

Prepared in cooperation with the Wyoming Department of Agriculture and the Wyoming Department of Environmental Quality, on behalf of the Wyoming Ground-water and Pesticides Strategy Committee

Occurrence of Pesticides in Ground Water of Wyoming, 1995–2006



Scientific Investigations Report 2009–5024

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

Front cover photograph: Rural well sampled in Platte County, September 14, 2008. Photograph by Seth Davidson, U.S. Geological Survey.

Back cover photographs: Upper photographs left to right: (1) Hydrologist processing water sample, August 2003. Photograph by Cheryl Miller, U.S. Geological Survey. (2) Hydrologist using an electric tape to measure water level, Goshen County, August 1998. Photograph by Laura Gianakos, U.S. Geological Survey. (3) Hydrologist beginning sampling of domestic well in Goshen County, August 1998. Photograph by Cheryl Miller, U.S. Geological Survey.
Lower photograph: Rural well sampled in Platte County, September 14, 2008. Photograph by Seth Davidson, U.S. Geological Survey.

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By Timothy T. Bartos, Cheryl A. Eddy-Miller, and Laura L. Hallberg

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

U.S. Department of the Interior

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U.S. Geological Survey

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Conversion Factors and Datums

Multiply	By	To obtain
Length		
inch (in.)	2.54	centimeter (cm)
inch (in.)	25.4	millimeter (mm)
foot (ft)	0.3048	meter (m)
meter (m)	3.281	foot (ft)
mile (mi)	1.609	kilometer (km)
Volume		
ounce, fluid (fl. oz)	0.02957	liter (L)
Flow rate		
inch per hour (in/h)	0.0254	meter per hour (m/h)

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

$$^{\circ}\text{F}=(1.8\times^{\circ}\text{C})+32$$

Specific conductance is given in microsiemens per centimeter at 25 degrees Celsius ($\mu\text{S}/\text{cm}$ at 25°C).

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

Abbreviations and Acronyms

Abbreviated Water-Quality Units Used in This Report:

mg/L	milligram per liter
µg/L	microgram per liter
µS/cm	microsiemens per centimeter at 25 degrees Celsius

Abbreviations and Acronyms Used in This Report:

<	less than
>	greater than
≤	less than or equal to
CAL	common assessment level
CSAL	compound-specific assessment level
CTA	contingency-table analysis
DO	dissolved oxygen
GIS	geographic information system
GPSC	Ground-water and Pesticides Strategy Committee
KWOCR	Kruskal-Wallis test for ordered categorical responses
LHA	Lifetime Health Advisory
LRL	laboratory reporting level

LT-MDL	long-term method detection level
MCL	Maximum Contaminant Level
MDL	method detection limit
MRL	minimum reporting level
NAL	no assessment level
NAWQA	National Water-Quality Assessment
NLCD	National Land Cover Data
NWIS	National Water Information System of U.S. Geological Survey
NWQL	National Water Quality Laboratory of U.S. Geological Survey
QA	quality assurance
QC	quality control
RPD	relative percentage difference
RSD	Risk-Specific Dose
RSD4	Risk-Specific Dose at 10^{-4} Cancer Risk
SMP	State of Wyoming Generic Management Plan for Pesticides in Ground Water
SSURGO	Soil Survey Geographic database
STATSGO	State Soil Geographic database
USEPA	U.S. Environmental Protection Agency
USGS	U.S. Geological Survey
WDEQ	Wyoming Department of Environmental Quality

Occurrence of Pesticides in Ground Water of Wyoming, 1995–2006

By Timothy T. Bartos, Cheryl A. Eddy-Miller, and Laura L. Hallberg

Abstract

Little existing information was available describing pesticide occurrence in ground water of Wyoming, so the U.S. Geological Survey, in cooperation with the Wyoming Department of Agriculture and the Wyoming Department of Environmental Quality on behalf of the Wyoming Ground-water and Pesticides Strategy Committee, collected ground-water samples twice (during late summer/early fall and spring) from 296 wells during 1995–2006 to characterize pesticide occurrence. Sampling focused on the State's ground water that was mapped as the most vulnerable to pesticide contamination because of either inherent hydrogeologic sensitivity (for example, shallow water table or highly permeable aquifer materials) or a combination of sensitivity and associated land use.

Because of variations in reporting limits among different compounds and for the same compound during this study, pesticide detections were recensored to two different assessment levels to facilitate qualitative and quantitative examination of pesticide detection frequencies—a common assessment level (CAL) of 0.07 microgram per liter and an assessment level that differed by compound, referred to herein as a compound-specific assessment level (CSAL). Because of severe data censoring (fewer than 50 percent of the data are greater than laboratory reporting limits), categorical statistical methods were used exclusively for quantitative comparisons of pesticide detection frequencies between seasons and among various natural and anthropogenic (human-related) characteristics.

One or more pesticides were detected at concentrations greater than the CAL in water from about 23 percent of wells sampled in the fall and from about 22 percent of wells sampled in the spring. Mixtures of two or more pesticides occurred at concentrations greater than the CAL in about 9 percent of wells sampled in the fall and in about 10 percent of wells sampled in the spring. At least 74 percent of pesticides detected were classified as herbicides. Considering only detections using the CAL, triazine pesticides were detected much more frequently than all other pesticide classes, and the number of different pesticides classified as triazines was the largest of all classes.

More pesticides were detected at concentrations greater than the CSALs in water from wells sampled in the fall (28 different pesticides) than in the spring (21 different pesticides). Many pesticides were detected infrequently as nearly one-half of pesticides detected in the fall and spring at concentrations greater than the CSALs were detected only in one well. Using the CSALs for pesticides analyzed for in 11 or more wells, only five pesticides (atrazine, prometon, tebuthiuron, picloram, and 3,4-dichloroaniline, listed in order of decreasing detection frequency) were each detected in water from more than 5 percent of sampled wells. Atrazine was the pesticide detected most frequently at concentrations greater than the CSAL.

Concentrations of detected pesticides generally were small (less than 1 microgram per liter), although many infrequent detections at larger concentrations were noted. All detected pesticide concentrations were smaller than U.S. Environmental Protection Agency (USEPA) drinking-water standards or applicable health advisories. Most concentrations were at least an order of magnitude smaller; however, many pesticides did not have standards or advisories.

The largest percentage of pesticide detections and the largest number of different pesticides detected were in samples from wells located in the Bighorn Basin and High Plains/Casper Arch geographic areas of north-central and southeastern Wyoming. Prometon was the only pesticide detected in all eight geographic areas of the State.

Pesticides were detected much more frequently in samples from wells located in predominantly urban areas than in samples from wells located in predominantly agricultural or mixed areas. Pesticides were detected distinctly less often in samples from wells located in predominantly rangeland/undeveloped areas. The frequency of pesticide detection in samples from wells located in either predominantly agricultural or mixed land-use areas was intermediate to those samples from urban and rangeland/undeveloped areas. Using the CAL, the proportion of wells with at least one pesticide detected was significantly different among the four land-use categories for both the fall and the spring.

Pesticide detections in ground water were examined in relation to hydrogeology (aquifer type, water-level depth, well depth, and well type). The percentage of wells with at least one pesticide detected was larger for wells completed

in unconsolidated-deposit aquifers than for wells completed in bedrock aquifers. Using the CAL, the proportion of wells with at least one pesticide detected was significantly different between unconsolidated and bedrock aquifers sampled in the fall but not in the spring. Also using the CAL, the proportion of wells with at least one pesticide detected was significantly different among different categories of well depth and well type. The proportion of samples with pesticides detected at concentrations greater than their respective CSALs (detection frequency) was significantly different among water-level-depth categories for one pesticide—deethylatrazine (spring but not fall samples). In most cases, pesticide detection frequencies decreased as well depth increased, but no clear increase or decrease in pesticide detection frequencies was noted as water-level depth increased. The proportion of samples with pesticides detected at concentrations greater than their respective CSALs was significantly different among different categories of well depth and well type for three pesticides (prometon, tebuthiuron, and bromacil, listed in order of decreasing detection frequency) detected in both the fall and spring, and for one pesticide detected (diuron) in the spring.

Pesticide detections in ground water were examined in relation to selected soil properties (organic matter content, soil permeability, and soil hydrologic index) from the State Soil Geographic (STATSGO) database mapped within a 500-meter (1,640-foot) radius surrounding each sampled well. The proportion of samples with pesticides detected at concentrations greater than their respective CSALs was significantly different among organic-matter-content categories for four pesticides (atrazine, tebuthiuron, flumetsulam, and fipronil sulfide, listed in order of decreasing detection frequency) detected in the fall and in one pesticide (tebuthiuron) detected in the spring. The proportion of samples with pesticides detected at concentrations greater than their respective CSALs was significantly different among soil-permeability categories for three pesticides (deethylatrazine, tebuthiuron, and aldicarb sulfone, listed in order of decreasing detection frequency) detected in the fall and for two pesticides (atrazine and tebuthiuron) detected in the spring. The proportion of samples with pesticides detected at concentrations greater than their respective CSALs was significantly different among soil-hydrologic-index categories (derived from several soil properties) for two pesticides (atrazine and deethylatrazine) detected in both fall and spring. For most pesticides, no clear trend of increasing or decreasing frequency of detection was noted as organic matter content and soil permeability increased, and there was not a clear trend among the soil-hydrologic-index categories.

One water-quality constituent (nitrate) and three different water-quality characteristics (specific conductance, pH, and dissolved oxygen) were examined in relation to the occurrence of pesticides in ground water. Using the CAL, the proportion of wells with at least one pesticide detected was significantly different between the nitrate concentration categories of less than and greater than or equal to 1.1 milligrams per liter for the fall and the spring. The proportion of samples detected at

concentrations greater than their respective CSALs was much larger for the “elevated” nitrate concentration category than for the other nitrate concentration category for almost every pesticide tested, and the difference was significant between the two nitrate concentration categories for three pesticides (atrazine, prometon, and deethylatrazine, listed in order of decreasing detection frequency) in both the fall and spring, one pesticide (tebuthiuron) in the fall, and one pesticide (bromacil) in the spring.

The proportion of samples with pesticides detected at concentrations greater than their respective CSALs (detection frequency) was much larger for the saline-water category than for the freshwater category (on the basis of specific conductance) for almost every pesticide tested. The proportion of samples with pesticides detected at concentrations greater than their respective CSALs was significantly different between the two specific conductance categories for one pesticide (tebuthiuron) in both the fall and spring and for one pesticide (prometon) only in the fall.

Using the CAL, the proportion of wells with at least one pesticide detected was significantly different among the three pH categories—acidic, circumneutral, and alkaline—for the fall and spring. The proportion of samples with pesticides detected at concentrations greater than their respective CSALs was significantly different among the three pH categories for three pesticides (prometon, tebuthiuron, and bromacil, listed in order of decreasing detection frequency) detected in both the fall and spring and for one pesticide (diuron) in the spring. For many pesticides, no clear trend of increasing or decreasing frequency detection was noted as pH increased.

The proportion of samples with pesticides detected at concentrations greater than their respective CSALs was significantly different between the two dissolved oxygen categories (representative of anoxic and oxic conditions) for one pesticide (tebuthiuron) in the fall.

Introduction

Since 1986, the U.S. Environmental Protection Agency (USEPA) has been developing a strategy to address ground-water contamination by pesticides and other agricultural chemicals. In October 1991, the USEPA completed the “Pesticides and Ground-Water Strategy” that describes, in part, a new Federal-State partnership approach to address potential risks posed to ground water by the use of pesticides (Wyoming Ground-water and Pesticides Strategy Committee, 1999). In response, the State of Wyoming created the Ground-water and Pesticide Strategy Committee (GPSC) consisting of members of local, State, and Federal government, as well as industry and interest groups, to prepare the State of Wyoming Generic Management Plan for Pesticides in Ground Water (SMP; Wyoming Ground-water and Pesticides Strategy Committee, 1999). The SMP includes information describing individuals and organizations involved with implementation of the

SMP, ground-water contamination prevention, ground-water monitoring, and required responses if pesticides are detected in ground water.

In Wyoming, little existing information was available describing pesticide occurrence in ground water. In accordance with the SMP, the GPSC began a program to conduct “baseline ground-water sampling” to characterize current pesticide occurrence in Wyoming’s ground water. In addition, the GPSC identified 20 pesticides (18 parent pesticides and 2 degradation products) to be of greatest interest during baseline ground-water sampling (defined as “focal compounds” and referred to herein as “focal pesticides”).

The U.S. Geological Survey (USGS), in cooperation with the Wyoming Department of Agriculture and the Wyoming Department of Environmental Quality (WDEQ) and acting on behalf of the GPSC, began statewide implementation of this baseline ground-water sampling in 1995. The objectives of the baseline sampling were to:

1. Summarize the occurrence of pesticides in ground water in the State of Wyoming, and
2. Evaluate the occurrence of pesticides in relation to selected natural and anthropogenic (human-related) characteristics such as geography, land use, hydrogeology, soils, and selected water-quality constituents and characteristics.

As part of this baseline sampling, water samples were collected during fall and spring from 296 wells in Wyoming during 1995–2006 and analyzed for pesticides. To date, data from these ground-water samples have been published in the USGS Annual Water Data Reports for Wyoming (Water Years 1995–1999 are available as hardcopy only and are listed at <http://wy.water.usgs.gov/pubs/statebiblio/data.htm#wdrn> and Water Years 2000–2006 are available online at <http://wy.water.usgs.gov/pubs/adr/index.htm>) and summarized by county in a series of 22 USGS Fact Sheets (listed individually in the “Selected References” section at the end of this report and provided on a CD-ROM at the back of the report). Ground-water-quality data for these and all USGS water-quality samples can be obtained on the Worldwide Web from the National Water Information System (NWISWeb at <http://waterdata.usgs.gov/wy/nwis/>). Descriptions of wells sampled for this study are available in NWISWeb and USGS Annual Data Reports for Wyoming.

Purpose and Scope

The purposes of this report are to (1) present a summary on the occurrence of pesticides in ground water in the State of Wyoming during 1995–2006 and to (2) describe relations between pesticide occurrence and selected natural and anthropogenic factors. The summary of pesticide occurrence includes detection frequencies; occurrence of mixtures; detections by type, class, and individual pesticides; concentrations and comparisons to USEPA standards and health advisories;

and detections in relation to pesticide use. Natural and anthropogenic factors that were evaluated for relations with pesticide occurrence include geography, land use, hydrogeology, soils, nitrate, and other water-quality characteristics.

Acknowledgments

The authors gratefully acknowledge the generous assistance of landowners throughout Wyoming who provided access to their property and wells for the baseline sampling. The authors also acknowledge assistance with site selection from the many Conservation Districts and County Weed and Pest Districts in Wyoming. David L. Lorenz (USGS) is thanked for his invaluable assistance and guidance with the categorical statistical methods used in this report.

Methods of Investigation

This section describes the methods used for the selection of sampling locations, collection of ground-water samples and analysis for pesticides using USGS laboratory analytical methods and reporting conventions, and the collection and analysis of quality-control samples as part of a quality-assurance program. Finally, the approach used to censor data, assemble final data sets, and analyze data using statistical methods is described.

Selection of Sampling Locations

Baseline ground-water sampling to describe the occurrence and distribution of pesticides in ground water of Wyoming began in 1995 and was completed in 2006. During this time, water samples were collected twice—once each during late summer/fall (August through November and referred to herein as “fall”) and spring (March through May)—from 296 wells (except for one well that was only sampled in the fall). The wells were located in areas of “high” or “medium-high” ground-water vulnerability to pesticide contamination that were mapped for the entire State of Wyoming (Hamerlinck and Arneson, 1998) as part of the SMP. The most vulnerable ground water was determined for the uppermost or shallowest aquifers in Wyoming by using a geographic information system (GIS) to overlay and combine digital information describing hydrogeologic and land-use characteristics (Hamerlinck and Arneson, 1998). Using this procedure, ground water was identified and mapped as vulnerable due to inherent “sensitive” hydrogeologic characteristics (for example, shallow water table or highly permeable aquifer materials) and overlying land use involving the application of pesticides.

The ground-water vulnerability map (fig. 1) then was used in combination with cropland extent, percentage of urban area, and 1991 pesticide sales in each county (Wyoming

Ground-water and Pesticides Strategy Committee, 1999) to evaluate and rank each county in order of highest to lowest ground-water vulnerability to pesticide contamination. Each Wyoming county then was sampled in order of this predetermined rank (fig. 1). Some county ranks were elevated above others due to previous pesticide detections in historical ground-water-quality samples. All 23 Wyoming counties were sampled on the basis of ranked order with the exception of Goshen County (southeastern Wyoming), which was selected as a pilot study, and Niobrara and Weston Counties (east-central Wyoming), which were combined due to minimal mapped vulnerability. The majority of the wells sampled during the study were located in the most vulnerable areas mapped in each county (shown “high” vulnerability in fig. 1), with a few sampled wells located in the second-most vulnerable areas (“medium-high” vulnerability in fig. 1).

Sample Collection and Chemical Analyses

Ground-water samples were collected and processed in a mobile water-quality laboratory using USGS National Water-Quality Assessment (NAWQA) procedures (Koterba and others, 1995) and the USGS National Field Manual for the Collection of Water-Quality Data (U.S. Geological Survey, 1997–2006). Samples were sent to the USGS National Water Quality Laboratory (NWQL) in Denver, Colo., for analysis using different methods selected to detect 20 pesticides (18 parent pesticides and 2 pesticide degradates) identified in the SMP as focal pesticides of greatest concern (table 1). The USGS NWQL analytical methods selected to detect focal pesticides in ground-water samples also could detect many additional nonfocal (as many as 136) pesticides (table 1). Ground-water samples were analyzed for all pesticides listed in table 1, with the exception of difenzoquat (not listed in table 1), for which analytical methods were not available. However, some of these pesticides listed in table 1 were analyzed for in relatively few samples because of changes to laboratory analytical schedules during the baseline study. Samples collected to detect the semivolatile pesticide *cis*- and *trans*-1,3-dichloropropene (trade name telone) were sent to TestAmerica Laboratory (formerly known as Quanterra and Severn Trent) in Denver, Colo., for analysis using USEPA method 8260B (U.S. Environmental Protection Agency, 1986).

Data Reporting and Treatment

Ground-water samples were analyzed using USGS analytical methods with laboratory reporting limits much smaller than typically used in routine pesticide monitoring of public drinking-water supplies. Consequently, it is likely that much more frequent rates of detection were obtained than would have been possible with less sensitive analytical methods. Reporting limits varied by pesticide, and many reporting limits changed during the course of the study, so pesticide detections were recensored to account for variations

in reporting limits among the different compounds and for the same compound before data were summarized and analyzed. Detections were recensored to two different assessment levels to facilitate qualitative and quantitative examination of pesticide detection frequencies. The types of reporting limits used and the process used to recensor data and assemble final data sets for analysis are discussed in this section of the report.

Laboratory Reporting Limits

During this study, the USGS NWQL reported analytical results for pesticides relative to three types of reporting limits, referred to as “original NWQL censoring.” Very small concentrations are censored and reported as “less than” values by the NWQL to avoid false-positive detections (reporting detections when the analytes are not actually present in the sample). Censoring levels, generally known as “reporting limits,” are specific to analytical methods and can change over time as methods change.

The oldest and most basic of three types of reporting limits used by the NWQL during this study was the minimum reporting level (MRL), which is defined as the minimum concentration of a constituent that can be reliably measured using a given analytical method (Timme, 1995). This is the least “robust” of three reporting limits used during this study for pesticide analyses as “establishment of the MRL has been inconsistent across methods and typically inadequately defined and often undocumented” (Childress and others, 1999, p. 2). Use of the MRL was infrequent during this study as it was applied only to one laboratory method (NWQL laboratory schedule 1379) that was used for selected pesticide analyses in 25 ground-water samples collected during fall and spring 1995 in Goshen County (southeastern Wyoming) and for selected pesticide analyses in 25 ground-water samples collected during spring 1997 in Park County (northwestern Wyoming).

The second of three types of reporting limits used by the NWQL during this study was the method detection limit (MDL), which is defined as the minimum concentration of a constituent that can be identified, measured, and reported with 99-percent confidence to be significantly greater than zero (Childress and others, 1999). The NWQL determined the MDL using the “USEPA MDL procedure” (U.S. Environmental Protection Agency, 1997). At the MDL concentration, the risk of false-positive detection is no more than 1 percent. The MDL generally is less than and more statistically defined than the MRL. Some detections greater than or less than the MDL were qualified using an “E” remark code because of measurement uncertainty (U.S. Geological Survey Water Quality Laboratory Technical Memorandum 94.12, 1994). Values given an “E” remark code are considered semiquantitative. The NWQL set the reporting limit equivalent to the MDL for many pesticide analyses during this study including NWQL analytical schedules 2001 (Zaugg and others, 1995) and 2060 (Furlong and others, 2001) and for many of the analytes in schedule 2050 (U.S. Geological Survey, 1997).

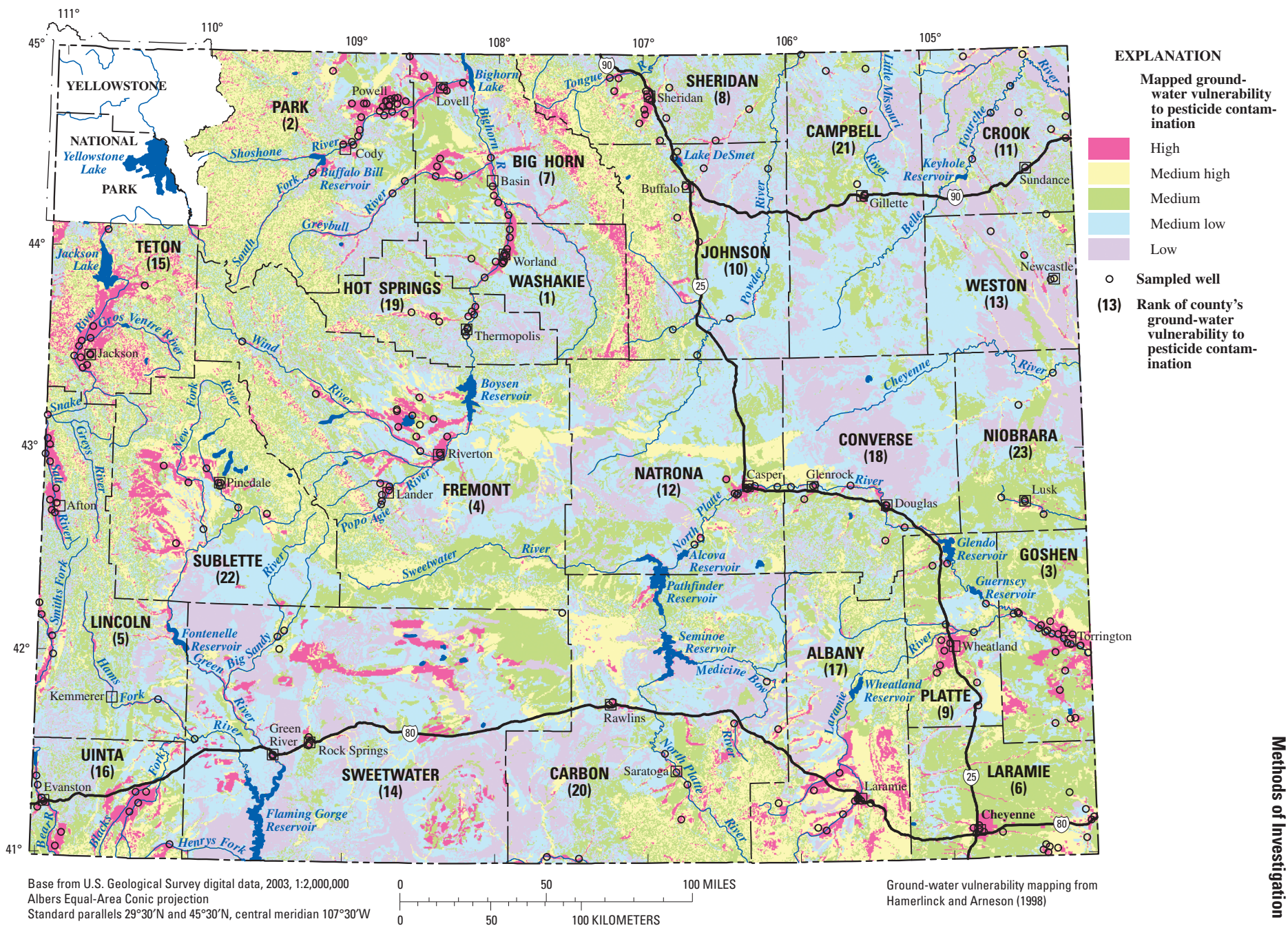


Figure 1. Mapped ground-water vulnerability to pesticide contamination (from Hamerlinck and Arneson, 1998) and sampled wells, Wyoming, 1995–2006.

Table 1. Pesticides analyzed, trade names, pesticide actions, classes, laboratory reporting limits, and U.S. Environmental Protection Agency standards or health advisories.

[Compounds detected with original censoring during study are in **bold type**; USGS, U.S. Geological Survey; µg/L, micrograms per liter; USEPA, U.S. Environmental Protection Agency; --, not applicable; U, chemical was analyzed for, but not detected; analytical method type: 1 = USGS laboratory schedule 2001, 2 = USGS laboratory schedule 2050, 3 = USGS laboratory schedule 1379, 4 = USGS laboratory schedule 2060, 5 = USGS laboratory schedule 2033; 6 = Severn Trent Laboratories, USEPA method 8260B; USEPA standard or health advisory: RSD4 = U.S. Environmental Protection Agency Risk-Specific Dose at 10⁻⁴ Cancer Risk (U.S. Environmental Protection Agency, 2006); MCL = U.S. Environmental Protection Agency Maximum Contaminant Level (U.S. Environmental Protection Agency, 2006); LHA = U.S. Environmental Protection Agency Lifetime Health Advisory (U.S. Environmental Protection Agency, 2006)]

Pesticide	Trade name	Pesticide action	Pesticide class (or parent compound class)	USGS laboratory parameter code	Analytical method ¹ (see head- note)	Minimum laboratory reporting limit (µg/L)	Maximum laboratory reporting limit (µg/L)	USEPA standard or health advisory (µg/L)
Acetochlor	Guardian, Harness, Relay	Preplant herbicide	Amide/chloroacet- amide	49260	1, 3, 5	0.002	0.05	--
Acifluorfen	Blazer, Tackle 2S, Astic	Herbicide	Miscellaneous acid	49315	2, 4	.007	.24	100 (RSD4)
Alachlor ²	Alanex, Lasso, Shroud	Herbicide	Amide/acetanilide	46342	1, 3, 5	.002	.05	2 (MCL)
Aldicarb ²	Temik	Insecticide, nemati- cide, acaricide	Carbamate	49312	2, 4	.02	1.86	3 (MCL) ³
Aldicarb sulfone ²	Aldicarb degradate, Standak, Aldoxycarb	--	Carbamate	49313	2, 4	.02	1.31	2 (MCL) ³
Aldicarb sulfoxide ²	Aldicarb degradate	--	Carbamate	49314	2, 4	.008	.27	4 (MCL) ³
Ametryn	Evik	Herbicide	Triazine	38401	3	.05	--	60 (LHA)
Atrazine ²	Aatrex, Atranex	Herbicide	Triazine	39632	1, 3, 4, 5	.001	.05	3 (MCL)
Azinphos-methyl	Guthion, Crysthion	Insecticide	Organophosphate	82686	1, 5	.001	.05	--
Bendiocarb	Ficam, Garrox, Turcam	Insecticide	Carbamate	50299	4	.02	.03	--
Benfluralin	Balan, Benefin	Herbicide	Dinitroaniline	82673	1, 5	.002	.013	--
Benomyl	Benlate, Benex	Fungicide	Carbamate	50300	4	.004	.022	--
Bensulfuron, methyl	Escuri, Londax	Herbicide	Urea/sulfonylurea	61693	4	.02	--	--
Bentazon	Basagram, Bentazone	Herbicide	Miscellaneous	38711	2, 4	.01	.06	200 (LHA)
Bromacil ²	Hyvar X	Herbicide	Miscellaneous	04029	2, 3, 4	.01	1.1	70 (LHA)
Bromoxynil	Buctril, Brominal, Agristar	Herbicide	Miscellaneous	49311	2, 4	.01	1.6	--
Butachlor	Butanex, Lambast, Machete	Herbicide	Amide	04026	3	.05	--	--
Butylate	Sutan+, Genate Plus	Herbicide	Carbamate	04028	1, 3	.002	.05	400 (LHA)
Carbaryl	Carbatox, Sevin	Insecticide	Carbamate	49310	2, 4	.008	.08	4,000 (RSD4)
Carbaryl	Carbatox, Sevin	Insecticide	Carbamate	82680	1, 5	.003	.046	4,000 (RSD4)
Carbofuran	Furadan, Futura	Insecticide	Carbamate	49309	2, 4	.006	3.33	40 (MCL)
Carbofuran	Furadan, Futura	Insecticide	Carbamate	82674	1, 5	.003	.02	40 (MCL)
Carboxin	Kisvax, Oxatin, Vitavax	Fungicide	Miscellaneous	04027	3	.05	--	700 (LHA)

Table 1. Pesticides analyzed, trade names, pesticide actions, classes, laboratory reporting limits, and U.S. Environmental Protection Agency standards or health advisories.
—Continued

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Pesticide	Trade name	Pesticide action	Pesticide class (or parent compound class)	USGS laboratory parameter code	Analytical method ¹ (see head- note)	Minimum laboratory reporting limit (µg/L)	Maximum laboratory reporting limit (µg/L)	USEPA standard or health advisory (µg/L)
Chloramben, methyl ester	Chloramben	Herbicide	Miscellaneous acid	61188	2, 4	0.01	0.42	100 (LHA)
Chlorimuron	Classic, Darban, Lory	Herbicide	Urea/sulfonylurea	50306	4	.01	.046	--
2-Chloro-2',6'-dieth- ylacetanilide	Butenachlor degradate	--	Amide	61618	5	.005	.006	--
4-Chloro-2-methyl- phenol	MCPA degradate	--	Urea	61633	5	.005	.006	--
Chlorothalonil	Bravo	Fungicide	Organochlorine	49306	2, 4	.01	.48	150 (RSD4)
Chlorpyrifos	Dursban, Lorsban	Insecticide	Organophosphate	38933	1, 5	.004	.006	2 (LHA)
Clopyralid ²	Stinger, Lontrel	Herbicide	Pyridinecarboxylic acid	49305	2, 4	.01	1.82	--
Cyanazine ²	Bladex	Selective herbicide	Triazine	04041	1, 3, 5	.004	.20	1 (LHA)
Cycloate	Ro-Neet	Selective herbicide	Carbamate/thiocar- bamate	04031	3, 4	.01	.05	--
<i>lambda</i> -Cyhalothrin	Commodore, Icon	Insecticide	Pyrethroid	61595	5	.009	.014	--
Cyfluthrin	Aztec, Bug-b-gon, Laser, Raid, Tempo	Insecticide	Pyrethroid	61585	5	.027	.053	--
Cypermethrin	Barricade, Cymbush	Insecticide	Pyrethroid	61586	5	.009	.046	--
2,4-D ²	Dacamine, Weed-B-Gon	Herbicide	Chlorophenoxy	39732	2, 4	.01	.73	70 (MCL)
2,4-DB	Butoxone, Butyrac	Selective herbicide	Chlorophenoxy	38746	2, 4	.01	.25	--
2,4-D methyl ester	--	Herbicide	Chlorophenoxy	50470	4	0.009	0.016	--
Dacthal mono-acid	Dacthal degradate	--	Organochlorine	49304	2, 4	.01	.15	--
DCPA ²	Dacthal	Herbicide	Organochlorine	82682	1, 5	.002	.004	70 (LHA)
<i>p,p'</i> -DDE	DDT degradate	--	Organochlorine	34653	1	.003	.01	--
Deethylatrazine (CIAT)	Atrazine degradate	--	Triazine	04040	1, 3, 4, 5	.002	.05	--

