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A Compilation of Existing Data for Aquifer Sensitivity and Ground-Water Vulnerability Assessment for the Caddo Indian Tribe in Parts of Caddo and Canadian Counties, Oklahoma

Water-Resources Investigations Report 00–4089

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

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By Carol J. Becker

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Denver, CO 80225

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CONVERSION FACTORS, ABBREVATIONS, AND VERTICAL DATUM

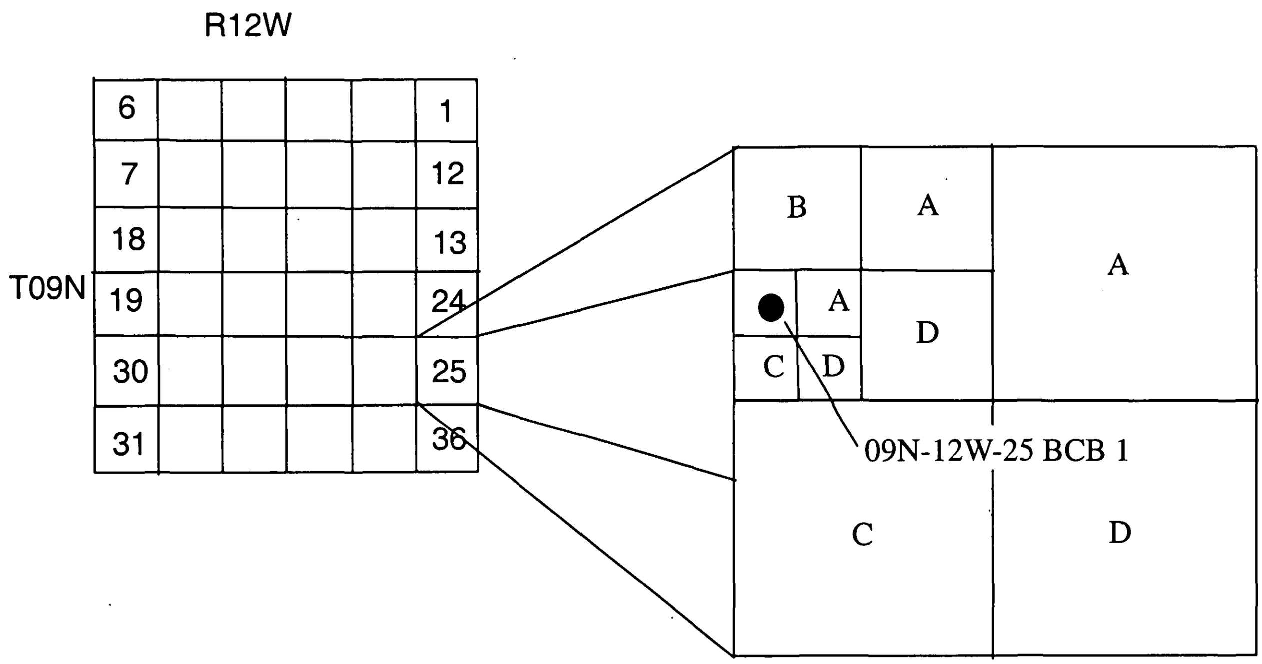
Multiply	By	To obtain
foot (ft)	0.3048	meter
mile (mi)	1.609	kilometer
acre	0.004047	square kilometer
square mile (mi^2)	2.590	square kilometer
foot per day (ft/d)	0.3048	meter per day
gallon per day (gal/d)	0.003785	cubic meter per day

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

Altitude, as used in this report, refers to distance above or below sea level.

EXPLANATION OF THE SITE-NUMBERING SYSTEM

Well locations in the NITROGEN.DAT and the WTRLVL.DAT files in the DATA_OTHER directory are specified by latitude and longitude in degrees, minutes, seconds, and by a local site-numbering system, which is the public land-survey location in Oklahoma. The local site-numbering system consists of the township number, north or south; range number, east or west; and the section number. Each section is divided into four quarters, A, B, C, and D. The township numbers are north of the third parallel and the range numbers are west of the Indian Meridian. A section is equal to one square mile and fractional parts are given from larger to smaller areas of the section. The final digit (1) is the sequential number of a well within the smallest fractional subdivision (10 acres, in the example shown). The diagram shown below illustrates the location of a well described as: 09N-12W-25 BCB 1



A Compilation of Existing Data for Aquifer Sensitivity and Ground-Water Vulnerability Assessment for the Caddo Indian Tribe in Parts of Caddo and Canadian Counties, Oklahoma

By Carol J. Becker

ABSTRACT

The U.S. Environmental Protection Agency is working with the Caddo Indian Tribe to develop a Pesticide Management Plan to prevent contamination of ground water that may result from the registered use of pesticides. The purpose of this project was to assist the Caddo Indian tribe in developing a Pesticide Management Plan for about 900 square miles in parts of Caddo and Canadian Counties in Oklahoma by providing information about aquifer-sensitivity and ground-water vulnerability assessment methods and digital data that can be used to develop assessment maps.

The CD-ROM contains six digital datasets that describe various hydrologic components of the aquifer: aquifer boundaries, ground-water level elevations, hydraulic conductivity, net recharge, surficial geology, and land-surface elevations, and eight data files that describe physical and cultural features and boundaries in the study area. Additionally, the CD-ROM contains files of depth to ground-water measurements and nitrogen concentration in ground water, retrieved from the U.S. Geological Survey National Water Information System data base. The report also describes digital data and information from other sources that can be used with assessment methods. An annotated list of aquifer sensitivity and ground-water vulnerability assessment methods and a list of pesticides associated with some of the crops grown in Caddo County are included.

INTRODUCTION

The Rush Springs aquifer is a source of drinking water in most of Caddo County and the southwestern part of Canadian County. Various pesticides are applied to croplands that constitute more than a third of the land in Caddo County. The U.S. Environmental Protection Agency (EPA) is working with the Caddo Indian tribe to develop a Pesticide Management Plan to prevent contamination of ground water that may result from the use of registered pesticides. An important component in the development of a Pesticide Management Plan is ascertaining where the Rush Springs aquifer may be sensitive and where ground water may be vulnerable to contamination.

This project was developed through an interagency agreement between the EPA and the U.S. Geological Survey. The purpose was to assist the Caddo Indian tribe in developing a Pesticide Management Plan for about 900 square miles in parts of Caddo and Canadian Counties in Oklahoma (fig. 1), by providing information about aquifer-sensitivity and ground-water vulnerability assessment methods and digital data that can be used to develop assessment maps.

Purpose and Scope

The purpose of this report is to provide information on aquifer sensitivity and ground-water vulnerability assessment methods and to provide a CD-ROM with previously published digital data and other information that can be used to develop assessment maps for the study area. The project involved modifying digital data published by the U.S. Geological Survey, retrieving data from the U.S. Geological Survey

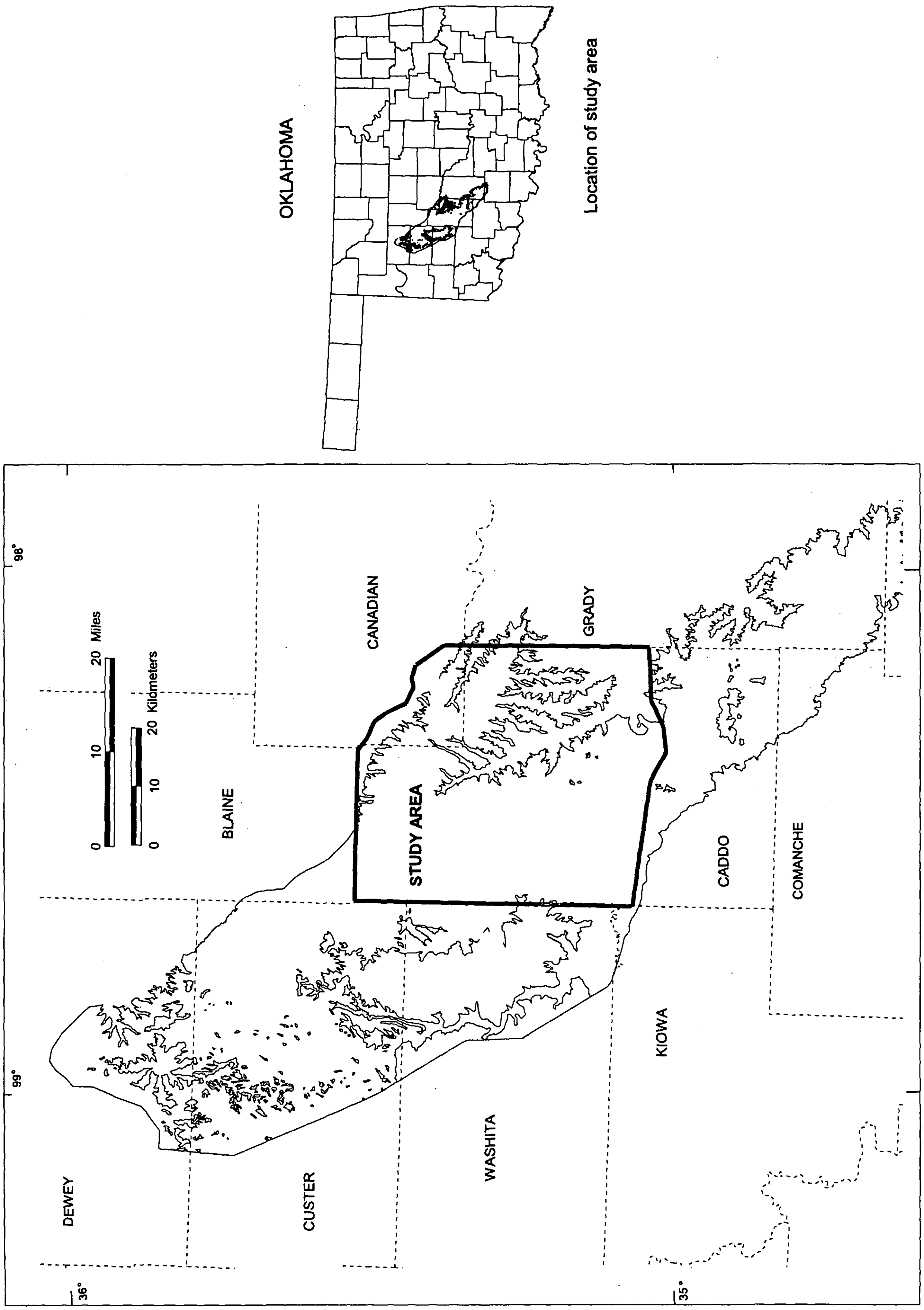


Figure 1. Location of the Rush Springs aquifer and study area in parts of Caddo and Canadian Counties, Oklahoma.

