Prepared in cooperation with the
City of Burlington, Iowa

Simulated Ground-Water Flow and Water Quality of the Mississippi River Alluvium near Burlington, Iowa, 1999

Water-Resources Investigations Report 00–4274

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

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By Robert A. Boyd

U.S. GEOLOGICAL SURVEY

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Iowa City, Iowa
2001

U.S. DEPARTMENT OF THE INTERIOR
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CONVERSION FACTORS, ABBREVIATIONS, AND VERTICAL DATUM

Multiply	By	To obtain
inch	2.54	centimeter
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
gallon per minute (gal/min)	0.06309	liter per second
foot per day (ft/d)	0.3048	meter per day
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) may be converted to degrees Celsius (°C) as follows:

$$°C = (°F - 32) / 1.8$$

Abbreviated water-quality units used in this report: Chemical concentrations are expressed in metric units. Chemical concentrations are reported in milligrams per liter (mg/L) or micrograms per liter (µg/L). Milligrams per liter and micrograms per liter express concentrations of chemical constituents in solution as weight (milligrams or micrograms) of solute per unit volume (liter) of water. Milligrams per liter are equal to parts per million for concentrations less than 7,000 mg/L. Micrograms per liter are equal to 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

The City of Burlington, Iowa, obtains some of its public water supply by withdrawing ground water from the Mississippi River alluvium, an alluvial aquifer adjacent to the Mississippi River. The U.S. Geological Survey, in cooperation with the City of Burlington, conducted a hydrologic study of the Mississippi River alluvium near Burlington in 1999 to improve understanding of the flow system, evaluate the effects of hypothetical pumping scenarios on the flow system, and evaluate selected water-quality constituents in parts of the alluvium.

A steady-state, ground-water flow model was constructed for a 7-square-mile area of the alluvium using October 1999 hydrologic conditions to help conceptualize the flow system, identify sources of water to the alluvium, and assess potential effects from additional hypothetical ground-water withdrawals from the lower alluvium. The model was discretized into a 70-row by 68-column grid using cells measuring 200 feet by 200 feet. Three model layers were used to represent flow in the upper part of the alluvium, lower part of the alluvium, and bedrock. The primary sources of ground water to the alluvium were subsurface flow from areas of the alluvium adjacent to the modeled area, recharge from precipitation, subsurface flow from Flint River stream-channel deposits adjacent to the alluvium, and river leakage. The primary components of outflow from the flow system were river leakage, municipal ground-water withdrawals (pumpage), and leakage to drainage ditches.

Three hypothetical pumping scenarios were used to assess the potential effects of increased ground-water withdrawals from the lower part of the alluvium: (1) pumping a second existing municipal well at a rate of 0.5 million gallons per day, (2) pumping a hypothetical well completed in an area between the city water-treatment facility and Flint River at a rate of 1.0 million gallons per day, and (3) pumping a hypothetical well completed in an area south of the Flint River at a rate of 1.0 million gallons per day. Maximum additional simulated draw-down in the upper alluvium ranged from less than 3 feet (for scenario 1) to about 9 feet (for scenario 3). Maximum additional simulated drawdown in the lower alluvium ranged from about 12 feet (for scenario 1) to about 34 feet (for scenario 3). Water budgets for each scenario indicated future additional withdrawals from the flow system near Burlington's existing municipal wells would significantly increase the amount of river leakage into the flow system.

Water samples collected from the alluvium indicated ground water can be classified as a calcium-magnesium-bicarbonate type. Reducing conditions likely occur in some localized areas of the alluvium, as suggested by relatively large concentrations of dissolved iron (4,390 micrograms per liter) and manganese (2, 430 micrograms per liter) in some ground-water samples. Nitrite plus nitrate was detected at concentrations greater than or equal to 8 milligrams per liter in three samples collected from observation wells completed in close proximity to cropland; the

nitrite plus nitrate concentration in one ground-water sample exceeded the U.S. Environmental Protection Agency Maximum Contaminant Level for nitrate in drinking water (10 milligrams per liter as N). Triazine herbicides (atrazine, cyanazine, propazine, simazine, and selected degradation products) and chloroacetanilide herbicides (acetochlor, alachlor, and metolachlor) were detected in some water samples. A greater number of herbicide compounds were detected in surface-water samples than in ground-water samples. Herbicide concentrations typically were at least an order of magnitude greater in surface-water samples than in ground-water samples. The Maximum Contaminant Level for alachlor (2 micrograms per liter) was exceeded in a sample from Dry Branch Creek at Tama Road and for atrazine (3 micrograms per liter) was exceeded in samples collected from Dry Branch Creek at Tama Road and the county drainage ditch at Tama Road.

INTRODUCTION

The City of Burlington, Iowa, obtains much of its public water supply by withdrawing surface water from the Mississippi River. The remainder of the public water supply is obtained by pumping ground water from the Mississippi River alluvium, an alluvial aquifer adjacent to the Mississippi River. The city uses a maximum of about 6 Mgal/d for public water supply; about 1.3 Mgal/d is ground water and the remainder is surface water withdrawn from the Mississippi River. City of Burlington water managers are considering options to pump more ground water from the alluvium to decrease the amount of surface water used for public water supply. Increasing the amount of ground water used for public water supply likely will reduce water-treatment costs because ground water has lower turbidity and organic-carbon concentration than river water, provides a water supply with more consistent water quality, and reduces the risk posed to the safety of the public water supply by accidental releases of hazardous substances to the Mississippi River.

The U.S. Geological Survey (USGS), in cooperation with the City of Burlington, conducted a hydrologic study of the Mississippi River alluvium near Burlington to improve understanding of the ground-water system. The purposes of this study were (1) to evaluate the shallow ground-water flow system and identify sources of water to the Mississippi River alluvium near Burlington under current (1999) pumping conditions, (2) to evaluate the effects of hypothetical pumping scenarios on the shallow ground-water flow system in the alluvium, and (3) to assess the occurrence of selected water-quality constituents in the alluvium. Results of the study also will help contribute to a better understanding of ground-water systems in similar alluvial settings.

Purpose and Scope

The purpose of this report is to present results of the study. The report contains a description of a computer model constructed to help conceptualize the ground-water flow system; results of model simulations used to identify sources of water to the alluvium and to assess the potential effects of hypothetical additional ground-water withdrawals from the alluvium; and the results of chemical analyses of water samples collected from the study area. Hydrogeologic and water-quality data used in this report were collected from January to November 1999.

Description of Study Area

The study area covers about 7 mi^2 along the Mississippi River in southeastern Iowa (fig. 1). Most of the study area is within Des Moines County, Iowa, but the southeastern part of the study area extends into the main channel of the Mississippi River beyond the Iowa-Illinois border. The topography consists of a relatively flat alluvial plain bounded by steep bluffs that separate the alluvial valley deposits from upland areas. The alluvium on the Iowa side of the Mississippi River narrows in width from about 7,000 ft near the northern part of the study area to less than 1,000 ft along the southern part of the study area. Land-surface altitude in the alluvial valley within the study area ranges between about 520 ft to about 550 ft above sea level and increases to about 700 ft above sea level along the upland areas.

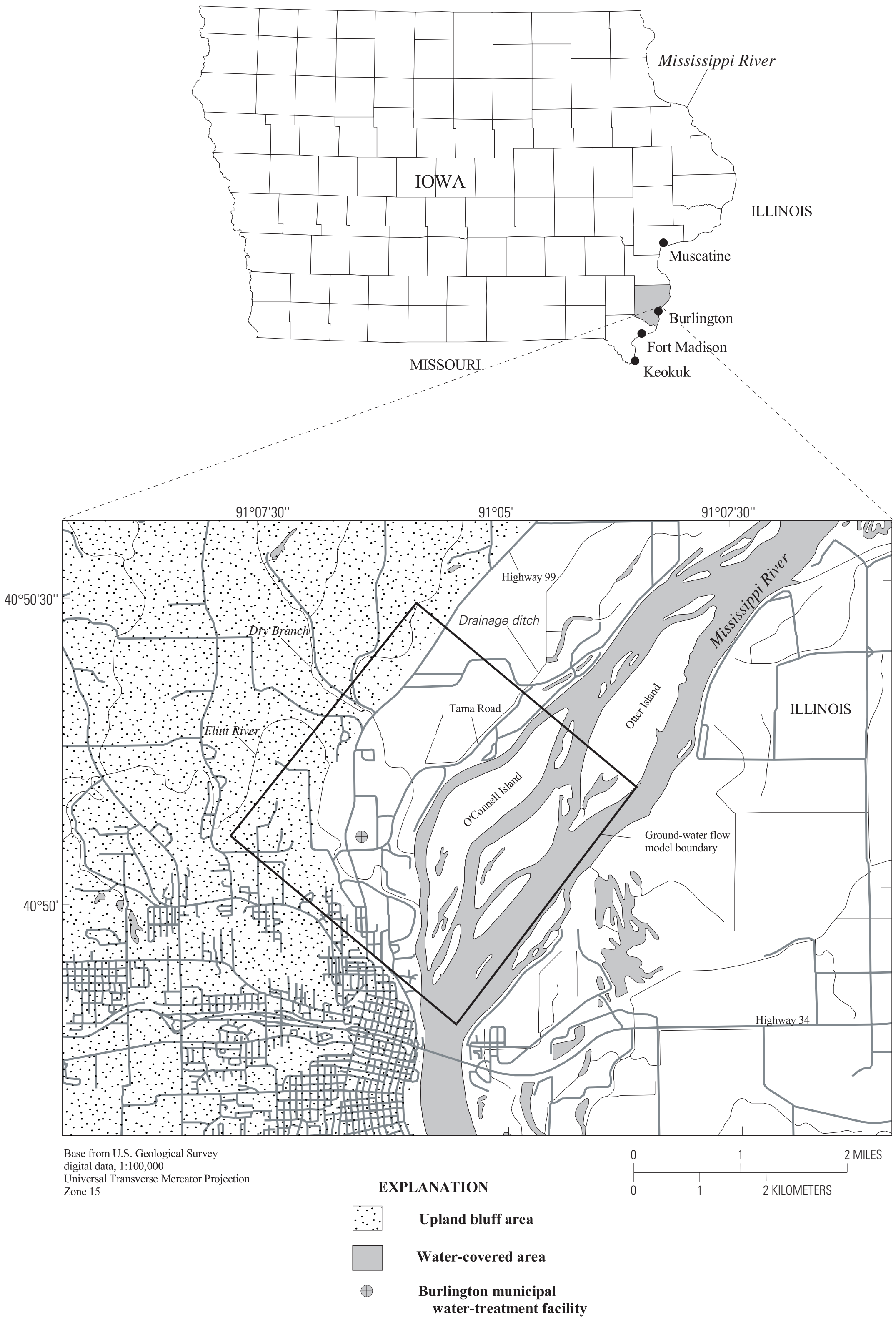


Figure 1. Location of study area and ground-water flow model boundary near Burlington, Iowa.

Southeastern Iowa has a typical subhumid, continental climate. Mean monthly temperatures at Burlington range between 21.8°F in January to 75.7°F in July (National Oceanic and Atmospheric Administration, electronic data accessed at http://www.crh.noaa.gov on November 26, 1999). Mean annual precipitation for 1961–90 was 36.06 inches. Much of the precipitation is produced by thunderstorms in spring and summer months. Mean monthly precipitation ranges from 1.16 inches during February to 4.24 inches during July (National Oceanic and Atmospheric Administration, electronic data accessed at http://www.crh.noaa.gov on November 26, 1999).

The area north of Flint River (also known as Flint Creek) is primarily used for rural housing and row-crop agriculture. Corn and soybeans are the primary crops. The area south of the Flint River and east of Highway 99 is used for industrial activity. The industrial activity includes facilities for agricultural equipment manufacturing, wicker basket and furniture manufacturing, agricultural fertilizer distribution, and liquid propane-gas distribution. Rural residences are present throughout the study area, with suburbanized areas located on the upland areas outside of the alluvial valley. Des Moines County had an estimated population of 42,400 in 1998; the cities of Burlington and West Burlington had a combined population of about 31,000 (Burlington/West Burlington Area Chamber of Commerce, electronic data accessed at http://www.growburlington.com on July 14, 2000).

The eastern part of the study area includes the Mississippi River. Several islands and sandbars in the Mississippi River create side channels within the study area. The side channels are well connected to the main river channel. Total width of the main river channel and side channels (including intervening islands and sandbars) ranges between about 3,000 ft and 8,000 ft near the study area. The U.S. Army Corps of Engineers facilitates commercial navigation along the upper Mississippi River by controlling river stage with a series of lock and dam structures and maintaining channel depth with dredging operations. Lock and Dam No. 18 is located about 6 mi upriver from Burlington, beyond the northern boundary of the study area. Lock and Dam No. 19 is located near Keokuk, Iowa, about 40 mi downriver from Burlington.

A system of levees extending along the Mississippi River protects low-lying areas of the river valley from flooding. Natural drainage to the Mississippi River is limited by the levee system. A system of drainage ditches has been constructed in the river valley to facilitate drainage and maintain water levels in the alluvium that are favorable to row-crop agriculture. During wet periods, water is pumped from the drainage ditches into the Mississippi River.

METHODS OF INVESTIGATION

Several types of data were collected during the study to help define the hydrogeology of the Mississippi River alluvium, to assist in constructing a ground-water flow model, and to evaluate selected water-quality constituents in ground water within the study area. Data-collection locations included ground-water observation wells and surface-water sites (fig. 2). During the study, ground-water observation wells were installed, ground-water levels were measured, streamflow and stream stages were measured, aquifer tests were conducted to determine hydraulic properties, and water-quality samples were collected and analyzed.

Well Construction and Nomenclature

Fourteen ground-water observation wells were installed in December 1998. The observation wells were installed as groups of two wells at seven separate locations within the study area. One observation well at each location was installed at a relatively shallow depth (about 40 ft below land surface) in the upper part of the alluvium (hereinafter referred to as the upper alluvium); the other observation well was installed at a greater depth (between 85 and 140 ft below land surface) in the lower part of the alluvium (hereinafter referred to as the lower alluvium).

Thirteen of the wells were installed using 4.25-inch inside-diameter continuous-flight hollow-stem auger drilling; one well, BMW–1(140), was installed using direct mud-rotary drilling. Samples of drill cuttings returned to land surface were collected at about 10-ft intervals or upon a major change in lithology. Wells were constructed with 2-inch outside-diameter polyvinyl-chloride (PVC) casing and screen. The screen length was 2.5 ft and the screen-slot size was 0.020 inch. A filter pack of clean, coarse sand was placed in the annular space adjacent to the screened interval. A bentonite-grout seal was placed above the filter pack. The remaining annular space was

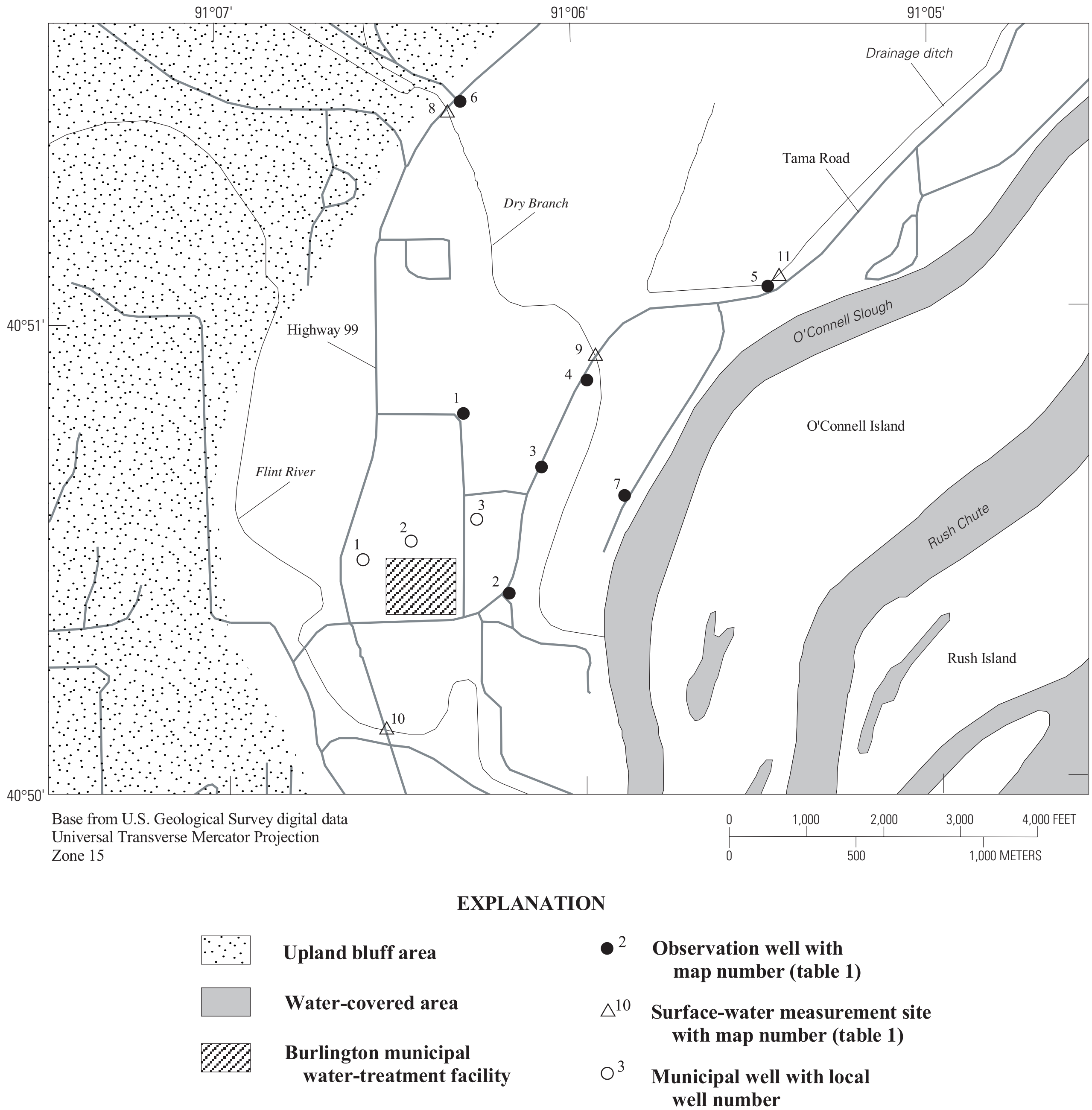


Figure 2. Location of measurement and sampling sites in the study area near Burlington, Iowa, 1999.

backfilled with natural aquifer material to within 3 ft of land surface. A bentonite seal and concrete pad were placed in the upper 3 ft of the borehole. Wells were secured by placing a locking steel protective cover in the concrete pad.

