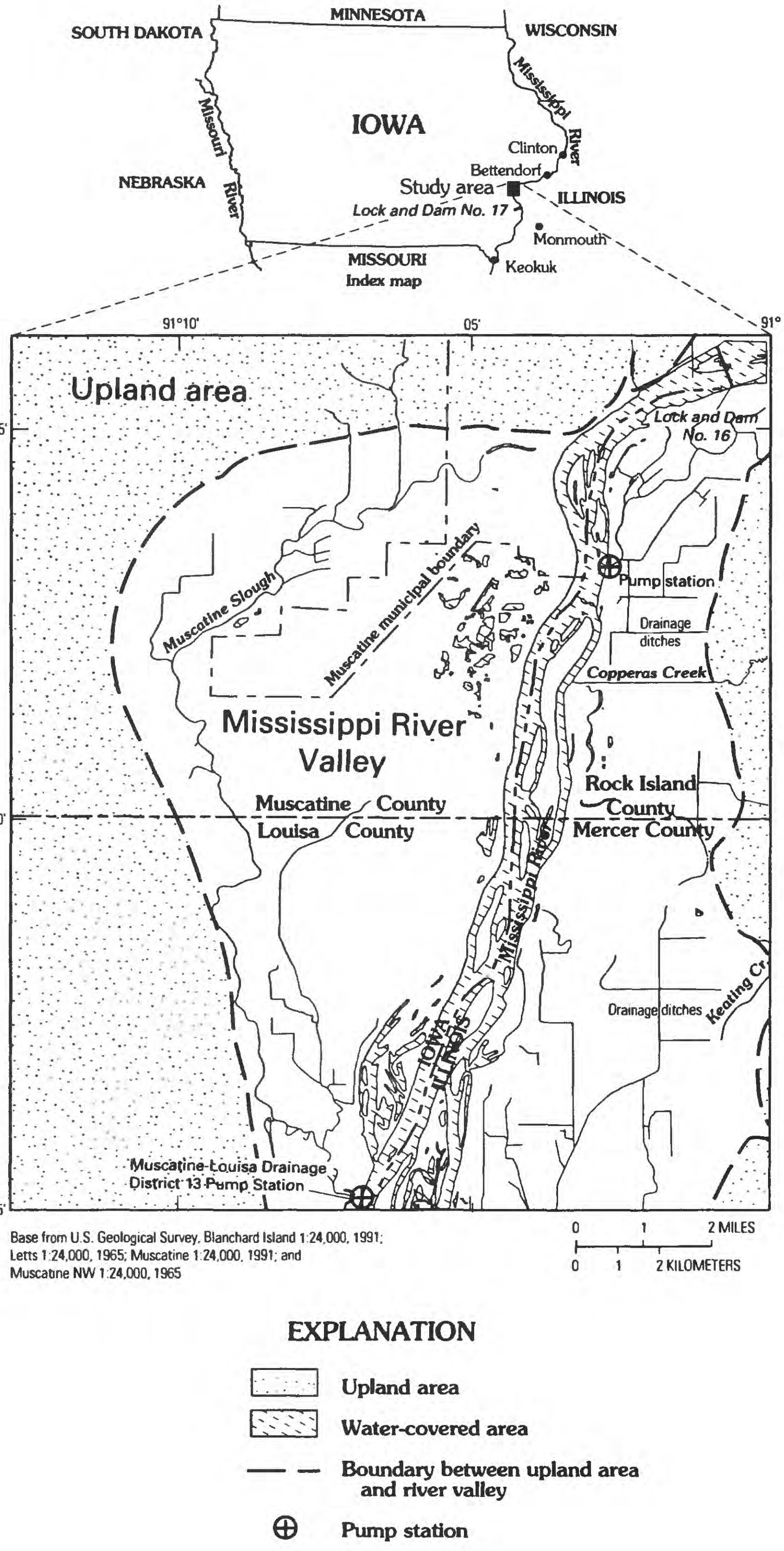


Figure 1. Location of study area.

for 1951–80, is 34.60 in. Mean monthly precipitation ranges from 1.11 in. during January to 4.41 in. during July. Mean monthly temperature ranges from 20.7 °F in January to 75.6 °F in July (National Oceanic and Atmospheric Administration, 1992).

The U.S. Army Corps of Engineers (COE) controls the Mississippi River stage with a series of lock and dam structures, and the channel depth is maintained by dredging operations to facilitate commercial navigation along the upper Mississippi River. Lock and Dam No. 16 is located in the northern part of the study area, and Lock and Dam No. 17 is located south of the study area 20 mi downstream from Lock and Dam No. 16 (fig. 1). The normal pool stage upstream from Lock and Dam No. 17 is 536 ft. The mean annual Mississippi River stage in the study area is about 3 ft higher since Lock and Dam No. 17 became operational in 1937 (Hansen and Steinhilber, 1977). The width of the river channel varies from 2,500 to 4,000 ft, and the altitude of the channel bottom is approximately 520 ft (Hansen and Steinhilber, 1977).

The lowlands in the river valley are protected by a levee complex extending along both sides of the Mississippi River. A network of drainage ditches are dredged periodically to assist in maintaining water levels in the alluvium favorable for agricultural production. The levee system along the Mississippi River limits natural drainage to the river, so pump stations are operated to discharge water from the drainage ditches into the Mississippi River (fig. 1). The levee system has been extended along Copperas Creek in Illinois (fig. 1), so that the stage in the downstream reach of that creek reflects that of the Mississippi River.

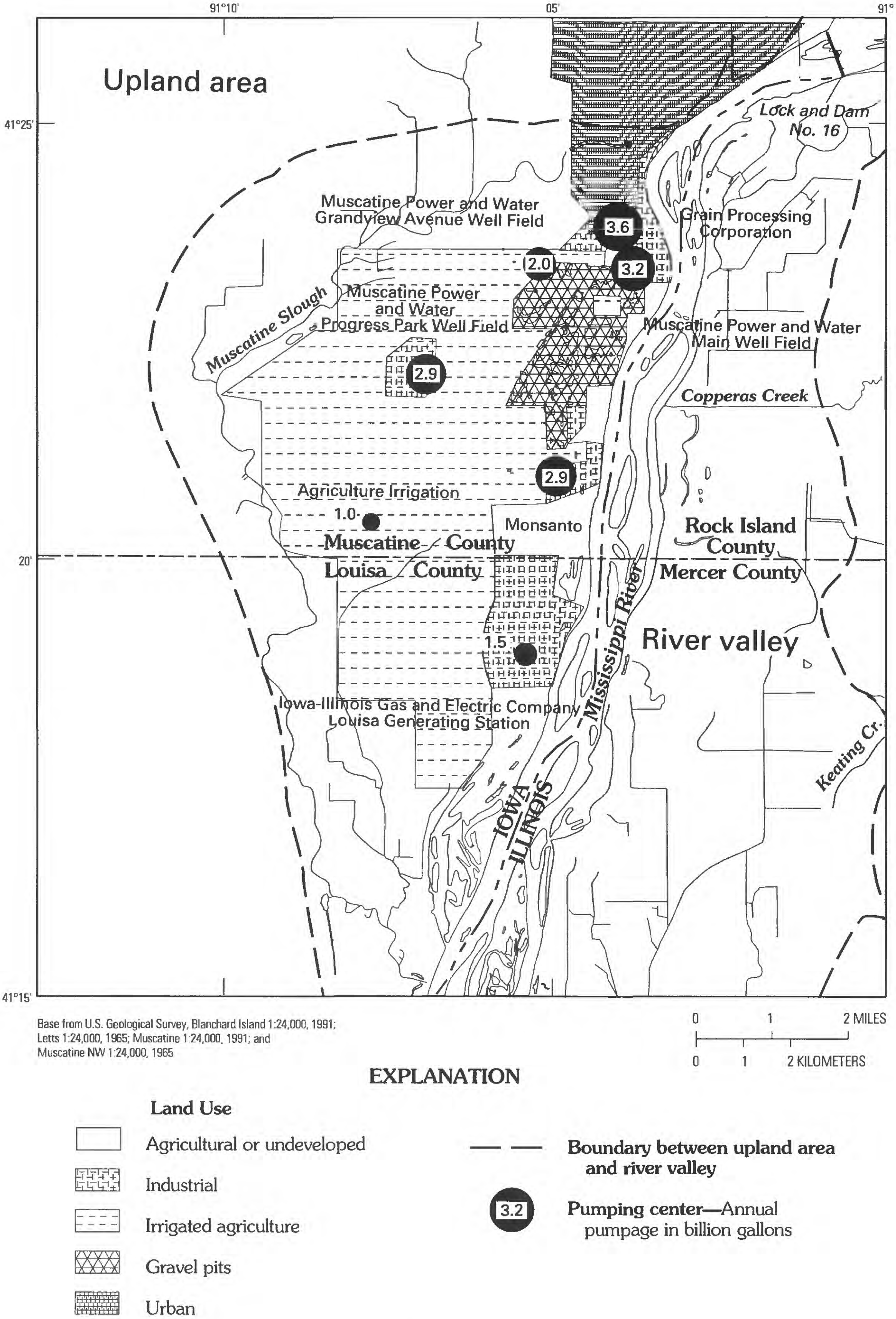
The Muscatine Slough (fig. 1) with its associated drainage ditches drains 52.3 mi^2 in Iowa. Upland areas comprise 38.2 percent of the drainage area and alluvium the remainder. Streamflow and stage in the slough is controlled by a pump station located at the south end of the slough near the southern boundary of the study area. The pump station is operated by Muscatine-Louisa Drainage District 13 and contains four pumps with a combined design capacity of 337,500 gal/min (752 ft^3/s).

Land use in the Mississippi River Valley is primarily agricultural. There is a large area on the Iowa side of the river where sandy soils predominate and require supplemental irrigation by ground-water withdrawals (fig. 2). Corn and soybeans are the primary crops in nonirrigated areas, whereas corn, soybeans, potatoes, muskmelons, and watermelons are grown under irrigation (Vince Lawson, Iowa State University Muscatine Island Field Station, oral commun., 1994). Industrial activity is varied and includes corn processing, agrichemical manufacturing, railroad car refurbishing, plastics manufacturing, and electric power generation at facilities in proximity to the Mississippi River. A sand-and-gravel extraction industry has resulted in an area of active and abandoned gravel pits in Muscatine County (fig. 2). The urbanized area associated with the City of Muscatine, which had a population of 22,881 in 1990 (U.S. Bureau of the Census, 1992), is located in the northern part of the study area (fig. 2).

Municipal, industrial, and irrigation ground-water withdrawals in Muscatine and Louisa Counties have increased from 1970 to 1990 (table 1). Average daily withdrawals from the alluvium were approximately 48 Mgal in 1990. The well fields for ground-water withdrawals from the alluvium (pumping centers) are predominantly near the Mississippi River in Iowa (fig. 2). The annual pumpage for 1990 is depicted by circles of varied size in figure 2. The circle for agriculture irrigation is shown for comparison purposes; irrigation wells are located throughout the area of irrigated, agricultural land use. Annual irrigation pumpage, estimated from water-use permits filed with the Iowa Department of Natural Resources (IDNR), was 1 Bgal in 1990 when the annual precipitation was 50.40 in. (National Oceanic and Atmospheric Administration, 1990). For comparison, irrigation pumpage was estimated at 3.8 Bgal in 1989 when the annual precipitation was 26.72 in. (National Oceanic and Atmospheric Administration, 1989).

Acknowledgments

The following corporations and local agencies provided hydrologic data, access to property for hydrologic data collection, or permission to construct observation wells on their property: Grain Processing Corporation; Iowa-Illinois Gas and Electric Power Company, Halane Farms, Iowa State University Muscatine Island Field Station, Louisa County Conservation Board, Monsanto Corporation, Muscatine Power and Water, and Thatcher Tubes. The following landowners provided access to irrigation wells for data collection or permission to construct observation wells on their property: F. Bartenhagen, B. Braun, J. Hoopes, L. Roudybush, and J. Wilson.



Base from U.S. Geological Survey, Blanchard Island 1:24,000, 1991; Letts 1:24,000, 1965; Muscatine 1:24,000, 1991; and Muscatine NW 1:24,000, 1965

Figure 2. Land use and pumping centers in study area, 1990.

METHODS OF INVESTIGATION

The data-collection locations used in the study included ground-water sites (observation wells, municipal-supply wells, and industrial-supply wells) and surface-water sites (fig. 3). The study included construction of wells and collection of ground-water level, streamflow, stage, aquifer-test, and water-quality data. These data were used to help define the hydrogeology of the Mississippi River alluvium and to assist in the construction of the ground-water flow model.

Well Construction and Nomenclature

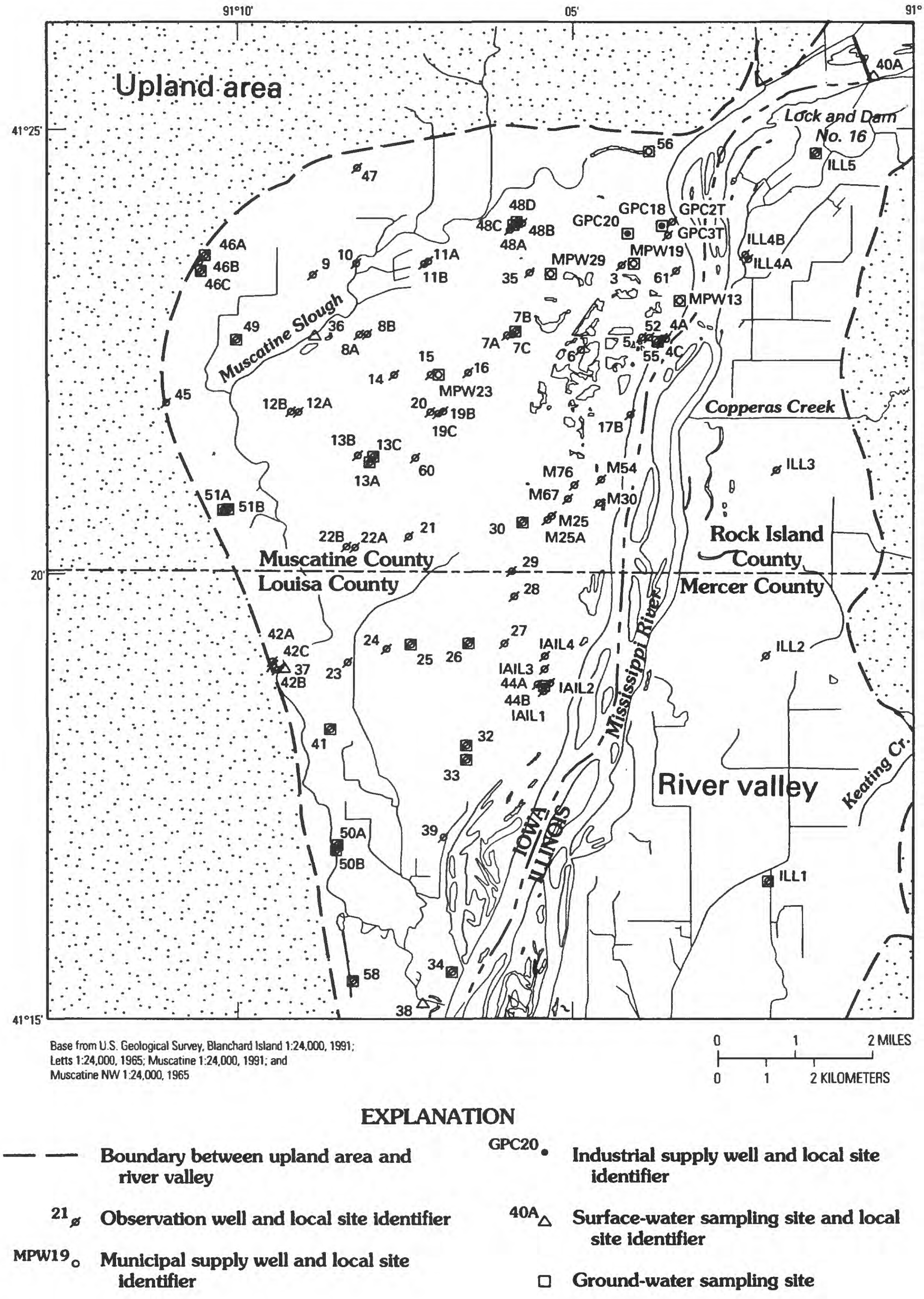
Available wells were used for data-collection sites whenever possible. These wells had casing materials consisting of steel or polyvinyl chloride (PVC). However, 31 new observation wells were installed during the summer of 1992 to obtain additional geologic information and to collect water-level data and ground-water samples from an areal and vertical distribution designed to meet the study objectives. Five wells ranging in depth from 183 to 243 ft below surface were installed in bedrock, and 26 wells were installed at various depths (30 to 100 ft) in the unconsolidated alluvium and glacial till. Some of the wells were installed in clusters, which were comprised of two to four single-riser, limited-interval wells that were closely spaced to provide data from different stratigraphic levels at approximately the same location.

Five wells were installed in bedrock during the summer of 1992 using direct mud-rotary drilling. The uppermost 50 ft of bedrock was penetrated at each location. Samples of the well cuttings were collected at 10-ft intervals for geologic description. Casing and well screen consisted of 2-in. outside-diameter (O.D.), flush-threaded PVC pipe. The screen slot size was 0.020 in.; screen length in the bedrock wells ranged from 10 to 30 ft. The longer screens were installed in boreholes where little visible porosity or open-fracture indications were noted during visual examination of well cuttings. A filter pack of washed and sized coarse-grained sand was placed adjacent to the screened interval using a tremie tube to avoid bridging. A 5-ft thick grout seal was placed above the filter pack, the annulus was backfilled with aquifer material, and a bentonite seal was installed in the upper 3 ft of the borehole.

Twenty-six wells were installed in the unconsolidated alluvium and glacial till during the summer of 1992 by using 4.25-in. inside-diameter continuous-flight hollow-stem augers. Cuttings returned to the surface by the auger flights during penetration were collected at 5-ft intervals for geologic description. The hollow-stem auger assembly was used as a temporary casing during well construction to prevent collapse of the borehole wall during penetration of unconsolidated materials. A string of 2-in. O.D. PVC pipe with attached 2.5-ft screen was installed inside the auger column. The auger flights were rotated in reverse while being slowly withdrawn, allowing the formation materials to collapse around the well screen and act as a natural filter pack. In those boreholes where the well was screened in glacial till, an artificial filter pack consisting of clean, coarse sand was placed by trickling the sand into the annulus between the well casing and the interior of the hollow-stem augers. The annular space between the borehole wall and the solid riser above the filter pack was backfilled with natural aquifer material. Annular seals above the filter pack were not used because the relatively homogeneous alluvial sand did not have discernible, laterally continuous silt and clay units. However, bentonite was used as a seal in the upper 3 ft of all boreholes to prevent the infiltration of surface water along the outside of the well casing.

The 31 wells installed during the summer of 1992 were capped with a vented cap and developed to provide a representative water sample and water level. The wells completed in unconsolidated alluvium were developed by pumping until the water ran clear and physical properties (pH, temperature, and specific conductance) stabilized. The wells completed in glacial till were developed by bailing, and the wells completed in bedrock were developed by airlifting. The 31 newly drilled wells, and other available wells used by the USGS to collect water-level measurements during the study, were surveyed for vertical control referenced to sea level.

Table 2 lists the sites used for data collection in the study by local site identifier and USGS station identification number, where applicable, and includes well-construction data. Observation wells are designated by local site identifier (for example, 47); clusters of observation wells are designated by local site identifier that includes alpha characters to differentiate closely spaced sites (for example, 13A, 13B, 13C); "GPC" followed by a number indicates industrial supply wells operated by Grain Processing Corpora-



Base from U.S. Geological Survey, Blanchard Island 1:24,000, 1991; Letts 1:24,000, 1965; Muscatine 1:24,000, 1991; and Muscatine NW 1:24,000, 1965

Figure 3. Data-collection sites in study area.

Table 2. Data-collection sites and well-construction data

[LOCALID, local site identifier; STATIONID, station identification number; LSD, land-surface altitude, in feet above sea level (no values right of decimal indicates that altitude was estimated from U.S. Geological Survey 7.5-minute series topographic maps); MP, measuring point altitude, in feet above seal level; TD, total well depth, in feet; LITH, lithology at TD; a, alluvium; ls, limestone; t, glacial till; TYPE, site type; o, observation well; sw, surface water; i, industrial-supply well; m, municipal-supply well; DATA, data collected at the site; M, monthly water-level data; C, hourly water-level data; WQ, water-quality samples; I, intermittent water-level data; MI, monthly water-level data supplied by Iowa-Illinois Gas and Electrc Company; MS, monthly water-level data supplied by Monsanto Chemical Company; PIPE/DIA, well-casing material/outside diameter, in inches; S, steel; PVC, polyvinyl chloride; --, no data]

LOCALID (fig. 3)	STATIONID	LSD	MP	TD	LITH	TYPE	DATA	PIPE/DIA
3	412325091042201	542.76	545.37	75	a	o	M,C	S/6
4A	412238091034201	551.21	554.64	25	a	o	M	S/1.25
4C	412238091034203	559.65	563.13	35	a	o	M	S/1.25
5	412240091040501	547.99	552.54	20	a	o	M	S/1.25
6	412234091045001	544.87	545.66	27	a	o	M	S/1.25
7A	412242091055001	545.34	546.37	95	a	o	M	S/1.25
7B	412242091055002	545.34	546.68	27	a	o	M,WQ	S/1.25
7C	412242091055003	545.34	546.57	62	a	o	M	S/1.25
8A	412243091080001	538.60	539.08	105	a	o	M	S/1.25
8B	412243091080002	538.60	538.84	27	a	o	M	S/1.25
9	412323091085201	537.69	538.04	27	a	o	M	S/1.25
10	412329091080801	540.69	542.61	28	a	o	M	S/1.25
11A	412329091070801	539.94	541.22	23	a	o	M	S/1.25
11B	412329091070802	539.94	541.34	65	a	o	M	S/1.25
12A	412151091091001	545.98	547.82	100	a	o	M	S/1.25
12B	412151091091002	545.98	547.83	27	a	o	M	S/1.25
13A	412120091080401	546.33	549.68	27	a	o	M,C,WQ	S/6
13B	412120091080402	546.33	549.22	189	ls	o	M,C	PVC/2
13C	412120091080403	546.33	549.26	100	a	o	M,C,WQ	PVC/2
14	412217091074001	543.19	546.33	23	a	o	M	S/1.25
15	412215091070201	544.53	546.98	30	a	o	M	S/1.25
16	412233091064001	544.18	546.21	30	a	o	M	S/1.25
17B	412150091041602	545	546.8	28	a	o	M	S/1.25
19B	412151091065102	546.50	547.72	28	a	o	M	S/1.25
19C	412151091065103	546.50	549.04	129	a	o	M	S/1.25
20	412150091070901	547.47	550.02	35	a	o	M	S/1.25
21	412023091072701	545.47	545.33	25	a	o	M	S/12
22A	412015091081901	544.09	546.78	25	a	o	M	PVC/2
22B	412015091081902	544.09	546.05	67	a	o	M	PVC/2
23	411859091082201	535.84	539.00	25	a	o	M	S/1.25
24	411911091075301	538.16	539.61	35	a	o	M	S/6
25	411915091072901	540.89	542.97	25	a	o	M,WQ	S/1.25
26	411905091063301	544.45	547.74	30	a	o	M,C,WQ	S/6
27	411909091060501	548.91	552.08	25	a	o	M	PVC/2
28	411945091055701	544.51	547.39	18	a	o	M	S/1.25

Table 2. Data-collection sites and well-construction data—Continued

LOCALID (fig. 3)	STATIONID	LSD	MP	TD	LITH	TYPE	DATA	PIPE/DIA
29	412002091055601	543.79	545.97	60	a	o	M	S/6
30	412040091054701	543.10	546.50	20	a	o	M,WQ	PVC/2
32	411754091063401	541.00	542.12	35	a	o	M,C,WQ	S/6
33	411752091063601	541	--	80	a	o	WQ	PVC/4
34	411540091064201	537.80	537.99	180	ls	o	M,WQ	S/4
35	412326091053601	542.56	544.89	30	a	o	M	S/6
36	412241091085401	--	--	--	--	sw	WQ,I	--
37	411857091092601	--	--	--	--	sw	WQ,I	--
38	411507091065801	--	--	--	--	sw	WQ,I	--
39	411702091070701	538.10	542.61	30	a	o	M	S/1.25
40A	412532091003501	--	--	--	--	sw	WQ	--
41	411819091083701	535.11	537.19	38	a	o	M,WQ	S/1.25
42A	411857091092901	539.86	542.77	87	a	o	M	PVC/2
42B	411857091092902	539.86	542.54	22	t	o	M	PVC/2
42C	411857091092903	539.86	542.64	191	ls	o	M	PVC/2
44A	411847091052901	571	--	80	a	i	WQ	S/18
44B	411847091053201	571.4	574.4	185	ls	o	M	S/3
45	412147091110201	577.36	579.74	40	a	o	M	PVC/2
46A	412340091102401	594.23	596.69	42	t	o	M,C,WQ	PVC/2
46B	412340091102402	594.23	597.10	243	ls	o	M,C	PVC/2
46C	412340091102403	594.23	597.10	95	a	o	M,C,WQ	PVC/2
47	412430091081301	537.95	539.76	30	a	o	M	PVC/2
48A	412355091055501	543.15	545.60	40	a	o	M,C,WQ	PVC/2
48B	412355091055502	543.15	545.50	63	a	o	M	PVC/2
48C	412355091055503	543.15	545.56	183	ls	o	M,C	PVC/2
48D	412355091055504	543.15	543.84	100	a	o	M,C,WQ	PVC/2
49	412242091095301	538.21	540.66	40	a	o	M,WQ	PVC/2
50A	411659091083701	537.44	540.16	40	a	o	M,WQ	PVC/2
50B	411659091083702	537.44	539.73	72	a	o	M,WQ	PVC/2
51A	412044091101301	540.81	543.43	32	a	o	M,WQ	PVC/2
51B	412044091101302	540.81	543.70	90	a	o	M,WQ	PVC/2
52	412238091034801	547.32	549.41	38	a	o	M,C	PVC/2
55	412236091034501	548.02	550.62	32	a	o	M,C,WQ	PVC/2
56	412444091035501	539.67	542.39	42	a	o	M,WQ	PVC/2
58	411531091081501	537.25	540.18	62	a	o	M,WQ	PVC/2
60	412120091072901	546.96	549.64	40	a	o	M	PVC/2
61	412326091034201	544.60	547.82	183	ls	o	M,C	PVC/4
GPC2T	412402091033501	551.85	554.65	40	a	o	M	PVC/2
GPC3T	412357091034001	547.90	549.30	40	a	o	M	PVC/2
GPC18	412356091034201	547.3	--	70	a	i	WQ	S/20

Table 2. Data-collection sites and well-construction data—Continued

LOCALID (fig. 3)	STATIONID	LSD	MP	TD	LITH	TYPE	DATA	PIPE/DIA
GPC20	412350091040901	549.3	--	70	a	i	WQ	S/20
IAIL1	--	--	546.46	150	a	o	MI	S/4
IAIL2	--	--	571.06	150	a	o	MI	S/4
IAIL3	--	--	580.65	150	a	o	MI	S/4
IAIL4	--	--	583.04	150	a	o	MI	S/4
ILL1	411630091021101	532.38	533.53	30	a	o	M,WQ	PVC/2
ILL2	411906091020701	535.31	538.35	30	a	o	M	PVC/2
ILL3	412107091020301	540.13	541.87	30	a	o	M	PVC/2
ILL4A	412332091022801	541.28	544.43	30	a	o	M	PVC/2
ILL4B	412332091022802	541.28	542.78	15	a	o	M	PVC/2
ILL5	412436091011001	539.85	540.40	34	a	o	M,WQ	PVC/2
M25	--	--	547.14	124	a	o	MS	PVC/2
M25A	--	--	546.07	30	a	o	MS	PVC/2
M30	--	--	545.26	40	a	o	MS	PVC/2
M54	--	--	543.25	40	a	o	MS	PVC/2
M67	--	--	548.56	40	a	o	MS	PVC/2
M76	--	--	547.52	40	a	o	MS	PVC/2
MPW13	412300091031801	545	--	54	a	m	WQ	S/30
MPW19	412329091041301	548	--	69	a	m	WQ	S/18
MPW23	412215091065601	547	--	125	a	m	WQ	S/18
MPW29	412331091051201	545	--	130	a	m	WQ	S/24

tion; "GPC" followed by a number and the letter "T" indicates observation wells on Grain Processing Corporation's property; "ILL" with a number designates observation wells in Illinois; "IAILL" with a number designates an alluvial observation well adjacent to an Iowa-Illinois Gas and Electric Company industrial supply well; "M" with a number designates an observation well on Monsanto Corporation's property; and "MPW" followed by a number designates a municipal supply well operated by MPW. The 15-digit station identification number contains well location information; the first six numbers refer to latitude (degrees, minutes, seconds), the next seven numbers refer to longitude (degrees, minutes, seconds), and the last two numbers are used to differentiate between closely spaced wells.

Well control points are shown on geologic sections *A–A'*, *B–B'*, *C–C'*, *D–D'*, *E–E'*, and *F–F'* (plate 1). Geologic information for these wells was obtained from historical files at the Iowa Department of Natural Resources, Iowa City, Iowa, and at the Illinois State Water Survey, Urbana, Illinois.

Collection of Ground-Water-Level Data

Ground-water levels were collected to document seasonal variations in lateral and vertical flow directions and to assist in the conceptualization of the ground-water flow system. Water levels were collected manually from more than 70 observation wells on a monthly basis using a calibrated steel tape (table 2). Fourteen of these wells (sites 3, 13A, 13B, 13C, 32, 46A, 46B, 46C, 48A, 48C, 48D, 52, 55, 61) were equipped with continuous data recorders and unvented pressure transducers to collect hourly water levels. Site 26 was equipped with a continuous data recorder and a float mechanism to collect hourly water levels.

An incremental change in the length of the water column above the unvented pressure transducer produces a response that is converted to a water-level change and stored in memory. In addition to changes in water level, the hermetically sealed unit is affected by changes in atmospheric pressure. Hourly readings of atmospheric pressure recorded at site 61 and a comparison of periodic manual water-level measurements with recorded water levels were used to develop a relation to correct for atmospheric effects on the sealed unit. Although atmospheric effects on the sealed unit are removed, water-level fluctuations caused by changes in atmospheric pressure on the potentiometric surface are retained in the corrected water levels.

Determination of Streamflow and Collection of Stage Data

Streamflow in the Muscatine Slough is controlled by a pump station that discharges water from the slough into the Mississippi River. The pump station contains four pumps that are activated either by a pre-set stage or with manual controls. An estimate of mean daily streamflow was determined from discharge measurements, rated pump capacity, and pump operation time. Discharge measurements were made on about a monthly basis from a bridge located 1,300 ft upstream of the pump station (site 38, fig. 3) using the midsection current-meter method (Buchanan and Somers, 1984). The discharge measurements, which were made when one to four pumps at the pump station were operating, were used to quantify the amount of water being discharged during various pump combinations. This allowed a rated pump capacity to be calculated for the pumps. Mean daily streamflow (discharge) during a month was calculated from the sum of the product of pump-operation time and rated pump capacity for each pump in operation during the month divided by the number of days in the month. Pump-station personnel provided verbal estimates of pump-operation time. During the period of study, pumps were not equipped with reliable meters recording operating time.

