Hydrogeologic Significance of Pesticide and Nitrate Concentrations in the Water-Table Aquifer and Memphis Aquifer in the Memphis Area, Tennessee

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Introduction

The Memphis, Tennessee, area uses ground water pumped from the Memphis aquifer as a major source of drinking water. The Memphis aquifer was assumed to be protected from surface contamination by the overlying deposits of low hydraulic conductivity which separate the Memphis aquifer from the alluvial and fluvial deposits that make up the shallow water-table aquifers. Graham and Parks (1986), Parks (1990), and Kingsbury and Parks (1993) determined that the confining unit between the Memphis aquifer and water-table aquifers is heterogeneous and discontinuous in many areas, allowing for direct recharge to the Memphis aquifer from the water-table aquifer. Therefore, water in the Memphis aquifer in the Memphis area could be vulnerable to contamination by surface-applied chemicals, such as pesticides and fertilizers.

Purpose and scope

As part of the National Water-Quality Assessment (NAWQA) Program, the U.S. Geological Survey (USGS) began an assessment of water quality in the Mississippi Embayment (MISE) study unit. Ground-water samples from 32 wells installed (Gonthier, 2003) in urban and recently industrialized locations throughout the Memphis area (figure 1) were collected during spring 1997 and were analyzed for nutrients, major ions, volatile organic compounds (VOCs), trace elements, and pesticides. Pesticide and nutrient (nitrate plus nitrite) data collected as part of the study and reported by Gonthier (2003) were used in this study to assess the correlation between the anthropogenic compounds present in the ground water and the hydrogeology of the corresponding wells.

Hydrogeologic Setting

Memphis is located in Shelby County in southwestern Tennessee. Memphis lies in the northern part of the Mississippi Embayment, which is part of the East Gulf Coastal Plain physiographic province (Cushing and others, 1964). The Mississippi Embayment is characterized structurally as a large southward plunging syncline or valley-like feature with the axis running near the present-day Mississippi River. The syncline is filled with sediments derived from sea regressions and transgressions which shaped the geology of the Embayment (Arthur and Taylor, 1997). The deposition of sediments such as sand, silt, and clay are responsible for the many aquifer systems found throughout the Embayment and within the Memphis study area.

Stratigraphic units of interest in the study area are of Tertiary and Quaternary age (table 1). The Memphis Sand constitutes the Memphis aquifer, the primary aquifer from which ground water is withdrawn for drinking water in the Memphis area.

