NITRATE AND PESTICIDE DISTRIBUTION in the WEST FORK DES MOINES RIVER ALLUVIAL AQUIFER

Technical Information Series 18

Iowa Department of Natural Resources

Larry J. Wilson, Director

April 1990

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ABSTRACT

Groundwater and river water in the alluvial system of the West Fork Des Moines River were monitored to investigate the distribution of nitrate and pesticides. The distribution of nitrate in groundwater varies between locations, vertically within the aquifer, and with time. Nitrate concentrations increase in response to precipitation and snowmelt events and decrease as infiltration decreases. Nitrate concentrations decrease with depth. This decrease may be related to the flow regime of the aquifer. Gradients in the aquifer are dominantly horizontal resulting in lateral flow paths. In addition, deeper parts of the aquifer may be recharged from groundwater low in nitrate, such as occurs in the glacial materials. Denitrification might also be occurring in areas with persistently high water tables.

Pesticides were detected in both groundwater and river water with a maximum of four compounds detected. Concentrations were similar, except for alachlor (Lasso), which was found at higher concentrations in groundwater.

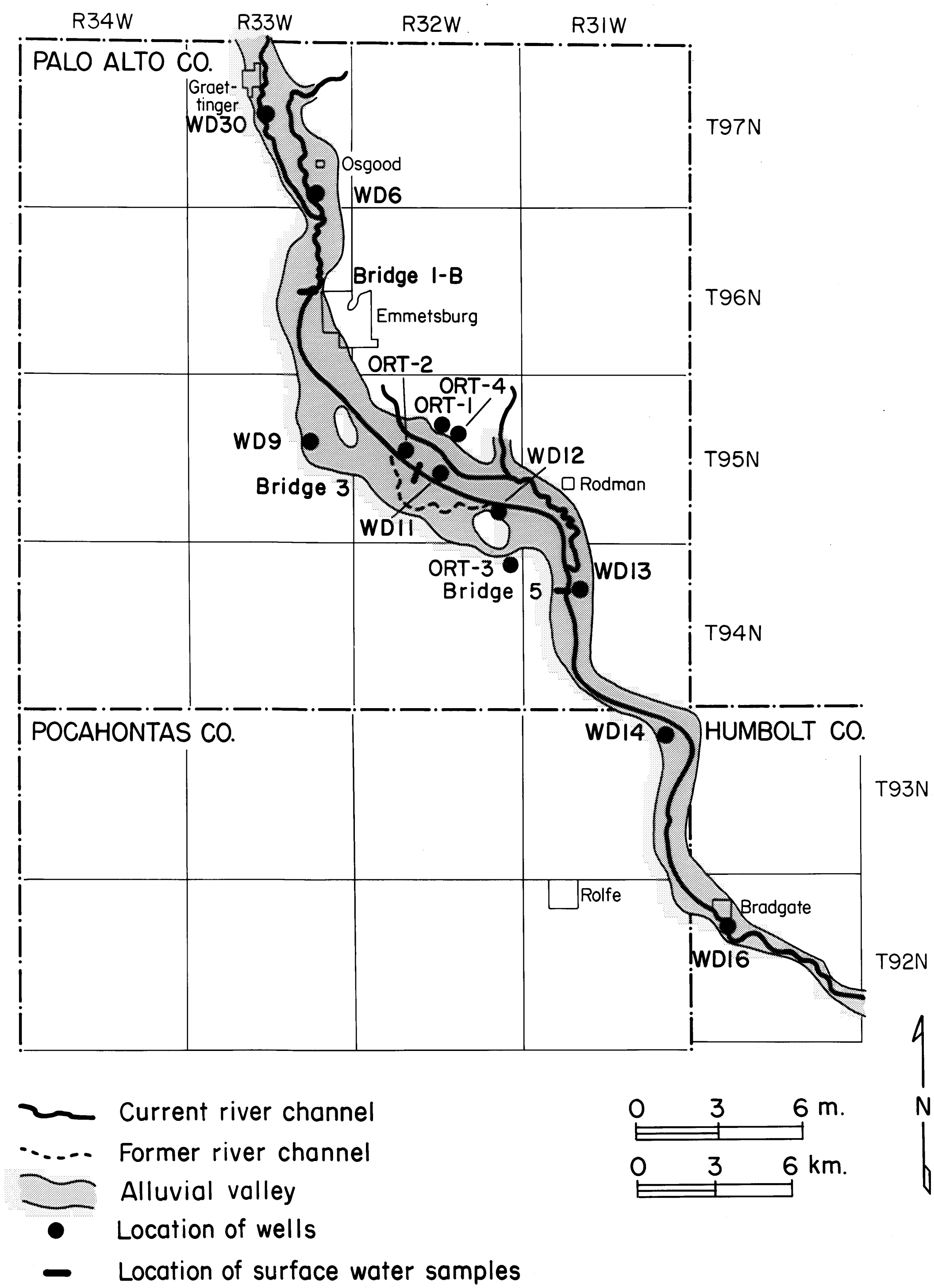

Figure 1. Area of investigation for this study

INTRODUCTION

Study of alluvial aquifers with regard to water availability and quality has been done since 1981 by the Department of Natural Resources' Geological Survey Bureau (formerly the Iowa Geological Survey). Resulting research has shown that these aquifers can be highly susceptible to contamination and that nitrate and pesticide concentrations vary significantly (Thompson 1984, 1986, 1987).

