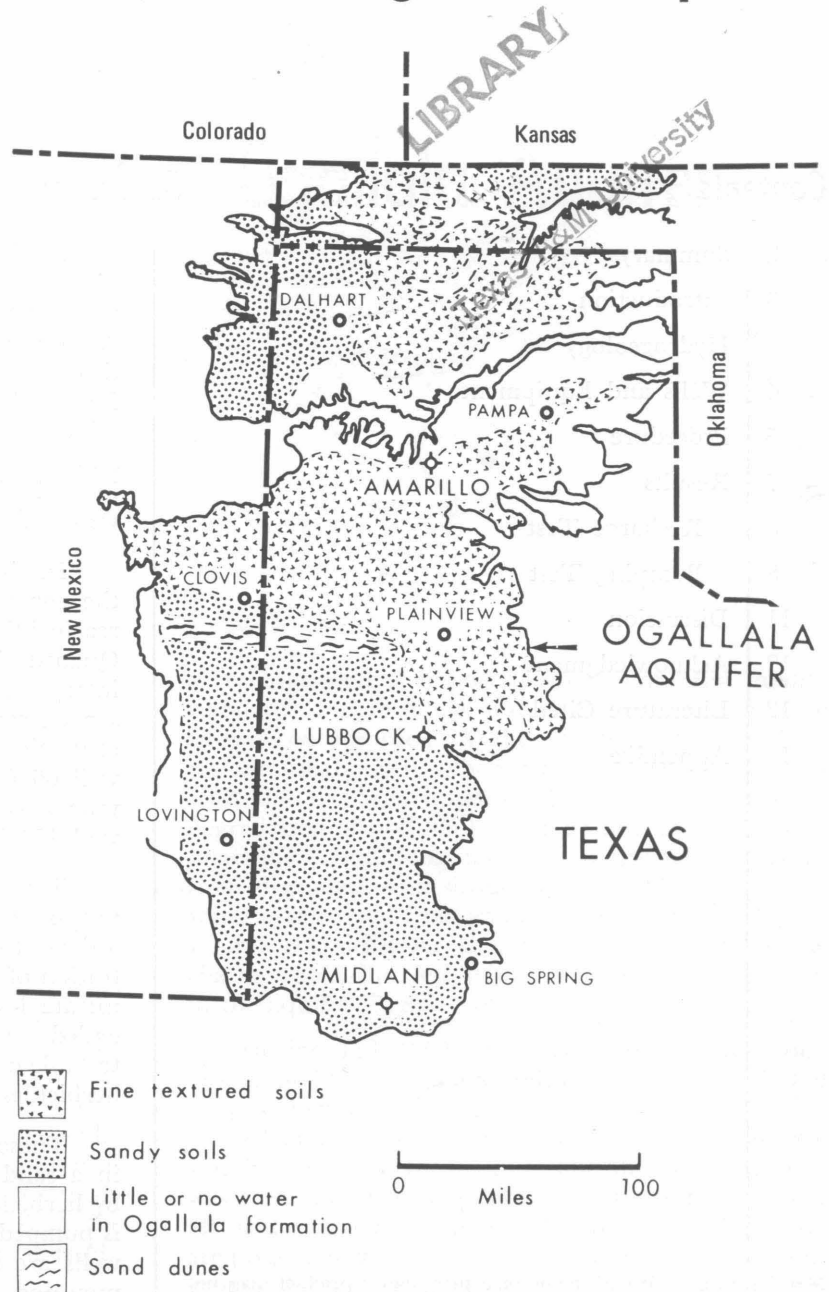


Determining

The Fate of Herbicides in the Ogallala Aquifer



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Summary

During the fall of 1969, water containing sodium nitrate at 11.85 parts per million (ppm) N, trifluralin at 0.024 ppm, atrazine at 1.28 ppm and picloram at 0.125 ppm was injected into the Ogallala aquifer through a dual-purpose well. Recharge continued for 10 days at an average rate of 360 gallons per minute (gpm). As the chemicals were injected, water samples were periodically pumped from 6-inch wells located 30, 66 and 150 feet from the dual-purpose well to determine herbicide movement in the aquifer.

In the well 30 feet from the dual-purpose well the concentration of nitrate, picloram and atrazine reached the injection concentration in 56 to 120 hours. Quantitative analyses for trifluralin could not be interpreted because of unexpected adsorption to sample containers. After 10 days of recharging, concentrations of nitrate, picloram and atrazine in the well 66 feet away were the same as in the injected water. None of the compounds were detected in the well 150 feet from the dual-purpose well.

Ten days after recharging stopped, the dual-purpose well was pumped for 9 days at 500 gpm and 3 days at 480 gpm, at which time the nitrate concentration of the pumped water equaled the background nitrate level of the ground water. When pumping ended, the water did not contain herbicides in detectable quantities, and over 90 percent of the injected herbicides had been recovered.

These results indicate that a dual-purpose well in a sand aquifer that is accidentally contaminated by herbicides will not be a serious hazard if the well is pumped soon after recharging. Since dual-purpose wells are normally used for seasonal recharging and pumping, the injected water or herbicides would not move very far before pumping began. Water from a well that was contaminated with a herbicide could be used to irrigate a tolerant crop.

Determining

The Fate of Herbicides in the Ogallala Aquifer

A. D. SCHNEIDER, A. F. WIESE, O. R. JONES AND A. C. MATHERS*

WHEN AQUIFERS ARE RECHARGED by natural or artificial processes, they may receive runoff from agricultural lands. In the Texas High Plains, dual-purpose wells are being used on a limited scale to recharge playa water to the Ogallala aquifer. With this procedure, any contaminant in the playa water is injected directly into the aquifer, thereby creating a possible pollution hazard.

Playa water may contain small quantities of agricultural chemicals such as herbicides and insecticides. Wiese *et al.* (9) analyzed the runoff water from several fields in the Texas High Plains that were treated with atrazine, propazine and trifluralin. The maximum concentrations of the three herbicides were 0.04, 0.23 and 0.04 ppm, respectively. Other researchers¹ have found no herbicides or insecticides in the playa water, but the playa sediments contained some dieldrin, aldrin and DDT. Most of the pesticide residues were attributed to mosquito control in the playas rather than to runoff from agricultural lands.

Knowledge of the fate of contaminants that enter

a recharge well is important in determining quality standards for recharge water. Some materials are filtered or adsorbed by the aquifer within a short distance of the well; others move through the aquifer with the recharge water (3, 7, 8). In the aquifer, degradation of pollutants without sunlight and under anaerobic conditions may be completely different from degradation in surface water. When recharged water is recovered from an aquifer by pumping, highly soluble chemicals are usually recovered with the recharge water, but less soluble chemicals may remain in the aquifer (7, 8).

During fall 1969, water containing three commonly used herbicides and sodium nitrate was injected into the Ogallala aquifer through a dual-purpose well located at the USDA Southwestern Great Plains Research Center at Bushland. The dual-purpose well was then pumped long enough to recover essentially all of the recharged water. The results of this study are presented and compared with results from previous ground-water recharge pollution studies at the Research Center.

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¹Personal communication from D. M. Wells, Texas Tech University Water Resources Center.

