

Rapid Recharge of Parts of the High Plains Aquifer Indicated by a Reconnaissance Study in Oklahoma, 1999

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INTRODUCTION

The High Plains aquifer underlies about 174,000 square miles in parts of eight states, including about 7,100 square miles in northwestern Oklahoma (fig. 1). This aquifer consists of the saturated part of the Ogallala Formation and saturated materials of Quaternary Age that are hydraulically connected to the Ogallala. The High Plains aquifer in northwestern Oklahoma is the primary source of water to an important agricultural region. Most water is withdrawn from the aquifer for irrigating wheat and other grain crops, with the remainder used for livestock (primarily cattle and swine), municipal, and domestic needs. Historically, water from precipitation was thought to take hundreds or thousands of years to reach the water table because the depth of the water table is greater than 100 feet over most of the aquifer and the low-permeability beds in the Ogallala would impede downward flow. It also was thought that land uses would take a similar period of time to affect water quality in the aquifer.

The U.S. Geological Survey, in cooperation with the Oklahoma Water Resources Board, conducted a reconnaissance investigation that included determination of recharge ages and water quality in early 1999. Samples were collected from 12 domestic wells (fig. 1), ranging in depth from 25 to 300 feet. Recharge age, which indirectly indicates travel time from the land surface to the water table, was determined by analyses of isotopes of hydrogen and helium, or carbon. Water samples also were analyzed for physical properties, major ions, trace metals, and nutrients.

RECHARGE AGES OF GROUND WATER

Concentrations and ratios of tritium and helium-3 are used to estimate ages of recharge of ground water, particularly where unsaturated zones are thick or of low-permeability (Johnston and others, 1998). Tritium is a radioactive isotope

of hydrogen having a relatively rapid decay rate (half-life of 12.3 years). The majority of tritium in water was made by atmospheric testing of thermo-nuclear/ hydro-

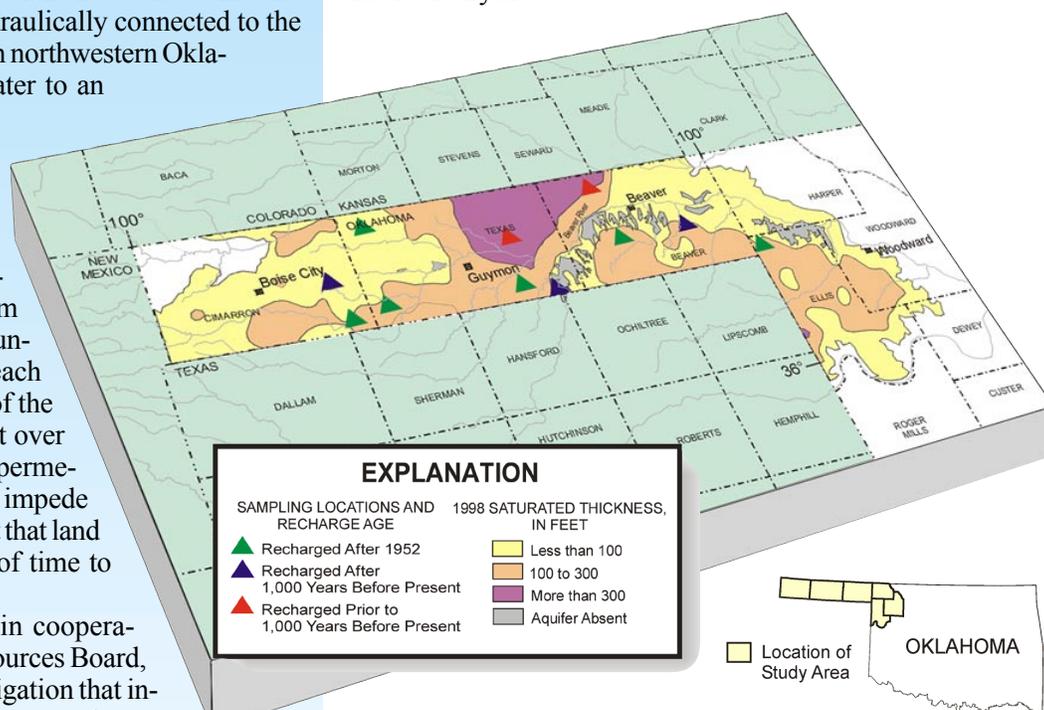


Figure 1. Ground-water recharge ages for 12 wells and 1998 saturated thickness of the High Plains aquifer in Oklahoma.

