Prepared as part of the
National Water-Quality Assessment Program

Occurrence of Agricultural Chemicals in Shallow Ground Water and the Unsaturated Zone, Northeast Nebraska Glacial Till, 2002–04

Scientific Investigations Report 2007–5228

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

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By Jennifer S. Stanton, Gregory V. Steele, and Jason R. Vogel

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Front cover: (top left) Collecting water from monitoring well W–18, northeast Nebraska, to be processed in mobile laboratory. (bottom right) Developing a monitoring well in northeast Nebraska glacial till. Photographs by G.V. Steele, U.S. Geological Survey.

Back cover: (top left) Typical agricultural setting in northeast Nebraska glacial till looking northwest from Well D–26. (bottom right) Monitoring well and sample delivery line at the monitoring well. Photographs by G.V. Steele, U.S. Geological Survey.

Foreword

The U.S. Geological Survey (USGS) is committed to serve the Nation with accurate and timely scientific information that helps enhance and protect the overall quality of life and facilitates effective management of water, biological, energy, and mineral resources (*http://www.usgs.gov/*). Information on the quality of the Nation's water resources is of critical interest to the USGS because it is so integrally linked to the long-term availability of water that is clean and safe for drinking and recreation and that is suitable for industry, irrigation, and habitat for fish and wildlife. Escalating population growth and increasing demands for multiple water uses make water availability, now measured in terms of quantity *and* quality, even more critical to the long-term sustainability of our communities and ecosystems.

The USGS implemented the National Water-Quality Assessment (NAWQA) Program to support national, regional, and local information needs and decisions related to water-quality management and policy (*http://water.usgs.gov/nawqa/*). Shaped by and coordinated with ongoing efforts of other Federal, State, and local agencies, the NAWQA Program is designed to answer: (1) What is the condition of our Nation's streams and ground water? (2) How are the conditions changing over time? (3) How do natural features and human activities affect the quality of streams and ground water, and where are those effects most pronounced? By combining information on water chemistry, physical characteristics, stream habitat, and aquatic life, the NAWQA Program aims to provide science-based insights for current and emerging water issues and priorities. NAWQA results can contribute to informed decisions that result in practical and effective water-resource management and strategies that protect and restore water quality.

Since 1991, the NAWQA Program has implemented interdisciplinary assessments in more than 50 of the Nation's most important river basins and aquifers, referred to as "study units" (*http://water.usgs.gov/nawqa/nawqamap.html*). Collectively, these "study units" account for more than 60 percent of the overall water use and population served by public water supply and are representative of the Nation's major hydrologic landscapes, priority ecological resources, and agricultural, urban, and natural sources of contamination.

Each assessment is guided by a nationally consistent study design and methods of sampling and analysis. The assessments thereby build local knowledge about water-quality issues and trends in a particular stream or aquifer while providing an understanding of how and why water quality varies regionally and nationally. The consistent, multiscale approach helps determine if certain types of water-quality issues are isolated or pervasive and allows direct comparisons of how human activities and natural processes affect water quality and ecological health in the Nation's diverse geographic and environmental settings. Comprehensive assessments of pesticides, nutrients, trace metals, volatile organic compounds, and aquatic ecology are developed at the national scale through comparative analysis of the study-unit findings (*http://water.usgs.gov/nawqa/natsyn.html*).

The USGS places high value on the communication and dissemination of credible, timely, and relevant science so the most recent and available knowledge about water resources can be applied in management and policy decisions. We hope this NAWQA publication will provide the needed insights and information to meet your needs and thereby foster increased awareness and involvement in the protection and restoration of our Nation's waters.

The NAWQA Program recognizes that a national assessment by a single program cannot address all water-resource issues of interest. External coordination at all levels is critical for a fully integrated understanding of watersheds and for cost-effective management, regulation, and conservation of our Nation's water resources. The program, therefore, depends extensively on the advice, cooperation, and information from other Federal, State, interstate, tribal, and local agencies, non-government organizations, industry, academia, and other stakeholder groups. The assistance and suggestions of all are greatly appreciated.

Robert M. Hirsch
Associate Director for Water

Contents

Foreword ...iii
Abstract ...1
Introduction...1
    Purpose and Scope ...2
    Acknowledgments ...2
Description of Study Area ...2
    Hydrogeologic Setting ...2
    Land-Use Setting...5
Methods of Investigation...7
    Site Selection and Well Installation...7
    Sample Collection and Analysis ...9
    Data Treatment...9
    Quality Control ...15
        Field-Blank Samples...15
        Replicate Samples ...15
        Environmental-Matrix Spike Samples ...16
Occurrence of Agricultural Chemicals in Shallow Ground Water ...17
    Nutrients...17
    Pesticides...19
Occurrence of Chemicals in the Unsaturated Zone ...24
Factors Related to Occurrence of Agricultural Chemicals in Shallow Ground Water...25
    Water Depth...26
    Aquifer-Sediment and Soil Characteristics...26
    Land Use...26
    Geologic Unit ...26
    Well Type ...28
Summary...30
References Cited...30
Appendix 1. Pesticides analyzed in ground-water samples collected from northeast Nebraska glacial till, 2003–04...36
Appendix 2. Unsaturated-zone borehole-sediment sample results, northeast Nebraska glacial till, May–October 2002 ...42
Appendix 3. Nitrate as nitrogen and pesticide concentrations in ground-water samples collected from domestic wells, northeast Nebraska glacial till, 1994–95...48

Figures

1–6. Maps showing:
    1. Location of study area, northeast Nebraska glacial till ...3
    2. Distribution of primary land-use types overlying northeast Nebraska glacial till, 1992, and location of flow-path study site ...4
    3. Distribution of major crops grown, by county, northeast Nebraska glacial till, 2002 ...6

    4. Use of ground water, by county, northeast Nebraska glacial till, 2000........................8
    5. Distribution of average nitrogen application rates from manure and commercial fertilizer, by county, and nitrate as nitrogen concentrations in ground-water samples, northeast Nebraska glacial till, spring 2003 and May 2004 21
    6. Number of pesticide compounds detected in ground-water samples, northeast Nebraska glacial till, spring 2003 and May 2004...22
7. Graphs showing concentrations of pesticide compounds in ground-water samples, northeast Nebraska glacial till, 2003–04 25
8. Map showing nitrate as nitrogen concentrations in ground-water samples collected from domestic wells, northeast Nebraska, 1994–95 29

Tables

1. Ten most frequently applied pesticides over northeast Nebraska glacial till, 1997 7
2. Monitoring wells sampled in 2003, northeast Nebraska glacial till...................................10
3. Monitoring wells sampled in 2004, northeast Nebraska glacial till...................................12
4. Laboratory analysis and onsite preservation and treatment methods for measured water-quality constituents, northeast Nebraska glacial till, 2003–04...............................14
5. Constituents detected in field-blank samples, northeast Nebraska glacial till, 2003–04 16
6. Apparent recharge date of ground-water samples collected from monitoring wells, northeast Nebraska glacial till, 2003–04 18
7. Descriptive statistics for nitrogen and phosphorus compounds in ground-water samples, northeast Nebraska glacial till, 2003 19
8. Concentrations of nitrogen and phosphorus compounds in ground-water samples from flow-path wells and selected glacial-till network wells, northeast Nebraska glacial till, Maple Creek watershed, 2004 20
9. Pesticide detections in ground-water samples collected in May and October 2004, northeast Nebraska glacial till, Maple Creek watershed 24
10. Relations between nitrate as nitrogen concentrations in ground-water samples collected from glacial-till network wells and well-borehole and surficial soil characteristics, northeast Nebraska glacial till, 2003...27
11. Pesticide compound detections in ground-water samples collected from glacial-till network wells related to well-borehole and surficial soil characteristics, northeast Nebraska glacial till, 2003...27
12. Distribution of median nitrate as nitrogen concentrations and pesticide compound detections in glacial-till network wells, by land-use feature, northeast Nebraska glacial till, 2003..28
13. Distribution of nitrate as nitrogen concentrations and pesticide compound detections in ground-water samples collected from glacial-till network wells, by geologic unit, northeast Nebraska glacial till, 2003 28

Conversion Factors, Abbreviations, and Datum

Multiply	By	To obtain
	Length	
inch (in.)	2.54	centimeter (cm)
foot (ft)	0.3048	meter (m)
micron (µm)	0.00003937	inch (in.)
mile (mi)	1.609	kilometer (km)
millimeter (mm)	0.03937	inch (in.)
	Area	
acre	4,047	square meter (m^2)
square mile (mi^2)	2.590	square kilometer (km^2)
	Volume	
million gallons per day (Mgal/d)	3,785	cubic meter per day (m^3/d)
gallon (gal)	0.003785	cubic meter (m^3)
	Mass	
pound, avoirdupois (lb)	0.4536	kilogram (kg)
	Density	
gram per cubic centimeter (g/cm^3)	62.43	pound per cubic foot (lb/ft^3)
	Application rate	
pound per acre (lb/acre)	1.121	kilogram per hectare (kg/ha)
	Flow rate	
inch per hour (in/h)	25.4	millimeter per hour (mm/h)
	Concentration	
microgram per liter (µg/L)	1	part per billion (ppb)
milligram per kilogram (mg/kg)	1.601×10^{-5}	ounce per pound (oz/lb)
milligram per liter (mg/L)	1	part per million (ppm)
milligram per liter (mg/L)	0.05841	grain per gallon (gr/gal)

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

$$°F=(1.8\times°C)+32.$$

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

$$°C=(°F-32)/1.8.$$

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

Occurrence of Agricultural Chemicals in Shallow Ground Water and the Unsaturated Zone, Northeast Nebraska Glacial Till, 2002–04

By Jennifer S. Stanton, Gregory V. Steele, and Jason R. Vogel

Abstract

Agricultural chemicals applied at the land surface in northeast Nebraska can move downward, past the crop root zone, to ground water. Because agricultural chemicals applied at the land surface are more likely to be observed in the shallowest part of an aquifer, an assessment of shallow ground-water and unsaturated zone quality in the northeast Nebraska glacial till was completed between 2002 and 2004. Ground-water samples were collected at the first occurrence of ground water or just below the water table at 32 sites located in areas likely affected by agriculture. Four of the 32 sites were situated along a ground-water flow path with its downgradient end next to Maple Creek. Twenty-eight sites were installed immediately adjacent to agricultural fields throughout the glacial-till area. In addition to those 32 sites, two sites were installed in pastures to represent ground-water conditions in a non-cropland setting. Ground-water samples were analyzed for physical properties and concentrations of nitrogen and phosphorus compounds, selected pesticides and pesticide degradates, dissolved solids, major ions, trace elements, and dissolved organic carbon. Chlorofluorocarbons (CFCs) or sulfur hexafluoride (SF_6) concentrations were analyzed at about 70 percent of the monitoring wells to estimate the residence time of ground water. Borehole-core samples were collected from 28 of the well boreholes. Sediment in the unsaturated zone was analyzed for nitrate, chloride, and ammonia concentrations.

Analytical results indicated that the agricultural chemicals most often detected during this study were nitrates and herbicides. Nitrate as nitrogen (nitrate–N) concentrations (2003 median 9.53 milligrams per liter) indicated that human activity has affected the water quality of recently recharged ground water in approximately two-thirds of the wells near corn and soybean fields. The principal pesticide compounds that were detected reflect the most-used pesticides in the area and included parent or degradate compounds of acetochlor, alachlor, atrazine, and metolachlor. Overall, pesticide concentrations in ground-water samples collected in 2003 and 2004 were small and did not exceed public drinking-water standards where established. On average, more pesticides were detected in the flow-path wells than in the glacial-till network wells. The presence of a perennial stream within 1,640 feet of a well was correlated to smaller nitrate–N concentrations in the well water, and the presence of a road ditch within 164 feet of the well was correlated to the presence of detectable pesticides in the well water. All other variables tested showed no significant correlations to nitrate–N concentrations or pesticide detections.

Unsaturated zone soil cores collected in 2002 from well boreholes indicated that nitrogen in the forms of nitrate–N and ammonia as nitrogen (ammonia–N) was available in the unsaturated zone for transport to ground water. Concentrations of nitrate–N and ammonia–N in these soil cores were inversely correlated to depth, and nitrate–N concentrations were correlated to chloride concentrations.

Introduction

Ground water is the primary source for drinking water, irrigation, industry, and water supplies for animal production in the glacial-till area of northeast Nebraska. Row-crop agriculture is the dominant land use in this area. Applications of agricultural amendments (such as fertilizers, pesticides, and soil conditioners), changes in soil structure from tillage, increased recharge, and changes to ground-water flow patterns are associated with cropland (Böhlke, 2002). Agricultural amendments directly introduce nutrients and pesticides to the hydrologic system. Changes in soil structure and application of irrigation water increase recharge rates. Increased recharge aids movement of human-related and natural chemical constituents (such as nitrogen in soil organic matter and dissolved solids) past the root zone to ground water (Scanlon and others, 2005). Indirect effects of row-crop agriculture may include increased rates of mineral weathering, mineral solubility, and trace element dissolution rates (Böhlke, 2002).

In 1991, the U.S. Geological Survey (USGS) implemented the National Water-Quality Assessment (NAWQA) Program to provide scientifically sound information for managing the Nation's water resources. The goals of the NAWQA Program are to assess the status and long-term trends of the Nation's surface- and ground-water quality and to understand the natural and human factors that affect it (Gilliom and others, 1995). To evaluate the effects of cropland and hydrogeologic settings on ground-water quality, samples were collected from monitoring wells installed as part of two studies conducted within the Central Nebraska Basins (CNBR) Study Unit of the NAWQA Program (fig. 1). Because agricultural chemicals applied at the land surface are more likely to be observed in the shallowest part of an aquifer, shallow ground-water samples were collected from monitoring wells that were constructed with screens placed just below the anticipated lowest depth of the water table.

The Agricultural Chemicals Transport (ACT) study, conducted as part of the NAWQA Program, was designed to understand the transport and fate of agricultural chemicals through the hydrologic cycle in selected agricultural settings, including the Maple Creek watershed (fig. 1). As part of the ACT study, four clusters of monitoring wells were installed along a ground-water flow path with its downgradient end next to Maple Creek (flow-path study site, fig. 2). Water-quality results from ground-water samples collected from the shallowest well at each of the four well clusters were used in this report to assess the ground-water quality near the water table. In this report, these wells will be referred to as the flow-path wells.

The Agricultural Land-Use (AgLUS) study also was conducted as part of the NAWQA Program to specifically determine the effect of agriculture on ground-water quality. Wells were installed immediately adjacent to agricultural fields throughout the glacial-till area and were screened open to either the first occurrence of ground water or just below the water table to provide a broad-scale evaluation of recently recharged ground water that would most likely be affected by nearby land use. These wells will be referred to as glacial-till network wells in this report.

Purpose and Scope

This report describes the occurrence of agricultural chemicals in the shallow ground water beneath and adjacent to cropland in the northeast Nebraska glacial till and in the unsaturated zone. Specifically, agricultural chemicals include nutrients and pesticides. Ground-water samples were collected from 34 monitoring wells from spring 2003 through fall 2004. Ground-water samples were analyzed for physical properties and concentrations of nitrogen and phosphorus compounds, selected pesticides and pesticide degradates, dissolved solids, major ions, trace elements, and dissolved organic carbon. Twenty-four of the 34 monitoring wells also were sampled for chlorofluorocarbons (CFCs) or sulfur hexafluoride (SF_6) concentrations to estimate the residence time of ground water. Borehole core samples were collected during well installation at 28 well sites in 2002. Sediment in the unsaturated zone was analyzed for nitrate as nitrogen (nitrate–N), ammonia as nitrogen (ammonia–N), and chloride concentrations. The relation between ground-water quality and selected land-use and hydrogeologic variables was examined.

Acknowledgments

The authors thank the many landowners who allowed installation of a monitoring well on their property. This study could not have been conducted without their support.

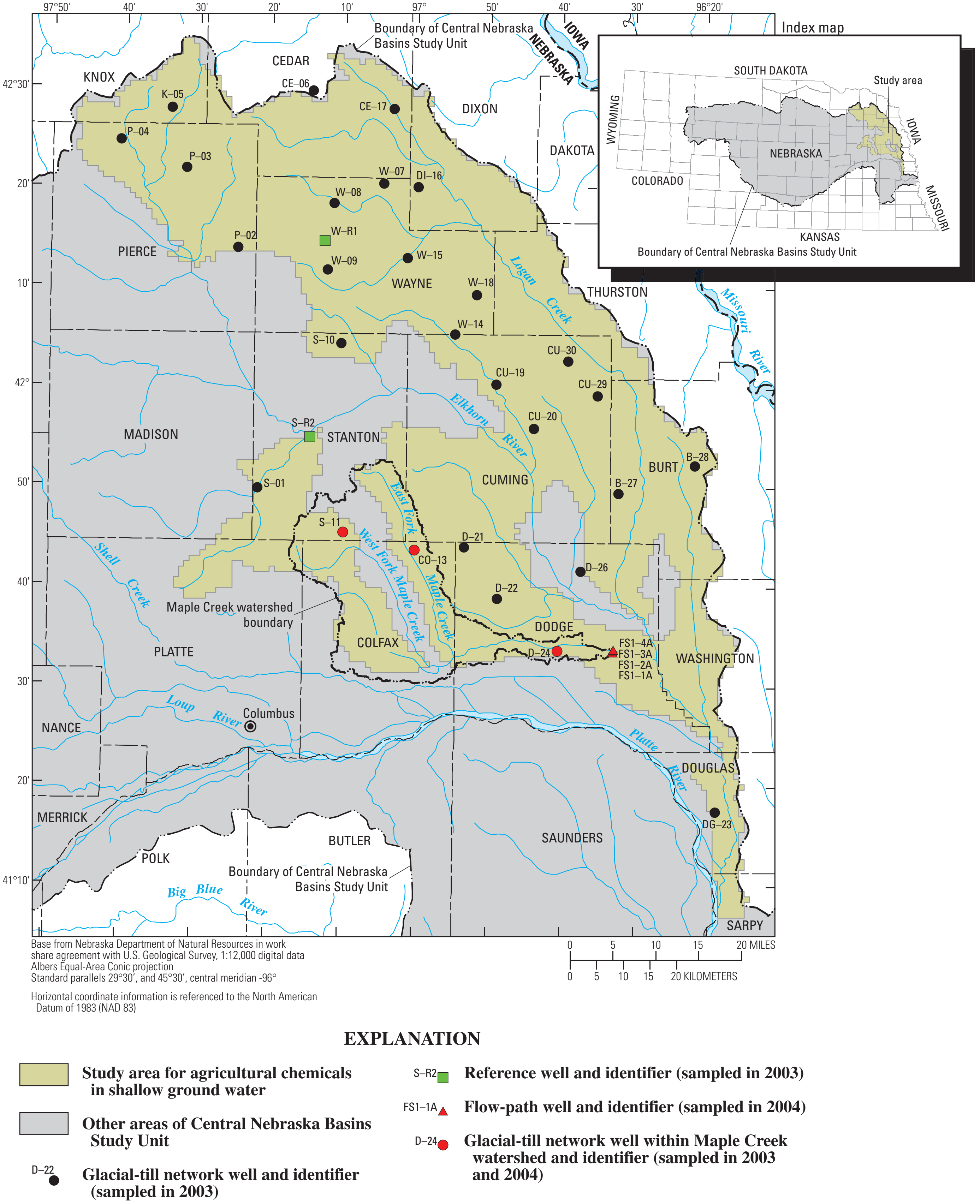
Description of Study Area

The study area is within the boundaries of the glacial till north of the Platte River in northeast Nebraska (fig. 1). This area of glacial till covers approximately 2,700 square miles (mi^2) in the lower Elkhorn River Basin. The study area has a continental climate receiving mean annual precipitation of 28.5 inches (in.) between 1971 and 2000. Total precipitation at Columbus, Nebraska, was 25.6 in. in 2003 and 28.4 in. in 2004 (National Climatic Data Center, 2007). Most of the area has a somewhat low permeable surface and subsurface. Topography consists of mostly rolling hills with areas of flat terraces and flood plains along larger streams (Newport, 1957).

Hydrogeologic Setting

The hydrogeology of the study area is a very complex mixture of deep to shallow regional and local aquifers located in the glaciated area of eastern Nebraska. Aquifer units in the study area include regional units that, because they are too deep, are untapped by the monitoring wells used in this study. These units, consisting of sand and gravel deposits of Pliocene and Pleistocene age, have been identified as Plio-Pleistocene deposits by Gosselin and others (1996) and are hydraulically connected locally to shallower aquifers and streams. Consequently, where these deeper aquifers discharge to shallower ones, they can play an important role in the water quality of the shallower deposits in which the monitoring wells for this study are installed. The regional ground-water-flow direction in the study area is from northwest to the southeast (Flowerday and others, 1998).

Hydrologic units in the study area vary from confined to unconfined systems of which bedrock of Cretaceous age—including the Dakota Sandstone, Graneros Shale, Greenhorn Limestone, Carlile Shale, Niobrara Formation, and the Pierre Shale—typically serves as the lower limit of the regional unconsolidated aquifers. Bedrock of Tertiary age is located in the extreme northwestern part of the study area (Bentall and others, 1971; Gosselin and others, 1996). In most of the study area, the Cretaceous-age bedrock units generally do not yield a sufficient amount of freshwater for most uses. In the eastern part of the study area, potable water can be found in the

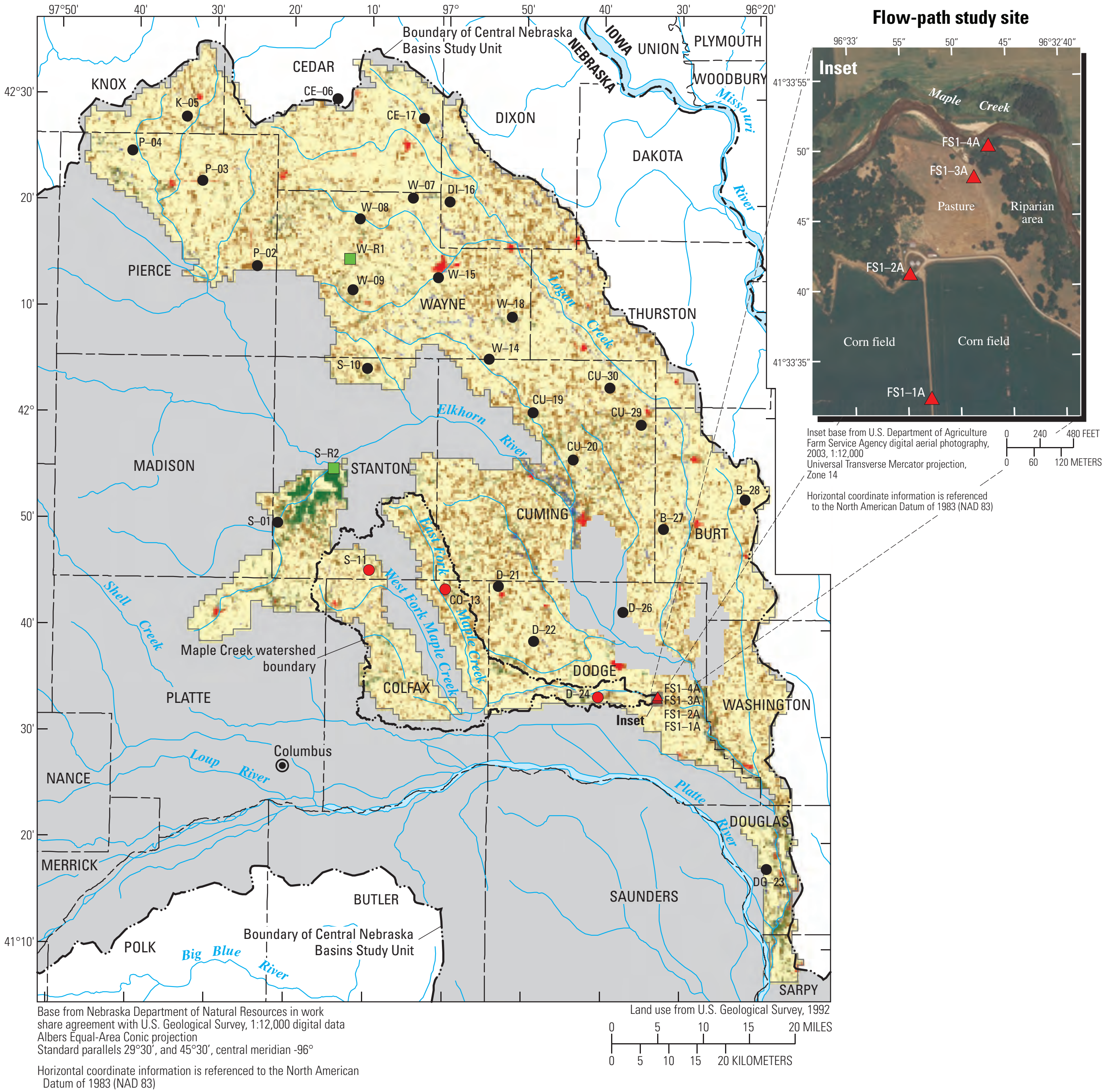


Base from Nebraska Department of Natural Resources in work share agreement with U.S. Geological Survey, 1:12,000 digital data
Albers Equal-Area Conic projection
Standard parallels 29°30', and 45°30', central meridian -96°

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

EXPLANATION

Figure 1. Location of study area, northeast Nebraska glacial till.



