In cooperation with the City of Cedar Rapids, Iowa

Effectiveness of an Alluvial Wetland on Improving Ground-Water Quality in a Municipal Well Field, Cedar Rapids, Iowa, 1998–2006

Scientific Investigations Report 2008–5108

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By Douglas J. Schnoebelen

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

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CONVERSION FACTORS AND DATUMS

Inch/Pound to SI

Multiply	By	To obtain
Length		
inch (in.)	2.54	centimeter (cm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
Area		
acre	4,047	square meter (m^2)
square mile (mi^2)	2.590	square kilometer (km^2)
Volume		
cubic foot (ft^3)	0.02832	cubic meter (m^3)
quart (qt)	0.9464	liter (L)
million gallons (Mgal)	3,785	cubic meter (m^3)
Flow rate		
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)
million gallons per day (Mgal/d)	0.04381	cubic meter per second (m^3/s)
Mass		
ounce, avoirdupois (oz)	28.35	gram (g)
pound, avoirdupois (lb) per year (yr)	0.4536	kilogram (kg) per year (yr)

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

$$°F=(1.8×°C)+32$$

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

$$°C=(°F-32)/1.8$$

Vertical coordinate information is referenced to the North American Vertical Datum of 1988 (NAVD 88).

Horizontal coordinate information is referenced to the North American Datum of 1983 (NAD 83).

Altitude, as used in this report, refers to distance above the vertical datum.

*Transmissivity: The standard unit for transmissivity is cubic foot per day per square foot times foot of aquifer thickness [(ft^3/d)/ft^2]ft. In this report, the mathematically reduced form, foot squared per day (ft^2/d), is used for convenience.

Specific conductance is given in microsiemens per centimeter at 25 degrees Celsius (µS/cm at 25 °C).

Concentrations of chemical constituents in water are given either in milligrams per liter (mg/L) or micrograms per liter (µg/L).

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Abstract

Nutrients and pesticides are water-quality topics of concern in Iowa. Nitrate concentrations in the Cedar River and other streams in Iowa are among the highest in the Nation. A 12-mile reach of the Cedar River upstream from Cedar Rapids, Iowa, is identified on the Total Maximum Daily Load list for nitrate impairment by the U.S. Environmental Protection Agency. In addition, pesticide concentrations in water samples from alluvial aquifers in Iowa have been ranked as some of the largest in the Nation. The Cedar River, like many rivers with alluvium, affects the alluvial aquifer that is used as a municipal water supply for Cedar Rapids, Iowa. A continuing challenge for the Cedar Rapids Water Department is to provide drinking water that meets all drinking-water regulations; this is made more of a challenge because of the high (often over 10 milligrams per liter) nitrate concentrations in the Cedar River and the presence of other potential chemicals of concern, such as pesticides.

An alluvial wetland proved useful in improving water quality. Samples from observation wells completed in the alluvial wetland near the municipal well field had nitrate concentrations that were four to six times lower when compared to river or upland sites; however, iron and manganese concentrations in samples from observation wells in the wetland areas were an order of magnitude higher when compared to the river or an upgradient well. Biological and chemical reduction processes were determined to mobilize inorganic constituents in accordance with physical chemistry principles. Generally, selected pesticides and two pesticide degradates of atrazine that were sampled for in alluvial wetland wells remained relatively unchanged, and indicated only a slight decrease in concentration compared to the Cedar River water samples. Pesticides were not detected above regulatory limits in any of the observation wells; however, one sample from the Cedar River had an atrazine detection at 4.5 micrograms per liter, which is above the maximum contaminant level of 3.0 micrograms per liter for drinking-water regulations for that compound. Results indicate that alluvial wetlands may provide substantial reductions of nitrate concentrations in ground water, and may be a useful strategy for the reduction of nitrate for municipal wells. Results for reducing pesticides were less dramatic than for nitrate, as pesticide concentrations were reduced slightly from the river to the wetland.

Introduction

At the beginning of the century, wetlands often were regarded as "wastelands" and economical only if they were converted to "dry land." In the last three decades, the multiple importance of wetlands on habitat and diversity of species, the unique role they play in providing a transition from land to water, and the effect of wetlands on water quality have become more recognized (Brix, 1994). Wetlands have been used to treat point-source wastewater (Kadlec and Knight, 1995), and non-point-source urban and agricultural runoff (Olson and Marshall, 1993; Schulz and Peall, 2001).

Natural wetland areas in Iowa were drained and filled as agriculture moved west when settlers crossed the Mississippi River. Wetlands were estimated in Iowa circa 1780 at 4,000,000 acres or 11.1 percent of the total surface area and in the 1980's at 421,900 acres or only 1.2 percent of the total surface area—a reduction of 89 percent (Dahl, 1990). In addition, anthropogenic activities led to additions and disruptions in the nitrogen cycle (Vitousek and others, 1997). Generally, alluvial wetlands associated with bottomland forested and oxbow lake areas may persist, as they are subject to periodic flooding and often are not suitable for sustained agriculture. Alluvial wetlands commonly occur in the eastern one-half of Iowa along the Mississippi River and its major tributaries (Lammers and Van Der Valk, 1979).

In east-central Iowa, alluvial aquifers near the major rivers are a source of water for many communities. Nutrients and pesticides are water-quality topics of concern in Iowa and the Midwest (Goolsby and Battaglin, 1993; Hallberg and others, 1996; and Goolsby and others, 1999). In particular, municipal wells for the city of Cedar Rapids, Iowa, are completed in the Cedar River alluvium, a shallow [5–95 feet (ft) deep] alluvial aquifer adjacent to the Cedar River.

Nitrate-nitrogen (hereafter referred to as "nitrate") concentrations that exceed 10 milligrams per liter (mg/L) in the Cedar River are of concern to the city of Cedar Rapids because the alluvial aquifer is directly affected by the Cedar River. The U.S. Environmental Protection Agency (USEPA) has set 10.0 mg/L as the Maximum Contaminant Limit (MCL) of nitrate in drinking water (U.S. Environmental Protection Agency, 1986). The Cedar River is the source of most of the nitrate in the alluvial aquifer because of induced infiltration from the river due to pumping (Schulmeyer and Schnoebelen, 1998; Boyd, 1999). Nitrate concentrations in the Cedar River during the spring often are more than 10 mg/L, and can reach 18 mg/L during spring runoff (City of Cedar Rapids, written commun., 2006). Trend analysis for several sites on the Cedar River have indicated increases for nitrate concentrations during the last 20 to 25 years (Schnoebelen and others, 1999). In addition, water resource managers in the Cedar River Basin are concerned with nitrate impairment in streams draining to the Mississippi River as nitrate has been linked to possible hypoxia problems in the Gulf of Mexico (Turner and Rabalais, 1994). A 12-mile (mi) reach of the Cedar River upstream from Cedar Rapids, Iowa, is identified on the Total Maximum Daily Load (TMDL) list for nitrate impairment (Iowa Department of Natural Resources, 1994; U.S. Environmental Protection Agency, 2007). Large nitrate concentrations in the Cedar River can cause large nitrate concentrations in the ground water in the municipal well field. Once ground water is contaminated, it is expensive and almost impossible to clean up (National Research Council, 1993).

A continuing challenge for the Cedar Rapids Water Department is to provide drinking water that meets all drinking water regulations regardless of whether or not the nitrate concentrations are large in the Cedar River. At times, some municipal wells in the Cedar Rapids well field exceed the USEPA nitrate limit, and must be turned off or blended with water from other wells (North and others, 2003). Currently (2008), the city of Cedar Rapids water-treatment facility has no way to mitigate large nitrate concentrations. In addition, pesticides can be of concern in surface and ground water in river basins dominated by agriculture (Larson and others, 1997); however the city of Cedar Rapids currently (2008) does not have an immediate concern with pesticides in water (Cedar Rapids Water Department, oral commun., 2007). There may be a cause for concern in the future as pesticide use has increased nationally since the 1960's (Larson and others, 1997). Increased demand for biofuels, such as ethanol, potentially may increase nutrient and pesticide use in the Cedar River Basin if more corn is grown (National Research Council, 2007). To address concerns about water quality in the alluvial aquifer adjacent to the Cedar River, the U.S. Geological Survey (USGS), in cooperation with the City of Cedar Rapids, Iowa, studied the effectiveness of an alluvial wetland on improving ground-water quality near a municipal wellfield through riverbank filtration. In riverbank filtration, production wells—which are placed near the banks of the river—pump water from the alluvial aquifer creating a "head" difference

between the river and the aquifer inducing water from the river into the aquifer. Future well construction may be able to take advantage of natural or constructed wetland areas with riverbank filtration in helping to reduce concentrations of chemicals of concern from the Cedar River to the municipal wells.

Purpose and Scope

This report describes the results of water-quality sampling and monitoring to evaluate the effectiveness of an alluvial wetland on improving ground-water quality in the municipal well field near Cedar Rapids, Iowa. The report documents the interaction of surface water (Cedar River) and ground water (alluvial aquifer) in terms of water quality. In addition, previous ground-water modeling work (Schulmeyer and Schnoebelen, 1998; Turco and Buchmiller, 2004) were used to gain a better understanding of flow paths and ground-water movement through the wetland area. This report documents the potential use of riverbank filtration through an alluvial wetland and the resulting water quality. Data from the study can be used by the city of Cedar Rapids in the location of new wells to maximize water quality and water quantity.

Study Area Description

Cedar Rapids is in Linn County in east-central Iowa. Water for the city of Cedar Rapids is supplied by three well fields (Seminole, East, and West) along the Cedar River (fig. 1). The wetland study area is in a natural alluvial wetland near the Cedar River within the Seminole wellfield, near municipal well number S 4 (fig. 2). The city of Cedar Rapids has a population of about 121,000 (U.S. Census Bureau, 2007). Several large industries are major water users so that per capita water usage is nearly three times the national average for a city of this size (Cedar Rapids Water Department, written commun., 2004). The flood plain ranges from about 1,000 to 3,300 ft wide in the study area. Backwater and wetlands are common in the floodplain near the Cedar River. The upland topography is characterized by rolling hills of low relief; upstream land use is more than 90 percent agriculture. Corn and soybeans are the primary crops, and livestock raised in the area include cattle and hogs. Most of the total nitrogen inputs in the Cedar River Basin are from chemical fertilizer and animal manure (Becher and others, 2000; Becher and others, 2001).

Typically, the city of Cedar Rapids collects 10 to 26 samples each month from the Cedar River for nitrate analysis from May through July (the time of greatest runoff from fertilizer application in the basin) and 4 to 5 samples each month during the remainder of the year. Samples were collected from 1998 to 2006 and analyzed by the City of Cedar Rapids by EPA Method 300.0 (U.S. Environmental Protection Agency, 1993). Using these data, the monthly mean—for the maximum nitrate concentrations for the Cedar River at Cedar Rapids, Iowa, (station number 05464500; fig. 1) compiled from 1998 to 2006—ranged from 3.7 mg/L in

Figure 1. Location of Cedar Rapids, Seminole, East, and West municipal well fields, and the wetland study area.

Figure 2.   The Cedar River and observation wells within the wetland study area of the Cedar Rapids Seminole well field.

September to 12.9 mg/L in May (fig. 3). The monthly mean—for the median nitrate concentration compiled by month from 1998 to 2006—ranged from 2.6 mg/L in September to 10.0 mg/L in June (fig. 3).

Hydrogeology

Hydrogeology in the study area consists of an unconsolidated surficial layer of glacial till, loess, and the Cedar River alluvium (alluvial aquifer) underlain by carbonate bedrock of Devonian and Silurian age (bedrock aquifer). The alluvial aquifer typically consists of a sequence of coarse sand and gravel at the base, grading upwards to finer sand, silt, and clay near the surface. The sand and gravel may contain carbonate, shale, and ferro-magnesium-rich rock fragments. The alluvial

aquifer ranges from about 5 to 95 ft thick. The thickness of the alluvium decreases as distance from the Cedar River increases; the thinnest alluvium is adjacent to the valley walls. The alluvial valley is bounded by steep bluffs of uplands that include bedrock exposures, and can rise almost 200 ft above the river floodplain. The alluvial aquifer is recharged by infiltration from the Cedar River, precipitation, and seepage from the underlying bedrock and adjacent hydrogeologic units. In areas under the effect of municipal pumping, ground-water flow is from the Cedar River toward the well fields; in areas outside the effect of municipal pumping, ground-water flow is toward the Cedar River. The Cedar River is in direct hydraulic connection with the alluvial aquifer (Turco and Buchmiller, 2004). Hansen (1970) calculated an approximate transmissivity of the alluvial aquifer to be about 20,000 feet squared per day (ft^2/d).

