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Baseline Water Quality and Preliminary Effects of Artificial Recharge on Ground Water, South-Central Kansas, 1995-98

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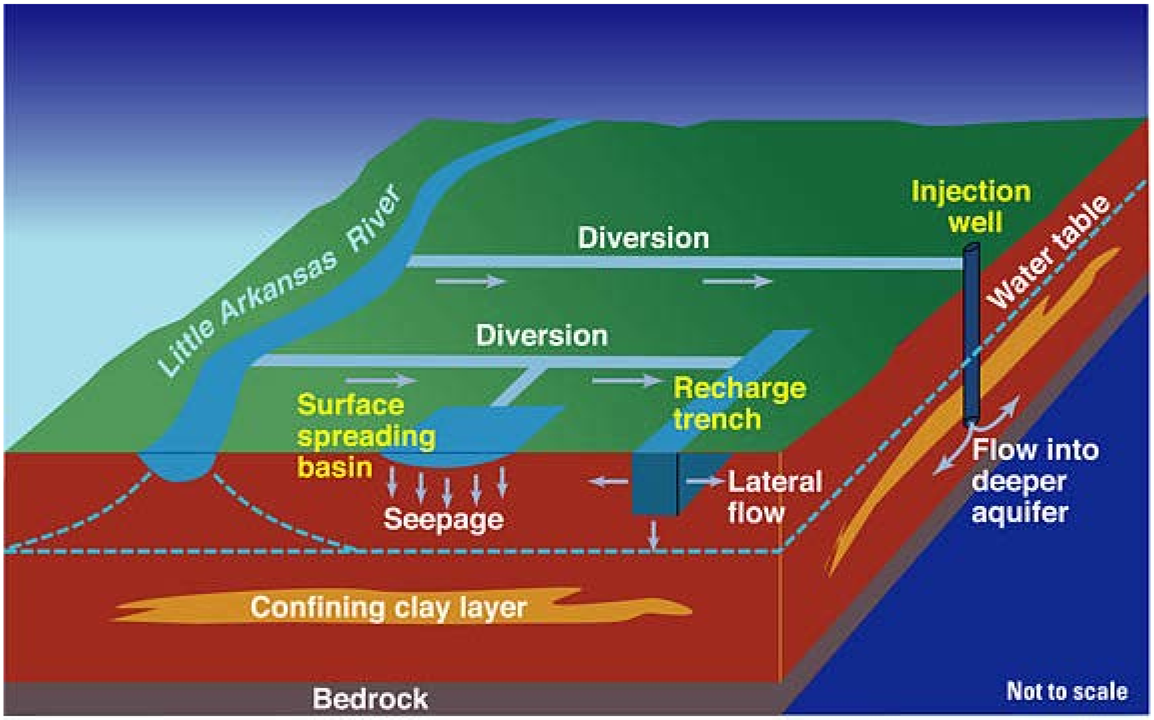

Schematic of the artificial recharge process

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CONVERSION FACTORS, ABBREVIATIONS, AND VERTICAL DATUM

Multiply	By	To obtain
cubic foot per second (ft^3/s)	0.02832	cubic meter per second
foot (ft)	0.3048	meter
gallon per minute (gal/min)	0.06309	liter per second
inch (in.)	2.54	centimeter
mile (mi)	1.609	kilometer
million gallons (Mgal)	3.785	cubic meter
square mile (mi^2)	2.590	square kilometer

Temperature can be converted to degrees Celsius (°C) or degrees Fahrenheit (°F) by the equations:
°C = 5/9 (°F - 32) °F = 9/5 (°C) + 32.

Milliequivalnets per liter (meq/L) can be calculated with the following equation:
meq/L=(concentration in milligrams per liter)(1/molecular weight in grams)(valence).

Sea level: In this report, "sea level" refers to the National Geodetic Vertical Datum of 1929--a geodetic datum derived from a general adjustment of the first-order level nets of the United States and Canada, formerly called Sea Level Datum of 1929.

Abstract

To investigate the feasbility of artificial recharge as a method of meeting future water-supply needs and to protect the *Equus* Beds aquifer from saltwater intrusion from natural and anthropogenic sources to the west, the *Equus* Beds Ground-Water Recharge from Demonstration Project was begun in 1995. The project is a cooperative effort between the city of Wichita and the Bureau of Reclamation, U.S. Department of the Interior. During the project, high flows from the Little Arkansas River are captured and recharged into the *Equus* Beds aquifer through recharge basins, a trench, or a recharge well, located at two recharge sites near Halstead and Sedgwick, Kansas. To document baseline concentrations and compatibility of stream (recharge) and aquifer water, the U.S. Geological Survey collected water samples from February 1995 through August 1998. These samples were analyzed for dissolved solids, total and dissolved inorganic constituents, nutrients, organic and volatile organic compounds, radionuclides, and bacteria.

Results of baseline sampling indicated that the primary constituents of concern for recharge were sodium, chloride, nitrite plus nitrate, iron and manganese, total coliform bacteria, and atrazine. Chloride and atrazine were of particular concern because concentrations of these constituents in water from the Little Arkansas River frequently exceeded regulatory criteria. The Little Arkansas River is used as the source water for recharge. The U.S. Environmental Protection Agency Secondary Maximum Contaminant Level for chloride is 250 mg/L (milligrams per liter), and the Maximum Contaminant Level for atrazine is 3.0 µg/L (micrograms per liter) as an annual mean. Baseline concentrations of chloride in surface water ranged from 8.0 to 400 µg/L. Baseline concentrations of atrazine in surface water ranged from less than 0.10 to 46 µg/L.

Concentrations of chloride and atrazine have increased in water from some of the wells at both the Halstead and Sedgwick recharge sites after recharge began, although concentrations remained within the range of baseline values in the *Equus* Beds aquifer and are considerably less than U.S. Environmental Protection Agency drinking-water criteria. However, a substantial quantity of water has not been recharged at the Sedgwick site to determine the overall effects of artificial recharge on aquifer quality. Continued monitoring is necessary to determine long-term effects at both sites.

Major ion and trace element concentrations in source water and receiving water were analyzed to determine the compatibility of recharge and receiving ground water for artificial recharge. Stiff diagrams of major ions were used to show the similarity or differences between source surface water and receiving ground water. The water from both sources, for the most part, was chemically compatible to the receiving aquifer water at both recharge sites.

It may be possible to decrease the monitoring frequency at the Halstead recharge site because water-quality changes in receiving water at this site are very gradual. However, real-time water-quality monitoring of surrogates needs to be site specific for the determination of chloride and atrazine. Real-time water-quality monitoring potentially can be used to more effectively manage the artificial recharge process, enabling project officials to respond more rapidly to changes in water quality.

INTRODUCTION

Background

The Wichita well field, initiated in the 1940's and completed in the 1950's in the *Equus* Beds aquifer, is one of the primary sources of water for the city of Wichita and the surrounding area in south-central Kansas. Historical water use for municipal supply and irrigation caused water levels in the *Equus* Beds aquifer to decline as much as 30 ft by 1993 (Aucott and others, 1998). Lower water levels not only represent a diminished water supply but also encourage saltwater intrusion from the Burrton oil field to the northwest and from the Arkansas River to the southwest into the freshwater of the beds (Myers and others, 1996).

Cheney Reservoir was first used in 1965 to supplement Wichita's water supply. In 1994, city officials changed water-policy practices and began to use the reservoir for a larger percentage of water supply for the area. Since 1993, ground-water levels have risen by more than 10 ft in some areas of the Wichita well field, primarily because of increased use of water from Cheney Reservoir and decreased pumping in the well field area (Aucott and others, 1998). However, an expected increase in demand from both water sources could cause supply shortages in the near future (2010) (Warren and others, 1995).

The *Equus* Beds Ground-Water Recharge Demonstration Project was begun in 1995 to investigate the feasibility of artificially recharging the *Equus* Beds aquifer as one alternative to meet future water-supply needs and to protect the aquifer from saltwater intrusion from natural and anthropogenic sources. Throughout the project, high flows from the Little Arkansas River are captured and recharged into the aquifer through various techniques, including recharge basins, a trench, and a recharge well. Before artificial recharge can be determined to be a viable alternative, the water-quality effect of artificially recharging the *Equus* Beds aquifer needs to be assessed.

The *Equus* Beds Ground-Water Recharge Demonstration Project is a cooperative effort between the city of Wichita and the Bureau of Reclamation, U.S. Department of the Interior. Additional participants in the project are the U.S. Geological Survey (USGS), *Equus* Beds Groundwater Management District No. 2 (Halstead, Kansas), and the U.S. Environmental Agency (USEPA). Project work is coordinated with the Kansas Department of Health and Environment (KDHE), the Kansas Water Office, and the Kansas Department of Agriculture, Division of Water Resources. Burns and McDonnell Engineering Consultants (Kansas City, Missouri) and Mid-Kansas Engineering Consultants (Wichita, Kansas) provide engineering expertise and project management. The maintenance and operation of the recharge facilities are performed by the city of Wichita.

The *Equus* Beds Ground-Water Recharge Demonstration Project is a part of the High Plains States Ground-Water Recharge Demonstration Program, which is a cooperative effort among the Bureau of Reclamation, USGS, and USEPA to study the potential for artificial recharge and its effects in 17 Western States. The USGS also has worked cooperatively with the city of Wichita for many years in evaluating the ground-water system and interaction with streams in the area to further the understanding of the entire hydrologic system and to provide information to improve local decisionmaking.