Inset base from U.S. Department of Agriculture Farm Service Agency digital aerial photography, 2003, 1:12,000
Universal Transverse Mercator projection, Zone 14

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Albers Equal-Area Conic projection
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Horizontal coordinate information is referenced to the North American Datum of 1983 (NAD 83)

Land use from U.S. Geological Survey, 1992

EXPLANATION

Land use

- 🟨 Cropland
- 🟫 Pasture / Hay
- 🟩 Forest / Shrubland / Grasslands
- 🟥 Urban
- 🟦 Open water and wetlands
- ⬜ Other areas of Central Nebraska Basins Study Unit

D–22 ● **Glacial-till network well and identifier (sampled in 2003)**

S–R2 🟩 **Reference well and identifier (sampled in 2003)**

FS1–1A ▲ **Flow-path well and identifier (sampled in 2004)**

D–24 ● **Glacial-till network well within Maple Creek watershed and identifier (sampled in 2003 and 2004)**

Figure 2. Distribution of primary land-use types overlying northeast Nebraska glacial till, 1992, and location of flow-path study site.

Dakota Sandstone. Although dissolved-solids concentrations there generally are less than 500 mg/L (Ellis, 1984), elsewhere the Dakota Sandstone typically contains water that is highly mineralized. The primary source of water to the Dakota Sandstone is the several sand-and-gravel units that overlie it. Bentall and others (1971) reported that beneath Cuming and Thurston Counties the Greenhorn Limestone is a water-bearing unit and the Carlile Shale is also a known local source of water supply. The Niobrara Formation provides a local water supply in the study area. However, neither the Graneros Shale nor the Pierre Shale are known to yield water to wells (Bentall and others, 1971). In the extreme northwestern part of the study area, the Ogallala Formation of Tertiary age yields some water to wells.

Aquifers in the study area also include coarse-grained alluvial deposits that lie in paleovalleys beneath glacial till of Pleistocene age. Where upland areas overlie the paleovalleys, ground-water levels can be more than 130 feet (ft) deep (Fredrick and others, 2006). Gosselin and others (1996) report that the thickness of these coarse-grained alluvial deposits varies from location to location but generally is less than 300 ft. The paleovalley deposits can be as much as 5 mi wide and 200 ft thick in the Maple Creek area (Fredrick and others, 2006). Coarse-grained alluvial deposits also can be localized within the glacial till (Verstraeten and Ellis, 1995). These localized deposits vary substantially in thickness and areal extent and typically occur as perched or semi-perched aquifers within the glacial-till deposits. Available data are not sufficient to adequately delineate the occurrence and distribution of these localized deposits, but in most of the study area they collectively are considered discontinuous aquifers (Verstraeten and Ellis, 1995). Ground-water levels in these discontinuous aquifers vary substantially depending on the source. Water levels in perched aquifers can be located near the land surface, whereas water levels in the paleovalleys can be located hundreds of feet below the land surface.

Aquifers also are found in alluvium in the major river valleys and the adjacent terraces. Numerous stream valleys, which have incised the glacial sediment, contain alluvium deposited by these streams that locally can be tens of feet thick. These alluvial aquifers consist of coarse-grained alluvium of Quaternary age that is found beneath the flood plains and in the terraces, which generally are capped with loess. The alluvial aquifers are permeable sand-and-gravel deposits with intermixed and interbedded silt and clay deposits (Verstraeten and Ellis, 1995). Moreover, these deposits are capable of yielding large amounts of water to irrigation wells (Gosselin and others, 1996). The primary sources of recharge for these aquifers are precipitation, runoff from upland areas, and infiltration during times of high river stage (Verstraeten and Ellis, 1995). Fredrick and others (2006) report that ground-water levels range from near surface to about 70 ft along the loess-capped terraces.

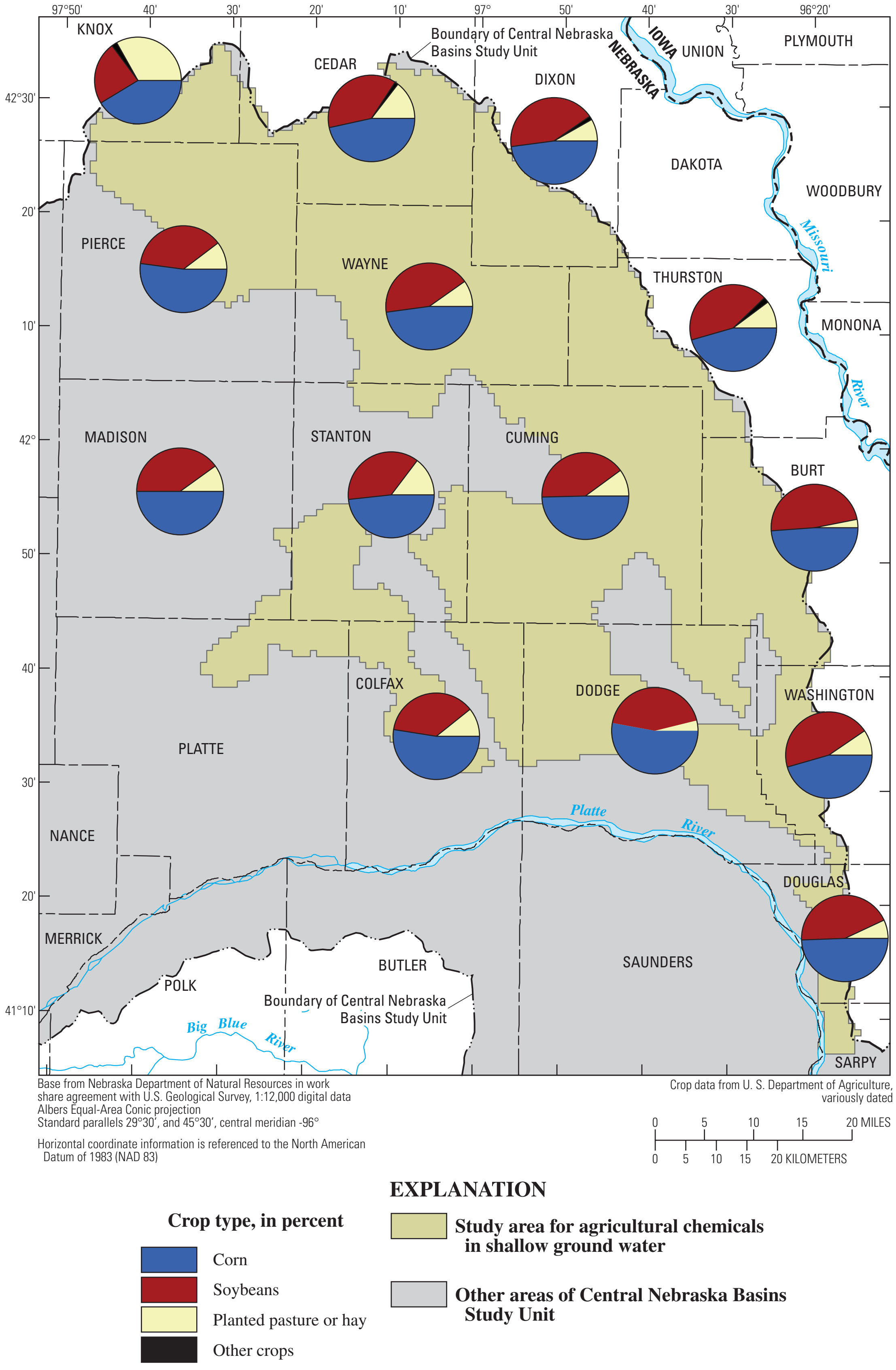
In the area of the flow-path wells, the primary aquifer unit is the alluvial material and terrace deposits described in the preceding paragraph. Depths below land surface for the aquifer in this area vary from about 70 ft under the loess-capped terraces (Fredrick and others, 2006) to less than 1 ft adjacent to Maple Creek. The thickness of the alluvial aquifer, obtained from a driller's log of nearby irrigation wells, is about 175 ft (Nebraska Department of Natural Resources, 2007).

Land-Use Setting

Land use in the study area is dominated by agriculture. According to interpreted Landsat Thematic Mapper satellite images composing the National Land Cover Dataset (NLCD), in 1992 about 81 percent of the study area was used for row crops, and 16 percent was used for pasture or hay (fig. 2). The remaining 3 percent of the study area was classified as forest, urban, open water, or wetlands (U.S. Geological Survey, 1992). The crops most commonly grown in the study area in 2002 were corn and soybeans (fig. 3). Planted pasture or hay and oats also were grown (U.S. Department of Agriculture, variously dated).

Nitrogen fertilizers are applied to cropland in the study area. The amount of nitrogen applied to cropland from manure and commercial fertilizer has been estimated for each county in the study area (Ruddy and others, 2006). Average nitrogen application rates from commercial fertilizer and manure between 1987 and 1997 ranged from 44 (Knox County) to 123 pounds per acre (lb/acre) (Cuming County). Fertilizer application estimates were based on State-level fertilizer sales compiled by the Association of American Plant Food Control Officials (AAPFCO). Estimates of county fertilizer use were calculated by multiplying the total State fertilizer sales by the portion of the State's fertilized acreage that was in each county as determined by the Census of Agriculture. Manure application rates were calculated from county-level livestock populations obtained from the 1997 Census of Agriculture (U.S. Department of Agriculture, 1999). Nitrogen content of manure was estimated using methods described by Goolsby and others (1999). Loss of nitrogen through volatilization was accounted for when estimating animal manure nitrogen. According to the farm operator at the flow-path study site, nitrogen fertilizer was applied to the corn field surrounding flow-path well FS1–1A after planting (May 8, 2004) (fig. 2). No fertilizer or manure was applied to the land surface around the other flow-path wells. However, cattle were grazed near wells FS1–3A and FS1–4A during parts of the year.

Pesticides (insecticides, herbicides, and fungicides) commonly are applied to cropland to control weeds and insects. The types and amounts of pesticides applied to each area are related to the types of crops grown. When pesticides move past the soil profile to a ground-water resource that is used for drinking water, they can cause potential health concerns (U.S. Environmental Protection Agency, 2004). Atrazine and metolachlor were the pesticides most commonly applied to crops in 1997 in the study area (table 1) (National Center for Food and Agricultural Policy, 1997; U.S. Department of Agriculture,



Base from Nebraska Department of Natural Resources in work share agreement with U.S. Geological Survey, 1:12,000 digital data
Albers Equal-Area Conic projection
Standard parallels 29°30', and 45°30', central meridian -96°

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

Crop data from U. S. Department of Agriculture, variously dated

Figure 3. Distribution of major crops grown, by county, northeast Nebraska glacial till, 2002.

Table 1. Ten most frequently applied pesticides over northeast Nebraska glacial till, 1997.

[Pesticide application rates on crops were estimated from the National Center for Food and Agricultural Policy (NCFAP) (1997) and county-level information on harvested crops in the 1997 Census of Agriculture (U.S. Department of Agriculture, 1999); lb/acre, pound per acre; a.i., active ingredient]

Pesticide name	Average amount applied to cropland (lb/acre of a.i.)
Metolachlor	0.33
Atrazine	.32
Acetochlor	.14
Glyphosate[1]	.14
Alachlor	.08
Pendimethalin	.07
Trifluralin	.06
Cyanazine	.05
Terbufos	.04
Carbofuran	.04
Total	**1.27**

[1] Not analyzed in samples collected as part of this study.

1999; Naomi Nakagaki, U.S. Geological Survey, written commun., July 2005). Although the estimated application rates do not necessarily represent conditions during the time that water composing the ground-water samples was recharged, they do provide a general idea of the types and relative amounts of pesticides that are applied. According to the landowner, 0.6 lb/acre of metolachlor and 0.8 lb/acre of atrazine were applied to the corn field at the flow-path study site at the time of planting (May 9, 2004), 1 lb/acre of atrazine was applied about 5 days after planting, and 0.5 lb/acre of chlorpyrifos was applied in July 2004.

Most water used in the study area is for cropland irrigation. In 2000, an estimated 218 million gallons per day (Mgal/d) were used for that purpose in the study area (U.S. Geological Survey, 2004). Ground-water withdrawals for irrigation varied by county and ranged from 8 to 118 Mgal/d. Irrigation water is applied mainly during the summer months (June through August) when crop water demands are largest. Other primary water uses include publicly supplied drinking water, self-supplied domestic drinking water, industrial, and livestock (fig. 4). At the flow-path study site, an estimated 10 in. of irrigation water were applied in each of 2003 and 2004 during a 6-week period in July and August.

Methods of Investigation

Water samples were collected from 34 monitoring wells (fig. 1). Four of the wells were installed between September 2003 and March 2004 as part of a flow-path ACT study in Maple Creek Valley, and 28 wells distributed throughout the glacial-till area of northeast Nebraska were installed in 2002 as part of an AgLUS. Additionally, two reference wells were installed to represent background, or naturally occurring, ground-water-quality conditions.

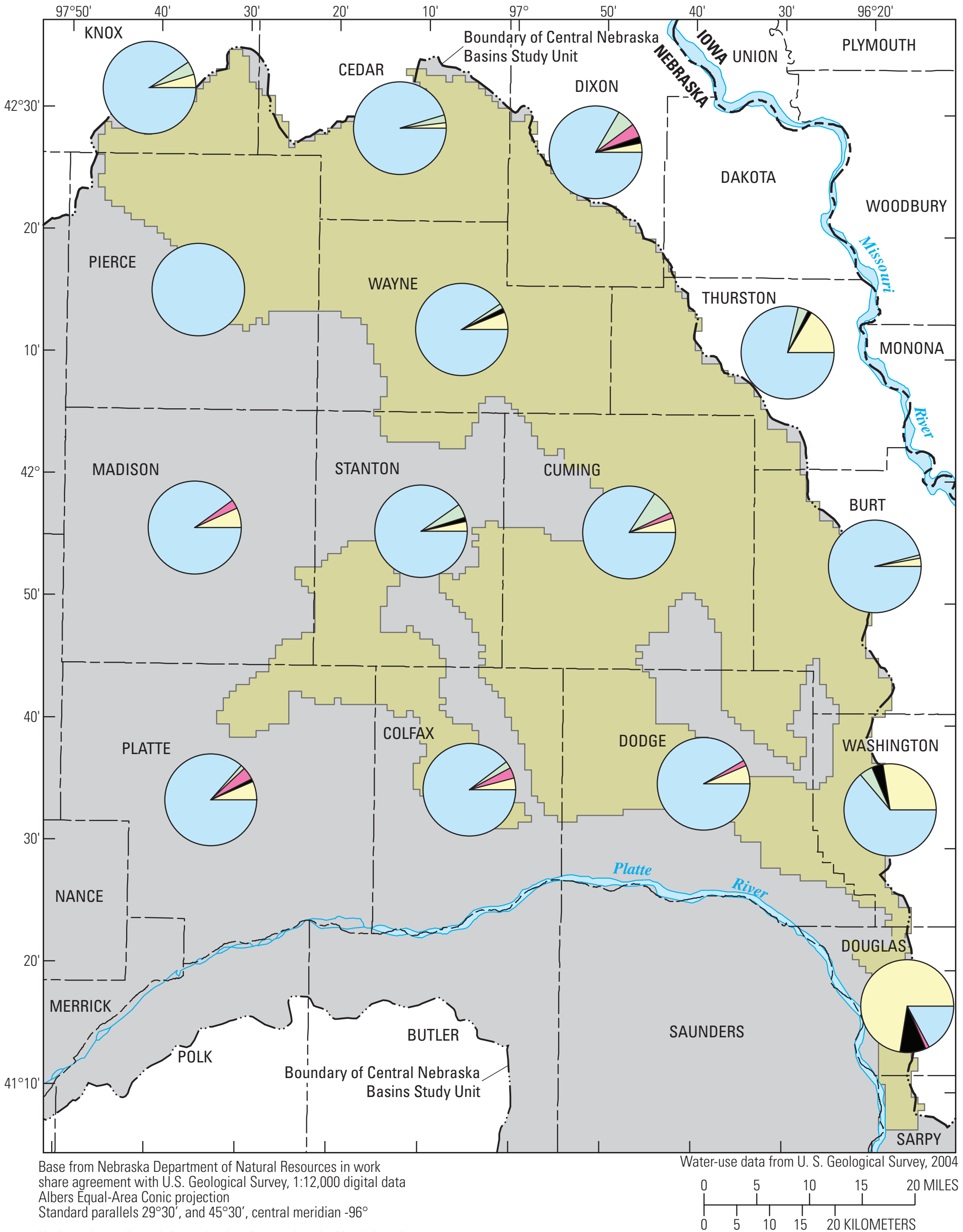
Site Selection and Well Installation

The flow-path wells sampled as part of this study were located in the southern part of the glaciated area of northeast Nebraska about 5 mi upstream from the confluence of Maple Creek and the Elkhorn River. The flow-path study site was chosen to represent localized ground-water flow from agricultural lands to discharge points at a nearby stream flanked by riparian woodland areas (fig. 2). Specific site descriptions for this study site are provided in Fredrick and others (2006). The flow path begins in a cropped field (corn in 2004) (well FS1–1A) with additional wells located adjacent to the corn field (well FS1–2A), in a pasture (well FS1–3A), and in a riparian woodland area adjacent to Maple Creek (well FS1–4A). Each well location is within a cluster of three wells with the shallowest well located just below the anticipated lowest depth of the water table. Two additional piezometers were placed at depth below the shallowest well at each site but are not discussed in this report. All samples not collected specifically from the flow-path wells were collected from the glacial-till network of wells or were reference wells.

The glacial-till network wells sampled in this study were located in the glacial-till areas of northeastern Nebraska where soil zones are poorly drained. A primary criterion for site selection was location of the wells in areas characterized by intrinsic aquifer susceptibility as indicated by selected hydrologic landscape regions (Winter, 2001; Wolock and others, 2004) and land use that was at least 20 percent corn and soybeans. Therefore, the boundaries of the study area were based primarily on hydrologic landscape regions with modifications to exclude areas where land use was not classified as having greater than 20 percent corn and soybean production.

Site locations for the glacial-till well network were selected using a stratified random approach (Scott, 1990). Using a geographical information system (GIS), the study area was divided into 30 cells of equal area, and each of these 30 cells then was subdivided into 30 equal-area subcells. From the 30 subcells, one random primary polygon and four random alternate polygons were chosen by a scripted GIS algorithm. Thus, within each of the 30 cells, there were 30 subcells from which one primary and four alternate subcells were randomly chosen. Following the selection of the random points (centers of the subcells), land use within about a 2-mi radius of the random point was screened to ensure the monitoring wells fit the criteria of the study. If the land use fell within the guidelines of the study, landowners were contacted for permission to install a monitoring well.

Two reference wells were located in areas of no cultivated crop production for the past 5 years. Both reference wells were



Base from Nebraska Department of Natural Resources in work share agreement with U.S. Geological Survey, 1:12,000 digital data
Albers Equal-Area Conic projection
Standard parallels 29°30', and 45°30', central meridian -96°

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

Water-use data from U. S. Geological Survey, 2004

EXPLANATION

Water-use categories, in percent

- 🟦 Irrigation
- 🟨 Public supply
- ⬛ Self-supplied domestic
- 🟪 Industrial
- 🟩 Livestock

Water-use category is shown only when composing greater than 1 percent of total water use.

- 🟫 **Study area for agricultural chemicals in shallow ground water**
- ⬜ **Other areas of Central Nebraska Basins Study Unit**

Figure 4. Use of ground water, by county, northeast Nebraska glacial till, 2000.

targeted for placement in pastures that were at least 1,640 ft from any cropped field. However, one well (SR–2) was located within 700 ft of a corn field but upgradient from crops with respect to the estimated ground-water flow direction.

Wells were installed using methods that maximized the likelihood that water-quality samples represented aquifer conditions and that equipment and construction materials were not a source or sink of sampled analytes (Lapham and others, 1997). Wells were installed using hollow-stem auger techniques that introduced no drilling fluids. Well casings and screens were constructed of 2-in. diameter polyvinyl chloride (PVC). Because agricultural chemicals applied at the land surface are more likely to be observed in the shallowest part of an aquifer, monitoring wells were constructed with short screens placed at the first occurrence of ground water (most of the glacial-till network sites) or just below the anticipated lowest depth of the water table (tables 2 and 3). The annular space above the well screen and filter pack was filled with bentonite grout, and a concrete pad and protective steel cover were placed around the well.

Sample Collection and Analysis

Fifty-eight ground-water samples were collected from the 34 monitoring wells in 2003 and 2004 (tables 2 and 3). Water samples were analyzed to determine physical properties and concentrations of nitrogen and phosphorus compounds, selected pesticides and pesticide degradates, dissolved solids, major ions, trace elements, and dissolved organic carbon. Samples from the 28 glacial-till network wells distributed throughout the glaciated area and samples from two reference wells were collected during April, May, and June 2003 to coincide with the approximate time that agricultural chemicals would be applied to crops (table 2). In 2004, samples from the four flow-path wells plus samples from three of the glacial-till network wells within the Maple Creek watershed were collected in March (pre-plant), May (post-plant), August and early September (growing season), and October (post-harvest) (table 3). Samples from those seven sites were only analyzed for pesticides and pesticide degradates in May and October of 2004. Twenty-four of the ground-water samples collected in spring of 2003 and 2004 were analyzed for either CFCs (CFC–11, CFC–12, and CFC–113) or SF_6 concentrations to estimate the approximate recharge date of the water sample. Sediment-core samples were collected at 28 well boreholes during installation between May and October 2002. Analytical laboratories for water samples and laboratory analytical methods are briefly summarized for measured water-quality constituents in table 4.