National Water Information System (NWIS) data base, and locating other information that describes the Rush Springs aquifer or other features in the study area.

The CD-ROM contains six digital datasets that describe various hydrologic components of the aquifer: aquifer boundaries, ground-water level elevations, hydraulic conductivity, net recharge, surficial geology, and land-surface elevations, and eight data files that describe physical and cultural features and boundaries in the study area. Additionally, the CD-ROM contains files of nitrogen concentration in ground water and depth to ground-water measurements retrieved from the NWIS data base. This report also describes digital data and information from other sources that can be used with assessment methods. An annotated list of aquifer sensitivity and ground-water vulnerability assessment methods and a list of pesticides associated with some of the crops grown in Caddo County are included.

Description of Study Area

The study area is about 900 square miles in the northern two thirds of Caddo County and the southwestern corner of Canadian County. The southern boundary is the Washita River (fig. 2), which drains most of the study area and the northern boundary is the Canadian River, which drains the far northern part of the study area.

The Rush Springs aquifer is the most important source of ground water for irrigation, livestock and domestic uses in Caddo County. The total estimated ground-water withdrawals in 1995 for Caddo County was 32.10 million gallons per day. About 29.27 million gallons per day were withdrawn for irrigation and 1.15 million gallons per day were withdrawn for water supply (Tortorelli, 1999, tables 1 and 4).

The study area lies in the rolling plains of west-central Oklahoma. Agriculture is the primary land use. In 1998, about 46 percent of the land in Caddo County was used for cropland, about 8 percent of which was irrigated; about 23 percent of the land was used for pasture land; and about 20 percent was used for rangeland (U.S. Department of Agriculture, 1999d) (table 1). Wheat, sorghum, peanuts, and smaller amounts of soybeans, cotton, and corn are the principal crops.

The Rush Springs aquifer in the study area comprises the Rush Springs Formation, and overlying terrace and alluvial deposits along parts of the Canadian and Washita Rivers. Underlying the Rush Springs Formation is the Marlow Formation, a confining unit composed of interbedded sandstones, siltstones, mudstones, gypsum-anhydrite, and dolomite (Becker and Runkle, 1998). The Rush Springs Formation is described as a massive to highly cross-bedded sandstone with some interbedded dolomite or gypsum (Becker, and Runkle, 1998, p. 7). The terrace and alluvial deposits are composed of unconsolidated layers of gravel, sand, silt, and clay. The thickness of the Rush Springs Formation increases in a south-southwesterly direction and is thinnest along the northeastern boundary of the study area, where it has been truncated by erosion. The southwestern boundary of the aquifer is defined as the Washita River (Becker and Runkle, 1998, p. 3) because a high dissolved mineral content in the ground water limits use southwest of the river.

Acknowledgments

The author thanks the Caddo Indian Tribe of Oklahoma for their cooperation.

VULNERABILITY ASSESSMENT METHODS AND SELECTION CONSIDERATIONS

Assessment methods can be divided into two general categories: aquifer sensitivity and ground-water vulnerability (U.S. Environmental Protection Agency, 1993). Considerations when selecting an assessment method include: the scale and size of the area to be assessed, intended use of the results, availability and suitability of data required by assessment method, availability of software and hardware, and technical expertise available to conduct the assessment.

Aquifer sensitivity methods provide information about aquifer susceptibility or risk of pollution. These assessment methods usually consider the following geohydrologic components: depth to water, land slope, net recharge, soil characteristics, vadose zone characteristics, and aquifer lithology. Ground-water vulnerability methods consider additional components, including pesticide characteristics and soil properties. Pesticide characteristics include solubility, water to organic carbon partitioning ratio, and half-life.

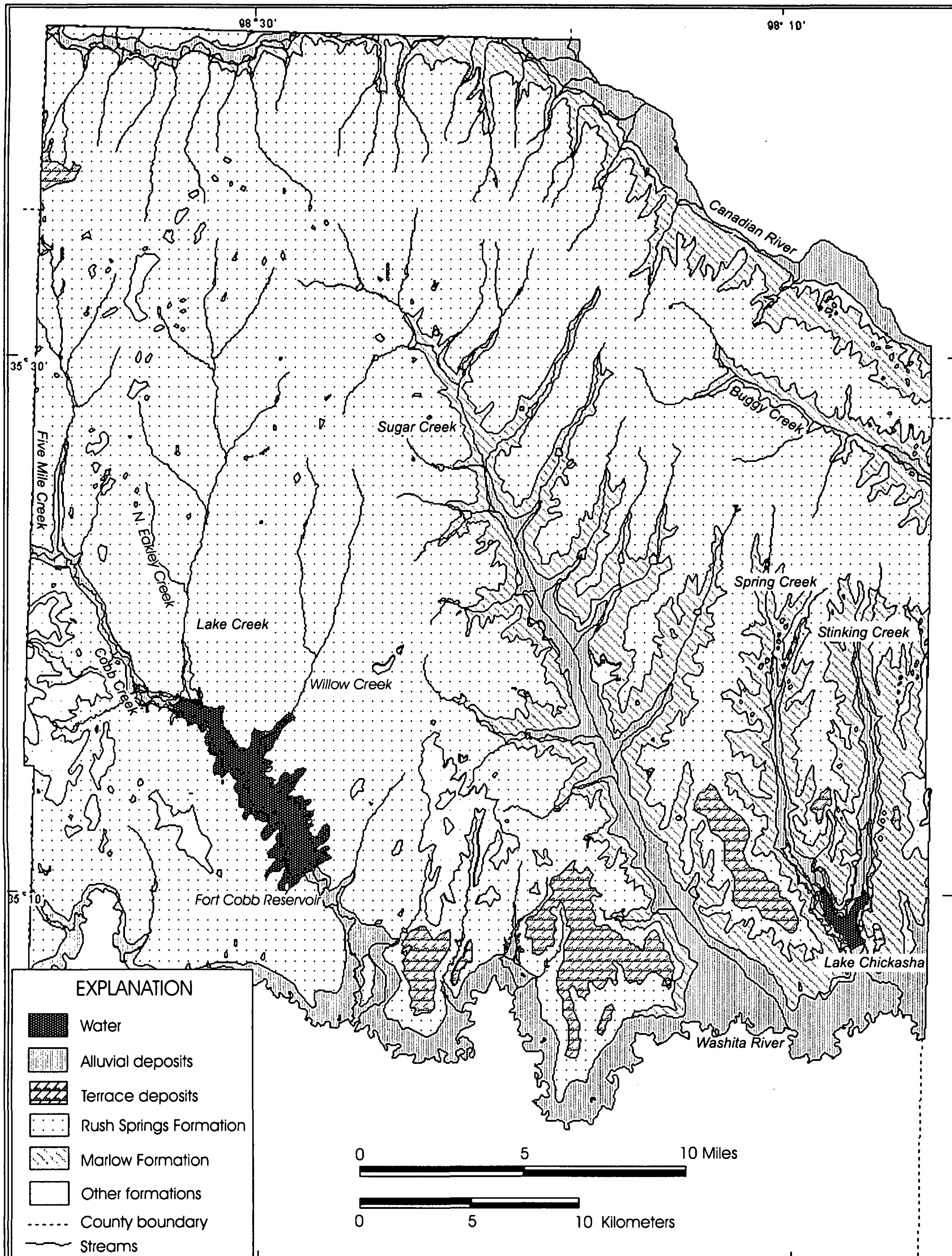


Figure 2. Extent of the Rush Springs Formation and overlying terrace and alluvial deposits in the study area, parts of Caddo and Canadian Counties, Oklahoma (geology from Cederstrand, J.R., 1996).

Table 1. Caddo County land use in 1998 (U.S. Department of Agriculture, 1999d)

[Percentages do not add up to 100 because of independent rounding]

Land use	Acres	Percent
Cropland	310,095	37.56
Cropland - irrigated	69,015	8.36
Cropland - orchards, groves, horticultural crops	89	0.01
Rangeland - open grasslands	147,843	17.91
Rangeland - post oak/blackjack oak; low density - less than 35%	17,313	2.10
Rangeland - post oak/blackjack oak; high density - greater than 35%	2,559	0.31
Rangeland - cottonwood/elm/hackberry; low density - less than 20%	741	0.09
Rangeland - cottonwood/elm/hackberry; high density - greater than 20%	148	0.02
Rangeland - salt cedar/baccharis; low density - less than 10%	128	0.02
Pastureland	191,057	23.14
Pastureland - irrigated.	632	0.08
Forest - bottom land hardwoods	10,119	1.23
Forest - post oak/blackjack oak	52,038	6.30
Woodland - windbreaks and cropland	702	0.08
Woodland - windbreaks and pasture	49	0.01
Wetland - nonforested (grass or shrubs or both)	20	0.00
Urban ranchette - house and lot/tract (2 to 20 acres)	2,293	0.28
Farmstead (greater than 5 acres)	3,241	0.39
Highway - multilane (4 lanes or more)	1,551	0.19
Bare exposed rock	79	0.01
Oil-waste land	1,038	0.13
Quarries and gravel pits; greater than 5 acres	316	0.04
Cemeteries	49	0.01
Bottomland woods and range	99	0.01
Water/bare sand channel (rivers)	544	0.07
Urban/built-up land	6,502	0.79
Water (lakes and ponds)	7,184	0.87
Total	825,536	

Organic carbon content and infiltration rate are the most important soil properties affecting the movement of pesticide into the ground water. Other components used by ground-water vulnerability methods may include: agricultural practices and method of pesticide application. Some of the documented aquifer sensitivity and ground-water vulnerability assessment methods, the data requirements, and a description of the method are shown in Appendices 1 and 2.