Purpose and Scope

The purposes of this report are: (1) to describe baseline water quality of the Little Arkansas River and the *Equus* Beds aquifer for the *Equus* Beds Ground-Water Recharge Demonstration Project and (2) to describe preliminary effects of artificial recharge from April 1996 through August 1998 on ground-water levels and water quality of the aquifer at two locations--the Halstead recharge site and the Sedgwick recharge site. The compatibility of recharge source water with the receiving ground water and constituents of concern for artificial recharge as related to monitoring frequency and future recharge operations are also discussed.

Preliminary effects of artificial recharge on water levels in the *Equus* Beds aquifer were determined by comparing baseline water levels (measurements made prior to any recharge activities) to water-level measurements made after artificial recharge began. Preliminary effects of artificial recharge on water quality of the *Equus* Beds aquifer were determined by comparing baseline concentrations and artificial recharge concentrations of selected constituents in water collected from ground-water monitoring wells.

Compatibility of recharge source water with receiving ground water was determined by comparing major-ion chemistry for water from various data-collection sites during baseline and artificial recharge conditions. Also, an examination of water temperatures, turbidity, dissolved oxygen, iron, and manganese were used as measures of whether source water, when combined with receiving ground water, could cause plugging of aquifer material and thus inhibit artificial recharge activities.

Constituents of concern were identified as those water-quality constituents that frequently exceeded USEPA water-quality criteria and had the potential to affect artificial recharge operations. The benefits of continued monitoring of these constituents during future recharge operations are also outlined.

Information in this report may be used to evaluate the effects of artificial recharge to date (1999) and to adjust future monitoring frequency and (or) scope. The methodology described in this report can be applied to similar recharge studies in other parts of the United States and foreign lands with similar hydrologic conditions.

DESCRIPTION OF STUDY AREA

Equus Beds Ground-Water Recharge Demonstration Project

The study area for the *Equus* Beds Ground-Water Recharge Demonstration Project encompasses approximately 165 mi^2 and extends northwest of Wichita across parts of Harvey and Sedgwick Counties in south-central Kansas (fig. 1). The study area is bounded by the Arkansas River on the southwest and includes the Little Arkansas River on the northeast. The Wichita well field encompasses 55 mi^2 and is located within the study area. The drainage area for the Little Arkansas River Basin is about 1,200 mi^2. Land use in the basin is primarily agricultural and includes the production of livestock (pasture and rangeland) and field crops. Field crops produced include corn, sorghum, soybeans, and wheat (Kansas Department of Agriculture and U.S. Department of Agriculture, 1997). Agricultural chemicals applied to enhance crop production in the area include fertilizers (such as nitrate, ammonia, and phosphorus) and pesticides (primarily alachlor and atrazine).

The *Equus* Beds aquifer, a part of the larger High Plains aquifer, consists of alluvial deposits of sand and gravel interbedded with clay or silt. In the study area, the general direction of ground-water movement in the *Equus* Beds aquifer is to the east (Aucott and others, 1998). However, in the vicinity of the well field and the Little Arkansas River, ground-water movement has been altered by pumping wells and a low-head dam on the river (fig. 2). The Little Arkansas River is primarily a gaining stream within the study area as indicated by higher water levels in wells adjacent to the stream (Myers and others, 1996; Aucott and others, 1998). This is not the case, however, near the Halstead monitoring site (07143680, fig. 1) where a low-head dam about 1 mi downstream causes higher water levels in the stream than in the adjacent aquifer, resulting in stream-water recharge of the aquifer in this vicinity (fig. 2).

The McPherson channel is a trough of unconsolidated deposits about 200 ft thick within the *Equus* Beds aquifer that extends from Lindsborg (about 30 mi north of the study area) to Halstead (Spinazola and others, 1985). This buried alluvial valley is a major flow path for ground-water movement within the *Equus* Beds aquifer (Leonard and Kleinschmidt, 1976) and is important as it relates to the movement of chemical constituents. Flow of ground water in the vicinity of the McPherson channel is towards the center of the channel and southward. The towns of Lindsborg and McPherson are upgradient from the study area, and wastewater discharge from these towns may be sources of chemical constituents, such as chloride, in the aquifer water.

The encroachment of saltwater into the *Equus* Beds aquifer has been a concern in the area for many years. The sources of this saltwater include mineralized water from the Arkansas River (Spinazola and others, 1985; Myers and others, 1996), oil-field brines from the Burrton area west of the study area and northwest of the Wichita well field, and mineralized water in the underlying Wellington aquifer (Leonard and Kleinschmidt, 1976; Spinazola and others, 1985). Other possible sources of saltwater are municipal waste and industrial discharges from upgradient urban areas in McPherson and Newton (Donald Whittemore, Kansas Geological Survey, oral commun., January 1999).

Halstead Recharge System

Artificial recharge began at the Halstead recharge site on May 29, 1997. The Halstead recharge system consists of the USGS streamflow-gaging station on the Little Arkansas River at Highway 50 near Halstead (station 07143672, fig. 2), the Halstead diversion well site (fig. 2), and the Halstead recharge site (fig. 2). Water for the demonstration project may be diverted from the well completed in the alluvium adjacent to the Little Arkansas River only when flow in the river exceeds 42 ft^3/s at the gaging station from April 1 through September 30 and 20 ft^3/s from October 1 through March 31 in accordance with the Kansas Department of Agriculture, Division of Water Resources, permit conditions (Burns and McDonnell, 1998). The flow requirements at this site did not apply to aquifer tests conducted from April through July 1996. By pumping the diversion well, the ground water stored in the bank deposits of the Little Arkansas River is withdrawn, thereby decreasing the water levels surrounding the diversion well and causing surface water from the Little Arkansas River to be induced into the alluvium. The water quality and quantity at the diversion well site are monitored through samples from five shallow monitoring wells, a deep monitoring well, and the diversion well, which has a pumping capacity of about 1,000 gal/min (fig. 3).

Discharge from the diversion well then is pumped about 2 mi through an underground pipeline to the Halstead recharge site (fig. 3) where it is recharged into the aquifer using one of three methods-recharge basins, a recharge trench, or a recharge well. There are two recharge basins at the Halstead site that are each capable of recharging 50 to 120 gal/min to the aquifer.

At the Halstead recharge site, a clay layer occurs approximately 30 ft below land surface (fig.4) and impedes the vertical flow of recharge water into the *Equus* Beds aquifer. This impediment creates a "mounding" of water that rises to the level of the basin bottom and results in slowed percolation. A recharge trench was installed by the city of Wichita to promote vertical movement of recharge water into the aquifer (fig. 3). The recharge trench is 100 ft long, 3 ft wide, and approximately 15 ft deep and has been tested at recharge rates of 100 to 120 gal/min (Burns and McDonnell, written commun., 1998). In addition, a recharge well is used to inject water into the lower parts of the *Equus* Beds aquifer. The recharge well is deep (225 ft) and is capable of recharging about 900 gal/min to the aquifer. The vertical-flow problems associated with recharge water at this site do not affect the recharge well because the recharge water is injected beneath the clay layer (fig.4).

Sedgwick Recharge System

Artificial recharge at the Sedgwick recharge site began in April 1998. Unlike the Halstead recharge system, where water is withdrawn from the alluvium, the water in the Sedgwick recharge system is diverted directly from the Little Arkansas River for recharge. In the Sedgwick recharge system, water may be withdrawn from the river near USGS streamflow-gaging station 07144100 (fig. 1) at all times when streamflow exceeds 40 ft^3/s (Burns and McDonnell, 1998). At the intake site, a polymer is added as a coagulant aid to reduce turbidity as water passes through a parallel plate separator (Burns and McDonnell, 1998). Next, powdered activated carbon (PAC) is added to remove atrazine and other organic compounds from the water. The treated source water then is pumped about 2 mi by underground pipeline to the Sedgwick recharge site.

Once the treated source water reaches the Sedgwick recharge site (fig. 5), it is pumped to a settling basin to allow the remaining suspended sediment and PAC to settle out of the water. From the settling basin, treated source water is pumped to one of three recharge basins and allowed to infiltrate into the aquifer. A hydrogeologic section across the Sedgwick recharge site between deep monitoring wells DMW-S10 and DMW-S14 is shown in figure 6. Clay layers could impede recharge to the *Equus* Beds aquifer; however, at this location, the water table is usually above the uppermost clay layer, and therefore, flow of recharge water to the water table occurs rapidly. The water levels from the shallow and deep monitoring wells shown in figure 6 are the same. This is an indication of hydraulic connection between the upper sand-and-gravel layers and the lower layers at this site. Infiltration rates as high as 950 gal/min have been observed (Burns and McDonnell, written commun., 1998). High permeability of the sand-and-gravel layer at the site also contributes to rapid infiltration.

METHODS

The potential for water-quality degradation of an aquifer is a major concern for any artificial recharge project. For the *Equus* Beds Ground-Water Recharge Demonstration Project, surface- and ground-water quality are monitored frequently throughout the study area according to a monitoring plan established in consultation with State and Federal agencies. Surface-water quantity and quality are monitored at two USGS streamflow-gaging stations on the Little Arkansas River--Little Arkansas River at Highway 50 near Halstead (station 07143672, fig. 1) and Little Arkansas River near Sedgwick (station 07144100, fig. 1). Flow at both stations is affected by ground-water withdrawals, surface-water diversions, and return flow from irrigated areas (Putnam and others, 1997, p. 288 and 290).

Monitoring wells used in this study were installed by the city of Wichita and constructed of polyvinyl chloride pipe. Wells typically are screened in the lowermost 10 ft of the casing. For dates of completion, type of drill rig, development methods, and other information on individual monitoring wells, refer to Burns and McDonnell (1996).