The stage of the Muscatine Slough was measured by USGS personnel, and stage data for the Mississippi River were obtained from the COE. The stage in the Muscatine Slough at site 38 was measured on about a monthly basis from a reference point on the bridge using a calibrated steel tape. Similarly, the stage of the Muscatine Slough was measured periodically from bridges at sites 36 and 37 (fig. 3). The COE supplied mean monthly, mean daily, and incremental 6-hour river stage data for Lock and Dam No. 16 and Lock and Dam No. 17. Stage information was used to calculate the gradient of the water surfaces and to estimate stage at discrete points along the slough and river channels in the study area.

Determination of Aquifer Properties

Aquifer properties include hydraulic conductivity (ft/d), transmissivity (ft^2/d), and storage coefficient (dimensionless). Transmissivity and hydraulic conductivity were calculated using aquifer-test analysis methods. Unless specifically referenced as vertical hydraulic conductivity, hydraulic conductivity will refer to horizontal hydraulic conductivity in this report. Hansen and Steinhilber (1977) reported an average storage coefficient of 0.15 to 0.21 for the alluvium.

Ground-water levels respond to changes in river stage and the effect of river stage decreases with increasing distance from the river. The transmissivity of an alluvial aquifer can be determined using either the stage-ratio method or the time-lag method by comparing changes in ground-water levels to changes in the stage of the river (Ferris, 1963). In the stage-ratio analysis, the ratio of the ground-water level to the river stage is plotted versus distance from the river. In the time-lag analysis, the time between a change in river stage and the corresponding maximum or minimum water level recorded at the observation wells is plotted versus distance from the river. A storage coefficient of 0.2 was used in calculations of transmissivity for these analyses. An estimate of hydraulic conductivity is derived from transmissivity by dividing by the thickness of the aquifer.

Sites 55 and 52 monitor ground-water levels on an hourly basis in the alluvium and are located 350 and 600 ft from the Mississippi River, respectively (fig. 3). The water-level data were used with Mississippi River stage data obtained at 6-hour increments by the COE to determine transmissivity of the alluvium by the stage-ratio and time-lag methods.

A method described by Theis and others (1963) was used to estimate transmissivity of the alluvium from specific capacity [(gal/min)/ft] data. Specific capacities determined from 24-hour pump tests were available for MPW's municipal supply wells (J. L. Doering, Muscatine Power and Water, written commun., 1992). A storage coefficient of 0.2 was assumed for the calculation of transmissivity. Hydraulic conductivity then was estimated by dividing the transmissivity by the thickness of the aquifer open to the screened interval of the well.

Hydraulic conductivity can be estimated by analyzing the changes in water levels with time in a well after a known displacement of the water level in the well by the introduction or removal of a slug of water or material. The hydraulic conductivity of the bedrock was calculated using the Bouwer and Rice method for partially penetrating wells (Bouwer, 1989). Water-level changes were recorded by a pressure transducer after the introduction of a 0.5-gal slug of water at site 46B, after the removal of a slug of water at site 48C, and after the introduction and removal of a slug constructed of a length of sand-filled 1.25-in. O.D. PVC pipe at site 13B. Water levels were recorded every 15 minutes during the first 2 hours of the tests and then were recorded on an hourly basis for several days. Water levels returned to the assumed static level within 1 to 2 days.

Water-Quality Sampling and Analyses

Samples for water-quality analyses were collected at 31 ground-water sites and 4 surface-water sites (table 2, fig. 3) on a quarterly basis to examine the areal and temporal variability of selected water-quality constituents. Onsite measurements of pH, temperature, and specific conductance were determined at the time of sample collection. Water-quality samples were analyzed for the following dissolved constituents at the USGS National Water-Quality Laboratory (NWQL), Arvada, Colorado, using methods described in Fishman and Friedman (1989): major ions (calcium, magnesium, sodium, potassium, alkalinity, sulfate, chloride, and fluoride), nutrients (nitrite nitrogen, nitrite-plus-nitrate nitrogen, ammonia nitrogen, ammonia plus organic nitrogen, phosphorus, and orthophosphorus), trace metals (aluminum, arsenic, cadmium, chromium, copper, iron, lead, manganese, mercury, molybdenum, nickel, and zinc), bromide, and boron.

Samples were collected after three well volumes were removed. The range in diameter of the observation wells, static water-table depths, and well yields required several different sampling techniques. Observation wells that had a 1.25-in. O.D. were pumped and sampled with a peristaltic pump. Observation wells that were constructed with 2-in. O.D. PVC were pumped and sampled with a portable submersible pump made of stainless steel and equipped with Teflon[1] tubing. Observation wells that were larger than 2-in. O.D. first were pumped by a centrifugal pump and then bailed for sampling. Industrial and municipal supply wells that had permanently installed pumps were sampled at the well head. Wells that could not be pumped because of poor yield were bailed and sampled with a stainless-steel bailer.

Surface-water sites were sampled at fixed positions with a depth-integrated sampler. Sites on the Muscatine Slough (sites 36, 37, 38) were sampled from bridges, whereas the Mississippi River was sampled at mid-channel on the upstream side of Lock and Dam No. 16 (site 40A, fig. 3) from a walkway on the lock and dam structure.

Pumps and bailers were cleaned with laboratory detergent, rinsed with organic-free deionized water, and allowed to air dry. Filter plates and peristaltic-pump tubing were cleaned using the same technique and included a once-daily rinse with a solution of 5-percent hydrochloric acid (HCL). NWQL analytical requirements were used to prepare, preserve, and store samples in the field. Samples for dissolved constituents were filtered through 0.45-micrometer pore-size cellulose filter in a polycarbonate filter plate. Samples for metal analysis were preserved with nitric acid with the exception of mercury samples, which were preserved with nitric acid and potassium dichromate. Samples for calcium, magnesium, sodium, and potassium analysis were preserved with nitric acid, whereas samples for alkalinity, boron, bromide, chloride, fluoride, and sulfate analyses were untreated. Nutrient samples were preserved with mercuric chloride and shipped by next-day air freight to the NWQL for analysis. All samples were stored on ice during transport from the field to the laboratory.

Onsite quality-control (QC) procedures included blank and replicate samples. Blank samples were made from organic-free deionized water obtained from the water-quality laboratory at the USGS office in Iowa City, Iowa. Blank samples were processed through pumps, bailers, filter plates, and filters as regular samples to verify cleanliness of sampling equipment and technique. Replicate samples were collected simultaneously with a regular sample to assess variability caused by sampling technique or sample handling (onsite and in laboratory). QC samples accounted for 5 percent of the total number of samples collected.

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[1] The use of trade names in this report is for identification purposes only and does not constitute endorsement by the U.S. Geological Survey.

NWQL accuracy is monitored continually by analyses of internal standards and by participation in the USGS interlaboratory evaluation program. The program provides a measure of analytical accuracy as selected organic constituents in natural matrix reference materials are analyzed by several laboratories every 6 months. The median value determined from the results of all participating laboratories becomes the most probable value (MPV) for the constituent and is compared to individual laboratory results. Refer to Long and Farrar (1993) for a more detailed discussion of the interlaboratory evaluation program.

HYDROGEOLOGY

Background information on geology is important to the understanding of the occurrence and movement of ground water in the study area. Discussion of geology in this report is limited to the geologic information pertinent to the study of the ground-water flow system in the alluvium and the construction of the ground-water flow model. For a more detailed discussion of the geology of eastern Iowa or of the Mississippi River Valley near Muscatine refer to the following reports: Udden (1899), Anderson (1968), Parker (1971), Hansen (1972), Piskin and Bergstrom (1975), Hansen and Steinhilber (1977), Anderson (1983), Horick (1984), Prior (1991), and Bettis and others (1992).

The surface water and ground water in the Mississippi River Valley are hydraulically connected in a hydrologic system with natural hydrologic boundaries. Refer to Coble and Roberts (1971), Wahl and others (1978), Olcott (1992), and Southard and others (1994) for additional information on the water resources of eastern Iowa.

A major flood occurred in 1993 during the study, so some of the hydrologic data collected is representative of extreme conditions. Large amounts of precipitation over an extended period of time caused widespread flooding in the upper Mississippi River Basin (Parret and others, 1993). Precipitation in east-central Iowa was 171 percent of normal from October 1992–September 1993 and more than 200 percent of normal during June, July, and August 1993. The mean monthly discharge of the Mississippi River was well above normal from April through September 1993 at Clinton and Keokuk, Iowa (fig. 1) (Southard and others, 1994).

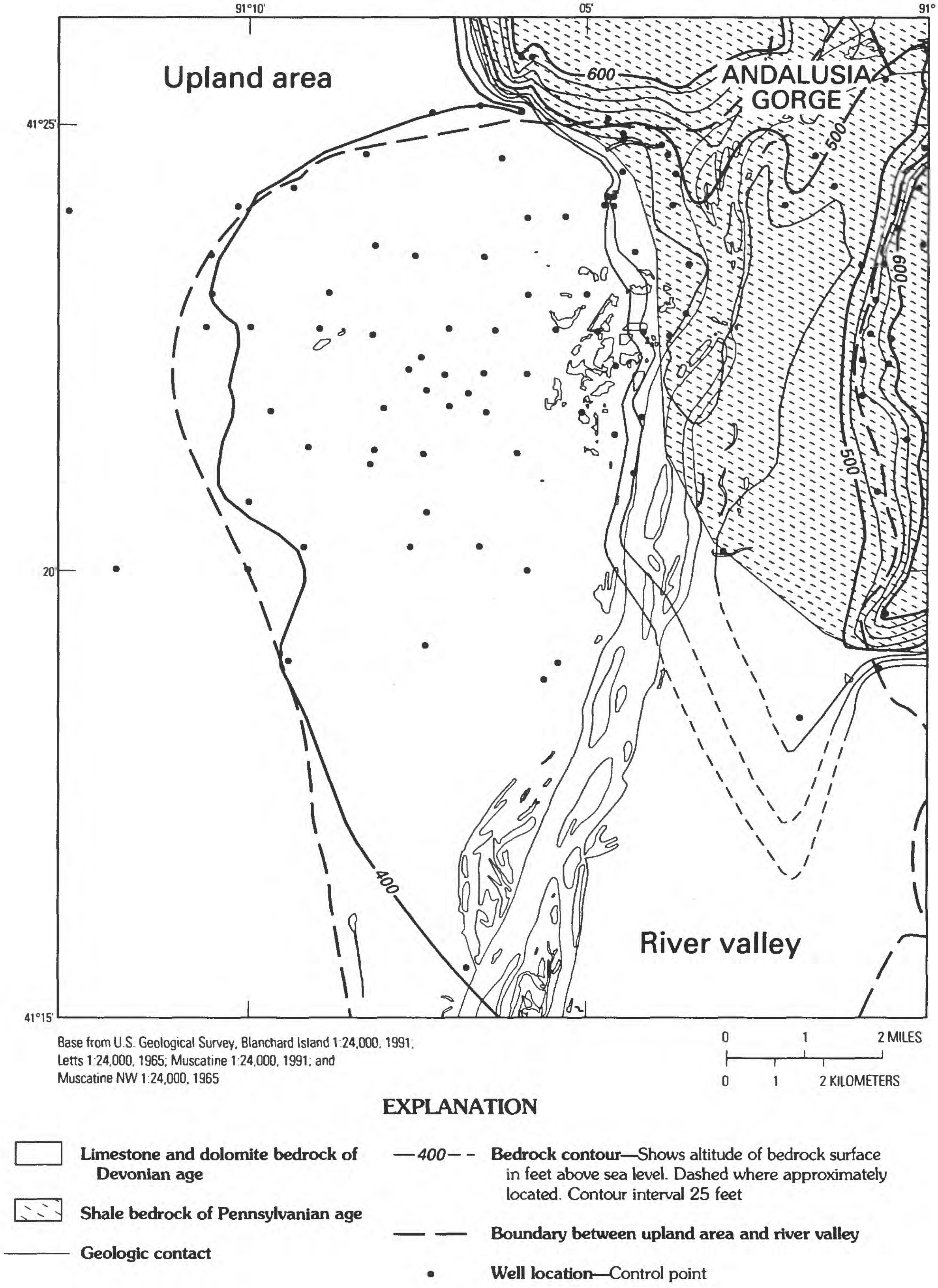
Geology and Water-Bearing Characteristics

The geographic alignment of the Mississippi River Valley in the Iowa and Illinois area was caused in part by ancestral ice-marginal streams accompanying glacial advances from the northwest and northeast. Massive meltwater streams eroded a bedrock valley along the present State boundary of Iowa and Illinois about 25,000 years before present (Prior, 1991). The orientation of the Mississippi River Valley changes abruptly, and the valley width increases from about 2 mi to about 8 mi south of the Andalusia Gorge, an incised channel in the bedrock located in the northeast part of the study area (fig. 4).

Changes in flow regime of the Mississippi River resulted in a variety of fluvial depositional environments in the river valley. Deposition of extensive sand and gravel deposits occurred in the northern part of the study area as the meltwaters emerged from the Andalusia Gorge and entered the wider part of the bedrock valley. Variations in the volume of glacial meltwater and sediment load in the river caused changes in the depositional pattern in the valley and in the river channel's location. The area occupied by the Muscatine Slough (fig. 1) is a paleochannel on the western side of the valley, and the slough has been maintained by runoff from the western bluffs and by floodwaters from the (pre-levee) Mississippi River (Bettis and others, 1992). A diverse array of fluvial geomorphologic features (oxbow lakes, terraces, alluvial fans, abandoned channels, eolian dunes, and backwater sloughs) occur in the study area.

Bedrock consisting of limestone, dolomite, and shale underlies the alluvial deposits (alluvium) in the Mississippi River Valley and the glacial drift (glacial till and loess) that covers the uplands on both sides of the valley. The altitude of the bedrock surface ranges from about 400 ft above sea level in the river valley to more than 600 ft in the bluffs adjacent to the Andalusia Gorge (fig. 4).

The geologic units in the study area include the Maquoketa Formation of Ordovician age; dolomite of Silurian age; shale and limestone of Middle and Upper Devonian age; shale, mudstone, and sandstone of Pennsylvanian age; and glacial deposits, alluvium, and colluvium of Quaternary age (table 3). Geologic sections *A–A'*, *B–B'*, *C–C'*, *D–D'*, *E–E'*, and *F–F'* (plate 1) depict the stratigraphy of the six predominant lithologies (in order of increasing grain size, silty sand and clay, fine-to-coarse sand, fine-to-coarse sand containing some gravel, fine-to-coarse sand and



Base from U.S. Geological Survey, Blanchard Island 1:24,000, 1991; Letts 1:24,000, 1965; Muscatine 1:24,000, 1991; and Muscatine NW 1:24,000, 1965

Figure 4. Bedrock surface and lithology in study area.

Table 3. Geologic units in the study area and their water-bearing characteristics
[undiff., undifferentiated; gal/min, gallons per minute]

System	Series	Geologic unit	Lithology	Water-bearing characteristics	Equivalent layer in the digital ground-water flow model
Quaternary	Holocene	Alluvium; colluvium and alluvial-fan deposits	Sand and gravel, interbedded with silt and clay (alluvium); silt, clay, and sand (colluvium and alluvial-fan deposits)	Wells yield more than 1,000 gal/min in gravel layers (alluvium); limited permeability (colluvium and alluvial-fan deposits)	Layers 1 and 2 (upper and lower alluvium)
Quaternary	Pleistocene	Glacial drift	Windblown silt and sand (loess); clay, sand, silt, and gravel (glacial till)	Limited permeability	Lateral (no-flow) boundary
Pennsylvanian	Desmoinesian	undiff.	Interbedded shale, mudstone, and sandstone	Local confining unit	Confining unit
Devonian	Upper and Middle	undiff.; Cedar Valley Formation	Shale and argillaceous fine-grained limestone (undiff.); Limestone (Cedar Valley Formation)	Limited permeability; locally, where fractured, wells may yield 50 to 200 gal/min	Layer 3
Silurian	Niagaran	undiff.	Dolomite with some chert and limestone	Wells yield as much as 100 gal/min (higher yields when fractured)	Layer 3
Ordovician	Cincinnatian	Maquoketa Formation	Shale and dolomite	Regional confining unit	Basal (no-flow) boundary

gravel, gravel and fine-to-coarse sand, and gravel and coarse sand) that comprise the alluvium in the study area. These predominant lithologies were selected, after an examination of available geologic data, to show the general stratigraphy of the alluvium while providing enough detail to represent the areal distribution of lithologies and likely trends in hydraulic properties.

The Maquoketa Formation of Ordovician age is a regional confining unit in eastern Iowa and hydraulically separates the overlying aquifer of Silurian age from underlying aquifers of Ordovician and Cambrian age. The Maquoketa Formation is predominantly shale and is about 250 ft thick in the study area (Parker, 1971).

The undifferentiated rocks of Silurian age are about 250 ft thick and are comprised principally of dolomite with some chert and limestone. This unit is a regional aquifer in eastern Iowa; porosity and hydraulic conductivity are predominantly of secondary origin and are related to dolomitization and fracturing. Wells may yield as much as 100 gal/min (Wahl and others, 1978). A typical well yield for the study area is about 50 gal/min (Paul Van Dorpe, Iowa Department of Natural Resources, oral commun., 1994).

Rocks of Middle and Upper Devonian age range in thickness from 100 to 200 ft in eastern Iowa. Limestones of the Cedar Valley Formation (Middle Devonian age) are overlain by thin, discontinuous shales of Upper Devonian age. The Cedar Valley Formation is the uppermost bedrock aquifer in the study area. Regionally, the hydraulic conductivity is small, but where the unit is extensively fractured it may yield moderate supplies (50–200 gal/min) to wells.

The limestone of the Cedar Valley Formation and the underlying, undifferentiated rocks of Silurian age may be in hydraulic connection where both units are pervasively fractured. When this condition occurs, wells that are completed in the combined section of Silurian and Devonian age may yield 100 to 500 gal/min in eastern Iowa (Horick, 1984). Geologic data examined for the present study did not indicate a pervasive system of open, connected fractures in the carbonate bedrock in the study area.

An erosional remnant of rocks of Pennsylvanian age overlies the limestone bedrock of Devonian age in the northeast part of the study area (fig. 4). The rocks of Pennsylvanian age are composed principally of shale with thin interbeds of mudstone and sandstone. Thickness of the unit varies from 0 to about 60 ft within the study area and, where present, forms a confining unit.

Unconsolidated deposits of Quaternary age include Pleistocene (pre-Illinoian to late Wisconsinan) glacial till and loess and Holocene alluvium and colluvium. Deposits of glacial till compose the bluffs on both sides of the Mississippi River Valley. The till ranges in thickness from 70 ft on the bluffs west of the City of Muscatine to more than 300 ft on the uplands in the western part of the study area. The clay-rich till contains some silt and sand with minor sand and gravel interbeds. A veneer (5 to 20 ft) of loess caps the upland areas. The loess is composed of eolian silt and clay. Both glacial till and loess have limited hydraulic conductivity but locally can yield adequate supplies for domestic and livestock needs (Coble and Roberts, 1971).

Holocene colluvium and alluvial-fan deposits are present along the base of the valley walls near the margins of the Mississippi River Valley. These deposits are relatively thin (colluvium generally is less than 10 ft thick; alluvial-fan deposits are less than 50 ft thick) and are of limited areal extent. The deposits are composed of silt, clay, sand, and pebbles of mixed lithology, which are derived from the glacial drift-covered uplands and valley walls (Bettis and others, 1992).

The Holocene alluvium in the Mississippi River Valley consists predominantly of stratified sand and gravel ranging in size from fine-grained sand to boulders. Although silt and clay are minor components of the alluvium, they occur both as surficial deposits and as randomly distributed lenses within the sand and gravel (Hansen and Steinhilber, 1977). The depositional sequences have a textural fining-upward component with a complex internal structure, but coalescing of individual depositional units has produced thick, areally extensive units of relatively uniform composition (Galloway and Hobday, 1983).

The thickness of the alluvium increases from about 40 ft in the northeast to more than 140 ft in the southern and western parts of the study area (fig. 5). The grain size of the alluvial materials generally decreases from north to south. For the purposes of this report, upper and lower alluvium refers to the upper and lower half of the unit. For example, in an area where the alluvial deposits are 140 ft thick, the upper alluvium consists of material from ground surface to a depth of 70 ft, and the lower alluvium consists of material from a depth of 70 ft to a depth of 140 ft.

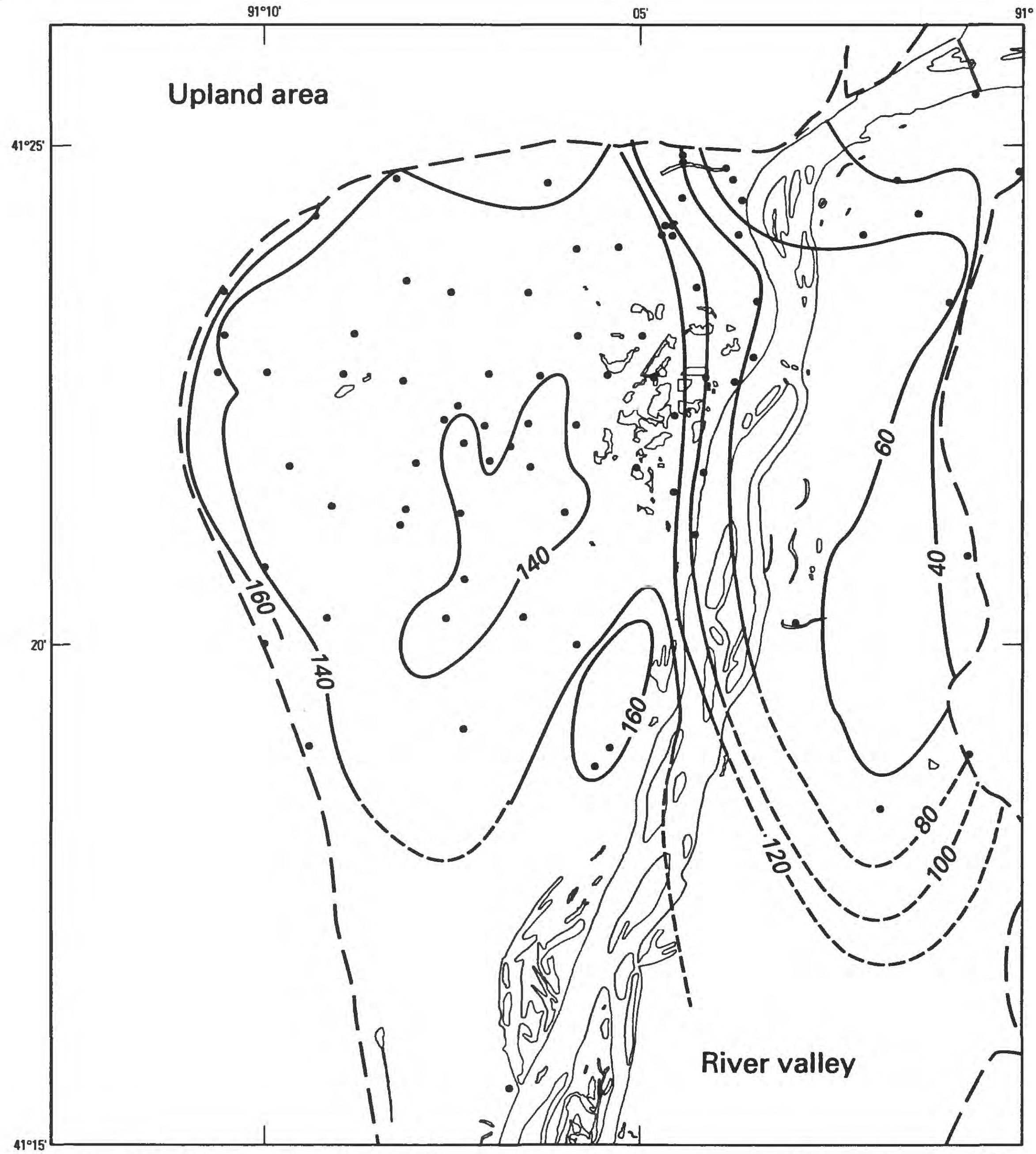
Surface Water

The Mississippi River is the major surface-water feature in the study area, and its stage has an important effect on ground-water levels in the alluvium. During February 1993, the mean stage of the Mississippi River immediately downstream of Lock and Dam No. 16 was 538.4 ft, and immediately upstream of Lock and Dam No. 17 it was 535.8 ft (U.S. Army Corps of Engineers, written commun., 1993). The average gradient of the river surface through the study area is approximately 0.13 ft/mi.

The stage in Muscatine Slough at site 38 during the period of study ranged from 527.9 ft on October 20, 1993, to 533.5 ft on August 16, 1993 (fig. 6). The change in the stage of the slough between sites 36 and 38 varied from 0.3 ft on March 3, 1993, to 3.3 ft on September 2, 1993. The gradient of the water surface in the slough depends on pump discharge and time since pumping began or ended. The maximum discharge from the slough measured during the period of study was 636 ft^3/s on August 16, 1993 (fig. 6), and represents the extreme conditions caused by the flood of 1993.

The altitude of the land surface in the river valley and the associated drainage ditches on the Illinois side of the Mississippi River in the southeastern part of the study area are lower than on the Iowa side. The stages in the drainage ditches on both sides of the river were measured on October 5, 1993, to quantify this difference. The stage in the Muscatine Slough was 530.6 ft, 528.5 ft, and 527.8 ft at sites 36, 37, and 38, respectively (fig. 3). On the Illinois side of the river, the stage was 534.2 ft, 528.3 ft, and 524.4 ft in drainage ditches near sites ILL5, ILL2, and ILL 1, respectively (fig. 3).

A series of generally ephemeral streams delivers runoff from the adjacent bluffs to the river valley. The



Base from U.S. Geological Survey, Blanchard Island 1:24,000, 1991; Letts 1:24,000, 1965; Muscatine 1:24,000, 1991; and Muscatine NW 1:24,000, 1965

EXPLANATION

— *160* — — **Line of equal thickness of alluvium**—Dashed where approximately located. Interval 20 feet

— — **Boundary between upland area and river valley**

● **Well location**—Control point

Figure 5. Thickness of alluvium in the Mississippi River Valley.

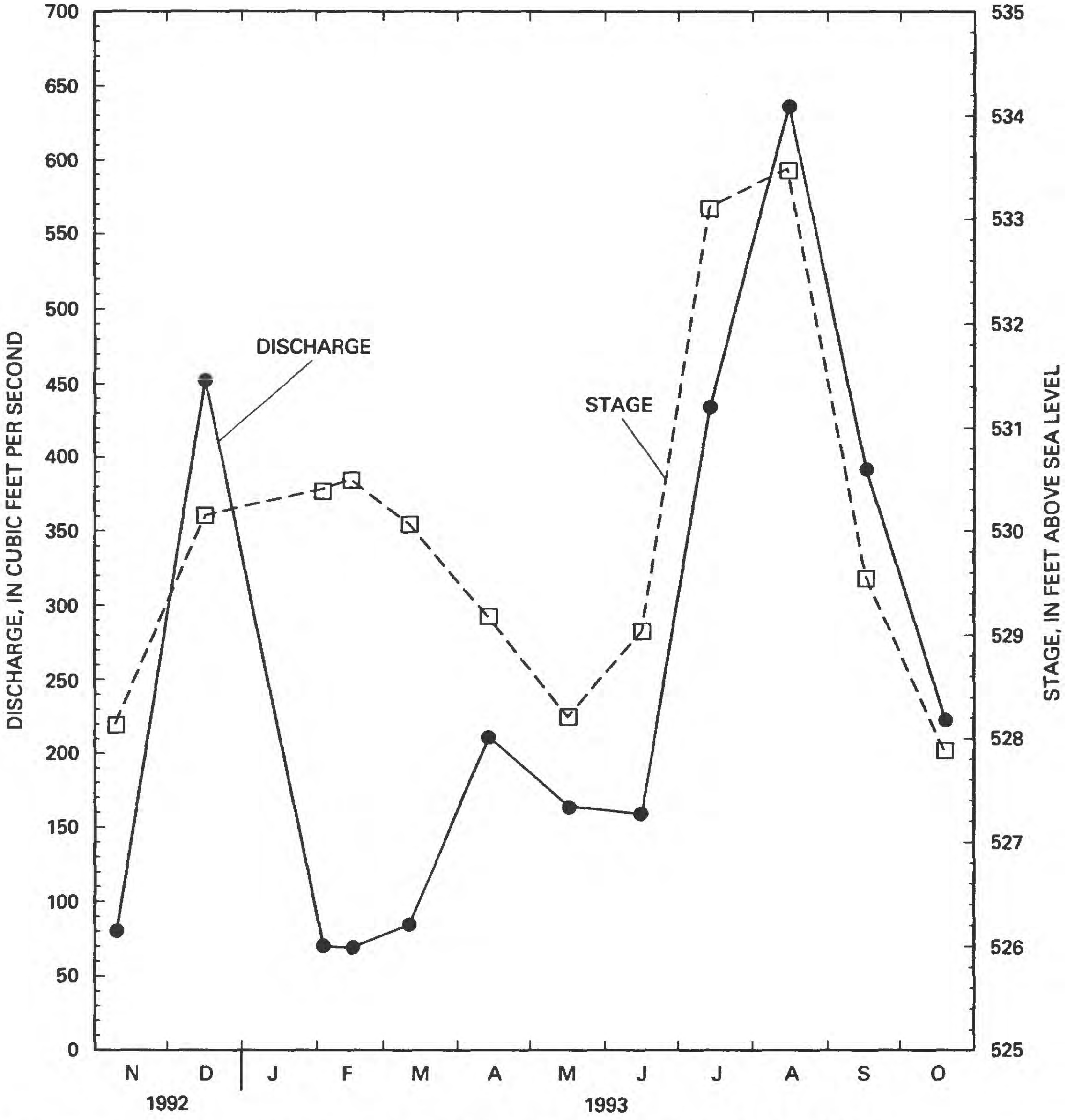


Figure 6. Discharge and stage in Muscatine Slough (site 38), November 1992–October 1993.

runoff is intercepted by the Muscatine Slough in Iowa and by the drain network in Illinois. Some of the bluff runoff can infiltrate into the ground-water system because of the permeable nature of the alluvium.

Ground Water

Ground water occurs in and is transmitted through interconnected openings in the alluvium and bedrock. Hydraulic conductivity describes the ability to transmit water and depends on the size and arrangement of the interconnected openings (Heath, 1987). Hydraulic conductivities of the predominant lithologies composing the geologic units vary through several orders of magnitude (table 4). Relatively impermeable lithologies are glacial till, shale, and limestone and dolomite, whereas the gravel and sand deposits of the alluvium are very permeable. Heath (1987) provides a general range of hydraulic conductivity for selected lithologies (table 4). Hansen and Steinhilber (1977) estimated hydraulic conductivity for gravel and coarse sand and for fine-to-coarse sand in the study area from samples of geologic materials and transmissivity data derived from pumping tests (table 4). For the present study, hydraulic conductivi-

Table 4. Estimated or calculated horizontal hydraulic conductivity in the study area

[(p), predominant lithologies in alluvium (see figs. 13 and 14, plate 1); f-c, fine to coarse; --, no data; (a), derived from transmissivity estimates by the stage-ratio and time-lag method (Ferris, 1963); (b), derived from transmissivity estimates from specific-capacity data (Theis and others, 1963), 12 wells in Muscatine Power and Water (MPW) Main Well Field (M), 4 wells in MPW Grandview Field (GV), 5 wells in MPW Progress Park Field (PP); (c), slug-test data from wells 13B, 46B, and 48C analyzed by Bouwer and Rice method (Bouwer, 1989)]

	Horizontal hydraulic conductivity, in feet per day, and source of data			
Lithology	**Heath (1987)**	**Hansen and Steinhilber (1977)**	**Aquifer-test analyses from this study**	**Used in the ground-water flow model (see figs. 13 and 14)**
Gravel	500–6,000	--	--	--
Gravel and coarse sand (p)	--	500	550–570 (a) 280–560 (b, M)	600
Gravel and sand (f-c) (p)	--	--	420 (b, GV)	500
Sand (f-c) and gravel (p)	--	--	260–420 (b, PP)	400
Fine-to-coarse sand, some gravel (p)	--	--	--	300
Fine-to-coarse sand (p)	1–500	40–150	--	200
Silty sand	0.01–50	--	--	--
Silty sand and clay (p)	--	--	--	150
Clay	1 x 10^{-7}–1 x 10^{-3}	--	--	--
Glacial till	1 x 10^{-6}–1	--	--	--
Shale	1 x 10^{-7}–1 x 10^{-3}	--	--	--
Limestone and dolomite (fractured to cavernous)	1 x 10^{-4}–10,000	--	1 x 10^{-3}–4 x 10^{-3} (c)	1 x 10^{-3}

ties were calculated by aquifer-test analyses for gravel and coarse sand, gravel and sand, sand and gravel, and limestone and dolomite (table 4). The small hydraulic conductivity of the bedrock is characteristic of carbonate rocks with a limited fracture system.