Wells were developed by airlifting. Observation well groups were surveyed with a global positioning system to determine location (latitude and longitude). Conventional surveying methods were used to establish vertical control (referenced to sea level) for each observation well. Table 1 lists data-collection sites in the study area and well-construction information. Observation wells are designated by a local site name (for example, BMW–1(32), where "BMW" indicates Burlington Municipal Wellfield, "1" indicates the well-group number, and "(32)" indicates the total depth of the well). Observation wells also are designated by a unique 15-digit station-identification number that was assigned in the USGS Ground-water Site Information data base (for example, the station-identification number for site BMW–1(32) is 405052091062102).

Ground-Water-Level Measurements

Ground-water levels in each observation well were measured monthly with a calibrated electronic tape. Ground-water levels were recorded to the nearest 0.01 ft. Data were used to assess seasonal variations in horizontal and vertical components of flow directions, to help conceptualize the ground-water flow system, and to help calibrate the ground-water flow model.

Aquifer Properties

Fourteen slug tests, one in each observation well, were conducted to estimate horizontal hydraulic conductivity of the geologic material adjacent to the screened interval of the well. In this report, hydraulic conductivity will refer to horizontal hydraulic conductivity unless specifically referenced as vertical hydraulic conductivity. During a slug test, water-level changes are measured in a well after displacing the initial water level by introducing or removing a slug of water or material. Slugs constructed of sand-filled 1.25-inch outside-diameter PVC pipe were used to displace the static water level in observation wells. Several different slugs (each constructed to displace 1 ft to 3 ft of water) were used to conduct the slug

Table 1. Data-collection sites and observation-well construction information for the hydrologic study of the Mississippi River alluvium near Burlington, Iowa, 1999

[LSD, land-surface altitude in feet above sea level (no value to the right of decimal point indicates elevation estimated from U.S. Geological Survey 7.5-minute Burlington quadrangle topographic map); MP, measuring-point altitude in feet above sea level; NA, not applicable]

Site name [and map number (fig. 2)]	Station identification number	LSD	MP	Total well depth (feet below land surface)	Depth (in feet below land surface) of screened interval (top/bottom)
BMW–1(32) [1]	405052091062102	539.10	541.65	32	29.5/32
BMW–1(140) [1]	405052091062101	539.10	541.88	140	137.5/140
BMW–2(41) [2]	405028091061402	534.49	537.64	41	38.5/41
BMW–2(136) [2]	405028091061401	534.49	537.42	136	133.5/136
BMW–3(37) [3]	405044091060802	533.56	537.09	37	34.5/37
BMW–3(85) [3]	405044091060801	533.56	537.03	85	82.5/85
BMW–4(37) [4]	405055091060002	532.02	535.04	37	34.5/37
BMW–4(101) [4]	405055091060001	532.02	535.08	101	98.5/101
BMW–5(36) [5]	405106091052802	522.43	525.21	36	33.5/36
BMW–5(136) [5]	405106091052801	522.43	525.17	136	133.5/136
BMW–6(38) [6]	405132091062002	554.66	558.00	38	35.5/38
BMW–6(127) [6]	405132091062001	554.66	557.63	127	124.5/127
BMW–7(40) [7]	405040091055402	526.72	529.23	40	37.5/40
BMW–7(102) [7]	405040091055401	526.72	529.74	102	99.5/102
Dry Branch Creek at Highway 99 [8]	05469670	NA	560.89	NA	NA
Dry Branch Creek at Tama Road [9]	05469680	NA	542.25	NA	NA
Flint Creek at Highway 99 [10]	05469710	NA	543.29	NA	NA
County drainage ditch at Tama Road [11]	05469650	NA	523	NA	NA

tests. Water-level changes were measured with pressure transducers and data recorders. Water levels initially were recorded at 2-second intervals, but the recording interval was gradually increased as the slug-test duration increased. The hydraulic conductivity was calculated according to the Bouwer and Rice method for partially penetrating wells (Bouwer, 1989).

Water-Quality Sampling and Analyses

Ground-water and surface-water samples for chemical analyses were collected May 20 and May 21, 1999. Results were used to assess areal variability of constituent concentrations and to identify areas where selected constituents occur at concentrations that may be undesirable for public water supplies. Acid-neutralizing capacity (alkalinity), dissolved oxygen, pH, specific conductance, and water temperature were measured with portable instruments in the field at the time of sampling. Samples were analyzed for the following dissolved constituents at the USGS National Water-Quality Laboratory in Arvada, Colorado, using methods documented by Fishman and Friedman (1989) for common ions (bromide, calcium, chloride, fluoride, iron, magnesium, manganese, potassium, silica, sodium, and sulfate), nutrients (ammonia nitrogen, ammonia plus organic nitrogen, nitrite nitrogen, nitrite plus nitrate nitrogen, phosphorus, and orthophosphorus); and using methods documented by Sandstrom and others (1994) for pesticides and pesticide-degradation products (acetochlor, alachlor, ametryn, atrazine, bromacil, butachlor, butylate, carboxin, cyanazine, cycloate, deethylatrazine, deisopropylatrazine, diphenamid, hexazinone, metolachlor, metribuzin, prometon, prometryn, propachlor, propazine, simazine, simetryn, terbacil, trifluralin, and vernolate).

Eleven ground-water samples were collected with a submersible pump after purging about three borehole volumes from the observation well. Several observation wells were pumped dry before three borehole volumes were removed; these wells were allowed to recover overnight and water samples were collected the following day. One field-replicate sample was collected from BMW–1(32). Two surface-water samples were collected with a submersible pump near the channel centroid. Samples for analyses of dissolved inorganic constituents were filtered inline with a disposable, 0.45-micrometer pore-size, cellulose-fiber filter. Samples for analyses of pesticides were filtered inline with a 0.45-micrometer pore-size, glass-fiber filter in a stainless-steel filter plate. Samples for analyses of calcium, iron, magnesium, manganese, potassium, silica, and sodium were preserved with nitric acid. Samples for analyses of bromide, chloride, fluoride, sulfate, nutrients, and pesticides were not chemically preserved. All water samples were chilled during transport from the field and shipment to the laboratory.

HYDROGEOLOGY

Hydrogeologic information pertinent to the study of the ground-water flow system and construction of the ground-water flow model is presented below. The geology of eastern Iowa is discussed in more detail in reports by Parker (1971), Hansen (1972), Anderson (1983), Horick (1984), and Prior (1991). Geologic units within the study area and their water-bearing characteristics are summarized in table 2.

Geology and Water-Bearing Characteristics

The Mississippi River alluvium consists of unconsolidated deposits of sand, gravel, silt, and clay. The deposits are of fluvial and glaciofluvial origin. The alluvium has a thickness of about 140 to 150 ft in the study area. Three distinct zones occur within the alluvium: (1) an upper zone with a thickness of about 40 ft; (2) an intervening zone of clay and glacial till with a thickness of about 20 to 30 ft; and (3) a lower zone with a thickness of about 80 ft. The intervening layer of clay and glacial till is assumed to occur throughout the modeled area but was thin or absent in the borehole drilled to install observation well BMW–1(140). Relatively few water-supply wells are completed in the alluvium within the study area because most residences and businesses are connected to a rural water-supply system. The City of Burlington has three production wells completed in the lower alluvium. A trailer park east of Highway 99 and south of Dry Branch Creek obtains water from a well completed in the lower alluvium.

Table 2. Geologic units in the study area near Burlington, Iowa

[gal/min, gallons per minute]

System	Lithology	Water-bearing characteristics	Equivalent layer in the ground-water flow model
Quaternary	Unconsolidated deposits of sand, gravel, silt, glacial till, and clay	Burlington municipal wells yield 700–900 gal/min	Layer 1 (upper alluvium) Layer 2 (lower alluvium)
Mississippian	Limestone and dolomite with interbedded shale, mudstone, sandstone, chert, gypsum, and anhydrite	Limited permeability; domestic wells yield 5–15 gal/min; municipal wells yield 25 to 50 gal/min	Layer 3 (where present in the study area)
Devonian	Limestone and dolomite with interbedded shale, mudstone, chert, gypsum, and anhydrite	Limited permeability; where extensively fractured, domestic wells yield 10 to 30 gal/min and municipal wells yield 50 to 200 gal/min	Layer 3
Silurian	Dolomite with interbedded limestone, shale, and chert	Limited permeability; wells can yield 100 gal/min (or greater where extensively fractured)	Layer 3
Ordovician	Shale with interbedded dolomite	Regional confining unit	Basal confining unit (no flow boundary)

The alluvium is underlain by rocks of Mississippian and Devonian age that consist of limestone and dolomite with interbedded strata of shale, mudstone, chert, gypsum, and anhydrite. The rocks of Mississippian and Devonian age outcrop in the bluffs that separate the alluvial valley from the upland area. The Mississippian-age strata are 100 to 300 ft thick and the Devonian-age strata are 100 to 200 ft thick near the study area (Karsten and Burkart, 1985). The study area is near the contact between the Mississippian-age and Devonian-age strata, and it is possible that the Mississippian-age strata are not present in some parts of the study area. Rocks of Silurian age underlie the Mississippian- and Devonian-age strata near the study area. The Silurian-age deposits consist of dolomite with some interbedded limestone, shale, and chert and have a maximum thickness of about 250 ft (Karsten and Burkart, 1985; Lucey and others, 1995). There are no water-supply wells completed in the Mississippian-, Devonian-, and Silurian-age strata within the model area; ground water from these strata is not used because it typically has high dissolved-solids and sulfate concentrations (Karsten and Burkart, 1985).

The Maquoketa Formation of Ordovician age is a regional confining unit that underlies all of eastern Iowa. The Maquoketa Formation consists primarily of shale and is about 250 ft thick. The Maquoketa Formation hydraulically separates the overlying aquifers from a deeper system of regional aquifers of Ordovician and Cambrian age (Parker, 1971).

Surface Water

The Mississippi River is the major surface-water feature in the study area. The U.S. Army Corps of Engineers regulates the river stage with a series of lock and dam structures. Lock and Dam No. 18 is about 6 mi upriver from Burlington. Lock and Dam No. 19 is about 40 mi downriver at Keokuk, Iowa. The normal pool elevation between Lock and Dam No. 18 and No. 19 is 518 ft above sea level but was higher than this elevation during the period of study. The average gradient of the river surface between Burlington and Fort Madison, Iowa (about 19 mi downriver) is about 0.3 ft/mi. Figure 3 shows the Mississippi River stage at Burlington during 1999.

Flint River (also known locally as Flint Creek) is a perennial stream that delivers runoff from the bluffs west of the alluvial valley to the Mississippi River. Coble and Roberts (1971) estimated the total drainage area to be about 107 mi^2 and the annual average discharge rate to be 70 ft^3/s. A discharge of 39 ft^3/s was measured on June 23, 1999. The stage in

Flint Creek east of Highway 99 is affected by the Mississippi River and likely is in backwater for much of the year.

Dry Branch is an ephemeral stream that delivers runoff from the bluffs west of the alluvial valley to the Mississippi River. The channel is dry for most of the year, but discharge is observed after periods of significant rainfall. Discharge was measured in Dry Branch at Highway 99 and about 4,000 ft downstream at Tama Road three times from April to June 1999 (table 3). Dry Branch generally is a losing stream between Highway 99 and Tama Road, and some of the water in the stream infiltrates into the ground-water system.

Ground Water

Hydraulic conductivity describes the ability of geologic materials to transmit water. Hydraulic conductivity for unconsolidated materials (such as the Mississippi River alluvium) generally varies with particle size: clays and silts tend to have lower hydraulic conductivity values, whereas sands and gravels tend to have higher hydraulic conductivity values (Todd, 1980). The hydraulic conductivity for a 30-ft-thick zone of fine to coarse sand in the lower alluvium near Burlington municipal well 3 was estimated to be about 153 ft/d based on a pumping test (CH2M Hill, 1983). For this study, hydraulic conductivities in the Mississippi River alluvium were estimated with slug-test analyses in 14 observation wells (table 4). Estimated hydraulic conductivity values in the observation wells ranged over six orders of magnitude. The wide range in hydraulic conductivity values reflects the natural heterogeneity of geologic materials. Hydraulic conductivities used in the calibrated flow model differed from some of the estimated slug-test values.

Ground water in the upper alluvium is unconfined. Ground water in the lower alluvium is partially confined in most parts of the modeled area but may be unconfined in areas where the intervening clay and glacial till zone is thin or absent. Ground water in the underlying bedrock likely is confined in most parts of the modeled area. The direction of ground-water flow

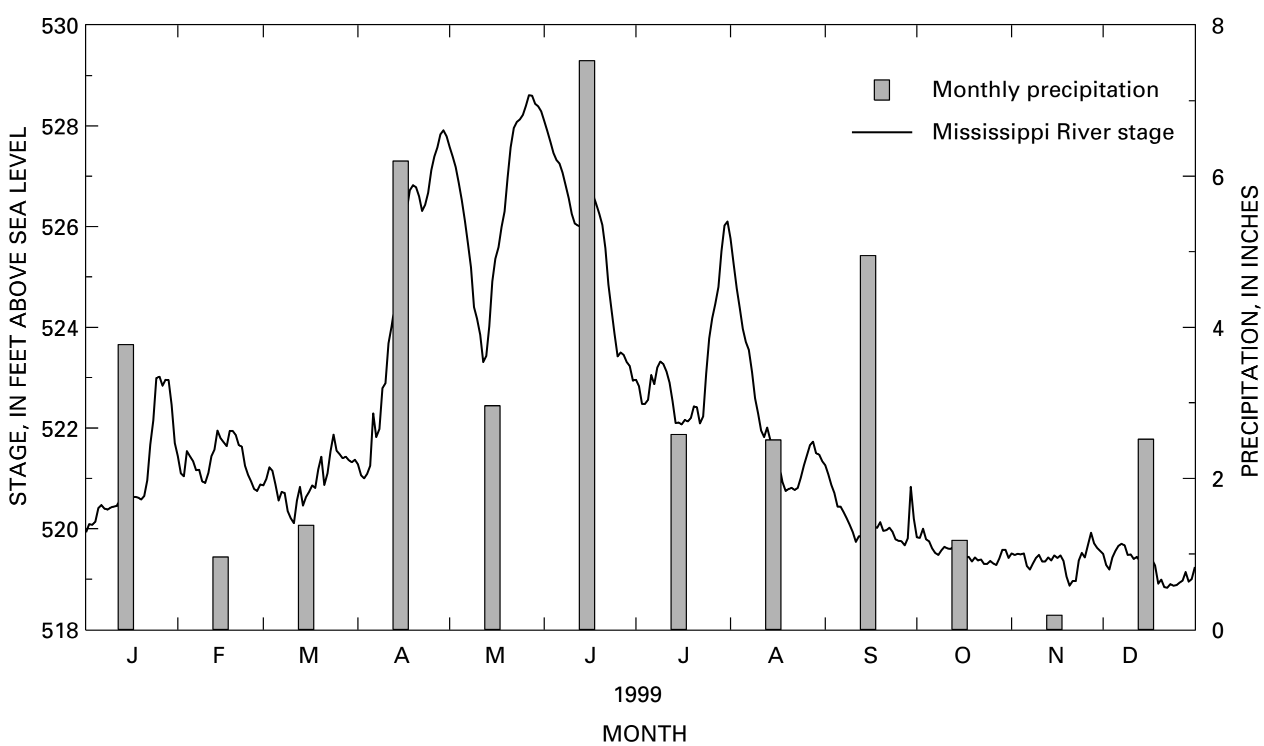


Figure 3. Mississippi River stage and monthly precipitation at Burlington, Iowa, 1999.

Table 3. Stream discharge and water loss in Dry Branch Creek between Highway 99 and Tama Road near Burlington, Iowa, April to June 1999

[mm–dd–yy, month-day-year; ft^3/s, cubic feet per second]

Date (mm–dd–yy)	Streamflow discharge: Dry Branch at Highway 99 (ft^3/s)	Streamflow discharge: Dry Branch at Tama Road (ft^3/s)	Stream-flow loss (ft^3/s)	Percent loss in stream-flow
04–15–99	6.2	4.8	1.4	23
05–11–99	2.8	1.9	0.9	32
06–23–99	1.9	1.4	0.5	26

in the alluvium generally is from the upland bluffs toward the Mississippi River except in local areas influenced by pumping of municipal wells. Some ground water likely flows down the alluvial valley (from north to south), as indicated by Lucey and others (1995) in a study of the alluvium near Muscatine, Iowa. The regional direction of ground-water flow in the underlying bedrock generally is from the northwest toward the southeast (Horick, 1984). A potentiometric surface map, based on measured water levels, is not presented because sufficient control points in the study area were lacking. Water levels measured in observation wells during the study are summarized in table 5 and listed in table 11 at the end of the report. Water levels in the upper and lower alluvium tended to be highest from May to July, a period corresponding to increased rainfall from thunderstorms and high Mississippi River stages; water levels tended to be lowest during the fall.

Inflows (recharge) to the saturated part of the alluvium in the study area include infiltration of precipitation, river leakage when river stages are greater than water-level altitudes in the alluvium, infiltration of runoff from adjacent upland areas, and subsurface flow from areas adjacent to the modeled area. Outflows (discharge) from the alluvium in the study area include municipal pumping, leakage to rivers and drainage ditches, subsurface flow to areas adjacent to the modeled area, and evapotranspiration during the growing season.

