AQUIFER RECHARGE UTILIZING PLAYA LAKE WATER AND FILTER UNDERDRAINS PHASE IV

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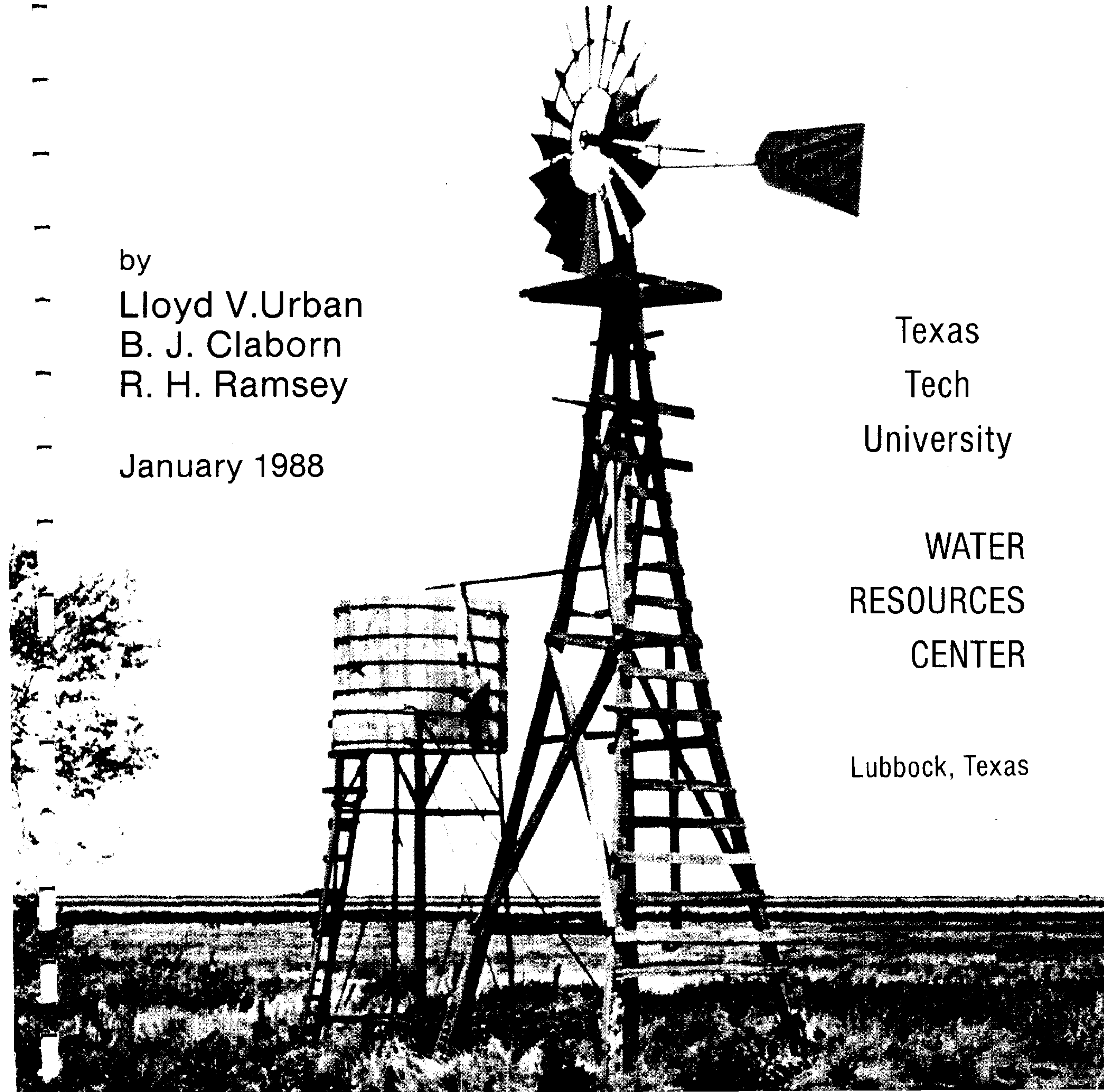
January 1988



Texas
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Lubbock, Texas

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PHASE IV

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Final Report to

TEXAS WATER DEVELOPMENT BOARD
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Aquifer Recharge Utilizing Playa Lake Water and Filter Underdrains -- Phase IV

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INTRODUCTION

Adaptation to aridity is of immediate concern to the inhabitants of a substantial portion of the land surface of the earth. In the United States, the area affected by recurrent drought is generally that between the 100th meridian and the crest of the Cascade-Sierra range of Washington, Oregon, and California. The portion of Texas included in this region consists of the High Plains and the Trans-Pecos. While much of Arizona, California, Nevada, and Utah is more arid, the problems there differ from those of Texas in that the Colorado River carries flows far greater than those of the Canadian, Pecos, and Rio Grande and that their aquifers are much less extensive than is the Ogallala.

Focusing on the High Plains region of West Texas and employing statistics and forecasts presented by the Texas Department of Water Resources in 1984 (1) it may be stated that

"1. Surface-water supplies are very scarce, with practically all such supplies already developed and dedicated.

"2. The High Plains (Ogallala) Aquifer -- the major source of municipal and irrigation water is being overdrafted....

"3. Municipal and industrial water supplies are becoming more difficult to obtain and more expensive as the water table declines. Some major cities of the area will need additional supplies by 1990....

"4. Localized flooding is a problem throughout the Region."

Projected water demands (1;p. 45) from 1980 through 2030 for the region indicate that the supply exceeded the demand by about 1 percent in 1980; that it will be between the high and low estimate for demand in 1990, 2000, and 2010; and that it will be less than the lowest estimated demand in 2020 and 2030. Virtually the entire demand is expected to be for irrigation, and the source of supply to be groundwater. Additional municipal well fields and surface-water reservoirs as well as major water conveyance and treatment facilities will be needed.

The climate of the region is arid; average precipitation varies from about 22 inches per year along the 100th meridian (eastern boundary of the Panhandle) to less than 16 inches along the Texas-New Mexico line.

Geologic evidence (2,3) indicates that the High Plains of West Texas and Eastern New Mexico consist of a series of coalescent fan lobes created by outflows from the Rocky Mountains which buried the preexisting topography to a variable depth leaving a plane surface sloping to the southeast at about ten feet per mile. The climate during and subsequent to deposition has ranged from semi-arid to arid with few permanent streams. "Deposition of eolian sediment transported from the west in mid- to late-pleistocene time eliminated most surface drainage on the

Southern High Plains. Playa-lake basins developed, aided by ground-water circulation that also favored escarpment retreat by seepage erosion." (3)

The resultant surface drainage consists of the Canadian River flowing in a valley of significant width, of several "rivers" heading on the plains and flowing, when they do flow, in steep-walled canyons of which the contributing areas are often a mile or less in width, and of playa lake basins of which the typical drainage area is less than one square mile. The "lakes" seldom have a depth when full exceeding ten feet and, with six to eight feet of potential annual evaporation, they are often dry.

Historically, the water of the Ogallala Aquifer was replenished slowly by seepage associated with the playa lakes; it discharged in a series of springs near the base of an escarpment which forms the eastern edge of the High Plains. Under the irrigation regime of the past half century the natural recharge has been less than the draft on the groundwater. The water table has receded and the spring flow has been reduced or eliminated. A similar pattern on a smaller scale has affected the aquifers and springs of the Trans-Pecos region.

With the exception of some irrigation on the flood plains of the Pecos River and a few short reaches on other streams, agriculture in West Texas has been a gamble on the weather or has depended on the pumping of supplemental groundwater from the Ogallala and some minor aquifers.

In many years dryland farming has been successful in large portions of West Texas. In general, a major part of the highly variable annual rainfall occurs in the growing season --- but the risk of a year without crops is so great that the prudent farmer is prepared to also pump groundwater when necessary. Texas law, while following the appropriative doctrine for determining water rights to streamflow, provides that groundwater rights accompany the title to the land in which the groundwater occurs --- and the rate of horizontal flow of groundwater in the Ogallala is extremely slow. Equity in pumping is further protected through the rules of locally organized and managed underground water conservation districts that govern the waste of groundwater.

The large municipalities of the area tend to store and use surface water insofar as it is available, supplementing the supply in seasons of high demand with groundwater. Potentially, this situation may become increasingly competitive with agriculture in that municipalities can afford to buy farm land for its water rights and that municipal dwellers can finance lawns, parks, and recreational ponds with little concern for hydrologic realities.

The impact on water tables and springs has been detrimental. Of 281 original major and historically significant Texas springs studied by Brune (4), sixty-three had completely failed by the early 1970's.

Recent Developments in Conservation

A deep faith in conservation has been characteristic of the rural population of West Texas since agriculture was first attempted in this semi-arid region. While the preponderance of the precipitation in an average year on the High Plains usually occurs during the growing season, there have been few typical years and many disastrous ones in which the rains were inadequate, poorly timed, or both.

With virtually no perennial streams or lakes, and with impoundments created by dams being necessarily shallow and subject to high rates of evaporation and seepage, recourse was had first to windmills which proved adequate for watering stock and providing garden vegetables. Later, developments in the vertical turbine pump led to the spectacular advances in agriculture experienced in the region in the last forty years. But such pumps require ever-more-expensive fuel and the groundwater supply, while large, is finite.

The farmers of the area learned early to combine the natural precipitation with reduced draft on their underground water to save fuel and to conserve their groundwater supply. They have been aided in this program by extensive research on the local, state, federal, and international levels interpreted and taught in the schools and in field demonstrations by local underground water conservation districts and extension services.

Among the practices being currently perfected for conserving water in agricultural use are

- the close regulation of flow in furrows by dikes which eliminate soil erosion and provide more uniform water distribution,

- recovery by low-lift pumping of tailwater which does reach the end of a furrow,
- irrigation by employment of alternate furrows,
- soil moisture testing to avoid excessive application of irrigation water,
- the employment of sprinkler systems with well-designed nozzles and drop lines that minimize evaporation of the water droplets between nozzle and furrow,
- conservation tillage in which herbicides are employed to minimize the loss of moisture which results from cultivation,
- basin tillage to facilitate the retention of rainfall,
- terracing and leveling to restrict runoff,
- use of underground pipelines to avoid the evaporation and deep percolation of open ditches,
- the development of drought-tolerant strains of crops,
- the use of growth regulators and evaporation suppressants,
- --- and the end of such innovations is by no means in sight.

Historically, municipalities have a poor record in water conservation. Since accumulations of storm water in streets, underpasses, basements, and even in most parks is intolerable it is disposed of by the most expedient means at hand. The cost of conveyance of water from distant sources has led to the use of larger-than-necessary pipes to avoid early duplication, and the desire to establish the largest feasible water right by proving use has encouraged the subsidization of waste.

New realities of municipal growth, tighter budgets inadequate for developing new sources of supply or even paralleling existing mains, and potential litigation over the quality of discharged water are now making urban conservation an economic necessity.

Three fundamental concepts, relatively little practiced in the past, combined with the fine-tuning of agricultural water use, can be depended upon to extend and/or maintain the life of an aquifer. These are water reuse, groundwater recharge, and the secondary recovery of groundwater. Progress in reuse and secondary recovery have been reported elsewhere (5). This report will focus on recent research on artificial recharge of the Ogallala utilizing storm water collected in playa lakes.

Playa Lakes

By far the greater portion of the storm drainage on the High Plains of Texas is to local playa lakes. These natural surface depressions occur with a frequency of 1 to 2 per square mile (2.6 square kilometers) and range in size from a few acres at a shallow depth to some over 200 acres (80 hectares) and 10 to 20 feet (3 to 6 meters) in depth. These lakes are characterized by a naturally occurring liner of almost impermeable clay or clay/silt. In general, the larger lakes are located in the northern portion of the region. The general slope of the land surface is from northwest to southeast; consequently, the drainage area for most lakes is located north and west of the lake with a very short (quarter to half mile) (five eighths to one and a quarter kilometers) region to the southeast. With sufficient runoff, the shallower lakes fill to overflowing and drain to the next lake down slope.

Because the lake beds are sometimes inundated, and may remain so for a considerable period of time due to their clay lining, farmers have not been able to fully utilize the land for production. Some have used the lake bottoms for pasture for a few head of cattle; others have used bench leveling to reclaim as much of the land as practicable. A few have drilled wells near, or in, the lakes in attempts to drain the water quickly into the underground aquifer; almost without exception, these recharge efforts met with failure because the high silt content of the lake water quickly clogged the pore space in the aquifer, resulting in very slow injection rates. Other operators have constructed pits in the lake to concentrate the water into a smaller area. Recharge initially occurred from the pits but they too clogged and the rate of drainage became unsatisfactory.