Ground-water quality is monitored throughout the study area at the following data-collection sites: the Halstead diversion well site, consisting of five shallow monitoring wells (43-70 ft deep) and one deep monitoring well (120 ft deep); the Halstead recharge site, consisting of two shallow (27 and 29 ft deep) and two deep (220 ft deep) monitoring wells; the Sedgwick recharge site, consisting of two shallow (34.5 and 59 ft deep) and two deep (190 and 195 ft deep) monitoring wells; 12 background monitoring wells (40-59 ft deep) located immediately adjacent to the Little Arkansas River; and 10 domestic wells near the Halstead and Sedgwick recharge sites (generally less than 100 ft deep).

Background and domestic wells were used to provide baseline water-quality information on the shallow part of the *Equus* Beds aquifer in the study area. The background wells were designed to monitor water quality. However, domestic wells were designed to provide water supply to landowners and were not installed with the same specifications as the monitoring wells. This should be considered when comparing constituent concentrations for water samples from domestic wells to water samples from monitoring wells. Both shallow and deep wells were sampled during the demonstration project because the shallow and deep zones are geologically different and thus may react differently with the source water artificially recharged to the aquifer. Additional information about these wells, including altitude and screened interval, is given in table 1a and 1b.

Sample collection began in February 1995 and continued at most data-collection sites through September 1997 to document baseline water quality in the Little Arkansas River and the *Equus* Beds aquifer. Samples to determine the preliminary effects of artificial recharge on the *Equus* Beds aquifer were collected from October 1997 through August 1998. Analysis of surface and ground water was performed for dissolved solids, total and dissolved inorganic constituents, nutrients, organic compounds, volatile organic compounds (VOC's), radionuclides, and bacteria. Table 2 defines the time periods for baseline conditions and artificial recharge conditions for each of the data-collection site groupings. A complete list of constituents analyzed is given in table 3a, 3b, 3c, and 3d. Further information related to the data-collection sites, constituents analyzed, data-collection methods, sample frequency, preservation, holding times, and reporting limits can be found in Ziegler and Combs (1997). A preliminary determination of compatibility of recharge source water and receiving ground water was made through the examination of major-ion chemistry and comparison of particular constituents such as dissolved oxygen, iron, and manganese.

Most of the surface-water samples collected for analysis of triazine herbicides were obtained using automated samplers. Results of analyses of surface-water samples collected by automated samplers were compared to results of analyses of samples collected using depth- and width-integrating techniques (Ward and Harr, 1990). Ground-water samples were collected with a submersible pump, using methods described in Wood (1976), Koterba and others (1995), and Puls and Barcelona (1996).

Triazine herbicides were analyzed by enzyme-linked immunosorbent assay (ELISA) (Thurman and others, 1990). Selected samples were verified by gas chromatography/mass spectrometry (GC/MS). A previous study (Christensen and Ziegler, 1998a) indicated a good relation between ELISA-determined triazine concentrations and the GC/MS-determined atrazine concentrations in the artificial recharge study area. In fact, the slope of the regression line, 0.81, indicates that the results of the two analyses are similar for surface water (Christensen and Ziegler, 1998b). Therefore, triazine herbicide concentrations determined by ELISA are referred to as atrazine concentrations in this report. However, the relation between triazine herbicide concentrations determined by ELISA and atrazine concentrations determined by GC/MS is not acceptable for ground-water samples because concentrations of atrazine are more frequently equal to or less than the reporting limit for ELISA (0.10 mg/L, microgram per liter). Therefore, in figures 20, 27, and 28, atrazine concentrations determined by ELISA are reported for surface-water samples, whereas atrazine concentrations determined by GC/MS are reported for ground-water samples.

BASELINE WATER QUALITY, 1995-98

Information on the water quality of the *Equus* Beds aquifer and the Little Arkansas River before artificial recharge began was established as a basis for determining what effects, if any, artificial recharge would have on existing ground-water conditions. Baseline water-quality monitoring also was done to establish the constituents of concern for artificial recharge in the study area.

Surface- and ground-water samples were collected from February 1995 through September 1997 to document baseline concentrations of selected chemical constituents, except at the Halstead diversion well site where baseline water-quality monitoring ended in March 1996 because an aquifer test began in April 1996. At the Sedgwick recharge site, baseline water-quality monitoring was extended through February 1998 because recharge operations did not begin at this site until April 1998. In addition, baseline water-quality monitoring of domestic wells near Sedgwick continued until August 1998.

Summary results of baseline water-quality sampling are presented in tables 4-10. Summary tables give the range in detected concentrations, the number of samples analyzed, and the median concentrations (where applicable) for physical properties and selected constituents (table 4a, 4b, and 4c), filtered major ions (table 5a, 5b, and 5c), nutrients (table 6a, and 6b), selected trace elements (table 7a, 7b, and 7c), total organic carbon (table 8), and total coliform bacteria (table 9) in samples from surface- and ground-water data-collection sites. Table 10a, 10b, 10c, 10d, 10e, 10f, 10g, 10h, 10i, 10j, 10k, and 10l displays the range in detected concentrations, number of samples analyzed, and the median concentrations (where applicable) for all organic compounds in filtered samples. Individual data values for all samples collected are on file at the USGS office in Lawrence, Kansas.

Filtered constituents were reported because Ziegler and others (1997) found that in an artificial recharge study it was more appropriate and cost effective to analyze samples for filtered rather than total-recoverable concentrations. In this recharge study, sediment is removed from surface water before it is recharged through basins or trenches. In addition, onsite turbidity measurements in ground-water samples are required to be less than 10 NTU (nephelometric turbidity units), making analysis of total-recoverable concentrations unnecessary for inorganic and most organic compounds (Ziegler and Combs, 1997). However, total concentrations are used for total organic carbon, VOC's, acid and base/neutral organic compounds, and total coliform bacteria.

Although human activities can affect the concentrations of an inorganic constituent, natural concentrations may be large. Therefore, not all detected inorganic constituents are reported in tables 4a, 4b, 4c, 5a, 5b, 5c, 6a, 6b, 7a, 7b, 7c, 8), and 9. Inorganic constituents are listed in those tables if the concentration in any sample was larger than 20 percent of the USEPA's Maximum Contaminant Level (MCL), the Secondary Maximum Contaminant Level (SMCL), the Drinking-Water Equivalent Level (DWEL), or the Health Advisory Level (HAL) for that constituent. In addition, some properties and constituents with no MCL, SMCL, DWEL, or HAL are included in tables 4-9 if they are of particular interest for operation or design of recharge facilities and (or) are needed to describe the water chemistry.

Table 10a, 10b, 10c, 10d, 10e, 10f, 10g, 10h, 10i, 10j, 10k, and 10l reports organic compounds that were detected in any sample. Different reporting guidelines were used for these tables because many organic compounds, such as pesticides, do not occur naturally in the environment but result from human activity. VOC's, acid, or base/neutral organic compounds, were not detected in any samples from any data-collection site.

Selected constituents from tables 4-10 are discussed in the following sections. Each selected constituent is examined in terms of the concentations in surface water and ground water. Constituents of concern for artificial recharge activities are defined, especially as related to frequent large concentrations, relative to the regulatory criteria for dringing water, (MCL, SMCL, DWEL, or HAL), in surface water-the source water for recharge.

Physical Properties and Selected Constituents

Physical properties and selected constituents summarized in table 4a, 4b, 4c for baseline water-quality conditions are specific conductance, pH, water temperature, turbidity, dissolved oxygen, total hardness, alkalinity, suspended solids, and dissolved solids. It is important to consider the physical properties of a water sample because these properties are unique in a number of respects and sometimes are affected by other properties. For example, dissolved ions have a tendency to increase specific conductance (Hem, 1992).

The only physical properties or constituents that have a regulatory criterion are pH, laboratory turbidity, and dissolved solids. The range in pH for all sites during baseline monitoring was 4.4 to 8.6 (standard units). The SMCL's acceptable range is 6.5 to 8.5 (U.S. Environmental Protection Agency, 1999).

Both onsite turbidity and laboratory turbidity are reported in table 4a, 4b, 4c. Onsite turbidity, which is typically smaller than laboratory turbidity, is measured because a ground-water sample is required to have an onsite turbidity not greater than 10 NTU for water-quality analyses (Ziegler and Combs, 1997). There were four instances when onsite turbidity exceeded 10 NTU. Two of these occurred at the Sedgwick recharge site in wells that were recently drilled (wells SMW-S13 and SMW-S11), one occurred in domestic well DW-10 near Sedgwick, and one occurred in the first sample collected from background well TH-08-A1. Laboratory turbidity was measured at greater than the MCL for drinking water of 0.5 to 1.0 NTU in water from some data-collection sites. The range in laboratory turbidity in baseline surface water was 0.30 to 1,200 NTU. The range in water from wells was 0.13 to 1,300 NTU. These larger laboratory turbidities in ground water probably are a result of iron precipitates being formed after sampling. The value of 1,300 NTU occurred in water from a shallow well at the Sedgwick recharge site (well SMW-S13) shortly after the well was drilled. The well may not have been completely developed, which also may account for the larger laboratory turbidity.

Dissolved solids concentrations exceeded regulatory criteria at most sites. Dissolved solids concentration is the total amount of dissolved material in the water and can be attributed to the dissolved major ions present. In the study area, the large dissolved solids concentrations detected during baseline conditions were associated with large sodium, bicarbonate, and chloride concentrations. These and other major ions are discussed in the following section.

Major Ions

Major ions result primarily from the dissolution of rocks and minerals or from discharges of municipal or industrial sources. Excessively large concentrations of major ions are objectionable in drinking water because of possible physiological effects, unpalatable mineral tastes, and greater costs because of corrosion or the need for additional treatment (U.S. Environmental Protection Agency, 1986). Regulatory criteria have been assigned for sodium, sulfate, chloride, and fluoride(table 5a, 5b, 5c).