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Pesticide	Trade name	Pesticide action	Pesticide class (or parent compound class)	USGS laboratory parameter code	Analytical method ¹ (see head- note)	Minimum laboratory reporting limit (µg/L)	Maximum laboratory reporting limit (µg/L)	USEPA standard or health advisory (µg/L)
Deethyl, deisopro- pyl-atrazine (CAAT)	Atrazine degradate	--	Triazine	04039	4	0.04	--	--
Deisopropylatrazine (CEAT)	Atrazine/cyanazine/simazine degradate	--	Triazine	04038	3, 4	.01	0.08	--
Desulfinylfipronil	Fipronil degradate	--	Pyrazole	62170	1, 5	.004	.012	--
Desulfinylfipronil amide	Fipronil degradate	--	Pyrazole	62169	1, 5	.009	.029	--
Diazinon	Basudin, Spectracide, Knoxout	Insecticide, nemati- cide	Organophosphate	39572	1, 5	.002	.008	1 (LHA)
Dicamba²	Banvel, Banex	Herbicide	Miscellaneous acid	38442	2, 4	.01	.35	4,000 (LHA)
Dichlobenil	Barrier, Casoron, Rootx	Herbicide	Organochlorine	49303	2	.02	1.2	--
3,4-Dichloroaniline	Propanil degradate	--	Urea	61625	5	.004	--	--
3,5-Dichloroaniline	Iprodione degradate	--	Miscellaneous	61627	5	.004	.012	--
Dichlorprop	Weedone, Polymone	Herbicide	Chlorophenoxy	49302	2, 4	.01	.13	--
<i>cis</i> -1,3-Dichloropro- pene ²	Telone	Nematicide	Miscellaneous	34704	6	.09	100	40 (RSD4)
<i>trans</i> -1,3-Dichloro- propene ²	Telone	Nematicide	Miscellaneous	34699	6	.09	100	40 (RSD4)
Dicrotophos	Bidrin, Penetrex	Insecticide	Organophosphate	38454	5	.08	--	--
Dieldrin	Panoram D-31, Octalox	Insecticide	Organochlorine	39381	1, 5	.001	.009	0.2 (RSD4)
2,6-Diethylaniline	Alachlor degradate	--	Amide/acetanilide	82660	1, 5	.002	.006	--
Dimethoate	Cygon, Defend, Rogor	Insecticide	Organophosphate	82662	1, 5	.006	.01	--
Dinoseb	Premerge	Herbicide	Miscellaneous	49301	2, 4	.01	.21	7 (MCL)
Diphenamid	Dymid, Enide	Selective herbicide	Amide	04033	3, 4	.01	.05	200 (LHA)
Disulfoton	Di-Syston	Insecticide, acaricide	Organophosphate	82677	1, 5	.02	.06	0.7 (LHA)
Disulfoton sulfone	Disyston sulfone	Insecticide	Organophosphate	61640	5	.01	--	--

Table 1. Pesticides analyzed, trade names, pesticide actions, classes, laboratory reporting limits, and U.S. Environmental Protection Agency standards or health advisories.
—Continued

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Pesticide	Trade name	Pesticide action	Pesticide class (or parent compound class)	USGS laboratory parameter code	Analytical method ¹ (see head- note)	Minimum laboratory reporting limit (µg/L)	Maximum laboratory reporting limit (µg/L)	USEPA standard or health advisory (µg/L)
Diuron	Durashield, Karmex	Herbicide	Urea	49300	2, 4	0.01	0.42	200 (RSD4)
DNOC (2-Methyl- 4,6-dinitrophenol)	Dinitro-o-cresol, Elgetol	Herbicide	Miscellaneous	49299	2	.01	.42	--
alpha-Endosulfan	--	Insecticide	Organochlorine	34362	5	.005	.011	--
Endosulfan sulfate	Endosulfan degradate	--	Organochlorine	61590	5	.014	.022	--
EPTC	Eptam, Eradicane	Herbicide	Carbamate	82668	1, 5	.002	.015	--
Ethalfuralin	Eptam, Eradicane	Herbicide	Dinitroaniline	82663	1	.004	.013	--
Ethion	Klear-all, Rhodocide	Insecticide	Organophosphate	82346	5	.004	.016	--
Ethion monoxon	Ethion degradate	--	Organophosphate	61644	5	.002	.02	--
Ethoprop (Ethopro- phos)	Mocap, Prophos	Insecticide, nemati- cide	Organophosphate	82672	1, 5	.003	.012	--
2-Ethyl-6-methylan- iline	Metolachlor degradate	--	Amide	61620	5	.004	.01	--
Fenamiphos	Nemacur	Insecticide	Organophosphate	61591	5	.03	--	0.7 (LHA)
Fenamiphos sulfone	Fenamiphos degradate	--	Organophosphate	61645	5	.049	.053	--
Fenamiphos sulf- oxide	Fenamiphos degradate	--	Organophosphate	61646	5	.04	--	--
Fenuron	Fenuron	Herbicide	Urea	49297	2, 4	.01	1.0	--
Fipronil	Combat, Frontline, Maxforce, Regent	Insecticide	Pyrazole	62166	1, 5	.007	.016	--
Fipronil sulfide	Fipronil degradate	--	Pyrazole	62167	1, 5	.005	.013	--
Fipronil sulfone	Fipronil degradate	--	Pyrazole	62168	1, 5	.005	.024	--
Flumetsulam	Broadstrike, Python	Herbicide	Miscellaneous	61694	4	.01	.06	--
Fluometuron	Cotoran	Herbicide	Urea	38811	2, 4	.01	.36	90 (LHA)
Fonofos	Dyfonate	Insecticide	Organophosphate	04095	1, 5	.003	.008	10 (LHA)
alpha-HCH	--	Insecticide	Organochlorine	34253	1, 3, 5	.002	.007	--

Table 1. Pesticides analyzed, trade names, pesticide actions, classes, laboratory reporting limits, and U.S. Environmental Protection Agency standards or health advisories.—Continued

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Pesticide	Trade name	Pesticide action	Pesticide class (or parent compound class)	USGS laboratory parameter code	Analytical method ¹ (see head- note)	Minimum laboratory reporting limit (µg/L)	Maximum laboratory reporting limit (µg/L)	USEPA standard or health advisory (µg/L)
<i>gamma</i> -HCH	Lindane, Isotoz	Insecticide	Organochlorine	39341	1	0.004	0.011	0.2 (MCL)
Hexazinone ²	Buckshot, Pronone, Velpar	Herbicide	Triazine	04025	3, 5	.013	.05	400 (LHA)
Hydroxyatrazine (OIET)	Atrazine degradate	--	Triazine	50355	4	.008	.032	--
3-Hydroxycarbo- furan	Carbofuran degradate	--	Carbamate	49308	2, 4	.006	.57	--
Imazaquin	Scepter	Herbicide	Miscellaneous	50356	4	.02	.04	--
Imazethapyr	New Path, Pursuit	Herbicide	Miscellaneous	50407	4	.02	.04	--
Imidacloprid	Admire, Provado	Insecticide	Miscellaneous	61695	4	.007	.031	--
Iprodione	Chipco, Rovral	Fungicide	Dicarboximide	61593	5	.026	.538	--
Isofenphos	Amaze, Pryfon	Insecticide	Organophosphate	61594	5	.003	.011	--
3-keto Carbofuran	Carbofuran degradate	--	Carbamate	50295	4	.01	.02	--
Linuron	Linurex, Lorox	Herbicide	Urea	38478	2, 4	.01	1.47	--
Linuron	Linurex, Lorox	Herbicide	Urea	82666	1	.002	.039	--
Malaoxon	Malathion degradate	--	Organophosphate	61652	5	.03	.039	--
Malathion	Cythion, Malaspray	Insecticide	Organophosphate	39532	1, 5	.005	.031	100 (LHA)
MCPA	Solve, MCP	Herbicide	Chlorophenoxy	38482	2, 4	.01	.20	30 (LHA)
MCPB	Butoxone M40, Thistrol	Herbicide	Chlorophenoxy	38487	2, 4	.01	.26	--
Metalaxyl	Apron, Ridamil, Subdue	Fungicide	Miscellaneous	50359	4	.01	.02	--
Metalaxyl	Apron, Ridamil, Subdue	Fungicide	Miscellaneous	61596	5	.005	.018	--
Methidathion	Somanil, Supracide	Insecticide	Organophosphate	61598	5	.006	.009	--
Methiocarb	Mesuroi	Insecticide	Carbamate	38501	2, 4	.008	1.99	--
Methomyl	Lannate, Nudrin	Insecticide	Carbamate	49296	2, 4	.004	1.09	200 (LHA)
Methyl paraoxon	Methyl parathion degradate	--	Organophosphate	61664	5	.02	.03	--
Methyl parathion	Penncap-M, Paratox	Insecticide	Organophosphate	82667	1, 5	.006	.035	1 (LHA)
Metolachlor ²	Bicep, Dual	Herbicide	Amide	39415	1, 3, 5	.002	.05	700 (LHA)

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Metribuzin ²	Lexone, Sencor	Herbicide	Triazine	82630	1, 3, 5	0.004	0.05	70 (LHA)
Metsulfuron ²	Ally, Escort	Herbicide	Urea/sulfonylurea	61697	4	.03	.07	--
Molinate	Hydram, Ordram	Herbicide	Carbamate	82671	1, 5	.002	.007	--
Myclobutanil	Rally, Systhane	Fungicide	Miscellaneous	61599	5	.008	.033	--
Napropamide	Devrinol	Herbicide	Amide	82684	1	.003	.01	--
1-Naphthol	Fourrine	Insecticide	Carbamate	49295	2, 5	.09	--	--
Neburon	Granurex, Propuron	Herbicide	Urea	49294	2, 4	.01	.41	--
Nicosulfuron	Accent, OneHope	Herbicide	Urea/sulfonylurea	50364	4	.01	.04	--
Norflurazon	Zorial, Solicam	Herbicide	Miscellaneous	49293	2, 4	.02	.32	--
Oryzalin	Surflan	Herbicide	Dinitroaniline	49292	2, 4	.01	1.25	--
Oxamyl	Vydate	Insecticide, acaricide, nematicide	Carbamate	38866	2, 4	.01	.68	200 (MCL)
Oxyfluorfen	Goal	Herbicide	Miscellaneous	61600	3	.007	.017	--
Parathion	Alkron, Bladan, Fighter	Insecticide	Organophosphate	39542	1	.004	.022	--
Pebulate	Tillam	Herbicide	Carbamate	82669	1	.002	.009	--
Pendimethalin	Prowl, Stomp	Herbicide	Dinitroaniline	82683	1, 5	.004	.009	--
cis-Permethrin	Ambush, Pounce	Insecticide	Pyrethroid	82687	1, 5	.005	.016	--
Phorate	Thimet, Rampart	Insecticide	Organophosphate	82664	1, 5	.03	.10	--
Phorate oxon	Phorate degradate	--	Organophosphate	61666	5	.03	.10	--
Phosmet	Imidan, Percolate, Prolate	Insecticide	Organophosphate	61601	5	.008	--	--
Phosmet oxon	Phosmet degradate	--	Organophosphate	61668	5	.05	--	--
Picloram ²	Tordon	Herbicide	Pyridinecarboxylic acid	49291	2, 4	.02	.26	500 (MCL)
Prometon	Pramitol, Gesafram	Herbicide	Triazine	04037	1, 3, 5	.01	.05	100 (LHA)
Prometryn	Caparol, Selectin	Herbicide	Triazine	04036	3, 5	.005	.05	--

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Pronamide (Propyza- mide)	Kerb	Herbicide	Amide	82676	1, 5	0.003	0.009	200 (RSD4)
Propachlor	Ramrod, Prolex	Herbicide	Amide	04024	1, 3	.007	.05	100 (RSD4)
Propanil	Stamp	Herbicide	Amide	82679	1, 5	.004	.016	--
Propargite	Comite, Omite	Insecticide, acaricide	Miscellaneous	82685	1, 5	.01	.06	--
Propazine	Milogard, Tritol	Herbicide	Triazine	38535	3	.05	--	100 (LHA)
Propham	Chem Hoe	Herbicide	Carbamate	49236	2, 4	.01	7.9	100 (LHA)
Propiconazole	Banner	Fungicide	Miscellaneous	50471	4	.01	.02	--
<i>cis</i> -Propiconazole		--	Miscellaneous	79846	5	.008	.013	--
<i>trans</i> -Propiconazole		--	Miscellaneous	79847	5	.01	.03	--
Propoxur	Baygone, Suncide	Fungicide	Carbamate	38538	2, 4	.008	.71	3 (LHA)
Siduron	Tupersan	Herbicide	Urea	38548	4	.02	--	--
Simazine ²	Aquazine, Primatol, Princep	Herbicide	Triazine	04035	1, 3, 5	.005	.05	4 (MCL)
Simetryn	Cymetrix, Gy-bon	Herbicide	Triazine	04030	3	.05	--	--
Sulfometuron, methyl	Oust	Herbicide	Urea/sulfonylurea	50337	4	.009	.091	--
2,4,5-T	Dacamine, Emulsavert, Line Rider	Herbicide	Chlorophenoxy	39742	2, 4	.01	.32	70 (LHA)
2,4,5-TP	Silvex, Weed-B-Gon	Herbicide	Chlorophenoxy	39762	2	.02	.25	50 (MCL)
Tebuconazole	Elite, Folicur, Raxil	Fungicide	Azole	62852	5	--	--	--
Tebuthiuron ²	Graslan, Spike	Herbicide	Urea	82670	1, 4, 5	.01	.026	500 (LHA)
Tefluthrin	Demand, Force, Karate	Insecticide	Pyrethroid	61606	5	.003	.008	--
Terbacil	Sinbar, Herbicide 732	Herbicide	Miscellaneous	04032	3, 4	.01	.05	90 (LHA)
Terbacil	Sinbar, Herbicide 732	Herbicide	Miscellaneous	82665	1	.007	.034	90 (LHA)
Terbufos	Counter, Contraven	Insecticide	Organophosphate	82675	1, 5	.01	.02	0.4 (LHA)
Terbutylazine	Gardoprim	Herbicide	Triazine	04022	1, 3, 5	U	.01	--

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Pesticide	Trade name	Pesticide action	Pesticide class (or parent compound class)	USGS laboratory parameter code	Analytical method ¹ (see head- note)	Minimum laboratory reporting limit (µg/L)	Maximum laboratory reporting limit (µg/L)	USEPA standard or health advisory (µg/L)
Thiobencarb	Bolero, Saturn	Herbicide	Carbamate	82681	1, 5	0.002	0.01	--
Triallate	Far-Go, Avadex BW	Herbicide	Carbamate	82678	1	.001	.008	--
Tribenuron	Express, Urgent	Herbicide	Urea/sulfonylurea	61159	4	.009	--	--
Tribuphos	Def, Easy off-D, Folex	Herbicide	Organophosphate	61591	5	.004	.035	--
Triclopyr	Garlon	Herbicide	Chlorophenoxy	49235	2, 4	.02	.36	--
Trifluralin	Treflan, Trim	Herbicide	Dinitroaniline	04023	3	.05	--	10 (LHA)
Trifluralin	Treflan, Trim	Herbicide	Dinitroaniline	82661	1, 5	.002	.012	10 (LHA)
Urea, 3,4-Chloro- phenyl, methyl	Diuron degradate	--	Urea	61692	4	.02	.04	--
Vernolate	Surpass, Vernam	Herbicide	Carbamate	04034	2	.05	--	--

¹<http://nwql.cr.usgs.gov/USGS/catalog/index.cfm>

²Identified as a focal pesticide in the State of Wyoming's Generic Management Plan for Pesticides in Ground Water (SMP; Wyoming Ground-Water and Pesticides Strategy Committee, 1999).

³The MCL is under administrative stay pending review by U.S. Environmental Protection Agency. The MCL for any combination of 2 or more of these 3 chemicals (aldicarb, aldicarb sulfoxide, and aldicarb sulfone) should not exceed 7 µg/L because of similar mode of action.

The LRL is the third type of reporting limit used by the NWQL during this study. In 1998, the NWQL began to change from censoring at the MDL to censoring at a laboratory reporting level (LRL) to minimize both false-positive and false-negative detections (reporting a nondetection when the actual concentration in the sample is greater than the MDL; Childress and others, 1999). During this transition, the NWQL began to set the reporting limit equivalent to the LRL rather than the MDL for as many pesticide analyses as possible in most NWQL analytical schedules used during this study. Every individual pesticide analysis was reviewed using information provided by the NWQL to determine the type of reporting limit used (MRL, MDL, or LRL).

The LRL is statistically calculated on an annual basis using quality-control data for each analyte to determine the long-term method detection level (LT-MDL). The LT-MDL is determined from the standard deviation of long-term laboratory spike samples and is set to a concentration to minimize false-positive detections to no more than 1 percent; however, the risk of false-negative detections is greater than 1 percent. The LRL is set to a concentration to minimize these false-negative detections to no more than 1 percent, equal to twice the LT-MDL. Using this NWQL reporting convention, reported concentrations greater than the LRL are not censored or qualified. Concentrations measured as less than the LT-MDL are reported as “less than” (<) the LRL. Concentrations measured between the LT-MDL and the LRL are quantified but qualified with an “E” remark code.

Concentrations smaller than the LRL, but greater than the LT-MDL, are qualified as estimated using an “E” remark code. In some cases, concentrations smaller than the LT-MDL are quantified but are qualified with an “E” remark code, indicating that the analyte was “positively identified” and that laboratory quality-control criteria were met, although there is an increased risk (greater than 1 percent) of false-positive detections (Childress and others, 1999). An “E” remark code also can be used if the analyte did not meet method-specific laboratory quality-control criteria.

For this study, detections qualified with an “E” remark code were treated as quantified values regardless of whether the value was associated with an MRL, MDL, or LRL. This approach preserves all of the information provided by the laboratory and acknowledges that values with an “E” remark code have concentrations greater than true nondetections. The resulting data set was appropriate for analysis using categorical statistical methods that classified pesticide analyses as either “detections” or “nondetections” greater than a selected assessment (censoring) level.

Recensoring and Assessment Levels

Because of the use of three different types of “reporting limits” and variability in reporting-limit values during this study (1995–2006), analytical results received from the NWQL with original censoring were recensored. Recensoring was necessary to account for different types of reporting limits

(MRL, MDL, or LRL) and (or) variable laboratory reporting limits either for a specific pesticide or between individual pesticides. Laboratory reporting limits typically vary over time due to changes in analytical methods, differences in laboratory equipment, equipment sensitivity, experience and skill of equipment operators, and (or) laboratory conditions. Recensoring to a common value (referred to herein as the assessment level) allows for accurate calculation and comparison of detection frequencies and concentrations between individual pesticides or groups of pesticides with different types and values of reporting limits, as well as the use of quantitative statistical methods to examine pesticide occurrence.

Typically, recensoring is conducted by comparing concentrations of reported detections to all laboratory reporting limits; all detections less than the largest laboratory reporting limit are recoded as nondetections, and all detections greater than the largest laboratory reporting limit are retained as detections at the originally reported laboratory concentrations. Unfortunately, pesticide reporting limits varied widely during this study (table 1), and selection of the largest laboratory reporting limit for recensoring would result in many, if not most, detections being recoded as nondetections. Consequently, an approach was used to recensor the data in an attempt to retain as many pesticide detections as possible while still adhering to a rigorous and defensible procedure for assembly of the final data set.

Recensoring and assembly of the final data set began by obtaining information from the NWQL to determine the type and value of reporting limits associated with all individual pesticides detected during this study. The reporting limit can affect the detection frequency of pesticide compounds—pesticides with smaller reporting limits are likely to have greater detection frequencies (Burkart and Kolpin, 1993; Barbash and others, 1999; Kolpin and others, 2000; Gilliom and others, 2006). For all detected pesticides, every individual pesticide analysis was reviewed using information provided by the NWQL (<http://nwql.cr.usgs.gov/usgs/ltml/ltml.cfm>) to determine the type of reporting limit used (MRL, MDL, or LRL) as well as the value at the time of analysis for the entire study period (1995–2006).

Initially, pesticide analyses reported in relation to the MRL or MDL were censored using the laboratory-provided values, whereas analyses reported in relation to an LRL generally were recensored to the LT-MDL concentration. Because this was an analysis of a large sampling network, a greater level of uncertainty (increased risk of false-negative error) for any individual value as a result of recensoring data at the LRL to the LT-MDL was considered acceptable (Childress and others, 1999). Individual analyses with reporting limits much larger than reported by the NWQL for the method (“elevated reporting limits”) indicated likely problems at the time of analysis due to sample characteristics (for example, matrix effects) and (or) laboratory procedures/equipment. These analyses with elevated reporting limits generally were removed from the data set if the reporting limits for an individual pesticide were two times or more greater than reported by the NWQL at

the time of analysis using the same analytical method for the same pesticide. Detections then were recensored to two different assessment levels to facilitate qualitative and quantitative examination of pesticide detection frequencies—an assessment level that differed by compound, referred to herein as a compound-specific assessment level (CSAL), and a common assessment level (CAL) of 0.07 microgram per liter ($\mu\text{g/L}$) (table 2).

To remove the effect of variable reporting limits, detection frequencies of pesticides were calculated using the assessment levels. The assessment level is a fixed concentration that was applied to pesticide analyses received from the laboratory and was applied subsequent to the laboratory reporting limits (table 2). Concentrations reported by the laboratory as detections, but less than the selected assessment level, were considered as nondetections in the calculation of detection frequencies and in statistical analyses. For this study, the CAL of 0.07 $\mu\text{g/L}$ was selected as a compromise between the need to facilitate comparisons with compounds with larger reporting limits and the need to minimize the loss of pesticide detections for compounds detected only at small concentrations. Recensoring to the CAL allowed for qualitative and quantitative comparisons among pesticides but resulted in the loss of many detections of the same pesticide, primarily those with the smallest reporting limits. Consequently, a process similar to that used to select the CAL was applied to individual pesticides to determine values for the CSALs that would be a compromise between the need to censor to larger reporting limits and the need to minimize the loss of detections at small concentrations with much smaller reporting limits (table 2).

Quality-Control Samples and Quality Assurance

In addition to collection of environmental water-quality samples, three types of quality-control (QC) samples were collected as part of the overall quality-assurance (QA) program—field-blank samples, replicate samples, and field-matrix spike samples. The QC samples were collected, preserved, and analyzed using the same methods and equipment as for environmental samples. Collection and evaluation of QC samples, in addition to strict sample collection, processing, and analysis procedures, composed the field QA program.

Blank Samples

Field-blank samples were collected to evaluate bias from the potential introduction of contamination to environmental samples during sample collection, sampling equipment cleaning, and laboratory analytical procedures. Specially prepared water that is certified to be free of organic constituents was used as the source water for all blank samples. Samples were collected at a rate of one field-blank sample for about every 12 environmental samples collected (8.3 percent).

A total of 48 field-blank samples were collected for analysis resulting in 3,953 individual analyses. When

evaluating uncensored data with original NWQL censoring from these 3,953 analyses, 9 pesticide detections in field-blank samples were seen. However, when these field-blank detections are evaluated in relation to applicable censoring levels, all pesticide detections in field-blank samples were less than all recensored detections for a given pesticide compound. Results of the field-blank samples indicated that decontamination procedures were adequate and that field and laboratory contamination of environmental samples by pesticides was minimal.

Replicate Samples

A replicate sample (duplicate) is a sample collected immediately after the primary environmental sample to assess combined effects of sample-collection and laboratory procedures on measurement variability (precision). Forty-three samples were collected for replicate analysis, a frequency of about 1 replicate for every 14 environmental samples (7.1 percent). These replicate and environmental samples had a total of 2,050 pairs of individual analyses of which 71 pairs had detections of a pesticide in both samples (4 sample pairs had detections in only one set of samples). All reported detections were used in analysis of the replicate data including the values assigned an “E” remark code, which accounted for about one-half of reported detections. All data were used without recensoring.

The relative percentage difference (RPD) was calculated to compare the constituent concentrations measured in both the environmental (sample1) and replicate (sample2) samples using the following equation:

$$RPD = \text{absolute value} \left(\frac{\text{sample1} - \text{sample2}}{\left(\frac{\text{sample1} + \text{sample2}}{2} \right)} \right) \times 100. \quad (1)$$

RPDs were not calculated for pairs where one value was reported as less than the laboratory reporting limit.

For the 71 pairs of individual results with detections, 56 pairs had a RPD of less than 20 percent. Of those 15 pairs with a RPD of greater than 20 percent, the difference generally was attributable to small concentration differences that resulted in relatively large RPDs because both environmental and replicate sample concentrations were small. These results were considered acceptable for this baseline study, and consequently, no detections were qualified or deleted on the basis of calculated RPDs.

Field-Matrix Spike Samples

Field-matrix spike samples were analyzed to evaluate bias and variability from the environmental ground-water matrix or potential degradation of the constituent during sample processing, storage, and analysis. Field-matrix spike

Table 2. Detected pesticides in ground-water samples collected during fall and spring using original National Water Quality Laboratory censoring, laboratory reporting limit range, and assigned assessment levels, Wyoming, 1995–2006.

[Pesticides are listed in order of decreasing detection frequency by jointly ranking fall and spring detections with original censoring (no assessment level applied) and grouped by four types. NWQL, National Water Quality Laboratory; NAL, no assessment level applied; µg/L, micrograms per liter. Assessment level: CSAL, compound-specific assessment level; CAL, common assessment level. F, fall; S, spring]

Detected pesticide	Detection with original NWQL censoring (NAL)	Laboratory reporting limit range (µg/L)	Assigned CSAL (µg/L)	Assigned CAL (µg/L)
Herbicides				
Atrazine	F, S	0.001–0.05	0.004	0.07
Prometon	F, S	0.01–0.05	.05	.07
Tebuthiuron	F, S	0.01–0.026	.01	.07
Simazine	F, S	0.005–0.05	.05	.07
Picloram	F, S	0.02–0.26	.06	.07
Oxyfluorfen	F	0.007–0.017	.017	.07
Bromacil	F, S	0.01–1.1	.06	.07
Diuron	F, S	0.01–0.42	.06	.07
Metolachlor	F, S	0.002–0.05	.009	.07
Hexazinone	S	0.013–0.05	.05	.07
Sulfometuron, methyl	F	0.009–0.091	.09	.07
Clopyralid	F, S	0.01–1.82	.26	.07
Flumetsulam	F	0.01–0.06	.06	.07
DCPA	F, S	0.002–0.004	.004	.07
2,4–D methyl ester	F	0.009–0.016	.009	.07
Chlorimuron	F	0.01–0.046	.046	.07
Metsulfuron	F	0.03–0.07	.07	.07
Bentazon	F, S	0.01–0.06	.06	.07
Cyanazine	F, S	0.004–0.2	.013	.07
2,4–D	F, S	0.01–0.73	.15	.07
Metribuzin	F, S	0.004–0.05	.05	.07
Triallate	F, S	0.001–0.008	.003	.07
Dichlorprop	F, S	0.01–0.13	.06	.07
Triclopyr	F, S	0.02–0.36	.36	.07
Norflurazon	F, S	0.02–0.32	.06	.07
Trifluralin	F	0.002–0.012	.012	.07
Bromoxynil	F	0.01–1.6	.07	.07
Oryzalin	F	0.01–1.25	.31	.07
Benfluralin	F	0.002–0.013	.013	.07
Alachlor	S	0.002–0.05	.05	.07
Dicamba	S	0.01–0.35	.13	.07
Herbicide degradates				
Deethylatrazine	F, S	0.002–0.05	0.05	0.07
Deisopropylatrazine	F, S	0.01–0.08	.05	.07
3,4-Dichloroaniline	F	0.004	.004	.07
Hydroxyatrazine	F	0.008–0.032	.016	.07

Table 2. Detected pesticides in ground-water samples collected during fall and spring using original National Water Quality Laboratory censoring, laboratory reporting limit range, and assigned assessment levels, Wyoming, 1995–2006.—Continued

[Pesticides are listed in order of decreasing detection frequency by jointly ranking fall and spring detections with original censoring (no assessment level applied) and grouped by four types. NWQL, National Water Quality Laboratory; NAL, no assessment level applied; µg/L, micrograms per liter. Assessment level: CSAL, compound-specific assessment level; CAL, common assessment level. F, fall; S, spring]

Detected pesticide	Detection with original NWQL censoring (NAL)	Laboratory reporting limit range (µg/L)	Assigned CSAL (µg/L)	Assigned CAL (µg/L)
Insecticides				
<i>alpha</i> -Endosulfan	F	0.005–0.011	0.006	0.07
Imidacloprid	F, S	0.007–0.241	.02	.07
Carbaryl	F	0.003–0.046	.05	.07
Carbofuran	F	0.003–0.02	.02	.07
Dieldrin	F	0.001–0.009	.008	.07
Malathion	F	0.005–0.031	.014	.07
Diazinon	S	0.002–0.008	.008	.07
<i>cis</i> -Permethrin	F	0.005–0.016	.016	.07
Insecticide degradates				
Aldicarb sulfoxide	F, S	0.008–0.27	0.14	0.07
Aldicarb sulfone	F, S	0.02–1.31	.11	.07
Fipronil sulfide	F	0.005–0.013	.006	.07
Fipronil sulfone	F	0.005–0.024	.012	.07
3-Hydroxycarbofuran	F	0.007–0.57	.05	.07

samples were collected in the same manner as the environmental samples, immediately following collection of the environmental samples. The samples then were injected with a known concentration of selected pesticides. Forty-five samples were field spiked, a frequency of about 1 spike for every 13 environmental samples (7.7 percent). These spike and environmental samples resulted in the calculation of 3,683 spike recoveries.

Laboratory recoveries of most field-matrix spike samples ranged from 60 to 120 percent of the pesticide or degradate known to be in the sample. Overall recoveries of pesticides and degradates during the study averaged about 80 percent, which indicates a possible low bias in reported pesticide concentrations. Analysis of a subset of field-matrix spike data that included only pesticides and degradates detected in environmental samples showed about the same average (79 percent). Eight pesticides and degradates detected in environmental samples (all aldicarb compounds, 2,4-DB, 2,4-D methyl ester, clopyralid, dicamba, and picloram), however, had field-matrix spike recoveries indicating a general low bias (average recoveries less than 60 percent). Tebuthiuron concentrations may have been biased slightly high as the average calculated recovery was 121 percent. These results were considered acceptable for this study, and consequently, no detections were qualified or deleted on the basis of poor recoveries.

Statistical Methods

Because of severe data censoring (fewer than 50 percent of the data were greater than laboratory reporting limits or assessment levels), two categorical statistical methods were used exclusively for quantitative comparisons of pesticide detection frequencies between seasons and among various groups of natural and anthropogenic characteristics. These tests were contingency-table analysis (CTA) and the Kruskal-Wallis test for ordered categorical responses (KWOCR) (Helsel and Hirsch, 1992; Helsel, 2005).

Pesticide data were tabulated by row and column according to the grouped characteristics selected for analysis and whether or not the pesticide was detected at concentrations greater than or less than the CAL or CSAL. The null hypothesis tested was that detection or nondetection of any pesticide was independent of the grouped characteristic selected for examination. Rejection of the null hypothesis at a probability (p-value) of 0.05 (alpha level) was considered evidence supporting the alternative hypothesis that there was a relation between the variable (pesticide) and the factor (grouped characteristic) tested. Results of statistical tests indicating computed probabilities (p-values) close to and slightly larger than the alpha level of 0.05 ($0.05 < p < 0.09$) often are reported in the text as “close to statistical significance.” The CTA was used when the response variable was nominal (no ordering

of categories), and the KWOCR was used when the response variable was ordinal (values or a category could be ordered into a sequence from smallest to largest).

An algorithm within ArcGIS 9.2 (Environmental Systems Research Inc., 1999–2007) was used to classify various continuous ordinal variables into categorical ordinal variables for statistical analysis using the KWOCR. This algorithm (referred to as “Jenks” or “natural breaks”) was used to group continuous data into classes “based on natural groupings inherent in the data” and “identifies breakpoints by picking the class breaks that best groups similar values and maximizes the differences between classes” (Environmental Systems Research Inc., 2008). Median values presented herein were calculated using standard methods (Helsel and Hirsch, 1992).

