Demonstration and Evaluation of Artificial Recharge to the Blaine Aquifer in Southwestern Oklahoma

Executive Summary

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Oklahoma Water Resources Board
Technical Report 97-5S

In cooperation with:
U.S. Bureau of Reclamation
U.S. Geological Survey
U.S. Enivironmental Protection Agency
Southwest Water and Soil Conservation District

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Acknowledgments

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Blaine Gypsum
Groundwater Recharge Demonstration Project

Local Sponsor: Oklahoma Water Resources Board
Federal Agency: U.S. Bureau of Reclamation

KEY DATES

Cooperative Agreement: October 2, 1990
Period of Agreement: Federal fiscal years 1990-1995
Agreement Extension: Federal fiscal year 1997
Began Monitoring: April 1988
Began Construction: February 1992
End Construction: May 1993
Began Operation: June 1993
Completion: October 2, 1997

INTRODUCTION

Background

The Blaine Gypsum Groundwater Recharge Demonstration Project used gravity-flow recharge wells to augment groundwater supplies in an aquifer heavily pumped for irrigation.

The project was one of 13 demonstration projects implemented by the Bureau of Reclamation (Reclamation) and local sponsors in cooperation with the U.S. Environmental Protection Agency (EPA) and the U.S. Geological Survey (USGS) under the "High Plains States Groundwater Demonstration Program Act" of 1983. The primary purpose of this act was to advance state-of-the-art groundwater recharge techniques.

This report summarizes the project activities and findings. More information can be found in the *Blaine Gypsum Groundwater Recharge Demonstration Project Final Report* and in Oklahoma Water Resources Board Technical Report 97-5: *Demonstration and Evaluation of Artificial Recharge to the Blaine Aquifer in Southwestern Oklahoma*. A summary of water quantity and quality data is available in a supplementary data report. Copies of these reports may be obtained by contacting Ms. Susan Birchfield, Oklahoma Water Resources Board, 3800 North Classen Boulevard, Oklahoma City, OK 73118; telephone: (405) 530-8800.

Participants

The study was sponsored by the Oklahoma Water Resources Board (OWRB), which oversaw the construction of the recharge facilities, operated and maintained the project, and conducted the monitoring program. The OWRB also analyzed and interpreted the data and wrote the final report.

The OWRB worked in cooperation with the Southwest Water and Soil Conservation District (District). The District secured permits, land, and easements; assisted with the maintenance of the recharge facilities; and served as a liaison between the OWRB and local entities.

Reclamation, USGS, and EPA evaluated the project proposal, Development Plan, Quality Assurance Plan, Monitoring and Mitigation Plan, and quarterly and final reports. The USGS provided technical assistance for the water quality analysis and interpretation. The EPA reported to Congress on the impacts to surface water and groundwater quality. Reclamation worked with the U.S. Fish and Wildlife Service (FWS) to assure that any adverse impacts on fish and wildlife resources were mitigated.

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Project Description

The purpose of the Blaine Gypsum Groundwater Recharge Demonstration Project was to demonstrate the feasibility and effectiveness of recharging surface runoff into the cavernous Blaine aquifer with gravity-flow wells. Specific study objectives were to determine:

1. The volume of water artificially recharged to the aquifer.
2. The impact of artificial recharge on the water quality of the aquifer.
3. The economic feasibility of this method of artificial recharge.

The project expanded the District's existing recharge program, which began in 1968. The District had constructed about 70 recharge wells and four diversions prior to the demonstration project. About 45 recharge wells are currently in operation in addition to the project wells.

The study area encompasses 373 square miles in southwestern Oklahoma and adjacent parts of Texas, and is defined by the drainage basin for Sandy Creek (Figure 1). The project consisted of five recharge sites located within three miles of Hollis (Figure 2). Recharge to the aquifer was accomplished with gravity-flow recharge wells that intercepted surface runoff and channeled the untreated water into cavities within the aquifer. An impoundment at one site diverted runoff into the recharge well.

The Blaine aquifer is a major source of irrigation water in southwestern Oklahoma. Water is obtained from cavities, solution channels, and fractures present in the gypsum and dolomite beds of the Blaine Formation. Karst features such as caves, sinkholes, disappearing streams, and springs occur within the study area.

The ambient water quality of the Blaine aquifer is very poor, with high concentrations of total dissolved solids, sulfate and other ions. The highly mineralized aquifer is defined by the EPA as a potential source of drinking water, but is not currently used as a drinking water supply. However, water from the Blaine aquifer is used extensively for irrigation of cotton, winter wheat, alfalfa and other row crops.

Regulatory Issues

Under Oklahoma's water law, stream water is considered public water. A stream water use permit is required to use stream water for artificial recharge. The applicant must show a present and future need for the water, as well other factors, to obtain a permit. Because stream water belongs to the public, a permittee does not have to own the land where the diversion will take place, but must have an easement or other means of access to the point of diversion. At least once during any continuous seven year period the entire amount of water must be put to use or the permit may be reduced or canceled.

Unlike stream water, groundwater is considered a private property right. The amount of water a permit holder may use is determined by the amount of land the individual owns or leases that overlies the groundwater basin and by the maximum annual yield of that basin as determined by a study. To obtain a groundwater permit the applicant must show that the groundwater will be used beneficially and will not be wasted, but does not have to show a *need* for the groundwater. The taking of groundwater must be from wells on lands dedicated to the permit.

