Prepared in cooperation with the
OKLAHOMA DEPARTMENT OF AGRICULTURE, FOOD AND FORESTRY

Possible Sources of Nitrate in Ground Water at Swine Licensed-Managed Feeding Operations in Oklahoma, 2001

Water-Resources Investigations Report 02–4257

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On Cover: Monitoring wells near swine licensed-managed feeding operations. Photographs taken by Mark F. Becker, U.S. Geological Survey.

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Conversion Factors and Datum

Multiply	By	To obtain
	Length	
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
	Volume	
gallon (gal)	3.785	liter (L)

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

°F = (1.8 × °C) + 32

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

°C = (°F - 32) / 1.8

Vertical coordinate information is referenced to the *insert datum name (and abbreviation) here, for instance, "North American Vertical Datum of 19988 (NAVD 88)."*

Horizontal coordinate information is referenced to the *insert datum name (and abbreviation) here, for instance, "North American Datum of 19988 (NAVD 88)."*

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

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

Possible Sources of Nitrate in Ground Water at Swine Licensed-Managed Feeding Operations in Oklahoma, 2001

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Abstract

Samples collected and analyzed by the Oklahoma Department of Agriculture, Food, and Forestry from 1999 to 2001 determined that nitrate exceeded the U.S. Environmental Protection Agency maximum contaminant level for public drinking-water supplies of 10 milligrams per liter as nitrogen in 79 monitoring wells at 35 swine licensed-managed feeding operations (LMFO) in Oklahoma.

The LMFOs are located in rural agricultural settings where long-term agriculture has potentially affected the ground-water quality in some areas. Land use prior to the construction of the LMFOs was assessed to evaluate the types of agricultural land use within a 500-meter radius of the sampled wells.

Chemical and microbiological techniques were used to determine the possible sources of nitrate in water sampled from 10 wastewater lagoons and 79 wells. Samples were analyzed for dissolved major ions, dissolved trace elements, dissolved nutrients, nitrogen isotope ratios of nitrate and ammonia, wastewater organic compounds, and fecal coliform bacteria. Bacteria ribotyping analysis was done on selected samples to identify possible specific animal sources.

A decision process was developed to identify the possible sources of nitrate. First, nitrogen isotope ratios were used to define sources as animal, mixed animal and fertilizer, or fertilizer. Second, wastewater organic compound detections, nitrogen-isotope ratios, fecal coliform bacteria detections, and ribotyping were used to refine the identification of possible sources as LFMO waste, fertilizer, or unidentified animal or mixtures of these sources. Additional evidence provided by ribotyping and wastewater organic compound data can, in some cases, specifically indicate the animal source. Detections of three or more wastewater organic compounds that are indicators of animal sources and detections of fecal coliform bacteria provided additional evidence of an animal source.

LMFO waste was designated as a possible source of nitrate in water from 10 wells. The source of waste in water from five of those wells was determined through ribotyping, and the source of waste in water from the remaining five wells was determined by detections of three or more animal-waste compounds in the well samples. LMFO waste in the water from wells with unidentified animal source of nitrate does not indicate that LMFO waste was not the source, but indicated that multiple animal sources, including LMFO waste, may be the source of the nitrate.

Introduction

Swine licensed-managed feeding operations (LMFOs) are large-scale swine farms. The animal waste generated by LMFOs is stored in wastewater lagoons located near the farms. The wastewater lagoons contain large quantities of nutrients and micro-organisms, and therefore, could effect ground-water quality. Oklahoma Rule Number 35:17-3-11E5c (Oklahoma Department of Agriculture, Food, and Forestry, 1999) requires LMFO operators to install a leak detection system or monitoring wells.

The Oklahoma Department of Agriculture, Food, and Forestry (ODAFF) annually collects ground-water samples from the monitoring wells near LMFOs and analyzes the samples for specific conductance, pH, ammonium as nitrogen, nitrate as nitrogen, total phosphorus, and the presence of fecal coliform bacteria. Nitrate concentrations in ground-water samples collected and analyzed by ODAFF from 1999 through 2001 exceeded the U.S. Environmental Protection Agency (USEPA) maximum contaminant level (MCL) of 10 milligrams per liter nitrate as nitrogen for public drinking-water supplies (U.S. Environmental Protection Agency, 1995) in 79 monitoring wells near 35 LMFOs. The LMFOs and monitoring wells are located in areas of current and historical agriculture activities, so the source of the nitrate in the ground water could be from wastewater lagoons (LMFO waste), nitrogen fertilizer applications on row crops, or livestock grazing.

Sources of nitrate in ground water at the LMFO could come from the wastewater lagoon through land application of wastewater or lagoon leakage or from previous and current agricultural land-use practices. LMFO wastewater lagoons hold solid and liquid animal wastes and wash water from barns. Lagoon wastewater is commonly discharged through a large spray application system or center-pivot irrigation system on adjacent cropland or pastures. Total nitrogen concentrations as much as 300 milligrams per liter have been reported in swine wastewater lagoons in Oklahoma (Joseph Downey, Downey and Gutentag, LLC, written commun., 2000), indicating the potential for nitrogen-compound contamination of ground water by lagoon leakage. Most of the monitoring wells sampled by ODAFF from 1999 through 2001 are located in aquifers where nitrate concentrations have historically exceeded the background concentration threshold of 3 milligrams per liter, and agriculture has been a contributor of nitrate to the ground water [Adams and others (1994), Becker (1994), Litke (2000), McMahon (2001), Becker and others (2002); and B. B. Bruce, U.S. Geological Survey, written commun., 2001].

Determining the sources of nitrate in ground water would aid ODAFF in assessing whether the LMFOs negatively affect nearby ground-water quality. Techniques to differentiate between LMFO waste, mixed animal and fertilizer, or fertilizer as sources of nitrate in ground water are important in agricultural areas. To address these needs, the U.S. Geological Survey (USGS), in cooperation with ODAFF, conducted a study using chemical and microbiological techniques to determine possible sources of nitrate in ground water near selected LMFOs in Oklahoma.

Purpose and Scope

This report describes results of the study to determine possible sources of nitrate in ground water from 79 monitoring wells at 35 LMFOs (fig. 1) in Oklahoma. ODAFF selected the LMFOs and wells based on annual ground-water samples collected and analyzed from 1999 through 2001 that had nitrate concentrations exceeding the USEPA MCL of 10 milligrams per liter of nitrate as nitrogen.

LMFO wastewater lagoons and monitoring wells were sampled from May 2001 to August 2001 and analyzed for water properties, dissolved major ions, dissolved trace elements, nutrients, nitrogen-isotope ratios in nitrate and ammonia, wastewater organic compounds (compounds associated with household items, agriculture, pharmaceuticals, animal hormones and sterols, plant sterols, and hydrocarbons), and fecal coliform bacteria. Isolates of *E. coli* bacteria from fecal coliform bacteria colonies in well samples were ribotyped, a form of deoxyribonucleic acid (DNA) fingerprinting, and compared against isolates from the lagoon samples and a library of known sources to determine the specific animal source of fecal coliform bacteria.

An evaluation of antecedent land use was done to identify the different types of agricultural land use that existed near the 79 monitoring wells prior to the construction of the LMFOs. Land-use percentages for 1988-1992 within a 500-meter radius of the wells were determined with geographic information system software and land-use information from the National Land Cover Dataset (NLCD) (U.S. Geological Survey, 2000).

This report does not include a detailed hydrogeologic investigation at the specific sites. The extent of nitrate contamination at any given site was beyond the scope of the study.

Nitrate for this study is reported as nitrite plus nitrate with nitrite generally being an insignificant amount of the sum of the two compounds. Nitrite plus nitrate will be identified as nitrate as nitrogen for purposes of clarity in this report.

Acknowledgments

The authors thank the owners and operators of the LMFOs for providing site information and access to the wastewater lagoons and monitoring wells; David Berry with ODAFF for assisting in sampling; and U.S. Geological Survey personnel Lee Ann Alf, Dale Boyle, Marty Phillips, and Martin Schneider for their efforts and dedication during the sampling of the lagoons and wells.

Hydrogeology

Three types of aquifers underlie the LMFOs of this study: major bedrock, minor bedrock, or alluvial and terrace. Major bedrock aquifers are large regional aquifers that have water quality and yields suitable for use as industrial, irrigation, domestic, and public supply (fig. 1). Minor bedrock aquifers are either local or regional geologic units that have water quality that is unsuitable for consumption or yields that are marginal. Alluvial and terrace aquifers are relatively narrow bands of unconsolidated sediments adjacent to streams that have water quality and yields sufficient for industrial, irrigation, domestic and public supplies.

The only major bedrock aquifer in the LMFO areas is the High Plains aquifer, also referred to as the Ogallala aquifer (fig. 1). The High Plains aquifer in Oklahoma consists of the Ogallala Formation of Tertiary age, is hydraulically connected to younger units, and contains heterogeneous clastic material ranging in size from clay to gravel (Luckey and Becker, 1999). The minor bedrock aquifers range in age from Pennsylvanian to Permian and are well indurated clastic deposits.

The Beaver/North Canadian and Cimarron alluvial and terrace aquifers consist primarily of interbedded sands, clays, and gravels of Quaternary age. Water-table elevations generally follow local topography, direction of ground-water flow is usually from areas of higher elevation to lower elevation, and ground water ultimately discharges to the river. More detailed descriptions of the hydrogeology of the alluvial and terrace aquifers of the Beaver/North Canadian and Cimarron Rivers are reported by Davis and Christenson (1981) and Adams and Bergman (1996).

Methods of study

Seven chemical and microbiological methods were used to investigate the sources of nitrate in the water sampled from 8 lagoons and 79 monitoring wells at 35 LMFOs. Samples col-

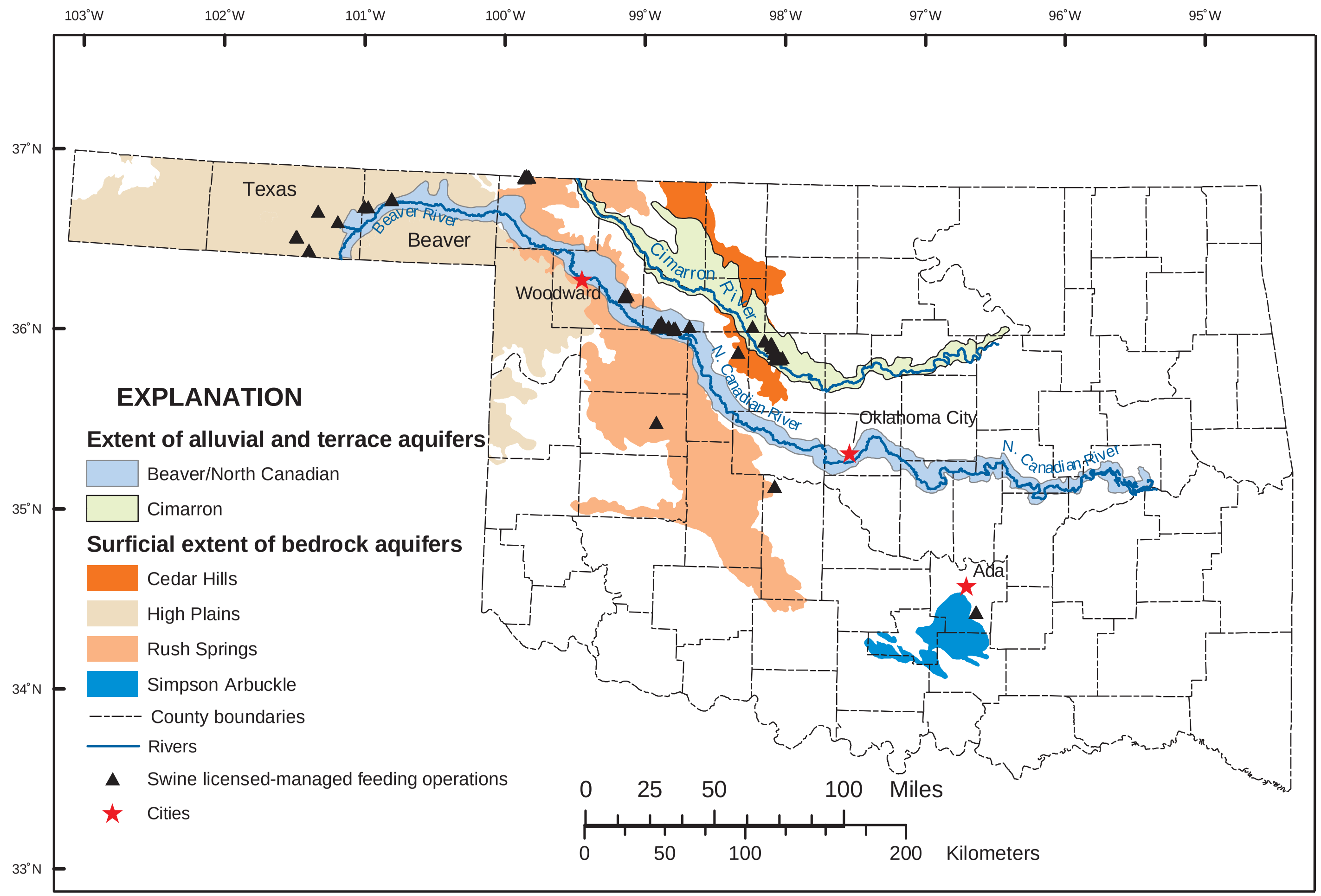

Figure 1. Location of swine licensed-managed feeding operations where lagoons and wells were sampled in 2001.

lected from wastewater lagoons and monitoring wells were analyzed for dissolved major ions, dissolved trace elements, nutrients, nitrogen isotope ratios of nitrate and ammonia, wastewater organic compounds, and fecal coliform bacteria. Bacteria ribotyping was used to determine the possible source of *E. coli* bacteria isolates. Two additional lagoons at one LMFO were sampled and analyzed only for dissolved major ions and dissolved trace elements.

Because prior agricultural land-use activities may affect nitrate concentrations in the ground water, antecedent land use near the monitoring wells was mapped using the NLCD digital coverages developed from Landsat images taken from 1988 to 1992.

Site selection and sampling methods

According to the Oklahoma rules (Oklahoma Department of Agriculture, Food, and Forestry, 1999), monitoring wells are to be installed within 150 feet of the crown of the outer berm of the wastewater lagoon and drilled at least through the first aquifer encountered, but one downgradient well and one upgradient well are not to exceed a depth of 50 feet below the base of the lagoon. One downgradient well shall be drilled to the first aquifer encountered or the first impermeable layer, but not to exceed a depth of 100 feet below the bottom of the lagoon.

The 79 monitoring wells sampled for this study were selected by the ODAFF because water samples from those wells had exceeded the USEPA MCL of 10 milligrams per liter for nitrate as nitrogen. Table 1 shows the wells, locations, aquifer type, land-surface elevations, well depths and depths to water at the time of sampling. Wells 23 and 36 also are supply wells for the LMFO and were pumping prior to and during the sampling period, so the depth to water was not measured.

All 22 major bedrock aquifer wells were completed in the High Plains aquifer. The depth to water in the major bedrock aquifer wells ranged from 15.37 to 113.30 feet (table 1) with a median of 54.30 feet. Those well depths ranged from 28.6 to 128 feet (table 1) with a median of 71.3 feet. Eight wells were completed in minor bedrock aquifers. The depth to water in the minor bedrock aquifer wells ranged from 6.29 to 11.86 feet (table 1) with a median of 8.97 feet. Well depth in minor bedrock aquifer wells ranged from 14.8 to 50.9 feet (table 1) with a median of 16.4 feet. Forty-nine wells were installed in the Beaver/North Canadian and Cimarron alluvial and terrace aquifers. Depth to water in the wells in the alluvial and terrace aquifers ranged from 3.07 to 64.97 feet (table 1) with a median of 28.61 feet. Those well depths ranged from 20.6 to 94.4 feet (table 1), with a median of 55.5 feet.

Eight wastewater lagoons were selected for sampling to characterize the effluent, and to determine if effluent was the source of nitrate in ground water at the selected LMFOs. Lagoon selection was based upon the spatial distribution of the selected sites and the type of operation. Spatial distributions of lagoons to be sampled were determined to cover a range of climatic conditions and possible differences in the percentages of agricultural land uses represented. Different types of operations, such as finishing, nursery, or sow farms were selected because of the differences of operational procedures at the different facilities.

The study was conducted in accordance with USGS protocols (Brunett and others, 1997), which addresses methods of collection, processing, analysis, storage, review, and publication of ground-water data. Ground-water-quality samples were collected according to USGS and ODAFF protocols (Wilde and other, 1998; Shirazi, 1999). Well volumes of the saturated portion of the wells were calculated and three well volumes were purged prior to sample collection. Measurements of specific conductance, pH, temperature, dissolved oxygen, and turbidity were taken every 5 minutes to assess the stability of the water-quality conditions prior to sampling. With the exception of the two pumping wells, disposable Teflon bailers were used to purge and sample the wells. Dissolved major ions, dissolved trace elements, nutrients, and nitrogen isotope well samples were filtered in the field through a 0.45-micron disposable capsule filter. All tubing and buckets were decontaminated after use with quality-assured, phosphate-free soap, rinsed with deionized water, and placed in sealed plastic bags until used. Water samples collected for fecal coliform bacteria were poured directly from the bailer into sterile containers, chilled, and processed in less than 6 hours from the time the sample was collected. Processing, filtration, and interpretation of fecal coliform bacteria was done by methods described by Myers and Sylvester (1997). Major ions, nutrients, nitrogen isotope, and wastewater organic compounds samples were chilled and preserved, if necessary. Samples were stored at 4 degrees Celsius and shipped to the laboratory, by an overnight courier.

E. coli isolates from well samples for ribotyping were obtained from the fecal coliform bacteria colonies cultured by the USGS. Plates containing fecal coliform bacteria colonies were kept chilled and shipped overnight to the laboratory. *E. coli* isolates from lagoon and cattle source samples for ribotyping were cultured by the Institute of Environmental Health, Seattle, WA, from raw material, collected in sterile 120-milliliter containers, chilled, and shipped overnight. Lagoon samples, with the exception of the nutrient samples, were filtered by the analyzing laboratories. All nutrient, nitrogen isotope, and wastewater organic compound samples were chilled to 4 degrees Celsius following collection and shipped overnight within 72 hours of being collected. Major ions were stored in 500- and 250-milliliter polyethylene bottles. Filtered trace element samples were stored in 500-milliliter acid-rinsed bottles and preserved with reagent grade nitric acid at a pH of less than 2.0. Nutrient samples were filtered and stored in 125-milliliter, brown, polyethylene bottles. Nitrogen isotope samples were filled to capacity, stored in 1-liter polyethylene bottles, and sealed with a polyseal cap minimizing head space in the bottle. The sample was preserved with 2 milliliters of reagent grade sulfuric acid. Whole-water samples for wastewater organic compound analysis were stored in 1-liter, baked, amber glass bottles sealed with Teflon-lined caps.

Table 1. Location and well information for 10 lagoons and 79 monitoring wells sampled at swine licensed-managed feeding operations in Oklahoma

[L, lagoon; dms, degrees, minutes, seconds; Legal location is in section, township, range; ECM, east of Cimarron Meridian; W, west; E, east; --, no data]

Lagoon and well numbers	Site identification number	Latitude (dms)	Longitude (dms)	Aquifer type	Legal location	Land-surface elevation (feet)	Well depth (feet)	Depth to water (feet)
L1	343756096364402	343755	963645	--	19 02N 07E	--	--	--
L2	351857098004304	351904	980033	--	26 10N 08W	--	--	--
L3	360635098032902	360634	980330	--	21 19N 08W	--	--	--
L4	361028098440703	361053	984416	--	30 20N 14W	--	--	--
L5	361028098440705	361053	984416	--	30 20N 14W	--	--	--
L6	361028098440706	361053	984416	--	30 20N 14W	--	--	--
L7	362118099050001	362118	990500	--	25 22N 18W	--	--	--
L8	363605101241301	363605	1012413	--	35 02N 17ECM	--	--	--
L9	365009100450901	365009	1004509	--	5 04N 28ECM	--	--	--
L10	365956099473701	365956	994737	--	16 29N 24W	--	--	--
1	343756096364401	343757	963644	Minor Bedrock	19 02N 07E	790	15.6	10.00
2	343756096364403	343750	963647	Minor Bedrock	19 02N 07E	780	15.4	7.45
3	351857098004301	351907	980031	Minor Bedrock	26 10N 08W	1,370	17.3	11.86
4	351857098004302	351904	980036	Minor Bedrock	26 10N 08W	1,340	19.2	8.69
5	351857098004303	351906	980036	Minor Bedrock	26 10N 08W	1,340	17.9	10.07
6	353922098503101	353922	985031	Minor Bedrock	30 14N 15W	1,745	50.9	9.25
7	360134097591401	360134	975914	Alluvial/Terrace	19 18N 07W	1,120	25.4	7.82
8	360135097591801	360135	975918	Alluvial/Terrace	19 18N 07W	1,120	20.6	7.08
9	360146098013602	360145	980135	Alluvial/Terrace	23 18N 08W	1,160	32.6	14.21
10	360212097583601	360213	975836	Alluvial/Terrace	17 18N 07W	1,120	21.3	3.07
11	360317098015301	360317	980153	Alluvial/Terrace	11 18N 08W	1,135	36.8	12.50
12	360317098015302	360320	980157	Alluvial/Terrace	10 18N 08W	1,145	63.9	19.72
13	360317098015303	360324	980151	Alluvial/Terrace	11 18N 08W	1,135	67.5	19.19
14	360325098010701	360325	980107	Alluvial/Terrace	11 18N 08W	1,135	49.7	9.14
15	360339098170301	360339	981703	Minor Bedrock	5 18N 10W	1,180	14.8	6.50
16	360339098170701	360336	981707	Minor Bedrock	5 18N 10W	1,180	15.0	6.29
17	360416098013601	360417	980137	Alluvial/Terrace	2 18N 08W	1,160	50.6	11.07
18	360521098022501	360521	980225	Alluvial/Terrace	27 19N 08W	1,180	28.3	16.08
19	360521098022502	360522	980229	Alluvial/Terrace	27 19N 08W	1,180	29.3	12.60
20	360618098024501	360607	980257	Alluvial/Terrace	22 19N 08W	1,185	28.8	11.36
21	360618098024502	360618	980245	Alluvial/Terrace	22 19N 08W	1,185	20.7	8.12
22	360634098030901	360634	980309	Alluvial/Terrace	21 19N 08W	1,185	30.4	7.95
23	360634098030902	360634	980309	Alluvial/Terrace	21 19N 08W	1,185	--	--
24	360635098032901	360635	980329	Alluvial/Terrace	21 19N 08W	1,190	26.3	11.75
25	360729098060901	360729	980609	Alluvial/Terrace	18 19N 08W	1,185	31.8	14.97

Table 1. Location and well information for 10 lagoons and 79 monitoring wells sampled at swine licensed-managed feeding operations in Oklahoma—Continued.

Lagoon and well numbers	Site identification number	Latitude (dms)	Longitude (dms)	Aquifer type	Legal location	Land-surface elevation (feet)	Well depth (feet)	Depth to water (feet)
26	360735098060801	360735	980608	Alluvial/Terrace	18 19N 08W	1,185	30.7	13.52
27	361028098440701	361029	984408	Alluvial/Terrace	30 20N 14W	1,680	39.8	21.52
28	361028098440702	361052	984416	Alluvial/Terrace	30 20N 14W	1,690	65.4	33.67
29	361028098440704	361056	984416	Alluvial/Terrace	30 20N 14W	1,700	73.7	41.40
30	361028098440705	361051	984338	Alluvial/Terrace	30 20N 14W	1,690	45.0	19.75
31	361028098440706	361058	984338	Alluvial/Terrace	30 20N 14W	1,710	38.3	18.83
32	361115098504701	361115	985047	Alluvial/Terrace	19 20N 15W	1,740	61.2	44.90
33	361116098463001	361116	984630	Alluvial/Terrace	23 20N 15W	1,720	52.6	30.80
34	361117098504301	361117	985043	Alluvial/Terrace	19 20N 15W	1,735	78.2	44.50
35	361118098463301	361118	984633	Alluvial/Terrace	23 20N 15W	1,725	78.7	28.82
36	361121098504501	361121	985045	Alluvial/Terrace	19 20N 15W	1,735	--	--
37	361122098462801	361122	984628	Alluvial/Terrace	23 20N 15W	1,725	71.6	28.40
38	361122098493901	361122	984939	Alluvial/Terrace	20 20N 15W	1,730	46.7	33.67
39	361133098485701	361133	984857	Alluvial/Terrace	20 20N 15W	1,740	90.4	47.57
40	361136098374401	361136	983744	Alluvial/Terrace	19 20N 13W	1,720	41.9	24.71
41	361139098374801	361139	983748	Alluvial/Terrace	19 20N 13W	1,710	57.5	25.02
42	361139098485901	361139	984859	Alluvial/Terrace	20 20N 15W	1,740	86.2	41.00
43	361143098374801	361143	983748	Alluvial/Terrace	19 20N 13W	1,725	52.9	28.23
44	361146098504501	361146	985045	Alluvial/Terrace	19 20N 15W	1,745	58.3	51.79
45	361152098504401	361152	985044	Alluvial/Terrace	19 20N 15W	1,740	59.8	48.29
46	361157098494101	361157	984941	Alluvial/Terrace	20 20N 15W	1,750	94.4	50.40
47	361203098494301	361203	984943	Alluvial/Terrace	20 20N 15W	1,760	78.4	25.04
48	361210098112201	361210	981122	Alluvial/Terrace	20 20N 09W	1,210	38.4	22.59
49	361215098491301	361215	984913	Alluvial/Terrace	17 20N 15W	1,770	62.2	30.70
50	361215098491501	361215	984915	Alluvial/Terrace	17 20N 15W	1,770	68.8	34.70
51	361240098494201	361240	984942	Alluvial/Terrace	17 20N 15W	1,775	80.9	39.22
52	361240098494401	361240	984944	Alluvial/Terrace	17 20N 15W	1,775	76.9	38.50
53	361245098494401	361245	984944	Alluvial/Terrace	17 20N 15W	1,780	76.8	38.50
54	362100099050301	362057	990503	Alluvial/Terrace	25 22N 18W	1,950	76.8	64.97
55	362118099050301	362118	990503	Alluvial/Terrace	25 22N 18W	1,950	79.1	63.75
56	362136099041201	362136	990412	Alluvial/Terrace	25 22N 18W	1,895	79.7	29.02
57	362136099051001	362136	990510	Alluvial/Terrace	26 22N 18W	1,960	74.4	55.08
58	363153101185001	363153	1011850	Major Bedrock	23 01N 17ECM	2,067	78.3	54.96
59	363601101241301	363601	1012413	Major Bedrock	35 02N 17ECM	3,070	123.0	103.82
60	363602101244501	363602	1012445	Major Bedrock	34 02N 17ECM	3,078	128.0	99.87
61	364150101071901	364150	1010719	Major Bedrock	25 03N 17ECM	2,830	124.0	103.85
62	364500101155301	364500	1011553	Major Bedrock	2 03N 17ECM	2,930	126.0	113.30

Table 1. Location and well information for 10 lagoons and 79 monitoring wells sampled at swine licensed-managed feeding operations in Oklahoma—Continued.