Fluoride did not exceed its MCL of 4.0 mg/L in any baseline sample. However, sodium, sulfate, and chloride exceeded their respective regulatory criteria at some data-collection sites during baseline sampling. Sodium and chloride were detected at values greater than their DWEL and SMCL of 20 and 250 mg/L, respectively, during baseline water-quality monitoring. The range of sodium in surface-water samples was 4.4 to 200 mg/L; the range in water from wells was 14 to 150 mg/L. Figure 7 shows the ranges in sodium concentrations of the baseline samples. Individual data points were used when there were less than six water samples from the site. The concentration of sodium in water is closely related to the concentration of chloride. Chloride concentrations in surface-water samples ranged from 8.0 to 400 mg/L; in water from ground-water wells, the range was less than 5.0 to 290 mg/L (fig. 7). In both cases, the range of concentrations is larger in the surface-water samples than in the ground-water samples. Sources for sodium and chloride in the Little Arkansas River may be related to past oil and gas activities near McPherson and Burrton or from wastewater-treatment and industrial discharges from McPherson and Newton (Donald Whittemore, Kansas Geological Survey, oral commun., 1999). Additional sources include seepage from ground water affected by the dissolution of marine sediment, concentration by irrigation, and seepage from sewage lagoons, which tend to be enriched in sodium and chloride (Kemmer, 1979).

Because baseline monitoring was limited to one sample from each of the four monitoring wells, seasonal variation of sodium and chloride concentrations could not be documented at the Halstead recharge site. However, water samples collected in April 1998 from domestic wells near Halstead were used to help define the baseline conditions in that part of the study area.

Nutrients

Nutrients, including species of nitrogen and phosphorus, are required for the growth and reproduction of plants. Agricultural activities, sewage-treatment plants, and domestic sewage lagoons are sources of nutrients in surface and ground water. Large nutrient concentrations in drinking water may have undesirable health effects in humans. For example, nitrate concentrations greater than 10 mg/L as nitrogen in drinking water can cause methemoglobinemia in infants 6 months and younger (U.S. Environmental Protection Agency, 1986); consequently, KDHE has set the MCL for nitrite plus nitrate at 10 mg/L (Kansas Department of Health and Environment, 1994). No other nutrient has regulatory criteria for drinking water.

The nitrite plus nitrate as nitrogen (referred to as nitrite plus nitrate in the remainder of this report) concentration in surface water during baseline water-quality monitoring ranged from less than 0.02 to 3.0 mg/L (table 6a, and 6b, fig. 8.). In water from wells, the range was less than 0.01 to 15 mg/L (table 6a, and 6b, fig. 8.). The larger concentrations occurred in water from shallow wells at the Halstead and Sedgwick recharge sites. The disposal of sewage on the land surface can cause nitrate contamination in ground water (Freeze and Cherry, 1979), and there is a sewage lagoon east of the Halstead recharge site (fig. 3). Although ground-water flow is generally to the east, mounding beneath the sewage lagoon could result in local radial flow that could affect the water in the monitoring wells at the Halstead recharge site. At the Sedgwick site, fertilizer application on nearby fields may have an effect on nitrate concentrations in shallow wells because a significant portion of the nitrogen applied to crops like corn may not be used by the plants and the nitrogen may percolate to the ground water (Hammer, 1986). None of the water samples from deep wells had nitrite plus nitrate concentrations larger than 3.0 mg/L; in fact, nitrite plus nitrate was not detectable in most samples from deep wells.

Trace Elements

Trace elements refer to solutes in natural water that nearly always occur in concentrations less than 1.0 mg/L (Hem, 1992, p. 129). Of particular concern in this study are the concentrations of iron and manganese. Iron and manganese can precipitate and cause plugging of plumbing and stain laundry. In addition, the tendency of these trace elements to form a precipitate could affect the recharge process by plugging aquifer materials or equipment. During baseline water-quality monitoring, iron was detected at concentrations larger than the USEPA SMCL of 300 mg/L in water samples from both surface-water monitoring sites (table 7a, 7b, and 7c). In fact, iron occurred at concentrations as large as 860 mg/L in samples from the Halstead surface-water site and is associated with suspended sediment (Ziegler and others, 1997). Iron was detected in water from all wells except the deep monitoring wells at the Sedgwick recharge site. The range of iron concentrations in water from wells was less than 5.0 to 17,000 mg/L. The largest concentration occurred in water from domestic well DW-10 near Sedgwick.

Manganese has an SMCL of 50 mg/L and is chemically similar to iron. Manganese also may precipitate and interfere with recharge. Manganese concentrations in surface-water samples ranged from less than 5.0 to 1,100 mg/L and in ground-water samples from less than 5.0 to 4,300 mg/L. Larger concentrations of both iron and manganese probably are associated with more chemically reducing conditions (small dissolved-oxygen concentrations) in ground water, especially in water from the background wells and the Halstead diversion well site (fig. 9).

Other trace elements, such as arsenic and selenium, which may have health concerns, were detected occasionally. The largest arsenic concentration was 24 mg/L detected in water from shallow monitoring well EB-145-A3 at the Halstead diversion well site; this concentration is 48 percent of the arsenic MCL. The largest selenium concentration was 11 mg/L in water from shallow monitoring well SMW-S13 at the Sedgwick recharge site; this concentration is 22 percent of the selenium MCL. These concentrations of arsenic and selenium are probably naturally occurring but may concentrate in irrigation drainage in some areas.

Total Organic Carbon

Total organic carbon (TOC) is an approximate determination of the total concentration of organic material in an unfiltered water sample (Drever, 1982). The largest TOC concentration during baseline sampling was 27 mg/L in a sample from the Halstead surface-water monitoring site (table 8). Organic carbon concentrations in ground water are generally smaller than those in surface water (Hem, 1992). The largest TOC concentration in a ground-water sample was 8.2 mg/L from well SMW-S13 at the Sedgwick recharge site. Large TOC concentrations can form trihalomethanes (THMs) when combined with chlorine during water-treatment processes. THMs are suspected cancer-causing agents (Pine and others, 1996). TOC also may be a concern for the recharge demonstration project because large concentrations in surface water may interfere with treatment of the water for the removal of atrazine by competing for adsorption sites on the powdered activated carbon (PAC). There is no MCL for TOC.

Bacteria

The presence of total coliform bacteria in water is not directly harmful to humans, but in large numbers it may indicate the presence of other species that are pathogenic (Hem, 1992). The largest density of total coliform bacteria detected during baseline water-quality monitoring was 9,000,000 col/100 mL (colonies per 100 milliliters of water) in a sample from the Sedgwick surface-water monitoring site (table 9). The largest densities were associated with large discharges. Large densities in surface water may be the result of municipal wastewater discharge or runoff from livestock-producing areas. The MCL goal for total coliform bacteria is 0 col/100 mL in finished drinking water. Baseline coliform densities in water from most wells in the study area ranged from less than 1 to 64 col/100 mL.

Water from the background wells, however, had densities as large as 490 col/100 mL, possibly due to their immediate proximity to the Little Arkansas River (fig. 1). Results from baseline monitoring indicated that total coliform bacteria would affect ground-water recharge only if treatment of the source water did not remove bacteria.

Organic Compounds

Of the 173 organic compounds analyzed (including dissolved pesticides, total recoverable organochlorine and organophosphate pesticides, total recoverable volatile organic compounds, acid compounds, and base/neutral compounds), 32 different pesticide parent compounds or metabolites were detected and are listed in table 10a, 10b, 10c, 10d, 10e, 10f, 10g, 10h, 10i, 10j, 10k, and 10l. Of these 32 organic compounds, 28 were detected in surface-water samples, and 16 were detected in ground-water samples collected during baseline water-quality monitoring. Of the organic compounds in surface-water samples, concentrations of alachlor, atrazine, cyanazine, metolachlor, and propazine exceeded 20 percent of their respective MCLs (or HALs) in at least one sample (table 10a, 10b, 10c, 10d, 10e, 10f, 10g, 10h, 10i, 10j, 10k, and 10l).

Alachlor is an herbicide commonly used on corn, grain sorghum, and soybeans. Alachlor has an MCL of 2.0 mg/L. Concentrations in excess of the MCL occurred in samples from both surface-water monitoring sites during baseline water-quality monitoring, with the largest concentration of 7.4 mg/L occurring at the Halstead surface-water monitoring site (table 10a, 10b, 10c, 10d, 10e, 10f, 10g, 10h, 10i, 10j, 10k, and 10l). Alachlor was detected in some ground-water samples as well but did not exceed the MCL.

Atrazine, a herbicide used on corn and grain sorghum, has an MCL of 3.0 mg/L as an annual mean (Kansas Department of Health and Environment, 1994). The largest concentrations of atrazine detected during baseline water-quality monitoring at the Halstead and Sedgwick surface-water monitoring sites were 46 and 34 mg/L (by ELISA analysis), respectively (fig. 10). However, neither monitoring site on the Little Arkansas River had an annual mean atrazine concentration greater than the MCL from February 1995 through September 1997. A previous study (Christensen and Ziegler, 1998a) reported that 90 percent of the annual runoff load of atrazine in the Little Arkansas River generally occurred during a short period of time from May through July, indicating that atrazine is of primary concern during spring and early summer. Atrazine was detected in water from nearly all wells, although at smaller concentrations than in surface water, and concentrations were all less than the MCL.

Cyanazine has an HAL of 1.0 mg/L, and in the study area it is used most often to control weeds in the production of corn. Cyanazine was detected in water from both surface-water monitoring sites during baseline water-quality sampling, with a range in concentrations from less than 0.004 to 0.53 mg/L in water from the Halstead surface-water site and from less than 0.004 to 2.1 mg/L in water from the Sedgwick surface-water site. Cyanazine concentrations were less than 0.10 mg/L in samples from all ground-water monitoring sites.