Ground-water samples were collected from monitoring wells using procedures described in the USGS national field manual (U.S. Geological Survey, variously dated) and by the U.S. Geological Survey Reston Chlorofluorocarbon Laboratory (U.S. Geological Survey, 2005). Water samples were processed onsite in a mobile laboratory using methods designed to minimize changes to the water-sample chemistry. Water samples for nutrient, pesticide, and major ion analysis were pumped from wells using a stainless-steel submersible pump and delivered to the mobile laboratory through Teflon tubing with stainless-steel connections. Water samples for CFCs and SF_6 analyses were delivered to the mobile laboratory using refrigerator-grade copper tubing. Prior to sample collection, stagnant water was flushed from the well by purging at least three casing volumes from the well. While purging, specific conductance, pH, water temperature, dissolved oxygen, and turbidity were measured until readings were stable (U.S. Geological Survey, variously dated). Once measurements stabilized, water samples were collected in precleaned bottles within an enclosed chamber to prevent sample contamination. To prevent degradation of water samples and to maintain the initial concentration of compounds between the time of sample and laboratory analyses, bottles were preserved according to the requirements of the laboratories. Preservation practices differ among analytes and may include chilling, filtration, and (or) chemical treatment (table 4).

Continuous sediment-core samples were collected prior to well installation using a 4-in. split-core sampler. Sediment samples then were collected from the continuous-core samples at 10-ft intervals or at major changes in lithology. Chemical analyses of sediment samples were performed by the University of Nebraska Soil and Plant Analytical Laboratory in Lincoln, Nebraska (Carolyn Bossung, University of Nebraska-Lincoln, written commun., June 2004). Particle-size analyses were performed by a combination of laser diffraction and sieving by the U.S. Geological Survey in Menlo Park, California (Gee and Or, 2002).

Data Treatment

In 1998, the USGS National Water-Quality Laboratory (NWQL) began implementing a new method for reporting analytical results (Childress and others, 1999). Two concentration levels are used in the new method; the long-term method detection level (LT–MDL) and the laboratory reporting level (LRL) minimize both false-positive and false-negative errors. LT–MDLs and LRLs vary among constituents and analytical methods. LT–MDL is determined from the standard deviation of long-term laboratory spike-sample measurements and is set to the level at which false-positive errors are minimized to no more than 1-percent probability. LRL is set to the level at which false-negative errors are minimized to no more than 1-percent probability and is generally equal to twice the LT–MDL. Using this reporting convention, if a reported concentration is greater than both the LRL and the smallest laboratory calibration standard, it is not censored or qualified. If a reported concentration is smaller than the LT–MDL, it is coded as “less than” the LRL, unless information-rich laboratory methods (organic constituent methods that have additional qualitative information provided by the instrumentation) are used. LT–MDLs and LRLs are reevaluated annually by

Table 2. Monitoring wells sampled in 2003, northeast Nebraska glacial till.

[NA, not applicable]

Well identifier (fig. 1)	U.S. Geological Survey site number	Well type	Geologic unit	Latitude (decimal degrees)	Longitude (decimal degrees)	Sample date	Depth of well (feet below land surface)	Depth to top of well screen (feet below land surface)	Depth to bottom of well screen (feet below land surface)	Depth to water level (feet below land surface)	Water-collecting road ditch within 164 feet
B–27	414931096321101	Glacial-till network	Pleistocene loess	41.82530	-96.53637	June 5	25	15	25	8.79	no
B–28	415220096214801	Glacial-till network	Pleistocene loess	41.87219	-96.36326	April 28	17	7	17	10.13	yes
CE–06	422947097142701	Glacial-till network	Pleistocene sand and gravel	42.49663	-97.24098	May 20	23.5	13.5	23.5	9.46	yes
CE–17	422802097031601	Glacial-till network	Holocene alluvium	42.46747	-97.05469	May 19	20	15	20	2.10	yes
CO–13	414343096595801	Glacial-till network	Holocene alluvium	41.72866	-96.99968	June 4	25	15	25	11.05	yes
CU–19	420024096485901	Glacial-till network	Holocene alluvium	42.00670	-96.81637	May 28	22	17	22	9.41	no
CU–20	415558096434501	Glacial-till network	Pleistocene loess	41.93300	-96.72929	April 29	45	35	45	38.48	yes
CU–29	415918096350501	Glacial-till network	Pleistocene glacial till	41.98857	-96.58498	April 30	32	22	32	18.42	yes
CU–30	420248096300901	Glacial-till network	Pleistocene glacial till	42.04663	-96.65237	May 29	30	20	25	27.55	yes
D–21	414401096531301	Glacial-till network	Pleistocene loess	41.73376	-96.88711	June 2	29.5	19.5	29.5	13.16	yes
D–22	413853096483801	Glacial-till network	Pleistocene loess	41.64808	-96.81053	June 4	32	27	32	26.10	no
D–24	413340096402701	Glacial-till network	Holocene alluvium	41.56108	-96.67425	May 15	24.5	19.5	24.5	21.04	yes
D–26	414141096371701	Glacial-till network	Pleistocene loess	41.69483	-96.62150	June 4	57	52	57	50.31	no
DG–23	411733096185501	Glacial-till network	Holocene alluvium	41.29259	-96.31530	June 9	15	10	15	4.02	no
DI–16	422011096595401	Glacial-till network	undifferentiated Pleistocene deposits	42.33641	-96.99834	May 5	65	60	65	58.13	yes
K–05	422756097334901	Glacial-till network	Pleistocene sand and gravel	42.46561	-97.56350	May 20	45	40	45	22.11	no
P–02	421357097243201	Glacial-till network	Pleistocene glacial till	42.23239	-97.40900	May 27	25	20	25	8.31	yes
P–03	422156097314301	Glacial-till network	Pleistocene glacial till	42.36556	-97.52864	May 21	39	29	39	34.02	yes
P–04	422441097404601	Glacial-till network	Pleistocene glacial till	42.41133	-97.67950	May 20	60	50	60	51.02	yes
S–01	414948097212601	Glacial-till network	undifferentiated Pleistocene deposits	41.83015	-97.35736	May 13	35	30	35	32.10	yes
S–10	420425097101301	Glacial-till network	Pleistocene loess	42.07361	-97.17028	May 7	30	20	30	22.35	no
S–11	414527097094101	Glacial-till network	Pleistocene glacial till	41.75758	-97.16146	June 3	65	55	65	47.17	yes
W–07	422031097043501	Glacial-till network	Pleistocene sand and gravel	42.34199	-97.07663	May 6	73	68	73	62.30	yes
W–08	421829097112401	Glacial-till network	Pleistocene loess	42.30811	-97.18997	May 8	35	25	35	22.23	yes
W–09	421149097121301	Glacial-till network	Pleistocene loess	42.19694	-97.20361	May 7	37	32	37	31.92	no
W–14	420526096543901	Glacial-till network	undifferentiated Pleistocene deposits	42.09056	-96.91083	May 1	35	25	35	13.69	yes
W–15	421303097011601	Glacial-till network	Holocene alluvium	42.21750	-97.02111	May 7	34.8	29.8	34.8	15.61	no
W–18	420922096514401	Glacial-till network	Pleistocene loess	42.15622	-96.86235	May 5	39	34	39	26.84	yes
S–R2	415458097142201	Reference	Holocene alluvium	41.91623	-97.23966	June 3	29	24	29	17.25	NA
W–R1	421445097123801	Reference	Pleistocene loess	42.24575	-97.21067	May 28	53	48	53	45.47	NA

Table 2. Monitoring wells sampled in 2003, northeast Nebraska glacial till.—Continued

[NA, not applicable]

Well identifier (fig. 1)	U.S. Geological Survey site number	Well type	Geologic unit	Latitude (decimal degrees)	Longitude (decimal degrees)	Sample date	Perennial stream within 1,640 feet	Farmhouse within 164 feet	Manure storage or pasture within 164 feet	Irrigation well within 1,640 feet	Irrigated cropland within 1,640 feet
B–27	414931096321101	Glacial-till network	Pleistocene loess	41.82530	-96.53637	June 5	no	no	no	yes	yes
B–28	415220096214801	Glacial-till network	Pleistocene loess	41.87219	-96.36326	April 28	no	no	no	yes	no
CE–06	422947097142701	Glacial-till network	Pleistocene sand and gravel	42.49663	-97.24098	May 20	no	no	no	no	yes
CE–17	422802097031601	Glacial-till network	Holocene alluvium	42.46747	-97.05469	May 19	no	no	no	no	no
CO–13	414343096595801	Glacial-till network	Holocene alluvium	41.72866	-96.99968	June 4	yes	no	no	no	no
CU–19	420024096485901	Glacial-till network	Holocene alluvium	42.00670	-96.81637	May 28	no	no	no	no	no
CU–20	415558096434501	Glacial-till network	Pleistocene loess	41.93300	-96.72929	April 29	no	yes	no	no	no
CU–29	415918096350501	Glacial-till network	Pleistocene glacial till	41.98857	-96.58498	April 30	no	no	no	no	no
CU–30	420248096300901	Glacial-till network	Pleistocene glacial till	42.04663	-96.65237	May 29	no	no	no	no	no
D–21	414401096531301	Glacial-till network	Pleistocene loess	41.73376	-96.88711	June 2	no	no	no	no	no
D–22	413853096483801	Glacial-till network	Pleistocene loess	41.64808	-96.81053	June 4	no	no	no	no	no
D–24	413340096402701	Glacial-till network	Holocene alluvium	41.56108	-96.67425	May 15	yes	no	no	yes	yes
D–26	414141096371701	Glacial-till network	Pleistocene loess	41.69483	-96.62150	June 4	no	no	no	no	no
DG–23	411733096185501	Glacial-till network	Holocene alluvium	41.29259	-96.31530	June 9	no	no	yes	no	yes
DI–16	422011096595401	Glacial-till network	undifferentiated Pleistocene deposits	42.33641	-96.99834	May 5	no	no	no	yes	yes
K–05	422756097334901	Glacial-till network	Pleistocene sand and gravel	42.46561	-97.56350	May 20	no	no	yes	no	no
P–02	421357097243201	Glacial-till network	Pleistocene glacial till	42.23239	-97.40900	May 27	no	yes	yes	no	no
P–03	422156097314301	Glacial-till network	Pleistocene glacial till	42.36556	-97.52864	May 21	no	no	yes	no	no
P–04	422441097404601	Glacial-till network	Pleistocene glacial till	42.41133	-97.67950	May 20	yes	yes	no	no	yes
S–01	414948097212601	Glacial-till network	undifferentiated Pleistocene deposits	41.83015	-97.35736	May 13	yes	no	no	no	no
S–10	420425097101301	Glacial-till network	Pleistocene loess	42.07361	-97.17028	May 7	no	no	no	no	no
S–11	414527097094101	Glacial-till network	Pleistocene glacial till	41.75758	-97.16146	June 3	yes	no	no	no	no
W–07	422031097043501	Glacial-till network	Pleistocene sand and gravel	42.34199	-97.07663	May 6	no	no	no	yes	yes
W–08	421829097112401	Glacial-till network	Pleistocene loess	42.30811	-97.18997	May 8	no	no	no	no	no
W–09	421149097121301	Glacial-till network	Pleistocene loess	42.19694	-97.20361	May 7	no	no	no	no	no
W–14	420526096543901	Glacial-till network	undifferentiated Pleistocene deposits	42.09056	-96.91083	May 1	no	no	no	no	no
W–15	421303097011601	Glacial-till network	Holocene alluvium	42.21750	-97.02111	May 7	no	no	no	yes	yes
W–18	420922096514401	Glacial-till network	Pleistocene loess	42.15622	-96.86235	May 5	no	no	no	no	no
S–R2	415458097142201	Reference	Holocene alluvium	41.91623	-97.23966	June 3	NA	NA	NA	NA	NA
W–R1	421445097123801	Reference	Pleistocene loess	42.24575	-97.21067	May 28	NA	NA	NA	NA	NA

Table 3. Monitoring wells sampled in 2004, northeast Nebraska glacial till.

Well identifier (fig. 2)	U.S. Geological Survey site number	Well type	Geologic unit	Latitude (decimal degrees)	Longitude (decimal degrees)	Sample date	Depth of well (feet below land surface datum)	Depth to top of well screen (feet below land surface)	Depth to bottom of well screen (feet below land surface)	Depth to water level (feet below land surface)
FS1–1A	413334096325301	Flow path	Pleistocene sand and gravel	41.55958	-96.54808	March 30	79	74	79	70.39
						May 19				not available
						August 16				71.09
						October 4				71.47
FS1–2A	413341096325501	Flow path	Pleistocene sand and gravel	41.56139	-96.54853	March 29	81.1	76.1	81.1	69.51
						May 18				not available
						August 17				70.21
						October 7				70.38
FS1–3A	413348096324801	Flow path	Pleistocene sand and gravel	41.56325	-96.54678	March 31	60	55	60	51.05
						May 20				not available
						August 18				51.83
						October 6				52.03
FS1–4A	413350096324701	Flow path	Pleistocene sand and gravel	41.56395	-96.54655	April 1	18.2	13.2	18.2	12.80
						May 24				10.00
						August 17				14.05
						October 5				14.22
D–24	413340096402701	Glacial-till network	Holocene alluvium	41.56108	-96.67425	March 23	24.5	19.5	24.5	18.50
						May 25				18.46
						September 8				18.84
						October 13				18.11

Table 3. Monitoring wells sampled in 2004, northeast Nebraska glacial till.—Continued

Well identifier (fig. 2)	U.S. Geological Survey site number	Well type	Geologic unit	Latitude (decimal degrees)	Longitude (decimal degrees)	Sample date	Depth of well (feet below land surface datum)	Depth to top of well screen (feet below land surface)	Depth to bottom of well screen (feet below land surface)	Depth to water level (feet below land surface)
CO–13	414343096595801	Glacial-till network	Holocene alluvium	41.72866	-96.99968	March 25	25	15	25	11.95
				41.72866	-96.99968	May 26	25	15	25	8.44
						September 9				12.24
						October 12				12.45
S–11	414527097094101	Glacial-till network	Pleistocene glacial till	41.75758	-97.16146	March 24	65	55	65	46.80
						May 25				46.83
						August 19				43.13
						October 14				42.49

Table 4. Laboratory analysis and onsite preservation and treatment methods for measured water-quality constituents, northeast Nebraska glacial till, 2003–04.

[USGS, U.S. Geological Survey; NWQL, National Water Quality Laboratory; µm, micron; °C, degrees Celsius; C-18, carbon 18; GC/MS, gas chromatography/mass spectrometry; LC/MS, liquid chromatography/mass spectrometry; <, less than; UV, ultraviolet; mL, milliliter]

Constituent or constituent group	Analyzing laboratory	Analytical method(s)	Reference(s)	Onsite treatment and preservation method(s)
Depth to water, specific conductance, pH, temperature, dissolved oxygen, and turbidity	Measured onsite	Various methods	USGS, variously dated	None.
Nitrogen and phosphorus compounds	USGS NWQL, Lakewood, CO	Various methods	Fishman, 1993; Patton and Kryskalla, 2003	Filter through 0.45-µm filter, chill, and maintain at 4°C.
Pesticides and pesticide degradates	USGS NWQL, Lakewood, CO	C-18 solid-phase extraction and capillary-column GC/MS	Zaugg and others, 1995; Lindley and others, 1996; Furlong and others, 2001; Madsen and others, 2003	Filter through 0.7-µm baked glass-fiber filter, chill, and maintain at 4°C.
Selected pesticide degradates	USGS Organic Geochemistry Research Laboratory, Lawrence, KS	Online solid-phase extraction and LC/MS; solid-phase extraction and GC/MS; solid-phase extraction and capillary-column GC/MS with selected-ion monitoring	Zimmerman and Thurman, 1999; Kish and others, 2000; Lee and Strahan, 2003	Filter through 0.7-µm baked glass-fiber filter, chill, and maintain at 4°C.
Dissolved solids and major ions	USGS NWQL, Lakewood, CO	Inductively coupled plasma	Fishman and Friedman, 1989; Fishman, 1993; American Public Health Association, 1998	Anions, filter through 0.45-µm filter; cations, filter through 0.45-µm filter, acidify sample to pH <2 with nitric acid (HNO_3).
Carbonate alkalinity	Analyzed onsite	Inflection-point titration	USGS, variously dated	Filter through 0.45-µm filter.
Trace elements	USGS NWQL, Lakewood, CO	Inductively coupled plasma, atomic absorption spectrometry	Fishman and Friedman, 1989; Faires, 1993; McLain, 1993; Garbarino, 1999	Filter through 0.45-µm filter and acidify to < 2 with nitric acid (HNO_3).
Dissolved organic carbon	USGS NWQL, Lakewood, CO	UV-light promoted persulfate oxidation and infrared spectrometry	Brenton and Arnett, 1993	Filter through 0.7-µm baked glass-fiber filter, acidify to pH < 2 with 1 mL of 4.5N sulfuric acid (H_2SO_4), chill, and maintain at 4°C.
Chlorofluorocarbons	USGS Chlorofluorocarbon Laboratory, Reston, VA	Purge-and-trap, gas chromatography with electron-capture detector	Bullister, 1984; Bullister and Weiss, 1988; Busenberg and Plummer, 1992; Plummer and Busenberg, 1999	No contact with atmosphere.
Sulfur hexafluoride	USGS Chlorofluorocarbon Laboratory, Reston, VA	Purge-and-trap, gas chromatography with electron-capture detector	Busenberg and Plummer, 2000	No contact with atmosphere.

NWQL on the basis of laboratory spike-sample measurements and may change with time.

Concentrations are qualified as estimated in several situations. If a reported concentration is smaller than either the LRL or the smallest laboratory calibration standard but greater than the LT–MDL, the value is qualified as estimated using an “E” remark code. An “E” remark code also is used if the reported concentration is larger than the largest laboratory calibration standard. Pesticides were analyzed and reported using information-rich laboratory methods. These methods report concentrations smaller than the LT–MDL if an analyte is positively identified and all other laboratory quality-control criteria are satisfied. The reported concentrations smaller than the LT–MDL are qualified with an “E” remark code. Finally, if a compound does not meet method-specific performance criteria, reported concentrations are qualified with an “E” remark code.

Water-quality data commonly are positively skewed (most data occur at small values but a few extreme large values are present). For this reason, nonparametric statistical methods were used in this report to evaluate the analytical results. The nonparametric Wilcoxon, or Mann-Whitney, rank-sum test (two-sided) was used to compare observations between groups of data (Wilcoxon, 1945). In this report, a p-value of less than 0.10 indicates that there was a significant difference between two groups of data. If more than 50 percent of the values were censored, no statistical comparison was attempted. The nonparametric Spearman’s rho test was used to correlate observations between variables in a dataset (Bhattacharyya and Johnson, 1977). Rho is the “linear correlation coefficient computed on the ranks of the data” (Helsel and Hirsch, 1992). In this report, a p-value of less than 0.10 indicates that the correlation of the two variables was statistically significant. Fisher’s exact test (Agresti, 1990) was used to detect group differences in categorical data. A p-value of less than 0.10 indicates there was a statistically significant difference between the two groups of data.

To apply statistical tests, it was sometimes necessary to substitute censored (“less than”) values with a numeric value. Substitutions were applied using methods described by Helsel (2005) and were dependent upon the laboratory reporting methods of each constituent. Censored data were set to a value smaller than the smallest LT–MDL to effectively be treated as a tied rank that was smaller than any estimated or uncensored value. Estimated values were treated as quantitative results.

Quality Control

Additional samples were collected to assess the reliability of sample processing and analytical methods. These quality-control samples included field-blank, replicate, and environmental-matrix spike samples.

Field-Blank Samples

Field-blank samples were collected to determine the occurrence and magnitude of sample contamination during sample collection, equipment cleaning, transport, and analysis. When field-blank samples were collected, sample bottles were filled with ultrapure water prepared at NWQL instead of well water. Prior to use, the prepared water was analyzed and certified to be free of the environmental sample analytes. Field-blank samples otherwise were collected using the same procedures and equipment as environmental samples. Field-blank samples were collected and analyzed for nitrogen and phosphorus compounds, pesticide compounds, major ions, trace elements, and dissolved organic carbon. It is not possible to prepare meaningful age-dating field-blank samples; therefore, age-dating field-blank samples were not collected.

Results of field-blank sample analyses are summarized in table 5. Concentrations of analytes detected in field-blank samples were compared with concentrations of analytes in environmental samples to determine the potential for environmental sample contamination. If the magnitude of the field-blank sample concentrations approached the environmental sample concentrations, environmental sample concentrations may have been affected by sampling contamination. Concentrations of metolachlor, aluminum, manganese, zinc, and dissolved organic carbon in at least one field-blank sample were larger than the smallest concentrations found in environmental samples. Therefore, at small concentrations, it was not possible to determine if environmental concentrations of these constituents were representative of aquifer conditions or the result of sampling contamination. Because relatively few analytes were detected in field-blank samples, equipment decontamination and sample handling procedures adequately prevented positive bias of reported concentrations.

Replicate Samples

Replicate samples are two environmental samples collected sequentially to represent a duplication of the same sample water. They are collected to determine variability of the data as a result of sampling and analytical procedures. The relative percentage difference (RPD) between concentrations of paired replicate samples was calculated using the formula:

$$RPD = \frac{\left| Sample\,1 - Sample\,2 \right|}{\left(\frac{Sample\,1 + Sample\,2}{2} \right)} \text{ x } 100 \,. \tag{1}$$

When there is no variability between the paired analyses, the RPD is zero. The RPD was not calculated if one or both of the paired replicate concentrations were less than the largest laboratory reporting level (LRL) or identified as an estimated value by the laboratory. The individual constituents having the largest average RPDs were atrazine (25.0 percent),

Table 5. Constituents detected in field-blank samples, northeast Nebraska glacial till, 2003–04.

[P, phosphorus; E, estimated; ND, not detected; --, median not calculated; M, presence verified but not quantified]

Constituent	Number of detections/ number of field-blank samples	Median concentration of detected analytes in field-blank samples	Maximum concentration in field-blank samples	Range of concentrations in environmental samples
Nitrogen and phosphorus compounds (concentrations in milligrams per liter)				
Orthophosphate as P	3/8	E0.005	0.007	ND–1.28
Pesticide compounds (concentrations in micrograms per liter)				
Metolachlor	1/6	--	E.006	ND–E0.002
Major ions (concentrations in milligrams per liter)				
Calcium	4/5	.04	.09	11.2–406
Magnesium	2/5	E.004	E.004	2.49–90.5
Sodium	4/5	.11	.16	4.50–281
Silica	5/5	.22	2.27	19.4–50.4
Trace elements (concentrations in micrograms per liter)				
Aluminum	2/4	--	11	ND–28
Barium	3/4	--	M	14–664
Cobalt	1/4	--	E.007	0.045–9.11
Copper	2/4	.3	.4	0.5–11.5
Iron	1/5	--	10	ND–5,810
Manganese	4/7	1.0	1.8	ND–18,300
Nickel	3/4	.15	.16	0.76–16.2
Silver	1/4	--	.2	ND
Strontium	2/3	.29	.34	50–2,160
Vanadium	1/4	--	E.1	0.5–9.6
Uranium	1/4	--	E.01	0.02–162
Zinc	3/4	E.9	2.7	E0.6–14.3
Dissolved organic carbon (concentrations in milligrams per liter)				
Dissolved organic carbon	2/4	1.1	1.6	0.4–4.8

copper (22.9 percent), metolachlor ethanesulfonic acid (ESA) (12.3 percent), ammonia (11.3 percent), dissolved organic carbon (10.5 percent), and manganese (10.4 percent). The larger RPDs for these constituents might be explained by their small concentrations near the LRL. With small concentrations and few significant figures, small differences can have large calculated variability. For example, an environmental sample concentration of 0.01 mg/L and a replicate sample concentration of 0.02 mg/L yield an RPD of 50 percent. Except for nickel, RPDs were 5 percent or less for constituents with measured concentrations greater than 10 times the LRL.