The scale and size of area to be assessed should be considered when selecting an assessment method. Aquifer sensitivity methods are generally more appropriate for screening large areas (more than one county) or comparing the sensitivity of one aquifer to another. The data required for aquifer sensitivity methods are commonly small scale and generalize broad areas. At a subcounty level, ground-water vulnerability assessment methods may be more suitable. These methods focus on smaller areas and account for chemical and physical properties of soil and pesticide usage. The two methods can be used together in steps and at different scales. For example, an aquifer sensitivity method can be used to assess large areas. After sensitive areas have been located, large-scale data layers can be constructed that describe soil properties and pesticide usage to assess the ground-water vulnerability to contamination. The advantage of making separate maps is the ability to update the data layers for the ground-water vulnerability maps as information is collected or changed.

The use of the end product is considered when selecting an assessment method. The results should be easily interpreted and provide the information needed to manage a pesticide program. Some methods, for example DRASTIC (Aller and others, 1987), show relative numerical scores that represent degree of potential for contamination. Other methods use a specific number of classes with sensitivity ratings. The VULPEST model produces a set of probability results (Villeneuve and others, 1990).

The availability and suitability of data required for the assessment method is another important consideration. Some methods require data available from publications or data bases, such as depth to water, aquifer lithology, or slope of the land surface. Other models require crop management, transpiration, or hydrologic processes, which may be difficult to define or understand. Additionally, the format, accuracy, completeness, and scale of the data must be suitable to use.

Computer software and knowledge about geographic information systems is needed to construct most assessment models; and the ability to understand and interpret data that may relate to hydrogeology, soils, pesticides, and agronomic practices.

PREVIOUS AQUIFER SENSITIVITY ASSESSMENT OF THE RUSH SPRINGS AQUIFER

The aquifer sensitivity assessment method DRASTIC (Aller and others, 1987) was used by Osborn and others (1998) to assess the sensitivity of major aquifers in Oklahoma, including the Rush Springs. The map, based on a grid cell size of 3,150 x 3,150 feet (960 x 960 meters) or about 227 acres, is shown for the study area in figure 3.

The DRASTIC method compiles seven physical and geohydrologic characteristics of the aquifer: depth to water, net recharge, aquifer media, soil media, slope of topography, effect of the vadose zone, and hydraulic conductivity of the aquifer. The assessment method produces a map showing index numbers that represent a relative measure of aquifer sensitivity. The DRASTIC indices for the Rush Springs in the study area ranged from 70 to 139; less sensitive areas are represented by lower numbers, more sensitive areas are represented by higher numbers (fig. 3).

CD-ROM DATA FORMATS

The CD-ROM has six digital datasets describing the Rush Springs aquifer and eight digital datasets describing physical and cultural features and boundaries. Twelve of the datasets were previously published (table 2) and are available from the Internet. The datasets on the CD-ROM have been cropped from the original maps to encompass only the study area, except for COUNTY, which contains all the county boundaries in Oklahoma and WATRSHD, which contains the watershed boundary that encompasses the study area.

Nitrogen-ion concentrations in ground water and depth to ground-water measurements were retrieved from the U.S. Geological Survey NWIS data base and are in the files NITROGEN.DAT and WTRLVL.DAT in the DATA_OTHER directory. Table 2 shows the directory organization on the CD-ROM.

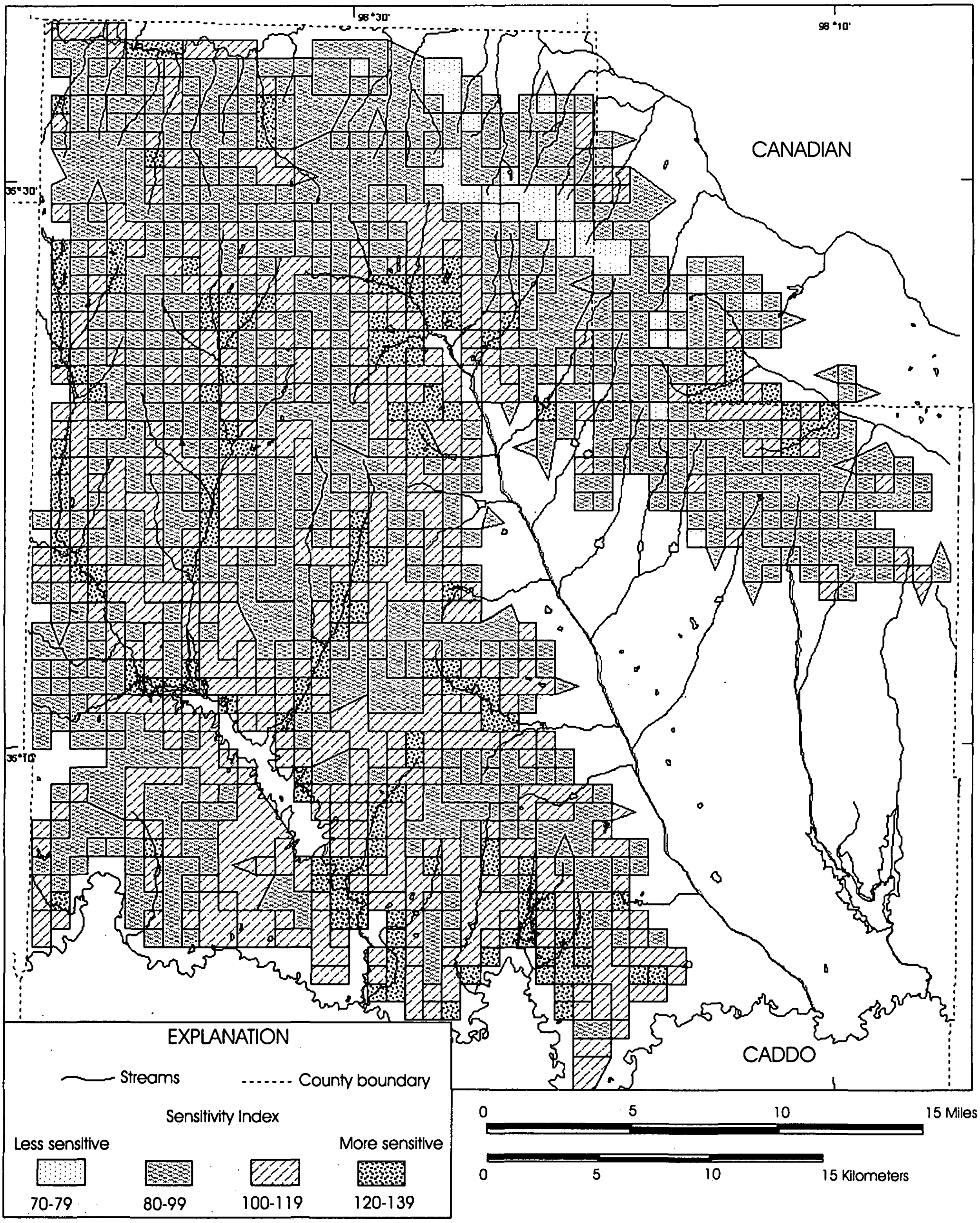


Figure 3. Aquifer-sensitivity map of the Rush Springs aquifer in the study area, parts of Caddo and Canadian Counties, Oklahoma, created by Osborn and others (1998) using DRASTIC aquifer-sensitivity method (Aller and others, 1987) and digital datasets created by Runkle and Rea (1997).

Table 2. CD-ROM organization of datasets and related files

A_NOTICE.TXT	Liability disclaimer	
A_README.1ST	Descriptive text	
\DATA_ARC\		
	\AQBOUND	Aquifer boundary (Runkle and Rea, 1997)
	\WLELEV	Ground-water level elevation contours (Runkle and Rea, 1997)
	\COND	Polygons of hydraulic conductivity values (Runkle and Rea, 1997)
	\RECHARG	Polygons of recharge values (Runkle and Rea, 1997)
	\GEOLOGY	Surficial geologic features (Cederstrand, 1996)
	\NED	Digital representation of land surface (U.S. Geological Survey, 1999)
	\COUNTY	County boundaries (Rea and Becker, 1997)
	\ELEVCON	Land-surface elevation contours (Rea and Becker, 1997)
	\NAMES	Names of physical and cultural geographic features from 7.5-minute topographic quadrangles (Rea and Becker, 1997)
	\QUAD24	Index of 7.5-minute topographic quadrangles (Rea and Becker, 1997)
	\ROADS	Roads, highways, and address ranges (Rea and Becker, 1997)
	\STREAMS	Streams, rivers, and lakes (Rea and Becker, 1997)
	\TNRGSEC	Township, range, and sections (Rea and Becker, 1997)
	\WATRSHD	8-digit watershed boundary (Rea and Becker, 1997)
\DATA_OTHER\		
	NITROGEN. DAT	Nitrogen-ion concentrations measured in ground water
	WTRLVL.DAT	Depth to ground-water measurements
\DOCUMENT\		
	'FILE'.TXT	Metadata files for each digital data layer in the ARC_DATA directory and descriptive text files for the two data files in the DATA_OTHER directory

Table 3. Albers Equal Area projection parameters

[GRS1980, Geodetic Reference System 1980; NAD83, North American Datum 1983]

Projection parameters	
Spheroid	GRS 1980
Datum	NAD83
First standard parallel	29° 30′ 00″ North
Second standard parallel	45° 30′ 00″ North
Central meridian	96° 00′ 00″ West
Latitude of projection origin	23° 00′ 00″ North
Coordinate system parameters:	
False easting	0
False northing	0
Planimetric units of measure	meters

The digital data are provided in a PC ARC/INFO (ESRI, 1998) export-file format (.e00). Complete documentation files are in the DOCUMENT directory. The documentation files comply with the Federal Geographic Data Committee Content Standards for Digital Geospatial Metadata (FGDC, 1998) The metadata files contain detailed descriptions of the datasets, and include narrative sections describing the procedures used to produce the datasets in digital form. The text files for NITROGEN.DAT and WTRLVL.DAT in the DATA_OTHER directory include a narrative section describing the data and formats.

The digital data are in the Albers Equal Area map projection (Snyder, 1987) (table 3). The table provides map projection information.

DIGITAL DATA DESCRIBING THE RUSH SPRINGS AQUIFER

Aquifer Boundaries

The AQBOUND file (Runkle and Rea, 1997) contains digitized boundaries for the Rush Springs aquifer in the study area. The data layer represents the hydrologic boundaries of the Rush Springs aquifer used in a ground-water flow model (Becker, 1998). The aquifer in the study area for the ground-water flow model, was considered to be composed of the Rush Springs Formation and overlying terrace and alluvial deposits along parts of the Canadian and Washita Rivers (Becker and Runkle, 1998). Some of the aquifer boundaries were produced from a 1:250,000-scale surficial geology map (Carr and Bergman, 1976).