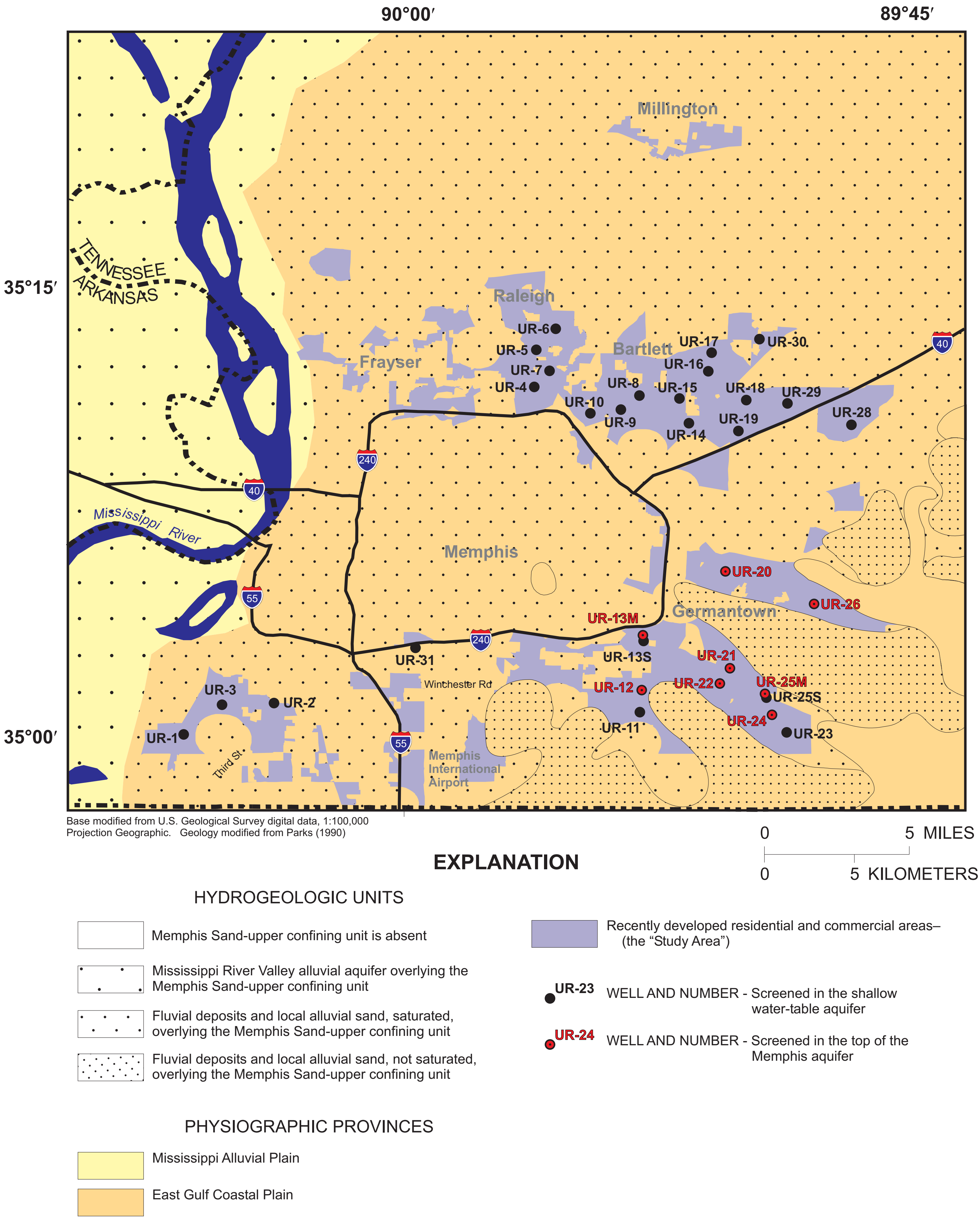

Figure 1. Hydrogeology and physiography in the Memphis vicinity, Tennessee, 1997.
(modified from Gonthier, 2003)

Table 1. Stratagraphic column with geologic units and their hydrogeologic characteristics within the Memphis area, Tennessee.

[Modified from Kingsbury and Parks (1993).]

Time unit			Statigraphic units		Hydrogeologic significance	
Era	Period	Epoch	Group	Formation	Hydrology	Lithology
Cenozoic	Quaternary	Holocene and Pleistocene		Alluvium	water-table aquifer	sand, gravel, silt and clay
		Pleistocene		Loess	low hydraulic conductivity, retards recharge to the water- table aquifer	silt, silty clay, and minor sand
	Quaternary and Tertiary (?)	Pleistocene and Pliocene (?)		Fluvial deposits	water-table aquifer	sand, gravel, minor clay, and ferruginous sandstone
	Tertiary	Eocene	Jackson	Jackson	Jackson-upper Claiborne confining unit*	fine clay, silt, and sand
			Claiborne	Cockfield		
				Cook Mountain		
				Memphis Sand	Memphis aquifer	sand, silt, with clay lenses throughout formation
		Eocene and Paleocene (?)	Wilcox	Flour Island	confining unit	clay and silt with some sand and lignite

* The groups and formations comprising the Jackson-upper Claiborne confining unit are currently being reevaluated by the Mississippi Office of Geology as to their existence up to the Mississippi-Tennessee border and are referred to in this paper as the upper confining unit.

The Memphis Sand, also known as the "500-foot" sand, is comprised mainly of fine to coarse-grained sand with some clay lenses. It overlies the Flour Island Formation, a clay and silt unit, which serves as the lower confining unit of the Memphis aquifer and upper confining unit of the underlying Fort Pillow aquifer. Deposits from the upper Claiborne Group and Jackson Formation overlie the Memphis Sand. These deposits are referred to by Parks (1990) as the Jackson-upper Claiborne confining unit. However, because current geologic investigations and mapping efforts are being conducted to better define the stratigraphy of these deposits, they will be referred to in this paper as the upper confining unit.