HYDROGEOLOGY

The main features of the Ogallala Formation at Bushland, Texas, are shown in Figure 1. The formation consists of fine sand and calcium carbonate with some silt and clay. The calcium carbonate occurs primarily in nodules and in lenses. The D_{50} sand size is usually less than 0.25 millimeters (mm), and the uniformity coefficient varies from about 1.5 to 3.5. (D_{10} , D_{50} and D_{60} are the particle sizes in a granular material such that 10, 50 and 60 percent, respectively, of the material is smaller. The uniformity coefficient is the ratio of the D_{60} size to the D_{10} size.) The caprock above the Ogallala Formation consists of indurated calcium carbonate about 2 feet thick, and the Triassic Redbed below the formation consists of dense red clay. The permeability of the formation varies little in the horizontal direction, but it varies considerably between different layers in the vertical direction.

The estimated coefficient of transmissibility of the aquifer, derived from pumping and recharge tests, is about 15,000 to 20,000 gallons per day per foot (gpd/ft) (4). The specific yield is probably 0.20 or greater. This specific yield is based on water yield-time curves obtained with a neutron moisture meter and detention times obtained from well recharge tests with tracers.

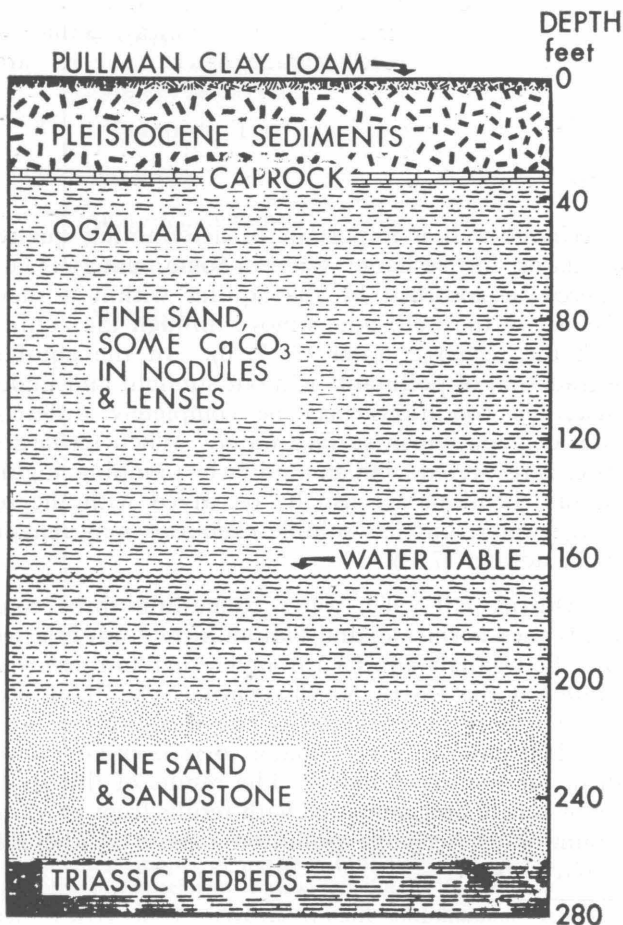


Figure 1. The Ogallala Formation at Bushland, Texas.

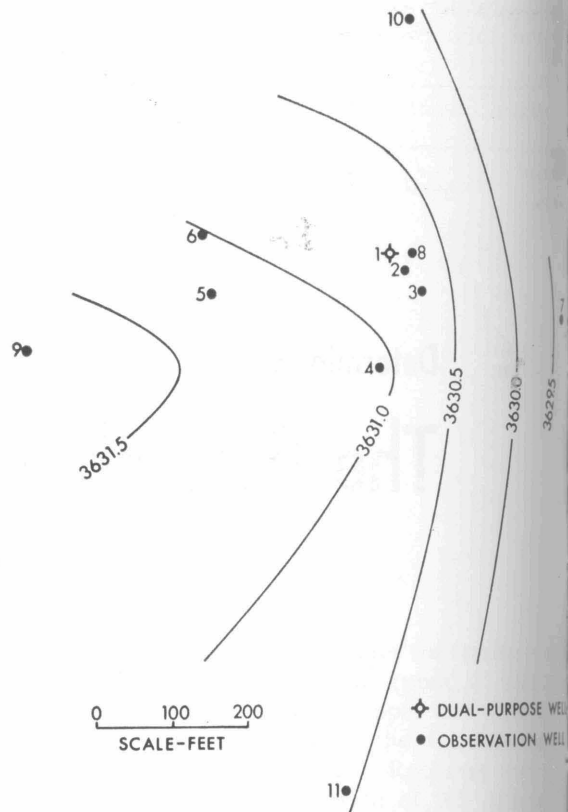


Figure 2. Plan view of experimental wells and water level contours (MSL) before recharge began on October 28, 1969.

Ground water contours before the study began are shown in Figure 2. The slope of the water table is steeper than the average 10 feet-per-mile west to east slope for the region. Heavy pumping for irrigation to the east and a limited amount of ground water recharge to the west are believed to be the cause. During June and July 1969, about 30 acre-feet of water was pumped from Well 1, and 20 acre-feet of this water was recharged into an experimental basin located 1,200 feet to the west.

WELLS AND EQUIPMENT

The locations of the dual-purpose well, observation wells and recharge equipment are shown in Figures 2 and 3. The recharge water was pumped from an irrigation well 2,450 feet northwest of Well 1 and conveyed through underground concrete pipe and surface aluminum pipe.

Well 1, a dual-purpose well, is equipped with turbine pump for pumping and injection pipes for recharging. This well was drilled 28 inches in diameter, cased to the water table with 16-inch steel pipe and screened through the saturated sand with 90 feet of continuous-slot spiral well screen. The well was gravel packed and developed by pumping and bailing. The turbine pump has a maximum capacity of 1,000 gpm, about twice the sustained production rate of the well. Two injection pipes 2 inches in diameter are suspended inside the well casing to convey water

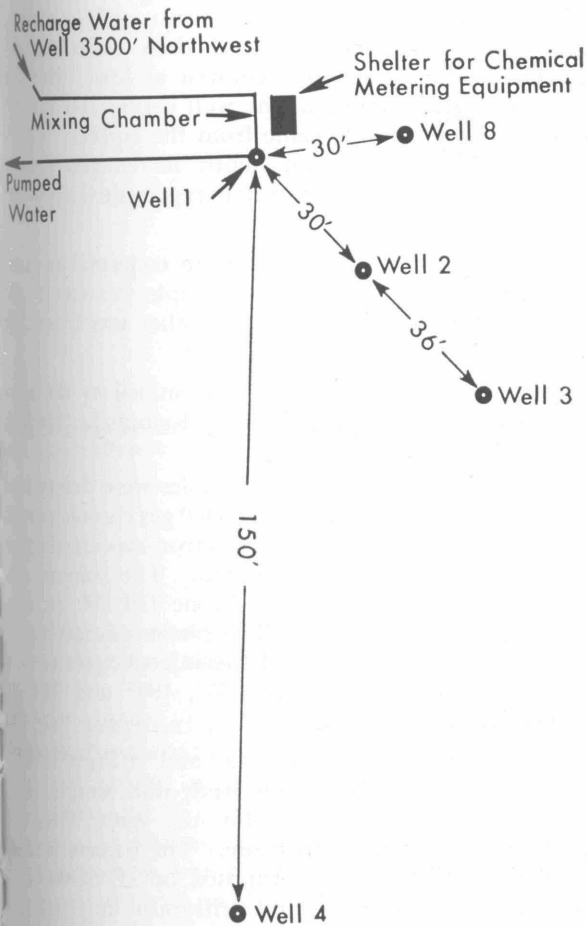


Figure 3. Plan view of the experimental wells used for ground-water sampling and the recharge equipment.

from the ground surface to the water table without air entrainment. This equipment was described by Scalf *et al.* (8).