Previous geologic, hydrologic, and water-quality investigations on the Des Moines River alluvial aquifer have been reported by Thompson (1984). Briefly, results showed that the aquifer is capable of supplying large amounts of water for irrigation, municipal, livestock and domestic uses. Nitrate contamination of the groundwater was thought to be confined to the upper part of the aquifer, within ten feet of the water-table surface. The distribution of nitrate was not uniform and appeared to be controlled both by denitrification and shallow, lateral flow systems. Pesticide sampling was limited, but both atrazine and alachlor(Lasso) were found in groundwater samples.

To more fully understand the nature and extent of water-quality degradation, further studies were undertaken in 1985 and 1986. The objective of this research was to evaluate spatial and temporal water-quality variability with particular reference to nitrate (NO_3) and pesticide concentrations. The occurrence of agricultural chemicals in Iowa's groundwater, even in low concentrations, is of concern because of the potential hazard to health through long-term exposure. Elevated nitrate concentrations have been linked to higher incidences of cardiovascular disease, birth defects, and several forms of cancer as well as to methemoglobinemia, a potentially fatal infant disease. There is currently much uncertainty about the health effects of pesticides and their coexistence with nitrate and other chemicals. Some studies suggest there is a health risk, but more data are needed to adequately define impacts on human health.

The area of investigation for the 1985-86 study is shown in Figure 1. Monitoring-well locations are identical to the previous study (Thompson, 1984), but additional wells were added at each site in order to investigate changes in water quality with depth (Fig. 1). Sampling frequency was twice monthly, except during winter months when sampling was monthly. Monitoring occurred from September 1985 until October 1986.

SPATIAL AND TEMPORAL DISTRIBUTION OF NITRATE

The nitrate monitoring results from this study are shown in Table 1. The average (mean) nitrate concentration in monitoring wells was 8.9 mg/l NO_3, which is lower than expected in view of the predicted sensitivity of the alluvial system and the intensive agriculture in the alluvial plain. This is also lower than other alluvial systems in northwest Iowa (Thompson 1986, 1987).

Overall, nitrate concentrations in the groundwater are low and spatially variable. Detectable nitrate concentrations (>5 mg/l NO_3) were found at seven of the eight well sites (133/497 samples). However, during most sampling periods, nitrate was present at only four sites (6/23 wells). Only two well sites (24/497 samples) exceeded the nitrate maximum contaminant level (MCL) of 45 mg/l NO_3 (10 mg/l NO_3-N).

In contrast, river samples usually showed detectable concentrations of nitrate. At the three sampling stations, river nitrate concentrations averaged 17.3 to 19.8 mg/l NO_3 (3.8-4.4 mg/l NO_3-N) with individual samples ranging from <5 to 40 mg/l NO_3 (<1-8.9 mg/l NO_3-N). Since groundwater contributes, on an average, over 50% of the flow to the Des Moines River in the study area (Thompson, 1984), the river reflects groundwater quality. The Des Moines River in the study area has lower nitrate concentrations than other major interior rivers in Iowa (Thompson et al., 1986).

Nitrate concentrations also vary with time. Increases in nitrate concentrations in the wells are generally related to recharge of the groundwater system. Nitrate concentrations in all monitoring wells were averaged for each sampling period and the averages varied from 4.3 to 13.4 mg/l NO_3 (<1-3.0 mg/l NO_3-N), while concentrations in individual wells varied from <5 to 127 mg/l NO_3 (<1-28.2 mg/l NO_3-N) over the entire study period.

Table 1. Nitrate monitoring results in milligrams per liter (mg/l).