Figure 3.   Monthly means of the maximum and median nitrate concentrations for the Cedar River at Cedar Rapids, Iowa, 1998–2006.

Subsequent investigations by Schulmeyer (1995) indicate transmissivity ranges from about 1,500 to about 19,000 ft^2/d (depending on type of alluvium) using the modified Theis equation (Heath, 1987). In May, 2006, a contractor to the city of Cedar Rapids performed an aquifer test using well S 10 (an abandoned well in the Seminole well field located on the edge of the river bank; fig. 1). Results of this aquifer test yielded a transmissivity value of approximately 15,000 ft^2/d (Cedar Rapids Water Plant, oral commun., 2007).

Wetlands

In a classification system used by the U.S. Fish and Wildlife Service (Cowardin and others, 1979), palustrine and riverine wetlands occur near the Cedar River. Palustrine wetlands are characterized by vegetation as forested, deciduous, or broad-leaved deciduous with lower perennial plants or emergent vegetation and are flooded intermittently or seasonally. Riverine wetlands occur within channels near streams and rivers. Vegetation is characterized by rooted herbaceous plants and floating or submersed aquatic plants. The term "alluvial wetland" is used to refer to both types of wetlands (palustrine and riverine) in this report. The soil type is hydric with underlying sand and some silt. Several natural oxbow ponds also occur within the study area. Most of the ponds are connected to the Cedar River, and some ponds are connected intermittently to the Cedar River, with flow only occurring when discharge in the Cedar River exceeds about 5,000 cubic feet per second (ft^3/s). Flooding in the Seminole well field typically occurs when discharge in the Cedar River exceeds about 7,000 ft^3/s.

The dominant wetland plants present in the study area are listed in table 1. Silver maples (*Acer saccharinum*) are the most prevalent (80 percent), particularly in the study area near municipal well S 4 (Seminole 4). Vegetation such as water hemp (*Amaranthus tuberculatus*), beggar ticks (*Bidens frondosa*), fog fruit (*Phyla lanceolata*), and cursed crowfoot (*Ranunculus sceleratus*) are dominant near the open muddy perimeters of the oxbow in the study area. In the upper part of the study area that is less prone to flooding, Reeds canary grass (*Phalarus arundinaceae*) dominates.

Table 1.   List of dominant wetland plant species found in the study area (Jan Ballew, U.S. Geological Survey, written commun., 2000).

Common name	Taxonomic name
Green ash	*Fraxinus pennsylvanica*
Black willow	*Salix nigra*
Cottonwood	*Populus deltoides*
Pink turtlehead	*Chelone obliqua*
Riverbank grape	*Vitis reparia*
Sandbar willow	*Salix exigua*
Silver maple	*Acer saccharinum*
Sycamore	*Platanus occidentalis*
Wood nettle	*Laportea canadensis*
Water hemp	*Amaranthus tuberculatus*
Beggar ticks	*Bidens frondosa*
Fog fruit	*Phyla lanceolata*
Cursed crowfoot	*Ranunculus sceleratus*
Reeds canary grass	*Phalaris arundinaceae*
Ontario aster	*Aster ontarionis*
White grass	*Leersia virgicus*
Common clearweed	*Pilea pumila*
Late figwort	*Scrophularia marilandica*
Poison ivy	*Toxicodendron radicans*
Stinging nettle	*Urtica dioica*
Hairy blue violet	*Viola sororia*

Acknowledgments

Study Methods

The study incorporated methods of water-quality sampling and analysis combined with an existing ground-water model for evaluating the effectiveness of the wetland area on water quality. Water samples were collected from the Cedar River Edgewood Bridge (site CRE for Cedar River Edgewood), observation wells (sites with prefix CRM for Cedar Rapids Municipal) and municipal wells (sites with prefix S, for Seminole) completed in the alluvial aquifer. Statistics (minimum, maximum, mean, median) were compiled for all water-quality samples. In addition, methods to ensure the quality assurance of samples are discussed, and data on quality-control samples are presented. A typical municipal pumping scenario was simulated (Roy Hesemann, City of Cedar Rapids Water Department, written commun., 2006) with the ground-water model (Turco and Buchmiller, 2004) to gain an understanding of ground-water flow paths from the Cedar River to the observation wells.

Water-Quality Sampling and Analysis

Water samples were collected by USGS personnel from six, 2-inch (in.) outer diameter observation wells installed in the alluvial wetland study area and a site on the Cedar River near the well field (fig. 2). Well CRM 25 (upgradient well) is located just upgradient from the wetland area near a corn field in the upland area. Wells CRM 27, CRM 23, and CRM 26 (wetland wells) are in or near the wetland area that contains water most of the year, and wells CRM 24 and CRM 22 (near river wells) are near the Cedar River in the part of the wetland that is slightly higher, and that typically does not contain water most of the year (fig. 2). The wells were installed by USGS personnel using hollow-stem auger drilling techniques, completed with polyvinyl-chloride (PVC) flush-joint casing. Bentonite grout was installed around the casing 6 to 8 ft below land surface and capped with a cement pad at the surface. Wells ranged from 18 to 47.5 ft deep.

Quarterly sampling of the six wells and the Cedar River was conducted for about nine years (1998 to 2006). The topography slopes from the northwest in the upland area to the southeast toward the Cedar River (fig. 2). Ground-water modeling and particle tracking has shown that ground-water flow is from the upland area toward the wetland, and ground-water flow also is from the river toward the wetland because of pumping in the municipal well field (Mike Turco, U.S. Geological Survey, written commun., 2003; Turco and Buchmiller, 2004). Scenarios with the ground-water model in 2006 using particle tracking to illustrate flow paths are discussed in detail later in this report under the section headings "Ground-Water Modeling" and "Flow Paths".

Before collecting water samples, each observation well was pumped to remove approximately three borehole volumes of water. Water samples were collected using a stainless-steel submersible pump and chemically inert fluoropolymer tubing. Onsite measurements of specific conductance, pH, water temperature, alkalinity, and dissolved oxygen were performed at the time of sample collection. The specific conductance, pH, water temperature, and dissolved oxygen were measured in a flow-through chamber. Water samples for analysis of nutrients and major ions were filtered through a 0.45-micrometer pore size polycarbonate capsule filter in the field. Water samples for pesticide analysis were filtered through a 142-millimeter diameter, 0.7-micrometer pore size borosilicate glass-fiber filter, and placed in a stainless steel filter unit. All samples were collected according to USGS protocols (U.S. Geological Survey National Field Manual, 1997–2006) and analyzed according to procedures described by Fishman (1993). Water samples were kept on ice and shipped by overnight air express to the USGS National Water-Quality Laboratory (NWQL) in Denver, Colorado, for analysis.

The nutrient, carbon, and field constituents analyzed for in the water samples, the Chemical Abstracts Service (CAS) registry number, the USGS National Water Information System (NWIS) data-base code, and the laboratory reporting level (LRL) are given in table 2. The term "nitrate" as used in this report includes the nitrite species, as this form of the nitrogen species typically is a small concentration (less than 0.1 mg/L). The major ions and selected pesticides and two pesticide degradate compounds, followed by the CAS number, NWIS data-base code, and LRL are listed in tables 3 and 4. The LRL is used for specifying quantifiable limits for constituents listed tables 2, 3, and 4 (unless footnoted otherwise). The LRL is defined more rigorously by statistics than the older minimum reporting level (MRL) that it replaces at the NWQL (Oblinger-Childress and others, 1999).

Quality Assurance and Quality Control

To properly interpret water-quality data and to ensure that these data are reliable and accurate, quality-assurance (QA) procedures and quality-control (QC) samples are needed. Generally, quality assurance includes using correct procedures and protocols, proper documentation (log books and field sheets), and approved analytical methods. Quality-control samples typically are used to estimate the magnitude of bias and variability of the environmental samples. Bias is systematic error that can "skew" results in either a positive

Table 2. Nutrients, dissolved organic carbon, and field measurements analyzed in water samples, chemical abstract number, National Water Information System data-base code, laboratory reporting level, and reporting units.

[CAS, Chemical Abstracts Service; NWIS, National Water Information System; LRL, laboratory reporting level; mg/L, milligrams per liter; --, no data; µS/cm, microsiemens per centimeter]

Water-quality constituent	CAS registry number[1]	NWIS code	LRL	Reporting units
Nutrients and dissolved organic carbon				
Nitrogen, ammonia, as N	7664-41-7	00608	0.041	mg/L
Nitrogen, nitrate + nitrite, as N	--	00631	0.047	mg/L
Nitrogen, nitrite, as N	14797-65-0	00613	0.008	mg/L
Phosphorus, ortho, as P	14265-44-2	00671	0.018	mg/L
Dissolved organic carbon	--	00681	0.40	mg/L
Field measurements				
Alkalinity	--	39086	--	mg/L
Dissolved oxygen	--	31501	--	mg/L
pH	--	00400	--	Standard units
Specific conductance	--	00095	--	µS/cm
Temperature, water	--	00010	--	degrees Celsius

[1]This report contains CAS Registry Numbers®, which is a Registered Trademark of the American Chemical Society. CAS recommends the verification of the CAS Registry Numbers through CAS Client Services℠.

Table 3. Major ions analyzed in water samples, chemical abstract number, National Water Information System data-base code, laboratory reporting level, and reporting units.

[CAS, Chemical Abstracts Service; NWIS, National Water Information System; LRL, laboratory reporting level; µg/L, micrograms per liter; mg/L, milligrams per liter; --, no data]

Water-quality constituent	CAS registry number[1]	NWIS code	LRL	Reporting units
Boron	7440-42-8	01020	1.8	µg/L
Bromide	24959-67-9	71870	0.02	mg/L
Calcium	7440-70-2	00915	0.02	mg/L
Calcium bicarbonate	3983-19-5	00453	0.02	mg/L
Calcium carbonate	471-34-1	00442	0.02	mg/L
Chloride	16887-00-6	00940	0.12	mg/L
Fluoride	16984-48-8	00950	0.10	mg/L
Iron	7439-89-6	01046	6.0	µg/L
Magnesium	7439-95-4	00925	0.014	mg/L
Manganese	7439-96-5	01056	0.2	µg/L
Potassium	7440-09-7	00935	0.04	mg/L
Silica	7631-86-9	00955	0.018	mg/L
Sodium	7440-23-5	00930	0.02	mg/L
Sulfate	14808-79-8	00945	0.18	mg/L
Total dissolved solids	--	70300	10	mg/L

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Table 4.   Selected pesticides and pesticide degradates analyzed in water samples, chemical abstract number, National Water Information System database code, laboratory reporting level, and reporting units.

[CAS, Chemical Abstracts Service; NWIS, National Water Information System; LRL, laboratory reporting level; µg/L, micrograms per liter]

Constituent	CAS registry number[1]	NWIS code	LRL (µg/L)	Reporting units
CIAT[2]	6190-65-4	04040	0.05	µg/L
CEAT[2]	1007-28-9	04038	0.05	µg/L
Acetochlor	34256-82-1	49260	0.05	µg/L
Alachlor	15972-60-8	46342	0.05	µg/L
Ametryn	834-12-8	38401	0.05	µg/L
Atrazine	1912-24-9	39632	0.05	µg/L
Bromacil	314-40-9	04029	0.05	µg/L
Butachlor	23184-66-9	04026	0.05	µg/L
Butylate	2008-41-5	04028	0.05	µg/L
Carboxin	5234-68-4	04027	0.05	µg/L
Cyanazine	21725-46-2	04041	0.20	µg/L
Cycloate	1134-23-2	04031	0.05	µg/L
Diphenamid	957-51-7	04033	0.05	µg/L
Hexazinone	51235-04-2	04025	0.05	µg/L
Metolachlor	51218-45-2	39415	0.05	µg/L
Metribuzin	21087-64-9	82630	0.05	µg/L
Prometon	1610-18-0	04037	0.05	µg/L
Prometryn	7287-19-6	04036	0.05	µg/L
Propachlor	1918-16-7	04024	0.05	µg/L
Propazine	139-40-2	38535	0.05	µg/L
Simazine	122-34-9	04035	0.05	µg/L
Simetryn	1014-70-6	04030	0.05	µg/L
Terbacil	5902-51-2	04032	0.05	µg/L
Trifluralin	1582-09-8	04023	0.05	µg/L
Vernolate	1929-77-7	04034	0.05	µg/L

[1]This report contains CAS Registry Numbers®, which is a Registered Trademark of the American Chemical Society. CAS recommends the verification of the CAS Registry Numbers through CAS Client Services[SM].