Metolachlor has an HAL of 70 mg/L and is used to control weeds in the production of corn, grain sorghum, and soybeans. The largest concentration of metolachlor detected during baseline water-quality monitoring was 45 mg/L in water from the Halstead surface-water monitoring site (table 10a, 10b, 10c, 10d, 10e, 10f, 10g, 10h, 10i, 10j, 10k, and 10l). Metolachlor was detected in smaller concentrations in water from the Sedgwick surface-water monitoring site and in ground water from the Sedgwick recharge site, from the Halstead diversion well site, and from background monitoring wells adjacent to the Little Arkansas River.

Propazine is an herbicide that has not been sold in the United States since 1990, but it is often found as an impurity in the atrazine that is applied to fields of corn and grain sorghum and as a result is detected in small amounts in surface water (Thurman and others, 1998). Propazine has an HAL of 10 mg/L. Baseline concentrations in surface-water samples ranged from less than 0.01 to 5.2 mg/L. Propazine was detected in samples from two shallow monitoring wells (SMW-S11 and SMW-S13) at the Sedgwick recharge site, but it was not detected in ground-water samples from any other site during baseline monitoring.

Although alachlor, cyanazine, metolachlor, and propazine were all detected in concentrations exceeding 20 percent of their respective MCL or HAL during baseline water-quality monitoring, atrazine was the only pesticide detected with great frequency at concentrations greater than its MCL, especially during spring and summer runoff when herbicide application was followed by periods of intense rainfall (Christensen and Ziegler, 1998a). Atrazine also was detected in samples from nearly all wells.

PRELIMINARY EFFECTS OF ARTIFICIAL RECHARGE, 1996-98

Halstead Recharge System

The instantaneous discharge of the Little Arkansas River at Highway 50 near Halstead (fig. 11) frequently exceeded the minimum flow requirements of the demonstration project permit (42 ft^3/s) during late spring and early summer. The minimum flow requirements for October 1 through March 31 (20 ft^3/s) also were frequently exceeded. In fact, from October 1, 1997, through March 31, 1998, streamflow in the Little Arkansas River at Highway 50 near Halstead remained above 20 ft^3/s for the entire period. The flow requirements at this site did not apply to aquifer tests conducted from April through July 1996.

Effects on Ground-Water Levels

Water levels in the Little Arkansas River at Halstead (station 07143680, fig. 3), near the diversion well site, were nearly always higher than water levels in the adjacent monitoring wells at the site (fig. 11), indicating that the stream generally was recharging the aquifer at this location. Water levels in the stream were higher at this location as a result of backwater from a low-head dam located about 1 mi downstream from the diversion site (fig. 2).

From May 29, 1997, through July 31, 1998, at the Halstead recharge site, a total of about 307 Mgal were recharged into the *Equus* Beds aquifer (fig. 12). Most of this water was recharged using the recharge well at the site. The recharge well began operation in August 1997, and as of July 31, 1998, it had recharged about 272 Mgal (Burns and McDonnell, 1998). The amount of water recharged with the recharge trench and recharge basins is small in comparison. The effect of these recharge activities on water levels can be evaluated by examining water-level data from the monitoring wells at the Halstead recharge site (fig. 13). Water levels in shallow monitoring wells showed little or no change from May 1997 through July 1998. However, water levels in deep wells showed increasing water-level altitudes during extended periods of artificial recharge. Water levels receded, however, when artificial recharge stopped.

Effects on Ground-Water Quality

The water pumped from the Halstead diversion well was sampled approximately every 5 days during recharge activities at a control building on the Halstead recharge site. As indicated in the previous description of the "Halstead Recharge System," the source water at the Halstead diversion well site originates in the river alluvium; therefore, the quality of the source water diverted for recharge was not the same as the quality of the surface water from the Little Arkansas River. Generally, the constituents in the diverted water, such as dissolved solids, bacteria, and organic compounds, occurred in smaller concentrations than in the surface water. This happens, in part, because the aquifer materials, especially clay and organic matter, act as a natural filter capable of removing some chemical constituents as the water passes through. In addition, the ground water near the stream mixes with the surface water that is induced into the alluvial aquifer from the Little Arkansas River and dilutes the concentrations in the ground water.

During artificial recharge conditions at the Halstead site (May 1997 through July 1998), sodium concentrations in water from the Little Arkansas River at Highway 50 near Halstead ranged from 11 to 500 mg/L, with a median concentration of 100 mg/L; from April 1996 through July 1998 concentrations in ground water from the Halstead diversion well site ranged from 49 to 120 mg/L (fig. 14). Sodium concentrations in water diverted for recharge from the diversion well ranged from 51 to 72 mg/L. From May 1997 through July 1998, sodium concentrations in water from shallow monitoring wells SMW-H4 and SMW-H14 at the Halstead recharge site ranged from 45 to 100 mg/L compared to the baseline concentrations of 40 and 150 mg/L (table 5a, 5b, and 5c). The largest effect on sodium concentrations in water from the shallow monitoring wells may be related to the small domestic sewage-treatment lagoon east of the recharge site. An additional source of sodium could be subsurface geologic formations. In water from deep monitoring wells DMW-H1 and DMW-H13, sodium concentrations ranged from 27 to 69 mg/L, compared to the baseline concentrations of 29 and 31 mg/L (fig. 14). Sodium concentrations in water from the deep monitoring wells have increased; however, not enough baseline samples were collected to describe changes in seasonal variability of sodium (table 5a, 5b, and 5c).

From October 1997 through July 1998, chloride concentrations in surface water from the Little Arkansas River at Highway 50 near Halstead ranged from 20 to 930 mg/L (table 5a, 5b, and 5c);from April 1996 through July 1998 in ground water from the Halstead diversion well site, the range in chloride concentrations was from 12 to 280 mg/L (fig. 15). Chloride concentrations in water from the diversion well ranged from 22 to 78 mg/L (table 5a, 5b, and 5c). From May 29, 1997, through July 1998, chloride concentrations in water from shallow monitoring wells SMW-H4 and SMW-H14 at the Halstead recharge site ranged from 39 to 110 mg/L, compared to baseline concentrations of 20 and 290 mg/L. In water from the two shallow monitoring wells, the chloride concentration of one sample exceeded the SMCL of 250 mg/L prior to recharge; this did not occur in any of the 31 samples collected after recharge. The sewage lagoon east of the site probably contributes to the larger chloride concentrations in shallow wells during both baseline and artificial recharge conditions. In water from deep monitoring wells DMW-H1 and DMW-H13, chloride concentrations ranged from 5.8 to 64 mg/L, compared to baseline concentrations of 5.8 and 8.3 mg/L fig. 15).

From October 1997 through July 1998, nitrite plus nitrate concentrations in water from the Little Arkansas River at Highway 50 near Halstead ranged from less than 0.02 to 2.4 mg/L; from April 1996 through July 1998 in ground water from the Halstead diversion well site, the range was 0.01 to 0.03 mg/L (table 6a, and 6b, fig. 16). Nitrite plus nitrate concentrations in diverted water ranged from less than 0.02 to 0.78 mg/L. From May 29, 1997, through July 1998, in water from shallow monitoring wells SMW-H4 and SMW-H14 at the Halstead recharge site, concentrations ranged from 0.01 to 9.1 mg/L, compared to baseline concentrations of 1.7 and 7.0 mg/L (table 6a, and 6b), indicating similar nitrite plus nitrate concentrations before and after recharge in the shallow wells. However, these concentrations are near the MCL of 10 mg/L for nitrite plus nitrate. These large nitrite plus nitrate concentrations in water from the shallow monitoring wells may be due to the sewage lagoon east of the Halstead recharge site and fertilizers applied on nearby fields. In 29 water samples from deep monitoring wells at the Halstead recharge site, there was only one detection of nitrite plus nitrate greater than 0.02 mg/L. Nitrite plus nitrate was not detected in water from the deep monitoring wells during baseline water-quality sampling. As with the shallow wells, nitrite plus nitrate concentrations in water from the deep monitoring wells at the Halstead recharge site were similar before and after recharge.

From October 1997 through July 1998, iron concentrations in water from the Little Arkansas River at Highway 50 near Halstead ranged from less than 5.0 to 30 mg/L (table 7a,7b, and 7c). From April 1996 through July 1998 in water from monitoring wells at the Halstead diversion well site, iron concentrations ranged from less than 10 to 4,900 mg/L (fig. 17). Water from the well at the diversion well site (well EB-145-PD5, fig. 3) showed an increase in iron concentrations since recharge activities began, probably because of induced surface water from the Little Arkansas River. Iron concentrations in water from the diversion well ranged from 170 to 1,200 mg/L. Iron concentrations in water from shallow monitoring wells SMW-H4 and SMW-H14 at the Halstead recharge site were relatively small from May 29, 1997, through July 1998, with a range from less than 5.0 to 6.6 mg/L, compared to similar baseline concentrations of less than 5.0 and 11 mg/L. In water from deep monitoring wells DMW-H1 and DMW-H13, the range was 17 to 1,300 mg/L, compared to baseline concentrations of 7.9 and 300 mg/L. Although there was an increase in iron concentrations in water from the deep monitoring wells, samples from domestic wells in the Halstead area during April 1998 also indicate some large concentrations of iron in water from the aquifer (table 7a,7b, and 7c).