To use the stored water from artificial recharge, the applicant should hold both stream water and groundwater permits for the area where the water is injected and stored. The District obtained a stream water use permit to divert stream water into injection wells for artificial recharge of the Blaine aquifer. Individual landowners within the study area have the groundwater use permits for irrigation.

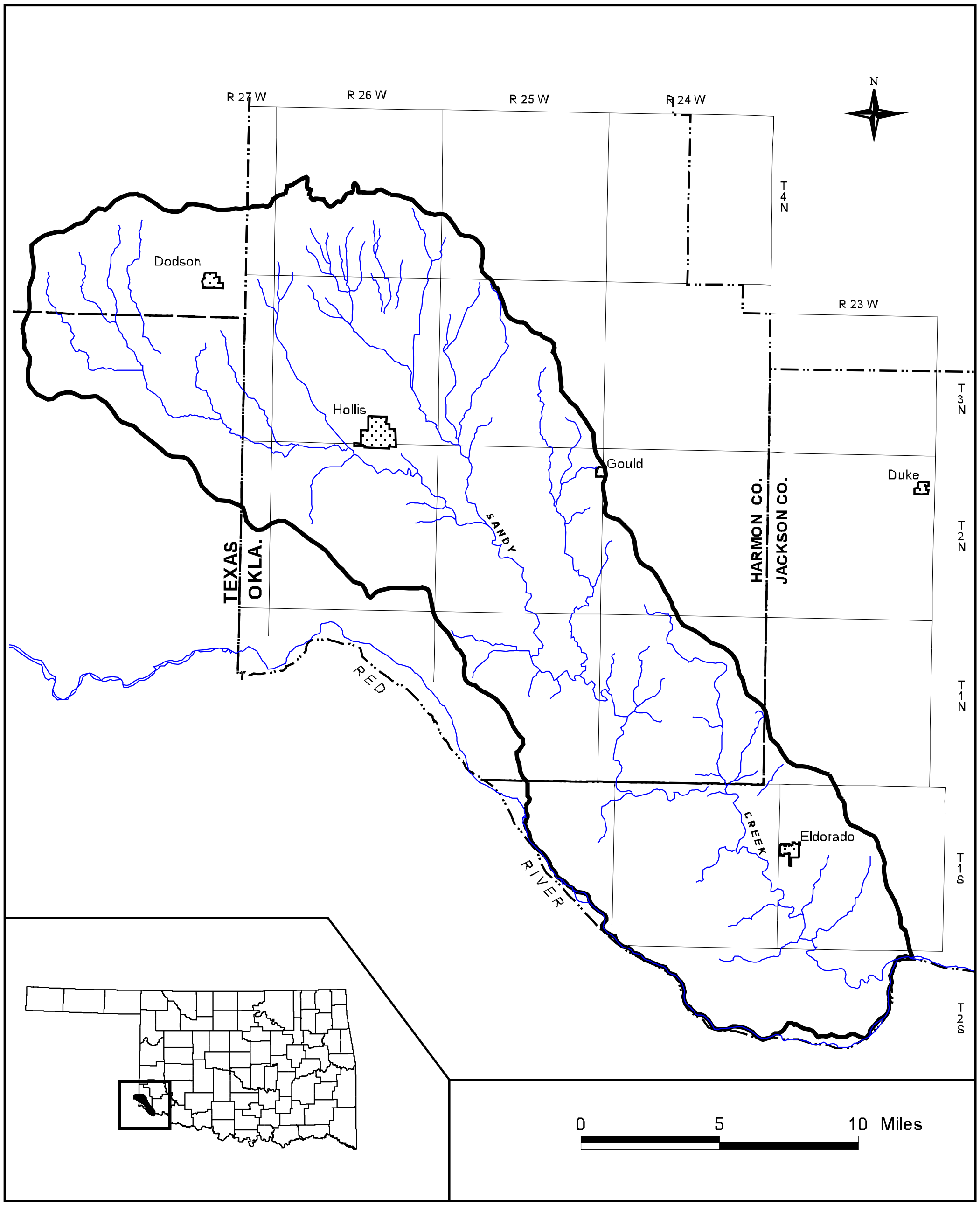

Figure 1. Study area of the Blaine Gypsum Groundwater Recharge Demonstration Project.