Summary of Pesticide Occurrence

The general occurrence of pesticides is described in this section of the report. The overall frequency of detection of pesticides in wells sampled during this study is examined. Pesticides are classified by type and class, and the occurrence of pesticides as mixtures is examined. Detection frequencies for individual pesticides are summarized, discussed, and examined in relation to time of sampling (season). Finally, detected pesticides were compared to reported agricultural use in Wyoming. In this report, pesticide detection frequencies and concentrations (“pesticide occurrence”) are presented in parts of the report with original censoring from the NWQL [referred to as no assessment level (NAL)] and with recensoring to two different assessment levels (the CSAL and CAL). Pesticide occurrence with original censoring (NAL) is presented in tables and figures to summarize data previously published in 22 USGS county-specific pesticide fact sheets (many readers are familiar with the data uncensored in this manner) and to show the effects of recensoring to two assessment levels. However, for reasons described previously in the “Reporting and Data Treatment” section of the report, quantitative (statistical) analysis of pesticide occurrence without recensoring is not “robust,” and pesticide occurrence without recensoring is limited to qualitative descriptions in the text. Consequently, pesticide occurrence in the text generally is described and statistically examined using data recensored to the CSAL and (or) CAL.

Although detection frequencies and measured concentrations are presented in tables and figures in relation to both assessment levels, the determination of whether pesticide occurrence is described in relation to the CSAL or CAL depends upon the type of analysis conducted. In the text, individual pesticide occurrence generally is described and statistically examined in relation to various natural and anthropogenic characteristics using the CSAL (which is typically but not always a concentration smaller than the CAL), whereas the detection of one or more pesticides in the same well and comparison between different pesticides generally is described

and statistically examined in relation to various natural and anthropogenic characteristics using the CAL. However, there are some cases in the text where qualitative comparison using different assessment levels was warranted.

Detection Frequency by Well Sampled

The overall detection frequency of pesticides in ground water was examined by calculating the percentage of wells with at least one pesticide detected at concentrations greater than the CAL. One or more pesticides were detected at concentrations greater than the CAL in water from 68 of 296 wells sampled (about 23 percent) in the fall and in water from 66 of 295 wells sampled (about 22 percent) in the spring (fig. 2). The proportion of wells with at least one pesticide detected at concentrations greater than the CAL was not significantly different between fall and spring (p -value = 0.9394, CTA). Median concentrations calculated for both fall and spring pesticide detections greater than the CAL were similar (fig. 2).

Occurrence of Pesticide Mixtures

Pesticides detected in ground water commonly occur as mixtures of two or more different compounds (Barbash and Resek, 1996, and references therein; Gilliom and others, 2006). The mixtures can include both parent pesticides and degradates that result from the use of different pesticides for multiple purposes within the same geographic area.

Mixtures of two or more pesticides at concentrations greater than the CAL occurred in about 9 percent of wells sampled in the fall and in about 10 percent of wells sampled in the spring (fig. 3). Most mixtures were composed of two to four different pesticides; more than five different pesticides with concentrations greater than the CAL were identified only in one well sampled in the fall (fig. 3A). The health effects of water containing pesticide mixtures are unknown (Gilliom, 2001; Gilliom and others, 2006). In ground water, pesticides also are found frequently in samples containing other contaminants such as nitrate and volatile organic compounds (Squillace and others, 2002).

Pesticide Detections by Type

Detected pesticides were classified into one of four types (table 2; fig. 4). At least 74 percent of detected pesticides were classified as herbicides regardless of whether data were examined with original censoring (NAL) or with either assessment level (CSAL and CAL). Pesticides classified as herbicide degradates, insecticides, or insecticide degradates were detected much less frequently. The percentages of pesticides classified into the four groups were nearly identical for fall and spring. The prevalence of pesticides classified as herbicides was expected because herbicide use is more common than

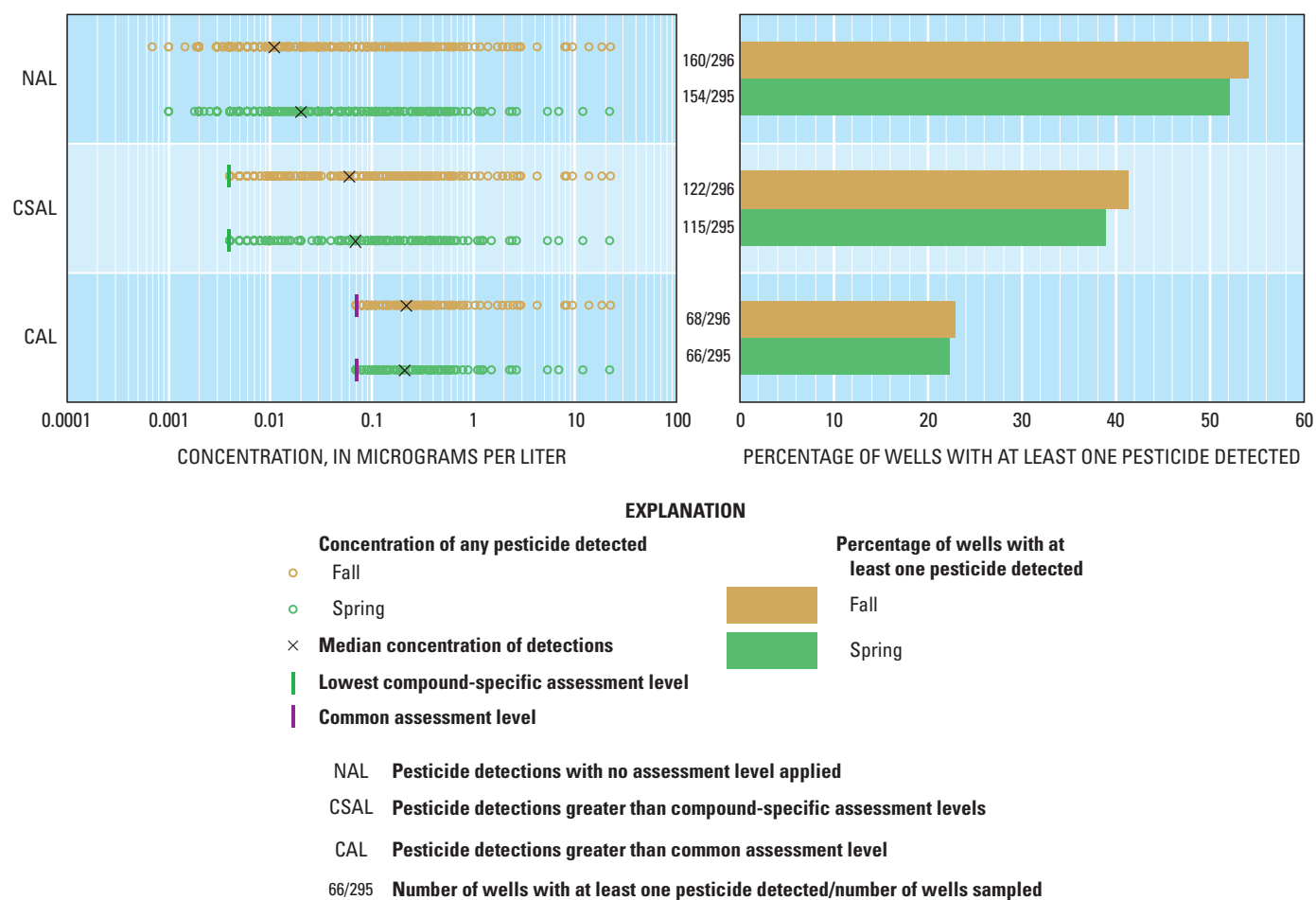


Figure 2. Pesticide concentrations and percentage of wells with at least one pesticide detected for fall and spring, Wyoming, 1995–2006.

insecticide use in Wyoming (Ferrell and others, 1996), and the ground-water samples were analyzed with laboratory schedules composed of relatively few insecticides and degradates (both herbicide and insecticide) compared to herbicides.

Pesticide Detections by Class

Detected pesticides also were classified by their chemical structure into 1 of 10 classes or 2 miscellaneous (herbicide or insecticide) classes for pesticides not easily classifiable (table 3; fig. 5). Regardless of assessment level, pesticides classified into one of five classes (triazine, urea, pyridinecarboxylic acid, miscellaneous herbicide, and carbamate) were most commonly detected. Pesticides classified into the remaining seven classes were rarely detected.

Triazine pesticides were detected at a frequency much greater than all other pesticide classes. In fact, pesticides classified as triazines comprised about 48 percent (fall) and 45 percent (spring) of all detections at concentrations greater

than the CAL. Detected triazines were either herbicides or herbicide degradates. In addition, the number of detected pesticides classified as triazines was the largest of all classes regardless of assessment level (table 3).

Individual Pesticide Detections

The general occurrence of individual pesticide compounds is described in this section of the report. Reported pesticide concentrations and calculated detection frequencies are summarized in both tabular and graphical form for both fall and spring. All data are presented and summarized with original censoring (NAL) and in comparison with both assessment levels (CSAL and CAL). Quantitative (statistical) examination of individually detected pesticides was made using the CSALs.

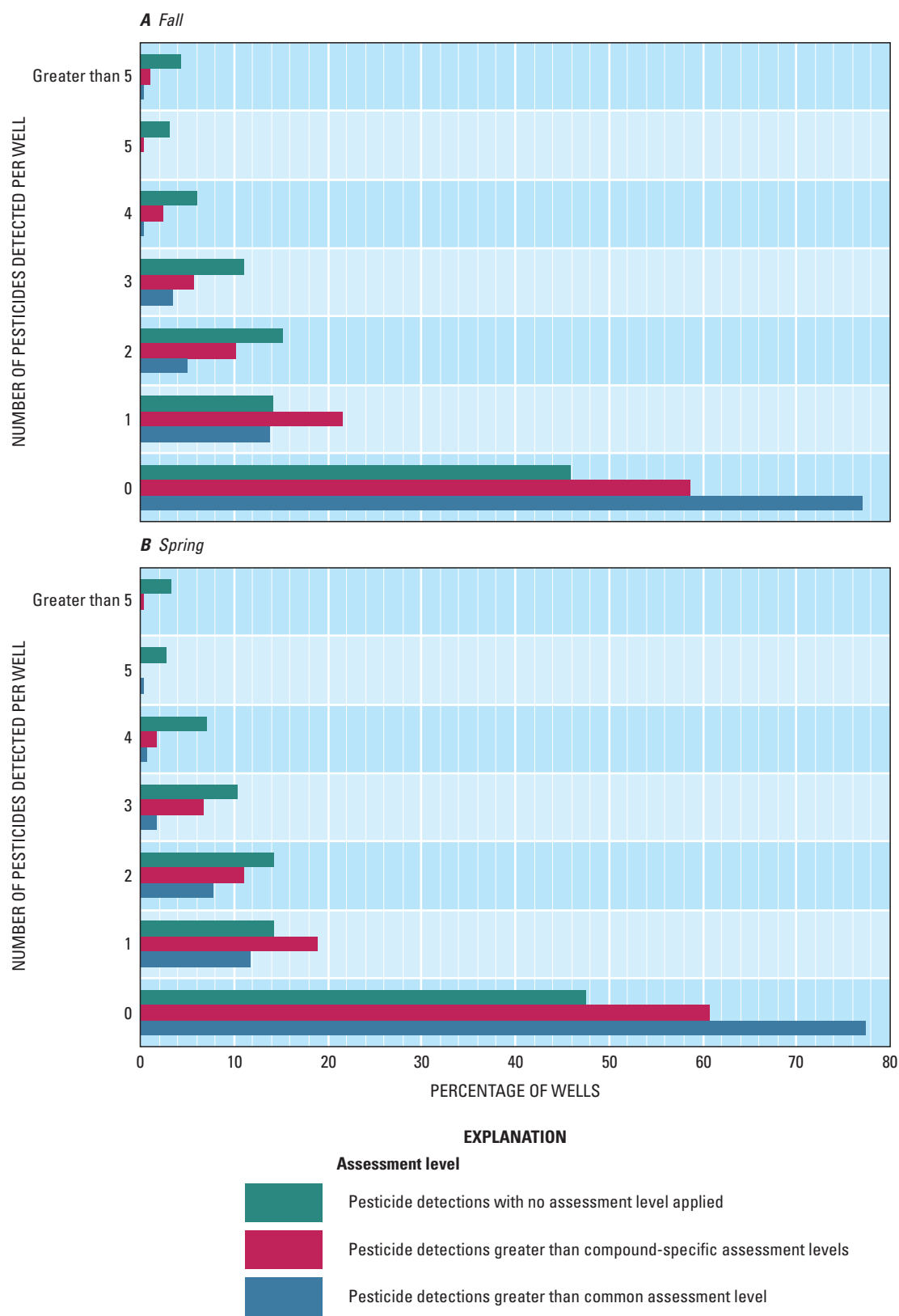


Figure 3. Number of pesticides detected per well in ground-water samples collected in Wyoming, 1995–2006. A, Fall; B, Spring.

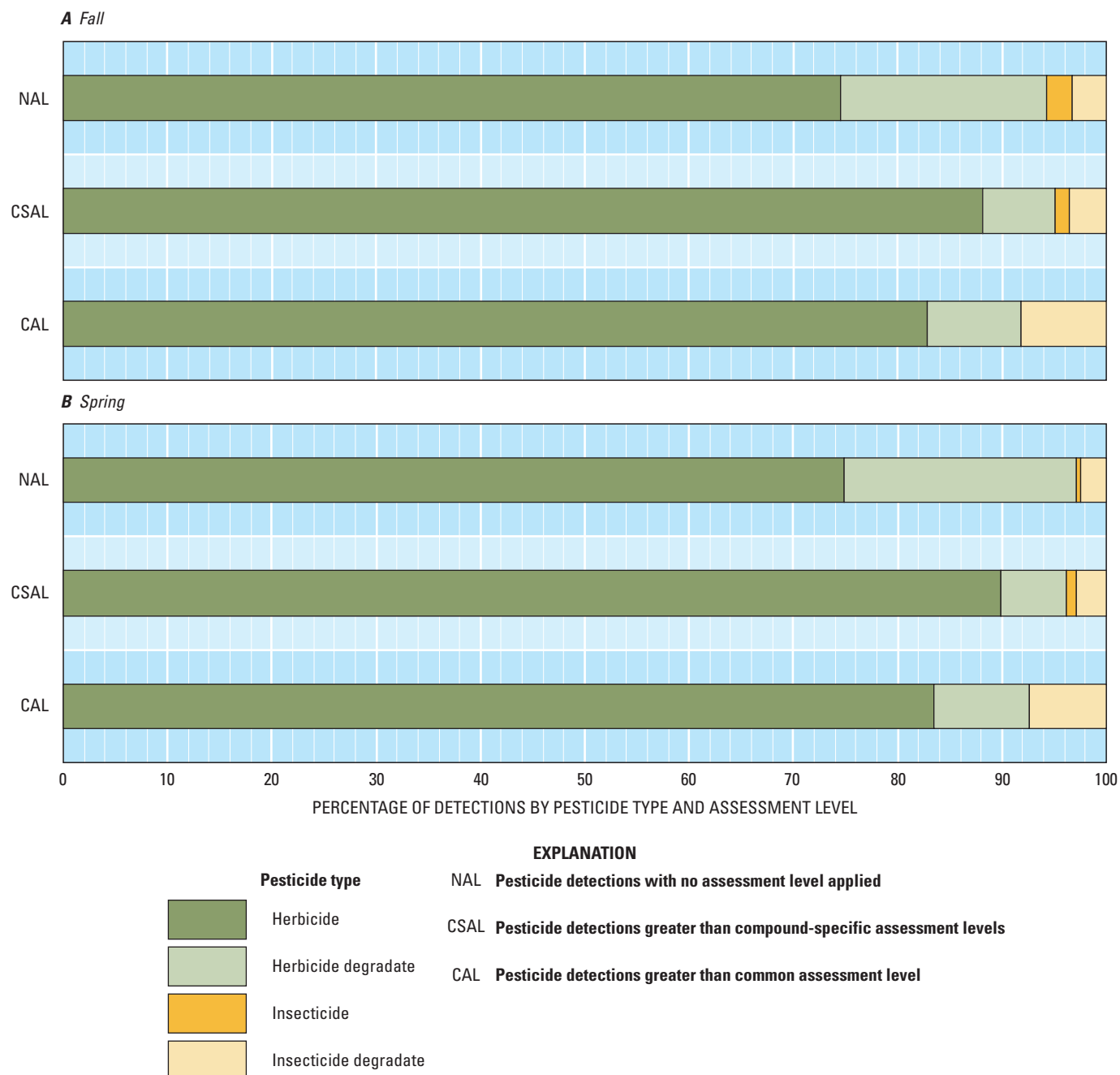


Figure 4. Pesticide detections relative to pesticide type in ground-water samples collected in Wyoming, 1995–2006. *A*, Fall; *B*, Spring.

Table 3. Pesticide detections relative to pesticide class in ground-water samples collected during fall and spring in Wyoming, 1995–2006.

[Pesticide classes listed in order of decreasing detection frequency by jointly ranking fall and spring detections by class with no assessment level. Assessment level: NAL, no assessment level applied; CSAL, compound-specific assessment level; CAL, common assessment level. Pesticide type: H, herbicide; HD, herbicide degradate; I, insecticide; ID, insecticide degradate. Symbol: --, no pesticide detected]

Pesticide class	Assessment level	Fall			Spring		
		Number of pesticide detections in class/number of detections (percentage)	Number of different pesticides detected in class	Pesticides detected	Number of pesticide detections in class/number of detections (percentage)	Number of different pesticides detected in class	Pesticides detected
Triazine	NAL	299/436 (68.6)	8	Atrazine (H), cyanazine (H), metribuzin (H), prometon (H), simazine (H), deisopropylatrazine (HD), deethylatrazine (HD), hydroxyatrazine (HD)	300/410 (73.2)	8	Atrazine (H), cyanazine (H), hexazinone (H), metribuzin (H), prometon (H), simazine (H), deisopropylatrazine (HD), deethylatrazine (HD).
	CSAL	139/227 (61.2)	7	Atrazine (H), cyanazine (H), prometon (H), simazine (H), deisopropylatrazine (HD), deethylatrazine (HD), hydroxyatrazine (HD)	130/208 (62.5)	7	Atrazine (H), cyanazine (H), hexazinone (H), prometon (H), simazine (H), deisopropylatrazine (HD), deethylatrazine (HD).
	CAL	53/111 (47.7)	4	Atrazine (H), prometon (H), simazine (H), deethylatrazine (HD)	49/109 (45)	6	Atrazine (H), cyanazine (H), prometon (H), simazine (H), deisopropylatrazine (HD), deethylatrazine (HD).
Urea	NAL	46/436 (10.6)	6	Chlorimuron (H), diuron (H), metsulfuron (H), sulfometuron (methyl) (H), tebuthiuron (H), 3,4-Dichloroaniline (HD)	44/410 (10.7)	2	Diuron (H), tebuthiuron (H).
	CSAL	34/227 (15.0)	3	Diuron (H), tebuthiuron (H), 3,4-Dichloroaniline (HD)	37/208 (17.8)	2	Diuron (H), tebuthiuron (H).
	CAL	16/111 (14.4)	2	Diuron (H), tebuthiuron (H)	20/109 (18.3)	2	Diuron (H), tebuthiuron (H).
Pyridinecarboxylic acid	NAL	28/436 (6.4)	2	Clopyralid (H), picloram (H)	24/410 (5.9)	2	Clopyralid (H), picloram (H).
	CSAL	22/227 (9.7)	2	Clopyralid (H), picloram (H)	17/208 (8.2)	2	Clopyralid (H), picloram (H).
	CAL	19/111 (17.1)	2	Clopyralid (H), picloram (H)	20/109 (18.3)	2	Clopyralid (H), picloram (H).

Table 3. Pesticide detections relative to pesticide class in ground-water samples collected during fall and spring in Wyoming, 1995–2006.—Continued

[Pesticide classes listed in order of decreasing detection frequency by jointly ranking fall and spring detections by class with no assessment level. Assessment level: NAL, no assessment level applied; CSAL, compound-specific assessment level; CAL, common assessment level. Pesticide type: H, herbicide; HD, herbicide degradate; I, insecticide; ID, insecticide degradate. Symbol: --, no pesticide detected]

Pesticide class	Assessment level	Fall			Spring		
		Number of pesticide detections in class/number of detections (percentage)	Number of different pesticides detected in class	Pesticides detected	Number of pesticide detections in class/number of detections (percentage)	Number of different pesticides detected in class	Pesticides detected
Miscellaneous (herbicide)	NAL	21/436 (4.8)	7	Bentazon (H), bromacil (H), bromoxynil (H), DCPA (H), flumetsulam (H), norflurazon (H), oxyfluorfen (H)	16/410 (3.9)	5	Bentazon (H), bromacil (H), DCPA (H), dicamba (H), norflurazon (H).
	CSAL	13/227 (5.7)	5	Bentazon (H), bromacil (H), bromoxynil (H), DCPA (H), flumetsulam (H)	12/208 (5.8)	3	Bentazon (H), bromacil (H), dicamba (H).
	CAL	9/111 (8.1)	4	Bentazon (H), bromacil (H), bromoxynil (H), flumetsulam (H)	11/109 (10.1)	3	Bentazon (H), bromacil (H), dicamba (H).
Carbamate	NAL	15/436 (3.4)	6	Triallate (H), carbaryl (I), carbofuran (I), aldicarb sulfone (ID), aldicarb sulfoxide (ID), 3-hydroxycarbofuran (ID)	11/410 (2.7)	3	Triallate (H), aldicarb sulfone (ID), aldicarb sulfoxide (ID).
	CSAL	8/227 (3.5)	3	Carbofuran (I), aldicarb sulfone (ID), aldicarb sulfoxide (ID)	7/208 (3.4)	3	Triallate (H), aldicarb sulfone (ID), aldicarb sulfoxide (ID).
	CAL	9/111 (8.1)	2	Aldicarb sulfone (ID), aldicarb sulfoxide (ID)	8/109 (7.3)	2	Aldicarb sulfone (ID), aldicarb sulfoxide (ID).
Amide	NAL	8/436 (1.8)	1	Metolachlor (H)	9/410 (2.2)	2	Alachlor (H), metolachlor (H).
	CSAL	3/227 (1.3)	1	Metolachlor (H)	2/208 (1.0)	1	Metolachlor (H).
	CAL	0	0	--	0	0	--
Organochlorine	NAL	4/436 (0.9)	3	Triclopyr (H), <i>alpha</i> -endosulfan (I), dieldrin (I)	1/410 (0.2)	1	Triclopyr (H).
	CSAL	1/227 (0.4)	1	Triclopyr (H)	1/208 (0.5)	1	Triclopyr (H).
	CAL	1/111 (0.9)	1	Triclopyr (H)	1/109 (0.9)	1	Triclopyr (H).

Table 3. Pesticide detections relative to pesticide class in ground-water samples collected during fall and spring in Wyoming, 1995–2006.—Continued

[Pesticide classes listed in order of decreasing detection frequency by jointly ranking fall and spring detections by class with no assessment level. Assessment level: NAL, no assessment level applied; CSAL, compound-specific assessment level; CAL, common assessment level. Pesticide type: H, herbicide; HD, herbicide degradate; I, insecticide; ID, insecticide degradate. Symbol: --, no pesticide detected]

Pesticide class	Assessment level	Fall			Spring		
		Number of pesticide detections in class/number of detections (percentage)	Number of different pesticides detected in class	Pesticides detected	Number of pesticide detections in class/number of detections (percentage)	Number of different pesticides detected in class	Pesticides detected
Pyrazole	NAL	4/436 (0.9)	2	Fipronil sulfide (ID), fipronil sulfone (ID)	0	0	--
	CSAL	2/227 (0.9)	1	Fipronil sulfide (ID)	0	0	--
	CAL	0	0	--	0	0	--
Dinitroaniline	NAL	4/436 (0.9)	3	Benfluralin (H), oryzalin (H), trifluralin (H)	0	0	--
	CSAL	1/227 (0.4)	1	Oryzalin (H)	0	0	--
	CAL	1/111 (0.9)	1	Oryzalin (H)	0	0	--
Chlorophenoxy (acid)	NAL	3/436 (0.7)	3	2,4-D (H); 2,4-D methyl ester (H); dichlorprop (H)	3/410 (0.7)	2	2,4-D (H); dichlorprop (H).
	CSAL	3/227 (1.3)	3	2,4-D (H); 2,4-D methyl ester (H); dichlorprop (H)	0	0	--
	CAL	3/111 (2.7)	3	2,4-D (H); 2,4-D methyl ester (H); dichlorprop (H)	0	0	--
Miscellaneous (insecticide)	NAL	2/436 (0.5)	2	Imidacloprid (I), <i>cis</i> -permethrin (I)	1/410 (0.2)	1	Imidacloprid (I).
	CSAL	1/227 (0.4)	1	Imidacloprid (I)	1/208 (0.5)	1	Imidacloprid (I).
	CAL	0	0	--	0	0	--
Organophosphate	NAL	2/436 (0.5)	1	Malathion (I)	1/410 (0.2)	1	Diazinon (I).
	CSAL	0	0	--	1/208 (0.5)	1	Diazinon (I).
	CAL	0	0	--	0	0	--

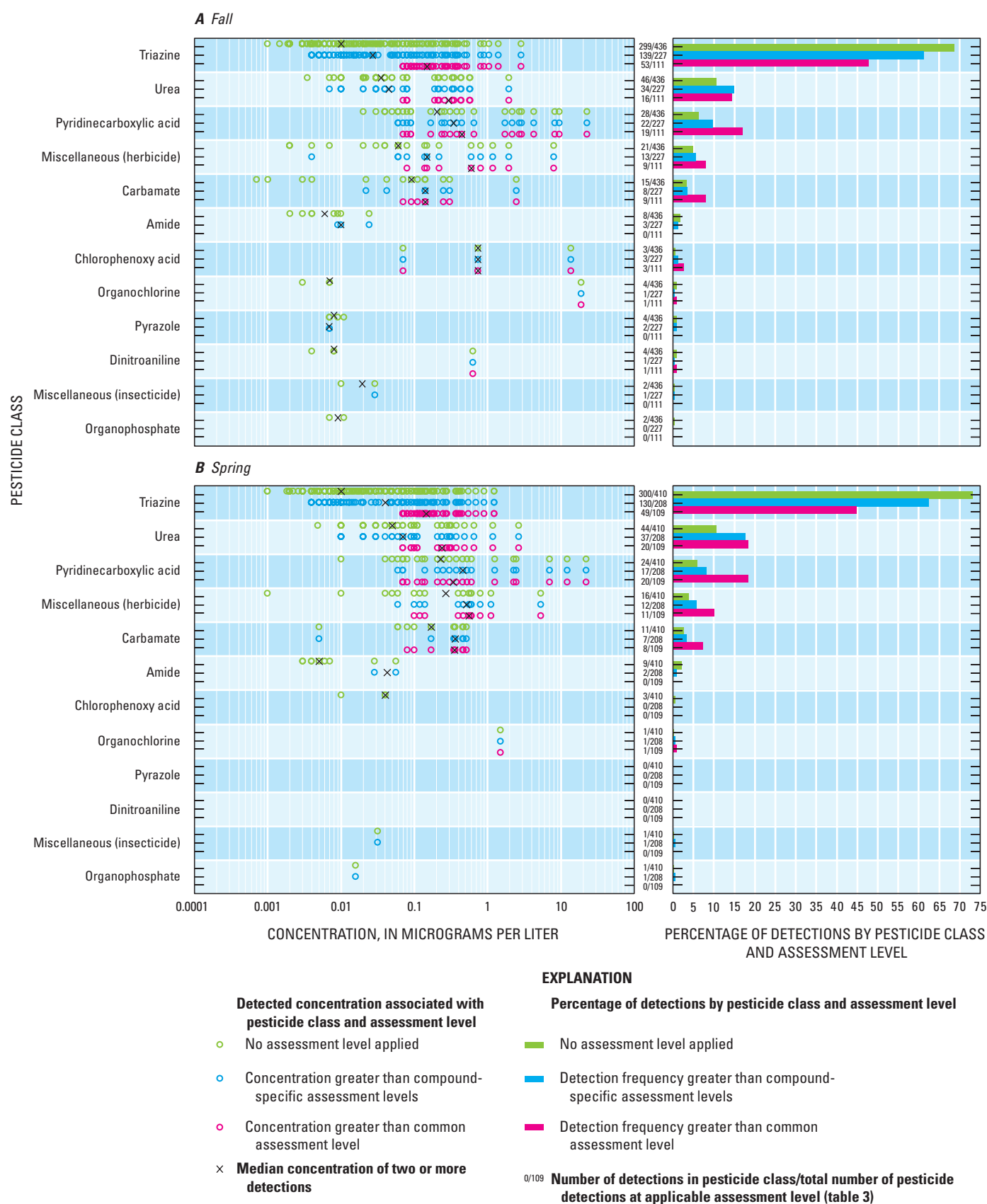


Figure 5. Pesticide concentrations and detections relative to pesticide class in ground-water samples collected in Wyoming, 1995–2006. *A*, Fall; *B*, Spring. Pesticide classes are listed in order of decreasing detection frequency by jointly ranking fall and spring detections with no assessment level.

Detected Concentrations and Calculated Detection Frequencies

Concentrations of all detected pesticides and calculated detection frequencies are summarized for fall (table 4) and spring (table 5). Detected pesticides also are identified by type. Detection frequencies, concentration ranges, and median values differed greatly in some cases by assessment level.

In general, the number of pesticides detected and the frequency of detection were greater in the fall than in the spring. Considering only detections with original censoring (NAL), 44 different pesticides were detected in water from wells sampled in the fall (table 4), whereas 27 different pesticides were detected in water from wells sampled in spring (table 5). The number of pesticides detected was smaller and did not differ as much by season when censored to individual pesticide CSALs. Twenty-eight different pesticides were detected at concentrations greater than the CSALs in water from wells sampled in fall, whereas 21 different pesticides were detected in water from wells sampled in spring.

Figure 6 shows the concentrations and frequencies of pesticides detected most often—pesticides detected with original censoring (NAL) in 1 percent or more of wells sampled in either the fall or the spring. Using figure 6, graphical comparisons can be made between individual pesticides detected in the same season or between the same pesticide in both seasons with and without censoring.

Many pesticides were detected infrequently (tables 4 and 5). Thirteen of 28 pesticides detected (about 46 percent) at concentrations greater than the CSALs in water from wells sampled in the fall were detected only in one well. Ten of 21 pesticides detected (about 48 percent) at concentrations greater than the CSALs in water from wells sampled in the spring were detected only in one well. Considering only detections using the CSALs, 14 of 20 focal pesticides identified in the SMP were detected at least once in water sampled from wells during either the fall or spring.

Considering only concentrations greater than the CSALs, only five pesticides were each detected more than 5 percent of the time in water from wells sampled in either fall or spring (tables 4 and 5; fig. 6). Four of these five frequently detected pesticides were herbicides (atrazine, prometon, tebuthiuron, and picloram, listed in order of decreasing detection frequency), whereas the fifth frequently detected pesticide was an herbicide degradate (3,4-dichloroaniline). Three of these pesticides (atrazine, prometon, and tebuthiuron) have properties indicating high potential to be transported to ground water as they are moderately to highly soluble in water, adsorb only weakly to soil particles, and are persistent in soils and water (on the basis of soil and water half-lives; Gilliom and others, 2006, appendix 2, table A). With the exception of prometon

and 3,4-dichloroaniline, all of these frequently detected pesticides were identified as focal pesticides of concern in the SMP. The “large” detection frequency calculated for the herbicide degradate 3,4-dichloroaniline (about 9 percent, table 4) is the result of infrequent analysis as the pesticide was analyzed in water from only 11 wells sampled.