Environmental-Matrix Spike Samples

Environmental-matrix spike samples typically are used to quantify the gain or loss of organic-compound analytes because of water-matrix properties, sample holding time, or onsite and laboratory procedures. A spike recovery of 100 percent indicates no matrix interference or degradation and good analytical recovery. Environmental-matrix pesticide spike samples were prepared by adding known amounts of 99 pesticide compounds into replicate samples while onsite. The average percentage recovery of individual pesticide compounds was calculated from the environmental-matrix spike samples and is reported in Appendix 1. Eighty-six of the 99 pesticide compounds analyzed were within an acceptable range of 60 to 120 percent recovery (Furlong and others, 2001). Of the 13 pesticide compounds analyzed that did not fall into the range of acceptable recovery, 10 always were reported as estimated values by NWQL because of known problems with gas chromatography or extraction or because they did not otherwise meet method performance criteria (Zaugg and others, 1995; Furlong and others, 2001).

Occurrence of Agricultural Chemicals in Shallow Ground Water

Agricultural chemicals applied at the land surface are more likely to be observed in the shallowest part of an aquifer because recently recharged ground water generally is located at the top of an aquifer near chemical sources. Ground-water samples were collected from 34 monitoring wells from spring 2003 through spring 2004. Ground-water samples were analyzed for physical properties and concentrations of nitrogen and phosphorus compounds, selected pesticides and pesticide degradates, dissolved solids, major ions, trace elements, and dissolved organic carbon. Laboratory results have previously been reported in U.S. Geological Survey water-data reports (Hitch and others, 2004; Hitch and others, 2005; U.S. Geological Survey, 2006).

Samples from a portion of the sites were analyzed for CFCs (CFC–11, CFC–12, and CFC–113) or SF_6 to determine the apparent date the water was isolated from the atmosphere (recharge date). Age-dating techniques can be affected by processes such as mixing of waters within the aquifer, the time it takes for atmospheric gases to reach deep saturated zones, microbial degradation, sorption onto organic carbon and minerals, and contamination from sources other than atmospheric gases (Plummer and Busenberg, 1999). Therefore, ages are referred to as “apparent ages.” The results from this analysis indicated that all analyzed water samples contained at least a portion of water that had resided in the aquifer for less than 50 years, and most had an apparent recharge date that was within the past 30 years (table 6). Because widespread application of agricultural chemicals primarily has been within the past 50 years, samples likely represent water that has been exposed to potential agricultural contaminants.

Nutrients

Nitrogen and phosphorus are nutrients commonly applied to agricultural lands to improve the fertility of soils and improve crop yields. These nutrients can migrate past the soil horizon and to ground water. Nitrogen and phosphorus compounds can exist as different forms in water. Water samples were analyzed for nitrite reported as nitrogen, nitrite plus nitrate as nitrogen, ammonia as nitrogen, ammonia plus organic nitrogen as nitrogen (2003 samples only), and orthophosphate as phosphorus (tables 7 and 8). Dissolved orthophosphate concentrations are typically small in ground water because phosphorus has a very low solubility and readily sorbs to soil particles (Miller and Donahue, 1990). Therefore, most of the following discussion will focus on nitrogen compounds.

Nitrate is the dominant form of nitrogen in oxygenated water, whereas nitrite, ammonia, and organic nitrogen are more stable when oxygen concentrations are small. Dissolved oxygen concentrations indicated that about 62 percent of ground-water samples collected in the study area were oxygenated (greater than 1.0 mg/L dissolved oxygen) (Hitch and others, 2004). Nitrite was detected in 13 of the 58 (22 percent) ground-water samples collected in 2003 and 2004 with concentrations up to 0.021 mg/L (tables 7 and 8) (Hitch and others, 2004). Nitrite composed a maximum of 3.5 percent of the nitrite plus nitrate concentration as nitrogen where nitrite was detected and nitrite plus nitrate as nitrogen concentrations were not estimated. Therefore, nitrite plus nitrate concentrations will be referred to as nitrate as nitrogen (nitrate–N) concentrations in this report. Ammonia was detected in 15 of the 58 samples (26 percent), with concentrations up to 0.90 mg/L (tables 7 and 8). Three of the five samples collected from the glacial-till well network in 2003 that contained detectable ammonia also had a dissolved-solids concentration larger than 1,000 mg/L. Ammonia plus organic nitrogen concentrations in samples collected in 2003 ranged from undetected to 1.3 mg/L (table 7).

Nitrogen in the form of nitrate–N is mobile, persistent, and is the most common ground-water contaminant in the Nation (Mueller and Helsel, 1996). Although, nitrate–N is found naturally in ground water, elevated concentrations generally are caused by human-related sources (Spalding and Kitchen, 1988; Bruce and others, 2003; McMahon and Böhlke, 2006). The maximum background concentration of nitrate–N representing naturally occurring sources in ground water is estimated to be about 2 to 4 mg/L nationwide (Madison and Brunett, 1985; Gosselin, 1991; Mueller and Helsel, 1996; McMahon, 2001; Becker and others, 2002). Nitrate–N concentrations in samples collected in spring 2003 from the 28 glacial-till network wells ranged from undetected to 69.5 mg/L, with a median of 9.53 mg/L (table 7). Nitrate–N concentrations in 19 samples (68 percent) were greater than 4 mg/L, indicating that human activity has affected nitrate–N concentrations in recently recharged ground water near corn and soybean fields. Although the sampled wells are not representative of wells typically used as a source of drinking water, concentrations in 13 samples (46 percent) were larger than 10 mg/L, the USEPA Maximum Contaminant Level for nitrate–N in drinking water (fig. 5) (U.S. Environmental Protection Agency, 2004). Nitrate–N concentrations in the two reference wells sampled in 2003 were 1.71 and 8.96 mg/L (table 7).

The four flow-path and three glacial-till network wells in the Maple Creek watershed were sampled four times during 2004—March (pre-plant), May (post-plant), August and early September (growing season), and October (post-harvest). Although the flow-path wells were located within a small area, nitrate–N concentrations in ground-water samples collected from those wells were variable (table 8). In May 2004, the largest nitrate–N concentration from the flow-path wells was in shallow ground water beneath the pasture (21.1 mg/L as N,

Table 6. Apparent recharge date of ground-water samples collected from monitoring wells, northeast Nebraska glacial till, 2003–04.

[CFCs, chlorofluorocarbons; SF^6, sulfur hexafluoride]

Well identifier (fig. 2)	U.S. Geological Survey site number	Sample date	Well type	Age-dating method	Apparent date of recharge
B–27	414931096321101	June 5, 2003	Glacial-till network	CFCs	mid- to late 1980s
B–28	415220096214801	April 28, 2003	Glacial-till network	CFCs	around 1990
CE–06	422947097142701	May 20, 2003	Glacial-till network	CFCs	1989 or older
CE–17	422802097031601	May 19, 2003	Glacial-till network	CFCs	mid-1970s or older
CO–13	414343096595801	June 4, 2003	Glacial-till network	CFCs	mid-1960s to mid-1970s
D–21	414401096531301	June 2, 2003	Glacial-till network	CFCs	late 1970s to early 1980s
D–22	413853096483801	June 4, 2003	Glacial-till network	CFCs	mid-1980s
D–24	413340096402701	May 15, 2003	Glacial-till network	CFCs	mid-1980s
DI–16	422011096595401	May 5, 2003	Glacial-till network	CFCs	late 1970s
FS1–2A	413341096325501	August 17, 2004	Flow path	SF6	late 1980s
FS1–3A	413348096324801	August 18, 2004	Flow path	SF6	late 1980s to early 1990s
FS1–4A	413350096324701	August 17, 2004	Flow path	SF6	early 1990s
K–05	422756097334901	May 20, 2003	Glacial-till network	CFCs	early to mid-1980s
P–02	421357097243201	May 27, 2003	Glacial-till network	CFCs	mid-1970s
P–03	422156097314301	May 21, 2003	Glacial-till network	CFCs	mid-1980s to early 1990s
P–04	422441097404601	May 20, 2003	Glacial-till network	CFCs	mid- to late 1980s
S–10	420425097101301	May 7, 2003	Glacial-till network	CFCs	mid- to late 1980s
S–11	414527097094101	June 3, 2003	Glacial-till network	CFCs	early to mid-1980s
S–R2	415458097142201	June 3, 2003	Reference	CFCs	mid-1980s
W–07	422031097043501	May 6, 2003	Glacial-till network	CFCs	mid-1980s
W–08	421829097112401	May 8, 2003	Glacial-till network	CFCs	mid- to late 1980s
W–14	420526096543901	May 1, 2003	Glacial-till network	CFCs	mid-1960s to 1970
W–15	421303097011601	May 7, 2003	Glacial-till network	CFCs	mid- to late 1970s
W–18	420922096514401	May 5, 2003	Glacial-till network	CFCs	mid- to late 1960s or older

well FS1–3A). Nitrate–N also was detected in ground water beneath the cropped field (13.0 mg/L as N, well FS1–1A) but was not detected in the shallow ground water on the edge of the cropped field (well FS1–2A) and in the riparian zone (well FS1–4A). Nitrate–N concentrations in May 2004 beneath the pasture and cropped field at the flow-path study site were larger than the median concentration in samples collected from the glacial-till network wells during the same time period in 2003 (table 7). The larger nitrate–N concentration in water from well FS1–3A during May 2004 may have resulted from the absence of the loess cap that would impede the downward movement of water. The loess cap is present at wells FS1–1A and FS1–2A. Concentrations generally were similar throughout the growing season with the exception of samples collected from well FS1–3A. In March, the nitrate–N concentration of the ground-water sample from well FS1–3A was less than the reporting level of 0.06 mg/L (undetected), whereas ground-water samples collected in May, August, and October ranged from 19.4 to 21.1 mg/L (table 8). Nitrate–N concentrations in water from wells FS1–1A and FS1–4A decreased slightly during the summer months (May and August).

Nitrate–N concentrations in two of the glacial-till network wells in the Maple Creek watershed stayed about the same throughout the growing season in 2004. Nitrate–N concentrations in well CO–13 (fig. 1) were always less than the

Table 7. Descriptive statistics for nitrogen and phosphorus compounds in ground-water samples, northeast Nebraska glacial till, 2003.

[Constituents are dissolved; USEPA, U.S. Environmental Protection Agency; N, nitrogen; mg/L, milligrams per liter; ND, not detected; MCL, Maximum Contaminant Level; LTHA, Lifetime Health Advisory, the concentration of a chemical in drinking water that is not expected to cause any adverse noncarcinogenic effects for a lifetime of exposure; --, no data or not calculated; P, phosphorus; E, estimated]

Constituent or property	Concentrations			Number of detections	Number of drinking-water exceedances	USEPA drinking-water standard/ type of standard[1]
	Minimum	Median	Maximum			
Glacial-till network wells (28 samples analyzed)						
Nitrite as N, in mg/L	ND	ND	0.017	3	0	1 / MCL
Nitrite plus nitrate as N (nitrate–N), in mg/L	ND	9.53	69.5	27	13	10 / MCL
Ammonia as N, in mg/L	ND	ND	.90	5	0	30 / LTHA
Ammonia plus organic nitrogen as N, in mg/L	ND	.14	1.3	18	--	--
Orthophosphate as P, in mg/L	ND	.06	.24	24	--	--
Reference wells (2 samples analyzed)						
Nitrite as N, in mg/L	ND	--	ND	0	0	1 / MCL
Nitrite plus nitrate as N (nitrate–N), in mg/L	1.71	--	8.96	2	0	10 / MCL
Ammonia as N, in mg/L	ND	--	ND	0	0	30 / LTHA
Ammonia plus organic nitrogen as N, in mg/L	ND	--	.21	1	--	--
Orthophosphate as P, in mg/L	.12	--	.36	2	--	--

[1] Drinking-water standards from U.S. Environmental Protection Agency (2004).

reporting level of 0.06 mg/L, and concentrations in well S–11 (fig. 5) were close to 4.0 mg/L. Well D–24 (fig. 5) had variable nitrate–N concentrations that were largest in the spring (38.9 mg/L as N on March 23, 2004) and declined throughout the growing season to less than one-half the original concentration (16.5 mg/L as N on October 13, 2004). The nitrate–N concentration in ground water collected from this well in May of the previous (2003) growing season as part of the glacial-till well network was 11.4 mg/L.

Orthophosphate as phosphorus (P) concentrations in ground-water samples collected in spring 2003 from the glacial-till well network ranged from undetected to 0.24 mg/L (table 7). Orthophosphate–P concentrations were larger in the two reference wells (0.12 and 0.36 mg/L) than in most of the other glacial-till network samples. A nitrate–N concentration larger than background levels and the detection of orthophosphate–P in reference wells might indicate that enrichment is a result of county and (or) region-wide application of these nutrients; the reference well with the larger nitrate–N concentration was located in a county that had larger amounts of nitrogen applied at the land surface (fig. 5). Other explanations likely include historical land use (grazing) or perhaps unreported fertilizer applications near these wells.

In the Maple Creek area in 2004, orthophosphate–P concentrations in shallow ground water were similar and consistent throughout the year beneath the corn field (well FS1–1A: mean=0.24 mg/L as P, standard deviation=0.01 mg/L as P) and the riparian area (well FS1–4A: mean=0.23 mg/L as P, standard deviation=0.05 mg/L as P) and were similar to the maximum orthophosphate–P concentration detected in the nearby glacial-till network well (well D–24, located in similar proximity to Maple Creek as well FS1–1A, about 6.5 mi upstream). Concentrations of orthophosphate–P in shallow ground water beneath the pasture (well FS1–3A: mean=0.45 mg/L as P, standard deviation=0.03 mg/L as P) were consistent throughout the year but at concentrations nearly twice as large as the maximum concentration detected in the glacial-till network wells in 2003. The shallow ground-water samples collected from the edge-of-field well FS1–2A in March and May had the largest concentrations of orthophosphate-P of any sample collected during the ACT study (0.86 and 0.87 mg/L as P), whereas concentrations in samples from that site collected in August and October 2004 were both less than the reporting level. The maximum orthophosphate-P concentration was 1.28 mg/L in water from well CO–13 (May 26, 2004).

Pesticides

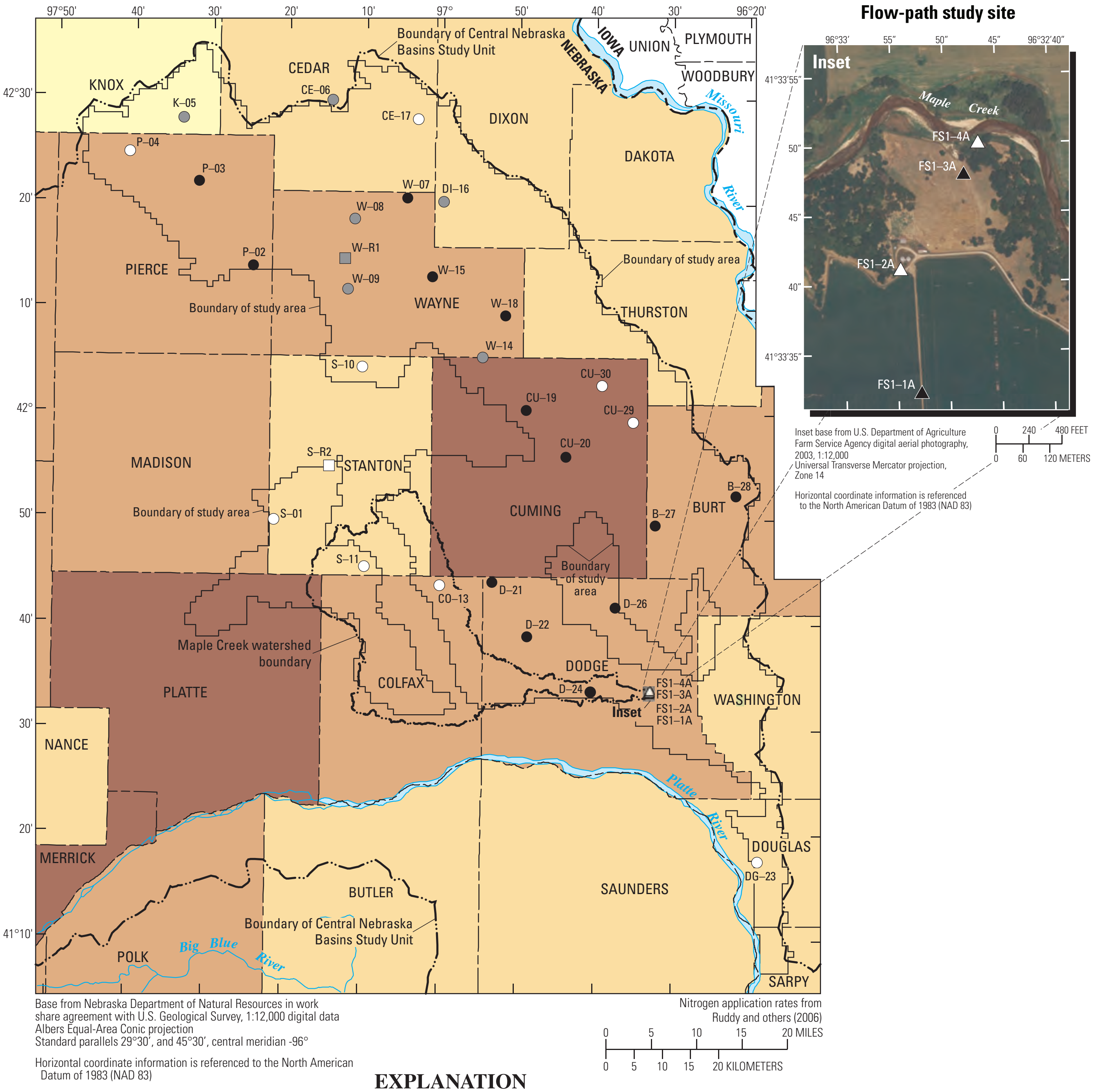
Pesticides can migrate to ground water as the original compound or break down into degradation products. Water samples collected in 2003 were analyzed for 90 pesticides and 17 pesticide degradates, and water samples collected in 2004 were analyzed for 43 pesticides and 39 pesticide degradates (Appendix 1) (Hitch and others, 2004, 2005).

Thirteen (46 percent) of the 28 samples collected in spring 2003 from wells in the glacial-till network had at least one detectable pesticide concentration (fig. 6). Pesticides detected were atrazine (triazine class) (five samples), bentazon (one sample), flumetsulam (sulfonanilide class) (one

Table 8. Concentrations of nitrogen and phosphorus compounds in ground-water samples from flow-path wells and selected glacial-till network wells, northeast Nebraska glacial till, Maple Creek watershed, 2004.

[Constituents are dissolved. Nitrate-N, nitrate as nitrogen; mg/L, milligrams per liter; N, nitrogen; P, phosphorus; ND, not detected; E, estimated; <, less than]

Well identifier (fig. 2)	Sample date	Nitrite (mg/L as N)	Nitrate-N (mg/L)	Ammonia (mg/L as N)	Orthophosphate (mg/L as P)
Flow-path wells					
FS1–1A	March 30	0.021	13.4	ND	0.232
	May 19	.011	13.0	ND	.248
	August 16	.014	11.1	ND	.231
	October 4	.009	11.7	ND	.243
FS1–2A	March 29	ND	ND	0.24	.858
	May 18	ND	ND	.28	.867
	August 17	.014	ND	.24	<.006
	October 7	ND	ND	.26	E.003
FS1–3A	March 31	ND	ND	ND	.408
	May 20	ND	21.1	ND	.448
	August 18	ND	19.4	ND	.476
	October 6	ND	19.9	ND	.476
FS1–4A	April 1	.014	.88	ND	.230
	May 24	E.004	ND	ND	.174
	August 17	.016	.55	ND	.243
	October 5	.030	.85	ND	.288
Glacial-till network wells					
D–24	March 23	ND	38.9	ND	.238
	May 25	ND	28.4	E.02	.249
	September 8	ND	20.2	ND	.241
	October 13	ND	16.5	E.03	.236
CO–13	March 25	ND	ND	.66	.94
	May 26	ND	ND	.58	1.28
	September 9	ND	ND	.71	.98
	October 12	.014	E.04	.87	.356
S–11	March 24	ND	4.01	ND	.042
	May 25	ND	3.86	ND	.042
	August 19	ND	3.87	ND	.040
	October 14	ND	3.95	ND	.043



Inset base from U.S. Department of Agriculture Farm Service Agency digital aerial photography, 2003, 1:12,000
Universal Transverse Mercator projection, Zone 14

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

Base from Nebraska Department of Natural Resources in work share agreement with U.S. Geological Survey, 1:12,000 digital data
Albers Equal-Area Conic projection
Standard parallels 29°30', and 45°30', central meridian -96°

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

Nitrogen application rates from Ruddy and others (2006)

EXPLANATION

Average nitrogen application rates from manure and fertilizer (1987–97), in pounds per acre of cropland per year

- 🟨 0–50
- 🟧 51–75
- 🟧 76–100
- 🟫 Greater than 100

Nitrate as nitrogen concentrations, in milligrams per liter

Glacial-till network well (spring 2003 sample)

- ○ Less than or equal to 4.00
- ● 4.01 to 10.0
- ● Greater than 10.0

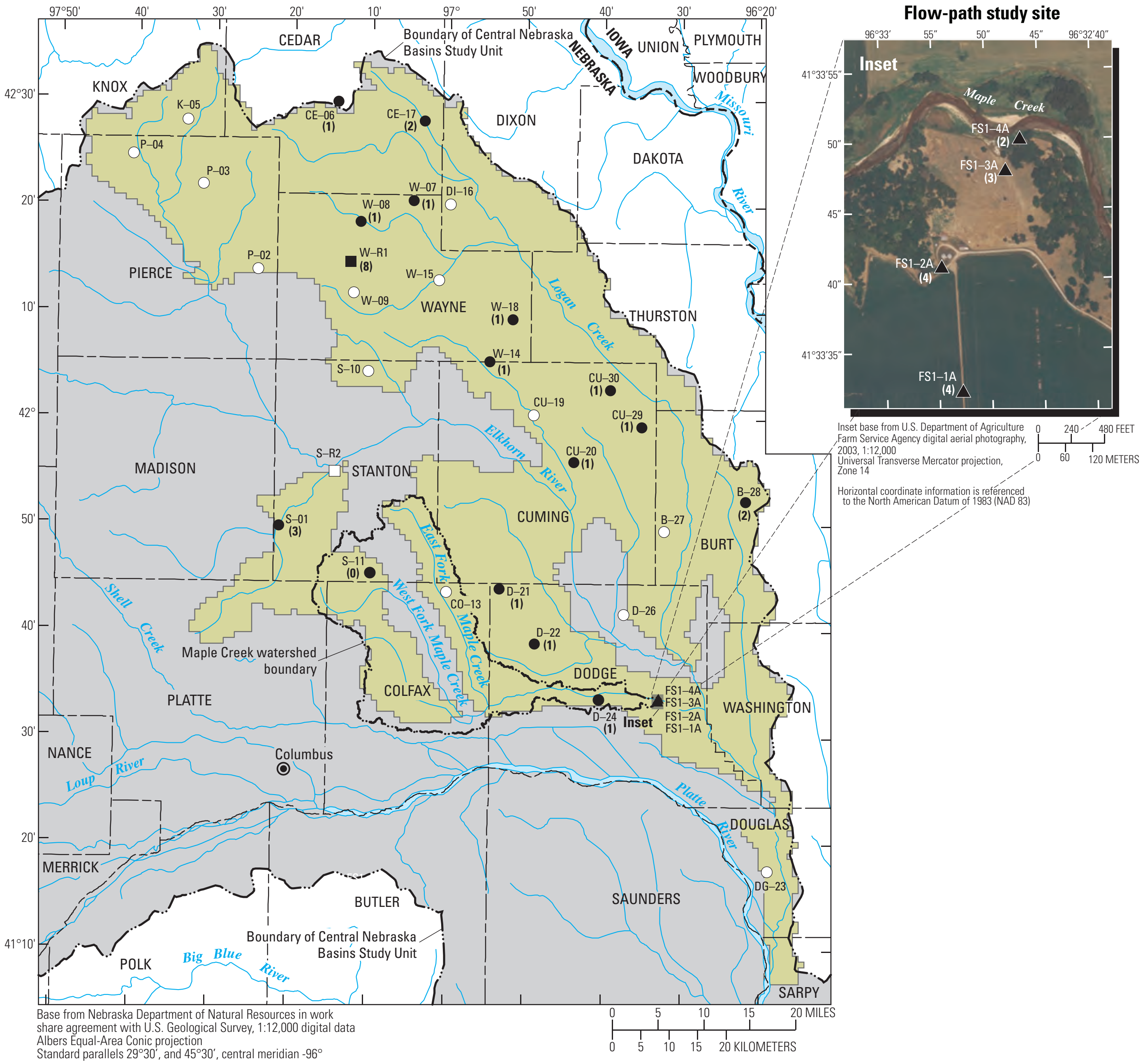
Reference well (spring 2003 sample)

- □ Less than or equal to 4.00
- ■ 4.01 to 10.0

Flow-path well (May 2004 sample)

- △ Less than or equal to 4.00
- ▲ 4.01 to 10.0
- ▲ Greater than 10.0

Figure 5. Distribution of average nitrogen application rates from manure and commercial fertilizer, by county, and nitrate as nitrogen concentrations in ground-water samples, northeast Nebraska glacial till, spring 2003 and May 2004.