Lagoon and well numbers	Site identification number	Latitude (dms)	Longitude (dms)	Aquifer type	Legal location	Land-surface elevation (feet)	Well depth (feet)	Depth to water (feet)
63	364722100545501	364722	1005455	Major Bedrock	25 04N 27ECM	2,745	126.0	108.19
64	364728100563501	364728	1005635	Major Bedrock	24 04N 27ECM	2,745	122.0	95.97
65	365006100451001	365006	1004510	Major Bedrock	5 04N 28ECM	2,660	127.0	85.20
66	365024100450701	365024	1004507	Major Bedrock	5 04N 28ECM	2,660	76.7	72.90
67	365919099490901	365919	994909	Major Bedrock	17 29N 24W	1,950	72.8	56.25
68	365938099490901	365938	994909	Major Bedrock	17 29N 24W	1,945	61.1	46.90
69	365941099475101	365941	994751	Major Bedrock	16 29N 24W	1,940	65.2	53.65
70	365941099490701	365941	994907	Major Bedrock	17 29N 24W	1,945	66.2	47.58
71	365942099473701	365942	994737	Major Bedrock	16 29N 24W	1,925	53.5	39.63
72	365944099473401	365944	994734	Major Bedrock	16 29N 24W	1,925	47.6	39.43
73	365945099474901	365945	994749	Major Bedrock	16 29N 24W	1,955	76.5	62.50
74	365945099491401	365945	994914	Major Bedrock	17 29N 24W	1,920	38.2	32.66
75	365947099492101	365947	994921	Major Bedrock	17 29N 24W	1,905	28.6	15.37
76	365948099491701	365948	994917	Major Bedrock	17 29N 24W	1,911	29.1	19.08
77	365954099473701	365954	994737	Major Bedrock	16 29N 24W	1,950	76.6	60.80
78	370002099484101	370002	994841	Major Bedrock	17 29N 24W	1,915	38.7	25.35
79	370003099483501	370003	994835	Major Bedrock	16 29N 24W	1,915	35.4	24.6

Analytical Methods

Chemical constituents and fecal coliform bacteria were analyzed at five different laboratories. The analyzing laboratory, methods used for analysis, and references to the methods are listed in table 2.

Fecal coliform bacteria samples from the wells and lagoons were collected in sterile polyethylene bottles, chilled, and processed within 6 hours of collection. Most of the filtration and incubation of fecal coliform bacteria samples were done at the offices of the USGS in Oklahoma City and Woodward, Oklahoma. On occasion, samples were cultured in the field settings in order to remain within the 6-hour sample holding time.

Quality Assurance and Quality Control

Quality assurance practices were implemented to maintain consistency with sampling protocols throughout the study and to assure clean practices. All bailers were disposed of following the sampling to avoid bacterial cross contamination of wells. The bailers were rinsed prior to sampling with an antibacterial agent consisting of a solution of dilute methanol and deionized water and lowered into the well with sterilized line. Temporary sample containers and tubing that were reused for filtered samples were decontaminated with quality-assured lab soap and rinsed with deionized water. Unfiltered samples were poured directly from the bailer into the sample bottle. Filtered samples were obtained within an enclosure using a disposable 0.45-micron filter and reusable decontaminated tubing.

Blank control plates were used for every lagoon and well sample for fecal coliform bacteria analyses. Spikes composed of LMFO waste were used to check for the efficacy of the media. Plates were refrigerated prior to processing and were disposed of after 3 days if unused. Plates with fecal colonies that were processed for ribotyping were kept refrigerated and shipped chilled. LMFO waste and cattle manure collected for ribotyping were placed in sterile cups, sealed, chilled, and shipped overnight.

Nutrient and wastewater organic compound samples from monitoring wells were analyzed using quality-control and quality-assurance practices of the National Water-Quality Laboratory in Lakewood, Colorado. Routine analyses of replicates, spikes, and blind reference samples were performed (Pritt and Raese, 1995).

Three primary types of quality-control samples were collected at the sampling sites: equipment blanks, field blanks, and replicates. Equipment blanks were collected in a setting where chances for contamination were negligible and used to determine if there was contamination from the sampling equipment or procedure. Two equipment blanks for major ions, trace elements, nutrients, and wastewater organic compounds were collected prior to sampling. Field blanks were collected at the site using the identical protocols for collecting the environmental sample and used to determine if there was contamination from the equipment, procedures, or setting. Replicate samples were collected sequentially and were used to check if handling, sampling, or analytical methods can bias the results. Six field blanks and replicate samples were collected for major ions, trace elements, and nutrients. Four replicate samples were collected for nitrogen isotopes and analyzed by the USGS National Water Quality Laboratory, Lakewood, CO. Six field blank and five replicate samples were analyzed for wastewater organic compounds.

Identification of Possible Sources of Nitrate

A decision process was developed to utilize all water-quality data to identify the possible sources of nitrate in the wells with elevated nitrate concentrations selected by ODAFF. First, nitrogen isotope ratios were used to define source categories as animal, mixed animal and fertilizer, or fertilizer (Kendall, 1998). Second, wastewater organic compound detections, nitrogen-isotope ratios, fecal coliform bacteria detections, and ribotyping were used to refine the identification of possible sources of nitrate. Additional evidence provided by wastewater organic compound data and ribotyping can, in some cases, specifically indicate the animal source. Detections of three or more wastewater organic compounds that are indicators of animal sources and fecal coliform bacteria provided additional evidence of an animal source.

Land Use

Agricultural land use in the study areas prior to the construction of the swine LMFOs was evaluated. Digital NLCD coverages of land-use information within the study areas were available from October 1988 to March 1992. The NLCD is based on 30-meter Landsat thematic map data acquired through the Multi-Resolution Land Characterization Consortium, and provide a detailed identification of the land use. Land uses included cultivated cropland, pasture, range land, and farmsteads. Percentage of land use within 500-meter of the sampled wells were determined with geographic information system software and land-use information from the NLCD (U.S. Geological Survey, 2000).

Geographic information system ARC/INFO software was used to create areas, referred to as well areas, within a 500-meter radius for each of the 79 monitoring wells. A general land-use data set was compiled for the LMFO areas of study (table 3). Land-use information for each well area was clipped out from the larger land-use data set to create the well area. The number of cells in a given land-use category were divided by the total number of cells in the well area multiplied by 100 to yield the percentage of land use.

Five major land-use categories were determined (table 3) and, on average, those five categories account for about 99 percent of all land-use categories in the well areas. Cultivated cropland and grassland were the major land uses in the well areas prior to the construction of the LMFOs. Cultivated cropland (agriculture and row crops) on average accounted for about 57

Table 2. Constituents analyzed for this study, analyzing laboratory, laboratory method, and method references

[m-FC, media-fecal coliform; °C, degrees Celsius; --, not available]

Constituents	Analyzing laboratory	Laboratory method	Method references
Fecal coliform	USGS; Oklahoma City and Woodward, Oklahoma	Membrane filtration, m-FC media, 24 hours at 44.5°C	Myers and Sylvester (1997)
Bacterial source tracking	Institute of Environmental Health, Seattle, Washington	Ribotype-gel electrophoresis	Schlottmann and others (2000)
Dissolved anions	USEPA, R.S. Kerr Research Laboratory, Ada, Oklahoma		--
Dissolved cations and trace elements	Mantech, Ada, Oklahoma	Inductively coupled plasma-optical emission spectrometry	
Nutrients (USGS schedule 2752)	USGS National Water-Quality Laboratory, Lakewood, Colorado	Colorimetric automated-segmented flow	Farrar (1997)
Stable isotopes of nitrogen	Boston University Stable Isotope Laboratory, Boston, Massachusetts	Nitrogen reduction gas chromatography/mass spectroscopy	Rittenberg (1948), Holmes and others (1998), Sigman and others (1997)
Wastewater organic compounds (USGS lab code 8033)	USGS National Water-Quality Laboratory, Lakewood, Colorado	Solid phase extraction capillary column gas chromatography/mass spectroscopy	Brown and others (1999)

percent of the land use. Grassland accounted for an average of about 30 percent. The average amount of land use for the remaining three categories - water, forest, and shrub land - accounted for about 11 percent.

Water Quality and Chemical and Microbiological Techniques

Use of water-quality sampling results to determine possible sources of the nitrate are discussed in this section. Sources are defined as animal, mixed animal and fertilizer, and fertilizer by analyses of nutrients, nitrogen isotopes, wastewater organic compounds, bacteria, and ribotyping. Wastewater organic compounds also were used to identify a LMFO waste source.

Quality control samples indicated the water-quality analytical results were acceptable, the field methods were effective, and neither the equipment nor setting biased the samples. The nutrient blank samples had two detections of ammonia and one for nitrate. Ammonia concentrations in the well samples were generally less than the analytical reporting level and did not exceed 0.5 milligram per liter. The concentrations of blank ammonia samples would not adversely affect the ammonia results for the well samples. The blank detections for ammonia were one to six orders of magnitude less in concentrations than the lagoon samples. The nitrate concentration in the blank sample was two to three orders of magnitude less than the concentration detected in the well samples. The analytical reporting levels were increased for caffeine, phenol, and N,N-diethyl-meta-toluamide (DEET) due to detections of contamination of these compounds in the field blanks. Caffeine and DEET were used by field personnel during the sampling, and, despite the precautions taken by field and lab personnel, some contamination did occur. As a result of the contamination in the field blanks, the analytical reporting level for environmental samples was increased to twice the concentration of the maximum concentration measured in the field blank to minimize erroneous positive detections. This screen reduced the number of caffeine detections, removed most reported detections for phenol, and removed all reported detections for DEET.

No substantial differences between the analytical results of the environmental samples and the replicate samples for nutrient and wastewater organic compound analyses were noted. One wastewater organic compound analysis contained several detections at concentrations less than the analytical reporting level in the replicate sample, although no detections were reported in the environmental sample. These detections may be

Table 3. Percentage land use from 1988 to 1992 within a 500-meter radius of monitoring wells located at swine licensed-managed feeding operations in Oklahoma

Well number	Site identification number	Aquifer type	Percentage land use					Percent of total land use reported[1]
			Water	Forest	Shrub land	Grass-land	Culti-vated crop-land	
1	343756096364401	Minor Bedrock	0.1	15.8	0.5	17.6	66.1	100.0
2	343756096364403	Minor Bedrock	0.1	21.1	0.6	24.8	53.5	100.0
3	351857098004301	Minor Bedrock	1.7	2.1	3.8	42.7	49.7	100.0
4	351857098004302	Minor Bedrock	2.8	3.7	5.1	40.3	48.2	100.0
5	351857098004303	Minor Bedrock	2.8	3.8	5.5	43.0	44.9	100.0
6	353922098503101	Minor Bedrock	0.0	0.0	0.0	9.1	90.9	100.0
7	360134097591401	Alluvial/Terrace	0.2	21.6	1.5	30.9	45.7	100.0
8	360135097591801	Alluvial/Terrace	0.2	15.5	0.9	31.1	52.2	100.0
9	360146098013602	Alluvial/Terrace	7.9	24.0	18.9	49.0	0.2	100.0
10	360212097583601	Alluvial/Terrace	0.9	2.5	0.9	9.6	85.3	99.3
11	360317098015301	Alluvial/Terrace	0.0	14.6	10.7	44.4	30.2	100.0
12	360317098015302	Alluvial/Terrace	0.0	19.1	11.6	34.3	35.0	100.0
13	360317098015303	Alluvial/Terrace	0.0	9.3	12.2	49.8	28.7	100.0
14	360325098010701	Alluvial/Terrace	0.1	10.8	3.4	19.0	66.6	100.0
15	360339098170301	Minor Bedrock	0.8	0.0	0.0	11.2	88.0	100.0
16	360339098170701	Minor Bedrock	0.0	0.0	0.0	9.1	90.9	100.0
17	360416098013601	Alluvial/Terrace	0.0	0.0	0.0	6.2	93.8	100.0
18	360521098022501	Alluvial/Terrace	0.0	0.5	0.3	5.9	93.3	100.0
19	360521098022502	Alluvial/Terrace	0.0	0.5	0.3	5.5	93.7	100.0
20	360618098024501	Alluvial/Terrace	0.0	0.0	0.0	6.7	93.3	100.0
21	360618098024502	Alluvial/Terrace	0.0	0.0	0.0	4.6	95.4	100.0
22	360634098030901	Alluvial/Terrace	0.0	0.0	0.0	0.3	99.7	100.0
23	360634098030902	Alluvial/Terrace	0.0	0.0	0.0	0.3	99.7	100.0
24	360635098032901	Alluvial/Terrace	0.0	0.0	0.0	5.2	94.8	100.0
25	360729098060901	Alluvial/Terrace	3.9	3.7	0.0	9.0	83.4	100.0
26	360735098060801	Alluvial/Terrace	4.6	4.4	0.2	7.4	83.4	100.0
27	361028098440701	Alluvial/Terrace	0.0	1.2	6.5	32.1	60.3	100.0
28	361028098440702	Alluvial/Terrace	0.0	2.3	1.8	26.8	68.5	99.4

Table 3. Percentage land use from 1988 to 1992 within a 500-meter radius of monitoring wells located at swine licensed-managed feeding operations in Oklahoma—Continued.

Well number	Site identification number	Aquifer type	Percentage land use					Percent of total land use reported[1]
			Water	Forest	Shrub land	Grass-land	Culti-vated crop-land	
29	361028098440704	Alluvial/Terrace	0.0	1.4	0.1	33.4	64.5	99.4
30	361028098440705	Alluvial/Terrace	0.0	23.2	10.4	42.3	24.0	100.0
31	361028098440706	Alluvial/Terrace	0.0	13.4	4.7	37.1	44.8	100.0
32	361115098504701	Alluvial/Terrace	0.0	4.3	7.7	40.3	47.5	99.8
33	361116098463001	Alluvial/Terrace	0.0	24.1	10.7	53.0	12.3	100.0
34	361117098504301	Alluvial/Terrace	0.0	4.9	8.4	29.8	56.6	99.8
35	361118098463301	Alluvial/Terrace	0.0	25.9	10.8	50.5	12.8	100.0
36	361121098504501	Alluvial/Terrace	0.0	3.7	5.5	28.9	61.6	99.8
37	361122098462801	Alluvial/Terrace	0.0	15.2	6.2	65.0	13.6	100.0
38	361122098493901	Alluvial/Terrace	0.0	8.3	18.4	42.2	31.1	100.0
39	361133098485701	Alluvial/Terrace	0.0	3.7	19.7	39.7	36.6	99.8
40	361136098374401	Alluvial/Terrace	0.0	15.4	0.9	27.8	55.9	100.0
41	361139098374801	Alluvial/Terrace	0.0	16.5	3.1	18.6	61.8	100.0
42	361139098485901	Alluvial/Terrace	0.0	2.4	14.8	30.2	52.5	99.9
43	361143098374801	Alluvial/Terrace	0.0	17.9	4.5	16.4	61.1	100.0
44	361146098504501	Alluvial/Terrace	0.0	27.1	10.3	27.7	34.9	100.0
45	361152098504401	Alluvial/Terrace	0.0	27.2	11.7	39.9	21.2	100.0
46	361157098494101	Alluvial/Terrace	0.0	2.1	3.2	10.6	84.1	100.0
47	361203098494301	Alluvial/Terrace	0.0	0.5	2.0	10.4	87.2	100.0
48	361210098112201	Alluvial/Terrace	0.0	30.3	11.6	31.4	26.7	100.0
49	361215098491301	Alluvial/Terrace	0.0	13.6	2.9	20.5	63.0	100.0
50	361215098491501	Alluvial/Terrace	0.0	13.7	2.8	15.8	67.8	100.0
51	361240098494201	Alluvial/Terrace	0.0	11.8	0.6	15.6	71.9	99.9
52	361240098494401	Alluvial/Terrace	0.0	12.0	0.6	17.3	70.0	99.9
53	361245098494401	Alluvial/Terrace	0.0	13.0	0.7	27.6	58.5	99.9
54	362100099050301	Alluvial/Terrace	0.0	0.0	5.9	93.8	0.0	99.7
55	362118099050301	Alluvial/Terrace	0.0	0.0	7.3	92.7	0.0	100.0
56	362136099041201	Alluvial/Terrace	0.0	23.2	13.9	62.8	0.1	100.0
57	362136099051001	Alluvial/Terrace	0.0	0.6	12.2	86.9	0.3	100.0
58	363153101185001	Major Bedrock	0.0	0.0	0.0	25.7	70.2	95.9

Table 3. Percentage land use from 1988 to 1992 within a 500-meter radius of monitoring wells located at swine licensed-managed feeding operations in Oklahoma—Continued.

Well number	Site identification number	Aquifer type	Percentage land use					Percent of total land use reported[1]
			Water	Forest	Shrub land	Grass-land	Culti-vated crop-land	
59	363601101241301	Major Bedrock	0.0	7.9	1.7	35.2	55.1	100.0
60	363602101244501	Major Bedrock	0.0	3.9	0.7	7.5	87.9	100.0
61	364150101071901	Major Bedrock	0.0	0.0	40.7	22.7	36.6	100.0
62	364500101155301	Major Bedrock	0.0	0.0	9.2	35.6	54.8	99.7
63	364722100545501	Major Bedrock	1.2	0.0	0.0	21.3	77.6	100.0
64	364728100563501	Major Bedrock	0.0	0.0	1.4	24.2	72.8	98.4
65	365006100451001	Major Bedrock	0.0	0.0	0.9	98.0	0.5	99.4
66	365024100450701	Major Bedrock	0.0	0.0	0.1	82.7	17.2	100.0
67	365919099490901	Major Bedrock	0.0	0.0	0.0	6.7	92.6	99.3
68	365938099490901	Major Bedrock	0.0	0.0	0.0	1.5	98.0	99.5
69	365941099475101	Major Bedrock	0.0	0.0	0.0	52.0	47.9	99.9
70	365941099490701	Major Bedrock	0.0	0.0	0.0	3.1	96.5	99.7
71	365942099473701	Major Bedrock	0.0	0.0	0.0	53.1	45.6	98.7
72	365944099473401	Major Bedrock	0.0	0.0	0.0	49.5	49.2	98.7
73	365945099474901	Major Bedrock	0.0	0.0	0.0	49.2	50.5	99.7
74	365945099491401	Major Bedrock	0.0	0.0	0.2	13.9	85.5	99.7
75	365947099492101	Major Bedrock	0.0	0.0	0.6	22.3	75.8	98.6
76	365948099491701	Major Bedrock	0.0	0.0	0.6	22.1	75.5	98.2
77	365954099473701	Major Bedrock	0.0	0.0	0.0	43.8	51.2	94.9
78	370002099484101	Major Bedrock	0.0	0.0	0.1	25.6	73.0	98.7
79	370003099483501	Major Bedrock	0.0	0.0	0.5	37.9	60.4	98.7
	Average percent land use		0.4	6.9	4.5	30.6	57.4	99.7

[1]Land-use percentages may not equal 100 percent due to minor land uses that were not included in the analysis or data rounding.

an artifact of the sampling method and low analytical detection levels.

Water Properties

Water properties are general indicators of water quality. The water properties measured were specific conductance, pH, temperature, and dissolved oxygen (table 4). Water properties were measured during purging of the wells at 5-minute intervals prior to sampling. Water property measurements were made at six of eight lagoons and 79 wells.

Specific conductance is a measure of the electrical conductivity of water and can provide an indirect estimate of the dissolved minerals. The median specific conductance of the lagoons was about 10 times greater than the median specific conductance of the monitoring wells (table 5).

The concentration of dissolved oxygen controls the solubility or speciation of ions such as nitrate and ammonia. When the concentration of dissolved oxygen is very low (anaerobic conditions) ammonia is stable and nitrate is reduced to nitrogen gas. Under aerobic conditions, ammonia is converted to nitrate and nitrate is stable. The median dissolved oxygen concentrations in the well samples were, in some cases, about one order of magnitude greater than in the lagoon samples (table 5). Dissolved oxygen measured in the lagoons may be an artifact of algae and other plants that produce oxygen during the day and cease activity in the absence of daylight. Precise measurements of dissolved oxygen concentrations in the lagoons could not be made because of this process.

Major Ions and Trace Elements

Concentrations of dissolved major ions (Appendix 1) and trace elements (Appendix 2) from samples collected from 10 lagoons and 76 of the 79 wells were analyzed by the USEPA, R.S. Kerr Research Laboratory and Mantech in Ada, Oklahoma. A similarity in concentrations of some constituents between the lagoons and the wells would allow major ions to be used as an indicator of LMFO waste. Major ions, for this study, did not provide any substantial evidence of LMFO waste in ground water, but wells may not have been located to intercept leakage from the lagoons.

Concentrations of calcium, magnesium, and sulfate are greater in water from wells than in water from lagoons, and concentrations of potassium, sodium, and chloride are greater in water from lagoons (table 6). Calcium, magnesium, potassium, and sodium are not conservative, therefore, are not effective environmental tracers. Chloride is generally conservative, and in sufficient concentrations, could be used as an environmental tracer indicating LMFO waste. Chloride is naturally occurring in places and sufficient information on the well construction, the geology, and the hydrology of the site is needed to use chloride at concentrations greater than background concentrations of the ground water to identify LMFO waste. Potassium and sodium, though not conservative, may be an indicator of LMFO waste if measured at substantially greater concentrations than the background concentrations of ground water.

Concentrations of most dissolved trace elements were less than the analytical reporting level. The analytical reporting level ranged from <0.002 to <0.35 milligram per liter in samples from lagoons and wells. Reducing conditions of a lagoon, the abundance of organic material, and sulfur may limit solubility of trace elements in lagoons by complexation and precipitation.

Boron, barium, and strontium were the most detected trace elements in the well samples. These trace elements would be difficult to use as an indicator of LMFO waste due to the natural variability in ground water.

Nutrients

Nitrogen is one of the most abundant elements and is essential for plant and animal growth. The major sources of nitrogen in ground water are precipitation, oxidation of soil organic matter, fertilizer, animal manure, and sewage effluent. Fertilizers and animal waste, including human, have been associated with nitrate contamination in the United States (Mueller and Helsel, 1996; U.S. Geological Survey, 1999). Biochemical processes in soil convert nitrogen gas in the atmosphere to nitrite and nitrate. Biochemical processes in treatment facilities and soil convert ammonia and organic nitrogen, the reduced forms of nitrogen found in fertilizer and animal waste, to nitrite and nitrate.

Nitrate concentrations greater than 3.0 milligrams per liter in ground water were considered to be the result of human influence (fertilizer applications on row crops, cattle grazing, or animal waste) based on work by Mueller and Helsel (1996) and Madison and Brunett (1984). Madison and Brunett (1984) used existing data from 87,000 wells collected over 25 years to determine some general concentrations of nitrate in ground water to assess the effect of human activities. Nitrate at concentrations less than 0.2 milligram per liter were considered to be natural background, and concentrations from 0.21 to 3.0 milligrams per liter were considered to be transitional between background and possible human influence. Background concentration of ammonia is estimated by Mueller and Helsel (1996) to be less than 0.1 milligram per liter.

Nitrate concentration in water samples from the 79 wells ranged from 1.4 to 96.8 milligrams per liter; 65 of the samples had concentrations exceeding 10 milligrams per liter (table 7). Samples from 14 wells had nitrate concentrations less than 10 milligrams per liter and one sample was less than 2.0 milligrams per liter. The concentrations of nitrate in samples from all 79 wells were reported previously by the ODAFF to exceed 10 milligrams per liter, and sampling results from this study also indicate a possible human influence. The differences in concentrations between the two sampling events reflect undetermined causes for nitrate variability, such as contributions from a contaminant source, fluctuations in ground-water flow conditions because of recharge or discharge, biochemical processes con-

Table 4. Water properties and fecal coliform bacteria measured in samples from lagoons and monitoring wells at swine licensed-managed feeding operations in Oklahoma, 2001

[L, lagoon; yyyymmdd, year, month, day; µS/cm, microsiemens per centimeter at 25 degrees Celsius; mg/L, milligram per liter; --, no data; col/100 mL, colony per 100 milliliters; E, estimated; k, non-ideal colony count]

Lagoon and well numbers	Site identification number	Date (yyyymmdd)	Time	Specific conductance (µS/cm)	pH, whole water standard	Temperature, degrees Celsius	Oxygen, dissolved (mg/L)	Coliform, fecal, col/100 mL
L1	343756096364402	20010720	1000	8,870	7.7	30.6	0.1	E140,000k
L2	351857098004304	20010615	1100	--	--	--	--	22,000
L3	360635098032902	20010615	1200	--	--	--	--	E213,000k
L4	361028098440703	20010716	1300	948	7.2	18	3.8	E140,000k
L7	362118099050001	20010712	1200	8,520	8.6	27	1.9	E16k
L8	363605101241301	20010711	0800	7,520	8	24.5	0.3	1000
L9	365009100450901	20010531	1300	7,160	8.3	24.5	1	560
L10	365956099473701	20010717	1300	18,300	7.6	28.5	0.2	E100k
1	343756096364401	20010720	1130	859	7.1	21	3.4	E63
2	343756096364403	20010720	1400	1,870	7.4	24.7	5	E26k
3	351857098004301	20010614	900	1,270	7.1	16.7	5.9	0
4	351857098004302	20010615	1000	1,310	7.3	15.7	5.5	0
5	351857098004303	20010614	1200	1,340	7.1	15.5	7.8	<1
6	353922098503101	20010618	1100	3,060	7.2	16.1	6.4	9,000
7	360134097591401	20010530	1400	348	6.8	18.6	5	0
8	360135097591801	20010529	1000	535	7.3	17.5	2.7	0
9	360146098013602	20010703	1100	937	6.8	17.3	5	0
10	360212097583601	20010702	1200	409	6.8	17.2	4.6	0
11	360317098015301	20010619	1300	2,090	7	17.2	1.6	0
12	360317098015302	20010620	0900	638	7.2	17.8	5.5	0
13	360317098015303	20010620	1200	1,290	7.1	17.8	1.7	10,000
14	360325098010701	20010620	1400	516	7.6	18.5	7.8	0
15	360339098170301	20010517	1300	955	7.4	16	7.3	32,000
16	360339098170701	20010517	1500	680	7.6	15.2	4.2	53,000
17	360416098013601	20010703	0900	948	7.2	17.4	3.6	0
18	360521098022501	20010626	1000	539	6.8	17	2.3	E2k
19	360521098022502	20010626	1200	966	6.6	16.5	4.3	0
20	360618098024501	20010619	0900	164	6.3	17.6	1.7	E5k
21	360618098024502	20010531	1300	714	6.2	15.5	7.2	0
22	360634098030901	20010625	1400	957	7.5	16.6	1.2	0
23	360634098030902	20010702	1000	811	7.3	23.8	2.5	0
24	360635098032901	20010625	1100	878	6.3	16.4	1.1	0
25	360729098060901	20010529	1400	644	7.1	17.7	3.5	7,000
26	360735098060801	20010529	1200	875	7.2	15.7	6.6	50,000
27	361028098440701	20010716	1200	948	7.2	18	3.8	0

Table 4. Water properties and fecal coliform bacteria measured in samples from lagoons and monitoring wells at swine licensed-managed feeding operations in Oklahoma, 2001—Continued.