Atrazine was the pesticide detected most frequently (as a parent compound) in water from wells sampled in either fall or spring at concentrations greater than the CSAL (tables 4 and 5; fig. 6). Atrazine was detected in water from 82 of 294 wells (about 28 percent) sampled and analyzed for the compound in the fall and in water from 78 of 284 wells (about 27 percent) sampled and analyzed for the compound in the spring. Several atrazine degradates also were detected in water at concentrations greater than the respective CSALs, although much less often than the parent compound—deethylatrazine [13 of 296 wells sampled in the fall (about 4 percent) and 12 of 295 wells (about 4 percent) sampled in the spring], deisopropylatrazine [1 of 96 wells (about 1 percent) sampled in the fall and 1 of 121 wells (less than 1 percent) sampled in the spring], and hydroxyatrazine, which was only detected in 1 of 70 wells (1.4 percent) sampled during the fall. Atrazine is a selective triazine herbicide used primarily on corn. Nationally, atrazine is the most frequently detected pesticide in ground water underlying agricultural areas (Gilliom and others, 2006). Degradates of atrazine and other pesticides commonly are found as frequently as or more frequently than the parent compounds in ground water in the United States (Gilliom, 2001; Gilliom and others, 2006).

In the baseline study reported herein, four pesticide degradates were detected, although the corresponding parent pesticide was not detected. Degradates of the insecticides aldicarb (aldicarb sulfone and aldicarb sulfoxide) and fipronil (fipronil sulfone and fipronil sulfide) were detected infrequently (tables 4 and 5; fig. 6), and neither parent compound was detected in water from any wells sampled during this study. However, the two fipronil sulfone detections should be viewed with caution because both detections were recoded as nondetections when recensored to the CSAL (table 4). Pesticide degradates can be as persistent and mobile in water as their parent compounds, and in some cases, degradates are more persistent and more mobile in water than their parent compounds (Gilliom and others, 2006, and references therein).

Individual pesticides detected in both the fall and spring at a frequency equal to or greater than 1 percent using the CSALs were compared statistically using the CTA to assess seasonal differences (table 6). For all pesticides tested, the proportion of samples in which pesticides were detected at concentrations greater than respective CSALs (detection frequency) was not significantly different between fall and spring (all *p*-values > 0.05, CTA).

Table 4. Summary of pesticide detections and concentrations in ground-water samples collected during the fall in Wyoming, 1995–2006.

[Pesticides listed in order of decreasing detection frequency with no assessment level applied. Pesticides in **bold type** are focal pesticides. Abbreviations: USEPA, U.S. Environmental Protection Agency; µg/L, micrograms per liter; MCL, Maximum Contaminant Level; LHA, Lifetime Health Advisory; RSD4, Risk-Specific Dose at 10⁻⁴ Cancer Risk. Assessment level: NAL, no assessment level applied; CSAL, compound-specific assessment level; CAL, common assessment level. Pesticide type: H, herbicide; HD, herbicide degradate; I, insecticide; ID, insecticide degradate. Symbol: --, no detections or not applicable]

Pesticide	Pesticide type	Number of detections/ number of analyses			Detection frequency (percentage)			Detected concentration range (µg/L)			Median of detected concentrations (µg/L)			USEPA standard or health advisory ¹ (µg/L)
		NAL	CSAL	CAL	NAL	CSAL	CAL	NAL	CSAL	CAL	NAL	CSAL	CAL	
Atrazine	H	95/296	82/294	9/296	32.1	27.9	3.0	0.002–0.890	0.004–0.890	0.070–0.890	0.008	0.010	0.185	3 (MCL)
Prometon	H	93/295	39/295	33/295	31.5	13.2	11.2	0.001–2.88	0.05–2.88	0.07–2.88	.02	.11	.13	100 (LHA)
Deethylatrazine	HD	81/296	13/296	10/296	27.4	4.4	3.4	0.001–0.81	0.05–0.81	0.07–0.81	.006	.12	.19	--
Tebuthiuron	H	32/294	31/294	14/294	10.9	10.5	4.8	0.004–1.97	0.01–1.97	0.07–1.97	.04	.04	.33	500 (LHA)
Oxyfluorfen	H	1/11	0/11	0/11	9.1	0	0	0.007	--	--	--	--	--	--
3,4-Dichloroaniline	HD	1/11	1/11	0/11	9.1	9.1	0	0.007	0.007	--	--	--	--	--
<i>alpha</i> -Endosulfan	I	1/11	0/11	0/11	9.1	0	0	0.003	--	--	--	--	--	--
Picloram	H	24/284	20/281	17/282	8.5	7.1	6.0	0.03–9.50	0.06–9.50	0.07–9.50	.20	.28	.38	500 (MCL)
Simazine	H	23/295	2/295	1/295	7.8	.7	.3	0.002–0.093	0.058–0.093	0.093	.006	.076	--	4 (MCL)
Sulfometuron, methyl	H	3/71	0/71	0/71	4.2	0	0	0.020–0.022	--	--	.021	--	--	--
Bromacil	H	9/291	8/286	6/286	3.1	2.8	2.1	0.04–8.07	0.06–8.07	0.15–8.07	.60	.70	.99	70 (LHA)
Hydroxyatrazine	HD	2/70	1/70	0/70	2.9	1.4	0	0.007–0.02	0.02	--	.01	--	--	--
Flumetsulam	H	2/71	2/71	1/71	2.8	2.8	1.4	0.06–0.08	0.06–0.08	0.08	.07	.07	--	--
Fipronil sulfide	ID	2/71	2/71	0/71	2.8	2.8	0	0.007	0.007	--	.007	.007	--	--
Fipronil sulfone	ID	2/71	0/71	0/71	2.8	0	0	0.009–0.011	--	--	.010	--	--	--
Diuron	H	8/292	2/291	2/291	2.7	.7	.7	0.01–0.19	0.08–0.19	0.08–0.19	.04	.14	.14	200 (RSD4)
Metolachlor	H	8/295	3/275	0/295	2.7	1.1	0	0.002–0.024	0.009–0.024	--	.006	.010	--	700 (LHA)
Deisopropylatrazine	HD	2/96	1/96	0/96	2.1	1.0	0	0.01–0.05	0.05	--	.03	--	--	--
Aldicarb sulfoxide	ID	5/285	3/280	5/259	1.8	1.1	1.9	0.07–2.47	0.14–2.47	0.07–2.47	.14	.25	.14	4 (MCL)
2,4–D methyl ester	H	1/71	1/71	1/71	1.4	1.4	1.4	0.737	0.737	0.737	--	--	--	--
Chlorimuron	H	1/71	0/71	0/71	1.4	0	0	0.008	--	--	--	--	--	--
Clopyralid	H	4/284	2/282	2/134	1.4	.7	1.5	0.02–22.6	0.45–22.6	0.45–22.6	.24	11.5	11.5	--
DCPA	H	4/293	1/293	0/293	1.4	.3	0	0.002–0.004	0.004	--	.002	--	--	70 (LHA)
Metsulfuron	H	1/71	0/71	0/71	1.4	0	0	0.03	--	--	--	--	--	--
Imidacloprid	I	1/71	1/71	0/71	1.4	1.4	0	0.029	0.029	--	--	--	--	--
Aldicarb sulfone	ID	4/285	3/281	4/136	1.4	1.1	2.9	0.09–0.30	0.14–0.30	0.09–0.30	.14	.14	.14	2 (MCL)
Bentazon	H	3/284	1/284	1/284	1.1	0.4	0.4	0.03–0.14	0.14	0.14	.04	--	--	200 (LHA)

Table 4. Summary of pesticide detections and concentrations in ground-water samples collected during the fall in Wyoming, 1995–2006. —Continued

[Pesticides listed in order of decreasing detection frequency with no assessment level applied. Pesticides in **bold type** are focal pesticides. Abbreviations: USEPA, U.S. Environmental Protection Agency; µg/L, micrograms per liter; MCL, Maximum Contaminant Level; LHA, Lifetime Health Advisory; RSD4, Risk-Specific Dose at 10⁻⁴ Cancer Risk. Assessment level: NAL, no assessment level applied; CSAL, compound-specific assessment level; CAL, common assessment level. Pesticide type: H, herbicide; HD, herbicide degradate; I, insecticide; ID, insecticide degradate. Symbol: --, no detections or not applicable]

Pesticide	Pesticide type	Number of detections/ number of analyses			Detection frequency (percentage)			Detected concentration range (µg/L)			Median of detected concentrations (µg/L)			USEPA standard or health advisory ¹ (µg/L)
		NAL	CSAL	CAL	NAL	CSAL	CAL	NAL	CSAL	CAL	NAL	CSAL	CAL	
Cyanazine	H	2/295	1/276	0/276	.7	.4	0	0.007–0.018	0.018	--	.012	--	--	1 (LHA)
Trifluralin	H	2/293	0/293	0/293	.7	0	0	0.004–0.008	--	--	.006	--	--	10 (LHA)
Carbaryl	I	2/293	0/293	0/293	.7	0	0	0.003–0.004	--	--	.004	--	--	4,000 (RSD4)
Carbofuran	I	2/293	2/293	0/293	.7	.7	0	0.022–0.042	0.022–0.042	--	.032	0.032	--	40 (MCL)
Dieldrin	I	2/293	0/293	0/293	.7	0	0	0.007	--	--	.007	--	--	0.2 (RSD4)
Malathion	I	2/293	0/293	0/293	.7	0	0	0.007–0.011	--	--	.009	--	--	100 (LHA)
Triallate	H	1/282	0/282	0/282	.4	0	0	0.001	--	--	--	--	--	--
2,4-D	H	1/290	1/288	1/196	.3	.3	.5	13.8	13.8	13.8	--	--	--	--
Benfluralin	H	1/293	0/293	0/293	.3	0	0	0.008	--	--	--	--	--	--
Bromoxynil	H	1/290	1/289	1/289	.3	.3	.3	0.22	0.22	0.22	--	--	--	--
Dichlorprop	H	1/290	1/290	1/290	.3	.3	.3	0.07	0.07	0.07	--	--	--	--
Metribuzin	H	1/295	0/295	0/295	.3	0	0	0.006	--	--	--	--	--	70 (LHA)
Norflurazon	H	1/292	0/291	0/291	.3	0	0	0.02	--	--	--	--	--	--
Oryzalin	H	1/291	1/227	1/135	.3	.4	.7	0.63	0.63	0.63	--	--	--	--
Triclopyr	H	1/290	1/290	1/187	.3	.3	.5	18.6	18.6	18.6	--	--	--	--
<i>cis</i> -Permethrin	I	1/293	0/293	0/293	.3	0	0	0.01	--	--	--	--	--	--
3-Hydroxycarbofuran	ID	1/291	0/290	0/290	.3	0	0	0.001	--	--	--	--	--	--

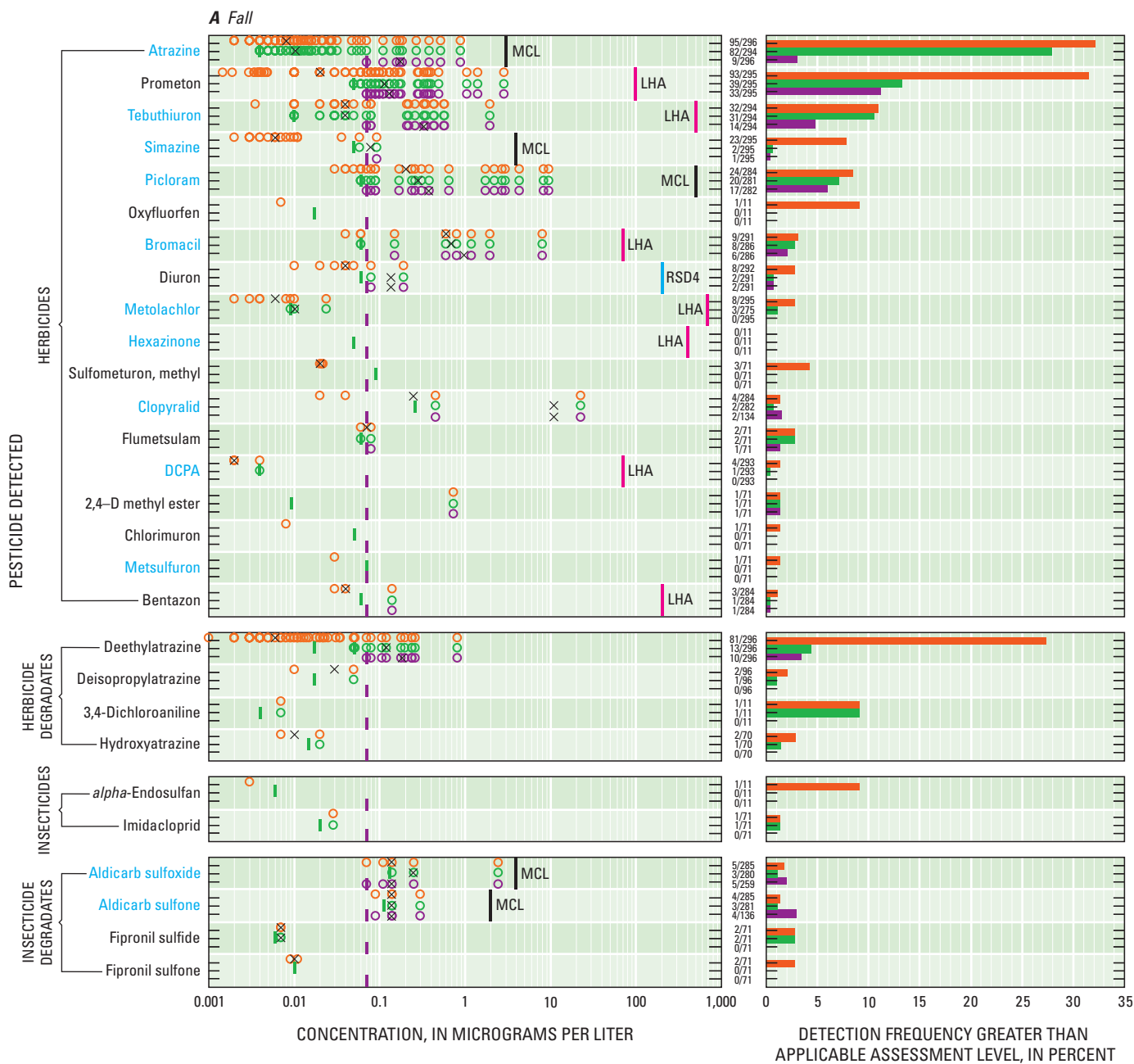
¹Source: U.S. Environmental Protection Agency, 2006.

Table 5. Summary of pesticide detections and concentrations in ground-water samples collected during the spring in Wyoming, 1995–2006.

[Pesticides listed in order of decreasing detection frequency with no assessment level applied. Pesticides in **bold type** are focal pesticides. Abbreviations: USEPA, U.S. Environmental Protection Agency; µg/L, micrograms per liter; MCL, MCL, Maximum Contaminant Level; LHA, Lifetime Health Advisory; RSD4, Risk-Specific Dose at 10⁻⁴ Cancer Risk. Assessment level: NAL, no assessment level applied; CSAL, compound-specific assessment level; CAL, common assessment level. Pesticide type: H, herbicide; HD, herbicide degradate; I, insecticide; ID, insecticide degradate. Symbol: --, no detections or not applicable]

Pesticide	Pesticide type	Number of detections/ number of analyses			Detection frequency (percentage)			Detected concentration range (µg/L)			Median of detected concentrations (µg/L)			USEPA standard or health advisory ¹ (µg/L)
		NAL	CSAL	CAL	NAL	CSAL	CAL	NAL	CSAL	CAL	NAL	CSAL	CAL	
Atrazine	H	95/295	78/284	10/295	32.2	27.5	3.4	0.001–0.900	0.004–0.900	0.090–0.900	0.008	0.010	0.164	3 (MCL)
Prometon	H	84/294	35/294	27/294	26.8	11.9	9.2	0.002–1.24	0.05–1.24	0.07–1.24	.03	.11	.14	100 (HAL)
Deethylatrazine	HD	79/295	12/295	9/295	26.8	4.1	3.1	0.002–0.550	0.05–0.550	0.073–0.550	.007	.146	.190	--
Tebuthiuron	H	35/295	34/295	17/295	11.9	11.5	5.8	0.005–1.18	0.01–1.18	0.07–1.18	.06	.06	.24	500 (HAL)
Deisopropylatrazine	HD	12/121	1/121	1/121	9.9	.8	.8	0.01–0.19	0.19	0.19	.03	--	--	--
Simazine	H	25/294	2/294	1/294	8.5	.7	.3	0.002–0.112	0.069–0.112	0.112	.008	.090	--	4 (MCL)
Picloram	H	19/291	16/288	15/288	6.5	5.6	5.2	0.01–12.2	0.06–12.2	0.07–12.2	.30	.42	.46	500 (MCL)
Bromacil	H	12/294	10/288	9/288	4.1	3.5	3.1	0.04–5.38	0.06–5.38	0.10–5.38	.27	.44	.47	70 (LHA)
Diuron	H	9/294	3/294	3/294	3.1	1.0	1.0	0.01–2.69	0.07–2.69	0.07–2.69	.04	.11	.11	200 (RSD4)
Hexazinone	H	1/35	1/35	0/35	2.9	2.9	0	0.06	0.06	--	--	--	--	400 (LHA)
Metolachlor	H	8/294	2/259	0/294	2.7	.8	0	0.003–0.056	0.029–0.056	--	.006	.042	--	700 (LHA)
Clopyralid	H	5/288	1/285	5/116	1.7	.4	4.3	0.07–22.0	22.0	0.07–22.0	.11	--	.11	--
Aldicarb sulfone	ID	5/292	3/288	5/120	1.7	1.0	4.2	0.08–0.36	0.17–0.36	0.08–0.36	.17	.35	.17	2 (MCL)
Aldicarb sulfoxide	ID	5/292	3/291	3/243	1.7	1.0	1.2	0.06–0.52	0.46–0.52	0.46–0.52	.46	.47	.47	4 (MCL)
Imidacloprid	I	1/71	1/70	0/70	1.4	1.4	0	0.032	0.032	--	--	--	--	--
2,4-D	H	2/294	0/292	0/182	.7	0	0	0.04	--	--	.04	--	--	70 (MCL)
Cyanazine	H	2/294	1/259	1/259	.7	.4	.4	0.008–0.13	0.13	0.13	.07	--	--	1 (LHA)
Metribuzin	H	2/294	0/294	0/294	.7	0	0	0.007–0.010	--	--	.008	--	--	70 (LHA)
Triallate	H	1/284	1/259	0/284	.4	.4	0	0.005	0.005	--	--	--	--	--
Alachlor	H	1/294	0/294	0/294	.3	0	0	0.004	--	--	--	--	--	2 (MCL)
Bentazon	H	1/294	1/294	1/294	.3	.3	.3	0.59	0.59	0.59	--	--	--	200 (LHA)
DCPA	H	1/294	0/294	0/294	.3	0	0	0.001	--	--	--	--	--	70 (LHA)
Dicamba	H	1/292	1/292	1/292	.3	.3	.3	1.11	1.11	1.11	--	--	--	4,000 (LHA)
Dichlorprop	H	1/294	0/293	0/293	.3	0	0	0.01	--	--	--	--	--	--
Norflurazon	H	1/294	0/293	0/293	.3	0	0	0.01	--	--	--	--	--	--
Triclopyr	H	1/294	1/294	1/197	.3	.3	.5	1.51	1.51	1.51	--	--	--	--
Diazinon	I	1/294	1/294	0/294	.3	.3	0	0.016	0.016	--	--	--	--	1 (LHA)

¹Source: U.S. Environmental Protection Agency, 2006.



EXPLANATION

- Detected concentration associated with assessment level**
- No assessment level applied
 - Concentration greater than compound-specific assessment level
 - Concentration greater than common assessment level
 - × Median concentration of two or more detections

- Pesticide names in blue are focal pesticides.
Pesticide names in black are nonfocal pesticides.
- Compound-specific assessment level
 - Common assessment level
 - MCL U.S. Environmental Protection Agency (2006) Maximum Contaminant Level (MCL)
 - LHA U.S. Environmental Protection Agency (2006) Lifetime Health Advisory (LHA)
 - RSD4 U.S. Environmental Protection Agency (2006) Risk-Specific Dose at 10⁻⁴ cancer risk (RSD4)

- 0/71 **Number of detections/number of samples at applicable assessment level (tables 4 and 5)**
- Detection frequency associated with assessment level**
- No assessment level applied
 - Detection frequency greater than compound-specific assessment level
 - Detection frequency greater than common assessment level

Figure 6. Concentration and detection frequency of selected pesticides in ground-water samples collected in Wyoming, 1995–2006. A, Fall; B, Spring. Pesticides are grouped by pesticide type and are listed in order of decreasing detection frequency by jointly ranking fall and spring detections with no assessment level.

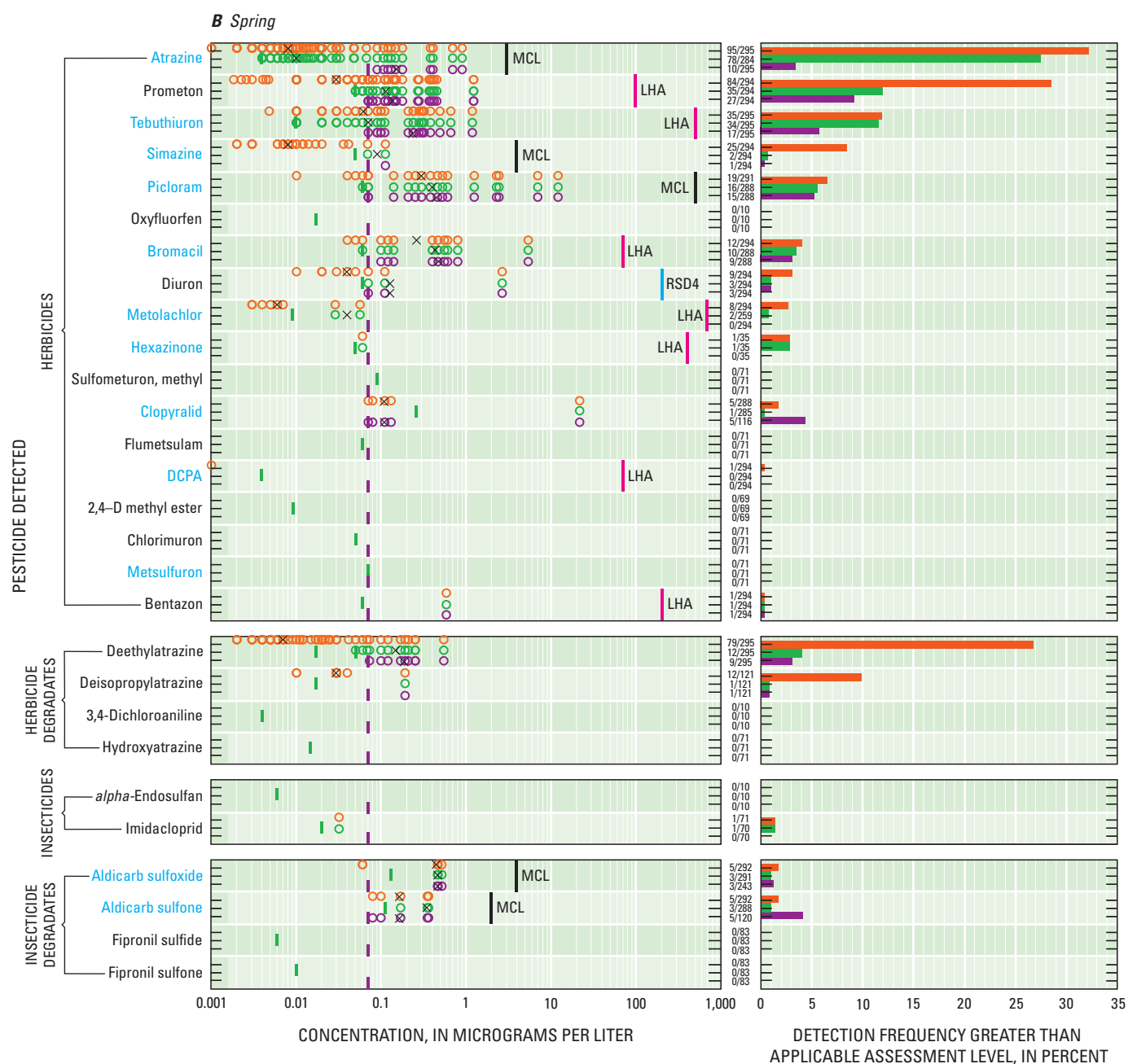


Figure 6. Concentration and detection frequency of selected pesticides in ground-water samples collected in Wyoming, 1995–2006. A, Fall; B, Spring. Pesticides are grouped by pesticide type and are listed in order of decreasing detection frequency by jointly ranking fall and spring detections with no assessment level.—Continued

Table 6. Results of contingency-table analysis (CTA) comparing selected pesticide detections in ground-water samples collected during fall and spring in Wyoming, 1995–2006.

[Only individual pesticides detected in both the fall and spring at a frequency equal to or greater than 1 percent using CSALs were tested. Statistical test (significance indicated by p-value <0.05) between fall and spring samples. H, herbicide; CSAL, compound-specific assessment level; HD, herbicide degradate; ID, insecticide degradate; I, insecticide]

Tested pesticide	Pesticide type	Assessment level used	Probability (p-value)
Atrazine	H	CSAL	0.9828
Prometon	H	CSAL	.7208
Deethylatrazine	HD	CSAL	.9931
Tebuthiuron	H	CSAL	.8038
Picloram	H	CSAL	.5532
3,4-Dichloroaniline	H	CSAL	.9610
Bromacil	H	CSAL	.8224
Diuron	H	CSAL	.9908
Aldicarb sulfoxide	ID	CSAL	.7166
Aldicarb sulfone	ID	CSAL	.7038
Imidacloprid	I	CSAL	.4826

Detected Pesticide Concentrations and Comparison to Standards or Health Advisories

Concentrations of detected pesticides generally were small (less than 1 µg/L), although a few infrequent detections at larger concentrations were noted (tables 4 and 5; fig. 6). Nationally, pesticides detected in ground water typically are found at similar small concentrations (Gilliom and others, 2006). Ten different pesticides (prometon, tebuthiuron, picloram, bromacil, aldicarb sulfoxide, clopyralid, 2,4-D, diuron, dicamba, and triclopyr, listed in order of decreasing detection frequency) were detected at concentrations greater than 1 µg/L at least once in water from at least one well sampled in either fall or spring (tables 4 and 5). The largest pesticide concentration measured (22.6 µg/L, table 4) in water from wells sampled in either fall or spring was a detection of the herbicide clopyralid.

Pesticide concentrations presented in this report are compared with several USEPA drinking-water standards or health advisories for finished (treated) water established in the Safe Drinking Water Act. The USEPA has established standards for physical properties and chemical constituents in drinking water that may have adverse effects on human health or that may cause cosmetic effects (for example, skin or tooth discoloration) or aesthetic effects (for example, color, taste, or odor), and these standards have been adopted by the WDEQ as Wyoming's ground-water protection standards. The Maximum Contaminant Level (MCL) is legally enforceable and health-based and is the maximum permissible level for a constituent in drinking water that is delivered to a user of a public-water

system (U.S. Environmental Protection Agency, 2006). A health advisory is a nonenforceable level that establishes acceptable constituent concentrations for different exposure periods (1 day, 10 days, long-term, and lifetime). A Lifetime Health Advisory (LHA) is the concentration of a chemical that would not result in any known or anticipated adverse noncarcinogenic health effects over a lifetime of exposure (70 years; U.S. Environmental Protection Agency, 2006). The Risk-Specific Dose (RSD) is a concentration of a chemical with a specific risk level under certain exposure conditions over a lifetime (70 years; U.S. Environmental Protection Agency, 2006). USEPA standards and health advisory levels serve as technical guidance to evaluate the suitability of water collected from private wells for human consumption. In addition, pesticide detections were evaluated by the GPSC and compared to Wyoming ground-water-quality standards in accordance with the SMP (Wyoming Ground-water and Pesticides Strategy Committee, 1999).

All detected pesticide concentrations were smaller than USEPA drinking-water standards or health advisories where applicable (many pesticides did not have standards or advisories; tables 4 and 5; fig. 6). Most pesticide detections were an order of magnitude smaller than USEPA standards or health advisories. One detection of the insecticide degradate aldicarb sulfoxide was measured in the fall at a concentration (2.47 µg/L, table 4) within the same order of magnitude as the USEPA MCL (4 µg/L); however, this detection was about five times larger than the next largest sample concentration, which was about an order of magnitude less than the MCL.

Detected Pesticides in Relation to Use

All parent pesticides detected during the baseline ground-water sampling were compared to a survey describing 1994 agricultural pesticide use in Wyoming (Ferrell and others, 1996) (fig. 7). Although pesticide use is reported for the year 1994 and prior to the beginning of the baseline ground-water sampling examined in this report (1995), the survey described in Ferrell and others (1996) was the last conducted and is the most recent describing Wyoming agricultural pesticide use. Ferrell and others (1996) reported agricultural pesticide use in relation to both cropland (row crops, small grains, hay, and alfalfa) and noncropland (improved pasture and rangeland). Figure 7 shows all parent pesticides detected with original censoring (NAL) in relation to reported 1994 agricultural use in Wyoming. Pesticides are grouped by type and are listed in order of decreasing detection frequency by jointly ranking fall and spring detections with no assessment level applied (NAL). Some detected parent pesticides shown in figure 7 were reported as nondetections when censored to their respective CSALs.

Seventeen of the 40 parent pesticides detected during the baseline ground-water sampling had no reported 1994 agricultural use in Wyoming (fig. 7). With the exception of picloram, four of the five frequently detected pesticides (atrazine through picloram in figure 7) had use reported for only two cropland

	PESTICIDE	Row crops				Small grains			Hay and alfalfa		Improved pasture	Range-land
		Sugarbeets	Dry beans	Corn	Potatoes	Barley	Oats	Wheat	Hay (not alfalfa)	Alfalfa		
HERBICIDES	Atrazine			●				●				
	Prometon											
	Tebuthiuron										●	●
	Simazine											
	Picloram			●	●	●	●	●	●	●	●	●
	Oxyfluorfen											
	Bromacil											
	Diuron											
	Metolachlor		●	●	●							
	Hexazinone											
	Sulfometuron, methyl											
	Clopyralid	●	●	●		●	●	●	●	●	●	●
	Flumetsulam											
	DCPA											
	2,4-D methyl ester			●		●	●	●		●	●	●
	Chlorimuron											
	Metsulfuron					●	●	●	●	●	●	●
	Bentazon		●			●						
	Cyanazine			●								
	2,4-D	●		●	●	●				●		
	Metribuzin			●	●					●		
	Triallate					●		●				
	Dichlorprop											
	Triclopyr											
	Norflurazon											
	Trifluralin	●	●							●		
	Dicamba			●		●	●	●		●	●	●
	Bromoxynil			●		●	●	●		●		
	Oryzalin											
	Benfluralin ¹									●		
	Alachlor		●	●								
INSECTICIDES	alpha-Endosulfan											
	Aldicarb ²	●								●		
	Imidacloprid	●	●	●						●		
	Carbaryl	●		●	●	●	●	●		●		
	Carbofuran	●		●	●	●	●	●		●		
	Dieldrin											
	Malathion		●	●				●	●	●	●	
	Diazinon			●								
	cis-Permethrin										●	

¹Benfluralin is defined as benefin in Ferrell and others (1996).

²Only aldicarb degradates (aldicarb sulfone and aldicarb sulfoxide) were detected.

EXPLANATION

Pesticide names in blue are focal pesticides.

Pesticide names in black are nonfocal pesticides.

■ No reported agricultural pesticide use

Agricultural pesticide use

● Pesticide used on 1 percent or more of total crop acres

● Pesticide used on less than 1 percent of total crop acres

Figure 7. Parent pesticides detected in ground-water samples collected during fall and spring, 1995–2006, relative to reported 1994 agricultural use in Wyoming. Pesticides are grouped by type and are listed in order of decreasing detection frequency by jointly ranking fall and spring detections with original censoring (no assessment level applied). Reported 1994 agricultural pesticide use from Ferrell and others (1996).