From October 1997 through July 1998, manganese concentrations in water from the Little Arkansas River at Highway 50 near Halstead ranged from less than 5.0 to 340 mg/L. In ground water from the Halstead diversion well site for April 1996 through July 1998, concentrations of manganese ranged from less than 5.0 to 3,400 mg/L (fig. 17). Manganese concentrations in diverted water ranged from 450 to 810 mg/L. For the Halstead recharge site from May 29, 1997, through July 1998, manganese concentrations ranged from less than 5.0 to 15 mg/L in water from shallow monitoring wells SMW-H4 and SMW-H14, compared to baseline concentrations of 20 and 68 mg/L (table 7a,7b, and 7c). The range in manganese concentrations in water from deep monitoring wells DMW-H1 and DMW-H13 was from 230 to 750 mg/L, compared to baseline concentrations of 210 and 260 mg/L.

Concentrations of both iron and manganese are affected by environmental conditions (Hem, 1992). Because the conditions are more chemically reducing (less oxygen available) in ground water, concentrations of iron and manganese tend to be higher in ground water from the diversion well site than in surface water from the Little Arkansas River near Halstead. Iron and manganese can plug the aquifer material when they precipitate as oxides. At the Halstead recharge site, precipitation of iron caused some problems during infiltration tests by plugging the upper filter fabric in the recharge trench (Burns and McDonnell, 1998). The original filter fabric was replaced to alleviate this problem, and the new filter fabric was cleaned during subsequent recharge operations. However, no iron plugging problems have been observed in the recharge well. Manganese has an oxidation process similar to iron (Hem, 1992) and also may precipitate and interfere with recharge.

Total organic carbon concentrations in water from the Little Arkansas River at Highway 50 near Halstead were 6.6 and 6.7 mg/L (table 8) for the two samples collected during artificial recharge conditions (October 1997 through July 1998). The range in total organic carbon concentrations during baseline conditions was 3.8 to 27 mg/L. This greater range probably is due to the greater number of samples collected during baseline conditions. No substantial changes in total organic carbon were observed in water samples from the Halstead diversion well site or the Halstead recharge site.

The possible filtering effect of clay layers overlying the *Equus* Beds aquifer is particularly evident in the concentrations of total coliform bacteria and atrazine in water from the Halstead recharge system. Total coliform bacteria densities in water from the Little Arkansas River at Highway 50 near Halstead ranged from 110 to 53,000 col/100 mL (table 9) from October 1997 through July 1998. At the diversion well site, total coliform bacteria densities in water from shallow monitoring wells ranged from less than 2 to 14 col/100 mL. Total coliform bacteria densities in water from the diversion well ranged from less than 1 to less than 100 col/100 mL. In water from shallow monitoring wells SMW-H4 and SMW-H14 at the Halstead recharge site, densities ranged from less than 1 to 4 col/100 mL during artificial recharge conditions; the range before recharge was less than 1 to 1 col/100 mL (table 9). In water from deep monitoring wells, one sample collected in July 1997 from well DMW-H13 had a bacteria density of 80 col/100 mL; however, most of the other samples had bacteria densities less than 1 col/100 mL, approximating baseline conditions. In addition to the filtering effect of the clay layers, small dissolved-oxygen content is a possible factor causing decreased bacterial densities in ground water from the Halstead recharge system during artificial recharge conditions.

From October 1997 through July 1998, atrazine concentrations in surface water from the Little Arkansas River at Highway 50 near Halstead ranged from less than 0.10 to 12 mg/L (by ELISA) during artificial recharge conditions. At the Halstead diversion well site, concentrations in ground water were less than 0.001 to 2.2 mg/L (by GC/MS) (table 10a, 10b, 10c, 10d, 10e, 10f, 10g, 10h, 10i, 10j, 10k, and 10l, fig. 18). Water from the deep monitoring well at the diversion well site (well EB-145-PD5, fig. 3) showed an increase in atrazine concentrations since recharge activities began, presumably because of surface water from the river being induced into the ground water. Atrazine concentrations in water from the diversion well ranged from less than 0.006 to 0.09 mg/L (by GC/MS). Atrazine concentrations in water from the shallow and deep monitoring wells at the Halstead recharge site ranged from less than 0.001 to 0.09 mg/L (by GC/MS) during artificial recharge conditions. Concentrations of atrazine in water from the monitoring wells generally were no larger than those in water from the diversion well and did not exceed the largest baseline concentration of 0.14 mg/L in water from shallow monitoring well SMW-H4. However, baseline atrazine concentrations were higher in water from the shallow monitoring wells at the Halstead recharge site than in water from the diversion well, indicating that shallow ground water may be affected by pesticides applied on nearby fields.

Concentrations of sodium, chloride, nitrite plus nitrate, bacteria, and atrazine were generally larger in surface water from the Little Arkansas River at Highway 50 near Halstead than in ground water from the diversion well site before and after recharge. From the examination of baseline- and artificial-recharge data collected from the Halstead surface-water site (station 07143672, fig. 1) and diversion well site, several additional observations were made with respect to chloride and atrazine. First, there were seasonal fluctuations in both chloride and atrazine (figs. 19a, 19b, 20a, and 20b) in surface water. However, these seasonal fluctuations did not coincide. Chloride concentrations were largest during the winter (fig. 19a and 19b), whereas atrazine concentrations were largest in spring and early summer (fig. 20a and 20b). Second, there is a time lag in seasonal fluctuations between chloride and atrazine concentrations in the surface water and chloride and atrazine concentrations in the ground water, although significant changes in the chloride concentrations in water from some wells are not evident from the data. During periods of extended pumping, the time lag appears to have decreased possibly because of increased hydraulic gradient between surface and ground water near the diversion well site. Finally, chloride and atrazine concentrations in samples from the deep monitoring wells at the Halstead recharge site increased after recharge began to values approximating that of the recharge water (figs. 19a, 19b, 20a, and 20b).

Sedgwick Recharge System

Effects on Ground-Water Levels

Samples were collected and preliminary testing at the Sedgwick recharge site began in October 1997. Testing was intermittent until April 1998, when recharge operations began. As of July 31, 1998, about 31 Mgal of water had been recharged to the *Equus* Beds aquifer at the Sedgwick site. All of the water at this site was recharged through basins (fig. 5). The effect of the recharge activity on water levels can be evaluated by examining water-level data from the monitoring wells (SMW-S11, SMW-S13, DMW-S10, and DMW-S14, fig. 21). During artificial recharge, all four monitoring wells showed initial increases in water levels; however, water levels receded after about 2 months of recharge.

Effects on Ground-Water Quality

Samples of recharge water were collected daily, and monitoring wells were sampled monthly. Because the source water diverted from the Little Arkansas River is treated prior to pumping into the basins, most physical properties, such as turbidity and suspended solids, generally had smaller concentrations in the recharge water than in the surface water from the Sedgwick site (station 07144100, fig. 1).

Sodium concentrations in water from the Little Arkansas River at Sedgwick (station 07144100, fig. 1) ranged from 11 to 110 mg/L from October 1997 through July 1998 (table 5a, 5b, and 5c). Sodium concentrations in treated source water diverted from the Little Arkansas River ranged from 21 to 81 mg/L. From April through July 1998, in water from shallow monitoring wells SMW-S11 and SMW-S13 at the Sedgwick recharge site, the range in sodium concentrations before recharge was 14 to 58 mg/L. After recharge activities began, the range was 20 to 50 mg/L. In water from deep wells DMW-S10 and DMW-S14, the range in sodium concentrations during baseline conditions was 83 to 93 mg/L; during artificial recharge conditions, the range was 75 to 86 mg/L. The median sodium concentration in water from these deep wells was actually smaller during artificial recharge conditions (81 mg/L) than during baseline conditions (86 mg/L). With respect to sodium, it would appear that the recharge activities at the Sedgwick site do not have a substantial effect on the water quality of the *Equus* Beds aquifer (fig. 22). However, there was not enough water recharged at this site to determine annual fluctuations that may occur.

From October 1997 through July 1998, chloride concentrations in treated source water diverted from the Little Arkansas River for recharge ranged from 26 to 180 mg/L. Chloride concentrations in water from shallow monitoring wells SMW-S11 and SMW-S13 ranged from 10 to 78 mg/L (fig. 23). From April through July 1998, water from deep monitoring well DMW-S14 showed a decrease in chloride concentrations since recharge began, whereas chloride concentrations in water from deep monitoring well DMW-S10 remain unchanged (table 5a, 5b, and 5c). Generally, chloride concentrations in the source water were not affected by treatment (fig. 24). Once the recharged water infiltrated into the aquifer, the concentrations of chloride in water from nearby monitoring wells generally did not change substantially from what they were prior to recharge (fig. 24).

From October 1997 through July 1998, nitrite plus nitrate concentrations in water from the Little Arkansas River at Sedgwick ranged from less than 0.02 to 2.9 mg/L (table 6a and 6b). In the treated source water diverted from the Little Arkansas River, nitrite plus nitrate concentrations ranged from 0.13 to 1.8 mg/L. In water from shallow monitoring wells SMW-S11 and SMW-S13, nitrite plus nitrate concentrations ranged from 1.8 to 13 mg/L prior to artificial recharge; during artificial recharge conditions, the range in concentrations in water from these wells was 1.2 to 15 mg/L (fig. 25). The large concentrations of nitrite plus nitrate in water from these shallow wells (larger than source-water concentrations) may be the result, at least partly, of fertilizer application on nearby fields. During baseline conditions in water from deep monitoring wells DMW-S10 and DMW-S14, nitrite plus nitrate concentrations ranged from 0.05 to 2.7 mg/L; during artificial recharge conditions, the range was 0.16 to 4.6 mg/L. The median concentrations in water from these deep wells were 0.09 mg/L before recharge and 2.0 mg/L after recharge. Even though the median nitrite plus nitrate concentrations in water from these wells increased during artificial recharge conditions, there were not enough samples collected prior to recharge to define the seasonal variability of the nitrite plus nitrate concentrations, and the increased median concentrations may be a reflection of unknown seasonal variability. Baseline conditions occurred from June 1997 through February 1998, and artificial recharge conditions occurred from April through July 1998, making definition of seasonal variability difficult at this site.