[L, lagoon; yyyymmdd, year, month, day; µS/cm, microsiemens per centimeter at 25 degrees Celsius; mg/L, milligram per liter; --, no data; col/100 mL, colony per 100 milliliters; E, estimated; k, non-ideal colony count]

Lagoon and well numbers	Site identification number	Date (yyyymmdd)	Time	Specific conductance (µS/cm)	pH, whole water standard	Temperature, degrees Celsius	Oxygen, dissolved (mg/L)	Coliform, fecal, col/100 mL
28	361028098440702	20010716	1400	567	7.1	17.6	6.9	0
29	361028098440704	20010716	1700	523	6.9	17.7	5.3	0
30	361028098440705	20010717	0900	387	7.1	18	9.2	0
31	361028098440706	20010717	1200	472	7.1	16.9	9.1	0
32	361115098504701	20010802	1100	530	6.5	17.5	8.4	0
33	361116098463001	20010524	1500	680	7	17.5	4.8	0
34	361117098504301	20010802	1300	489	6.8	17.5	8.3	0
35	361118098463301	20010524	1000	523	7.1	17	7.2	0
36	361121098504501	20010807	0900	415	7.1	17	8.6	0
37	361122098462801	20010611	1300	564	7	17.5	5.4	0
38	361122098493901	20010821	0900	935	6.7	16.5	8.4	0
39	361133098485701	20010807	1000	914	6.6	17.5	5.3	0
40	361136098374401	20010731	1300	1,210	6.4	17.5	4.1	0
41	361139098374801	20010731	1100	1,320	6.5	17.5	5.4	0
42	361139098485901	20010807	1200	1,240	6.6	17	5.9	0
43	361143098374801	20010731	0900	554	6.7	17	7.8	0
44	361146098504501	20010801	1300	497	6.1	17	5.4	0
45	361152098504401	20010802	0900	700	6.3	17	5.8	0
46	361157098494101	20010607	1400	256	6.4	18	7	0
47	361203098494301	20010611	1100	313	6.8	17	7	0
48	361210098112201	20010808	1200	264	6.7	17.5	8.6	0
49	361215098491301	20010606	1000	491	6.7	17.5	7.5	160
50	361215098491501	20010606	1200	528	6.8	17.6	7	0
51	361240098494201	20010801	0900	408	6.3	17.5	8.2	0
52	361240098494401	20010607	0900	548	6.8	17	6.6	0
53	361245098494401	20010606	1400	500	6.8	17	6.6	0
54	362100099050301	20010628	1000	261	6.5	17	7.7	0
55	362118099050301	20010628	1300	278	7	16.5	7.7	0
56	362136099041201	20010626	1400	402	7.8	17	7.7	0
57	362136099051001	20010626	1000	347	6.8	17	7.5	0
58	363153101185001	20010710	1000	2,920	6.4	15.5	1.4	0
59	363601101241301	20010710	1700	1,050	7.7	15.5	5.4	0
60	363602101244501	20010710	1400	1,170	7.6	15.5	4.9	0
61	364150101071901	20010605	1500	616	7.6	16.5	6.8	0
62	364500101155301	20010605	1300	715	7.5	16.5	7.5	0
63	364722100545501	20010709	1400	2,680	6.7	16.5	9.9	0
64	364728100563501	20010709	1700	1,930	6.8	16.5	10.2	0

Table 4. Water properties and fecal coliform bacteria measured in samples from lagoons and monitoring wells at swine licensed-managed feeding operations in Oklahoma, 2001—Continued.

[L, lagoon; yyyymmdd, year, month, day; µS/cm, microsiemens per centimeter at 25 degrees Celsius; mg/L, milligram per liter; --, no data; col/100 mL, colony per 100 milliliters; E, estimated; k, non-ideal colony count]

Lagoon and well numbers	Site identification number	Date (yyyymmdd)	Time	Specific conduc-tance (µS/cm)	pH, whole water standard	Tempera-ture, degrees Celsius	Oxygen, dissolved (mg/L)	Coliform, fecal, col/100 mL
65	365006100451001	20010531	0900	803	7.6	17	5.8	0
66	365024100450701	20010530	1000	2,190	7.4	17	6.1	0
67	365919099490901	20010613	1000	2,180	7.3	16.8	6.3	0
68	365938099490901	20010613	1300	1,010	7.8	17.2	7.6	0
69	365941099475101	20010716	1300	1,160	7.5	17	9.2	E3k
70	365941099490701	20010613	1500	1,350	7.7	17.1	6.9	0
71	365942099473701	20010717	0900	1,270	7.3	17	6	0
72	365944099473401	20010717	1100	1,040	7.4	16.5	3.4	0
73	365945099474901	20010716	1100	1,220	7.5	17.5	8.6	0
74	365945099491401	20010614	1000	1,980	7.5	16.5	7.6	0
75	365947099492101	20010614	1200	1,120	7.5	15.8	7.3	0
76	365948099491701	20010716	1000	1,350	7.4	16.5	8.2	0
77	365954099473701	20010717	1200	817	7.7	17.5	7.7	0
78	370002099484101	20010612	1200	1,050	7.8	16.4	3	E39k
79	370003099483501	20010612	1400	1,690	7.5	16.6	6.4	0

Table 5. Minimum, maximum, and median of specific conductance, pH, temperature, and dissolved oxygen measured in samples from lagoons and monitoring wells at swine licensed-managed feeding operations in Oklahoma, 2001

[µS/cm, microsiemens per centimeter; °C, degrees Celsius; mg/L, milligrams per liter]

Water Property	Specific conductance (µS/cm)	pH	Temperature (°C)	Dissolved oxygen (mg/L)
Lagoons				
Minimum	948	7.2	18	0.1
Maximum	18,300	8.6	30	3.8
Median	8,020	7.8	26	0.6
Wells				
Minimum	164	6.1	15.2	1.1
Maximum	3,060	7.8	24.7	6.0
Median	817	6.4	17	6.4

Table 6. Descriptive statistics for major ions measured in samples from 10 lagoons and 76 of 79 monitoring wells at swine licensed-managed feeding operations in Oklahoma, 2001

[all concentrations in milligrams per liter]

Statistic	Calcium	Magnesium	Sodium	Potassium	Sulfate	Chloride
			Lagoons			
Mean	52	20	399	1,254.7	10	680
Median	49	12	242	961.2	5	417
Minimum	23	4	155	453.3	0.10	200
Maximum	109	56	1,473	2,587.3	41	2,460
			Wells			
Mean	78	30	75	2.4	96	72
Median	63	20	33	1.6	50	35
Minimum	12	4	6	0.3	<0.10	0.12
Maximum	389	189	368	9.7	1,490	436

trolling the concentration, temporal variability, and differences in sampling or laboratory procedures.

Total ammonia concentrations in samples from wells ranged from <0.1 to 1.7 milligrams per liter with a median of 0.17 milligram per liter. Total ammonia concentrations were less than the minimum reporting level of 0.1 milligram per liter in samples from 15 wells. Dissolved ammonia concentrations were less than the minimum reporting level of 0.04 milligram per liter in samples from 63 of the wells. Ammonia concentration exceeded 0.1 milligram per liter in samples from 5 of the 79 wells with a maximum concentration of 0.47 milligram per liter.

Dissolved phosphorous concentrations in samples from wells were two to four orders of magnitude less than concentrations in the lagoon samples. Orthophosphate phosphorous concentrations in samples from seven lagoons ranged in concentration from <0.02 to 105 milligrams per liter. Most orthophosphate phosphorous concentrations in samples from wells were less than 0.1 milligram per liter (table 7).

Nitrogen Isotopes

Nitrogen isotope ratios were used in this study to determine the general source of nitrates in ground water. Nitrogen isotopes of nitrate were analyzed in eight lagoons and 79 wells. The nitrogen isotopes of ammonia were analyzed in two lagoons and 43 wells. The analysis for the nitrogen isotope of ammonia was added later in the study, so the number of these analyses differ from the number of nitrogen isotope of nitrate analyses.

Nitrogen has two stable isotopes, ^{15}N, and the more abundant ^{14}N. The units used to report nitrogen isotopes ratios are expressed as delta (δ) values in parts per thousand, denoted as permil (‰), enrichments or depletions relative to a standard of known composition (atmospheric N_2). Equation 1 shows the computation to determine $\delta^{15}N$:

$$\delta^{15}N = \{\{(^{15}N/^{14}N)\text{ source}/(^{15}N/^{14}N)\text{ air}\}-1\} * 1000 \qquad (1)$$

where $^{15}N/^{14}N$ is the ratio of the heavier, less abundant isotope to the lighter isotope;
source is the sample; and
air is the internationally accepted standard gas, atmospheric N_2 (Kendall and Aravena, 1999).

Nitrogen compounds are altered by chemical, biological, and physical processes that may result in the preferential enrichment or depletion of one isotope relative to the other. Isotopic enrichment or depletion is referred to as fractionation. Sufficient fractionation may result in distinct isotopic compositions that allows identification of the source of nitrate in the environment. Kendall (1998) and Kendall and Aravena (1999) highlighted several case studies where nitrogen isotopes were used to determine the source and fate of nitrate in the environment. Specific studies were conducted using nitrogen isotopes to

Table 7. Nutrients in samples from eight lagoons and 79 monitoring wells at selected swine licensed-managed feeding operations in Oklahoma, 2001

[L, lagoon; all concentrations in milligrams per liter; <, less than; E, estimated; --, no data]

Lagoon and well numbers	Site identification number	Nitrogen, ammonia, dissolved	Nitrogen, ammonia, total	Nitrite+nitrate as nitrogen, dissolved	Nitrite, dissolved	Phosphorous, dissolved	Phosphorous, orthophos-phate, dissolved
L1	343756096364402	492	590	0.093	0.06	34.2	31.6
L2	351857098004304	998	1,000	0.136	0.183	107	105
L3	360635098032902	291	270	1.99	0.521	8.59	8.89
L4	361028098440703	<4.1	520	0.063	0.032	<0.006	23.4
L7	362118099050001	27.8	69	0.047	0.041	20.1	15.6
L8	363605101241301	435	410	E0.03	0.026	0.157	<3.6
L9	365009100450901	--	550	E0.032	0.041	90.2	--
L10	365956099473701	0.967	2,300	E0.133	0.069	24	<0.02
1	343756096364401	E0.039	0.15	11.5	E0.004	0.009	<0.02
2	343756096364403	<0.04	0.17	4.17	<0.006	0.033	0.027
3	351857098004301	<0.04	E0.08	56.5	<0.006	0.013	<0.02
4	351857098004302	E0.029	0.2	31	E0.005	0.013	0.096
5	351857098004303	<0.04	0.26	24	E0.003	0.018	E0.009
6	353922098503101	0.061	0.45	36.6	0.006	0.016	0.027
7	360134097591401	<0.04	0.13	17.9	<0.006	0.049	E0.012
8	360135097591801	<0.04	0.17	41.5	E0.003	0.039	0.025
9	360146098013602	0.042	0.1	71.7	0.011	0.031	0.025
10	360212097583601	<0.04	<0.1	5.04	<0.006	0.023	0.019
11	360317098015301	E0.034	0.28	18.2	0.009	0.027	0.025
12	360317098015302	<0.04	E0.07	13.1	<0.006	0.07	0.06
13	360317098015303	<0.04	0.16	9.64	<0.006	0.087	0.076
14	360325098010701	E0.031	E0.06	13.2	<0.006	0.048	0.039
15	360339098170301	E0.024	0.11	96.8	E0.003	0.008	<0.018
16	360339098170701	E0.028	0.26	14.8	<0.006	0.009	<0.018
17	360416098013601	E0.039	0.13	20.1	0.008	0.017	E0.013
18	360521098022501	<0.04	0.19	16.2	E<0.006	0.006	<0.02
19	360521098022502	<0.04	0.15	21.6	0.277	0.01	<0.02

Table 7. Nutrients in samples from eight lagoons and 79 monitoring wells at selected swine licensed-managed feeding operations in Oklahoma, 2001—Continued.

[L, lagoon; all concentrations in milligrams per liter; <, less than; E, estimated; --, no data]

Lagoon and well numbers	Site identification number	Nitrogen, ammonia, dissolved	Nitrogen, ammonia, total	Nitrite+nitrate as nitrogen, dissolved	Nitrite, dissolved	Phosphorous, dissolved	Phosphorous, orthophos-phate, dissolved
20	360618098024501	0.47	0.17	12.3	0.016	0.018	0.126
21	360618098024502	<0.04	E0.07	15.9	<0.006	0.013	<0.02
22	360634098030901	E0.025	0.12	5.03	0.017	0.048	0.1
23	360634098030902	<0.04	<0.1	4.1	E0.004	0.139	0.126
24	360635098032901	0.083	0.4	19.8	0.007	0.021	E0.009
25	360729098060901	<0.04	E0.09	13.3	E0.003	0.053	0.036
26	360735098060801	E0.021	0.17	36.9	<0.006	0.092	0.022
27	361028098440701	<0.04	0.27	27.2	E0.005	0.468	0.46
28	361028098440702	<0.04	0.17	14.2	E0.004	0.027	0.026
29	361028098440704	E0.022	0.12	15.9	E0.004	0.062	0.055
30	361028098440705	<0.04	E0.06	12.7	E0.004	0.102	0.092
31	361028098440706	E0.034	E0.08	13	E0.003	0.065	0.062
32	361115098504701	<0.04	0.14	17.6	<0.006	0.145	0.132
33	361116098463001	E0.024	E0.07	11.4	<0.006	0.091	0.052
34	361117098504301	<0.04	0.13	10.2	<0.006	0.111	0.099
35	361118098463301	0.082	E0.1	1.4	0.037	0.158	0.117
36	361121098504501	E0.021	0.11	9.85	<0.006	0.112	0.11
37	361122098462801	<0.04	E0.07	8.11	<0.008	0.135	0.119
38	361122098493901	E0.024	0.34	28.9	<0.006	0.033	0.03
39	361133098485701	E0.03	0.26	10.9	<0.006	0.124	0.117
40	361136098374401	<0.04	0.27	39.9	<0.006	0.115	0.111
41	361139098374801	<0.04	0.23	21.4	<0.006	0.079	0.061
42	361139098485901	E0.038	0.41	12.4	<0.006	0.179	0.168
43	361143098374801	E0.021	0.21	19.7	<0.006	0.085	0.074
44	361146098504501	<0.04	0.17	17.5	<0.006	0.106	0.1
45	361152098504401	0.063	0.18	23.1	<0.006	0.11	0.105
46	361157098494101	<0.04	<0.1	15.4	<0.008	0.065	0.054
47	361203098494301	<0.04	0.1	7.54	<0.008	0.089	0.073
48	361210098112201	E0.021	E0.05	18.1	<0.006	0.017	0.02

Table 7. Nutrients in samples from eight lagoons and 79 monitoring wells at selected swine licensed-managed feeding operations in Oklahoma, 2001—Continued.

[L, lagoon; all concentrations in milligrams per liter; <, less than; E, estimated; --, no data]

Lagoon and well numbers	Site identification number	Nitrogen, ammonia, dissolved	Nitrogen, ammonia, total	Nitrite+nitrate as nitrogen, dissolved	Nitrite, dissolved	Phosphorous, dissolved	Phosphorous, orthophosphate, dissolved
49	361215098491301	0.162	0.11	9.34	<0.12	0.077	<0.36
50	361215098491501	0.087	0.14	13.1	E0.061	0.104	<0.36
51	361240098494201	<0.04	E0.07	24.5	<0.008	0.085	0.071
52	361240098494401	<0.04	0.1	12.4	<0.008	0.102	0.087
53	361245098494401	<0.04	0.17	9.95	<0.006	0.126	0.103
54	362100099050301	0.081	E0.08	14.7	0.01	0.122	0.132
55	362118099050301	<0.04	<0.1	8.22	0.009	0.116	0.105
56	362136099041201	<0.04	E0.07	12.4	<0.006	0.011	<0.02
57	362136099051001	0.082	E0.08	10.1	0.056	0.449	0.408
58	363153101185001	0.088	0.23	41.6	<0.006	<0.006	<0.02
59	363601101241301	<0.04	0.28	43.5	<0.006	0.009	<0.02
60	363602101244501	E0.034	1.7	22.3	1.03	0.006	<0.02
61	364150101071901	0.136	0.18	16.2	<0.12	0.025	<0.36
62	364500101155301	0.06	0.17	10.6	<0.12	0.022	<0.36
63	364722100545501	E0.034	0.65	35.4	<0.006	0.022	0.02
64	364728100563501	0.083	0.7	30.5	<0.006	0.018	<0.02
65	365006100451001	0.119	0.12	8.59	<0.006	0.009	<0.02
66	365024100450701	0.421	0.44	37.4	<0.006	0.044	E0.098
67	365919099490901	<0.04	0.28	24	E0.003	0.048	0.025
68	365938099490901	<0.04	0.28	41	<0.006	0.108	0.029
69	365941099475101	<0.04	0.33	10.9	E0.004	0.025	E0.017
70	365941099490701	<0.04	0.35	12.6	<0.006	0.111	0.044
71	365942099473701	<0.04	0.18	E3.37	E0.003	0.04	0.038
72	365944099473401	<0.04	0.18	17.1	E0.004	0.03	0.027
73	365945099474901	<0.04	0.3	12.2	E0.005	0.188	0.021
74	365945099491401	<0.04	0.32	33.8	<0.006	0.077	E0.017
75	365947099492101	<0.04	0.17	39.5	<0.006	0.031	0.024
76	365948099491701	<0.04	0.18	47.3	<0.006	0.018	E0.011
77	365954099473701	<0.04	0.15	26.9	<0.006	0.026	0.024

Table 7. Nutrients in samples from eight lagoons and 79 monitoring wells at selected swine licensed-managed feeding operations in Oklahoma, 2001—Continued.

[L, lagoon; all concentrations in milligrams per liter; <, less than; E, estimated; --, no data]

Lagoon and well numbers	Site identification number	Nitrogen, ammonia, dissolved	Nitrogen, ammonia, total	Nitrite+nitrate as nitrogen, dissolved	Nitrite, dissolved	Phosphorous, dissolved	Phosphorous, orthophosphate, dissolved
78	370002099484101	<0.04	0.16	38.6	<0.008	0.18	0.168
79	370003099483501	<0.04	0.2	48.8	<0.008	0.088	0.075

determine if animal waste, sewage, fertilizer, or soil nitrate was the source of nitrate in ground water (Kreitler, 1975 and 1979; Kreitler and Browning, 1983; and Wassenaar, 1995).

Natural soil $\delta^{15}N$ of nitrate (fig. 2) ranges from about 2 to 10‰ (Kendall and Aravena, 1999). Most synthetic fertilizers have $\delta^{15}N$ of nitrate in a range of –4 to +4‰ with a mean $\delta^{15}N$ of nitrate equal to +2.75± 0.76‰ and the mean $\delta^{15}N$ of ammonia equal to –0.9±1.88‰ (Kendall and Aravena, 1999). The $\delta^{15}N$ of nitrate in animal waste, including human, based on work by Kreitler (1975, 1979), ranges from about 10 to 20‰ (Kendall and Aravena, 1999). Nitrogen isotope ratio data from numerous sources are shown in figure 2 (Kendall and Aravena, 1999).

Precipitation and synthetic fertilizer have similar $\delta^{15}N$ because of the common atmospheric source of nitrogen. Nitrate in precipitation may have a greater range of $\delta^{15}N$ values, because of fractionation caused by industrial processes that emit nitrogen compounds into the atmosphere. Although nitrate from fertilizer and atmospheric nitrogen have similar $\delta^{15}N$ ranges, the nitrate concentrations in precipitation are negligible to the nitrate concentrations in water collected near LMFOs for this study and contribute considerably less than the potential nitrogen loading to ground water from agricultural activities. The median of annual mean seasonal concentrations for ammonia and nitrate in precipitation in northwest Oklahoma from 1984 through 2000 is 0.34 and 1.16 milligrams per liter (National Atmospheric Deposition Program, 2002).

The $\delta^{15}N$ of ammonia and the $\delta^{15}N$ of nitrate in the well samples were not the same. The relative percent difference between $\delta^{15}N$ of ammonia and $\delta^{15}N$ of nitrate ranged from 0.35 to 802 with a median of 114. An identical match would be 0 and the larger the number the greater the difference. The relative percent difference in $\delta^{15}N$ is due to the stability of each compound and the differences in equilibrium from differing rates of fractionation of ammonia and nitrate.

Three nitrate source categories — animal, mixed animal and fertilizer, and fertilizer — were selected for this study based upon the nitrate $\delta^{15}N$ measured in the ground-water samples. Nitrate in the water, for this study, is assumed to be primarily from an animal or fertilizer source. The mixed animal and fertilizer source indicates that the primary sources are a combination of animal waste and fertilizer. All ground-water samples with $\delta^{15}N$ less than 2‰, for this report, are designated as fertilizer source, values ranging from 2 to 8‰ are designated as mixed animal and fertilizer source, and greater than 8‰ are designated as an animal source.

Seven of the lagoons had $\delta^{15}N$ values of nitrate indicative of an animal source, with values ranging from +50.28 to –2.74‰ and a median of +33.78‰. The lagoon with the depleted $\delta^{15}N$ of nitrate may be due to the low nitrate concentration in the lagoon sample. These data indicate that enriched $\delta^{15}N$ of nitrate in ground water could be used to support LMFO waste as a source of nitrate. Most of the nitrate sources were either a mixed animal and fertilizer or animal source. Nineteen well samples had $\delta^{15}N$ values indicating a fertilizer source, 26 samples had $\delta^{15}N$ indicating an animal source, and 34 samples had $\delta^{15}N$ indicating a mixed animal and fertilizer source (fig. 3).

The distribution of nitrate concentrations $\delta^{15}N$ (nitrate-isotope ratio) derived source categories (fig. 3) indicates that the largest nitrate concentrations occur in the animal category. The Kruskal-Wallis rank sum test (Helsel and Hirsch, 1992) was calculated by S-Plus software (MathSoft, 1999) to determine if there was a significant difference in median nitrate concentrations among the three $\delta^{15}N$ derived source categories. The rank-sum test indicated that the nitrate concentrations of the animal category ($p=0.0046$) were significantly different than the mixed animal and fertilizer and the fertilizer categories.

Wastewater Organic Compounds

Wastewater organic compounds were analyzed in this study to identify possible sources of nitrate. Wastewater organic compound concentrations were analyzed in water samples from eight lagoons and from 78 wells. One well sample was not analyzed properly and was not resampled. The types of wastewater organic compounds analyzed typically occur in domestic and industrial wastewater and include compounds derived from: pesticides, hydrocarbons, industrial, animal waste, household use, and detergents (table 8).

Lagoon samples had the greatest number of wastewater organic compound detections, ranging from one to 16 with a median of 12 (table 9). Wastewater organic compounds were detected in 34 well samples, with the maximum number of six compounds detected per well (table 9).

The nine wastewater organic compounds from animal waste analyzed were 17-beta-estradiol, 3-beta-coprastanol, skatol, beta-sitosterol, beta-stigmastanol, cholesterol, equilenin, estrone, and ethynyl estradiol (table 8). Only 17-beta-estradiol and ethynyl estradiol were not detected.

It is possible that samples from wells having sufficient numbers of detections of wastewater organic compounds from animal waste have LMFO lagoon waste in the ground water. LMFO lagoon waste was analyzed because it is a potential source of nitrate, and results are listed in Appendix 3 and shown in figure 4. Although other types of wastewater organic compounds were detected in the LMFO lagoons, the origin of these compounds is unidentified. The wastewater organic compounds from animal waste are specific to animals and were the most frequently detected wastewater organic compounds in LMFO lagoon samples (fig. 4).

Samples from wells with animal designated as the source of nitrate by nitrogen isotope ratios also had the highest number of detections of wastewater organic compound detections from animal waste (fig. 4). Samples from wells that were designated as having fertilizer as the source of nitrate had the fewest detections of wastewater organic compounds from animal waste (fig. 4).

