A Reconnaissance Study of the Effect of Irrigated Agriculture on Water Quality in the Ogallala Formation, Central High Plains Aquifer

Introduction

In 1998, the U.S. Geological Survey's National Water-Quality Assessment (NAWQA) Program began a regional study of water quality in the High Plains aquifer. The High Plains aquifer underlies an area of about 174,000 square miles in parts of eight States. Because of its large size, the High Plains aquifer has been divided into three regions: the Southern High Plains, Central High Plains, and Northern High Plains (fig. 1*A*). Although an assessment of water quality in each of the three regions is planned, the initial focus will be the Central High Plains aquifer.

Anyone who has flown over the Central High Plains in the summer and has seen the large green circles associated with center pivot sprinklers (fig. 2) knows that irrigated agriculture is a widespread land use. Pesticides and fertilizers applied on those irrigated fields will not degrade ground-water quality if they remain in or above the root zone (fig. 3). However, if those chemicals move downward through the unsaturated zone to the

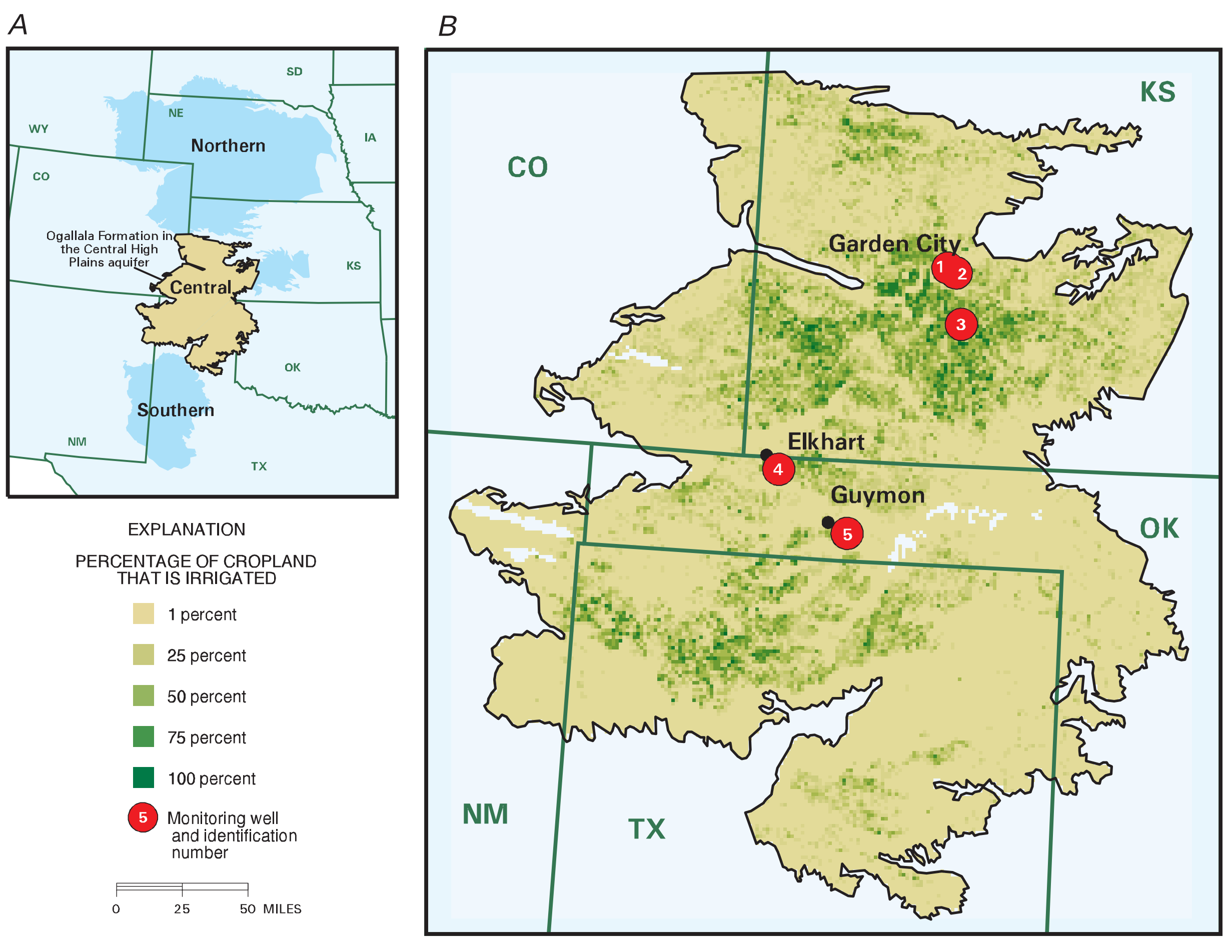

Figure 1. (*A*) Location of the High Plains aquifer. The portion of the Central High Plains aquifer composed of sediments of the Ogallala Formation is outlined in black**.** (*B*) Location of irrigated cropland and monitoring wells in the Ogallala Formation, Central High Plains aquifer.

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water table, they may degrade the quality of the ground water. Water is the principal agent for transporting chemicals from land surface to the water table, and in the semiarid Central High Plains, irrigation often represents the most abundant source of water during the growing season.