The metadata contains more information about the AQBOUND file in the DOCUMENT directory. The original map extent of the AQBOUND file can be downloaded and the metadata viewed on the Internet at URL
http://water.usgs.gov/pubs/ofr/ofr96-453/index.html

Ground-Water Level Elevation Contours

Depth to water (thickness of the unsaturated zone or vadose zone) is the distance in feet from land surface to the water table. Depth to water is a hydrologic parameter used in many aquifer sensitivity and ground-water vulnerability assessment methods. Generally, the closer the ground water is to land surface, the more susceptible it is to contamination from pesticides or fertilizers.

The WLELEV file (Runkle and Rea, 1997) contains digitized ground-water level elevation contours for the Rush Springs aquifer. The contours represent water-level eleva- tions in the aquifer prior to 1950, before the aquifer was developed for irrigation. A map showing the contours was originally published at a scale of 1:250,000 in a ground-water modeling report (Becker, 1998, fig. 4). A map showing more recent ground-water level elevation contours (1986 to 1991) was published by Becker and Runkle (1998, fig. 8).

Depth to water is calculated by subtracting ground-water level elevations from land-surface elevations. A geographic information system was used to subtract the data layer WLELEV from a digital representation of the land surface for the DRASTIC aquifer-sensitivity assessment of the Rush Springs aquifer (Osborn and others, 1998). The National Elevation Dataset, referred to as NED on the CD-ROM, is a digital representation of the land surface.

The metadata contains more information about the WLELEV file in the DOCUMENT directory. The original map extent of the WLELEV file can be downloaded and the metadata viewed on the Internet at URL
http://water.usgs.gov/pubs/ofr/ofr96-453/index.html

Hydraulic Conductivity

Hydraulic conductivity describes the ability of an aquifer to transmit water and may be expressed in feet per day. An aquifer having a high hydraulic conductivity would allow ground water (and pesticides) to move at a faster rate than an aquifer having a lower hydraulic conductivity. Hydraulic conductivity for the Rush Springs aquifer, ranges from 0.8 to 10.0 feet per day (0.24 to 3.05 meters per day).

The COND file (Runkle and Rea, 1997) contains digitized polygons attributed with constant hydraulic conductivity values based on a grid cell size of 9,843 x 9,843 feet (3,000 x 3,000 meters). The data were used as input for the ground-water flow model of the Rush Springs aquifer (Becker, 1998) and were published in the model report (Becker, 1998, fig. 7). The COND dataset was used in the DRASTIC aquifer-sensitivity assessment of the Rush Springs aquifer (Osborn and others, 1998). The grid cells were resized to 960 x 960 meters (3,150 x 3,150 feet) for the assessment.

The hydraulic conductivity values represented in the COND file are based on specific capacity data and aquifer tests (Becker, 1998, p. 3). The values represent areal generalizations and do not reflect local variability of the aquifer. As a result, the value attributed to a grid cell may not accurately reflect the hydraulic conductivity of the aquifer within the cell. A large-scale vulnerability assessment may require field mapping or using aerial photographs to better define the extent of permeable sediments along creeks and rivers that were not included in the model.

The metadata contains more information about the COND file in the DOCUMENT directory. The original map extent can be downloaded and the metadata viewed on the Internet at URL
http://water.usgs.gov/pubs/ofr/ofr96-453/index.html

Net Recharge

Aquifer recharge is a hydrologic parameter used in some assessment methods. Recharge describes the amount of water that enters an aquifer and is expressed as inches per year. Under normal conditions, an aquifer is in a state of equilibrium, meaning that the volume of water that enters the aquifer is equal to the amount discharged from the aquifer. Recharge is affected by precipitation, runoff, evapotranspiration, and vertical hydraulic conductivity of the soils and sediments in the unsaturated zone.

The RECHARG file (Runkle and Rea, 1997) contains digitized polygons attributed with constant recharge values based on a grid cell size of 9,843 x 9,843 feet (3,000 x 3,000 meters). The data were used as input for the ground-water flow model of the Rush Springs aquifer and are published in the model report (Becker, 1998, fig. 8). The RECHARG dataset was used as a data layer in the DRASTIC aquifer-sensitivity assessment of the Rush Springs aquifer (Osborn and others, 1998). The grid cells were resized to 3,150 x 3,150 feet (960 x 960 meters) for the assessment.

The recharge values used in the ground-water flow model and presented in the RECHARG file are based on stream discharge measured at sites in drainage basins in the Rush Springs study area during low-flow periods in March 1989 and February 1991 (Becker, 1998 p. 16). The 87 recharge rates range from 0.09 to 3.20 inches per year (0.23 to 8.13 centimeters per year), and the average estimated recharge is about 2 inches per year (5.08 centimeters per year), or about 7 percent of the average annual precipitation. The recharge values represented in the RECHARG file are areal generalizations and may not accurately represent aquifer recharge in local areas.

The metadata contains more information about the RECHARG file in the DOCUMENT directory. The original map extent of the RECHARG file can be downloaded and the metadata viewed on the Internet at URL
http://water.usgs.gov/pubs/ofr/ofr96-453/index.html

Surficial Geology

The lithology of the aquifer can play an important role in aquifer vulnerability to pesticides. For example, very vulnerable aquifers such as terrace and alluvial deposits and karstic limestone, typically have high vertical hydraulic conductivities and are more likely to allow the downward movement of pesticides into the aquifer than less vulnerable aquifers with lower hydraulic conductivities such as shales or silty sandstones.

The GEOLOGY file contains digital data for a 1:250,000-scale surficial geology map (Cederstrand, 1996). The GEOLOGY file shows the location and contacts of formations and overlying terrace and alluvial deposits in the study area. The GEOLOGY file was used to create data layers describing aquifer media and effect of the vadose zone for the DRASTIC aquifer-sensitivity assessment of the Rush Springs aquifer (Osborn and others, 1998). The grid cell size for the model was 3,150 x 3,150 feet (960 x 960 meters).

The metadata in GEOLOGY.TXT in the DOCUMENT directory provides additional information about the data file and geologic descriptions of the formations depicted on the map. The original map extent of the GEOLOGY file can be downloaded and the metadata viewed on the Internet at URL
http://ok.water.usgs.gov/gis/geology/index.html

National Elevation Dataset, NED

The NED file is a high resolution digital representation of the land surface. This dataset was developed in a seamless raster format with a grid cell size of 98.43 x 98.43 feet (30 x 30 meters) (U.S. Geological Survey, 1999).

The NED file can be used to construct two data layers describing hydrologic components of the aquifer. The first layer is the percent slope of land surface, which is an important factor in assessing rates of runoff. Precipitation that falls on an area having a high slope may runoff into streams or creeks instead of infiltrating into the aquifer. The second data layer is thickness of the unsaturated zone. The NED file can be used to construct a digital representation of the land surface from which a data layer representing groundwater level elevations can be subtracted, as described in the WLELEV section.

The metadata contains more information about the NED file in the DOCUMENT directory. Information about NED also can be obtained on the Internet at URL

http://edc.usgs.gov/glis/hyper/guide/usgs_dem
or from:
U.S. Geological Survey
EROS Data Center
47914 252nd Street
Sioux Falls, SD 57198-0001
800-252-4547

DIGITAL DATA DESCRIBING THE STUDY AREA

Eight files on the CD-ROM in the DATA_ARC directory contain digital data describing physical and cultural features and boundaries in the study area. The data files were originally published by Rea and Becker (1997) and are available for all 77 counties in Oklahoma. The datasets are based on 1:100,000-scale source maps and can be used for project planning and management, data organization, and map making. The COUNTY file contains county boundaries and names. The ELEVCON file contains land-surface elevation contours in meters and feet above the National Geodetic Vertical Datum of 1929. The NAMES file contains the names and locations of physical and cultural geographic features of the U.S. Geological Survey 7.5-minute topographic quadrangles. The QUAD24 file contains an index for the U.S. Geological Survey 7.5-minute topographic quadrangles with boundaries and names. The ROADS file contains highways, roads, and addresses. The STREAMS file contains streams, rivers, lakes, and other surface-water features (names of the surface-water features are in the NAMES file). The TNRGSEC file contains township, range, and section line boundaries and numbers. The WATERSHD file contains the area, boundary, and hydrologic-unit codes, for the 8-digit watershed boundary that encompasses the study area.

ADDITIONAL SOURCES OF INFORMATION

Additional sources of information on pesticides, nitrogen-ion concentrations, land use and land cover, soils, and depth to ground-water measurements are described in this section. Pesticide usage information for the study area is only available at a county level. Nitrogen-ion concentrations in ground water for the study area are in a file on the CD-ROM and may help locate areas where the aquifer is sensitive to contamination. Digital datasets for land use and land cover, and soil characteristics are available for the study area at a scale of 1:20,000.

Pesticide Use and Pesticide Concentrations in Surface Water, Ground Water, and Streamside Seeps

Pesticides are applied to the soil and plant foliage to control weeds, fungus, insects, and nematodes in the study area. County-level pesticide use information is available from the U.S. Department of Agriculture, U.S. Geological Survey, and Oklahoma State University County Extension Service. The county-level information is limited and does not provide pesticide usage for specific crops, the application rates, or the application locations. Available measurements of pesticide concentrations in surface water, ground water, and streamside seeps for the study area were limited.

The U.S. Department of Agriculture, 1997 Census of Agriculture provides an estimate of the number of acres and farms that pesticides and fertilizers were applied to in Caddo County (U.S. Department of Agriculture-National Agricultural Statistics Service, 1999). The census shows that in 1997 herbicides were applied on 131,757 acres of crops and pasture land and insecticides were applied on 48,719 acres of hay and other crops in Caddo County (table 4).