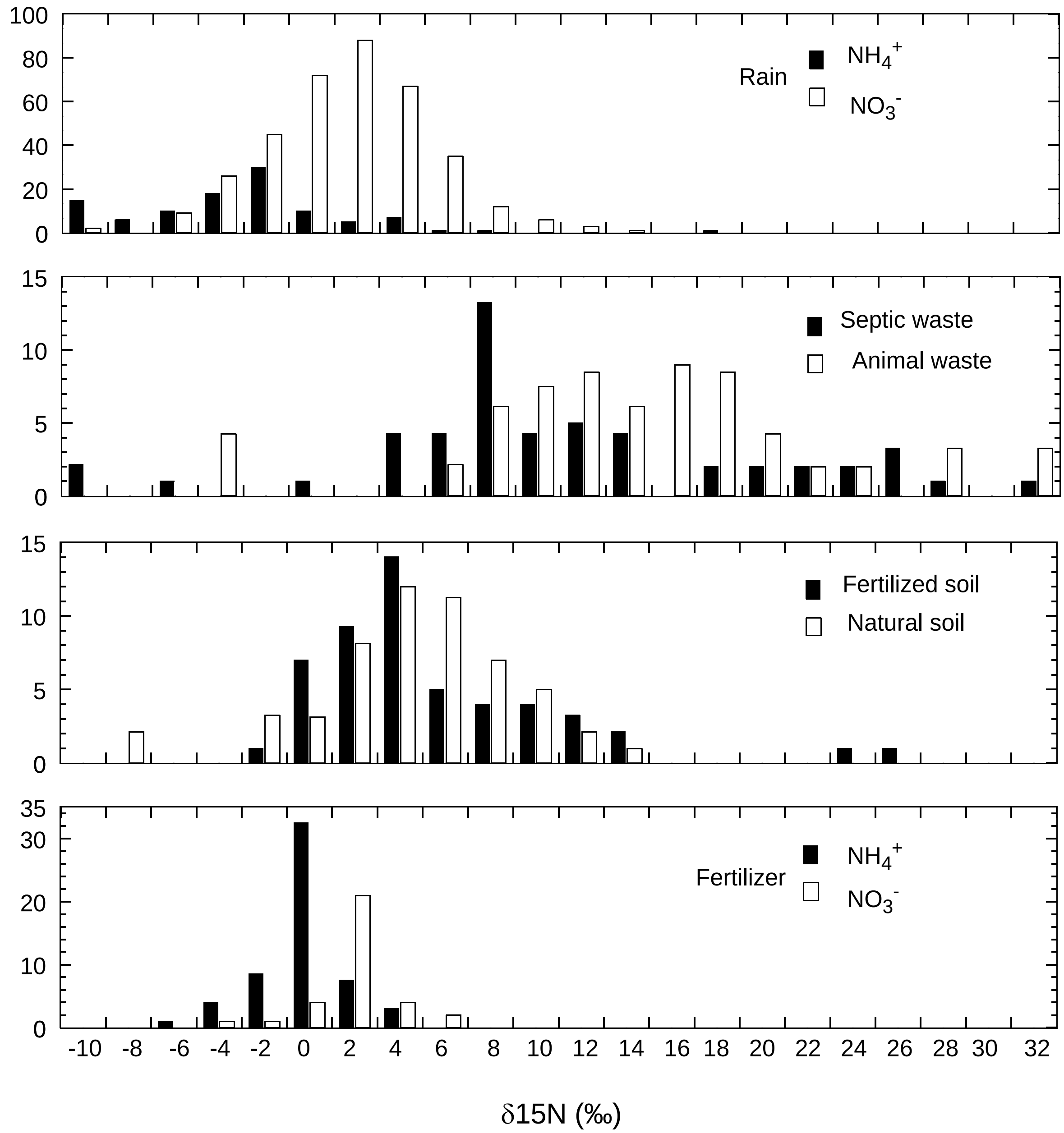

Figure 2. Distribution of d15N from major sources of nitrates in the hydrosphere (based on Kendall, 1998).

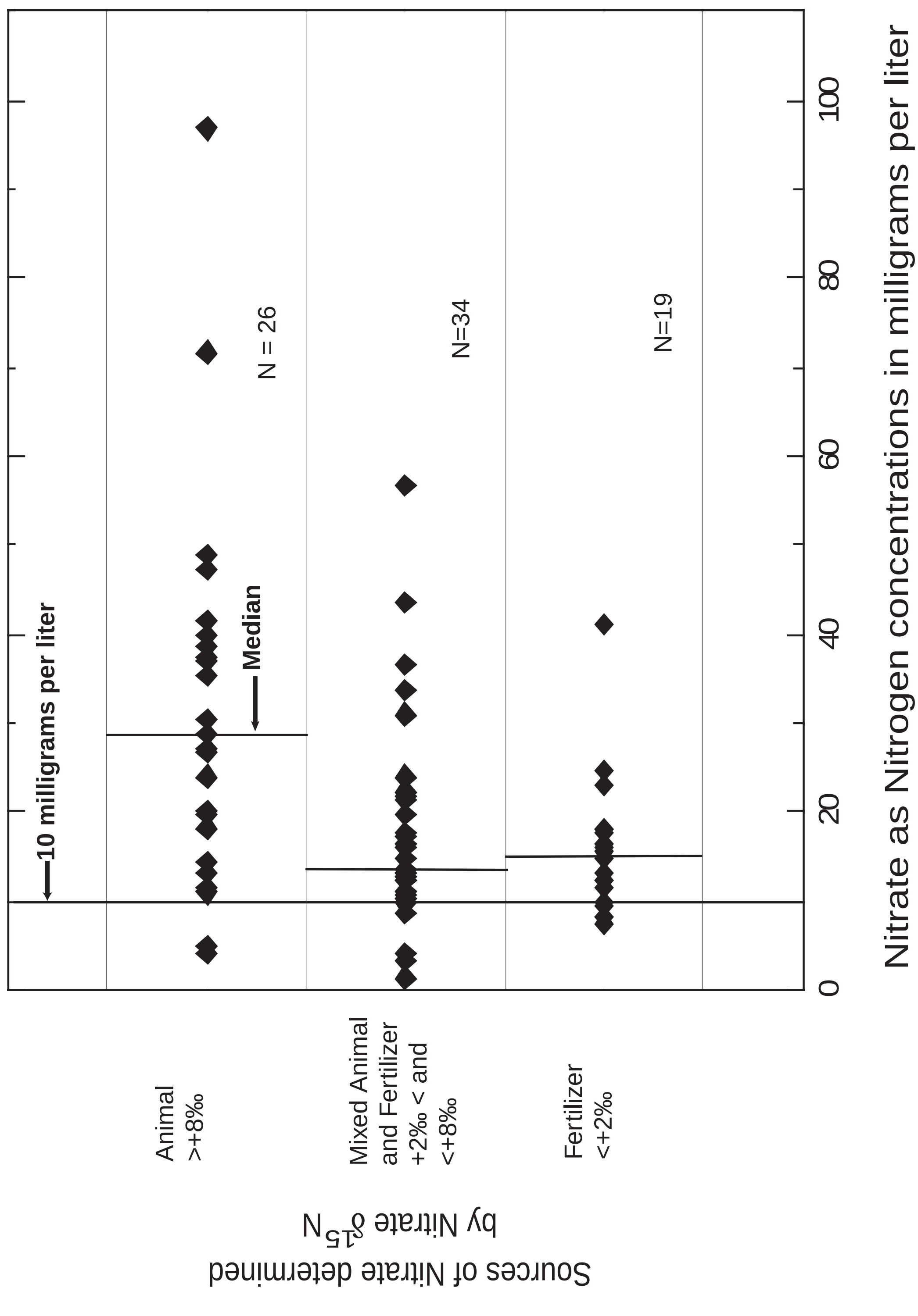

Figure 3. Nitrate concentrations in samples from 79 monitoring wells at swine licensed-managed feeding operations in Oklahoma distributed by source categories determined by nitrogen-isotope ratios of nitrate.

Table 8. Compound names and general sources of wastewater organic compounds analyzed in samples from eight lagoons and 78 of 79 monitoring wells at swine licensed-managed feeding operations in Oklahoma

[data from U.S. Geological Survey (2002)]

Compound name	General sources of compound
1,4-Dichlorobenzene	Household
17-beta-Estradiol	Animal
1-Methylnaphthalene	Hydrocarbon
2,6-Dimethylnaphthalene	Hydrocarbon
2-Methylnaphthalene	Hydrocarbon
3-beta-Coprostanol	Animal
3-Methyl-1(H)-indole (skatol)	Animal
3-tert-Butyl-4-hydroxy anisole (BHA)	Household
4-Cumylphenol	Detergent
4-n-Octylphenol	Detergent
4-tert-Octylphenol	Detergent
5-Methyl-1H-benzotriazole	Industrial
Acetophenone	Household
Acetyl hexamethyl tetrahydronaphthalene (AHTN)	Household
Anthracene	Hydrocarbon
Anthraquinone	Household
Benzo(a)pyrene	Hydrocarbon
Benzophenone	Household
beta-Sitosterol	Animal
beta-Stigmastanol	Animal
Bisphenol A	Household
Bromacil	Pesticide
Bromoform	Household
Caffeine	Household
Camphor	Household
Carbaryl	Pesticide
Carbazole	Household
Chlorpyrifos	Pesticide
Cholesterol	Animal
Cotinine	Household
Diazinon	Pesticide
Dichlorvos	Pesticide
d-Limonene	Household
Equilenin	Animal
Estrone	Animal
Ethynyl estradiol	Animal
Fluoranthene	Hydrocarbon
Hexahydrohexamethyl Cyclopentabenzopyran (HHCB)	Household

Table 8. Compound names and general sources of wastewater organic compounds analyzed in samples from eight lagoons and 78 of 79 monitoring wells at swine licensed-managed feeding operations in Oklahoma—Continued.

[data from U.S. Geological Survey (2002)]

Compound name	General sources of compound
Indole	Household
Isoborneol	Household
Isophorone	Industrial
Isopropylbenzene (cumene)	Industrial
Isoquinoline	Household
Menthol	Household
Metalaxyl	Pesticide
Methyl salicylate	Household
Metolachlor	Pesticide
N,N'-diethyl-methyl-toluamide (DEET)	Pesticide
Naphthalene	Hydrocarbon
Nonylphenol, diethoxy- (total)	Detergent
Octylphenol, diethoxy-	Detergent
Octylphenol, monoethoxy-	Detergent
para-Cresol	Industrial
para-Nonylphenol (total)	Detergent
Pentachlorophenol	Pesticide
Phenanthrene	Hydrocarbon
Phenol	Household
Prometon	Pesticide
Pyrene	Hydrocarbon
Tetrachloroethylene	Industrial
tri(2-Chloroethyl) phosphate	Household
tri(Dichlorisopropyl)phosphate	Household
Tributylphosphate	Detergent
Triclosan	Household
Triethyl citrate (ethyl citrate)	Household
Triphenyl phosphate	Household
tris(2-Butoxyethyl) phosphate	Household

Table 9. Wastewater organic compound detections, nitrogen isotopes, nutrients, fecal coliform bacteria detections, ribotyping sources, and possible sources of nitrate in samples from eight lagoons and 79 monitoring wells collected from swine licensed-managed feeding operations in Oklahoma, 2001

[δ15N, nitrogen-isotope ratios; E, estimated; <, less than; K, non-ideal count; air, standard of comparison to atmospheric nitrogen; LMFO, licensed managed feeding operation; --, no data]

Well number	Site identification number	Wastewater organic compound detections							Nitrogen isotopes $\delta^{15}N$ (air) (per mil)	Nutrients (in milligrams per liter)			Fecal coliform bacteria detections	Ribotype animal sources							Possible sources of nitrate		
		Detergents	Household	Animal waste	Industrial	Hydrocarbons	Pesticides	Total detections		Ammonia	Ammonia + organic nitrogen	Nitrite + nitrate as nitrogen		Unidentified	Avian	Deer	Cattle	Swine	Human	No *E coli*	LMFO waste	Fertilizer	Unidentified animal
Lagoons																							
L1	343756096364402	3	4	5	2			14	38.18	492	590	0.093	E140,000k					X			X		
L2	351857098004304		3	6	2	2		13	43.83	998	1,000	0.136	22,000					X			X		
L3	360635098032902		3	5	1			9	19.81	291	270	1.99	E213,000k					X			X		
L4	361028098440703		3	5	2			10	10.53	<4.1	520	0.063	E140,000k					X			X		
L7	362118099050001		1					1	50.28	27.8	69	0.047	E16k					X			X		
L8	363605101241301	3	5	5	2	1		16	-2.74	435	410	E0.03	1,000					X			X		
L9	365009100450901	1	5	7	2			15	45.28	--	550	E0.032	560					X			X		
L10	365956099473701	1	3	5	1			10	33.78	0.967	2300	E0.133	E100k					X			X		
Wells																							
1	343756096364401		1					1	23.58	E0.039	0.15	11.5	X							X			X
2	343756096364403			1				1	7.64	<0.04	0.17	4.17	X							X		X	X
3	351857098004301								5.70	<0.04	E0.08	56.5										X	X
4	351857098004302								7.26	E0.029	0.2	31										X	X
5	351857098004303								9.96	<0.04	0.26	24	X					X			X		X
6	353922098503101								7.78	0.061	0.45	36.6	X					X			X	X	X
7	360134097591401								0.78	<0.04	0.13	17.9										X	
8	360135097591801		2			4		6	14.58	<0.04	0.17	41.5											X
9	360146098013602								22.07	0.042	0.1	71.7											X
10	360212097583601								9.78	<0.04	<0.1	5.04											X
11	360317098015301								16.45	E0.034	0.28	18.2											X
12	360317098015302								6.16	<0.04	E0.07	13.1										X	X
13	360317098015303						1	1	5.00	<0.04	0.16	9.64	X							X		X	X

Table 9. Wastewater organic compound detections, nitrogen isotopes, nutrients, fecal coliform bacteria detections, ribotyping sources, and possible sources of nitrate in samples from eight lagoons and 79 monitoring wells collected from swine licensed-managed feeding operations in Oklahoma, 2001—Continued.

[δ15N, nitrogen-isotope ratios; E, estimated; <, less than; K, non-ideal count; air, standard of comparison to atmospheric nitrogen; LMFO, licensed managed feeding operation; --, no data]

Well number	Site identification number	Wastewater organic compound detections							Nitrogen isotopes $\delta^{15}N$ (air) (per mil)	Nutrients (in milligrams per liter)			Fecal coliform bacteria detections	Ribotype animal sources							Possible sources of nitrate		
		Detergents	Household	Animal waste	Industrial	Hydrocarbons	Pesticides	Total detections		Ammonia	Ammonia + organic nitrogen	Nitrite + nitrate as nitrogen		Unidentified	Avian	Deer	Cattle	Swine	Human	No *E coli*	LMFO waste	Fertilizer	Unidentified animal
14	360325098010701								3.40	E0.031	E0.06	13.2										X	X
15	360339098170301								11.40	E0.024	0.11	96.8	X					X	X		X		X
16	360339098170701								4.84	E0.028	0.26	14.8	X					X			X	X	X
17	360416098013601						1	1	11.40	E0.039	0.13	20.1	X							X			X
18	360521098022501		1	3				4	3.15	<0.04	0.19	16.2									X	X	X
19	360521098022502						1	1	7.31	<0.04	0.15	21.6										X	X
20	360618098024501	1	1					2	0.86	0.47	0.17	12.3	X							X		X	X
21	360618098024502		1				1	2	0.10	<0.04	E0.07	15.9										X	X
22	360634098030901	--							15.00	E0.025	0.12	5.03											X
23	360634098030902		1					1	8.06	<0.04	<0.1	4.1											X
24	360635098032901		1					1	36.48	0.083	0.4	19.8											X
25	360729098060901		1					2	5.30	<0.04	E0.09	13.3	X	X		X						X	X
26	360735098060801								12.56	E0.021	0.17	36.9	X							X			X
27	361028098440701								11.30	<0.04	0.27	27.2											X
28	361028098440702			3				3	8.23	<0.04	0.17	14.2											X
29	361028098440704								5.82	E0.022	0.12	15.9										X	X
30	361028098440705								3.90	<0.04	E0.06	12.7										X	X
31	361028098440706								8.60	E0.034	E0.08	13											X
32	361115098504701								1.54	<0.04	0.14	17.6										X	
33	361116098463001								0.12	E0.024	E0.07	11.4										X	
34	361117098504301		1					1	2.42	<0.04	0.13	10.2										X	X
35	361118098463301		1					1	2.52	0.082	E0.1	1.4										X	X
36	361121098504501								0.83	E0.021	0.11	9.85										X	
37	361122098462801	1	1					2	1.30	<0.04	E0.07	8.11										X	
38	361122098493901								11.63	E0.024	0.34	28.9											X

Table 9. Wastewater organic compound detections, nitrogen isotopes, nutrients, fecal coliform bacteria detections, ribotyping sources, and possible sources of nitrate in samples from eight lagoons and 79 monitoring wells collected from swine licensed-managed feeding operations in Oklahoma, 2001—Continued.

[δ15N, nitrogen-isotope ratios; E, estimated; <, less than; K, non-ideal count; air, standard of comparison to atmospheric nitrogen; LMFO, licensed managed feeding operation; --, no data]

Well number	Site identification number	Wastewater organic compound detections							Nitrogen isotopes $\delta^{15}N$ (air) (per mil)	Nutrients (in milligrams per liter)			Fecal coliform bacteria detections	Ribotype animal sources							Possible sources of nitrate		
		Detergents	Household	Animal waste	Industrial	Hydrocarbons	Pesticides	Total detections		Ammonia	Ammonia + organic nitrogen	Nitrite + nitrate as nitrogen		Unidentified	Avian	Deer	Cattle	Swine	Human	No *E coli*	LMFO waste	Fertilizer	Unidentified animal
39	361133098485701			1				1	3.08	<0.03	0.26	10.9										X	X
40	361136098374401		1	4				5	11.09	<0.04	0.27	39.9									X		X
41	361139098374801								6.46	<0.04	0.23	21.4										X	X
42	361139098485901								-1.20	E0.038	0.41	12.4										X	
43	361143098374801			1				1	7.40	E0.021	0.21	19.7										X	X
44	361146098504501								5.25	<0.04	0.17	17.5										X	X
45	361152098504401								-4.58	0.063	0.18	23.1										X	
46	361157098494101		1					1	-0.88	<0.04	<0.1	15.4										X	
47	361203098494301								-2.05	<0.04	0.1	7.54										X	
48	361210098112201								-3.32	E0.021	E0.05	18.1										X	
49	361215098491301								0.66	0.162	0.11	9.34	X	X	X		X	X	X		X	X	X
50	361215098491501								-0.44	0.087	0.14	13.1										X	
51	361240098494201		1	1		4		6	1.67	<0.04	E0.07	24.5										X	X
52	361240098494401		1					2	3.11	<0.04	0.1	12.4										X	X
53	361245098494401								4.71	<0.04	0.17	9.95										X	X
54	362100099050301								1.61	0.081	E0.08	14.7										X	
55	362118099050301								1.73	<0.04	<0.1	8.22										X	
56	362136099041201								2.96	<0.04	E0.07	12.4										X	X
57	362136099051001		1					1	3.16	0.082	E0.08	10.1										X	X
58	363153101185001			4	2			6	11.84	0.088	0.23	41.6									X		X
59	363601101241301	1						1	4.42	<0.04	0.28	43.5										X	X
60	363602101244501								7.73	E0.034	1.7	22.3										X	X
61	364150101071901								0.48	0.136	0.18	16.2										X	
62	364500101155301		1					1	2.66	0.06	0.17	10.6										X	X
63	364722100545501			2			1	3	15.90	E0.034	0.65	35.4											X

Table 9. Wastewater organic compound detections, nitrogen isotopes, nutrients, fecal coliform bacteria detections, ribotyping sources, and possible sources of nitrate in samples from eight lagoons and 79 monitoring wells collected from swine licensed-managed feeding operations in Oklahoma, 2001—Continued.

[δ15N, nitrogen-isotope ratios; E, estimated; <, less than; K, non-ideal count; air, standard of comparison to atmospheric nitrogen; LMFO, licensed managed feeding operation; --, no data]

Well number	Site identification number	Wastewater organic compound detections							Nitrogen isotopes $\delta^{15}N$ (air) (per mil)	Nutrients (in milligrams per liter)			Fecal coliform bacteria detections	Ribotype animal sources							Possible sources of nitrate		
		Detergents	Household	Animal waste	Industrial	Hydrocarbons	Pesticides	Total detections		Ammonia	Ammonia + organic nitrogen	Nitrite + nitrate as nitrogen		Unidentified	Avian	Deer	Cattle	Swine	Human	No *E coli*	LMFO waste	Fertilizer	Unidentified animal
64	364728100563501	1					1	2	19.93	0.083	0.7	30.5											X
65	365006100451001								2.14	0.119	0.12	8.59										X	X
66	365024100450701						1	1	14.18	0.421	0.44	37.4											X
67	365919099490901	2	1					3	5.66	<0.04	0.28	24										X	X
68	365938099490901								1.79	<0.04	0.28	41										X	
69	365941099475101		1					1	14.30	<0.04	0.33	10.9	X							X			X
70	365941099490701	1						1	4.56	<0.04	0.35	12.6										X	X
71	365942099473701		1	1				2	7.51	<0.04	0.18	E3.37										X	X
72	365944099473401								3.39	<0.04	0.18	17.1										X	X
73	365945099474901		1	3				4	3.16	<0.04	0.3	12.2									X	X	X
74	365945099491401								3.36	<0.04	0.32	33.8										X	X
75	365947099492101								4.57	<0.04	0.17	39.5										X	X
76	365948099491701								9.41	<0.04	0.18	47.3											X
77	365954099473701								36.72	<0.04	0.15	26.9											X
78	370002099484101								14.35	<0.04	0.16	38.6	X							X			X
79	370003099483501								15.82	<0.04	0.2	48.8											X

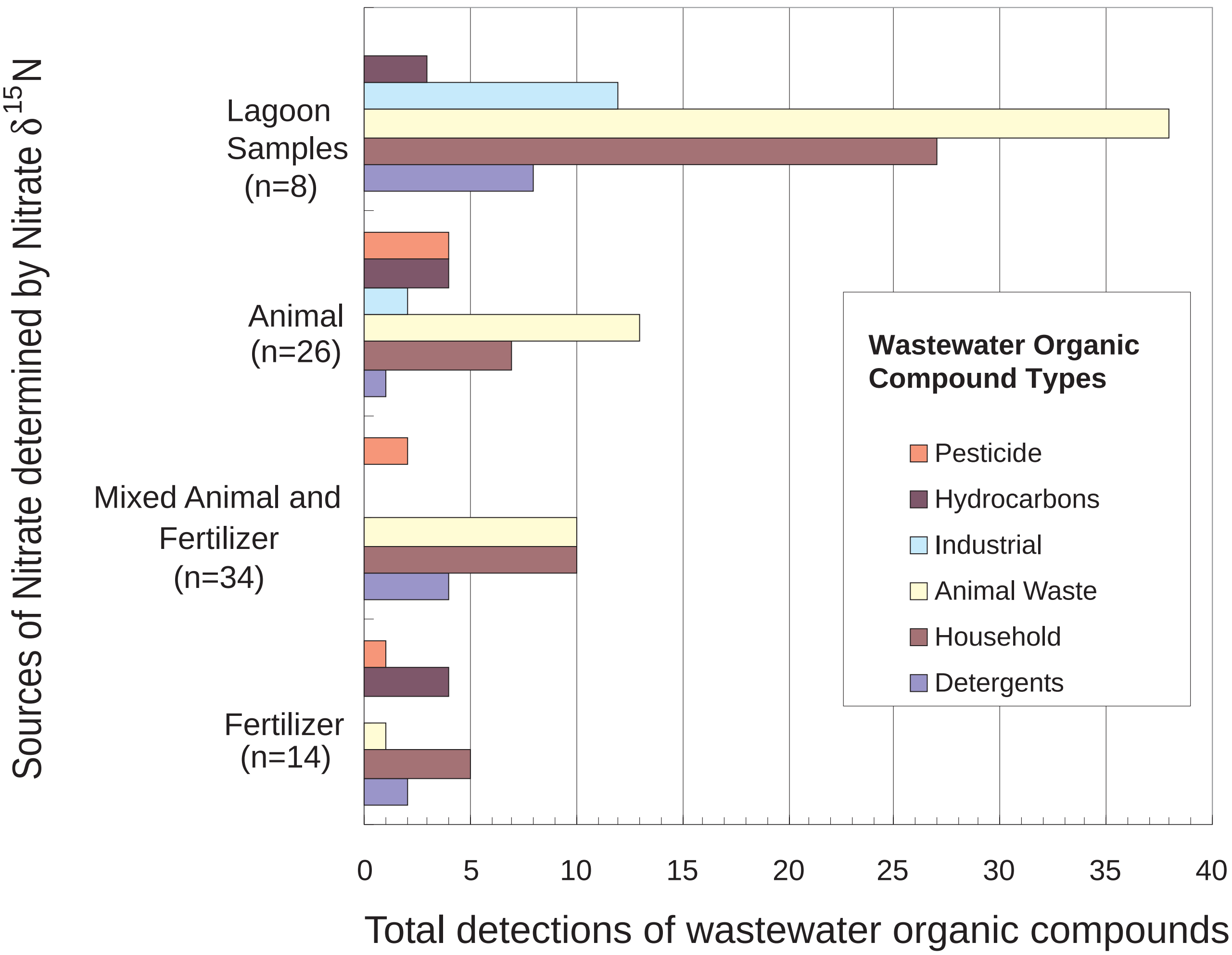

Figure 4. Wastewater organic compounds detections in samples from eight lagoons and 78 of 79 monitoring wells at swine licensed-managed feeding operations in Oklahoma showing wells samples grouped by source categories determined by nitrogen-isotope ratios of nitrate.

Bacteria and Ribotyping

Fecal coliform bacteria are indicators of water quality and contamination by an animal source. Water samples from eight lagoons and all wells were sampled and cultured for fecal coliform bacteria. Fecal coliform bacteria were detected in eight lagoon samples and in water from 14 wells (table 9). The small number of well samples containing fecal coliform bacteria was consistent with the findings of the ODAFF (Dan Parrish, ODAFF, oral commun., 2001), where fecal coliform bacteria were not detected in annual samples collected in 1999 and 2001 in any of the 79 wells sampled in this study.

Fecal coliform bacteria counts from the lagoons were variable. Four of the lagoons had relatively low counts and were retested twice to confirm those results. The counts in the low-count lagoons ranged from estimated 16 to 1,000 colonies per 100 milliliters and the high-count lagoons ranged from 22,000 to an estimated 213,000 colonies per 100 milliliters. Data were not sufficient to explain the variability of concentrations of fecal coliform bacteria in the lagoons. Testing for additional or alternative species of bacteria may be necessary to find a biological tracer to be used as an indicator of LMFO waste.

Hagedorn (2002) reported "Ribotyping involves the bacterial genes that code for ribosomal RNA. Because such genes are highly conserved in micro-organisms, ribotyping has been widely accepted for microbial identification. Ribotyping involves cutting the total genomic bacterial DNA with different DNAases, or restriction enzymes, followed by gel electrophoresis. Following electrophoresis, southern blotting is performed to blot the DNA bands onto nylon membranes from the gels. DNA probes must be prepared for bacterial 16S and 23S rRNA and labeled with some type of detection system. Membrane hybridization is then performed to hybridize the probes with the appropriate DNA bands on the nylon filter. Difference in the size and location of the ribosomal RNA bands on the filters can then be used to differentiate between the sources that the fecal bacteria were obtained from."