The observation wells used for pumping water samples are shown in Figure 3. Wells 2, 3 and 4 are 6-inch wells screened through the entire aquifer. Well 8 is a 2-inch well with a 4-foot-long well screen set about 20 feet below the water table. Water level recorders were installed in the six 6-inch observation wells located at distances greater than 150 feet from Well 1.

Two propeller meters were placed in series to measure the recharge and pumping rates. One of

these meters was connected to a strip recorder that continuously recorded the flow rate.

The chemical metering equipment was designed to pump 5 gallons per hour (gal/hr) of chemical concentrate into a mixing chamber in the recharge pipeline. The metering and agitation system consisted of a 150-gallon concentrate tank, an 8-roller nylon pump, a diaphragm pressure regulator, a positive bypass hose and an orifice plate that delivered 5 gal/hr at 30 pounds per square inch (psi). The positive bypass discharged into the bottom of the 150-gallon tank to keep the nonsoluble chemicals in suspension. The mixing chamber consisted of successive right- and left-hand flight auger sections welded inside the 8-inch pipe. The mixing chamber was described by Scalf *et al.* (8).

PROCEDURE

The herbicides added to the recharge water were picloram, atrazine and trifluralin; sodium nitrate was also added as a tracer. The commercial names and formulations for the chemicals are listed in Table 1. The herbicides are commonly used, or their widespread use is anticipated, and they represent a wide range of solubilities. When nitrate and tritium were injected into Well 1 during a previous study, both materials proved to be accurate tracers (7, 8).

Recharge began at 10:20 a.m. October 28 and continued for 10 days, with the chemicals being continuously fed into the recharge water. The recharge rate averaged 360 gallons per minute (gpm) with a variation of -1.9 to +1.1 percent. A total of 5.20 million gallons (43.2 million pounds) of water was injected into Well 1. Each day 0.293 gallons (1108 cubic centimeters) of Tordon 22K, 7.5 pounds of AAtrex, 0.028 gallons (106 cc) of Treflan and 300 pounds of sodium nitrate were mixed with 125 gallons of Ogallala ground water. This mixture was transferred to a 300-gallon tank on a field sprayer for further mixing and was then pumped into the concentration tank that fed the chemical metering equipment. Table 1 shows the total amount and average concentration of the chemicals injected into Well 1. The chemical feed rate varied considerably during the first 4 days because the chemical pump failed, and the flow rate from a new pump had to be adjusted during the test.

TABLE 1. CHEMICALS MIXED WITH THE RECHARGE WATER

Chemical	Total added	Average concentration	Water solubility	Commercial name	Formulation
	Lb	Ppm	Ppm		
Picloram	5.42	0.125	400,000	Tordon 22K	2 lb/gal potassium salt of picloram
Atrazine	55.5	1.28	70	AAtrex	80% wettable powder
Trifluralin	1.04	0.024	<1	Treflan	4 lb/gal emulsifiable concentrate
Nitrate (NO ₃ -N)	440	11.85 ¹	730,000		Fertilizer grade NaNO ₃ , 16% N

¹Includes 1.66 ppm NO₃-N as the average level of nitrate in the ground water.

After recharge ended, Well 1 remained idle for 10 days to simulate the likely interval between recharging and pumping a dual-purpose well. Beginning at 11:00 a.m. November 17, Well 1 was pumped for 9 days at an average rate of 500 gpm and for 3 additional days at an average rate of 480 gpm. The pumping rate was reduced on the tenth day because the pumping level was near the depth where the turbine pump would break suction. During the 12 days of pumping, 8.57 million gallons (71.6 million pounds) of water was pumped from Well 1. Because the injected water mixed with the ground water and was displaced by the natural ground-water flow, a pumping volume $1\frac{2}{3}$ times as great as the recharge volume was required to recover most of the injected water.

Since herbicides may be adsorbed on the aquifer particles, the sand in the water pumped from Well 1 was continually sampled. A tube that diverted 1 percent of the flow through a settling tank was installed in the top of the pump column pipe. The sand in the settling tank was removed at 24-hour intervals and frozen until the herbicide concentration could be determined.

During the pumping and recharge cycles, water samples were collected at regular intervals from all wells shown on Figure 3. At Well 1 the recharge water samples were withdrawn just before the water entered the injection pipes in the well casing (Figure 4). During pumping, samples were obtained from a faucet in the pump discharge pipe. The 2-inch well (Well 8) was sampled with a piston pump operated by a pump jack. Before collecting a sample this well was pumped for 10 minutes to insure that the sample came from the aquifer around the well point. After several hours of pumping, the cone of depression dropped below the well point; consequently, this well could not be sampled during the remainder of the pumping test. The 6-inch wells were sampled by lowering the portable submersible pump shown in

Figure 5 to the center of the saturated formation, pumping for 30 minutes and then collecting the sample. This procedure removed at least twice the volume of static water in the well casing and insured that the water sample came from the aquifer. Check samples taken at 20-foot depth increments showed that the single sample accurately represented the water from the aquifer around the well.

Duplicate water samples were collected in quart polyethylene containers. One sample was sent to the laboratory for analyses, and the other was frozen for analysis at a later date, if needed.

Nitrate and nitrite were determined by the automated, colorimetric procedures of Kamphake, Hannay, and Cohen (5).

Herbicides in the water samples were determined with a Barber-Coleman Model 5360 gas chromatograph equipped with a radium 226 electron capture detector and a 6-foot spiral glass column. The column contained 10% Dow Corning Silicone Oil 200 on Anakrom ABS 80/90 mesh P. The carrier gas was repurified nitrogen at 20 psi, and the injector, column and detector temperatures were 235°, 190° and 210° C, respectively.

The analyses for atrazine and trifluralin were developed specifically for the study since simple, rapid techniques were essential for the more than 600 herbicide determinations made. The trifluralin analysis was similar to that proposed by M. G. Merkle. The levels of atrazine and trifluralin injected into Well 1 were selected so that the concentrations gave equal and maximum peak heights with different retention times on the recorder. The analyses for the two herbicides consisted of extracting 100 cc of water for 15 minutes with 100 cc of hexane in an Erlenmeyer flask on a mechanical stirrer. One to 2 minutes after the stirring ended, the hexane and water separated. The hexane which rose to the top was carefully poured

²Personal communication.

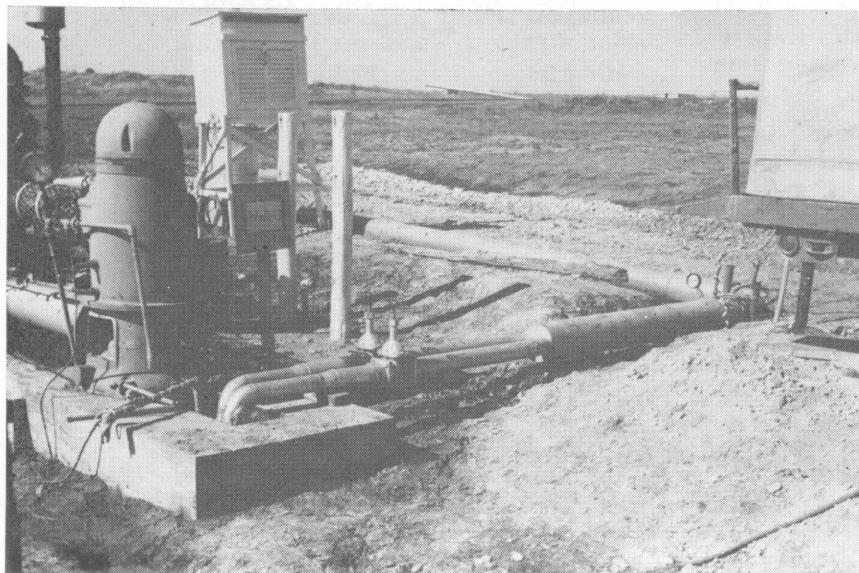


Figure 4. Well 1 and the recharge water pipeline.