The upper confining unit is heterogeneous and laterally discontinuous (Parks, 1990), and its eastern limit is in the southeastern part of Shelby County (figure 1). Throughout the Memphis area, there are many places in which the confining unit is very thin or entirely absent. The overlying water-table aquifer is found within Quaternary aged alluvium and Tertiary to Quaternary aged fluvial deposits. Recharge to the fluvial deposits can be hindered by overlying loess deposits that are thickest on the bluffs near the alluvial plain of the Mississippi River. Direct recharge and surface-water contamination from the water-table aquifer into the Memphis aquifer can occur where the upper confining unit is very thin or absent. Kingsbury and Parks (1993) have also identified various fault zones that have displaced the Memphis Sand. If these displacements are greater than the upper confining unit thickness then the Memphis aquifer will come in direct contact with the water-table aquifer, allowing for direct recharge from the surface. Geophysical logs and S-wave reflection surveys have revealed channels within the confining unit in which recharge may also occur from the water-table aquifer to the Memphis Sand (Ground-Water Institute, 2001).

Data Collection and Analysis

The ground-water urban land-use study (Gonthier, 2003) followed the procedures outlined by NAWQA protocol. Standard procedures for the installation and documentation of the study wells are outlined by Lapham and others (1995). Thirty of the 32 sampled wells in the study were installed by the USGS during summer 1996, and 2 were existing wells belonging to Memphis, Light, Gas, and Water (table 2). Twenty-four of the wells were completed in the water-table aquifer, and 8 were completed in the upper part of the Memphis aquifer. All eight of the Memphis aquifer wells are located in the southeast part of Memphis, where the upper confining unit is known to often be thin or absent. Two pairs of wells (UR-13S, UR-13M, UR-25S, UR-25M) were nested with one well screened in the water-table aquifer and a deeper well screened in the Memphis aquifer. The upper confining unit for the Memphis aquifer was found to be absent in two of the wells (UR-22 and UR-24) screened in the Memphis aquifer.

During spring 1997, water was collected from all 32 wells and analyzed for major ions, nutrients, trace elements, pesticides, VOCs, and tritium. Collection of water samples and quality assurance was completed using guidelines described by Koterba and others (1995). Water samples were collected at each well after several casing volumes of water had been purged from the well, and field measurements remained stable.

Table 2. Description and number of the 32 wells sampled in the study area, April-May 1997.
[--, no data available]

Well number	Water-level below land surface (feet)	Well Depth (feet)	Water Column (feet)	Aquifer	Memphis upper-confining unit present?
UR-24	66.2	100	33.8	Memphis	no
UR-22	79.4	98	18.6	Memphis	no
UR-12	99.8	109	9.2	Memphis	yes
UR-20	53.7	76	22.3	Memphis	yes
UR-13M	64.9	98	33.1	Memphis	yes
UR-25M	73.2	94	20.8	Memphis	yes
UR-26	69.7	108	38.3	Memphis	yes
UR-21	74.9	88	13.1	Memphis	yes
UR-01	19.6	70	50.4	Water table	--
UR-02	25.4	68	42.6	Water table	--
UR-03	14.9	68	53.1	Water table	yes
UR-04	22.3	38	15.7	Water table	yes
UR-05	36.1	46	9.9	Water table	--
UR-06	28.0	40	12.0	Water table	--
UR-07	26.7	49	22.3	Water table	yes
UR-08	8.3	44	35.7	Water table	yes
UR-09	13.1	45	31.9	Water table	yes
UR-10	17.5	48	30.5	Water table	yes
UR-11	12.9	53	40.1	Water table	yes
UR-13S	13.5	33	19.5	Water table	yes
*UR-14	71.6	90	18.4	Water table	--
*UR-15	25.0	--	--	Water table	--
UR-16	63.6	88	24.4	Water table	yes
UR-17	18.5	48	29.5	Water table	yes
UR-18	62.0	68	6.0	Water table	--
UR-19	42.6	56	13.4	Water table	--
UR-23	34.2	43	8.8	Water table	yes
UR-25S	15.3	43	27.7	Water table	yes
UR-28	18.9	39	20.1	Water table	yes
UR-29	70.2	87	16.8	Water table	--
UR-30	73.1	80	6.9	Water table	--
UR-31	27.7	43	15.3	Water table	--

* Well installed and maintained by Memphis Light, Gas, and Water (MLGW).