It has been observed by both farmers and playa lake researchers that the water level in a lake recedes rapidly immediately after a large runoff event, then much more slowly as the lake reaches a shallower depth. This phenomenon is due to the geological constitution of the lake basin. As described previously, the bottom of the lake is comprised of a clay--typically, Randall Clay--sometimes to a depth of 30 or more feet (9 m). On proceeding upslope, the clay liner becomes thinner and finally feathers out. Whenever the runoff is sufficient to raise the water level above the clay liner, recharge can occur through the surrounding soil profile which is typically a silty sand or silty loam. Thus, the infiltration rate is initially large; however, after the water level recedes back into the clay liner zone, very little, if any, recharge takes place. Water level declines, thereafter, correspond very well to evaporation from a free surface. Wood and Osterkamp (6) have suggested that a considerable volume of water is recharged naturally through the zone immediately above the clay liner. Their thesis was supported by water level observations and by the chemistry of soil extracts from this region. These investigations suggested the possibility that there is not sufficient water remaining in the playa lake after the rapid infiltration period to warrant continued research efforts into practicable means of artificial recharge. The quantification of the amount available for artificial recharge was the focus of a recent study of historical data from twenty-two playas by Claborn, Urban and Oppel (7). Thirty to fifty percent of the runoff was found to have been recharged by natural means, e.g., through the area outside of the assumed impermeable clay bottom of the lake. These figures suggest that a volume roughly equal to or greater than the natural recharge is now lost to evaporation; this volume is available for artificial recharge to the aquifer. Estimates of the total volume of runoff into the region's playas range from 1.8 to 5.7 million acre-feet per year (8).

Past Recharge Efforts

Efforts by various researchers to recharge playa lake water as a water conservation measure date back at least to 1955 (9), and continue to the present (10). Recharge through wells has been the most popular method although pits have also been used. Except for an occasional gravel aquifer, these attempts have failed because of clogging of the aquifer by the extremely fine suspended sediments in the playa lake water. These sediments are maintained in suspension by wind generated waves. Samples brought into the laboratory require 3-5 days of quiescent environment to effect settlement. Removal of the silt from the face of the well bore by pumping after a period of injection has not been completely effective, with the result that the well gradually loses its recharge capability. The recharge rate from a pit also has been shown to decrease with time; however, it is possible, between recharge events, to mechanically remove the silt from the bottom and sides of the pit and thus restore the recharge capacity. While this is a technically feasible measure, it is expensive and thus it does not appear likely to be widely adopted by the farmer. Johnson, Crawford, and Davis (11) reported satisfactory results using playa lake water in a pressure injection experiment at pressures of 50 to 80 psi (345-552 kPa). With current costs of energy this method cannot be justified economically for agricultural applications.

Field Test of Filter Materials

Researchers at Texas Tech University have recently approached the problem from a different perspective. Utilizing procedures optimized by a laboratory study and employing "wick" filters, geotextiles, and other available drainage materials, a field test of a concept utilizing these materials and a new method of installation in a playa lake was undertaken (Figure 1). By burying filters in shallow sand-filled trenches in the lake bottom and covering the trenches with a thin layer of the natural clay, it was anticipated that recharge water in significant quantities could be obtained. Concerns being addressed by this and other ongoing research efforts include studies of system design, installation and maintenance, economics and water quality.

In the initial field test, sixteen different filter materials and installation techniques were investigated at a site near Shallowater, Texas (Figure 2 and Table I). Data were collected from an event in 1985 (June 19-29) and an event of longer duration in 1986 (May 8 - July 31). Data included flow rates and quality of lake, ground and recharge water. In their November, 1985, report, Urban, Claborn and Ramsey noted that the recharge well had difficulty in accepting the rates of recharge water produced by the filters (among several other inadequacies in the experimental setup), and outlined several "post-event" modifications. They reported the following conclusions (8):

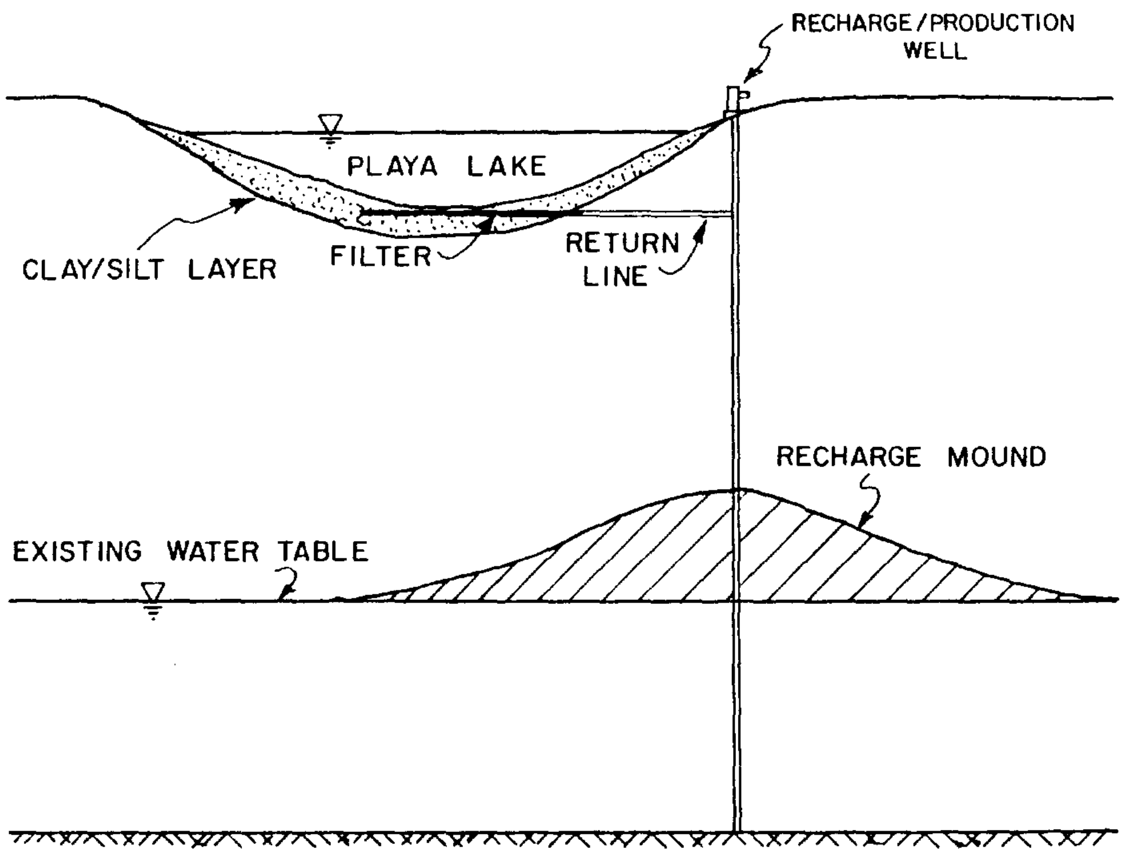

Figure 1. Recharge System Concept

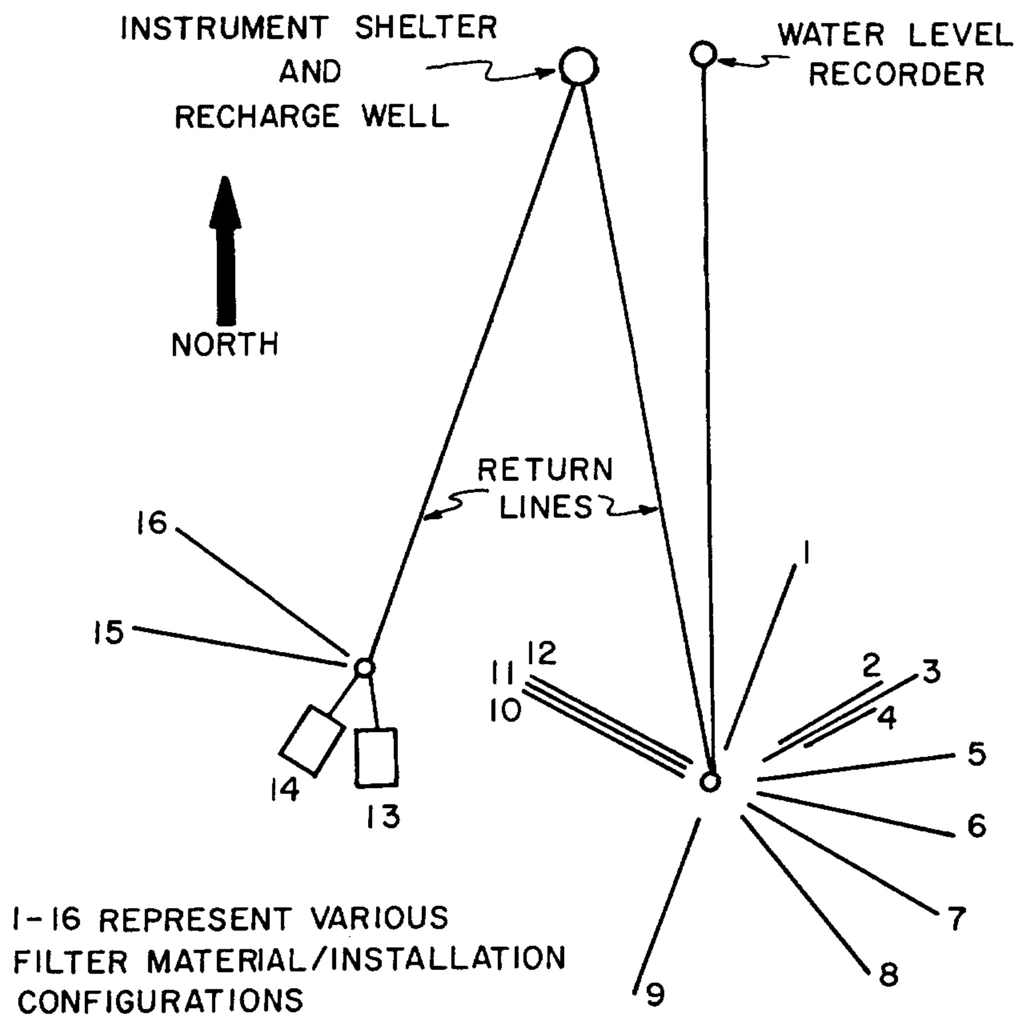

Figure 2. Field Test System Layout

TABLE 1. FILTER MATERIALS AND INSTALLATION VARIATIONS IN SHALLOWATER RECHARGE FIELD TEST

Filter No.	Material/Installation Parameters
1	Perforated PVC Wrapped in Enkadrain (3" dia.)
2	HITEK Filter (4" wide, 60' long)
3	HITEK Filter (4" wide, 100' long)
4	HITEK Filter (4" wide, 40' long)
5	Mebradrain Filtrer (4" wide, 100' long)
6	Castleboard Filter (4" wide, 100' long)
7	HITEK Filter (8" wide, 100' long)
8	French Drain (100' long, gravel wrapped in POLYFILTER-X)
9	Perforated PVC wrapped in POLYFILTER-X
10	HITEK Filter (4" wide, 9" of clay cover)
11	HITEK Filter (4" wide, 6" of clay cover)
12	HITEK Filter (4" wide, 3" of clay cover)
13	Enkadrain Blanket (6' x 20')
14	Enkamat/Polypropylene Blanket (6' x 20')
15	Alidrain (4" wide, 100' long)
16	Miradrain (12" wide, 100' long)

"1. The geotech fabric tested to date is inadequate when used alone; it either does not stop the suspended sediment or clogs to the point of uselessness because of the sediment.

"2. A layer of the natural lake bottom material will provide the filtering needed, but it impedes the flow of water.

"3. The clay layer will crack (shrink) when dry allowing coarser material (sand) to coat the crack. This coarse material provides a hydraulically favorable path for the lake water without providing the needed filtering action.

"4. Roots of annual plants, which have penetrated into the sand portion of the filter system, decay during the winter months leaving a short-circuit for the water. These paths allow unfiltered water to enter the system until sufficient deposition occurs to effect filtration.

"5. Care must be taken during filter installation to prevent spurious comparisons between the various configurations. This was particularly evidenced when the 40-ft length of 4-inch HITEK filter exhibited greater rates than either the 60-ft or 100-ft lines of the same material.

"6. The filter system should be sized to drain the lake in six to eight days of continuous operation. Most lines showed rapid decline in rate after this period.

"7. Lines 1, 2, 3, 5, 6, 8, and 15 exhibited very low rates. The 4-inch-wide material did not perform well.

"8. Based on the comparison between lines 10 (9-inch), 11 (6-inch), and 12 (3-inch), increasing the thickness of the clay layer is not as critical to high flow rates as had originally been assumed.

"9. 'Blanket' type installations do not differ in performance significantly from the line type.

> "10. Most of the decline in rate of flow is attributable to the decline in head as the lake declines, and to the concentrated deposition of new sediment where the water enters the soil...."

In quality studies it was found that, with the exception of the hardness level of the filtrate sample, the water samples tested met the EPA primary drinking water standards for inorganic chemicals and fluoride and only exceeded the proposed guidelines for secondary drinking standards in iron and manganese content. Additional studies were suggested to determine the presence of organic chemicals which might violate the drinking water standards and the microbiological characteristics of the filtrate over a recharge event (8).