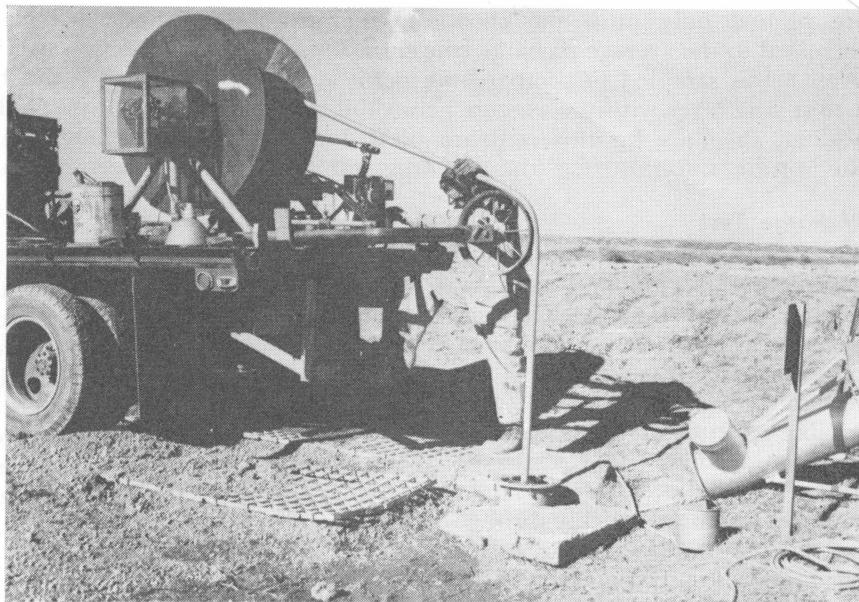


Figure 5. Portable submersible pump being used to sample Well 3.

off and concentrated to 5 cc. Five microliters (μ liters) of the concentrate was injected into the gas chromatograph.

The analysis of picloram was a modification of the method proposed by Hall *et al.* (1). One hundred cubic centimeters of acidified water was extracted three times with 30 cc of ethyl-ether. The ether was evaporated to dryness, and then 10 cc of 12.5 percent boron trifluoride solution in methyl alcohol was used to convert picloram acid to the methyl ester of picloram. The methyl ester was washed with 10 cc of water and dissolved in 10 cc of hexane. Then 5 μ liters were injected into the gas chromatograph.

Standard curves were developed by extracting water with known concentrations of the herbicides. Herbicide analyses were accurate to about one-tenth of the concentrations injected into Well 1.

Duplicate herbicide analyses were made on each sample sent to the laboratory. Only the trifluralin analyses that were made immediately proved to be valid because this herbicide adsorbed to the polyethylene containers. The amount of picloram in the samples decreased about 20 percent from the first to the second analyses. Consequently, the first analysis was generally used for these two herbicides. The atrazine concentrations in the first and second analyses were almost equal.

RESULTS

The nitrate and herbicide concentrations in the wells during pumping and recharging are shown in Figures 6 to 12. These data are presented in more detail in Appendix Tables 1 to 7. On the figures showing the recharge data, the curves for Well 2

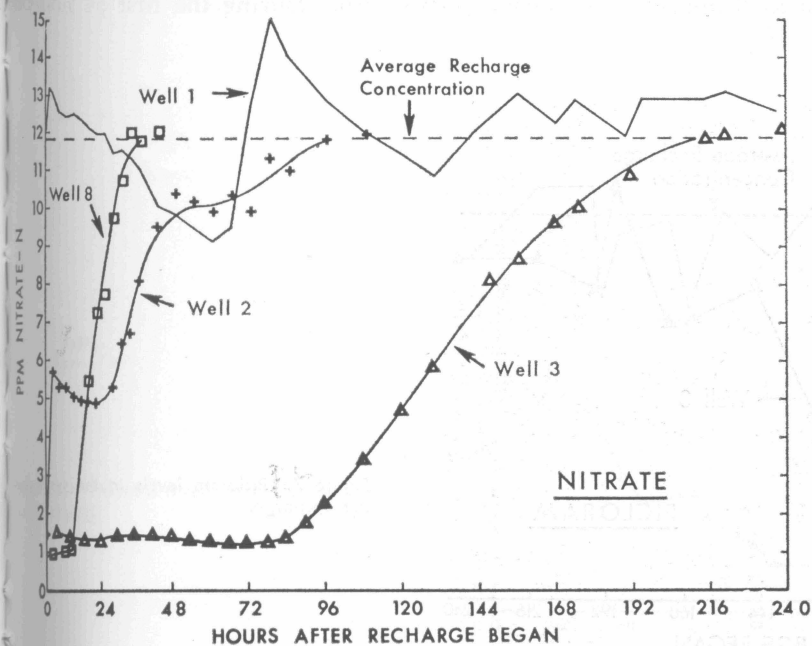


Figure 6. Nitrate levels in the wells during recharge.

are plotted only until the chemical concentration increased to the average recharge concentration. Since Well 8 was sampled to compare the permeability of a thin sand layer with the average permeability of the aquifer, the data for this well are plotted only for the nitrate tracer during the recharge test.

Recharge Test

The nitrate concentrations in the observation wells generally followed a normal sigmoidal curve as they increased to the average recharge concentration, Figure 6. Well 2 was an exception because it contained 5.71 ppm nitrate-N after only 3 hours of recharge. This probably was caused by a highly permeable stratum or a thicker gravel pack just above the water table. The screen of Well 1 extended about 3 feet into dewatered sand, and recharge water could have moved quickly through this material without having to displace the ground water. The low chemical concentration in Well 1 during the second and third days delayed the time required for the nitrate in Well 2 to reach the average recharge concentration. In Well 8, the nitrate level began to increase in 12 hours, and it reached the average recharge concentration in 30 hours. Since the screen in Well 8 is only 4 feet long, this curve represents a thin stratum of the saturated formation rather than the entire aquifer. Small amounts of recharged nitrate may have reached Well 3 during the first 3 days, but there was no significant increase until 89 hours. After that, the nitrate level in Well 3 increased slowly and reached the average recharge concentration after about 210 hours. None of the nitrate was detected in Well 4, 150 feet from the dual-purpose well.

Picloram moved through the aquifer at approximately the same rate as the nitrate tracer (Figure 7). It was first detected in Wells 2 and 3 at the same time that the nitrate levels began to increase. In Well 2 the picloram level increased to 0.10 ppm in 6 hours

and declined to less than 0.06 ppm before reaching the average recharge concentration after 57 hours. During the last 3 days of recharging, the picloram level in Well 3 approached the average recharge concentration, but only one sample exceeded this concentration. This was probably the result of the high level of picloram in the injected water at about 18 hours.