One objective of NAWQA's High Plains Regional Ground-Water study is to evaluate the effect of irrigated agriculture on the quality of recently recharged water in the Ogallala Formation of the Central High Plains aquifer (figs. 1*A* and 1*B*). The Ogallala Formation is the principal geologic unit in the Central High Plains aquifer, and it consists of poorly sorted clay, silt, sand, and gravel that generally is unconsolidated (Gutentag and others, 1984). Approximately 23 percent of the cropland overlying the Ogallala Formation is irrigated (U.S. Department of Agriculture, 1999).

The NAWQA Program generally defines recently recharged ground water to be water recharged in the last 50 years. The water table in the Ogallala Formation is separated from overlying land-use practices by as much as 400 feet of unsaturated sediments. Consequently, one may hypothesize that recently recharged water is not present in the formation. The U.S. Geological Survey conducted a reconnaissance study in 1999 to establish (a) if recently recharged water was present in the Ogallala Formation underlying irrigated cropland and (b) if agricultural land-use practices affect water quality. Results from the reconnaissance study will be used to determine whether a full-scale land-use study is warranted.

Figure 2. Areal photograph of irrigated cropland overlying the Ogallala Formation, Central High Plains aquifer.

Monitoring Wells Were Installed Adjacent to Irrigated Fields

Most existing water wells in the Ogallala Formation are irrigation and domestic wells. Both types of wells are characterized by screened intervals located considerable distances below the water table. The age of ground water generally increases