A large difference in the water-yielding characteristics between the very permeable alluvium and the relatively impermeable bedrock and glacial till (table 4) indicates that the majority of ground-water movement occurs in the alluvium. Input (recharge) to the ground-water system includes infiltration of precipitation, stream leakage when the river stage is higher than the altitude of the ground-water surface in the adjacent alluvium, infiltration of runoff from adjacent upland areas, subsurface flow through glacial till at the bluff boundary on the north, east, and west sides of the river valley, subsurface flow in the alluvium down the Mississippi River Valley from the north, and vertical leakage from the bedrock. Output (discharge) from the system includes flow to drainage ditches and streams, pumping, subsurface flow in the alluvium down the Mississippi River Valley to the south, and evapotranspiration during the growing season in areas of shallow water table.

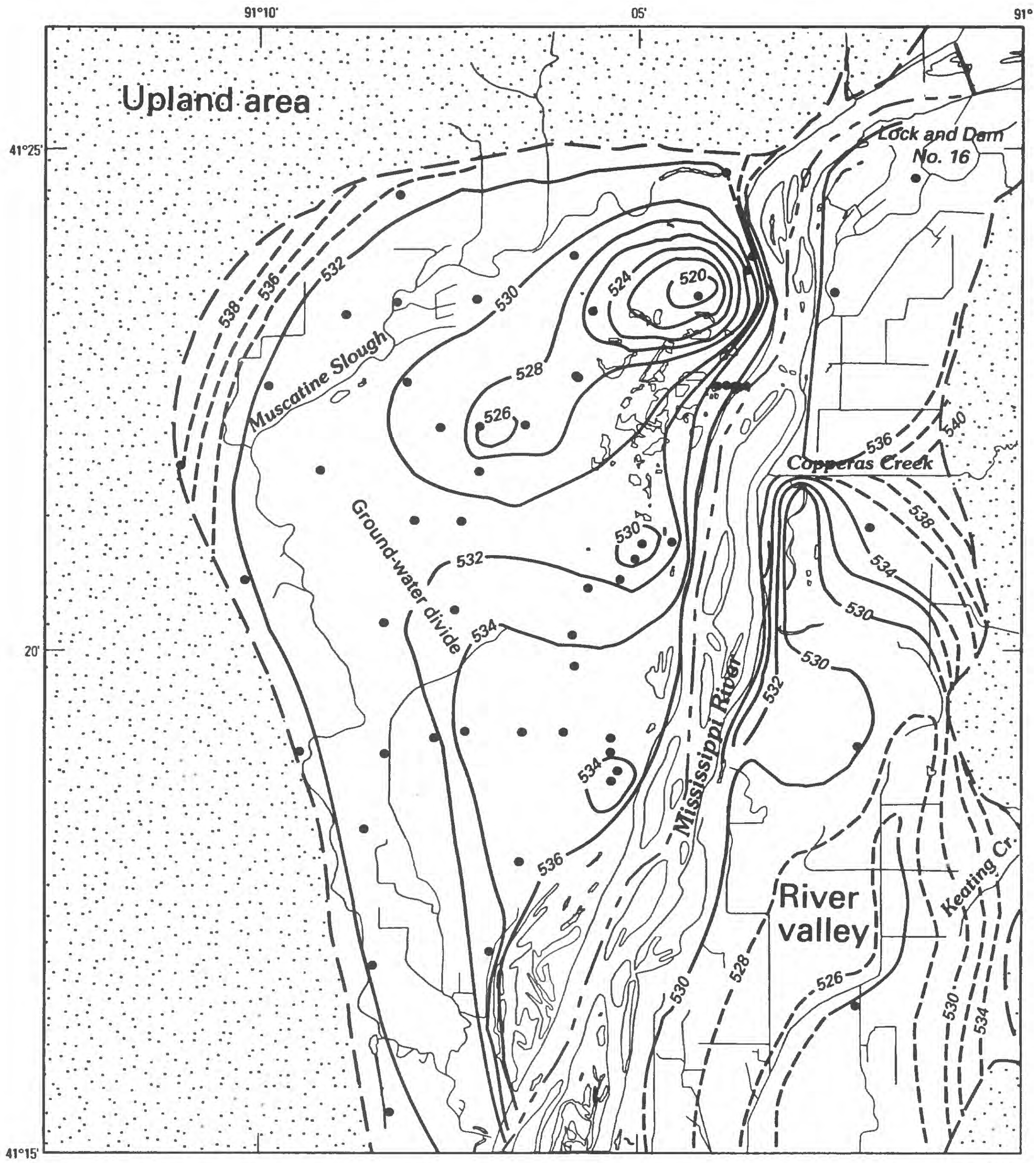
The configuration of the potentiometric surface in the upper alluvium on February 26, 1993, is shown in figure 7. A predominant feature is a cone of depression resulting from ground-water withdrawals at the pumping centers (fig. 2) in the northern part of the study area. Monthly municipal and industrial pumpage generally varies little throughout a given year, and the cone of depression probably represents an approximate average condition caused by the pumping stress. A ground-water divide occurs in Iowa between Muscatine Slough and the cone of depression caused by the pumping centers. The stage in Muscatine Slough at site 38 was 530.4 ft on March 3, 1993, and the slough functioned as a ground-water sink. Potentiometric contours near streams entering the river valley from the upland area, which are interpretive based on estimated stream stage from USGS 7.5-minute topographic maps and the measured water levels in observation wells, indicate streamflow infiltrating the permeable alluvium. The potentiometric surface in Illinois is affected by the drain network, and ground-water flow is toward the drainage ditches. Ground water moves perpendicular to the contours of the potentiometric surface with the lateral flow component being predominant over the vertical flow component.

The relation of the mean monthly stage of the Mississippi River in February (538.4 ft below Lock and Dam No. 16) to the potentiometric surface in the upper alluvium resulted in flow from the river into the adjacent alluvium. A gradient from the river into the adjacent alluvium ordinarily occurs due to the network of drainage ditches on both sides of the river and to the ground-water withdrawals at the pumping centers in Iowa. The direction of this gradient can reverse after large amounts of recharge to the alluvium.

There is effective hydraulic connection between the alluvium (site 13A) and the bedrock (site 13B) with small vertical hydraulic-head differences (fig. 8). Generally, water levels in the well completed in the bedrock are higher than those in the alluvium, so there is a small upward vertical gradient throughout the study period. Confined conditions in the bedrock result in hydraulic head being affected by changes in atmospheric pressure to a greater degree than water levels in the well completed in the alluvium.

Changes in the vertical component of ground-water flow (upward or downward) between the alluvium and bedrock occur near pumping centers adjacent to the Mississippi River and are dependent on river stage and climatic conditions. Site 61 monitors water levels in a well completed in the bedrock in MPW's Main Well Field, and site 3, located about 4,000 ft west of site 61, monitors water levels in a well completed in the lower alluvium (fig. 3). Hydraulic connection between the units is evident from the similar response to changing river stage (fig. 9). By assuming that the hydraulic head in the bedrock at site 3 is similar to that in the bedrock at site 61, changes in vertical flow direction between the upper and lower alluvium in this area can be inferred. Hydraulic head in the alluvium was higher than in the bedrock from March through August 1993, reflecting a downward component of flow. The extended period of greater-than-normal precipitation and river stage during the flood of 1993 caused downward flow from the alluvium to the bedrock near the river. Hydraulic head in the bedrock was higher than in the alluvium, which reflected an upward component of flow after September 1993 when the river stage decreased and drier climatic conditions prevailed.

Mean daily water levels in wells at sites 52 and 55 correspond to changes in the Mississippi River (fig. 10). There is a time lag of about 1 day for the effects of a peak stage of the river to be recorded at site 52 located 600 ft from the river's edge. The



Base from U.S. Geological Survey, Blanchard Island 1:24,000, 1991; Letts 1:24,000, 1965; Muscatine 1:24,000, 1991; and Muscatine NW 1:24,000, 1965

EXPLANATION

—532— — **Potentiometric contour**—Shows altitude at which water level would have stood in tightly cased wells. Dashed where approximately located. Contour interval 2 feet. Datum is sea level

— — **Boundary between upland area and river valley**

● **Ground-water-level measuring site**

Figure 7. Potentiometric surface in upper alluvium, February 26, 1993.

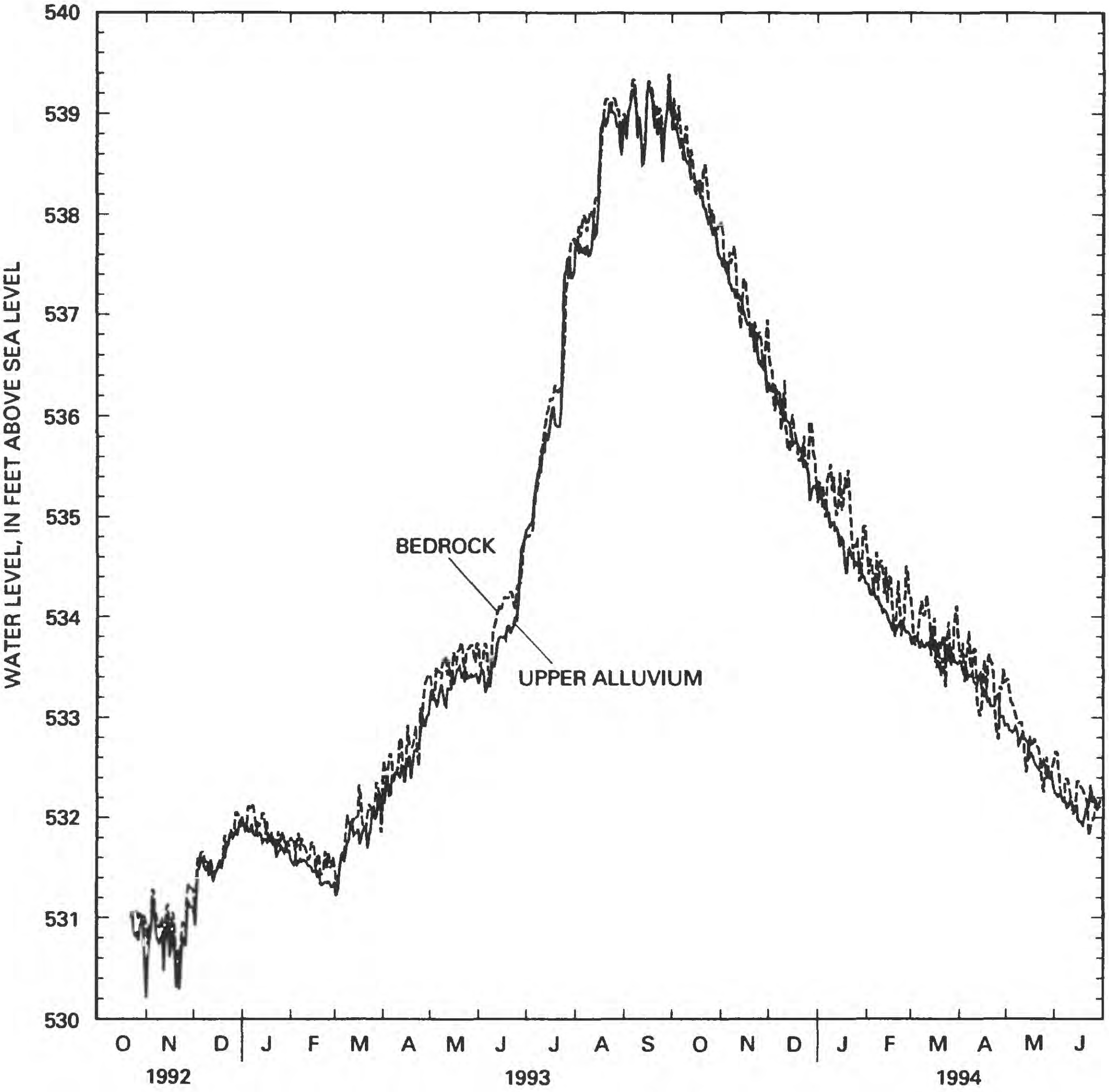


Figure 8. Water levels in wells at sites 13A (upper alluvium) and 13B (bedrock), October 1992–June 1994.

predominant gradient is from the river to the alluvium. Significant volumes of water from the Mississippi River can recharge the alluvial aquifer when a high river stage occurs for extended periods.

Water levels in a well at site 13A have been measured on a monthly to weekly basis since 1966 as part of a ground-water monitoring network cooperatively funded by the IDNR and the USGS (Southard and others, 1994). The well is located in Muscatine County near the ground-water divide between Muscatine Slough and the cone of depression in the northern part of the study area. There was a general downward trend in water levels during the 1970's and 1980's (fig. 11) caused by increased ground-water withdrawals and climatic variation. A net decline of about 3 ft in the mean annual water level occurred at site 13A from 1970 until 1992. Wetter climatic conditions returned in the early 1990's, which reversed the general decline in water levels, and the seasonal variations in water levels fluctuated around a mean annual water level of about 531.0 ft from 1990 through 1992.

Simulation of Ground-Water Flow

A computer program developed by the USGS (MODFLOW) was used to simulate ground-water flow in the study area. The program simulates flow in three dimensions by using a block-centered, finite-difference approach, which simultaneously solves a series of mathematical equations that describe

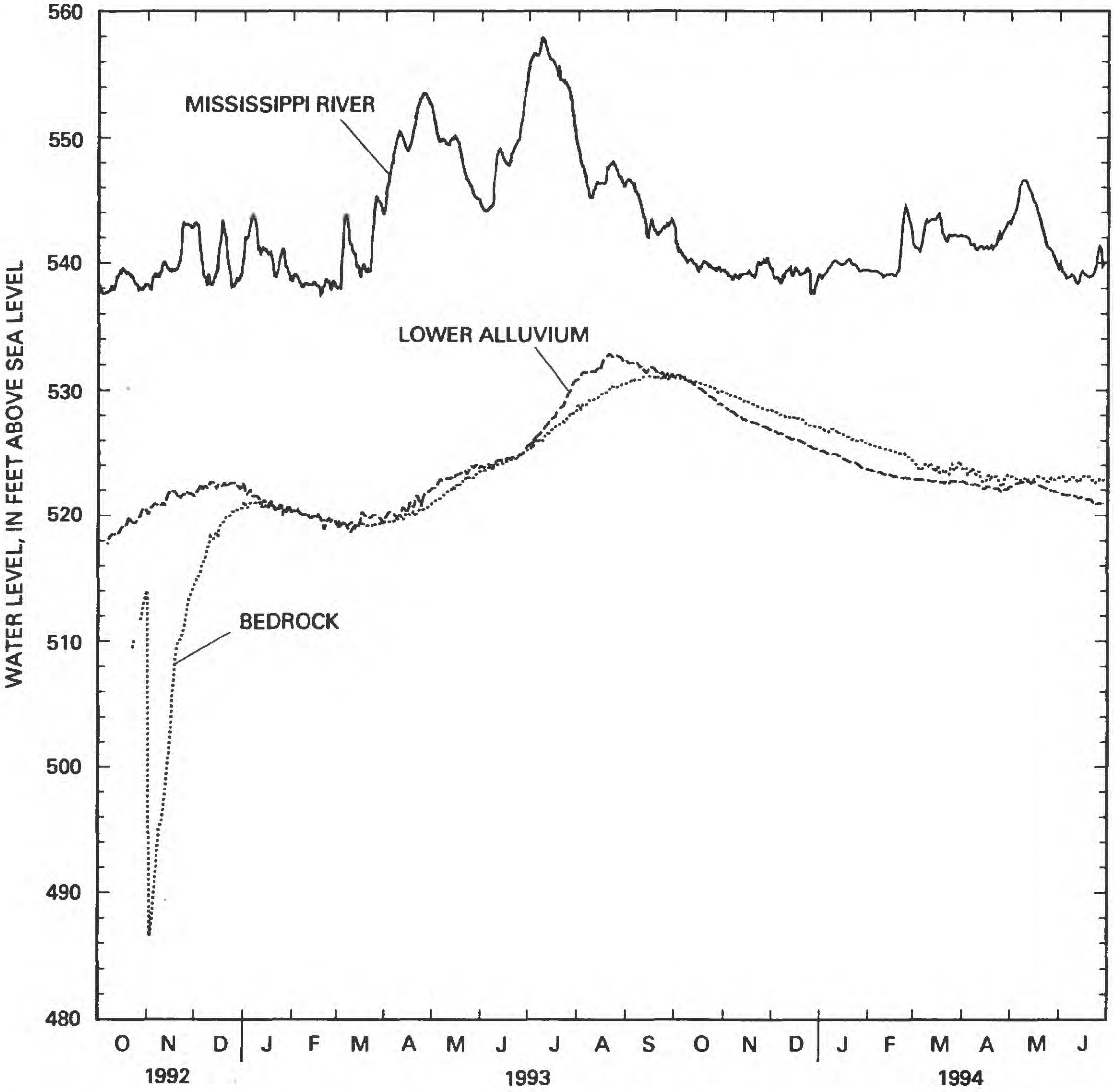


Figure 9. Water levels at sites 40A (Mississippi River), 3 (well completed in lower alluvium), and 61 (well completed in bedrock), October 1992–June 1994.

saturated ground-water flow (McDonald and Harbaugh, 1988). The finite-difference equations are solved using the strongly implicit procedure.

Although it is a simplified mathematical approximation of the physical system, a ground-water flow model is valuable as an aid to improved understanding of a complex flow system and as a tool to quantify sources of ground water. The model can evaluate how changing stresses (for example, pumpage) can affect ground-water levels and sources of ground water.

Onsite observations and hydrogeologic data collected during the period of study are the basis for conceptualizing the ground-water system, as previously described, and developing the ground-water flow model. Most ground-water flow occurs in the alluvium rather than adjacent geologic units. The streams, drainage ditches, alluvium, and shallow bedrock in the Mississippi River Valley compose a hydrologic system in hydraulic connection. Spatial limits of the model were defined mainly by the natural hydrologic boundaries of this system. The Maquoketa Formation is a confining unit underlying the limestone and dolomite bedrock, and glacial till of small hydraulic conductivity forms lateral boundaries on the north, east, and west. Subsurface flow through glacial till at the bluff boundary and subsurface flow through the small thickness of alluvium in the narrow part of the

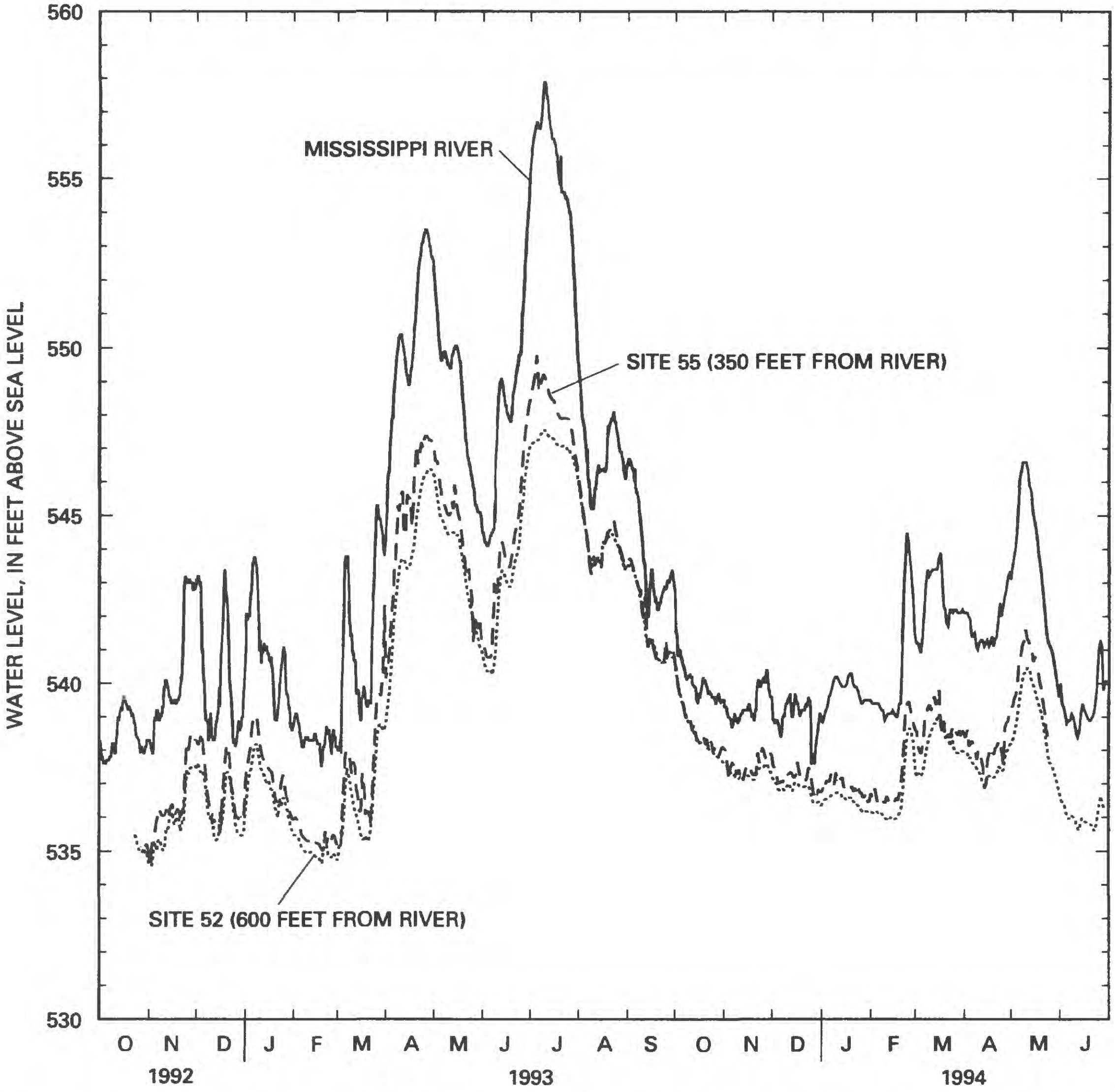


Figure 10. Water levels at sites 40A (Mississippi River), 55 (well completed in upper alluvium), and 52 (well completed in upper alluvium), October 1992–June 1994.

Mississippi River Valley from the north are considered insignificant. Subsurface flow down the Mississippi River Valley to the south is considered significant and is accounted for in the model.

Construction of the ground-water flow model assumed equilibrium, or steady-state, conditions. Steady-state conditions occur when inflow to the system equals outflow. February 1993 hydrologic conditions are considered an acceptable estimate of the ground-water system at equilibrium and were selected for the simulation. The mean annual water level in the well at site 13A, based on monthly measurements, was 531.0 ft for 1990 through 1992. Therefore, the water level measured at site 13A on February 26, 1993 (531.4 ft), is representative of recent conditions under current pumping rates. Annual ground-water withdrawals from the pumping centers increased less than 2 percent from 1990 through 1992, and it is assumed that these water levels represent an approximate steady-state condition that includes the effect of pumping. Streamflow and stage measurements in Muscatine Slough for February 1993 indicate a period of generally stable conditions (fig. 6).

Model Description and Assumptions

The steady-state model consists of three layers to represent the alluvium and part of the bedrock. The

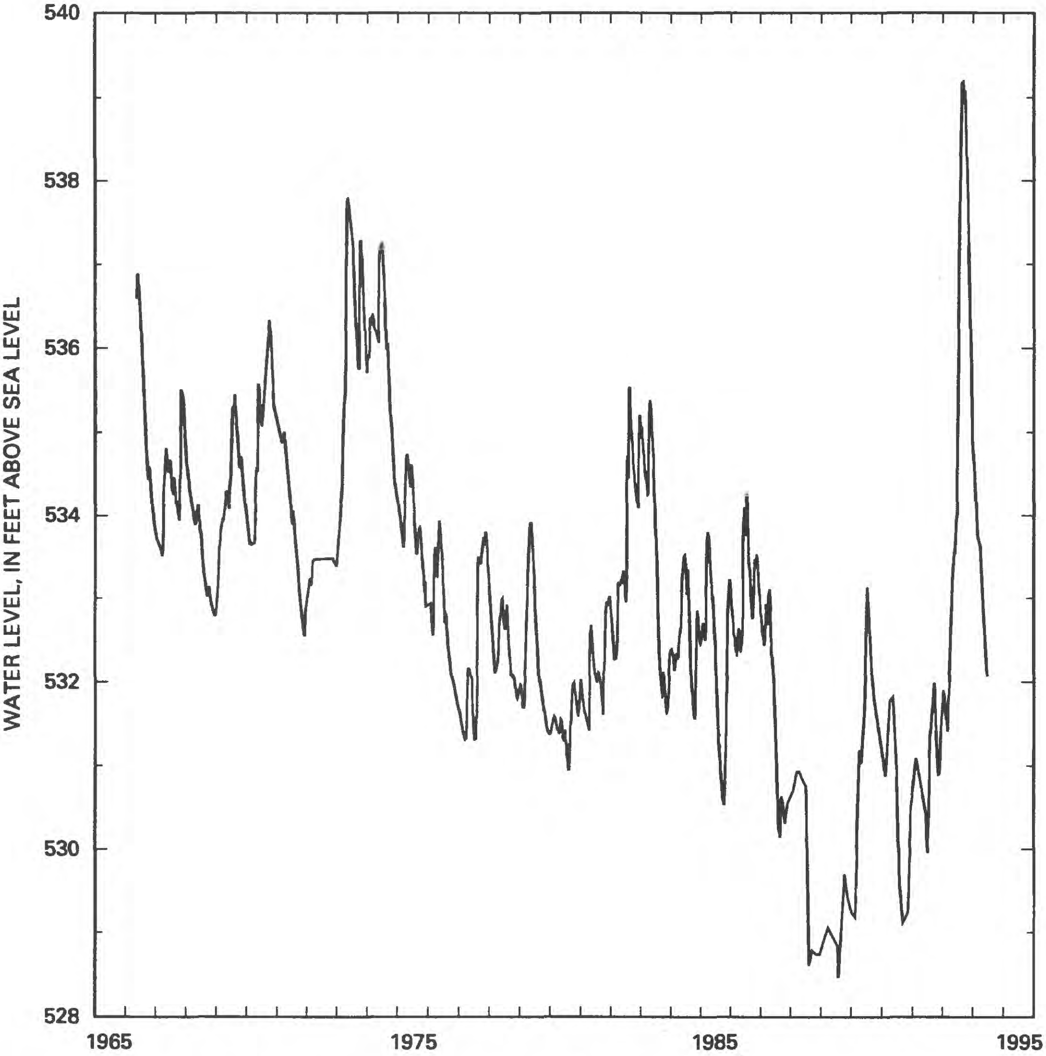


Figure 11. Water level in well at site 13A (upper alluvium), May 1966–June 1994.

relation between the geologic units and the equivalent layers in the ground-water flow model is shown on geologic section *A–A'* (plate 1). The alluvium is divided into layers 1 and 2, which represent the upper and lower alluvium, respectively, and layer 3, which represents the bedrock. The alluvium is modeled in this manner because the ground-water withdrawals at the pumping centers are from the lower alluvium and because differences in hydraulic conductivities between the upper and lower alluvium are interpreted from geologic data (plate 1). Flow in layer 1 is modeled as unconfined, or under water-table conditions, whereas flow in layers 2 and 3 is modeled as confined.

A 30-row by 24-column grid was used to divide the area of study into an array of 2,000-ft by 2,000-ft blocks, or cells (fig. 12). The grid was used to discretize each successive model layer. The cell area was identical in each layer, but its vertical dimension varied with layer thickness. The active cells of the model coincide with the river valley and the inactive cells with the upland areas. The model code calculates a ground-water level at the center, or node, of each active cell and a ground-water flux across each cell face based on water-level gradients between cells. Cells are identified by a row, column, layer designation.

Boundary conditions are specified at the periphery of the model grid to represent perceived flow conditions. The upper surface of the modeled area is a free surface that represents the water table, and a specified-flux boundary is used to represent areal recharge. The distribution of areal recharge is discussed in the following section on "Model Parameters."

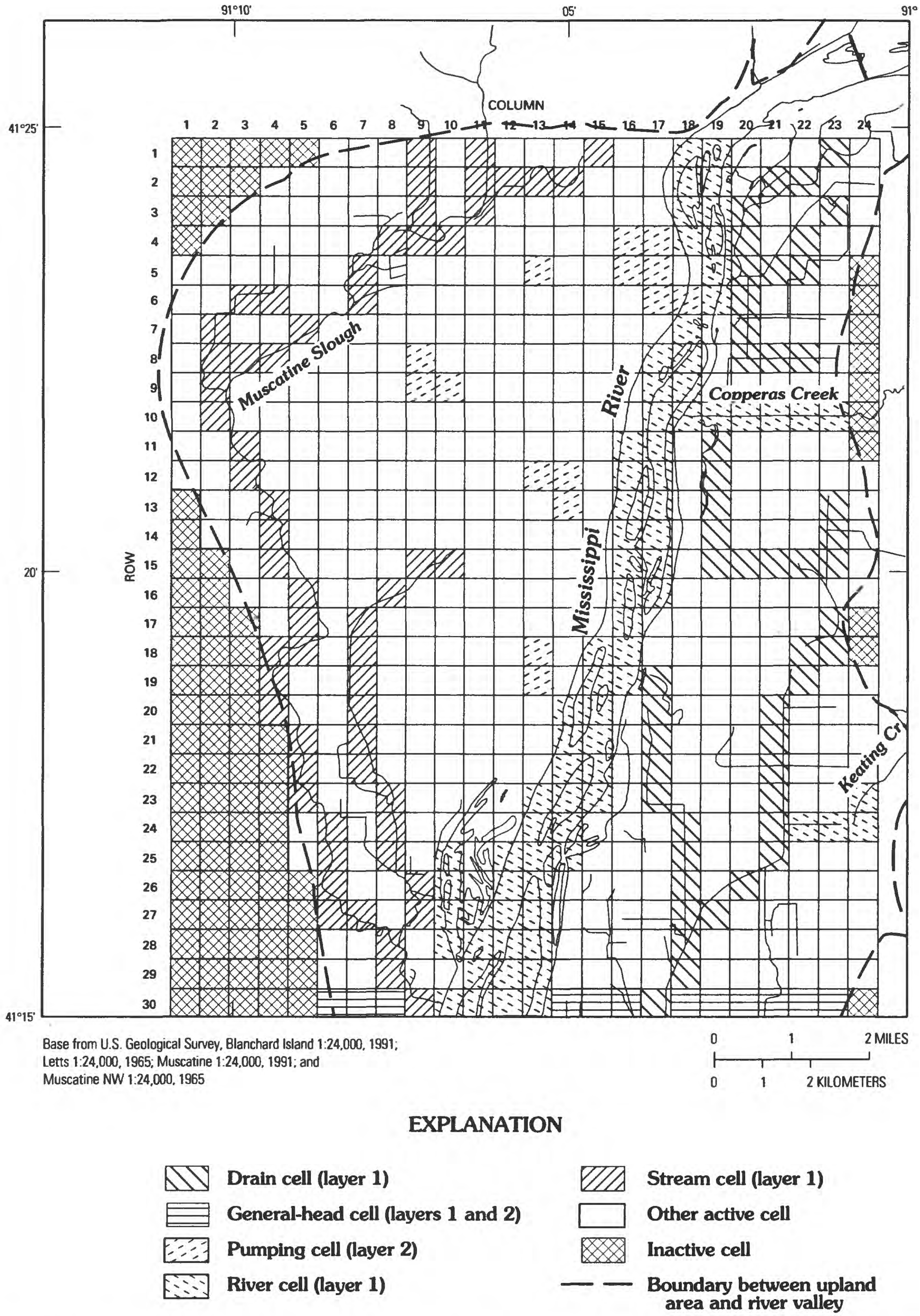


Figure 12. Model grid and boundary conditions for layers 1 and 2.