Atrazine also moved freely through the aquifer with the recharge water and increased to the average recharge concentration in all wells where the tracer was detected (Figure 8). It was detected at the same time as the nitrate in Well 2 and about 12 hours after the nitrate in Well 3. The nitrate and atrazine curves for Well 2 were similar, but for Well 3 the atrazine curve was displaced about 24 hours to the right of the nitrate curve.

Since the trifluralin in the samples collected during recharge adsorbed to the polyethylene containers, the data cannot be interpreted quantitatively. The analyses did show, however, that during the 11 days of recharge some trifluralin reached all three observation wells where the other herbicides were detected.

Pumping Test

Figure 9 shows the nitrate concentrations in Wells 1, 2 and 3 decreasing to the background level during the pumping test. In Well 3, nitrate began to decrease after only 12 hours, but in Wells 1 and 2 it remained nearly constant for 3 days before beginning to decrease. The nitrate reached the background level after 214 hours in Well 3 and during the twelfth day in Wells 1 and 2. With a background level of 1.66 ppm nitrate-N, the calculated nitrate recovery was 93 percent.

During pumping, the picloram concentration in all wells declined until each was essentially free of the herbicide (Figure 10). During the first 54 hours of

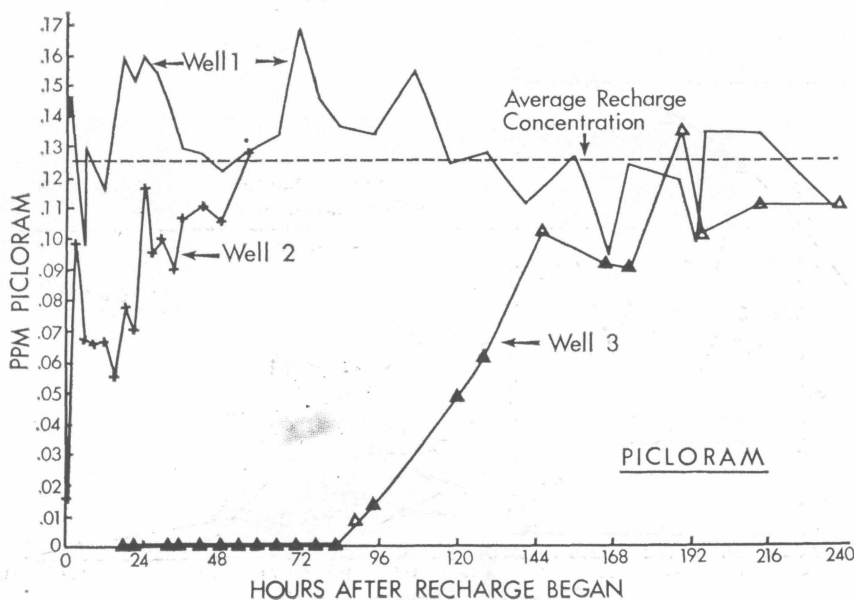


Figure 7. Picloram levels in the wells during recharge.

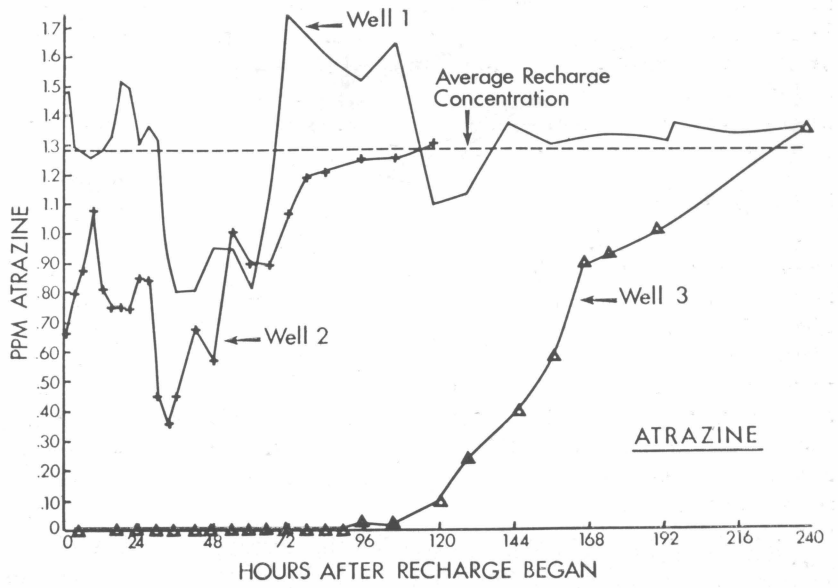


Figure 8. Atrazine levels in the wells during recharge.

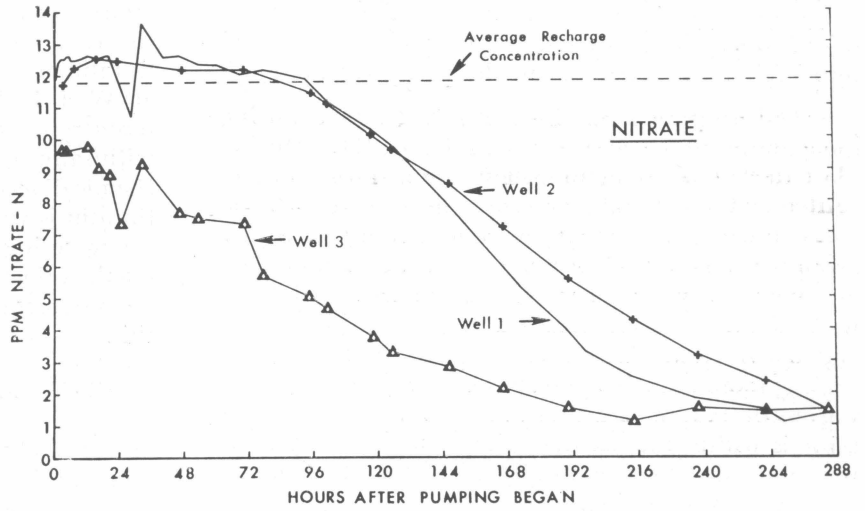


Figure 9. Nitrate levels in the wells during pumping.

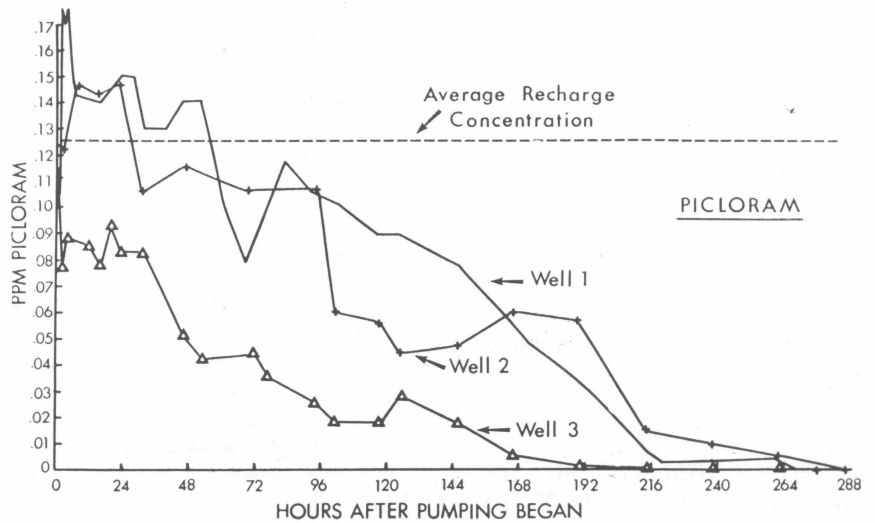


Figure 10. Picloram levels in the wells during pumping.