<u>Expanded Field Study</u>

In early 1986, work was initiated on a large-scale project which incorporated experiences acquired from the previous studies. Water Resources Center personnel (with cooperation and assistance from the High Plains Underground Water Conservation District No. 1 and with support from the Texas Water Development Board and the Texas Advanced Technology Program) designed and constructed a recharge facility at the Shallowater site.

The facility included a recharge well (screened at two depths) and three filter fields located near the lowest part of the lake (Figure 3). Each of the three blocks included approximately 2,400 feet of a filter material arranged in a grid pattern over an area of approximately 3/4 acre. Flows from Blocks 1 and 2 were directed into the instrument shelter where flow rates

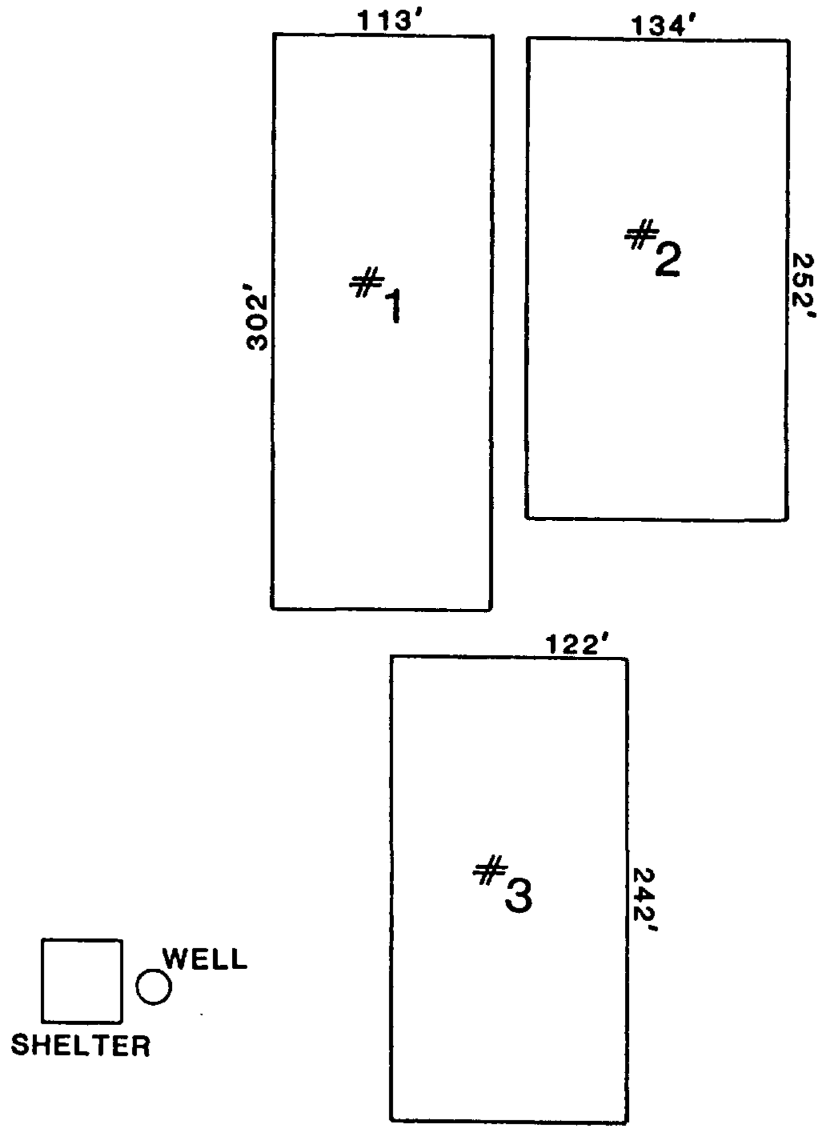

Figure 3. Layout of Large-Scale Filter Systems

were measured using a triangular weir, while flow from Block 3 discharged directly into the recharge well after passing through a propeller-type flow meter (Figure 4).

Block 1 (referred to as the "ADS System") includes 16 rectangular trenches, each 16 inches wide and 16 inches deep dug into the bottom of the playa with a conventional trenching machine. The filter material used was 3-inch-diameter ADS "Drainguard," consisting of a flexible, perforated plastic pipe with a fabric sleeve. The filter was laid in a sand bed in each trench, with 6 inches of sand covering the filter and 6 inches of natural playa material completing the backfill. Each line is connected to a central collector at the center of the block, and a return line conveys the flow by gravity to the shelter (Figure 5).

Block 2 (referred to as the "HITEK System") is shown in Figure 6. It includes 2,375 feet of 12-inch-wide HITEK "Stripdrain" filters placed in V-shaped trenches. Sand was placed in the base of the trenches to create a 6-inch backfill depth, followed by a final 6-inch layer of playa bottom material. The "V" shape was utilized to minimize sand requirements. However, as a maintainer with a scraper blade was employed to construct the trenches, difficulty in achieving desired cross sectional shape and bottom slope was encountered.

Block 3 (called the "Pan System") was the most complex design (see Figure 7). A 12-inch layer of soil was excavated from the bottom of the playa basin, creating a pan. Forty trenches, 16-inches wide by eight-inches deep, were then dug in the pan. A