[2]Atrazine degradates: 2-Chloro-4-amino-6-isopropyl-amino-*s*triazine (CIAT) and 2-Chloro-4-ethylamino-6-amino-*s*-triazine (CEAT).

or negative direction. The most common source of positive bias in water-quality studies is contamination of samples from airborne gases and particulates, or inadequately cleaned sampling equipment. Variability is the degree of random error of independent measurements of the sample quantity and may be the result of errors in laboratory analytical procedures or in collection of samples in the field. QA/QC procedures are required to ensure that the data collected meet standards of reliability and accuracy.

The QA/QC for the study followed USGS protocols (U.S. Geological Survey, 1998) and other USGS guidelines (Mueller and others, 1997). Approximately 10 percent of the total samples collected for the study were analyzed for quality control and included equipment blanks, field blanks, and replicates. Generally, blanks are used to estimate sample bias, whereas replicates are used to estimate sample variability.

A blank sample is a water sample that is intended to be free of the analytes of interest. Equipment blank samples of

deionized water guaranteed by the manufacturer to be free of organic compounds, and another type of deionized water guaranteed by the manufacturer to be free of inorganic compounds, were passed through all sampling equipment at the beginning of the field season. Equipment blank samples are collected in a "clean" environment, such as the laboratory, to examine the cleanliness of the equipment before sampling. A field blank is a specific type of blank sample collected in the field and used to demonstrate that: equipment has been cleaned adequately to remove contamination introduced by samples obtained at the previous site; sample collection and processing have not resulted in contamination; and sample handling, transport, and laboratory analysis have not introduced contamination (Mueller and others, 1997). Field blank samples of the deionized inorganic and organic free water were collected by passing this water through all pumps, filter plates, and filters to verify cleanliness of sampling equipment and technique. Field blank sample concentrations for inorganic and organic constituents typically were equivalent to the LRL. In other words, the blanks were "clean" and did not indicate any contamination from the equipment or sample processing methods. There was no cross-contamination of samples from sampling equipment between sample collection.

Replicates are two or more samples collected or processed so that the samples are considered to be essentially identical in composition. Each replicate sample is an aliquot of the native water sample that is processed and prepared in the same way as the environmental sample. A replicate sample set consists of two samples—a regular environmental sample and the replicate environmental sample. For the purposes of this report, the terms "environmental sample" and "replicate sample" are used to identify the particular samples in a replicate pair.

One objective of the replicate samples was to estimate the precision of concentration values from sample processing and analysis. Analyses of organic constituents generally show more variability than analyses of inorganic constituents. Replicate samples were compared by using relative percent differences. Relative percent difference (RPD) between replicate samples was calculated by the following using the equation:

$$RPD = |S1-S2| / \left(\frac{S1+S2}{2} \right) \times 100$$

where:
- S1   is equal to the concentration in the environmental sample, and
- S2   is equal to the concentration in the replicate sample.

Typically, if the relative percent difference is large it can indicate greater variability in those samples. Generally, variability for all constituents in the replicate samples were within 10 percent of the environmental samples. The median RPD for nutrients, organic carbon, and common ions ranged from 0 to 9.5 percent, and the median RPD for pesticides ranged from 0 to 5.3 percent (table 5). It should be noted that when comparing small or low concentrations between some replicate samples, the RPD can appear relatively large, because slight differences (common at the lowest detection levels) can result in higher RPDs. This is the case for RPDs that had the largest percentage (10 percent or greater).

Surrogates are added to all environmental and quality-control samples for pesticide analysis before sample preparation in the laboratory. A surrogate is similar to the physical and chemical properties of the analytes of interest, but normally is not found in environmental samples. Typically, the number of surrogates varies from one to four compounds. Surrogates provide quality control by monitoring matrix effects and gross processing errors (Wershaw and others, 1987). Surrogate recoveries for organic chemicals are expressed in percent, and typically range from 80 to 120 percent. Surrogate recoveries that consistently are less than 70 percent may indicate that many of the targeted compounds may be present in greater concentrations than reported. The surrogate median percent recoveries ranged from 78.0 to 86.7 percent and the mean percent recoveries ranged from 77.5 to 87.4 percent and are listed in table 6.

Ground-Water Modeling

Two ground-water flow models have been used to better understand the ground-water flow system of the Cedar River and the alluvial aquifer, particularly near well field areas. The first ground-water model of the alluvial aquifer in the Cedar Rapids area was more regional in scope [231 square miles (mi^2)] and was completed by Schulmeyer and Schnoebelen, (1998) in cooperation with the city of Cedar Rapids. This model, which had a 500- by 500-ft grid size, indicated that the primary sources of inflow to the alluvial aquifer included infiltration from the Cedar River (74.2 percent), infiltration from underlying hydrogeologic units (20.9 percent), and infiltration from precipitation (4.9 percent). Pumpage by municipal water-supply wells from the alluvial aquifer accounted for 78 percent of the system outflow. The USGS, in cooperation with the city of Cedar Rapids, modeled the well field area in more detail (45 mi^2) (Turco and Buchmiller, 2004). In addition, the model used grid sizes as small as 50- by 50-ft within the well field to better define flow to individual wells. The model was intended to aid in the detailed study of the surface- and ground-water interaction in the well field and to better evaluate the effect of the Cedar River on the quality of municipal water supplies. Results from the more detailed model indicate that 99 percent of the water discharging from the municipal wells infiltrates from the Cedar River (Turco and Buchmiller, 2004).

Both of the ground-water models (regional and detailed) confirm the large effect of the Cedar River on the alluvial aquifer in the municipal well fields. In this study, scenarios of ground-water flow and particle tracking were completed in 2006. The detailed ground-water model presented in Turco and Buchmiller (2004) was constructed using the Ground-water Modeling System (GMS) software (Brigham Young University, 1998). This study updated the model to GMS 6.0,

Table 5. Summary of replicate sample data for selected common nutrients, ions, pesticides and pesticide degradates, 1998–2006.

[mg/L, milligrams per liter; µg/L, micrograms per liter]

Constituent	Number of replicate samples	Relative percent difference			
		Minimum	Maximum	Mean	Median
Nutrients					
Ammonia (mg/L as N)	8	0.0	45.6	6.9	0.0
Nitrite + nitrate (mg/L as N)	8	0.0	18.5	4.0	1.5
Nitrite (mg/L as N)	8	0.0	15.4	4.2	0.76
Orthophosphate (mg/L as P)	8	2.3	28.6	10.4	6.4
Organic carbon (mg/L)	8	0.21	10.1	3.3	2.7
Major ions					
Alkalinity (mg/L as CaCO$_3$)	1	0.0	0.0	0.0	0.0
Bicarbonate (mg/L)	1	0.0	0.0	0.0	0.0
Carbonate (mg/L)	1	0.0	0.0	0.0	0.0
Boron (mg/L)	8	2.7	14.5	7.3	6.4
Bromide (mg/L)	8	0.44	23.5	11.5	9.5
Calcium (mg/L)	8	0.13	3.1	1.1	0.62
Chloride (mg/L)	8	0.16	9.7	2.9	1.8
Fluoride (mg/L)	8	0.0	22.9	6.7	1.8
Iron (mg/L)	8	0.0	11.8	5.1	4.2
Magnesium (mg/L)	8	0.12	3.4	1.3	1.3
Manganese (mg/L)	8	0.03	50	9.2	4.1
Potassium (mg/L)	8	0.0	2.6	1.4	1.5
Silica (mg/L)	8	0.14	2.0	0.69	0.49
Sodium (mg/L)	8	0.35	10.2	3.2	1.7
Sulfate (mg/L)	8	0.18	2.5	1.0	0.92
Residue on evaporation (mg/L)	8	0.0	2.2	0.96	1.0
Pesticides and pesticide degradates					
CIAT[1] (µg/L)	8	0.70	15.2	6.9	4.7
CEAT[1] (µg/L)	8	0.0	143.5	18.8	0.0
Acetochlor (µg/L)	8	0.0	148.7	25.1	0.0
Alachlor (µg/L)	8	0.0	0.0	0.0	0.0
Ametryn (µg/L)	8	0.0	17.7	2.215	0.0
Atrazine (µg/L)	8	1.2	13.2	3.7	1.8
Bromacil (µg/L)	8	0.0	0.0	0.0	0.0
Cyanazine (µg/L)	8	0.0	0.0	0.0	0.0
Cycloate (µg/L)	8	0.0	0.0	0.0	0.0
Diphenamid (µg/L)	8	0.0	0.0	0.0	0.0
Metolachlor (µg/L)	8	0.0	21.2	6.2	5.3
Metribuzin (µg/L)	8	0.0	0.0	0.0	0.0
Prometon (µg/L)	8	0.0	24.7	5.7	0.0
Propazine (µg/L)	8	0.0	9.5	1.4	0.0
Simazine (µg/L)	8	0.0	1.4	0.18	0.0
Terbacil (µg/L)	8	0.0	0.0	0.0	0.0
Trifluralin (µg/L)	8	0.0	0.0	0.0	0.0

[1]Atrazine degradates: 2-Chloro-4-amino-6-isopropyl-amino-*s*triazine (CIAT) and 2-Chloro-4-ethylamino-6-amino-*s*-triazine (CEAT).

Table 6. Surrogate pesticide data for observation wells and the Cedar River with minimum, maximum, median, and mean percent recovery, 1998–2006.

Well name	alpha-HCH-d6 surrogate (percent recovery)			
	Minimum	Maximum	Median	Mean
CRM 26	59.7	101.2	84.5	83.7
CRM 22	27.3	150.9	84.5	82.8
CRM 23	30.5	121.9	81.2	82.7
CRM 24	65.9	96.2	85.7	85.0
CRM 27	59.4	106.1	85.1	84.8
CRM 25	62.7	108.0	84.3	83.3
CRE	44.1	107.4	82.2	84.1

Well name	Diazinon-d10 surrogate (percent recovery)			
	Minimum	Maximum	Median	Mean
CRM 26	62.4	113.3	83.6	83.2
CRM 22	29.8	151.2	80.4	78.0
CRM 23	27.0	147.0	78.0	78.5
CRM 24	60.6	89.5	78.9	77.5
CRM 27	67.3	128.2	86.7	87.4
CRM 25	62.0	117.6	82.9	79.9
CRE	31.6	123.4	81.4	81.0

the most current version of the software available. Parameter values for the steady-state model were not changed from calibrated values; only changes to pumpage were made to simulate a typical summer pumping scenario for this report. The revised model is used to estimate general flow directions and velocity for steady-state (equilibrium) conditions, but the steady-state model does not indicate time required to reach new equilibrium conditions.

Effectiveness of the Alluvial Wetland on Ground-Water Quality

The results of the effectiveness of the alluvial wetland on the ground-water quality are presented using ground-water flow paths and water-quality results. In particular, nitrate concentrations were of primary concern to the city of Cedar Rapids given the history of large (more than 10 mg/L) nitrate concentrations in the Cedar River during certain times of the year (spring and winter). The iron, manganese, and dissolved-oxygen results are especially important in reduction-oxidation (redox) reactions that can cause well screen fouling and decreased well performance. In addition, results from selected pesticides and two pesticide degradates are presented, because agricultural chemicals commonly are detected in the Cedar

River (and other streams in Iowa). The pesticides detected in the study are in the micrograms per liter (parts per billion) range and at much lower concentrations than nitrate or other major ions that typically are detected in the milligram per liter range (parts per million). However, even low concentrations of pesticides may be harmful in drinking water. For example, the regulatory level for atrazine (a common pesticide used in Iowa) is 3.0 micrograms per liter (μg/L) for drinking water. Some pesticides may be carcinogenic; others may affect the hormone or endocrine system (U.S. Environmental Protection Agency, 2006).

The pumping of municipal water-supply wells induces flow from the Cedar River into the alluvial aquifer. As ground-water flows through the aquifer from the river, reactions can occur that alter the chemical composition of the water. Many of these reactions are microbially catalyzed redox reactions (Schulmeyer and Schnoebelen, 1998; Boyd, 1999). Analytical results of water samples collected from the Cedar River, municipal wells, and observation wells for major ions, dissolved organic carbon, nutrients, and field measurements are listed in table 7. Calcium, magnesium, and bicarbonate are the dominant ions in the surface and ground water (table 8). In addition, nitrate, sulfate, iron, and manganese can occur in large concentrations in certain wells or at certain times of the year. A comparison of water chemistry was made from water-sample analyses from the Cedar River, an observation well upgradient from the wetland area and river, wells in the wetland area, and near river wells between the wetland area and the river.