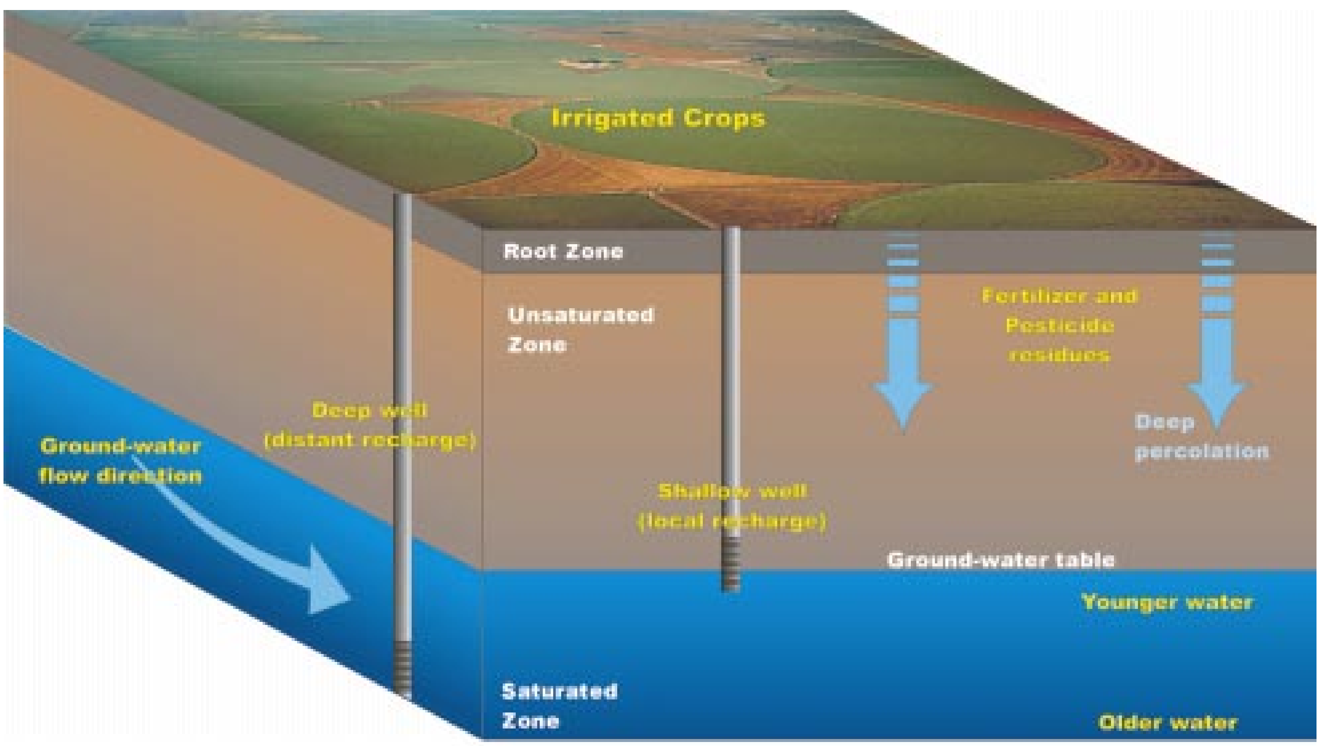

Figure 3. Water in the Ogallala Formation originates as precipitation or irrigation water at the land surface. Precipitation or irrigation water that percolates through the root and unsaturated zones underlying irrigated fields may transport fertilizer and pesticide residues to the formation. As more water percolates through the unsaturated zone, the ground water is driven deeper into the formation; therefore, the older water is at the bottom of the formation and the younger water is at the water table.

Figure 4. Well-drilling operation.

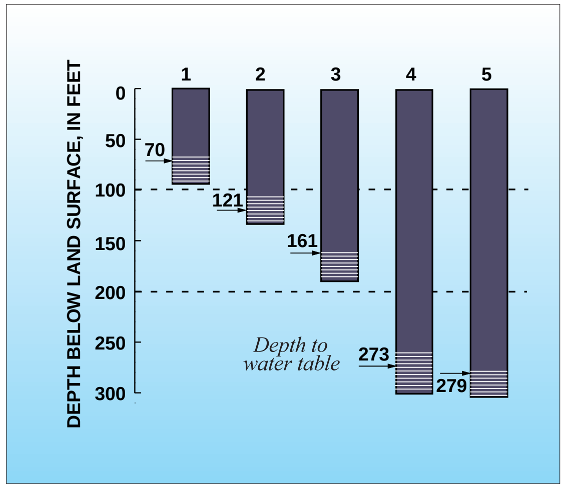

Figure 5. Depth to water table and screened intervals in monitoring wells.

with depth below the water table. Therefore, a well with a screened interval located a large distance below the water table would not intercept the most recently recharged water in the aquifer. Furthermore, the greater the depth of the screened interval below the water table, the more uncertainty there is in knowing the location of the recharge area for water intercepted by that well. As a result, irrigation and domestic wells are not ideal for evaluating the effect of irrigated agriculture on recently recharged ground water. Wells with short screened intervals located at the water table directly beneath the targeted land use are the most suitable for NAWQA land-use studies.

Five monitoring wells were installed in the Ogallala Formation directly adjacent to irrigated fields using established well-installation protocols (Lapham and others, 1995) (fig. 4). Each well consisted of 2-inch-diameter Schedule 40 polyvinyl chloride (PVC) casing and slotted screen. The screened interval was 20 feet long and approximately straddled the water table (fig. 5) so that the most recently recharged water in the formation could be sampled. The annular space around the outside of the screens was filled with silica sand; the annular space around the well casing was sealed with a bentonite-cement mixture from 10 feet above the screen to land surface. This seal prevented the downward movement of chemicals along the outside of the well casing. To examine the relation between water quality and depth to water, wells were installed in areas where the depth to ground water ranged from 0 to 100 feet (1 well), 100 to 200 feet (2 wells), and 200 to 300 feet (2 wells).