LOCATION	SCREENED INTERVAL (ft.)	AUG 27 1985	SEPT 18-19 1985	OCT 7-8 1985	OCT 23-24 1985	NOV 6-7 1985	NOV 20-21 1985	DEC 23 1985	JAN 21 1986
WD-30U	9-12	19	8	17	<5	12/10	13	20	<5
30L	13-15	17	5	<5	<5	<5	<5	<5	<5
WD-6	6-10	60	63	75	<5	74	85/87	62	7
6M	16-20	<5	<5	<5	<5	<5	<5/<5	<5	<5
6L	24.5-27		<5	<5	11	<5	<5	<5	<5
BRIDGE 1B			10	27	23	22	39		
WD-9U	3-8	<5	<5	6	<5	<5	<5/<5		
9M1	15-17		<5	<5	<5	<5	<5		
9M2	30-33		<5	<5	<5	<5	<5		
9L	43-47		<5	<5	83	<5	<5		
BRIDGE 3			11	27	23	23	35		
WD-11U	3-8	<5	<5	6	7	5	6	<5	<5
11M	15-19	<5	<5	<5	<5	<5	<5	<5	<5
11L	31-34		<5	<5	<5	<5	<5	<5	<5
WD-12U	5-8		<5	<5	<5	<5	36	<5	25
12M	14-16.5	<5	<5	<5	<5	<5	<5	<5	<5
12L	28-32		<5	<5	<5	<5	<5	<5	<5
BRIDGE 5			11	27	23	22	35		
WD-13U	12-16	<5	<5	<5	<5	<5	<5	<5	<5
13M	21-25	<5	<5	<5	<5	<5	<5	<5	<5
13L	33-35.5	<5	<5	<5	<5	<5	<5	<5	<5
WD-14U	5-9	18	14	11	8	10	5	<5	<5
14M	14-18	34	34	8	10	8	28/37	<5	29
14L	28-31	<5	<5	<5	<5	<5	<5	<5	<5
WD-16U	5-8	46	21	15	18	23/24	21	<5	
16L	13-14.5	32	32	17	8	39	36	11	21

Replicate measurements were done as part of a quality-control program.
<5 is the detection limit for this study

Table 1. (continued)

LOCATION	SCREENED INTERVAL (ft.)	FEB 19 1986	MAR 15 1986	APR 11 1986	APR 22 1986	MAY 7 1986	MAY 19 1986	JUNE 4 1986	JUNE 17 1986
WD-30U	9-12	16/16	<5	7	<5	<5	5	11	19
30L	13-15	6	<5	<5	<5	<5	<5	<5	<5/<5
WD-6	6-10	100	45	75	90	<5	99	101	100
6M	16-20	<5	<5	<5	<5	<5	<5/<5	5	<5
6L	24.5-27	<5	<5	<5	<5	<5	<5	<5	<5/<5
BRIDGE 1B		22		17	24	20	23	23	23
WD-9U	3-8	<5	<5	<5	<5	<5	<5	<5	<5
9M1	15-17	<5	<5	<5	<5	<5	<5/<5	<5	<5
9M2	30-33	<5/<5	<5	<5	<5	<5	<5	<5	<5
9L	43-47	<5	<5	<5	<5	<5	<5	<5	<5
BRIDGE 3				18	25	20	23	24	23
WD-11U	3-8	12/12	<5	<5/<5	<5	<5	<5	<5/<5	<5
11M	15-19	<5	<5	<5	<5	<5	<5	<5	<5
11L	31-34	<5	<5	<5	<5	<5	<5	<5	<5
WD-12U	5-8	21	<5/<5		<5	<5/<5	<5/<5	<5/<5	<5/<5
12M	14-16.5	<5	<5		<5	11	<5	<5	<5
12L	28-32	<5	<5		<5	<5/<5	<5/<5	<5	<5
BRIDGE 5		19		19	24	20	23	23	24
WD-13U	12-16	<5	<5	<5	<5	<5	<5	<5/<5	<5
13M	21-25	<5/<5	<5	<5	<5	<5	<5	<5	<5
13L	33-35.5	<5	<5	<5	<5	<5	<5	<5	<5
WD-14U	5-9	28	14	30/31	33	25	15	<5/<5	8
14M	14-18	44	42	31	31	23	35	17	
14L	28-31	<5	<5	<5/<5	<5	<5	<5	<5	<5
WD-16U	5-8	15	<5	18	16	25/22	<5	11	<5
16L	13-14.5	40	11	21	25	6/6	5/6	10	9

Replicate measurements were done as part of a quality-control program.
<5 is the detection limit for this study

Table 1. (continued)