Flow Paths

Pumping in the municipal well field has altered the hydrology and ground-water flow paths between the alluvial aquifer and the Cedar River. During periods of active pumping, a hydraulic gradient is induced between the Cedar River and the alluvial aquifer that, in turn, induces flow from the river into the unconfined aquifer. This has caused the Cedar River to have a losing stream reach in the area of the municipal well fields. A diagram of an aquifer recharging a stream with no pumping affect is shown in figure 4; a conceptual diagram illustrating the effect of pumping on the water flow to and from a river and an unconfined aquifer is shown in figure 5.

Results from a model scenario (typical summer pumping schedule) using particle tracking were completed to gain a better understanding of flow paths. The simulation involved tracking of hypothetical "particles" that were introduced into the Cedar River, which were then "tracked" using the model during a typical summer usage schedule (fig. 6). Induced infiltration of the Cedar River through the area of the wetlands and municipal wells is clearly shown by particle flow paths, although the upland well (CRM 25) does not seem to be affected by induced flow from the Cedar River (fig. 6). Additional analysis was completed using the ground-water

Table 7.   Statistical summary of nutrients, dissolved organic carbon, and field measurements with minimum, maximum, mean, and median by well group and the Cedar River, 1998–2006.

[mg/L milligrams per liter; <, less than; mmHg, millimeters mercury; deg C, degrees Celsius; µS/cm, microsiemens per centimeter; std units, standard units]

Constituent	Minimum	Maximum	Mean	Median
Upland well (CRM 25)				
Nutrients and dissolved organic carbon				
Ammonia (mg/L as N)	0.01	0.07	0.02	0.02
Nitrite + nitrate (mg/L as N)	3.05	7.7	5.0	5.0
Nitrite (mg/L as N)	<0.01	0.02	0.01	0.01
Orthophosphate (mg/L as P)	0.06	0.10	0.08	0.08
Dissolved organic carbon, (mg/L)	.7	1.6	1.0	.9
Field measurements				
Barometric pressure (mmHg)	732	764	746	745
Water temperature (deg C)	8.5	22.0	14.0	14.3
Specific conductance (µS/cm)	426	684	502	483
pH (std units)	6.3	7.1	6.7	6.8
Dissolved oxygen (mg/L)	0.1	13.2	6.4	6.7
Wetland wells (CRM 23, 26, and 27)				
Nutrients and organic carbon				
Ammonia (mg/L as N)	0.01	0.80	0.06	0.02
Nitrite + nitrate (mg/L as N)	<0.01	9.7	1.1	.08
Nitrite (mg/L as N)	<0.01	0.44	0.03	0.01
Orthophosphate (m/L as P)	.01	.14	.05	.03
Organic carbon (mg/L)	1.52	3.91	2.47	2.47
Field measurements				
Barometric pressure (mmHg)	731	764	747	747
Water temperature (deg C)	3.40	25.00	13.50	13.22
Specific conductance (µS/cm)	370	747	566	573
pH (std units)	6.59	7.51	7.00	7.02
Dissolved oxygen (mg/L)	<0.01	9.6	.54	.2
Near river wells (CRM 22 and 24)				
Nutrients and organic carbon				
Ammonia (mg/L as N)	.01	7.6	.62	.02
Nitrite + nitrate (mg/L as N)	.03	11.5	4.0	3.3
Nitrite (mg/L as N)	<0.01	0.30	0.03	<0.01
Orthophosphate (mg/L as P)	.01	.48	.12	.12
Organic carbon (mg/L)	1.34	4.27	2.20	2.16
Field measurements				
Barometric pressure (mmHg)	732	764	745	746
Water temperature (deg C)	0.3	26.1	15.0	17.0
Specific conductance (µS/cm)	390	715	534	523
pH (std units)	6.5	7.8	7.4	7.4
Dissolved oxygen (mg/L)	<0.01	11.4	.9	.2
Cedar River (CRE)				
Nutrients and organic carbon				
Ammonia (mg/L as N)	.01	.25	.03	.02
Nitrite + nitrate (mg/L as N)	.03	12.6	6.0	6.6
Nitrite (mg/L as N)	<0.01	0.08	0.02	0.01
Orthophosphate (mg/L as P)	<0.01	.16	.06	.05
Organic carbon (mg/L)	2.05	6.06	3.18	2.94
Field measurements				
Barometric pressure (mmHg)	724	764	746	746
Water temperature (deg C)	0.1	27.1	14.9	18.0
Specific conductance (µS/cm)	234	724	511	529
pH (std units)	7.4	9.2	8.2	8.2
Dissolved oxygen (mg/L)	6.6	18.4	11.6	12.0

Table 8. Statistical summary of major ions with minimum, maximum, mean, and median by well group and the Cedar River, 1998–2006.
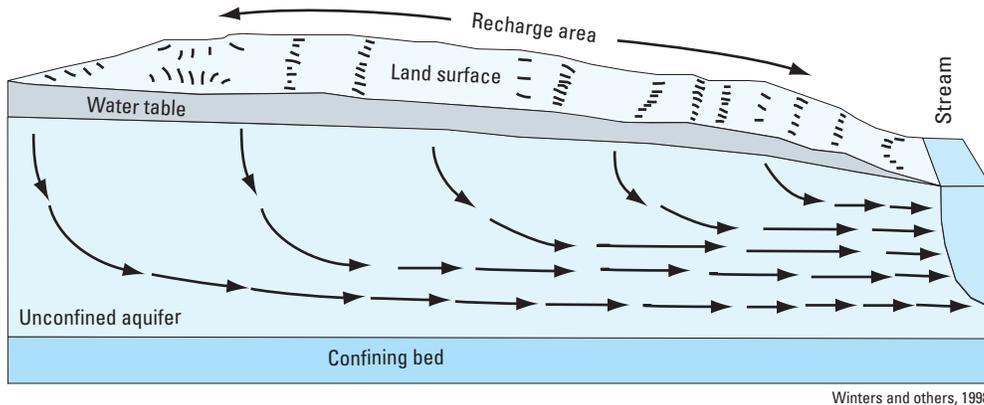
[mg/L milligrams per liter; <, less than; µg/L, micrograms per liter]

Constituent	Minimum	Maximum	Mean	Median
Upland well (CRM 25)				
Alkalinity (mg/L as $CaCO_3$)	132	219	168	162
Bicarbonate (mg/L)	161	267	206	198
Carbonate (mg/L)	<0.01	0.10	0.01	0
Bromide (mg/L)	<0.01	.1	<0.01	<0.01
Calcium (mg/L)	58	100	72	69
Chloride (mg/L)	11	22	16	14
Fluoride (mg/L)	.1	.2	.1	.1
Iron (µg/L)	4.0	12.7	6.0	5.0
Magnesium (mg/L)	11	18	13	1
Manganese (µg/L)	.3	18.7	2.8	1.6
Potassium (mg/L)	1.7	2.7	2.1	2.1
Silica (mg/L)	12	17	15	15
Sodium (mg/L)	7.7	14	10	9.6
Sulfate (mg/L)	.2	84	48	47
Residue on evaporation (mg/L)	255	436	313	299
Wetland wells (CRM 27, 23, and 26)				
Alkalinity (mg/L as $CaCO_3$)	164	362	231	227
Bicarbonate (mg/L)	200	442	281	277
Carbonate (mg/L)	<0.01	0.20	0.02	<0.01
Bromide (mg/L)	<0.01	.1	<0.01	<0.01
Calcium (mg/L)	57	113	79	78
Chloride (mg/L)	13	32	21	21
Fluoride (mg/L)	.1	.4	.2	.2
Iron (µg/L)	3.0	312	46	18
Magnesium (mg/L)	15	30	20	20
Manganese (µg/L)	.4	1103	369	229
Potassium (mg/L)	1.4	4.0	2.6	2.6
Silica (mg/L)	5.4	17	12	12
Sodium (mg/L)	6.4	16	9.7	9.1
Sulfate (mg/L)	.1	57	31	30
Residue on evaporation (mg/L)	255	426	335	335
Near river wells (CRM 22 and 24)				
Alkalinity (mg/L as $CaCO_3$)	123	263	192	193
Bicarbonate (mg/L)	149	319	233	234
Carbonate (mg/L)	<0.01	0.90	0.09	<0.01
Bromide (mg/L)	<0.01	.1	<0.01	<0.01
Calcium (mg/L)	36	89	63	63
Chloride (mg/L)	12	41	25	25
Fluoride (mg/L)	.1	.3	.2	.2
Iron (µg/L)	3.7	507	76	5.9
Magnesium (mg/L)	14	38	22	21
Manganese (µg/L)	0.5	2319	391	156
Potassium (mg/L)	1.5	5.2	2.6	2.5
Silica (mg/L)	5.5	25	10	9.7
Sodium (mg/L)	5.7	23	12	12
Sulfate (mg/L)	9.2	61	31	30
Residue on evaporation (mg/L)	222	420	309	306

Table 8.   Statistical summary of major ions with minimum, maximum, mean, and median by well group and the Cedar River, 1998–2006.—Continued
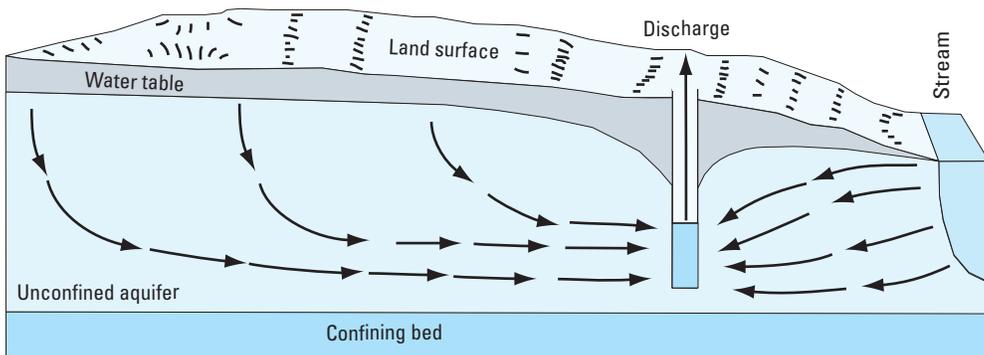
[mg/L milligrams per liter; <, less than; µg/L, micrograms per liter]

Constituent	Minimum	Maximum	Mean	Median
Cedar River (CRE)				
Alkalinity (mg/L as CaCO$_3$)	95	243	182	187
Bicarbonate (mg/L)	84	295	211	219
Carbonate (mg/L)	<0.01	36	3.2	0.9
Bromide (mg/L)	<0.01	.1	<0.01	<0.01
Calcium (mg/L)	<0.01	98	65	70
Chloride (mg/L)	<0.01	42	24	24
Fluoride (mg/L)	<0.01	.3	.2	.2
Iron (µg/L)	3.0	167	11.5	5.0
Magnesium (mg/L)	<0.01	29	21	21
Manganese (µg/L)	1.5	384	16	6.3
Potassium (mg/L)	<0.01	3.7	2.4	2.5
Silica (mg/L)	<0.01	20	8.4	8.9
Sodium (mg/L)	<0.01	25	11	10
Sulfate (mg/L)	<0.01	47	30	30
Residue on evaporation (mg/L)	5.0	470	308	326

Winters and others, 1998

Figure 4.   Conceptual cross sections of a gaining section of a stream.