The Mississippi River, Copperas Creek, Keating Creek, drainage ditches in Illinois, and Muscatine Slough and its associated drainage ditches form parts of the model boundary at the upper surface of layer 1 (fig. 12). The difference in water level between the river, drain, or stream cells and that in layer 1 and the streambed conductance affects the amount of leakage that occurs. Streambed conductance is a function of the vertical hydraulic conductivity, thickness of the streambed material, and the width and length of the channel. Streambed conductance is unknown and generally cannot be measured onsite, but an estimate is derived by analyzing model results (simulated water levels and streamflow) from several model iterations.

The Mississippi River, Copperas Creek, and Keating Creek are simulated by river cells that allow leakage through the river bottom to layer 1 based on the difference in water levels and streambed conductance. A river cell will provide or receive as much water as the model requires to reach a mathematical solution. These perennial streams are expected to continue to flow even if the water table in the alluvium is lower than the altitude of the river bottom. Mississippi River stage at each river cell was determined from the gradient between Lock and Dam No. 16 and Lock and Dam No. 17 based on mean monthly values for February 1993. The stage in the creeks and the location, length, and width of the river and creek channels were estimated from USGS 7.5-minute topographic maps. A streambed thickness of 1 ft was assumed. Streambed vertical hydraulic conductivities of 1 ft/d and 0.5 ft/d were used for cells representing the Mississippi River and cells representing the creeks, respectively. A larger vertical hydraulic conductivity was used for the Mississippi River because of periodic dredging operations.

Drainage ditches in Illinois are simulated by drain cells that allow leakage only from layer 1 to the drain. It is assumed that the stage in the drain reflects the altitude of the water table and that flow in these drainage ditches is predominantly from ground water. The stage in the drainage ditches is regulated by pump stations, and stage measurements made on October 5, 1993, were used in the model. (Stage measurements in Illinois drainage ditches were not available for February 1993). Channel location, length, and width were estimated from USGS 7.5-minute topographic maps. A streambed thickness of 1 ft and a vertical hydraulic conductivity of 5 ft/d were used for the streambed-conductance calculation.

The Muscatine Slough is simulated using a computer code that calculates leakage between layer 1 and the slough while accounting for streamflow entering or leaving each defined stream cell (Prudic, 1989). Stream cells function like river cells by allowing leakage from or to the aquifer based on the difference in water levels. However, stream cells can cease to flow rather than provide an infinite supply of water like a river cell. The large ground-water withdrawals in Iowa could cause parts of Muscatine Slough or its associated drainage ditches to cease flowing during periods of low recharge to the alluvium. Stream cells give the model the flexibility to simulate this situation. Streamflow that enters the slough from two ungaged creeks that drain the upland area to the north is specified for cells (1,9,1) and (1,11,1) so the flow is accounted for in the model simulation (fig. 12). Daily streamflow for these cells was estimated by converting February 1993 monthly runoff (in inches) calculated for Crow Creek at Bettendorf, Iowa (Southard and others, 1994), to a daily value and adjusting for differences in drainage basin areas. Crow Creek drains terrain similar to the upland areas in the study area. The stage in the two streams was estimated from USGS 7.5-minute topographic maps. Stage measurements made on March 3, 1993, at three sites (sites 36, 37, and 38; fig. 3) and USGS 7.5-minute topographic maps were used to estimate the stage at stream cells along the length of the slough. For all stream cells, channel location, length, and width were estimated from USGS 7.5-minute topographic maps. A streambed thickness of 1 ft and a streambed vertical hydraulic conductivity of 5 ft/d were used in the streambed-conductance calculation.

No-flow boundaries are used to simulate the limits of the modeled area where ground-water flow is assumed to be nonexistent or insignificant. The bottom of the modeled zone is at the top of the relatively impermeable Maquoketa Formation and is represented by a no-flow boundary on the underside of layer 3. The lateral hydrologic boundaries formed by the relatively impermeable glacial till adjacent to the alluvium (layers 1 and 2) establish logical hydrologic limits for modeling ground-water flow in the alluvium and shallow bedrock. These boundaries are considered impermeable and are modeled as no-flow boundaries. A no-flow boundary was used across the narrow part of the Mississippi River Valley in the northeast part of the model area because subsurface flow from the north is considered insignificant to the overall water budget (fig. 5).

The modeled area is not a closed hydrologic system, so a special type of boundary was selected for lateral model boundaries not designated as no-flow boundaries. Three types of boundaries were considered: (1) a constant-head boundary, which provides an infinite source of water; (2) a constant-flux boundary, which provides a uniform source of water; and (3) a general-head boundary, which represents an intermediate situation between the two previously described boundary conditions by placing a constant-head source at a distance far enough from the model boundary to minimize its effect on the simulation. When the system is stressed by increased pumpage, (1) the constant-head boundary will provide the maximum increase in the amount of water entering the model and minimize drawdowns; (2) the constant-flux boundary will provide the minimum increase in water entering the model and maximize drawdowns; and (3) the general-head boundary will provide an intermediate response allowing an increase in water budget and a decline in water levels.

General-head boundaries are used at the southern limits of layers 1 and 2 to simulate subsurface flow through the alluvium down the Mississippi River Valley. General-head boundaries also are used at the perimeter of layer 3 to allow ground water to enter or leave the system through the bedrock based on relative head differences between the model cells and the regional potentiometric surface. In both cases a constant-head source is placed 5 mi from the closest active cell in the model, and the hydraulic conductivity of the laterally adjacent unit is used in the computation of ground-water flux across the boundary. The ground-water level at the boundary was derived by projecting a regional gradient of the potentiometric surface in the upper alluvium for layers 1 and 2 or in the bedrock for layer 3. The general-head boundary allows for the simulation of future increased-pumpage scenarios.

Model Parameters

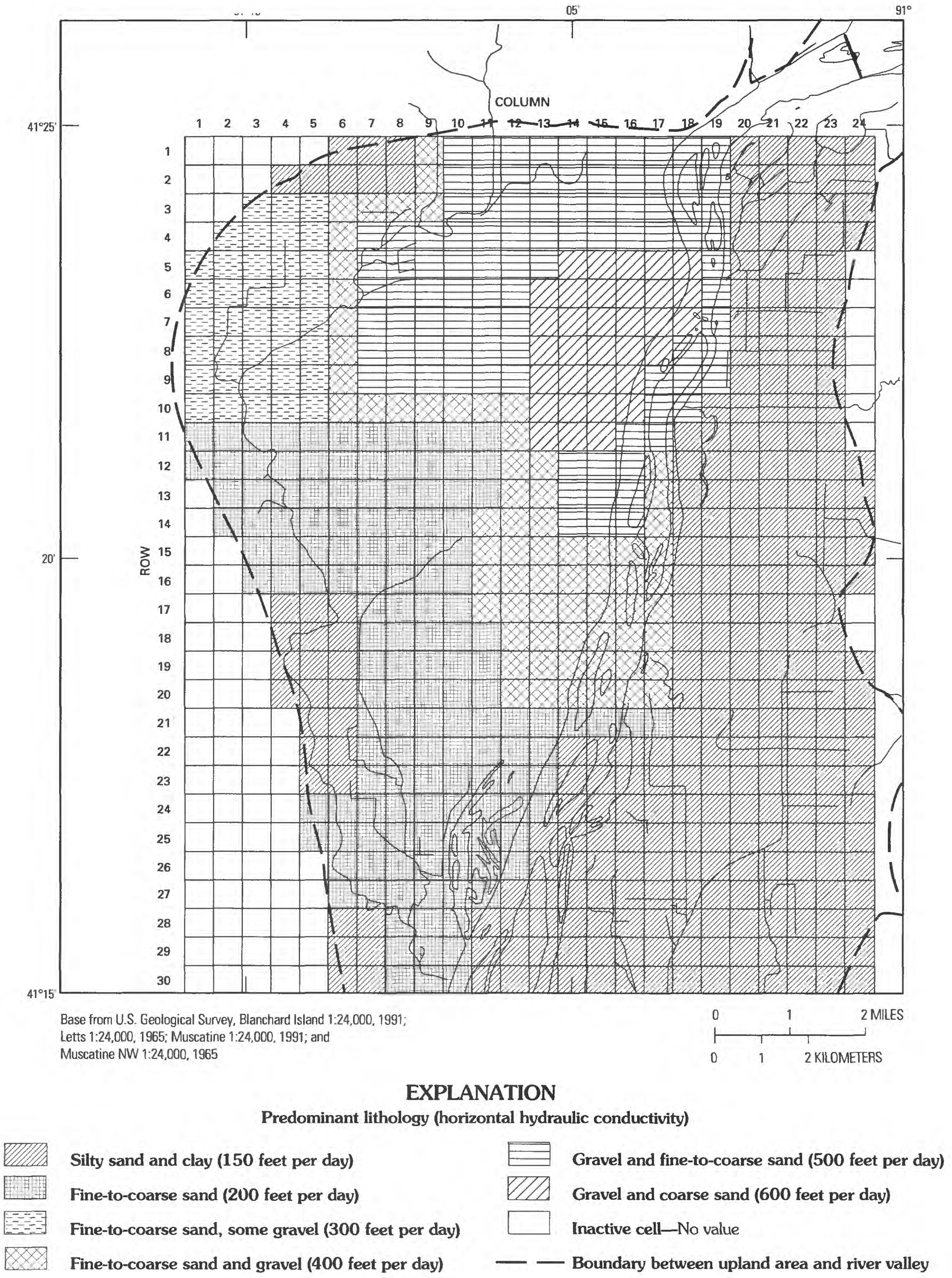
Model parameters, or variables, used in the ground-water flow equations are assigned to individual cells. Parameters are specified at the node of each active cell and represent an average for the entire cell. An areal variation in parameters can be depicted by assigning appropriate values to individual cells in the model array. Parameters that represent an areal distribution of the geometry of the model layers, horizontal and vertical hydraulic conductivity, recharge by areal precipitation and runoff from upland areas, and ground-water pumpage are used in the model.

The model code uses transmissivity to solve the mathematical equations and simulate ground-water flow. Hydraulic conductivity is multiplied by the layer thickness to calculate transmissivity at each node throughout the model grid. Alternatively, a transmissivity can be assigned.

A uniform transmissivity of 0.3 ft^2/d was assigned to nodes in layer 3 (bedrock) and calculated by assuming a thickness of 300 ft and a hydraulic conductivity of 0.001 ft/d. A uniform transmissivity was selected on the basis of slug-test results (table 4), limited hydrogeologic information about the bedrock, and the insensitivity of this aquifer property (discussed in a later section of the report) to model results. Shale bedrock in the northeast part of the study area is modeled as a confining unit, so horizontal flow in that unit is not represented in the model.

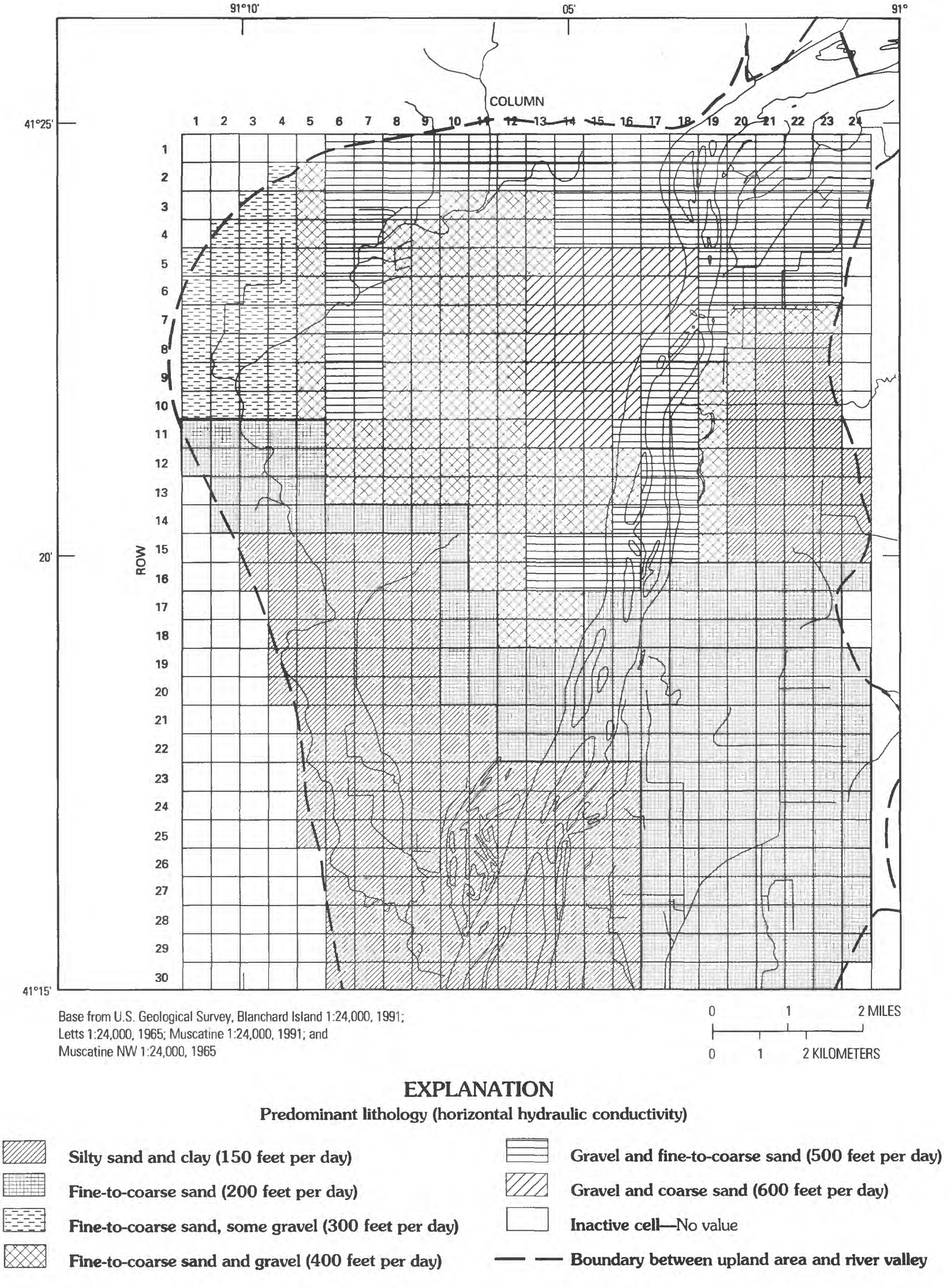
Areal distributions of hydraulic conductivity for layers 1 and 2 (figs. 13 and 14, respectively) were prepared from variations in predominant lithology on the basis of six geologic sections constructed through the model area (plate 1). Hydraulic conductivity initially assigned to the six predominant lithology types (silty sand and clay, fine-to-coarse sand, fine-to-coarse sand containing some gravel, fine-to-coarse sand and gravel, gravel and fine-to-coarse sand, and gravel and coarse sand) were based on an expected range determined from the scientific literature and aquifer-test analyses (table 4). The final hydraulic conductivities used in the model arrays for the upper and lower alluvium ranged from 150 to 600 ft/d (table 4) and were the result of the calibration process (discussed in a later section of the report).

Transmissivities in layers 1 and 2 are calculated by multiplying hydraulic conductivity by layer thickness. The thickness of layer 2 (lower alluvium) was determined in the model by subtracting the altitude of the midpoint of the alluvium from the altitude of the bedrock surface (fig. 4). The thickness of layer 1 (upper alluvium) was determined in the model by subtracting the altitude of the midpoint of the alluvium from the altitude of the top of the saturated material. The altitude of the top of the saturated material initially was input to the model as an estimated altitude of the potentiometric surface in the upper alluvium (fig. 7). The model code varies the altitude of the top of the saturated material in layer 1 and recomputes transmissivity in reaching a mathematical solution.



Base from U.S. Geological Survey, Blanchard Island 1:24,000, 1991; Letts 1:24,000, 1965; Muscatine 1:24,000, 1991; and Muscatine NW 1:24,000, 1965

Figure 13. Predominant lithology in upper alluvium and corresponding horizontal hydraulic conductivity assigned to layer 1.



Base from U.S. Geological Survey, Blanchard Island 1:24,000, 1991; Letts 1:24,000, 1965; Muscatine 1:24,000, 1991; and Muscatine NW 1:24,000, 1965

Figure 14. Predominant lithology in lower alluvium and corresponding horizontal hydraulic conductivity assigned to layer 2.

Vertical leakance is required by the model to control the rate of ground-water flow between layers. Vertical leakance between two adjacent model layers is calculated from the thickness of each layer between its node and the common layer contact and the vertical hydraulic conductivity of each layer (McDonald and Harbaugh, 1988, equation 51). Vertical leakance between two model layers with an intervening confining unit is calculated with the above properties and the vertical hydraulic conductivity and thickness of the confining unit (McDonald and Harbaugh, 1988, equation 52).

Vertical leakance for the calibrated model represents vertical hydraulic conductivities with a range of 1.5 to 6 ft/d in the alluvium, 1 ft/d in the limestone and dolomite bedrock, and 0.005 ft/d in the shale bedrock. Calculation of vertical leakance in the alluvium assumed that the ratio of vertical hydraulic conductivity to horizontal hydraulic conductivity was 1 to 100. The small hydraulic conductivity for the alluvium in the vertical direction compared to the horizontal direction represents an impediment to flow from intervening clay or silt layers and small-scale depositional features. The larger vertical than horizontal hydraulic conductivity in the limestone and dolomite bedrock is used to simulate the effective hydraulic connection with the overlying alluvium. Vertical flow through the shale is accounted for with a small vertical leakance between layers 2 and 3 where the confining unit is present in the northeast part of the study area.

Inputs to the ground-water system (recharge) include infiltration of precipitation, infiltration of runoff from upland areas to the river valley, leakage from river and stream cells, and flow across general-head boundaries. The model calculates leakage to rivers and streams and flow across general-head boundaries. An array to represent recharge from infiltration of precipitation and infiltration of runoff from upland areas was prepared as input.

Infiltration of precipitation to the water table was accounted for by applying a daily net recharge rate to all active cells. Hansen and Steinhilber (1977) estimated annual net recharge to the water table to be 0.5 ft/yr (0.0014 ft/d) in the Muscatine area from analysis of two alluvial-well hydrographs covering an 8-year period of record (1964–71). A daily net recharge rate of 0.003 ft/d was used in the model to simulate the assumed steady-state February 1993 conditions. Although greater than the rate reported by Hansen and Steinhilber, it is a plausible value for a sandy-soil area receiving 34.60 in/yr precipitation.

Runoff from upland areas was accounted for by increasing the areal recharge rate at the model cells that border the boundary between the river valley and the upland area. The incremental recharge rate at each cell was determined from a daily runoff volume assigned to each cell based on its contributing drainage area. This daily runoff volume was estimated by converting the monthly February 1993 runoff (in inches) from Crow Creek at Bettendorf, Iowa (Southard and others, 1994), to a daily value and adjusting for differences in drainage basin areas. Crow Creek drains terrain similar to the upland areas in the study area.

Outputs from the ground-water system (discharge) include pumpage, leakage to rivers, streams, and drains, and flow across general-head boundaries. The model calculates all of these fluxes except pumpage, for which an array was constructed for input to the model code. Evapotranspiration is an output from the system during the growing season but is not addressed in this model for assumed steady-state conditions in February 1993.

Average daily withdrawals from the ground-water system during February 1993 (6,091,000 ft^3/d, or 45.5 Mgal/d) were assigned to appropriate cells (fig. 12). Average daily pumpage during February 1993 for individual well fields was obtained from pumpage records obtained from the operators. The pumpage assigned to each cell was calculated by multiplying the ratio of the number of production wells located within the cell to the total number of production wells in the well field by the average daily pumpage for the well field.

Model Calibration

The steady-state model was calibrated through trial and error by varying hydraulic conductivity, vertical leakance, and drain, stream, and river conductance during numerous simulations. As these parameters were adjusted within reasonable limits, model output was analyzed to ascertain whether the adjustment improved the match between measured (February 26, 1993) and simulated ground-water levels and measured (February 1993) and simulated discharge in Muscatine Slough. The goal of the model calibration process is to minimize differences between the measured and simulated values. The calibration process continued until further incremental adjustments to model input parameters produced no perceivable improvement in model results.

During the calibration process, improvements in the model output were determined by calculating the average head difference (AVEH) and the root mean square error (RMSE) between measured and simulated ground-water levels. The AVEH is a measure of systematic error; it approaches zero when the sum of the differences between measured and simulated ground-water levels that are greater than zero equals the sum of the differences that are less than zero. The RMSE is a measure of the magnitude of error between measured and simulated ground-water levels over the entire model area. The RMSE is calculated as shown in equation 1 (Tucci, 1992):

$$\mathrm{RMSE} = \sqrt{\frac{\sum (M-S)^2}{N}} \qquad (1)$$

where,

M is the measured water level;

S is the simulated water level; and

N is the number of comparisons.

Measured ground-water levels (February 26, 1993) were determined for comparison with simulated levels from observation wells that coincide with model nodes or that are located within the boundaries of the cells. A total of 65 comparisons of measured and simulated water levels were made—43 in layer 1, 16 in layer 2, and 6 in layer 3. The calibrated values of AVEH and RMSE were, respectively, 0.2 ft and 0.9 ft in layer 1, 0.1 ft and 0.8 ft in layer 2, 0.7 ft and 1.3 ft in layer 3, and 0.2 ft and 0.9 ft in all three model layers. The RMSE for all three model layers represents 5.6 percent of the range of measured water levels (16.2 ft).

In addition to AVEH and RMSE, the calibration process attempted to minimize the percentage of error between estimated and simulated mean daily discharge for February 1993 in Muscatine Slough. The mean daily discharge for Muscatine Slough simulated by the calibrated model is 3,360,000 ft^3/d, which is 34 percent less than the amount estimated from pump operation time and rated pump capacity (5,080,000 ft^3/d). This comparison is considered reasonable because of the error associated with obtaining estimates of pump operation time. Model input data that affect flow to the slough, such as stream conductance, vertical leakance, horizontal hydraulic conductivity, and recharge, have been adjusted through a reasonable range of hydrologic values during calibration to maximize flow in the slough while minimizing AVEH and RMSE.

Another step in the calibration process involved evaluating the accuracy of simulated ground-water flow directions. A map of the simulated potentiometric surface in the upper alluvium (fig. 15) was compared to a potentiometric-surface map based on water levels measured on February 26, 1993 (fig. 7), to ensure similarities in interpreted ground-water flow. Vertical head differences at locations of well clusters were compared to those at corresponding model nodes.

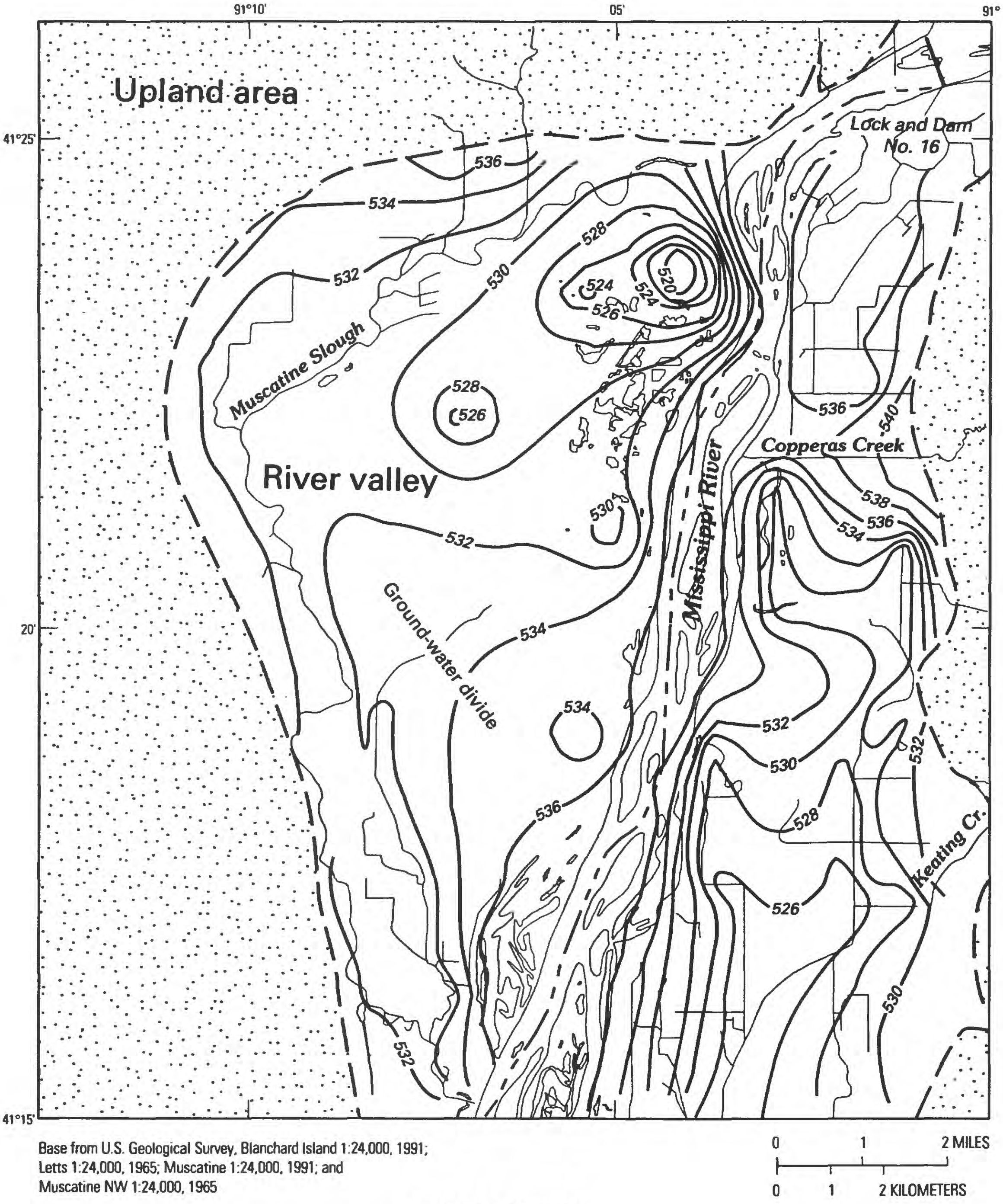
The steady-state model was considered calibrated when the following criteria were met:

1. Incremental changes in model input parameters did not produce an AVEH closer to zero or a smaller RMSE for all layers in the model;
2. The RMSE represented a small percentage of the range in measured ground-water levels;
3. Incremental changes in model input parameters did not decrease the percentage difference between estimated and simulated discharge in Muscatine Slough;
4. The simulated lateral ground-water flow directions compared favorably to flow directions interpreted from the potentiometric-surface map in the upper alluvium constructed using water levels measured on February 26, 1993 (fig. 7); and
5. The simulated head differences at locations of well clusters compared favorably to those derived from water levels measured on February 26, 1993.

Sensitivity Analysis

Construction of a ground-water flow model involves developing a set of model input parameters that are used in mathematical equations to simulate a hydrologic system. Uncertainty is associated with the parameters because limited measured data are represented as characteristic of one to several model cells. During calibration these model input parameters are varied until a reasonable match is produced between measured data and simulated results. Sensitivity analysis evaluates the response of the model to incremental changes in parameters and determines which have the greatest effect on results, such as water levels and discharge. If improvement in the model is desired, additional data collection would be directed toward refining the most sensitive parameters.

Simulated water-level response to incremental changes in selected input parameters is shown in figure 16. The RMSE is plotted against the multiplication factor used to vary the parameter. The calibrated



Base from U.S. Geological Survey, Blanchard Island 1:24,000, 1991; Letts 1:24,000, 1965; Muscatine 1:24,000, 1991; and Muscatine NW 1:24,000, 1965

EXPLANATION

— *532* — **Simulated potentiometric contour**—Shows altitude at which water would have stood in tightly cased well. Datum is sea level. Contour interval 2 feet

— — **Boundary between upland area and river valley**

Figure 15. Simulated potentiometric surface in upper alluvium, February 1993.

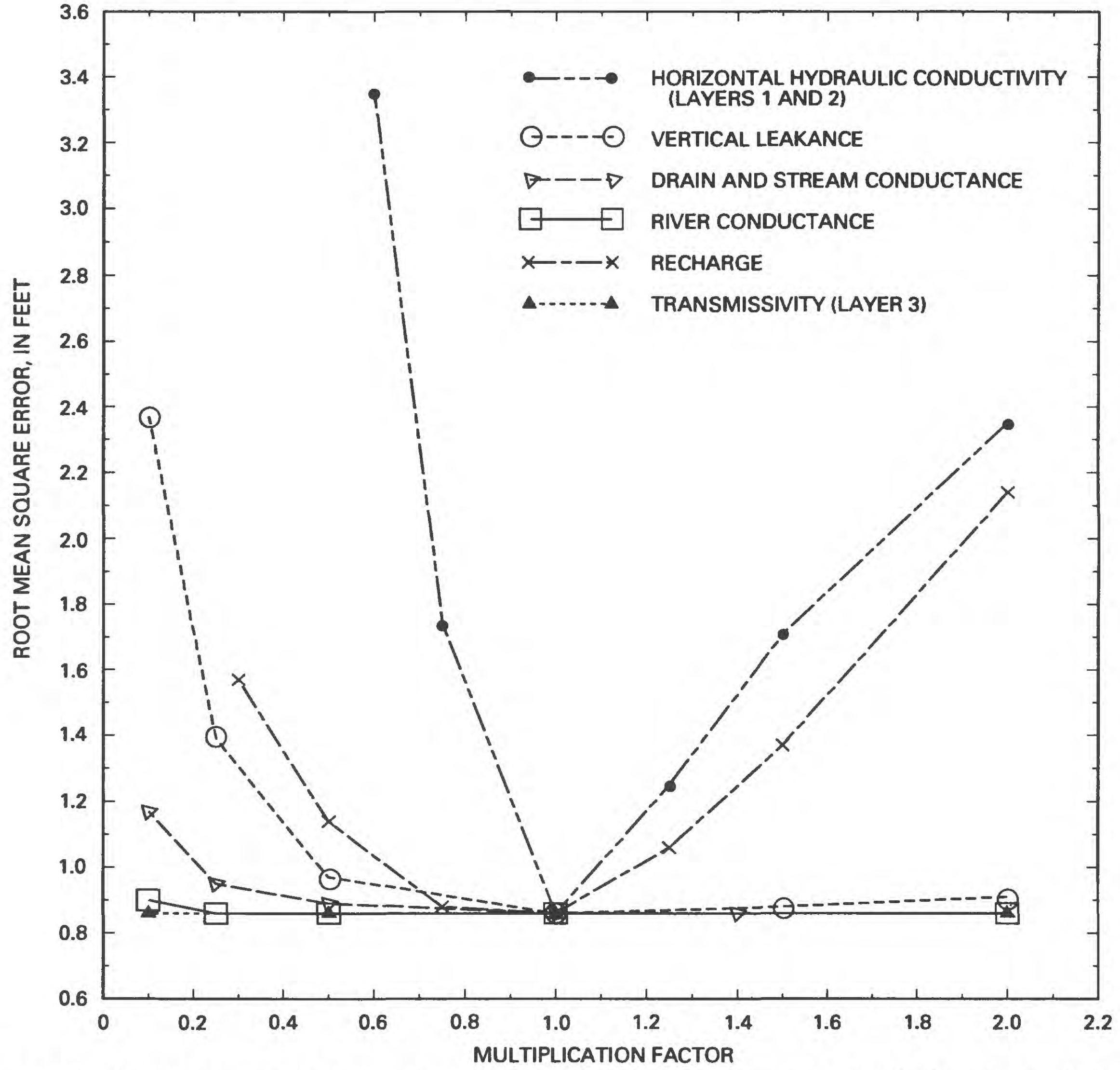


Figure 16. Root mean square error between measured and simulated water levels as a result of varying model input parameters.

model parameters are used as comparison and are represented by a multiplication factor of 1. The multiplication factor was applied uniformly to the entire model for the indicated parameter and ranged from 0.1 to 2.0. The parameter being tested was adjusted while the remaining model parameters were held at the calibrated values.