Although iron and manganese caused infiltration problems at the Halstead recharge site because they precipitated on the filter fabric in the recharge trench, they were not a factor at the Sedgwick site. The largest iron concentration detected in water from monitoring wells at the Sedgwick recharge site after recharge began was 68 mg/L. In fact, iron was not detected in most monitoring well samples. Manganese concentrations in ground water at the Sedgwick recharge site either decreased or did not change (fig. 26). Because concentrations of iron and manganese were generally larger during baseline conditions at the Sedgwick recharge site, iron and manganese may have precipitated during artificial recharge conditions and that precipitation may have been caused by the rapid infiltration of oxygenated recharge water.

From October 1997 through July 1998, TOC concentrations in water from the Little Arkansas River near Sedgwick ranged from 5.7 to 7.3 mg/L. Treated diverted water had slightly smaller concentrations during the same period-from 4.3 to 5.9 mg/L. In general, water from monitoring wells (SMW-S11, SMW-S13, DMW-S10, and DMW-S14) at the Sedgwick recharge site had smaller TOC concentrations during artificial recharge conditions than during baseline conditions.

From October 1997 through July 1998, total coliform bacteria in water from the Little Arkansas River near Sedgwick ranged from 30 to 27,000 col/ 100 mL. Total coliform bacteria ranged from less than 1 to 400 col/100 mL in treated source water diverted from the Little Arkansas River. However, densities of total coliform bacteria were not a significant concern in water from monitoring wells at the Sedgwick recharge site with only one detection (of 1 col/ 100 mL) after recharge began. Total coliform bacteria may become a concern during longer periods of recharge.

Atrazine, because of its frequent use on row crops in the study area and its potential effects on water quality, has been monitored frequently since February 1995 in water from the Little Arkansas River (Christensen and Ziegler, 1998a). Atrazine concentrations in surface water typically are larger in the spring and summer when herbicides are applied and when excessive rains cause greater runoff to streams (Goolsby and others, 1997). In treated source water from the Little Arkansas River, atrazine concentrations determined by ELISA ranged from less than 0.1 to 6.8 mg/L (fig. 27). The maximum atrazine concentration (determined by GC/MS) detected in water from shallow monitoring wells SMW-S11 and SMW-S13 was 0.36 mg/L, exceeding the baseline maximum concentration of 0.1 mg/L (fig. 27). Atrazine was not detected in water from the deep monitoring wells at the site. The addition of PAC to the treated source water was effective in decreasing the concentrations of atrazine to concentrations similar to baseline concentrations; therefore, concentrations of atrazine in water from nearby monitoring wells were similar to what they were prior to recharge, with the exception of atrazine concentrations in water from well SMW-S11. The seasonal variation in atrazine concentrations in water from the Little Arkansas River near Sedgwick and water from shallow monitoring wells SMW-S11 and SMW-S13 is shown in figure 28.

Documentation of the preliminary effects of artificial recharge at the Sedgwick site are important because of the large differences between constituent concentrations in the surface water and the baseline water-quality conditions of the receiving aquifer water. Sodium, chloride, bacteria, and atrazine were detected in larger concentrations in untreated surface water than in the receiving ground water. This is especially true in the case of bacteria and atrazine where surface-water concentrations were many times that of baseline ground-water concentrations.

Although sodium concentrations and bacteria densities in ground water have not shown definitive changes since artificial recharge began, concentrations of chloride and atrazine have increased in some of the monitoring wells at the Sedgwick recharge site. However, at this site, only 31 Mgal of water have been recharged compared with 307 Mgal recharged at the Halstead site. Continued monitoring at the Sedgwick site during further recharge operations will help ensure that the large concentrations of certain constituents in the source water do not adversely affect the quality of the receiving ground water.

COMPATIBILITY OF SOURCE WATER FOR ARTIFICIAL RECHARGE

Compatibility of source water for artificial recharge was determined by comparing major-ion and trace-element concentrations in source water and receiving ground water and by evaluating the potential for adverse chemical reactions. Stiff diagrams (Stiff, 1951) of mean concentrations of the major ions during baseline and artificial recharge conditions are shown in figure 29. The shape of the Stiff diagram was used to indicate if there were differences in the chemistry of the source water and that of the receiving ground water. For example, the addition of source water with small concentrations of calcium and bicarbonate to ground water with large concentrations of these constituents may dilute the existing large concentrations. Alternatively, depending on water chemistry, the source water may cause more calcium and bicarbonate to be dissolved from the aquifer material, which then, with further changing water chemistry, may lead to plugging of the aquifer material as the water flows downgradient, thereby limiting recharge.

The Stiff diagrams of the water from Little Arkansas River at Highway 50 near Halstead (station 07143672, fig. 1) are very similar to the Stiff diagrams of water from shallow monitoring wells at the Halstead diversion well site during baseline and artificial recharge conditions (fig. 29A). Stiff diagrams for water from the deep well, however, show smaller chloride plus fluoride concentrations compared to water from the shallow monitoring wells during baseline and artificial recharge conditions. The Stiff diagram for water from the deep well is similar to the Stiff diagram for source water from the diversion well. The Stiff diagram for source water also is similar to that for water from monitoring wells at the Halstead recharge site, although samples from the deep ground water at the recharge site had smaller concentrations of chloride (fig. 29B). The Stiff diagrams of water from the shallow monitoring wells at the Halstead recharge site during baseline conditions differ from source water from the diversion well and each other; however, during artificial recharge conditions, the Stiff diagram of water from the shallow monitoring wells is similar to that for the source water. Smaller increases in chloride concentrations in water from the deep wells at the Halstead diversion well site and from deep monitoring wells at the Halstead recharge site also are illustrated in figures 29A and 29B.

The Stiff diagram for water from the Little Arkansas River near Sedgwick is nearly identical to that for the treated source water used for recharge (fig. 29C). At the Sedgwick recharge site, shallow ground water has much smaller concentrations of chloride plus fluoride than concentrations of chloride plus fluoride in treated source water. The treated source water also has larger concentrations of bicarbonate plus carbonate that, when combined with the large calcium concentrations in shallow ground water, could lead to chemical precipitation of calcium carbonate. The precipitation of calcium carbonate may cause some plugging of aquifer materials. Shallow ground water at the Sedgwick site has much larger concentrations of sulfate compared to other ground water. Larger sulfate concentrations in the shallow ground water may be an indication of oxidation of sulfide minerals in the aquifer material, consistent with an unconfined aquifer. The part of the *Equus* Beds aquifer into which the shallow wells at the Sedgwick recharge site are drilled is generally unconfined (fig. 6), as compared to the Halstead recharge site, where the shallow part of the aquifer is confined by a clay layer (fig. 4). The median dissolved-oxygen concentration in water from the shallow wells at the Halstead recharge site is smaller than the median dissolved- oxygen concentration in water from the shallow wells at the Sedgwick recharge site (table 4a., 4b, and 4c), indicating that there is more oxygen available at the Sedgwick recharge site to oxidize the sulfide minerals in the aquifer material.

There are other possibilities, however, for the larger sulfate concentrations in water from shallow wells at the Sedgwick recharge site, such as the dissolution of gypsum.

In addition to the major ions evaluated using Stiff diagrams, trace elements such as iron and manganese also were examined. The oxidation-reduction (redox) potential of water determines whether redox-sensitive chemicals such as iron and manganese remain in solution or are precipitated by the addition of oxygen. Redox potential for iron and manganese in water samples were not determined during the study, but dissolved-oxygen concentrations in the ground water from the Halstead diversion well site and the Halstead recharge site were small. It is, therefore, unlikely that redox conditions will chemically precipitate iron and manganese and cause plugging of the aquifer material when source water is injected through the recharge well. However, when the source water is exposed to atmospheric oxygen, precipitates can form and may cause plugging of the recharge basins and trench as happened at the Halstead recharge trench. Surface water from the Little Arkansas River has large concentrations of dissolved oxygen that, when introduced into the ground water at the Sedgwick recharge site, could cause chemical precipitation of iron and manganese that could plug the aquifer material. As noted previously, large dissolved-oxygen concentrations in water from the shallow monitoring wells at the Sedgwick recharge site, during both baseline and artificial recharge conditions, are consistent with unconfined conditions. Concentrations of iron and manganese are significantly smaller after recharge (table 7a, 7b, and 7c), indicating that precipitation of iron and manganese may have occurred as a result of the addition of highly oxidized treated surface water from the Little Arkansas River near Sedgwick. There has been no decrease, however, in the rapid infiltration of treated source water into the *Equus* Beds aquifer through the recharge basins at the Sedgwick recharge site. Therefore, substantial plugging of the aquifer material due to chemical precipitation of iron and manganese at this site appears unlikely.

Physical properties of water, such as turbidity and temperature, also may affect recharge activities by contributing to the plugging of aquifer materials with sediment and dissolved minerals. Turbidity and water temperature of source and ground water at the Halstead diversion well and recharge sites are very similar and have minimal effect on aquifer plugging. At the Sedgwick site, however, even with sediment in the treated source water removed, turbidities and sediment in the treated source water are larger than those of the receiving ground water and could eventually cause plugging of the aquifer material. The primary effect of turbidity differences will be reduced infiltration at the Sedgwick site. Temperature differences in source and receiving ground water at the Sedgwick site can be large (greater than 10 °C), could result in increased chemical rates of reaction causing some dissolution of minerals from the aquifer material or precipitation of minerals from the source water, and may affect permeability.