gen-fusion bombs. Tritium concentrations were nearly undetectable in rainfall prior to the atmospheric testing of thermonuclear bombs that began in 1953. Tritium concentrations in rainfall peaked in 1963 and have decreased from about 550 tritium units (corrected for decay) to an average of about 25 tritium units in current rainfall. One of the decay products of tritium is helium-3, an isotope of the inert gas helium. The ratio of these isotopes is useful for determination of recharge ages, because it does not depend on the amount of tritium input and decreases in a predictable, time-dependent manner (Solomon and Sudicky, 1991).

Recharge ages of 7 of the 12 samples in which tritium concentration exceeded the method reporting limit of 2.5 tri-

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tium units (8 picocuries per liter) were calculated using tritium/helium-3 ratios. One of those samples leaked, precluding age dating, so a conservative recharge date of 1953 was estimated for that sample. The other six samples had recharge ages ranging from 1958 to 1986.

Because domestic wells generally have relatively long screens (20 to 50 feet), water from those wells commonly contains a mixture of water, with a variety of recharge ages. Recharge ages from water collected near the water table would probably be even younger than those of these samples, meaning that recharge to this aquifer is probably even more rapid than indicated by these ages.

Recharge ages of the remaining five samples were determined from ratios of carbon isotopes. Recharge ages for three of those samples were “recent” according to carbon-14 ratios, indicating recharge ages of less than 1,000 years before 1999. The other two samples, which had recharge ages of 5,000 years and 9,000 years before 1999 (fig. 1), were from the part of the aquifer with a saturated thickness greater than 300 feet in northern and central Texas County (Luckey and others, 2000). That area is underlain by a structural trough filled with collapsed sediments (Luckey and Becker, 1999). The depth of the trough and decreased hydraulic conductivity due to settlement and collapse of sedimentary materials may have slowed the movement of ground water.

WATER QUALITY

Water quality in the Ogallala aquifer and connected units of Quaternary Age is affected by physical and mineralogic characteristics of the aquifer and by activities at the land surface. The aquifer is comprised of poorly sorted clay, silt, sand, and gravel comprised of silicious and calcareous minerals, which are locally cemented by calcium carbonate caliche (Gutentag and others, 1984). Land over the aquifer is used for primarily for cropland agriculture, raising of livestock (primarily cattle and swine), with lesser areas used for residential and other purposes (Gutentag and others, 1984).

Physical Properties

Physical properties measured in water samples were temperature, specific conductance, dissolved oxygen, pH, and alkalinity. Water temperature varied within a relatively narrow range, from 14.3 to 17.4 degrees Celsius (fig. 2). Specific conductance ranged from 470 to 782 microsiemens per centimeter at 25 degrees Celsius (fig. 2), indicating a moderate amount of dissolved minerals. All water samples contained relatively large concentrations of dissolved oxygen, ranging from 5.2 to 10.8 milligrams per liter (fig. 2), indicating that reducing reactions such as denitrification (a process that removes nitrate) are not occurring in the aquifer. A possible source of dissolved oxygen in the samples was leaking pressure tank bladders in domestic well systems, but many wells were sampled at spigots located before the pressure tanks. Water samples recently (1999-2000) collected from monitoring wells completed in the aquifer using sealed sampling systems had similar dissolved oxygen concentrations (K. Dennehy, U.S. Geological Survey, oral commun., 2000). pHs of water samples were somewhat alkaline, ranging from