After collection, VOCs and nutrient samples were sent overnight on ice to the National Water Quality Laboratory (NWQL) in Denver, Colorado.

Pesticide samples were first shipped overnight to a nearby USGS office for solid-phase extraction, and then the samples were sent to the NWQL.

Results

Pesticides

Of the 85 pesticides analyzed, 26 were detected in at least one of the 32 wells. Out of these 26, atrazine and simazine were detected most frequently, occurring in 12 wells. Seven of the 12 were from the water-table aquifer and 5 from the Memphis aquifer. Metalochlor was detected in 10 wells (5 water-table and 5 Memphis aquifer) and deethylatrazine was detected in 8 wells (6 water-table and 2 Memphis aquifer). Deethylatrazine is a degradation product of the triazine pesticides and especially atrazine.

At least one pesticide was detected in all 8 Memphis aquifer wells and in 62 percent (15 of 24) of the water-table wells (figure 2). The well in which the most pesticides were detected was UR-24, which is located in the Memphis aquifer where the upper confining unit is known to be absent. UR-24, located in the southeastern Memphis area, had 12 pesticide detections, which is twice as many as the highest number of detections found in any other water-table well.

Nitrate and Dissolved Oxygen

The highest concentrations of nitrate plus nitrite, here after referred to as nitrate, are found in water collected from the water-table wells (figure 3). Nitrate was present in 71 percent (17 of 24) of samples from the water-table wells and in 25 percent (2 of 8) of the Memphis aquifer wells. The highest concentration of nitrate reported from the water-table wells was 6.18 mg/L, found in UR-9; whereas UR-22 had the highest concentration, 1.1 mg/L, of the wells completed in the Memphis aquifer.

In the nested wells, nitrate was not found in water from UR-25S or UR-25M, whereas nitrate was found in water from UR-13M (Memphis aquifer well) but not in water from UR-13S (water-table well). Dissolved oxygen concentrations were higher (5.8 mg/L) in the Memphis aquifer well than in the water-table well (0.2 mg/L) at this location. However, some error may have been introduced into the dissolved oxygen concentrations because of different sampling methods used for each aquifer due to low water levels in the Memphis aquifer. Water from the water table aquifer (UR-13S) was sampled with a pump whereas water form the Memphis aquifer (UR-13M) was sampled using a bailer, which may have allowed oxygen to be introduced into the sample.