Inset base from U.S. Department of Agriculture Farm Service Agency digital aerial photography, 2003, 1:12,000
Universal Transverse Mercator projection, Zone 14

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

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

EXPLANATION

🟩 Study area for agricultural chemicals in shallow ground water

⬜ Other areas of Central Nebraska Basins Study Unit

Glacial-till network well and identifier (spring 2003 sample)

B–27 ○ Pesticides or degradates not detected

CU–20 (1) ● Pesticides or degradates detected, with number of pesticide compounds detected in parentheses ( )

Reference well and identifier (spring 2003 sample)

S–R2 □ Pesticides or degradates not detected

W–R1 (8) ■ Pesticides or degradates detected, with number of pesticide compounds detected in parentheses ( )

Flow-path well and identifier (May 2004 sample)

FS1–3A (2) ▲ Pesticides or degradates detected, with number of pesticide compounds detected in parentheses ( )

Figure 6. Number of pesticide compounds detected in ground-water samples, northeast Nebraska glacial till, spring 2003 and May 2004.

sample), imazethapyr (imidazolinone class) (one sample), malathion (organothiophosphate acaricides or aliphatic organothiophosphate insecticides class) (one sample), and picloram (pyridine herbicides) (one sample). Pesticide degradates detected were compounds that can form from the breakdown of atrazine—deethylatrazine (five samples) and deethyldeisopropylatrazine (five samples). Deethylatrazine also is a degradate of propazine.

Atrazine and its degradation compounds were the most frequently detected pesticides in water samples from wells in the glacial-till well network, and atrazine was the second most frequently applied pesticide in the glacial-till area in 1997 (table 1). The median concentration of atrazine (estimated 0.004 µg/L) was equal to the median concentration of deethylatrazine (estimated 0.004 µg/L) and smaller than the median concentration of deethyldeisopropylatrazine (estimated 0.14 µg/L). About one-half of the samples containing degradation compounds of atrazine did not contain detectable concentrations of either atrazine or propazine. Thirty-six percent of the samples contained at least one of the atrazine or atrazine degradation compounds, similar to what was found in other agricultural areas across the Nation (Gilliom and others, 2006).

Ground-water samples collected between 1992 and 2001 as part of 52 studies across the Nation were evaluated to determine which human and natural factors (such as pesticide use, soil characteristics, hydrology, and climate) were related to atrazine detection frequencies. The result of this evaluation was a statistical model that estimated the frequency of pesticide detections in areas where pesticide concentrations had not been measured (Gilliom and others, 2006). In northeast Nebraska, the estimated frequency of atrazine detections as a percentage of shallow wells was greater than 75 percent. The actual frequency of atrazine detections in the glacial-till network was 18 percent (5 of 28 wells). If degradation products of atrazine are combined with atrazine detections, the detection frequency is 36 percent (10 of 28 wells). One reason the model did not accurately estimate the actual detection frequency in northeast Nebraska might be that the factors affecting pesticide detections in most areas of the country are not the same factors that affect pesticide detections in northeast Nebraska. The most important factors that explained variability in pesticide detections in the national model were the proportion of land with subsurface tile-drain systems and the average vertical permeability of soil. Another, less important, factor was atrazine use. These three factors explained 55 percent of the variability in atrazine detection frequencies in the areas where pesticide concentrations were measured between 1992 and 2001. The only factor tested that affected pesticide detections in the Nebraska glacial-till study area was the presence of a road ditch within 164 ft of the well, which is explained further in the section on “Factors Related to Occurrence of Agricultural Chemicals in Shallow Ground Water.”

Because the two reference wells were located away from cropland, it was expected that the two reference wells would have few detectable pesticide compounds. However, eight pesticide compounds (acetochlor, atrazine, deethylatrazine, desulfinylfipronil amide, diuron, fipronil sulfone, metolachlor, and prometon) were detected at well W–R1, more compounds than any other site. Possible explanations could be historical land use, unreported applications, or movement from upgradient applications.

Ground-water samples collected from the Maple Creek watershed in 2004 (four flow-path wells and three glacial-till network wells) were analyzed for pesticides in May and October (table 9). The only parent pesticide compound detected was atrazine in shallow ground water under the cropped field (well FS1–1A), adjacent to the cropped field (well FS1–2A), and in the riparian area (well FS1–4A). Pesticide degradates detected in water from the four flow-path wells were acetochlor ethanesulfonic acid (ESA), acetochlor oxanilic acid (OXA), alachlor ESA, deethylatrazine, metolachlor ESA, and metolachlor OXA. In general, concentrations of atrazine and its degradates decreased slightly from May to October 2004, whereas concentrations of acetochlor, alachlor, and metolachlor compounds increased slightly from May to October. Only pesticide degradates were detected in the three glacial-till network wells sampled in 2004. In May, alachlor ESA was detected in two wells, and metolachlor ESA was detected in one well. More pesticides were detected in October; deethylatrazine was detected in one well, alachlor ESA was detected in two wells, alachlor ESA second amide was detected in one well, and metolachlor ESA was detected in one well (table 9).

Pesticide concentrations in ground-water samples collected in 2003 and 2004 were small and did not exceed public drinking-water standards where established. Deethyldeisopropylatrazine, a pesticide degradate that does not have a public drinking-water standard, had the largest pesticide compound concentration in a ground-water sample (estimated 0.76 µg/L in water from well CE–06). The well with the largest number of pesticide detections in one sample was well W–R1, with eight different pesticide compounds detected (fig. 6).

The LRL can affect the detection frequency of pesticide compounds; analytes with smaller LRLs are likely to have greater detection frequencies. To remove the effect of variable LRLs, detection frequencies of pesticide compounds were compared using a common assessment level of 0.04 µg/L. In samples collected from wells in the glacial-till network in 2003, deethyldeisopropylatrazine was detected in five samples at concentrations greater than or equal to 0.04 µg/L (fig. 7). Diuron was detected in one of the reference wells. The pesticide compounds detected at greater than or equal to the 0.04-µg/L assessment level in flow-path samples in May 2004 were alachlor ESA (three samples) and metolachlor ESA (two samples) (table 9). In October, pesticide compounds detected in flow-path wells equal to or greater than 0.04 µg/L were acetochlor ESA (one sample), acetochlor OXA (one sample), alachlor ESA (three samples), and metolachlor ESA (two samples). In ground-water samples collected in May 2004 from the three glacial-till network wells in the Maple Creek watershed, alachlor ESA was detected in one well, and metolachlor ESA was detected in one well at concentrations greater

Table 9. Pesticide detections in ground-water samples collected in May and October 2004, northeast Nebraska glacial till, Maple Creek watershed.

[Constituents are dissolved; ESA, ethanesulfonic acid; OXA, oxanilic acid; SA, second amide; E, estimated; ND, not detected]

Well identifier (fig. 2)	Pesticide compound	Concentration in May 2004 (µg/L)	Concentration in October 2004 (µg/L)
Flow-path wells			
FS1–1A	Atrazine	0.037	0.028
	Deethylatrazine	E.031	E.021
	Alachlor ESA	.20	.26
	Metolachlor ESA	.20	.26
FS1–2A	Atrazine	.009	.008
	Deethylatrazine	E.014	E.013
	Alachlor ESA	.25	.34
	Metolachlor ESA	.16	.17
FS1–3A	Deethylatrazine	E.006	ND
	Alachlor ESA	.05	.06
	Metolachlor ESA	.03	.03
FS1–4A	Atrazine	ND	E.006
	Acetochlor ESA	ND	.07
	Acetochlor OXA	.02	.07
	Metolachlor OXA	.02	ND
Glacial-till network wells			
D–24	Alachlor ESA	.11	.13
	Deethylatrazine	ND	E.006
	Metolachlor ESA	.04	.06
CO–13	None detected		
S–11	Alachlor ESA	.03	.05
	Alachlor ESA SA	ND	.08

than or equal to the 0.04-µg/L assessment level. In October, alachlor ESA was detected in two wells, metolachlor ESA was detected in one well, and alachlor ESA second amide was detected in one well at concentrations greater than or equal to the 0.04-µg/L assessment level (table 9). Overall, the ESA degradates of alachlor and metolachlor accounted for 14 of the 17 pesticide compounds detected in 2004 at concentrations greater than or equal to the common assessment level of 0.04 µg/L.

The presence of pesticides in ground water collected near crop fields provides evidence that agricultural chemicals are moving downward and affect ground-water quality. The primary pesticide compounds detected were the parent compound or degradates of acetochlor, alachlor, atrazine, and metolachlor. Overall, pesticide degradates were more commonly detected and were detected at larger concentrations than parent compounds.

Occurrence of Chemicals in the Unsaturated Zone

Unsaturated-zone sediment samples were collected at 28 of the 30 glacial-till network and reference well sites between May and October 2002. Sediment cores were analyzed for texture and chemical constituents (nitrate–N, ammonia–N, and chloride) (Appendix 2). Nitrate–N and ammonia–N concentrations in sediment-core samples can indicate that nitrogen fertilizers are stored in the unsaturated zone and that nitrogen may move downward to ground water (Spalding and Kitchen, 1988). Nitrate–N was detected in unsaturated-zone sediment samples at concentrations ranging from 1.86 to 27.4 mg/kg, with a median of 4.04 mg/kg. Ammonia concentrations in sediment samples ranged from 0.84 to 17.8 mg/kg, with a median of 2.65 mg/kg. These concentrations were calculated by weight and, therefore, are not directly comparable to dissolved concentrations in water. However, data indicate that nitrogen in the forms of nitrate–N and ammonia–N is available in the unsaturated zone for transport to ground water. Nitrate–N and ammonia–N

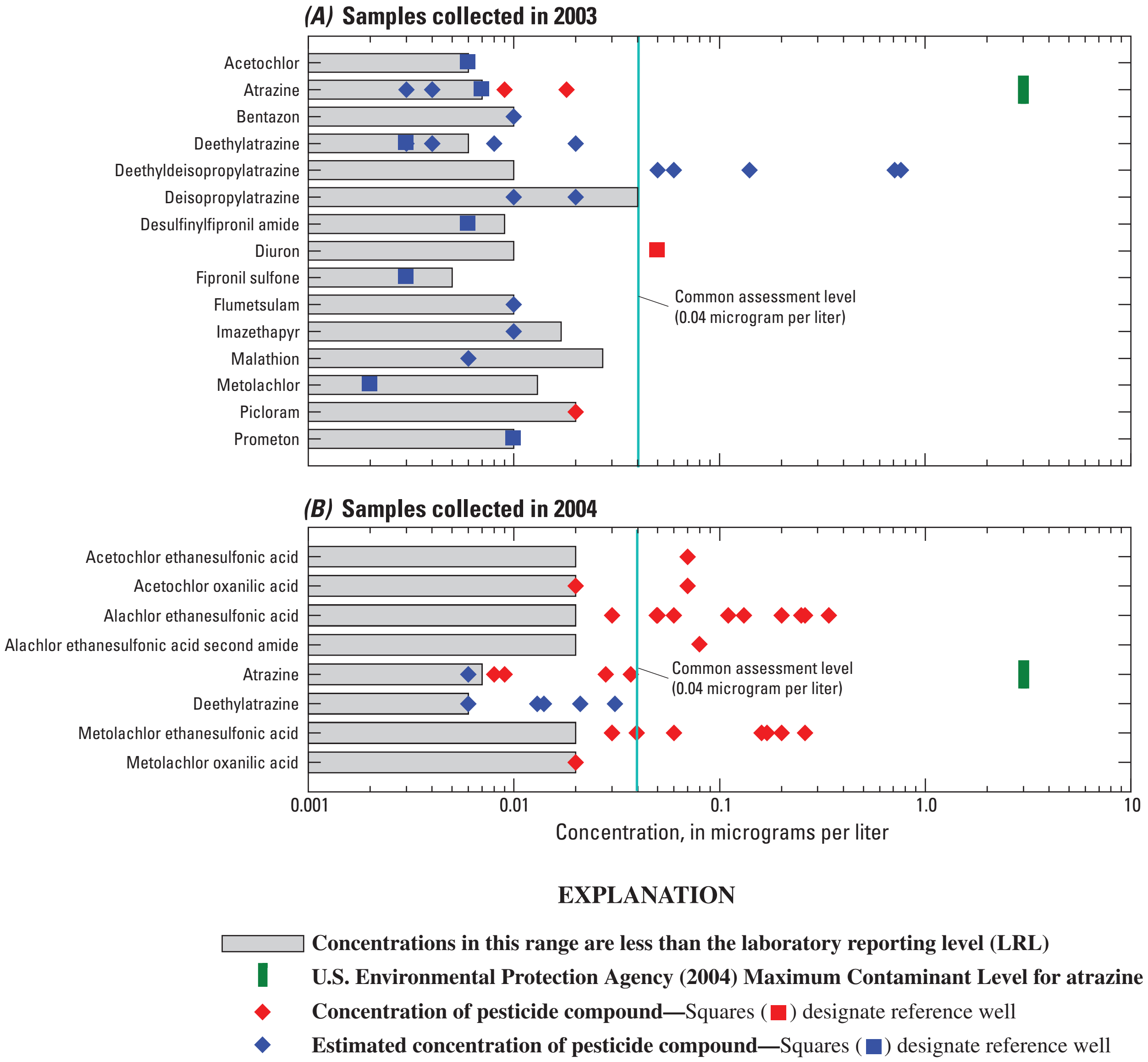


Figure 7. Concentrations of pesticide compounds in ground-water samples, northeast Nebraska glacial till, 2003–04.

concentrations in sediment samples were inversely correlated with sample depth (rho= -0.194, p=0.017 and rho= -0.306, p=0.004, respectively).

Nitrate–N concentrations were correlated with chloride concentrations (rho=0.303, p=<0.001). However, ammonia–N concentrations were not correlated with chloride (rho=0.022, p=0.833). Chloride is considered to be a conservative constituent that will accumulate in soils where evapotranspiration rates are large and recharge rates are small (Allison and others, 1985; Scanlon and Goldsmith, 1997; Scanlon and others, 2005; McMahon and others, 2006). Stored nitrate–N accompanied by chloride in the unsaturated zone can imply that the source of nitrate–N is, at least in part, naturally occurring salts that have accumulated as a result of evapotranspiration. However, this is not likely in this study area because its recharge rate is greater than the regions where this commonly occurs.

Factors Related to Occurrence of Agricultural Chemicals in Shallow Ground Water

Several factors were examined to determine their relation to the occurrence of agricultural chemicals in shallow ground water. Only samples collected from the 28 wells in the glacial-till network in 2003 were used as part of these analyses because random site-selection procedures were used for these wells. The variables considered for this analysis were water depth, aquifer-sediment and soil characteristics, land use, geologic unit, and well type. The residence time (amount of time since water has been isolated from contact with the atmosphere) of ground water typically is related to ground-water chemistry (McMahon and others, 2007). However, because of the study design, all ground-water samples had short residence times (less than 50 years) as determined by CFC and SF_6 results, and therefore, residence time could not be used as a variable to explain differences in ground-water quality.

Water Depth

Water levels were measured onsite at each well immediately before sample collection. Larger concentrations of agricultural chemicals typically are found in areas where ground water is closer to the land surface. In spring 2003, water levels in the study area ranged from 2.10 to 62.30 ft below land surface, with a median of 22.17 ft below land surface (table 2). No correlation was found between nitrate–N concentrations and depth to water using Spearman's rank correlation test (rho= -0.061, p= 0.751). The median depth to water in wells with no pesticide detections (22.23 ft; n=15) was not significantly different than the median depth to water in wells with pesticide detections (22.11 ft; n=13) using the Wilcoxon rank-sum statistical test (p= 0.928). One possible reason for the lack of relation with depth to water is that water levels in all of the wells were shallow (within 65 ft below the land surface) and may represent similar conditions. Pesticide detections in ground water at these sites could also be the result of recharge from other areas. Another possible reason for the lack of a relation could be that ground water was sampled during a time of the year when many of the pesticides that were analyzed in this study were not typically present in the shallow ground water; pesticides applied in spring 2003 may have not reached ground water at the time of sampling, and pesticides applied the previous year may have already degraded.

Aquifer-Sediment and Soil Characteristics

Aquifer-sediment (well borehole) and soil characteristics were measured at wells in the glacial-till network and compared to nitrate–N concentrations and pesticide detections in ground water from these wells. Sediment collected from the well boreholes indicated that most of the wells were bored through sediment that was predominantly (at least 70 percent) silt (Appendix 2). Only one glacial-till network well (well S–01, fig. 1) was completed in sediment that was less than 50 percent silt (Appendix 2). Mean characteristics of surficial soils within a 1,640-ft radius of the well, including sand content, silt content, clay content, bulk density, organic matter content, vertical permeability of soils, and horizontal permeability were determined from the 1994 State Soil Geographic (STATSGO) database (U.S. Department of Agriculture, 1994; Schwarz and Alexander, 1995; Wolock, 1997). Nitrate–N concentrations were not related to either aquifer sediment in the well borehole or soil characteristics (table 10). Additionally, a Wilcoxon rank-sum statistical test indicated that the occurrence of pesticides was not related to either aquifer sediment or soil characteristics (table 11).

Land Use

Land-use characteristics were documented in the vicinity of each well within 164- and 1,640-ft buffers. Land-use characteristics included the presence of water-collecting ditches, perennial streams, farm house, manure storage or pasture, irrigation wells, and irrigated cropland. Nitrate–N concentrations and pesticide detections were compared for well sites where these land-use characteristics were present or absent (tables 2 and 12). The percentage of various land uses such as cropland also was estimated within 1,640-ft of each well using aerial photography and onsite visual inspection. The only characteristic significantly related to nitrate–N concentrations was the presence or absence of a perennial stream within 1,640 ft of the well site. The median nitrate–N concentration at sites where a perennial stream was present was 1.96 mg/L, whereas the median nitrate–N concentration in samples collected from sites where a perennial stream was not present was 10.5 mg/L (p=0.053, table 12). In northeastern Nebraska, areas draining to streams often are steeper and therefore kept as pasture, woodland, or grassland rather than cropland. For comparison, at the flow-path wells, the average nitrate–N concentration in May 2004 was 7.1 mg/L at the wells within 1,640 ft of Maple Creek (wells FS1–2A, FS1–3A, and FS1–4A) and 13.0 mg/L at the well farther than 1,640 ft away from Maple Creek (well FS1–1A).

The only characteristic significantly related to the presence of pesticide compounds was the presence or absence of a road ditch within 164 ft of the well site. Sixty-three percent of the samples collected from the glacial-till network wells located near a road ditch had at least one pesticide compound detected, and 11 percent of the samples collected from the wells not located near a road ditch had at least one detectable pesticide compound (p=0.016, table 12). For comparison, all of the flow-path wells were more than 164 ft from a road ditch, with all four wells having at least one pesticide detected in May 2004. Larger concentrations of agricultural chemicals near road ditches are expected because road ditches provide a setting that promotes focused recharge. Runoff from precipitation and (or) applied irrigation water can carry chemicals to road ditches where the water will collect and eventually infiltrate downward to the saturated zone.

Geologic Unit

Differences in geologic units also may explain differences in nitrate–N concentrations and pesticide detections. Wells in the glacial-till network were completed in five geologic units—Holocene-age alluvium and Pleistocene-age loess, sand and gravel, glacial till, and undifferentiated deposits (table 13). The median nitrate–N concentration was largest in ground-water samples collected from the Pleistocene-age loess. Loess deposits in central and southwest Nebraska have been known to contain naturally occurring nitrogen (Boyce and others, 1976) and if the loess in northeast Nebraska is similar, the unit

Table 10. Relations between nitrate as nitrogen (nitrate–N) concentrations in ground-water samples collected from glacial-till network wells and well-borehole and surficial soil characteristics, northeast Nebraska glacial till, 2003.

Variable (characteristics within 1,640 feet of borehole)	Range of values	Spearman's rho	p-value[1]
Percentage of sand and gravel in well borehole[2]	10.8–46.1	-0.023	0.909
Percentage of silt in well borehole[2]	47.9–79.5	-.017	.929
Percentage of clay in well borehole[2]	6.0–9.8	.157	.435
Average sand content of soils, in percent[3]	3.94–22.87	.118	.542
Average silt content of soils, in percent[3]	48.58–71.73	.058	.765
Average clay content of soils, in percent[3]	23.38–32.26	.100	.606
Average bulk density of soils, in grams per cubic centimeter[3]	1.27–1.48	–.204	.289
Average organic matter content, in percent by weight[3]	0.85–3.17	.133	.492
Average vertical permeability of soils, in inches per hour[3]	0.79–1.46	–.097	.612
Average horizontal permeability of soils, in inches per hour[3]	0.89–2.50	–.142	.458

[1] p-values measure the probability that there is not a real correlation between two variables. Variables were considered correlated with nitrate–N if p-value was less than 0.10.

[2] Source: Well-borehole sediment-core samples.

[3] Source: 1994 STATSGO database (U.S. Department of Agriculture, 1994; Schwarz and Alexander, 1995; Wolock, 1997).

Table 11. Pesticide compound detections in ground-water samples collected from glacial-till network wells related to well-borehole and surficial soil characteristics, northeast Nebraska glacial till, 2003.

Variable (characteristics within 1,640 feet of borehole)	Median value near wells with no pesticides detected	Median value near wells with one or more pesticides detected	p-value (Wilcoxon rank-sum test)[1]
Percentage of sand and gravel in well borehole[2]	19.48	17.59	0.643
Percentage of silt in well borehole[2]	73.19	72.81	.940
Percentage of clay in well borehole[2]	7.95	9.07	.643
Average sand content of soils, in percent[3]	5.19	5.22	.853
Average silt content of soils, in percent[3]	66.93	66.93	.890
Average clay content of soils, in percent[3]	26.51	27.55	.404
Average bulk density of soils, in grams per cubic centimeter[3]	1.33	1.32	.331
Average organic matter content, in percent by weight[3]	1.35	1.56	.308
Average vertical permeability of soils, in inches per hour[3]	1.27	1.23	.308
Average horizontal permeability of soils, in inches per hour[3]	1.28	1.23	.211

[1] p-values measure the probability that there is not a real difference between two groups. Groups were considered different if p-value was less than 0.10.

[2] Source: Well-borehole sediment-core samples.

[3] Source: 1994 STATSGO database (U.S. Department of Agriculture, 1994; Schwarz and Alexander, 1995; Wolock, 1997).