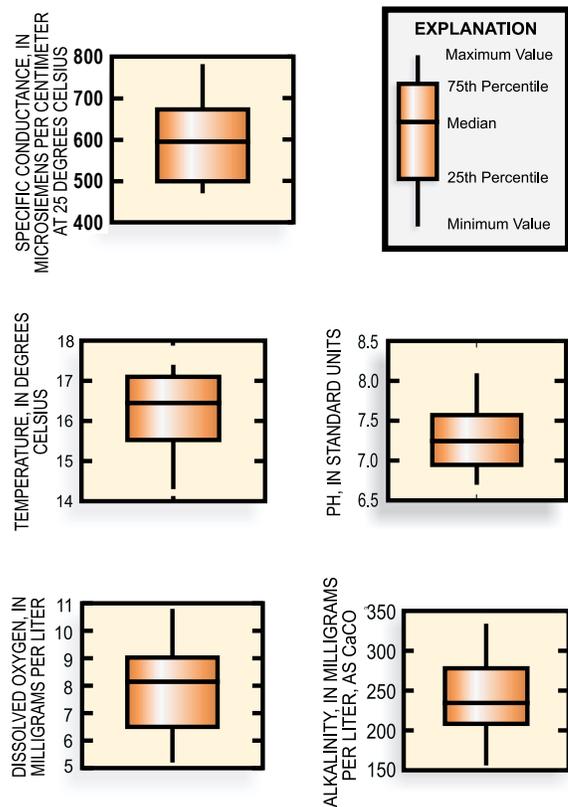


Figure 2. Physical properties in water samples from 12 wells completed in the High Plains aquifer.

6.7 to 8.1 (fig. 2). Alkalinities ranged from 156 to 334 milligrams per liter as calcium carbonate (fig. 2).

Major Ions and Trace Metals

Calcium concentrations, generally the greatest of the major ions (fig. 3), ranged from 27 to 110 milligrams per liter. The majority of calcium in these water samples was probably derived from dissolution of calcite, dolomite, or gypsum in the aquifer and in the overlying unsaturated zone. The relative abundance of calcium contributes to hardnesses ranging from 165 to 327 milligrams per liter as calcium carbonate; therefore, most of the water samples can be classified as hard to very hard (Hem, 1985). Magnesium concentrations were relatively low, ranging from 4.5 to 51 milligrams per liter. Sodium concentrations were also low, ranging from 8.9 to 46 milligrams per liter (fig. 3). Those ions may be associated with dissolution of minerals such as dolomite, feldspars, or mafic minerals. Potassium, with sources including fertilizers or grains of feldspar in the unsaturated zone and the aquifer, was detected in concentrations ranging from 0.76 to 6.2 milligrams per liter (fig. 3).

Chloride, which can be derived from natural brines, mafic minerals, road salts, animal wastes, or fertilizers, ranged in concentration from 2.1 to 62 milligrams per liter (fig. 3). Sulfate, which can be derived from fossil fuel combustion, oxidation of soil organic matter, metallic sulfides, animal wastes, or sulfate minerals (such as gypsum), ranged in concentra-

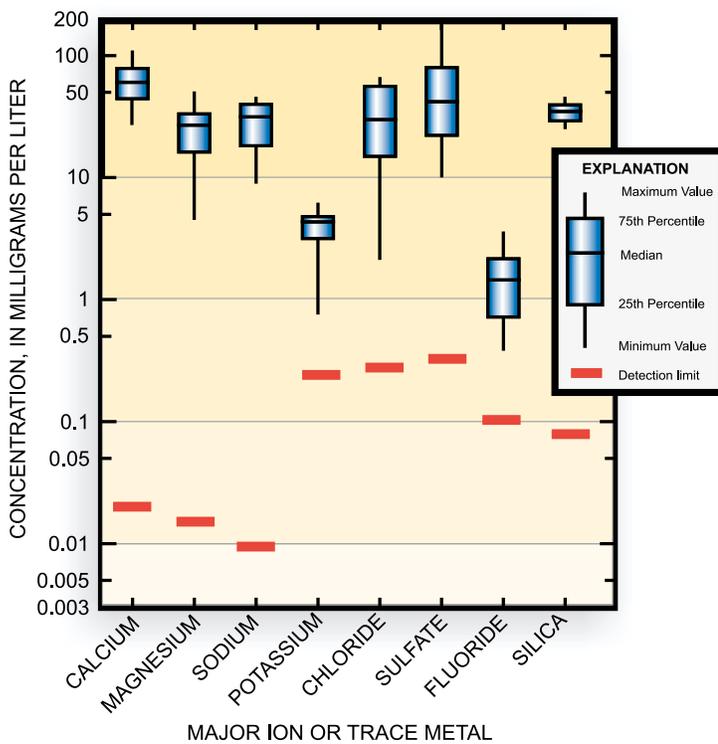


Figure 3. Major ion concentrations in water samples from 12 wells completed the High Plains aquifer.

tion from 10 to 180 milligrams per liter (fig. 3).