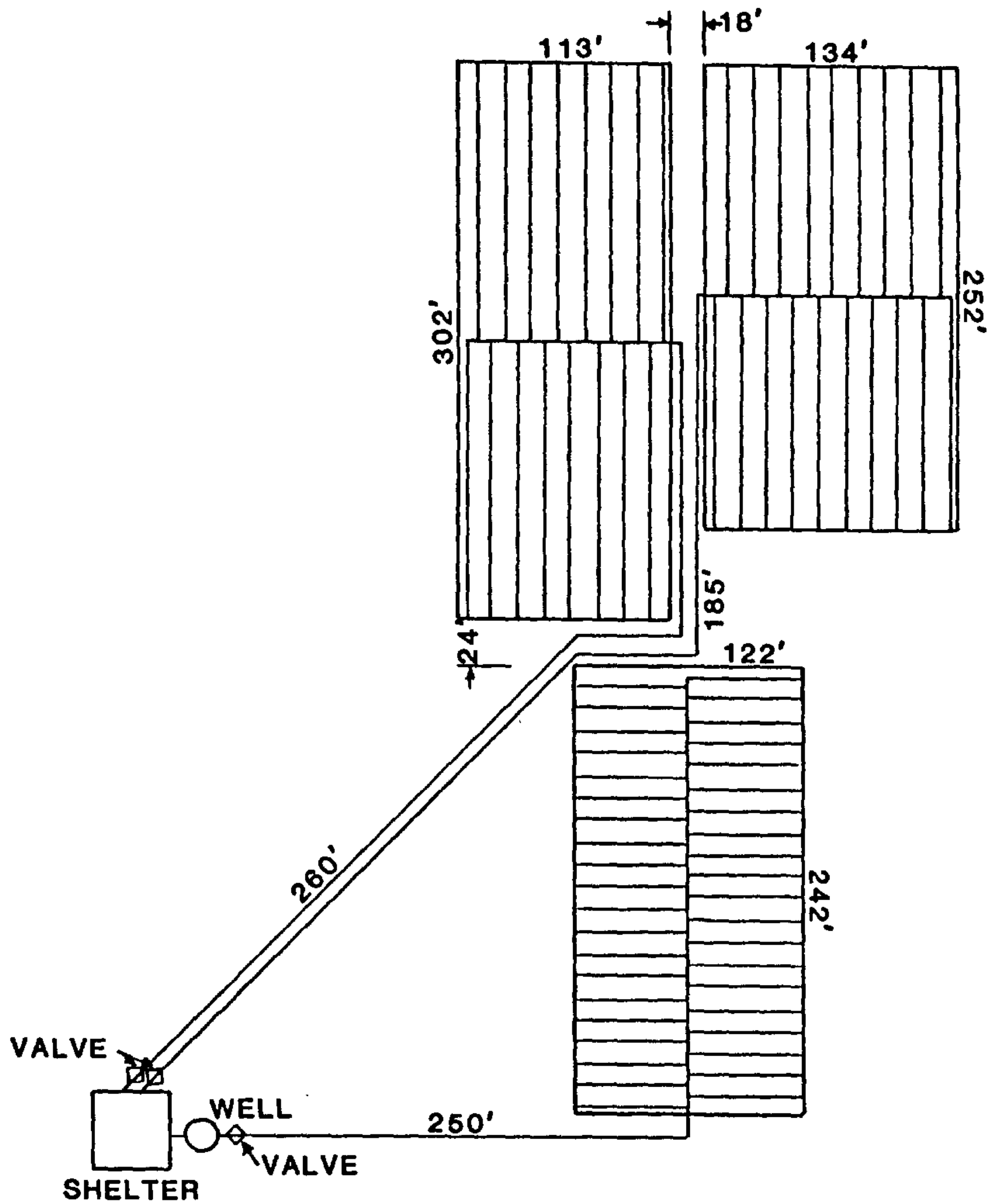

Figure 4. Filter and Return Line Orientation

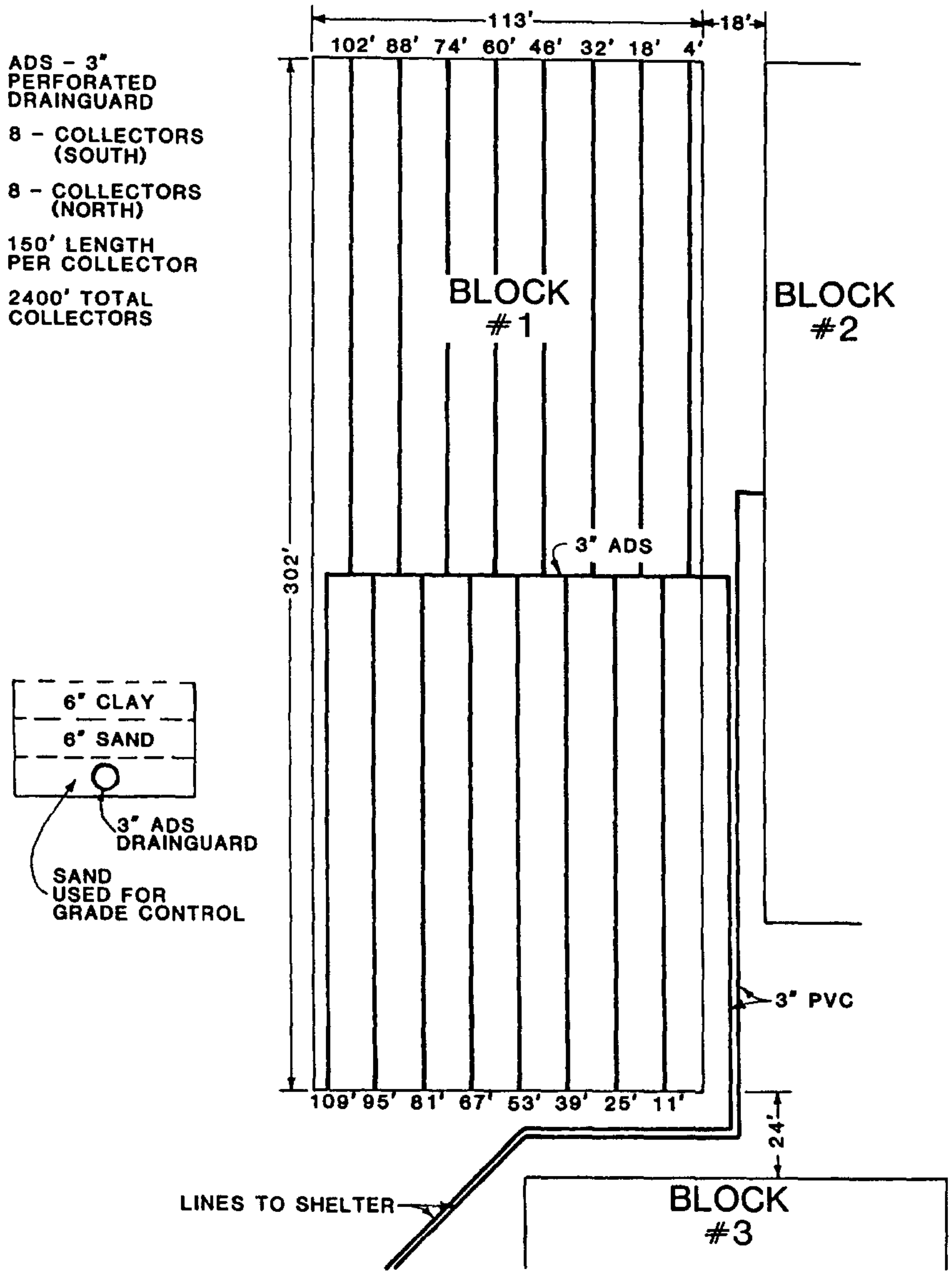

Figure 5. ADS System

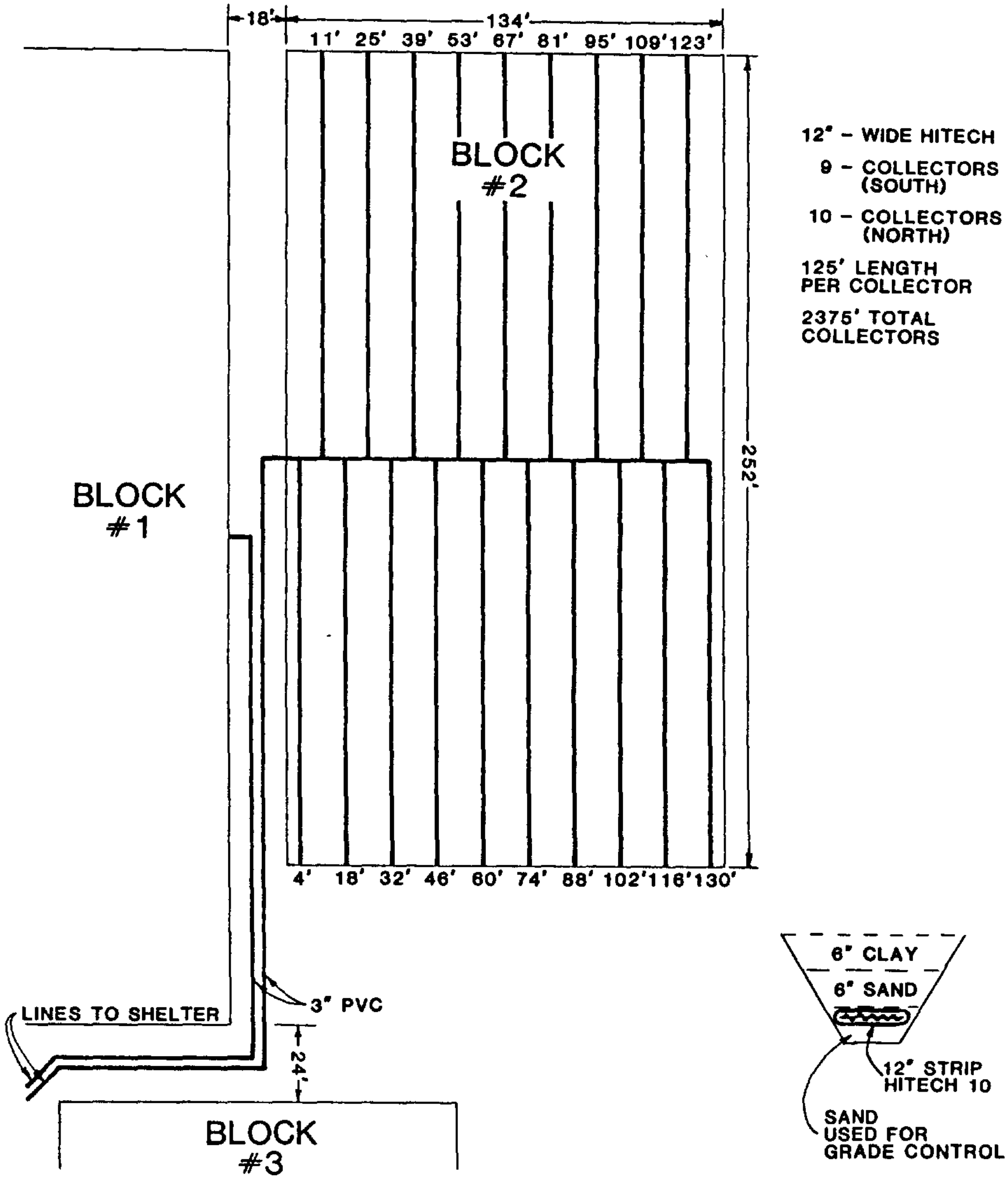

Figure 6. HITEK System

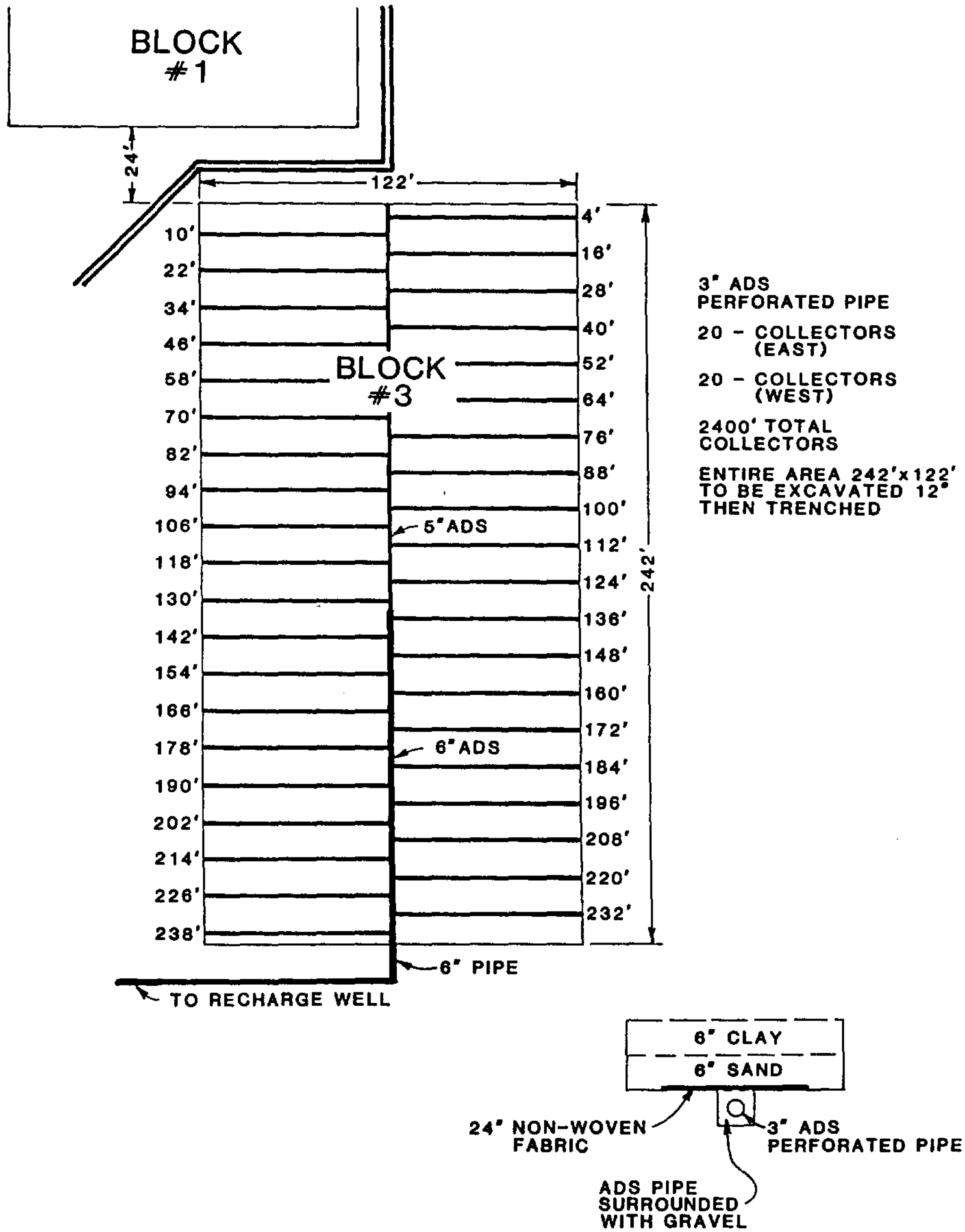

Figure 7. Pan System

layer of gravel was placed in the bottom of each trench, then three-inch perforated flexible plastic pipe was installed and covered with gravel. A two-foot-wide strip of fabric filter material was then installed directly above each trench and the pan was backfilled with six inches of sand and six inches of the natural material that had been removed from the base of the playa. Each drain line is connected to a central collection line in the center of the field, which conveys the flow to the recharge well.

Installation Costs

Installation costs varied with each system, as did the cost of the filter material. The total cost for each system (including earthwork, materials and labor) was as follows:

ADS:	$ 5,800
HITEK:	8,100
Pan:	15,400

Approximately the same amount of filter material was used for each installation; the cost differences were due primarily to the difference in excavation amounts and in sand/gravel requirements, particularly for the Pan system.

Additional costs included monitoring systems (approximately $1,500) and the recharge well (equipped with 40 feet of well screen and a three-stage submersible pump at approximately $8,000).

Large Scale Recharge System Performance - 1986

Three recharge "events" have occurred since the installation of the three large-scale filter systems -- August 4 to October

9, 1986; May 26 to June 25, 1987; and August 24 to October 2, 1987. Rainfall, evaporation and lake water level data for them are shown in Figures 1, 4 and 5 of the Appendix.

The 1986 event provided the initial opportunity to test each system and the recharge well on August 5, 1986. With the water level at exactly 12.0 inches (measured at the lowest point in the lake), depths over the ADS, HITEK, and Pan systems averaged approximately 8 inches, 7 inches and 6 inches, respectively. After opening the valve on the Pan system, a flow rate of 150 gpm was recorded. However, after only 15 minutes, the recharge well overflowed. A check on the recharge rate indicated that the well was capable of handling approximately 100 gpm. The Pan system was shut off, and the HITEK and ADS systems were turned on. Flows of 77.1 and 31.6 gpm, respectively, were recorded. By employing a gasoline-powered sump pump in the line between the Pan system and the recharge well, 60 gpm could be recirculated back into the lake. An additional 10 gpm could be pumped from the recharge well with a small submersible pump installed primarily for quality sampling purposes. In the days following, various combinations of flows were measured, with the ADS system producing filtered water at an almost constant rate of 30 gpm over a range of depth over the filter from 0 to 16 inches. The HITEK system demonstrated a greater degree of dependency on head, with flows ranging from 50 to 80 gpm over a 0 to 16 inch water depth over the filter. The Pan System could not be tested for long flow periods, but "spot checks" indicated that recharge rates of 150-160 gpm could have been sustained if the recharge well could have accepted the higher flow rates. During the first week approximately one million gallons, or three acre-feet, of water was recharged. Had the well been accepting all the filtrate, 1.15 acre-feet per day could have been recharged.

After one week, the rate of accepting recharge water by the well began to decline noticeably. This continued until September 2, 1986, when all systems were shut off after the water depth dropped below 4 inches in the lake. Over the next three-week period, the recharge well was redeveloped (by bucket bailer) and a 7-1/2 HP, three-stage, single-phase pump was installed. This permitted flow to take place from the recharge well to a nearby abandoned irrigation well or to be recycled back into the lake.

On September 24, 1986, the lake again filled to a depth of 12 inches, and recharge operations commenced on September 25th. Initial flow rates from the Pan, HITEK and ADS systems were 150 gpm, 67 gpm and 25 gpm, respectively. Over the next two-week period, flow from the Pan declined to 135 gpm, while flow from the HITEK System remained relatively constant. Flow from the ADS System increased slightly to 30 gpm. The flows in all three systems declined severely when the lake level dropped below 6 inches.

Large Scale Recharge System Performance - 1987

During the first event of 1987 (May 26 - June 25), the lake level reached a maximum depth of 21.5 inches (1.79 ft). Recharge was commenced on May 27th.

A three-stage submersible pump having been installed in the recharge well, maximum flow rates could be maintained through all three filter systems, and flow in excess of what the recharge well would accept could either be diverted back into the lake or be directed into a nearby abandoned irrigation well.

Flow through the ADS and HITEK systems were recorded at 31 gpm and 80 gpm, respectively. The flow meter of the Pan system fluctuated throughout the day from 100 to 160 gpm, indicating some possible mechanical malfunction.

After shutting off the systems for four days, due to rain and subsequent allowance for the lake to clarify, recharge operation recommenced on June 1st. With the lake level at its maximum during this event, flow rates were recorded as 190 gpm, 77 gpm, and 36 gpm for the Pan, HITEK, and ADS systems, respectively. Over the next 10 days, with the lake level dropping to 0.73 ft (8.75 in.), flow rates in the HITEK system gradually fell to 50 gpm and in the ADS system to 23.6 gpm. The recorded flow in the Pan system declined to 50 gpm on June 11th; however, the meter appeared to be malfunctioning over this portion of the first 1987 event.

After additional rainfall/runoff increased the lake levels to 1.29 ft (15.5 in.) on June 15th, recharge operations recommenced. The Pan resumed a 100-gpm flow rate, but the flow meter failed shortly thereafter. Over the next nine days, the HITEK system produced recharge water at a rate of 50 gpm, then declined as the lake level dropped. Similarly, the ADS system's flow dropped from 30 gpm to 27 gpm over the time period.