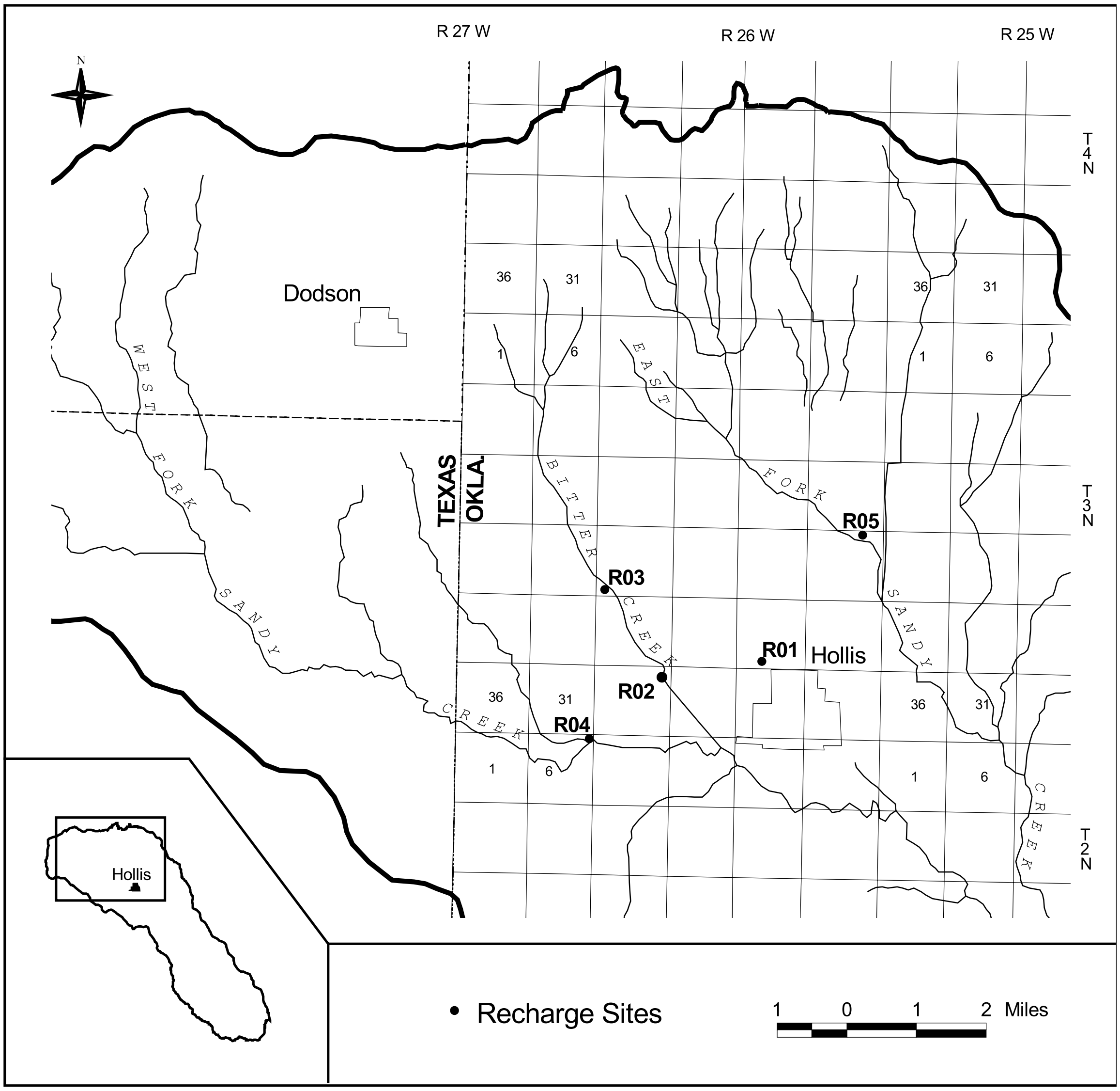

Figure 2. Project area showing recharge sites.

The five recharge wells were registered with the Oklahoma Department of Environmental Quality (ODEQ), which has statutory authority for the regulation of Class V injection wells. In Oklahoma, water quality monitoring is not required for Class V injection wells.

The project's Monitoring and Mitigation Plan addressed the environmental concerns regarding the potential impact of the recharge demonstration project on the groundwater and surface water in the study area. The Fish and Wildlife plan addressed wildlife and environmental aspects of the project and included information and suggestions provided by the U.S. Fish and Wildlife Service and the Oklahoma Department of Wildlife Conservation.

Before undertaking ground-disturbing activities, a Class III cultural resources ground survey was conducted in compliance with the National Historic Preservation Act. No significant cultural or historic sites were discovered at any of the construction sites.

PROJECT ACTIVITIES

Facilities

Each of the five recharge sites had one monitoring well located upgradient from the injection well and a minimum of two downgradient monitoring wells. Table 1 lists the site names and well identification numbers.

Table 1. Monitoring well numbering system

SITE NAME	SITE ID	RECHARGE WELL ID	MONITORING WELLS
Conservation Dam	R01	R1	R1M1, R1M2, R1M3, R1M4
Motley/Jones	R02	R2	R2M1, R2M3, R2M6
Paul Horton	R03	R3	R3M1, R3M2, R3M3, R3M4, R3M5, R3M6, R3M7
Kelly Horton	R04	R4	R4M1, R4M3, R4M6
Warren/Dill	R05	R5	R5M1, R5M2, R5M3, R5M4, R5M5, R5M6, R5M7

An impoundment was built at the R01 site to divert runoff into the recharge well. The impoundment has a capacity of 25 acre-feet and drains 369 acres. It serves an additional function by providing flood control for Hollis.

Recharge Wells

The recharge wells intercept surface runoff and channel the water into cavities and fractures within the Blaine Formation. Surface runoff is diverted to an inlet structure, where the untreated water flows by gravity into the recharge well. Wells are cased with 12-inch diameter casing to depths ranging from 155 to 270 feet. A screen around the inlet structure prevents large debris from entering and damaging or clogging the well. Slotted casing allows recharge water to enter the cavernous zones. Figure 3 shows a schematic of a recharge well.

Special Design Features

The OWRB worked with the District to improve its existing well design. Three new design features were incorporated into the recharge wells:

- Pressure cement grouting the entire annular space between the outer casing and wall of the hole.
- Adding an inner string of casing.
- Cement grouting the annular space between the inner and outer well casing.

These features should prevent dissolution in the shallow zones and subsequent well collapse.