A total of 13 well samples with sufficient fecal coliform bacteria colonies were used for ribotyping analysis. Cultures of *E. coli* are required for ribotyping and only 6 of the 13 wells yielded *E. coli* from fecal coliform bacteria colonies. *E. coli* isolates from the wells were statistically compared to isolates found in the source material and previously identified source isolates stored in a data base for the determination of the presumptive sources of bacteria. Water samples from five wells contained isolates that identified swine as a source of the bacteria in the well. Other source isolates identified in the wells along with swine were human, bovine, deer, and avian. Well number 25 had two isolates; one isolate was identified as deer and the other isolate could not be identified.

Possible Sources of Nitrate in Ground Water

Generally, the identification of possible sources of nitrate are subjective and are based on evidence from the chemical and microbiological techniques. With the exception of ribotyping, no one method acts as a definitive answer to the source of nitrate; however, collectively, the methods can strongly indicate the possible sources of nitrate. Wastewater organic compound detections, nitrogen-isotope ratios, fecal coliform bacteria detections, and ribotyping were used in combination to identify possible sources of nitrate in ground water near LMFOs. Possible sources of nitrate in well samples - LMFO waste, fertilizer, and unidentified animal - and mixtures of these possible sources are discussed in this section (fig. 5; table 9).

Wastewater organic compounds characteristic of animal waste - 3-beta-coprastanol, skatol, beta-sitosterol, beta-stigmastanol, cholesterol, equilenin, and estrone - were detected in seven of the eight lagoons sampled. The number of animal-waste compounds detected in the lagoons ranged from five to seven (table 9). These compounds are present in animal waste and were the most frequently detected group of wastewater organic compounds in lagoons. The detection of these animal-waste compounds in well samples indicated a possible LMFO waste source. Therefore, when three or more animal-waste compounds were

detected in well samples, LMFO waste was designated as a possible source for these samples (table 9).

Nitrogen isotopes, fecal coliform bacteria, and ribotyping were used to differentiate between animal and fertilizer sources and mixtures of sources. The presence of fecal coliform bacteria in the well samples indicated an animal source as one source of nitrate. An animal source was designated as the possible source if $\delta^{15}N$ were greater than +8.0‰, wastewater organic animal-waste compounds were detected, and ribotyping indicated possible specific animal sources. A mixture of animal and fertilizer as the possible source of nitrate was assumed when the $\delta^{15}N$ was between +2.0‰ to +8.0‰. If fecal coliform bacteria and animal-waste organic compounds were not detected, and the $\delta^{15}N$ was less than or equal to +2.0‰ the possible source was classified as fertilizer. Because animal sources, other than swine, identified by ribotyping occurred in samples from three wells, sources for these wells are indicated as unidentified animal (table 9).

LMFO waste was designated as a possible source of nitrate in samples from 10 wells. Source of LMFO waste in samples from five of those wells was determined by ribotyping and the source of LMFO waste in samples from the remaining five wells was determined by the detection of three or more animal-waste compounds. LMFO waste in samples from wells with unidentified animal source of nitrate does not indicate that LMFO waste was not the source, but could indicate that multiple animal sources, including LMFO waste, may be the source of the nitrate.

A mixed unidentified animal and fertilizer source of nitrate was designated for samples from 33 wells, unidentified animal

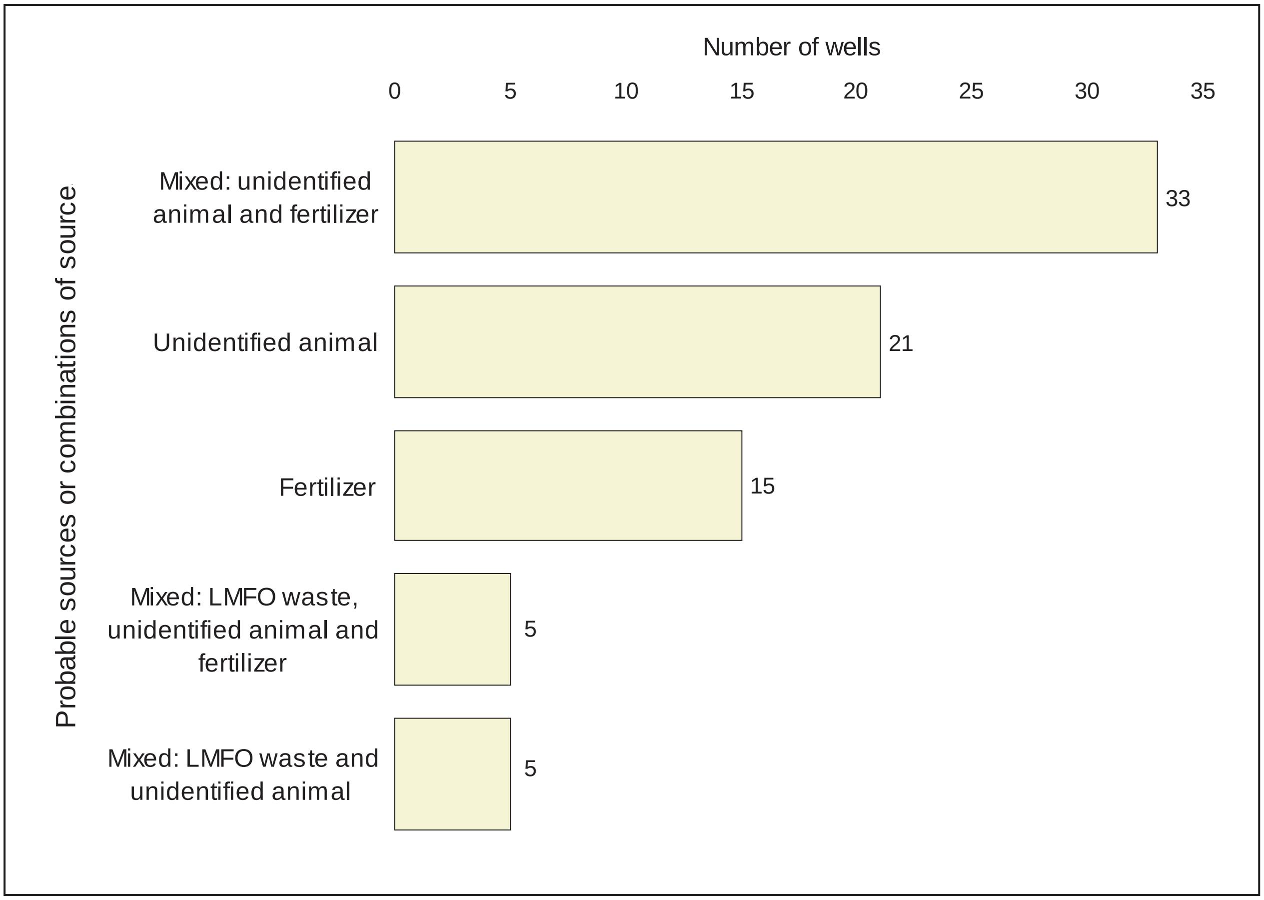

Figure 5. Distribution of possible sources or mixtures of possible sources of nitrate in ground water from 79 monitoring wells located at swine licensed-managed feeding operations in Oklahoma.

source was designated for samples from 21 wells, and a fertilizer source was designated for samples from 15 wells (fig 5). A mixed LMFO waste, unidentified animal, and fertilizer source was designated for samples from five wells, and LMFO waste and unidentified animal sources were designated for samples from five wells (fig. 5).

Most of the sources of nitrate were identified as mixed unidentified animal and fertilizer. The mixture of pasture, row crop, and LMFO land uses is consistent with these results. A Kruskal-Wallace rank sum test (MathSoft, 1999) was used to test for a correlation between the identified sources of nitrate and antecedent land use, but a significant correlation ($p < 0.05$) did not exist. The test was conducted comparing the identified sources of nitrate to the percent grassland or cropland and resulted in p-values of 0.429 for grassland and $p=0.076$ for cropland. The 500-meter radius well area may be a factor in the lack of a significant correlation between the identified nitrate source and the antecedent land use. Recharge areas for the wells sampled for the study may be larger than the well area and recharge amounts can vary and affect ground-water flow. Generally, a mixture of land uses within the buffer and the lack of prevailing land use makes the correlation less deterministic. Another factor is that winter wheat is the primary row crop and is used during the winter for grazing, so on the same land where fertilizer is applied, animals graze for several months of the year.

Summary

Nitrate concentrations in ground-water samples collected and analyzed annually by Oklahoma Department of Agriculture, Food, and Forestry (ODAFF) from 1999 through 2001 exceeded the U.S. Environmental Protection Agency (USEPA) maximum contaminant level of 10 milligrams per liter nitrate as nitrogen for public drinking-water supplies in 79 monitoring wells near 35 swine licensed-managed feeding operations (LMFOs). The LMFOs and monitoring wells are located in areas of current and historical agriculture activities, so the source of the nitrate in the ground water could be from wastewater lagoons (LMFO waste), nitrogen fertilizer applications on row crops, or livestock grazing.

Eight LMFO wastewater lagoons and 79 monitoring wells were sampled and analyzed for water properties, dissolved major ions, dissolved trace elements, nutrients, nitrogen-isotope ratios in nitrate and ammonia, wastewater organic compounds, and fecal coliform bacteria. Isolates of E. coli bacteria from fecal coliform bacteria colonies in well samples were ribotyped, a form of deoxyribonucleic acid (DNA) fingerprinting to determine the specific animal source of fecal coliform bacteria. Two additional lagoons at one facility were sampled and analyzed only for dissolved major ions and dissolved trace elements.

Three types of aquifers underlie the LMFOs of this study: major bedrock, minor bedrock, or alluvial and terrace. All 22 major bedrock aquifer wells were completed in the High Plains aquifer. Eight wells were located in minor bedrock aquifers. Forty-nine wells were installed in the Beaver/North Canadian and Cimarron alluvial and terrace aquifers.

Concentrations of calcium, magnesium, and sulfate were greater in water from wells than in water from lagoons, and concentrations of potassium, sodium, and chloride were greater in water from lagoons. Potassium and sodium, while not conservative, may be an indicator of LMFO waste if measured at substantially greater concentrations than the background concentrations in ground water. Concentrations of most dissolved trace elements were less than the analytical reporting level in samples from lagoons and wells.

Generally, the major sources of nitrogen in ground water are precipitation, oxidation of soil organic matter, fertilizer, animal manure, and sewage effluent. Nitrate at concentrations less than 0.2 milligram per liter are considered to be natural background, and concentrations from 0.21 to 3.0 milligrams per liter are considered transitional between background and possible human influence. Nitrate concentrations in water samples from the 79 wells sampled for this study ranged from 1.4 to 96.8 milligrams per liter, which indicate possible human influence.

A decision process was developed to identify possible sources of nitrate in ground water. First nitrogen-isotope ratios ($\delta^{15}N$) were used to define source categories as animal, mixed animal and fertilizer or fertilizer. Most of the nitrate source categories determined solely by $\delta^{15}N$ of nitrate were either a mixed animal and fertilizer or an animal source. Nineteen well samples had $\delta^{15}N$ values indicating a fertilizer source, 26 samples had $\delta^{15}N$ indicating an animal source, and 34 samples had $\delta^{15}N$ indicating a mixed animal and fertilizer source. The distribution of nitrate concentrations in well samples by source categories determined by $\delta^{15}N$ in nitrate indicates that the largest nitrate concentrations occur in the animal category. The Kruskal-Wallis rank-sum test indicated that the nitrate concentrations of the animal category ($p=0.0046$) were significantly different than the mixed animal and fertilizer and the fertilizer categories.

Next, wastewater organic compound detections, nitrogen-isotope ratios, fecal coliform bacteria detections, and ribotyping were used in combination to refine the identification of possible sources of nitrate in ground water. Wastewater organic compound concentrations were analyzed in water samples from eight lagoons and from 78 wells. The wastewater organic compounds analyzed typically occur in domestic and industrial wastewater and include compounds derived from pesticides, hydrocarbons, industrial, animal waste, household, and detergents. Lagoon samples had the greatest number of wastewater organic compound detections, ranging from one to 16, with a median of 12. Wastewater organic compounds were detected in 34 well samples, with the maximum number of six compounds detected in samples from each well. Five of the 34 wells were in the fertilizer-source category, 12 were in the animal source category, and 17 were in the mixed animal and fertilizer source category based on N-isotope ratios of nitrate.

The nine wastewater organic compounds from animal waste analyzed were 17-beta-estradiol, 3-beta-coprastanol, skatol, beta-sitosterol, beta-stigmastanol, cholesterol, equilenin, estrone, and ethynyl estradiol. Only 17-beta-estradiol and ethynyl estradiol were not detected in any sample. It is possible that samples from wells having several detections of wastewater organic compounds from animal waste have LMFO lagoon waste in the ground water.

Fecal coliform bacteria are indicators of water quality and contamination by an animal source. Fecal coliform bacteria were detected in eight lagoon samples and in water from 14 wells. Four of the lagoons had relatively low bacteria counts and were retested twice to confirm those results. The counts in the low-count lagoons ranged from estimated 16 to 1,000 colonies per 100 milliliters and the high-count lagoons ranged from 22,000 to an estimated 213,000 colonies per 100 milliliters. Data were not sufficient to explain the variability of concentrations of fecal coliform bacteria in the lagoons.

Ribotyping is a method of identifying the source of fecal bacteria by comparing DNA of *E. coli* bacteria isolates from known source material to *E. coli* bacteria cultured from environmental samples. A total of 13 well samples with sufficient fecal coliform bacteria colonies were used for ribotyping analysis. Cultures of *E. coli* are required for ribotyping and samples from only 6 of 10 of those 13 wells yielded *E. coli* from fecal coliform bacteria colonies. Water samples from five wells contained isolates that identify swine as a source of the bacteria in the well.

Three possible sources of nitrate - LMFO waste, fertilizer, and unidentified animal - and mixtures of these possible sources were used to characterize the possible sources of nitrate in the wells. A mixed unidentified animal and fertilizer source of nitrate was designated for samples from 33 wells, unidentified animal source was designated for samples from 21 wells, fertilizer source was the designated for samples from 15 wells, and a mixed LMFO waste, unidentified animal, and fertilizer source was designated for samples from five wells. LMFO waste and unidentified animal sources were designated for five wells. Most of the sources of nitrate were identified as mixed unidentified animal and fertilizer.

A Kruskal-Wallace rank sum test was used to test for a correlation between the identified sources of nitrate and antecedent land use, but no significant correlation was indicated.

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Appendices

Appendix 1. Dissolved major ions analyzed in samples from 10 lagoons and 76 of 79 monitoring wells at swine licensed-managed feeding operations in Oklahoma, 2001

[L, lagoon; yyyymmdd, year, month, day; all concentrations are in milligrams per liter]

Lagoon and well numbers	Site identification number	Date (yyyymmdd)	Calcium	Magnesium	Sodium	Potassium	Sulfate	Chloride
L1	343756096364402	20010720	41.75	9.75	250.05	1,383.36	5.83	391.00
L2	351857098004304	20010615	22.55	3.50	1,473.46	2,587.32	< 10	2,460.00
L3	360635098032902	22010625	55.88	28.83	168.21	453.29	23.50	200.00
L4	361028098440703	20010716	49.67	12.47	165.63	777.30	5.77	251.00
L5	361028098440707	20010717	42.86	11.74	175.80	861.91	3.59	301.00
L6	361028098440708	20010717	49.16	16.28	154.51	711.56	21.00	270.00
L7	362118099050001	20010628	48.60	34.29	481.43	1,606.89	40.90	990.00
L8	363605101241301	20010711	109.19	55.78	241.74	961.22	< 0.1	470.00
L9	365009100450901	20010531	50.23	4.68	304.71	673.86	2.54	443.00
L10	365956099473701	20010717	48.49	11.57	481.16	1,949.83	< 1.0	1,020.00
1	343756096364401	20010720	133.08	13.83	22.75	1.53	26.10	17.80
2	343756096364403	20010720	30.25	8.90	368.48	1.88	< 0.1	1.14
3	351857098004301	20010614	128.08	58.22	50.92	0.68	187.00	12.90
4	351857098004302	20010615	84.87	75.00	90.94	0.34	117.00	43.60
5	351857098004303	20010614	107.70	59.52	101.54	0.74	161.00	67.40
6	353922098503101	20010618	388.73	189.05	140.40	2.00	1,490.00	87.10
7	360134097591401	20010530	31.65	16.70	6.89	0.84	82.20	7.09
8	360135097591801	20010529	79.31	26.79	7.24	0.50	52.60	2.79
9	360146098013602	20010703	93.25	26.63	33.92	0.68	49.60	51.00
10	360212097583601	20010702	46.05	15.17	13.01	0.34	20.70	9.65
11	360317098015301	20010619	198.26	64.40	128.45	0.82	126.00	380.00
12	360317098015302	20010620	64.51	14.39	41.25	0.99	28.30	58.90
13	360317098015303	20010620	148.17	32.38	92.58	1.00	202.00	81.20
14	360325098010701	20010620	60.45	15.66	20.80	0.68	22.40	19.30
15	360339098170301	20010517	96.00	45.45	20.34	0.85	31.00	25.10
16	360339098170701	20010517	63.70	25.92	27.07	1.46	26.50	24.10
17	360416098013601	20010703	101.76	34.62	37.53	1.12	224.00	33.60
18	360521098022501	20010626	47.74	23.37	26.13	3.06	64.40	4.16
19	360521098022502	20010626	113.82	37.60	36.80	1.39	335.00	16.40
20	360618098024501	20010619	12.42	6.57	5.67	2.36	6.14	0.23
22	360634098030901	20010625	64.09	19.33	119.56	1.30	26.10	74.30
23	360634098030902	20010702	59.77	13.68	92.32	2.47	42.30	64.90
24	360635098032901	20010625	67.26	30.43	59.40	1.98	63.10	91.90
27	361028098440701	20010716	130.09	30.39	18.94	1.21	62.50	11.30
28	361028098440702	20010716	75.66	16.98	12.07	0.58	70.70	29.80
29	361028098440704	20010716	71.40	15.15	8.13	1.12	57.40	19.30

Appendix 1. Dissolved major ions analyzed in samples from 10 lagoons and 76 of 79 monitoring wells at swine licensed-managed feeding operations in Oklahoma, 2001—Continued.

[L, lagoon; yyyymmdd, year, month, day; all concentrations are in milligrams per liter]

Lagoon and well numbers	Site identification number	Date (yyyymmdd)	Calcium	Magnesium	Sodium	Potassium	Sulfate	Chloride
30	361028098440705	20010717	45.00	8.66	15.19	1.51	28.30	20.10
31	361028098440706	20010717	55.47	10.66	19.87	1.47	35.60	29.90
32	361115098504701	20010802	48.09	9.62	21.68	1.29	72.40	4.83
33	361116098463001	20010524	89.60	19.92	16.83	0.98	207.00	12.60
34	361117098504301	20010802	54.85	9.40	18.75	1.28	51.60	10.20
35	361118098463301	20010524	59.29	12.41	22.13	2.00	50.60	26.70
36	361121098504501	20010807	46.78	9.01	15.71	1.33	44.20	22.80
37	361122098462801	20010611	63.21	12.06	20.04	1.99	45.40	53.20
38	361122098493901	20010821	108.96	20.43	40.15	1.08	56.30	35.70
39	361133098485701	20010807	105.40	20.98	32.77	1.09	103.00	52.30
40	361136098374401	20010731	127.86	26.46	64.22	1.39	123.00	88.10
41	361139098374801	20010731	115.00	24.30	88.43	2.33	150.00	173.00
42	361139098485901	20010807	176.32	22.59	30.03	1.50	47.40	163.00
43	361143098374801	20010731	54.95	11.06	32.28	1.65	45.30	17.30
44	361146098504501	20010801	56.00	11.30	18.07	2.40	50.60	4.93
45	361152098504401	20010802	75.98	13.27	35.27	1.13	97.10	0.88
46	361157098494101	20010607	19.13	4.40	19.81	0.80	14.50	5.77
47	361203098494301	20010611	31.93	6.34	15.00	1.21	22.70	13.70
48	361210098112201	20010808	26.27	4.67	11.25	0.79	16.10	0.12
49	361215098491301	20010606	49.84	9.66	26.42	1.56	38.80	38.10
50	361215098491501	20010606	59.94	11.98	17.73	1.75	41.70	53.80
51	361240098494201	20010801	37.40	7.76	27.02	1.26	33.70	4.53
52	361240098494401	20010607	56.40	11.48	20.24	1.96	42.10	45.10
53	361245098494401	20010606	59.54	11.01	17.03	1.87	43.10	38.70
54	362100099050301	20010628	27.77	5.33	7.76	0.81	13.10	20.30
55	362118099050301	20010628	34.53	5.66	6.84	1.85	22.20	12.70
56	362136099041201	20010626	44.80	8.37	20.42	2.17	24.40	13.60
57	362136099051001	20010626	38.63	7.47	14.80	6.09	30.70	9.72
58	363153101185001	20010710	290.62	174.82	48.79	8.85	189.00	436.00
59	363601101241301	20010710	40.42	82.43	40.12	7.24	96.10	52.90
60	363602101244501	20010710	68.80	86.09	25.34	7.46	109.00	99.70
61	364150101071901	20010605	32.48	34.70	45.91	4.72	14.40	4.76
62	364500101155301	20010605	66.63	35.48	12.55	4.71	69.10	65.00
63	364722100545501	20010709	197.61	65.23	265.26	9.70	37.60	429.00
64	364728100563501	20010709	160.02	104.96	102.73	9.53	46.50	159.00
65	365006100451001	20010531	41.72	35.70	55.19	4.78	27.10	108.00
66	365024100450701	20010530	70.70	18.77	345.52	7.08	67.70	347.00
67	365919099490901	20010613	100.92	51.99	275.48	5.08	411.00	219.00

Appendix 1. Dissolved major ions analyzed in samples from 10 lagoons and 76 of 79 monitoring wells at swine licensed-managed feeding operations in Oklahoma, 2001—Continued.

[L, lagoon; yyyymmdd, year, month, day; all concentrations are in milligrams per liter]

Lagoon and well numbers	Site identification number	Date (yyyymmdd)	Calcium	Magnesium	Sodium	Potassium	Sulfate	Chloride
68	365938099490901	20010613	13.00	9.00	210.84	1.54	39.30	12.40
69	365941099475101	20010716	72.17	31.66	132.83	2.31	178.00	105.00
70	365941099490701	20010613	18.13	9.74	240.17	2.87	66.40	175.00
71	365942099473701	20010717	70.10	28.38	154.30	3.22	95.30	96.50
72	365944099473401	20010717	64.96	29.02	128.30	6.51	102.00	54.30
73	365945099474901	20010716	72.40	31.64	152.63	2.53	210.00	112.00
74	365945099491401	20010614	48.96	33.51	313.59	3.08	141.00	268.00
75	365947099492101	20010614	82.18	40.55	73.58	1.66	44.90	103.00
76	365948099491701	20010716	51.39	34.46	206.25	2.14	58.70	137.00
77	365954099473701	20010717	35.85	13.80	119.14	2.04	29.60	13.30
78	370002099484101	20010612	20.55	10.08	204.56	2.26	35.70	23.70
79	370003099483501	20010612	58.54	31.67	244.32	2.56	101.00	210.00

Appendix 2. Dissolved trace elements analyzed in samples from 10 lagoons and 76 of 79 monitoring wells at swine licensed-managed feeding operations in Oklahoma, 2001

[L, lagoon; yyyymmdd, year, month, day; <, less than; all concentrations in milligrams per liter]

Lagoon and well numbers	Site identification number	Date (yyyymmdd)	Aluminum	Antimony	Arsenic	Boron	Barium	Beryllium	Cadmium	Cobalt	Chromium
L1	343756096364402	20010720	< 0.260	< 0.170	< 0.330	2.215	< 0.020	< 0.040	< 0.040	< 0.030	< 0.030
L2	351857098004304	20010615	< 0.260	< 0.170	< 0.330	3.360	< 0.020	< 0.040	< 0.040	< 0.030	< 0.030
L3	360635098032902	22010625	< 0.130	< 0.085	< 0.165	0.742	0.021	< 0.020	< 0.020	< 0.015	< 0.015
L4	361028098440703	20010716	< 0.260	< 0.170	< 0.330	1.361	0.022	< 0.040	< 0.040	< 0.030	< 0.030
L5	361028098440707	20010717	< 0.260	< 0.170	< 0.330	1.499	0.024	< 0.040	< 0.040	< 0.030	< 0.030
L6	361028098440708	20010717	< 0.260	< 0.170	< 0.330	1.277	0.024	< 0.040	< 0.040	< 0.030	< 0.030
L7	362118099050001	20010628	< 0.260	< 0.170	< 0.330	2.642	< 0.020	< 0.040	< 0.040	< 0.030	< 0.030
L8	363605101241301	20010711	< 0.260	< 0.170	< 0.330	1.961	0.033	< 0.040	< 0.040	< 0.030	< 0.030
L9	365009100450901	20010531	0.058	< 0.017	0.042	0.936	0.058	< 0.004	< 0.004	0.005	0.004
L10	365956099473701	20010717	< 0.260	< 0.170	< 0.330	3.384	< 0.020	< 0.040	< 0.040	< 0.030	< 0.030
1	343756096364401	20010720	0.034	< 0.017	< 0.033	0.088	0.143	< 0.004	< 0.004	< 0.003	< 0.003
2	343756096364403	20010720	0.031	< 0.017	< 0.033	0.871	0.082	< 0.004	< 0.004	< 0.003	< 0.003
3	351857098004301	20010614	< 0.026	< 0.017	< 0.033	0.237	0.038	< 0.004	< 0.004	< 0.003	< 0.003
4	351857098004302	20010615	< 0.026	< 0.017	< 0.033	0.553	0.072	< 0.004	< 0.004	< 0.003	< 0.003
5	351857098004303	20010614	< 0.026	< 0.017	< 0.033	0.483	0.084	< 0.004	< 0.004	< 0.003	< 0.003
6	353922098503101	20010618	0.031	< 0.017	< 0.033	1.237	0.012	< 0.004	< 0.004	< 0.003	< 0.003
7	360134097591401	20010530	< 0.026	< 0.017	< 0.033	0.030	0.315	< 0.004	< 0.004	< 0.003	< 0.003
8	360135097591801	20010529	< 0.026	< 0.017	< 0.033	0.103	0.179	< 0.004	< 0.004	< 0.003	< 0.003
9	360146098013602	20010703	< 0.026	< 0.017	< 0.033	0.029	0.166	< 0.004	< 0.004	< 0.003	< 0.003
10	360212097583601	20010702	< 0.026	< 0.017	< 0.033	0.044	0.379	< 0.004	< 0.004	< 0.003	< 0.003
11	360317098015301	20010619	< 0.026	< 0.017	< 0.033	0.048	0.228	< 0.004	< 0.004	< 0.003	< 0.003
12	360317098015302	20010620	< 0.026	< 0.017	< 0.033	0.042	0.277	< 0.004	< 0.004	< 0.003	< 0.003
13	360317098015303	20010620	< 0.026	< 0.017	< 0.033	0.042	0.218	< 0.004	< 0.004	< 0.003	< 0.003
14	360325098010701	20010620	< 0.026	< 0.017	< 0.033	0.052	0.319	< 0.004	< 0.004	< 0.003	< 0.003
15	360339098170301	20010517	< 0.026	< 0.017	< 0.033	0.105	0.553	< 0.004	< 0.004	< 0.003	< 0.003
16	360339098170701	20010517	< 0.026	< 0.017	< 0.033	0.114	0.294	< 0.004	< 0.004	< 0.003	< 0.003
17	360416098013601	20010703	< 0.026	< 0.017	< 0.033	0.039	0.125	< 0.004	< 0.004	< 0.003	< 0.003

Appendix 2. Dissolved trace elements analyzed in samples from 10 lagoons and 76 of 79 monitoring wells at swine licensed-managed feeding operations in Oklahoma, 2001—Continued.