Collection of Water Samples

Water samples were collected from the monitoring wells according to the NAWQA Program protocol (Koterba and others, 1995), using a submersible pump made of stainless steel and Teflon. One water-quality sample was taken from each monitoring well. Generally, the sample-collection procedure consists of four steps.

(1) Pump a minimum of three casing volumes of water from the well to remove stagnant water from the well (fig. 6).

(2) Continue to pump the well at a slow rate until the pH, temperature, specific conductance, dissolved oxygen (fig. 7), and turbidity of the water stabilize, which indicates that water representative of the aquifer is being pumped from the well.

(3) Collect water samples for field and laboratory analysis of a broad spectrum of chemical constituents. Replicate and field equipment-blank samples also are collected to evaluate the precision of the chemical analyses and the potential for cross contamination between sampling sites.

(4) Wash the sampling equipment—including sample pumps, discharge lines, and filter apparatus—to prevent cross contamination between wells.

Chemical analyses were performed by U.S. Geological Survey laboratories in Denver, Colorado, Lawrence, Kansas, and Menlo Park, California.

Figure 6. Monitoring wells were pumped using a stainless steel submersible pump mounted in the back of a pickup truck (vehicle on left). Samples were processed inside a mobile laboratory (vehicle on right).

Figure 7. Interior view of mobile laboratory showing equipment used to measure pH, water temperature, specific conductance, and dissolved oxygen.

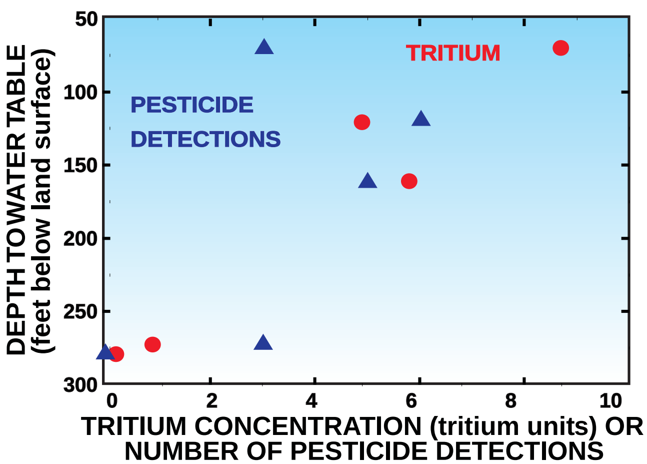

Figure 8. Relation between tritium concentrations, pesticide detections, and depth to water in the Ogallala Formation.

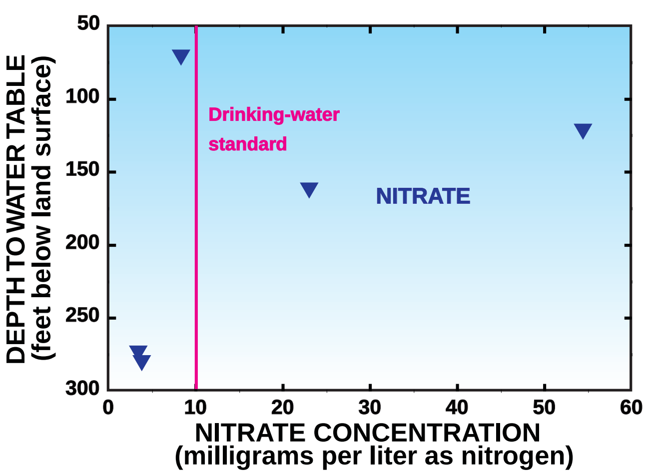

Figure 9. Relation between nitrate concentrations and depth to water in the Ogallala Formation.

Tritium Data Indicate Recently Recharged Water is Present in the Ogallala Formation

Tritium is a radioactive isotope of hydrogen that is present in some water molecules. Tritium in ground water largely comes from precipitation that percolated downward to the aquifer. Because tritium is radioactive, with a half-life of 12.4 years, its concentration in water decreases over time. Prior to the onset of atmospheric testing of nuclear weapons in the early 1950's, the tritium content of precipitation in the Central High Plains was probably on the order of 8 tritium units (TU) (Thatcher, 1962). Therefore, ground water that was recharged 50 years ago (the upper limit for recently recharged ground water) would contain about 0.5 TU in 1999. The tritium content of precipitation increased substantially after the onset of atmospheric nuclear weapons testing; therefore, ground water recharged since the early 1950's would contain appreciably more than 0.5 TU in 1999. At the time of sampling in 1999, water from each of the monitoring wells contained tritium (fig. 8 and table 1). However, only the well with the largest depth to water, well 5, contained less than 0.5 TU, indicating water from that well probably was recharged more than 50 years ago. In contrast, tritium concentrations in water from the other monitoring wells were larger than 0.5 TU, indicating that water intercepted by those wells contained at least some recently recharged water.