Winters and others, 1998

Figure 5.   Conceptual cross sections of a losing section of a stream due to pumping from a production well.
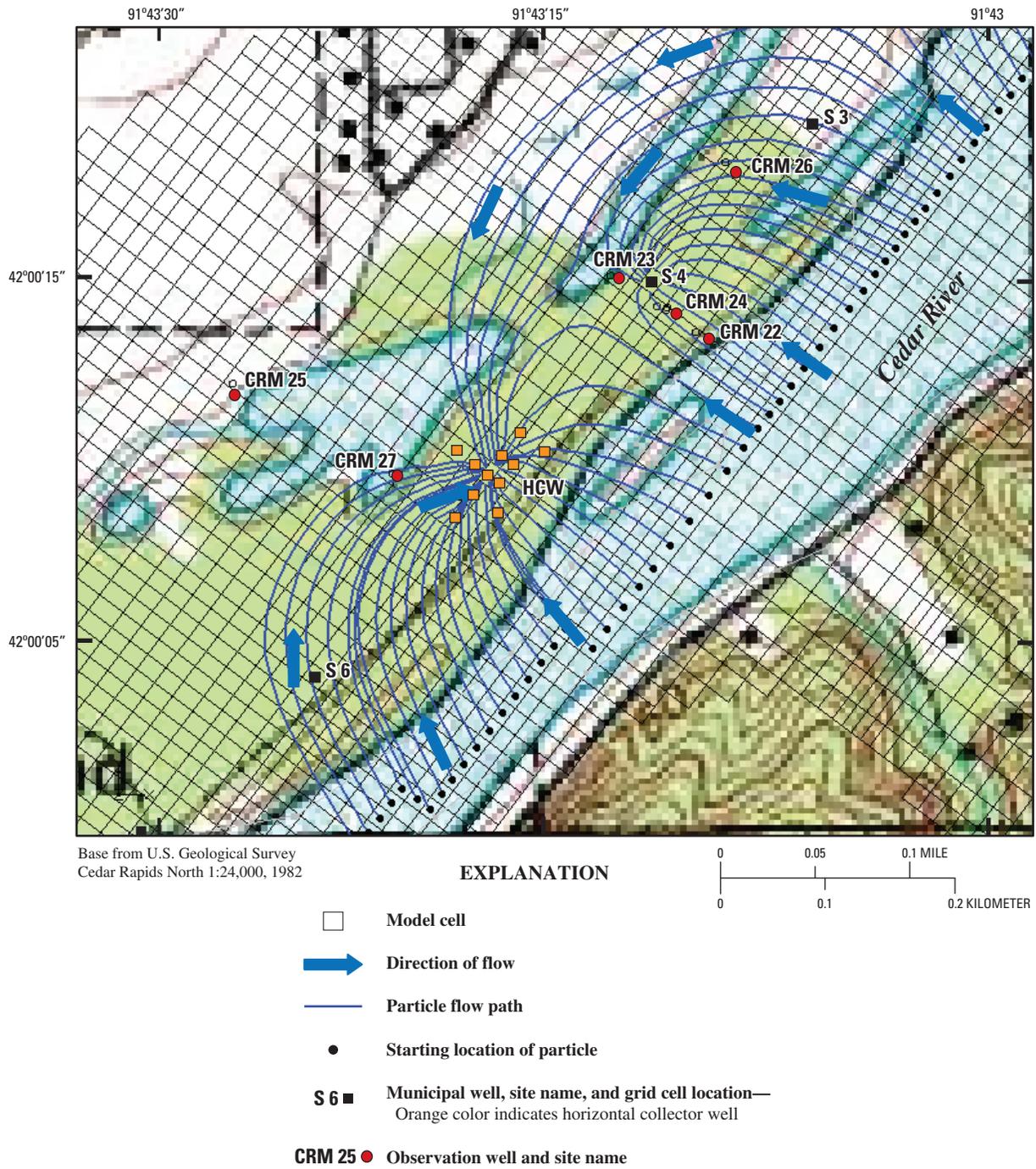
Figure 6.   Ground-water flow paths in the wetland study area with municipal wells pumping for a typical summer pumping schedule.

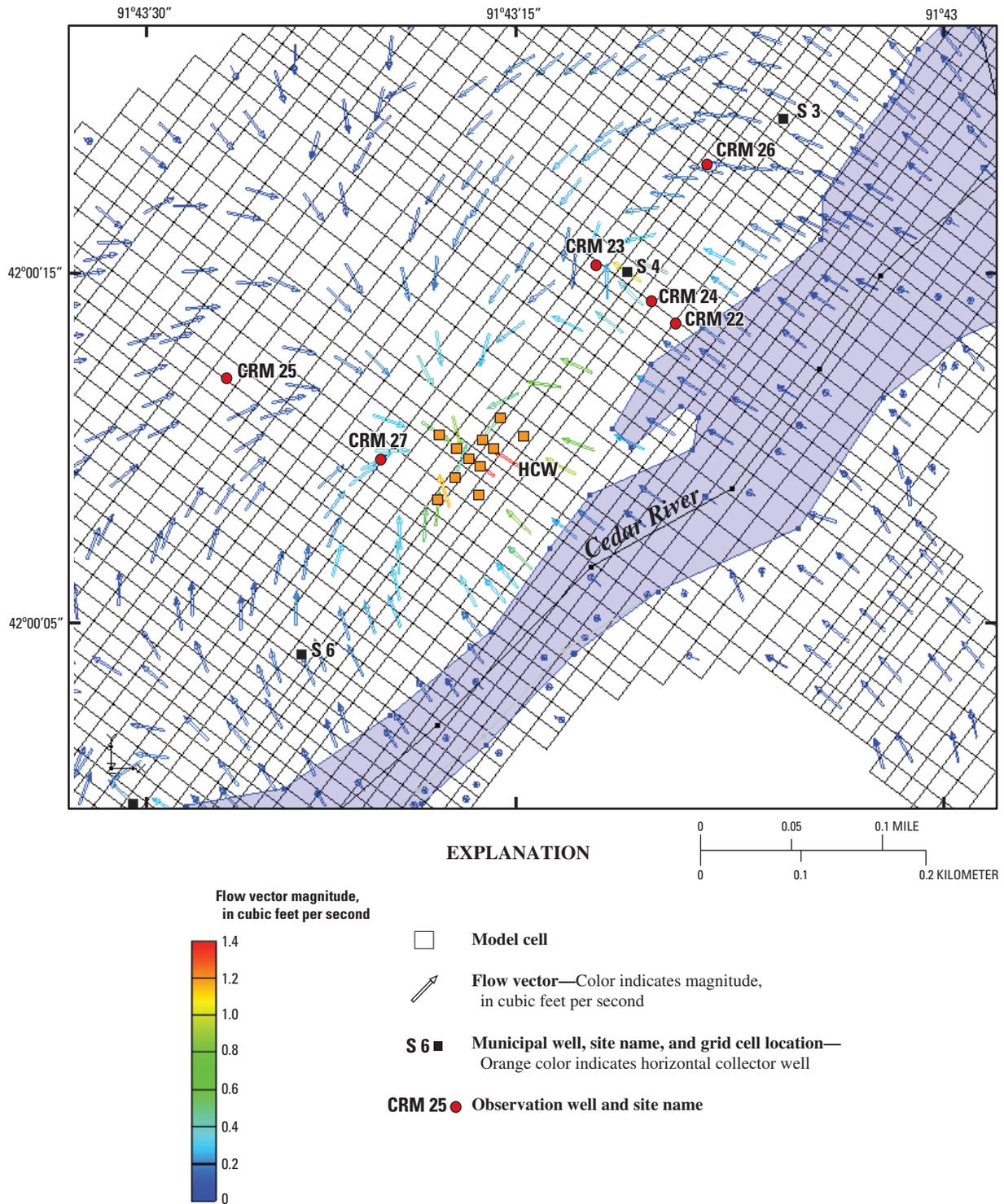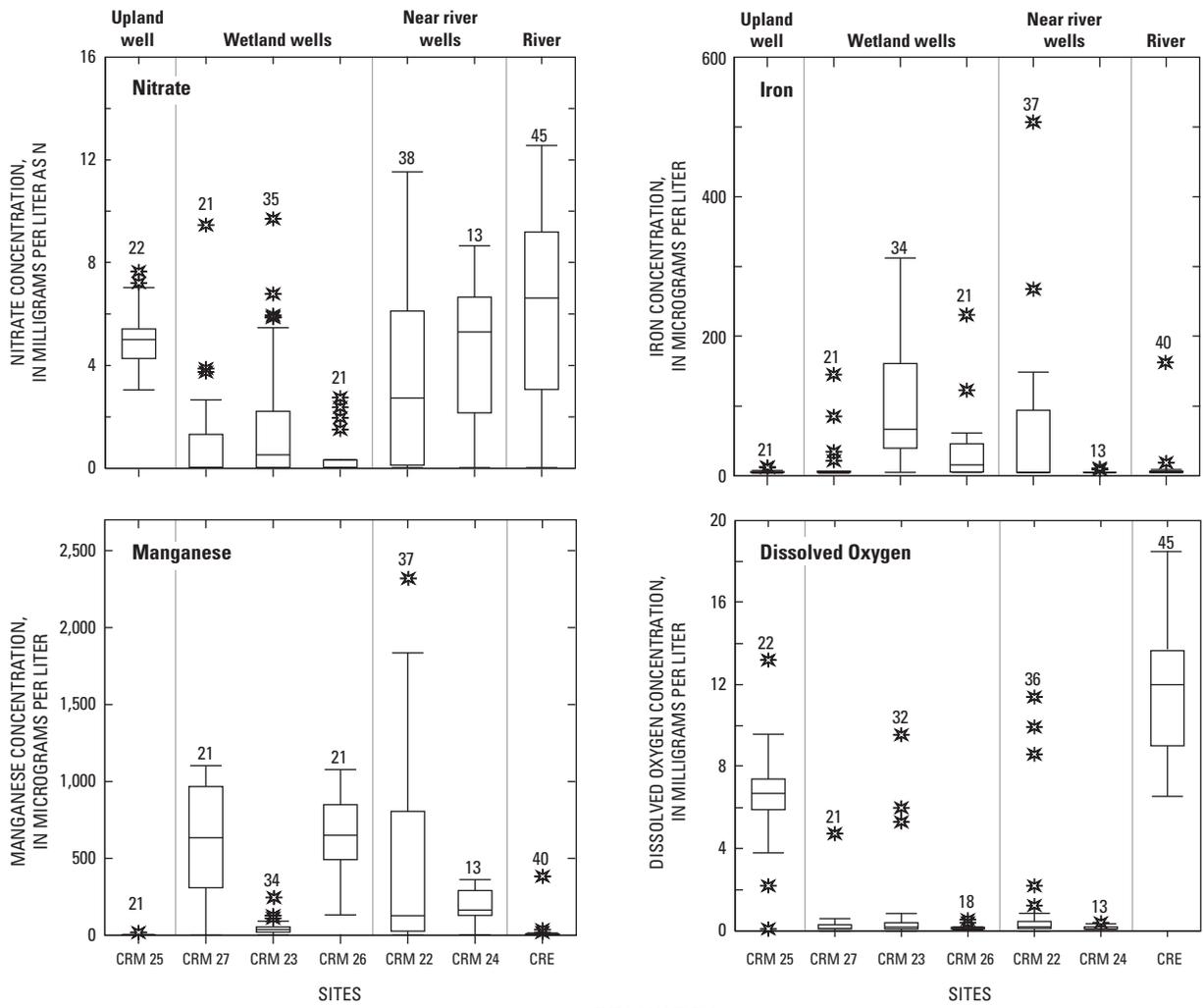**Figure 7.**   Ground-water flow vectors in the wetland study area with municipal wells pumping for a typical summer pumping schedule.