Construction

The five recharge wells were drilled by water well drilling firms in Hollis. Rotary drilling rigs were used to construct the wells, and fresh water was used as the drilling fluid.

While installing the 16-inch steel casing of recharge well R3, a drill tool broke, fell into the hole and could not be recovered. The casing was removed and the hole was abandoned and plugged. A new hole was drilled approximately 25 feet away from the original location and was completed without further difficulty.

The 12-inch inner casing did not fully enter the drill hole in the R4 and R5 recharge wells. Part of this difficulty was shale and gypsum material falling from the hole’s sides into the bottom, thus preventing the casing from reaching the bottom. This problem was solved by removing the 12-inch casing and purging the hole with water to remove the debris.

A crooked hole at the R4 well also caused casing installation problems. The drill bit was diverted slightly as it encountered gypsum, anhydrite, and dolomite layers. The driller finally succeeded in getting the casing into place by lubricating the outside of the casing with dishwashing detergent and applying more downward pressure on the pipe.

Operation and Maintenance

The recharge wells began operating in June 1993. The recharge wells were not operated on a schedule; they depended on runoff from precipitation in the normally dry creeks and ditches. The only maintenance required was weed and brush control around the inlet

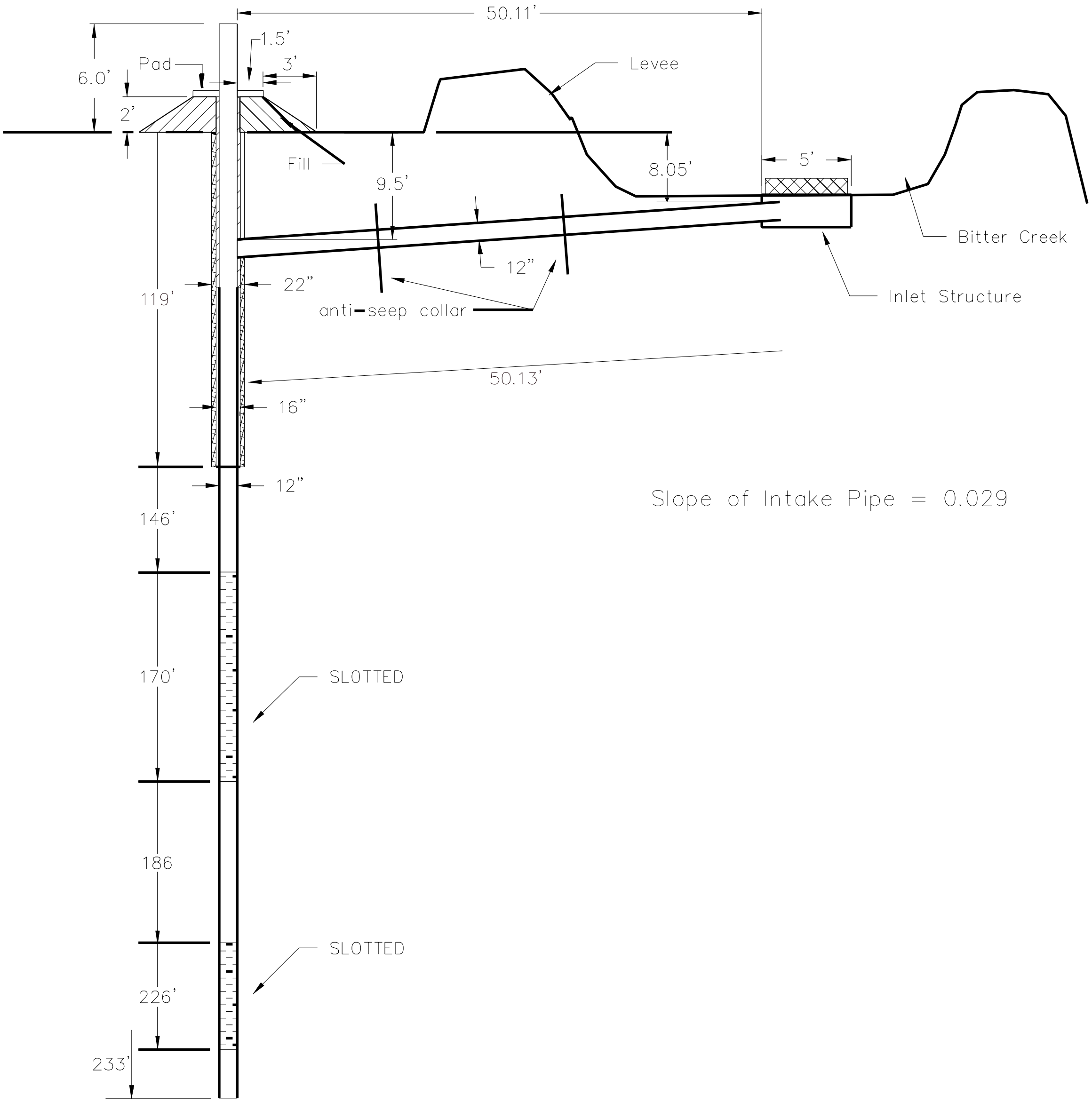

Figure 3. Schematic of recharge well R3.

structures, control of burrowing animals around the well and inlet pipe, and clearing debris off the debris screens that cover the inlet structures.