Pesticides Were Detected in Four of Five Samples

Application of synthetic organic pesticides in the United States largely began after World War II (Barbash and Resek, 1996). Thus, the presence of those pesticides in ground water can be a useful indicator of recently recharged ground water. It is important to analyze for the most commonly used pesticides in the Central High Plains if their presence is to be used as an indicator of recently recharged ground water in the Ogallala Formation. Water samples were analyzed for 53 pesticide compounds in this study. The list of pesticide analytes included (a) 8 of the 10 pesticides most heavily applied on cropland overlying the Ogallala Formation and (b) the degradation products from three of the four most heavily applied pesticides.

Pesticides or their degradation products were detected in four of the five water samples *(*fig. 8 and table 1*)*. Those four samples also contained the largest tritium concentrations. The most commonly detected pesticides also were some of the most heavily applied pesticides *(*table 1*)*. Thus, the pesticide data indicate that the Ogallala Formation did contain recently recharged ground water that was affected by agricultural activities. Only the water sample from well 2 contained a pesticide concentration (atrazine at 5.0 micrograms per liter) that exceeded a drinking-water standard (3 micrograms per liter for atrazine; U.S. Environmental Protection Agency, 1999a). The monitoring wells are not water-supply wells, but the Ogallala Formation is an important source of water to domestic and public-supply wells in the Central High Plains.

The water sample from well 5, with the largest depth to water, was the only one with no pesticide detections. This observation is consistent with the tritium data for that well, which indicate that water from that well probably was recharged more than 50 years ago. The relatively small tritium concentration in water from well 4, with the next largest depth to water, indicates a possible recharge date in the early 1950's. However, water from that well also contained measurable concentrations of atrazine and alachlor ethanesulfonic acid, a degradation product of alachlor. Atrazine was first sold commercially in 1959 and alachlor was first registered for use in 1969 (U.S. Environmental Protection Agency, 1999b); therefore, water intercepted by that well apparently contained a mixture of relatively old water and water that was recharged since about 1970. Ground-water samples commonly contain waters of varying ages. The range of ages in the mixture depends on various factors, including well-screen length, well-screen depth, and recharge rates.

Nitrate Concentrations Were Above Background Levels

Nitrate concentrations in the five water samples ranged from 3.4 to 54 milligrams per liter as nitrogen (mg-N/L) (fig. 9 and table 1), with a median concentration of 8.3 mg-N/L, all greater than the estimated national background nitrate concentration in ground water of 2 mg-N/L (Mueller and Helsel, 1996). Two of the five samples had nitrate concentrations above the drinking-water standard of 10 mg-N/L. It is possible that the natural background concentration of nitrate in the Ogallala Formation is larger than 2 mg-N/L; however, it is unlikely that the background concentration exceeds the median nitrate concentration of 8.3 mg-N/L for the water samples. Generally, nitrate concentrations above natural background levels are indicative of a human influence on the quality of ground-water recharge.

It is difficult to identify the source of elevated nitrate concentrations in ground water solely on the basis of nitrate-concentration data. Potential nitrate sources include commercial fertilizers such as anhydrous ammonium, natural soil organic nitrogen, and human and animal waste. Insight into the sources of nitrate can be gained by knowing the land use in the recharge area from which the water

Areal photograph of an active center pivot sprinkler.