Rainfall/runoff again filled the playa in late August, 1987. Recharge operations were resumed on August 31st, with the lake level at 1.48 ft (17.75 in.). The Pan meter indicated a flow rate of 190 gpm throughout the day, while the HITEK and ADS systems flowed at 91 and 40 gpm, respectively. With the lake level dropping to 10 inches, increasing to 18 inches and dropping again to 15.5 inches over the next 9 days, flow from the Pan system declined to 150 gpm. The HITEK system flow rate ranged from 84 to 90 gpm over this period, while the ADS system ranged from 40 to 47 gpm.

After shutting the system down for one week (due to rainfall) the recharge operation resumed on September 17th, with the lake level at 1.89 ft (22.7 in.). Flow rates recorded were 130 gpm (Pan), 75 gpm (HITEK) and 53 gpm (ADS). The Pan flow meter failed on the following day, and on subsequent days indicated flow rates ranging from zero to 90 gpm. It became apparent that the meter was "sticking" due to either sand or bacterial growth. As the lake level dropped, the HITEK and ADS systems exhibited flow rates similar to those experienced in prior events.

Performance of Original Test Filters (1986-87)

Although most of the 1986-87 research effort was concentrated on data collection for the three large-scale systems, the original test filters (installed in 1984) were periodically tested and/or allowed to run for periods of several hours at a time. Individual filter performance during the 1986-87 events, has been summarized and is presented in Table 2. The flow rates shown are average values taken from a total of seven different sampling occasions during each year. The average lake depth given is the average of the depths corresponding to the time of flow rate data collection.

Although it is recognized that the results would have been more meaningful if the filters had been allowed to run continuously as they had done in the 1984-85 tests, analysis and comparison with previously collected data yield the following observations:

1. Filters which performed well during the 1984-85 events generally continued to do so during the 1986-87 events. With the exception of Filter No. 7 (8" HITEK), it seemed that "bigger was better" with respect to the width or surface area of filter material.
2. Variations in average flow rate with respect to average water depth, coupled with zero flows in filters No. 8 and 9, indicate that some clogging may have occurred in the one-inch diameter return lines.
3. Comparison of flows in filters 10, 11, and 12 (4-inch HITEK) indicates that the thickness of clay cover is indeed an important factor, with reduced thickness yielding significantly greater flow rates.
4. The performance data for several of the filters indicate that the materials are capable of sustaining satisfactory flow rates for periodic recharge events over a period of at least four years.

TABLE 2. 1986-87 AVERAGE FLOW RATES - ORIGINAL FILTERS

Filter Number	1986 Flows (GPM) (Avg Lake Depth = 6.5 in.)	1987 Flows (GPM) (Avg Lake Depth = 8.64 in.)
1	0.29	2.95
2	0.04	0.02
3	0.96	0.74
4	0.07	0.37
5	0.06	0.42
6*	--	--
7	0.01	0.01
8	No flow	No flow
9	No flow	No flow
10	0.05	0.07
11	0.09	0.46
12	1.07	0.41
13	2.38	0.88
14	1.88	0.66
15	0.09	0.10
16	2.30	1.03

* Filter No. 6 was removed in early 1986. The 1984-85 data indicated that it had become clogged.

Water Quality Studies

Water quality studies were initiated in 1985 and continued through the 1987 event. Both "raw" playa lake water samples and filtrate samples were collected and analyzed in the environmental science laboratory at Texas Tech University. Additional samples were collected and sent to the State Health Department Laboratory in Austin. Results of these studies are reported in the Appendix.

Maintenance Requirements

During the course of these recharge studies, several operational/maintenance requirements evolved. These include weed control over the filter beds, recharge well chlorination and flow measurement device calibration.

As pointed out in a previous report (Urban, et al., 1985), weed control over the filter bed area is necessary to prevent roots from penetrating the filters and posing problems of "short circuiting" as the plants die and roots decay, leaving paths for unfiltered water to enter the system. This concern was verified when, during the installation of the large-scale filter system, one of the original filters (No. 15) was unearthed and severed. A portion of the original filter was removed and examined, revealing significant root penetration. In order to minimize root penetration, weed growth over the filter beds was controlled by disking or "roto-tilling" to a depth of 3-4 inches in 1986 as follows:

June, 1986 - Disking

July, 1986 - Roto-tilling

November, 1986 - Disking.

In 1987, weeds were controlled according to the following schedule:

May, 1987 - Disking

July/August, 1987 - Hoeing (too wet to plow)

November, 1987 - Shredding (disking to follow)

Recharge rates were observed to decline noticeably with time as the well apparently became clogged due to biological fouling. Literature surveys indicated that the well could be rejuvenated by periodic dosing with chlorine. A 65 percent mixture of calcium hypochlorite was utilized as follows:

October 1, 1986 - 6 lbs

October 8, 1986 - 4 lbs

June 11, 1987 - 2 lbs

September 2, 1987 - 3 lbs

September 9, 1987 - 6 lbs

October 5, 1987 - 4 lbs

After each application, the recharge well was allowed to "rest" overnight, and the well was pumped the following day until no noticeable chlorine odor was detected. Significant improvement (over original rates) was noted after each application.

As previously noted, several problems were encountered with the flow meter from the Pan system. This was attributed to either sand or biological fouling. On two occasions, the meter was removed and sent back to the manufacturer for renovation and recalibration. During the last 1987 event, the meter was removed, cleaned and replaced, but with no success. An alternative flow measuring device is currently being sought.

Conclusions and Recommendations

Work to date has resulted in the following conclusions regarding the use of filter underdrains to recharge playa lake water into the Ogallala:

1. The concept is technically viable. Field studies to date have demonstrated that commercially-available filter materials, when properly installed in a playa basin, can successfully recharge significant quantities of water that would otherwise be lost to evaporation.
2. Initial studies of water quality indicate that the recharge water is generally good. The inorganic content (of the recharge water) is much lower than that of the groundwater at the site. However, even though the suspended solids content of the filtrate is minimal as a result of passage through the filters, biological growths in the recharge well, which cause reductions in recharge rates, will have to be neutralized periodically.
3. Continuous maintenance, primarily in the form of weed control over the filter beds and periodic chlorination to rejuvenate the recharge well is necessary to sustain high recharge rates.

4. Taken collectively, the widespread application of the technology could have a significant impact on the long-term water supplies of the region, and hence the area's and state's economy and vitality.

Based on the results of this investigation and the potential value of applying the related concepts and technologies developed to date, the following recommendations are presented:

1. Additional research should be performed in the design, construction and operation of recharge wells. This appears to be the "weak link" in the system.
2. Additional efforts should be made in the sampling of water quality and in the monitoring of groundwater levels during the period of groundwater recharge. Also, additional sampling of heavy metals and priority organics is required because of the scarcity of present data points and the increasing level of importance being placed on these parameters in the environment.
3. A full-scale demonstration project should be constructed and operated to serve as a model for potential users to emulate. A "wildlife component" should also be included to demonstrate that the concept has potential for enhancing habitat for wildlife, migrating waterfowl and threatened species.

Acknowledgments

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APPENDIX

Water Quality Results From The Shallowater Aquifer Recharge Study

by

R.H. Ramsey, Y. Chen, and R.E. Zartman

Water Quality Results From The Shallowater Aquifer Recharge Study

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Introduction:

Water sampling and quality analysis activities have been conducted in the Shallowater Aquifer Recharge Study during the periods when the playa lake contained water from surface runoff since the initial filters were installed in the spring of 1985. Flow and quality results from the 1985 recharge event, which were presented in a previous report (7), led to the design and installation of three new filter types in the spring of 1986. Three recharge events have occurred since this installation - August 4, 1986 to October 9, 1986; May 26, 1987 to June 25, 1987; and August 24, 1987 to October 2, 1987. The results obtained from the quality analyses performed on samples taken during these events will be discussed in the following sections.

Sampling Activities:

Grab samples were collected in plastic sampling bottles or cube-containers at selected sampling points. Samples of the lake water were taken at an offshore point, some 10 to 15 meters from the northern edge of the lake. Grab samples of the filtrate from the ADS and HITEK filters were collected at the measuring weir in the instrument shelter. Filtrate from the Pan ststem was collected at a sampling point in the transmission line from the Pan system to the recharge well. Samples from each filter were taken after flow from the filter had continued for 15 minutes.

Surface samples were collected after initial inflow and again after any additional runoff had occurred. Recharge was delayed 24 to 72 hours after initial filling to allow settlement of suspended solids. When additional runoff entered the playa, recharge was discontinued and 72 hours were allowed to elapse before recharge was again initiated. Samples were taken at the beginning of recharge and every four days thereafter if no further runoff events occurred.

Sample Analysis:

The samples to be analyzed by personnel in the Civil Engineering Department Environmental Laboratory at Texas Tech University were refrigerated at 5^{o} C without further preservation. Conductivity readings were made with a YSI Model 32 conductance meter and corrected to 25^{o} C using a coefficient of 1.9 percent per degree of temperature rise. Total dissolved solids, measured by gravimetric methods on selected samples, were found to approximate 64 percent of the values obtained for the total conductivity. This factor was used to calculate TDS from the conductivity data for the whole sample population.

The characterization of samples taken from the lake, the three filters and the recharge well consisted of wet chemistry and ion chromatography methods. Wet chemistry methods, using the procedures outlined in Standard Methods (6), were followed to determine total suspended matter, total volatile suspended solids and bicarbonate. Turbidity measurements were determined using a Sargent-Welch S-83700 turbidimeter, A Dionex ion chromatographic instrument was used to determine all other anions and cations except the bicarbonate in the samples. General pretreatment included filtering the samples using a 0.2-micrometer membrane filter before injection. One-point calibration was used throughout the analysis and concentrations were calculated by comparing peak heights between samples and standards. Whenever the presence of a certain ion was not detected, the minimum detection limit for that particular ion was reported rather than a zero or a label of ND (not detected). Bicarbonate was determined by titration of samples against sulfuric acid to an end point of pH = 4.3, this being monitored by both a pH meter and a bromcresol green indicator.

The samples sent to the State Health Department Laboratory in Austin for analysis received appropriate preparation according to the parameters that were to be analyzed in each sample. Those to be analyzed for organics were collected in glass jars and sealed with a teflon pad whereas those to be analyzed for metals were collected in glass jars and preserved with nitric acid.

Results:

1986 Event (August 4 to October 9)

The geometric means of selected parameters in the water samples collected during the 1986 recharge event are shown in Table 1. Data obtained for the common cations and anions in the

TABLE 1

GEOMETRIC MEANS OF SELECTED WATER QUALITY PARAMETERS
FOR RECHARGE EVENT FROM AUGUST 4, 1986 TO OCTOBER 10, 1986

PARAMETER		PLAYA	#1-ADS	#2-HITEK	#3-Pan	GRW
COD	(mg/L)	31.9	16.4	16.8	17.2	0
Conduct.	(μS/cm)	256	402	404	363	1384
pH		7.42	7.49	7.64	7.47	7.8
SS	(mg/L)	63.3	2.9	4.6	5.4	12.6
TDS	(mg/L)	164	257	259	232	276
Turbidity	(NTU)	40.7	4.0	5.4	6.6	13

samples were found to be invalid because of the analytical procedures which were used. From the Table, it can be seen that both turbidity and suspended solids content of the filtrate were reduced from those found in the playa lake waters. The average reduction of the suspended solids was 93 percent and that of turbidity was 87 percent. Since the recharge well was not fully developed after its installation, fine sand and silt are included with the water pumped from the well; this has been the cause of the larger values found for suspended solids and turbidity in the well water samples.

COD levels of the playa lake water become smaller as the water passes through the soil and filter system. This probably occurs due to the utilization by soil microorganisms of a portion of the organic material as an energy source. Even though the COD levels in the playa lake water and in the filtrate from the filters are relatively low, the organic content of the recharge water is still sufficiently high to cause bacterial growth on the well screen and in the adjacent formation; this requires that the well be shut down periodically (every 7 days) and chlorinated to reestablish high recharge rates. The breakpoint chlorine demand for a sample of filtrate from the ADS filter taken on August 29, 1986 was found to be 0.17 mg/L, and for samples of composites of filter water taken from the recharge well on August 29 and October 2, 1986 the values were found to be 0.14 and 0.13 mg/L. A program of dosing the well with a chlorine solution has been adopted for use when the recharge rates go below 350 liters per minute. This program is as follows: the valves on the filtrate pipes leading from the filters are closed and a solution of 16 liters of water and 2 kg of calcium hyperchlorite is poured down the well. This solution is allowed to stand overnight and then the well is pumped for 2 hours to clear the fragments of biological growth from the well screen and the formation.

Levels of conductivity, TDS, and pH of the filtrate are seen to increase over the values given for the playa lake waters. The filtrate values, however, are lower than those values recorded for the well water sample taken prior to recharge.