Water levels were most sensitive to hydraulic conductivity in layers 1 and 2 and to recharge. Large RMSEs were associated with the incremental changes to hydraulic conductivity. Water levels were insensitive to transmissivity in layer 3, river conductance, and drain and stream conductance. Water levels were insensitive to increased vertical leakance but were sensitive to decreased vertical leakance (fig. 16).

The sensitivity of simulated river leakage was evaluated by varying model input parameters and determining the proportion of inflow to the groundwater system obtained from river leakage. The proportion of inflow obtained from river leakage was most sensitive to recharge and horizontal hydraulic conductivity, whereas changing vertical leakance, drain and stream conductance, river conductance, and transmissivity of layer 3 had less effect (fig. 17).

Vertical leakance between layers 1 and 2 can affect the magnitude of simulated drawdown in the alluvium. A decrease in vertical leakance between layers 1 and 2 results in greater drawdown, and an increase results in lesser drawdown. For example, multiplying the calibrated vertical leakance by 0.1

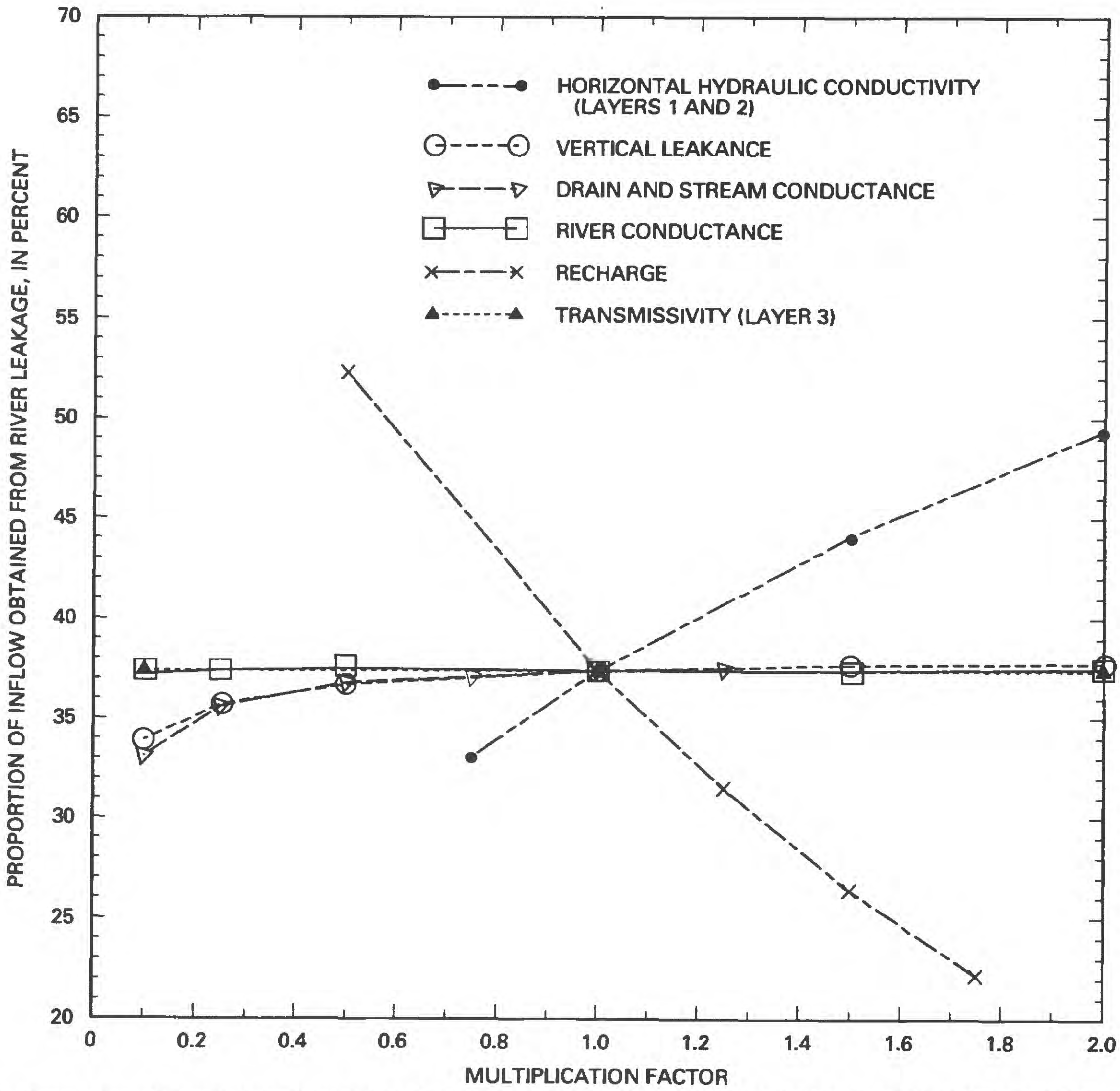


Figure 17. Proportion of simulated inflow obtained from river leakage as a result of varying model input parameters.

results in an increase in drawdown at cell 5, 19, 2 from 0.12 to 0.95 ft, whereas multiplying the calibrated vertical leakance by 10 results in a decrease in drawdown to 0.02 ft.

An evaluation of the sensitivity of discharge in Muscatine Slough was made by varying hydraulic conductivity in layers 1 and 2, drain and stream conductance, recharge, and vertical leakance. Of these parameters, discharge in Muscatine Slough was most sensitive to recharge followed by hydraulic conductivity in layers 1 and 2.

The sensitivity of the general-head boundaries to changes in hydraulic conductivity affecting flow entering or leaving the model through the bedrock was evaluated. The hydraulic conductivity was increased, and the flow contributed by the general-head boundary was compared to the total amount of ground-water flow entering the model. The calibrated model uses a hydraulic conductivity of 0.001 ft/d for the bedrock and general-head boundary, and flow entering the model from the general-head boundary is less than 0.1 percent of the total. Even by increasing the hydraulic conductivity to 100 ft/d, which is unreasonably large for the carbonate bedrock in this area, the ground-water contribution from the bedrock remains less than 4 percent of the total.

Model Limitations

The ground-water flow model constructed for this study is useful in evaluating the flow system to meet the objectives of this study. However, model results are a simulation of the system and the following model limitations should be considered:

1. In constructing a model to evaluate the ground-water flow system throughout the river valley, the study area was discretized into 2,000-ft by 2,000-ft cells. The model provides information to evaluate the flow system on a large scale. The model cannot accurately simulate water-level drawdown near individual pumping wells or be used to accurately simulate capture zones for individual wells; a model with a finer grid would be required for such detailed analysis.
2. Model input parameters, such as horizontal and vertical hydraulic conductivity and recharge rate, are applied at the node as an average value for the cell. The assumptions of uniformity for the entire cell introduces inaccuracies because of the heterogeneous nature of geologic materials and the variability of climatic conditions.
3. The steady-state model assumes that inflows to the ground-water system equal outflows. If this was not the case in February 1993, the change in ground-water storage would be a source of model error. For example, water levels could have been either rising or falling during the assumed equilibrium conditions.
4. Irrigation pumpage is not included in the steady-state model. Comparisons of simulated to measured water levels during the growing season is not possible unless a transient model is constructed using aquifer-storage terms with appropriate hydrologic input parameters. The ground-water system generally is not in equilibrium during the growing season as withdrawals from irrigation and evapotranspiration cause a change in ground-water storage.
5. During future simulations, if additional pumping centers are added to the model code or withdrawals at pumping centers are changed, model results can indicate the amount of drawdown or change in ground-water flow direction in relation to February 1993 conditions. This applies if the steady-state assumption is valid and model parameters, such as pumpage rates, river, slough, and drain stage, recharge rates, and general-head boundaries, have been revised appropriately.

Results of Simulation

The model calculates a ground-water level at the node of each 2,000-ft by 2,000-ft cell and a ground-water flux between cells from which a simulated water budget is computed. Ground-water flow directions derived from analysis of the computed ground-water levels and hydrologic sources and sinks quantified in the water budget assist in developing an improved understanding of the ground-water flow system.

A comparison of measured and simulated ground-water levels shows how accurately the results of the model simulate the ground-water system.There are 636 data points used in the computer preparation of the simulated potentiometric-surface map for the upper alluvium (fig. 15) compared to only 43 used in the manual construction of a potentiometric-surface map from water levels measured on February 26, 1993 (fig. 7). The potentiometric surface and general flow directions interpreted from water-level contours are similar for potentiometric-surface maps prepared from measured and simulated water levels. The influent nature of the streams entering the river valley from the adjacent upland areas are apparent in each case. A ground-water divide is apparent that is located between the Muscatine Slough and the cone of depression caused by the pumping centers. Flow is toward the drainage ditches in Illinois.

Differences between the potentiometric surface in the upper alluvium constructed from measured and simulated data are most apparent near the model boundaries, in the vicinity of the pumping centers, and in Illinois. Near model boundaries there are likely variations in hydraulic conductivity or recharge rates associated with the abrupt lithologic and topographic changes which the model cannot represent. The model calculates an average water level for the node of a pumping cell that can represent several pumping wells, so the water level is unlikely to compare favorably to a measured water level in an individual well. There is a lack of measured data available for Illinois, so the simulation produced a more detailed depiction of the potentiometric surface than is produced from the measured data.

An analysis of the steady-state model results was performed to determine the amount of drawdown that can be attributed to the pumping centers (February 1993 conditions) relative to conditions without pumping and the resulting effects on ground-water flow. A simulation using the calibrated model was run without pumping stresses (ground-water withdrawals), so that the computed water levels represented conditions without pumping. A subsequent simulation with the calibrated model, using the computed water levels from conditions without pumping as starting water levels for the simulation, resulted in a calculation of drawdown caused by the introduction of February 1993 pumping conditions. The simulated drawdown for the lower alluvium, from which pumpage occurs, shows the extent of the cumulative zone of influence of the pumping centers (fig. 18). As indicated by the line of 1-ft drawdown, the zone of influence extends beneath Muscatine Slough in the northwest part of the study area and beneath the Mississippi River in the central and northern parts of the area.

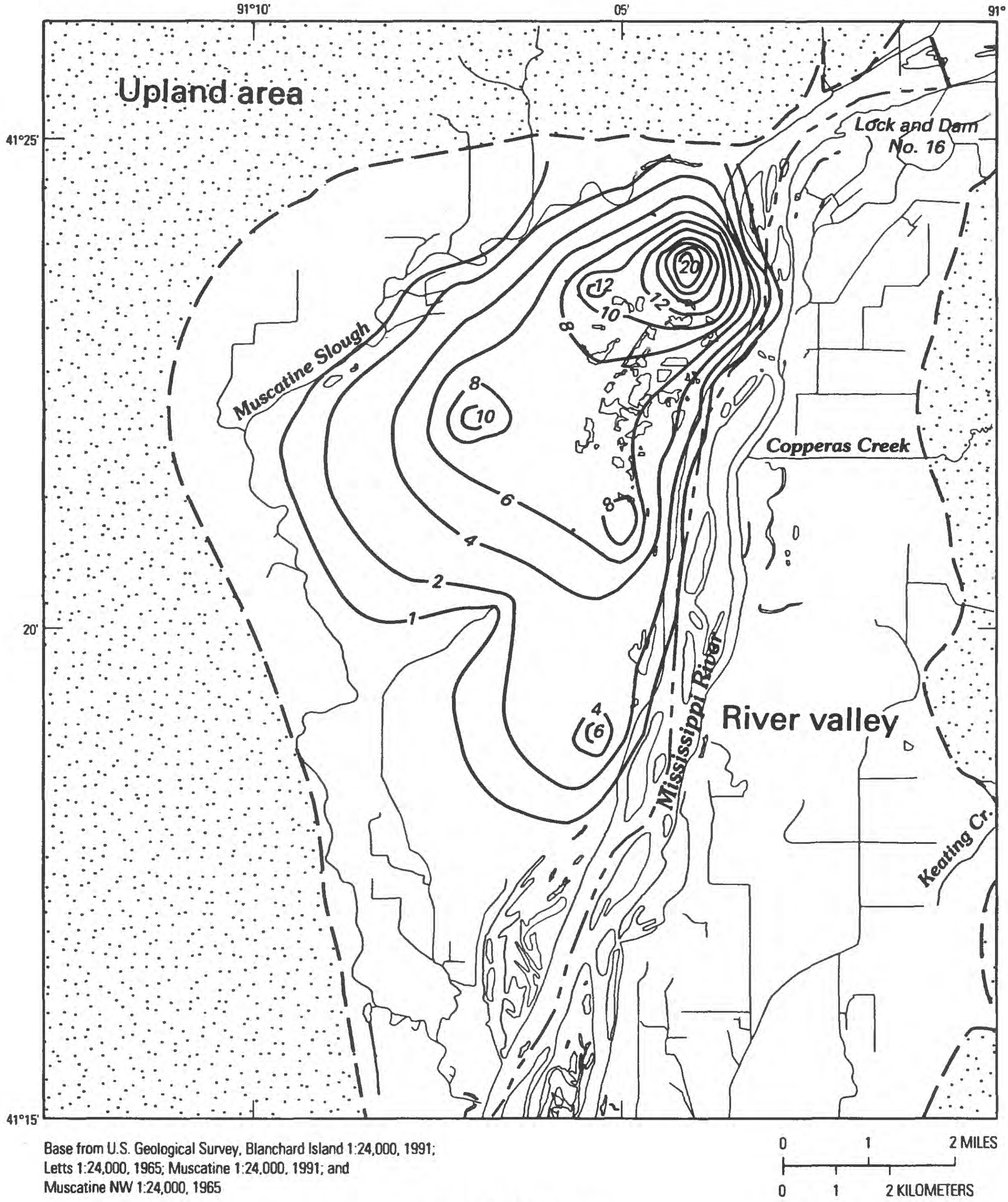
Sources of water recharging the alluvium under current pumping conditions can be identified from an analysis of the water budget (table 5). Under steady-state conditions, the model calculated 15,097,000 ft^3/d of inflow to the ground-water system and 15,113,000 ft^3/d of outflow from the system (table 5). There is a 0.11-percent discrepancy between the calculated inflow and outflow due to model error in approximating a solution to the mathematical equations.

The primary sources of inflow are recharge (infiltration of precipitation and upland runoff) and Mississippi River leakage (table 5). All of these sources enter the system through the upper alluvium. Recharge consists primarily of precipitation (48.3 percent), but upland runoff (11.5 percent) at the boundary between the river valley and the upland area is an important source of recharge. River leakage occurs primarily from the Mississippi River (35.8 percent) with minor amounts (1.6 percent) from Copperas Creek and Keating Creek in Illinois. Slough leakage, from Muscatine Slough and its associated drainage network, to the upper alluvium occurs where creeks enter the river valley in the northern reaches of the drainage network (cells 1,11,1; 4,10,1; and 1,9,1) and also results from a local downward gradient caused by the zone of influence from the pumping centers intercepting the slough in the northwest part of the area (cells 6,7,1 and 7,6,1). Upward leakage from the bedrock to the lower alluvium is calculated to be less than 0.1 percent of the total hydrologic budget (table 5). Based on the assumptions of the construction of this model, the bedrock is not a major contributor of ground water to the alluvium.

The primary components of outflow from the ground-water flow system are pumpage, flow to drainage ditches in Illinois (drain leakage), and slough leakage (table 5). Pumpage withdraws water from the lower alluvium, whereas drain and slough leakage leave the system from the upper alluvium. Flow across the general-head boundaries of the model, which primarily represents subsurface flow through the alluvium down the river valley, accounts for only 1.0 percent of the total.

Cell-by-cell flow data produced by the model can be combined to calculate ground-water flow between hydrologically important zones using ZONEBUDGET, a post-processing package (Harbaugh, 1990). The model was divided into three zones to quantify sources of ground water to the pumping centers in Iowa: (1) the zone west and north of Muscatine Slough from the slough to the boundary between the upland area and river valley; (2) the zone on the Illinois side of the Mississippi River from the center of the river channel east to the boundary between the upland area and river valley; and (3) the zone of active pumping on the Iowa side of the Mississippi River between Muscatine Slough and the river, which contains the pumping centers. Total inflow of 7,795,000 ft^3/d to the ground-water system in the zone of active pumping on the Iowa side of the river (zone 3) was simulated. The model calculated 10 percent of total inflow (781,000 ft^3/d) to zone 3 originates from zone 1 and that 5.2 percent of the inflow (402,700 ft^3/d) enters from zone 2 (fig. 19). This analysis indicates that significant sources of ground water occur beyond apparent natural hydrologic surface boundaries.

A steady-state model simulation was performed to quantify the ground-water flux between the three zones defined in the previous paragraph (fig. 19) under hypothetical conditions without ground-water withdrawals from the pumping centers (without pumping). By comparing these fluxes to those determined under assumed steady-state February 1993 conditions, an increase in the amount of ground water being diverted to the zone of active pumping on the Iowa side of the river (zone 3) can be estimated. The water-budget analysis for the simulation without pumping indicates that 25,100 ft^3/d, or 0.7 percent of inflow to the ground-water system that enters zone 3, originates from the zone west and north of Muscatine Slough (zone 1) and that 2,300 ft^3/d, or 0.1 percent of total inflow, originates from the zone on the Illinois side of



Base from U.S. Geological Survey, Blanchard Island 1:24,000, 1991;
Letts 1:24,000, 1965; Muscatine 1:24,000, 1991; and
Muscatine NW 1:24,000, 1965

EXPLANATION

— 2 — **Line of equal water-level drawdown—**
Interval, in feet, is variable

— — **Boundary between upland area and river valley**

Figure 18. Simulated drawdown in lower alluvium caused by pumping, February 1993.

Table 5. Simulated water budget under steady-state conditions

[Inflow, water being added to the ground-water system; ft^3/d, cubic feet per day; outflow, water being removed from the ground-water system; slough leakage, from or to Muscatine Slough and its associated drain network in Iowa; <, less than; pumpage, ground-water withdrawals by Grain Processing Corporation, Iowa-Illinois Gas and Electric Company, Monsanto Corporation, and Muscatine Power and Water; drain leakage, to the drain network in Illinois]

Budget component	Inflow (ft^3/d)	Percentage of total inflow	Outflow (ft^3/d)	Percentage of total outflow
Recharge—precipitation	7,295,000	48.3	0	0
Recharge—upland runoff	1,730,000	11.5	0	0
River leakage—Mississippi River	5,411,000	35.8	121,000	.8
River leakage—Copperas and Keating Creeks	236,000	1.6	291,000	1.9
Slough leakage	425,000	2.8	3,360,000	22.3
Upward leakage from bedrock or flow through alluvium	0[1]	< .1	155,000	1.0
Pumpage	0	0	6,091,000	40.3
Drain leakage	0	0	5,095,000	33.7
Total	**15,097,000**	**100.0**	**15,113,000**	**100.0**

[1] 5 ft^3/d.

the river (zone 2). Compared to the hypothetical conditions without pumping, an additional 755,900 ft^3/d are derived from zone 1, and an additional 400,400 ft^3/d are derived from zone 2 as a result of ground-water withdrawals at the pumping centers in Iowa under February 1993 steady-state conditions.

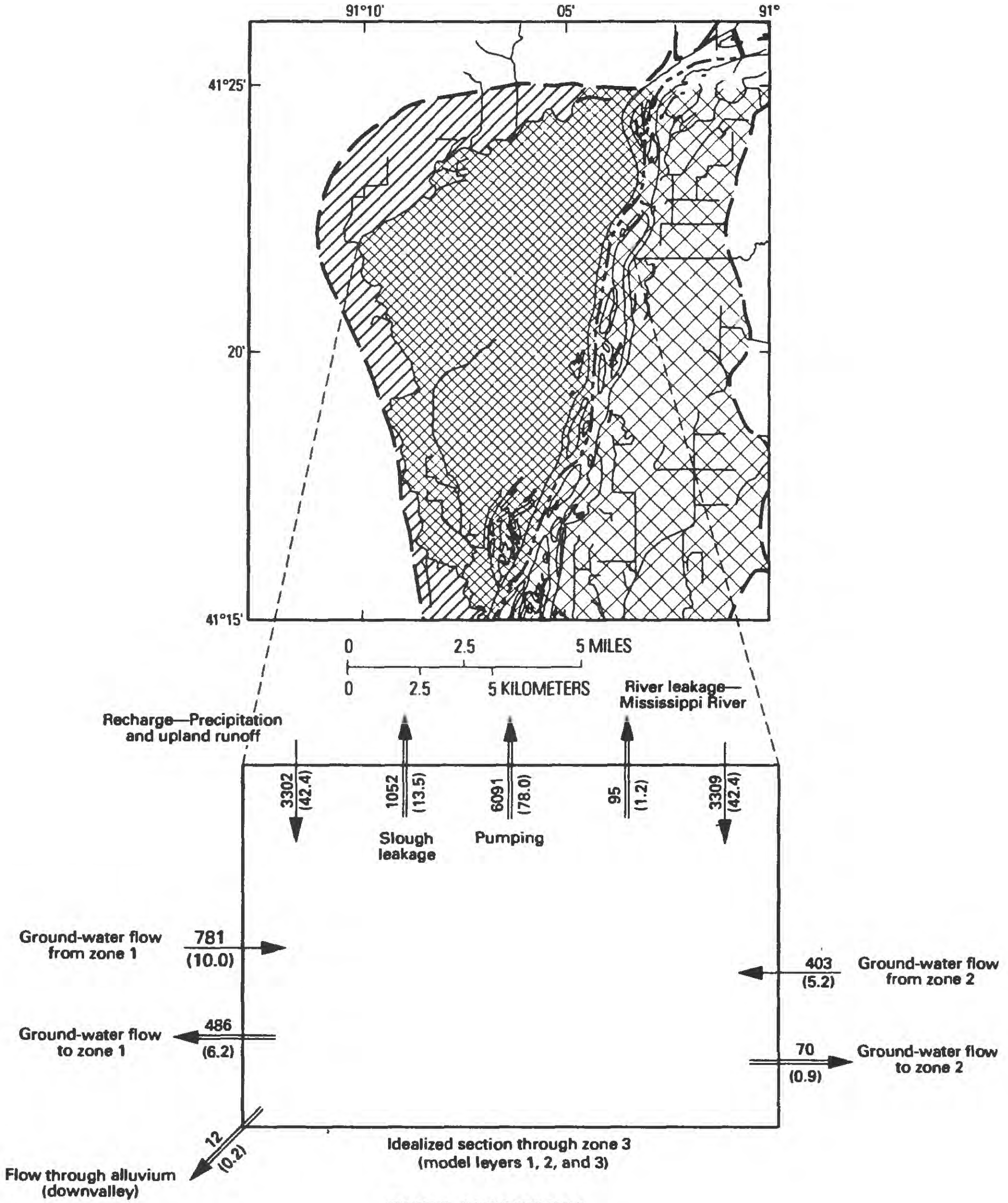
The process of quantifying fluxes from source areas can be useful in interpreting areal distributions or temporal variations in water quality. This information also can be used to identify areas of concern to be monitored for potential anthropogenic activities that could degrade water quality under different pumping scenarios.

WATER QUALITY

Physical properties and constituent concentrations for major ions, nutrients, trace metals, bromide, and boron in surface-water and ground-water samples collected from June 1992 through June 1994 are listed in table 6 at the end of this report. The data are listed by the local site identifier (see fig. 3 for location) and by the date on which the sample was collected. Results were examined for areal distribution and temporal variation, which can be used to assist in the interpretation of the ground-water flow system and to indicate susceptibility to potential degradation caused by human activity.

Analytical results for onsite QC blank samples verified the cleanliness of the sample-collection equipment, the sample-collection techniques, and the sample handling. Results for onsite QC replicate samples are shown in table 6 and generally indicate minimal variability, which verifies that sample-collection and handling procedures were appropriate. One exception is a replicate sample collected on September 2, 1993, at site 40A. The results for this QC sample are not comparable to the field sample, which indicates probable error in sample handling onsite or at the laboratory.

Water types can be distinguished by analyses of water-quality data using trilinear diagrams, which are constructed by expressing concentrations of major ions in milliequivalents per liter (meq/L) and subsequently calculating the percentage of major cations (calcium, magnesium, sodium, and potassium) and anions (bicarbonate, carbonate, sulfate, and chloride) (Hem, 1985). Characterizing differences and similarities of water types in the study area can be used to identify sources of recharge and to aid in the interpretation of ground-water flow.



EXPLANATION

▨ **Zone 1**—Zone west and north of Muscatine Slough from slough to boundary between the upland area and river valley

▩ **Zone 2**—Zone on the Illinois side of the Mississippi River from center of river channel east to boundary between the upland area and river valley

▦ **Zone 3**—Zone of active pumping on the Iowa side of the Mississippi River between Muscatine Slough and the river

— — **Boundary between upland area and river valley**

781 (10.0) → **Water-budget components of inflow to zone 3**—Numbers are volumes, in thousands of cubic feet per day and percentage of total inflow, in parentheses

70 (0.9) ⇒ **Water-budget components of outflow from zone 3**—Numbers are volumes, in thousands of cubic feet per day and percentage of total outflow, in parentheses

Figure 19. Simulated water-budget components for the zone of active pumping on the Iowa side of the Mississippi River.

Surface-Water Quality

Surface-water samples for constituent analyses were collected from the Mississippi River at Lock and Dam No. 16 (site 40A) and from three sites on Muscatine Slough (sites 36, 37, and 38, in downstream order). Water quality in the Mississippi River is representative of runoff from Illinois, Iowa, Minnesota, and Wisconsin, whereas water quality in the Muscatine Slough is representative of local conditions. General water chemistry is similar at these four sites, as trilinear diagram analyses indicate a calcium bicarbonate type water.

None of the constituents that were analyzed from samples collected at the four sites had concentrations exceeding the U.S. Environmental Protection Agency's (USEPA) Maximum Contaminant Level (MCL) for drinking water (U.S. Environmental Protection Agency, 1993). However, the Secondary Maximum Contaminant Level (SMCL) for manganese (50 µg/L, micrograms per liter) was exceeded in five samples collected at sites 36 and 37. A pH of 8.8 was measured on October 28, 1992, in the Mississippi River, which exceeded the SMCL range of 6.5–8.5 (table 6).

The areal distribution of surface-water quality in the study area was evaluated with samples collected at three sites on Muscatine Slough. Specific conductance decreases downstream during the summer, which reflects the effects of highly mineralized runoff from the upland area or highly mineralized ground-water flow from the area north and west of the slough in the northern reaches of the drainage system. Specific conductance decreases as less mineralized ground-water flow enters the slough in the southern reaches of the drainage system. However, during the winter there can be a downstream increase in specific conductance as indicated by samples collected on February 2, 1993 (table 6). Less mineralized runoff from snowmelt or precipitation on frozen ground in the upland area could account for smaller specific conductance in the northern reaches of the drainage system in winter.

Temporal variations are noteworthy for specific conductance (values ranged from 355 to 505 µS/cm, microsiemens per centimeter at 25 °C) and alkalinity (values ranged from 144 to 202 mg/L) in the Mississippi River (table 6). The smallest specific conductance and alkalinity occurred in samples collected October 28, 1992, whereas the largest values occurred in samples collected September 2, 1993, immediately after the flood in 1993 (Southard and others, 1994).

Other water-quality constituents demonstrating temporal variability in the Mississippi River include chloride and ammonia nitrogen. Large concentrations of the chloride ion probably indicate contamination because of its conservative geochemical properties and lack of significant natural sources. Chloride has been used as a natural tracer in a study of a near-surface hydrologic system in Iowa (Lucey, 1991). The variation and magnitude of chloride concentrations (15 and 23 mg/L) could indicate effects from waste disposal, urban runoff, or agricultural runoff. A maximum concentration for ammonia nitrogen (0.26 mg/L) was measured in a sample collected February 2, 1993, when there was minimal instream biological activity to alleviate anaerobic conditions (table 6).

The water quality upstream of site 36 on the Muscatine Slough shows extreme temporal variability. The largest (672 µS/cm) and smallest (336 µS/cm) specific-conductance values measured at the surface-water sites were obtained at site 36 on September 2, 1993, and on February 3, 1993, respectively. Calcium, magnesium, alkalinity, and sulfate concentrations also were small in the sample collected on February 3, 1993, whereas potassium, chloride, ammonia nitrogen, ammonia plus organic nitrogen, phosphorus, and orthophosphorus concentrations were large compared to other sample times (table 6). The decrease in calcium, magnesium, alkalinity, and sulfate concentrations indicate an influx of less-mineralized water, whereas the increase in potassium, chloride, and nutrient concentrations could indicate anthropogenic effects, such as waste disposal or agricultural chemicals. For example, runoff could transport agricultural chemicals from the upland area and river valley and become a major component of discharge in the northern part of the study area. The lack of biological activity and small discharge in the winter months would promote the development of anaerobic conditions after the sudden influx of nutrients, which would result in large concentrations of ammonia and orthophosphorus.

Ground-Water Quality

Ground-water samples were collected from 16 wells completed in the upper alluvium, 13 wells completed in the lower alluvium, one well completed in bedrock (site 34), and one well completed in a mixed lithology of glacial till at the boundary between the river valley and upland area (site 46A). The areal and vertical distribution and temporal variations of physical properties and constituent concentrations were evaluated.

Of the 13 wells completed in the lower alluvium, 7 are production wells (sites 44A, GPC18, GPC20, MPW13, MPW19, MPW23, MPW29), which do not provide representative samples from a discrete depth because of large pumping rates and large screened intervals open to the aquifer. The results of analyses for major ions and metals in samples from the wells completed in the lower alluvium drilled by the mud-rotary method (sites 13C, 46C, 48D) indicate effects of the drilling fluid, so the water-quality data for these wells are not representative of the ground water. Initially large sodium concentrations decreased through time, which indicates that later samples may approach ambient water-quality conditions (table 6).

There are predominantly two water types in the ground-water system—a calcium bicarbonate type water in samples from the upper and lower alluvium and a sodium sulfate type water in samples from the well completed in bedrock. Analyses using trilinear diagrams did not indicate occurrence of water types in the lower alluvium with geochemical characteristics intermediate between the two predominant water types, which supports the concept that there is minimal upward ground-water leakage from the bedrock to the alluvium.

A calcium sulfate type water occurs locally in the upper alluvium at sites 13A and 51A near Muscatine Slough and adjacent to the upland area in the west-central part of the study area (fig. 3). The existence of this different water type could result from human activity or lithology differences. A sodium chloride type water occurs locally at site 26, which indicates possible contamination from human activity.