TABLE 1. Concentrations of nitrate, tritium, and selected pesticides in water samples from the monitoring wells. Indented pesticide names indicate degradation products of the parent compound. Also listed are rankings of pesticide usage for selected pesticide applied to cropland overlying the Ogallala Formation

[na, not applicable or not analyzed; E, estimated concentrations; <, less than indicated concentration]

	[1]Pesticide usage, ranked according to pounds of active ingredient applied in the study area	Monitoring wells				
		1	2	3	4	5
Depth to water, feet below land surface	na	70.1	120.7	160.8	272.6	279.0
Nitrate, milligrams per liter as nitrogen	na	8.3	54	22	3.4	3.8
Nitrate-nitrogen stable isotope value, per mil	na	+7.7	+15.8	na	na	+6.5
Tritium, tritium units	na	8.7	4.9	5.8	0.9	0.2
Alachlor, micrograms per liter	4	<0.002	<0.002	<0.002	<0.002	<0.002
Alachlor ethanesulfonic acid, micrograms per liter	na	0.44	<0.05	1.5	0.12	<0.05
Alachlor oxanilic acid, micrograms per liter	na	<0.05	<0.05	0.08	<0.05	<0.05
Atrazine, micrograms per liter	1	0.006	5.0	1.2	0.40	<0.001
Deethylatrazine, micrograms per liter	na	0.014 E	1.7 E	0.60 E	0.12 E	<0.002
Metolachlor, micrograms per liter	3	<0.002	0.096	<0.002	<0.002	<0.002
Metolachlor ethanesulfonic acid, micrograms per liter	na	<0.05	2.8	<0.05	<0.05	<0.05
Metolachlor oxanilic acid, micrograms per liter	na	<0.05	1.2	<0.05	<0.05	<0.05
Simazine, micrograms per liter	67	<0.005	0.038	0.029	<0.005	<0.005

[1] Data from G. Thelin, U.S. Geological Survey, written commun., 1999

Tritium, pesticide, nitrate, and isotope data indicate that the Ogallala Formation contains recently recharged water that was affected by agricultural practices.

came and by measuring the stable nitrogen isotope composition of the nitrate (Bohlke and Denver, 1995). The nitrogen isotope composition of nitrate is based on the relative abundances of two naturally occurring stable isotopes of nitrogen (nitrogen-14 and nitrogen-15) in the nitrate molecule, which can be measured with great accuracy. Generally, the ranges in nitrogen isotope values for synthetic fertilizer, soil nitrogen, and human and animal waste differ from each other. These differences in isotope values make it possible to use nitrogen isotopes to identify nitrate sources. However, identifying nitrate sources based on nitrogen isotope measurements does have limitations. Some natural processes, such as microbial denitrification in anaerobic water, can alter the initial isotopic composition of nitrate.

Denitrification probably did not alter the nitrogen isotope composition of nitrate from the monitoring wells because the water was oxygenated (dissolved oxygen concentrations ranged from 4.7 to 8.2 milligrams per liter). Assuming that no other processes significantly altered the isotopic composition of the nitrate, then the isotope measurements and knowledge about land use surrounding the wells can be used to identify possible nitrate sources. For example, the water sample from well 2 contained 54 mg-N/L nitrate. Land use around that well consisted of irrigated fields fertilized with animal waste. The nitrogen isotope value for nitrate in the water sample was +15.8 per mil, which is within the range of nitrogen-isotope values characteristic of an animal-waste source of nitrate. Taking into consideration that isotope value, and other chemical measurements made on water from that well, it is likely that the nitrate was derived from animal waste, further indicating that agriculture has affected water quality in the Ogallala Formation.

What Have We Learned?

The tritium, pesticide, nitrate, and isotope data demonstrate the benefit of developing multiple lines of evidence to characterize the effects of land use on water quality. The tritium and pesticide data indicate that recently recharged water was present in the Ogallala Formation. The pesticide, nitrate, and isotope data indicate that the recently recharged water was affected by agricultural practices. These findings indicate that an irrigated-agriculture land-use study in the Ogallala portion of the Central High Plains aquifer is warranted.

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The U.S. Geological Survey (USGS) is conducting an assessment of ground-water quality in the High Plains aquifer as part of its National Water-Quality Assessment (NAWQA) Program. The long-term goals of NAWQA are to describe the status of and trends in the quality of a large representative part of the Nation's surface- and ground-water resources, and to identify major factors that affect the quality of these resources. The NAWQA Program focuses on water quality in more than 50 major river basins and aquifer systems across the Nation. The assessment activities in the High Plains NAWQA study area began in 1998.