Lagoon and well numbers	Site identification number	Date (yyyymmdd)	Aluminum	Antimony	Arsenic	Boron	Barium	Beryllium	Cadmium	Cobalt	Chromium
18	360521098022501	20010626	< 0.026	< 0.017	< 0.033	0.023	0.151	< 0.004	< 0.004	< 0.003	< 0.003
19	360521098022502	20010626	< 0.026	< 0.017	< 0.033	0.032	0.057	< 0.004	< 0.004	< 0.003	< 0.003
20	360618098024501	20010619	< 0.026	< 0.017	< 0.033	0.028	0.125	< 0.004	< 0.004	< 0.003	< 0.003
22	360634098030901	20010625	< 0.026	< 0.017	< 0.033	0.030	0.170	< 0.004	< 0.004	< 0.003	< 0.003
23	360634098030902	20010702	< 0.026	< 0.017	< 0.033	0.054	0.234	< 0.004	< 0.004	< 0.003	< 0.003
24	360635098032901	20010625	< 0.026	< 0.017	< 0.033	0.049	0.341	< 0.004	< 0.004	< 0.003	< 0.003
27	361028098440701	20010716	< 0.026	< 0.017	< 0.033	0.077	0.422	< 0.004	< 0.004	< 0.003	< 0.003
28	361028098440702	20010716	< 0.026	< 0.017	< 0.033	0.064	0.358	< 0.004	< 0.004	< 0.003	< 0.003
29	361028098440704	20010716	< 0.026	< 0.017	< 0.033	0.054	0.367	< 0.004	< 0.004	< 0.003	< 0.003
30	361028098440705	20010717	< 0.026	< 0.017	< 0.033	0.038	0.184	< 0.004	< 0.004	< 0.003	< 0.003
31	361028098440706	20010717	0.027	< 0.017	< 0.033	0.033	0.238	< 0.004	< 0.004	< 0.003	< 0.003
32	361115098504701	20010802	< 0.026	< 0.017	< 0.033	<0.021	0.161	< 0.004	< 0.004	< 0.003	< 0.003
33	361116098463001	20010524	< 0.026	< 0.017	< 0.033	0.026	0.072	< 0.004	< 0.004	< 0.003	< 0.003
34	361117098504301	20010802	< 0.026	< 0.017	< 0.033	0.027	0.256	< 0.004	< 0.004	< 0.003	< 0.003
35	361118098463301	20010524	< 0.026	< 0.017	< 0.033	0.057	0.129	< 0.004	< 0.004	< 0.003	< 0.003
36	361121098504501	20010807	< 0.026	< 0.017	< 0.033	0.037	0.184	< 0.004	< 0.004	< 0.003	< 0.003
37	361122098462801	20010611	< 0.026	< 0.017	< 0.033	0.046	0.262	< 0.004	< 0.004	< 0.003	< 0.003
38	361122098493901	20010821	< 0.026	< 0.017	< 0.033	0.041	0.246	< 0.004	< 0.004	< 0.003	< 0.003
39	361133098485701	20010807	< 0.026	< 0.017	< 0.033	0.047	0.176	< 0.004	< 0.004	< 0.003	< 0.003
40	361136098374401	20010731	< 0.026	< 0.017	< 0.033	0.046	0.115	< 0.004	< 0.004	< 0.003	< 0.003
41	361139098374801	20010731	< 0.026	< 0.017	< 0.033	0.056	0.112	< 0.004	< 0.004	< 0.003	< 0.003
42	361139098485901	20010807	< 0.026	< 0.017	< 0.033	0.028	0.814	< 0.004	< 0.004	< 0.003	< 0.003
43	361143098374801	20010731	< 0.026	< 0.017	< 0.033	0.055	0.217	< 0.004	< 0.004	< 0.003	< 0.003
44	361146098504501	20010801	< 0.026	< 0.017	< 0.033	0.034	0.429	< 0.004	< 0.004	< 0.003	< 0.003
45	361152098504401	20010802	< 0.026	< 0.017	< 0.033	0.029	0.252	< 0.004	< 0.004	< 0.003	< 0.003
46	361157098494101	20010607	< 0.026	< 0.017	< 0.033	0.023	0.146	< 0.004	< 0.004	< 0.003	< 0.003
47	361203098494301	20010611	< 0.026	< 0.017	< 0.033	0.033	0.338	< 0.004	< 0.004	< 0.003	< 0.003
48	361210098112201	20010808	< 0.026	< 0.017	< 0.033	<0.021	0.074	< 0.004	< 0.004	< 0.003	< 0.003
49	361215098491301	20010606	< 0.026	< 0.017	< 0.033	0.041	0.242	< 0.004	< 0.004	< 0.003	< 0.003

Appendix 2. Dissolved trace elements analyzed in samples from 10 lagoons and 76 of 79 monitoring wells at swine licensed-managed feeding operations in Oklahoma, 2001—Continued.

Lagoon and well numbers	Site identification number	Date (yyyymmdd)	Aluminum	Antimony	Arsenic	Boron	Barium	Beryllium	Cadmium	Cobalt	Chromium
50	361215098491501	20010606	< 0.026	< 0.017	< 0.033	0.047	0.211	< 0.004	< 0.004	< 0.003	< 0.003
51	361240098494201	20010801	< 0.026	< 0.017	< 0.033	0.029	0.157	< 0.004	< 0.004	< 0.003	< 0.003
52	361240098494401	20010607	< 0.026	< 0.017	< 0.033	0.054	0.348	< 0.004	< 0.004	< 0.003	< 0.003
53	361245098494401	20010606	<0.026	<0.017	<0.033	0.048	0.219	<0.004	<0.004	<0.003	<0.003
54	362100099050301	20010628	< 0.026	< 0.017	< 0.033	0.026	0.239	< 0.004	< 0.004	< 0.003	< 0.003
55	362118099050301	20010628	< 0.026	< 0.017	< 0.033	0.034	0.164	< 0.004	< 0.004	< 0.003	< 0.003
56	362136099041201	20010626	< 0.026	< 0.017	< 0.033	0.037	0.251	< 0.004	< 0.004	< 0.003	< 0.003
57	362136099051001	20010626	< 0.026	< 0.017	< 0.033	0.036	0.232	< 0.004	< 0.004	< 0.003	< 0.003
58	363153101185001	20010710	0.108	< 0.017	0.043	0.334	0.164	< 0.004	< 0.004	< 0.003	< 0.003
59	363601101241301	20010710	< 0.026	< 0.017	< 0.033	0.315	0.052	< 0.004	< 0.004	< 0.003	< 0.003
60	363602101244501	20010710	< 0.026	< 0.017	< 0.033	0.313	0.088	< 0.004	< 0.004	< 0.003	< 0.003
61	364150101071901	20010605	0.028	< 0.017	< 0.033	0.172	0.124	< 0.004	< 0.004	< 0.003	< 0.003
62	364500101155301	20010605	< 0.026	< 0.017	< 0.033	0.079	0.108	< 0.004	< 0.004	< 0.003	< 0.003
63	364722100545501	20010709	< 0.026	< 0.017	0.036	0.225	0.196	< 0.004	< 0.004	< 0.003	< 0.003
64	364728100563501	20010709	< 0.026	< 0.017	0.036	0.302	0.491	< 0.004	< 0.004	< 0.003	< 0.003
65	365006100451001	20010531	< 0.026	< 0.017	< 0.033	0.131	0.139	< 0.004	< 0.004	< 0.003	< 0.003
66	365024100450701	20010530	0.031	< 0.017	< 0.033	0.522	0.088	< 0.004	< 0.004	0.007	< 0.003
67	365919099490901	20010613	< 0.026	< 0.017	< 0.033	0.339	0.018	< 0.004	< 0.004	< 0.003	< 0.003
68	365938099490901	20010613	< 0.026	< 0.017	< 0.033	0.350	0.081	< 0.004	< 0.004	< 0.003	< 0.003
69	365941099475101	20010716	0.046	< 0.017	< 0.033	0.240	0.049	< 0.004	< 0.004	< 0.003	< 0.003
70	365941099490701	20010613	< 0.026	< 0.017	< 0.033	0.326	0.038	< 0.004	< 0.004	< 0.003	< 0.003
71	365942099473701	20010717	0.030	< 0.017	< 0.033	0.335	0.049	< 0.004	< 0.004	< 0.003	< 0.003
72	365944099473401	20010717	0.049	< 0.017	< 0.033	0.319	0.043	< 0.004	< 0.004	< 0.003	0.004
73	365945099474901	20010716	0.032	< 0.017	< 0.033	0.214	0.054	< 0.004	< 0.004	< 0.003	< 0.003
74	365945099491401	20010614	< 0.026	< 0.017	< 0.033	0.493	0.149	< 0.004	< 0.004	< 0.003	< 0.003
75	365947099492101	20010614	< 0.026	< 0.017	< 0.033	0.120	0.195	< 0.004	< 0.004	< 0.003	< 0.003
76	365948099491701	20010716	0.027	< 0.017	< 0.033	0.177	0.105	< 0.004	< 0.004	< 0.003	< 0.003
77	365954099473701	20010717	0.045	< 0.017	< 0.033	0.236	0.093	< 0.004	< 0.004	< 0.003	< 0.003
78	370002099484101	20010612	< 0.026	< 0.017	< 0.033	0.597	0.079	< 0.004	< 0.004	< 0.003	0.003

Appendix 2. Dissolved trace elements analyzed in samples from 10 lagoons and 76 of 79 monitoring wells at swine licensed-managed feeding operations in Oklahoma, 2001—Continued.

Lagoon and well numbers	Site identification number	Date (yyyymmdd)	Aluminum	Antimony	Arsenic	Boron	Barium	Beryllium	Cadmium	Cobalt	Chromium
79	370003099483501	20010612	< 0.026	< 0.017	< 0.033	0.271	0.066	< 0.004	< 0.004	< 0.003	< 0.003

Appendix 2. Dissolved trace elements analyzed in samples from 10 lagoons and 76 of 79 monitoring wells at swine licensed-managed feeding operations in Oklahoma, 2001—Continued

Lagoon and well numbers	Site identification number	Date (yyyymmdd)	Copper	Iron	Lead	Manganese	Molybdenum	Nickel	Selenium
L1	343756096364402	20010720	< 0.110	1.153	< 0.150	0.035	< 0.090	0.186	< 0.300
L2	351857098004304	20010615	< 0.110	3.820	< 0.150	< 0.030	< 0.090	0.266	< 0.300
L3	360635098032902	22010625	< 0.055	< 0.175	< 0.075	0.044	< 0.045	0.048	< 0.150
L4	361028098440703	20010716	< 0.110	< 0.350	< 0.150	< 0.030	< 0.090	0.082	< 0.300
L5	361028098440707	20010717	< 0.110	0.528	< 0.150	0.036	< 0.090	0.094	< 0.300
L6	361028098440708	20010717	< 0.110	< 0.350	< 0.150	0.035	< 0.090	0.074	< 0.300
L7	362118099050001	20010628	< 0.110	< 0.350	< 0.150	0.005	< 0.090	0.110	< 0.300
L8	363605101241301	20010711	< 0.110	< 0.350	< 0.150	0.134	< 0.090	0.066	< 0.300
L9	365009100450901	20010531	0.020	0.451	< 0.015	0.026	0.011	0.059	0.032
L10	365956099473701	20010717	< 0.110	1.283	< 0.150	< 0.030	< 0.090	0.205	< 0.300
1	343756096364401	20010720	< 0.011	< 0.035	< 0.015	0.038	< 0.009	< 0.003	< 0.030
2	343756096364403	20010720	< 0.011	< 0.035	< 0.015	< 0.003	< 0.009	< 0.003	< 0.030
3	351857098004301	20010614	< 0.011	< 0.035	< 0.015	< 0.003	< 0.009	< 0.003	< 0.030
4	351857098004302	20010615	< 0.011	< 0.035	< 0.015	< 0.003	< 0.009	< 0.003	< 0.030
5	351857098004303	20010614	< 0.011	< 0.035	< 0.015	< 0.003	< 0.009	< 0.003	< 0.030
6	353922098503101	20010618	< 0.011	< 0.035	< 0.015	0.008	< 0.009	< 0.003	< 0.030
7	360134097591401	20010530	< 0.011	< 0.035	< 0.015	< 0.003	< 0.009	< 0.003	< 0.030
8	360135097591801	20010529	< 0.011	< 0.035	< 0.015	< 0.003	< 0.009	0.004	< 0.030
9	360146098013602	20010703	< 0.011	< 0.035	< 0.015	< 0.003	< 0.009	< 0.003	< 0.030
10	360212097583601	20010702	< 0.011	< 0.035	< 0.015	< 0.003	< 0.009	< 0.003	< 0.030
11	360317098015301	20010619	< 0.011	< 0.035	< 0.015	0.114	< 0.009	< 0.003	< 0.030
12	360317098015302	20010620	< 0.011	< 0.035	< 0.015	< 0.003	< 0.009	< 0.003	< 0.030
13	360317098015303	20010620	< 0.011	< 0.035	< 0.015	0.005	< 0.009	< 0.003	< 0.030
14	360325098010701	20010620	< 0.011	< 0.035	< 0.015	< 0.003	< 0.009	< 0.003	< 0.030
15	360339098170301	20010517	< 0.011	< 0.035	< 0.015	< 0.003	< 0.009	< 0.003	< 0.030
16	360339098170701	20010517	< 0.011	< 0.035	< 0.015	< 0.003	< 0.009	< 0.003	< 0.030
17	360416098013601	20010703	< 0.011	< 0.035	< 0.015	< 0.003	< 0.009	< 0.003	< 0.030

Appendix 2. Dissolved trace elements analyzed in samples from 10 lagoons and 76 of 79 monitoring wells at swine licensed-managed feeding operations in Oklahoma, 2001—Continued

Lagoon and well numbers	Site identification number	Date (yyyymmdd)	Copper	Iron	Lead	Manganese	Molybdenum	Nickel	Selenium
18	360521098022501	20010626	< 0.011	< 0.035	< 0.015	< 0.003	< 0.009	< 0.003	< 0.030
19	360521098022502	20010626	< 0.011	< 0.035	< 0.015	< 0.003	< 0.009	< 0.003	< 0.030
20	360618098024501	20010619	< 0.011	< 0.035	< 0.015	0.006	< 0.009	< 0.003	< 0.030
22	360634098030901	20010625	< 0.011	< 0.035	< 0.015	0.085	< 0.009	< 0.003	< 0.030
23	360634098030902	20010702	< 0.011	< 0.035	< 0.015	< 0.003	< 0.009	< 0.003	< 0.030
24	360635098032901	20010625	< 0.011	< 0.035	< 0.015	0.093	< 0.009	< 0.003	< 0.030
27	361028098440701	20010716	< 0.011	< 0.035	< 0.015	< 0.003	< 0.009	< 0.003	< 0.030
28	361028098440702	20010716	< 0.011	< 0.035	< 0.015	< 0.003	< 0.009	< 0.003	< 0.030
29	361028098440704	20010716	< 0.011	< 0.035	< 0.015	< 0.003	< 0.009	< 0.003	< 0.030
30	361028098440705	20010717	< 0.011	< 0.035	< 0.015	< 0.003	< 0.009	< 0.003	< 0.030
31	361028098440706	20010717	< 0.011	< 0.035	< 0.015	< 0.003	< 0.009	< 0.003	< 0.030
32	361115098504701	20010802	< 0.011	< 0.035	< 0.015	< 0.003	< 0.009	< 0.003	< 0.030
33	361116098463001	20010524	< 0.011	< 0.035	< 0.015	< 0.003	< 0.009	< 0.003	< 0.030
34	361117098504301	20010802	< 0.011	< 0.035	< 0.015	< 0.003	< 0.009	< 0.003	< 0.030
35	361118098463301	20010524	< 0.011	< 0.035	< 0.015	< 0.003	< 0.009	< 0.003	< 0.030
36	361121098504501	20010807	0.012	< 0.035	< 0.015	< 0.003	< 0.009	< 0.003	< 0.030
37	361122098462801	20010611	< 0.011	< 0.035	< 0.015	< 0.003	< 0.009	< 0.003	< 0.030
38	361122098493901	20010821	< 0.011	< 0.035	< 0.015	< 0.003	< 0.009	< 0.003	< 0.030
39	361133098485701	20010807	< 0.011	< 0.035	< 0.015	< 0.003	< 0.009	< 0.003	< 0.030
40	361136098374401	20010731	< 0.011	< 0.035	< 0.015	< 0.003	< 0.009	0.005	< 0.030
41	361139098374801	20010731	< 0.011	< 0.035	< 0.015	< 0.003	< 0.009	< 0.003	< 0.030
42	361139098485901	20010807	0.014	< 0.035	< 0.015	< 0.003	< 0.009	< 0.003	< 0.030
43	361143098374801	20010731	< 0.011	< 0.035	< 0.015	< 0.003	< 0.009	< 0.003	< 0.030
44	361146098504501	20010801	< 0.011	< 0.035	< 0.015	< 0.003	< 0.009	< 0.003	< 0.030
45	361152098504401	20010802	< 0.011	< 0.035	< 0.015	< 0.003	< 0.009	< 0.003	< 0.030
46	361157098494101	20010607	< 0.011	< 0.035	< 0.015	< 0.003	< 0.009	< 0.003	< 0.030
47	361203098494301	20010611	< 0.011	< 0.035	< 0.015	< 0.003	< 0.009	< 0.003	< 0.030
48	361210098112201	20010808	0.018	< 0.035	< 0.015	< 0.003	< 0.009	< 0.003	< 0.030
49	361215098491301	20010606	< 0.011	< 0.035	< 0.015	< 0.003	< 0.009	< 0.003	< 0.030

Appendix 2. Dissolved trace elements analyzed in samples from 10 lagoons and 76 of 79 monitoring wells at swine licensed-managed feeding operations in Oklahoma, 2001—Continued

Lagoon and well numbers	Site identification number	Date (yyyymmdd)	Copper	Iron	Lead	Manganese	Molybdenum	Nickel	Selenium
50	361215098491501	20010606	< 0.011	< 0.035	< 0.015	< 0.003	< 0.009	< 0.003	< 0.030
51	361240098494201	20010801	< 0.011	< 0.035	< 0.015	< 0.003	< 0.009	< 0.003	< 0.030
52	361240098494401	20010607	< 0.011	< 0.035	< 0.015	< 0.003	< 0.009	< 0.003	< 0.030
53	361245098494401	20010606	<0.011	<0.035	<0.015	<0.003	<0.009	<0.003	<0.030
54	362100099050301	20010628	< 0.011	< 0.035	< 0.015	< 0.003	< 0.009	< 0.003	< 0.030
55	362118099050301	20010628	< 0.011	< 0.035	< 0.015	< 0.003	< 0.009	< 0.003	< 0.030
56	362136099041201	20010626	< 0.011	< 0.035	< 0.015	< 0.003	< 0.009	< 0.003	< 0.030
57	362136099051001	20010626	< 0.011	< 0.035	< 0.015	< 0.003	< 0.009	< 0.003	< 0.030
58	363153101185001	20010710	< 0.011	0.044	< 0.015	0.114	< 0.009	< 0.003	0.069
59	363601101241301	20010710	< 0.011	< 0.035	< 0.015	< 0.003	< 0.009	< 0.003	< 0.030
60	363602101244501	20010710	< 0.011	< 0.035	< 0.015	< 0.003	< 0.009	< 0.003	< 0.030
61	364150101071901	20010605	< 0.011	< 0.035	< 0.015	< 0.003	< 0.009	< 0.003	< 0.030
62	364500101155301	20010605	< 0.011	< 0.035	< 0.015	< 0.003	< 0.009	< 0.003	< 0.030
63	364722100545501	20010709	< 0.011	< 0.035	< 0.015	< 0.003	< 0.009	< 0.003	< 0.030
64	364728100563501	20010709	< 0.011	< 0.035	< 0.015	0.004	< 0.009	< 0.003	< 0.030
65	365006100451001	20010531	< 0.011	< 0.035	< 0.015	< 0.003	< 0.009	< 0.003	< 0.030
66	365024100450701	20010530	0.029	0.037	< 0.015	0.009	< 0.009	0.007	< 0.030
67	365919099490901	20010613	< 0.011	< 0.035	< 0.015	< 0.003	< 0.009	< 0.003	< 0.030
68	365938099490901	20010613	< 0.011	< 0.035	< 0.015	< 0.003	0.010	< 0.003	< 0.030
69	365941099475101	20010716	< 0.011	< 0.035	< 0.015	< 0.003	< 0.009	< 0.003	< 0.030
70	365941099490701	20010613	< 0.011	< 0.035	< 0.015	< 0.003	0.012	< 0.003	< 0.030
71	365942099473701	20010717	< 0.011	< 0.035	< 0.015	< 0.003	< 0.009	< 0.003	< 0.030
72	365944099473401	20010717	< 0.011	< 0.035	< 0.015	< 0.003	< 0.009	< 0.003	< 0.030
73	365945099474901	20010716	< 0.011	< 0.035	< 0.015	< 0.003	< 0.009	< 0.003	< 0.030
74	365945099491401	20010614	< 0.011	< 0.035	< 0.015	< 0.003	0.010	< 0.003	< 0.030
75	365947099492101	20010614	< 0.011	< 0.035	< 0.015	< 0.003	< 0.009	< 0.003	< 0.030
76	365948099491701	20010716	< 0.011	< 0.035	< 0.015	< 0.003	0.009	< 0.003	< 0.030
77	365954099473701	20010717	< 0.011	< 0.035	< 0.015	< 0.003	< 0.009	< 0.003	< 0.030
78	370002099484101	20010612	< 0.011	< 0.035	< 0.015	< 0.003	0.018	< 0.003	< 0.030

Appendix 2. Dissolved trace elements analyzed in samples from 10 lagoons and 76 of 79 monitoring wells at swine licensed-managed feeding operations in Oklahoma, 2001—Continued

Lagoon and well numbers	Site identification number	Date (yyyymmdd)	Copper	Iron	Lead	Manganese	Molybdenum	Nickel	Selenium
79	370003099483501	20010612	< 0.011	< 0.035	< 0.015	< 0.003	< 0.009	< 0.003	< 0.030

Appendix 2. Dissolved trace elements in 10 lagoons and 76 of 79 wells at swine licensed managed feeding operations in Oklahoma—Continued

Lagoon and well numbers	Site identification number	Date (yyyymmdd)	Silver	Strontium	Titanium	Thallium	Vanadium	Zinc
L1	343756096364402	20010720	< 0.020	0.220	< 0.080	< 0.270	< 0.100	0.352
L2	351857098004304	20010615	< 0.020	0.133	< 0.060	< 0.270	< 0.100	0.483
L3	360635098032902	22010625	< 0.010	0.317	< 0.040	< 0.135	< 0.050	0.273
L4	361028098440703	20010716	< 0.020	0.359	< 0.080	< 0.270	< 0.100	< 0.170
L5	361028098440707	20010717	< 0.020	0.317	< 0.080	< 0.270	< 0.100	< 0.170
L6	361028098440708	20010717	< 0.020	0.357	< 0.080	< 0.270	< 0.100	< 0.170
L7	362118099050001	20010628	< 0.020	0.143	< 0.080	< 0.270	< 0.100	< 0.170
L8	363605101241301	20010711	< 0.020	1.567	< 0.080	< 0.270	< 0.100	0.180
L9	365009100450901	20010531	< 0.002	0.640	0.040	0.038	0.032	0.055
L10	365956099473701	20010717	< 0.020	0.288	< 0.080	< 0.270	< 0.100	0.675
1	343756096364401	20010720	< 0.002	0.387	< 0.008	0.028	< 0.010	< 0.017
2	343756096364403	20010720	< 0.002	0.391	< 0.008	< 0.027	< 0.010	< 0.017
3	351857098004301	20010614	< 0.002	1.564	< 0.008	0.033	0.021	< 0.017
4	351857098004302	20010615	< 0.002	1.623	< 0.008	0.027	< 0.010	< 0.017
5	351857098004303	20010614	< 0.002	0.920	< 0.008	0.032	< 0.010	< 0.017
6	353922098503101	20010618	< 0.002	3.807	< 0.008	0.033	0.015	< 0.017
7	360134097591401	20010530	< 0.002	0.152	< 0.008	< 0.027	< 0.010	< 0.017
8	360135097591801	20010529	< 0.002	0.357	< 0.008	0.028	< 0.010	< 0.017
9	360146098013602	20010703	< 0.002	0.551	< 0.008	< 0.027	< 0.010	< 0.017
10	360212097583601	20010702	< 0.002	0.268	< 0.008	< 0.027	< 0.010	< 0.017
11	360317098015301	20010619	< 0.002	1.086	< 0.008	0.030	< 0.010	< 0.017
12	360317098015302	20010620	< 0.002	0.340	< 0.008	< 0.027	< 0.010	< 0.017
13	360317098015303	20010620	< 0.002	0.776	< 0.008	0.038	0.015	< 0.017
14	360325098010701	20010620	< 0.002	0.335	< 0.008	< 0.027	< 0.010	< 0.017
15	360339098170301	20010517	< 0.002	0.689	< 0.008	0.029	< 0.010	< 0.017
16	360339098170701	20010517	< 0.002	0.578	< 0.008	< 0.027	< 0.010	< 0.017
17	360416098013601	20010703	< 0.002	0.443	< 0.008	0.031	< 0.010	< 0.017
18	360521098022501	20010626	< 0.002	0.330	< 0.008	< 0.027	< 0.010	< 0.017