USEPA's MCL for nitrite-plus-nitrate as nitrogen and the SMCL for manganese and iron were exceeded in some of the samples collected during the study. Concentrations of nitrite-plus-nitrate nitrogen equalled or exceeded 10 mg/L in samples collected from five wells—sites 7B, 13A, 25, 26, and 32. The SMCLs for manganese (50 μg/L) and iron (300 μg/L) were exceeded in samples collected from a total of 19 and 14 wells, respectively. The SMCLs for sulfate (250 mg/L) and chloride (250 mg/L) were exceeded in samples collected from the well completed in bedrock, site 34 (table 6).

Areal Distribution

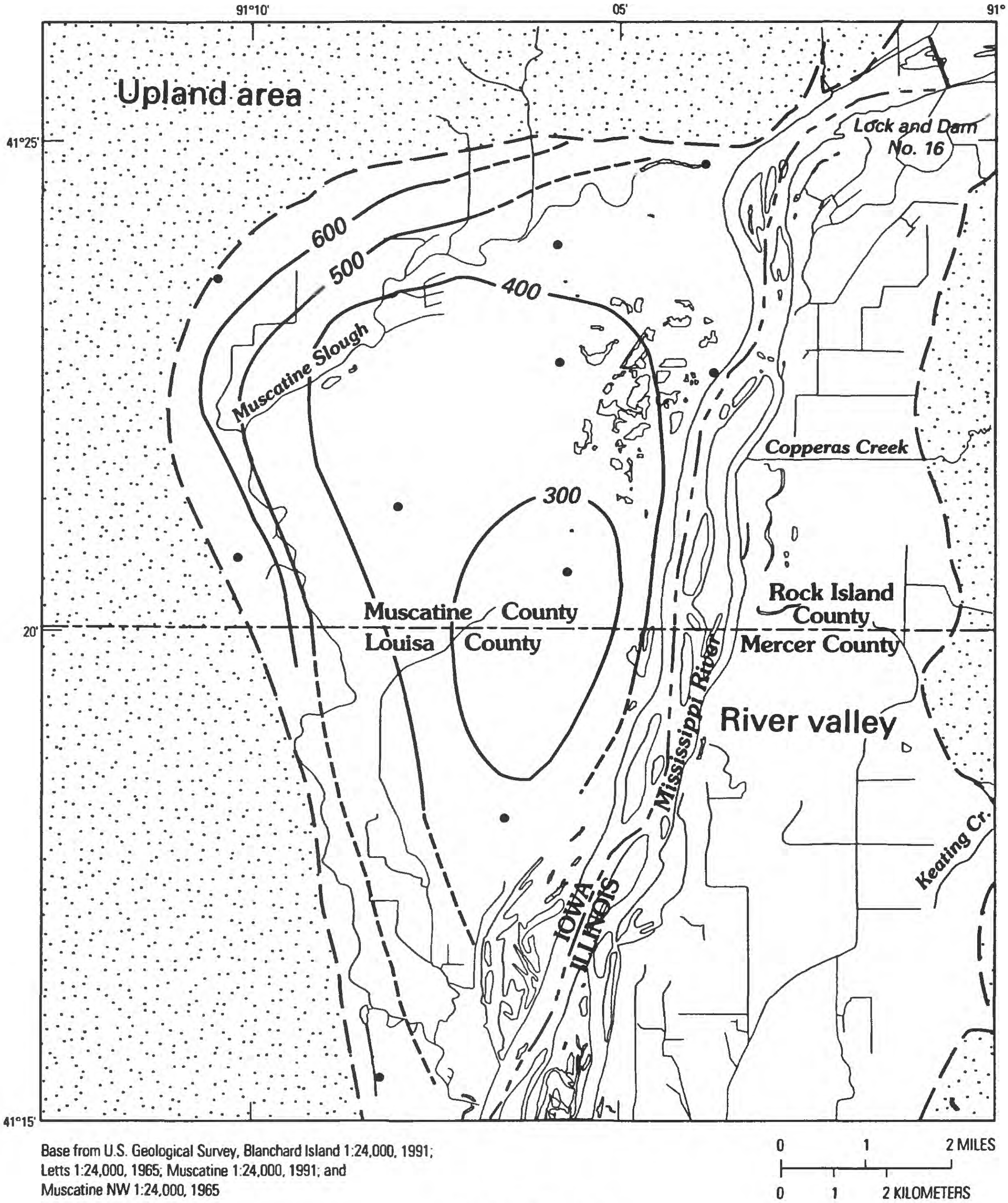
The areal distribution of selected water-quality properties and constituent concentrations results from the various sources of recharge to the ground-water system. In addition, the distribution can be affected by differences in lithologies, human activities, presence of organic carbon, and geochemical processes.

Specific conductance in samples collected from wells completed in the upper alluvium generally decrease from north to south and west to east on the Iowa side of the Mississippi River Valley (fig. 20). This distribution indicates that infiltration of runoff from upland areas or lithologic differences in the alluvium adjacent to the upland areas may cause an increase in dissolved ion concentrations. There are similar areal distributions for calcium, magnesium, and sulfate concentrations.

The most likely sources of the variations in chloride concentrations in the study area are the Mississippi River and contamination from human activities, such as agricultural chemicals, waste disposal, and road deicers. Chloride concentrations in alluvial ground water that are greater than the range measured in samples from the river (15 to 23 mg/L) could be indicative of contamination. Large chloride concentrations were measured in samples collected at sites 7B, 25, 26, 51A, ILL5, and GPC 20 (table 6).

The occurrence of nitrogen in ground water is affected by human activities, including nitrogen fertilizers, sewage effluents, animal manure, and municipal wastes (Chappelle, 1993). Nitrate (NO_3) is the predominate form of nitrogen under aerobic conditions. Accumulation of nitrate in ground water is dependent on a source of nitrate and the presence or absence of oxygen and organic carbon. Denitrification, the process converting nitrate to nitrogen gas (N_2), occurs under anaerobic conditions with the presence of organic material being a limiting factor. Nitrite (NO_2) is an unstable form of nitrogen as it is an intermediate step in denitrification and in its counterpart, nitrification, where ammonia (NH_3) is oxidized to nitrate (Chappelle, 1993). Studies have shown that large nitrate concentrations in ground water can be correlated with application of nitrogen fertilizers on coarse-textured, well-drained soils (Chappelle, 1993).

Nitrite-plus-nitrate nitrogen concentrations in ground water collected during February 1993 from the upper alluvium are largest in the area on the Iowa side of the Mississippi River with sandy (well-drained) soils (fig. 21). Concentrations decrease at sites near the

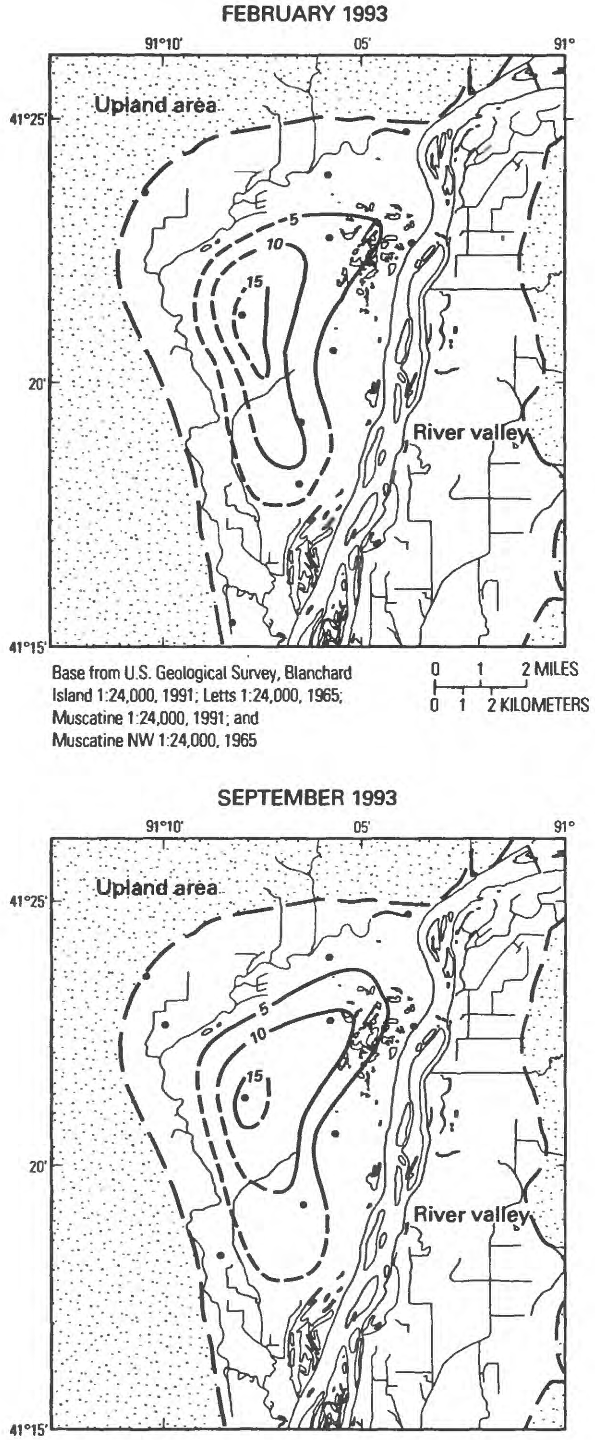


Base from U.S. Geological Survey, Blanchard Island 1:24,000, 1991; Letts 1:24,000, 1965; Muscatine 1:24,000, 1991; and Muscatine NW 1:24,000, 1965

EXPLANATION

—300— —	**Line of equal specific conductance**—Dashed where approximately located. Interval 100 microsiemens per centimeter at 25 degrees Celsius
— —	**Boundary between upland area and river valley**
●	**Ground-water sampling site**

Figure 20. Areal distribution of specific conductance in water from upper alluvium, February 1993.



Base from U.S. Geological Survey, Blanchard Island 1:24,000, 1991; Letts 1:24,000, 1965; Muscatine 1:24,000, 1991; and Muscatine NW 1:24,000, 1965

EXPLANATION

—*10*— — **Line of equal nitrite-plus-nitrate nitrogen concentration**—Dashed where approximately located. Interval 5 milligrams per liter

— — **Boundary between upland area and river valley**

• **Ground-water sampling site**

Figure 21. Areal distribution of nitrite-plus-nitrate nitrogen, upper alluvium, February and September 1993.

Mississippi River and Muscatine Slough (fig. 21) and with depth (table 6), indicating denitrification or a lack of a nitrogen source.

Geochemical processes and presence of dissolved organic carbon affect the distribution of dissolved iron and manganese in the study area. The presence of dissolved organic carbon in the alluvium produces a reducing environment favorable to iron- and manganese-reducing microorganisms and results in the dissolution of iron and manganese oxides on grain coatings. Dissolved iron and manganese can accumulate in ground water in the absence of dissolved oxygen (Chapelle, 1993). A degradation in water quality caused by an increase in iron and manganese concentrations has been documented as river water infiltrates through the river bottom into an adjacent alluvial aquifer (Bourg and Bertin, 1994). Although not toxic, large iron and manganese concentrations in alluvial aquifers are a common water-quality problem that affects taste, odor, and color, and causes staining and corrosion (Bourg and Bertin, 1993). Large iron or manganese concentrations occur in the upper and lower alluvium near the Mississippi River (sites 44A, 55, 56, GPC20, ILL5, MPW13, and MPW19), near the boundary between the river valley and the upland area and near Muscatine Slough (sites 41, 46C, 48A, 48D, 49, 50A, 50B, 51A, and 51B), and at site 30 located about 6,000 ft west of the Mississippi River. Large manganese concentrations occur in glacial till near the boundary between the river valley and the upland area (site 46A) (table 6).

Large concentrations of selected trace metals occur locally and could be indicative of contamination by human activity or result from various lithologies and geochemical processes. Large molybdenum concentrations in ground water from the lower alluvium at sites 13C, 46C, and 48D probably are caused by effects from drilling mud. Large zinc concentrations occur at sites 7B, 30, 55, and ILL5 (table 6). The observation well at site 7B is constructed of steel pipe, which could account for the zinc, but the other three wells are constructed of PVC pipe (table 2). Chromium (sites 30, 41, 48A, and 49) and mercury (sites 13C, 26, and ILL5) concentrations that are greater than the analytical reporting level occur in ground water from the upper alluvium.

Temporal Variation

The permeable characteristics of the alluvium allow periodic inputs of water to have potentially rapid effects on water quality. Variations of concentrations of selected water-quality constituents in the ground-water samples collected at several wells attest to the dynamic nature of the ground-water system as it responds to natural and human-induced changes in water quality.

Temporal variations in specific conductance and chloride concentrations at sites 7B, 26, 51A, and ILL5 could result from a change in the source of the dissolved ions or from local dilution by recharge. For example, chloride concentrations at site 7B varied from 3.2 to 72 mg/L during the sampling period (table 6). The smaller concentrations occurred after the flood in 1993.

The area of the upper alluvium containing ground water with nitrite-plus-nitrate nitrogen concentrations greater than 5 and 10 mg/L extended farther north and east in September 1993 than in February 1993 (fig. 21). Possible causes include development of more aerobic conditions in the aquifer causing increased nitrification, greater inputs of nitrogen to the system as precipitation infiltrates to the water table, or changes in land use or human activities as a result of 1993 recharge, such as more cultivated acres or more nitrogen fertilizer applied.

The movement of water from the upper alluvium to the lower alluvium in the southern part of the study area can be shown with chloride and nitrite-plus-nitrate nitrogen concentration data (fig. 22). Chloride concentrations in samples collected at site 32 (upper alluvium) decreased from more than 20 to less than 10 mg/L during the sampling period, whereas chloride concentrations in samples collected at site 33 (lower alluvium) increased abruptly from less than 5 mg/L in September 1993 to more than 20 mg/L in December 1993 (fig. 22). Recharge to the system during the flood of 1993 caused a decrease in the chloride concentration in the ground water in the upper alluvium. The large chloride and nitrite-plus-nitrate nitrogen concentrations measured in the December 1993 sample collected from site 33 are similar to concentrations measured in the February 1993 sample from site 32. Although the samples collected from sites 32 and 33 do not represent the same ground-water flow path, the abrupt change in chloride and nitrite-plus-nitrate nitrogen concentrations in the December 1993 sample collected from site 33 may reflect downward movement of ground water from the upper alluvium to the lower alluvium in the general area. The concentration data

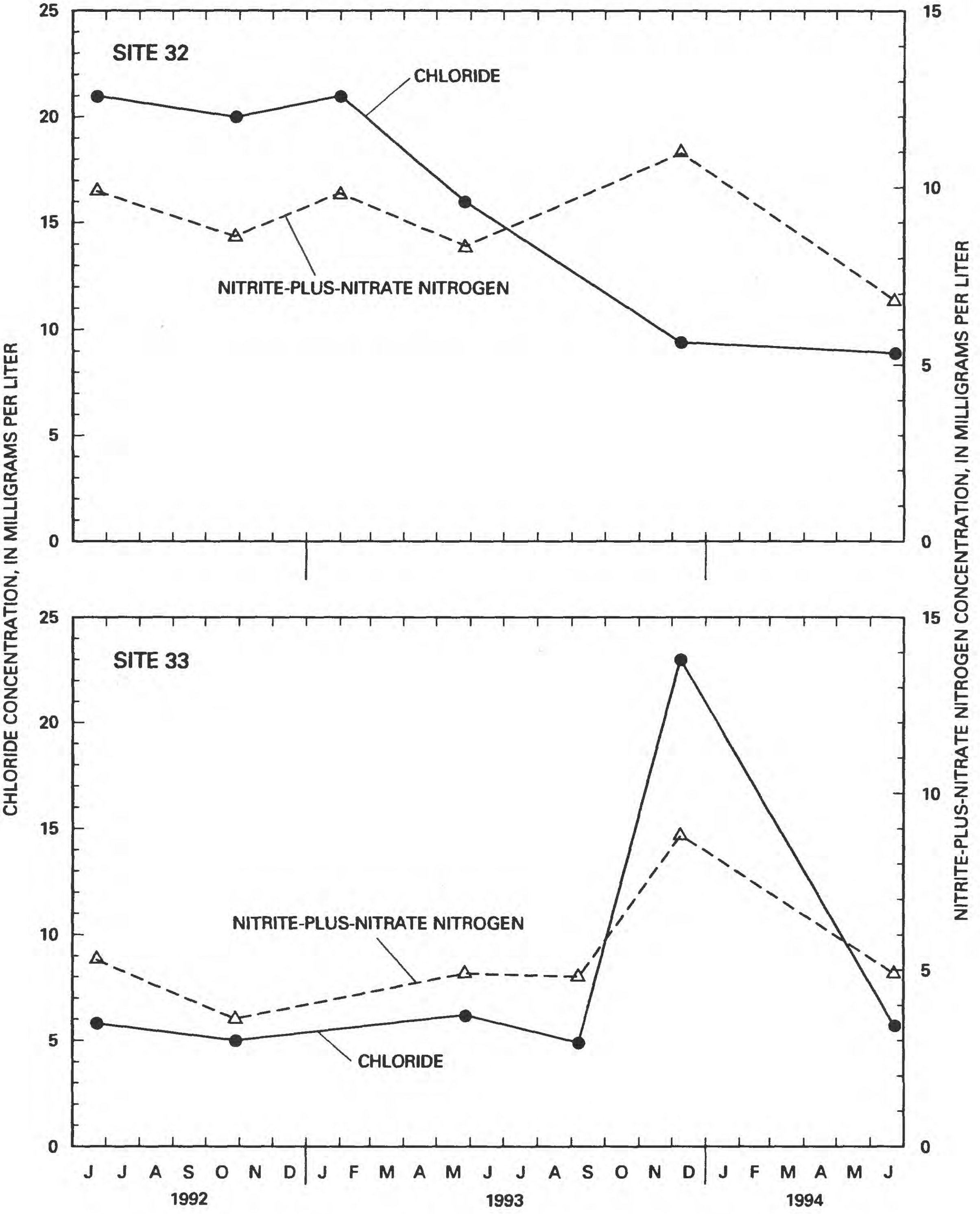


Figure 22. Chloride and nitrite-plus-nitrate nitrogen concentrations in samples from site 32 (upper alluvium) and site 33 (lower alluivium), June 1992–June 1994.

indicate that it may have taken 10 months for the water to move from the upper alluvium to the lower alluvium. Because the horizontal flow component is dominant over the vertical flow component, the flow path represented by the deeper sample originated at some unknown lateral distance from site 33.

The dynamics of the ground-water flow system and its geochemistry are revealed by the similarities in the chloride and nitrite-plus-nitrate nitrogen results from the September 1993 and June 1994 samples collected at site 33 (fig. 22). Water quality in the lower alluvium rapidly returned to conditions prevalent prior to the flood in 1993.

Nitrite-plus-nitrate concentrations in samples collected from site 33 ranged from 3.6 to 8.8 mg/L during the sampling period. The persistence of large nitrate concentrations could indicate the absence of organic carbon in the lower alluvium. Alternatively, the ground water from the upper alluvium that moves downward into the lower alluvium contains enough dissolved oxygen to limit the denitrification process.

A large concentration of iron and manganese occurred in a sample collected on December 9, 1993 at site 30. The area in the vicinity of site 30 was flooded for an extended period of time during the summer of 1993. This could result in the development of anaerobic conditions in the ground water and subsequent mobilization of iron and manganese.

WATER-QUALITY IMPLICATIONS OF SOURCES OF RECHARGE TO ALLUVIUM

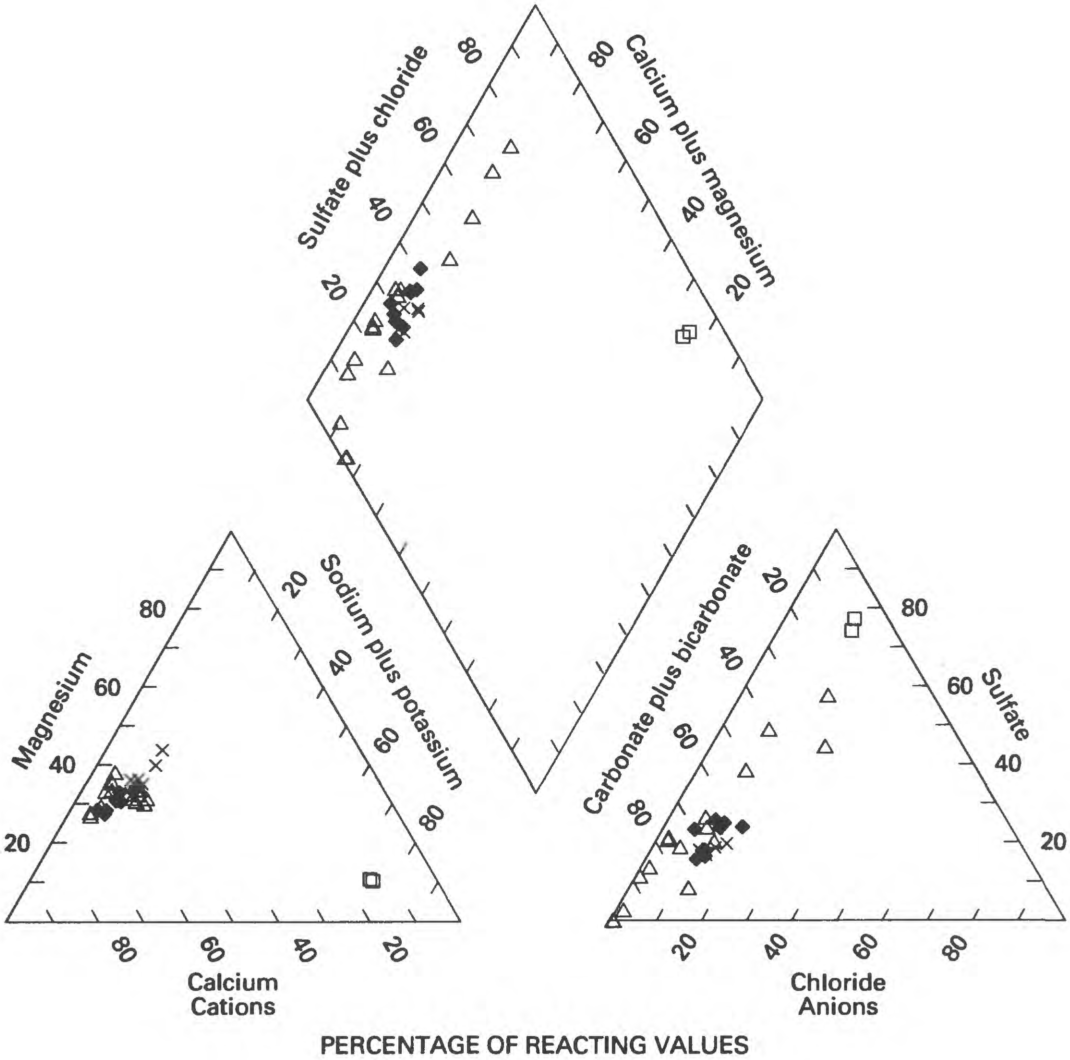
Precipitation is the major source of recharge to the alluvium in the study area, but samples to characterize quality of precipitation were not collected as part of this study. Precipitation-chemistry data are available from the National Atmospheric Deposition Program/National Trends Network (NADP/NTN) and can be used, in a general sense, to evaluate the effects of precipitation on ground-water quality. The NADP/NTN maintains long-term precipitation monitoring stations in 47 States to study geographical patterns and temporal trends in the chemical climate of the atmosphere (National Atmospheric Deposition Program, 1994). The nearest NADP/NTN station to the study area is located 42 mi to the southeast in Monmouth, Illinois (fig. 1).

The mean concentrations of selected constituents determined from 45 precipitation samples collected during 1993 at the NADP/NTN Monmouth station were calcium, 0.22 mg/L; chloride, 0.21 mg/L; sulfate, 2.25 mg/L; and nitrate, 2.00 mg/L (National Atmospheric Deposition Program, 1994). The concentration of major ions and nitrate in precipitation are much smaller than characteristically are found in ground water in the study area. Precipitation that percolates to the water table would tend to dilute the shallow ground water, thus decreasing concentrations of most dissolved ions.

Leakage from the Mississippi River is the second largest source of recharge to the alluvium. The water quality of the river has a major effect on the quality of ground water in the alluvium adjacent to the river. The similarities in water chemistry of the river and water withdrawn at the pumping centers is illustrated on a trilinear diagram (fig. 23). Variations in water quality of the Mississippi River, caused by seasonality or discharge, were documented from samples collected during this study. Upstream human activities also can affect water quality of the river. Large iron and manganese concentrations caused by geochemical processes in the river bottom also are characteristic of ground water near the river (Bourg and Bertin, 1993).

Runoff from streams draining upland areas is an important source of recharge to the alluvium at the boundary between the river valley and upland areas. Samples to characterize the water quality of this runoff were not collected during this study, but the possible effects of this runoff on ground-water quality can be inferred from the areal distribution of chemical constituents in the ground water. The amount of dissolved ions in solution is larger near the boundary between the river valley and upland area (fig. 20). This fact indicates either that infiltrating runoff contains large concentrations of dissolved ions or that different lithologies and geochemical processes occur in the alluvium near the boundary. Large concentrations of iron and manganese occur in the ground water near the boundary; these concentrations may be caused by the presence of organic material that is transported downward from the ground surface by infiltrating water or by the presence of organic material that was incorporated into the alluvium and glacial till during deposition.

Muscatine Slough is a minor source of recharge to the alluvium in limited reaches in the northern part of the study area. Concentrations of major ions and nutrients in Muscatine Slough are subject to seasonal variability and can affect water quality in the adjacent



EXPLANATION

Sample from

- □ **Bedrock**—Site 34
- ◆ **Pumping centers**—Sites 44A, GPC18, GPC20, MPW13, MPW23, MPW29
- × **Mississippi River**—Site 40A
- △ **Near boundary between river valley and upland area**—Sites 46A, 48A, 49, 50A, 50B, 51A, 51B, 56, 58

Figure 23. Trilinear diagram showing water-quality data from selected sampling sites, June 1992–June 1994.

aquifer. Large iron and manganese concentrations occur in the ground water near the slough. Increased pumpage from the alluvium could increase the downward gradient beneath Muscatine Slough and cause larger amounts of surface water to enter the ground-water system.

Upward leakage of ground water from the bedrock is a minor component of recharge to the alluvium. The sodium sulfate water in the bedrock (site 34), which may or may not be representative of the bedrock water throughout the study area, is less suitable for the intended use compared to the calcium bicarbonate water in the alluvium (fig. 23). Localized fractures in the bedrock that enhance hydraulic conductivity could provide conduits for highly mineralized water to enter the alluvium.

The quality of ground water induced from discrete zones of the alluvium by the pumping centers in Iowa has implications for the entire ground-water resource. Larger concentrations of carbonate or sulfate ions are characteristic of ground-water samples from the alluvium near the boundary between the river valley and upland area (sites 46A, 48A, 49, 50A, 51A, 51B, 56, and 58) compared to ground-water samples withdrawn at the pumping centers (sites 44A, GPC18, GPC 20, MPW13, MPW19, MPW23, MPW29) or to surface-water samples from the Mississippi River (site 40A, fig. 22). Results of the ground-water model indicate that 10 percent of the inflow to the zone of active pumping on the Iowa side of the river (zone 3, fig. 19) originates from the zone west and north of Muscatine Slough (zone 1, fig. 19) under February 1993 conditions. Increased pumpage could increase the contribution from this zone depending on the location of the additional pumpage. The model calculated that 5.2 percent of the inflow to zone 3 originates from the zone on the Illinois side of the Mississippi River from the center of the river channel east to the boundary between the upland area and river valley (zone 2, fig. 19). The extent of drawdown caused by February 1993 pumping and the limited water-quality information for the alluvium in Illinois (site ILL5) indicate the importance of considering past, current, and future land-use activities in these zones when evaluating the effects of sources of ground water for the pumping centers located in the northern part of the study area under different pumping scenarios.

SUMMARY

The sand and gravel deposits of the Mississippi River alluvium in Muscatine and Louisa Counties, Iowa, have been a dependable source of ground water that generally is suitable for municipal, industrial, and agricultural uses. Continued development of the resource has renewed concerns about water-table declines and potential deterioration in water quality. Hydrologic and geologic data were collected from June 1992 through June 1994 to study ground-water flow, sources of recharge, and water quality in the alluvium. This study was a cooperative effort between Muscatine Power and Water, Muscatine, Iowa, and the U.S. Geological Survey.

The study area covers approximately 80 mi^2 in parts of Muscatine and Louisa Counties in Iowa and Rock Island and Mercer Counties in Illinois. Land use is predominantly agricultural with areas of municipal and industrial development in Iowa. The pumping centers are located in Iowa, primarily near the Mississippi River.

A large difference in the water-yielding characteristics between the very permeable alluvium and the relatively impermeable bedrock and glacial till indicates that most of the water in the ground-water system occurs in the alluvium. There is effective hydraulic connection between the alluvium and the bedrock with small vertical head differences. Hydraulic conductivity in the alluvium generally decreases from north to south with decreasing grain size of the alluvial materials.

A steady-state, ground-water flow model was constructed using February 1993 hydrologic conditions as an aid to an improved understanding of the flow system and to quantify sources of ground water. Three model layers are used to represent the bedrock, the lower alluvium, and the upper alluvium. A 30-row by 24-column grid was used to discretize the layers into a series of 2,000-ft by 2,000-ft cells. A uniform horizontal hydraulic conductivity of 0.001 ft/d was used in the model layer representing the bedrock. Horizontal hydraulic conductivities for the upper and lower alluvium ranged from 150 to 600 ft/d.

An analysis of the steady-state model results was performed to determine the amount of water-level drawdown that can be attributed to the pumping centers for February 1993 conditions. As indicated by the line of 1-ft drawdown in the lower alluvium, the zone of influence extends beneath the Muscatine Slough in the northwest part of the study area and beneath the Mississippi River in the central and northern parts of the area.

The primary sources of inflow to the alluvial ground-water system are, in order of decreasing magnitude, infiltration of precipitation, leakage from the Mississippi River, and infiltration of upland runoff at the boundary between the river valley and the upland area. On the basis of model assumptions, the bedrock is not a major contributor of ground water to the alluvium.

Physical properties and concentrations for major ions, nutrients, trace metals, bromide, and boron were determined for surface-water and ground-water samples collected from June 1992 through June 1994. Samples were collected on a quarterly basis from the Mississippi River, Muscatine Slough, and observation wells completed in the upper and lower alluvium.

Temporal variation in water quality is noteworthy for surface-water samples. Water-quality constituents that demonstrate temporal variability in the Mississippi River include specific conductance, alkalinity, chloride, and ammonia nitrogen. A decrease in calcium, magnesium, alkalinity, specific conductance, and sulfate concentrations in the sample collected from Muscatine Slough at site 36 on February 2, 1993, compared to previous samples indicates an influx of less-mineralized water, whereas an increase in potassium, chloride, and nutrient concentrations indicate possible anthropogenic effects, such as waste disposal or agricultural chemicals.

There are predominantly two water types in the ground-water system—a calcium bicarbonate type water in samples from the upper and lower alluvium and a sodium sulfate type water in samples from the well completed in bedrock. A calcium sulfate type water occurs locally in the upper alluvium at sites 13A and 51A in the west-central part of the study area, which could result from human activity or lithology differences. A sodium chloride type water occurs locally at site 26, which indicates possible contamination from human activity.

Specific conductance in samples collected from wells completed in the upper alluvium generally decrease from north to south and west to east on the Iowa side of the Mississippi River Valley. This areal distribution indicates that infiltration of runoff from upland areas or lithologic differences in the alluvium adjacent to the upland areas may cause an increase in dissolved ion concentrations. There are similar areal distributions for calcium, magnesium, and sulfate concentrations.