Table 12. Distribution of median nitrate as nitrogen concentrations and pesticide compound detections in glacial-till network wells, by land-use feature, northeast Nebraska glacial till, 2003.

[Nitrate–N, nitrate as nitrogen; mg/L, milligrams per liter; >, greater than]

Land-use feature	Number of sites where feature is present (out of 28)	Median nitrate–N concentration at sites where feature is present (mg/L)	Median nitrate–N concentration at sites where feature is absent (mg/L)	p-value (Wilcoxon rank-sum test)[1]	Percentage of sites that have a pesticide detected where feature is present	Percentage of sites that have a pesticide detected where feature is absent	p-value (Fisher's exact test)[2]
Water-collecting road ditch within 164 feet	19	9.46	11.3	0.357	63	11	0.016
Perennial stream within 1,640 feet	5	1.96	10.5	.053	20	52	.333
Farmhouse within 164 feet	3	17.2	9.46	.391	33	48	>.5
Manure storage or pasture within 164 feet	4	12.6	9.53	>.5	0	54	.102
Irrigation well within 1,640 feet	6	15.85	7.81	.126	33	50	>.5
Irrigated cropland within 1,640 feet	8	10.5	9.18	>.5	25	55	.221

[1] Wilcoxon (1945).

[2] Agresti (1990).

Table 13. Distribution of nitrate as nitrogen concentrations and pesticide compound detections in ground-water samples collected from glacial-till network wells, by geologic unit, northeast Nebraska glacial till, 2003.

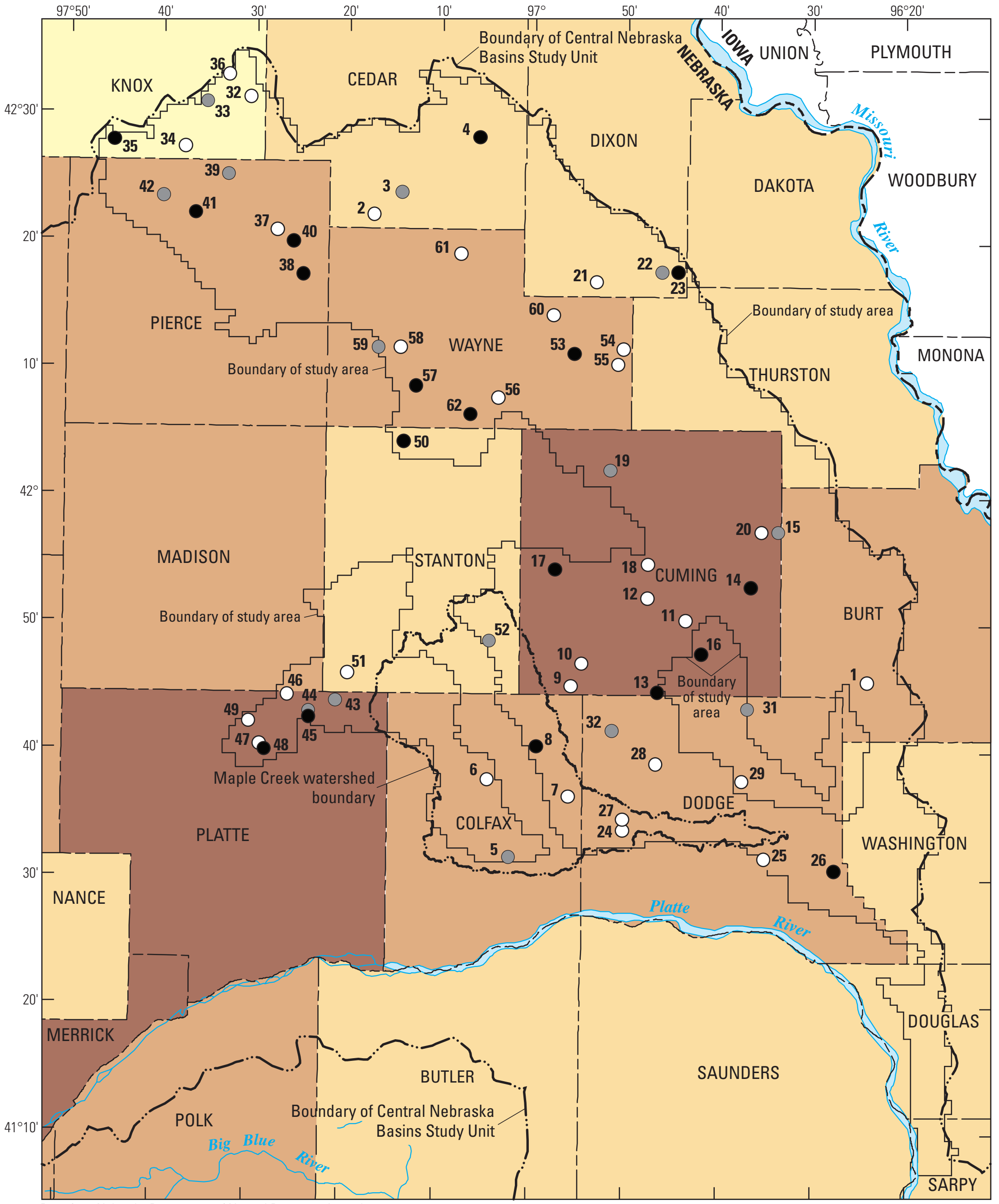
[nitrate–N, nitrate as nitrogen; mg/L, milligrams per liter; ND, not detected]

Geologic system	Geologic series	Geologic unit	Number of samples	Minimum nitrate–N concentration (mg/L)	Median nitrate–N concentration (mg/L)	Maximum nitrate–N concentration (mg/L)	Percentage of samples with at least one pesticide compound detected
Quaternary	Holocene	alluvium	6	ND	6.14	29.5	17
	Pleistocene	loess	10	1.14	19.3	69.5	60
		sand and gravel	3	1.07	4.91	6.35	67
		glacial till	6	.91	2.51	28.9	33
		undifferentiated deposits	3	8.9	9.6	15.1	67

may be contributing to nitrate–N concentrations in ground water in this unit. In addition, 60 percent of the ground-water samples collected from the loess also had at least one pesticide detected, indicating that agricultural chemicals are present in the unit and are very likely a contributing factor to the elevated nitrate–N concentrations. Samples collected from Pleistocene-age sand and gravel and undifferentiated deposits had the highest percentages of samples with at least one detectable pesticide compound. Statistical tests were not performed because the number of water samples collected from each geologic unit was small.

Well Type

Nitrate–N and pesticide concentrations in the 28 glacial-till network samples collected in 2003 were compared with water samples collected by the Nebraska Department of Health and Human Services in 1994 and 1995 from 62 rural domestic wells in the Lower Elkhorn Natural Resources District (fig. 8, Appendix 3) (University of Nebraska, 2000). Samples collected from domestic wells typically draw water from a range of depths across the aquifer and provide a good indication of the variability of water quality with depth. Thus, samples from domestic wells provide an evaluation of the overall water-quality conditions within the aquifer. Alternatively, because samples collected from water-table monitoring wells are closest to the source of agricultural chemicals



Base from Nebraska Department of Natural Resources in work share agreement with U.S. Geological Survey, 1:12,000 digital data
Albers Equal-Area Conic projection
Standard parallels 29°30', and 45°30', central meridian -96°

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

Nitrogen application rates from Ruddy and others (2006)
Nitrate-N concentrations from University of Nebraska (2000)

0 5 10 15 20 MILES
0 5 10 15 20 KILOMETERS

EXPLANATION

Average nitrogen application rates from manure and fertilizer (1987–97), in pounds per acre of cropland per year

- ▨ 26–50
- ▨ 51–75
- ▨ 76–100
- ▨ Greater than 100

Nitrate as nitrogen (nitrate-N) concentration, in milligrams per liter

- ○ Less than or equal to 4.00
- ● 4.01 to 10.0
- ● Greater than 10.0

5● **Domestic well and map number**—Data presented in Appendix 3

Figure 8. Nitrate as nitrogen concentrations in ground-water samples collected from domestic wells, northeast Nebraska, 1994–95.

that originate from above the aquifer, they are more likely to have the largest concentrations of those constituents. Depths of these 62 domestic wells had a wider range (20 to 330 ft below land surface, Appendix 3) and deeper median depth (120 ft below land surface) than the wells in the glacial-till network (15 to 73 ft; median depth 33.4 ft; table 2). The median nitrate–N concentration in water collected from wells in the glacial-till network in 2003 (9.53 mg/L, table 7) was significantly larger (p=0.069) than the median concentration in water collected from domestic wells in 1994 and 1995 (4.12 mg/L, Appendix 3).

Domestic well samples were analyzed for 12 pesticides—alachlor, atrazine, butylate, chlorpyrifos, cyanazine, ethyl parathion, fonofos, methyl parathion, metolachlor, metribuzin, terbufos, and trifluralin (Appendix 3). Except for ethyl parathion, all of these compounds also were analyzed in the 2003 samples from the glacial-till network wells and were used for comparison. Because the LRL can affect the detection frequency of pesticide compounds, a common LRL was used for each pesticide compound. The LRLs of the pesticides analyzed in domestic-well samples were larger (0.05 to 2.5 µg/L) than the LRLs of the same pesticides analyzed in glacial-till network samples (0.003 to 0.02 µg/L). Therefore, if the pesticide concentration in a glacial-till network sample was less than the domestic well LRL for that pesticide, it was not considered to be a detection for comparison purposes. Using this method of comparison, one domestic-well sample had detectable concentrations of one pesticide (atrazine), and none of the glacial-till network samples had detectable concentrations of any of the 11 pesticides compared. Water-quality comparisons by well type should be considered with caution because the amounts of nitrogen (Ruddy and others, 2006) and pesticides (Nebraska Agricultural Statistics Service, 2005) used in the study area have changed between 1994–95 and 2003–04, and these comparisons, therefore, could be skewed.

Summary

Because agricultural chemicals applied at the land surface are more likely to be observed in the shallowest part of an aquifer, shallow ground-water samples were collected and analyzed in 2003 and 2004 from 34 wells in the glaciated area of northeast Nebraska. Land use in this area was 97 percent agriculture, predominately corn and soybeans. Ground-water age dating indicated that the water in the samples from these shallow wells had recharged less than 50 years ago.

Analytical results indicated that the agricultural chemicals are present in recently recharged ground water. Nitrate–N concentrations indicated that human activity has affected approximately two-thirds of the wells near corn and (or) soybean fields. Nitrate–N concentrations in samples collected in spring 2003 from the 28 glacial-till network wells ranged from undetected to 69.5 mg/L, with a median of 9.53 mg/L. In May 2004, the largest nitrate–N concentration from the flowpath wells was in shallow ground water beneath the pasture (21.1 mg/L as N, well FS1–3A). Nitrate–N also was detected in ground water beneath the cropped field (13.0 mg/L as N, well FS1–1A) but was not detected in the shallow ground water on the edge of the cropped field (well FS1–2A) and in the riparian zone (well FS1–4A).

The principal pesticide compounds that were detected in samples collected from the 34 wells reflect the most-used pesticides in the area and include parent or degradate compounds of acetochlor, alachlor, atrazine, and metolachlor. Overall, pesticide concentrations in ground-water samples collected in 2003 and 2004 were small and did not exceed public drinking-water standards where established. Deethyldeisopropylatrazine, a pesticide degradate with no public drinking-water standard, was the pesticide compound with the largest concentration (estimated 0.76 µg/L).

Unsaturated-zone soil cores indicated that nitrogen in the forms of nitrate–N and ammonia–N was available in the unsaturated zone for transport to ground water. Additionally, the concentrations of nitrate–N and ammonia–N in these soil cores were inversely correlated to depth, and nitrate–N concentrations were correlated to chloride concentrations. For ground-water samples, the presence of a perennial stream within 1,640 ft of the well was correlated to smaller nitrate–N concentrations, and the presence of a road ditch within 164 ft of the well was correlated to the presence of detectable pesticides. All other variables tested showed no significant correlations to nitrate–N concentrations or pesticide detections.

Nitrate-N was the principal agricultural contaminant found in the shallow ground water and unsaturated zone beneath northeast Nebraska glacial till, particularly at concentrations that may be of concern to resource managers or planners. The median concentration in shallow ground water was not far below the drinking-water MCL, and the presence of elevated nitrate concentrations in ground water and unsaturated zone solids greater than concentrations present in the aquifer presently used for supplying domestic drinking water could have implications for attentive monitoring of the fate of these contaminants in the ground-water system of northeast Nebraska.

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Appendixes

Appendix 1. Pesticides analyzed in ground-water samples collected from northeast Nebraska glacial till, 2003–04.

[USGS, U.S. Geological Survey; CAS, Chemical Abstracts Service; USEPA, U.S. Environmental Protection Agency; µg/L, micrograms per liter; MCL, Maximum Contaminant Level; ESA, ethanesulfonic acid; OXA, oxanilic acid; SAA, sulfynil acetic acid; ESA SA, ethanesulfonic acid second amide; LTHA, Lifetime Health Advisory; --, not determined or not applicable]

Pesticide name	USGS parameter code	CAS number	Sample year	Highest laboratory reporting level (µg/L)	Mean field-matrix spike recovery (percent)	Pesticide type	USEPA drinking-water standard (µg/L) / type of standard[1]
1-Naphthol	49295	90–15–3	2004	0.09	--	degradate	--
2-Chloro-2,6-diethylacetanilide	61618	6967–29–9	2004	.005	--	degradate	--
2-Ethyl-6-methylaniline	61620	24549–06–2	2004	.004	--	degradate	--
2-Hydroxyatrazine (OIET)[2]	50355	2163–68–0	2003	.008	--	degradate	--
2,4-D	39732	94–75–7	2003	.02	138.1	herbicide	70 / MCL
2,4-DB[2]	38746	94–82–6	2003	.02	74.8	herbicide	--
2,4-D methyl ester	50470	1928–38–7	2003	.009	73.3	herbicide	--
2,6-Diethylaniline	82660	579–66–8	2003, 2004	.006	103.1	degradate	--
3-Hydroxycarbofuran	49308	16655–82–6	2003	.006	83.9	degradate	--
3-Ketocarbofuran[2]	50295	16709–30–1	2003	1.5	0.0	degradate	--
3,4-Dichloroaniline	61625	95–76–1	2004	.004	--	degradate	--
4-Chloro-2-methylphenol	61633	1570–64–5	2004	.006	--	degradate	--
Acetochlor	49260	34256–82–1	2003, 2004	.006	113.5	herbicide	--
Acetochlor ESA	61029	--	2004	.02	--	degradate	--
Acetochlor OXA	61030	--	2004	.02	--	degradate	--
Acetochlor SAA	62847	--	2004	.02	--	degradate	--
Acetochlor / metolachlor ESA SA	62850	--	2004	.02	--	degradate	--
Acifluorfen	49315	50594–66–6	2003	.007	96.0	herbicide	--
Alachlor	46342	15972–60–8	2003, 2004	.005	106.9	herbicide	2 / MCL
Alachlor ESA	50009	--	2004	.02	--	degradate	--
Alachlor ESA SA	62849	--	2004	.02	--	degradate	--
Alachlor OXA	61031	--	2004	.02	--	degradate	--
Alachlor SAA	62848	140939–16–8	2004	.02	--	degradate	--
Aldicarb[2]	49312	116–06–3	2003	.04	7.5	insecticide	3 / MCL
Aldicarb sulfone[2]	49313	1646–88–4	2003	.02	59.9	degradate	3 / MCL
Aldicarb sulfoxide[2]	49314	1646–87–3	2003	.008	56.7	degradate	4 / MCL
Alpha-HCH	34253	319–84–6	2003	.005	104.7	insecticide / degradate	--
Atrazine	39632	1912–24–9	2003, 2004	.007	107.9	herbicide	3 / MCL
Azinphos-methyl[2]	82686	86–50–0	2003, 2004	.05	75.4	insecticide	--
Azinphos-methyl, oxygen analog	61635	961–22–8	2004	.02	--	degradate	--

Appendix 1. Pesticides analyzed in ground-water samples collected from northeast Nebraska glacial till, 2003–04.—Continued

[USGS, U.S. Geological Survey; CAS, Chemical Abstracts Service; USEPA, U.S. Environmental Protection Agency; µg/L, micrograms per liter; MCL, Maximum Contaminant Level; ESA, ethanesulfonic acid; OXA, oxanilic acid; SAA, sulfynil acetic acid; ESA SA, ethanesulfonic acid second amide; LTHA, Lifetime Health Advisory; --, not determined or not applicable]

Pesticide name	USGS parameter code	CAS number	Sample year	Highest laboratory reporting level (µg/L)	Mean field-matrix spike recovery (percent)	Pesticide type	USEPA drinking-water standard (µg/L) / type of standard[1]
Bendiocarb	50299	22781–23–3	2003	0.03	75.9	insecticide	--
Benfluralin	82673	1861–40–1	2003, 2004	.01	81.8	herbicide	--
Benomyl	50300	17804–35–2	2003	.004	54.5	fungicide	--
Bensulfuron	61693	83055–99–6	2003	.02	116.7	herbicide	--
Bentazon[2]	38711	25057–89–0	2003	.01	53.8	herbicide	200 / LTHA
Bromacil[2]	04029	314–40–9	2003	.03	68.7	herbicide	90 / LTHA
Bromoxynil[2]	49311	1689–84–5	2003	.02	83.2	herbicide	--
Butylate	04028	2008–41–5	2003	.004	105.2	herbicide	400 / LTHA
Carbaryl[2]	82680	63–25–2	2003, 2004	.041	98.0	insecticide	700 / LTHA
Carbofuran[2]	82674	1563–66–2	2003	.02	108.1	insecticide	40 / MCL
Chloramben methyl ester[2]	61188	7286–84–2	2003	.02	74.1	herbicide	--
Chlorimuron	50306	90982–32–4	2003	.01	90.4	herbicide	--
Chlorothalonil[2]	49306	1897–45–6	2003	.04	9.4	fungicide	--
Chlorpyrifos	38933	2921–88–2	2003, 2004	.005	91.6	insecticide	20 / LTHA
Chlorpyrifos, oxygen analog	61636	5598–15–2	2004	.06	--	fungicide	--
cis-Permethrin	82687	54774–45–7	2003, 2004	.006	62.0	insecticide	--
Clopyralid	49305	1702–17–6	2003	.01	92.6	herbicide	--
Cyanazine	04041	21725–46–2	2003	.018	118.4	herbicide	1 / LTHA
Cycloate[2]	04031	1134–23–2	2003	.01	72.5	herbicide	--
Cyfluthrin	61585	68359–37–5	2004	.008	--	insecticide	--
Cypermethrin	61586	52315–07–8	2004	.009	--	insecticide	--
Dacthal monoacid	49304	887–54–7	2003	.01	116.5	degradate	--
DCPA	82682	1861–32–1	2003, 2004	.003	104.8	herbicide	70 / LTHA
Deethylatrazine (CIAT)[2]	04040	6190–65–4	2003, 2004	.006	65.7	degradate	--
Deethyldeisopropylatrazine(CAAT)[2]	04039	3397–62–4	2003	.04	--	degradate	--
Deisopropylatrazine (CEAT)[2]	04038	1007–28–9	2003	.04	53.3	degradate	--
Desulfinylfipronil	62170	--	2003, 2004	.012	--	degradate	--
Desulfinylfipronil amide	62169	--	2003, 2004	.029	--	degradate	--
Diazinon	39572	333–41–5	2003, 2004	.005	103.7	insecticide	0.6 / LTHA
Diazinon, oxygen analog	61638	962–58–3	2004	.01	--	degradate	--

Appendix 1. Pesticides analyzed in ground-water samples collected from northeast Nebraska glacial till, 2003–04.—Continued

[USGS, U.S. Geological Survey; CAS, Chemical Abstracts Service; USEPA, U.S. Environmental Protection Agency; µg/L, micrograms per liter; MCL, Maximum Contaminant Level; ESA, ethanesulfonic acid; OXA, oxanilic acid; SAA, sulfynil acetic acid; ESA SA, ethanesulfonic acid second amide; LTHA, Lifetime Health Advisory; --, not determined or not applicable]

Pesticide name	USGS parameter code	CAS number	Sample year	Highest laboratory reporting level (µg/L)	Mean field-matrix spike recovery (percent)	Pesticide type	USEPA drinking-water standard (µg/L) / type of standard[1]
Dicamba	38442	1918–00–9	2003	0.01	90.9	herbicide	--
Dichlorprop	49302	120–36–5	2003	.01	94.6	herbicide/ insecticide/ fumigant	--
Dichlorvos	38775	62–73–7	2004	.01	--	degradate	--
Dicrotophos	38454	141–66–2	2004	.08	--	insecticide	--
Dieldrin	39381	60–57–1	2003, 2004	.009	83.4	insecticide	--
Dimethenamid	61588	87674–68–8	2004	.02	--	herbicide	--
Dimethenamid ESA	61951	--	2004	.02	--	degradate	--
Dimethanamid OXA	62482	--	2004	.02	--	degradate	--
Dimethoate	82662	60–51–5	2004	.006	--	insecticide	--
Dinoseb	49301	88–85–7	2003	.01	94.4	herbicide	7 / MCL
Diphenamid	04033	957–51–7	2003	.03	79.9	herbicide	200 / MCL
Disulfoton	82677	298–04–4	2003	.02	35.3	insecticide	0.3 / LTHA
Diuron	49300	330–54–1	2003	.01	105.8	herbicide	10 / LTHA
EPTC	82668	759–94–4	2003	.01	88.9	herbicide	--
Ethalfluralin	82663	55283–68–6	2003	.009	94.4	herbicide	--
Ethion	82346	563–12–2	2004	.004	--	insecticide	--
Ethion monoxon	61644	17356–42–2	2004	.03	--	degradate	--
Ethoprop	82672	13194–48–4	2003	.005	81.5	insecticide	--
Fenamiphos	61591	22224–92–6	2004	.03	--	nematocide	2 / LTHA
Fenamiphos sulfone	61645	31972–44–8	2004	.008	--	degradate	--
Fenamiphos sulfoxide	61646	31972–43–7	2004	.03	--	degradate	--
Fenuron	49297	101–42–8	2003	.03	61.2	herbicide	--
Fipronil	62166	120068–37–3	2003, 2004	.016	--	insecticide	--
Fipronil sulfide	62167	120067–83–6	2003, 2004	.013	--	degradate	--
Fipronil sulfone	62168	120068–36–2	2003, 2004	.024	--	degradate	--
Flufenacet	62481	142459–58–3	2004	.02	--	herbicide	--
Flufenacet ESA	61952	--	2004	.02	--	degradate	--

Appendix 1. Pesticides analyzed in ground-water samples collected from northeast Nebraska glacial till, 2003–04.—Continued

[USGS, U.S. Geological Survey; CAS, Chemical Abstracts Service; USEPA, U.S. Environmental Protection Agency; µg/L, micrograms per liter; MCL, Maximum Contaminant Level; ESA, ethanesulfonic acid; OXA, oxanilic acid; SAA, sulfynil acetic acid; ESA SA, ethanesulfonic acid second amide; LTHA, Lifetime Health Advisory; --, not determined or not applicable]