Appendix 2. Dissolved trace elements in 10 lagoons and 76 of 79 wells at swine licensed managed feeding operations in Oklahoma—Continued

Lagoon and well numbers	Site identification number	Date (yyyymmdd)	Silver	Strontium	Titanium	Thallium	Vanadium	Zinc
19	360521098022502	20010626	< 0.002	0.637	< 0.008	< 0.027	< 0.010	< 0.017
20	360618098024501	20010619	< 0.002	0.103	< 0.008	< 0.027	< 0.010	< 0.017
22	360634098030901	20010625	< 0.002	0.451	< 0.008	0.029	< 0.010	< 0.017
23	360634098030902	20010702	< 0.002	0.236	< 0.008	0.027	< 0.010	0.024
24	360635098032901	20010625	< 0.002	0.501	< 0.008	0.028	< 0.010	< 0.017
27	361028098440701	20010716	< 0.002	0.736	< 0.008	0.029	0.033	< 0.017
28	361028098440702	20010716	< 0.002	0.369	< 0.008	< 0.027	< 0.010	< 0.017
29	361028098440704	20010716	< 0.002	0.325	< 0.008	< 0.027	< 0.010	< 0.017
30	361028098440705	20010717	< 0.002	0.200	< 0.008	< 0.027	< 0.010	< 0.017
31	361028098440706	20010717	< 0.002	0.250	< 0.008	< 0.027	< 0.010	< 0.017
32	361115098504701	20010802	< 0.002	0.280	< 0.008	< 0.027	< 0.010	< 0.017
33	361116098463001	20010524	< 0.002	0.420	< 0.008	< 0.027	< 0.010	< 0.017
34	361117098504301	20010802	< 0.002	0.256	< 0.008	< 0.027	< 0.010	< 0.017
35	361118098463301	20010524	< 0.002	0.292	< 0.008	< 0.027	< 0.010	< 0.017
36	361121098504501	20010807	< 0.002	0.203	< 0.008	< 0.027	< 0.010	< 0.017
37	361122098462801	20010611	< 0.002	0.297	< 0.008	< 0.027	< 0.010	< 0.017
38	361122098493901	20010821	< 0.002	0.434	< 0.008	0.028	< 0.010	< 0.017
39	361133098485701	20010807	< 0.002	0.455	< 0.008	0.030	< 0.010	< 0.017
40	361136098374401	20010731	< 0.002	0.672	< 0.008	0.034	< 0.010	< 0.017
41	361139098374801	20010731	< 0.002	0.595	< 0.008	0.034	< 0.010	< 0.017
42	361139098485901	20010807	< 0.002	0.599	< 0.008	0.033	< 0.010	< 0.017
43	361143098374801	20010731	< 0.002	0.305	< 0.008	< 0.027	< 0.010	0.019
44	361146098504501	20010801	< 0.002	0.351	< 0.008	< 0.027	< 0.010	< 0.017
45	361152098504401	20010802	< 0.002	0.370	< 0.008	0.032	< 0.010	< 0.017
46	361157098494101	20010607	< 0.002	0.125	< 0.008	< 0.027	< 0.010	< 0.017
47	361203098494301	20010611	< 0.002	0.161	< 0.008	< 0.027	< 0.010	< 0.017
48	361210098112201	20010808	< 0.002	0.090	< 0.008	< 0.027	< 0.010	< 0.017
49	361215098491301	20010606	< 0.002	0.224	< 0.008	< 0.027	< 0.010	< 0.017
50	361215098491501	20010606	< 0.002	0.252	< 0.008	< 0.027	< 0.010	< 0.017
51	361240098494201	20010801	< 0.002	0.200	< 0.008	< 0.027	< 0.010	< 0.017

Appendix 2. Dissolved trace elements in 10 lagoons and 76 of 79 wells at swine licensed managed feeding operations in Oklahoma—Continued

Lagoon and well numbers	Site identification number	Date (yyyymmdd)	Silver	Strontium	Titanium	Thallium	Vanadium	Zinc
52	361240098494401	20010607	< 0.002	0.256	< 0.008	< 0.027	< 0.010	< 0.017
53	361245098494401	20010606	<0.002	0.243	<0.008	<0.027	<0.010	<0.017
54	362100099050301	20010628	< 0.002	0.188	< 0.008	< 0.027	< 0.010	< 0.017
55	362118099050301	20010628	< 0.002	0.152	< 0.008	< 0.027	< 0.010	< 0.017
56	362136099041201	20010626	< 0.002	0.192	< 0.008	< 0.027	0.010	< 0.017
57	362136099051001	20010626	< 0.002	0.187	< 0.008	< 0.027	< 0.010	< 0.017
58	363153101185001	20010710	< 0.002	<0.006	< 0.008	< 0.027	0.025	< 0.017
59	363601101241301	20010710	< 0.002	3.625	< 0.008	< 0.027	0.046	< 0.017
60	363602101244501	20010710	< 0.002	3.595	< 0.008	< 0.027	0.034	< 0.017
61	364150101071901	20010605	< 0.002	1.259	< 0.008	< 0.027	0.023	< 0.017
62	364500101155301	20010605	< 0.002	1.779	< 0.008	< 0.027	0.013	< 0.017
63	364722100545501	20010709	< 0.002	3.396	< 0.008	< 0.027	0.016	< 0.017
64	364728100563501	20010709	< 0.002	4.574	< 0.008	< 0.027	0.019	0.127
65	365006100451001	20010531	< 0.002	2.059	< 0.008	< 0.027	0.016	< 0.017
66	365024100450701	20010530	< 0.002	1.032	< 0.008	< 0.027	0.028	< 0.017
67	365919099490901	20010613	< 0.002	0.931	< 0.008	0.028	0.021	< 0.017
68	365938099490901	20010613	< 0.002	0.210	< 0.008	< 0.027	0.060	< 0.017
69	365941099475101	20010716	< 0.002	0.753	< 0.008	< 0.027	0.013	< 0.017
70	365941099490701	20010613	< 0.002	0.313	< 0.008	< 0.027	0.037	< 0.017
71	365942099473701	20010717	< 0.002	0.598	< 0.008	< 0.027	0.012	< 0.017
72	365944099473401	20010717	< 0.002	0.699	< 0.008	< 0.027	< 0.010	< 0.017
73	365945099474901	20010716	< 0.002	0.810	< 0.008	< 0.027	0.012	< 0.017
74	365945099491401	20010614	< 0.002	0.568	< 0.008	< 0.027	0.025	< 0.017
75	365947099492101	20010614	< 0.002	1.238	< 0.008	< 0.027	< 0.010	< 0.017
76	365948099491701	20010716	< 0.002	0.961	< 0.008	< 0.027	0.018	< 0.017
77	365954099473701	20010717	< 0.002	0.216	< 0.008	< 0.027	< 0.010	< 0.017
78	370002099484101	20010612	< 0.002	0.315	< 0.008	< 0.027	0.023	< 0.017
79	370003099483501	20010612	< 0.002	0.829	< 0.008	< 0.027	0.020	< 0.017

Appendix 3. Wastewater organic compounds analyzed in samples from eight lagoons and 78 of 79 monitoring wells at swine licensed-managed feeding operations in Oklahoma, 2001

[L, lagoon; yyyymmdd, year, month, day; <, less than; E, estimated; --, no data; all concentrations in micrograms per liter, total]

Lagoon and well numbers	Site identification number	Date (yyyymmdd)	Time	Pesticide	Hydrocarbons			
				Bromacil	Benzo(a)pyrene	Fluoranthene	Phenanthrene	Pyrene
L1	343756096364402	20010720	1000	<0.5	<0.5	<0.5	<0.5	<0.5
L2	351857098004304	20010615	1100	<0.5	E 0.1	<0.5	E 0.4	<0.5
L3	360635098032902	20010625	1200	<0.5	<0.5	<0.5	<0.5	<0.5
L4	361028098440703	20010716	1300	<0.5	<0.5	<0.5	<0.5	<0.5
L7	362118099050001	20010628	1400	<0.5	<0.5	<0.5	<0.5	<0.5
L8	363605101241301	20010711	0800	<0.5	<0.5	0.6	<0.5	<0.5
L9	365009100450901	20010531	1300	<0.5	<0.5	<0.5	<0.5	<0.5
L10	365956099473701	20010717	1300	<0.5	<0.5	<0.5	<0.5	<0.5
1	343756096364401	20010720	1130	<0.5	<0.5	<0.5	<0.5	<0.5
2	343756096364403	20010720	1400	<0.5	<0.5	<0.5	<0.5	<0.5
3	351857098004301	20010614	0900	<0.5	<0.5	<0.5	<0.5	<0.5
4	351857098004302	20010615	1000	<0.5	<0.5	<0.5	<0.5	<0.5
5	351857098004303	20010614	1200	<0.5	<0.5	<0.5	<0.5	<0.5
6	353922098503101	20010618	1100	<0.5	<0.5	<0.5	<0.5	<0.5
7	360134097591401	20010530	1400	<0.5	<0.5	<0.5	<0.5	<0.5
8	360135097591801	20010529	1000	<0.5	E 0.1	E 0.3	E 0.1	E 0.2
9	360146098013602	20010703	1100	<0.5	<0.5	<0.5	<0.5	<0.5
10	360212097583601	20010702	1200	<0.5	<0.5	<0.5	<0.5	<0.5
11	360317098015301	20010619	1300	<0.5	<0.5	<0.5	<0.5	<0.5
12	360317098015302	20010620	0900	<0.5	<0.5	<0.5	<0.5	<0.5
13	360317098015303	20010620	1200	1.9	<0.5	<0.5	<0.5	<0.5
14	360325098010701	20010620	1400	<0.5	<0.5	<0.5	<0.5	<0.5
15	360339098170301	20010517	1300	<0.5	<0.5	<0.5	<0.5	<0.5
16	360339098170701	20010517	1500	<0.5	<0.5	<0.5	<0.5	<0.5
17	360416098013601	20010703	0900	1.4	<0.5	<0.5	<0.5	<0.5
18	360521098022501	20010626	1000	<0.5	<0.5	<0.5	<0.5	<0.5

Appendix 3. Wastewater organic compounds analyzed in samples from eight lagoons and 78 of 79 monitoring wells at swine licensed-managed feeding operations in Oklahoma, 2001—Continued.

[L, lagoon; yyyymmdd, year, month, day; <, less than; E, estimated; --, no data; all concentrations in micrograms per liter, total]

Lagoon and well numbers	Site identification number	Date (yyyymmdd)	Time	Pesticide	Hydrocarbons			
				Bromacil	Benzo(a)pyrene	Fluoranthene	Phenanthrene	Pyrene
19	360521098022502	20010626	1200	1.8	<0.5	<0.5	<0.5	<0.5
20	360618098024501	20010619	0900	<0.5	<0.5	<0.5	<0.5	<0.5
21	360618098024502	20010531	1300	E 0.3	<0.5	<0.5	<0.5	<0.5
23	360634098030902	20010702	1000	<0.5	<0.5	<0.5	<0.5	<0.5
24	360635098032901	20010625	1100	<0.5	<0.5	<0.5	<0.5	<0.5
25	360729098060901	20010529	1400	<0.5	<0.5	<0.5	<0.5	<0.5
26	360735098060801	20010529	1200	<0.5	<0.5	<0.5	<0.5	<0.5
27	361028098440701	20010716	1200	<0.5	<0.5	<0.5	<0.5	<0.5
28	361028098440702	20010716	1400	<0.5	<0.5	<0.5	<0.5	<0.5
29	361028098440704	20010704	1700	<0.5	<0.5	<0.5	<0.5	<0.5
30	361028098440705	20010717	0900	<0.5	<0.5	<0.5	<0.5	<0.5
31	361028098440706	20010717	1200	<0.5	<0.5	<0.5	<0.5	<0.5
32	361115098504701	20010802	1100	<0.5	<0.5	<0.5	<0.5	<0.5
33	361116098463001	20010524	1500	<0.5	<0.5	<0.5	<0.5	<0.5
34	361117098504301	20010802	1300	<0.5	<0.5	<0.5	<0.5	<0.5
35	361118098463301	20010524	1000	<0.5	<0.5	<0.5	<0.5	<0.5
36	361121098504501	20010807	0900	<0.5	<0.5	<0.5	<0.5	<0.5
37	361122098462801	20010611	1300	<0.5	<0.5	<0.5	<0.5	<0.5
38	361122098493901	20010821	0900	<0.5	<0.5	<0.5	<0.5	<0.5
39	361133098485701	20010807	1000	<0.5	<0.5	<0.5	<0.5	<0.5
40	361136098374401	20010731	1300	<0.5	<0.5	<0.5	<0.5	<0.5
41	361139098374801	20010731	1100	<0.5	<0.5	<0.5	<0.5	<0.5
42	361139098485901	20010807	1200	<0.5	<0.5	<0.5	<0.5	<0.5
43	361143098374801	20010731	0900	<0.5	<0.5	<0.5	<0.5	<0.5
44	361146098504501	20010801	1300	<0.5	<0.5	<0.5	<0.5	<0.5
45	361152098504401	20010802	0900	<0.5	<0.5	<0.5	<0.5	<0.5
46	361157098494101	20010607	1400	<0.5	<0.5	<0.5	<0.5	<0.5
47	361203098494301	20010611	1100	<0.5	<0.5	<0.5	<0.5	<0.5

Appendix 3. Wastewater organic compounds analyzed in samples from eight lagoons and 78 of 79 monitoring wells at swine licensed-managed feeding operations in Oklahoma, 2001—Continued.

[L, lagoon; yyyymmdd, year, month, day; <, less than; E, estimated; --, no data; all concentrations in micrograms per liter, total]

Lagoon and well numbers	Site identification number	Date (yyyymmdd)	Time	Pesticide	Hydrocarbons			
				Bromacil	Benzo(a)pyrene	Fluoranthene	Phenanthrene	Pyrene
48	361210098112201	20010808	1200	<0.5	<0.5	<0.5	<0.5	<0.5
49	361215098491301	20010606	1000	<0.5	<0.5	<0.5	<0.5	<0.5
50	361215098491501	20010606	1200	<0.5	<0.5	<0.5	<0.5	<0.5
51	361240098494201	20010801	0900	<0.5	E 0.1	E 0.1	E 0.070	E 0.1
52	361240098494401	20010607	0900	<0.5	<0.5	<0.5	<0.5	<0.5
53	361245098494401	20010606	1400	<0.5	<0.5	<0.5	<0.5	<0.5
54	362100099050301	20010628	1003	<0.5	<0.5	<0.5	<0.5	<0.5
55	362118099050301	20010628	1300	<0.5	<0.5	<0.5	<0.5	<0.5
56	362136099041201	20010601	1400	<0.5	<0.5	<0.5	<0.5	<0.5
57	362136099051001	20010626	1000	<0.5	<0.5	<0.5	<0.5	<0.5
58	363153101185001	20010710	1000	<0.5	<0.5	<0.5	<0.5	<0.5
59	363601101241301	20010710	1700	<0.5	<0.5	<0.5	<0.5	<0.5
60	363602101244501	20010710	1400	<0.5	<0.5	<0.5	<0.5	<0.5
61	364150101071901	20010605	1500	<0.5	<0.5	<0.5	<0.5	<0.5
62	364500101155301	20010605	1300	<0.5	<0.5	<0.5	<0.5	<0.5
63	364722100545501	20010709	1400	E 0.1	<0.5	<0.5	<0.5	<0.5
64	364728100563501	20010709	1700	2.2	<0.5	<0.5	<0.5	<0.5
65	365006100451001	20010531	0900	<0.5	<0.5	<0.5	<0.5	<0.5
66	365024100450701	20010530	1000	E 0.4	<0.5	<0.5	<0.5	<0.5
67	365919099490901	20010613	1000	<0.5	<0.5	<0.5	<0.5	<0.5
68	365938099490901	20010613	1300	<0.5	<0.5	<0.5	<0.5	<0.5
69	365941099475101	20010716	1300	<0.5	<0.5	<0.5	<0.5	<0.5
70	365941099490701	20010613	1500	<0.5	<0.5	<0.5	<0.5	<0.5
71	365942099473701	20010717	0900	<0.5	<0.5	<0.5	<0.5	<0.5
72	365944099473401	20010717	1100	<0.5	<0.5	<0.5	<0.5	<0.5
73	365945099474901	20010716	1100	<0.5	<0.5	<0.5	<0.5	<0.5
74	365945099491401	20010614	1000	<0.5	<0.5	<0.5	<0.5	<0.5
75	365947099492101	20010614	1200	<0.5	<0.5	<0.5	<0.5	<0.5

Appendix 3. Wastewater organic compounds analyzed in samples from eight lagoons and 78 of 79 monitoring wells at swine licensed-managed feeding operations in Oklahoma, 2001—Continued.

[L, lagoon; yyyymmdd, year, month, day; <, less than; E, estimated; --, no data; all concentrations in micrograms per liter, total]

Lagoon and well numbers	Site identification number	Date (yyyymmdd)	Time	Pesticide	Hydrocarbons			
				Bromacil	Benzo(a)pyrene	Fluoranthene	Phenanthrene	Pyrene
76	365948099491701	20010716	1000	<0.5	<0.5	<0.5	<0.5	<0.5
77	365954099473701	20010717	1200	<0.5	<0.5	<0.5	<0.5	<0.5
78	370002099484101	20010612	1200	<0.5	<0.5	<0.5	<0.5	<0.5
79	370003099483501	20010612	1400	<0.5	<0.5	<0.5	<0.5	<0.5

Appendix 3. Wastewater organic compounds analyzed in samples from eight lagoons and 78 of 79 monitoring wells at swine licensed-managed feeding operations in Oklahoma, 2001—Continued

Lagoon and well numbers	Site identification number	Industrial		Animal waste						
		Isophorone I	Para-cresol	3-beta-coprostanol	Skatol	Beta-sito-sterol	Stigmas-tanol	Cholesterol	Equilenin	Esterone
L1	343756096364402	E 0.2	6.4	300	110	130	220	150	<5	<5
L2	351857098004304	E 0.2	14	700	54	420	900	460	<5	E 4
L3	360635098032902	E 0.2	<1	E 290	E 0.2	E 130	E 25	E 280	<5	<5
L4	361028098440703	E 0.2	3.5	220	94	97	140	210	<5	<5
L7	362118099050001	<0.5	<1	<2	<1	<2	<2	<2	<5	<5
L8	363605101241301	E 0.2	190	230	220	93	53	200	<5	<5
L9	365009100450901	E 0.4	E 0.4	6.4	E 0.7	6.8	3.1	7.5	E 0.1	E 50
L10	365956099473701	<0.5	1200	540	380	330	700	260	<5	<5
1	343756096364401	<0.5	<1	<2	<1	<2	<2	<2	<5	<5
2	343756096364403	<0.5	<1	E 1	<1	<2	<2	<2	<5	<5
3	351857098004301	<0.5	<1	<2	<1	<2	<2	<2	<5	<5
4	351857098004302	<0.5	<1	<2	<1	<2	<2	<2	<5	<5
5	351857098004303	<0.5	<1	<2	<1	<2	<2	<2	<5	<5
6	353922098503101	<0.5	<1	<2	<1	<2	<2	<2	<5	<5
7	360134097591401	<0.5	<1	<2	<1	<2	<2	<2	<5	<5
8	360135097591801	<0.5	<1	<2	<1	<2	<2	<2	<5	<5
9	360146098013602	<0.5	<1	<2	<1	<2	<2	<2	<5	<5
10	360212097583601	<0.5	<1	<2	<1	<2	<2	<2	<5	<5
11	360317098015301	<0.5	<1	<2	<1	<2	<2	<2	<5	<5
12	360317098015302	<0.5	<1	<2	<1	<2	<2	<2	<5	<5
13	360317098015303	<0.5	<1	<2	<1	<2	<2	<2	<5	<5
14	360325098010701	<0.5	<1	<2	<1	<2	<2	<2	<5	<5
15	360339098170301	<0.5	<1	<2	<1	<2	<2	<2	<5	<5
16	360339098170701	<0.5	<1	<2	<1	<2	<2	<2	<5	<5
17	360416098013601	<0.5	<1	<2	<1	<2	<2	<2	<5	<5
18	360521098022501	<0.5	<1	E 1	<1	E 1	<2	E 1	<5	<5
19	360521098022502	<0.5	<1	<2	<1	<2	<2	<2	<5	<5

Appendix 3. Wastewater organic compounds analyzed in samples from eight lagoons and 78 of 79 monitoring wells at swine licensed-managed feeding operations in Oklahoma, 2001—Continued

Lagoon and well numbers	Site identification number	Industrial		Animal waste						
		Isophorone I	Para-cresol	3-beta-coprostanol	Skatol	Beta-sito-sterol	Stigmas-tanol	Cholesterol	Equilenin	Esterone
20	360618098024501	<0.5	<1	<2	<1	<2	<2	<2	<5	<5
21	360618098024502	<0.5	<1	<2	<1	<2	<2	<2	<5	<5
23	360634098030902	<0.5	<1	<2	<1	<2	<2	<2	<5	<5
24	360635098032901	<0.5	<1	<2	<1	<2	<2	<2	<5	<5
25	360729098060901	<0.5	<1	<2	<1	<2	<2	<2	<5	<5
26	360735098060801	<0.5	<1	<2	<1	<2	<2	<2	<5	<5
27	361028098440701	<0.5	<1	<2	<1	<2	<2	<2	<5	<5
28	361028098440702	<0.5	<1	2	<1	E 1	<2	E 2	<5	<5
29	361028098440704	<0.5	<1	<2	<1	<2	<2	<2	<5	<5
30	361028098440705	<0.5	<1	<2	<1	<2	<2	<2	<5	<5
31	361028098440706	<0.5	<1	<2	<1	<2	<2	<2	<5	<5
32	361115098504701	<0.5	<1	<2	<1	<2	<2	<2	<5	<5
33	361116098463001	<0.5	<1	<2	<1	<2	<2	<2	<5	<5
34	361117098504301	<0.5	<1	<2	<1	<2	<2	<2	<5	<5
35	361118098463301	<0.5	<1	<2	<1	<2	<2	<2	<5	<5
36	361121098504501	<0.5	<1	<2	<1	<2	<2	<2	<5	<5
37	361122098462801	<0.5	<1	<2	<1	<2	<2	<2	<5	<5
38	361122098493901	<0.5	<1	<2	<1	<2	<2	<2	<5	<5
39	361133098485701	<0.5	<1	<2	<1	<2	<2	<2	E 0.003	<5
40	361136098374401	<0.5	<1	E 1	<1	2	E 1	E 1	<5	<5
41	361139098374801	<0.5	<1	<2	<1	<2	<2	<2	<5	<5
42	361139098485901	<0.5	<1	<2	<1	<2	<2	<2	<5	<5
43	361143098374801	<0.5	<1	<2	<1	E 1	<2	<2	<5	<5
44	361146098504501	<0.5	<1	<2	<1	<2	<2	<2	<5	<5
45	361152098504401	<0.5	<1	<2	<1	<2	<2	<2	<5	<5
46	361157098494101	<0.5	<0.5	<2	<1	<2	<2	<2	<5	<5
47	361203098494301	<0.5	<1	<2	<1	<2	<2	<2	<5	<5
48	361210098112201	<0.5	<1	<2	<1	<2	<2	<2	<5	<5
49	361215098491301	<0.5	<1	<2	<1	<2	<2	<2	<5	<5

Appendix 3. Wastewater organic compounds analyzed in samples from eight lagoons and 78 of 79 monitoring wells at swine licensed-managed feeding operations in Oklahoma, 2001—Continued

Lagoon and well numbers	Site identification number	Industrial		Animal waste						
		Isophorone I	Para-cresol	3-beta-coprostanol	Skatol	Beta-sito-sterol	Stigmas-tanol	Cholesterol	Equilenin	Esterone
50	361215098491501	<0.5	<1	<2	<1	<2	<2	<2	<5	<5
51	361240098494201	<0.5	<1	<2	<1	<2	<2	E 1	<5	<5
52	361240098494401	<0.5	<1	<2	<1	<2	<2	<2	<5	<5
53	361245098494401	<0.5	<1	<2	<1	<2	<2	<2	<5	<5
54	362100099050301	<0.5	E 0.1	2	E 0.1	E 1	<2	E 1	<5	<5
55	362118099050301	<0.5	<1	<2	<1	<2	<2	<2	<5	<5
56	362136099041201	<0.5	<1	<2	<1	<2	<2	<2	<5	<5
57	362136099051001	<0.5	<1	<2	<1	<2	<2	<2	<5	<5
58	363153101185001	E 0.2	E 0.6	2	<1	E 1	E 1	2.5	<5	<5
59	363601101241301	<0.5	<1	<2	<1	<2	<2	<2	<5	<5
60	363602101244501	<0.5	<1	<2	<1	<2	<2	<2	<5	<5
61	364150101071901	<0.5	<1	<2	<1	<2	<2	<2	<5	<5
62	364500101155301	<0.5	<1	<2	<1	<2	<2	<2	<5	<5
63	364722100545501	<0.5	<1	E 0.3	<1	<2	<2	E 1	<5	<5
64	364728100563501	<0.5	<1	<2	<1	<2	<2	<2	<5	<5
65	365006100451001	<0.5	<1	<2	<1	<2	<2	<2	<5	<5
66	365024100450701	<0.5	<1	<2	<1	<2	<2	<2	<5	<5
67	365919099490901	<0.5	<1	<2	<1	<2	<2	<2	<5	<5
68	365938099490901	<0.5	<1	<2	<1	<2	<2	<2	<5	<5
69	365941099475101	<0.5	<1	<2	<1	<2	<2	<2	<5	<5
70	365941099490701	<0.5	<1	<2	<1	<2	<2	<2	<5	<5
71	365942099473701	<0.5	<1	E 0.3	<1	<2	<2	<2	<5	<5
72	365944099473401	<0.5	<1	<2	<1	<2	<2	<2	<5	<5
73	365945099474901	<0.5	<1	E 1	E 0.02	<2	E 0.5	<2	<5	<5
74	365945099491401	<0.5	<1	<2	<1	<2	<2	<2	<5	<5
75	365947099492101	<0.5	<1	<2	<1	<2	<2	<2	<5	<5
76	365948099491701	<0.5	<1	<2	<1	<2	<2	<2	<5	<5
77	365954099473701	<0.5	<1	<2	<1	<2	<2	<2	<5	<5
78	370002099484101	<0.5	<1	<2	<1	<2	<2	<2	<5	<5