The areal distribution of some water-quality constituents in ground water indicates effects from human activity and microbial processes. Localized large chloride concentrations were measured in samples collected at sites 7B, 25, 26, 51A, ILL5, and GPC 20. Nitrite-plus-nitrate nitrogen concentrations in ground water in samples collected from the upper alluvium generally are largest in the agricultural region with sandy (well-drained) soils on the Iowa side of the Mississippi River. Large iron or manganese concentrations occur in the upper and lower alluvium near the Mississippi River, near the boundary between the river valley and the upland area and near Muscatine Slough, and at site 30 located about 6,000 ft west of the Mississippi River, and result from microbial processes and the presence of dissolved organic carbon.

Temporal variations of concentrations of selected water-quality constituents in the ground-water samples collected at several wells attest to the dynamic nature of the ground-water system as it responds to natural and human-induced changes in water quality. Temporal variations in specific conductance and chloride concentrations at sites 7B, 26, 51A, and ILL5 could result from a change in the source of dissolved ions or local dilution by recharge.

Precipitation is the major source of recharge to the alluvium. The mean concentration of major ions and nitrate in precipitation are much smaller than characteristically are found in ground water in the study area. Precipitation that percolates to the water table would tend to dilute the shallow ground water, thus decreasing concentrations of most dissolved ions.

Leakage from the Mississippi River is the second largest source of recharge to the alluvium and has a major effect on ground-water quality in the alluvium adjacent to the river. Variations in water quality of the Mississippi River, caused by seasonality or discharge, were documented from samples collected during this study. Upstream human activities also can affect water quality.

Runoff from streams draining upland areas is an important source of recharge to the alluvium. The amount of dissolved ions in ground water is larger near the boundary between the river valley and upland area, which indicates that infiltrating runoff contains large concentrations of dissolved ions or that there are differences in lithologies or geochemical processes in the alluvium near this boundary.

Muscatine Slough is a minor source of recharge to the alluvium. Concentrations of major ions and nutrients in Muscatine Slough are subject to seasonal variability and can affect water quality in the adjacent aquifer. Increased pumpage from the alluvium could increase the downward gradient beneath Muscatine Slough.

Upward leakage of ground water from the bedrock is a minor component of recharge to the alluvium. The sodium sulfate water, which may not be representative of bedrock water throughout the study area, is less suitable for most uses compared to the calcium bicarbonate water in the alluvium. Localized fractures in the bedrock that enhance hydraulic conductivity could provide conduits for the highly mineralized water to enter the alluvium.

The quality of ground water induced from discrete zones of the alluvium by the pumping centers in Iowa has implications for the entire ground-water resource. Results of the ground-water model indicate that 10 percent of the inflow to the zone of active pumping on the Iowa side of the river originates from the zone west and north of Muscatine Slough under February 1993 conditions. Increased pumpage could increase the contribution from this zone depending on the location of the additional pumpage. The model calculated that 5.2 percent of the inflow to the zone of active pumping originates from the zone on the Illinois side of the Mississippi River from the center of the river channel east to the boundary between the upland area and river valley. The extent of drawdown caused by February 1993 pumping and the limited water-quality information for the alluvium in Illinois indicate the importance of considering past, current, and future land-use activities in these zones when evaluating the effects of sources of ground water for the pumping centers located in the northern part of the study area.

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SUPPLEMENTAL INFORMATION

Table 6. Physical properties and constituent concentrations in surface-water and ground-water samples, June 1992–June 1994, near Muscatine, Iowa

[LocalID, local site identifier; μS/cm, microsiemens per centimeter at 25 degrees Celsius; C, degrees Celsius; mg/L, milligrams per liter; --, no data; dis, dissolved; μg/L, micrograms per liter; <, less than the analytical method reporting limit]

LocalID (fig. 3)	Station number	Date (month-day-year)	Specific conductance (μS/cm)	pH, water whole, field (standard units)	Temperature, water (°C)	Calcium, dissolved (mg/L as Ca)	Magnesium, dissolved (mg/L as Mg)	Sodium, dissolved (mg/L as Na)	Potassium, dissolved (mg/L as K)	Alkalinity, laboratory (mg/L as $CaCO_3$)
7B	412242091055002	07-01-92	301	7.6	16.0	35	11	9.0	1.0	72
		11-02-92	470	8.1	14.0	44	12	44	1.7	119
		02-02-93	351	7.9	11.0	42	13	12	1.3	100
		05-25-93	509	7.4	13.0	41	13	43	1.7	117
		09-03-93	308	7.8	14.0	35	12	7.1	1.3	74
		12-06-93	220	8.3	11.0	28	10	2.7	.80	73
		12-06-93[2]	220	8.3	11.0	28	10	2.7	.80	74
		06-21-94	346	7.9	11.0	42	15	2.9	.90	83
13A	412120091080401	07-01-92	302	7.1	15.0	38	8.8	3.7	1.3	23
		10-29-92	342	7.7	14.0	40	9.7	3.7	1.4	32
		02-02-93	340	7.3	12.0	42	11	4.1	1.4	26
		05-26-93	389	7.4	13.0	43	12	5.0	1.4	41
		09-07-93	374	7.4	12.5	43	12	9.7	1.7	47
		12-09-93	240	7.8	13.0	30	7.5	2.7	1.7	36
		06-21-94	140	7.4	11.0	16	3.9	1.7	1.0	25
		06-21-94[2]	--	--	--	16	4.0	1.7	1.0	25
13C	412120091080403	10-29-92	390	8.8	14.0	17	5.3	55	1.7	72
		02-02-93	338	8.6	12.5	22	7.2	38	1.5	79
		05-26-93	333	8.2	15.0	21	6.7	32	1.5	78
		09-07-93	290	8.2	14.5	29	9.1	18	1.3	87
		12-09-93	287	8.3	13.0	30	9.6	17	1.4	99
		06-21-94	275	8.1	13.0	25	7.5	7.9	1.2	66
25	411915091072901	06-22-92	319	7.4	13.0	37	12	3.3	.80	29
26	411905091063301	10-28-92	388	8.4	13.0	23	6.3	43	4.0	72
		05-26-93	375	7.3	12.5	21	6.0	38	4.0	70
		09-07-93	407	7.6	13.5	30	8.3	39	5.0	66
		12-09-93	474	8.1	13.0	39	11	36	5.9	60
		06-23-94	418	7.6	8.5	34	9.9	28	5.2	55
30	412040091054701	06-22-92	307	7.1	13.0	42	14	2.6	.70	158
		11-02-92	299	7.3	13.0	40	13	2.7	.80	145

Table 6. Physical properties and constituent concentrations in surface-water and ground-water samples, June 1992–June 1994, near Muscatine, Iowa—Continued

LocalID (fig. 3)	Station number	Date (month-day-year)	Sulfate, dissolved (mg/L as SO_4)	Chloride, dissolved (mg/L as Cl)	Fluoride, dissolved (mg/L as F)	Bromide, dissolved (mg/L as Br)	Nitrogen, nitrite, dissolved (mg/L as N)	Nitrogen, NO_2+NO_3, dissolved (mg/L as N)	Nitrogen, ammonia, dissolved (mg/L as N)	Nitrogen, ammonia + organic, dissolved (mg/L as N)
7B	412242091055002	07-01-92	42	7.7	< 0.1	0.02	< 0.01	9.3	0.07	< 0.20
		11-02-92	35	56	< .1	.03	.01	8.0	.04	< .20
		02-02-93	31	20	< .1	--	.01	8.1	.08	< .20
		05-25-93	24	72	< .1	--	< .01	6.8	.07	< .20
		09-03-93	33	8.5	< .1	.04	< .01	12	.11	< .20
		12-06-93	26	3.2	< .1	.03	< .01	5.1	.06	< .20
		12-06-93[2]	26	3.4	< .1	.03	< .01	5.1	.06	< .20
		06-21-94	23	14	< .1	.04	< .01	14	.07	< .20
13A	412120091080401	07-01-92	36	14	< .1	.04	.01	19	.04	< .20
		10-29-92	36	15	< .1	.05	< .01	18	.02	< .20
		02-02-93	48	14	< .1	--	.02	19	.01	< .20
		05-26-93	52	15	< .1	--	.19	17	.24	.30
		09-07-93	56	12	< .1	.03	< .01	16	.05	< .20
		12-09-93	35	4.7	< .1	.03	< .01	10	.02	< .20
		06-21-94	22	1.0	< .1	.01	< .01	3.9	.02	< .20
		06-21-94[2]	21	.9	< .1	< .01	< .01	3.9	.02	< .20
13C	412120091080403	10-29-92	72	11	.2	.04	.63	8.9	.13	.20
		02-02-93	54	9.3	.1	--	.23	6.5	.07	< .20
		05-26-93	48	9.1	< .1	--	.18	6.3	.11	< .20
		09-07-93	43	7.6	.1	.04	.09	3.3	.05	< .20
		12-09-93	43	6.1	< .1	.05	.03	1.3	.05	< .20
		06-21-94	32	4.1	< .1	.04	< .01	2.5	.04	< .20
25	411915091072901	06-22-92	20	29	< .1	.03	< .01	18	.02	< .20
26	411905091063301	10-28-92	21	44	< .1	.03	< .01	7.6	< .01	< .20
		05-26-93	20	40	< .1	--	< .01	8.3	.03	< .20
		09-07-93	21	60	.1	.03	< .01	9	.01	< .20
		12-09-93	26	75	< .1	.04	< .01	10	.01	< .20
		06-23-94	21	61	< .1	.04	< .01	8.9	.01	< .20
30	412040091054701	06-22-92	14	1.2	.1	.02	< .01	2.2	< .01	< .20
		11-02-92	15	1.3	< .1	.03	.02	2.5	.01	< .20

Table 6. Physical properties and constituent concentrations in surface-water and ground-water samples, June 1992–June 1994, near Muscatine, Iowa—Continued

LocalID (fig. 3)	Station number	Date (month-day-year)	Phosphorus, dissolved (mg/L as P)	Phosphorus, ortho, dissolved (mg/L as P)	Aluminum, dissolved (µg/L as Al)	Arsenic, dissolved (µg/L as As)	Boron, dissolved (µg/L as B)	Cadium, dissolved (µg/L as Cd)	Chromium, dissolved (µg/L as Cr)	Copper, dissolved (µg/L as Cu)
7B	412242091055002	07-01-92	<0.01	<0.01	--	--	--	--	--	--
		11-02-92	< .01	< .01	--	<1	40	<1	3	<1
		02-02-93	< .01	.01	--	--	--	--	--	--
		05-25-93	< .01	< .01	30	<1	40	<1	<1	<1
		09-03-93	< .01	< .01	--	--	80	--	--	--
		12-06-93	< .01	< .01	<10	<1	50	<1	<1	<1
		12-06-93[2]	< .01	< .01	<10	<1	50	<1	<1	<1
		06-21-94	< .01	< .01	<10	<1	60	<1	<1	<1
13A	412120091080401	07-01-92	< .01	< .01	--	--	--	--	--	--
		10-29-92	< .01	< .01	<10	<1	30	<1	1	<1
		02-02-93	.01	< .01	--	--	--	--	--	--
		05-26-93	< .01	< .01	<10	<1	20	<1	<1	<1
		09-07-93	< .01	< .01	--	--	30	--	--	--
		12-09-93	< .01	< .01	<10	<1	30	<1	1	<1
		06-21-94	.01	.01	<10	<1	20	<1	<1	1
		06-21-94[2]	.04	< .01	<10	<1	30	<1	<1	1
13C	412120091080403	10-29-92	.05	.05	10	2	50	<1	1	<1
		02-02-93	.04	.04	--	--	--	--	--	--
		05-26-93	.05	.04	<10	1	30	<1	<1	<1
		09-07-93	.02	.03	--	--	40	--	--	--
		12-09-93	.02	.03	50	1	40	<1	<1	<1
		06-21-94	.01	.02	<10	<1	40	<1	<1	4
25	411915091072901	06-22-92	.04	.03	--	--	--	--	--	--
26	411905091063301	10-28-92	.02	.02	<10	<1	50	<1	<1	<1
		05-26-93	.01	.01	<10	<1	50	<1	<1	<1
		09-07-93	.01	.03	--	--	50	--	--	--
		12-09-93	< .01	.01	<10	<1	30	<1	<1	<1
		06-23-94	< .01	< .01	<10	<1	20	<1	<1	<1
30	412040091054701	06-22-92	< .01	.01	--	--	--	--	--	--
		11-02-92	< .01	.02	<10	<1	20	<1	1	3

Table 6. Physical properties and constituent concentrations in surface-water and ground-water samples, June 1992–June 1994, near Muscatine, Iowa—Continued

LocalID (fig. 3)	Station number	Date (month-day-year)	Iron, dissolved (µg/L as Fe)	Lead, dissolved (µg/L as Pb)	Manganese, dissolved (µg/L as Mn)	Mercury, dissolved (µg/L as Hg)	Molybdenum, dissolved (µg/L as Mo)	Nickel, dissolved (µg/L as Ni)	Zinc, dissolved (µg/L as Zn)
7B	412242091055002	07-01-92	--	--	--	--	--	--	--
		11-02-92	42	<1	17	<0.1	<1	<1	170
		02-02-93	--	--	--	--	--	--	--
		05-25-93	81	<1	11	<.1	<1	<1	70
		09-03-93	--	--	--	--	--	--	--
		12-06-93	110	<1	9	<.1	<1	<1	85
		12-06-93[2]	96	<1	8	<.1	<1	<1	83
		06-21-94	180	<1	12	<.1	<1	<1	120
13A	412120091080401	07-01-92	--	--	--	--	--	--	--
		10-29-92	9	<1	1	<.1	<1	<1	<3
		02-02-93	--	--	--	--	--	--	--
		05-26-93	8	<1	7	<.1	<1	<1	4
		09-07-93	--	--	--	--	--	--	--
		12-09-93	9	<1	4	<.1	<1	1	6
		06-21-94	10	<1	2	<.1	<1	<1	<3
		06-21-94[2]	21	<1	2	.6	<1	1	<3
13C	412120091080403	10-29-92	<3	<1	1	<.1	10	<1	<3
		02-02-93	--	--	--	--	--	--	--
		05-26-93	6	<1	3	.1	6	<1	<3
		09-07-93	--	--	--	--	--	--	--
		12-09-93	<3	<1	5	<.1	<1	<1	3
		06-21-94	5	<1	8	.2	<1	1	4
25	411915091072901	06-22-92	--	--	--	--	--	--	--
26	411905091063301	10-28-92	<3	<1	<1	<.1	<1	<1	4
		05-26-93	3	<1	3	.1	<1	<1	<3
		09-07-93	--	--	--	--	--	--	--
		12-09-93	<3	<1	<1	<.1	<1	<1	5
		06-23-94	8	<1	<1	<.1	<1	<1	<3
30	412040091054701	06-22-92	--	--	--	--	--	--	--
		11-02-92	6	<1	2	<.1	<1	3	29

Table 6. Physical properties and constituent concentrations in surface-water and ground-water samples, June 1992–June 1994, near Muscatine, Iowa—Continued

LocalID (fig. 3)	Station number	Date (month-day-year)	Specific conductance (µS/cm)	pH, water whole, field (standard units)	Temperature, water (°C)	Calcium, dissolved (mg/L as Ca)	Magnesium, dissolved (mg/L as Mg)	Sodium, dissolved (mg/L as Na)	Potassium, dissolved (mg/L as K)	Alkalinity, laboratory (mg/L as $CaCO_3$)
30	412040091054701	02-01-93	260	7.3	10.5	35	12	2.4	0.70	118
		05-25-93	317	7.0	18.0	40	13	6.8	1.2	123
		09-07-93	370	7.3	20.0	49	12	7.4	1.7	159
		12-09-93	385	7.3	18.0	56	13	7.4	1.3	175
		06-21-94	423	7.0	16.0	59	13	6.9	1.4	183
32	411754091063401	06-23-92	279	7.0	12.0	26	7.5	11	6.4	50
		10-28-92	284	7.5	11.5	27	7.8	10	5.8	52
		02-01-93	304	7.4	12.0	28	8.7	10	5.7	61
		05-27-93	282	7.3	11.0	25	7.2	11	4.4	52
		12-09-93	232	7.6	13.0	22	6.3	11	4.7	42
		06-23-94	211	7.3	7.5	22	6.5	5.5	4.4	45
33	411752091063601	06-23-92	195	7.7	13.5	25	7.4	3.1	.50	51
		10-28-92	185	8.6	14.0	22	6.6	2.8	.50	48
		05-27-93	210	8.1	13.0	23	6.9	2.8	.50	51
		09-07-93	175	7.8	14.0	21	6.4	2.5	.50	43
		12-09-93	280	8.4	12.0	33	10	3.2	.60	46
		06-23-94	190	8.0	10.0	22	6.7	2.5	.50	42
34	411540091064201	07-01-92	3,910	7.5	13.5	130	58	760	12	256
		05-26-93	4,310	7.4	13.0	160	70	970	15	258
		12-07-93	4,130	7.4	13.0	150	61	800	12	276
36	412241091085401	06-23-92	632	7.8	20.5	83	32	13	1.5	265
		02-03-93	336	7.5	1.5	33	12	7.7	8.8	110
		09-02-93	672	7.1	19.0	89	26	11	2.7	215
		06-21-94	598	7.6	28.5	70	26	13	1.7	193
37	411857091092601	06-23-92	445	7.9	24.5	49	24	11	1.4	162
		10-28-92	606	8.1	11.5	82	26	10	1.5	204
		02-03-93	495	7.5	3.0	64	22	12	3.4	189
		05-26-93	585	7.6	19.0	74	24	9.5	2.6	197
		09-02-93	520	7.1	19.5	70	21	7.3	3.2	175
		12-07-93	590	8.0	5.0	82	27	11	1.2	229

Table 6. Physical properties and constituent concentrations in surface-water and ground-water samples, June 1992–June 1994, near Muscatine, Iowa—Continued

LocalID (fig. 3)	Station number	Date (month-day-year)	Sulfate, dissolved (mg/L as SO_4)	Chloride, dissolved (mg/L as Cl)	Fluoride, dissolved (mg/L as F)	Bromide, dissolved (mg/L as Br)	Nitrogen, nitrite, dissolved (mg/L as N)	Nitrogen, NO_2+NO_3, dissolved (mg/L as N)	Nitrogen, ammonia, dissolved (mg/L as N)	Nitrogen, ammonia + organic, dissolved (mg/L as N)
30	412040091054701	02-01-93	15	1.0	0.1	--	0.01	2.8	0.02	<0.20
		05-25-93	26	14	.1	--	< .01	< .05	.04	.40
		09-07-93	19	12	.2	<0.01	< .01	< .05	.03	< .20
		12-09-93	18	14	.1	.02	< .01	.11	.03	< .20
		06-21-94	17	13	.1	.03	.02	.48	.05	.30
32	411754091063401	06-23-92	16	21	.2	.02	< .01	9.9	.02	< .20
		10-28-92	16	20	< .1	.04	< .01	8.6	< .01	< .20
		02-01-93	19	21	< .1	--	.02	9.8	< .01	< .20
		05-27-93	21	16	.1	--	< .01	8.3	< .01	< .20
		12-09-93	18	9.4	< .1	.02	< .01	11	< .01	< .20
		06-23-94	17	8.9	< .1	.02	< .01	6.8	.02	< .20
33	411752091063601	06-23-92	21	5.8	< .1	.01	< .01	5.3	.01	< .20
		10-28-92	20	5.0	< .1	.03	< .01	3.6	< .01	< .20
		05-27-93	20	6.2	< .1	--	< .01	4.9	< .01	< .20
		09-07-93	19	4.9	< .1	.02	< .01	4.8	.01	< .20
		12-09-93	22	23	< .1	.04	< .01	8.8	.02	< .20
		06-23-94	21	5.7	< .1	.03	< .01	4.9	.01	< .20
34	411540091064201	07-01-92	1,600	260	1.4	.42	< .01	< .05	2.3	2.8
		05-26-93	2,100	310	.9	--	< .01	< .05	2.8	3.5
		12-07-93	1,700	230	1.4	.44	< .01	.05	2.6	2.7
36	412241091085401	06-23-92	110	11	--	--	< .01	< .05	.02	< .20
		02-03-93	36	19	.2	--	.03	1.10	1.4	3.6
		09-02-93	110	16	.2	< .01	.05	1.10	.38	.60
		06-21-94	100	15	.3	< .01	< .01	< .05	.05	.30
37	411857091092601	06-23-92	70	13	.2	< .01	< .01	< .05	.02	.20
		10-28-92	90	12	.2	< .01	.01	.83	.01	.40
		02-03-93	64	16	.2	--	.03	1.50	.32	.90
		05-26-93	110	15	.1	--	.05	2.60	.38	.80
		09-02-93	85	11	.2	< .01	.05	2.00	.32	.60
		12-07-93	90	13	.2	.03	.02	2.60	.31	.30

Table 6. Physical properties and constituent concentrations in surface-water and ground-water samples, June 1992–June 1994, near Muscatine, Iowa—Continued

LocalID (fig. 3)	Station number	Date (month-day-year)	Phosphorus, dissolved (mg/L as P)	Phosphorus, ortho, dissolved (mg/L as P)	Aluminum, dissolved (µg/L as Al)	Arsenic, dissolved (µg/L as As)	Boron, dissolved (µg/L as B)	Cadium, dissolved (µg/L as Cd)	Chromium, dissolved (µg/L as Cr)	Copper, dissolved (µg/L as Cu)
30	412040091054701	02-01-93	0.01	0.01	--	--	--	--	--	--
		05-25-93	.02	.02	20	<1	<10	<1	<1	6
		09-07-93	<.01	.01	--	--	30	--	--	--
		12-09-93	<.01	<.01	<10	<1	30	<1	2	1
		06-21-94	.02	<.01	<10	<1	30	<1	<1	6
32	411754091063401	06-23-92	<.01	<.01	--	--	--	--	--	--
		10-28-92	.01	.01	<10	<1	20	<1	<1	<1
		02-01-93	.02	.01	--	--	--	--	--	--
		05-27-93	.02	.01	<10	<1	20	<1	<1	<1
		12-09-93	.02	.02	<10	<1	20	<1	<1	<1
		06-23-94	.01	<.01	<10	<1	20	<1	<1	<1
33	411752091063601	06-23-92	<.01	.02	--	--	--	--	--	--
		10-28-92	.03	.02	<10	<1	<10	<1	<1	<1
		05-27-93	.03	.03	<10	1	20	<1	<1	<1
		09-07-93	.02	.03	--	--	10	--	--	--
		12-09-93	.02	.04	<10	<1	20	<1	<1	<1
		06-23-94	.02	.02	<10	<1	10	<1	<1	<1
34	411540091064201	07-01-92	.05	.04	--	--	--	--	--	--
		05-26-93	<.01	<.01	20	<1	1,300	<1	<1	<1
		12-07-93	<.01	<.01	20	<1	1,000	<1	<1	<1
36	412241091085401	06-23-92	<.01	<.01	--	--	--	--	--	--
		02-03-93	.94	.92	--	--	--	--	--	--
		09-02-93	<.01	.02	--	--	50	--	--	--
		06-21-94	.02	.01	<10	1	40	<1	<1	1
37	411857091092601	06-23-92	.02	.01	--	--	--	--	--	--
		10-28-92	.04	.03	10	<1	40	<1	<1	<1
		02-03-93	.01	.02	--	--	--	--	--	--
		05-26-93	.01	<.01	30	<1	30	<1	<1	<1
		09-02-93	.01	.01	--	--	30	--	--	--
		12-07-93	.01	.01	<10	1	30	<1	<1	<1

Table 6. Physical properties and constituent concentrations in surface-water and ground-water samples, June 1992–June 1994, near Muscatine, Iowa—Continued

LocalID (fig. 3)	Station number	Date (month-day-year)	Iron, dissolved (μg/L as Fe)	Lead, dissolved (μg/L as Pb)	Manganese, dissolved (μg/L as Mn)	Mercury, dissolved (μg/L as Hg)	Molybdenum, dissolved (μg/L as Mo)	Nickel, dissolved (μg/L as Ni)	Zinc, dissolved (μg/L as Zn)
30	412040091054701	02-01-93	--	--	--	--	--	--	--
		05-25-93	<3	<1	13	0.1	<1	2	23
		09-07-93	--	--	--	--	--	--	--
		12-09-93	220	<1	160	<.1	<1	6	17
		06-21-94	12	<1	27	<.1	<1	9	45
32	411754091063401	06-23-92	--	--	--	--	--	--	--
		10-28-92	6	<1	2	<.1	<1	<1	5
		02-01-93	--	--	--	--	--	--	--
		05-27-93	<3	<1	1	<.1	<1	<1	<3
		12-09-93	6	<1	1	<.1	<1	<1	4
		06-23-94	<3	<1	<1	<.1	<1	<1	4
33	411752091063601	06-23-92	--	--	--	--	--	--	--
		10-28-92	<3	<1	<1	<.1	<1	1	<3
		05-27-93	<3	<1	<1	<.1	<1	<1	<3
		09-07-93	--	--	--	--	--	--	--
		12-09-93	<3	<1	1	<.1	<1	<1	16
		06-23-94	<3	<1	<1	<.1	2	<1	<3
34	411540091064201	07-01-92	--	--	--	--	--	--	--
		05-26-93	940	<1	330	<.1	<1	<1	20
		12-07-93	980	<1	350	<.1	<1	<1	30
36	412241091085401	06-23-92	--	--	--	--	--	--	--
		02-03-93	--	--	--	--	--	--	--
		09-02-93	--	--	--	--	--	--	--
		06-21-94	4	<1	230	<.1	<1	2	6
37	411857091092601	06-23-92	--	--	-	--	--	--	--
		10-28-92	<3	<1	430	<.1	1	<1	4
		02-03-93	--	--	--	--	--	--	--
		05-26-93	20	<1	530	<.1	<1	<1	<3
		09-02-93	--	--	--	--	--	--	--
		12-07-93	<3	<1	600	<.1	<1	2	6

Table 6. Physical properties and constituent concentrations in surface-water and ground-water samples, June 1992–June 1994, near Muscatine, Iowa—Continued

LocalID (fig. 3)	Station number	Date (month-day-year)	Specific conductance (µS/cm)	pH, water whole, field (standard units)	Temperature, water (°C)	Calcium, dissolved (mg/L as Ca)	Magnesium, dissolved (mg/L as Mg)	Sodium, dissolved (mg/L as Na)	Potassium, dissolved (mg/L as K)	Alkalinity, laboratory (mg/L as $CaCO_3$)
37	411857091092601	06-21-94	520	8.4	29.0	59	24	10	1.4	165
38	411507091065801	06-23-92	420	7.9	22.0	54	19	10	1.3	202
		02-03-93	552	7.4	3.5	53	17	13	2.9	163
		09-02-93	460	7.2	20.5	59	18	7.0	2.4	164
		06-21-94	442	8.4	28.0	50	21	9.1	1.5	158
40A	412532091003501	06-30-92	418	8.3	23.0	38	23	11	2.2	162
		10-28-92	355	8.8	11.0	42	17	10	2.3	144
		02-02-93	465	8.0	1.0	53	22	13	3.0	181
		05-26-93	459	7.7	12.0	51	21	8.5	2.7	171
		09-02-93	505	8.0	23.0	60	24	9.1	4.1	202
		09-02-93[1]	--	--	--	< .02	< .01	< .20	< .1	<1
		09-02-93[2]	505	8.0	23.0	< .02	< .01	< .20	< .1	<1
		12-07-93	434	8.5	2.5	53	22	11	2.3	185
		06-21-94	485	8.2	30.0	47	24	13	2.9	171
41	411819091083701	11-02-92	378	7.1	11.5	54	10	4.1	.2	135
		05-26-93	386	6.9	13.0	49	9.7	3.6	.2	131
		12-08-93	360	7.1	11.0	53	10	3.4	.2	133
44A	411847091052901	06-24-92	373	7.4	13.0	52	14	5.3	.6	155
		11-04-92	368	7.9	13.0	54	14	5.3	.7	152
		05-27-93	406	7.5	13.0	52	14	5.5	.7	156
		09-07-93	374	7.5	14.0	54	14	5.7	.7	149
		12-09-93	366	7.7	15.0	54	14	5.0	.7	148
		06-23-94	375	7.4	10.0	54	15	5.2	.7	157
46A	412340091102401	11-03-92	730	7.2	12.0	100	40	8.1	3.0	284
		02-03-93	690	7.6	12.0	82	30	6.7	1.7	257
46C	412340091102403	11-03-92	794	7.9	13.0	39	15	120	5.6	323
		02-03-93	780	7.4	11.5	71	27	70	6.1	373
		05-25-93	717	7.1	13.0	98	36	14	7.2	345
48A	412355091055501	10-29-92	650	7.5	11.0	100	24	7.7	.9	185
		02-02-93	434	7.6	11.5	110	27	7.9	.9	327

Table 6. Physical properties and constituent concentrations in surface-water and ground-water samples, June 1992–June 1994, near Muscatine, Iowa—Continued

LocalID (fig. 3)	Station number	Date (month-day-year)	Sulfate, dissolved (mg/L as SO_4)	Chloride, dissolved (mg/L as Cl)	Fluoride, dissolved (mg/L as F)	Bromide, dissolved (mg/L as Br)	Nitrogen, nitrite, dissolved (mg/L as N)	Nitrogen, NO_2+NO_3, dissolved (mg/L as N)	Nitrogen, ammonia, dissolved (mg/L as N)	Nitrogen, ammonia + organic, dissolved (mg/L as N)
37	411857091092601	06-21-94	79	13	0.3	0.01	0.05	1.1	0.12	0.50
38	411507091065801	06-23-92	23	15	.2	<.01	<.01	<.05	.02	<.20
		02-03-93	48	20	.2	--	.03	2.2	.27	.80
		09-02-93	58	11	.2	<.01	.06	2.5	.37	.60
		06-21-94	51	14	.2	.02	.04	.97	.03	.30
40A	412532091003501	06-30-92	39	23	.2	<.01	.03	1.0	.05	.40
		10-28-92	27	15	.2	.01	.03	2.3	<.01	<.20
		02-02-93	34	20	.1	--	.03	3.1	.26	.80
		05-26-93	53	16	<.1	--	.02	2.0	.09	.50
		09-02-93	44	23	.2	<.01	.08	2.5	.04	.50
		09-02-93[1]	<.1	2.5	<.1	<.01	.02	<.05	.01	<.05
		09-02-93[2]	<.1	2.5	<.1	<.01	.08	2.6	.03	.40
		12-07-93	37	16	.1	<.01	.01	2.0	.04	.30
		06-21-94	49	18	.2	<.01	.07	.91	.07	.50
41	411819091083701	11-02-92	42	7.9	.3	<.01	.02	<.05	.22	.20
		05-26-93	43	6.9	.2	--	<.01	<.05	.22	.30
		12-08-93	43	6.3	.3	.01	<.01	<.05	.21	<.20
44A	411847091052901	06-24-92	38	20	.1	.02	.02	.75	.03	<.20
		11-04-92	35	9.6	<.1	.03	.01	1.1	.06	<.20
		05-27-93	35	10	.1	--	<.01	.87	.02	<.20
		09-07-93	38	9.6	.1	.02	<.01	.85	.04	<.20
		12-09-93	39	8.4	<.1	.05	.01	1.3	.02	<.20
		06-23-94	34	8.6	<.1	.03	<.01	1.5	.02	<.20
46A	412340091102401	11-03-92	60	5.1	.2	.04	.02	.08	.19	1.1
		02-03-93	56	4.4	.2	--	.02	.05	.40	1.4
46C	412340091102403	11-03-92	110	12	.4	.02	.21	.33	.04	.20
		02-03-93	79	9.5	.3	--	.02	<.05	.22	.50
		05-25-93	62	10	.2	--	<.01	<.05	.25	.50
48A	412355091055501	10-29-92	52	15	0.2	.04	<.01	.05	.04	.60
		02-02-93	64	15	0.2	--	.01	<.05	.05	<.20