A report by Battaglin and Goolsby (1994; originally reported in Gianessi and Puffer, 1991) compiles annual use estimates of 96 herbicides for all counties in the conterminous United States for 1989. The data are published as digital data and are intended for estimating regional herbicide use, and for producing maps showing relative rates of herbicide use across broad regions (Battaglin and Goolsby, 1994). Table 5 shows use estimates from the report for 26 herbicides, including atrazine, metolachlor, and simazine, in Caddo County. Use estimates show that 2,4-D and

Table 4. Agricultural chemicals and fertilizers used in Caddo County, Oklahoma in 1997

[modified from U.S. Department of Agriculture-National Agricultural Statistics Service, (1999) 1997 Census of Agriculture, vol. 1: part 36, chapter 2, table 10]

Type of chemicals used	Number of farms	Acres
Synthetic fertilizers	1,119	290,823
Agricultural chemicals used to control:		
Insects on hay and other crops	255	48,719
Nematodes in crops	41	10,331
Diseases in crops and orchards	185	36,241
Weeds, grass, or brush in crops and pasture	612	131,757
On crops to control growth, thin fruit, or defoliate	30	2,263

Table 5. Estimates[1] of use for 26 herbicides in Caddo County, Oklahoma in 1989 (data from Battaglin and Goolsby [1994] and originally reported by Gianessi and Puffer [1991])

Pesticide	Acres treated	Pounds of active ingredient applied	Pounds used per square mile
acifluorfen	6,019	2,227	1.737
atrazine	1,768	3,097	2.42
alachlor	3,602	10,213	7.97
benefin	7,635	11,452	8.932
bentazon	1,505	1,128	0.88
bromoxynil	5,266	1,989	1.551
butylate	44	175	0.14
chlorsulfuron	33,743	674	0.526
cyanazine	146	146	0.11
dicamba	27,037	7,272	5.67
dipropetryn	1,307	2,613	2.038
ethalfluralin	70	105	0.082
EPTC	404	1,212	0.95
glyphosate	11,217	9,180	7.16
MCPA	13,080	6,553	5.11
metolachlor	9,628	21,964	17.13
metsulfuron-methyl	1,294	13	0.010
metribuzin	2,993	1,186	0.93
naptalam	9,630	14,445	11.266
norflurazon	5	2	0.002
oryzalin	5	4	0.003
paraquat	184	46	0.036
pendimethalin	15,882	12,873	10.04
picloram	11,518	2,974	2.320
prometryn	1,307	2,091	1.631
propazine	3,575	7,150	5.58
sethoxydim	1,832	340	0.265
simazine	9	5	0.004
tebuthiuron	3,174	3,174	2.476
terbacil	404	303	0.236
terbutryn	894	1,787	1.394
trifluralin	16,140	11,263	8.79
vernolate	602	1,505	1.174
2,4-D	45,160	22,549	17.59
2,4-DB	18,864	8,030	6.263

[1]The data may contain under estimates of acreages. The herbicide-use estimates are totals of use on all crops treated.
http://water.usgs.gov/lookup/getspatial?herbicide1
http://water.usgs.gov/lookup/getspatial?herbicide2
http://water.usgs.gov/lookup/getspatial?herbicide3
http://water.usgs.gov/lookup/getspatial?herbicide4
http://water.usgs.gov/lookup/getspatial?herbicide5
http://water.usgs.gov/pubs/wri944176/index.html#HDR1

chlorsulfuron were applied to the largest number of acres and 2,4-D and metolachlor were used in the largest amounts in Caddo County in 1989.

Other types of pesticides used in Caddo County include fungicides, insecticides, and nematocides. A list of pesticides associated with wheat, peanuts, and corn production and commonly used in Caddo County is provided in Appendix 3 (David Nowlin, Oklahoma Cooperative Extension Service, Division of Agricultural Sciences and Natural Resource, Caddo County, written commun., 1999). This list shows that in addition to the herbicides on table 5, the herbicides trisulfuron and imazethapyr are commonly used in Caddo County.

The U.S. Geological Survey, Pesticide National Synthesis Project, reported that the most commonly found pesticides in ground water in agricultural areas were atrazine, deethylatrazine (a breakdown product of atrazine), metolachlor, and simazine (U.S. Geological Survey, 1998, table 7). At the time of this report (1999), there have been few ground-water samples analyzed for pesticides in Caddo County. Consequently, the extent and scope of pesticides in ground water is unknown. No analyses for pesticides in the study area were available from the U.S. Geological Survey NWIS data base. Ten analyses from the Oklahoma Department of Environmental Quality showed no detectable concentrations of pesticides in ground-water samples. The samples were taken from private wells and distribution points for public supply wells. Eight wells were sampled in 1995 and two wells were sampled in 1996 (Jay Wright, Oklahoma Department of Environmental Quality, written commun., 1999).

Pesticides have been detected in creeks and streamside seeps in the Fort Cobb Reservoir watershed. Oklahoma Department of Agriculture personnel sampled surface water north of Fort Cobb Reservoir at four sites along Lake Creek and one site along North Eakley Creek 11 times from April to October 1990 (fig. 2 and table 6). Atrazine was detected in North Eakley Creek in April, and at all four sites along Lake Creek in June 1990. Oklahoma Department of Agriculture personnel sampled eight wells between Lake Creek and Willow Creek, and Willow Creek and Cobb Creek in the Fort Cobb Reservoir watershed in 1990. Analyses showed no detectable concentrations of pesticides in ground-water samples (Rebecca Davidson, Caddo Tribe of Oklahoma, written commun., 1999). Oklahoma Conservation Commission personnel sampled five streamside seeps and five surface-water locations along Lake Creek between August 1998 and September 1999. Table 6 shows the pesticides detected. The four most commonly detected pesticides in surface water were aldicarb, alachlor, triclopyr, and carbofuran. The four most commonly detected pesticides in streamside seeps were aldicarb, alachlor, carbofuran, and 2,4-D (Chris Hise, Oklahoma Conservation Commission, written commun., 1999).

Nitrogen-Ion Concentrations

A potentially large nonpoint source of nitrogen in ground water is synthetic nitrogen fertilizer in Caddo County. Nitrogen is applied to croplands as anhydrous ammonia, ammonium nitrate, urea, and ammonium sulfate. A yearly application rate of 10.52 tons of nitrogen fertilizer per square mile in Caddo County was estimated by Battaglin and Goolsby (1994) from nitrogen-fertilizer sales for Caddo County between 1986 and 1991. The sales data reflect the total sales of fertilizer in Caddo County and do not consider the land use for which it was bought, or the county where the fertilizer was used (Battaglin and Goolsby, 1994).

Nitrate, the predominant nitrogen ion in water, is the most widespread agricultural contaminant found in drinking water. Nitrate concentrations can be used as an indicator of general ground-water quality and may be useful in predicting where the ground water is vulnerable to pesticides in agricultural areas (U.S. Environmental Protection Agency, 1996, p. 15).

Nitrate is known to exceed the U.S. Environmental Protection Agency primary drinking water standard for nitrate of 10 milligrams per liter as nitrogen (U.S. Environmental Protection Agency, 1999) in ground water in Caddo County. Nitrogen concentrations measured in ground water were retrieved from the U.S. Geological Survey NWIS data base. Figure 4 shows the locations of the 135 wells sampled and the 47 wells in which nitrogen-ion concentrations exceeded the primary drinking water standard. These data sites and associated nitrogen-ion concentrations are in the NITROGEN.DAT in the DATA_OTHER directory. The data are in a comma-delimited text format and consist of a location for each site defined by latitude and longitude in degrees, minutes, seconds, date of sample, a site identification number, a legal

Table 6. Pesticide detection information in surface water and streamside seeps in the Fort Cobb Reservoir watershed, Caddo County, Oklahoma, reported by Oklahoma State agencies

[SW, surface water; Seeps, streamside seeps; >, greater than detection limit]

Agency	Site	Pesticide detected	Concentration (parts per billion)	Sampling date
Oklahoma Department of Agriculture (Rebecca Davidson, Caddo Tribe of Okla., written commun., 1999)	4 SW sites along Lake Creek [1]	atrazine	0.131-0.406	June 4, 1990
	North Eakley Creek[1]	atrazine	5.09	April 23, 1990
Oklahoma Conservation Commission (Chris Hise, Oklahoma Conservation Commission, written commun., 1999)	5 SW sites along Lake Creek[2]	2,4-D	>0.7	August 1998 — September 1999
		alachlor	>0.05	
		aldicarb	>0.25	
		atrazine	>0.05	
		captan	>10.0	
		carbofuran	>0.06	
		chlorothalonil	>0.07	
		chlorpyrifos	>0.1	
		cyanazine	>0.04	
		metolachlor	>0.05	
		metribuzin	>0.04	
		picloram	>0.087	
		triclopyr	>0.03	
	5 seeps along Lake Creek[2]	2,4-D	>0.7	August 1998 — September 1999
		alachlor	>0.05	
		aldicarb	>0.25	
		atrazine	>0.05	
		captan	>10.0	
		carbofuran	>0.06	
		chlorothalonil	>0.07	
		chlorpyrifos	>0.1	
		metolachlor	>0.05	
		triclopyr	>0.03	

[1]Method of analysis is unknown.
[2]Method of analysis was enzyme linked immunosorbent assays (ELISA). Concentration is detection limit for ELISA method.

sample, a site identification number, a legal location, and the measured concentrations in milligrams per liter. The file NITROGEN.TXT in the DOCUMENT directory contains information about the file structure and how nitrogen concentrations are reported.