Table 4. Horizontal hydraulic conductivity values estimated with slug tests and used in the ground-water flow model for the Mississippi River alluvium near Burlington, Iowa, 1999

Site name [and map number (fig. 2)]	Lithology near screened interval of well	Horizontal hydraulic conductivity (feet per day): Estimated based on slug test	Horizontal hydraulic conductivity (feet per day): Value used in flow model cell
Upper alluvium			
BMW–1(32) [1]	Medium sand with gravel	76	55
BMW–2(41) [2]	Fine sand	0.32	2
BMW–3(37) [3]	Fine sand with till	18	15
BMW–4(37) [4]	Sandy clay	5.8	15
BMW–5(36) [5]	Fine to medium sand	58	70
BMW–6(38) [6]	Clay with sand	0.18	2
BMW–7(40) [7]	Fine sand	0.37	2
Lower alluvium			
BMW–1(140) [1]	Weathered shale	0.012	0.0025
BMW–2(136) [2]	Fine to medium sand with gravel	103	125
BMW–3(85) [3]	Medium sand with till	0.10	5
BMW–4(101) [4]	Till with sand	0.012	0.0025
BMW–5(136) [5]	Weathered shale with fine sand	0.015	0.05
BMW–6(127) [6]	Fine to medium sand	11	25
BMW–7(102) [7]	Fine sand	0.086	20

Table 5. Summary of ground-water levels measured in observation wells completed in the Mississippi River alluvium near Burlington, Iowa, 1999

[mm–dd–yy, month-day-year; feet asl, feet above sea level]

Site name [and map number (fig. 2)]	Highest water level			Lowest water level		
	Date (mm–dd–yy)	Depth to water (feet)	Altitude (feet asl)	Date (mm–dd–yy)	Depth to water (feet)	Altitude (feet asl)
			Upper alluvium			
BMW–1(32) [1]	06–23–99	11.59	527.51	11–18–99	16.93	522.17
BMW–2(41) [2]	05–20–99	7.35	527.14	11–18–99	13.68	520.81
BMW–3(37) [3]	05–19–99	6.71	526.85	11–18–99	12.48	521.08
BMW–4(37) [4]	05–20–99	6.02	526.00	11–18–99	11.51	520.51
BMW–5(36) [5]	07–30–99	2.64	519.79	11–18–99	4.80	517.63
BMW–6(38) [6]	06–23–99	26.28	528.38	03–19–99	28.92	525.74
BMW–7(40) [7]	07–30–99	4.29	522.43	11–18–99	10.22	516.50
			Lower alluvium			
BMW–1(140) [1]	06–23–99	12.59	526.51	10–13–99	16.54	522.56
BMW–2(136) [2]	01–19–99	19.54	514.95	03–19–99	29.15	505.34
BMW–3(85) [3]	07–30–99	26.20	507.36	01–19–99	31.37	502.19
BMW–4(101) [4]	06–23–99	8.15	523.87	11–18–99	10.32	521.70
BMW–5(136) [5]	05–19–99	1.13	521.30	11–18–99	2.89	519.54
BMW–6(127) [6]	06–23–99	30.34	524.32	11–18–99	32.49	522.17
BMW–7(102) [7]	07–30–99	13.88	512.84	01–19–99	19.06	507.66

SIMULATION OF GROUND-WATER FLOW

Ground-water flow in the study area was simulated with MODFLOW, a computer program developed by the USGS (McDonald and Harbaugh, 1988). MODFLOW simulates ground-water flow in three dimensions with a block-centered, finite-difference approach, which simultaneously solves a series of mathematical equations that represent saturated ground-water flow. The finite-difference equations were solved using the strongly implicit procedure.

A ground-water flow model is a simplified mathematical approximation of the physical flow system. The flow model for this study was used to help conceptualize the shallow ground-water flow system, identify sources of water to the Mississippi River alluvium, and evaluate the potential effects of hypothetical additional municipal ground-water withdrawals on the flow system. Limited onsite observations and hydrogeologic data were used to estimate hydraulic properties of the flow system. While adequate for the purposes of this study, the model likely is not suitable to conduct accurate predictive analyses because of the uncertainty associated with the estimated hydraulic properties.

The flow model was constructed by assuming steady-state conditions. Steady-state conditions occur when the volume of water flowing into the system equals the volume of water flowing out of the system. Hydrologic conditions within the study area in October 1999 were considered to be an acceptable estimate of steady-state conditions. Ground-water levels measured in observation wells in October 1999 were about the same as ground-water levels measured in September 1999 and November 1999 (table 11). Stage of the Mississippi River was relatively constant and there was relatively little rainfall during this time (fig. 3). Results of the ground-water flow model may not validly apply when steady-state conditions cannot be assumed. Steady-state conditions probably cannot be assumed during periods when ground-water levels rapidly change (such as during late spring and early summer when the Mississippi River stage rapidly changes or after large amounts of rainfall from thunderstorms).

The flow model was developed by conceptualizing the ground-water system on the basis of onsite observations and hydrogeologic data collected during the period of study, results from an exploratory study conducted in 1983 to select locations for the three municipal wells near the Burlington water-treatment plant (CH2M Hill, 1983), and the results of a ground-water flow model constructed by Lucey and others (1995) for an area of the Mississippi River alluvium near Muscatine, Iowa (about 45 miles north of Burlington). Spatial limits of the model were established by using existing natural hydrologic boundaries and defining distant boundaries for areas without existing natural boundaries. The Maquoketa Formation, a regional confining unit underlying the study area, was used as a boundary beneath the modeled area. The upland bluffs bordering the alluvial valley were used as lateral boundaries on the northwest, west, and southwest. The main channel of the Mississippi River was used as a lateral boundary for the upper alluvium on the east and southeast. Distant boundaries were specified to account for subsurface flow down the Mississippi River Valley from the northeast for the upper and lower alluvium; for subsurface flow through the lower alluvium from the east and southeast; and for subsurface flow through the bedrock from the northwest (the direction of regional ground-water flow in the bedrock). Most ground-water flow was assumed to occur in the alluvium rather than in adjacent, less permeable geologic units. The alluvium, rivers, and drainage ditches were assumed to be in hydraulic connection.

Model Description and Boundary Conditions

The modeled area was discretized into a 70-row by 68-column grid with cells measuring 200 ft by 200 ft. The model grid simulates an area of 14,000 ft by 13,600 ft, or about 7 mi^2. The principal axes of the grid were aligned with the trend of the bluffs that border the river valley. Three layers were used to simulate flow: layer 1 represents the upper alluvium, layer 2 represents the lower alluvium, and layer 3 represents the bedrock of Mississippian, Devonian, and Silurian age. Two layers were used to simulate flow in the alluvium because ground water for municipal supply is only pumped from the lower alluvium, differences were observed in hydraulic conductivities measured in the upper and lower alluvium, and the two zones are separated by a layer of clay and glacial till. The bedrock was included as a layer in the model because it could be a potential source for water pumped from the alluvium. Cells were identified by designating the row, column, and layer. Ground-water flow in layer 1 was simulated as unconfined, and ground-water flow in layer 2 and layer 3 was simulated as confined.

Boundary conditions were specified for the model (fig. 4) to simulate flow conditions along the periphery of the modeled area in relation to features within the modeled area. The upper surface of the flow model is a free surface that represents unconfined water-table conditions. Areal recharge to the upper surface of the flow model was represented with a specified-flux boundary. Areal recharge is discussed in more detail in the following section on "Model Parameters."

No-flow boundaries were used to simulate areas where ground-water flow was assumed not to occur or be insignificant. The bottom of the modeled area is at the top of the Maquoketa Formation, a relatively impermeable regional confining unit. The alluvial valley is bordered to the northwest, west, and southwest by upland bluffs consisting of glacial till and relatively impermeable interbedded limestone, dolomite, shale, and mudstone. The upland bluffs were simulated with no-flow boundaries because ground-water flow through the bluffs was considered to be insignificant.

Ground-water flow from areas adjacent to the model boundaries was simulated with a combination of general-head boundaries and specified-flux boundaries. General-head boundaries were used along the northeastern limit of layer 1 and layer 2 to simulate subsurface flow through the alluvium down the Mississippi River Valley; along the southeastern limit of layer 2 to simulate subsurface flow through the alluvium from the adjacent area in Illinois; and along the northwestern limit of layer 3 to simulate regional ground-water flow through the bedrock. The general-head boundary was used for these areas because the volumetric rate of ground water flowing into the modeled area was assumed to be limited in relation to the total water budget; because there were no data from outside the modeled area to estimate the ground-water flux across the boundaries; and to allow the head distribution to be changed as appropriate to conduct future modeling scenarios. For all general-head boundaries, a constant-head source was placed 1 mi from the closest active cell in the model. The hydraulic conductivity of the area between the constant-head source and the model

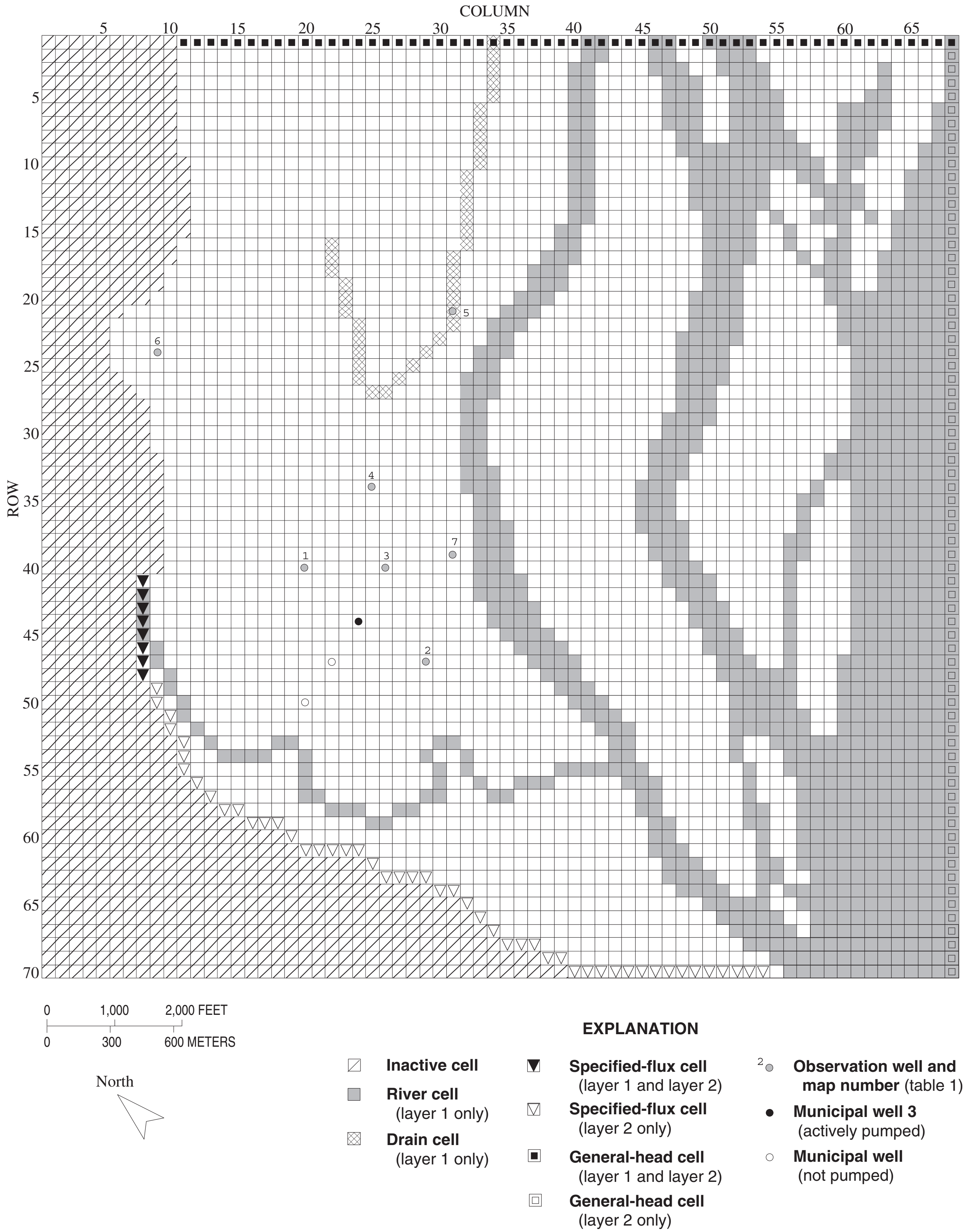


Figure 4. Model grid and boundary conditions used in layer 1 and layer 2 of the flow model for the Mississippi River alluvium near Burlington, Iowa, 1999.

boundary was assumed to be uniform and was set equal to the hydraulic conductivity of the adjacent active cell. Specified-flux boundaries were used to account for subsurface flow into layer 1 and layer 2 through Flint River stream-channel deposits adjacent to the modeled area and to account for subsurface flow into layer 2 along the upland bluff boundaries southwest of Flint River. Specified-flux boundaries were used because ground-water flow into the modeled area from these areas was assumed to be constant. The flux through layer-1 and layer-2 cells simulating flow through the Flint River stream-channel deposits was estimated by applying Darcy's Law and using the hydraulic conductivity of the adjacent active cell, an assumed hydraulic gradient of 0.015, and the cross-sectional area of the cell. The specified flux across layer-2 cells along the southwestern bluff boundaries was estimated during model calibration to be 10 percent of the flux through layer-2 cells simulating subsurface flow through the Flint River stream-channel deposits adjacent to the modeled area.

The Mississippi River, associated side channels, and Flint River were simulated by river cells that allow leakage to and from layer 1. The amount of leakage between the river cells and layer 1 is calculated using the head difference between the river cells and layer 1 and a streambed conductance term. A stage of 519.5 ft above sea level, the average stage of the Mississippi River at Burlington recorded during October 1999 by the U.S. Army Corps of Engineers (fig. 3), was assigned to each river cell for the Mississippi River and associated side channels. A uniform stage was used for these river cells because a pool elevation is maintained for navigation on the Mississippi River. The Flint River stage was measured at Highway 99 and was estimated elsewhere from the USGS Burlington 7.5-minute topographic map. The streambed conductance term, which generally is impractical to determine directly, is a function of the streambed material thickness, the vertical hydraulic conductivity of the streambed material, and the length and width of the channel. A streambed thickness of 1 ft was assumed for all river cells. The vertical hydraulic conductivity of streambed material was unknown. A vertical hydraulic conductivity value of 2 ft/d was assumed for streambed material in the Flint River and in side channels of the Mississippi River, and a value of 4 ft/d was assumed for streambed material in the main channel of the Mississippi River. A larger vertical hydraulic conductivity was assumed for the main channel of the Mississippi River because it is periodically dredged to maintain navigation.

The drainage ditch in the northwestern part of the study area was simulated with drain cells. Drain cells are similar to river cells but only allow leakage from layer 1 to the drain cell. It was assumed that flow in the drainage ditch primarily is from ground water. Ditch location was estimated from the USGS Burlington 7.5-minute topographic map. A streambed thickness of 1 ft and a vertical hydraulic conductivity value of 2 ft/d were assumed to calculate drain conductance for all drain cells.

Model Parameters

Model parameters are variables assigned to individual cells in the model array and are used in the flow equations that simulate ground-water flow within the modeled area. Parameters are assigned to the node at the center of each active cell and represent an average value for the entire cell. Parameters were used in the model to represent horizontal and vertical hydraulic conductivity, recharge by areal precipitation, and ground-water discharged from the flow system.

Transmissivity (hydraulic conductivity times the saturated thickness) is used by the model to solve the ground-water flow equations. Constant transmissivity values could not be specified for layer-1 cells because the saturated thickness in layer 1 fluctuates with the water table. Hydraulic conductivity was specified for each cell in layer 1 (fig. 5) and the model calculated the corresponding transmissivity. Transmissivity was specified for each cell in layer 2 (fig. 6) by multiplying hydraulic conductivity by an assumed layer thickness of 80 ft. Hydraulic conductivities in layer 1 and layer 2 near observation wells were initially estimated from slug-test results; hydraulic conductivities in areas not in the vicinity of observation wells were initially assigned arbitrary values within reasonable limits. All hydraulic conductivity values were adjusted as the model was calibrated. A transmissivity of 0.3 ft^2/d was specified for all cells in layer 3 by assuming a total thickness of 300 ft for the underlying bedrock of Mississippian, Devonian, and Silurian age, and assuming a hydraulic conductivity of 0.001. The uniform transmissivity applied to layer 3 was based on slug-test results and hydrogeologic data collected and analyzed by Lucey and others (1995) for a flow model constructed for the Mississippi River alluvium under similar conditions in Muscatine, Iowa (about 45 miles north of the Burlington study area).