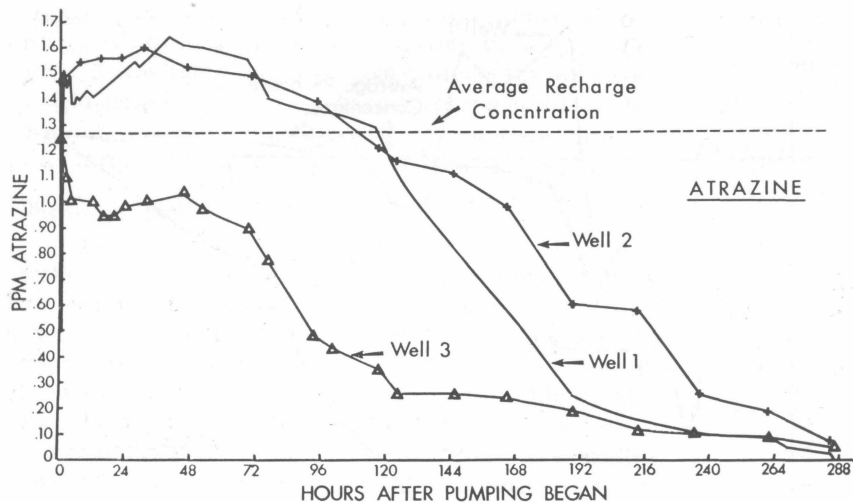


Figure 11. Atrazine levels in the wells during pumping.

pumping the picloram in Well 1 exceeded the average recharge concentration. After that, it declined to near the zero level after 220 hours, and at the end of the test, Well 1 was free of picloram. Well 3 contained traces of picloram until 216 hours, and Well 2 still contained a trace of picloram at the end of the test. Ninety-three percent of the picloram injected into Well 1 was recovered in the pumped water.

The atrazine levels in Wells 1, 2 and 3 during the pumping tests are shown in Figure 11. During the first 117 hours of pumping, the atrazine concentration in Wells 1 and 2 exceeded the average recharge concentration. After that, the concentration in Well 1 dropped quickly to 0.25 ppm at 189 hours and then declined slowly until the end of the test. All three wells, however, contained traces of atrazine at the end of the test. The measurements indicated that slightly more than 100 percent of the injected atrazine was recovered in the pumped water. Because this error is within the accuracy limits of the analyses, it was concluded that essentially all of the atrazine was recovered by pumping.

The trifluralin levels varied erratically during pumping and were difficult to interpret (Figure 12).

In Wells 2 and 3, trifluralin increased during the first day and then began to decrease. The concentration of trifluralin in Well 1 exceeded the average recharge concentration during the first 93 hours; it then dropped rapidly to less than 0.005 ppm at 123 hours and remained below this level until the end of the test. All of the wells contained a trace of trifluralin at the end of the test. The samples collected at Well 1 during pumping indicated a 98-percent recovery for trifluralin. Part of the variability in the trifluralin data may be due to variations in the chemical feed rate during recharging. Because trifluralin is very insoluble, the flow through the chemical metering equipment probably varied more than for the other chemicals. However, accurate trifluralin measurements at Well 1 are not available to verify this.

Trifluralin was the only herbicide that adsorbed to the sand (Table 2). The trifluralin concentration on the sand was high during the first 4 days of pumping, but it decreased to less than 1/10 the average recharge concentration by the end of the test. Only 660 pounds of sand was pumped during the 12 days; consequently, the amount of trifluralin recovered with

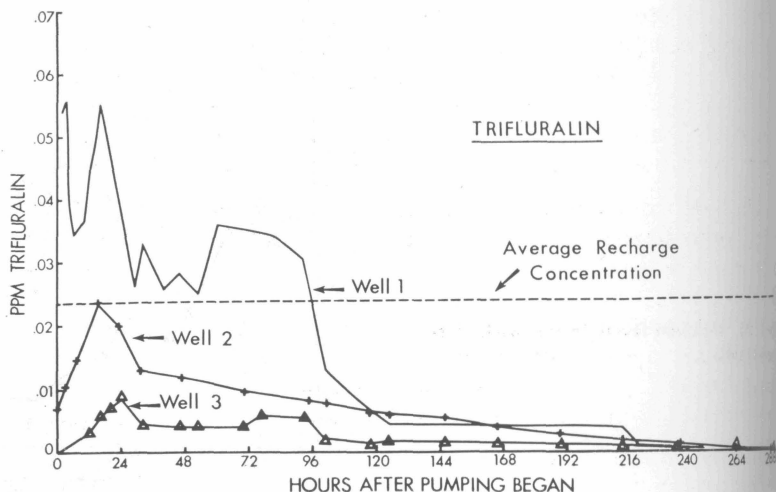


Figure 12. Trifluralin levels in the wells during pumping.

TABLE 2. SAND PUMPED FROM WELL 1 AND THE CONCENTRATION OF HERBICIDES ON THE SAND¹

Hours after start	Sand pumped	Trifluralin	Atrazine	Picloram
		Grams/day	Ppm	Ppm
0-24	29,300	.0694	1.18	.009
24-48	16,400	.1872	.42	.010
48-72	24,600	.0716	.40	.006
72-96	23,300	.0912	1.30	.018
96-120	29,000	.0600	.36	.011
120-144	31,300	.0244	.14	.009
144-168	20,600	.0280	0	.006
168-192	30,400	.0120	0	.007
192-216	19,600	.0106	0	.009
216-240	23,800	.0082	0	0
240-264	23,100	.0076	0	0
264-288	28,900	.0020	0	0
Total	300,300			

¹Herbicide concentrations were calculated using the dry weight of the sand.

the sand was small—0.012 gram. The amount of picloram and atrazine on the sand never exceeded the concentration in the water pumped during the same day.

DISCUSSION

The herbicides picloram, atrazine and trifluralin moved through the sand aquifer with the recharge water, and each was detected in observation wells located 30 and 66 feet from the dual-purpose well. However, no injected nitrate or herbicide was detected in Well 4 located 150 feet from the dual-purpose well. This was expected since the volume of ground water within 150 feet of Well 1 was 3½ times as great as the volume of injected water. One or more highly permeable layers could have caused the injected water to reach Well 4. Since this did not happen, the dispersion zone between the injected water and the ground water was narrow.

The nitrate curves for Wells 2 and 8 on Figure 6 indicate the variation in permeability of the aquifer. If the aquifer were homogeneous, the flow-through times³ for the 4-foot well point (Well 8) and the fully penetrating well (Well 2) would be equal. The flow-through time for Well 8 was 20 hours, and for Well 2 it was 29 hours. Thus, the horizontal permeability of the sand around the well point is greater than the average horizontal permeability of the formation.

The injected water was displaced to the east by natural flow during the 10-day pause, but this did not prevent recovering most of the water. After 5 days of pumping, the nitrate concentration was higher in Well 2 than in Well 1. This suggests that the center of the injected water moved toward Well 2 during the test. A sample calculation shows, however, that the displacement was small in comparison

³The flow-through time for a well is equal to the time at the inflection point of the curve.

to the distance the injected water moved from Well 1. On Figure 2 the ground water contours show an average water table slope of about 0.004 foot per foot (ft/ft), and a maximum gradient of 0.0054 ft/ft between Wells 4 and 7. The flow velocity calculated from the maximum gradient, the highest estimate of permeability (25 feet per day per foot), and the porosity (0.35) is only 11 feet per month.