Pesticide name	USGS parameter code	CAS number	Sample year	Highest laboratory reporting level (µg/L)	Mean field-matrix spike recovery (percent)	Pesticide type	USEPA drinking-water standard (µg/L) / type of standard[1]
Flufenacet OXA	62483	--	2004	0.02	--	degradate	--
Flumetsulam[2]	61694	98967–40–9	2003	.01	119.9	herbicide	--
Fluometuron	38811	2164–17–2	2003	.03	89.0	herbicide	90 / LTHA
Fonofos	04095	944–22–9	2003, 2004	.003	101.5	insecticide	10 / LTHA
Fonofos, oxygen analog	61649	--	2004	.002	--	degradate	--
Hexazinone	04025	51235–04–2	2004	.013	--	herbicide	400 / LTHA
Imazaquin[2]	50356	81335–37–7	2003	.02	111.3	herbicide	--
Imazethapyr[2]	50407	81335–77–5	2003	.02	120.0	herbicide	--
Imidacloprid	61695	138261–41–3	2003	.007	108.2	insecticide	--
Iprodione	61593	36734–19–7	2004	1	--	fungicide	--
Isofenphos	61594	25311–71–1	2004	.003	--	insecticide	--
Lindane	39341	58–89–9	2003	.004	103.7	insecticide	0.2 / MCL
Linuron	38478	330–55–2	2003	.01	98.1	herbicide	--
Malaoxon	61652	1634–78–2	2004	.008	--	degradate	--
Malathion	39532	121–75–5	2003, 2004	.027	91.5	insecticide	100 / LTHA
MCPA	38482	94–74–6	2003	.02	93.1	herbicide	4 / LTHA
MCPB[2]	38487	94–81–5	2003	.01	110.6	herbicide	--
Metalaxyl	50359	57837–19–1	2003	.02	76.2	fungicide	--
Metalaxyl	61596	57837–19–1	2004	.005	--	fungicide	--
Methidathion	61598	950–37–8	2004	.006	--	insecticide	--
Methiocarb[2]	38501	2032–65–7	2003	.008	91.2	insecticide	--
Methomyl[2]	49296	16752–77–5	2003	.004	77.2	insecticide	200 / LTHA
Methyl paraoxon	61664	950–35–6	2004	.03	--	degradate	--
Methyl parathion	82667	298–00–0	2003, 2004	.015	100.0	insecticide	2 / LTHA
Metolachlor	39415	51218–45–2	2003, 2004	.013	103.0	herbicide	100 / LTHA
Metolachlor ESA	61043	--	2004	.02	--	degradate	--
Metolachlor OXA	61044	--	2004	.02	--	degradate	--
Metribuzin	82630	21087–64–9	2003, 2004	.006	102.4	herbicide	200 / LTHA
Metsulfuron[2]	61697	74223–64–6	2003	.03	33.9	herbicide	--
Molinate	82671	2212–67–1	2003	.003	89.9	herbicide	--

Appendix 1. Pesticides analyzed in ground-water samples collected from northeast Nebraska glacial till, 2003–04.—Continued

[USGS, U.S. Geological Survey; CAS, Chemical Abstracts Service; USEPA, U.S. Environmental Protection Agency; µg/L, micrograms per liter; MCL, Maximum Contaminant Level; ESA, ethanesulfonic acid; OXA, oxanilic acid; SAA, sulfynil acetic acid; ESA SA, ethanesulfonic acid second amide; LTHA, Lifetime Health Advisory; --, not determined or not applicable]

Pesticide name	USGS parameter code	CAS number	Sample year	Highest laboratory reporting level (µg/L)	Mean field-matrix spike recovery (percent)	Pesticide type	USEPA drinking-water standard (µg/L) / type of standard[1]
Myclobutanil	61599	88671–89–0	2004	0.008	--	fungicide	--
3-(4-Chlorophenyl)-1-methyl urea	61692	5352–88–5	2003	.02	77.4	degradate	--
Napropamide	82684	15299–99–7	2003	.007	72.3	herbicide	--
Neburon	49294	555–37–3	2003	.01	98.1	herbicide	--
Nicosulfuron[2]	50364	111991–09–4	2003	.01	147.0	herbicide	--
Norflurazon[2]	49293	27314–3–2	2003	.02	99.9	herbicide	--
Oryzalin	49292	19044–88–3	2003	.02	76.3	herbicide	--
Oxamyl	38866	23135–22–0	2003	.01	77.7	insecticide	200 / MCL
p,p’-DDE	34653	72–55–9	2003	.003	62.1	degradate	--
Parathion	39542	56–38–2	2003	.01	112.3	insecticide	--
Pebulate	82669	1114–71–2	2003	.004	89.6	herbicide	--
Pendimethalin	82683	40487–42–1	2003, 2004	.022	73.7	herbicide	--
Phorate	82664	298–02–2	2003, 2004	.011	61.2	insecticide	--
Phorate, oxygen analog	61666	2600–69–3	2004	.1	--	degradate	--
Phosmet	61601	732–11–6	2004	.008	--	insecticide	--
Phosmet, oxygen analog	61668	3735–33–9	2004	.06	--	degradate	--
Picloram	49291	1918–02–1	2003	.02	94.5	herbicide	500 / MCL
Prometon	04037	1610–18–0	2003, 2004	.01	115.6	herbicide	100 / LTHA
Prometryn	04036	7287–19–6	2004	.005	--	herbicide	--
Propachlor	04024	1918–16–7	2003	.025	98.8	herbicide	90 / LTHA
Propachlor ESA	62766	--	2004	.05	--	degradate	--
Propachlor OXA	62767	--	2004	.02	--	degradate	--
Propanil	82679	709–98–8	2003	.011	95.1	herbicide	--
Propargite	82685	2312–35–8	2003	.02	75.2	acaricide	--
Propham	49236	122–42–9	2003	.01	95.2	herbicide	100 / LTHA
Propiconazole	50471	60207–90–1	2003	.02	85.3	fungicide	--
Propoxur	38538	114–26–1	2003	.008	92.6	insecticide	--
Propyzamide	82676	23950–58–5	2003, 2004	.004	92.7	herbicide	50 / LTHA
Siduron	38548	1982–49–6	2003	.02	87.2	herbicide	--
Simazine	04035	122–34–9	2003, 2004	.005	101.9	herbicide	4 / MCL

Appendix 1. Pesticides analyzed in ground-water samples collected from northeast Nebraska glacial till, 2003–04.—Continued

[USGS, U.S. Geological Survey; CAS, Chemical Abstracts Service; USEPA, U.S. Environmental Protection Agency; µg/L, micrograms per liter; MCL, Maximum Contaminant Level; ESA, ethanesulfonic acid; OXA, oxanilic acid; SAA, sulfynil acetic acid; ESA SA, ethanesulfonic acid second amide; LTHA, Lifetime Health Advisory; --, not determined or not applicable]

Pesticide name	USGS parameter code	CAS number	Sample year	Highest laboratory reporting level (µg/L)	Mean field-matrix spike recovery (percent)	Pesticide type	USEPA drinking-water standard (µg/L) / type of standard[1]
Sulfometuron[2]	50337	74222–97–2	2003	0.009	134.7	herbicide	--
Tebuthiuron	82670	34014–18–1	2003, 2004	.02	110.7	herbicide	500 / LTHA
Terbacil[2]	82665	5902–51–2	2003	.034	99.9	herbicide	90 / LTHA
Terbufos	82675	13071–79–9	2003, 2004	.02	70.9	insecticide	0.9 / LTHA
Terbufos, oxygen analog sulfone	61674	56070–15–6	2004	.07	--	degradate	--
Terbuthylazine	04022	5915–41–3	2004	.01	--	herbicide	--
Thiobencarb	82681	28249–77–6	2003	.005	100.2	herbicide	--
Triallate	82678	2303–17–5	2003	.002	92.9	herbicide	--
Triclopyr	49235	55335–06–3	2003	.02	101.9	herbicide	--
Trifluralin	82661	1582–09–8	2003, 2004	.009	85.8	herbicide	5 / LTHA

[1] Source: U.S. Environmental Protection Agency (2004).

[2] These pesticides are qualitatively identified and reported with an E (estimated value) because of problems with gas chromatography or extraction or do not meet laboratory method performance criteria (Zaugg and others, 1995).

Appendix 2. Unsaturated-zone borehole-sediment sample results, northeast Nebraska glacial till, May–October 2002.

[Nitrate–N, nitrate as nitrogen; Ammonia–N, ammonia as nitrogen; <, less than; >, greater than; mg/kg, milligrams per kilogram; mm, millimeter; NA, not analyzed]

Well identifier (fig. 1)	U.S. Geological Survey site number	Sample depth (feet below land surface)	Nitrate–N (mg/kg)	Ammonia–N (mg/kg)	Chloride (mg/kg)	Percentage of sample composed of indicated grain size							
						Clay (<2 microns) (<0.002 mm)	Silt (2–50 microns) (0.002–0.05 mm)	Very fine sand (50–100 microns) (0.05–0.1 mm)	Fine sand (100–250 microns) (0.1–0.25 mm)	Medium sand (250–500 microns) (0.25–0.5 mm)	Coarse sand (500–1,000 microns) (0.5–1 mm)	Very coarse sand (1,000–2,000 microns) (1–2 mm)	Gravel (>2,000 microns) (>2 mm)
B–27	414931096321101	0	7.96	2.54	10.8	7.12	63.8	22.0	5.18	1.08	0.81	0	0
B–27	414931096321101	10	4.67	3.64	12.0	10.2	78.9	9.75	1.20	0	0	0	0
B–27	414931096321101	20	NA	NA	NA	10.2	82.9	6.85	.03	0	0	0	0
B–28	415220096214801	0	7.01	3.53	8.76	7.32	69.6	22.6	.44	0	0	0	0
B–28	415220096214801	10	NA	NA	NA	10.0	77.8	10.6	1.52	0	0	0	0
B–28	415220096214801	20	NA	NA	NA	11.3	83.9	4.86	0	0	0	0	0
CE–06	422947097142701	0	6.74	2.11	10.2	6.88	65.0	24.5	3.45	.16	0	0	0
CE–06	422947097142701	10	NA	NA	NA	6.51	68.1	24.3	1.08	0	0	0	0
CE–06	422947097142701	20	NA	NA	NA	10.4	76.7	12.9	.01	0	0	0	0
CE–17	422802097031601	0	5.15	2.27	27.6	6.60	70.6	22.1	.76	0	0	0	0
CE–17	422802097031601	8	NA	NA	NA	11.3	81.0	7.21	.36	0	0	0	.08
CE–17	422802097031601	22	NA	NA	NA	2.41	11.8	3.01	26.4	42.2	13.7	.50	0
CO–13	414343096595801	0	5.96	2.63	15.1	7.05	73.1	18.3	.06	0	0	0	1.44
CO–13	414343096595801	10	6.39	2.79	8.77	6.47	73.8	19.1	.58	0	0	0	0
CO–13	414343096595801	20	NA	NA	NA	9.94	81.0	9.06	.01	0	0	0	0
CU–19	420024096485901	0	24.6	2.79	11.5	6.87	64.3	22.9	5.54	0	0	0	.48
CU–19	420024096485901	10	7.00	4.00	6.62	8.87	81.5	9.63	0	0	0	0	0
CU–19	420024096485901	20	NA	NA	NA	9.98	83.9	6.14	0	0	0	0	0

Appendix 2. Unsaturated-zone borehole-sediment sample results, northeast Nebraska glacial till, May–October 2002.—Continued

[Nitrate–N, nitrate as nitrogen; Ammonia–N, ammonia as nitrogen; <, less than; >, greater than; mg/kg, milligrams per kilogram; mm, millimeter; NA, not analyzed]

Well identifier (fig. 1)	U.S. Geological Survey site number	Sample depth (feet below land surface)	Nitrate–N (mg/kg)	Ammonia–N (mg/kg)	Chloride (mg/kg)	Percentage of sample composed of indicated grain size							
						Clay (<2 microns) (<0.002 mm)	Silt (2–50 microns) (0.002–0.05 mm)	Very fine sand (50–100 microns) (0.05–0.1 mm)	Fine sand (100–250 microns) (0.1–0.25 mm)	Medium sand (250–500 microns) (0.25–0.5 mm)	Coarse sand (500–1,000 microns) (0.5–1 mm)	Very coarse sand (1,000–2,000 microns) (1–2 mm)	Gravel (>2,000 microns) (>2 mm)
CU–20	415558096434501	0	2.96	2.37	13.2	9.06	75.6	13.7	1.62	0	0	0	0
CU–20	415558096434501	10	2.92	1.66	6.74	9.95	78.8	11.2	.02	0	0	0	0
CU–20	415558096434501	20	3.52	1.86	4.71	10.5	81.0	8.22	.26	0	0	0	0
CU–20	415558096434501	30	3.98	1.41	11.0	9.48	82.5	8.02	.01	0	0	0	0
CU–29	415918096350501	0	5.59	2.36	3.09	8.68	76.0	11.4	1.87	.24	0	0	1.80
CU–29	415918096350501	10	3.15	17.8	2.84	9.73	67.8	10.9	6.92	1.39	0	0	3.29
CU–29	415918096350501	20	NA	NA	NA	14.8	72.2	7.83	3.94	0	0	0	1.24
CU–29	415918096350501	30	NA	NA	NA	14.8	84.1	.02	0	0	0	0	1.12
CU–30	420248096300901	0	4.53	4.02	11.4	7.82	61.4	20.2	6.66	1.32	1.13	0	1.42
CU–30	420248096300901	10	4.46	2.96	9.89	9.82	78.9	7.65	.47	0	0	0	3.19
CU–30	420248096300901	20	4.22	3.62	10.20	9.12	84.1	6.65	.03	0	0	0	.06
CU–30	420248096300901	30	NA	NA	NA	11.1	75.9	11.9	.50	0	0	0	.67
D–21	414401096531301	0	8.53	3.81	16.5	6.74	58.9	13.6	1.88	0	0	0	19.0
D–21	414401096531301	10	3.24	1.74	8.55	9.47	78.5	12.0	.01	0	0	0	0
D–21	414401096531301	20	NA	NA	NA	10.3	85.1	4.53	0	0	0	0	0
D–21	414401096531301	30	NA	NA	NA	9.71	83.4	6.56	.36	0	0	0	0
D–22	413853096483801	0	3.72	2.11	9.85	8.28	76.0	15.3	.39	0	0	0	0
D–22	413853096483801	10	5.18	2.79	6.30	10.1	80.2	9.71	0	0	0	0	0
D–22	413853096483801	20	27.4	2.84	48.9	9.81	81.1	7.72	1.34	0	0	0	0
D–22	413853096483801	30	NA	NA	NA	10.5	85.2	4.33	0	0	0	0	0
D–22	413853096483801	35	NA	NA	NA	9.35	80.9	9.30	.44	0	0	0	0

Appendix 2. Unsaturated-zone borehole-sediment sample results, northeast Nebraska glacial till, May–October 2002.—Continued

[Nitrate–N, nitrate as nitrogen; Ammonia–N, ammonia as nitrogen; <, less than; >, greater than; mg/kg, milligrams per kilogram; mm, millimeter; NA, not analyzed]

Well identifier (fig. 1)	U.S. Geological Survey site number	Sample depth (feet below land surface)	Nitrate–N (mg/kg)	Ammonia–N (mg/kg)	Chloride (mg/kg)	Percentage of sample composed of indicated grain size							
						Clay (<2 microns) (<0.002 mm)	Silt (2–50 microns) (0.002–0.05 mm)	Very fine sand (50–100 microns) (0.05–0.1 mm)	Fine sand (100–250 microns) (0.1–0.25 mm)	Medium sand (250–500 microns) (0.25–0.5 mm)	Coarse sand (500–1,000 microns) (0.5–1 mm)	Very coarse sand (1,000–2,000 microns) (1–2 mm)	Gravel (>2,000 microns) (>2 mm)
D–24	413340096402701	0	3.89	3.07	4.33	4.91	52.4	29.7	10.2	1.79	1.01	0	0
D–24	413340096402701	8	3.45	3.56	12.3	9.06	79.1	10.6	1.13	0	0	0	.07
D–24	413340096402701	13	3.20	1.41	3.88	4.67	37.6	14.1	36.6	6.84	0	0	.22
D–26	414141096371701	0	4.65	3.20	9.57	6.80	63.1	28.2	1.90	0	0	0	0
D–26	414141096371701	10	11.9	2.92	61.2	8.00	78.7	13.3	.01	0	0	0	0
D–26	414141096371701	20	3.42	2.12	11.5	8.18	78.0	13.1	.59	0	0	0	0
D–26	414141096371701	28	3.63	2.16	3.92	8.97	82.1	8.91	0	0	0	0	0
D–26	414141096371701	40	3.82	2.19	4.90	NA	NA	NA	NA	NA	NA	NA	NA
DI–16	422011096595401	0	4.61	1.99	14.1	6.09	66.2	21.9	4.45	.78	.53	0	0
DI–16	422011096595401	10	3.34	2.48	8.76	8.70	79.0	12.3	.01	0	0	0	0
DI–16	422011096595401	20	3.31	2.84	20.6	8.51	79.8	11.5	.20	0	0	0	0
DI–16	422011096595401	30	3.39	1.51	14.77	9.17	79.5	11.4	.01	0	0	0	0
DI–16	422011096595401	40	3.69	2.85	14.05	NA	NA	NA	NA	NA	NA	NA	NA
DI–16	422011096595401	55	3.12	1.24	3.43	NA	NA	NA	NA	NA	NA	NA	NA
K–05	422756097334901	0	5.70	2.74	7.25	5.85	60.4	28.0	5.44	.25	0	0	.09
K–05	422756097334901	10	3.91	2.00	4.05	10.7	82.0	6.24	.18	0	0	0	.91
K–05	422756097334901	20	3.45	1.89	5.03	12.51	82.6	4.88	0	0	0	0	0
K–05	422756097334901	30	NA	NA	NA	8.46	75.3	10.3	5.68	0	0	0	.30
P–02	421357097243201	0	6.02	3.45	4.32	6.99	67.7	25.3	.08	0	0	0	0
P–02	421357097243201	10	NA	NA	NA	10.3	71.3	13.7	.04	0	0	0	4.71
P–02	421357097243201	15	NA	NA	NA	10.5	73.0	15.3	.78	0	0	0	.44
P–02	421357097243201	20	NA	NA	NA	10.4	73.1	13.8	2.68	0	0	0	0

Appendix 2. Unsaturated-zone borehole-sediment sample results, northeast Nebraska glacial till, May–October 2002.—Continued

[Nitrate–N, nitrate as nitrogen; Ammonia–N, ammonia as nitrogen; <, less than; >, greater than; mg/kg, milligrams per kilogram; mm, millimeter; NA, not analyzed]

Well identifier (fig. 1)	U.S. Geological Survey site number	Sample depth (feet below land surface)	Nitrate–N (mg/kg)	Ammonia–N (mg/kg)	Chloride (mg/kg)	Percentage of sample composed of indicated grain size							
						Clay (<2 microns) (<0.002 mm)	Silt (2–50 microns) (0.002–0.05 mm)	Very fine sand (50–100 microns) (0.05–0.1 mm)	Fine sand (100–250 microns) (0.1–0.25 mm)	Medium sand (250–500 microns) (0.25–0.5 mm)	Coarse sand (500–1,000 microns) (0.5–1 mm)	Very coarse sand (1,000–2,000 microns) (1–2 mm)	Gravel (>2,000 microns) (>2 mm)
P–03	422156097314301	0	2.40	2.66	5.41	5.87	59.7	30.3	4.02	0.04	0	0	0
P–03	422156097314301	10	1.86	2.13	4.08	8.01	65.6	20.8	5.41	.01	0	0	.21
P–03	422156097314301	20	1.99	1.33	2.62	4.51	25.0	4.05	31.6	32.4	2.33	0	0
P–03	422156097314301	23	2.35	2.35	5.52	NA	NA	NA	NA	NA	NA	NA	NA
P–03	422156097314301	30	2.68	1.87	15.8	12.1	72.3	13.1	.83	0	0	0	1.79
P–04	422441097404601	0	6.08	3.01	9.06	6.69	65.0	25.7	2.43	.06	0	0	.09
P–04	422441097404601	10	4.09	3.19	3.18	10.1	75.5	12.5	.04	0	0	0	1.88
P–04	422441097404601	20	3.94	1.96	3.92	11.0	76.6	12.4	0	0	0	0	0
P–04	422441097404601	30	4.43	1.93	2.69	11.2	78.8	9.96	0	0	0	0	0
P–04	422441097404601	40	4.51	1.54	5.15	NA	NA	NA	NA	NA	NA	NA	NA
P–04	422441097404601	50	4.18	1.45	3.36	NA	NA	NA	NA	NA	NA	NA	NA
S–01	414948097212601	0	5.26	2.42	9.54	6.28	63.1	24.9	4.94	0	0	0	.76
S–01	414948097212601	10	6.36	1.73	7.35	10.1	77.9	11.9	.03	0	0	0	0
S–01	414948097212601	18	3.68	1.09	5.82	4.66	32.6	11.5	23.6	23.9	3.65	0	0
S–01	414948097212601	30	2.69	1.19	4.58	2.71	18.0	7.47	32.3	34.5	5.05	.02	0
S–10	420425097101301	0	4.45	5.30	3.57	5.63	60.2	30.7	3.41	.06	0	0	0
S–10	420425097101301	10	3.36	3.06	1.78	8.40	78.1	13.0	.44	0	0	0	0
S–10	420425097101301	20	NA	NA	NA	10.0	78.8	11.2	0	0	0	0	0
S–10	420425097101301	30	NA	NA	NA	10.2	79.6	9.13	1.11	.01	0	0	0

Appendix 2. Unsaturated-zone borehole-sediment sample results, northeast Nebraska glacial till, May–October 2002.—Continued

[Nitrate–N, nitrate as nitrogen; Ammonia–N, ammonia as nitrogen; <, less than; >, greater than; mg/kg, milligrams per kilogram; mm, millimeter; NA, not analyzed]

Well identifier (fig. 1)	U.S. Geological Survey site number	Sample depth (feet below land surface)	Nitrate–N (mg/kg)	Ammonia–N (mg/kg)	Chloride (mg/kg)	Percentage of sample composed of indicated grain size							
						Clay (<2 microns) (<0.002 mm)	Silt (2–50 microns) (0.002–0.05 mm)	Very fine sand (50–100 microns) (0.05–0.1 mm)	Fine sand (100–250 microns) (0.1–0.25 mm)	Medium sand (250–500 microns) (0.25–0.5 mm)	Coarse sand (500–1,000 microns) (0.5–1 mm)	Very coarse sand (1,000–2,000 microns) (1–2 mm)	Gravel (>2,000 microns) (>2 mm)
S–11	414527097094101	0	5.03	3.17	12.7	8.01	72.1	17.6	2.25	0	0	0	0.08
S–11	414527097094101	10	2.22	1.97	8.08	9.61	81.0	9.2	.22	0	0	0	0
S–11	414527097094101	20	2.36	2.31	8.02	9.14	80.3	10.0	.56	0	0	0	0
S–11	414527097094101	28	4.20	3.09	4.90	9.02	80.0	10.7	.26	0	0	0	0
S–11	414527097094101	40	3.45	5.73	3.62	9.55	77.7	9.19	3.41	.15	0	0	.04
S–R2	415458097142201	0	4.24	1.95	7.31	2.60	24.8	11.5	4.0	18.7	2.24	.01	0
S–R2	415458097142201	10	3.01	.84	2.55	1.53	6.07	7.91	5.3	29.0	5.14	.01	0
S–R2	415458097142201	17	3.54	1.35	4.13	2.11	6.71	9.01	62.2	17.8	2.13	0	0
W–07	422031097043501	0	5.52	2.59	4.56	7.26	69.9	21.4	.03	0	0	0	1.43
W–07	422031097043501	10	3.71	3.13	19.6	9.53	80.2	10.3	0	0	0	0	0
W–07	422031097043501	20	4.71	2.66	22.7	14.6	70.9	6.29	0	0	0	0	8.12
W–07	422031097043501	30	4.40	3.04	4.30	14.1	73.7	7.78	2.86	0	0	0	1.49
W–07	422031097043501	40	4.16	3.59	3.92	NA	NA	NA	NA	NA	NA	NA	NA
W–07	422031097043501	50	5.24	3.94	3.23	NA	NA	NA	NA	NA	NA	NA	NA
W–07	422031097043501	58	5.12	6.26	1.95	NA	NA	NA	NA	NA	NA	NA	NA
W–07	422031097043501	60	4.11	1.86	3.68	NA	NA	NA	NA	NA	NA	NA	NA
W–08	421829097112401	0	4.12	4.30	9.11	7.53	67.0	23.0	2.17	0	0	0	.34
W–08	421829097112401	10	3.67	3.93	8.98	10.3	76.4	13.0	.04	0	0	0	.27
W–08	421829097112401	20	3.79	2.90	7.90	10.8	79.2	10.0	0	0	0	0	0
W–08	421829097112401	30	NA	NA	NA	9.45	76.0	14.5	.01	0	0	0	0