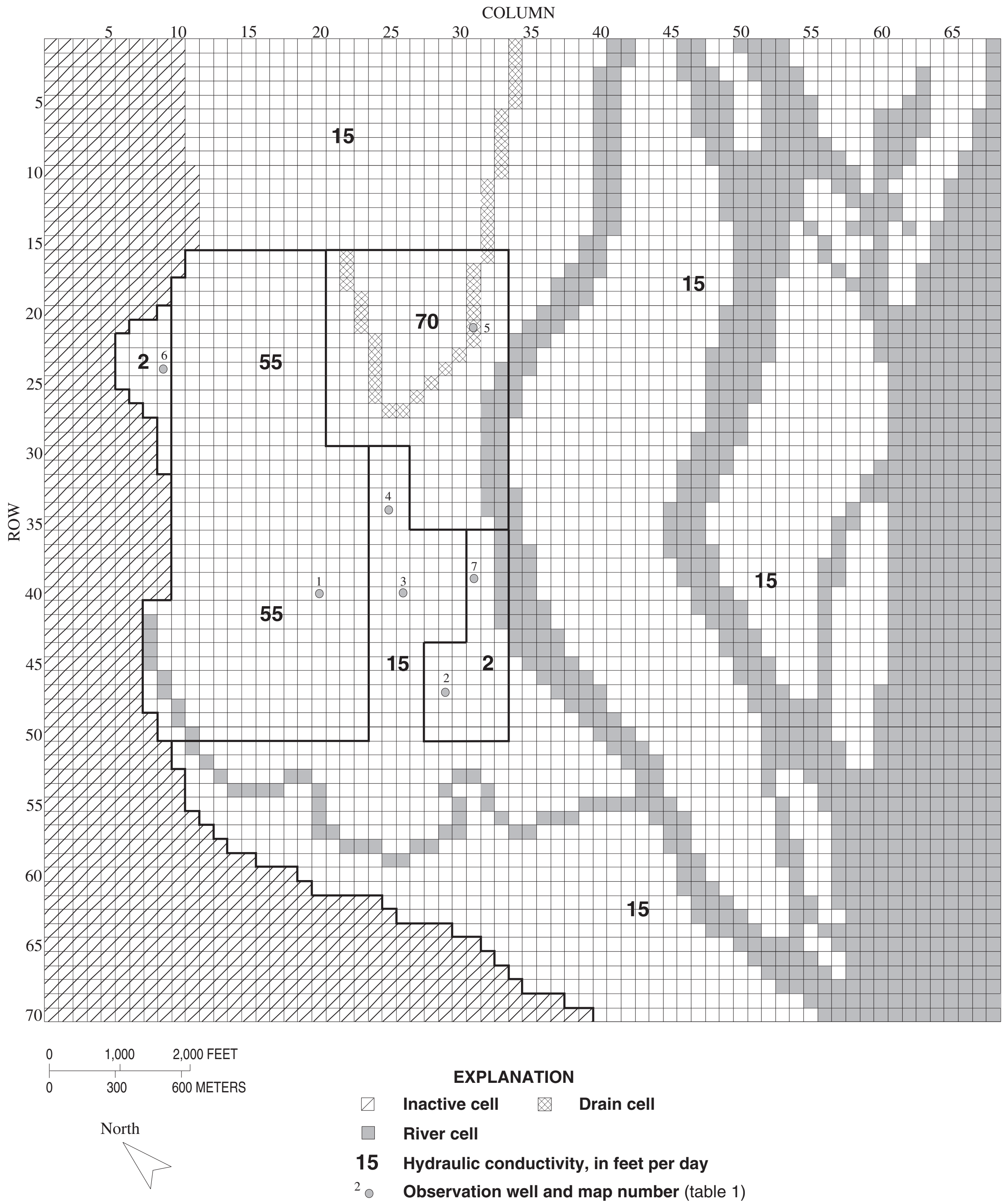


Figure 5. Horizontal hydraulic conductivity assigned to cells in layer 1 of the flow model for the Mississippi River alluvium near Burlington, Iowa, 1999.

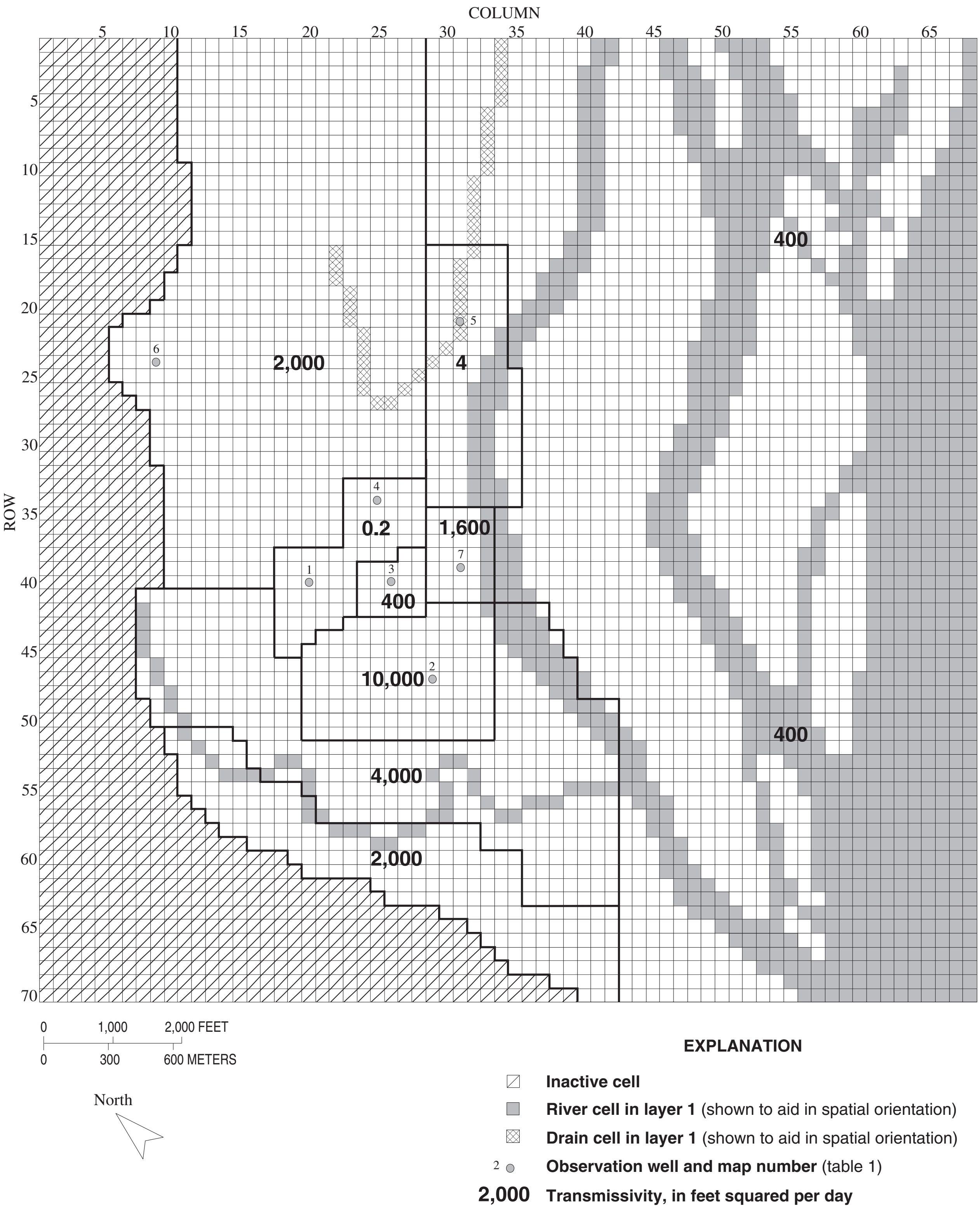


Figure 6. Transmissivity assigned to cells in layer 2 of the flow model for the Mississippi River alluvium near Burlington, Iowa, 1999.

The rate of vertical flow between model layers is controlled by vertical conductance. Vertical conductance is computed by multiplying the area of each cell by the vertical leakance. The vertical leakance in layer 1 and layer 2 for an area about 100 to 300 ft south of Burlington municipal well 3 (at row 44, column 24 in the model grid) was estimated by CH2M Hill (1983) to be between 0.000088/day and 0.00072/day based on a pumping test. The vertical leakance between layer 1 and layer 2 in other areas of the model initially was estimated using equation 52 specified in McDonald and Harbaugh (1988) for two adjacent model layers separated by a confining unit. Vertical leakance between layer 1 and layer 2 (fig. 7) was adjusted during model calibration. Adjustment of the vertical leakance is valid because of uncertainty in the vertical hydraulic conductivities of each model layer and the confining unit. A uniform vertical leakance of 0.000007/day was applied between layer 2 and layer 3 and was calculated using equation 51 specified in McDonald and Harbaugh (1988) for two adjacent model layers in direct contact.

A net recharge rate of 0.0014 ft/d (0.5 ft/yr) was used in the model to account for precipitation infiltrating to the water table. Hansen and Steinhilber (1977) analyzed hydrographs over an 8-year period (1964–71) from two wells in alluvium near Muscatine, Iowa, and estimated the annual net recharge to the water table to be 0.5 ft/yr. Karsten and Burkart (1985) indicated that recharge to alluvial aquifers in Iowa typically is between 10 to 20 percent of annual precipitation; the annual precipitation at Burlington is about 36 inches, so the recharge rate would be estimated as between 0.3 ft/yr and 0.6 ft/yr.

Types of discharge from the flow system included in the model were ground-water pumpage, river and drain leakage, and flow across general-head boundaries. For most of the period of data collection for this study, the city pumped only one of its three municipal wells (municipal well 3 at row 44, column 24 in the model grid) at a relative constant rate of 1.3 Mgal/d (Tim Mellinger, City of Burlington, oral commun., September 1999). Fluxes from river leakage, drain leakage, and flow across general-head boundaries were calculated by the model. Evapotranspiration was not considered as a significant type of discharge because flow conditions were evaluated at the end of the growing season for crops and natural vegetation.

Model Calibration

Model calibration is a process in which the differences between model-calculated ground-water levels and measured ground-water levels are minimized by adjusting model parameters. Ground-water levels measured on October 13, 1999, were used as a basis for calibration. Hydraulic conductivity, vertical leakance, drain and streambed conductance, and flow across model boundaries were varied, within reasonable limits, during numerous simulations until the differences between measured water levels and simulated water levels in respective corresponding model cells were less than 1 ft. Model calibration was further refined by continuing to vary model parameters until the average head difference (AVEH) and root-mean-square error (RMSE) were minimized. The AVEH is an indicator of systematic error and is the sum of the differences between simulated and measured water levels divided by the total number of measurements. The RMSE (eq. 1) indicates the magnitude of error between simulated and measured values.

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

where

- M is the measured water level,
- S is the water level simulated by the model, and
- N is the number of observations.

Table 6 lists water levels measured in observation wells on October 13, 1999, and water levels simulated by the calibrated model. The AVEH for the calibrated model was 0.025 ft. The RMSE for the calibrated model was 0.26 ft. The discrepancy between simulated and measured water levels likely results from the fact that the model is a simplified representation of a complex ground-water system. For example, the model represents heterogeneous aquifer properties with discretized model parameters estimated from few onsite measurements. The simulated potentiometric surface for layer 1 is shown in figure 8 and for layer 2 is shown in figure 9.

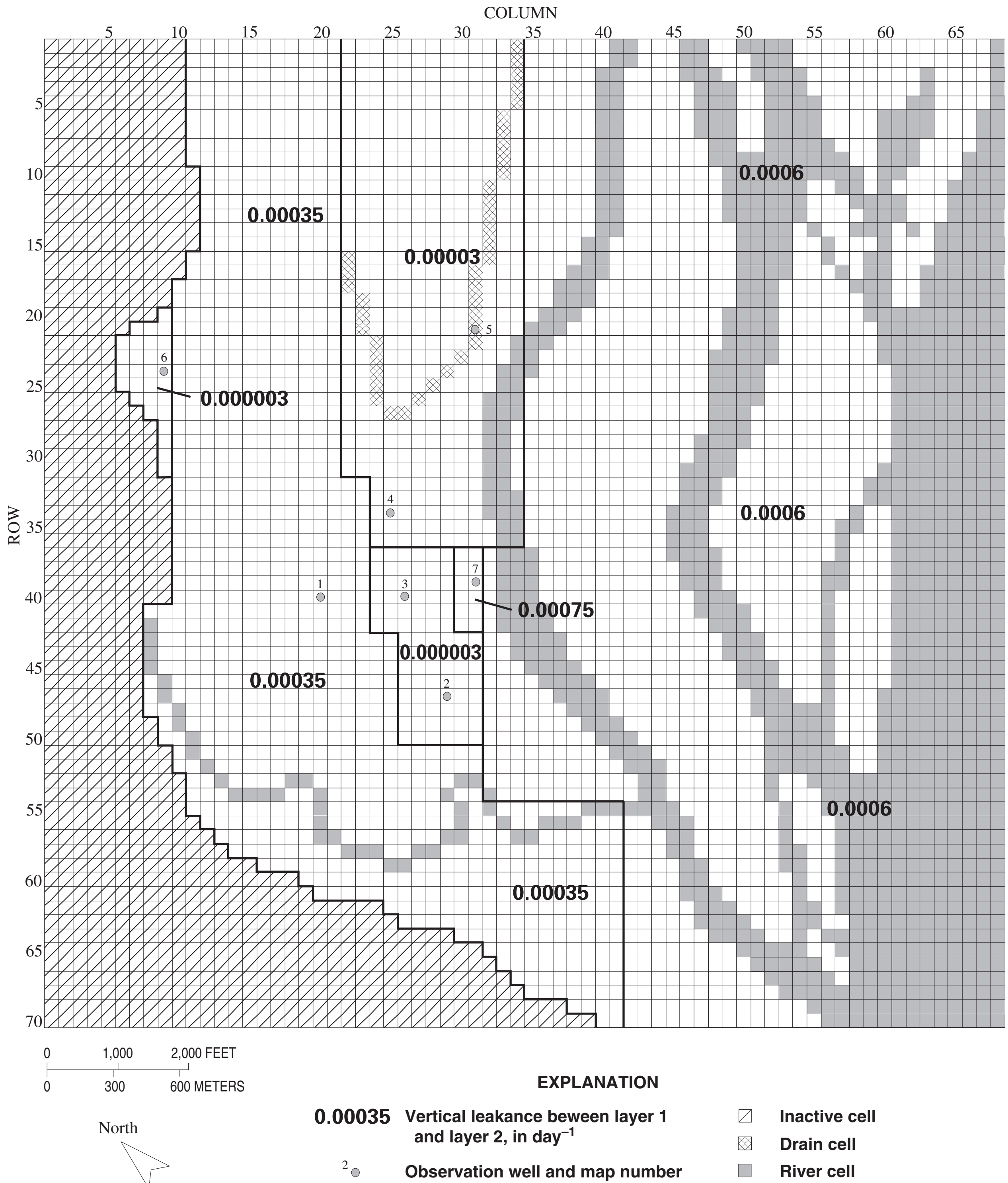


Figure 7. Vertical leakance assigned to cells between layer 1 and layer 2 of the flow model for the Mississippi River alluvium near Burlington, Iowa, 1999.

Table 6. Ground-water levels measured in observation wells near Burlington, Iowa on October 13, 1999, and simulated by using the ground-water flow model

[All water levels in feet above sea level]

Site name [and map number (fig. 2)]	Water-level altitude (feet above sea level)	
	Measured on October 13, 1999	Simulated by flow model
	Upper alluvium	
BMW–1(32) [1]	522.63	522.1
BMW–2(41) [2]	521.47	521.6
BMW–3(37) [3]	521.54	521.2
BMW–4(37) [4]	520.96	521.1
BMW–5(36) [5]	517.77	518.0
BMW–6(38) [6]	526.28	526.3
BMW–7(40) [7]	516.71	517.0
	Lower alluvium	
BMW–1(140) [1]	522.56	522.1
BMW–2(136) [2]	505.86	506.4
BMW–3(85) [3]	503.28	503.5
BMW–4(101) [4]	521.99	521.0
BMW–5(136) [5]	519.78	519.5
BMW–6(127) [6]	522.40	522.5
BMW–7(102) [7]	508.42	509.1

Sensitivity Analysis

The model was constructed using a set of model parameters to solve mathematical equations that simulate the ground-water flow system in the alluvium in the study area. Uncertainty exists in the ground-water flow model because a limited amount of collected data was used to estimate the model parameters. The effect of this uncertainty on the flow model was evaluated by independently varying selected model parameters and observing the sensitivity of model response. Each model parameter was varied by factors of one-half and two. Model sensitivity was measured with the RMSE (eq. 1) using the difference between simulated and measured ground-water levels in layer 1 and layer 2 (table 7).

Water levels were sensitive to transmissivity in layer 2, hydraulic conductivity in layer 1, vertical conductance between layer 1 and layer 2, and areal recharge. Water levels were insensitive to streambed conductance in the Mississippi River and associated side channels, streambed conductance in Flint River, and drain conductance.

The sensitivity of the model to the general-head boundaries used to simulate flow into the modeled area from adjacent areas of the alluvium was evaluated. The hydraulic conductivity values used to calculate conductance terms for the general-head boundaries were increased and decreased, and the change in flow across the general-head boundaries was compared to the total volume of water entering the modeled area. In the calibrated model, general-head boundaries contribute 50.5 percent of the total inflow. When the hydraulic conductivity values of these general-head boundaries were increased by a factor of two, general-head boundaries contributed 52.9 percent of the total inflow. When the hydraulic conductivity values were decreased by a factor of two, general-head boundaries contributed 46.5 percent of the total inflow.