Operation and maintenance costs of the five recharge wells and impoundment were very low ($53 per month), largely because water treatment was not required. A debris screen around the entrance of the drop inlet structure provided coarse filtration. Formation clogging in this karst aquifer was not a problem.

Monitoring

Program Description

Monitoring for both water quantity and water quality was conducted to determine the potential impact on the aquifer and environment.

Water quantity was monitored to determine the volume of water artificially recharged to the aquifer and the aquifer's response to recharge. Water quantity monitoring included recharge flow rates, groundwater levels, stream discharge, and precipitation amounts. Baseline monitoring began in April 1988 with monthly water level measurements of existing wells. Post-recharge monitoring began in June 1993, when the recharge wells were opened, and continued to June 1997, when the monitoring wells were plugged.

To determine the amount of surface water entering the recharge wells a pressure transducer within each recharge well's inlet pipe measured the overlying depth of water. The volumetric flow rate and recharge volume were calculated from these measurements.

Aquifer response to the recharge was monitored with water level measurements. Hourly water levels were recorded on electronic water level recorders in 24 monitoring wells located near the recharge wells. Monthly and periodic water levels were measured in 71 irrigation, recharge, stock, and observation wells located throughout the study area. A stream gauge measured stream flows on Sandy Creek, and two tipping bucket rain gauges recorded rainfall.

Water quality was monitored to determine effects of the recharge on the quality of the aquifer and the streams that receive discharge from the aquifer. Water quality was monitored for one year before recharge to determine baseline conditions. Post-recharge monitoring was conducted from June 1993 to May 1997. Samples were collected three times a year from:

- The inlet of each recharge well
- Three monitoring wells at each site
- Three stream sites

A flowmeter/sampler unit was programmed to collect an injectate (recharge water) sample from each recharge well during each sampling period. Groundwater samples were collected from the monitoring wells within seven days of collecting an injectate sample.

All water quality samples were analyzed for common ions, trace elements, organic compounds, and pesticides. Injectate samples were also analyzed for cyanide and specific pesticides used in the study area: trifluralin (Treflan), pendimethalin (Prowl), ethephon (Prep-new), aldicarb (Temik), and methyl parathion (Penncap-M).

Issues and Problems

Overall, monitoring operations resulted in the collection of large amounts of useful data to evaluate the effectiveness of the project. However, maintaining and operating electronic equipment in a rural area 180 miles from the office was difficult. Most of the project's time and expense were spent on the monitoring program.

The water-level recorders, rain gauges, stream gauge and flowmeter/samplers were programmed to record hourly measurements. Four years of hourly measurements on 32 units resulted in more than 1.1 million records of data stored in the project's databases. Data management was thus an essential component of the project.

The bombing of the Murrah Federal Building on April 19, 1995 destroyed the OWRB's main office. However, no data were lost and data collection was not interrupted. All data were backed up and stored offsite on magnetic tape. The OWRB Lawton field office continued project field operations.

The automatic flowmeter/samplers required much time and effort to ensure proper operation. Minor problems with the programming setup, battery voltage, transducer cable or suction tube caused data loss and missed samples.

Other problems with the electronic equipment resulted from:

- manufacturing defects
- fire and lightning
- flooding
- damage by animals
- equipment design limitations

A manufacturing defect in the pressure transducers caused every one of the 24 water level recorders to fail within six months of installation. Three to five months of water level measurements were lost while waiting for the manufacturer to repair the units. During subsequent years, the transducer failure rate was less than 10 percent.

Sediment load in the recharge water may have contributed to the silting in of some monitoring wells. Erosion control should reduce the deposition of sediment in fracture systems within the aquifer.

FINDINGS AND RESULTS

Hydrology

Water level change maps show that drawdown due to pumping is greatest in the northern portion of the study area near Hollis, where water levels declined as much as 60 feet in three months. The least change due to pumping was in the southern portion of the study area, where groundwater discharges, and in a small area south of Hollis, which may represent a natural recharge area.

Typical of karst aquifers, water level response to recharge was rapid. Water levels in monitoring wells rose as much as 25 feet in an hour. Water level response to recharge is the inverse of its response to pumping. Just as a cone of depression develops around a pumping well, a groundwater mound develops around an injection well.

Several factors affect the water level response to recharge in a monitoring well including:

- sources of recharge water
- The distance from the recharge source
- The transmissivity and storage coefficient of the aquifer
- Construction and development of the monitoring well
- Silting-in of the well

Because of the variability introduced by these factors, upgradient and downgradient responses to recharge could not be compared.

Locally, groundwater velocities can be very high. A dye tracing test conducted at the R01 site during an injection test resulted in a maximum groundwater velocity of about two miles/day and an average velocity of one mile/day. Regionally, velocity is estimated to be much slower, at about 9 ft/day.

Watersheds contributing to the recharge wells vary in size from about 250 to 14,000 acres. The total drainage area for the project's recharge wells is more than 23,000 acres. The total average annual runoff volume for the five sites is estimated to be 1,245 acre-feet. The R04 site, with the smallest watershed of 253 acres, has an estimated average annual runoff volume of 18 acre-feet, and the R05 site, with the largest watershed of 13,995 acres, has an estimated runoff volume of 758 acre-feet.

During the period of study, precipitation was generally higher than average. The driest year was 1994, with 3.71 inches below average (23.32 inches), and the wettest year was 1995, with 12.98 inches above average.