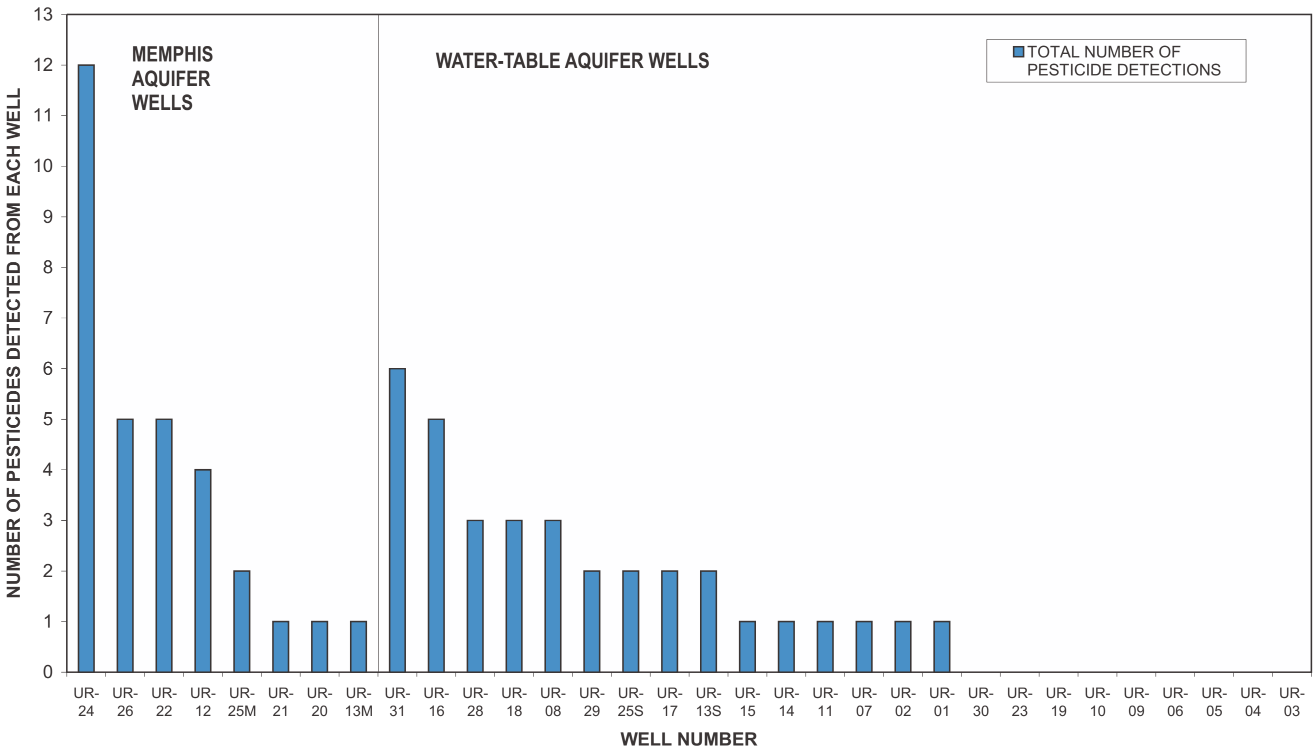

Figure 2. Total number of pesticides detected in water samples collected from each well in the study area.