Land Use and Land Cover

Land use and land cover data can provide information about where pesticides and fertilizer may be applied, where crops are irrigated, or where urban development occurs. The National Land Cover datasets are high resolution digital data describing land cover for the conterminous United States. The data were developed as part of the Multi-Resolution Land Characteristics Consortium, an interagency project involving the U.S. Geological Survey, U.S. Environmental Protection Agency, National Oceanographic and Atmospheric Administration, and the U.S. Forest Service. Land cover was mapped using 21 general land cover classes and is based upon 30-meter Landsat thematic mapper satellite data. The data are organized by state and can be downloaded and the metadata viewed on the Internet at URL http://www.epa.gov/mrlc/nlcd.html

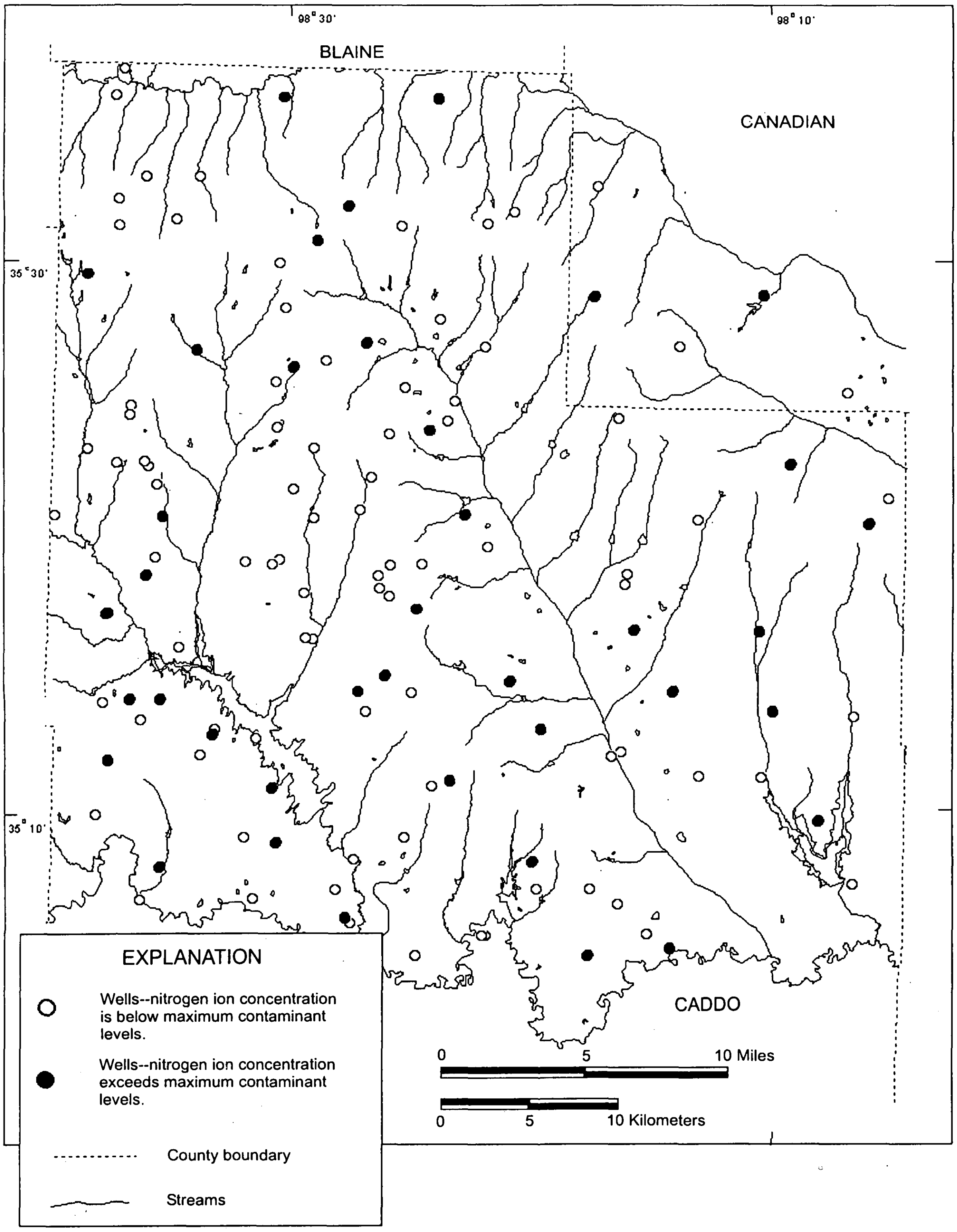


Figure 4. Well locations in the study area, parts of Caddo and Canadian Counties, Oklahoma, where nitrogen has been measured by the U.S. Geological Survey.

Currently (2000) the National Land Cover Data set describing land use for Oklahoma was preliminary and the accuracy assessment of the dataset was not completed.

Digital data describing land use and land cover are available from the U.S. Department of Agriculture at a scale of 1:20,000 for the study area. The Map Information Assembly and Display System (MIADS) Land Use/Land Cover dataset was developed between 1981-1988 from aerial photography and is described as a general purpose dataset (U.S. Department of Agriculture-National Resource Conservation Service, 1999). A map showing land use in Caddo County (U.S. Department of Defense, Atmospheric Radiation Measurement, 1999), constructed from the MIADS Land Use/Land Cover can be viewed at URL http://www.xdc.arm.gov/data_viewers/sgp_surfchar/Oklahoma_Land/caddo_l.html

Digital data describing county level land use and agricultural crop estimates for 1987 were published by Battaglin and Goolsby, (1994). The estimates are from the 1987 Census of Agriculture and are intended for estimating regional crop practices. The estimates are reported as either acres or a percentage of county area. (Battaglin and Goolsby, 1994).

Soils

The physical and chemical properties of soils help determine the transport of pesticides into the ground water. Pesticide adsorption onto soil is dependent on chemical properties of the pesticide and properties of the soil, such as pH, organic carbon content, infiltration rate, and clay content. Two digital soil geographic data bases containing soil property data are available for the study area. The Map Information Assembly and Display System/Map Unit Interpretation Database (MIAD/MUIR) and State Soil Geographic Database (STATSGO) were developed by and are available from the U.S. Department of Agriculture-National Resource Conservation Service.

The MIAD geographic (U.S. Department of Agriculture-National Resource Conservation Service, 1999) and the MUIR soil attribute (U.S. Department of Agriculture-National Resource Conservation Service, 1999b) data bases have a mapping scale of 1:20,000 and are appropriate for county and sub-county level projects. The MUIR data base contains the soil property attributes and is related to the soil unit polygons in MIAD by the soil unit symbol. Each soil unit or soil cell in the MIAD data base represents a soil that is composed of multiple layers with each layer having a high and a low value for each soil property. When using the MIAD data base, a weighted vertical average for the desired soil property for each soil cell must be calculated so each soil cell has only one value for each soil property (Alan Rea, U.S. Geological Survey, oral commun., 1999).

The STATSGO geographic data base (U.S. Department of Agriculture-National Resource Conservation Service, 1999c) was made by generalizing the county soil survey maps (U.S. Department of Agriculture, 1973, 1976) and is not appropriate for county-level decisions. STATSGO is mapped at a scale of 1:250,000, and was designed for regional, state, or multi-state planning. The STATSGO digital soil surveys were used to calculate the DRASTIC ratings for soils overlying the Rush Springs aquifer by Osborn and others (1998).

Depth to Ground-Water Measurements

Six hundred forty-two measurements of depth to water from land surface in the study area are in the file WTRLVL.DAT in the DATA_OTHER directory on the CD-ROM. The depth to water measurements were retrieved from the U.S. Geological Survey NWIS data base and were collected between 1986 and 1999 by the U.S. Geological Survey. The data in WTRLVL.DAT are in a comma delimited text format and consist of a location for each site defined by latitude and longitude in degrees, minutes, seconds, a site identification number, a legal location, and the depth to water in feet. The average depth to water was calculated for wells having more than one measurement. The WTRLVL.TXT file in the DOCUMENT directory on the CD-ROM contains more information about the WTRLVL.DAT file.

SUMMARY

The U.S. Environmental Protection Agency is working with the Caddo Indian tribe to develop a Pesticide Management Plan to prevent contamination of ground water that may result from the registered use of pesticides. An important component in the development of a Pesticide Management Plan is ascertaining where the Rush Springs aquifer may be sensitive and where ground water may be vulnerable to contamination.

The purpose of this report is to provide information on aquifer sensitivity and ground-water vulnerability assessment methods and to provide a CD-ROM with previously published digital data and other information that can be used to develop assessment maps for the study area.

Assessment methods can be divided into two general categories: aquifer sensitivity and ground-water vulnerability. Considerations when selecting an assessment method include: the scale and size of the area to be assessed, intended use of the results, availability and suitability of data required by assessment method, availability of software and hardware, and technical expertise available to conduct the assessment.

The CD-ROM associated with the report contains six data files that describe various hydrologic components of the aquifer: aquifer boundaries, ground-water level elevations, hydraulic conductivity, net recharge, surficial geology, and land-surface elevations, and eight data files that describe physical and cultural features and boundaries in the study area. Additionally, the CD-ROM contains files of nitrogen concentration in ground water and depth to ground-water measurements, retrieved from the U.S. Geological Survey National Water Information System data base.

County-level pesticide use information is available from the U.S. Department of Agriculture, U.S. Geological Survey, and Oklahoma State University County Extension Service. In 1998, herbicides were applied on 131,757 acres of crops and pasture land and insecticides were applied on 48,719 acres of hay and other crops in Caddo County. Pesticide use estimates show that 2,4-D and chlorsulfuron were applied to the largest number of acres and 2,4-D and metolachlor were used in the largest amounts in Caddo County in 1989.

Currently (2000), there have been few ground-water samples analyzed for pesticides in Caddo County. Consequently, the extent and scope of pesticides in ground water is unknown. Pesticides have been detected in creeks and streamside seeps in the Fort Cobb Reservoir watershed. The Oklahoma Department of Agriculture detected atrazine in North Eakley Creek in April 1990, and at four sites along Lake Creek in June 1990. Oklahoma Conservation Commission sampled five streamside seeps and five surface-water locations along Lake Creek between August 1998 and September 1999. The four most commonly detected pesticides in surface water were aldicarb, alachlor, triclopyr, and carbofuran. The four most commonly detected pesticides in streamside seeps were aldicarb, alachlor, carbofuran, and 2,4-D.

The National Land Cover datasets are high resolution digital data describing land cover for the conterminous United States. Land cover was mapped using 21 general land cover classes and is based upon 30-meter Landsat thematic mapper satellite data. The data are organized by state and can be downloaded from the Internet.

Two digital soil geographic data bases containing soil property data are available for the study area. The Map Information Assembly and Display System/Map Unit Interpretation Database and State Soil Geographic Database were developed by and are available from the U.S. Department of Agriculture-National Resource Conservation Service.