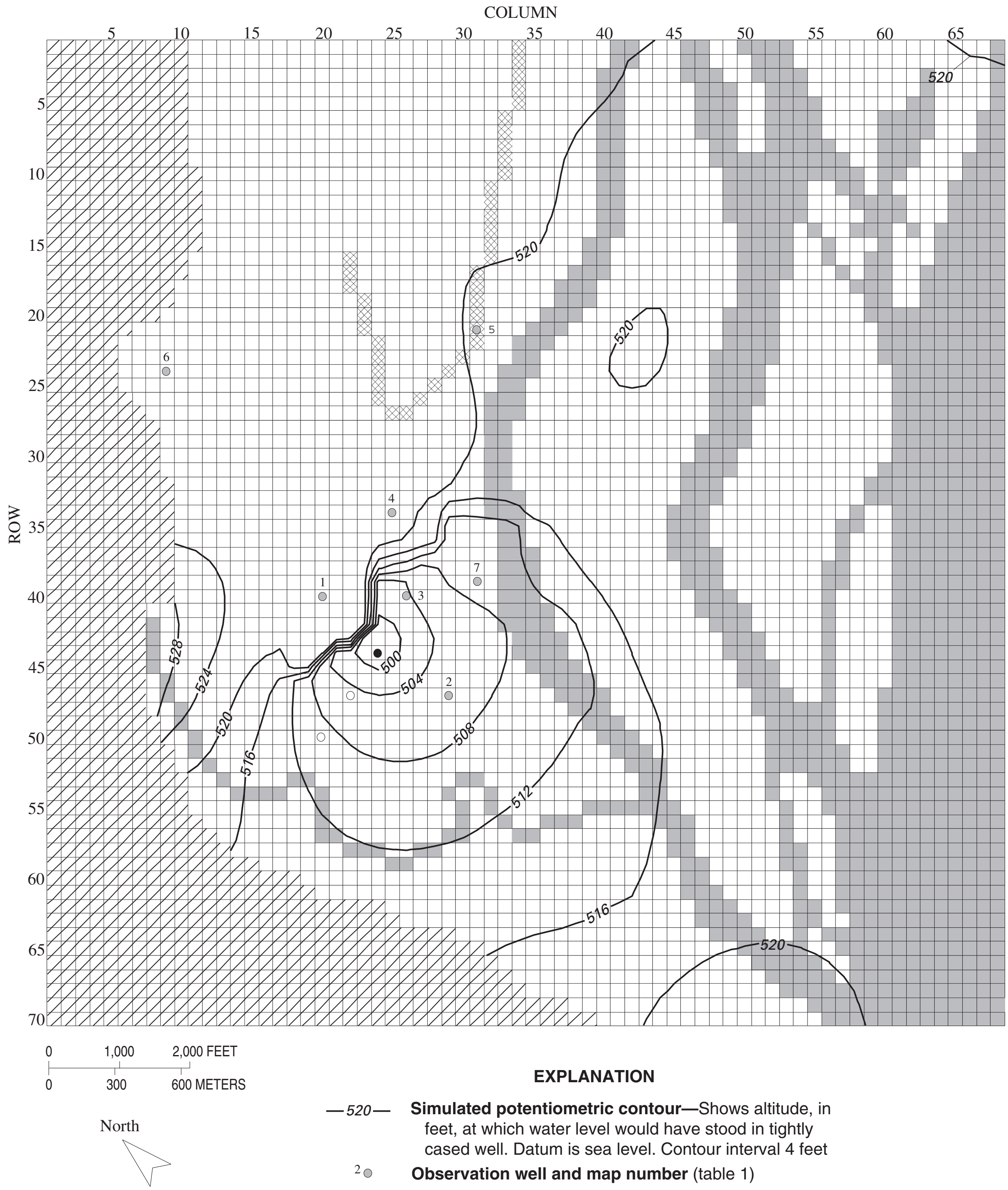
Model Limitations

The flow model for this study was constructed with limited onsite observations and hydrogeologic data to help conceptualize flow in the alluvium, identify sources of water to the alluvium, and evaluate the potential effects of hypothetical additional municipal ground-water withdrawals on the flow system. While adequate for the purposes of this study, the model likely is not suitable for accurate predictive analyses because of the uncertainty associated with using limited onsite data to estimate hydraulic properties. The following additional limitations should be considered when interpreting the flow model results:

1. The ground-water flow model was discretized using a grid with cells measuring 200 ft by 200 ft. Results of the ground-water flow model were used to evaluate the flow system on a relatively large scale. Results of the ground-water flow model cannot be used for detailed analyses such as simulating water-level drawdown near pumping wells or simulating contributing areas for individual wells. A ground-water flow model using smaller cells would be needed to conduct such detailed analyses.

2. The ground-water flow model was constructed using assumed steady-state conditions (the volume of water flowing into the system is the same as the volume of water flowing out of the system). Results of the ground-water flow model may not be valid when steady-state conditions

Figure 8. Simulated potentiometric surface in layer 1 of the flow model for the Mississippi River alluvium near Burlington, Iowa, October 1999.



EXPLANATION

— 520 — **Simulated potentiometric contour—**Shows altitude, in feet, at which water level would have stood in tightly cased well. Datum is sea level. Contour interval 4 feet

2 ● **Observation well and map number** (table 1)

● **Municipal well 3** (actively pumped)

○ **Municipal well** (not actively pumped)

Inactive cell

Drain cell in layer 1 (shown to aid in spatial orientation)

River cell in layer 1 (shown to aid in spatial orientation)

Figure 9. Simulated potentiometric surface in layer 2 of the flow model for the Mississippi River alluvium near Burlington, Iowa, October 1999.

Table 7. Results of the sensitivity analyses of the calibrated ground-water flow model for the Mississippi River alluvium near Burlington, Iowa

Parameter	Factor used to change parameter	Root mean square error (feet)
Calibrated flow model	--	0.427
Areal recharge rate	× 0.5	1.592
	× 2.0	2.640
Layer 1 hydraulic conductivity	× 0.5	1.572
	× 2.0	1.190
Layer 2 transmissivity	× 0.5	3.142
	× 2.0	2.376
Vertical conductance between layer 1 and layer 2	× 0.5	2.190
	× 2.0	1.862
Streambed conductance of Mississippi River and associated side channels	× 0.5	0.427
	× 2.0	0.438
Streambed conductance of Flint River	× 0.5	0.438
	× 2.0	0.427
Drain conductance	× 0.5	0.436
	× 2.0	0.431

cannot be assumed. Steady-state conditions probably cannot be assumed during periods when ground-water levels rapidly change (such as during late spring and early summer when ground-water levels respond to large stage changes in the Mississippi River or to large amounts of rainfall from thunderstorms).

3. Model parameters, such as hydraulic conductivity and recharge rate, were specified for the nodal point at the center of each cell. Model parameters are uniformly applied to the entire cell. The assumption of homogeneity can introduce inaccuracy because geologic materials and climatic conditions typically exhibit some heterogeneity.

4. Ground water flowing across modeled-area boundaries was simulated with a combination of general-head and specified-flux boundary conditions. The hydraulic conductivity used for the general-head boundary was set equal to the hydraulic conductivity of the adjacent active cell in the model grid and was assumed to be constant over the distance (1 mi) between the modeled area boundary and the corresponding constant-head source. If the actual hydraulic conductivity values are different than those used in the model, the volume of water flowing across the general-head boundaries will be different than that indicated in the water budget.

Simulation Results

Simulated ground-water levels were calculated at the node of each 200-ft by 200-ft cell in the calibrated flow model. Figure 8 shows the contoured simulated potentiometric surface for layer 1 of the flow model. Model results for layer 1 indicate ground water generally flows from the bluffs bordering the alluvial valley toward the Mississippi River and associated side channels. The drainage ditch in the northern part of the modeled area intercepts some ground water flowing toward the Mississippi River. Municipal pumping likely has caused some decline in ground-water levels in layer 1, as evidenced by the closed-depression, 518-ft contour in the area between the Burlington water-treatment facility and O’Connell Slough. Figure 9 shows the contoured simulated potentiometric surface for layer 2 of the flow model. Model results for layer 2 indicate drawdown from municipal pumping extends eastward beneath O’Connell Slough and to the area south of Flint River. Municipal pumping has relatively little effect on the northern part of the modeled area. The northern part of the modeled area likely represents conditions in relatively undeveloped parts of the Mississippi River alluvium. Simulation results indicate ground water in the northern part of the modeled area tends to flow upward, discharging either in the Mississippi River, associated side channels, or drainage ditch.

The water budget (table 8) for the calibrated flow model was analyzed to identify sources and sinks of water for the flow system and to determine if model results were consistent with the simplified conceptualization of the flow system used to construct the flow model. Total inflow to the modeled area was calculated to be 674,200 ft^3/d; total outflow from the modeled area was calculated to be 674,600 ft^3/d. The 0.06-percent discrepancy between inflow and outflow occurs because ground-water flow was simulated with a finite-difference approach which approximates a mathematical solution for ground-water flow equations.

Primary sources of inflow to the system are subsurface flow from adjacent areas of the alluvium (50.5 percent), recharge from precipitation (25.9 percent), subsurface flow through the adjacent area of Flint River stream-channel deposits (17.2 percent), and river leakage (6.4 percent). Much of the subsurface flow from adjacent areas of the alluvium discharges to the Mississippi River and associated side channels as indicated by the large outflow volume of river leakage. River leakage into the system

Table 8. Simulated water budget under steady-state conditions in the Mississippi River alluvium near Burlington, Iowa, 1999

[ft^3/d, cubic feet per day; <, less than]

Budget component	Inflow (ft^3/d)	Percentage of total inflow	Outflow (ft^3/d)	Percentage of total outflow
Recharge from precipitation	174,400	25.9	0	0.0
River leakage	43,000	6.4	424,800	62.9
Subsurface flow from:				
–adjacent areas of the Mississippi River alluvium	340,500	50.5	16,000	2.4
–adjacent area of Flint River stream-channel deposits	96,000	14.2	0	0.0
–bluff area south of Flint River	20,000	3.0	0	0.0
–adjacent areas of bedrock	100	<0.1	0	0.0
Bedrock leakage	200	<0.1	100	<0.1
Drain leakage	0	0.0	59,900	8.9
Municipal pumpage	0	0.0	173,800	25.8
Total	674,200	100.0	674,600	100.0

occurs within the zone of contribution to the pumped municipal well. Although river leakage is a relatively small component of total inflow, it is a significant percentage (24.7 percent) of the total water pumped for municipal supply. The relatively insignificant volume of inflow from bedrock leakage indicates the bedrock is not a major source of ground water to the alluvium.

Primary components of outflow from the system are river leakage (62.9 percent), municipal pumpage (25.8 percent), and drain leakage (8.9 percent). River and drain leakage flow out of the system through the upper alluvium (layer 1); municipal pumpage withdraws water from the lower alluvium (layer 2). The large volume of river leakage is consistent with a flow system in which ground water originating from infiltration of precipitation and subsurface flow from adjacent areas to the modeled area discharges to the Mississippi River and associated side channels.

Potential effects of additional future ground-water withdrawals on the flow system were evaluated through hypothetical pumping scenarios. The scenarios were conducted by withdrawing additional water from a simulated second municipal well completed in the lower alluvium and observing the resulting effects on the calibrated flow model. Three separate hypothetical pumping scenarios were considered: (1) pumping 0.5 Mgal/d from a second existing municipal well (municipal well 1 located at row 50, column 20 in the model grid), (2) pumping 1.0 Mgal/d from a hypothetical well (located at row 51, column 30 in the model grid) in an area between the Burlington water-treatment facility and Flint River, and (3) pumping 1.0 Mgal/d from a hypothetical well (located at row 58, column 41 in the model grid) in an area south of Flint River.

Simulated drawdown for scenario 1 (hypothetical pumping of 0.5 Mgal/d from municipal well 1) is shown for layer 1 (fig. 10) and for layer 2 (fig. 11). The maximum simulated additional drawdown in layer 1 is less than 3 ft and in layer 2 is about 12 ft. Simulated drawdown resulting for scenario 2 (pumping 1.0 Mgal/d from a hypothetical well in an area between the city water-treatment facility and Flint River) is shown for layer 1 (fig. 12) and for layer 2 (fig. 13). The maximum simulated additional drawdown in layer 1 is about 6 ft and in layer 2 is about 21 ft. Simulated drawdown for scenario 3 (pumping 1.0 Mgal/d from a hypothetical well in an area south of Flint River) is shown for layer 1 (fig. 14) and for layer 2 (fig. 15). The maximum simulated additional drawdown in layer 1 is about 9 ft and in layer 2 is about 34 ft. Scenarios 2 and 3 resulted in simulated drawdown of about 1 ft in layer 1 for a localized area on O’Connell Island, indicating future additional municipal withdrawals may affect water levels in this area.

Water budgets for the three hypothetical pumping scenarios used to evaluate potential additional ground-water withdrawals from the alluvium are shown in table 9. Additional ground-water withdrawals for each scenario significantly increased the amount of inflow from river leakage. River leakage provided 67 percent of additional water hypothetically pumped for scenario 1, 76 percent of water pumped for scenario 2, and 81 percent of water pumped for scenario 3.

Figure 10. Simulated drawdown in layer 1 of the flow model from hypothetical pumping of a second existing City of Burlington municipal well.

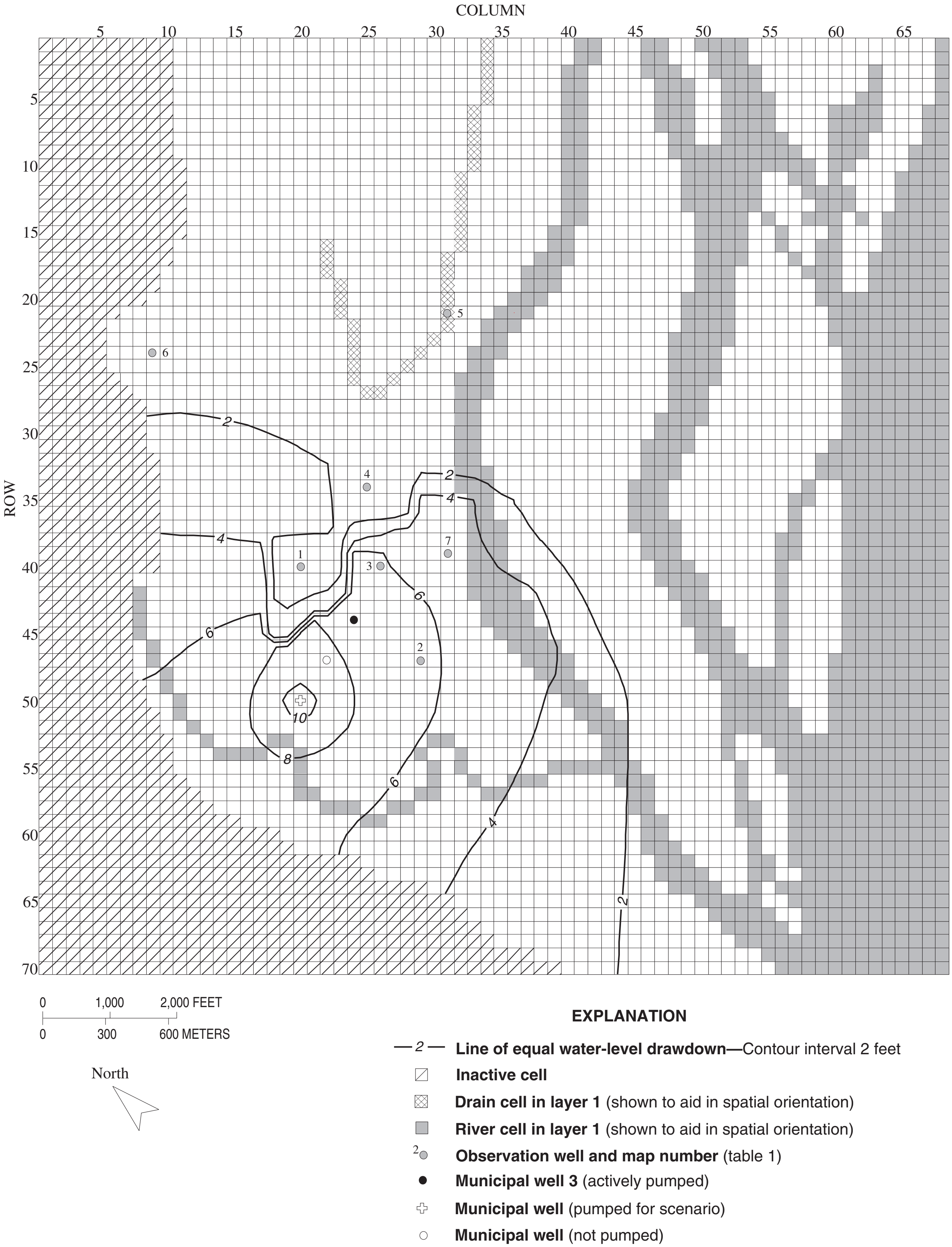


Figure 11. Simulated drawdown in layer 2 of the flow model from hypothetical pumping of a second existing City of Burlington municipal well.

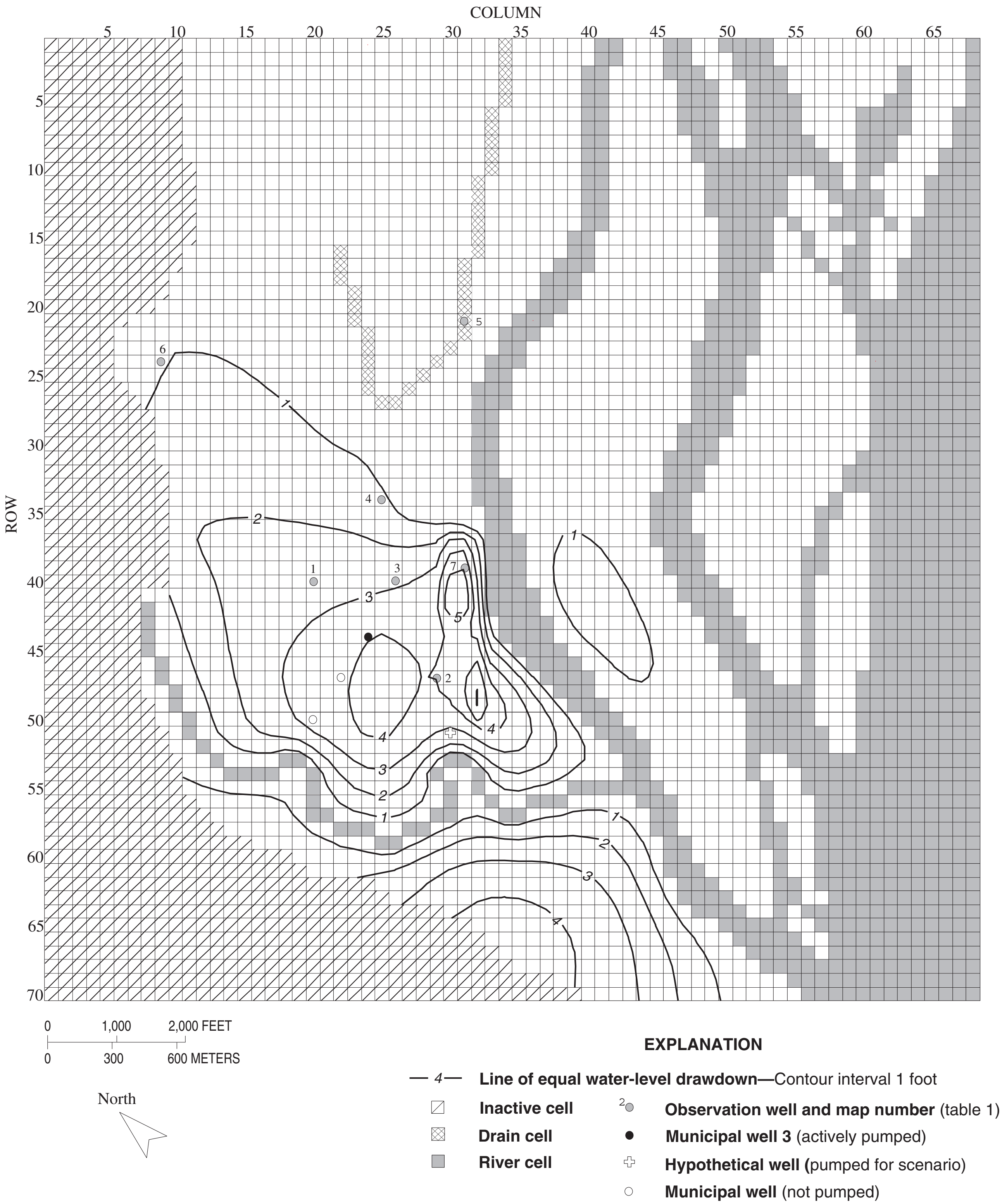


Figure 12. Simulated drawdown in layer 1 of the flow model from pumping a hypothetical municipal well north of Flint River.