If water that is injected through a well is to be recovered from the same well, the ratio of the pumped volume to the recharged volume will increase each day pumping is delayed. Two processes are responsible for this—displacement of the injected water by natural flow and mixing between the injected water and ground water. After a pause of several weeks to several months, complete recovery through the same well would no longer be practical or possible. In this study essentially all of the herbicides were recovered after a 10-day pause by pumping 1½ times the volume of recharged water. Thus, the herbicides can be recovered through a dual-purpose well as long as the injected water is not displaced away from the well. The allowable pause will depend on local conditions such as permeability, porosity and the regional ground-water gradient. In the Texas High Plains where playa water is usually available in May and June and pumping for irrigation continues until September, most of the recharged water would be pumped back within a few months.

The results with herbicides are similar to those of an earlier study at the Research Center in which nitrate and DDT were pollution parameters, and tritium was the recharge water tracer (7, 8). The nitrate moved through the aquifer at a rate similar to the tritium tracer, but the DDT was very strongly adsorbed to the Ogallala sand. Unlike the herbicides, there was never any breakthrough of DDT to Well 2 located 30 feet from the dual-purpose well. Three hours after the recharge test ended, a pumping test started, and the DDT concentration in the pumped water was 16 times the average recharge concentration. Within 1 hour the DDT level dropped below the average recharge concentration and continued to decrease for 2 more days. The DDT concentrations then became erratic, and the sampling frequency did not permit accurate calculation of the percent recovery. Ninety-four percent of the nitrate and tritium was recovered with the pumped water.

The trifluralin adsorbed to the sand near the recharge well, but to a lesser degree than the DDT. This herbicide was released from the formation much faster than it was injected, thus resulting in the steep decline in concentration beginning at about 96 hours (Figure 12). Unlike the DDT, essentially all of the trifluralin was recovered from the Ogallala sand.

The movement of coliform bacteria through the Ogallala aquifer was also studied when clarified playa water was recharged into the dual-purpose well and three surrounding wells (2, 3). Initially, the playa

water was recharged into Well 3 and recovered from the aquifer by pumping the dual-purpose well. Almost all of the coliform bacteria in the playa water were filtered by the fine Ogallala sand. In another phase of the study, clarified playa water was recharged into the dual-purpose well, and short intervals of pumping did not effectively remove coliform bacteria from the surrounding aquifer.

Rebhun and Schwarz (6) also reported coliform bacteria contamination after recharging water of drinking quality into wells in a sandstone aquifer. They concluded that suspended organic matter, even though of low concentrations, was filtered near the recharge wells and formed an organic mat. Shortly after recharge ended, conditions became favorable for decomposition of organic matter and bacterial growth. As a result, water pumped after a pause of 2 to 50 days showed high coliform bacteria counts. Similar results would be expected in any aquifer fine enough to filter the suspended organic material.

This herbicide study and the two previous studies at the Research Center offer some guidelines for determining quality standards for water recharged through wells. The coliform bacteria and DDT were effectively filtered or adsorbed by the fine Ogallala sand. This means that they are not likely to move very far through Ogallala sand. However, the DDT and coliform bacteria were difficult to recover from the aquifer. The herbicides and nitrate moved readily with the recharge water, but they were easily recovered by pumping.

ACKNOWLEDGMENT

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versity, and the Soil and Water Conservation Research Division, Agricultural Research Service, U. S. Department of Agriculture.

LITERATURE CITED

1. Hall, R. C., C. S. Giam and M. G. Merkle. 1970. A new technique for the determination of picloram and other herbicides containing carboxylic acid and ester groups. *Analytical Chemistry*, Vol. 42, No. 3, pp. 423-425.
2. Hauser, V. L. and F. B. Lotspeich. Treatment of playa lake water for recharge through wells. *Transactions of the ASAE*, Vol. 11, No. 1, pp. 108-111, 1968.
3. Jones, Ordie R. Movement of coliform bacteria and organic carbon in the Ogallala aquifer at Bushland, Texas. *Texas Agr. Exp. Sta. MP-873*, February 1968.
4. Jones, O. R. and A. D. Schneider. Comparison of methods for determining the specific yield of the Ogallala. *Proc. of the Ogallala Aquifer Symposium*, Texas Tech University, Lubbock, Texas. pp. 118-130, April 30-May 1, 1970.
5. Kamphake, L. J., S. A. Hannah and J. M. Cohen. Automated analysis for nitrate by hydrazine reduction. *USDA, R. A. Taft Sanitary Engineering Center, Cincinnati, Ohio*.
6. Rebhun, M. and J. Schwarz. Clogging and contamination processes in recharge wells. *Water Resources Research* Vol. 4, No. 6, pp. 1207-1217, December 1968.
7. Scalf, M. R., W. J. Dunlap, L. G. McMillion and J. W. Keeley. Movement of DDT and nitrate during groundwater recharge. *Water Resources Research*, Vol. 5, No. 3, pp. 1041-1051, October 1969.
8. Scalf, M. R., V. L. Hauser, L. G. McMillion, W. J. Dunlap and J. W. Keeley. Fate of DDT and nitrate in ground water. *Joint report of U. S. Dept. of Interior, Robert S. Kerr Water Research Center, Ada, Oklahoma, and U. S. Dept. of Agriculture, Southwestern Great Plains Research, Bushland, Texas, April 1968.*
9. Wiese, A. F., D. T. Smith and A. D. Schneider. Herbicide residue research on the High Plains. *Proc. of the Third Conference on Insect, Plant Disease, Weed and Brush Control*, pp. 149-154, Dec. 15-17, 1970. Texas A&M University.

APPENDIX

APPENDIX TABLE 1. HERBICIDE AND NITRATE CONCENTRATIONS IN WELL 1 DURING RECHARGE

Hours after recharge began	NO ₃ -N	Picloram	Atrazine
	Ppm	Ppm	Ppm
0.2	12.03	.134	1.48
1	13.19	.147	1.48
3	13.11	.098	1.29
6	12.56	.130	1.28
9	12.41		1.26
12	12.48	.116	1.29
15	12.33		1.33
18	12.10	.159	1.52
21	11.95	.151	1.49
24	11.95	.160	1.30
27	11.44	.156	1.37
30	11.58		1.32
33	11.36	.141	.93
36	11.00	.129	.80
42	10.03	.128	.81
48	9.83	.123	.96
54		.129	.95
60	9.10	.098	.82
66	9.49	.134	1.13
72	12.72	.168	1.74
78	15.05	.146	1.67
84	13.93	.137	1.61
96	12.80	.134	1.52
107	12.03	.155	1.64
119	11.44	.124	1.09
130	10.86	.128	1.13
143	12.03	.111	1.37
157	13.03	.129	1.30
168	12.25	.094	
174	12.87	.124	1.33
190	11.88	.117	1.32
195	12.87	.098	1.31
215	12.87	.134	1.33
222	13.03		
238	12.56	.111	1.39