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APPENDIX

Appendix 1. Documented aquifer-sensitivity assessment methods, data requirements, and method descriptions (modified from EPA, 1993)

Method	Authors	Input parameters	Description
DRASTIC (Parameter weighting and scoring)	Aller and others (1987)	Depth to water table, net recharge, aquifer media, soil media, slope of land surface, effect of vadose zone, and hydraulic conductivity	DRASTIC is an acronym for a ranking system that evaluates seven hydrologic factors. Each factor is independently weighted and then added together to form a numerical index. This index represents the relative degree of potential for pesticide pollution.
AGDRASTIC (Pesticide DRASTIC) (Parameter weighting and scoring)	Aller and others (1987)	Depth to water table, net recharge, aquifer media, soil media, slope of topography, effect of vadose zone, and hydraulic conductivity	AGDRASTIC is designed to be used where pesticides are a concern. AGDRASTIC differs from DRASTIC by assigning different relative weights to the seven hydrologic factors.
Greater Denver ground-water sensitivity assessment (Hydrogeologic setting classification)	Hearne and others, (1995)	Depth to water, hydraulic conductivity, recharge aquifer media, slope of land surface, and vadose zone media	Geology, depth to water and soils, and elevation data were processed to produce maps of seven hydrologic factors. Spatial and attribute data for these maps were stored and processed using geographic information software to produce a map depicting sensitivity of the uppermost aquifer. Each sensitivity map is described in quantitative terms.
Idaho ground-water vulnerability project	Rupert and others (1991)	Depth to bedrock, depth to water table, flooding frequency, recharge, and soil permeability	This method uses a modified AGDRASTIC scoring system. Modifications include: 1) a large amount of data on well depths; 2) more detailed soil data; 3) incorporation of irrigation as the largest contributor to ground-water recharge; 4) deletion of topography as a factor; and 5) subdivision of the soil characteristics factor into four subfactors.
Leachability classes of Kansas soils (Hydrogeologic setting classification)	Kissel and others (1982)	Soil permeability, and soil texture	This method groups Kansas soils into four classes of susceptibility. Susceptibility is based on soil profile texture and water infiltration rate (permeability).
Minnesota geologic sensitivity methods (Parameter weighting and scoring)	Geologic Sensitivity workgroup (1991)	Depth to water table, soil texture of parent materials, and vadose zone material	This method applies geologic sensitivity criteria using 1 to 3 levels of assessment. The geologic sensitivity criteria are five overlapping ranges of known or estimated vertical travel times that have been assigned relative sensitivity ratings from very high to very low. A level 1 assessment estimates the sensitivity of the water table aquifer using surface and near surface information. A level 2 assessment estimates the sensitivity of the water table aquifer using information from the entire vadose zone. A level 3 assessment evaluates the sensitivity of deep, confined aquifers.

Appendix 1. Documented aquifer-sensitivity assessment methods, data requirements, and method descriptions (modified from EPA, 1993)—Continued

Method	Authors	Input parameters	Description
SEEPAGE (Parameter weighting and scoring	Moore (1988 and 1989)	Aquifer net recharge, depth to water table, horizontal distance between site and point of water used, land slope, soil attenuation potential, soil depth, and vadose zone media	This method uses a relative ranking system for seven soil and aquifer parameters. Site index numbers are calculated for different areas and compared to determine the degree of aquifer sensitivity. The method accounts for whether the potential source of contaminant is concentrated or dispersed.
South Dakota aquifer contamination vulnerability maps (combination of hydrogeologic setting classification and parameter weighting and scoring	Lemme and others (1989)	Layer permeability, organic matter content, and soil depth	This method integrates soil, topographic, and geologic data to develop sensitivity values for surface water and aquifer contamination. Drilling logs and soil survey maps are used to assess aquifer sensitivity. Sensitivity is based on the permeability of the overlying material (percent of organic matter and thickness). The results are grouped into four classes and represented on maps.
Wisconsin soil attenuation potential	Cates and Madison (1990)	Depth of soil, permeability, soil drainage class, soil organic matter content, soil pH, subsoil, and soil texture	This method evaluates soil attenuation potentials within selected Wisconsin counties. Attenuation potentials are presented on county maps at a scale of 1:100,000. Method includes subsurface geological materials and depth to ground water for the Farmstead Assessment.
Wisconsin ground water susceptibility project (Parameter weighting and scoring)	Wisconsin Department of Natural Resources, Wisconsin Geological and Natural History Survey (1987)	Characteristics of surficial deposits, depth to bedrock, depth to water table, soil characteristics, and type of bedrock	Five hydrologic factors are identified as important parameters in determining contaminant transport from overlying materials to the ground water. The five factors were overlaid to produce a composite map.

Appendix 2. Documented ground-water vulnerability assessment methods, data requirements, and method descriptions (modified from EPA, 1993)

Method	Authors	Input parameters	Description
Agricultural pesticides and ground water in North Carolina: Identification of the most vulnerable areas (Pesticide loading)	Moreau and Danielson (1990)	Aquifer media, depth to water table, hydraulic conductivity of the aquifer, effect of vadose zone media, net recharge, pesticide use and loading, soil media, and topography	This aquifer sensitivity method combines DRASTIC with pesticide use and loading data. Relative vulnerability is categorized as: 1) most vulnerable; 2) next most vulnerable; 3) next least vulnerable; and 4) least vulnerable.
Chemical Movement in Layered Soils (CMLS94) (Simulation model)	Nofziger and Hornsby (1999)	Degradation half-life, partition coefficients, precipitation, soil and chemical properties	CMLS94 estimates the movement of chemicals in soils in response to downward movement of water. The model also estimates the degradation of the chemical and the amount remaining in the soil profile as a function of time. The model accounts for soils with 20 layers or horizons, and enables the user to enter partition coefficients and degradation half-lives of the chemical interest for each horizon.
GLEAMS (Simulation model)	U.S. Department of Agriculture-agricultural Research Service (1999)	Infiltration, pesticide half-life, pesticide partitioning coefficient and volatilization, plant uptake, precipitation, and runoff	A U.S. Department of Agriculture model that evaluates the effects of agricultural management practices on transport of pesticides in the root zone. The model incorporates rainfall, infiltration, and runoff. The model solves a one dimensional transient convective-dispersive equation for solute transport using a simplified water balance. It also can calculate the movement and transformation of nutrients.
Ground water ubiquity score (GUS) (Pesticide leaching method)	Gustafson (1989)	Koc and pesticide half-life	This method calculates a GUS index. The ground water ubiquity system is a numerical continuum scale that divides pesticides into nonleachers, transitionals, and leachers. A zone is designated on the GUS scale for each class of pesticides. The GUS index is based on curve fittings between pesticide half-lives and Koc values.
Ground water contamination likelihood (Pesticide leaching method)	Rao and others (1985)	Parameters characteristic of a pesticide and surface soil horizon	This method is based on surface soil horizon and pesticide parameters. The method calculates a continuous numerical index using a multiplicative exponential method.

Appendix 2. Documented ground-water vulnerability assessment methods, data requirements, and method descriptions (modified from EPA, 1993)—Continued

Method	Authors	Input parameters	Description
Jury's benchmark approach (Pesticide leaching method)	Jury and others (1983 and 1984)	Air content, bulk density, gaseous diffusion coefficient in air, Henry's Law constant; Koc, liquid diffusion coefficient in water, organic carbon, porosity, volumetric air content, volumetric water content, and water flow	Jury and others developed a series of indices to rank pesticides according to their potential to volatilize, leach, and degrade in soil. They presented indices to define convective velocity and diffusion that incorporate pesticide, hydrogeologic, and climatic factors.
LEACH Index (Pesticide leaching method)	Laskowski and others (1982)	Kd, pesticide degradation half-life, pesticide mass per volume, and pesticide vapor pressure	This method uses a benchmark approach incorporating the effects of pesticide solubility and persistence on leaching. It accounts for four pesticide chemical properties: 1) mass per volume; 2) degradation half-life; 3) vapor pressure; and 4) sorption coefficient.
LEACHM (Simulation model)	Hutson and Wagenet (1992)	Depth to water, evapotranspiration, hydraulic conductivity, pesticide diffusion coefficient, pesticide solution concentration, pesticide sorption coefficient, soil bulk density, and water flux density	LEACHM is a finite-difference model for simulating pesticide fate in the unsaturated zone. The model includes options for Freundlich sorption and kinetic linear (two-site) sorption, and provides for simulating transport in soil columns under steady-state and interrupted steady-state flow. It can simulate the effects of layered soils, precipitation and evapotranspiration cycles, plant growth, and the transport of parent pesticides and multiple metabolites. LEACHM is the only generally available one-dimensional unsaturated zone model that solves the water balance using Richard's equation. The model also includes an option for capacity flow. If the appropriate rate constant is entered, the model can simultaneously predict concentrations of parent compounds and metabolites. [LEACHM does not consider the effects of management practices, surface hydrology, and erosion processes.]
Montana relative aquifer vulnerability evaluation (RAVE) (Pesticide loading)	DeLuca and Johnson (1990)	Crop practices, depth to water table, horizontal distance between site and point-of-water use, organic matter content, pesticide application frequency, pesticide application method, pesticide leachability, soil texture, and topography	This method consists of a numeric scoring system based on nine factors. The RAVE score is intended for on-site determinations.

Appendix 2. Documented ground-water vulnerability assessment methods, data requirements, and method descriptions (modified from EPA, 1993)—Continued

Method	Authors	Input parameters	Description
OPUS (Simulation model)	Ferreira and Smith (1992)	Crop management, erosion, evapotranspiration, irrigation, land treatment, method of application, runoff, soil water movement, and tillage and plowing operations	OPUS consists of a computer simulation model of an agricultural system. The model simulates relative hydrogeologic erosion and chemical fate results from various management and climate scenarios. The objective of this model is to indicate system response relative to various management practices. OPUS operates on various time scales and may be used in various types of agricultural studies. The required inputs include a numerical description of topography, soils, climate, initial conditions, and management practices. Processes simulated by OPUS include hydrology (runoff, soil-water flux and evapotranspiration), erosion, management, crop growth, and agricultural chemicals. OPUS generates user-specified output.
Pesticide Assessment Tool for Rating Investigations of Transport (PATRIOT) (Simulation model)	U.S. Environmental Protection Agency (1999b)	Crop irrigation, pesticide properties, precipitation, soil morphology, and soil water retention	PATRIOT is a dynamic modeling system consisting of: 1) a combined flow and transport model (PRZM-2); 2) national scope data bases for rainfall, soils geographic occurrence, soil properties, pesticide properties and crop practices; 3) data base management; 4) a soil water retention parameter estimator; and 5) ranking procedures for comparing leaching potentials for various combinations of geologic materials to the water table.
PESTANS I (Simulation model)	Enfield and others (1982)	Partitioning coefficient; percolation (water balance factor); pesticide half-life; soil-water retention coefficient	PESTANS I is a one-dimensional steady-state model that is limited to projecting vertical movement through the unsaturated zone. It is computationally simple to run and is used to evaluate the relative ground-water contamination potential of various pesticides. Although the model requires very little input data, net recharge velocity may be difficult to estimate.
PESTANS II (Simulation model)	Enfield and others (1982)	Ground water gradient, percolation (water balance factor), hydraulic conductivity, partitioning coefficient, pesticide half-life, porosity, and soil-water retention coefficient **Note**: Factors must be provided in a form that is useful for the 2-D model.	PESTANS II is a two-dimensional transient numerical model that predicts both horizontal and vertical movement of water and pesticides. This model allows the user to vary degradation rates and soil absorption with depth. Additional input data on water flux and soil characteristics in the model allow separate predictions of the rate of leaching through the root zone and the vadose zone, as well as calculations of concentrations in the saturated zone. PESTANS II requires much more hydrogeologic input data, is more complex to run, and requires considerably more computational time than PESTANS I.