Table 6. Physical properties and constituent concentrations in surface-water and ground-water samples, June 1992–June 1994, near Muscatine, Iowa—Continued

LocalID (fig. 3)	Station number	Date (month-day-year)	Phosphorus, dissolved (mg/L as P)	Phosphorus, ortho, dissolved (mg/L as P)	Aluminum, dissolved (µg/L as Al)	Arsenic, dissolved (µg/L as As)	Boron, dissolved (µg/L as B)	Cadium, dissolved (µg/L as Cd)	Chromium, dissolved (µg/L as Cr)	Copper, dissolved (µg/L as Cu)
37	411857091092601	06-21-94	0.03	0.02	<10	2	30	<1	1	1
38	411507091065801	06-23-92	< .01	< .01	--	--	--	--	--	--
		02-03-93	< .01	.01	--	--	--	--	--	--
		09-02-93	.02	.02	--	--	30	--	--	--
		06-21-94	.01	< .01	<10	1	30	<1	<1	1
40A	412532091003501	06-30-92	< .01	< .01	--	--	--	--	--	--
		10-28-92	.01	< .01	<10	1	30	<1	<1	1
		02-02-93	.10	.08	--	--	--	--	--	--
		05-26-93	.06	.05	20	1	40	<1	<1	1
		09-02-93	.14	.14	--	--	30	--	--	--
		09-02-93[1]	< .01	< .01	--	--	<10	--	--	--
		09-02-93[2]	.13	.14	--	--	<10	--	--	--
		12-07-93	.02	.03	<10	<1	40	<1	1	<1
		06-21-94	.09	.08	<10	2	40	<1	<1	2
41	411819091083701	11-02-92	.28	.03	<10	2	10	<1	<1	<1
		05-26-93	.09	.04	30	1	10	<1	<1	<1
		12-08-93	< .01	< .01	<10	2	10	<1	8	<1
44A	411847091052901	06-24-92	.02	< .01	--	--	--	--	--	--
		11-04-92	< .01	< .01	<10	2	20	<1	<1	<1
		05-27-93	.03	< .01	<10	2	20	<1	<1	<1
		09-07-93	< .01	.02	--	--	10	--	--	--
		12-09-93	< .01	.02	<10	2	20	<1	<1	<1
		06-23-94	.02	.02	<10	1	20	<1	<1	<1
46A	412340091102401	11-03-92	< .01	.01	20	<1	30	<1	<1	<1
		02-03-93	.01	.02	--	--	--	--	--	--
46C	412340091102403	11-03-92	< .01	< .01	<10	<1	80	<1	3	2
		02-03-93	.02	.01	--	--	--	--	--	--
		05-25-93	< .01	< .01	40	1	30	<1	<1	1
48A	412355091055501	10-29-92	.03	.01	--	2	20	<1	1	<1
		02-02-93	.02	< .01	--	--	--	--	--	--

Table 6. Physical properties and constituent concentrations in surface-water and ground-water samples, June 1992–June 1994, near Muscatine, Iowa—Continued

LocalID (fig. 3)	Station number	Date (month-day-year)	Iron, dis-solved (µg/L as Fe)	Lead, dis-solved (µg/L as Pb)	Manga-nese, dis-solved (µg/L as Mn)	Mercury, dis-solved (µg/L as Hg)	Molyb-denum, dis-solved (µg/L as Mo)	Nickel, dis-solved (µg/L as Ni)	Zinc, dis-solved (µg/L as Zn)
37	411857091092601	06-21-94	35	<1	170	<0.1	<1	3	5
38	411507091065801	06-23-92	--	--	--	--	--	--	--
		02-03-93	--	--	--	--	--	--	--
		09-02-93	--	--	--	--	--	--	--
		06-21-94	<3	<1	5	<.1	<1	2	11
40A	412532091003501	06-30-92	--	--	--	--	--	--	--
		10-28-92	13	<1	1	<.1	1	2	<3
		02-02-93	--	--	--	--	--	--	--
		05-26-93	20	<1	4	.1	1	<1	4
		09-02-93	--	--	--	--	--	--	--
		09-02-93[1]	--	--	--	--	--	--	--
		09-02-93[2]	--	--	--	--	--	--	--
		12-07-93	13	<1	8	<.1	<1	1	5
		06-21-94	14	<1	6	<.1	<1	1	3
41	411819091083701	11-02-92	9,400	<1	1,100	<.1	<1	<1	10
		05-26-93	8,900	<1	1,000	<.1	<1	<1	7
		12-08-93	9,700	<1	1,100	<.1	<1	<1	<3
44A	411847091052901	06-24-92	--	--	--	--	--	--	--
		11-04-92	380	<1	140	<.1	1	<1	<3
		05-27-93	400	<1	150	<.1	1	<1	<3
		09-07-93	--	--	--	--	--	--	--
		12-09-93	420	<1	140	<.1	1	<1	3
		06-23-94	250	<1	100	<.1	<1	<1	12
46A	412340091102401	11-03-92	55	<1	1,400	<.1	1	4	18
		02-03-93	--	--	--	--	--	--	--
46C	412340091102403	11-03-92	10	<1	160	<.1	20	7	15
		02-03-93	--	--	--	--	--	--	--
		05-25-93	1,000	<1	1,600	<.1	2	12	18
48A	412355091055501	10-29-92	1,700	<1	1,800	<.1	<1	1	<3
		02-02-93	--	--	--	--	--	--	--

Table 6. Physical properties and constituent concentrations in surface-water and ground-water samples, June 1992–June 1994, near Muscatine, Iowa—Continued

LocalID (fig. 3)	Station number	Date (month-day-year)	Specific conductance (µS/cm)	pH, water whole, field (standard units)	Temperature, water (°C)	Calcium, dissolved (mg/L as Ca)	Magnesium, dissolved (mg/L as Mg)	Sodium, dissolved (mg/L as Na)	Potassium, dissolved (mg/L as K)	Alkalinity, laboratory (mg/L as $CaCO_3$)
48A	412355091055501	05-25-93	650	7.4	11.5	120	28	8.3	0.90	237
		05-25-93[2]	650	7.4	11.5	120	29	8.3	.90	269
		09-03-93	638	7.5	12.0	99	24	7.2	1.0	248
		12-08-93	488	7.7	11.0	73	20	7.4	.70	201
		06-22-94	620	7.3	9.0	93	25	7.5	1.1	272
48D	412355091055504	10-29-92	614	8.8	11.5	21	5.6	110	2.3	204
		02-02-93	588	8.1	11.0	48	17	62	1.8	259
		05-25-93	546	7.8	15.0	28	9.8	91	2.6	246
		05-25-93[1]	--	--	--	--	--	--	--	--
		09-03-93	572	8.0	14.0	55	19	53	2.1	271
		12-08-93	543	8.0	11.0	49	17	58	2.3	262
		06-22-94	593	7.8	10.0	58	21	43	2.2	272
49	412242091095301	05-25-93	329	7.2	12.5	42	14	4.7	.70	127
		09-03-93	333	7.4	12.5	43	13	4.6	.70	125
		12-08-93	325	7.6	11.0	45	14	4.7	.70	114
		06-22-94	339	7.3	9.0	43	14	4.6	.60	131
50A	411659091083701	05-26-93	550	7.1	13.0	56	21	15	.40	127
		12-08-93	525	6.9	11.0	59	21	16	.40	157
		06-22-94	545	6.8	9.0	59	22	16	.30	152
50B	411659091083702	05-26-93	643	7.2	12.5	74	26	24	.90	322
		12-08-93	640	7.3	11.0	82	27	26	.90	373
		06-22-94	653	7.2	9.0	77	26	23	.80	371
51A	412044091101301	02-01-93	686	6.7	11.0	69	26	18	.70	87
		12-08-93	573	6.7	11.0	60	20	14	.50	95
		06-22-94	774	6.5	8.5	77	27	17	.50	98
51B	412044091101302	02-01-93	651	7.3	11.0	86	31	8.1	1.5	355
		12-08-93	666	7.2	11.0	93	30	7.6	1.4	338
		06-22-94	655	7.2	9.0	94	31	8.0	1.6	342
55	412236091034501	11-03-92	463	7.9	11.0	49	20	9.9	1.8	173
		02-02-93	420	7.8	15.5	47	19	11	2.3	166

Table 6. Physical properties and constituent concentrations in surface-water and ground-water samples, June 1992–June 1994, near Muscatine, Iowa—Continued

LocalID (fig. 3)	Station number	Date (month-day-year)	Sulfate, dis-solved (mg/L as SO_4)	Chlor-ride, dis-solved (mg/L as Cl)	Fluo-ride, dis-solved (mg/L as F)	Bromide, dis-solved (mg/L as Br)	Nitro-gen, nitrite, dis-solved (mg/L as N)	Nitro-gen, NO_2+NO_3, dis-solved (mg/L as N)	Nitro-gen, ammo-nia, dis-solved (mg/L as N)	Nitro-gen, ammo-nia + organic, dis-solved (mg/L as N)
48A	412355091055501	05-25-93	65	16	0.2	--	<0.01	<0.05	0.06	<0.20
		05-25-93[2]	68	16	.1	--	<.01	<.05	.06	<.20
		09-03-93	85	19	.2	0.03	<.01	<.05	.05	<.20
		12-08-93	63	14	.2	.04	.02	.14	.05	<.20
		06-22-94	63	15	.2	.05	<.01	<.05	.05	<.20
48D	412355091055504	10-29-92	100	8.7	.3	.03	.29	.57	.02	<.20
		02-02-93	62	7.5	.2	--	<.01	<.05	.08	<.20
		05-25-93	70	8.0	.2	--	<.01	<.05	.06	<.20
		05-25-93[1]	--	--	--	--	<.01	<.05	.02	<.20
		09-03-93	59	7.8	.2	.03	<.01	<.05	.07	<.20
		12-08-93	54	6.6	.2	.04	<.01	<.05	.08	<.20
		06-22-94	50	8.0	.1	.04	<.01	<.05	.06	<.20
49	412242091095301	05-25-93	30	14	.3	--	<.01	<.05	.18	<.20
		09-03-93	36	12	.3	.02	<.01	<.05	.22	<.20
		12-08-93	33	12	.3	.05	<.01	<.05	.20	<.20
		06-22-94	29	12	.3	.02	<.01	<.05	.21	<.20
50A	411659091083701	05-26-93	120	19	.2	--	.01	<.05	.26	.40
		12-08-93	93	19	.3	.04	<.01	<.05	.26	.30
		06-22-94	99	19	.3	.01	.01	<.05	.27	.30
50B	411659091083702	05-26-93	.3	.9	.2	--	<.01	<.05	.87	.90
		12-08-93	<.1	1.5	.2	.02	<.01	<.05	.89	.90
		06-22-94	<.1	1.1	.3	.01	<.01	<.05	.88	1.0
51A	412044091101301	02-01-93	170	42	.2	--	.03	<.05	.18	.40
		12-08-93	110	46	.2	.05	.01	<.05	.18	<.20
		06-22-94	190	39	.2	.03	<.01	<.05	.18	<.20
51B	412044091101302	02-01-93	36	1.6	.2	--	.02	<.05	.09	<.20
		12-08-93	43	3.8	.2	.04	<.01	<.05	.09	<.20
		06-22-94	42	2.7	.2	.04	<.01	<.05	.09	<.20
55	412236091034501	11-03-92	36	17	<.1	<.01	.01	<.05	.02	.02
		02-02-93	36	15	.1	--	.02	<.05	.02	<.20

Table 6. Physical properties and constituent concentrations in surface-water and ground-water samples, June 1992–June 1994, near Muscatine, Iowa—Continued

LocalID (fig. 3)	Station number	Date (month-day-year)	Phosphorus, dissolved (mg/L as P)	Phosphorus, ortho, dissolved (mg/L as P)	Aluminum, dissolved (µg/L as Al)	Arsenic, dissolved (µg/L as As)	Boron, dissolved (µg/L as B)	Cadium, dissolved (µg/L as Cd)	Chromium, dissolved (µg/L as Cr)	Copper, dissolved (µg/L as Cu)
48A	412355091055501	05-25-93	<0.01	<0.01	30	2	<10	<1	10	<1
		05-25-93[2]	<.01	<.01	<10	2	20	<1	<1	<1
		09-03-93	<.01	<.01	--	--	20	--	--	--
		12-08-93	<.01	<.01	<10	2	30	<1	<1	<1
		06-22-94	<.01	<.01	10	1	20	<1	<1	<1
48D	412355091055504	10-29-92	.09	.07	110	2	40	<1	1	<1
		02-02-93	.02	.03	--	--	--	--	--	--
		05-25-93	.06	.06	30	<1	30	<1	<1	<1
		05-25-93[1]	<.01	<.01	--	--	--	--	--	--
		09-03-93	.02	.03	--	--	20	--	--	--
		12-08-93	.02	.03	10	<1	30	<1	<1	<1
		06-22-94	<.01	<.01	<10	<1	20	<1	<1	<1
49	412242091095301	05-25-93	.10	.09	<10	6	<10	<1	8	<1
		09-03-93	.13	.13	--	--	10	--	--	--
		12-08-93	.06	.06	<10	5	10	<1	<1	<1
		06-22-94	.12	.16	<10	5	10	<1	1	<1
50A	411659091083701	05-26-93	.23	<.01	10	<1	30	<1	<1	<1
		12-08-93	.02	<.01	<10	<1	20	<1	1	<1
		06-22-94	<.01	.02	<10	<1	20	<1	<1	<1
50B	411659091083702	05-26-93	.06	.02	20	<1	70	<1	<1	<1
		12-08-93	.02	.02	<10	<1	70	<1	<1	<1
		06-22-94	.03	.03	<10	<1	60	<1	<1	<1
51A	412044091101301	02-01-93	.42	<.01	--	--	--	--	--	--
		12-08-93	<.01	.01	<10	3	20	<1	<1	<1
		06-22-94	.05	<.01	<10	3	20	<1	<1	<1
51B	412044091101302	02-01-93	.10	.02	--	--	-	--	--	--
		12-08-93	<.01	<.01	<10	7	30	<1	<1	<1
		06-22-94	<.01	.01	<10	7	20	<1	<1	<1
55	412236091034501	11-03-92	<.01	<.01	<10	<1	30	<1	<1	3
		02-02-93	<.01	.01	--	--	--	--	--	--

Table 6. Physical properties and constituent concentrations in surface-water and ground-water samples, June 1992–June 1994, near Muscatine, Iowa—Continued

LocalID (fig. 3)	Station number	Date (month-day-year)	Iron, dissolved (µg/L as Fe)	Lead, dissolved (µg/L as Pb)	Manganese, dissolved (µg/L as Mn)	Mercury, dissolved (µg/L as Hg)	Molybdenum, dissolved (µg/L as Mo)	Nickel, dissolved (µg/L as Ni)	Zinc, dissolved (µg/L as Zn)
48A	412355091055501	05-25-93	2,200	<1	2,000	<0.1	<1	<1	4
		05-25-93[2]	2,000	<1	2,000	.1	<1	<1	6
		09-03-93	--	--	--	--	--	--	--
		12-08-93	870	<1	920	<.1	<1	<1	17
		06-22-94	1,100	<1	1,200	<.1	<1	<1	5
48D	412355091055504	10-29-92	36	<1	41	<.1	22	1	<3
		02-02-93	--	--	--	--	--	--	--
		05-25-93	10	<1	160	<.1	14	<1	6
		05-25-93[1]	--	--	--	--	--	--	--
		09-03-93	--	--	--	--	--	--	--
		12-08-93	15	<1	380	<.1	6	1	14
		06-22-94	28	<1	520	<.1	4	1	8
49	412242091095301	05-25-93	1,600	<1	100	<.1	<1	<1	<3
		09-03-93	--	--	--	--	--	--	--
		12-08-93	2,400	<1	98	<.1	<1	<1	5
		06-22-94	2,400	<1	95	<.1	<1	1	5
50A	411659091083701	05-26-93	12,000	<1	1,000	<.1	<1	<1	15
		12-08-93	11,000	<1	1,000	<.1	<1	<1	<3
		06-22-94	12,000	<1	1,000	<.1	<1	<1	<3
50B	411659091083702	05-26-93	7,800	<1	580	<.1	<1	<1	6
		12-08-93	8,900	<1	640	<.1	<1	<1	5
		06-22-94	8,500	<1	590	<.1	<1	<1	<3
51A	412044091101301	02-01-93	--	--	--	--	--	--	--
		12-08-93	27,000	<1	1,800	<.1	<1	3	9
		06-22-94	35,000	<1	2,100	<.1	<1	4	6
51B	412044091101302	02-01-93	--	--	--	--	--	--	--
		12-08-93	5,100	<1	350	<.1	<1	1	4
		06-22-94	5,100	<1	340	<.1	<1	3	7
55	412236091034501	11-03-92	8	<1	1,400	<.1	6	8	5
		02-02-93	--	--	--	--	--	--	--

Table 6. Physical properties and constituent concentrations in surface-water and ground-water samples, June 1992–June 1994, near Muscatine, Iowa—Continued

LocalID (fig. 3)	Station number	Date (month-day-year)	Specific conductance (µS/cm)	pH, water whole, field (standard units)	Temperature, water (°C)	Calcium, dissolved (mg/L as Ca)	Magnesium, dissolved (mg/L as Mg)	Sodium, dissolved (mg/L as Na)	Potassium, dissolved (mg/L as K)	Alkalinity, laboratory (mg/L as $CaCO_3$)
55	412236091034501	05-25-93	412	7.5	8.0	49	19	9.5	2.3	174
		09-07-93	403	7.6	13.5	45	17	11	2.5	164
		12-08-93	415	7.8	14.0	49	19	12	2.4	177
		06-23-94	454	7.6	8.0	55	21	8.5	2.9	182
56	412444091035501	02-01-93	455	7.4	12.0	52	17	13	1.8	189
		09-03-93	390	7.4	13.5	47	15	11	2.3	157
		12-08-93	410	7.5	12.0	50	16	12	1.8	163
		12-08-93[1]	410	7.5	12.0	.55	.03	.90	<.10	5.0
		06-22-94	450	7.3	10.0	54	17	12	2.0	179
58	411531091081501	02-01-93	594	7.5	12.0	80	27	15	1.4	335
GPC18	412356091034201	06-30-92	455	7.5	11.0	51	19	11	2.3	183
GPC20	412350091040901	06-30-92	500	7.5	14.5	70	20	12	1.3	193
		11-03-92	531	7.6	14.0	67	21	11	1.3	224
		05-27-93	560	7.2	13.5	75	22	11	1.4	199
		08-31-93	550	7.4	14.0	78	22	13	1.6	221
		12-02-93	561	7.7	14.0	76	23	13	1.4	233
		06-16-94	583	7.4	9.0	82	24	13	1.2	241
ILL1	411630091021101	09-03-93	495	7.4	12.0	77	21	4.9	.70	233
ILL5	412436091011001	02-01-93	693	7.3	11.5	89	35	5.4	.30	284
		05-26-93	759	7.1	12.0	96	36	7.5	.30	270
MPW13	412300091031801	06-23-92	393	7.3	11.0	47	18	10	2.2	164
		11-03-92	424	7.9	14.5	52	19	10	2.7	177
		02-03-93	420	7.8	15.0	45	18	10	2.7	165
		05-27-93	445	7.3	9.0	47	18	9.6	2.1	168
		09-01-93	484	7.2	17.5	71	19	8.9	1.8	202
		12-01-93	404	8.0	14.0	50	18	9.4	2.3	176
		06-17-94	480	7.4	6.0	53	19	9.7	2.4	178
MPW19	412329091041301	06-23-92	386	7.4	13.5	51	16	5.6	1.1	164
		06-09-93	414	7.9	14.0	50	17	7.4	1.3	134
		09-01-93	442	7.6	13.5	58	18	10	1.3	161

Table 6. Physical properties and constituent concentrations in surface-water and ground-water samples, June 1992–June 1994, near Muscatine, Iowa—Continued

LocalID (fig. 3)	Station number	Date (month-day-year)	Sulfate, dis-solved (mg/L as SO_4)	Chlor-ride, dis-solved (mg/L as Cl)	Fluo-ride, dis-solved (mg/L as F)	Bromide, dis-solved (mg/L as Br)	Nitro-gen, nitrite, dis-solved (mg/L as N)	Nitro-gen, NO_2+NO_3, dis-solved (mg/L as N)	Nitro-gen, ammo-nia, dis-solved (mg/L as N)	Nitro-gen, ammo-nia + organic, dis-solved (mg/L as N)
55	412236091034501	05-25-93	21	15	0.1	--	<0.01	<0.05	0.02	<0.20
		09-07-93	32	13	.2	<0 .01	.02	< .05	.02	< .20
		12-08-93	35	14	.1	.02	< .01	< .05	.02	< .20
		06-23-94	35	17	.2	< .01	--	--	--	--
56	412444091035501	02-01-93	16	18	.2	--	.02	< .05	1.0	1.0
		09-03-93	31	15	.2	< .01	.01	.05	1.0	1.1
		12-08-93	30	16	.2	.02	< .01	< .05	1.0	1.1
		12-08-93[1]	.1	.1	.1	< .01	< .01	< .05	< .01	< .20
		06-22-94	25	18	.2	.01	< .01	< .05	1.0	1.4
58	411531091081501	02-01-93	7.7	2.6	.2	--	.02	< .05	1.6	1.6
GPC18	412356091034201	06-30-92	31	16	.2	.02	.02	.13	.13	< .20
GPC20	412350091040901	06-30-92	44	22	.2	.02	< .01	.79	.08	< .20
		11-03-92	41	23	.1	.03	.01	1.0	.06	< .20
		05-27-93	49	27	.2	--	< .01	1.7	.04	.30
		08-31-93	49	25	.1	.03	< .01	1.6	.05	< .20
		12-02-93	46	22	.1	.03	< .01	1.0	.04	< .20
		06-16-94	52	26	.1	.03	< .01	1.2	.03	< .20
ILL1	411630091021101	09-03-93	53	5.4	.2	.06	< .01	< .05	.11	< .20
ILL5	412436091011001	02-01-93	46	47	.2	--	.01	< .05	.43	.50
		05-26-93	56	73	< .1	--	< .01	< .05	.44	.50
MPW13	412300091031801	06-23-92	33	16	.2	< .01	.01	.32	.23	.40
		11-03-92	36	15	.2	< .01	< .01	.07	.31	.50
		02-03-93	36	17	.2	--	.02	.13	.22	.40
		05-27-93	34	18	.2	--	.02	.26	.11	.30
		09-01-93	41	19	.7	.01	.04	.69	.02	.20
		12-01-93	33	13	.2	< .01	.01	.05	.12	.20
		06-17-94	33	17	.1	< .01	.03	.33	.11	.30
MPW19	412329091041301	06-23-92	29	18	.2	.04	< .01	1.60	.03	< .20
		06-09-93	39	15	< .1	.05	< .01	1.40	.03	< .20
		09-01-93	51	19	.10	.04	.02	2.00	.02	< .20

Table 6. Physical properties and constituent concentrations in surface-water and ground-water samples, June 1992–June 1994, near Muscatine, Iowa—Continued

LocalID (fig. 3)	Station number	Date (month-day-year)	Phosphorus, dissolved (mg/L as P)	Phosphorus, ortho, dissolved (mg/L as P)	Aluminum, dissolved (µg/L as Al)	Arsenic, dissolved (µg/L as As)	Boron, dissolved (µg/L as B)	Cadium, dissolved (µg/L as Cd)	Chromium, dissolved (µg/L as Cr)	Copper, dissolved (µg/L as Cu)
55	412236091034501	05-25-93	<0.01	<0.01	30	<1	30	<1	<1	2
		09-07-93	< .01	< .01	--	--	20	--	--	--
		12-08-93	< .01	< .01	<10	<1	30	<1	<1	2
		06-23-94	--	--	<10	<1	40	<1	<1	2
56	412444091035501	02-01-93	.30	.28	--	--	--	--	--	--
		09-03-93	.38	.31	--	--	40	--	--	--
		12-08-93	.16	.15	<10	<1	30	<1	<1	<1
		12-08-93[1]	< .01	< .01	80	<1	<10	<1	2	<1
		06-22-94	.21	.22	<10	<1	40	<1	<1	<1
58	411531091081501	02-01-93	.48	.17	--	--	--	--	--	--
GPC18	412356091034201	06-30-92	.01	.03	--	--	--	--	--	--
GPC20	412350091040901	06-30-92	< .01	.01	--	--	--	--	--	--
		11-03-92	.01	.01	<10	<1	50	<1	1	<1
		05-27-93	.07	.01	<10	<1	60	<1	<1	<1
		08-31-93	.02	.01	<10	<1	70	<1	<1	<1
		12-02-93	< .01	.02	--	--	40	--	--	--
		06-16-94	< .01	.02	--	--	70	--	--	--
ILL1	411630091021101	09-03-93	.18	.08	--	--	20	--	--	--
ILL5	412436091011001	02-01-93	.54	.04	--	--	--	--	--	--
		05-26-93	.09	.02	20	<1	10	<1	<1	<1
MPW13	412300091031801	06-23-92	.11	.10	--	--	--	--	--	--
		11-03-92	.10	.10	<10	2	40	<1	<1	3
		02-03-93	.07	.07	--	--	--	--	--	--
		05-27-93	.08	.08	<10	2	20	<1	<1	2
		09-01-93	.10	.09	<10	1	60	<1	<1	1
		12-01-93	.07	.08	--	--	40	--	--	--
		06-17-94	.14	.13	--	--	30	--	--	--
MPW19	412329091041301	06-23-92	.02	.03	--	--	--	--	--	--
		06-09-93	.03	.02	--	--	30	--	--	--
		09-01-93	.02	.02	<10	<1	40	<1	<1	1

Table 6. Physical properties and constituent concentrations in surface-water and ground-water samples, June 1992–June 1994, near Muscatine, Iowa—Continued

LocalID (fig. 3)	Station number	Date (month-day-year)	Iron, dis-solved (µg/L as Fe)	Lead, dis-solved (µg/L as Pb)	Manga-nese, dis-solved (µg/L as Mn)	Mercury, dis-solved (µg/L as Hg)	Molyb-denum, dis-solved (µg/L as Mo)	Nickel, dis-solved (µg/L as Ni)	Zinc, dis-solved (µg/L as Zn)
55	412236091034501	05-25-93	3	<1	1,400	<0.1	<1	7	12
		09-07-93	--	--	--	--	--	--	--
		12-08-93	8	<1	1,400	<.1	1	8	6
		06-23-94	3	<1	1,500	<.1	<1	37	<3
56	412444091035501	02-01-93	--	--	--	--	--	--	--
		09-03-93	--	--	--	--	--	--	--
		12-08-93	2,200	<1	300	<.1	<1	1	7
		12-08-93[1]	19	<1	<1	<.1	<1	<1	<3
		06-22-94	2,300	<1	330	<.1	<1	<1	3
58	411531091081501	02-01-93	--	--	--	--	--	--	--
GPC18	412356091034201	06-30-92	--	--	--	--	--	--	--
GPC20	412350091040901	06-30-92	--	--	--	--	--	--	--
		11-03-92	110	<1	410	<.1	<1	2	3
		05-27-93	91	<1	410	<.1	<1	1	<3
		08-31-93	89	<1	340	<.1	<1	<1	4
		12-02-93	83	--	340	--	--	--	--
		06-16-94	120	--	460	--	--	--	--
ILL1	411630091021101	09-03-93	--	--	--	--	--	--	--
ILL5	412436091011001	02-01-93	--	--	--	--	--	--	--
		05-26-93	7,500	<1	770	.1	<1	<1	16
MPW13	412300091031801	06-23-92	--	--	--	--	--	--	--
		11-03-92	99	<1	1,100	<.1	<1	6	<3
		02-03-93	--	--	--	--	--	--	--
		05-27-93	96	<1	950	<.1	1	4	<3
		09-01-93	52	<1	120	<.1	<1	2	<3
		12-01-93	88	--	870	--	--	--	--
		06-17-94	110	--	810	--	--	--	--
MPW19	412329091041301	06-23-92	--	--	--	--	--	--	--
		06-09-93	30	--	52	--	--	--	--
		09-01-93	35	<1	54	<.1	<1	<1	<3

Table 6. Physical properties and constituent concentrations in surface-water and ground-water samples, June 1992–June 1994, near Muscatine, Iowa—Continued

LocalID (fig. 3)	Station number	Date (month-day-year)	Specific conductance (µS/cm)	pH, water whole, field (standard units)	Temperature, water (°C)	Calcium, dissolved (mg/L as Ca)	Magnesium, dissolved (mg/L as Mg)	Sodium, dissolved (mg/L as Na)	Potassium, dissolved (mg/L as K)
MPW19	412329091041301	12-01-93	443	7.6	12.0	54	18	7.9	1.2
		06-17-94	427	6.7	9.5	57	19	6.8	1.3
MPW23	412215091065601	06-23-92	352	7.4	13.5	47	12	5.9	.90
		02-03-93	370	7.8	14.0	46	13	6.3	1.0
		09-01-93	368	7.4	14.5	47	12	6.4	.90
MPW29	412331091051201	06-23-92	391	7.4	13.5	52	16	7.9	1.0
		02-03-93	400	7.8	14.0	52	17	7.7	1.0
		09-01-93	397	7.8	13.5	52	16	7.2	.90

Local ID (fig. 3)	Station number	Date (month-day-year)	Alkalinity, laboratory (mg/L as $CaCO_3$)	Sulfate, dissolved (mg/L as SO_4)	Chloride, dissolved (mg/L as Cl)	Fluoride, dissolved (mg/L as F)	Bromide, dissolved (mg/L as Br)	Nitrogen, nitrite, dissolved (mg/L as N)	Nitrogen, NO_2+NO_3, dissolved (mg/L as N)
MPW19	412329091041301	12-01-93	166	40	15	<0.1	0.03	< 0.01	2.0
		06-17-94	178	35	14	< .1	.04	< .01	1.3
MPW23	412215091065601	06-23-92	100	32	17	.1	.03	.01	7.4
		02-03-93	103	32	15	< .1	--	.02	9.0
		09-01-93	103	32	19	< .1	.04	.03	9.1
MPW29	412331091051201	06-23-92	149	47	14	.1	.04	.01	0.7
		02-03-93	153	43	13	.1	--	.02	0.8
		09-01-93	155	42	15	.1	.04	.03	0.9

Table 6. Physical properties and constituent concentrations in surface-water and ground-water samples, June 1992–June 1994, near Muscatine, Iowa—Continued

LocalID (fig. 3)	Station number	Date (month-day-year)	Nitrogen, ammonia, dissolved (mg/L as N)	Nitrogen, ammonia + organic, dissolved (mg/L as N)	Phosphorus, dissolved (mg/L as P)	Phosphorus, ortho, dissolved (mg/L as P)	Boron, dissolved (µg/L as B)	Iron, dissolved (µg/L as Fe)	Manganese, dissolved (µg/L as Mn)
MPW19	412329091041301	12-01-93	0.03	<0.20	<0.01	0.02	40	33	50
		06-17-94	.03	< .20	.03	.03	40	38	53
MPW23	412215091065601	06-23-92	.03	< .20	< .01	.02	--	--	--
		02-03-93	.03	< .20	.01	.02	--	--	--
		09-01-93	.05	< .20	.04	.03	20	--	--
MPW29	412331091051201	06-23-92	.02	< .20	< .01	.01	--	--	--
		02-03-93	< .01	< .20	< .01	.02	--	--	--
		09-01-93	.01	< .20	.03	<200	40	--	--

[1] Quality-control blank sample.

[2] Quality-control replicate sample.

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