CONSTITUENTS OF CONCERN FOR FUTURE MONITORING

It was determined from the baseline water-quality monitoring that constituents of concern for artificial recharge activity were sodium, chloride, nitrite plus nitrate, iron, manganese, total coliform bacteria, and atrazine. Sodium and chloride were a concern as related to monitoring frequency and future recharge operations because of the possibility of contamination of the *Equus* Beds aquifer both from source water with large sodium and chloride concentrations and from natural and anthropogenic sources west and northwest of the Wichita well field. Nitrite plus nitrate is a concern mainly because of its effect on human health but also because it is subject to large seasonal variability; the largest baseline concentrations of nitrite plus nitrate occurred during periods when recharge operations were likely. Iron and manganese were a concern because of their tendency to precipitate and thus interfere with the recharge process. Total coliform bacteria were a concern because of large baseline detections in surface water. Atrazine was a concern because of its frequent detection above its MCL and the occurrence of large concentrations during times when recharge was likely. Alachlor, cyanazine, metolachlor, and propazine were also a concern because of occasional detections that exceeded 20 percent of their respective MCL or HAL.

The constituents of concern were monitored during recharge activities on a more frequent basis than the other constituents listed in tables 4-10. However, monitoring of other inorganic and organic constituents was continued to determine an adequate baseline for concentrations of these constituents. It was determined from baseline monitoring that chloride and atrazine concentrations frequently exceeded regulatory criteria in the surface water that was used as a source for recharge. Chloride and atrazine were monitored frequently because of their large and variable concentrations in surface water and because they can be used to indicate when recharge activities need adjustment in treatment or need to be discontinued. Monitoring frequency is also an important consideration in future recharge operations as seasonal definition of constituent concentrations is necessary to describe effects of future recharge.

Monitoring for the constituents of concern in source water was conducted at least every 5 days immediately after recharge began at the Halstead and Sedgwick sites. The data collected at the Halstead recharge site (figs. 19a, 19b, 20a, and 20b) illustrate that changes in quality of source and receiving ground water are very gradual and probably could be defined adequately with monthly samples of source water and quarterly samples of receiving ground water. However, at the Sedgwick site, monitoring of selected constituents- primarily chloride, bacteria, and atrazine-would benefit from more frequent sampling because of the large variability in these constituent concentrations. Increased monitoring frequency in the shallow monitoring wells would improve definition of the effects of source water on shallow ground water. Quarterly sampling probably is sufficient for deep ground water at the Sedgwick site because recharge activities seem to have little effect on water quality in the deep monitoring wells and because quarterly sampling is sufficient to define seasonal variability.

Real-time monitoring of source water potentially can improve the effectiveness of the current monitoring program for the *Equus* Beds Ground-Water Recharge Demonstration Project and is important to the maintenance of good quality water in the *Equus* Beds aquifer. Real-time data are recorded hourly and transmitted every 4 hours to the USGS office in Lawrence, Kansas, and displayed on the Internet at **http://ks.water.usgs.gov**. With real-time monitoring, an undesirable level of a constituent in source water can be identified almost immediately and action taken to either treat the water before recharge or the decision could be made not to recharge until water-quality conditions improved.

To achieve real-time water-quality monitoring, it would be necessary to use surrogates for the constituents of primary concern, chloride and atrazine. A surrogate is a physical property or properties that are monitored continually in-stream that may be substituted for a particular water-quality constituent for which continual data are not available. For example, specific conductance, which is currently being monitored in real time for source water, may be determined by an in-stream probe and could be used as a surrogate for the analysis of chloride concentrations in source water. A comparison of specific conductance and chloride concentrations in water from the Little Arkansas River at Highway 50 near Halstead shows a direct relation with a correlation coefficient (r^2) of 0.92 (fig. 30A). Source water from the Halstead diversion well shows a similar relation between specific conductance and chloride (fig. 30B).

The slopes of the regression lines for the relations between specific conductance and chloride in water from the Sedgwick recharge site are different than those for water from the Halstead recharge site. A comparison of specific conductance and chloride in water from the Sedgwick site shows a slope of 0.14 for both the surface water and treated source water (figs. 30C and figs. 30D). The slopes of the relations for the Halstead site are 0.19 for water diverted from the Little Arkansas River at Highway 50 near Halstead and 0.13 for water from the Halstead diversion well. The correlation coefficients are also slightly different between the two sites. The surface water and treated source water for the Sedgwick site have correlation coefficients of 0.85 and 0.83, respectively. The surface water and diversion well water for the Halstead sites show slightly better correlation coefficients of 0.92 and 0.91, respectively. The difference in the relation between the Halstead site and the Sedgwick site indicates that the computation of chloride concentrations, made on the basis of measured values of its surrogate (specific conductance), would need to be site specific and that the accuracy of the computed values also would need to be site specific.

The ELISA screen for triazine herbicides could be used as a surrogate for atrazine to provide real-time monitoring of source water. There is about a 2-day turnaround for ELISA analysis compared with about 40 days for GC/MS analysis. In figure 31, 191 pairs of water samples from the Halstead and Sedgwick surface-water monitoring sites (stations 07143672 and 07144100, fig. 1) were analyzed for triazine herbicides by ELISA and for atrazine by GC/MS. The relation between triazine-herbicide concentrations determined by ELISA and atrazine concentrations determined by GC/MS has a correlation coefficient of $r^2=0.85$. Not only are the results of the two procedures similar, but the ELISA analysis would allow for many samples to be analyzed at low cost.

The use of surrogates enables real-time water-quality monitoring for the constituents of primary concern. This would allow project officials to take appropriate action if the quality of the surface water changes substantially or if SMCLs or MCLs are exceeded.

SUMMARY AND CONCLUSIONS

One of the primary sources of water for the city of Wichita in south-central Kansas is the Wichita well field, completed in the *Equus* Beds aquifer. The *Equus* Beds Ground-Water Recharge Demonstration Project was begun in 1995. The project was designed to investigate the feasibility of artificially recharging the *Equus* Beds aquifer to meet increased demand for water supplies and to protect this important aquifer from saltwater intrusion from natural and anthropogenic sources to the west and northwest. An evaluation of the preliminary effects of artificial recharge on water quality will, in part, determine if a full-scale recharge project is feasible.

The project is a cooperative effort between the city of Wichita and the Bureau of Reclamation, U.S. Department of the Interior. During the project, high flows from the Little Arkansas River are captured and recharged into the *Equus* Beds aquifer through recharge basins, a trench, or a recharge well, located at two recharge sites near Halstead and Sedgwick, Kansas. To document baseline concentrations and compatibility of stream (recharge) and aquifer water, the U.S. Geological Survey collected water samples from February 1995 through August 1998. These samples were analyzed for dissolved solids, total and dissolved inorganic constituents, nutrients, organic and volatile organic compounds, radionuclides, and bacteria.

Determination of baseline water-quality conditions indicated that the constituents of concern were sodium, chloride, nitrite plus nitrate, iron and manganese, total coliform bacteria, and atrazine. Chloride and atrazine were of particular concern because concentrations of these constituents in surface water from the Little Arkansas River frequently exceeded regulatory criteria. The Little Arkansas River is used as the source water for recharge. The U.S. Environmental Protection Agency Secondary Maximum Contaminant Level for chloride is 250 mg/L, and the Maximum Contaminant Level for atrazine is 3.0 mg/L as an annual mean. Baseline concentrations of chloride in surface water ranged from 8.0 to 400 mg/L. Baseline concentrations of atrazine in surface water ranged from less than 0.10 to 46 mg/L. Chloride and atrazine concentrations were large and variable in surface water when compared with the receiving ground water.

From May 1997 through July 1998, a total of about 338 Mgal of water were artificially recharged at the sites near Halstead and Sedgwick, Kansas. At the Halstead recharge site, some increases in concentrations of chloride and atrazine in water from deep monitoring wells were evident after recharge began even though concentrations remained considerably less than the respective SMCL and MCL established by the U.S. Environmental Protection Agency for drinking water. At the Sedgwick recharge site, chloride concentrations decreased after recharge began in water from one of two deep monitoring wells. In water from the other deep well, concentrations of chloride remained unchanged. Atrazine concentrations increased in water from shallow monitoring wells at the Sedgwick site after recharge began. In water samples from deep wells, atrazine concentrations remained less than the MCL or were not detected during artificial recharge conditions. Not enough water has been recharged at the Sedgwick site to date (1999) to determine the overall effects of artificial recharge on receiving ground-water quality. Continued monitoring is necessary to determine long-term effects of artificial recharge at both sites.

Major-ion and trace-element concentrations in source water and receiving ground water were determined to assess the compatibility of the water for artificial recharge. Stiff diagrams of major ions were used to show the similarity or differences in water chemistry between the source water and receiving ground water. Water from both sources were chemically compatible to the receiving aquifer water at both recharge sites. In addition, trace elements were examined along with dissolved-oxygen concentrations to determine whether redox-sensitive chemical constituents would remain in solution or precipitate once source water was introduced into the *Equus* Beds aquifer. Major-ion and trace-element concentrations in the source water and receiving water at both recharge sites were similar and probably would not cause detrimental plugging of aquifer materials with the exception of possible iron and manganese precipitation at the Halstead site when source water is exposed to oxygen.

It may be possible to decrease monitoring frequency at the Halstead site because water-quality changes in receiving ground water at this site are very gradual. However, more information is needed at the Sedgwick site. Real-time water-quality monitoring could improve the effectiveness of the current monitoring program used by the *Equus* Beds Ground-Water Recharge Demonstration Project. The use of surrogates for the determination of chloride and atrazine concentrations in source water needs to be site specific and provide a more timely picture of the water quality, thus enabling project officials to alter treatment of water more effectively or to stop artificial recharge until water-quality conditions improve.

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