Appendix 2. Documented ground-water vulnerability assessment methods, data requirements, and method descriptions (modified from EPA, 1993)—Continued

Method	Authors	Input parameters	Description
PRZM (Simulation model)	Carsel and others (1985)	Adsorption and desorption properties of pesticides, advection and dispersion processes, evapotranspiration, percolation, precipitation, and soil erosion	PRZM is a one-dimensional, dynamic, continuous, mechanistic pesticide transport model. PRZM requires two input files, one containing hydrology, crop, pesticide, and soil information, the other containing daily meteorological data. PRZM has been modified to include a stochastic (probabilistic) solution. The model provides concentrations or masses of pesticides expressed in fluxes or in accumulated quantities leaving a defined depth.
PRZM-2 (Simulation model)	Mullins and others (1993)	Agronomic practices, crop type, degradation and sorption of pesticides, precipitation, soil morphology, and soil water retention characteristics	PRZM-2 is a union of PRZM and VADOFT. VADOFT is a one-dimensional, finite-element, flow and transport model. It simulates the movement of water and chemicals within the soil profile from the bottom of the root zone to the top of the water table.
The Root Zone Water Quality Model (RZWQM) (Simulation model)	Ahuja and others (1992)	Crop residue, chemical transport, evapotranspiration, heat flow, infiltration, macropore flow, nutrient cycling, organic matter content, soil chemistry, soil pH, soil water redistribution, surface runoff, tillage and plowing operations, vegetative cover, water, nutrient, temperature, and pesticide stresses	The Root Zone Water Quality Model is a physical process model that simulates the movement of water, nutrients, and pesticides over and through the root zone at a representative location within a field. The model simulates the following processes: physical (hydrology and hydraulics of water and solute transport), nutrient, pesticide, plant growth, management, and soil chemistry. This model needs a thorough evaluation of soil properties and the relation to macropore flow.
The Seasonal Soil Compartment Model (SESOIL)	Bonazountas and others (1993)	Hydrologic cycle; evapotranspiration, exfiltration, ground-water runoff, infiltration, rainfall, soil moisture, and surface runoff. Pollutant fate cycle; advection, biological transformation, cation exchange, chemical degradation and decay, complexation of metals, diffusion and volatilization, distribution coefficient (Kd), Henry's Law constant, hydrolysis, molecular weight, and organic carbon partition coefficient (Koc). Sediment cycle; sediment resuspension and sediment washloads	The Seasonal Soil Compartment model was developed for long-term environmental hydrologic, sediment, and pollutant fate simulations. The physical setting is depicted as four distinct unsaturated soil layers or compartments, each having uniform properties. The model simulates the chemical transport and fate processes of leaching, volatilization, hydrolysis, and biodegradation. The model can describe water transport, pollutant transport and transformation, soil quality, pollutant migration to ground water, and other processes. It can provide the distribution of the chemical in the soil column that extends from the ground surface to the lower end of the unsaturated soil layer.

Appendix 2. Documented ground-water vulnerability assessment methods, data requirements, and method descriptions (modified from EPA, 1993)—Continued

Method	Authors	Input parameters	Description
The Soil and Pesticide Interaction Screening Procedure (SPISP) (Pesticide Leaching Method)	Goss (1991)	Infiltration rate, Koc, lithic soil subgroups, pesticide half-life, pesticide solubility, shallow and perched water tables, soil K factor, soil erodibility, and soil organic matter	The Soil and Pesticide Interaction Screening Procedure categorizes estimated pesticide losses three ways: 1) leached; 2) absorbed runoff; and 3) solution runoff. The model uses algorithms based on soil properties to group soils into four loss potential categories for leaching and three loss potential categories for runoff. The model also uses algorithms based on pesticide properties. The soil and pesticide groupings are combined in a matrix to give an overall loss potential: high, intermediate, or low. This potential is a first-time evaluation of the effect of using a particular pesticide on a specified soil.
VIP (Simulation model)	McLean and others (1988)		The VIP model involves numerical solution algorithms and non-equilibrium kinetics to describe the behavior of pesticides in the unsaturated zone and predict pesticide mass transport to the atmosphere and ground water.
VULPEST (Simulation model)	Villeneuve and others (1990)	Crop characteristics: climatic data, crop annual rank, crop type number, emergence data, evapotranspiration maximum potential, and maturation date. Pesticide properties: application depth, application frequency, application rate, day of application, degradation constant, Koc, and pesticide solubility. Soil characteristics: clay content of horizons, density of horizons, depth to water table, hydraulic conductivity of horizons, land slope, number of horizons, organic content of horizons, porosity of horizons, porosity of the substratum, sand and silt content of horizons, thickness of horizons, thickness of pedological soil, and vertical hydraulic conductivity of the substratum.	The VULPEST model uses the deterministic advective dispersion equation and the Monte Carlo stochastic approach to evaluate ground-water contamination by pesticides. VULPEST has been used as a management tool to permit the best use of pesticides in association with a ground-water protection scheme. The model accounts for the characteristics of nonpoint source contamination and provides a set of probabilistic results. Results obtained from VULPEST include the maximum concentration, the average annual concentration and the cumulative mass for each Monte Carlo simulation. The model is reported as a useful tool in identifying vulnerable sites and quantifying the type and rate of pesticide that can be applied to minimize the risk of contamination.

Appendix 3. Pesticides associated with wheat, peanuts, and corn production and that are commonly used in Caddo County, Oklahoma (David Nowlin, Oklahoma Cooperative Extension Service, Division of Agricultural Sciences and Natural Resource, Caddo County, written commun., 1999)

Common name	Trade name	Usage	Type of pesticide
	WHEAT		
2,4-D amine	2,4-D	yes	herbicide
2,4-D ester	2,4-D		herbicide
metsulfuron-methyl	Ally, Finesse	yes	herbicide
trisulfuron	Amber	yes	herbicide
permethrin	Ambush, Pounce		insecticide
esfenvalerate	Asana		insecticide
imazamethabenz m-isomer	Assert		herbicide
imazamethabenz p-isomer	Assert		herbicide
atrazine	Atrazine		herbicide
difenzoquat	Avenge		herbicide
dicamba	Banvel	yes	herbicide
triadimefon	Bayleton		fungicide
cyanazine	Bladex		herbicide
benomyl	Benlate		insecticide
bromoxynil	Buctril		insecticide
dimethoate	Cygon	yes	insecticide
disulfoton	Di-Syston		insecticide
trichlorfon	Dylox		insecticide
ethyl parathion	Ethyl parathion		insecticide
tribenuron-methyl	Express		herbicide
triallate	Far-Go		herbicide
carbofuran	Furadan		insecticide
chlorsulfuron	Glean	yes	herbicide
paraquat	Gramoxone		herbicide
diclofop-methyl	Hoelon		herbicide
terbutryn	Igran		herbicide
diuron	Karmex		herbicide
methomyl	Lannate		insecticide
chlorpyrifos	Lorsban, Dursban	yes	insecticide
malathion	Malathion	yes	insecticide
mancozeb	Manzate		fungicide
MCPAamine	MCPA		herbicide
MCPA ester	MCPA		herbicide
thiabendazole	Mertect		fungicide
methyl parathion	Methyl parathion	yes	insecticide
fenoxaprop-ethyl	Option-whip		herbicide
thifensulfuron	Pinnacle		herbicide
glyphosate	Roundup	yes	herbicide

Appendix 3. Pesticides associated with wheat, peanuts, and corn production and that are commonly used in Caddo County, Oklahoma (David Nowlin, Oklahoma Cooperative Extension Service, Division of Agricultural Sciences and Natural Resource, Caddo County, written commun., 1999)—Continued

Common name	Trade name	Usage	Type of pesticide
metribuzin	Sencor, Lexone		herbicide
carbaryl	Sevin		insecticide
propanil	Stam		herbicide
clopyralid	Stinger		herbicide
phorate	Thimet		insecticide
endosulfan	Thiodan		insecticide
propiconazole	Tilt, Orbit		fungicide
thophanate-methyl	Topsin		fungicide
picloram	Tordan		herbicide
trifluralinl	Treflan		herbicide
	PEANUTS		
pendimethalin	Prowl EC	yes	herbicide
trifuralin	Treflan EC	yes	herbicide
imazethapyr	Pursuit 2L	yes	herbicide
2,4-DB	Butyrac 200	yes	herbicide
acifluorfenl	Blazer 4L		herbicide
sethoxydim	Poast Plus 1E		herbicide
metolachlor	Dual	yes	herbicide
aldicarb	Temik 15G	yes	nematicide
PCNB	Terraclor		fungicide
chlorothalonil	Bravo	yes	fungicide
tebuconazole	Folicur	yes	fungicide
flutolanil	Monocut	yes	fungicide
mancozeb	Dithane DF	yes	fungicide
copper hydroxide	Kocide	yes	fungicide
lambda-cyhalothrin	Karate Z	yes	insecticide
esfenvalerate	Asana XL		insecticide
acephate	Orthene 75S	yes	insecticide
Bacillus-thuringiensis var kurstaki	Javelin		insecticide
propargite	Omite, Comite	yes	insecticide
chlorpyrifos	Lorsban 15G		insecticide
carbaryl	Sevin		insecticide
	CORN		
alachlor	Cornbelt saddle Confidence		herbicide
atrazine	Atrazine	yes	herbicide
simazine	Stall		herbicide
metalochlor	Dual 8EC		herbicide

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