Figure 8. Concentrations of nitrate, iron, manganese, and dissolved oxygen in the wetland study area, 1998–2006.
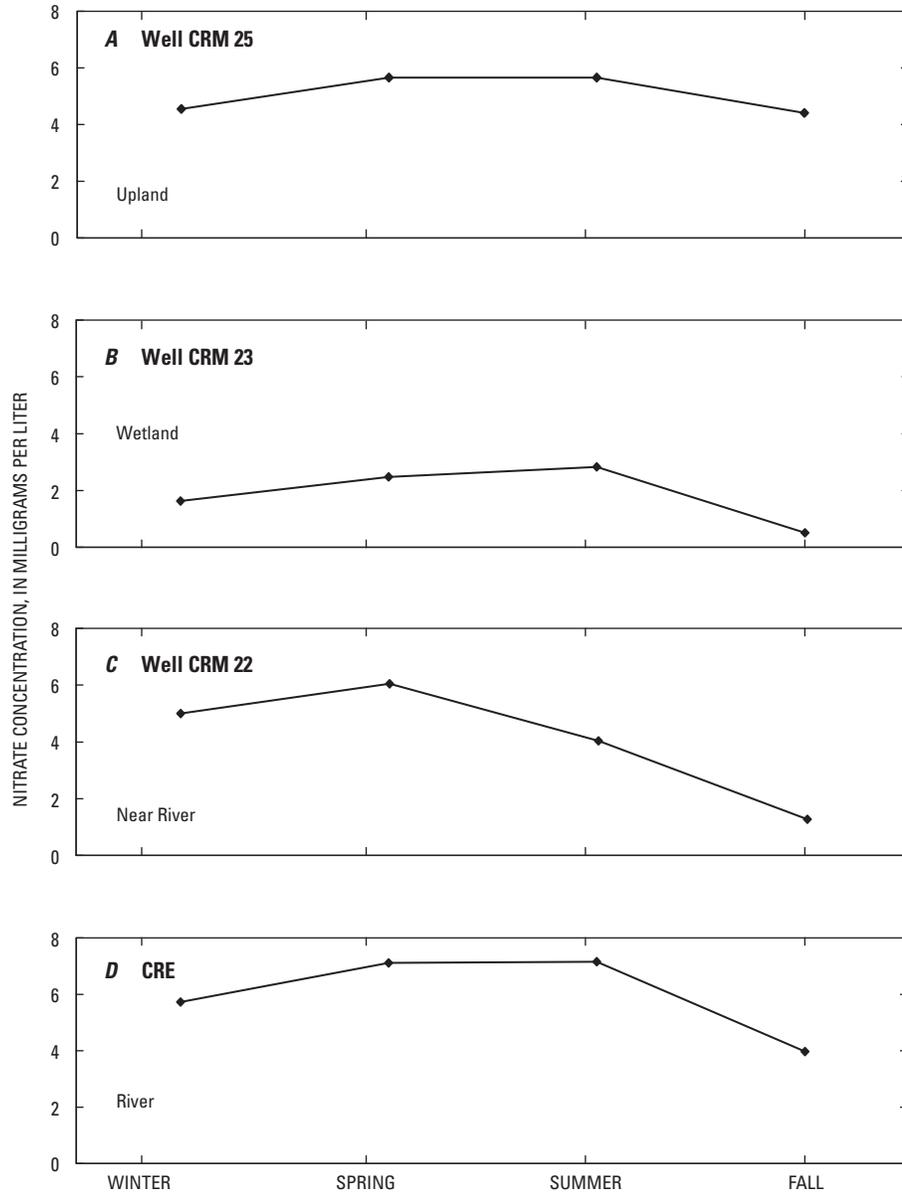
Figure 9.   Seasonal means for nitrate concentrations for water samples from *A*, the upland well, *B*, a wetland well, *C*, a near river well, and *D*, the Cedar River, 1998–2006.

model to illustrate the vector ground-water flow field in the study area (fig. 7). The ground-water flow vectors denote magnitude (cubic feet per second) and direction. The results of the ground-water flow vectors again indicate that much of the water to the municipal wells is coming from the Cedar River (fig. 7). Again, the upland well (CRM 25) does not show any water being sourced to this well from the Cedar River in the study area (fig. 7). The scenarios shown in figures 6 and 7 clearly illustrate the strong effect that the Cedar River could have on water quality in the alluvial aquifer.

Nitrate, Iron, Manganese, and Dissolved Oxygen

Concentrations of nitrate in eastern Iowa streams are among the highest in the nation (Kalkhoff and others, 2000). In addition, nitrate concentrations in water samples from alluvial aquifers in eastern Iowa have been determined to be greater than those sampled elsewhere in the mid-continent (Illinois, Indiana, and Minnesota) and the Nation (Kalkhoff and others, 2000). Nitrate is regulated in drinking water at 10 mg/L as nitrogen, and secondary standards have been set

(generally for aesthetic and nuisance problems) for iron at 0.3 mg/L (300 µg/L) and manganese at 0.05 mg/L (50 µg/L) by the U.S. Environmental Protection Agency (1986, 1992). Dissolved-oxygen concentrations in ground water can be an important catalyst for redox reactions that affect concentrations of nitrate, iron, and manganese concentrations. Excess concentrations of iron and manganese can affect the taste, color, and odor of water, can cause staining of clothes and fixtures, and can cause buildups in pipes, well casings, and water heaters. Chemical reactions involving nitrate, iron, manganese, and dissolved-oxygen concentrations were examined in detail.

A comparison of water chemistry for nitrate, iron, manganese, and dissolved oxygen was made from water analyses from the Cedar River, an observation well upgradient from the wetland area (CRM 25), wells in the wetland area, (CRM 23, CRM 26, and CRM 27), and wells between the wetland area and the river (CRM 22 and CRM 24). Nitrate concentrations often are 4 to 6 times lower in samples from observation wells completed in the wetland area than in the Cedar River or the observation well (CRM 25) in the upland area (fig. 8). Dissolved oxygen in the ground water decreases from the upland area to the wetland wells, and from the river to the wetland wells (fig. 8). However, iron and manganese concentrations in samples from the observation wells in the wetland areas were an order of magnitude higher when compared to the river or upland well (fig. 8). The nitrate concentrations in the upland well were larger than expected; however, the well was immediately downgradient from a corn field on which nitrogen fertilizer is applied.

Seasonal trends in nitrate concentrations for the river, upland, wetland, and near river wells were graphed during the study period (fig. 9) to examine possible temporal trends, as spring runoff can have large nitrate concentrations in the Cedar River. For this report, winter is defined as January through March, spring is April through June, summer is July through September, and fall is October through December. Water samples from the wetland area well (CRM 23), near river well (CRM 22), and the Cedar River generally displayed similar nitrate trends (high in the spring and low in the fall) whereas the upland well was more constant (fig. 9). The seasonal nitrate concentrations consistently were lower in the wetland area compared to the other wells in the study area (fig. 9).
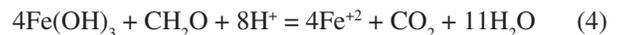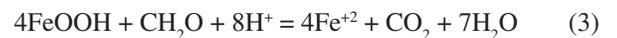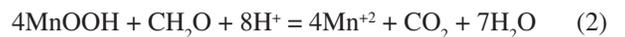
As water moves from the river towards the observation wells, microorganisms obtain energy for metabolic processes by catalyzing the oxidation of organic matter with a progressive series of reducing reactions (Stumm and Morgan, 1981). The reducing reactions occur in a thermodynamically predictable sequence—dissolved oxygen, nitrate, manganese, sulfate, and carbon (Stumm and Morgan, 1981). Dissolved-oxygen concentration is highest in the river and the upgradient well (CRM 25), becoming depleted as it moves toward wells in the wetland area (CRM 27, CRM 23, and CRM 26) (fig. 8). Nitrate concentrations are lowest in wells completed in the wetland area, in contrast to manganese and iron concentrations, which are increased (fig. 8).

Processes that transform nitrogen in ground water include mineralization, hydrolysis, and bacterially mediated reactions. Denitrification typically requires a supply of nitrate, organic carbon, reducing conditions (low dissolved oxygen), and denitrifying bacteria (Starr and Gillham, 1993). Nitrate typically is reduced to elemental nitrogen (N_2) by bacterially mediated denitrification (Stumm and Morgan, 1981), as shown in equation 1.

$$1/5NO_3^- + 6/5H^+ \ e = 1/10N_2(g) + 3/5H_2O \qquad (1)$$

Dissimilatory nitrate reduction (DNR), also bacterially mediated, possibly can occur, and this reaction produces ammonium (Nolan, 1999). However, most nitrate reduction probably occurs from denitrification rather than DNR (Tiedje and others, 1982), because DNR requires strongly anaerobic habitats, such as that present in estuarine sediments (Nolan, 1999). Because ammonium was detected only in small quantities in the water samples from wetland wells (0.80 mg/L or less), denitrification most likely is the predominant nitrogen-reducing process in the wetland area.
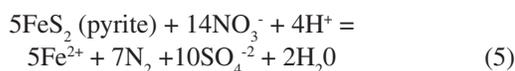
Reduction under anaerobic conditions further proceeds from nitrate (NO_3^-), to manganese oxides (Mn^{+4} as MnO_2), to iron oxides (Fe^{+3} as $FeOOH$), and finally to sulfate (SO_4^{-2}), bicarbonate (HCO_3^-), and nitrogen (N_2) (Stumm and Morgan, 1981). The reduced forms of iron (Fe II) and manganese (Mn II) are more soluble in water and are more mobile than oxidized forms (Hem, 1985) and, under anaerobic conditions, are in a favored redox state (Stumm and Morgan, 1981). As nitrate in the ground water is depleted, microbes oxidize organic matter by catalyzing iron and manganese reduction and oxidation reactions as shown in equations 2, 3, and 4 below [Nolan (1999), citing unpublished equations by John K. Bohlke, U.S. Geological Survey].

$$4MnOOH + CH_2O + 8H^+ = 4Mn^{+2} + CO_2 + 7H_2O \qquad (2)$$

$$4FeOOH + CH_2O + 8H^+ = 4Fe^{+2} + CO_2 + 7H_2O \qquad (3)$$

$$4Fe(OH)_3 + CH_2O + 8H^+ = 4Fe^{+2} + CO_2 + 11H_2O \qquad (4)$$

As nitrate in the ground water is depleted, iron and manganese reduction begins. The reduction of Fe^{+3} to Fe^{+2} and Mn^{+4} to Mn^{+2} from aquifer grain coatings can cause large concentrations of these ions in ground water (Chapelle, 1993; Bourg and Bertin, 1994). Ferrihydrite ($FeOOH$) and manganite ($MnOOH$), occurring as oxyhydroxide coatings on clay and silt particles, are the most likely oxidized forms of iron (Fe^{+3}) and manganese (Mn^{+3} and Mn^{+4}) in the alluvial aquifer. Oxidized forms of iron and manganese might occur in the alluvial aquifer as crystalline minerals, such as hematite (Fe_2O_3) and hausmannite (Mn_3O_4) (Boyd, 1999).

Another possibility for denitrification may be the reduced forms of iron and sulfur from pyrite as the electron donors in

denitrification reactions (Tesoriero and others, 2000). Pyrite (FeS_2) can occur in freshwater wetlands (Marnette and others, 1993) and may occur in a disseminated form in shale outwash material present in alluvium. Two denitrification reaction equations with pyrite and reduced iron are shown in equations 5 and 6 below (Kolle and others, 1985). However, it is thought that denitrification (as shown in equations 5 and 6) in the study area are less likely given the small amount of pyrite observed in the aquifer material from well cuttings during well drilling, but these reactions may be locally important in other alluvial aquifers.

$$5FeS_2 \text{ (pyrite)} + 14NO_3^- + 4H^+ =$$
$$5Fe^{2+} + 7N_2 + 10SO_4^{-2} + 2H_2O \qquad (5)$$

$$5Fe^{2+} + NO_3^- + 7H_2O = 5FeOOH \text{ (goethite)} + 0.5N_2 + 9H^+ \quad (6)$$

This research in the Cedar Rapids well field indicates that the location of a supply well in or near natural wetland areas may benefit from natural reduction of nitrate concentrations with the disadvantage of increased iron and manganese concentrations. Increased iron and manganese concentrations may cause increased precipitation and encrustation of iron and manganese compounds on the well screen that could (if left untreated) lead to a decrease in well production with time. Conversely, treatment for iron and manganese in water may be more economical for water managers than treatment for nitrate. Iron and manganese concentrations in water delivered to the water plant are removed easily by conventional treatment methods such as flocculation. In contrast, the removal of excess nitrate for drinking water is difficult and extremely costly (City of Cedar Rapids Municipal Water Plant, written commun., 2005). Wells located in alluvial wetland areas may require a more frequent well treatment (cleaning and acidizing) schedule than wells not located in an alluvial wetland. Future expansion of the well fields may take advantage of natural wetland areas to help reduce nitrate concentrations.

Selected Pesticides

Pesticides are used to control unwanted vegetation, insects, and other pests in agricultural and urban areas. Typically, large amounts (thousands of pounds per year) of common herbicides are applied to corn and soybean crops during the growing season in Iowa and in the Cedar River Basin (Schnoebelen and others, 2003). Triazine (atrazine and cyanazine) and chloroacetanilide (acetochlor and metolachlor) herbicides are generally the most extensively used herbicides in eastern Iowa. Insecticides are detected less often most likely due to their lower use relative to herbicides, short persistence, and selected application during periods of reduced runoff (Schnoebelen and others, 2003). Pesticide degradates are formed when a parent pesticide compound breaks down or degrades. Pesticide degradates often have been detected at

larger concentrations than their parent compounds (Kalkhoff and others, 2000; Kolpin and others, 2000; Schnoebelen and others, 2003; and Kolpin and others, 2004). Federal drinking water regulations have not been established for pesticide degradates at this time (U.S. Environmental Protection Agency, 2007). Generally, selection of pesticides to be analyzed in this study was based on previous work in the Cedar River Basin and other basins in eastern Iowa (Schnoebelen and others, 2003). Results from the selected pesticides and two pesticide degradates of atrazine analyzed for in this study are listed in table 9.