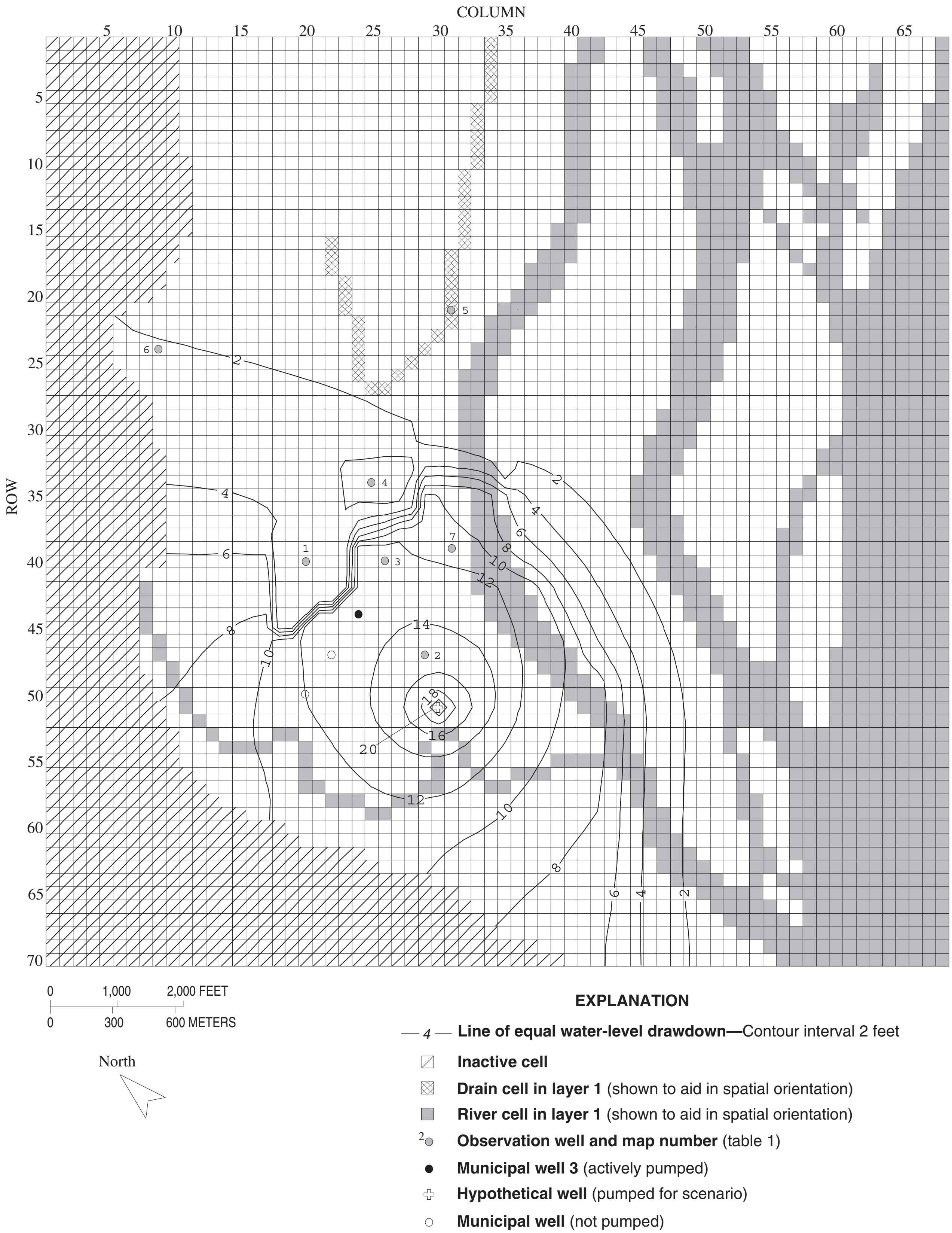


Figure 13. Simulated drawdown in layer 2 of the flow model from pumping a hypothetical municipal well north of Flint River.

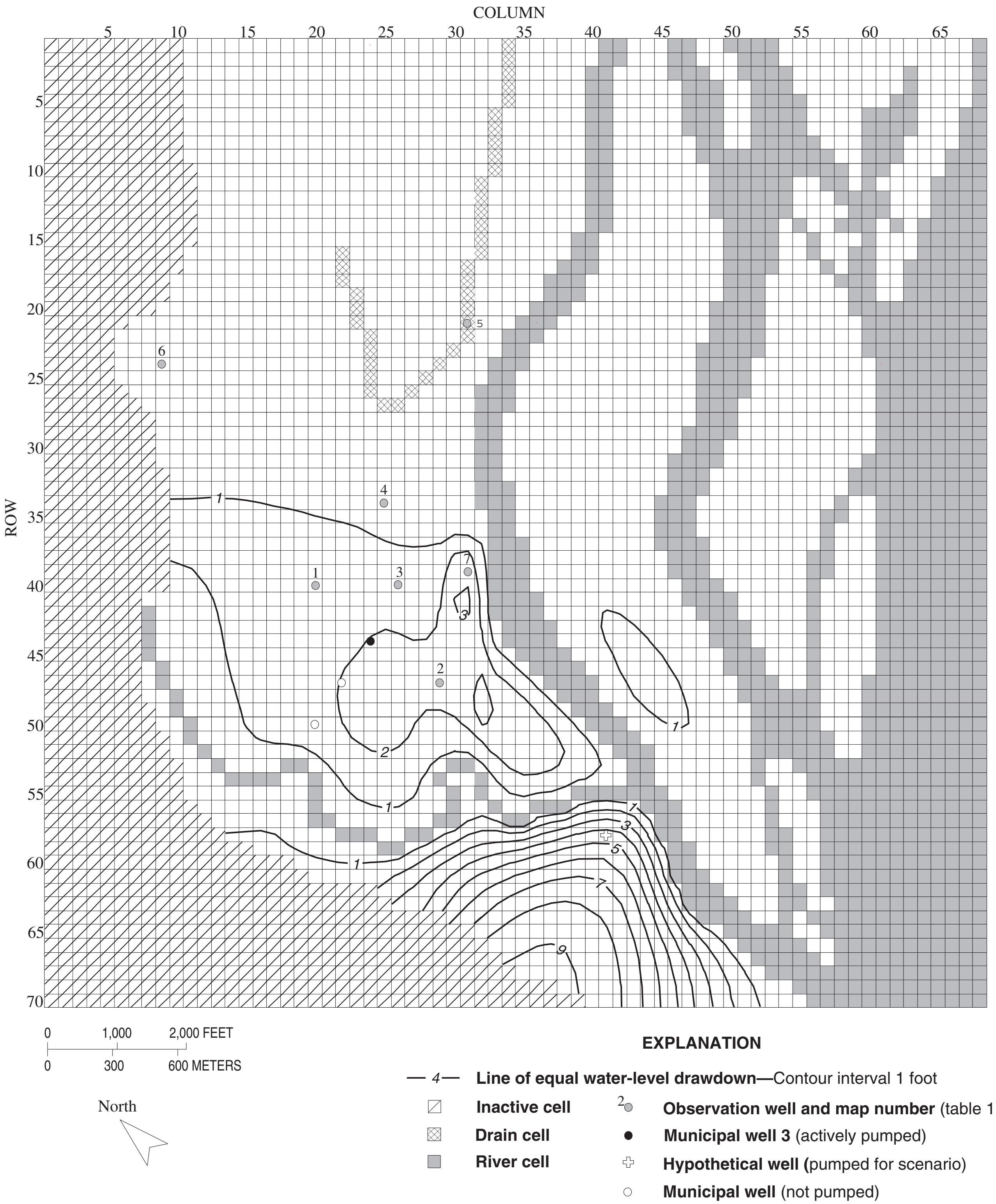


Figure 14. Simulated drawdown in layer 1 of the flow model from pumping a hypothetical municipal well south of Flint River.

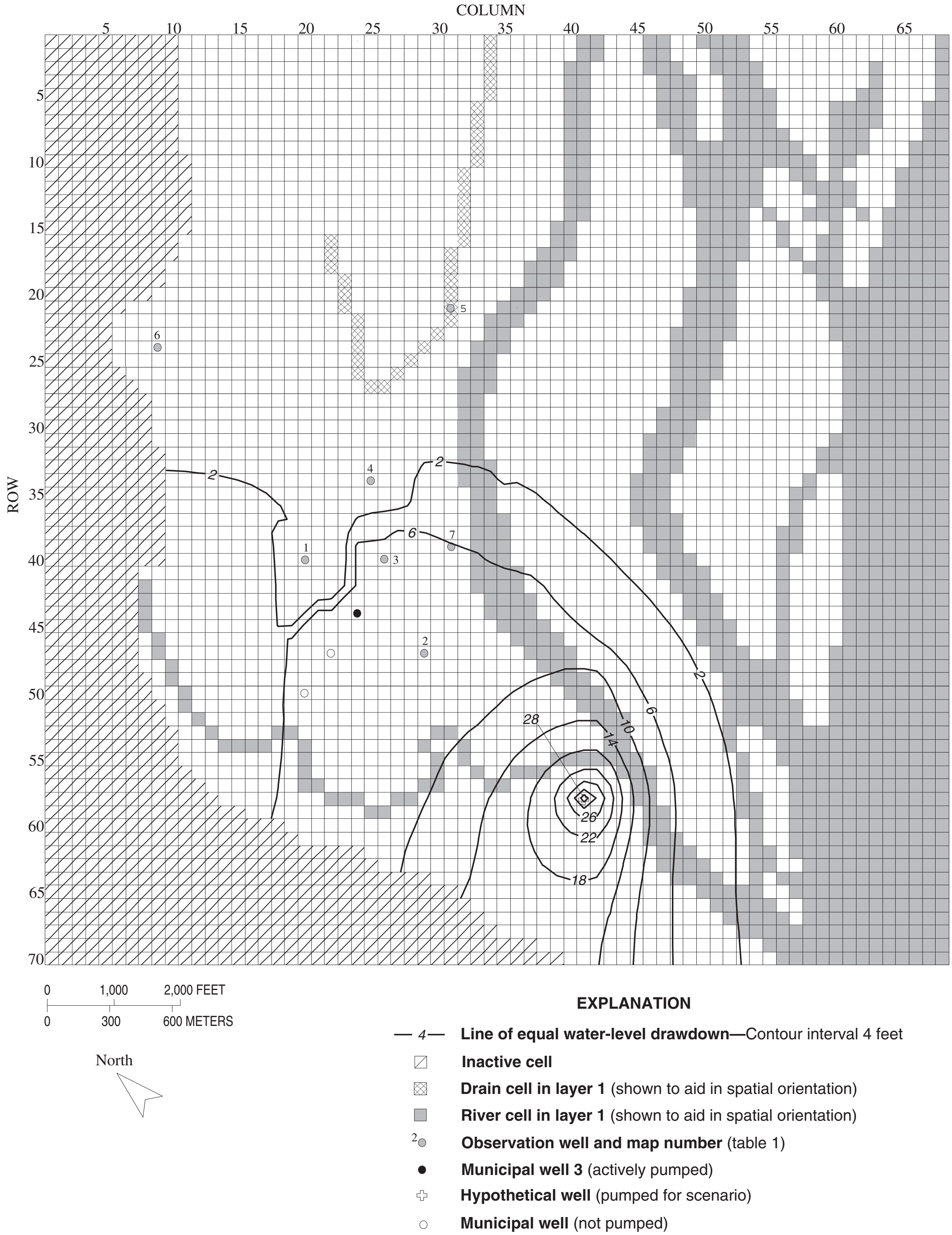


Figure 15. Simulated drawdown in layer 2 of the flow model from pumping a hypothetical municipal well south of Flint River.

Table 9. Simulated water budgets for pumping scenarios used to assess hypothetical additional ground-water withdrawals from the Mississippi River alluvium near Burlington, Iowa, 1999

[Scenario 1, pumping 0.5 million gallons per day from a second existing municipal well; Scenario 2, pumping 1 million gallons per day from a second hypothetical well north of Flint River; Scenario 3, pumping 1 million gallons per day from a second hypothetical well south of Flint River]

Budget component	Calibrated model	Scenario 1	Scenario 2	Scenario 3
	Inflow (cubic feet per day)			
Recharge from precipitation	174,400	174,000	174,000	174,000
River leakage	43,000	87,700	144,700	150,900
Subsurface flow from:				
–adjacent areas of the alluvium	340,500	341,100	341,500	341,200
–adjacent area of Flint River stream-channel deposits	96,000	96,000	96,000	96,000
–bluff area south of Flint River	20,000	20,000	20,000	20,000
–adjacent areas of bedrock	100	100	100	100
Bedrock leakage	200	200	200	200
Drain leakage	0	0	0	0
Municipal pumpage	0	0	0	0
Total	674,200	719,100	776,500	782,400
	Outflow (cubic feet per day)			
Recharge from precipitation	0	0	0	0
River leakage	424,800	409,400	402,000	404,000
Subsurface flow through:				
–adjacent areas of the alluvium	16,000	14,600	14,200	15,000
–adjacent area of Flint River stream-channel deposits	0	0	0	0
–bluff area south of Flint River	0	0	0	0
–adjacent areas of bedrock	0	0	0	0
Bedrock leakage	100	100	100	100
Drain leakage	59,900	55,200	53,500	56,400
Municipal pumpage	173,800	240,600	307,500	307,500
Total	674,600	719,900	777,300	783,000

WATER QUALITY

Physical properties and constituent concentrations for common ions, nutrients, and pesticides detected in water samples collected from study area sites on May 20–21, 1999 are summarized in table 10. Results of analyses for all ground-water and surface-water samples are listed at the end of the report for common ions (table 12), nutrients (table 13), physical properties (table 14), and pesticides with pesticide-degradation products (table 15). Surface-water samples were not collected during baseflow conditions, so the chemical composition of the samples likely reflects surface runoff rather than ground water in the alluvium.

Common-ion compositions in the water samples collected from the study area were evaluated with a trilinear diagram (fig. 16). The trilinear diagram represents common-ion compositions from many analyses on a single graph, making differences and similarities in water types readily apparent. The trilinear diagram is constructed by expressing cation (calcium, magnesium, and sodium plus potassium) and anion (bicarbonate, chloride, and sulfate) concentrations in milliequivalents per liter and plotting these values on the diagram as percentages of the total milliequivalents per liter (Freeze and Cherry, 1979).