Appendix 2. Unsaturated-zone borehole-sediment sample results, northeast Nebraska glacial till, May–October 2002.—Continued

[Nitrate–N, nitrate as nitrogen; Ammonia–N, ammonia as nitrogen; <, less than; >, greater than; mg/kg, milligrams per kilogram; mm, millimeter; NA, not analyzed]

Well identifier (fig. 1)	U.S. Geological Survey site number	Sample depth (feet below land surface)	Nitrate–N (mg/kg)	Ammonia–N (mg/kg)	Chloride (mg/kg)	Percentage of sample composed of indicated grain size							
						Clay (<2 microns) (<0.002 mm)	Silt (2–50 microns) (0.002–0.05 mm)	Very fine sand (50–100 microns) (0.05–0.1 mm)	Fine sand (100–250 microns) (0.1–0.25 mm)	Medium sand (250–500 microns) (0.25–0.5 mm)	Coarse sand (500–1,000 microns) (0.5–1 mm)	Very coarse sand (1,000–2,000 microns) (1–2 mm)	Gravel (>2,000 microns) (>2 mm)
W–09	421149097121301	0	3.10	4.68	2.74	9.95	74.1	12.8	1.87	0.16	0	0	1.11
W–09	421149097121301	10	2.28	2.46	3.23	NA	NA	NA	NA	NA	NA	NA	NA
W–09	421149097121301	20	5.34	1.96	2.42	9.95	80.4	9.61	.03	0	0	0	0
W–09	421149097121301	30	4.90	1.88	2.50	9.80	80.4	9.78	0	0	0	0	0
W–14	420526096543901	0	4.75	5.56	3.57	8.34	70.7	19.9	1.02	0	0	0	0
W–14	420526096543901	10	2.47	3.52	6.04	10.7	78.0	9.74	.57	0	0	0	.98
W–14	420526096543901	20	NA	NA	NA	10.0	84.6	5.34	.04	0	0	0	0
W–14	420526096543901	30	NA	NA	NA	9.82	81.1	8.70	.32	0	0	0	.05
W–15	421303097011601	0	5.09	7.46	3.34	7.70	63.7	21.8	6.35	.43	0	0	0
W–15	421303097011601	10	4.83	4.55	1.71	10.8	78.5	10.6	.06	0	0	0	0
W–15	421303097011601	20	NA	NA	NA	10.6	78.3	10.7	.38	0	0	0	0
W–15	421303097011601	30	NA	NA	NA	5.03	35.6	7.20	12.1	13.4	12.6	6.51	7.71
W–R1	421445097123801	0	3.08	3.33	7.84	9.03	72.4	16.9	.07	0	0	0	1.58
W–R1	421445097123801	10	3.14	3.44	3.92	10.1	79.3	10.5	.04	0	0	0	0
W–R1	421445097123801	20	2.87	2.20	8.14	9.71	79.6	10.7	.05	0	0	0	0
W–R1	421445097123801	30	3.35	2.81	7.11	10.4	81.7	7.88	.01	0	0	0	0
W–R1	421445097123801	40	3.98	1.43	8.42	NA	NA	NA	NA	NA	NA	NA	NA

Appendix 3. Nitrate as nitrogen and pesticide concentrations in ground-water samples collected from domestic wells, northeast Nebraska glacial till, 1994–95.

[Source: University of Nebraska (2000). Nitrate–N, nitrate as nitrogen; mg/L, milligrams per liter; µg/L, micrograms per liter; <, less than]

Map identifier (fig. 8)	Database number	County	Well depth (feet below land surface)	Date sampled (month/day/year)	Longitude (decimal degrees)	Latitude (decimal degrees)	Nitrate–N (mg/L)	Alachlor (µg/L)	Atrazine (µg/L)	Butylate (µg/L)	Chlorpyrifos (µg/L)	Cyanazine (µg/L)
1	115912	Burt	50	3/23/1995	-96.40028	41.75997	1.4	<0.2	<0.1	<0.2	<0.4	<2.5
2	115992	Cedar	250	5/11/1995	-97.2857	42.36977	2.0	<.2	<.1	<.2	<.4	<2.5
3	115993	Cedar	250	5/11/1995	-97.23723	42.39881	8.7	<.2	<.1	<.2	<.4	<2.5
4	116018	Cedar	180	5/9/1995	-97.09855	42.47099	33.0	<.2	<.1	<.2	<.4	<2.5
5	115819	Colfax	120	1/25/1995	-97.03495	41.52887	8.3	<.2	<.1	<.2	<.4	<2.5
6	115853	Colfax	320	1/25/1995	-97.07339	41.63012	2.6	<.2	<.1	<.2	<.4	<2.5
7	115856	Colfax	305	2/15/1995	-96.92979	41.60842	3.3	<.2	<.1	<.2	<.4	<2.5
8	115885	Colfax	40	1/25/1995	-96.98784	41.67397	197	<.2	<.1	<.2	<.4	<2.5
9	113649	Cuming	150	4/17/1995	-96.92744	41.75366	1.0	<.2	<.1	<.2	<.4	<2.5
10	113650	Cuming	100	4/17/1995	-96.90814	41.78264	3.2	<.2	<.1	<.2	<.4	<2.5
11	113651	Cuming	52	4/13/1995	-96.72362	41.8401	<.1	<.2	.26	<.2	<.4	<2.5
12	113652	Cuming	100	4/13/1995	-96.79171	41.8695	<.1	<.2	<.1	<.2	<.4	<2.5
13	113653	Cuming	140	4/13/1995	-96.77279	41.74624	1.9	<.2	<.1	<.2	<.4	<2.5
14	113654	Cuming	55	4/17/1995	-96.60824	41.88356	27.1	<.2	<.1	<.2	<.4	<2.5
15	113655	Cuming	66	4/17/1995	-96.5596	41.95571	5.9	<.2	<.1	<.2	<.4	<2.5
16	113657	Cuming	80	4/13/1995	-96.69528	41.79673	15.1	<.2	<.1	<.2	<.4	<2.5
17	113659	Cuming	150	4/17/1995	-96.95648	41.90592	11.5	<.2	<.1	<.2	<.4	<2.5
18	113660	Cuming	30	4/13/1995	-96.79178	41.9131	<.1	<.2	<.1	<.2	<.4	<2.5
19	113661	Cuming	70	4/13/1995	-96.85913	42.03611	4.4	<.2	<.1	<.2	<.4	<2.5
20	113663	Cuming	235	4/18/1995	-96.58865	41.95588	.6	<.2	<.1	<.2	<.4	<2.5
21	115977	Dixon	96	5/9/1995	-96.8861	42.2825	<.1	<.2	<.1	<.2	<.4	<2.5
22	115978	Dixon	40	5/9/1995	-96.77027	42.29661	9.4	<.2	<.1	<.2	<.4	<2.5
23	115979	Dixon	72	5/9/1995	-96.74092	42.29646	13.5	<.2	<.1	<.2	<.4	<2.5
24	115824	Dodge	70	11/2/1994	-96.83329	41.56467	1.1	<.2	<.1	<.2	<.4	<2.5
25	115831	Dodge	320	2/27/1995	-96.58222	41.52791	<.1	<.2	<.1	<.2	<.4	<2.5
26	115834	Dodge	22	2/28/1995	-96.45827	41.51313	15.3	<.2	<.1	<.2	<.4	<2.5
27	115857	Dodge	100	2/27/1995	-96.83323	41.5792	.1	<.2	<.1	<.2	<.4	<2.5
28	115859	Dodge	220	2/28/1995	-96.77544	41.65177	<.1	<.2	<.1	<.2	<.4	<2.5
29	115860	Dodge	107	2/28/1995	-96.62172	41.62927	.1	<.2	<.1	<.2	<.4	<2.5
30	115888	Dodge	110	2/28/1995	-96.85311	41.69537	4.2	<.2	<.1	<.2	<.4	<2.5

Appendix 3. Nitrate as nitrogen and pesticide concentrations in ground-water samples collected from domestic wells, northeast Nebraska glacial till, 1994–95.—Continued

[Source: University of Nebraska (2000). Nitrate–N, nitrate as nitrogen; mg/L, milligrams per liter; µg/L, micrograms per liter; <, less than]

Map identifier (fig. 8)	Database number	County	Well depth (feet below land surface)	Date sampled (month/day/year)	Longitude (decimal degrees)	Latitude (decimal degrees)	Nitrate–N (mg/L)	Alachlor (µg/L)	Atrazine (µg/L)	Butylate (µg/L)	Chlorpyrifos (µg/L)	Cyanazine (µg/L)
31	115896	Dodge	326	2/28/1995	-96.61249	41.72379	9.9	<0.2	<0.1	<0.2	<0.4	<02.5
32	116016	Knox	280	5/18/1995	-97.50936	42.52199	.5	<.2	<.1	<.2	<.4	<2.5
33	116017	Knox	305	5/18/1995	-97.58784	42.51443	9.0	<.2	<.1	<.2	<.4	<2.5
34	116019	Knox	200	5/18/1995	-97.62693	42.45633	<.1	<.2	<.1	<.2	<.4	<2.5
35	116021	Knox	160	5/18/1995	-97.75434	42.46326	15.8	<.2	<.1	<.2	<.4	<2.5
36	116061	Knox	330	5/17/1995	-97.54877	42.55088	2.2	<.2	<.1	<.2	<.4	<2.5
37	113664	Pierce	280	4/25/1995	-97.45998	42.34772	.4	<.2	<.1	<.2	<.4	<2.5
38	113665	Pierce	110	4/25/1995	-97.41144	42.28993	33.9	<.2	<.1	<.2	<.4	<2.5
39	113669	Pierce	265	4/25/1995	-97.54797	42.42013	5.2	<.2	<.1	<.2	<.4	<2.5
40	113672	Pierce	165	4/25/1995	-97.43061	42.33327	12.6	<.2	<.1	<.2	<.4	<2.5
41	113676	Pierce	100	4/25/1995	-97.6058	42.36916	13.9	<.2	<.1	<.2	<.4	<2.5
42	115994	Pierce	90	5/9/1995	-97.66427	42.39104	6.1	<.2	<.1	<.2	<.4	<2.5
43	115872	Platte	120	10/26/1994	-97.34479	41.73243	9.6	<.2	<.1	<.2	<.4	<2.5
44	115873	Platte	100	10/25/1994	-97.39197	41.71796	5.3	<.2	<.1	<.2	<.4	<2.5
45	115874	Platte	120	10/25/1994	-97.39193	41.71082	13.1	<.2	<.1	<.2	<.4	<2.5
46	115875	Platte	93	10/25/1994	-97.4306	41.73986	.2	<.2	<.1	<.2	<.4	<2.5
47	115876	Platte	210	10/25/1994	-97.47953	41.6747	3.8	<.2	<.1	<.2	<.4	<2.5
48	115877	Platte	120	10/25/1994	-97.46987	41.66739	109.2	<.2	<.1	<.2	<.4	<2.5
49	115879	Platte	250	10/25/1994	-97.49867	41.70377	2.1	<.2	<.1	<.2	<.4	<2.5
50	113679	Stanton	60	4/19/1995	-97.22869	42.07266	13.6	<.2	<.1	<.2	<.4	<2.5
51	113680	Stanton	237	4/19/1995	-97.32417	41.76855	<.1	<.2	<.1	<.2	<.4	<2.5
52	113681	Stanton	65	4/19/1995	-97.07257	41.81184	8.7	<.2	<.1	<.2	<.4	<2.5
53	113688	Wayne	125	4/24/1995	-96.92524	42.18836	11.1	<.2	<.1	<.2	<.4	<2.5
54	113689	Wayne	144	4/24/1995	-96.83759	42.19552	3.9	<.2	<.1	<.2	<.4	<2.5
55	113691	Wayne	100	4/24/1995	-96.84721	42.17445	<.1	<.2	<.1	<.2	<.4	<2.5
56	113692	Wayne	208	4/19/1995	-97.0614	42.13059	.1	<.2	<.1	<.2	<.4	<2.5
57	113693	Wayne	32	4/27/1995	-97.20732	42.14506	17.5	<.2	<.1	<.2	<.4	<2.5
58	113694	Wayne	190	4/27/1995	-97.23684	42.19563	<.1	<.2	<.1	<.2	<.4	<2.5
59	113695	Wayne	20	4/27/1995	-97.27558	42.1956	6.9	<.2	<.1	<.2	<.4	<2.5
60	113698	Wayne	220	4/24/1995	-96.96378	42.2391	.4	<.2	<.1	<.2	<.4	<2.5
61	113699	Wayne	180	4/27/1995	-97.12957	42.31872	3.8	<.2	<.1	<.2	<.4	<2.5
62	113700	Wayne	55	4/19/1995	-97.11029	42.10876	32.7	<.2	<.1	<.2	<.4	<2.5

Appendix 3. Nitrate as nitrogen and pesticide concentrations in ground-water samples collected from domestic wells, northeast Nebraska glacial till, 1994–95.—Continued

[Source: University of Nebraska (2000). Nitrate–N, nitrate as nitrogen; mg/L, milligrams per liter; µg/L, micrograms per liter; <, less than]

Map identifier (fig. 8)	Database number	County	Well depth (feet below land surface)	Date sampled (month/day/year)	Longitude (decimal degrees)	Latitude (decimal degrees)	Ethyl parathion (µg/L)	Fonofos (µg/L)	Methyl parathion (µg/L)	Metolachlor (µg/L)	Metribuzin (µg/L)	Terbufos (µg/L)	Trifluralin (µg/L)
1	115912	Burt	50	3/23/1995	-96.40028	41.75997	<0.1	<0.05	<0.1	<2.1	<0.8	<0.2	<0.4
2	115992	Cedar	250	5/11/1995	-97.2857	42.36977	<.1	<.05	<.1	<2.1	<.8	<.2	<.4
3	115993	Cedar	250	5/11/1995	-97.23723	42.39881	<.1	<.05	<.1	<2.1	<.8	<.2	<.4
4	116018	Cedar	180	5/9/1995	-97.09855	42.47099	<.1	<.05	<.1	<2.1	<.8	<.2	<.4
5	115819	Colfax	120	1/25/1995	-97.03495	41.52887	<.1	<.05	<.1	<2.1	<.8	<.2	<.4
6	115853	Colfax	320	1/25/1995	-97.07339	41.63012	<.1	<.05	<.1	<2.1	<.8	<.2	<.4
7	115856	Colfax	305	2/15/1995	-96.92979	41.60842	<.1	<.05	<.1	<2.1	<.8	<.2	<.4
8	115885	Colfax	40	1/25/1995	-96.98784	41.67397	<.1	<.05	<.1	<2.1	<.8	<.2	<.4
9	113649	Cuming	150	4/17/1995	-96.92744	41.75366	<.1	<.05	<.1	<2.1	<.8	<.2	<.4
10	113650	Cuming	100	4/17/1995	-96.90814	41.78264	<.1	<.05	<.1	<2.1	<.8	<.2	<.4
11	113651	Cuming	52	4/13/1995	-96.72362	41.8401	<.1	<.05	<.1	<2.1	<.8	<.2	<.4
12	113652	Cuming	100	4/13/1995	-96.79171	41.8695	<.1	<.05	<.1	<2.1	<.8	<.2	<.4
13	113653	Cuming	140	4/13/1995	-96.77279	41.74624	<.1	<.05	<.1	<2.1	<.8	<.2	<.4
14	113654	Cuming	55	4/17/1995	-96.60824	41.88356	<.1	<.05	<.1	<2.1	<.8	<.2	<.4
15	113655	Cuming	66	4/17/1995	-96.5596	41.95571	<.1	<.05	<.1	<2.1	<.8	<.2	<.4
16	113657	Cuming	80	4/13/1995	-96.69528	41.79673	<.1	<.05	<.1	<2.1	<.8	<.2	<.4
17	113659	Cuming	150	4/17/1995	-96.95648	41.90592	<.1	<.05	<.1	<2.1	<.8	<.2	<.4
18	113660	Cuming	30	4/13/1995	-96.79178	41.9131	<.1	<.05	<.1	<2.1	<.8	<.2	<.4
19	113661	Cuming	70	4/13/1995	-96.85913	42.03611	<.1	<.05	<.1	<2.1	<.8	<.2	<.4
20	113663	Cuming	235	4/18/1995	-96.58865	41.95588	<.1	<.05	<.1	<2.1	<.8	<.2	<.4
21	115977	Dixon	96	5/9/1995	-96.8861	42.2825	<.1	<.05	<.1	<2.1	<.8	<.2	<.4
22	115978	Dixon	40	5/9/1995	-96.77027	42.29661	<.1	<.05	<.1	<2.1	<.8	<.2	<.4
23	115979	Dixon	72	5/9/1995	-96.74092	42.29646	<.1	<.05	<.1	<2.1	<.8	<.2	<.4
24	115824	Dodge	70	11/2/1994	-96.83329	41.56467	<.1	<.05	<.1	<2.1	<.8	<.2	<.4
25	115831	Dodge	320	2/27/1995	-96.58222	41.52791	<.1	<.05	<.1	<2.1	<.8	<.2	<.4
26	115834	Dodge	22	2/28/1995	-96.45827	41.51313	<.1	<.05	<.1	<2.1	<.8	<.2	<.4
27	115857	Dodge	100	2/27/1995	-96.83323	41.5792	<.1	<.05	<.1	<2.1	<.8	<.2	<.4
28	115859	Dodge	220	2/28/1995	-96.77544	41.65177	<.1	<.05	<.1	<2.1	<.8	<.2	<.4
29	115860	Dodge	107	2/28/1995	-96.62172	41.62927	<.1	<.05	<.1	<2.1	<.8	<.2	<.4
30	115888	Dodge	110	2/28/1995	-96.85311	41.69537	<.1	<.05	<.1	<2.1	<.8	<.2	<.4

Appendix 3. Nitrate as nitrogen and pesticide concentrations in ground-water samples collected from domestic wells, northeast Nebraska glacial till, 1994–95.—Continued

[Source: University of Nebraska (2000). Nitrate–N, nitrate as nitrogen; mg/L, milligrams per liter; µg/L, micrograms per liter; <, less than]

Map identifier (fig. 8)	Database number	County	Well depth (feet below land surface)	Date sampled (month/day/year)	Longitude (decimal degrees)	Latitude (decimal degrees)	Ethyl parathion (µg/L)	Fonofos (µg/L)	Methyl parathion (µg/L)	Metolachlor (µg/L)	Metribuzin (µg/L)	Terbufos (µg/L)	Trifluralin (µg/L)
31	115896	Dodge	326	2/28/1995	-96.61249	41.72379	<0.1	<0.05	<0.1	<2.1	<0.8	<0.2	<0.4
32	116016	Knox	280	5/18/1995	-97.50936	42.52199	<.1	<.05	<.1	<2.1	<.8	<.2	<.4
33	116017	Knox	305	5/18/1995	-97.58784	42.51443	<.1	<.05	<.1	<2.1	<.8	<.2	<.4
34	116019	Knox	200	5/18/1995	-97.62693	42.45633	<.1	<.05	<.1	<2.1	<.8	<.2	<.4
35	116021	Knox	160	5/18/1995	-97.75434	42.46326	<.1	<.05	<.1	<2.1	<.8	<.2	<.4
36	116061	Knox	330	5/17/1995	-97.54877	42.55088	<.1	<.05	<.1	<2.1	<.8	<.2	<.4
37	113664	Pierce	280	4/25/1995	-97.45998	42.34772	<.1	<.05	<.1	<2.1	<.8	<.2	<.4
38	113665	Pierce	110	4/25/1995	-97.41144	42.28993	<.1	<.05	<.1	<2.1	<.8	<.2	<.4
39	113669	Pierce	265	4/25/1995	-97.54797	42.42013	<.1	<.05	<.1	<2.1	<.8	<.2	<.4
40	113672	Pierce	165	4/25/1995	-97.43061	42.33327	<.1	<.05	<.1	<2.1	<.8	<.2	<.4
41	113676	Pierce	100	4/25/1995	-97.6058	42.36916	<.1	<.05	<.1	<2.1	<.8	<.2	<.4
42	115994	Pierce	90	5/9/1995	-97.66427	42.39104	<.1	<.05	<.1	<2.1	<.8	<.2	<.4
43	115872	Platte	120	10/26/1994	-97.34479	41.73243	<.1	<.05	<.1	<2.1	<.8	<.2	<.4
44	115873	Platte	100	10/25/1994	-97.39197	41.71796	<.1	<.05	<.1	<2.1	<.8	<.2	<.4
45	115874	Platte	120	10/25/1994	-97.39193	41.71082	<.1	<.05	<.1	<2.1	<.8	<.2	<.4
46	115875	Platte	93	10/25/1994	-97.4306	41.73986	<.1	<.05	<.1	<2.1	<.8	<.2	<.4
47	115876	Platte	210	10/25/1994	-97.47953	41.6747	<.1	<.05	<.1	<2.1	<.8	<.2	<.4
48	115877	Platte	120	10/25/1994	-97.46987	41.66739	<.1	<.05	<.1	<2.1	<.8	<.2	<.4
49	115879	Platte	250	10/25/1994	-97.49867	41.70377	<.1	<.05	<.1	<2.1	<.8	<.2	<.4
50	113679	Stanton	60	4/19/1995	-97.22869	42.07266	<.1	<.05	<.1	<2.1	<.8	<.2	<.4
51	113680	Stanton	237	4/19/1995	-97.32417	41.76855	<.1	<.05	<.1	<2.1	<.8	<.2	<.4
52	113681	Stanton	65	4/19/1995	-97.07257	41.81184	<.1	<.05	<.1	<2.1	<.8	<.2	<.4
53	113688	Wayne	125	4/24/1995	-96.92524	42.18836	<.1	<.05	<.1	<2.1	<.8	<.2	<.4
54	113689	Wayne	144	4/24/1995	-96.83759	42.19552	<.1	<.05	<.1	<2.1	<.8	<.2	<.4
55	113691	Wayne	100	4/24/1995	-96.84721	42.17445	<.1	<.05	<.1	<2.1	<.8	<.2	<.4
56	113692	Wayne	208	4/19/1995	-97.0614	42.13059	<.1	<.05	<.1	<2.1	<.8	<.2	<.4
57	113693	Wayne	32	4/27/1995	-97.20732	42.14506	<.1	<.05	<.1	<2.1	<.8	<.2	<.4
58	113694	Wayne	190	4/27/1995	-97.23684	42.19563	<.1	<.05	<.1	<2.1	<.8	<.2	<.4
59	113695	Wayne	20	4/27/1995	-97.27558	42.1956	<.1	<.05	<.1	<2.1	<.8	<.2	<.4
60	113698	Wayne	220	4/24/1995	-96.96378	42.2391	<.1	<.05	<.1	<2.1	<.8	<.2	<.4
61	113699	Wayne	180	4/27/1995	-97.12957	42.31872	<.1	<.05	<.1	<2.1	<.8	<.2	<.4
62	113700	Wayne	55	4/19/1995	-97.11029	42.10876	<.1	<.05	<.1	<2.1	<.8	<.2	<.4

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