Fluoride did not exceed the Maximum Contaminant Level of 4.0 milligrams per liter (U.S. Environmental Protection Agency, 1999). Silica, derived from dissolution of quartz and other silicate mineral grains in the aquifer, ranged in concentration from 25 to 46 milligrams per liter (fig. 3).

NUTRIENT CONTAMINATION FROM LAND USE

Nitrate as nitrogen was detected in the greatest concentration of the analyzed nutrients, ranging from 1.81 to 12.3 milligrams per liter (fig. 4). The Maximum Contaminant Level of 10 milligrams per liter (U.S. Environmental Protection Agency, 1999) was exceeded in two samples. Nitrate concentration greater than 10 milligrams per liter can cause “blue-baby” syndrome (methemoglobinemia—a condition that prevents blood from carrying oxygen), and has been tentatively linked to increased rates of stomach cancer, birth defects, miscarriage, leukemia, non-Hodgkin’s lymphoma, reduced body growth and slower reflexes, and increased thyroid size in humans.

Nitrate concentration was greater than 3 milligrams in water samples from 8 of the

12 wells, which may indicate degradation by man’s activities (Madison and Brunett, 1985). A previous summary of groundwater quality of this aquifer (Becker, 1994) indicated that about 20 percent of water samples had nitrate-nitrogen concentrations greater than 3 milligrams per liter.

About half the samples had detectable concentrations of organic nitrogen, ranging from 0.1 to 0.58 milligram per liter. Organic nitrogen compounds in ground water may be derived from soils or animal wastes. Ammonium was detected in only one sample, at a low concentration of 0.023 milligram per liter. Oxidizing conditions in the aquifer would tend to facilitate its rapid conversion to nitrate. Dissolved phosphorus concentrations ranged from less than 0.004 to 0.009 milligram per liter (fig. 4). Dissolved orthophosphorus concentrations ranged from less than 0.01 to 0.041 milligram per liter (fig. 4).

The percentages of land devoted to five major types of land use (pasture, non-irrigated crops, irrigated crops, feedlots, surface water, and “other” (primarily roads and homesteads) within one-half mile of each well were calculated and compared to nitrate concentrations in the water samples. There were no statistically significant correlations between the percentage of land uses near the wells and nitrate concentrations in water samples. However, the percentage of land with feedlots in the areas near the wells were related to ratios of nitrogen isotopes in nitrate in the water samples.

Ratios of the isotopes nitrogen-14 (^{14}N) and nitrogen-15 (^{15}N) in nitrate relative to those in the atmosphere ($\delta^{15}\text{N}$) can indicate sources of nitrate. Nitrate from synthetic fertilizers have a similar isotopic ratio as the atmosphere, in which $\delta^{15}\text{N}$ equals about 0-2 parts per mil (o/oo) because synthetic fertilizers are derived from atmospheric nitrogen through the Haber-Bosch process (Heaton, 1986). Bacteria, fungi, and animal cells tend to preferentially take up and metabolize lighter molecules containing greater proportions of ^{14}N . Thus, the heavier ^{15}N isotope is more concentrated