(atrazine) or two noncropland categories (tebuthiuron), or had no reported agricultural use (prometon and simazine). Of the 23 parent pesticides detected with reported agricultural use in Wyoming, clopyralid had use reported for the most land-use categories. Picloram likely had the largest agricultural use on the basis of application of the pesticide to 1 percent or more of total crop acres for six different agricultural categories (indicated by red dots in figure 7).

Pesticide detections associated with noncropland (pasture and rangeland) use were noted (fig. 7). Eight different pesticides with reported noncropland use were detected. These pesticides had little reported 1994 agricultural use on the basis of application to less than 1 percent of total improved pasture or rangeland acres. Pesticides detected during this study, but with no identified agricultural use in the 1994 survey, may be attributed to infrequent use in Wyoming at the time of the 1994 survey, nonagricultural use, or use in Wyoming subsequent to the survey (after 1994).

Most detected parent pesticides were reportedly used primarily for agricultural cropland purposes in 1994, but two of the pesticides detected most frequently during this study (prometon and tebuthiuron) either had no reported agricultural use (prometon) or limited noncropland use (tebuthiuron) in Wyoming (fig. 7). In the United States, both pesticides are associated primarily with noncropland use, and detections in ground water are more commonly associated with urban areas (Gilliom and others, 2006). Prometon is not registered for agricultural use in the United States, but the broad-spectrum herbicide is used to control weeds in noncropland areas such as rangelands, around buildings and storage areas, industrial sites, as well as along roads, fences, railroads, pipelines, power lines, and other rights-of-way (Meister, 2002; Gilliom and others, 2006). Prometon also can be used in and under asphalt to prevent weeds from growing (Ciba-Geigy Corporation, 1994). Prometon has been found in ground water underlying both urban and agricultural areas in the United States, but more commonly in urban areas; detections in agricultural areas probably are the result of nonagricultural applications in these areas (Gilliom and others, 2006). Tebuthiuron is registered by the USEPA as a general-use herbicide, and like prometon, is used in noncropland areas as a broad-spectrum herbicide to control weeds, grasses, and woody plants (Meister, 2002; Cornell University Pesticide Management Education Program, 2008).

Relation of Pesticide Occurrence to Selected Factors

Various natural and anthropogenic factors that might affect the occurrence of pesticides in Wyoming's ground water were evaluated and are described in this section of the report. Pesticide occurrence is qualitatively and quantitatively summarized and evaluated in relation to geography, land use, hydrogeology, soils, and nitrate and selected water-quality characteristics.

Geography

Pesticide detections were examined in relation to Wyoming geography. To facilitate comparisons among different geographic areas, the State was divided into eight regional geographic areas on the basis of similar environmental setting using both natural (geography, physiography, hydrology, and geology) and anthropogenic (crops grown and likely agricultural pesticide use) characteristics. The eight regional geographic areas—Bighorn Basin, Central Basins, Green River Basin, High Plains/Casper Arch, Northwest Basins, Overthrust Belt, Powder River Basin, and Wind River Basin—are shown in figure 8 along with wells sampled during 1995–2006.

Pesticides detected in each geographic area are listed and summarized in table 7. Sampled wells with no pesticide detections and with at least one pesticide detected using the CAL are shown in figure 8 in relation to geographic area. Regardless of assessment level and considering both seasons, the largest percentage of pesticide detections and the largest number of different pesticides detected occurred in samples from wells located in the Bighorn Basin and High Plains/Casper Arch geographic areas (table 7). In fact, using the CAL, samples from wells in the Bighorn Basin and High Plains/Casper Arch geographic areas combined comprised about 69 percent of all detections in the fall, and about 63 percent of all detections in the spring. Pesticide use for agricultural purposes in both geographic areas is likely among the largest as both geographic areas comprise two of three “major crop producing areas in Wyoming” (Wyoming Department of Agriculture, 1995, p. 20); the Wind River Basin is the third major crop-producing area. Pesticides were detected distinctly less often in samples from wells in other geographic areas. Considering only concentrations greater than the CAL, the proportion of samples with at least one pesticide detected was significantly different among the eight geographic areas for both the fall (p -value < 0.0001 , CTA, table 8) and the spring (p -value < 0.0001 , CTA, table 8).

All pesticides detected in either the fall or spring are summarized in relation to the eight geographic areas in table 9. Considering only concentrations greater than their respective CSALs, only six herbicides (atrazine, prometon, tebuthiuron, picloram, bromacil, and diuron, listed in order of decreasing detection frequency) and one degradate (deethylatrazine) were detected in either the fall or spring in three or more different geographic areas (although some pesticides were not analyzed in samples from all eight geographic areas, table 9). Of these seven compounds, prometon was the only pesticide detected in either season in all eight geographic areas (samples collected in the spring, table 9). Considering only concentrations greater than their respective CSALs, 17 pesticides were detected in only one geographic area in the fall, and 12 pesticides were detected in only one geographic area in the spring. The proportion of samples detected at concentrations greater than their respective CSALs (detection frequency) was significantly different among the eight geographic areas

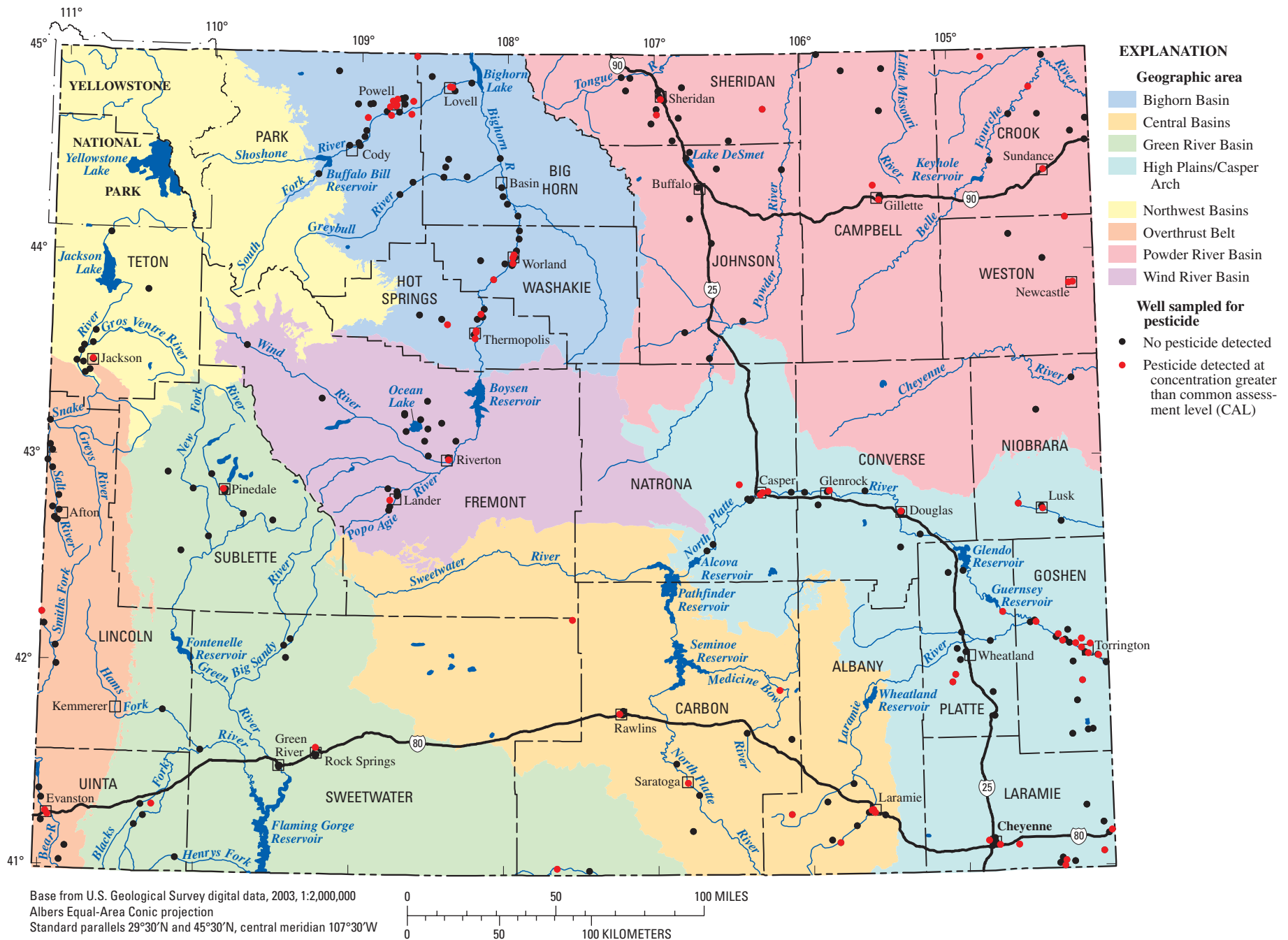


Figure 8. Geographic areas and ground-water wells sampled in Wyoming during 1995–2006.

Table 7. Pesticide detections in ground-water samples collected during fall and spring relative to eight regional geographic areas in Wyoming, 1995–2006.

[Geographic areas listed in order of decreasing pesticide detection frequency by jointly ranking fall and spring detections with no assessment level applied. Assessment level: NAL, no assessment level applied; CSAL, compound-specific assessment level; CAL, common assessment level. Pesticide type: H, herbicide; HD, herbicide degradate; I, insecticide; ID, insecticide degradate. Symbol: --, not applicable]

Geographic area	Assessment level	Fall		
		Number of pesticides detected in geographic area/number of pesticide detections in all geographic areas (percentage)	Number of different pesticides detected in geographic area	Pesticides detected
Bighorn Basin	NAL	167/436 (38.3)	21	Atrazine (H), bentazon (H), bromacil (H), bromoxynil (H), cyanazine (H), DCPA (H), diuron (H), metolachlor (H), metribuzin (H), norflurazon (H), picloram (H), prometon (H), simazine (H), tebuthiuron (H), trifluralin (H), deethylatrazine (HD), deisopropylatrazine (HD), carbaryl (I), carbofuran (I), aldicarb sulfone (ID), aldicarb sulfoxide (ID)
	CSAL	70/227 (30.8)	12	Atrazine (H), bentazon (H), bromacil (H), bromoxynil (H), metolachlor (H), picloram (H), prometon (H), tebuthiuron (H), deethylatrazine (HD), carbofuran (I), aldicarb sulfone (ID), aldicarb sulfoxide (ID)
	CAL	28/111 (25.2)	9	Atrazine (H), bentazon (H), bromoxynil (H), picloram (H), prometon (H), tebuthiuron (H), deethylatrazine (HD), aldicarb sulfone (ID), aldicarb sulfoxide (ID)
High Plains/ Casper Arch	NAL	109/436 (25.0)	15	2,4-D (H), 2,4-D methyl ester (H), atrazine (H), bromacil (H), clopyralid (H), cyanazine (H), diuron (H), metolachlor (H), oryzalin (H), picloram (H), prometon (H), simazine (H), tebuthiuron (H), triclopyr (H), deethylatrazine (HD)
	CSAL	78/227 (34.4)	14	2,4-D (H), 2,4-D methyl ester (H), atrazine (H), bromacil (H), clopyralid (H), cyanazine (H), metolachlor (H), oryzalin (H), picloram (H), prometon (H), simazine (H), tebuthiuron (H), triclopyr (H), deethylatrazine (HD)
	CAL	49/111 (44.1)	12	2,4-D (H), 2,4-D methyl ester (H), atrazine (H), bromacil (H), clopyralid (H), oryzalin (H), picloram (H), prometon (H), simazine (H), tebuthiuron (H), triclopyr (H), deethylatrazine (HD)
Powder River Basin	NAL	44/436 (10.1)	19	Atrazine (H), bromacil (H), DCPA (H), diuron (H), metsulfuron (H), oxyfluorfen (H), picloram (H), prometon (H), simazine (H), sulfometuron (H), tebuthiuron (H), 3,4-dichloroaniline (HD), deethylatrazine (HD), <i>alpha</i> -endosulfan (I), carbaryl (I), dieldrin (I), imidacloprid (I), fipronil sulfide (ID), fipronil sulfone (ID)
	CSAL	16/227 (7.0)	9	Atrazine (H), bromacil (H), DCPA (H), picloram (H), prometon (H), tebuthiuron (H), 3,4-dichloroaniline (HD), imidacloprid (I), fipronil sulfide (ID)
	CAL	7/111 (6.3)	3	Bromacil (H), picloram (H), prometon (H)

Table 7. Pesticide detections in ground-water samples collected during fall and spring relative to eight regional geographic areas in Wyoming, 1995–2006.—Continued

[Geographic areas listed in order of decreasing pesticide detection frequency by jointly ranking fall and spring detections with no assessment level applied. Assessment level: NAL, no assessment level applied; CSAL, compound-specific assessment level; CAL, common assessment level. Pesticide type: H, herbicide; HD, herbicide degradate; I, insecticide; ID, insecticide degradate. Symbol: --, not applicable]

Geographic area	Assessment level	Spring		
		Number of pesticides detected in geographic area/number of pesticide detections in all geographic areas (percentage)	Number of different pesticides detected in geographic area	Pesticides detected
Bighorn Basin	NAL	169/410 (41.2)	18	Atrazine (H), bentazon (H), bromacil (H), cyanazine (H), DCPA (H), diuron (H), hexazinone (H), metolachlor (H), metribuzin (H), norflurazon (H), picloram (H), prometon (H), simazine (H), tebuthiuron (H), deethylatrazine (HD), deisopropylatrazine (HD), aldicarb sulfone (ID), aldicarb sulfoxide (ID).
	CSAL	71/208 (34.1)	12	Atrazine (H), bentazon (H), bromacil (H), hexazinone (H), metolachlor (H), picloram (H), prometon (H), tebuthiuron (H), deethylatrazine (HD), deisopropylatrazine (HD), aldicarb sulfone (ID), aldicarb sulfoxide (ID).
	CAL	30/109 (27.5)	10	Atrazine (H), bentazon (H), bromacil (H), picloram (H), prometon (H), tebuthiuron (H), deethylatrazine (HD), deisopropylatrazine (HD), aldicarb sulfone (ID), aldicarb sulfoxide (ID).
High Plains/ Casper Arch	NAL	108/410 (26.3)	16	2,4-D (H), alachlor (H), atrazine (H), bromacil (H), clopyralid (H), cyanazine (H), diuron (H), metolachlor (H), metribuzin (H), picloram (H), prometon (H), simazine (H), tebuthiuron (H), triclopyr (H), deethylatrazine (HD), diazinon (I).
	CSAL	64/208 (30.8)	13	Atrazine (H), bromacil (H), clopyralid (H), cyanazine (H), diuron (H), metolachlor (H), picloram (H), prometon (H), simazine (H), tebuthiuron (H), triclopyr (H), deethylatrazine (HD), diazinon (I).
	CAL	39/109 (35.8)	10	Atrazine (H), bromacil (H), clopyralid (H), diuron (H), picloram (H), prometon (H), simazine (H), tebuthiuron (H), triclopyr (H), deethylatrazine (HD).
Powder River Basin	NAL	40/410 (9.8)	12	Atrazine (H), bromacil (H), clopyralid (H), dicamba (H), diuron (H), picloram (H), prometon (H), simazine (H), tebuthiuron (H), triallate (H), deethylatrazine (HD), imidacloprid (I).
	CSAL	20/208 (9.6)	9	Atrazine (H), bromacil (H), dicamba (H), picloram (H), prometon (H), simazine (H), tebuthiuron (H), triallate (H), imidacloprid (I).
	CAL	12/109 (11.0)	6	Bromacil (H), clopyralid (H), dicamba (H), picloram (H), prometon (H), tebuthiuron (H).

Table 7. Pesticide detections in ground-water samples collected during fall and spring relative to eight regional geographic areas in Wyoming, 1995–2006. —Continued

[Geographic areas listed in order of decreasing pesticide detection frequency by jointly ranking fall and spring detections with no assessment level applied. Assessment level: NAL, no assessment level applied; CSAL, compound-specific assessment level; CAL, common assessment level. Pesticide type: H, herbicide; HD, herbicide degradate; I, insecticide; ID, insecticide degradate. Symbol: --, not applicable]

Geographic area	Assessment level	Fall		
		Number of pesticides detected in geographic area/number of pesticide detections in all geographic areas (percentage)	Number of different pesticides detected in geographic area	Pesticides detected
Central Basins	NAL	36/436 (8.3)	16	Atrazine (H), bromacil (H), chlorimuron (H), clopyralid (H), dichlorprop (H), diuron (H), flumetsulam (H), picloram (H), prometon (H), simazine (H), sulfometuron (H), tebuthiuron (H), deethylatrazine (HD), deisopropylatrazine (HD), hydroxyatrazine (HD), malathion (I)
	CSAL	26/227 (11.5)	12	Atrazine (H), bromacil (H), clopyralid (H), dichlorprop (H), diuron (H), flumetsulam (H), picloram (H), prometon (H), tebuthiuron (H), deethylatrazine (HD), deisopropylatrazine (HD), hydroxyatrazine (HD)
	CAL	16/111 (14.4)	10	Atrazine (H), bromacil (H), clopyralid (H), dichlorprop (H), diuron (H), flumetsulam (H), picloram (H), prometon (H), tebuthiuron (H), deethylatrazine (HD)
Wind River Basin	NAL	37/436 (8.5)	8	Atrazine (H), DCPA (H), picloram (H), prometon (H), simazine (H), tebuthiuron (H), deethylatrazine (HD), 3-hydroxycarbofuran (ID)
	CSAL	17/227 (7.5)	4	Atrazine (H), picloram (H), prometon (H), tebuthiuron (H)
	CAL	2/111 (1.8)	2	Picloram (H), prometon (H)
Green River Basin	NAL	28/436 (6.4)	17	Atrazine (H), benfluralin (H), bromacil (H), clopyralid (H), diuron (H), picloram (H), prometon (H), simazine (H), sulfometuron (H), tebuthiuron (H), triallate (H), trifluralin (H), deethylatrazine (HD), <i>cis</i> -permethrin (I), dieldrin (I), fipronil sulfide (ID), fipronil sulfone (ID)
	CSAL	13/227 (5.7)	6	Atrazine (H), bromacil (H), diuron (H), prometon (H), tebuthiuron (H), fipronil sulfide (ID)
	CAL	6/111 (5.4)	4	Bromacil (H), diuron (H), prometon (H), tebuthiuron (H)
Overthrust Belt	NAL	11/436 (2.5)	6	Atrazine (H), picloram (H), prometon (H), simazine (H), tebuthiuron (H), deethylatrazine (HD)
	CSAL	7/227 (3.1)	5	Atrazine (H), picloram (H), prometon (H), simazine (H), tebuthiuron (H)
	CAL	3/111 (2.7)	2	Picloram (H), prometon (H)
Northwest Basins	NAL	4/436 (0.9)	2	Prometon (H), malathion (I)
	CSAL	0/227 (0)	0	--
	CAL	0/111 (0)	0	--

Table 7. Pesticide detections in ground-water samples collected during fall and spring relative to eight regional geographic areas in Wyoming, 1995–2006.—Continued

[Geographic areas listed in order of decreasing pesticide detection frequency by jointly ranking fall and spring detections with no assessment level applied. Assessment level: NAL, no assessment level applied; CSAL, compound-specific assessment level; CAL, common assessment level. Pesticide type: H, herbicide; HD, herbicide degradate; I, insecticide; ID, insecticide degradate. Symbol: --, not applicable]

Geographic area	Assessment level	Spring		
		Number of pesticides detected in geographic area/number of pesticide detections in all geographic areas (percentage)	Number of different pesticides detected in geographic area	Pesticides detected
Central Basins	NAL	39/410 (9.5)	12	2,4-D (H), atrazine (H), bromacil (H), clopyralid (H), dichloroprop (H), diuron (H), picloram (H), prometon (H), simazine (H), tebuthiuron (H), deethylatrazine (HD), deisopropylatrazine (HD).
	CSAL	22/208 (10.6)	7	Atrazine (H), bromacil (H), diuron (H), picloram (H), prometon (H), tebuthiuron (H), deethylatrazine (HD).
	CAL	13/109 (11.9)	6	Bromacil (H), clopyralid (H), diuron (H), picloram (H), prometon (H), tebuthiuron (H).
Wind River Basin	NAL	25/410 (6.1)	6	Atrazine (H), picloram (H), prometon (H), simazine (H), tebuthiuron (H), deethylatrazine (HD).
	CSAL	14/208 (6.7)	4	Atrazine (H), picloram (H), prometon (H), tebuthiuron (H).
	CAL	3/109 (2.8)	3	Picloram (H), prometon (H), tebuthiuron (H).
Green River Basin	NAL	19/410 (4.6)	6	Bromacil (H), clopyralid (H), diuron (H), picloram (H), prometon (H), tebuthiuron (H).
	CSAL	12/208 (5.8)	5	Bromacil (H), diuron (H), picloram (H), prometon (H), tebuthiuron (H).
	CAL	9/109 (8.3)	6	Bromacil (H), clopyralid (H), diuron (H), picloram (H), prometon (H), tebuthiuron (H).
Overthrust Belt	NAL	8/410 (2.0)	3	Atrazine (H), prometon (H), simazine (H).
	CSAL	4/208 (1.9)	2	Atrazine (H), prometon (H).
	CAL	2/109 (1.8)	1	Prometon (H).
Northwest Basins	NAL	2/410 (0.5)	1	Prometon (H).
	CSAL	1/208 (0.5)	1	Prometon (H).
	CAL	1/109 (0.9)	1	Prometon (H).

Table 8. Results of contingency-table analysis (CTA) comparing selected pesticide detections in ground-water samples collected during fall and spring from eight regional geographic areas in Wyoming, 1995–2006.

[Statistically significant differences (p-value<0.05) among eight regional geographic areas (table 7) indicated in **bold type**; CAL, common assessment level; CSAL, compound-specific assessment level; H, herbicide; HD, herbicide degradate; ID, insecticide degradate; I, insecticide; <, less than; --, not applicable]

Tested variable	Pesticide type	Assessment level used	Probability (p-value)	
			Fall	Spring
Percentage of wells with at least one pesticide detected	--	CAL	<0.0001	<0.0001
Atrazine	H	CSAL	<.0001	<.0001
Prometon	H	CSAL	.0399	.3051
Deethylatrazine	HD	CSAL	.0008	.0182
Tebuthiuron	H	CSAL	.0406	.0070
Picloram	H	CSAL	.4016	.4704
Deisopropylatrazine	HD	CSAL	.4281	--
3,4-Dichloroaniline	H	CSAL	.7662	--
Bromacil	H	CSAL	.7849	.1964
Diuron	H	CSAL	--	.4839
Metolachlor	H	CSAL	.7618	--
Hexazinone	H	CSAL	--	.8139
Aldicarb sulfoxide	ID	CSAL	.1436	.1704
Aldicarb sulfone	ID	CSAL	.1517	.1777
Hydroxyatrazine	HD	CSAL	.6052	--
Flumetsulam	H	CSAL	.2628	--
Imidacloprid	I	CSAL	.4356	.3982
Fipronil sulfide	ID	CSAL	.4899	--
2,4-D methyl ester	H	CSAL	.3396	--

for four pesticides (atrazine, prometon, deethylatrazine, and tebuthiuron, listed in order of decreasing detection frequency) detected in the fall and three pesticides (atrazine, deethylatrazine, and tebuthiuron) detected in the spring (p-values for all compounds < 0.05, CTA, table 8).

Land Use

Pesticide detections were examined in relation to land use. Land use within a 500-m (1,640-ft) radius surrounding each sampled well was classified using an enhanced version of the USGS 1992 National Land Cover Data (NLCD) set (Nakagaki and Wolock, 2005). The NLCD classified land use for each 30-by-30-m area of the United States. For the study described herein, a GIS was used to manipulate the NLCD to classify all land uses within the 500-m radius surrounding all sampled wells. Individual land uses classified within the 500-m radius then were used to classify land use into one of four predominant land-use categories using the following criteria: (1) agricultural [greater than (>) 50 percent agricultural land and less than or equal to (\leq) 5 percent urban land]; (2) urban (> 25 percent urban land use and \leq 25 percent

agricultural land); (3) rangeland/undeveloped (\leq 5 percent urban land and \leq 25 percent agricultural land); and (4) mixed (all other combinations of urban, agricultural, and rangeland/undeveloped land). Each sampled well then was assigned to one of these four land-use categories to relate pesticide detections to overlying land use.

On the basis of reviews of previous studies and on USGS NAWQA guidance (Koterba, 1998, and references therein), a 500-m radius was assumed to represent the recharge area to sampled wells. This approach was used because information describing the rate and direction of ground-water flow necessary to determine the shape and size of recharge areas to each sampled well generally was not available; use of a 500-m radius has been found to work reasonably well when trying to relate land-use activities to ground-water quality in underlying shallow surficial aquifers (Koterba, 1998, and references therein). Pesticide detections in shallow ground water throughout the United States often are related to overlying land use (Gilliom and others, 2006).

Detected pesticide concentrations and the overall frequency of detection in samples (represented by the percentage of wells with at least one pesticide detected) are shown

by land use in figure 9. Regardless of assessment level and season, pesticides were detected much more frequently in samples from wells located in predominantly urban areas than in samples from wells located in predominantly agricultural, mixed, or rangeland/undeveloped areas. Pesticides were detected distinctly less often in samples from wells located in predominantly rangeland/undeveloped areas (fig. 9). The frequency of pesticide detection in samples from wells located in a predominantly agricultural or mixed land-use areas was intermediate to that of urban and rangeland/undeveloped areas; however, using the CAL, the difference was more distinct, and the percentage of wells located in areas classified as either predominantly agricultural or mixed with at least one pesticide detected was less than one-half that of wells located in predominantly urban areas regardless of season. Considering only detections greater than the CAL, the proportion of wells with at least one pesticide detected was significantly different among the four land-use categories for both the fall (p -value < 0.0001 , KWOCR, table 10) and the spring (p -value < 0.0001 , KWOCR, table 10).

Concentrations and frequencies of pesticides detected most often—pesticides detected with original censoring (NAL) in 1 percent or more of wells sampled in either fall or the spring—are shown by land-use category in figure 10. Using figure 10, graphical comparisons can be made between individual pesticides detected in the same season or between spring and fall detections of the same pesticide with and without recensoring. Considering only concentrations greater than their respective CSALs for either fall or spring, eight pesticides [bromacil, clopyralid, flumetsulam, 2,4-D methyl ester, deisopropylatrazine (fall), 3,4-dichloroaniline, hydroxyatrazine, and imidacloprid, listed in order of decreasing detection frequency; fig. 10A] were detected only in water from wells located in predominantly urban areas, three pesticides (DCPA, bentazon, and aldicarb sulfone; fall, fig. 10A) were detected only in water from wells located in predominantly agricultural areas, and two pesticides (hexazinone and deisopropylatrazine; spring, fig. 10B) were detected only in water from wells located in predominantly mixed land-use areas. Considering only concentrations greater than their respective CSALs, no pesticide was detected in samples from wells located only in predominantly rangeland/undeveloped areas. Remaining pesticides detected at concentrations greater than their respective CSALs and shown in figure 10 were associated with sampled wells located in two to four different predominant land uses.

As noted previously herein, two of the pesticides detected most frequently during this study (prometon and tebuthiuron) either have no reported agricultural use (prometon) or limited noncropland use (tebuthiuron) in Wyoming. As expected, both of these pesticides were detected most commonly in sampled wells located in predominantly urban areas, although many detections were associated with sampled wells located in predominantly agricultural or mixed areas. This was not surprising and likely reflects the use of both pesticides for

many different nonagricultural applications throughout all land uses in Wyoming.

The occurrence of some pesticides did not necessarily correspond to the predominant land use assigned to sampled wells (fig. 10). The detection of many pesticides most commonly associated with agricultural use in water from wells located in predominantly urban, mixed, and rangeland/undeveloped areas was likely caused by at least one of three factors: (1) in most cases, the predominant land use assigned to each sampled well was not the only land use present within a 500-m radius of the well, and the detected pesticide may be due to the other less common land uses; (2) pesticides can be transported in ground water from other areas with different land use; and (3) pesticides can be transported in the atmosphere and (or) precipitation from other areas.

The frequencies of pesticide detection among the four land-use categories were compared using the CSALs for individual pesticides detected in either the fall or spring at a frequency equal to or greater than 1 percent (table 10). The proportion of samples detected at concentrations greater than their respective CSALs (detection frequency) was significantly different among the four land-use categories for four pesticides (atrazine, prometon, tebuthiuron, and bromacil, listed in order of decreasing detection frequency) detected in both the fall and spring (p -values for all four compounds < 0.05 , KWOCR, table 10).

Hydrogeology

Four different hydrogeologic characteristics—aquifer type, water-level depth, well depth, and well type—were evaluated to examine their relation to the occurrence of pesticides in ground water. In some previous studies, these characteristics have been shown to affect the occurrence of pesticides in ground water (Barbash and Resek, 1996, and references therein).

Aquifer Type

On the basis of determined geologic formation and lithology, all sampled wells were assigned to one of two different aquifer types—unconsolidated deposits or consolidated bedrock. The frequency of pesticide detection was examined in relation to these two different types of aquifers. Water from wells completed in unconsolidated aquifers accounted for 79 to 87 percent of pesticide detections (fig. 11) regardless of season or assessment level. Other investigators also have found pesticide detections to be generally more frequent in unconsolidated aquifers compared to consolidated (bedrock) aquifers (Barbash and Resek, 1996, and references therein). In the Wyoming baseline study, more sampled wells were completed in surficial aquifers in unconsolidated deposits (223 of 296 wells sampled) than in bedrock (73 of 296 wells sampled). Sampled unconsolidated aquifers were composed of clay, silt, sand, and (or) gravel of Quaternary age, whereas

Table 9. Pesticide detection frequencies and concentrations in ground-water samples collected during fall and spring relative to eight regional geographic areas in Wyoming, 1995–2006.