The trilinear diagram representation indicates that water samples collected from the study area are of a calcium-magnesium-bicarbonate type. There is some

Table 10. Summary of chemical constituent concentrations detected in water samples collected from sites near Burlington, Iowa, May 20–21, 1999

[mg/L, milligrams per liter; --, not applicable; <, less than; µg/L, micrograms per liter; 13 samples were collected (11 ground-water and 2 surface-water samples)]

Constituent	Units	Number of concentrations exceeding reporting limit (and minimum reporting limit	Concentration: Ground-water samples Minimum	Concentration: Ground-water samples Maximum	Concentration: Surface-water samples Minimum	Concentration: Surface-water samples Maximum
Common ions						
Bicarbonate	mg/L as HCO_3	13 (--)	65	434	275	299
Bromide	mg/L as Br	11 (0.01)	<0.01	0.07	<0.01	<0.01
Calcium	mg/L as Ca	13 (0.02)	27	94	63	71
Chloride	mg/L as Cl	13 (0.10)	2.5	26	15	16
Fluoride	mg/L as F	13 (0.10)	<0.10	0.32	0.19	0.27
Iron	µg/L as Fe	13 (10)	<10	4,390	<10	30
Magnesium	mg/L as Mg	13 (0.10)	9.2	36	20	28
Manganese	µg/L as Mn	13 (3)	2.6[a]	2,430	10	766
Potassium	mg/L as K	13 (0.10)	1.1	4.0	1.9	2.7
Silica	mg/L as SiO_2	13 (0.10)	12	24	9.8	17
Sodium	mg/L as Na	13 (0.20)	6.7	42	9.0	11
Sulfate	mg/L as SO_4	13 (0.10)	6.1	128	28	44
Nutrients						
Nitrogen, ammonia	mg/L as N	11 (0.02)	<0.02	1.3	0.02	0.22
Nitrogen, ammonia plus organic	mg/L as N	12 (0.10)	<0.10	1.5	0.28	0.46
Nitrogen, nitrite	mg/L as N	6 (0.01)	<0.01	0.02	0.02	0.03
Nitrite plus nitrate	mg/L as N	9 (0.05)	<0.05	11	0.90	3.1
Phosphorus	mg/L as P	13 (0.01)	0.01	1.1	0.03	0.10
Phosphorus, ortho	mg/L as P	13 (0.01)	0.013	0.18	0.03	0.08
Pesticides and pesticide-degradation products						
Acetochlor	µg/L	2 (0.05)	<0.05	<0.05	0.71	1.7
Alachlor	µg/L	2 (0.05)	0.019[a]	<0.05	0.11	4.8
Atrazine	µg/L	5 (0.05)	0.015[a]	0.13	3.6	5.4
Cyanazine	µg/L	0 (0.20)	<0.20	<0.20	0.09[a]	<0.20
Deethylatrazine	µg/L	5 (0.05)	0.01[a]	0.51	0.30	0.61
Deisopropylatrazine	µg/L	4 (0.05)	<0.05	0.35	0.18	0.21
Metolachlor	µg/L	3 (0.05)	0.006[a]	<0.05	0.49	0.60
Metribuzin	µg/L	1 (0.05)	<0.05	<0.05	<0.05	0.08
Prometon	µg/L	0 (0.05)	<0.05	<0.05	0.02[a]	<0.05
Propazine	µg/L	1 (0.05)	<0.05	<0.05	<0.05	0.06
Simazine	µg/L	0 (0.05)	<0.05	<0.05	0.02[a]	0.03[a]

[a]Estimated concentration less than the corresponding minimum reporting limit.

variability in the ionic composition of samples collected from the upper and lower alluvium. The differences in ionic composition of samples were relatively small and probably result from factors such as differences in mineralogical composition of aquifer materials in the two zones, cation-exchange reactions that occur as ground water flows through the clay and glacial till layer separating the two zones, and localized oxidation-reduction reactions. The similarity of water types in the upper and lower alluvium indicates the bedrock does not contribute significant amounts of water to the alluvium. Water samples were not collected from the bedrock for this study, but Karsten and Burkart (1985) indicate that ground water in the bedrock likely has higher dissolved-solids and sulfate concentrations than ground water in the alluvium. If the bedrock contributed significant amounts of water to the alluvium, samples likely would plot on the trilinear diagram as two more distinct clusters (one reflecting the calcium-magnesium-bicarbonate type water in the upper alluvium and one reflecting mixing between water types in the lower alluvium and bedrock).

Reducing conditions likely occur in localized areas near well clusters BMW–2 and BMW–5 as suggested by relatively large concentrations of dissolved iron (4,390 micrograms per liter [µg/L]) and manganese (2,430 µg/L) and very small dissolved-oxygen and nitrite plus nitrate concentrations. Drever (1988) states that reducing conditions commonly occur in response to the decay of organic matter. The decay of organic matter is enhanced by a series of microbial-catalyzed chemical reactions that consume dissolved oxygen and nitrate and release iron and manganese from aquifer materials into solution. Extreme reducing conditions can reduce sulfate to hydrogen sulfide; the characteristic "rotten egg" odor associated with hydrogen sulfide was noted at BMW–5(36) when the sample was collected.

Nutrients (species of nitrogen and phosphorus) were detected in many of the samples collected from the study area. The Maximum Contaminant Level

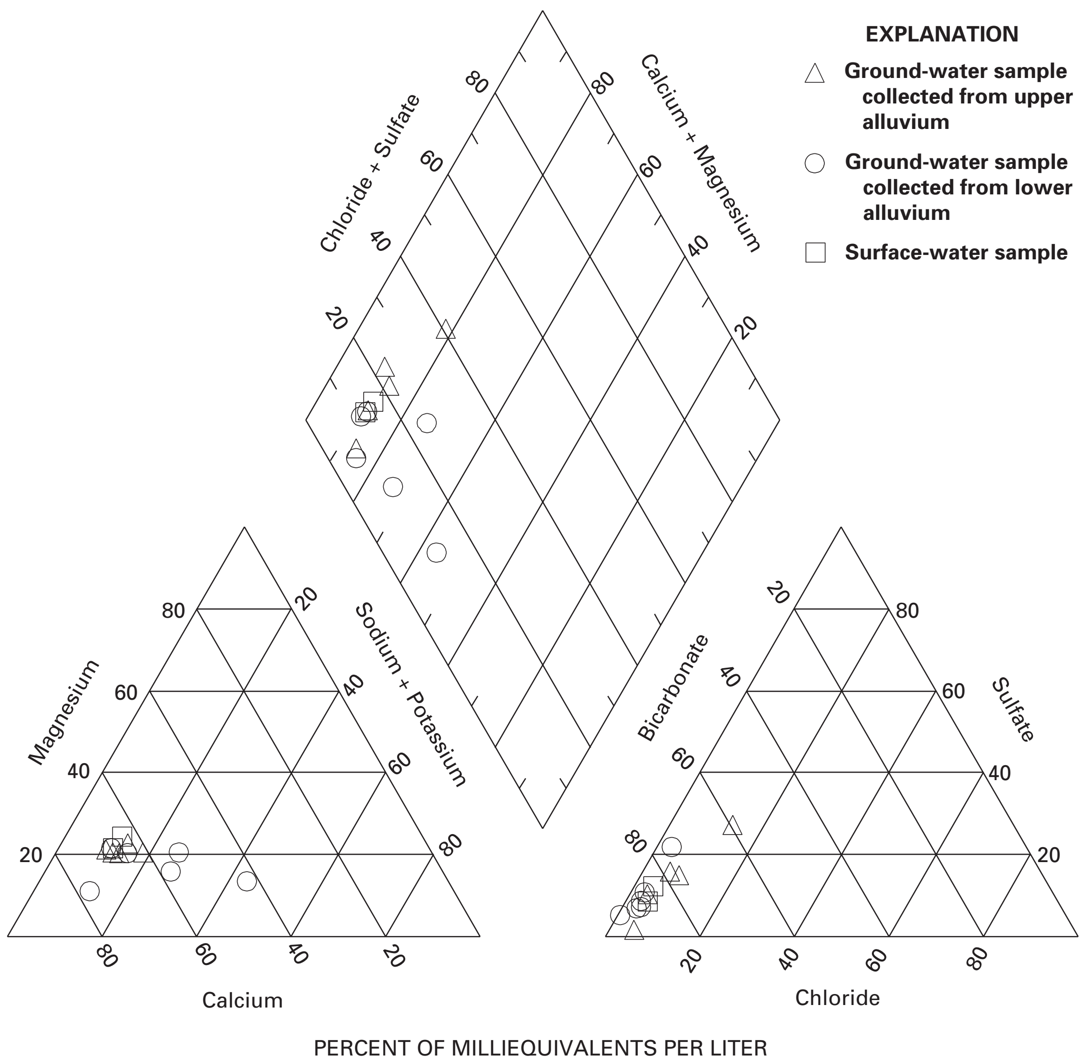


Figure 16. Trilinear diagram summarizing common-ion compositions in ground-water and surface-water samples collected near Burlington, Iowa, May 1999.

(MCL) for nitrite plus nitrate in drinking water (10 mg/L as N) (U.S. Environmental Protection Agency, 1996) was exceeded in the sample from BMW–1(140). The nitrite plus nitrate concentration in two other samples [from BMW–1(32) and BMW–4(37)] was greater than or equal to 8 mg/L as N. The occurrence of nitrite plus nitrate in ground water might be related to fertilizer applications to cropland in the study area; sites BMW–1 and BMW–4 were in close proximity to cropland, and water samples were collected during the period of springtime fertilizer applications.

Triazine herbicides (atrazine, cyanazine, propazine, simazine, and selected degradation compounds) and chloroacetanilide herbicides (acetochlor, alachlor, and metolachlor) were detected in some samples. These herbicides are applied to cropland used for corn or soybeans; water samples were collected during the period of springtime herbicide applications. A greater number of herbicide compounds were detected in the two surface-water samples (collected from Dry Branch Creek at Tama Road and the County drainage ditch at Tama Road) than in ground-water samples collected from the alluvium. Herbicides generally were detected at greater concentrations (about an order of magnitude or more) in surface-water samples than in ground-water samples. The MCL for alachlor in drinking water (2 µg/L) (U.S. Environmental Protection Agency, 1996) was exceeded in the sample collected from Dry Branch Creek at Tama Road and the MCL for atrazine in drinking water (3 µg/L) (U.S. Environmental Protection Agency, 1996) was exceeded in the samples collected from Dry Branch Creek at Tama Road and the County drainage ditch at Tama Road.

SUMMARY

A steady-state, ground-water flow model was constructed for a 7-square-mile area of the Mississippi River alluvium near Burlington, Iowa, using October 1999 hydrologic conditions. The model was discretized into a 70-row by 68-column grid using a series of cells measuring 200 ft by 200 ft. Three model layers were used to represent the upper alluvium, lower alluvium, and bedrock. The flow model was used to help conceptualize the flow system, identify sources of water to the alluvium, and assess potential effects from additional hypothetical ground-water withdrawals from the alluvium.

The simulated potentiometric surface for the upper alluvium indicates ground water primarily flows from the bluff areas bordering the alluvial valley toward the Mississippi River. Municipal pumping likely has caused some decline in ground-water levels in the upper alluvium within an area between the Burlington water-treatment facility and O’Connell Slough. The simulated potentiometric surface for the lower alluvium indicates that drawdown resulting from municipal ground-water withdrawals extends eastward beneath O’Connell Slough and southward beyond Flint River. Ground-water flow in areas of the lower alluvium beyond the zone of influence of municipal pumping tends to flow upward toward the Mississippi River, associated side channels, and drains.

The primary sources of inflow to the model are subsurface flow from adjacent areas of alluvium beyond the model boundaries (50.5 percent of the simulated water budget), recharge from precipitation (25.9 percent of the simulated water budget), subsurface flow from Flint River stream-channel deposits adjacent to the model area (17.2 percent of the simulated water budget), and river leakage (6.4 percent of the water budget). The bedrock does not contribute significant water to the alluvium. The primary components of outflow from the system are river leakage (62.9 percent of the water budget), municipal pumpage 25.8 percent of the water budget), and drain leakage (8.9 percent of the water budget).

Three hypothetical pumping scenarios were used to assess the potential effects of increased ground-water withdrawals from the lower alluvium on the flow system: (1) pumping a second existing municipal well at a rate of 0.5 Mgal/d, (2) pumping a hypothetical well north of Flint River at a rate of 1.0 Mgal/d, and (3) pumping a hypothetical well south of Flint River at a rate of 1.0 Mgal/d. Maximum additional simulated drawdown in the upper alluvium ranged from less than 3 ft (for scenario 1) to about 9 ft (for scenario 3). Maximum additional simulated drawdown in the lower alluvium ranged from about 12 ft (for scenario 1) to about 34 ft (for scenario 3). Additional ground-water withdrawals for each pumping scenario significantly increased the amount of river leakage into the flow system and also decreased the amount of outflow from river leakage and drain leakage.

Water samples collected from the alluvium indicate ground water can be classified as a calcium-magnesium-bicarbonate type. Reducing conditions likely occur in localized areas of the alluvium as indicated by relatively large dissolved-iron and dissolved-manganese concentrations. Nitrite plus nitrate concentrations were greatest (8 to 11 mg/L as N) in samples collected from wells in close proximity to cropland. The MCL for nitrite plus nitrate in drinking water (10 mg/L as N) (U.S. Environmental Protection Agency, 1996) was exceeded in a sample from BMW–1(140). Triazine and chloroacetanilide herbicides were detected in some water samples. A greater number of herbicide compounds were detected in surface-water samples than in ground-water samples. Herbicide concentrations typically were greater (by about an order of magnitude or more) in surface-water samples than in ground-water samples. The MCL for alachlor in drinking water (2 µg/L) (U.S. Environmental Protection Agency, 1996) was exceeded in the water sample collected from Dry Branch Creek at Tama Road, and the MCL for atrazine in drinking water (3 µg/L)(U.S. Environmental Protection Agency, 1996) was exceeded in water samples collected from Dry Branch Creek at Tama Road and the Des Moines County drainage ditch at Tama Road.

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SUPPLEMENTAL INFORMATION

Table 11. Ground-water levels measured in observation wells in the Mississippi River alluvium near Burlington, Iowa, 1999

[mm-dd-yy, month-day-year; bls, below land surface; asl, above sea level]

Site name [and map number (fig. 2)]	Date (mm–dd–yy)	Water-level measurement	
		Depth to water (feet bls)	Altitude (feet asl)
BMW–1(32) [1]	01–19–99	14.79	524.31
	02–17–99	15.87	523.23
	03–19–99	14.41	524.69
	03–30–99	14.50	524.60
	04–15–99	14.18	524.92
	05–11–99	12.01	527.09
	05–20–99	11.72	527.38
	06–23–99	11.59	527.51
	07–30–99	14.16	524.94
	08–27–99	15.43	523.67
	09–23–99	16.26	522.84
	10–13–99	16.47	522.63
	11–18–99	16.93	522.17
BMW–1(140) [1]	01–19–99	16.45	522.65
	02–17–99	15.83	523.27
	03–19–99	16.31	522.79
	03–30–99	15.87	523.23
	04–15–99	15.69	523.41
	05–11–99	14.73	524.37
	05–20–99	14.66	524.44
	06–23–99	12.59	526.51
	07–30–99	14.46	524.64
	08–27–99	15.64	523.46
	09–23–99	16.34	522.76
	10–13–99	16.54	522.56
	11–18–99	16.09	523.01
BMW–2(41) [2]	01–19–99	12.40	522.09
	02–17–99	10.44	524.05
	03–19–99	11.37	523.12
	03–30–99	11.13	523.36
	04–15–99	10.36	524.13
	05–11–99	8.75	525.74
	05–20–99	7.35	527.14
	06–23–99	8.40	526.09
	07–30–99	9.56	524.93
	08–27–99	11.76	522.73
	09–23–99	13.00	521.49
	10–13–99	13.02	521.47
	11–18–99	13.68	520.81
BMW–2(136) [2]	01–19–99	19.54	514.95
	02–17–99	23.76	510.73
	03–19–99	29.15	505.34
	03–30–99	29.09	505.40
	04–15–99	29.09	505.40
	05–11–99	26.86	507.63
	05–20–99	25.21	509.28
	06–23–99	26.30	508.19
	07–30–99	24.34	510.15
	08–27–99	28.01	506.48
	09–23–99	28.57	505.92
	10–13–99	28.63	505.86
	11–18–99	28.59	505.90

Table 11. Ground-water levels measured in observation wells in the Mississippi River alluvium near Burlington, Iowa, 1999—Continued

[mm-dd-yy, month-day-year; bls, below land surface; asl, above sea level]

Site name [and map number (fig. 2)]	Date (mm–dd–yy)	Water-level measurement	
		Depth to water (feet bls)	Altitude (feet asl)
BMW–3(37) [3]	01–19–99	8.58	524.98
	02–17–99	8.97	524.59
	03–19–99	9.89	523.67
	03–30–99	9.94	523.62
	04–15–99	9.03	524.53
	05–11–99	7.42	526.14
	05–19–99	6.71	526.85
	06–23–99	6.87	526.69
	07–30–99	8.89	524.67
	08–27–99	10.82	522.74
	09–23–99	11.86	521.70
	10–13–99	12.02	521.54
	11–18–99	12.48	521.08
BMW–3(85) [3]	01–19–99	31.37	502.19
	02–17–99	30.13	503.43
	03–19–99	31.22	502.34
	03–30–99	30.80	502.76
	04–15–99	29.21	504.35
	05–11–99	28.91	504.65
	05–19–99	27.81	505.75
	06–23–99	28.70	504.86
	07–30–99	26.20	507.36
	08–27–99	29.80	503.76
	09–23–99	30.31	503.25
	10–13–99	30.28	503.28
	11–18–99	30.22	503.34
BMW–4(37) [4]	01–19–99	9.51	522.51
	02–17–99	8.19	523.83
	03–19–99	8.95	523.07
	03–30–99	8.94	523.08
	04–15–99	8.05	523.97
	05–11–99	6.53	525.49
	05–20–99	6.02	526.00
	06–23–99	6.13	525.89
	07–30–99	8.01	524.01
	08–27–99	9.84	522.18
	09–23–99	10.90	521.12
	10–13–99	11.06	520.96
	11–18–99	11.51	520.51
BMW–4(101) [4]	01–19–99	9.48	522.54
	02–17–99	8.84	523.18
	03–19–99	9.10	522.92
	03–30–99	8.49	523.53
	04–15–99	8.29	523.73
	05–11–99	8.36	523.66
	05–19–99	8.34	523.68
	06–23–99	8.15	523.87
	07–30–99	8.80	523.22
	08–27–99	9.46	522.56
	09–23–99	9.86	522.16
	10–13–99	10.03	521.99
	11–18–99	10.32	521.70

Table 11. Ground-water levels measured in observation wells in the Mississippi River alluvium near Burlington, Iowa, 1999—Continued

[mm-dd-yy, month-day-year; bls, below land surface; asl, above sea level]