Pesticide concentrations generally are greater in surface water than in ground water in regions dominated by agriculture (Barbash and Resek, 1996). However, in alluvial aquifers located near rivers, pesticides can enter the ground water through surface- and ground-water interaction. Burkhart and Kolpin (1993) determined that the frequency of herbicide detection in ground water beneath the mid-continent United States was more than twice as high in wells located within 100 ft of a river than in wells located farther from streams. Previous investigations of atrazine exchange between the Cedar River and its alluvial aquifer document the dynamic nature of the surface- and ground-water interactions (Squillace and others, 1993; Wang and Squillace, 1994). Liszewski and Squillace (1991) determined that atrazine concentrations in the alluvial aquifer rise with increasing concentrations in the Cedar River for wells located within 100 ft of the river. Blum and others (1993) determined that transient increases in atrazine concentrations in the Platte River near Ashland, Nebraska, led to similar, but smaller increases in the municipal-supply wells and observation wells adjacent to the river. These studies indicate that low molecular weight hydrophobic organic compounds present in surface water can move into alluvial aquifers (Schwarzenbach and Westall, 1981). These organic compounds can be persistent and mobile; for these reasons, it was important to analyze for selected pesticides and the two degradates in the study area.

The selected pesticide and pesticide degradate data were evaluated in terms of occurrence (what pesticide compounds were detected and frequency of detection) and concentrations. The pesticides acetochlor, atrazine, metolachlor, and the two degradates of atrazine; 2-Chloro-4-ethylamino-6-amino-s-triazine (CEAT) and 2-Chloro-4-amino-6-isopropyl-amino-striazine (CIAT), were the compounds most commonly detected (fig. 10). Acetochlor, atrazine, and metolachlor typically are the most commonly used pesticides in Iowa (Schnoebelen and others, 2003). The pesticides butachlor, butylate, carboxin, hexazinone, prometryn, propachlor, simetryn, and vernolate were sampled for but never detected at the LRL of 0.5 µg/L. Typically these compounds are rarely used or applied in small amounts in eastern Iowa (Schnoebelen and others, 2003).

Generally, the mean and median pesticide concentration for the Cedar River and the observation wells were low (less than 0.5 µg/L, table 9). The largest concentration for any pesticide detected was 4.5 µg/L for atrazine in a Cedar River sample (collected June 15, 1999). The most commonly

Table 9. Statistical summary of selected pesticides and pesticide degradates, with minimum, maximum, mean, and median by well group and the Cedar River, 1998–2006.

[μg/L, micrograms per liter; ND; non detected constituent; in the case of more than one site, ND means that the constituent was a non-detect at all sites; if the constituent was detected at some site(s) in the group and not others, the statistics were calculated only for the sites where the constituent was detected]
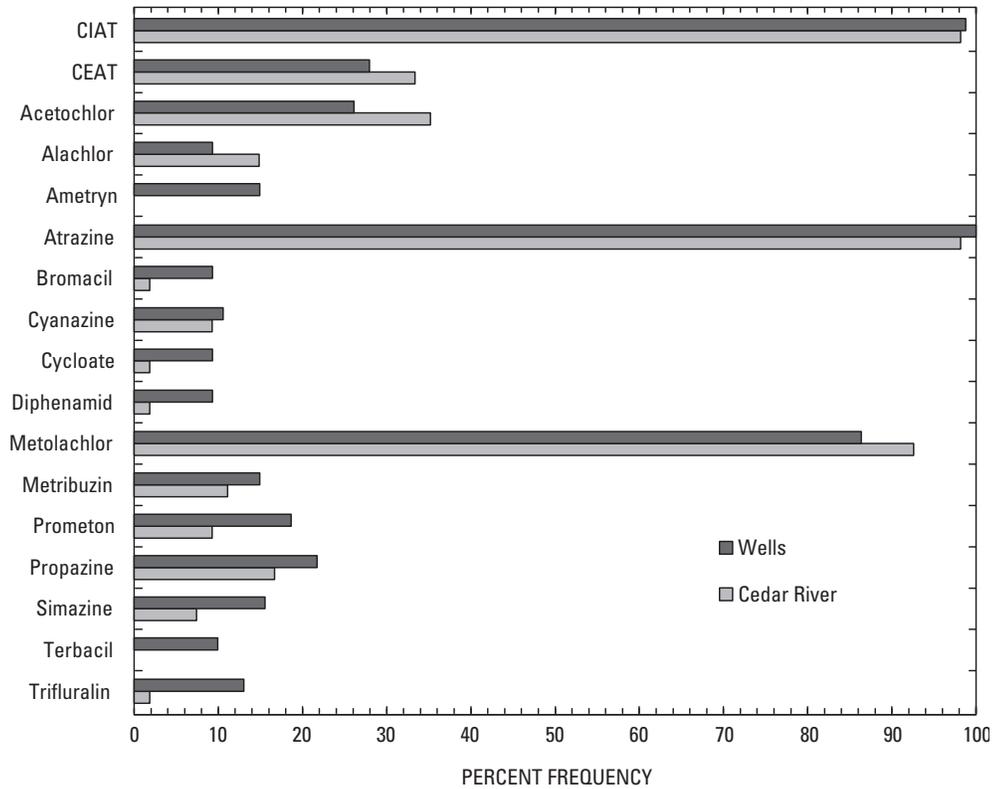
Constituent	Minimum	Maximum	Mean	Median
Upgradient well (CRM 25)				
CIAT[1] (μg/L)	0.071	0.499	0.249	0.260
CEAT[1] (μg/L)	.025	.103	.025	.034
Acetochlor (μg/L)	.025	.057	.025	.027
Alachlor (μg/L)	ND	ND	ND	ND
Ametryn (μg/L)	ND	ND	ND	ND
Atrazine (μg/L)	.022	1.34	.087	.147
Bromacil (μg/L)	ND	ND	ND	ND
Cyanazine (μg/L)	ND	ND	ND	ND
Cycloate (μg/L)	ND	ND	ND	ND
Diphenamid (μg/L)	ND	ND	ND	ND
Metolachlor (μg/L)	.002	.210	.025	.032
Metribuzin (μg/L)	.025	.043	.025	.027
Prometon (μg/L)	.003	.025	.025	.023
Propazine (μg/L)	.023	.025	.025	.025
Simazine (μg/L)	.019	.025	.025	.025
Terbacil (μg/L)	ND	ND	ND	ND
Trifluralin (μg/L)	.004	.025	.025	.024
Wetland wells (CRM 27, 23, and 26)				
CIAT[1] (μg/L)	0.019	0.246	0.074	0.090
CEAT[1] (μg/L)	.025	.123	.025	.033
Acetochlor (μg/L)	.014	.271	.025	.033
Alachlor (μg/L)	ND	ND	ND	ND
Ametryn (μg/L)	.003	.025	.025	.023
Atrazine (μg/L)	.034	1.02	.123	.194
Bromacil (μg/L)	ND	ND	ND	ND
Cyanazine (μg/L)	.010	.100	.062	.100
Cycloate (μg/L)	ND	ND	ND	ND
Diphenamid (μg/L)	ND	ND	ND	ND
Metolachlor (μg/L)	.003	.440	.027	.041
Metribuzin (μg/L)	.019	.050	.026	.025
Prometon (μg/L)	.007	.025	.025	.024
Propazine (μg/L)	.003	.025	.025	.023
Simazine (μg/L)	.007	.025	.024	.025
Terbacil (μg/L)	ND	ND	ND	ND
Trifluralin (μg/L)	.003	.025	.024	.025

Table 9.   Statistical summary of selected pesticides and pesticide degradates, with minimum, maximum, mean, and median by well group and the Cedar River, 1998–2006.—Continued

[µg/L, micrograms per liter; ND; non detected constituent; in the case of more than one site, ND means that the constituent was a non-detect at all sites; if the constituent was detected at some site(s) in the group and not others, the statistics were calculated only for the sites where the constituent was detected]

Constituent	Minimum	Maximum	Mean	Median
Near-river wells (CRM 24 and 22)				
CIAT[1] (µg/L)	0.039	0.287	0.092	0.105
CEAT[1] (µg/L)	.025	.116	.025	.035
Acetochlor (µg/L)	.009	.248	.025	.032
Alachlor (µg/L)	ND	ND	ND	ND
Ametryn (µg/L)	.003	.025	.023	.025
Atrazine (µg/L)	.043	.925	.110	.200
Bromacil (µg/L)	ND	ND	ND	ND
Cyanazine (µg/L)	.015	.100	.076	.100
Cycloate (µg/L)	ND	ND	ND	ND
Diphenamid (µg/L)	ND	ND	ND	ND
Metolachlor (µg/L)	.011	.209	.044	.070
Metribuzin (µg/L)	.016	.034	.025	.025
Prometon (µg/L)	.008	.025	.025	.023
Propazine (µg/L)	.003	.025	.025	.023
Simazine (µg/L)	.006	.025	.025	.023
Terbacil (µg/L)	.011	.025	.025	.025
Trifluralin (µg/L)	.004	.025	.025	.024
Cedar River (CRE)				
CIAT[1] (µg/L)	0.025	0.620	0.114	0.139
CEAT[1] (µg/L)	.015	.260	.025	.057
Acetochlor (µg/L)	.010	1.00	.025	.100
Alachlor (µg/L)	.001	.112	.025	.028
Ametryn (µg/L)	ND	ND	ND	ND
Atrazine (µg/L)	.025	4.50	.135	.469
Bromacil (µg/L)	.018	.500	.025	.049
Cyanazine (µg/L)	.004	.100	.037	.057
Cycloate (µg/L)	.005	.025	.025	.025
Diphenamid (µg/L)	.002	.025	.025	.024
Metolachlor (µg/L)	.010	.890	.071	.132
Metribuzin (µg/L)	.003	.053	.025	.026
Prometon (µg/L)	.006	.030	.025	.024
Propazine (µg/L)	.004	.050	.025	.025
Simazine (µg/L)	.005	.025	.025	.023
Terbacil (µg/L)	ND	ND	ND	ND
Trifluralin (µg/L)	.005	.025	.025	.025

[1]Atrazine degradates: 2-Chloro-4-amino-6-isopropyl-amino-*s*triazine (CIAT) and 2-Chloro-4-ethylamino-6-amino-*s*-triazine (CEAT).