[Geographic areas where pesticides were detected are listed in order of decreasing frequency with no assessment level applied. Assessment level: NAL, no assessment level applied; CSAL, compound-specific assessment level; CAL, common assessment level. Geographic area: BH, Bighorn Basin; CB, Central Basins; GR, Green River Basin; HC, High Plains/Casper Arch; NW, Northwest Basins; OB, Overthrust Belt; PR, Powder River Basin; WR, Wind River Basin. Symbol: --, no detections or not applicable]

Fall														
Pesticide	Geo-graphic area where detected	Number of detections/ number of analyses			Detection frequency in geographic area (percentage)			Detected concentration range (micrograms per liter)			Median concentration of detections (micrograms per liter)			Geographic area where pesticide was not analyzed
		NAL	CSAL	CAL	NAL	CSAL	CAL	NAL	CSAL	CAL	NAL	CSAL	CAL	
Herbicides														
Atrazine	BH	44/66	37/66	1/66	66.7	56.1	1.5	0.002–0.158	0.004–0.158	0.158	0.006	0.008	--	--
	WR	10/20	9/20	0/20	50.0	45.0	0	0.003–0.026	0.004–0.026	--	.006	.006	--	--
	HC	31/78	26/76	7/78	39.7	34.2	9.0	0.002–0.890	0.004–0.890	0.07–0.890	.011	.014	0.270	--
	CB	3/21	3/21	1/21	14.3	14.3	4.8	0.015–0.173	0.015–0.173	0.173	.015	.015	--	--
	OB	2/21	2/21	0/21	9.5	9.5	0	0.005–0.013	0.005–0.013	--	.009	.009	--	--
	GR	2/28	2/28	0/28	7.1	7.1	0	0.006–0.007	0.006–0.007	--	.006	.006	--	--
	PR	3/50	3/50	0/50	6.0	6.0	0	0.005–0.022	0.005–0.022	--	.005	.005	--	--
Prometon	BH	31/66	8/66	7/66	47.0	12.1	10.6	0.003–0.49	0.06–0.49	0.08–0.49	.01	.15	.17	--
	CB	7/20	6/20	6/20	35.0	30.0	30.0	0.01–2.88	0.07–2.88	0.07–2.88	.09	.12	.12	--
	PR	16/50	2/50	1/50	32.0	4.0	2.0	0.003–0.07	0.06–0.07	0.07	.01	.06	.07	--
	HC	20/78	16/78	14/78	25.6	20.5	17.9	0.001–1.40	0.06–1.40	0.08–1.40	.10	.11	.12	--
	GR	7/28	3/28	2/28	25.0	10.7	7.1	0.01–1.05	0.05–1.05	0.09–1.05	.04	.09	.57	--
	WR	5/20	2/20	1/20	25.0	10.0	5.0	0.01–0.08	0.05–0.08	0.08	.01	.06	--	--
	NW	3/12	0/12	0/12	25.0	0	0	0.002–0.02	--	--	.01	--	--	--
	OB	4/21	2/21	2/21	19.0	9.5	9.5	0.004–0.36	0.1–0.36	0.1–0.36	.06	.23	.23	--
Tebuthiuron	CB	5/21	5/21	2/21	23.8	23.8	9.5	0.01–0.58	0.01–0.58	0.44–0.58	.03	.03	.51	--
	WR	4/20	4/20	0/20	20.0	20.0	0	0.01–0.05	0.01–0.05	--	.02	.02	--	--
	GR	5/28	5/28	2/28	17.9	17.9	7.1	0.02–0.43	0.02–0.43	0.33–0.43	.04	.04	.38	--
	BH	9/66	9/66	6/66	13.6	13.6	9.1	0.01–1.97	0.01–1.97	0.08–1.97	.08	.08	.22	--
	HC	7/76	6/76	4/76	9.2	7.9	5.3	0.004–0.57	0.03–0.57	0.07–0.57	.07	.16	.30	--
	OB	1/21	1/21	0/21	4.8	4.8	0	0.01	0.01	--	--	--	--	--
	PR	1/50	1/50	0/50	2.0	2.0	0	0.03	0.03	--	--	--	--	--
Simazine	WR	4/20	0/20	0/20	20.0	0	0	0.002–0.011	--	--	.004	--	--	--
	BH	11/66	0/66	0/66	16.7	0	0	0.003–0.011	--	--	.006	--	--	--
	HC	4/78	1/78	1/78	5.1	1.3	1.3	0.006–0.093	0.093	0.093	.024	--	--	--
	CB	1/20	0/20	0/20	5.0	0	0	0.008	--	--	--	--	--	--
	OB	1/21	1/21	0/21	4.8	4.8	0	0.058	0.058	--	--	--	--	--
	GR	1/28	0/28	0/28	3.6	0	0	0.011	--	--	--	--	--	--
	PR	1/50	0/50	0/50	2.0	0	0	0.006	--	--	--	--	--	--
Picloram	CB	3/21	3/21	1/21	14.3	14.3	4.8	0.06–0.09	0.06–0.09	0.09	.06	.06	--	--
	HC	9/75	7/74	7/75	12.0	9.5	9.3	0.04–4.31	0.08–4.31	0.08–4.31	.24	.26	.26	--
	PR	5/50	5/50	5/50	10.0	10.0	10.0	0.17–9.50	0.17–9.50	0.17–9.50	2.19	2.19	2.19	--
	WR	2/20	2/20	1/20	10.0	10.0	5.0	0.06–1.73	0.06–1.73	1.73	.90	.90	--	--
	OB	2/21	1/21	1/21	9.5	4.8	4.8	0.03–0.31	0.31	0.31	.17	--	--	--
	GR	1/22	0/22	0/22	4.5	0	0	0.04	--	--	--	--	--	--
	BH	2/63	2/61	2/61	3.2	3.3	3.3	0.07–0.65	0.07–0.65	0.07–0.65	.36	.36	.36	--

Table 9. Pesticide detection frequencies and concentrations in ground-water samples collected during fall and spring relative to eight regional geographic areas in Wyoming, 1995–2006.—Continued

[Geographic areas where pesticides were detected are listed in order of decreasing frequency with no assessment level applied. Assessment level: NAL, no assessment level applied; CSAL, compound-specific assessment level; CAL, common assessment level. Geographic area: BH, Bighorn Basin; CB, Central Basins; GR, Green River Basin; HC, High Plains/Casper Arch; NW, Northwest Basins; OB, Overthrust Belt; PR, Powder River Basin; WR, Wind River Basin. Symbol: --, no detections or not applicable]

Pesticide	Geo-graphic area where detected	Spring												Geographic area where compound was not analyzed
		Number of detections/ number of analyses			Detection frequency in geographic area (percentage)			Detected concentration range (micrograms per liter)			Median concentration of detections (micrograms per liter)			
		NAL	CSAL	CAL	NAL	CSAL	CAL	NAL	CSAL	CAL	NAL	CSAL	CAL	
Herbicides														
Atrazine	BH	48/66	38/66	1/66	72.7	57.6	1.5	0.002–0.180	0.004–0.180	0.180	0.007	0.010	0.180	--
	HC	29/78	24/68	9/78	37.2	35.3	11.5	0.001–0.900	0.004–0.900	0.090–0.900	.010	.030	.147	--
	WR	7/20	7/20	0/20	35.0	35.0	0	0.004–0.033	0.004–0.033	--	.008	.008	--	--
	CB	6/21	4/20	0/21	28.6	20.0	0	0.002–0.030	0.005–0.030	--	.009	.016	--	--
	OB	2/21	2/21	0/21	9.5	9.5	0	0.006–0.009	0.006–0.009	--	.008	.008	--	--
	PR	3/49	3/49	0/49	6.1	6.1	0	0.004–0.009	0.004–0.009	--	.005	.005	--	--
Prometon	CB	8/21	6/21	4/21	38.1	28.6	19.0	0.003–1.24	0.05–1.24	0.07–1.24	.06	.11	.26	--
	BH	25/66	8/66	7/66	37.9	12.1	10.6	0.004–0.45	0.06–0.45	0.07–0.45	.03	.15	.18	--
	PR	14/48	3/48	1/48	29.2	6.2	2.1	0.002–0.14	0.05–0.14	0.14	.02	.06	--	--
	WR	5/20	2/20	1/20	25.0	10.0	5.0	0.01–0.11	0.06–0.11	0.11	.04	.08	--	--
	GR	7/28	2/28	1/28	25.0	7.1	3.6	0.01–0.37	0.05–0.37	0.37	.03	.21	--	--
	HC	19/78	11/78	10/78	24.4	14.1	12.8	0.002–1.24	0.05–1.24	0.07–1.24	.07	.11	.12	--
	OB	4/21	2/21	2/21	19.0	9.5	9.5	0.005–0.42	0.11–0.42	0.11–0.42	.07	.26	.26	--
	NW	2/12	1/12	1/12	16.7	8.3	8.3	0.02–0.14	0.14	0.14	.08	--	--	--
Tebuthiuron	CB	7/21	7/21	4/21	33.3	33.3	19.0	0.01–1.18	0.01–1.18	0.30–1.18	.30	.30	.52	--
	WR	4/20	4/20	1/20	20.0	20.0	5.0	0.01–0.09	0.01–0.09	0.09	.04	.04	--	--
	GR	5/28	5/28	2/28	17.9	17.9	7.1	0.01–0.24	0.01–0.24	0.11–0.24	.05	.05	.18	--
	BH	10/66	9/66	6/66	15.2	13.6	9.1	0.005–0.28	0.01–0.28	0.07–0.28	.08	.10	.16	--
	HC	6/78	6/78	3/78	7.7	7.7	3.8	0.03–0.49	0.03–0.49	0.09–0.49	.07	.07	.32	--
	PR	3/49	3/49	1/49	6.1	6.1	2.0	0.01–0.31	0.01–0.31	0.31	.02	.02	--	--
Simazine	CB	3/21	0/21	0/21	14.3	0	0	0.003–0.010	--	--	.008	--	--	--
	BH	9/66	0/66	0/66	13.6	0	0	0.002–0.014	--	--	.006	--	--	--
	OB	2/21	0/21	0/21	9.5	0	0	0.003–0.036	--	--	.020	--	--	--
	HC	7/78	1/78	1/78	9.0	1.3	1.3	0.007–0.112	0.112	0.112	.017	--	--	--
	PR	3/48	1/48	0/48	6.2	2.1	0	0.006–0.069	0.069	--	.007	--	--	--
	WR	1/20	0/20	0/20	5.0	0	0	0.012	--	--	.012	--	--	--
Picloram	PR	6/48	6/48	6/48	12.5	12.5	12.5	0.14–12.2	0.14–12.2	0.14–12.2	.57	.57	.57	--
	WR	2/20	1/20	1/20	10.0	5.0	5.0	0.01–1.26	1.26	1.26	.64	--	--	--
	HC	6/78	4/78	3/78	7.7	5.1	3.8	0.04–2.45	0.06–2.45	0.07–2.45	.06	1.18	2.30	--
	CB	1/19	1/19	1/19	5.3	5.3	5.3	0.21	0.21	0.21	.21	--	--	--
	BH	3/66	3/66	3/66	4.5	4.5	4.5	0.07–0.46	0.07–0.46	0.07–0.46	.25	.25	.25	--
	GR	1/27	1/24	1/24	3.7	4.2	4.2	0.38	0.38	0.38	.38	--	--	--

Table 9. Pesticide detection frequencies and concentrations in ground-water samples collected during fall and spring relative to eight regional geographic areas in Wyoming, 1995–2006.—Continued

[Geographic areas where pesticides were detected are listed in order of decreasing frequency with no assessment level applied. Assessment level: NAL, no assessment level applied; CSAL, compound-specific assessment level; CAL, common assessment level. Geographic area: BH, Bighorn Basin; CB, Central Basins; GR, Green River Basin; HC, High Plains/Casper Arch; NW, Northwest Basins; OB, Overthrust Belt; PR, Powder River Basin; WR, Wind River Basin. Symbol: --, no detections or not applicable]

Fall														
Pesticide	Geo-graphic area where detected	Number of detections/ number of analyses			Detection frequency in geographic area (percentage)			Detected concentration range (micrograms per liter)			Median concentration of detections (micrograms per liter)			Geographic area where pesticide was not analyzed
		NAL	CSAL	CAL	NAL	CSAL	CAL	NAL	CSAL	CAL	NAL	CSAL	CAL	
Herbicides—Continued														
Oxyfluorfen	PR	1/7	0/7	0/7	14.3	0	0	0.007	--	--	--	--	--	BH, CB, GR, NW, OB, WR
Bromacil	CB	2/21	1/21	1/21	9.5	4.8	4.8	0.04–0.80	0.80	0.80	0.42	--	--	--
	HC	4/77	4/76	3/76	5.2	5.3	3.9	0.06–8.07	0.06–8.07	0.15–8.07	.66	0.66	1.18	--
	GR	1/27	1/27	1/27	3.7	3.7	3.7	1.96	1.96	1.96	--	--	--	--
	PR	1/50	1/50	1/50	2.0	2.0	2.0	0.60	0.60	0.60	--	--	--	--
	BH	1/63	1/62	0/62	1.6	1.6	0	0.06	0.06	--	--	--	--	--
Diuron	CB	2/21	1/21	1/21	9.5	4.8	4.8	0.02–0.19	0.19	0.19	.10	--	--	--
	GR	1/28	1/28	1/28	3.6	3.6	3.6	0.08	0.08	0.08	--	--	--	--
	HC	2/77	0/76	0/76	2.6	0	0	0.04	--	--	.04	--	--	--
	PR	2/50	0/50	0/50	4.0	0	0	0.03–0.05	--	--	.04	--	--	--
	BH	1/63	0/63	0/63	1.6	0	0	0.01	--	--	--	--	--	--
Metolachlor	BH	7/66	2/66	0/66	10.6	3.0	0	0.002–0.024	0.009–0.024	--	.004	.016	--	--
	HC	1/78	1/59	0/78	1.3	1.7	0	0.01	0.01	--	--	--	--	--
Hexazinone	--	--	--	--	--	--	--	--	--	--	--	--	--	BH, CB, GR, NW, OB, WR
Sulfometuron	GR	1/12	0/12	0/12	8.3	0	0	0.021	--	--	--	--	--	NW, OB, WR
	PR	1/15	0/15	0/15	6.7	0	0	0.02	--	--	--	--	--	--
	CB	1/20	0/20	0/20	5.0	0	0	0.022	--	--	--	--	--	--
Clopyralid	CB	2/21	1/21	1/20	9.5	4.8	5.0	0.02–0.45	0.45	0.45	.24	--	--	--
	GR	1/22	0/21	0/12	4.5	0	0	0.04	--	--	--	--	--	--
	HC	1/75	1/75	1/36	1.3	1.3	2.8	22.6	22.6	22.6	--	--	--	--
Flumetsulam	CB	2/20	2/20	1/20	10.0	10.0	5.0	0.06–0.08	0.06–0.08	0.08	.07	.07	.08	NW, OB, WR
DCPA	WR	2/20	0/20	0/20	10.0	0	0	0.002	--	--	.002	--	--	--
	PR	1/50	1/50	0/50	2.0	2.0	0	0.004	0.004	--	--	--	--	--
	BH	1/66	0/66	0/66	1.5	0	0	0.002	--	--	--	--	--	--
2,4–D methyl ester	HC	1/13	1/13	1/13	7.7	7.7	7.7	0.737	0.737	0.737	--	--	--	NW, OB, WR

Table 9. Pesticide detection frequencies and concentrations in ground-water samples collected during fall and spring relative to eight regional geographic areas in Wyoming, 1995–2006.—Continued

[Geographic areas where pesticides were detected are listed in order of decreasing frequency with no assessment level applied. Assessment level: NAL, no assessment level applied; CSAL, compound-specific assessment level; CAL, common assessment level. Geographic area: BH, Bighorn Basin; CB, Central Basins; GR, Green River Basin; HC, High Plains/Casper Arch; NW, Northwest Basins; OB, Overthrust Belt; PR, Powder River Basin; WR, Wind River Basin. Symbol: --, no detections or not applicable]

[illegible]

Table 9. Pesticide detection frequencies and concentrations in ground-water samples collected during fall and spring relative to eight regional geographic areas in Wyoming, 1995–2006.—Continued

[Geographic areas where pesticides were detected are listed in order of decreasing frequency with no assessment level applied. Assessment level: NAL, no assessment level applied; CSAL, compound-specific assessment level; CAL, common assessment level. Geographic area: BH, Bighorn Basin; CB, Central Basins; GR, Green River Basin; HC, High Plains/Casper Arch; NW, Northwest Basins; OB, Overthrust Belt; PR, Powder River Basin; WR, Wind River Basin. Symbol: --, no detections or not applicable]

[illegible]

Table 9. Pesticide detection frequencies and concentrations in ground-water samples collected during fall and spring relative to eight regional geographic areas in Wyoming, 1995–2006. —Continued

[Geographic areas where pesticides were detected are listed in order of decreasing frequency with no assessment level applied. Assessment level: NAL, no assessment level applied; CSAL, compound-specific assessment level; CAL, common assessment level. Geographic area: BH, Bighorn Basin; CB, Central Basins; GR, Green River Basin; HC, High Plains/Casper Arch; NW, Northwest Basins; OB, Overthrust Belt; PR, Powder River Basin; WR, Wind River Basin. Symbol: --, no detections or not applicable]

Pesticide	Geo-graphic area where detected	Spring												Geographic area where compound was not analyzed	
		Number of detections/ number of analyses			Detection frequency in geographic area (percentage)			Detected concentration range (micrograms per liter)			Median concentration of detections (micrograms per liter)				
		NAL	CSAL	CAL	NAL	CSAL	CAL	NAL	CSAL	CAL	NAL	CSAL	CAL		
Herbicides—Continued															
Chlorimuron	--	--	--	--	--	--	--	--	--	--	--	--	--	--	NW, OB, WR
Metsulfuron	--	--	--	--	--	--	--	--	--	--	--	--	--	--	NW, OB, WR
Bentazon	BH	1/66	1/66	1/66	1.5	1.5	1.5	0.59	0.59	0.59	--	--	--	--	--
Cyanazine	BH	1/66	0/41	0/41	1.5	0	0	0.008	--	--	--	--	--	--	--
	HC	1/78	1/68	1/68	1.3	1.5	1.5	0.130	0.130	0.130	--	--	--	--	--
2,4-D	CB	1/21	0/21	0/20	4.8	0	0	0.04	--	--	--	--	--	--	--
	HC	1/78	0/78	0/51	1.3	0	0	0.04	--	--	--	--	--	--	--
Metribuzin	BH	1/66	0/66	0/66	1.5	0	0	0.007	--	--	--	--	--	--	--
	HC	1/78	0/78	0/78	1.3	0	0	0.010	--	--	--	--	--	--	--
Triallate	PR	1/42	1/42	0/42	2.4	2.4	0	0.005	0.005	--	--	--	--	--	--
Dichlorprop	CB	1/21	0/21	0/21	4.8	0	0	0.01	--	--	--	--	--	--	--
Triclopyr	HC	1/78	1/78	1/62	1.3	1.3	1.6	1.51	1.51	1.51	--	--	--	--	--
Norflurazon	BH	1/66	0/66	0/66	1.5	0	0	0.01	--	--	--	--	--	--	--
Trifluralin	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Bromoxynil	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Oryzalin	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Benfluralin	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Alachlor	HC	1/78	0/78	0/78	1.3	0	0	0.004	--	--	--	--	--	--	--
Dicamba	PR	1/48	1/48	1/48	2.1	2.1	2.1	1.11	1.11	1.11	--	--	--	--	--

Table 9. Pesticide detection frequencies and concentrations in ground-water samples collected during fall and spring relative to eight regional geographic areas in Wyoming, 1995–2006.—Continued

[Geographic areas where pesticides were detected are listed in order of decreasing frequency with no assessment level applied. Assessment level: NAL, no assessment level applied; CSAL, compound-specific assessment level; CAL, common assessment level. Geographic area: BH, Bighorn Basin; CB, Central Basins; GR, Green River Basin; HC, High Plains/Casper Arch; NW, Northwest Basins; OB, Overthrust Belt; PR, Powder River Basin; WR, Wind River Basin. Symbol: --, no detections or not applicable]

Fall														
Pesticide	Geo-graphic area where detected	Number of detections/ number of analyses			Detection frequency in geographic area (percentage)			Detected concentration range (micrograms per liter)			Median concentration of detections (micrograms per liter)			Geographic area where pesticide was not analyzed
		NAL	CSAL	CAL	NAL	CSAL	CAL	NAL	CSAL	CAL	NAL	CSAL	CAL	
Herbicide degradates														
Deethylatrazine	BH	39/66	1/66	1/66	59.1	1.5	1.5	0.001–0.107	0.107	0.107	0.004	--	--	--
	WR	9/20	0/20	0/20	45.0	0	0	0.004–0.020	--	--	.005	--	--	--
	HC	25/78	11/78	8/78	32.1	14.1	10.3	0.002–0.810	0.05–0.810	0.07–0.810	.034	.180	.220	--
	CB	2/21	1/21	1/21	9.5	4.8	4.8	0.012–0.120	0.120	0.120	.066	--	--	--
	PR	4/50	0/50	0/50	8.0	0	0	0.004–0.022	--	--	.006	--	--	--
	OB	1/21	0/21	0/21	4.8	0	0	0.003	--	--	.003	--	--	--
	GR	1/28	0/28	0/28	3.6	0	0	0.006	--	--	.006	--	--	--
Deisopropyl-atrazine	BH	1/11	0/11	0/11	9.1	0	0	0.01	--	--	.01	--	--	NW, OB, WR
	CB	1/20	1/20	0/20	5.0	5.0	0	0.05	0.05	--	.05	--	--	--
3,4-Dichloro-aniline	PR	1/7	1/7	0/7	14.3	14.3	0	0.007	0.007	--	--	--	--	BH, CB, GR, NW, OB, WR
Hydroxyatra-zine	CB	2/19	1/19	0/19	10.5	5.3	0	0.007–0.020	0.020	--	.014	--	--	NW, OB, WR
Insecticides														
<i>alpha</i> -Endo-sulfan	PR	1/7	0/7	0/7	14.3	0	0	0.003	--	--	--	--	--	BH, CB, GR, NW, OB, WR
Imidacloprid	PR	1/15	1/15	0/15	6.7	6.7	0	0.029	0.029	--	--	--	--	NW, OB, WR
Carbaryl	PR	1/50	0/50	0/50	2.0	0	0	0.003	--	--	--	--	--	--
	BH	1/66	0/66	0/66	1.5	0	0	0.004	--	--	--	--	--	--
Carbofuran	BH	2/66	2/66	0/66	3.0	3.0	0	0.022–0.042	0.022–0.042	--	.032	.032	--	--
Dieldrin	GR	1/28	0/28	0/28	3.6	0	0	0.007	--	--	--	--	--	--
	PR	1/50	0/50	0/50	2.0	0	0	0.007	--	--	--	--	--	--
Malathion	NW	1/12	0/12	0/12	8.3	0	0	0.011	--	--	--	--	--	--
	CB	1/20	0/20	0/20	5.0	0	0	0.007	--	--	--	--	--	--
Diazinon	--	--	--	--	--	--	--	--	--	--	--	--	--	--
<i>cis</i> -Permethrin	GR	1/28	0/28	0/28	3.6	0	0	0.01	--	--	.01	--	--	--

Table 9. Pesticide detection frequencies and concentrations in ground-water samples collected during fall and spring relative to eight regional geographic areas in Wyoming, 1995–2006.—Continued

[Geographic areas where pesticides were detected are listed in order of decreasing frequency with no assessment level applied. Assessment level: NAL, no assessment level applied; CSAL, compound-specific assessment level; CAL, common assessment level. Geographic area: BH, Bighorn Basin; CB, Central Basins; GR, Green River Basin; HC, High Plains/Casper Arch; NW, Northwest Basins; OB, Overthrust Belt; PR, Powder River Basin; WR, Wind River Basin. Symbol: --, no detections or not applicable]

[illegible]

Table 9. Pesticide detection frequencies and concentrations in ground-water samples collected during fall and spring relative to eight regional geographic areas in Wyoming, 1995–2006.—Continued

[Geographic areas where pesticides were detected are listed in order of decreasing frequency with no assessment level applied. Assessment level: NAL, no assessment level applied; CSAL, compound-specific assessment level; CAL, common assessment level. Geographic area: BH, Bighorn Basin; CB, Central Basins; GR, Green River Basin; HC, High Plains/Casper Arch; NW, Northwest Basins; OB, Overthrust Belt; PR, Powder River Basin; WR, Wind River Basin. Symbol: --, no detections or not applicable]

Pesticide	Geo-graphic area where detected	Fall													Geographic area where pesticide was not analyzed
		Number of detections/ number of analyses			Detection frequency in geographic area (percentage)			Detected concentration range (micrograms per liter)			Median concentration of detections (micrograms per liter)				
		NAL	CSAL	CAL	NAL	CSAL	CAL	NAL	CSAL	CAL	NAL	CSAL	CAL		
Insecticide degradates															
Aldicarb sulf-oxide	BH	5/63	3/61	5/61	7.9	4.9	8.2	0.07–2.47	0.14–2.47	0.07–2.47	0.14	0.25	0.14	--	
Aldicarb sulfone	BH	4/63	3/62	4/51	6.3	4.8	7.8	0.09–0.3	0.14–0.3	0.09–0.3	.14	.14	.14	--	
Fipronil sulfide	GR	1/12	1/12	0/12	8.3	8.3	0	0.007	0.007	--	--	--	--	NW, OB, WR	
	PR	1/15	1/15	0/15	6.7	6.7	0	0.007	0.007	--	--	--	--		
Fipronil sulfone	GR	1/12	0/12	0/12	8.3	0	0	0.011	--	--	--	--	--	NW, OB, WR	
	PR	1/15	0/15	0/15	6.7	0	0	0.009	--	--	--	--	--		
3-Hydroxycarbofuran	WR	1/20	0/19	0/19	5.0	0	0	0.0007	--	--	--	--	--	--	

Table 9. Pesticide detection frequencies and concentrations in ground-water samples collected during fall and spring relative to eight regional geographic areas in Wyoming, 1995–2006.—Continued

[Geographic areas where pesticides were detected are listed in order of decreasing frequency with no assessment level applied. Assessment level: NAL, no assessment level applied; CSAL, compound-specific assessment level; CAL, common assessment level. Geographic area: BH, Bighorn Basin; CB, Central Basins; GR, Green River Basin; HC, High Plains/Casper Arch; NW, Northwest Basins; OB, Overthrust Belt; PR, Powder River Basin; WR, Wind River Basin. Symbol: --, no detections or not applicable]

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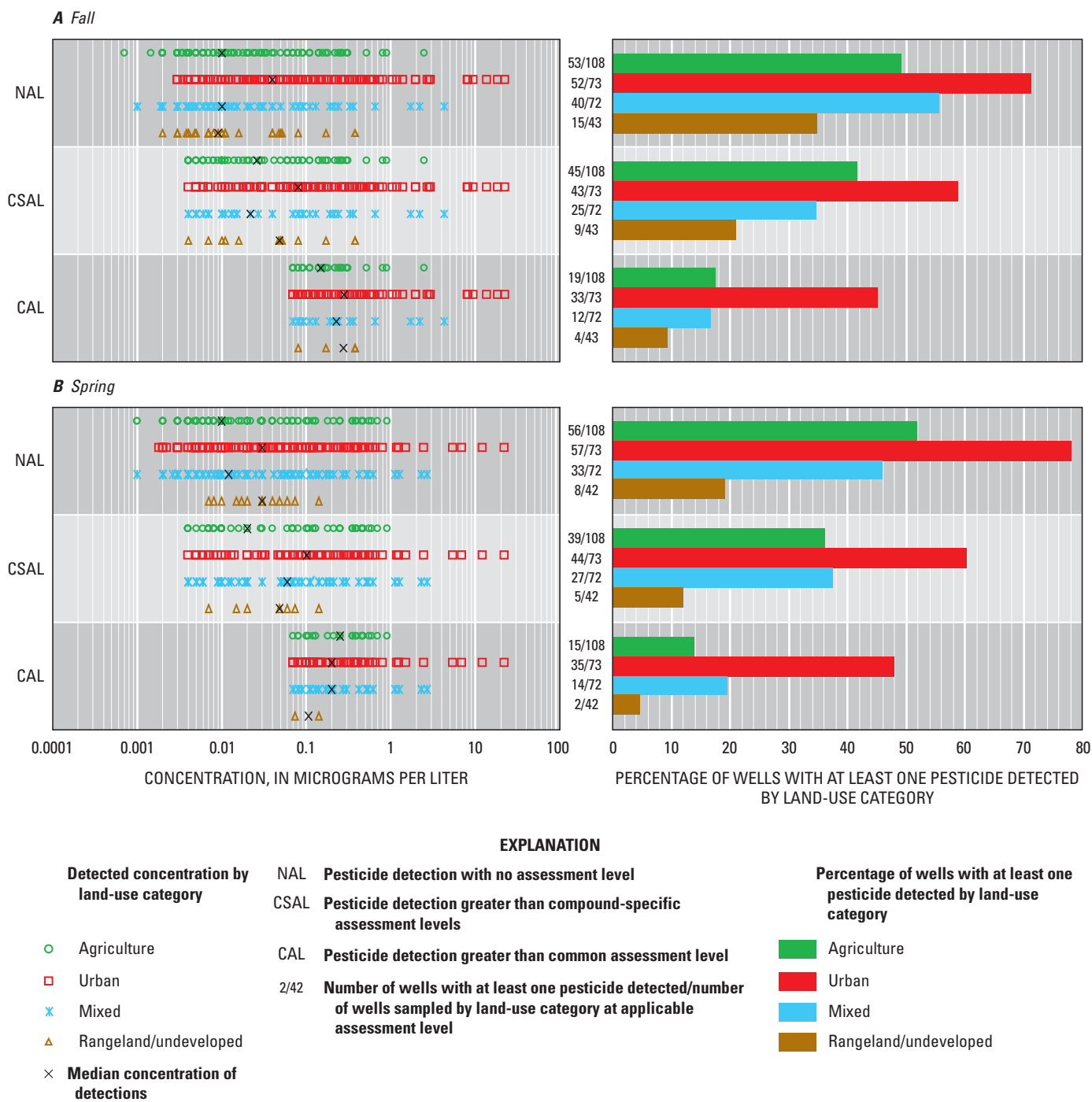


Figure 9. Pesticide concentrations and percentage of wells with at least one pesticide detected relative to land-use category in Wyoming, 1995–2006. *A*, Fall; *B*, Spring.

sampled bedrock aquifers were composed of siliciclastic sedimentary rocks primarily of Tertiary age. Most sampled wells completed in bedrock aquifers were composed of rocks of Tertiary age because they are present at or near land surface throughout much of Wyoming (Love and Christiansen, 1985).

Regardless of assessment level, the percentage of wells with at least one pesticide detected was larger for wells completed in unconsolidated aquifers than in bedrock aquifers (fig. 12). Considering only concentrations greater than the CAL, the proportion of wells with at least one pesticide detected was significantly different between unconsolidated and bedrock aquifers sampled in the fall (p -value = 0.0444, CTA, table 11) but not in the spring (p -value = 0.1217, CTA, table 11).

The frequencies of pesticide detection between the two types of aquifers were compared using the CSALs for individual pesticides detected in either the fall or spring at a frequency equal to or greater than 1 percent (table 11). For all pesticides tested, the proportion of samples detected at concentrations greater than their respective CSALs (detection frequency) was not significantly different between aquifer types for the fall or spring (all p -values > 0.05, CTA); however, the least insignificant differences were for prometon and tebuthiuron. The detection of these two pesticides probably is the primary source of the overall statistically significant difference between aquifer types in the fall.

Water-Level Depth

The relation between pesticides and water depth was investigated by comparing measured water levels with the frequency of pesticide detections at concentrations greater than applicable assessment levels. Measured water levels ranged from about 2 to 113 feet (ft) below land surface and were grouped into four depth categories (2–15, 15.1–33, 33.1–64, and 64.1–113 ft below land surface) using the Jenks method prior to statistical testing using the KWOCR. Most sampled aquifers were believed to be unconfined, and therefore, measured water levels likely represented the water table in most cases.

The overall detection frequency of pesticides among the four water-level depth categories was examined. Considering only concentrations greater than the CAL, the proportion of wells with at least one pesticide detected was not significantly different among the four water-level depth categories for the fall (p -value = 0.4108, KWOCR, table 11) or the spring (p -value = 0.9330, KWOCR, table 11).

The frequencies of pesticide detection among water-level-depth categories were compared using the CSALs for individual pesticides detected in either the fall or spring at a frequency equal to or greater than 1 percent (table 11). Some individual pesticides were not detected in all four water-level-depth categories, and in this case, pesticide detections were examined in relation to three depth intervals. In most cases, no clear increase or decrease in pesticide detection frequencies was noted as water-level depth increased. For all tested

pesticides except deethylatrazine, the proportion of samples detected at concentrations greater than their respective CSALs (detection frequency) was not significantly different among the water-level-depth categories for the fall or spring (all p -values > 0.05, KWOCR, table 11). For deethylatrazine, the proportion of samples detected at concentrations greater than the CSAL decreased as water level increased among the four water-level-depth categories, and the difference was significant for the spring (p -value = 0.0093, KWOCR, table 11) but not for the fall; however, the fall p -value was very close to statistical significance (p -value = 0.0636, KWOCR, table 11).

Frequencies of pesticide detection and pesticide concentrations have been reported to decrease with increasing depth to the water table in a few studies (Barbash and Resek, 1996, and references therein; Gilliom and others, 2006). Greater depths to the water table indicate greater unsaturated zone thickness, which generally increases the time required for pesticides applied at the land surface to reach the water table. This increased traveltime allows for increased opportunities to affect parent pesticide transport through processes such as transformation, sorption, dispersion, and volatilization. An inverse relation between pesticide detection and water-table depth was not observed in this study (with the exception of the pesticide deethylatrazine), and this result is similar to most other studies examining the relation. In fact, Barbash and Resek (1996, p. 283) noted that “most of the reviewed studies did not detect significant relations between pesticide occurrence and water-table depth.”