Recharge Volume

The amount of water recharged to the aquifer through a recharge well is controlled primarily by the volume of surface runoff, the amount of runoff captured by the well, well capacity, and aquifer storage capacity. Recharge at each site is influenced by the amount of runoff captured by the wells, spatial variation of rainfall, and aquifer storage capacity.

While the exact volume of recharge contributed by the project could not be determined due to the methodology and equipment limitations discussed below, the recharge volume was estimated based on the existing data and extrapolated from recharge measurements. An estimated recharge volume of 1,056 acre-feet of recharge water entered the aquifer from August 1993 through September 1996. Field observations and other measurements determined that approximately 188 acre-feet were obtained from irrigation tailwater.

Figure 4 graphically displays the total recharge volume by year. The most annual recharge occurred in 1995 with 726 acre-feet, and the least in 1994 with 72 acre-feet. The average annual recharge volume per well was 70 acre-feet, and the average annual pumpage per irrigation well was 142 acre-feet. Thus, each recharge well provided about one half the water produced from one irrigation well.

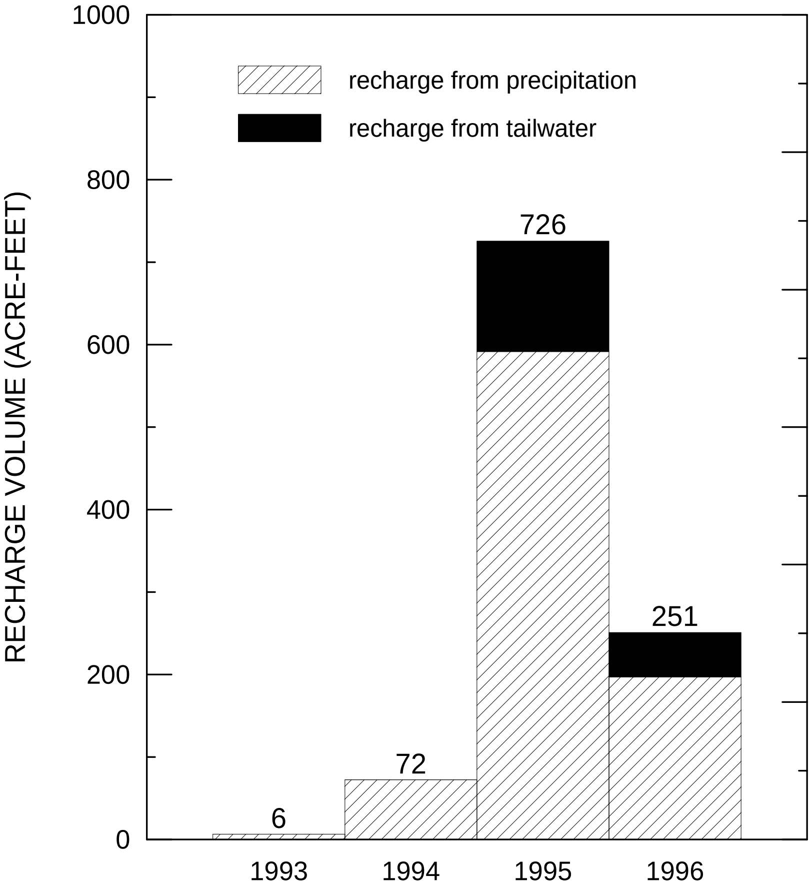

Figure 4. Total estimated recharge volume by year.

The volume of recharge to the aquifer could not be precisely determined because of the methodology, equipment limitations, and incomplete flow measurements. Flow measurements were incomplete due to equipment problems that resulted from mechanical failure;

damage from environmental factors such as fire, lightning, flooding, and rodents; and programming errors.

A significant limitation with the flowmeter/sampler units was that they did not directly measure the flow rate. Each recharge well was equipped with a pressure transducer, installed within the inlet pipe near the entrance of the inlet structure. The pressure transducer measured the overlying water depth from which the volumetric flow rate was calculated.

Two problems arose from using the pressure transducers. First, the pressure transducers did not accurately measure water depth due to turbulent flow at the inlet structure. The resulting flow rates were an order of magnitude too low for the R02-R04 sites, resulting in recharge volumes that were too low. Secondly, when the well or aquifer did not accommodate all of the water, the recorded flow rates were too high. This resulted in recharge volumes that were too high at the R05 site, and possibly the R01 site.

Recharge volumes were estimated for events where flow measurements were incomplete or missing. Total estimated recharge volumes appear reasonable; however, caution should be use in comparing the volumes of one site to another. For the reasons discussed above, recharge volumes at the R02-R04 sites may be underestimated and the volume at the R05 site may be overestimated.

Runoff captured by the wells can be greatly enhanced with an impoundment or retention structure, as demonstrated at the Conservation Dam Site (R01). The impoundment enabled the site to capture all of the calculated runoff, while wells at the other sites captured only two to 36 percent of the calculated runoff. The impoundment covers five acres of land area, a small investment considering the returns.

Assuming the District's recharge wells perform the same as the project wells, then the District's 45 wells and the project's five wells contribute about 3,500 acre-feet of recharge water a year to the aquifer. This is about 20 percent of the average 17,000 acre-feet produced each year. To compensate for the water produced, an additional 193 recharge wells would need to be drilled.

Water Quality

Groundwater and Injectate

The ambient water quality of the Blaine aquifer is very poor, with high concentrations of total dissolved solids, sulfate and other ions.