EXPLANATION

CIAT   2-chloro-4-amino-6-isopropyl-amino-*s*-triazine
CEAT   2-chloro-4-ethylamino-6-amino-*s*-triazine

Figure 10.   Occurrence of selected pesticide and pesticide degradate compounds detected in water samples in the wetland study area, 1998–2006.
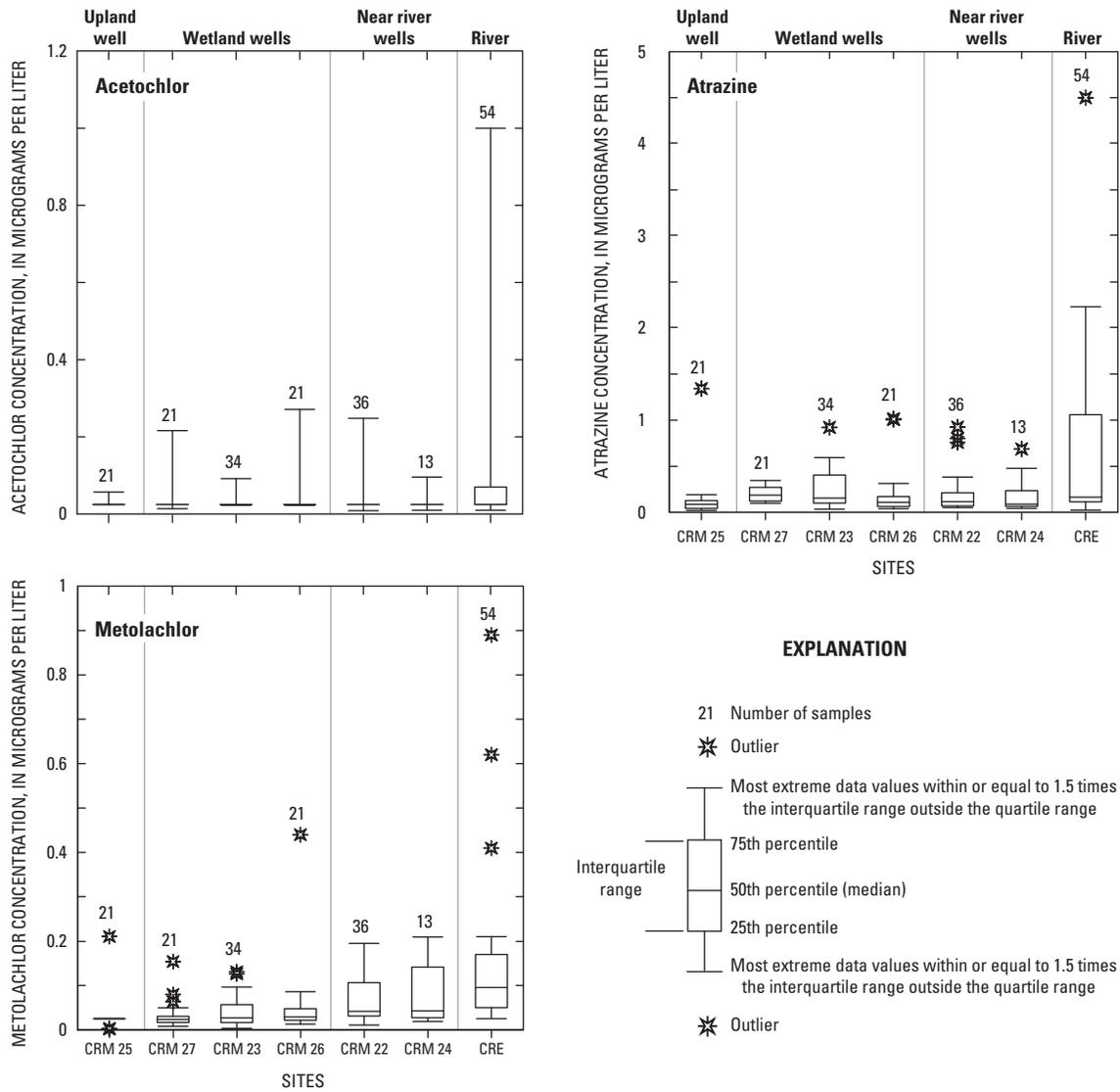
Figure 11.   Concentrations of the pesticides acetochlor, atrazine, and metolachlor in the wetland study area, 1998–2006.
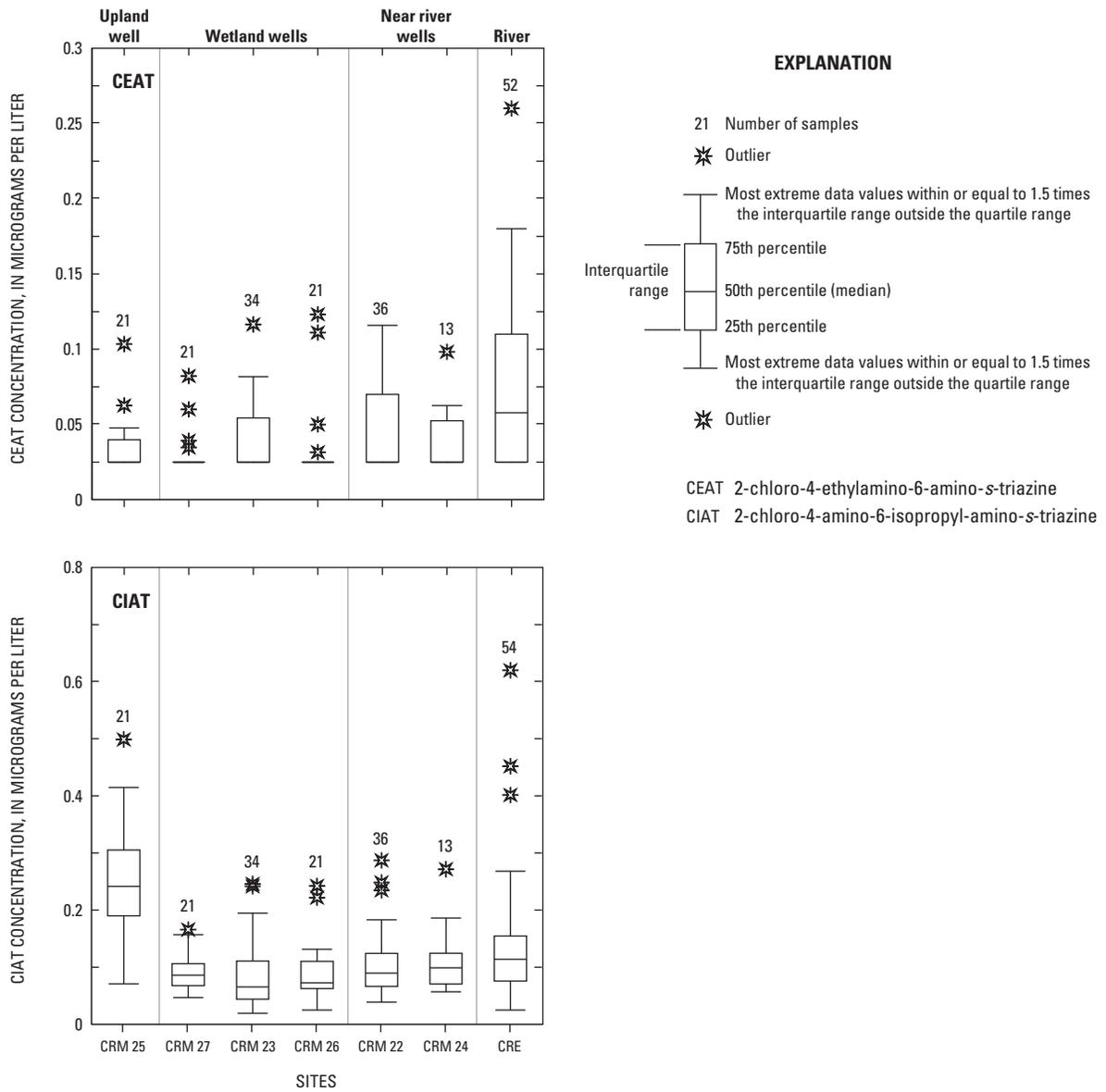
Figure 12.   Atrazine degradate compounds detected in water samples from the wetland study area, 1998–2006.

detected pesticides acetochlor, atrazine, metolachlor, and atrazine degradates (CEAT and CIAT) for the upland well (CRM 25), wetland wells (CRM 23, CRM 26, and CRM 27), the near river wells (CRM 22 and CRM 24), and the Cedar River are shown in figures 11 and 12. Generally, the boxplots show slightly increased concentrations of pesticide (acetochlor, atrazine, and metolachlor) detections in the river when compared to the wells (fig. 11). This generally is true for degradates with the exception of CIAT, which was slightly larger in the upland well (fig. 12). There usually is not a large reduction in pesticide concentrations in the river compared to the wetland wells, as was determined with nitrate. Median concentrations of acetochlor, atrazine, and metolachlor in the river were 0.100, 0.469, and 0.132 µg/L as compared to 0.33, 0.194, and 0.041 µg/L for these respective compounds in the wetland observation wells (table 9). Median concentrations of CIAT and CEAT, the two pesticide degradates of atrazine, were 0.139 and 0.057 µg/L respectively, in the Cedar River and 0.090 and 0.033 µg/L respectively, in the wetland observation wells (table 9).

Summary

The importance of wetlands on habitat, species, and water quality has been recognized during the last three decades. Many natural wetlands in Iowa were drained and filled as agriculture moved west; however, alluvial wetlands in river valleys are still common. Alluvial aquifers near these rivers are a primary source of water for many communities such as the city of Cedar Rapids, Iowa. Nutrients and pesticides are water-quality topics of concern in Iowa. Concentrations of nitrate in the Cedar River and other streams in eastern Iowa are among the largest in the Nation. A 12-mile reach of the Cedar River upstream from Cedar Rapids, Iowa, is identified on the Total Maximum Daily Load (TMDL) list for nitrate impairment by the U.S. Enviormental Protection Agency. In addition, pesticide concentrations in water samples from alluvial aquifers in eastern Iowa have been ranked as some of the largest in the Nation. Municipal wells for the city of Cedar Rapids are completed in the Cedar River alluvium, a shallow (5 to 95 feet deep) alluvial aquifer near the Cedar River. The U.S. Geological Survey, in cooperation with the City of Cedar Rapids, Iowa, studied the effectiveness of an alluvial wetland on improving ground-water quality in a municipal well field. The study area is in a natural alluvial wetland in the Seminole municipal well field, one of three wellfields used by the city of Cedar Rapids. The alluvial aquifer is recharged by infiltration from the Cedar River, precipitation, and seepage from the underlying bedrock and adjacent hydrogeologic units. In areas under the effect of municipal pumping, ground-water flow is from the Cedar River to the wellfields; in areas outside the effect of municipal pumping, ground-water flow is toward the Cedar River. Most of the recharge to the alluvial aquifer (over

90 percent) is from the Cedar River in the areas of municipal pumping.

The study incorporated methods of water-quality sampling and analysis with the use of an existing ground-water model for evaluating the effectiveness of the wetland on water quality. Water samples were collected from six observation wells installed in an approximate transect through the alluvial wetland study area and one sample from the Cedar River quarterly from 1998 to 2006. Wells ranged from 18 to 47.5 feet deep. Analysis of water samples included nutrients, dissolved organic carbon, field measurements, major ions, and selected pesticides and two pesticide degradates. All samples collected followed U.S. Geological Survey protocols. Quality-control samples of blanks and replicates were used as part of the quality-assurance procedure. The ground-water model for the area was used to illustrate flow paths and ground-water flow vectors. The modeling scenario showed ground-water flow through the alluvial wetland to the municipal wells. A well upgradient from the alluvial wetland did not appear to be affected by the Cedar River.

A comparison of water chemistry for nitrate, iron, manganese, and dissolved oxygen was made from water analyses from the Cedar River, an observation well upgradient from the wetland area (CRM 25), wells in the wetland area, (CRM 23, CRM 26, and CRM 27), and near river wells between the wetland area and the river (CRM 22 and CRM 24). Nitrate concentrations often were 4 to 6 times lower in samples from observation wells completed in the wetland area than in the Cedar River or the observation well (CRM 25) in the upland area. Seasonal trends in nitrate concentrations consistently were lower in water samples from wells in the wetland area compared to the Cedar River. However, iron and manganese concentrations in samples from the observation wells in the wetland areas were an order of magnitude higher when compared to the river or upland well. Dissolved oxygen in the ground water decreases from the upland well to the wetland wells, and from the near river wells to the wetland wells.

Selected pesticides and pesticide degradate data from the study indicated the commonly detected pesticides were acetochlor, atrazine, and metolachlor; these also are the most commonly used pesticides in Iowa. In addition, the two pesticide degradate products of atrazine (CIAT and CEAT) typically were present in the Cedar River and the observation wells. The mean and median pesticide concentration for the Cedar River and the observation wells were low [less than 0.500 micrograms per liter (µg/L)]; the largest concentration for any pesticide detected was 4.5 µg/L for atrazine in a Cedar River sample. Slightly increased concentrations of pesticides (acetochlor, atrazine, and metolachlor) were detected in the river compared to the wells. Median concentrations of acetochlor, atrazine, and metolachlor in the river were 0.100, 0.469, and 0.132 µg/L as compared to 0.330, 0.194, and 0.041 µg/L for these respective compounds in the wetland observation wells. Median concentrations of CIAT and CEAT, the two pesticide degradates of atrazine, were 0.139 and 0.057 µg/L, respectively, in the Cedar River and 0.090 and 0.033 µg/L,

respectively, in the wetland observation wells. There is not a large reduction in pesticide concentrations from the river to the wetland wells as observed with nitrate.

The alluvial wetlands were determined to be effective in improving water quality for nitrate when compared to samples from the Cedar River or observation wells nearest the river. However, iron and manganese concentrations were increased during denitrification reactions and reactions with ferro-magnesium minerals that were present in the aquifer. In addition, selected pesticide compounds and two degradates were reduced slightly from the river to the wetland, but were not as effectively removed as nitrate. Locating municipal wells in natural alluvial wetlands may improve water quality, particularly for nitrate.

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