Well Depth

The relation between pesticides and well depth was investigated by comparing measured or reported well depths with the frequency of pesticide detection using applicable assessment levels. Measured or reported well depths ranged from about 7 to 200 ft below land surface and were grouped into four well-depth categories (7–29, 30–56, 57–91, and 92–200 ft below land surface) using the Jenks method prior to statistical testing using the KWOCR.

The overall detection frequency of pesticides among the four well-depth categories was examined. Considering only concentrations greater than the CAL, the percentage of wells with at least one pesticide detected generally decreased with increasing depth, and the difference was significant for well-depth categories for the fall (p -value = 0.0002, KWOCR, table 11) and the spring (p -value = 0.0001, KWOCR, table 11).

The frequencies of pesticide detection among well-depth categories were compared using the CSALs for individual pesticides detected in either the fall or spring at a frequency equal to or greater than 1 percent. In most cases, pesticide detection frequencies decreased as well depth increased, although detection frequencies for a few pesticides increased between one or two well-depth intervals (even though the detection frequency generally decreased from the shallowest to deepest well-depth interval). The proportion of samples

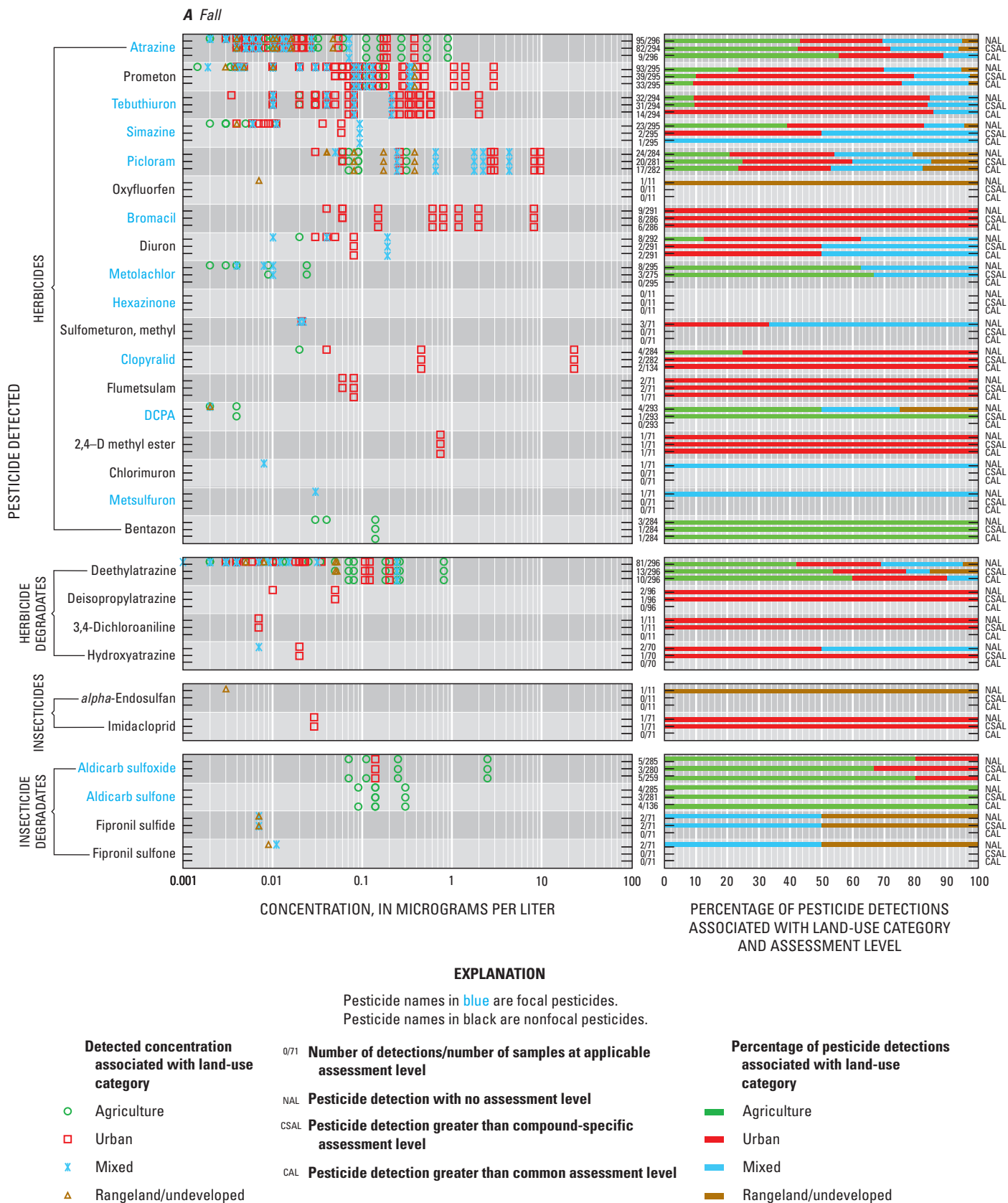


Figure 10. Selected pesticide concentrations and detections in ground-water samples collected relative to land use, Wyoming, 1995–2006. A, Fall; B, Spring. Pesticides are grouped by pesticide type and are listed in order of decreasing detection frequency by jointly ranking fall and spring detections with no assessment level.

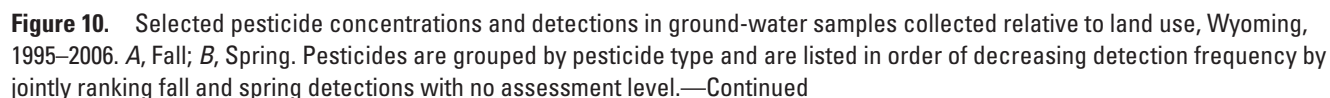


Table 10. Results of contingency-table analysis (CTA) or Kruskal-Wallis test for ordered categorical responses (KWOCR) comparing selected pesticide detections in ground-water samples collected during fall and spring and land-use categories in Wyoming, 1995–2006.

[Statistically significant differences (p-value<0.05) between four land-use categories (agricultural, urban, rangeland/undeveloped, and mixed) indicated in **bold type**; CAL, common assessment level; CSAL, compound-specific assessment level; H, herbicide; HD, herbicide degradate; ID, insecticide degradate; I, insecticide; <, less than; --, not applicable]

Tested variable	Pesticide type	Assessment level used	Probability (p-value)	
			Fall	Spring
Percentage of wells with at least one pesticide detected	--	CAL	<0.0001	<0.0001
Atrazine	H	CSAL	.0509	.0535
Prometon	H	CSAL	<.0001	<.0001
Deethylatrazine	HD	CSAL	.4419	.3556
Tebuthiuron	H	CSAL	<.0001	<.0001
Picloram	H	CSAL	.5424	.3428
Deisopropylatrazine	HD	CSAL	.4836	--
3,4-Dichloroaniline	H	CSAL	.8214	--
Bromacil	H	CSAL	<.0001	<.0001
Diuron	H	CSAL	--	.2787
Metolachlor	H	CSAL	.5334	--
Hexazinone	H	CSAL	--	.2490
Aldicarb sulfoxide	ID	CSAL	.5768	.5737
Aldicarb sulfone	ID	CSAL	.1713	.5764
Hydroxyatrazine	HD	CSAL	.6558	--
Flumetsulam	H	CSAL	.3675	--
Imidacloprid	I	CSAL	.6690	.6558
Fipronil sulfide	ID	CSAL	.4738	--
2,4-D methyl ester	H	CSAL	.6690	--

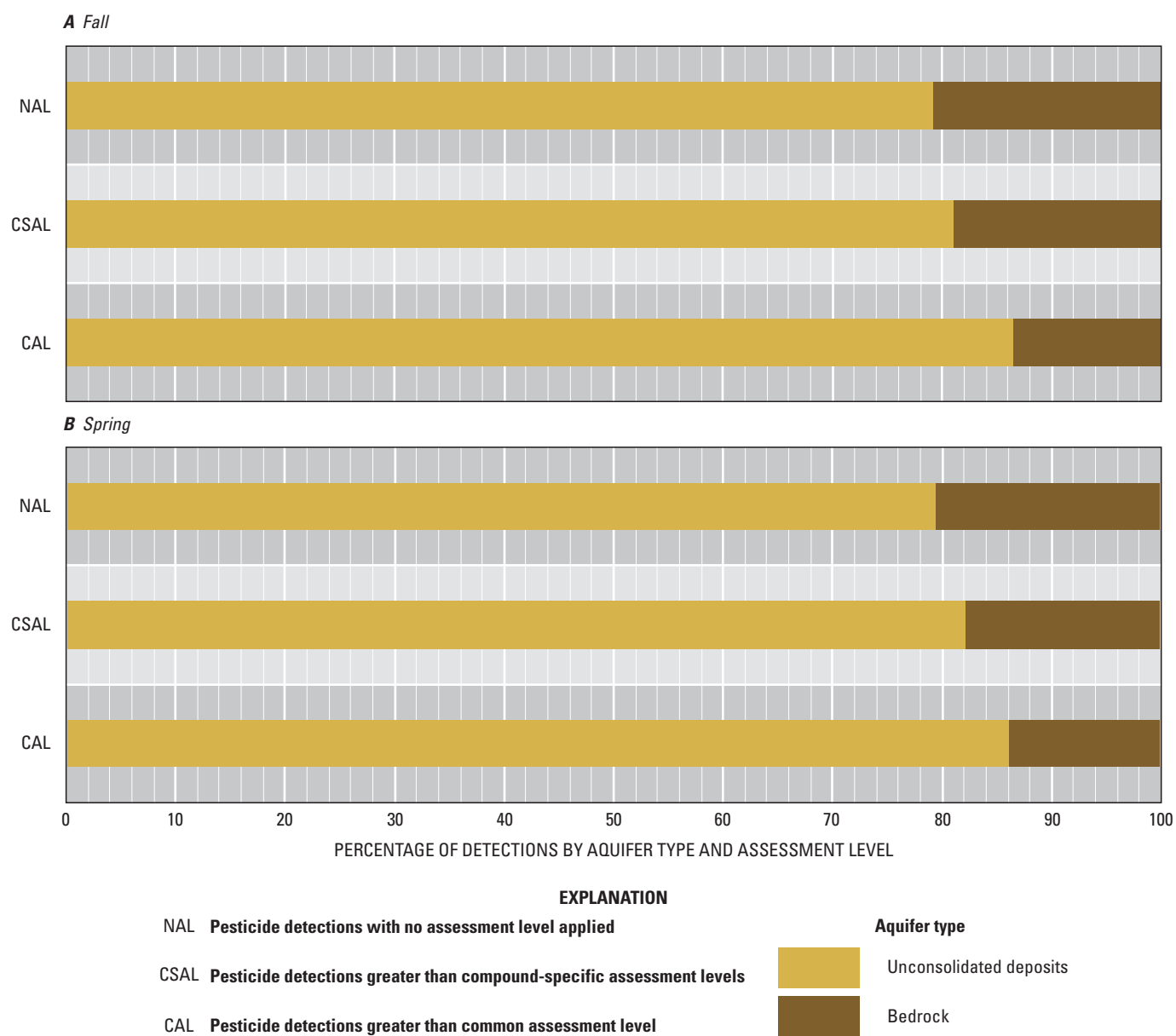


Figure 11. Pesticide detections in ground-water samples collected relative to aquifer type, Wyoming, 1995–2006. *A*, Fall; *B*, Spring.

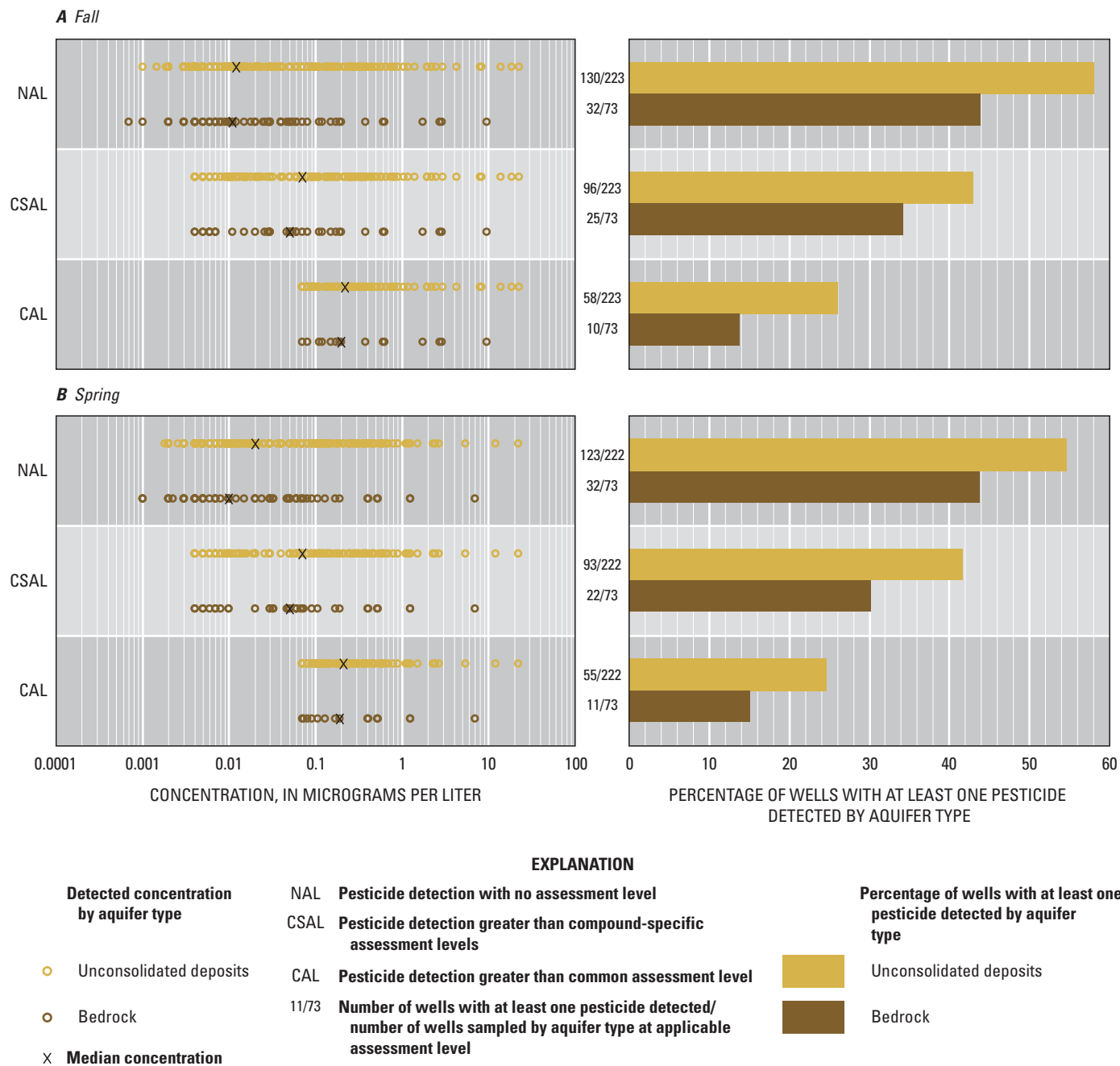


Figure 12. Pesticide concentrations and percentage of wells with at least one pesticide detected relative to aquifer type, Wyoming, 1995–2006. *A*, Fall; *B*, Spring.

Table 11. Results of contingency-table analysis (CTA) or Kruskal-Wallis test for ordered categorical responses (KWOCR) comparing selected pesticide detections in ground-water samples collected during fall and spring and hydrogeologic characteristics in Wyoming, 1995–2006.

[Statistically significant differences (p-value<0.05) indicated in **bold type**; CAL, common assessment level; CSAL, compound-specific assessment level; H, herbicide; HD, herbicide degradate; ID, insecticide degradate; I, insecticide; <, less than; --, not applicable]

Tested variable	Pesticide type	Assessment level used	Hydrogeologic characteristic							
			Aquifer type ¹		Water-level depth ²		Well depth ³		Well type ⁴	
			Probability (p-value)		Probability (p-value)		Probability (p-value)		Probability (p-value)	
			Fall	Spring	Fall	Spring	Fall	Spring	Fall	Spring
Percentage of wells with at least one pesticide detected	--	CAL	0.0444	0.1217	0.4108	0.9330	0.0002	0.0001	0.0002	0.0001
Atrazine	H	CSAL	.1659	.2194	.9863	.8562	.7420	.2053	.1133	.2407
Prometon	H	CSAL	.2095	.0882	.3609	.6587	.0001	.0124	<.0001	<.0001
Deethylatrazine	HD	CSAL	.8466	.7171	.0636	.0093	.5884	.3660	.0979	.3549
Tebuthiuron	H	CSAL	.0708	.0982	.3491	.5331	.0023	.0002	.0005	<.0001
Picloram	H	CSAL	.7399	.7664	.6511	.2686	.3326	.8210	.1241	.2712
Deisopropylatrazine	HD	CSAL	.7952	--	.9334	--	.7055	--	.4625	--
3,4-Dichloroaniline	H	CSAL	.3869	--	.7515	--	.7530	--	.5169	--
Bromacil	H	CSAL	.6880	.9584	.6765	.6505	.0013	.0002	.0009	<.0001
Diuron	H	CSAL	--	.7515	--	.4633	--	.5943	--	.0272
Metolachlor	H	CSAL	.7449	--	.2238	--	.5251	--	.4540	--
Hexazinone	H	CSAL	--	.5119	--	.1850	--	.5355	--	.8139
Aldicarb sulfoxide	ID	CSAL	.7185	.7446	.6872	.9494	.4683	.9308	.3694	.8128
Aldicarb sulfone	ID	CSAL	.7399	.7470	.6890	.9494	.5348	.9317	.8033	.8103
Hydroxyatrazine	HD	CSAL	.9309	--	.9459	--	.7391	--	.4673	--
Flumetsulam	H	CSAL	.5628	--	.8634	--	.4802	--	.2253	--
Imidacloprid	I	CSAL	.9205	.8844	.9473	.7952	.7485	.7212	.4798	.4673
Fipronil sulfide	ID	CSAL	.3882	--	.8505	--	.6745	--	.8711	--
2,4-D methyl ester	H	CSAL	.9205	--	.9473	--	.7485	--	.4798	--

¹Differences between unconsolidated and bedrock.

²Differences among four categories (2–15, 15.1–33, 33.1–64, and 64.1–113 feet below land surface).

³Differences among four categories (7–29, 30–56, 57–91, and 92–200 feet below land surface).

⁴Differences among three categories (domestic-supply, stock, and other).

detected at concentrations greater than their respective CSALs (detection frequency) decreased as well depth increased for three pesticides (prometon, tebuthiuron, and bromacil, listed in order of decreasing detection frequency), and the difference was significant for both fall and spring (p-values for all three compounds < 0.05, KWOCR, table 11).

The inverse relation between pesticide detection and well depth seen in the baseline study has been observed in other studies. Frequencies of pesticide detection and pesticide concentrations generally decreased with increasing well depths in most studies that examined this relation (Barbash and Resek, 1996, and references therein). In fact, Barbash and Resek (1996, p. 290) comprehensively reviewed many different studies examining pesticides in ground water, and they found that “well depth was the factor most commonly found to be correlated with pesticide detections in ground water,” and “inverse relations between well depths and pesticide detection frequencies and concentrations have been documented in many locations.” A greater well depth generally indicates greater depth of the water table and well-screen interval below the water table. Both characteristics generally increase the time required for pesticides applied at the land surface to reach the water table. This increased traveltime allows for increased opportunities to affect parent pesticide transport through processes such as transformation, sorption, dispersion, and volatilization.

Well Type

During this study, ground-water-quality samples were collected from four different types of wells—domestic-supply wells (58 percent of sampled wells), monitoring wells (22 percent of sampled wells), stock wells (12 percent of sampled wells), and other miscellaneous wells (8 percent of sampled wells). The relation between pesticides and well type was investigated by comparing well type with the frequency of pesticide detection using applicable assessment levels. The different types of sampled wells were grouped into three well-type categories on the basis of water use—a domestic-supply well category, a stock well category, and “other” well category (composed of monitoring and other miscellaneous wells)—for statistical testing using the CTA.

The overall detection frequency of pesticides between the three well-type categories was examined. Pesticides were always detected much more frequently in the “other” and domestic-supply well categories than in the stock well category. In most cases, pesticides were detected more frequently in the “other” well category than in the domestic-supply well category, although detection frequencies were very similar for some pesticides. Considering only concentrations greater than the CAL, the proportion of wells with at least one pesticide detected was greater for the “other” well category than for the domestic-supply well and stock well categories for both fall and spring, and the difference was significant

for both fall (p-value = 0.0002, CTA, table 11) and spring (p-value = 0.0001, CTA, table 11).

The frequencies of pesticide detection between well-type categories were compared using the CSALs for individual pesticides detected in either the fall or spring at a frequency equal to or greater than 1 percent. The proportion of samples detected at concentrations greater than their respective CSALs (detection frequency) was larger for the “other” well category than for the domestic-supply well and stock well categories for most pesticides tested in table 11, and the difference was significant for three pesticides (prometon, tebuthiuron, and bromacil, listed in order of decreasing detection frequency) in both the fall and spring (p-values for all three compounds < 0.05, CTA, table 11) and one pesticide (diuron) in the spring (p-value = 0.0272, CTA, table 11).

Differences in pesticide detection frequencies among different types of wells have been observed in other studies, most likely due to the different types of construction, hydrogeologic setting, and pumping patterns associated with a specific type of well (Barbash and Resek, 1996, and references therein). In this study, the difference in detection frequency among well types may be due to differences in well depth among the types of wells sampled. Well depth, as noted previously, is the factor most commonly found to correlate with pesticide detections in ground water. Detection frequencies for most pesticides in this study were largest for the “other” well category, and monitoring wells comprised 74 percent of the wells in this category. Median water-level depth was similar among all three well categories, but the median well depth of the “other” well category (20 ft), consisting of many shallow monitoring wells, was less than one-half that of the domestic-supply well category (50 ft) and stock well category (52.5 ft). Pesticide detection frequencies among different types of wells are often largest in monitoring wells, and in summarizing previous studies, Barbash and Resek (1996, p. 293) noted that “monitoring wells usually exhibit the highest detection frequencies, since they are typically shallow, and often screen close to the water table.”

Soils

Pesticide detections were examined in relation to selected soil properties from the State Soil Geographic (STATSGO) database (U.S. Department of Agriculture, 1991). STATSGO data were used instead of the larger scale Soil Survey Geographic (SSURGO) database (U.S. Department of Agriculture, 1995) because SSURGO coverage was not available for all areas in Wyoming. The STATSGO data used in this study were from a digital data set compiled by Schwarz and Alexander (1995) for a national model of water quality. Three different soil characteristics selected from this data set—organic matter content, soil permeability, and an index developed from soil hydrologic groupings—were evaluated in relation to the occurrence of pesticides in the underlying ground water. A GIS was used to manipulate the digital data set to quantify these

soil characteristics within a 500-m radius surrounding each sampled well (selection and use of 500-m radius described previously in the "Land Use" section of the report).

In some previous studies, soil characteristics have been related to the occurrence of pesticides in ground water (Barbash and Resek, 1996, and references therein). Consequently, pesticides detected during this study were compared to organic matter content and soil permeability, as well as a soil hydrologic index derived from several soil properties.

Organic Matter Content

Organic matter content is the amount of organic material in the soil, in percentage by weight (Schwarz and Alexander, 1995). The relation between pesticides and organic matter content was investigated by comparing organic matter content with the frequency of pesticide detection using applicable assessment levels. Organic matter content was grouped into four different ordinal categories (0–0.3, 0.31–0.5, 0.51–0.8, and 0.81–1.4 percent by weight) using the Jenks method prior to statistical testing using the KWOCR.

The overall detection frequency of pesticides among the four organic-matter-content categories was examined. Considering only concentrations greater than the CAL, the proportion of wells with at least one pesticide detected was not significantly different among the four organic-matter-content categories for fall or spring (both p -values > 0.05 , KWOCR, table 12).

The frequencies of pesticide detection among the four organic-matter-content categories were compared using the CSALs for individual pesticides detected in either the fall or spring at a frequency equal to or greater than 1 percent. For most pesticides, no clear trend of increasing or decreasing frequency of detection was noted among the four categories as organic matter content increased. In fact, detection frequencies for many pesticides both increased and decreased among the four organic-matter-content categories as organic matter content increased. The proportion of samples detected at concentrations greater than their respective CSALs (detection frequency) was significantly different among the four organic-matter-content categories for four pesticides (atrazine, tebuthiuron, flumetsulam, and fipronil sulfide, listed in order of decreasing detection frequency) detected in the fall and in one pesticide (tebuthiuron) detected in the spring (p -values for all compounds < 0.05 , KWOCR, table 12). The proportion of atrazine detections at concentrations greater than the CSAL was close to statistical significance (p -value = 0.0885, table 12) among the four organic-matter-content categories for samples collected in the spring. However, although the proportion of samples detected at concentrations greater than their respective CSALs (detection frequency) was significantly different among the four organic-matter-content categories for the four pesticides detected in the fall, detection frequencies for tebuthiuron in both fall and spring increased and decreased among the four organic-matter-content categories as organic matter content increased, whereas detection frequencies for

atrazine, flumetsulam, and fipronil sulfide increased among the four soil-permeability categories as soil permeability increased.

Barbash and Resek (1996) indicate that organic matter (organic carbon content) is one of the most important soil characteristics that affects transport of pesticides through the root zone and into the subsurface and underlying ground water. These investigators noted that organic carbon content and soil permeability are "two factors" that "influence pesticide behavior in the subsurface in a concerted fashion" and "whereas lower permeability restricts pesticide movement by slowing the downward migration of the bulk soil solution, the presence of larger amounts of organic matter reduces the mass of pesticide reaching greater depths through the combined effects of enhanced microbial activity and hydrophobic sorption" (Barbash and Resek, 1996, p. 274). In this study, however, detection frequencies for many pesticides both increased and decreased among the four organic-matter-content categories as organic matter content increased, including one pesticide (tebuthiuron) for which the proportion of samples detected at concentrations greater than their respective CSALs (detection frequency) was significantly different among the four organic-matter-content categories. This may be due to the fact that the effects of organic matter content (as well as soil permeability and other soil properties) often are not correlated with pesticide detection in many studies because the relation "may only be discernible among areas that exhibit substantial contrasts in these properties, or where differences in soil properties are not overwhelmed by variations in other factors" (Barbash and Resek, 1996, p. 277).

Soil Permeability

Soil permeability is determined using laboratory measurements and is defined as the amount of water that will move downward through a unit area of saturated soil in unit time, under unit hydraulic gradient, measured in inches per hour (Schwarz and Alexander, 1995). The relation between pesticides and soil permeability was investigated by comparing soil permeability with the frequency of pesticide detection using applicable assessment levels. Soil permeability was grouped into four different ordinal categories (0.17–2.30, 2.31–4.26, 4.27–6.62, and 6.63–12.4 in/h) using the Jenks method prior to statistical testing using the KWOCR.

The overall detection frequency of pesticides was examined among the four soil-permeability categories. Considering only concentrations greater than the CAL, the proportion of wells with at least one pesticide detected was significantly different among the four soil-permeability categories for fall (p -value = 0.0395, KWOCR, table 12) but not spring (p -value > 0.05 , KWOCR, table 12).

The frequencies of pesticide detection among the four soil-permeability categories were compared using the CSALs for individual pesticides detected in either the fall or spring at a frequency equal to or greater than 1 percent (table 12). For most pesticides, no clear trend of increasing or decreasing

Table 12. Results of Kruskal-Wallis test for ordered categorical responses (KWOCR) comparing selected pesticide detections in ground-water samples collected during fall and spring and soil characteristics in Wyoming, 1995–2006.

[Statistically significant differences (p-value<0.05) indicated in **bold type**; CAL, common assessment level; CSAL, compound-specific assessment level; H, herbicide; HD, herbicide degradate; ID, insecticide degradate; I, insecticide; <, less than; --, not applicable]

Tested variable	Pesticide type	Assessment level used	Soil characteristic					
			Organic-matter content ¹		Soil permeability ²		Soil hydrologic index ³	
			Probability (p-value)		Probability (p-value)		Probability (p-value)	
			Fall	Spring	Fall	Spring	Fall	Spring
Percentage of wells with at least one pesticide detected	--	CAL	0.2600	0.3177	0.0395	0.2727	0.0887	0.6260
Atrazine	H	CSAL	.0032	.0885	.2746	.0103	.0003	<.0001
Prometon	H	CSAL	.6663	.6219	.1132	.8366	.4637	.4473
Deethylatrazine	HD	CSAL	.3989	.7439	.0126	.1558	<.0001	.0001
Tebuthiuron	H	CSAL	.0175	.0234	.0253	.0095	.3401	.0828
Picloram	H	CSAL	.1783	.8056	.6436	.2621	.4048	.5448
Deisopropylatrazine	HD	CSAL	.1146	--	.1188	--	.1718	--
3,4-Dichloroaniline	H	CSAL	.2636	--	.6592	--	.6259	--
Bromacil	H	CSAL	.6968	.4962	.2257	.4465	.6640	.8568
Diuron	H	CSAL	--	.3087	--	.7602	--	.3574
Metolachlor	H	CSAL	.3226	--	.3747	--	.7643	--
Hexazinone	H	CSAL	--	.7165	--	.6823	--	.9607
Aldicarb sulfoxide	ID	CSAL	.7141	.7346	.2989	.2706	.7349	.7286
Aldicarb sulfone	ID	CSAL	.3130	.7344	.0301	.2786	.2130	.7281
Hydroxyatrazine	HD	CSAL	.1850	--	.2228	--	.3373	--
Flumetsulam	H	CSAL	.0306	--	.6448	--	.7260	--
Imidacloprid	I	CSAL	.3522	.3600	.8446	.8507	.4972	.4753
Fipronil sulfide	ID	CSAL	.0227	--	.4331	--	.0727	--
2,4-D methyl ester	H	CSAL	.3522	--	.8446	--	.7647	--

¹Differences among four categories (0–0.3, 0.31–0.5, 0.51–0.8, and 0.81–1.4 percent by weight).

²Differences among four categories (0.17–2.30, 2.31–4.26, 4.27–6.62, and 6.63–12.4 inches per hour).

³Differences among three or four soil-hydrologic-index categories.

frequency of detection was noted among the four categories as soil permeability increased. In fact, detection frequencies for many pesticides both increased and decreased among the four soil-permeability categories as soil permeability increased. The proportion of samples detected at concentrations greater than their respective CSALs (detection frequency) was significantly different among the four soil-permeability categories for three pesticides (deethylatrazine, tebuthiuron, and aldicarb sulfone, listed in order of decreasing detection frequency) detected in the fall and two pesticides (atrazine and tebuthiuron) detected in the spring (p-values for all compounds < 0.05, KWOCR, table 12). However, although the proportion of samples detected at concentrations greater than their respective CSALs (detection frequency) was significantly different among the four soil-permeability categories for these four pesticides, detection frequencies for

deethylatrazine and tebuthiuron both increased and decreased among the four soil-permeability categories as soil permeability increased, whereas detection frequencies for both atrazine and aldicarb sulfone both increased among the four soil-permeability categories as soil permeability increased.

As previously mentioned, Barbash and Resek (1996) indicated that soil permeability is one of the most important soil characteristics that affects transport of pesticides through the root zone and into the subsurface and underlying ground water. In this study, detection frequencies for many pesticides both increased and decreased among the four soil-permeability categories as soil permeability increased, even for pesticides where the proportion of samples detected at concentrations greater than their respective CSALs (detection frequency) was significantly different among the four soil-permeability categories. This may be due to the fact that the effects of

soil permeability (as well as soil organic matter content and other soil properties) often are not correlated with pesticide detection in many studies because the relation “may only be discernible among areas that exhibit substantial contrasts in these properties, or where differences in soil properties are not overwhelmed by variations in other factors” (Barbash and Resek, 1996, p. 277).