The well water sample taken on August 4, 1986, prior to recharge, also had values of 210 mg/L for sulfate, 185 mg/L for chloride, 10 mg/L for fluoride, and 5 mg/L for nitrate-nitrogen. Values of playa lake water and filtrate composite samples taken during this event and sent to the Division of Water Hygiene -- Texas Department of Health in Austin for analysis are given in Table 2. These results show that the waters being recharged are of higher quality for these parameters than is the groundwater. Also shown in Table 2 are values obtained by this laboratory for the sample analyzed during the 1985 event. Parameter values for the playa lake samples were similar in each of the three sampling events. However, an examination of the values for the composite filtrate sample shows that there has been a reduction in conductivity, Ca, HCO_3^-, and the other analysis parameters influenced by these three components between the 1985 and 1986 recharge events. Leaching of the soil by the subsequent volumes of

TABLE 2

WATER SAMPLE CHARACTERISTICS FROM ANALYSES PERFORMED
BY THE DIVISION OF WATER HYGIENE-TEXAS DEPARTMENT OF HEALTH
AUSTIN, TEXAS

PARAMETER	PLAYA LAKE WATER			FILTRATE COMPOSITE		
	5-27-85	9-3-86	10-1-86	5-27-85	9-3-86	10-1-86
Ca^{2+} (mg/L)	32	44	28	133	62	43
Cl^- (mg/L)	2	5	5	4	5	5
F^+ (mg/L)	1.1	0.5	0.8	1.0	1.0	0.9
Mg^{2+} (mg/L)	6	7	4	19	8	5
N/NO_3^- (mg/L)	0.04	< 0.01	< 0.01	< 0.01	0.99	0.02
Na^+ (mg/L)	3	1	3	5	1	4
SO_4^{2-} (mg/L)	4	2	8	3	3	9
Tot. Hardness as $CaCO_3$ (mg/L)	103	136	88	361	188	127
pH	8.2	7.6	7.8	7.9	7.6	7.7
Conduc. (µmhos/cm)	226	350	245	755	418	320
Tot. Alkal. as $CaCO_3$ (mg/L)	109	165	103	376	199	140
P. Alkal. as $CaCO_3$ (mg/L)	0	0	0	0	0	0
HCO_3^- (mg/L)	133	201	126	459	243	171
CO_3^{2-} (mg/L)	-	0	0	-	0	0
Dissolved solids (mg/L)	121	186	133	384	218	170

playa lake water flowing through the filters could have caused this decrease.

Figure 1 shows the reduction in playa lake level plotted against the rainfall amounts and daily pan evaporation rates recorded at the lake site during the recharge event. Actually, the 1986 event is two events as evidenced by the data points showing no water in the lake for four days beginning August 20. The effects of rain events and subsequent rises in the playa lake surface level due to the runoff accompanying the rain events can be seen. The effects of natural recharge on the lake surface are seen in the rapid reduction experienced during the days immediately after rainfall and before recharge is once again initiated. Daily amounts of recharge, both natural and artificial, as evidenced by the changes in the lake level, greatly exceeded the amount of evaporation recorded for the same period at the playa lake site. The rapid decrease in elevation of the lake surface from the day before the playa is empty results from not measuring lake elevations after the playa level goes below the elevations of the filter unit surfaces. Therefore, the slope of the last interval should be ignored.

1987 Events (May 26 to June 25 and August 24 to October 2)

The geometric means of various parameters measured during the two events are shown in Table 3. During each event, the recharge rate, initially some 800 liters per minute, would decrease with time. The recharge process had to be interrupted several times during each event until the program established in

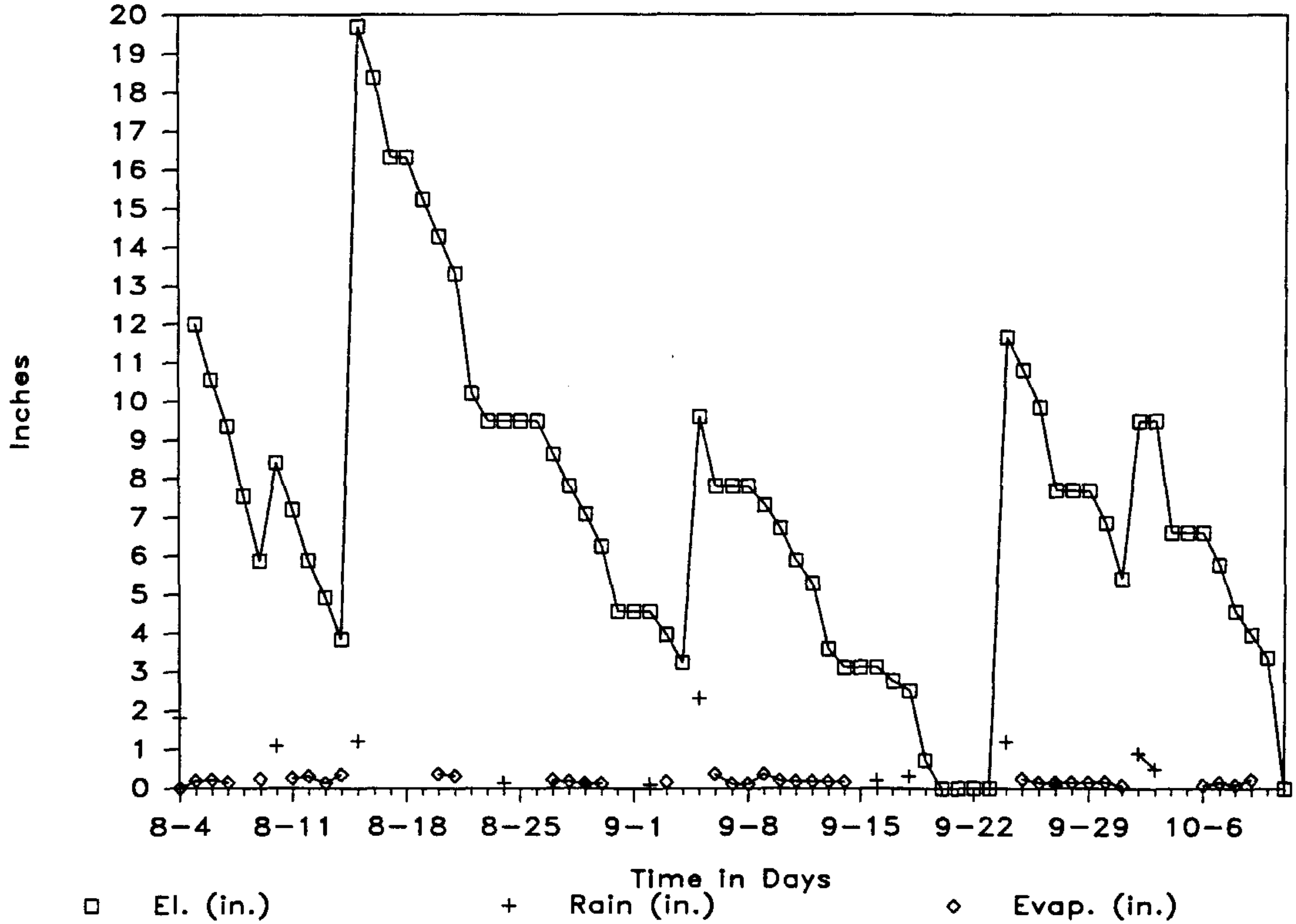

Figure 1. Playa Lake Levels

From Aug. 4 to Oct. 10, 1986

TABLE 3

GEOMETRIC MEANS OF SELECTED WATER QUALITY PARAMETERS
FOR 1987 RECHARGE EVENTS AT SHALLOWATER PLAYA

PARAMETER		EVENT 1					EVENT 2				
		1[a]	2	3	4	5	1	2	3	4	5
Ca	(mg/L)	40.1	77.5	74.0	82.4	96.6	50.5	60.4	58.4	56.6	77.5
Cl	(mg/L)	3.3	3.3	2.8	3.0	193	2.2	2.9	2.5	2.2	177
F	(mg/L)	0.9	0.8	0.7	0.8	1.7	0.9	0.9	0.8	1.7	2.8
HCO_3^-	(mg/L)	177	284	270	267	314	193	230	237	227	252
K	(mg/L)	20.9	14.3	14.8	13.1	10.9	17.8	14.9	14.2	14.5	15.7
Mg	(mg/L)	4.6	8.4	8.1	6.2	110	4.6	9.1	8.4	7.9	81.2
Na	(mg/L)	2.1	1.8	1.4	1.4	127	3.1	1.8	1.3	1.6	124
NO_3-N	(mg/L)	0.03	0.03	0.05	0.05	6.1	0.01[b]	0.01	0.01	0.01	0.02
pH		6.8	6.6	6.6	6.5	6.6	7.1	7.5	7.5	7.5	7.6
SO_4^{2-}	(mg/L)	2.7	1.0	0.9	4.0	329	4.0	0.9	1.0	1.8	296
Tot.S[c]	(mg/L)	-	-	-	-	-	317	289	337	265	833
TDS[c]	(mg/L)	-	-	-	-	-	245	281	324	255	801
TSS[d]	(mg/L)						72	8	13	10	32

[a] Sampling Points: 1 = Playa Lake Water (8 samples for event 1 and 9 samples for event 2)

2 = ADS (6 samples for both event 1 and event 2)
3 = HITEK (6 samples for both event 1 and event 2)
4 = Pan (5 samples for event 1 and 6 samples for event 2)
5 = Groundwater (2 samples for event 1 and 3 samples for event 2).

[b] Value for minimum detection limit is used when no detection occurred.

[c] Total Solids and Total Dissolved Solids values were calculated from 3 sample episodes during the recharge event.

[d] TSS = Tot.S - TDS.

1986 for chlorination and well pumpage was used. Even though the amount of suspended solids in the filtrate has been reduced, dissolved organics in the filtrate lead to bacterial growths in the well environs. Another factor which could have caused declining recharge rates with time was the iron content of the recharged water. The latter factor would be mitigated by the increased pH of the water from the filtration process since the higher value of pH decreases the amount of dissolved iron that can be retained in the recharged water.

Plots of the anion-cation distribution, using the geometric means in Table 3 for the various sampling points for the two events, are shown in Figures 2 and 3. Similarities between the values found for the common cations and anions is apparent from a comparison of the two figures. The values for groundwater prior to the beginning of the first recharge event were essentially similar to the values found at the beginning of the 1986 event. The values of the groundwater at the start of the second event also show recovery of quality prior to the start of the first event for the year.

The fluoride level had been reduced from 10 mg/L at the start of the 1986 event to 1.7 mg/L at the start of the first event in 1987. As noted previously, the impacts of the recharged water on the values for the groundwater are fairly temporary as can be seen by comparing the values recorded in Table 3 for the start of the second recharge event some 55 days after the end of the previous recharge event and by a comparison of the bar graphs in Figures 2

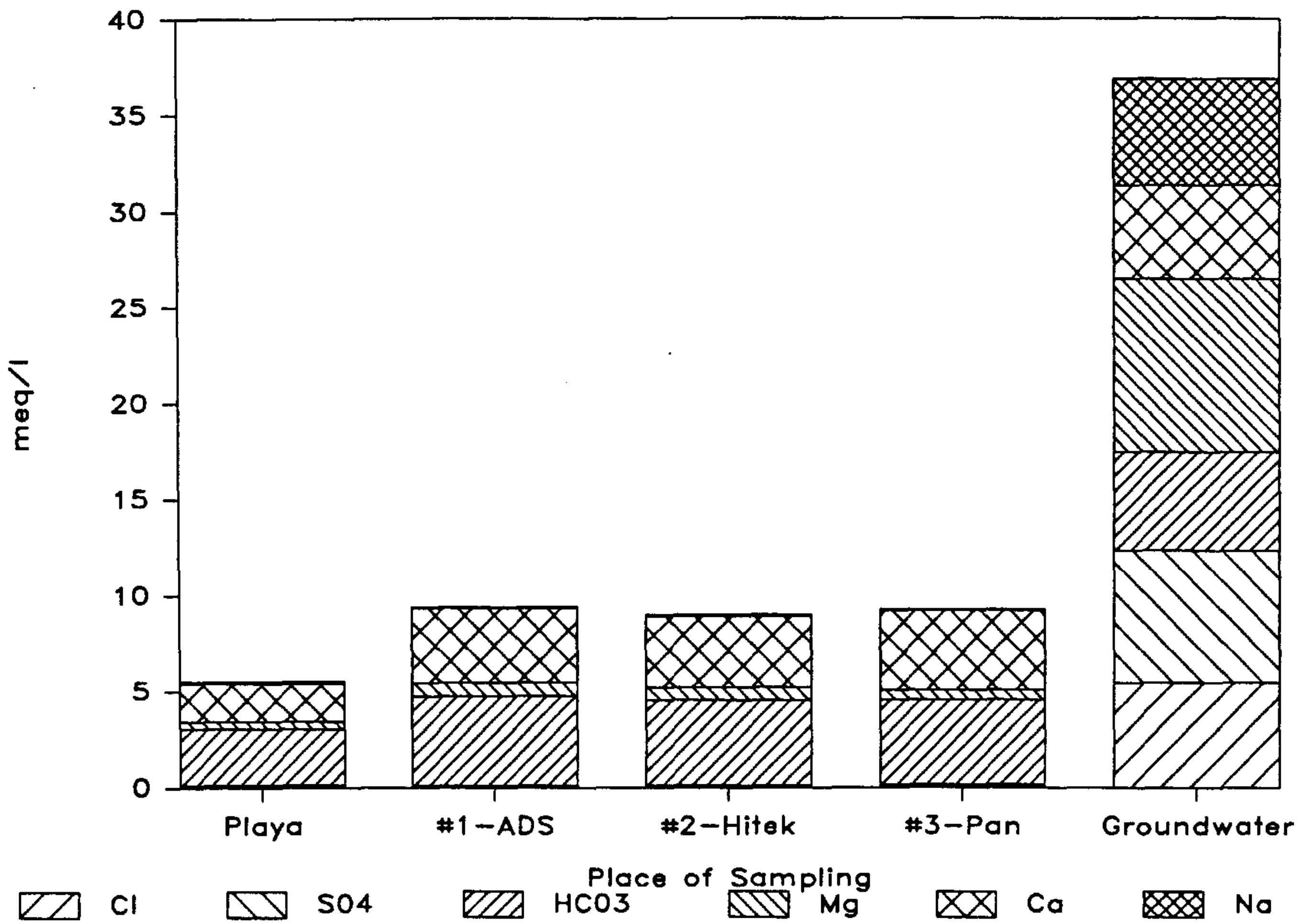

Figure 2. Cation-Anion Distribution
(May 26, 1987 to June 25,1987)