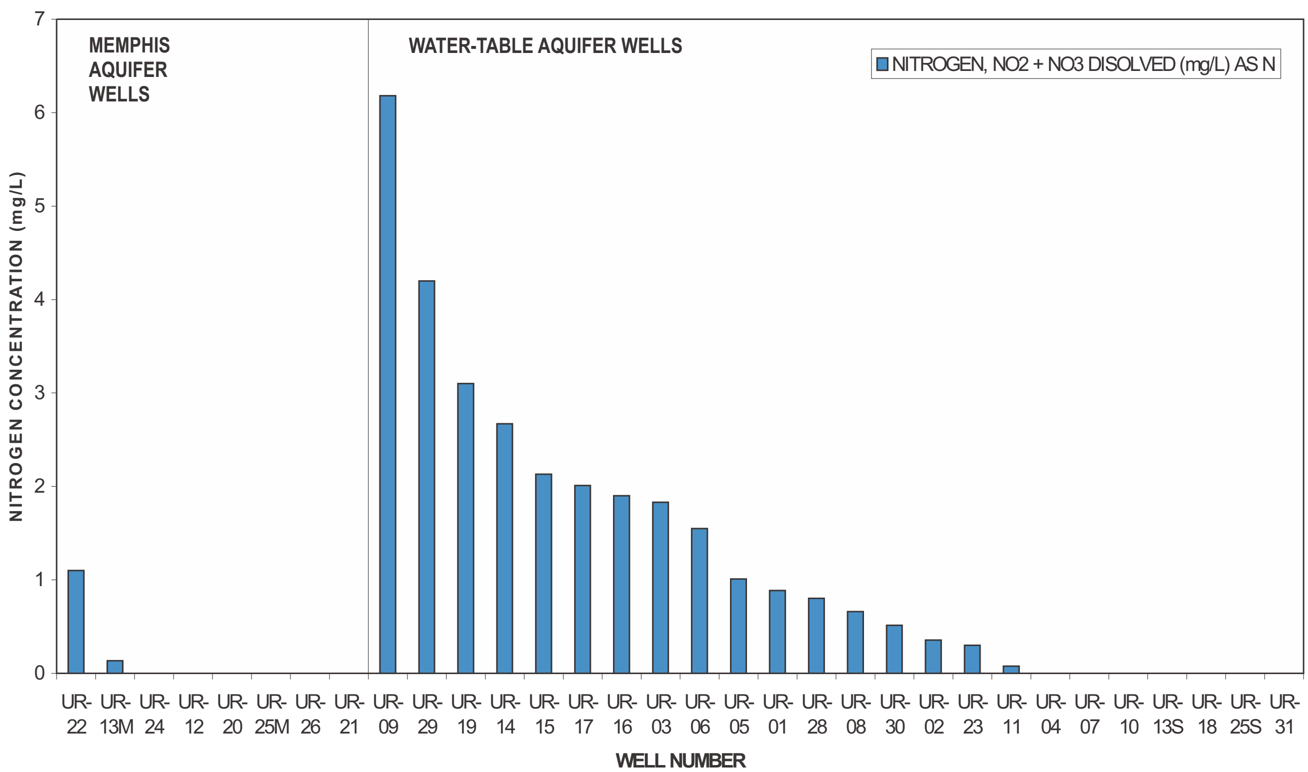

Figure 3. Nitrogen concentrations detected in water samples collected from each well in the study area.

Discussion

When interpreting the data from the water-table wells and the Memphis wells, it is important to keep in mind two limiting factors which make it difficult to compare the two types: 1.) Three times more water-table aquifer wells were sampled than Memphis aquifer wells. This skews the comparison of the two aquifers and also creates an unequal geographical distribution of the wells. 2.) The wells representing the Memphis aquifer are located in the upper 20 to 50 ft. (5 percent) of the Memphis Sand unit and may not represent the entire Memphis aquifer. However, because the hydrogeologic properties of the nested wells and wells located in areas where the upper confining unit is known to be absent are understood, the pesticide and nitrate data can be used to better understand the lateral discontinuity and heterogeneous nature of the upper confining unit.

The presence of pesticides, a strictly anthropogenic class of compounds, nitrate (which can have a natural and anthropogenic source), and dissolved oxygen in the Memphis Sand wells suggests recharge is occurring within the Memphis area probably due to a lack of homogeneity and continuity of sediments in the upper confining unit. Most of the pesticides investigated in this study are relatively water soluble and once introduced into the ground water, will generally stay in solution. Although the pesticides undergo microbial degradation, the process is slow. Therefore, these pesticides can be said to act as conservative tracers in the short term and once in the ground water, the concentrations should remain constant and move with ground water, subject to dilution and absorption phenomenon. Pesticide concentrations in ground water may not be uniformly distributed because of seasonal application. The variations in the pesticide concentrations throughout the water-table aquifer and Memphis aquifer are in part functions of the non-uniform distribution and the hydraulic conductivity of overlying units.

The two Memphis Sand wells in which the upper confining unit is known to be absent (UR-22 and UR-24) demonstrate a relation between direct recharge from the water-table aquifer and the number of pesticides and concentration of nitrate found in the water samples. Water analyzed from UR-24 had the highest number of pesticide detections and UR-22 tied for the second highest number of pesticide detections. The highest concentration of nitrate in the Memphis Sand wells was found in water collected from UR-22. Pesticides and nitrate both have surficial anthropogenic sources generally found in surface-water and shallow unconfined aquifers. The frequent occurrence of pesticides within the Memphis Sand wells, especially the two unconfined wells, may be an indication of a leaky upper confining unit.

Nitrate and dissolved oxygen concentrations in the nested UR-13S and UR-13M wells suggests that direct recharge occurs to the Memphis aquifer, even when the upper confining unit is locally present. Higher nitrogen concentrations and dissolved oxygen levels in UR-13M could be the result of surface recharge moving through horizontal paths in the upper confining unit created by faulting or channelization within the unit. Nitrate and dissolved oxygen are both used in reactions upon entering ground-water systems and are transformed. Therefore, it would be expected to find a decline in dissolved oxygen and nitrate concentration with deeper, older ground water.

Instead, in the case of UR-13S and UR-13M, the deeper aquifer contains higher concentrations of dissolved oxygen and nitrate. These higher concentrations at depth may indicate a discontinuity within the confining unit and recent infiltration or recharge from an indirect source unrelated to UR-13S.

Summary and Conclusions

The combination of pesticide and nutrient data from the NAWQA ground-water study along with earlier hydrogeologic investigations show that the Memphis aquifer can be subjected to localized surface-water contamination. A more specifically designed study with a greater number of wells is needed to more precisely quantify the discontinuity of the upper confining unit. Many studies and investigations are currently being conducted to gain a better hydrogeologic understanding of the aquifer system which supplies the Memphis, Tennessee, area.

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