Recharge water, in contrast to the mineralized groundwater, is generally low in dissolved solids. As fresh water is introduced into the aquifer, gypsum and dolomite dissolve, causing calcium, magnesium and sulfate concentrations to increase until the water becomes saturated with respect to gypsum and dolomite, and returns to equilibrium.

The general water quality of the aquifer appears to improve after recharge. Because most of the post-recharge samples were collected within seven days of a recharge event, these changes reflect short-term dilution effects on the aquifer and do not necessarily reflect long-term effects.

Statistical analysis of general-chemistry constituents indicates that concentrations of most parameters either decreased after recharge or did not significantly change. Total dissolved solids (TDS), which is a good indicator of general water quality, decreased as much as 1,000 mg/L. The decrease in TDS was statistically significant at four of the sites. A decrease in nitrate occurred at all five sites, but was statistically significant at only two sites.

A few parameters (total suspended solids, phosphorus, calcium, and potassium) increased after recharge at some sites. Phosphorus increased at four sites; however, this may be due to adsorption to suspended solids.

Low levels of pesticides were periodically detected in groundwater and injectate (recharge water), but did not persist over time. The most commonly found herbicides were trifluralin (Treflan) and pendimethalin (Prowl), which are used for pre-emergent control of grass and weeds. Concentrations of both herbicides were below regulatory levels. Methyl parathion (Penncap-M), an organophosphorus insecticide, was detected once in groundwater samples from two wells.

Low levels of volatile organic compounds (VOCs) were also detected periodically. Toluene, xylene, 1,2,4-trimethylbenzene, 1,1,1-trichloroethane, and chloroform were detected in a few groundwater and injectate samples. Concentrations were significantly below the maximum contaminant levels (MCLs).

Cyanide exceeded the MCL once in the baseline groundwater samples and twice in post-recharge samples. Laboratory error is suspected for some results.

Several trace element analyses exceeded their respective MCL in groundwater and injectate samples. These trace element results generally correspond to samples with high total suspended solids (TSS), suggesting the elements were bound to the suspended clay particles and were not mobile in water.

Surface Water

The water quality of Sandy Creek and the Red River is poor; both have high TDS, sulfate, and chloride. Neither is suitable for use as a drinking water supply without costly treatment.

Recharge water introduced to the aquifer through the project that is not recovered from pumping will discharge to Sandy Creek about 20 miles downstream from the project's recharge wells. Assuming a regional groundwater velocity of 9 ft/day, it would take groundwater about 32 years to travel from the project area to the discharge area. Further-more, contribution of the project's recharge water on the creek would be indistinguishable from the many other possible sources of recharge and non-point source pollution to the stream.

There is no indication that the project's operations have affected the water quality of Sandy Creek or the Red River. Future impact of the project on surface water is considered negligible.

Project Costs

The original cooperative agreement for the project authorized a budget of $1,991,615. The sponsor's cost-share was 20 percent. On December 12, 1994, the cooperative agreement was modified to extend the project two years, with an additional budget of $148,606. The sponsor shared 50 percent of this cost. The project's total budget was $2,140,221. These numbers exclude federal administrative costs. Monitoring and research costs for the project represent about 30 percent of the total cost, and would not normally be required for the construction and operation of recharge wells.

Economic Feasibility

Using gravity-flow recharge wells to augment groundwater supplies is very cost effective, largely because water treatment is not required. Operation and maintenance costs are therefore very low. The average annual cost of recharge is $2,899 per well, including the cost of construction, operation and maintenance. The value of irrigation water is estimated to be $0.53 per 1,000 gallons of water pumped, and the cost of recharge is calculated to be $0.13 per 1,000 gallons of water recharged. This provides a benefit-to-cost ratio of greater than four to one.

FUTURE PLANS AND RECOMMENDATIONS

Monitoring

Future projects that use electronic equipment in rural areas should investigate technology that would allow checking the status of equipment from the office. This would allow the equipment to be checked more frequently and result in less loss of data.

A significant limitation with the flowmeter/sampler units was that they did not directly measure the flow rate. Instead, a pressure transducer measured water depth, or head. A better method to measure the flow rates would be to measure the velocity in the inlet pipe directly with an acoustic flow meter.

Recharge Activities

The OWRB will turn over the operation and maintenance of the five project recharge wells and impoundment to the District. It is hoped that the District can benefit from this project's results, including the recharge well design modifications and the determination of optimum placements for recharge wells and diversions.

The District could increase the amount of recharge captured by the wells by making minor modifications to some sites. Small retention structures placed downstream of some project wells may enable the wells to capture more runoff. The R03 site may benefit from a low water dam, and the R02 and R04 sites from small berms. Because the primary limitation at the R05 site is the tight rock formation with poor fracture development, the R5 recharge well may benefit from well development or hydrofracturing.

The District could further increase the amount of recharge water by installing additional recharge wells and retention structures in appropriate locations. Figure 5 shows the optimal area to drill new recharge wells. This area is upgradient of or within irrigation pumping centers, where conditions for cavern development are most favorable, and where water depth is greater than 20 feet. Impoundments could reduce the number of wells needed for the same results.

The OWRB recommends that the District incorporate the following design features into new recharge wells to prevent dissolution in the shallow zones and subsequent well collapse:

- Pressure cement grout the entire annular space between the outer casing and wall of the hole.

- Add an inner string of casing.