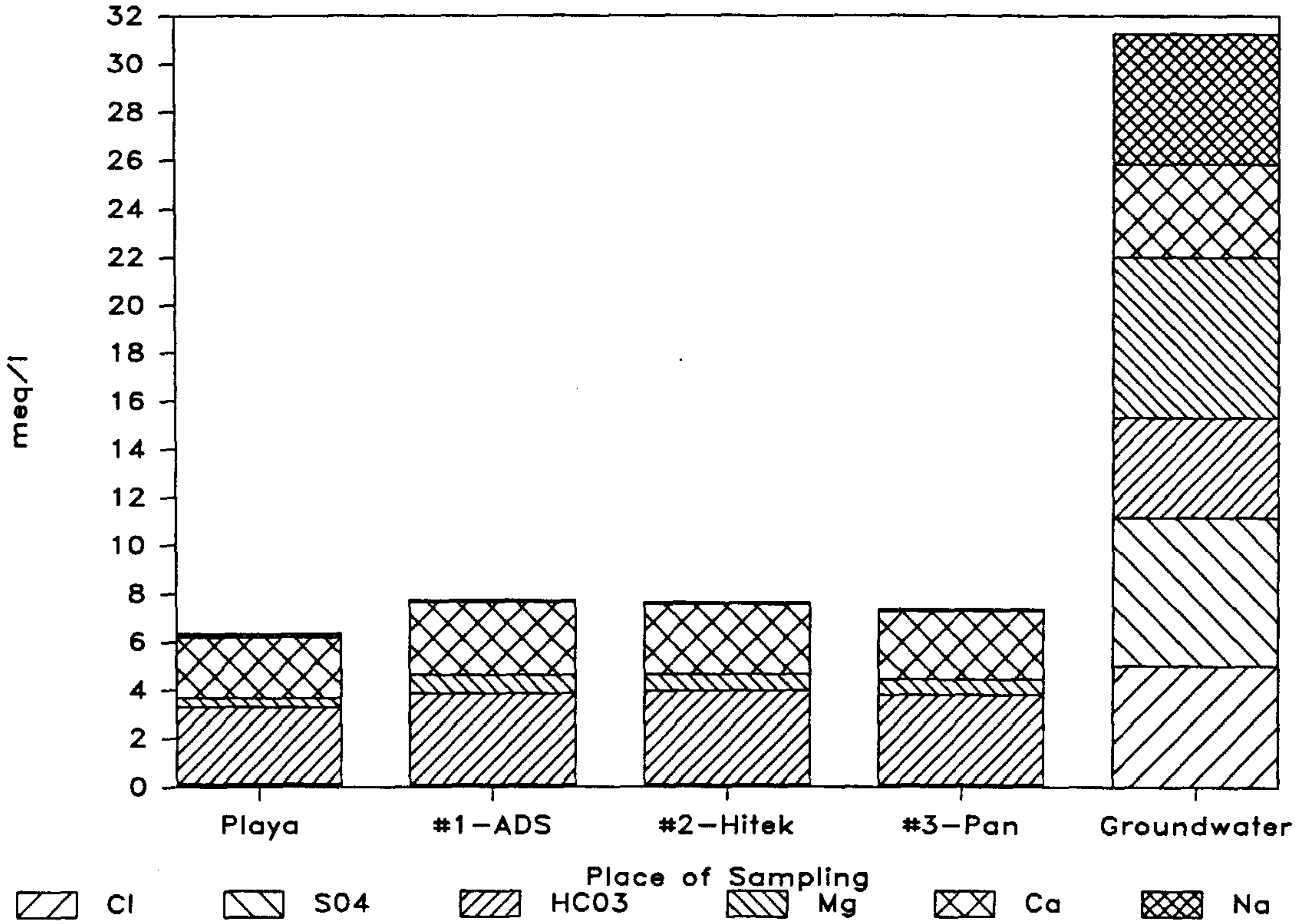

Figure 3. Cation – Anion Distribution
(Aug. 24 to Oct. 2,1987)

and 3. The initial groundwater parameter values are somewhat lower for the second recharge event but they are still much higher than the parameter values of the filtrate recharged. Both Ca and HCO_3^- of the filtrate in the second event are lower than those found for the filtrate in the first event. Values for the other cations and anions which were analyzed seem to be fairly uniform. The levels of SO_4 and Cl in the filtrate samples were seen to decrease over time from the initiation of sampling in the first recharge event of the year as was observed in the 1985 event (7). The variations in pH between the two events are unexplainable.

The geometric means of selected anions and cations of the playa lake waters for the 1985 event and the two events in 1987 are shown in Table 4. The quality of lake waters for these parameters during the recharge events is similar. The land use in the contributing watershed consists of land cropped to cotton and fallowed crop land with sparse growths of weeds. Measurements of turbidity and total solids would be expected to vary among the events because of the variation of runoff rates experienced during the recharge event, plant growth in the playa basin, and the duration and speed of winds experienced at the lake site.

Table 5 shows the results of analyses of samples sent to the Division of Water Hygiene - Texas Department of Health in Austin for metals. Levels of mercury in both the lake water sample and the filtrate composite sample exceeded the EPA's MCL for the primary drinking-water standards. This material is probably associated with pesticides that have been used on the watershed in

TABLE 4

GEOMETRIC MEANS IN MG/L OF SELECTED WATER QUALITY CHARACTERISTICS OF PLAYA LAKE WATER AT THE SHALLOWATER PLAYA FOR THE 1985 AND 1987 RECHARGE EVENTS

PARAMETER (mg/L)	1985 (5-8 to 6-21)	1987 (4-29 to 5-6)	1987 (8-24 to 10-2)
Ca	31.8	40.1	50.5
Cl	1.3	3.3	2.2
F	1.0	0.9	0.9
HCO_3^-	129	177	192.6
K	8.2	20.9	17.8
Mg	5.8	4.6	4.6
Na	1.9	2.1	3.1
NO_3-N	0.03	0.03	0.01[a]
SO_4^{2-}	3.5	2.7	4.0

[a] Value for minimum detection limit is used when no detection occurred.

TABLE 5

WATER SAMPLE ANALYSIS FOR HEAVY METALS PERFORMED BY THE DIVISION OF WATER HYGIENE-TEXAS DEPARTMENT OF HEALTH, AUSTIN, TEXAS (9-28-87)

PARAMETER (mg/L)	PLAYA LAKE WATER	FILTRATE COMPOSITE
Arsenic	< 0.01	0.021
Barium	< 0.50	< 0.5
Cadmium	< 0.01	< 0.01
Chromium	< 0.02	< 0.02
Copper	< 0.02	< 0.02
Iron	0.60[a]	0.33[a]
Lead	< 0.05	< 0.05
Manganese	0.04	1.13[a]
Mercury	0.0058[b]	0.0058[b]
Selenium	< 0.002	< 0.002
Silver	< 0.01	< 0.01
Zinc	0.03	< 0.02

[a] Exceeds the proposed guidelines for secondary drinking-water standards.

[b] Exceeds the MCL of the primary drinking water standard.

the past. Iron levels in both samples exceeded the proposed guideline level for this element in the EPA's secondary drinking-water standards. The amounts of iron shown by these samples could account for some of the decline in recharge rates due to precipitation of iron hydroxide caused by changes in the water pH as well as growth of iron bacteria in the well environs. Manganese levels in the composite filtrate sample also exceeded the levels for this element in the proposed guidelines for secondary drinking-water standards. Analysis of companion samples for organics (Endrin, Lindane, Methoxychlor, Toxaphene, 2,4-D, and 2,4,5-TP) showed values below instrument detection limits.

Tables 6 and 7 give equivalent ratios developed using geometric means, in meq/L, for selected water characteristics for the different sampling points. In waters with low mineral concentrations, small changes in the sample values can lead to marked changes in the relative values expressed as ratios (3).

Table 6 shows the ratios developed for the playa lake waters and groundwater for three recharge events. In general, the ratio values for the lake waters and the groundwater are consistent over the three events. The differences in ratio values between the lake waters and the groundwater show that these waters are distinctly different in composition. The Mg/Ca ratio for the groundwater shows that the minerals containing Mg are more soluable than the Ca-containing minerals in the aquifer materials. Matthess (3)

TABLE 6

EQUIVALENT RATIOS FOR SELECTED WATER CHARACTERISTICS IN MEQ/L FOR THE PLAYA LAKE WATERS DURING RECHARGE EVENTS AND THE GROUNDWATER PRIOR TO RECHARGE

RATIO	1985 MAY-JUNE		1987 MAY-JUNE		1987 AUG-OCT	
	LAKE	GRW[a]	LAKE	GRW[b]	LAKE	GRW[b]
Mg^{2+}/Ca^{2+}	0.30	1.27	0.19	1.88	0.15	1.73
Ca^{2+}/Cl^-	43	0.83	21.5	0.89	40.6	0.77
HCO_3^-/Cl^-	57	0.94	31.2	0.94	51	0.83
Mg^{2+}/Cl^-	12.9	1.05	4.07	1.66	6.10	1.34
Na^+/Cl^-	2.24	0.83	0.98	1.01	2.17	1.08
SO_4^{2-}/Cl^-	1.97	0.82	0.60	1.26	1.34	1.23
Ca^{2+}/Na^+	19.4	1.00	21.9	0.87	18.7	0.72
HCO_3^-/Na^+	25.7	1.13	31.8	0.93	23.5	0.77
K^+/Na^+	2.56	0.09	5.85	0.05	3.38	0.07
$(Ca+Mg)/SO_4$	28.3	2.3	42.3	2.02	34.8	1.71
I_{BA}[c]	-0.12	+0.10	-0.18	-0.03	-0.16	-0.08
SAR[d]	0.44	11.0	0.08	2.11	0.11	2.35

[a] geometric mean of 4 grab samples of water from four wells in vicinity of playa lake.

[b] geometric means of water samples taken from recharge well prior to recharge events.

[c] base exchange index where positive index is:

$$I_{BA} = [Cl^- - (Na^+ + K^+)]meq/L\ (Cl^- meq/L)^{-1}$$

and where negative index is:

$$I_{BA} = [Cl^- - (Na^+ + K^+)]meq/L\ [(SO_4^{2-} + HCO_3^-)meq/L]^{-1}.$$

[d] $SAR = [Na^+][(Ca^{2+} + Mg^{2+})/2]^{-0.5}$.

TABLE 7

EQUIVALENT RATIOS FOR SELECTED WATER CHARACTERISTICS IN MEQ/L FOR THE PLAYA LAKE WATERS AND FILTRATE DURING RECHARGE EVENTS AND THE GROUNDWATER PRIOR TO RECHARGE

PARAMETER	EVENT 1					EVENT 2				
	1[a]	2	3	4	5	1	2	3	4	5
Mg^{2+}/Ca^{2+}	0.19	0.25	0.23	0.23	1.88	0.15	0.18	0.18	0.12	1.73
Ca^{2+}/Cl^-	21.5	36.8	41.3	45.5	0.89	40.6	41.5	46.8	48.6	0.77
HCO_3^-/Cl^-	31.2	46.1	55.1	60.0	0.94	51.0	50.0	56.0	51.7	0.83
Mg^{2+}/Cl^-	4.07	9.15	9.8	10.5	1.66	6.1	7.42	8.43	6.02	1.34
Na^+/Cl^-	0.98	0.96	0.8	0.89	1.01	2.17	0.84	0.77	0.72	1.08
SO_4^{2-}/Cl^-	0.60	0.23	0.3	0.6	1.26	1.34	0.22	0.23	0.98	1.23
Ca^{2+}/Na^+	21.9	38.5	51.5	40.6	0.87	18.7	49.4	60.6	67.5	0.72
HCO_3^-/Na^+	31.8	48.1	68.7	53.4	0.93	23.5	59.4	72.7	71.9	0.77
K^+/Na^+	5.9	4.9	6.42	5.33	0.05	3.38	4.67	6.22	5.50	0.07
$(Ca+Mg)/SO_4$	42	201	173	93	2.02	34.8	219	233	55.5	1.71
I_{BA}[b]	-0.18	-0.1	-0.09	-0.10	-0.03	-0.16	-0.08	-0.08	-0.07	-0.08
SAR[c]	0.08	0.06	0.04	0.05	2.11	0.11	0.05	0.04	0.04	2.35

[a] Sampling Points:
1 = Playa Lake Water (8 samples for event 1 and 9 samples for event 2)
2 = ADS (6 samples for both event 1 and event 2)
3 = HITEK (6 samples for both event 1 and event 2)
4 = Pan (5 samples for event 1 and 6 samples for event 2)
5 = Groundwater (2 samples for event 1 and 3 samples for event 2).