Appendix 3. Wastewater organic compounds analyzed in samples from eight lagoons and 78 of 79 monitoring wells at swine licensed-managed feeding operations in Oklahoma, 2001—Continued

Lagoon and well numbers	Site identification number	Industrial		Animal waste						
		Isophorone I	Para-cresol	3-beta-coprostanol	Skatol	Beta-sito-sterol	Stigmas-tanol	Cholesterol	Equilenin	Esterone
79	370003099483501	<0.5	<1	<2	<1	<2	<2	<2	<5	<5

Appendix 3. Wastewater organic compounds analyzed in samples from eight lagoons and 78 of 79 monitoring wells at swine licensed-managed feeding operations in Oklahoma, 2001—Continued

Lagoon and well numbers	Site identification number	Household							
		BHA	Acetophenone	Anthraquinone	Bisphenol A	Bromoform	Caffeine	Camphor	Carbazole
L1	343756096364402	<5	1	<0.5	<1	<0.5	1.1	<0.5	<0.5
L2	351857098004304	<5	0.7	<0.5	<1	<0.5	<0.5	<0.5	0.93
L3	360635098032902	<5	E 0.3	<0.5	<1	<0.5	<0.5	E 0.2	<0.5
L4	361028098440703	<5	1.8	<0.5	<1	<0.5	<0.5	E 0.1	<0.5
L7	362118099050001	<5	E 0.2	<0.5	<1	<0.5	<0.5	<0.5	<0.5
L8	363605101241301	E 1	1.2	<0.5	<1	<0.5	E 0.2	<0.5	<0.5
L9	365009100450901	<5	0.9	<0.5	<1	<0.5	E 0.3	E 0.3	<0.5
L10	365956099473701	<5	2.5	<0.5	<1	<0.5	<0.5	<0.5	<0.5
1	343756096364401	<5	<0.5	<0.5	<1	<0.5	E 0.2	<0.5	<0.5
2	343756096364403	<5	<0.5	<0.5	<1	<0.5	E 0.1	<0.5	<0.5
3	351857098004301	<5	<0.5	<0.5	<1	<0.5	--	<0.5	<0.5
4	351857098004302	<5	<0.5	<0.5	<1	<0.5	<0.5	<0.5	<0.5
5	351857098004303	<5	<0.5	<0.5	<1	<0.5	<0.5	<0.5	<0.5
6	353922098503101	<5	<0.5	<0.5	<1	<0.5	<0.5	<0.5	<0.5
7	360134097591401	<5	<0.5	<0.5	<1	<0.5	<0.5	<0.5	<0.5
8	360135097591801	<5	<0.5	E 0.1	<1	<0.5	E 0.2	<0.5	<0.5
9	360146098013602	<5	<0.5	<0.5	<1	<0.5	<0.5	<0.5	<0.5
10	360212097583601	<5	<0.5	<0.5	<1	<0.5	<0.5	<0.5	<0.5
11	360317098015301	<5	<0.5	<0.5	<1	<0.5	E 0.1	<0.5	<0.5
12	360317098015302	<5	<0.5	<0.5	<1	<0.5	<0.5	<0.5	<0.5
13	360317098015303	<5	<0.5	<0.5	<1	<0.5	<0.5	<0.5	<0.5
14	360325098010701	<5	<0.5	<0.5	<1	<0.5	<0.5	<0.5	<0.5
15	360339098170301	<5	<0.5	<0.5	<1	<0.5	<0.5	<0.5	<0.5
16	360339098170701	<5	<0.5	<0.5	<1	<0.5	<0.5	<0.5	<0.5
17	360416098013601	<5	<0.5	<0.5	<1	<0.5	<0.5	<0.5	<0.5
18	360521098022501	<5	<0.5	<0.5	<1	<0.5	<0.5	<0.5	<0.5
19	360521098022502	<5	<0.5	<0.5	<1	<0.5	<0.5	<0.5	<0.5
20	360618098024501	<5	<0.5	<0.5	<1	<0.5	E 0.04	E 0.1	<0.5

Appendix 3. Wastewater organic compounds analyzed in samples from eight lagoons and 78 of 79 monitoring wells at swine licensed-managed feeding operations in Oklahoma, 2001—Continued

Lagoon and well numbers	Site identification number	Household							
		BHA	Acetophenone	Anthraquinone	Bisphenol A	Bromoform	Caffeine	Camphor	Carbazole
21	360618098024502	<5	<0.5	<0.5	<1	E 0.1	E 0.04	<0.5	<0.5
23	360634098030902	<5	<0.5	<0.5	<1	<0.5	<0.5	<0.5	<0.5
24	360635098032901	<5	<0.5	<0.5	<1	<0.5	<0.5	<0.5	<0.5
25	360729098060901	<5	<0.5	<0.5	E 0.1	<0.5	<0.5	<0.5	<0.5
26	360735098060801	<5	<0.5	<0.5	<1	<0.5	E 0.1	<0.5	<0.5
27	361028098440701	<5	<0.5	<0.5	<1	<0.5	<0.5	<0.5	<0.5
28	361028098440702	<5	<0.5	<0.5	<1	<0.5	<0.5	<0.5	<0.5
29	361028098440704	<5	<0.5	<0.5	<1	<0.5	<0.5	<0.5	<0.5
30	361028098440705	<5	<0.5	<0.5	<1	<0.5	<0.5	<0.5	<0.5
31	361028098440706	<5	<0.5	<0.5	<1	<0.5	<0.5	<0.5	<0.5
32	361115098504701	<5	<0.5	<0.5	<1	<0.5	E 0.05	<0.5	<0.5
33	361116098463001	<5	<0.5	<0.5	<1	<0.5	<0.5	<0.5	<0.5
34	361117098504301	<5	<0.5	<0.5	<1	<0.5	E 0.2	<0.5	<0.5
35	361118098463301	<5	<0.5	<0.5	1.1	<0.5	<0.5	<0.5	<0.5
36	361121098504501	<5	<0.5	<0.5	<1	<0.5	<0.5	<0.5	<0.5
37	361122098462801	<5	<0.5	<0.5	<1	<0.5	<0.5	<0.5	<0.5
38	361122098493901	<5	<0.5	<0.5	<1	<0.5	<0.5	<0.5	<0.5
39	361133098485701	<5	<0.5	<0.5	<1	<0.5	<0.5	<0.5	<0.5
40	361136098374401	<5	<0.5	<0.5	E 0.1	<0.5	<0.5	<0.5	<0.5
41	361139098374801	<5	<0.5	<0.5	<1	<0.5	<0.5	<0.5	<0.5
42	361139098485901	<5	<0.5	<0.5	<1	<0.5	<0.5	<0.5	<0.5
43	361143098374801	<5	<0.5	<0.5	<1	<0.5	E 0.1	<0.5	<0.5
44	361146098504501	<5	<0.5	<0.5	<1	<0.5	<0.5	<0.5	<0.5
45	361152098504401	<5	<0.5	<0.5	<1	<0.5	<0.5	<0.5	<0.5
46	361157098494101	<5	<0.5	<0.5	E 0.4	<0.5	<0.5	<0.5	<0.5
47	361203098494301	<5	<0.5	<0.5	<1	<0.5	<0.5	<0.5	<0.5
48	361210098112201	<5	<0.5	<0.5	<1	<0.5	<0.5	<0.5	<0.5
49	361215098491301	<5	<0.5	<0.5	<1	<0.5	<0.5	<0.5	<0.5
50	361215098491501	<5	<0.5	<0.5	<1	<0.5	<0.5	<0.5	<0.5

Appendix 3. Wastewater organic compounds analyzed in samples from eight lagoons and 78 of 79 monitoring wells at swine licensed-managed feeding operations in Oklahoma, 2001—Continued

Lagoon and well numbers	Site identification number	Household							
		BHA	Acetophenone	Anthraquinone	Bisphenol A	Bromoform	Caffeine	Camphor	Carbazole
51	361240098494201	<5	<0.5	E 0.1	<1	<0.5	E 0.1	<0.5	<0.5
52	361240098494401	<0.5	<0.5	<0.5	<1	E 0.3	<0.5	<0.5	<0.5
53	361245098494401	<5	<0.5	<0.5	<1	<0.5	E 0.05	<0.5	<0.5
54	362100099050301	<5	<0.5	<0.5	<1	<0.5	E 0.1	<0.5	<0.5
55	362118099050301	<5	<0.5	<0.5	<1	<0.5	E 0.04	<0.5	<0.5
56	362136099041201	<5	<0.5	<0.5	<1	<0.5	<0.5	<0.5	<0.5
57	362136099051001	<5	<0.5	<0.5	<1	<0.5	<0.5	<0.5	<0.5
58	363153101185001	<5	<0.5	<0.5	<1	<0.5	<0.5	<0.5	<0.5
59	363601101241301	<0.5	<0.5	<0.5	<1	<0.5	<0.5	<0.5	<0.5
60	363602101244501	<5	<0.5	<0.5	<1	<0.5	<0.5	<0.5	<0.5
61	364150101071901	<5	<0.5	<0.5	<1	<0.5	<0.5	<0.5	<0.5
62	364500101155301	<5	<0.5	<0.5	E 0.1	<0.5	<0.5	<0.5	<0.5
63	364722100545501	<5	<0.5	<0.5	<1	<0.5	<0.5	<0.5	<0.5
64	364728100563501	<5	<0.5	<0.5	<1	<0.5	<0.5	<0.5	<0.5
65	365006100451001	<5	<0.5	<0.5	<1	<0.5	<0.5	<0.5	<0.5
66	365024100450701	<5	<0.5	<0.5	<1	<0.5	<0.5	<0.5	<0.5
67	365919099490901	<5	<0.5	<0.5	<1	<0.5	<0.5	<0.5	<0.5
68	365938099490901	<5	<0.5	<0.5	<1	<0.5	<0.5	<0.5	<0.5
69	365941099475101	<5	<0.5	<0.5	<1	<0.5	E 0.04	<0.5	<0.5
70	365941099490701	<5	<0.5	<0.5	<1	<0.5	<0.5	<0.5	<0.5
71	365942099473701	<5	<0.5	<0.5	<1	<0.5	<0.5	<0.5	<0.5
72	365944099473401	<5	<0.5	<0.5	<1	<0.5	<0.5	<0.5	<0.5
73	365945099474901	<5	<0.5	<0.5	<1	<0.5	<0.5	<0.5	<0.5
74	365945099491401	<5	<0.5	<0.5	<1	<0.5	<0.5	<0.5	<0.5
75	365947099492101	<5	<0.5	<0.5	<1	<0.5	<0.5	<0.5	<0.5
76	365948099491701	<5	<0.5	<0.5	<1	<0.5	<0.5	<0.5	<0.5
77	365954099473701	<5	<0.5	<0.5	<1	<0.5	<0.5	<0.5	<0.5
78	370002099484101	<5	<0.5	<0.5	<1	<0.5	<0.5	<0.5	<0.5
79	370003099483501	<5	<0.5	<0.5	<1	<0.5	<0.5	<0.5	<0.5

Appendix 3. Wastewater organic compounds analyzed in samples from eight lagoons and 78 of 79 monitoring wells at swine licensed-managed feeding operations in Oklahoma, 2001—Continued

Lagoon and well numbers	Site identification number	Household					
		Indole	Isoquinoline	Methyl salicylate	Phenol	Tri(2-choro-ethyl)phosphate	Tri(dichoriso-propyl)phos-phate
L1	343756096364402	2.4	<0.5	<0.5	E 7.1	<0.5	E 0.4
L2	351857098004304	1.6	<0.5	<0.5	E 6.2	<0.5	<0.5
L3	360635098032902	E 0.2	<0.5	<0.5	<2.4	E 0.1	<0.5
L4	361028098440703	<0.5	<0.5	<0.5	E 3.4	<0.5	<0.5
L7	362118099050001	<0.5	<0.5	<0.5	E 0.7	<0.5	<0.5
L8	363605101241301	<0.5	1	<0.5	E 80.0	<0.5	<0.5
L9	365009100450901	0.8	<0.5	<0.5	E 0.6	<0.5	<0.5
L10	365956099473701	<0.5	<0.5	<0.5	E 74.0	<0.5	<0.5
1	343756096364401	<0.5	<0.5	<0.5	<2.4	<0.5	<0.5
2	343756096364403	<0.5	<0.5	<0.5	<2.4	<0.5	<0.5
3	351857098004301	<0.5	<0.5	<0.5	<2.4	<0.5	<0.5
4	351857098004302	<0.5	<0.5	<0.5	E 0.4	<0.5	<0.5
5	351857098004303	<0.5	<0.5	<0.5	<2.4	<0.5	<0.5
6	353922098503101	<0.5	<0.5	<0.5	E 0.7	<0.5	<0.5
7	360134097591401	<0.5	<0.5	<0.5	<2.4	<0.5	<0.5
8	360135097591801	<0.5	<0.5	<0.5	<2.4	<0.5	<0.5
9	360146098013602	<0.5	<0.5	<0.5	<2.4	<0.5	<0.5
10	360212097583601	<0.5	<0.5	<0.5	<2.4	<0.5	<0.5
11	360317098015301	<0.5	<0.5	<0.5	E 0.6	<0.5	<0.5
12	360317098015302	<0.5	<0.5	<0.5	E 0.3	<0.5	<0.5
13	360317098015303	<0.5	<0.5	<0.5	<2.4	<0.5	<0.5
14	360325098010701	<0.5	<0.5	<0.5	E 1.0	<0.5	<0.5
15	360339098170301	<0.5	<0.5	<0.5	<2.4	<0.5	<0.5
16	360339098170701	<0.5	<0.5	<0.5	<2.4	<0.5	<0.5
17	360416098013601	<0.5	<0.5	<0.5	<2.4	<0.5	<0.5
18	360521098022501	<0.5	<0.5	E 0.01	E 0.2	<0.5	<0.5
19	360521098022502	<0.5	<0.5	<0.5	E 0.4	<0.5	<0.5

Appendix 3. Wastewater organic compounds analyzed in samples from eight lagoons and 78 of 79 monitoring wells at swine licensed-managed feeding operations in Oklahoma, 2001—Continued

Lagoon and well numbers	Site identification number	Household					
		Indole	Isoquinoline	Methyl salicylate	Phenol	Tri(2-choro-ethyl)phosphate	Tri(dichoriso-propyl)phos-phate
20	360618098024501	<0.5	<0.5	<0.5	E 0.5	<0.5	<0.5
21	360618098024502	<0.5	<0.5	<0.5	E 0.2	<0.5	<0.5
23	360634098030902	<0.5	<0.5	<0.5	E 0.3	<0.5	<0.5
24	360635098032901	<0.5	<0.5	E 0.03	E 0.	<0.5	<0.5
25	360729098060901	<0.5	<0.5	<0.5	E 0.5	<0.5	<0.5
26	360735098060801	<0.5	<0.5	<0.5	<2.4	<0.5	<0.5
27	361028098440701	<0.5	<0.5	<0.5	E 0.3	<0.5	<0.5
28	361028098440702	<0.5	<0.5	<0.5	E 0.2	<0.5	<0.5
29	361028098440704	<0.5	<0.5	<0.5	<2.4	<0.5	<0.5
30	361028098440705	<0.5	<0.5	<0.5	<2.4	<0.5	<0.5
31	361028098440706	<0.5	<0.5	<0.5	<2.4	<0.5	<0.5
32	361115098504701	<0.5	<0.5	<0.5	<2.4	<0.5	<0.5
33	361116098463001	<0.5	<0.5	<0.5	E 0.3	<0.5	<0.5
34	361117098504301	<0.5	<0.5	<0.5	<2.4	<0.5	<0.5
35	361118098463301	<0.5	<0.5	<0.5	E 0.6	<0.5	<0.5
36	361121098504501	<0.5	<0.5	<0.5	<2.4	<0.5	<0.5
37	361122098462801	<0.5	<0.5	E 0.02	<2.4	<0.5	<0.5
38	361122098493901	<0.5	<0.5	<0.5	<2.4	<0.5	<0.5
39	361133098485701	<0.5	<0.5	<0.5	<2.4	<0.5	<0.5
40	361136098374401	<0.5	<0.5	<0.5	<2.4	<0.5	<0.5
41	361139098374801	<0.5	<0.5	<0.5	<2.4	<0.5	<0.5
42	361139098485901	<0.5	<0.5	<0.5	<2.4	<0.5	<0.5
43	361143098374801	<0.5	<0.5	<0.5	E 1.3	<0.5	<0.5
44	361146098504501	<0.5	<0.5	<0.5	<2.4	<0.5	<0.5
45	361152098504401	<0.5	<0.5	<0.5	<2.4	<0.5	<0.5
46	361157098494101	<0.5	<0.5	<0.5	E 0.2	<0.5	<0.5
47	361203098494301	<0.5	<0.5	<0.5	<2.4	<0.5	<0.5
48	361210098112201	<0.5	<0.5	<0.5	<2.4	<0.5	<0.5

Appendix 3. Wastewater organic compounds analyzed in samples from eight lagoons and 78 of 79 monitoring wells at swine licensed-managed feeding operations in Oklahoma, 2001—Continued

Lagoon and well numbers	Site identification number	Household					
		Indole	Isoquinoline	Methyl salicylate	Phenol	Tri(2-choro-ethyl)phosphate	Tri(dichoriso-propyl)phos-phate
49	361215098491301	<0.5	<0.5	<0.5	E 0.2	<0.5	<0.5
50	361215098491501	<0.5	<0.5	<0.5	E 0.3	<0.5	<0.5
51	361240098494201	<0.5	<0.5	<0.5	<2.4	<0.5	<0.5
52	361240098494401	<0.5	<0.5	<0.5	<2.4	<0.5	<0.5
53	361245098494401	<0.5	<0.5	<0.5	<2.4	<0.5	<0.5
54	362100099050301	E 0.2	<0.5	<0.5	<2.4	<0.5	<0.5
55	362118099050301	<0.5	<0.5	<0.5	E 0.5	<0.5	<0.5
56	362136099041201	<0.5	<0.5	<0.5	E 0.7	<0.5	<0.5
57	362136099051001	<0.5	<0.5	E 0.02	E 0.4	<0.5	<0.5
58	363153101185001	<0.5	<0.5	<0.5	<2.4	<0.5	<0.5
59	363601101241301	<0.5	<0.5	<0.5	<2.4	<0.5	<0.5
60	363602101244501	<0.5	<0.5	<0.5	<2.4	<0.5	<0.5
61	364150101071901	<0.5	<0.5	<0.5	<2.4	<0.5	<0.5
62	364500101155301	<0.5	<0.5	<0.5	<2.4	<0.5	<0.5
63	364722100545501	<0.5	<0.5	<0.5	<2.4	<0.5	<0.5
64	364728100563501	<0.5	<0.5	<0.5	<2.4	<0.5	<0.5
65	365006100451001	<0.5	<0.5	<0.5	E 0.8	<0.5	<0.5
66	365024100450701	<0.5	<0.5	<0.5	E 0.3	<0.5	<0.5
67	365919099490901	<0.5	<0.5	E 0.01	<2.4	<0.5	<0.5
68	365938099490901	<0.5	<0.5	<0.5	<2.4	<0.5	<0.5
69	365941099475101	<0.5	<0.5	E 0.01	E 0.4	<0.5	<0.5
70	365941099490701	<0.5	<0.5	<0.5	<2.4	<0.5	<0.5
71	365942099473701	<0.5	<0.5	E 0.01	<2.4	<0.5	<0.5
72	365944099473401	<0.5	<0.5	<0.5	E 0.2	<0.5	<0.5
73	365945099474901	<0.5	<0.5	<0.5	E 0.4	<0.5	<0.5
74	365945099491401	<0.5	<0.5	<0.5	<2.4	<0.5	<0.5
75	365947099492101	<0.5	<0.5	<0.5	<2.4	<0.5	<0.5
76	365948099491701	<0.5	<0.5	<0.5	<2.4	<0.5	<0.5

Appendix 3. Wastewater organic compounds analyzed in samples from eight lagoons and 78 of 79 monitoring wells at swine licensed-managed feeding operations in Oklahoma, 2001—Continued

Lagoon and well numbers	Site identification number	Household					
		Indole	Isoquinoline	Methyl salicylate	Phenol	Tri(2-choroethyl)phosphate	Tri(dichorisopropyl)phosphate
77	365954099473701	<0.5	<0.5	<0.5	<2.4	<0.5	<0.5
78	370002099484101	<0.5	<0.5	<0.5	E 0.2	<0.5	<0.5
79	370003099483501	<0.5	<0.5	<0.5	<2.4	<0.5	<0.5

Appendix 3. Wastewater organic compounds analyzed in samples from eight lagoons and 78 of 79 monitoring wells at swine licensed-managed feeding operations in Oklahoma, 2001—Continued

Lagoon and well numbers	Site identification number	Household		Detergents	
		Triclosan	Tris(2-butoxyethyl) phosphate	Para-nonylphenol total	Tributylphosphate
L1	343756096364402	<1	<0.5	E 2.2	2.5
L2	351857098004304	<1	<0.5	<5	<0.5
L3	360635098032902	<1	<0.5	<5	<0.5
L4	361028098440703	<1	<0.5	<5	<0.5
L7	362118099050001	<1	<0.5	<5	<0.5
L8	363605101241301	<1	<0.5	<5	2
L9	365009100450901	E 0.4	<0.5	<5	<0.5
L10	365956099473701	<1	0.6	<5	3.4
1	343756096364401	<1	<0.5	<5	<0.5
2	343756096364403	<1	<0.5	<5	<0.5
3	351857098004301	<1	<0.5	<5	<0.5
4	351857098004302	<1	<0.5	<5	<0.5
5	351857098004303	<1	<0.5	<5	<0.5
6	353922098503101	<1	<0.5	<5	<0.5
7	360134097591401	<1	<0.5	E 1	<0.5
8	360135097591801	<1	<0.5	E 1	<0.5
9	360146098013602	<1	<0.5	<5	<0.5
10	360212097583601	<1	<0.5	<5	<0.5
11	360317098015301	<1	<0.5	<5	<0.5
12	360317098015302	<1	<0.5	<5	<0.5
13	360317098015303	<1	<0.5	<5	<0.5
14	360325098010701	<1	<0.5	<5	<0.5
15	360339098170301	<1	<0.5	<5	<0.5
16	360339098170701	<1	<0.5	<5	<0.5
17	360416098013601	<1	<0.5	<5	<0.5
18	360521098022501	<1	<0.5	<5	<0.5
19	360521098022502	<1	<0.5	<5	<0.5
20	360618098024501	<1	<0.5	E 1	<0.5

Appendix 3. Wastewater organic compounds analyzed in samples from eight lagoons and 78 of 79 monitoring wells at swine licensed-managed feeding operations in Oklahoma, 2001—Continued

Lagoon and well numbers	Site identification number	Household		Detergents	
		Triclosan	Tris(2-butoxyethyl) phosphate	Para-nonylphenol total	Tributylphosphate
21	360618098024502	<1	<0.5	<5	<0.5
23	360634098030902	<1	1.7	<5	<0.5
24	360635098032901	<1	<0.5	<5	<0.5
25	360729098060901	<1	<0.5	E 1	<0.5
26	360735098060801	<1	<0.5	<5	<0.5
27	361028098440701	<1	<0.5	<5	<0.5
28	361028098440702	<1	<0.5	<5	<0.5
29	361028098440704	<1	<0.5	<5	<0.5
30	361028098440705	<1	<0.5	<5	<0.5
31	361028098440706	<1	<0.5	<5	<0.5
32	361115098504701	<1	<0.5	<5	<0.5
33	361116098463001	<1	<0.5	<5	<0.5
34	361117098504301	<1	<0.5	<5	<0.5
35	361118098463301	<1	<0.5	<5	<0.5
36	361121098504501	<1	<0.5	<5	<0.5
37	361122098462801	<1	<0.5	<5	<0.5
38	361122098493901	<1	<0.5	<5	<0.5
39	361133098485701	<1	<0.5	<5	<0.5
40	361136098374401	<1	<0.5	<5	<0.5
41	361139098374801	<1	<0.5	<5	<0.5
42	361139098485901	<1	<0.5	<5	<0.5
43	361143098374801	<1	<0.5	<5	<0.5
44	361146098504501	<1	<0.5	<5	<0.5
45	361152098504401	<1	<0.5	<5	<0.5
46	361157098494101	<1	<0.5	<0.5	<0.5
47	361203098494301	<1	<0.5	<0.5	<0.5
48	361210098112201	<1	<0.5	<5	<0.5
49	361215098491301	<1	<0.5	<5	<0.5
50	361215098491501	<1	<0.5	<5	<0.5

Appendix 3. Wastewater organic compounds analyzed in samples from eight lagoons and 78 of 79 monitoring wells at swine licensed-managed feeding operations in Oklahoma, 2001—Continued

Lagoon and well numbers	Site identification number	Household		Detergents	
		Triclosan	Tris(2-butoxyethyl) phosphate	Para-nonylphenol total	Tributylphosphate
51	361240098494201	<1	<0.5	<5	<0.5
52	361240098494401	<1	<0.5	<0.5	<0.5
53	361245098494401	<1	<0.5	<5	<0.5
54	362100099050301	<1	<0.5	<5	<0.5
55	362118099050301	<1	<0.5	<5	<0.5
56	362136099041201	<1	<0.5	<5	<0.5
57	362136099051001	<1	<0.5	<5	<0.5
58	363153101185001	<1	<0.5	<5	<0.5
59	363601101241301	<1	<0.5	<0.5	<0.5
60	363602101244501	<1	<0.5	<5	<0.5
61	364150101071901	<1	<0.5	<5	<0.5
62	364500101155301	<1	<0.5	<5	<0.5
63	364722100545501	<1	<0.5	<5	<0.5
64	364728100563501	<1	<0.5	<5	<0.5
65	365006100451001	<1	<0.5	<5	<0.5
66	365024100450701	<1	<0.5	<5	<0.5
67	365919099490901	<1	<0.5	E 1	<0.5
68	365938099490901	<1	<0.5	<5	<0.5
69	365941099475101	<1	<0.5	<5	<0.5
70	365941099490701	<1	<0.5	<5	<0.5
71	365942099473701	<1	<0.5	<5	<0.5
72	365944099473401	<1	<0.5	<5	<0.5
73	365945099474901	<1	E 0.3	<5	<0.5
74	365945099491401	<1	<0.5	<5	<0.5
75	365947099492101	<1	<0.5	<5	<0.5
76	365948099491701	<1	<0.5	<5	<0.5
77	365954099473701	<1	<0.5	<5	<0.5
78	370002099484101	<1	<0.5	<5	<0.5
79	370003099483501	<1	<0.5	<5	<0.5