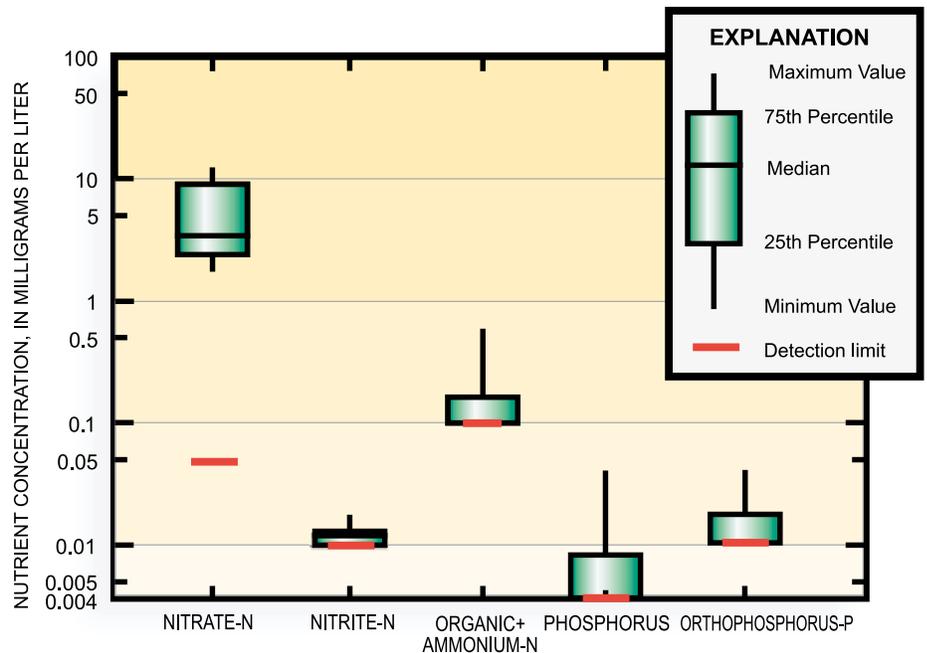


Figure 4. Nutrient concentrations in water samples from 12 wells completed in the High Plains aquifer.

in the remaining animal wastes, in which $\delta^{15}\text{N}$ is equal to or greater than 10 ‰ (Heaton, 1986). Nitrate leached from soils has $\delta^{15}\text{N}$ values of about 5 ‰ (Heaton, 1986). Mixtures of fertilizers, animal wastes, and other sources have intermediate ratios of nitrogen isotopes ($\delta^{15}\text{N}$ values ranging from 2 to 10 ‰).

Both wells producing water with $\delta^{15}\text{N}$ values greater than 10 ‰ had the greatest percentages of land area within one-half mile occupied by feedlots—32 and 33 percent, respectively. Those wells also produced water with elevated concentrations of nitrate (fig. 5) The well producing water with the greatest nitrate concentration (12.3 milligrams per liter, fig. 5) had the least $\delta^{15}\text{N}$ value (2 ‰), indicating that most of the nitrate was probably from fertilizer. That well had primarily pasture (80 percent) and non-irrigated cropland (19 percent) comprising the land uses within one-half mile. Samples from nine of the wells had lesser nitrate concentrations and intermediate nitrogen-isotope ratios, indicating that the source of nitrate may have been a mixture of soils, fertilizers, atmospheric deposition, and animal wastes.

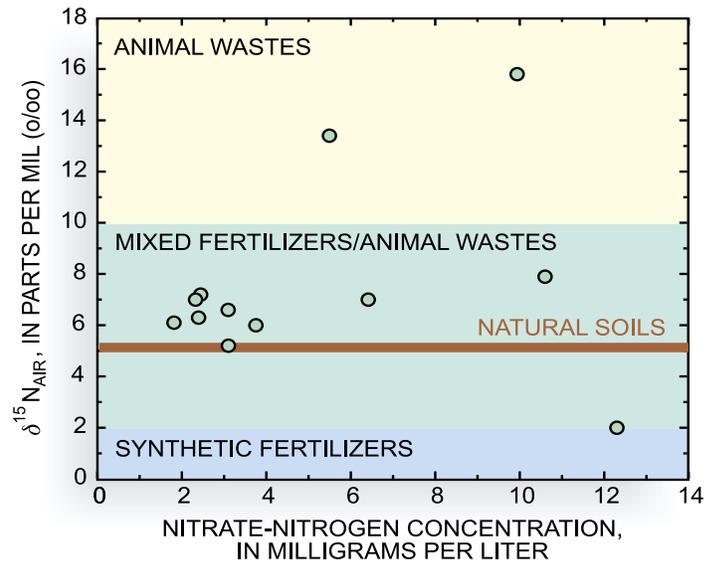


Figure 5. Nitrate-nitrogen concentrations and ratios of nitrogen isotopes in nitrate in water samples from 12 wells and 1998 saturated thickness of the High Plains aquifer in Oklahoma.

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