Site name [and map number (fig. 2)]	Date (mm–dd–yy)	Water-level measurement	
		Depth to water (feet bls)	Altitude (feet asl)
BMW–5(36) [5]	01–19–99	4.54	517.89
	02–17–99	3.64	518.79
	03–19–99	4.26	518.18
	03–30–99	4.28	518.15
	04–15–99	3.28	519.15
	05–11–99	3.78	518.65
	05–19–99	3.10	519.33
	06–23–99	3.52	518.91
	07–30–99	2.64	519.79
	08–27–99	3.83	518.60
	09–23–99	4.57	517.86
	10–13–99	4.66	517.77
	11–18–99	4.80	517.63
BMW–5(136) [5]	01–19–99	17.21	505.22
	02–17–99	1.72	520.71
	03–19–99	2.15	520.28
	03–30–99	1.66	520.77
	04–15–99	1.70	520.73
	05–11–99	1.26	521.17
	05–19–99	1.13	521.30
	06–23–99	1.29	521.14
	07–30–99	1.14	521.29
	08–27–99	2.04	520.39
	09–23–99	2.54	519.89
	10–13–99	2.65	519.78
	11–18–99	2.89	519.54
BMW–6(38) [6]	01–19–99	27.41	527.25
	02–17–99	28.37	526.29
	03–19–99	28.92	525.74
	03–30–99	28.12	526.54
	04–15–99	28.31	526.35
	05–11–99	27.83	526.83
	05–20–99	27.83	526.83
	06–23–99	26.28	528.38
	07–30–99	27.00	527.66
	08–27–99	27.84	526.82
	09–23–99	28.03	526.63
	10–13–99	28.38	526.28
	11–18–99	28.42	526.24
BMW–6(127) [6]	01–19–99	31.59	523.07
	02–17–99	31.05	523.61
	03–19–99	31.44	523.22
	03–30–99	31.29	523.37
	04–15–99	31.30	523.36
	05–11–99	30.64	524.02
	05–20–99	30.54	524.12
	06–23–99	30.34	524.32
	07–30–99	31.05	523.61
	08–27–99	31.62	523.04
	09–23–99	31.99	522.67
	10–13–99	32.26	522.40
	11–18–99	32.49	522.17

Table 11. Ground-water levels measured in observation wells in the Mississippi River alluvium near Burlington, Iowa, 1999—Continued

[mm-dd-yy, month-day-year; bls, below land surface; asl, above sea level]

Site name [and map number (fig. 2)]	Date (mm–dd–yy)	Water-level measurement	
		Depth to water (feet bls)	Altitude (feet asl)
BMW–7(40) [7]	01–19–99	8.44	518.28
	02–17–99	7.93	518.79
	03–19–99	8.56	518.16
	03–30–99	8.46	518.26
	04–15–99	5.83	520.89
	05–11–99	5.75	520.97
	06–23–99	5.21	521.51
	07–30–99	4.29	522.43
	08–27–99	8.42	518.30
	09–23–99	9.83	516.89
	10–13–99	10.01	516.71
	11–18–99	10.22	516.50
BMW–7(102) [7]	01–19–99	19.06	507.66
	02–17–99	17.50	509.22
	03–19–99	18.53	508.19
	03–30–99	18.25	508.47
	04–15–99	16.44	510.28
	05–11–99	16.24	510.48
	06–23–99	15.76	510.96
	07–30–99	13.88	512.84
	08–27–99	17.60	509.12
	09–23–99	18.29	508.43
	10–13–99	18.30	508.42
	11–18–99	18.27	508.45

Table 12. Common-ion concentrations in ground-water and surface-water samples collected near Burlington, Iowa, May 20–21, 1999

[mg/L, milligrams per liter; µg/L, micrograms per liter; <, less than; --, sample not collected or analyzed; constituents listed with U.S. Geological Survey parameter codes in parentheses]

Site name [and map number (fig. 2)]	Bicarbonate (mg/L as HCO^3) (00453)	Bromide (mg/L as Br) (71870)	Calcium (mg/L as Ca) (00915)	Chloride (mg/L as Cl) (00940)	Fluoride (mg/L as F) (00950)	Iron (µg/L as Fe) (01046)
Upper alluvium						
BMW–1(32) [1]	65	0.016	27	14	<0.10	<10
BMW–1(32) [1][a]	65	.019	27	15	0.12	<10
BMW–2(41) [2]	375	.055	82	17	<0.10	2,340
BMW–3(37) [3]	312	.069	83	24	0.20	96
BMW–4(37) [4]	244	.047	74	26	.16	25
BMW–5(36) [5]	316	<0.01	62	18	.18	4,390
BMW–6(38) [6]	--	--	--	--	--	--
BMW–7(40) [7]	--	--	--	--	--	--
Lower alluvium						
BMW–1(140) [1]	239	0.024	74	8.7	<0.10	<10
BMW–2(136) [2]	434	.045	94	19	0.13	441
BMW–3(85) [3]	325	.020	63	12	.32	142
BMW–4(101) [4]	354	.022	68	2.5	.18	73
BMW–5(136) [5]	243	.030	41	11	.32	<10
BMW–6(127) [6]	397	.036	85	16	.16	18
BMW–7(102) [7]	--	--	--	--	--	--
Surface water						
County drainage ditch at Tama Road [11]	275	<.01	63	16	0.19	30
Dry Branch Creek at Tama Road [9]	299	<.01	71	15	.27	<10

Site name [and map number (fig. 2)]	Magnesium (mg/L as Mg) (00925)	Manganese (µg/L as Mn) (01056)	Potassium (mg/L as K) (00935)	Silica (mg/L as Si) (00955)	Sodium (mg/L as Na) (00930)	Sulfate (mg/L as SO_4) (00945)
Upper alluvium						
BMW–1(32) [1]	9.2	3.0	1.5	22	6.7	30
BMW–1(32) [1][a]	9.2	3.0	1.5	22	6.7	30
BMW–2(41) [2]	25	476	4.0	24	10	46
BMW–3(37) [3]	26	312	1.6	15	15	64
BMW–4(37) [4]	23	257	1.1	20	9.9	48
BMW–5(36) [5]	22	2,430	2.3	18	12	6.1
BMW–6(38) [6]	--	--	--	--	--	--
BMW–7(40) [7]	--	--	--	--	--	--
Lower alluvium						
BMW–1(140) [1]	10	2.6	1.7	19	9.7	30
BMW–2(136) [2]	36	690	3.4	19	42	128
BMW–3(85) [3]	18	747	3.9	17	25	25
BMW–4(101) [4]	22	620	2.9	16	13	20
BMW–5(136) [5]	13	5.8	3.7	12	38	20
BMW–6(127) [6]	28	160	1.7	14	13	39
BMW–7(102) [7]	--	--	--	--	--	--
Surface water						
County drainage ditch at Tama Road [11]	20	766	1.9	17	9.0	28
Dry Branch Creek at Tama Road [9]	28	10	2.7	9.8	11	44

[a]Field-replicate sample.

Table 13. Nutrient concentrations in ground-water and surface-water samples collected near Burlington, Iowa, May 20–21, 1999

[mg/L, milligrams per liter; --, sample not collected or analyzed; <, less than; constituents listed with U.S. Geological Survey parameter codes in parentheses]

Site name [and map number (fig. 2)]	Nitrogen, ammonia (mg/L as N) (00608)	Nitrogen, nitrite (mg/L as N) (00613)	Nitrogen, ammonia plus organic (mg/L as N) (00623)	Nitrite plus nitrate (mg/L as N) (00631)	Phosphorus (mg/L as P) (00666)	Phosphorus, ortho (mg/L as P) (00671)
Upper alluvium						
BMW-1(32) [1]	<0.02	<0.01	0.06	8.0	0.17	0.15
BMW-1(32) [1][a]	<.02	<.01	.06	7.9	.18	.16
BMW-2(41) [2]	.14	<.01	.51	<.05	.07	.03
BMW-3(37) [3]	<.02	.02	<.10	1.5	.01	.01
BMW-4(37) [4]	.02	.01	.11	8.3	.02	.02
BMW-5(36) [5]	1.3	<.01	1.5	<.05	1.1	.14
BMW-6(38) [6]	--	--	--	--	--	--
BMW-7(40) [7]	--	--	--	--	--	--
Lower alluvium						
BMW-1(140) [1]	.02	<.01	.12	11	.02	.03
BMW-2(136) [2]	.94	<.01	1.0	<.05	.01	.02
BMW-3(85) [3]	.78	.01	1.0	<.05	.20	.18
BMW-4(101) [4]	.58	.02	.70	.05	.02	.04
BMW-5(136) [5]	.03	<.01	.11	.54	.03	.03
BMW-6(127) [6]	.02	<.01	.11	.16	.01	.02
BMW-7(102) [7]	--	--	--	--	--	--
Surface water						
County Drainage ditch at Tama Road [11]	.22	.03	.46	.90	.03	.03
Dry Branch Creek at Tama Road [9]	.02	.02	.28	3.1	.10	.08

[a]Field-replicate sample.

Table 14. Physical properties measured in ground-water and surface-water samples collected near Burlington, Iowa, May 20–21, 1999

[mg/L, milligrams per liter; µS/cm, microsiemens per centimeter at 25 degrees Celsius; --, not measured]

Site name [and map number (fig. 2)]	Dissolved oxygen (mg/L)	pH (standard units)	Specific conductance (µS/cm)	Water temperature (degrees Celsius)
Upper alluvium				
BMW-1(32) [1]	7.1	6.0	274	13
BMW-1(32) [1][a]	7.1	6.0	274	13
BMW-2(41) [2]	.15	7.3	646	12
BMW-3(37) [3]	.10	7.3	667	14
BMW-4(37) [4]	2.2	7.1	602	13
BMW-5(36) [5]	.10	7.3	551	14
BMW-6(38) [6]	--	--	--	--
BMW-7(40) [7]	--	--	--	--
Lower alluvium				
BMW-1(140) [1]	1.2	6.9	514	14
BMW-2(136) [2]	.10	7.1	894	15
BMW-3(85) [3]	--	7.7	567	14
BMW-4(101) [4]	.20	7.2	545	14
BMW-5(136) [5]	--	7.3	468	--
BMW-6(127) [6]	.30	7.4	694	14
BMW-7(102) [7]	--	--	--	--
Surface water				
County drainage ditch at Tama Road [11]	5.2	7.6	514	18
Dry Branch Creek at Tama Road [9]	8.3	8.3	595	23

[a]Field-replicate sample.

Table 15. Dissolved pesticide and pesticide-degradation product concentrations in ground-water and surface-water samples collected near Burlington, Iowa, May 20–21, 1999

[All concentrations reported in micrograms per liter; <, less than; --, sample not collected or analyzed; constituents listed with U.S. Geological Survey parameter codes in parentheses]

Site name [and map number (fig. 2)]	Acetochlor (49260)	Alachlor (46342)	Ametryn (38401)	Atrazine (39632)	Bromacil (04029)
Upper alluvium					
BMW–1(32) [1]	<0.05	<0.05	<0.05	0.10	<0.05
BMW–1(32) [1][a]	<.05	<.05	<.05	.09	<.05
BMW–2(41) [2]	<.05	<.05	<.05	<.05	<.05
BMW–3(37) [3]	<.05	<.05	<.05	<.05	<.05
BMW–4(37) [4]	<.05	<.05	<.05	<.05	<.05
BMW–5(36) [5]	<.05	<.05	<.05	.12	<.05
BMW–6(38) [6]	--	--	--	--	--
BMW–7(40) [7]	--	--	--	--	--
Lower alluvium					
BMW–1(140) [1]	<.05	<.05	<.05	.13	<.05
BMW–2(136) [2]	<.05	<.05	<.05	<.05	<.05
BMW–3(85) [3]	<.05	<.05	<.05	<.05	<.05
BMW–4(101) [4]	<.05	<.05	<.05	<.05	<.05
BMW–5(136) [5]	<.05	.019[b]	<.05	.015[b]	<.05
BMW–6(127) [6]	<.05	<.05	<.05	<.05	.04[b]
BMW–7(102) [7]	--	--	--	--	--
Surface water					
County drainage ditch at Tama Road [11]	1.7	.11	<.05	5.4	<.05
Dry Branch Creek at Tama Road [9]	.71	4.8	<.05	3.6	<.05

Site name [and map number (fig. 2)]	Butachlor (04026)	Butylate (04028)	Carboxin (04027)	Cyanazine (04041)	Cycloate (04031)
Upper alluvium					
BMW–1(32) [1]	<0.05	<0.05	<0.05	<0.20	<0.05
BMW–1(32) [1][a]	<.05	<.05	<.05	<.20	<.05
BMW–2(41) [2]	<.05	<.05	<.05	<.20	<.05
BMW–3(37) [3]	<.05	<.05	<.05	<.20	<.05
BMW–4(37) [4]	<.05	<.05	<.05	<.20	<.05
BMW–5(36) [5]	<.05	<.05	<.05	<.20	<.05
BMW–6(38) [6]	--	--	--	--	--
BMW–7(40) [7]	--	--	--	--	--
Lower alluvium					
BMW–1(140) [1]	<.05	<.05	<.05	<.20	<.05
BMW–2(136) [2]	<.05	<.05	<.05	<.20	<.05
BMW–3(85) [3]	<.05	<.05	<.05	<.20	<.05
BMW–4(101) [4]	<.05	<.05	<.05	<.20	<.05
BMW–5(136) [5]	<.05	<.05	<.05	<.20	<.05
BMW–6(127) [6]	<.05	<.05	<.05	<.20	<.05
BMW–7(102) [7]	--	--	--	--	--
Surface water					
County drainage ditch at Tama Road [11]	<.05	<.05	<.05	<.20	<.05
Dry Branch Creek at Tama Road [9]	<.05	<.05	<.05	.09[b]	<.05

Table 15. Dissolved pesticide and pesticide-degradation product concentrations in ground-water and surface-water samples collected near Burlington, Iowa, May 20–21, 1999—Continued

[All concentrations reported in micrograms per liter; <, less than; --, sample not collected or analyzed; constituents listed with U.S. Geological Survey parameter codes in parentheses]

Site name [and map number (fig. 2)]	Deethylatrazine (04040)	Deisopropyl-atrazine (04038)	Diphenamid (04033)	Hexazinone (04025)	Metolachlor (39415)
Upper alluvium					
BMW–1(32) [1]	0.35	0.35	<0.05	<0.05	<0.05
BMW–1(32) [1][a]	.29	.28	<.05	<.05	<.05
BMW–2(41) [2]	<.05	<.05	<.05	<.05	<.05
BMW–3(37) [3]	<.05	<.05	<.05	<.05	<.05
BMW–4(37) [4]	.01[b]	<.05	<.05	<.05	<.05
BMW–5(36) [5]	.04[b]	<.05	<.05	<.05	.05
BMW–6(38) [6]	--	--	--	--	--
BMW–7(40) [7]	--	--	--	--	--
Lower alluvium					
BMW–1(140) [1]	.51	.29	<.05	<.05	<.05
BMW–2(136) [2]	<.05	<.05	<.05	<.05	<.05
BMW–3(85) [3]	.01[b]	<.05	<.05	<.05	<.05
BMW–4(101) [4]	<.05	<.05	<.05	<.05	<.05
BMW–5(136) [5]	.01[b]	<.05	<.05	<.05	.006[b]
BMW–6(127) [6]	.07	<.05	<.05	<.05	<.05
BMW–7(102) [7]	--	--	--	--	--
Surface water					
County drainage ditch at Tama Road [11]	.61	.21	<.05	<.05	.60
Dry Branch Creek at Tama Road [9]	.30	.18	<.05	<.05	.49

Site name [and map number (fig. 2)]	Metribuzin (82630)	Prometon (04037)	Prometryn (04036)	Propachlor (04024)	Propazine (38535)
Upper alluvium					
BMW–1(32) [1]	<0.05	<0.05	<0.05	<0.05	<0.05
BMW–1(32) [1][a]	<.05	<.05	<.05	<.05	<.05
BMW–2(41) [2]	<.05	<.05	<.05	<.05	<.05
BMW–3(37) [3]	<.05	<.05	<.05	<.05	<.05
BMW–4(37) [4]	<.05	<.05	<.05	<.05	<.05
BMW–5(36) [5]	<.05	<.05	<.05	<.05	<.05
BMW–6(38) [6]	--	--	--	--	--
BMW–7(40) [7]	--	--	--	--	--
Lower alluvium					
BMW–1(140) [1]	<.05	<.05	<.05	<.05	<.05
BMW–2(136) [2]	<.05	<.05	<.05	<.05	<.05
BMW–3(85) [3]	<.05	<.05	<.05	<.05	<.05
BMW–4(101) [4]	<.05	<.05	<.05	<.05	<.05
BMW–5(136) [5]	<.05	<.05	<.05	<.05	<.05
BMW–6(127) [6]	<.05	<.05	<.05	<.05	<.05
BMW–7(102) [7]	--	--	--	--	--
Surface water					
County drainage ditch at Tama Road [11]	<.05	<.05	<.05	<.05	<.05
Dry Branch Creek at Tama Road [9]	.08	.02[b]	<.05	<.05	.06

Table 15. Dissolved pesticide and pesticide-degradation product concentrations in ground-water and surface-water samples collected near Burlington, Iowa, May 20–21, 1999—Continued

[All concentrations reported in micrograms per liter; <, less than; --, sample not collected or analyzed; constituents listed with U.S. Geological Survey parameter codes in parentheses]

Site name [and map number (fig. 2)]	Simazine (04035)	Simetryn (04030)	Terbacil (04032)	Trifluralin (04023)	Vernolate (04034)
Upper alluvium					
BMW-1(32) [1]	<0.05	<0.05	<0.05	<0.05	<0.05
BMW-1(32) [1][a]	<.05	<.05	<.05	<.05	<.05
BMW-2(41) [2]	<.05	<.05	<.05	<.05	<.05
BMW-3(37) [3]	<.05	<.05	<.05	<.05	<.05
BMW-4(37) [4]	<.05	<.05	<.05	<.05	<.05
BMW-5(36) [5]	<.05	<.05	<.05	<.05	<.05
BMW-6(38) [6]	--	--	--	--	--
BMW-7(40) [7]	--	--	--	--	--
Lower alluvium					
BMW-1(140) [1]	<.05	<.05	<.05	<.05	<.05
BMW-2(136) [2]	<.05	<.05	<.05	<.05	<.05
BMW-3(85) [3]	<.05	<.05	<.05	<.05	<.05
BMW-4(101) [4]	<.05	<.05	<.05	<.05	<.05
BMW-5(136) [5]	<.05	<.05	<.05	<.05	<.05
BMW-6(127) [6]	<.05	<.05	<.05	<.05	<.05
BMW-7(102) [7]	--	--	--	--	--
Surface water					
County drainage ditch at Tama Road [11]	.03[b]	<.05	<.05	<.05	<.05
Dry Branch Creek at Tama Road [9]	.02[b]	<.05	<.05	<.05	<.05

[a]Field-replicate sample.

[b]Estimated concentration less than the corresponding minimum reporting limit.

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