- Cement grout the annular space between the inner and outer casing.

In addition to increasing the amount of recharge, the District could protect the aquifer's storage capacity by using erosion control to decrease the high sediment load in the recharge water.

It should be noted that the technology used in this project is limited to karst aquifers. It is particularly suitable for the Blaine aquifer, which is in a cavernous gypsum formation and is not used as a drinking water supply. The technology should be applicable to other karst aquifers in other regions. If the recharge project could affect a drinking water supply, pre-treatment of the injectate may be needed.

The OWRB views artificial recharge as a water supply management tool that can be incorporated into long-range water resources planning. Results from this study will provide pertinent information in determining the maximum annual yield of the Blaine aquifer.

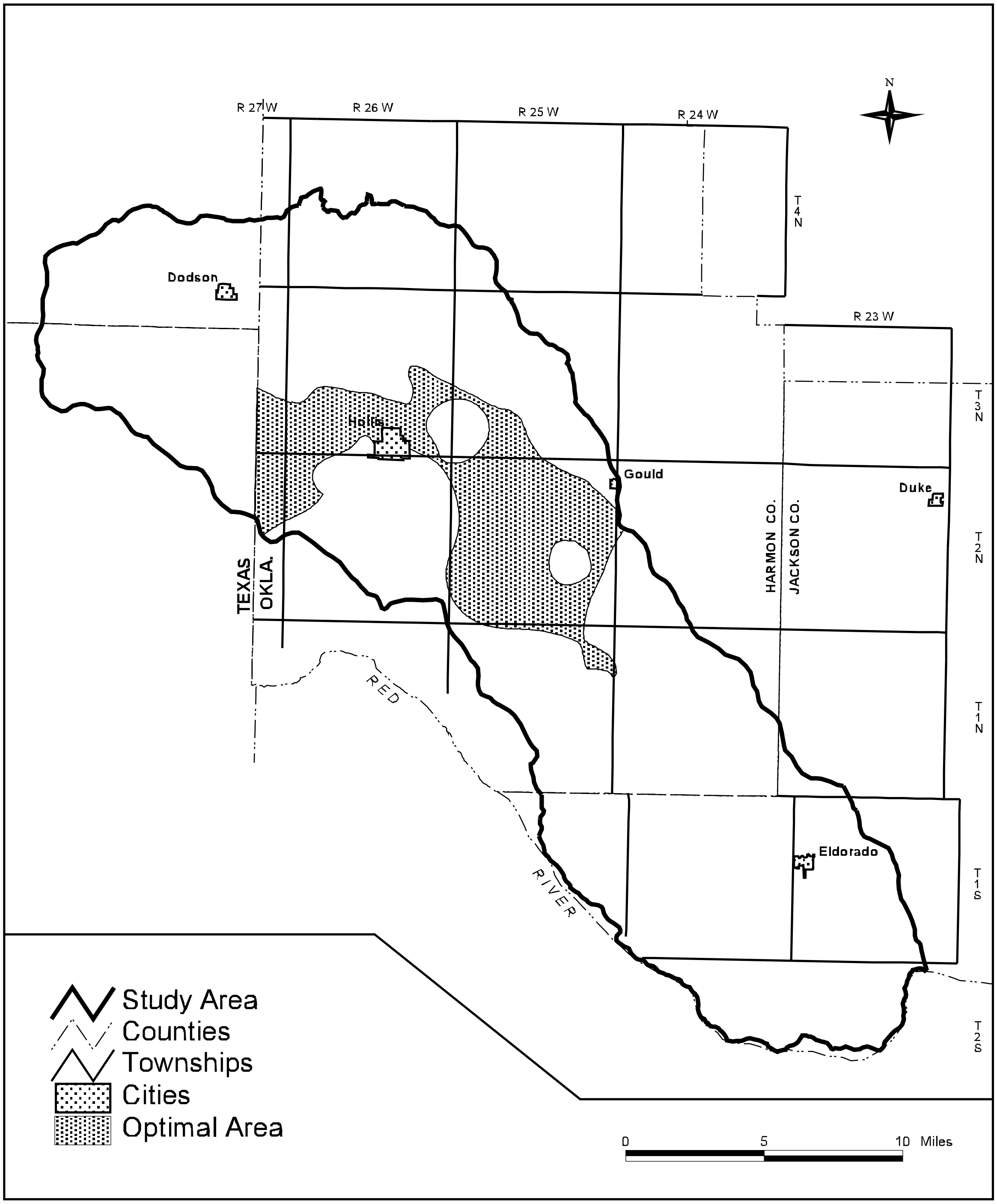

Figure 5. Optimal location for recharge wells.

CONCLUSIONS

The Blaine Gypsum Groundwater Demonstration Project met its objectives:

- The project contributed an estimated total volume of 1,056 acre-feet of recharge water to the aquifer, with an average annual recharge volume per well of 70 acre-feet.

- No harmful effects of the project on the water quality of the Blaine aquifer or stream water were detected. A positive impact of the recharge operations was the short-term improvement of water quality of the aquifer as recharge water diluted the highly mineralized groundwater.

- The project demonstrated that artificial recharge using gravity-flow recharge wells in the Blaine aquifer is economically feasible, with a benefit-to-cost ratio greater than four to one. Operation and maintenance costs were very low, largely because water treatment was not required.

- The project has advanced the state-of-the-art technology in artificial recharge by documenting well design features and operational success.