Soil Hydrologic Index

The soil hydrologic index was developed by Schwarz and Alexander (1995) from soil hydrologic groups presented in the STATSGO data set. The soil hydrologic group is a letter rating that combines several soil hydrologic characteristics and is the minimum steady-ponded infiltration rate for bare ground. Soil hydrologic groups consist of four different categories (A through D), with category A having the largest saturated hydraulic conductivity. The soil hydrologic index converts the four hydrologic groups into unitless numeric codes through coding transformations, where A = 1 (rapid infiltration rates, deep soils, well-drained to excessively drained sands and gravels), B = 2 (moderate infiltration rates, deep and moderately deep, moderately well and well-drained soils with moderately coarse textures), C = 3 (slow infiltration rates, soils with layers impeding downward movement of water, or soils with moderately fine or fine textures), and D = 4 (very slow infiltration rates, soils are clayey, have a high water table, or are shallow with an impervious layer). Mixtures of soil hydrologic groups are assigned the value 4. A GIS was used to manipulate the digital data set to quantify the indices within a 500-m radius surrounding all sampled wells; wells not located exclusively within one group were assigned an index number determined through proportional weighting on the basis of percentages within the 500-m radius.

The relation between pesticides and soil hydrologic index was investigated by comparing the soil hydrologic index with the frequency of pesticide detection using applicable assessment levels. The soil hydrologic index was grouped into three or four different ordinal categories using the Jenks method prior to statistical testing using the KWOCR.

The overall detection frequency of pesticides was examined among four soil-hydrologic-index categories. Considering only concentrations greater than the CAL, the proportion of wells with at least one pesticide detected was not significantly different among the four soil-hydrologic-index categories for fall and spring (all p -values > 0.05 , KWOCR, table 12).

The frequencies of pesticide detection among three or four soil-hydrologic-index categories were compared using the CSALs for individual pesticides detected in either the fall or spring at a frequency equal to or greater than 1 percent (table 12). The number of soil-hydrologic-index categories varied by pesticide (either three or four categories). For most pesticides, no clear trend of increasing or decreasing frequency of detection was noted among the four categories. In fact, detection frequencies for many pesticides both increased and decreased among the four soil-hydrologic-index categories.

The proportion of samples detected at concentrations greater than their respective CSALs (detection frequency) generally decreased for two pesticides (atrazine and deethylatrazine) as the soil hydrologic index increased among the three or four soil-hydrologic-index categories, and the difference was significant for both fall and spring (p -values for both compounds < 0.05 , KWOCR, table 12). Pesticides often can be detected more commonly beneath coarser soils with greater permeability (represented by a smaller soil hydrologic index number) (Barbash and Resek, 1996).

Nitrate and Selected Water-Quality Characteristics

One water-quality constituent (nitrite plus nitrate as nitrogen) and three different water-quality characteristics (specific conductance, pH, and dissolved oxygen) were examined in relation to the occurrence of pesticides in ground water. In some previous studies, these constituents and characteristics have been shown to be related to the occurrence of pesticides in ground water (Barbash and Resek, 1996, and references therein).

Nitrate

Water from most wells sampled and analyzed for pesticides during this study also was analyzed for selected nutrients, including nitrogen species such as nitrite plus nitrate (as nitrogen). Because nitrite was detected infrequently at very small concentrations and generally composed very little of the nitrite plus nitrate as nitrogen concentrations, nitrite plus nitrate concentrations as nitrogen are referred to as “nitrate” herein. The most common anthropogenic sources of nitrogen in shallow ground water are from leaching of fertilizers from agricultural lands, animal manure, or septic-system effluent (Alley, 1993, and references therein).

The relation between pesticides and nitrate was investigated by comparing measured nitrate concentrations indicative of ground-water contamination from anthropogenic activities with the frequency of pesticide detection using applicable assessment levels. Concentrations of nitrate in ground water in the conterminous United States greater than 3 milligrams per liter (mg/L) (Madison and Brunett, 1985), 2 mg/L (Mueller and Helsel, 1996), or 1.1 mg/L (Nolan and Hitt, 2003) have been reported to be the result of anthropogenic activities. Measured nitrate concentrations were grouped into two ordinal categories—concentrations less than and greater than or equal to the 1.1-mg/L threshold value reported by Nolan and Hitt (2003) to represent nitrate contamination of shallow ground water by anthropogenic activities.

The overall detection frequency of pesticides between the two nitrate concentration categories was examined. Considering only concentrations greater than the CAL, the proportion of wells with at least one pesticide detected was significantly

different between the nitrate concentration categories for both the fall and spring (p -values < 0.0001 , KWOCR, table 13).

The frequencies of pesticide detection between the two nitrate concentration categories were compared using the CSALs for individual pesticides detected in either the fall or spring at a frequency equal to or greater than 1 percent (table 13). The proportion of samples detected at concentrations greater than their respective CSALs (detection frequency) was much larger for the “elevated” nitrate concentration category than for the other nitrate concentration category for almost every pesticide tested in table 13 (data not shown). The proportion of samples detected at concentrations greater than their respective CSALs (detection frequency) was significantly different between the two nitrate concentration categories for three pesticides (atrazine, prometon, and deethylatrazine, listed in order of decreasing detection frequency) in both the fall and spring, one pesticide (tebuthiuron) in the fall, and one pesticide (bromacil) in the spring (p -values for all compounds < 0.05 , KWOCR, table 13). The proportion of tebuthiuron and picloram detections at concentrations greater than the CSAL were very close to statistical significance between the two nitrate concentration categories for samples collected in the spring (p -value = 0.0507 and p -value = 0.0558, respectively, KWOCR, table 13).

Many studies have found that pesticides are detected more frequently in ground water as nitrate concentrations increase (Barbash and Resek, 1996, and references therein). This relation has been attributed to application of fertilizers in conjunction with pesticides to produce crops in agricultural areas. Elevated nitrate concentrations indicative of anthropogenic activities have been found frequently in ground-water samples containing other contaminants such as pesticides and volatile organic compounds (Squillace and others, 2002).

Specific Conductance

Specific conductance was measured onsite in water from most sampled wells and analyzed for pesticides during this study. Measurements of specific conductance in water from wells sampled during this study were examined in relation to pesticide occurrence by comparing measured specific conductance with the frequency of pesticide detection above applicable assessment levels (table 13). Measured specific conductance values were grouped into two ordinal categories representing freshwater [specific conductance values $\leq 1,665$ microsiemens per centimeter at 25 degrees Celsius ($\mu\text{S}/\text{cm}$)] and saline water (specific conductance values $> 1,665 \mu\text{S}/\text{cm}$) prior to statistical testing using the KWOCR. The specific conductance value of $1,665 \mu\text{S}/\text{cm}$ was assumed to represent the boundary between fresh and saline water by assuming multiplication of the value by 0.6 to convert values into representative dissolved-solids concentrations (salinity) (Hem, 1985).

The overall detection frequency of pesticides was examined between the two specific conductance categories. Considering only concentrations greater than the CAL, the

proportion of wells with at least one pesticide detected was not significantly different between the two specific conductance categories for the fall and the spring (p -values > 0.05 , KWOCR, table 13).

The frequencies of pesticide detection between the two specific conductance categories were compared using the CSALs for individual pesticides detected in either the fall or spring at a frequency equal to or greater than 1 percent (table 13). The proportion of samples detected at concentrations greater than their respective CSALs (detection frequency) was much larger for the saline-water category than for the freshwater category for almost every pesticide tested in table 13. The proportion of samples detected at concentrations greater than their respective CSALs (detection frequency) was significantly different between the two specific conductance categories for one pesticide (tebuthiuron) in both the fall and spring and one pesticide (prometon) only in the fall (p -values for both compounds < 0.05 , KWOCR, table 13). The percentage of picloram detections at concentrations greater than the CSAL was very close to statistical significance between the two specific conductance categories for samples collected in the fall (p -value = 0.0638, KWOCR, table 13). However, although the proportion of samples detected at concentrations greater than their respective CSALs (detection frequency) was significantly different between fresh and saline water for these three pesticides, detection frequencies for tebuthiuron (fall and spring detections) and prometon (fall detections) were larger for the saline-water category than for the freshwater category, whereas the detection frequency for picloram (fall detections) was larger for the freshwater category than for the saline-water category.

It is unclear what processes may be responsible for the observed relation between pesticide detection and specific conductance for several pesticides. On the basis of a limited literature search, few studies (or parts of studies) have examined the relation between dissolved solids (and by inference, specific conductance) and pesticide detection in ground water. Barbash and Resek (1996) did note that ionic strength is unlikely to have much effect on pesticide reactivity in most natural water. It is possible that this observed relation is a result of the statistical process or is due to co-occurrence of dissolved solids (specific conductance) with some other (unrecognized) factor.

pH

The water-quality characteristic pH was measured onsite in water from most sampled wells and analyzed for pesticides during this study. Measurements of pH in water from wells sampled during this study were examined in relation to pesticide occurrence by comparing measured pH with the frequency of pesticide detection using applicable assessment levels. Measured pH values were grouped into three ordinal categories—acidic ($\text{pH} < 6.8$), circumneutral ($6.8 \leq \text{pH} \leq 7.3$), and alkaline ($\text{pH} > 7.3$)—prior to statistical testing using the KWOCR.

Table 13. Results of Kruskal-Wallis test for ordered categorical responses (KWOCR) comparing selected pesticide detections in ground-water samples collected during fall and spring and nitrate and selected water-quality characteristics in Wyoming, 1995–2006.

[Statistically significant differences (p-value<0.05) indicated in **bold type**; CAL, common assessment level; CSAL, compound-specific assessment level; H, herbicide; HD, herbicide degradate; ID, insecticide degradate; I, insecticide; <, less than; ≤, less than or equal to; >, greater than; ≥, greater than or equal to; μS/cm, microsiemens per centimeter; mg/L, milligrams per liter; --, not applicable]

Tested variable	Pesticide type	Assessment level used	Constituent or characteristic							
			Nitrate ¹		Specific conductance ²		pH ³		Dissolved oxygen ⁴	
			Probability (p-value)		Probability (p-value)		Probability (p-value)		Probability (p-value)	
			Fall	Spring	Fall	Spring	Fall	Spring	Fall	Spring
Percent of wells with at least one pesticide detected	--	CAL	<0.0001	<0.0001	0.6038	0.1022	0.0008	0.0022	0.5485	0.4246
Atrazine	H	CSAL	<0.0001	<0.0001	.4460	.9558	.2448	.1281	.3370	.2020
Prometon	H	CSAL	<0.0001	.0014	.0072	.0905	.0107	.0008	.3892	.4279
Deethylatrazine	HD	CSAL	.0005	.0007	.2329	.2822	.8077	.4808	.9694	.6193
Tebuthiuron	H	CSAL	.0351	.0507	.0070	.0061	.0020	.0072	.0416	.0567
Picloram	H	CSAL	.4565	.0558	.0638	.4029	.4764	.4311	.2645	.5132
Deisopropylatrazine	HD	CSAL	.3122	--	.2005	--	.5738	--	.2871	--
3,4-Dichloroaniline	H	CSAL	.3613	--	.3613	--	.2636	--	.4142	--
Bromacil	H	CSAL	.2031	.0237	.4365	.0854	.0002	<.0001	.6957	.1975
Diuron	H	CSAL	--	.6030	--	.9142	--	.0006	--	.9532
Metolachlor	H	CSAL	.6056	--	.2357	--	.8452	--	--	--
Hexazinone	H	CSAL	--	.5186	--	.5862	--	.7704	--	--
Aldicarb sulfoxide	ID	CSAL	.1008	.0943	.8383	.2513	.1431	.6001	--	--
Aldicarb sulfone	ID	CSAL	.0947	.0933	.2758	.2516	.7077	.6097	--	--
Hydroxyatrazine	HD	CSAL	.2070	--	.3103	--	.6489	--	.2943	--
Flumetsulam	H	CSAL	.7582	--	.3173	--	.6564	--	.2871	--
Imidacloprid	I	CSAL	.2153	.2123	.3173	.3031	.6564	.6578	.3476	.2899
Fipronil sulfide	ID	CSAL	.2366	--	.9840	--	.0704	--	.9289	--
2,4-D methyl ester	H	CSAL	.2153	--	.3173	--	.6564	--	.3476	--

¹Difference between two categories, nitrate concentrations <1.1 mg/L and ≥1.1 mg/L.

²Difference between two categories, freshwater (≤1,665 μS/cm) and saline water (>1,665 μS/cm).

³Difference among three categories, acidic, pH <6.8; circumneutral, 6.8≤pH ≤7.3; alkaline, pH >7.3.

⁴Difference between two categories, dissolved oxygen concentrations <1 mg/L and ≥1 mg/L.

The overall detection frequency of pesticides was examined among the three pH categories. Considering only concentrations greater than the CAL, the proportion of wells with at least one pesticide detected was significantly different among the three pH categories for the fall (p -value = 0.0008, KWOCR, table 13) and the spring (p -value = 0.0022, KWOCR, table 13).

The frequencies of pesticide detection among the three pH categories were compared using the CSALs for individual pesticides detected in either the fall or spring at a frequency equal to or greater than 1 percent (table 13). For many pesticides, no clear trend of increasing or decreasing frequency of detection was noted among the three categories as pH increased. In fact, detection frequencies for many pesticides both increased and decreased among the three pH categories as pH increased. The proportion of samples detected at concentrations greater than their respective CSALs (detection frequency) was significantly different among the three pH categories for three pesticides (prometon, tebuthiuron, and bromacil, listed in order of decreasing detection frequency) detected in both the fall and spring and one pesticide (diuron) detected in the spring (p -values for all compounds < 0.05, KWOCR, table 13). The proportion of fipronil sulfide detections at concentrations greater than the CSAL was very close to statistical significance among the three pH categories for samples collected in the fall (p -value = 0.0704, KWOCR, table 13). However, although the proportion of samples detected at concentrations greater than their respective CSALs (detection frequency) was significantly different among the three pH categories for these five pesticides, detection frequencies for prometon and tebuthiuron (spring detections) both increased and decreased among the three pH categories as pH increased, whereas detection frequencies for tebuthiuron, bromacil, diuron, and fipronil sulfide (fall detections listed in order of decreasing detection frequency) increased among the three pH categories as pH increased.

Differences in pH have been observed to directly or indirectly affect pesticide transformations and concentrations (Barbash and Resek, 1996, and references therein). Unfortunately, most studies (Barbash and Resek, 1996) have been conducted in the laboratory rather than onsite, so results of this study were not compared with similar studies.

Dissolved Oxygen

Dissolved oxygen (DO) was measured onsite in water from less than one-half of the sampled wells and analyzed for pesticides during this study. Measurements of DO in water from wells sampled during this study were examined in relation to pesticide occurrence by comparing measured DO with the frequency of pesticide detection greater than applicable assessment levels. The amount of DO in ground water can be used to infer the oxidation/reduction (redox) state of ground water. The redox state can affect the solubility and speciation of many dissolved constituents in ground water (Hem, 1985). Redox conditions can directly or indirectly affect pesticide

transformations and concentrations (Barbash and Resek, 1996, and references therein). Ground water with little to no DO indicates reducing (anoxic or anaerobic) or near-reducing conditions, and ground water with DO indicates oxygenated (oxic or aerobic) conditions. In this report, measured DO values less than 1 mg/L were assumed to represent anoxic conditions, whereas measured DO values equal to or greater than 1 mg/L were assumed to represent oxic conditions. Measured DO values then were grouped according to these values into two ordinal categories representing anoxic and oxic conditions.

The overall detection frequency of pesticides was examined between the two DO categories. Considering only concentrations greater than the CAL, the proportion of wells with at least one pesticide detected was not significantly different between the two DO categories for the fall and the spring (p -values > 0.05, KWOCR, table 13).

The frequencies of pesticide detection between the two DO categories were compared using the CSALs for individual pesticides detected in either the fall or spring at a frequency equal to or greater than 1 percent (table 13). The proportion of samples detected at concentrations greater than their respective CSALs (detection frequency) was significantly different between the two DO categories for one pesticide (tebuthiuron) in the fall (p -value = 0.0416, KWOCR, table 13). The proportion of tebuthiuron detections at concentrations greater than the CSAL was very close to statistical significance between the two DO categories for samples collected in the spring (p -value = 0.0567, KWOCR, table 13). Few studies have been conducted examining the relation between redox conditions and pesticides in ground water (Barbash and Resek, 1996).

Summary

To address concerns regarding ground-water contamination by pesticides and other agricultural chemicals, the U.S. Environmental Protection Agency (USEPA) developed and recommended a new Federal-State partnership in October 1991 to address the potential risks posed to ground water by the use of pesticides. In response, the State of Wyoming formed the Ground-water and Pesticides Strategy Committee (GPSC) consisting of members of local, State, and Federal government, as well as industry and interest groups, to prepare the State of Wyoming Generic Management Plan (SMP) for Pesticides in Ground Water. The SMP includes information describing individuals and organizations involved with implementation of the SMP, ground-water contamination prevention, ground-water monitoring, and required responses if pesticides are detected in ground water.

In Wyoming, little existing information was available describing pesticide occurrence in ground water. Consequently, the GPSC decided that a large component of the SMP would be to conduct “baseline ground-water sampling” to characterize current pesticide occurrence in Wyoming’s

ground water. In addition, the GPSC identified 20 pesticides (18 parent pesticides and 2 pesticide degradates) to be of greatest interest during baseline ground-water sampling.

The U.S. Geological Survey (USGS), in cooperation with the Wyoming Department of Agriculture and the Wyoming Department of Environmental Quality and acting on behalf of the GPSC, began statewide implementation of baseline ground-water sampling in 1995 and completed it in 2006. During 1995–2006, water samples were collected twice (during fall and spring) from 296 wells located in areas of “high” or “medium-high” ground-water vulnerability to pesticide contamination that were mapped for the entire State of Wyoming as part of the SMP. Ground-water samples were collected using standard USGS procedures.

Ground-water samples were analyzed using USGS laboratory methods with analytical reporting limits much smaller than typically used in routine pesticide monitoring of public drinking-water supplies. Consequently, it is likely that much more frequent rates of detection were obtained than would have been possible with less sensitive analytical methods. Reporting limits varied by pesticide, and many changed during the course of the study; therefore, pesticide detections were recensored to account for variations in reporting limits before data were summarized and analyzed. Detections were recensored to two different assessment levels to facilitate qualitative and quantitative examination of pesticide detection frequencies—a common assessment level (CAL) of 0.07 microgram per liter ($\mu\text{g/L}$) for all pesticides and a compound-specific assessment level (CSAL) that differed by pesticide.

Because of severe data censoring (fewer than 50 percent of the data were greater than laboratory reporting limits), categorical statistical methods were used exclusively for quantitative comparisons of pesticide detection frequencies between seasons and among various natural and anthropogenic (human-related) characteristics. Pesticide data were classified into two groups according to the characteristics selected for analysis and whether or not the pesticide was detected at concentrations greater than or less than the CSAL or CAL. The null hypothesis tested was that detection or nondetection of any pesticide was independent of the grouped characteristic selected for examination. Rejection of the null hypothesis at a probability (*p*-value) of 0.05 (alpha level) was considered evidence supporting the alternative hypothesis that there was a relation between the variable (pesticide) and the factor (grouped characteristic) tested.

One or more pesticides were detected at concentrations greater than the CAL in water from about 23 percent of wells sampled in the fall and in water from about 22 percent of wells sampled in the spring. The proportion of wells with at least one pesticide detected at concentrations greater than the CAL was not significantly different between fall and spring (*p*-value > 0.05). Mixtures of two or more pesticides occurred at concentrations greater than the CAL in about 9 percent of wells sampled in the fall and in about 10 percent of wells sampled in the spring. Most mixtures were composed of two to four different pesticides. At least 74 percent or more

of pesticides detected were classified as herbicides. Pesticides classified as triazines, ureas, pyridinecarboxylic acids, miscellaneous herbicides, or carbamates were most commonly detected. Considering only detections using the CAL, triazine pesticides were detected much more frequently than all other pesticide classes and comprised about 48 percent (fall) and 45 percent (spring) of all detections. In addition, the number of different pesticides classified as triazines was the largest of all classes.

Twenty-eight different pesticides were detected at concentrations greater than the CSALs in water from wells sampled in fall, whereas 21 different pesticides were detected in water from wells sampled in spring. Many pesticides were detected infrequently because 13 of 28 pesticides detected (about 46 percent) at concentrations greater than the CSALs in water from wells sampled in the fall were detected only in one well. Ten of 21 pesticides detected (about 48 percent) at concentrations greater than the CSALs in water from wells sampled in the spring were detected only in one well. Considering only detections using the CSALs, 14 of 20 focal pesticides identified in the SMP were detected at least once in water sampled from wells during either the fall or spring. Considering only detections using the CSALs and pesticides analyzed for in more than 11 wells, only five pesticides were each detected more than 5 percent of the time in water from wells sampled in either fall or spring (atrazine, prometon, tebuthiuron, picloram, and 3,4-dichloroaniline, listed in order of decreasing detection frequency). Atrazine was the pesticide detected most frequently in water from wells sampled in either fall or spring at concentrations greater than the CSAL (about 28 percent of wells in the fall and about 27 percent in the spring). Individual pesticides detected in both the fall and spring at a frequency equal to or greater than 1 percent using the CSALs were compared statistically to assess seasonal differences. For all pesticides tested, the proportion of samples with concentrations greater than their respective CSALs (detection frequency) was not significantly different (*p*-value > 0.05) between fall and spring.

Concentrations of detected pesticides generally were small (< 1 $\mu\text{g/L}$), although a few infrequent detections at larger concentrations were noted. Ten different pesticides were detected at concentrations greater than 1 $\mu\text{g/L}$ in water from at least one well sampled in either fall or spring. All detected pesticide concentrations were smaller than U.S. Environmental Protection Agency (USEPA) drinking-water standards or health advisories where applicable (many pesticides did not have standards or advisories). Most concentrations were at least an order of magnitude smaller than USEPA drinking-water standards or health advisories.

Regardless of assessment level and considering both seasons, the largest percentage of pesticide detections and the largest number of different pesticides detected were in water from wells located in the Bighorn Basin and High Plains/Casper Arch geographic areas of Wyoming (using the CAL, both areas combined comprised about 69 percent of all detections in the fall and about 63 percent of all detections in

the spring). Both geographic areas are major crop-producing areas in Wyoming. Pesticides were detected distinctly less often in water from wells in the other six geographic areas. Using the CAL, the proportion of wells with at least one pesticide detected was significantly different among the eight geographic areas for both the fall and the spring. Using the CSALs, only six herbicides (atrazine, prometon, tebuthiuron, picloram, bromacil, and diuron, listed in order of decreasing detection frequency) and one degradate (deethylatrazine) were detected in either the fall or spring in three or more different geographic areas. Of these seven compounds, prometon was the only pesticide detected in either season in all eight geographic areas. Using the CSALs, 17 pesticides were detected in only one geographic area in the fall, and 12 pesticides were detected in only one geographic area in the spring. The proportion of samples detected at concentrations greater than their respective the CSALs (detection frequency) was significantly different among the eight geographic areas for four pesticides (atrazine, prometon, deethylatrazine, and tebuthiuron, listed in order of decreasing detection frequency) detected in the fall and three pesticides (atrazine, deethylatrazine, and tebuthiuron) detected in the spring.

Pesticide detection frequencies were evaluated in relation to four land-use categories—urban, agricultural, rangeland/undeveloped, and mixed. Regardless of assessment level and season, pesticides were detected much more frequently in samples from wells located in predominantly urban areas than in samples from wells located in predominantly agricultural or mixed areas. Pesticides were detected distinctly less often in water from wells located in predominantly rangeland/undeveloped areas. The frequency of pesticide detection in water from wells located in either predominantly agricultural or mixed land-use areas was intermediate to water from wells located in urban and rangeland/undeveloped areas; however, using the CAL, the difference was more distinct, and the percentage of wells with at least one pesticide detected located in either predominantly agricultural or mixed areas was less than one-half that of wells located in predominantly urban areas regardless of season. Using the CAL, the proportion of wells with at least one pesticide detected was significantly different among the four land-use categories for both the fall and the spring (p -values < 0.05).

Using the CSALs for either fall or spring, eight pesticides [listed in order of decreasing detection frequency—bromacil, clopyralid, flumetsulam, 2,4-D methyl ester, deisopropylatrazine (fall), 3,4-dichloroaniline, hydroxyatrazine, and imidacloprid] were detected in water from wells located in predominantly urban areas, three pesticides (listed in order of decreasing detection frequency—DCPA, bentazon, and aldicarb sulfone) were detected only in samples from wells located in predominantly agricultural areas, and two pesticides [hexazinone and deisopropylatrazine (spring)] were detected only in samples from wells located in predominantly mixed land-use areas. Using the CSALs, no pesticide was detected in water from wells located only in predominantly rangeland/undeveloped areas. Remaining pesticides detected

at concentrations greater than their respective CSALs were associated with sampled wells located in two to four different predominant land uses. Two of the pesticides detected most frequently during this study (prometon and tebuthiuron) either have no reported agricultural use (prometon) or limited noncropland use (tebuthiuron) in Wyoming, and both were detected most commonly in sampled wells located in predominantly urban areas, although many detections were associated with sampled wells located in predominantly agricultural or mixed areas. This was not surprising and likely reflects the use of both pesticides for many different nonagricultural applications throughout all land uses in Wyoming. The occurrence of some pesticides did not necessarily correspond to the predominant land use assigned to sampled wells. The proportion of samples detected at concentrations greater than their respective CSALs (detection frequency) was significantly different among the four land-use categories for four pesticides (atrazine, prometon, tebuthiuron, and bromacil, listed in order of decreasing detection frequency) detected in both the fall and spring.

The frequency of pesticide detection was examined in relation to hydrogeology (aquifer type, water-level depth, well depth, and well type). The percentage of wells with at least one pesticide detected was larger for wells completed in unconsolidated-deposit aquifers than for wells completed in bedrock aquifers, and considering only concentrations greater than the CAL, the proportion of wells with at least one pesticide detected was significantly different between unconsolidated and bedrock aquifers sampled in the fall but not in the spring. For all pesticides tested, the proportion of samples detected at concentrations greater than their respective CSALs (detection frequency) was not significantly different between unconsolidated and bedrock aquifers for the fall or spring.

Using the CAL, the proportion of wells with at least one pesticide detected was not significantly different among four water-level depth categories for the fall or the spring (all p -values > 0.05). For all tested individual pesticides except deethylatrazine, the proportion of samples detected at concentrations greater than their respective CSALs (detection frequency) was not significantly different among the water-level depth categories for the fall or spring (all p -values > 0.05). For deethylatrazine, the proportion of samples detected at concentrations greater than the CSAL decreased as water level increased among four water-level depth categories, and the difference was significant for the spring but not for the fall.

Using the CAL, the proportion of wells with at least one pesticide detected generally decreased with increasing well depth, and the difference was significant for the fall and the spring. The proportion of samples detected at concentrations greater than their respective CSALs (detection frequency) decreased as well depth increased for three pesticides (prometon, tebuthiuron, and bromacil, listed in order of decreasing detection frequency), and the difference was significant for both fall and spring.

Pesticides were always detected much more frequently in the “other” and domestic-supply well categories than in the stock well category. In most cases, pesticides were detected more frequently in the “other” well category than in the domestic-supply well category, although detection frequencies were very similar for some pesticides. Using the CAL, the proportion of wells with at least one pesticide detected was larger for the “other” well category than for the domestic-supply well and stock well categories for both fall and spring, and the difference was significant for both fall and spring. The proportion of samples detected at concentrations greater than their respective CSALs (detection frequency) was larger for the “other” well category than for the domestic-supply well and stock well categories for most pesticides tested, and the difference was significant for three pesticides (prometon, tebuthiuron, and bromacil, listed in order of decreasing detection frequency) detected in both fall and spring and one pesticide (diuron) detected in the spring.

Pesticide detections in ground water were examined in relation to selected soil properties (organic matter content, soil permeability, and soil hydrologic index) from the State Soil Geographic (STATSGO) database mapped within a 500-m (1,640-ft) radius surrounding each sampled well. Using the CAL, the proportion of wells with at least one pesticide detected was not significantly different among four organic-matter-content categories for fall or spring. For most pesticides, no clear trend of increasing or decreasing frequency of detection was noted among the four categories as organic matter content increased. The proportion of samples detected at concentrations greater than their respective CSALs (detection frequency) was significantly different among the four organic-matter-content categories for four pesticides (atrazine, tebuthiuron, flumetsulam, and fipronil sulfide, in order of decreasing detection frequency) detected in the fall and in one pesticide (tebuthiuron) detected in the spring.

Using the CAL, the proportion of wells with at least one pesticide detected was significantly different among the four soil-permeability categories for fall but not spring. For most pesticides, no clear trend of increasing or decreasing frequency of detection was noted among the four categories as soil permeability increased. The proportion of samples detected at concentrations greater than their respective CSALs (detection frequency) was significantly different among the four soil-permeability categories for three pesticides (deethylatrazine, tebuthiuron, and aldicarb sulfone, listed in order of decreasing detection frequency) detected in the fall and two pesticides (atrazine and tebuthiuron) detected in the spring.

Using the CAL, the proportion of wells with at least one pesticide detected was not significantly different among the four soil-hydrologic-index categories (derived from STATSGO soil properties) for fall and spring. For most pesticides, no clear trend of increasing or decreasing frequency of detection was noted among the four soil-hydrologic-index categories. The proportion of samples detected at concentrations greater than their respective CSALs (detection frequency) generally decreased for two pesticides (atrazine and deethylatrazine) as

the soil hydrologic index increased, and the difference was significant for both fall and spring.

One water-quality constituent (nitrate) and three different water-quality characteristics (specific conductance, pH, and dissolved oxygen) were examined in relation to the occurrence of pesticides in ground water. Using the CAL, the proportion of wells with at least one pesticide detected was significantly different between the nitrate concentration categories of less than and greater than or equal to 1.1 milligrams per liter for both fall and spring. The proportion of samples detected at concentrations greater than their respective CSALs (detection frequency) was much larger for the “elevated” nitrate concentration category than for the other nitrate concentration category for almost every pesticide tested. The proportion of samples detected at concentrations greater than their respective CSALs (detection frequency) was significantly different between the two nitrate concentration categories for three pesticides (atrazine, prometon, and deethylatrazine, listed in order of decreasing detection frequency) in both the fall and spring, one pesticide (tebuthiuron) in the fall, and one pesticide (bromacil) in the spring.

Using the CAL, the proportion of wells with at least one pesticide detected was not significantly different between two specific conductance categories representing freshwater [specific conductance values $\leq 1,665$ microsiemens per centimeter at 25 degrees Celsius ($\mu\text{S}/\text{cm}$)] and saline water (specific conductance values $> 1,665$ $\mu\text{S}/\text{cm}$) for the fall and the spring. The proportion of samples detected at concentrations greater than their respective CSALs (detection frequency) was much larger for the saline-water category than for the freshwater category for almost every pesticide tested. The proportion of samples detected at concentrations greater than their respective CSALs (detection frequency) was significantly different between the two specific conductance categories for one pesticide (tebuthiuron) in both the fall and spring and one pesticide (prometon) only in the fall.

Using the CAL, the proportion of wells with at least one pesticide detected was significantly different among the three pH categories—acidic ($\text{pH} < 6.8$), circumneutral ($6.8 \leq \text{pH} \leq 7.3$), and alkaline ($\text{pH} > 7.3$)—for both fall and spring. For many pesticides, no clear trend of increasing or decreasing frequency of detection was noted among the three categories as pH increased. The proportion of samples detected at concentrations greater than their respective CSALs (detection frequency) was significantly different among the three pH categories for three pesticides (prometon, tebuthiuron, and bromacil, listed in order of decreasing detection frequency) detected in both the fall and spring and one pesticide (diuron) detected in the spring.

Using the CAL, the proportion of wells with at least one pesticide detected was not significantly different between the two dissolved oxygen (DO) categories—anoxic conditions (DO concentrations < 1 milligram per liter) and oxic conditions (DO concentrations ≥ 1 milligram per liter)—for the fall and the spring. The proportion of samples detected at concentrations greater than their respective CSALs (detection

frequency) was significantly different between the two DO categories for one pesticide (tebuthiuron) in the fall.

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