APPENDIX TABLE 2. HERBICIDE AND NITRATE CONCENTRATIONS IN WELL 2 DURING RECHARGE

Hours after recharge began	NO ₃ -N	Picloram	Atrazine
	Ppm	Ppm	Ppm
0.2	1.45	.016	0.67
3	5.71	.068	.80
6	5.27	.027	.87
9	5.27	.066	1.07
12	5.04	.017	.82
15	4.93	.055	.76
18	4.88	.077	.76
21	4.83	.070	.74
24		.117	.85
27	5.27	.095	.84
30	6.22	.099	.46
33	6.69	.090	.36
36	8.08	.107	.46
42	9.49	.111	.68
48	10.37	.124	.55
54	10.16	.128	1.01
60	9.89	.011	.90
66	10.30	.125	.89
72	9.89	.121	1.07
78	11.29	.142	1.19
84	11.00	.121	1.21
96	11.80	.110	1.25
107	11.88	.134	1.25
119	11.80	.130	1.30
130	11.88	.126	1.27
147	12.48	.132	1.14
157	12.18	.104	1.24
168	12.03	.135	1.22
174	11.95	.128	1.16
190	12.80	.095	1.25
195	12.80	.112	1.27
216	13.03	.108	1.25
222	13.03		
238	12.80	.138	1.31

APPENDIX TABLE 3. HERBICIDE AND NITRATE CONCENTRATIONS IN WELL 3 DURING RECHARGE

Hours after recharge began	NO ₃ -N	Picloram	Atrazine
	Ppm	Ppm	Ppm
5	1.54	0	0
11	1.40	0	0
17	1.30	0	0
23	1.30	0	0
29	1.45	0	0
35	1.45	0	0
41	1.45	0	0
47	1.40	0	0
53	1.30	0	0
59	1.30	0	0
65	1.26	0	0
71	1.26	0	0
77	1.26	0	0
83	1.35	0	0
89	1.74	.008	0
95	2.23	.013	.03
105	3.45	.024	.02
120	4.72	.049	.10
129	5.94	.061	.24
147	8.14	.102	.40
156	8.71	.104	.58
167	9.62	.092	.89
175	10.03	.090	.93
191	10.86	.135	1.00
197		.101	
215	11.88	.111	
221	11.95		
239	12.10	.108	1.34

APPENDIX TABLE 4. HERBICIDE AND NITRATE CONCENTRATIONS IN WELL 8 DURING RECHARGE

Hours after recharge began	NO ₃ -N	Picloram	Atrazine
	Ppm	Ppm	Ppm
0.2	0.92	.004	0
3	0.97		0
6		.001	0
9	1.02		0
12	1.06	.003	0
15	3.14		.12
18	5.48	.076	.30
21	7.22	.097	.34
24	7.71	.121	.61
27	9.76	.124	.55
30	10.72	.124	.89
33	11.95	.146	1.04
36	11.73	.108	1.10
42	12.03	.133	1.02
48	11.88		1.01
54	12.25	.130	1.03
60	11.07	.120	1.00
66	10.37	.123	1.09
72	9.89	.125	.85
78	9.62	.104	.82
84	10.03	.098	.82
96	10.72	.124	1.60
107	13.35	.133	1.46
119	12.87	.132	.98
130	12.64		1.51
143	11.80	.099	1.44
147			1.34
157	11.58	.086	1.24
168	12.48	.011	1.17
174	12.80	.129	1.13
190	12.80	.114	1.17
195	12.80	.094	1.25
215	12.80	.099	1.38
222	13.11		
238	12.80	.128	1.42

APPENDIX TABLE 5. HERBICIDE AND NITRATE CONCENTRATIONS IN WELL 1 DURING PUMPING

Hours after pumping began	NO ₃ -N	Picloram	Atrazine	Trifluralin
	Ppm	Ppm	Ppm	Ppm
.083	11.66	.114	1.51	.0716
.167	11.73	.132	1.54	.0672
.25	12.18	.132	1.56	.0596
.50	12.25	.158	1.58	.0520
.75	12.41	.168	1.55	.0468
1.00	12.41		1.51	.0468
1.25	12.41	.176	1.55	.0486
1.50	12.48	.176	1.44	.0550
1.75	12.48	.176	1.46	.0538
2.0	12.56	.176	1.46	.0542
2.5		.160	1.44	.0550
3.0	12.56	.154	1.48	.0558
3.5	12.56	.170	1.43	.0504
4	12.64	.176	1.38	.0406
5	12.64		1.38	.0380
6	12.48	.147	1.41	.0344
7	12.48	.143	1.39	.0350
10	12.56	.139	1.43	.0372
12	12.64	.120	1.41	.0448
16	12.56	.140	1.43	.0534
20	12.64		1.47	.0480
24	16.16	.151	1.52	
28	10.72	.150	1.54	.0264
32	13.68	.130	1.55	.0332
40	12.56	.130	1.64	.0260
46	12.64	.141	1.61	.0284
53	12.33	.141	1.60	.0252
60	12.33	.104	1.58	.0360
69	12.03	.078	1.56	
77	12.18		1.41	.0348
83	12.10	.118	1.38	.0340
93	11.88	.106	1.36	.0304
101	11.15	.102	1.35	.0128
117	10.30	.092	1.29	.0066
125	9.76	.092	1.09	.0044
146	7.89	.077	.81	.0046
165	6.05	.057	.58	.0044
172	5.32	.048	.51	.0042
189	4.02	.037	.26	
196	3.34	.028	.22	.0043
213	2.53	.008	.16	.0040
220		.003	.14	.0010
237	1.84	.003	.11	.0008
261	1.50	.004	.09	.0008
269	1.11	.001	.05	.0005
285	1.35	0	.03	.0004

APPENDIX TABLE 6. HERBICIDE AND NITRATE CONCENTRATIONS IN WELL 2 DURING PUMPING

Hours after pumping began	NO ₃ -N	Picloram	Atrazine	Trifluralin
	Ppm	Ppm	Ppm	Ppm
0	10.65	.124	1.48	.0072
3	11.73	.122	1.47	.0104
7	12.25	.145	1.54	.0146
15	12.56	.143	1.56	.0236
23	12.48	.148	1.56	.0200
31	7.95	.106	1.60	.0130
47	12.18	.116	1.52	.0120
70	12.18	.106	1.49	.0098
95	11.44	.107	1.39	.0084
101	11.07	.059	1.35	.0078
118	10.16	.056	1.21	.0064
125	9.62	.044	1.16	.0058
146	8.58	.047	1.12	.0056
166	7.10	.060	.98	.0040
190	5.54	.057	.60	.0030
214	4.29	.015	.58	.0020
238	3.14	.010	.25	.0012
262	2.33	.005	.19	.0005
286	1.45	0	.18	.0004

APPENDIX TABLE 7. HERBICIDE AND NITRATE CONCENTRATIONS
IN WELL 3 DURING PUMPING

Hours after pumping began	NO ₃ -N	Picloram	Atrazine	Trifluralin
	<u>Ppm</u>	<u>Ppm</u>	<u>Ppm</u>	<u>Ppm</u>
0	10.79	.124	1.25	
2	9.69	.077	1.09	
4	9.62	.088	1.01	
12	9.76	.086	.99	.0030
16	9.10	.078	.94	.0060
20	8.90	.093	.94	.0070
24	7.34	.083	.98	.0088
32	9.25	.083	.99	.0044
46	7.71	.051	1.03	.0040
53	7.53	.042	.97	.0042
70	7.34	.044	.90	.0042
77	5.71	.036	.77	.0058
94	5.04	.026	.48	.0054
101	4.66	.018	.43	.0020
118	3.76	.018	.36	.0014
125	3.29	.028	.26	.0018
146	2.83	.018	.26	.0016
166	2.18	.006	.24	.0014
190	1.54	.002	.19	.0014
214	1.16	0	.12	.0012
238	1.54	0	.11	.0010
262	1.45	0	.09	.0005
286	1.50	0	.05	.0002

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