[b] base exchange index where positive index is:

$I_{BA} = [Cl^- - (Na^+ + K^+)]meq/L\ (Cl^- meq/L)^{-1}$

and where negative index is:

$I_{BA} = [Cl^- - (Na^+ + K^+)]meq/L\ [(SO_4^{2-} + HCO_3^-)meq/L]^{-1}$.

[c] $SAR = [Na^+][(Ca^{2+} + Mg^{2+})/2]^{-0.5}$.

gives several reasons why the levels of Mg can exceed those of Ca. First, Mg can rise because of Mg-Ca ion exchange. Secondly, the higher solubility of magnesium compounds with respect to calcium-bearing materials could account for the increase in Mg content. Finally, when water saturated with $Ca(HCO_3)_2$ contacts gypsum or anhydrite-bearing rocks the soluble sulfates are dissolved or, if the solubility limit is reached, only the more soluble $MgSO_4$ or $MgCl_2$ may contribute to solutes. The levels of sulfate in groundwaters are higher, as evidenced by the values shown in Table 3, as well as the ratio values for $(Ca + Mg)/SO_4$.

A calculation of the base exchange index, I_{BA}, introduced by Schoeller (4, and 5) in Matthess (3), for the study values indicated a difference in water quality between the groundwater and the playa lake water. A negative base exchange index indicates that the alkaline earth ions (Ca + Mg) in the water have been exchanged for the alkali ions (Na + K) in the soil. A positive I_{BA} indicates that exchange of alkalis in the water for alkaline materials in the rock is favorable. This occurred for just one sampling point in Table 6. The use of data from the four wells in the vicinity for calculating this value may not, however, be indicative of what was happening on the experimental site at the time when the other data were obtained. The values of the I_{BA} for the groundwater in the 1987 events and the differences in the Ca/Na ratio between the lake waters and the groundwater show that exchange has taken place.

The SAR values in Table 6 and the conductivity values that can be calculated from the TDS shown in Table 3 give an indication of increased problems due to irrigation. The levels of sodium, chloride, and bicarbonate shown in Table 3 also indicate that damage could occur to vegetation if this water were to be applied with sprinklers [Ayers (1) in Bouwer (2)].

Table 7 shows ratio values for all sampling points during the 1987 recharge events. The ratio values of the filtrate are more similar to those of the playa lake waters than to the groundwater. In general, it can be seen from the values in both Table 3 and Table 7 that leaching and exchange of materials is taking place in the filter soil. The levels of K decrease whereas the levels of Ca and Mg increase in the filtrate. The increase in HCO_3^- in the filtrate could be caused by the decomposition of COD in the soil profile and the emission of CO_2 gas.

Figures 4 and 5 show the playa lake levels recorded during the two events in 1987. Again, the amounts of recharge, both natural and artificial, greatly exceed the amount of pan evaporation recorded for the same time period. No artifical recharge occurred in the 3-day period which followed a runoff event. The amounts of natural recharge that occurred in the first two to three days after a runoff event, however, appear large in relation to those experienced during later recharge days. A greater decrease in lake levels seems to occur after runoff events which raise the lake level more than 6 inches after the initial filling of the lake. This could result from increased hydrostatic pressure and/or a manifestation of the infiltration occurring in the annulus area noted by Wood and Osterkamp (8).

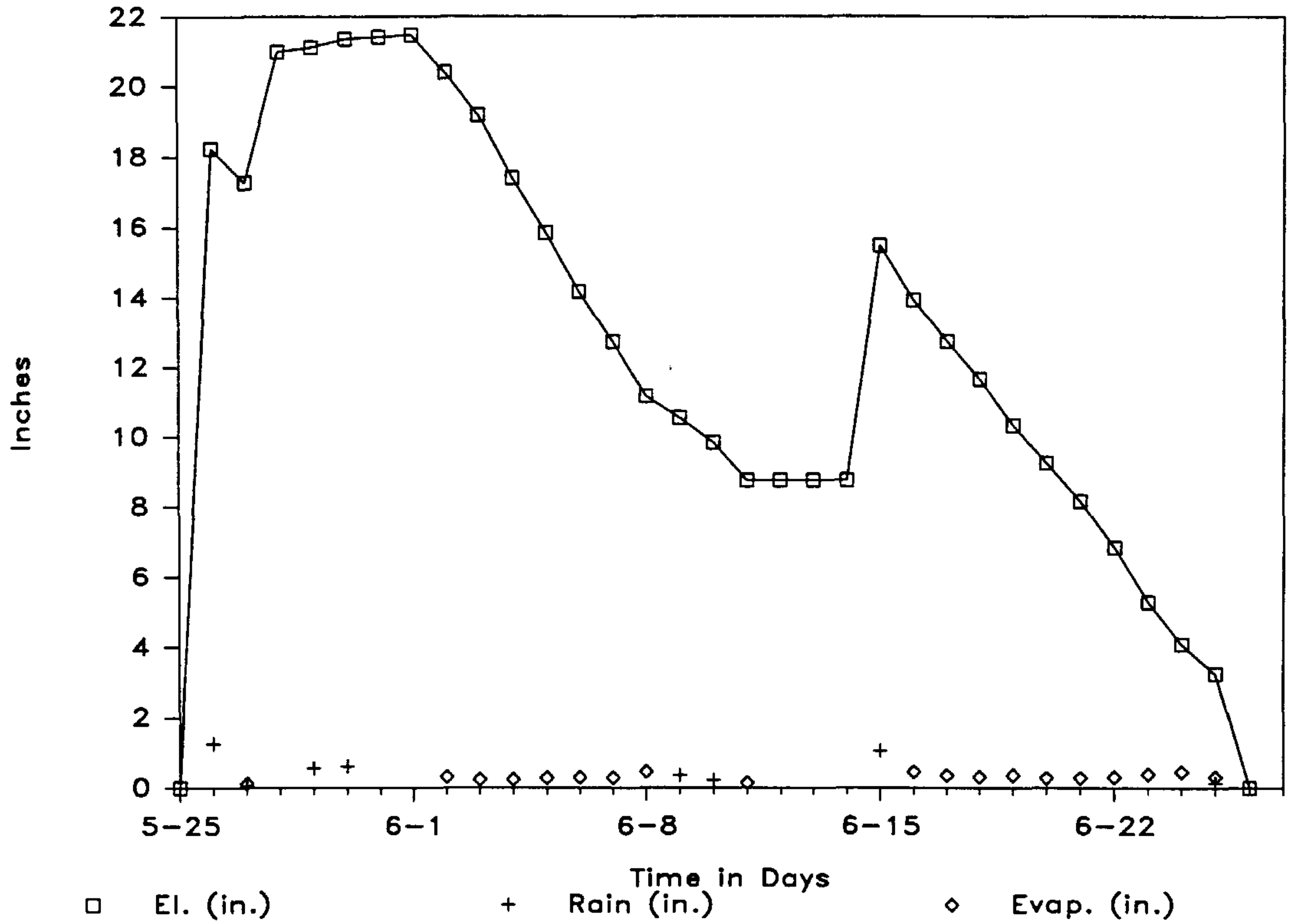

Figure 4. Playa Lake Levels

From May 26 to Jun. 25, 1987

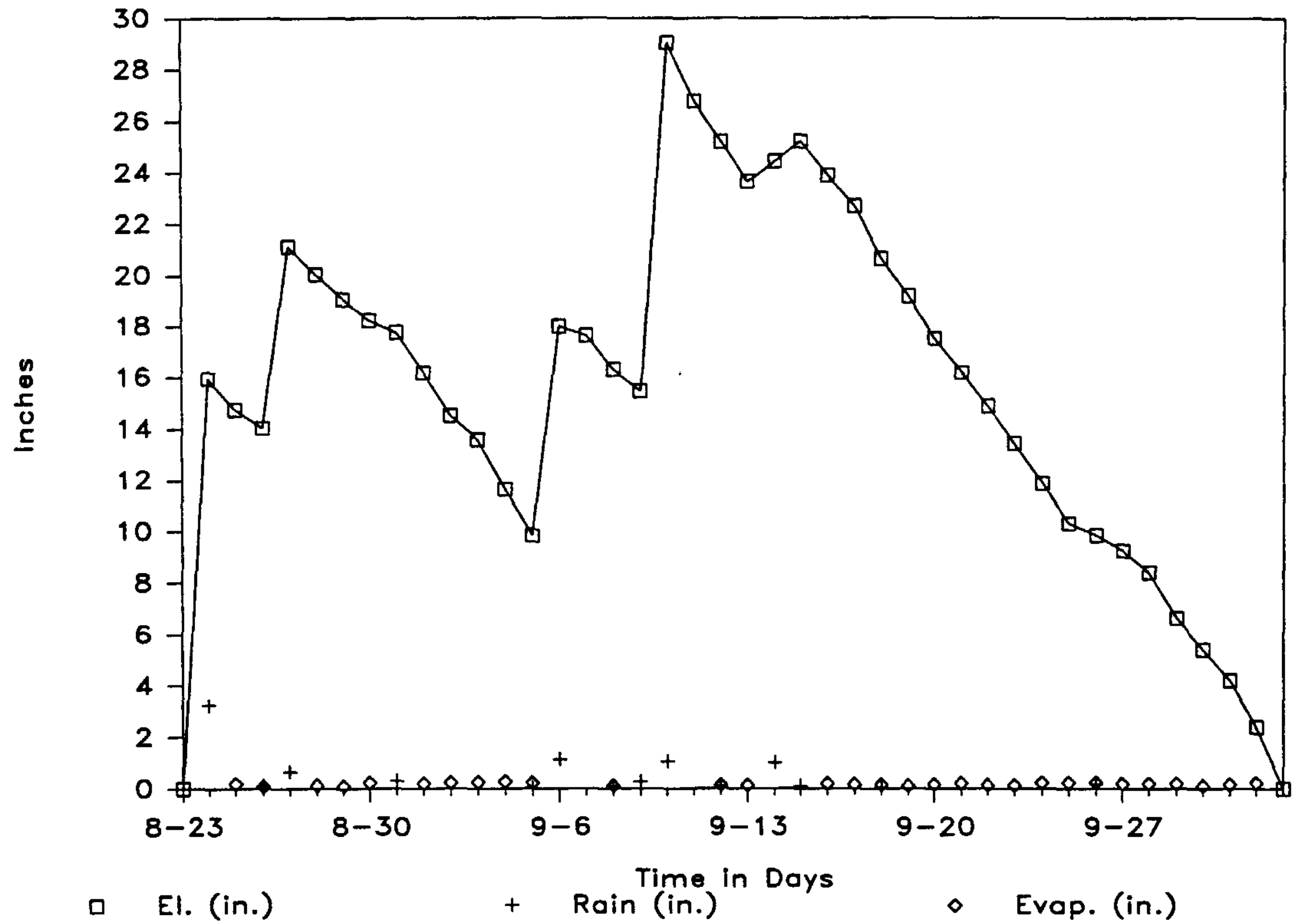

Figure 5. Playa Lake Levels
From Aug. 24 to Oct. 3, 1987

Future Work:

The differences which are evident between the characteristics of the filtrate and of the groundwater at the site would require some adjustment to obtain a new equilibrium condition. The changes caused in the recharged water and in the aquifer material as these adjustments occur need further definition. Additional water quality sampling and monitoring of groundwater levels as the groundwater mound subsides in both the recharge well and also in additional observation wells which would be installed to track the recharged water in the aftermath of a recharge occurs, are needed to monitor changes in groundwater quality and in movement of the recharged water.

Additional sampling of heavy metals and priority organics is required. Lack of equipment and expertise has led to a dependence on the State Health Department for analysis. Problems in the system of collection, transportation, and analysis of samples that has been utilized the past few years have caused a paucity of valid sample analytical results. Sample deterioration is probable in the transport of samples from the collection point to the State Health Department Laboratory in Austin. In-house expertise now available will give better results in this phase of future recharge events.

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