LOCATION	SCREENED INTERVAL (ft.)	JUNE 30 1986	JULY 21 1986	AUG 19 1986	AUG 09 1986	SEPT 21 1986	SEPT 21 1986	OCT 1986	AVG.
WD-30U	9-12	17/18	13/13	20	16	19	18/17	7	11.1
30L	13-15	5	<5	<5	<5	<5	<5	<5	<5
WD-6	6-10	98	97/97	88	105	127/121	101	110/111	76.5
6M	16-20	<5	<5	<5	<5	<5	<5/<5	<5	<5
6L	24.5-27	<5	<5	<5	<5	<5	<5	<5	
BRIDGE 1B		7	13	<5	<5	<5	17	19	17.3
WD-9U	3-8	<5/<5	<5	<5	<5	<5/<5	<5	<5	<5
9M1	15-17	<5	<5	<5	<5	<5	<5	<5	<5
9M2	30-33	<5	<5	<5	<5	<5	<5	<5	
9L	43-47	<5	<5/<5	<5	<5	<5	<5	<5	
BRIDGE 3		40	13	6	5/7	<5	17	19/19	19.6
WD-11U	3-8	<5	<5	<5	<5	<5	<5/<5	<5	<5
11M	15-19	<5	<5/<5		<5	<5	<5	<5	<5
11L	31-34	<5	<5		<5	<5	<5	<5	
WD-12U	5-8	<5	<5		<5	<5	<5	<5	<5
12M	14-16.5	<5	<5		<5/<5	<5	<5	<5	<5
12L	28-32	<5/<5	<5		<5	<5	<5	<5	
BRIDGE 5		40	15	6	5	<5	17/17	24	19.8
WD-13U	12-16	<5	<5	<5	<5	<5/<5	<5	<5	<5
13M	21-25	<5	<5	<5	<5	<5	<5	<5	<5
13L	33-35.5	<5	<5	<5	<5	<5	<5	<5	
WD-14U	5-9	25	20	21	25	10/8	14	7/7	14.8
14M	14-18	<5	30		67/75	10	62	7	26.6
14L	28-31	15	<5	<5	<5	<5	<5	<5	
WD-16U	5-8	28/14	15	42	62	68	52	17	23.0
16L	13-14.5	26	11	32/25	15/15	<5	20	21	19.3

Replicate measurements were done as part of a quality-control program.
<5 is the detection limit for this study

Table 2. Nitrate concentrations at different depths.

DEPTH (ft.)	NO. OF WELLS	NO. OF SAMPLES	RANGE NO_3 (mg/l)	AVERAGE NO_3 (mg/l)
0-10	6	133	<5 - 127	19.0
10-20	9	199	<5 - 75	6.1
20-30	4	85	<5 - 11	<5
30-40	3	61	<5	<5
>40	1	19	<5	<5

FACTORS CONTROLLING THE DISTRIBUTION OF NITRATE

There are several possible explanations for the variability of nitrate concentrations and these will be discussed. Recharge is an important factor in regulating infiltration and the delivery of nitrate to the groundwater. The flow system within the aquifer can control the distribution of nitrate and the travel time necessary for the nitrate to reach a given depth is also an important consideration. Denitrification, the transformation of nitrate to a gas, may explain the distribution of nitrate in the shallow wells.

Recharge

Following periods of high effective precipitation or melting events, nitrate concentrations increase in both groundwater and rivers. Research in other parts of the state has shown that precipitation and infiltration are the dominant mechanisms by which nitrate is delivered to the groundwater system (Hallberg et al., 1983). Figure 2 shows the average nitrate concentration of the groundwater and the river for each sampling period plotted versus precipitation at Emmetsburg, Iowa.

Vertical Stratification of Nitrate

Different concentrations of nitrate with depth are evident at most sites in this study (Table 2). Previous studies of alluvial systems have shown pronounced vertical stratification in which nitrate concentrations decrease with depth (Hendry et al., 1983; Thompson, 1986, 1987; Wehtje et al., 1983). This stratification has important implications for well placement in an alluvial aquifer making it possible to utilize low-nitrate water if the stratification is not disrupted by pumping or affected by a temporal change.

The cause of the nitrate decline with depth may be, in part, related to the flow system within the aquifer. Water-level measurements in the nested wells for the Des Moines River study indicate very low vertical gradients, suggesting little vertical movement of water. Characteristically, the alluvial deposits consist of highly layered fine to coarse gravel units and occasional sand lenses. The layered, anisotropic deposits promote lateral transport with limited vertical dispersion (Bouwer, 1978). For example, a recent field study of solute transport in a sand aquifer in Ontario, Canada (Mackay et al., 1986) showed that concentrations of the conservative tracers chloride and bromide showed little vertical change over a monitoring period of three years.

Travel-Time Considerations

The travel time necessary for a chemical to reach a given well depth is controlled both by the hydraulic conductivity of the aquifer materials and the flow path (or gradients). Travel time may also be a factor because nitrate applications have increased through time as a result of increased acreage as well as an increase in the amount of chemical nitrogen applied (Hallberg, 1986).

One way to examine vertical recharge in the aquifer is to measure groundwater age. Water deeper in the aquifer would be expected to be older if little downward movement of water occurs, and if recharge is through the alluvium.

Tritium analyses were performed on nested wells at two sites in order to estimate groundwater age. Lowest tritium values (18-22 ±2 Tritium Units) occur in the upper zones of the aquifer and increase with depth (Table 3). This increase suggests that groundwater age increases with depth

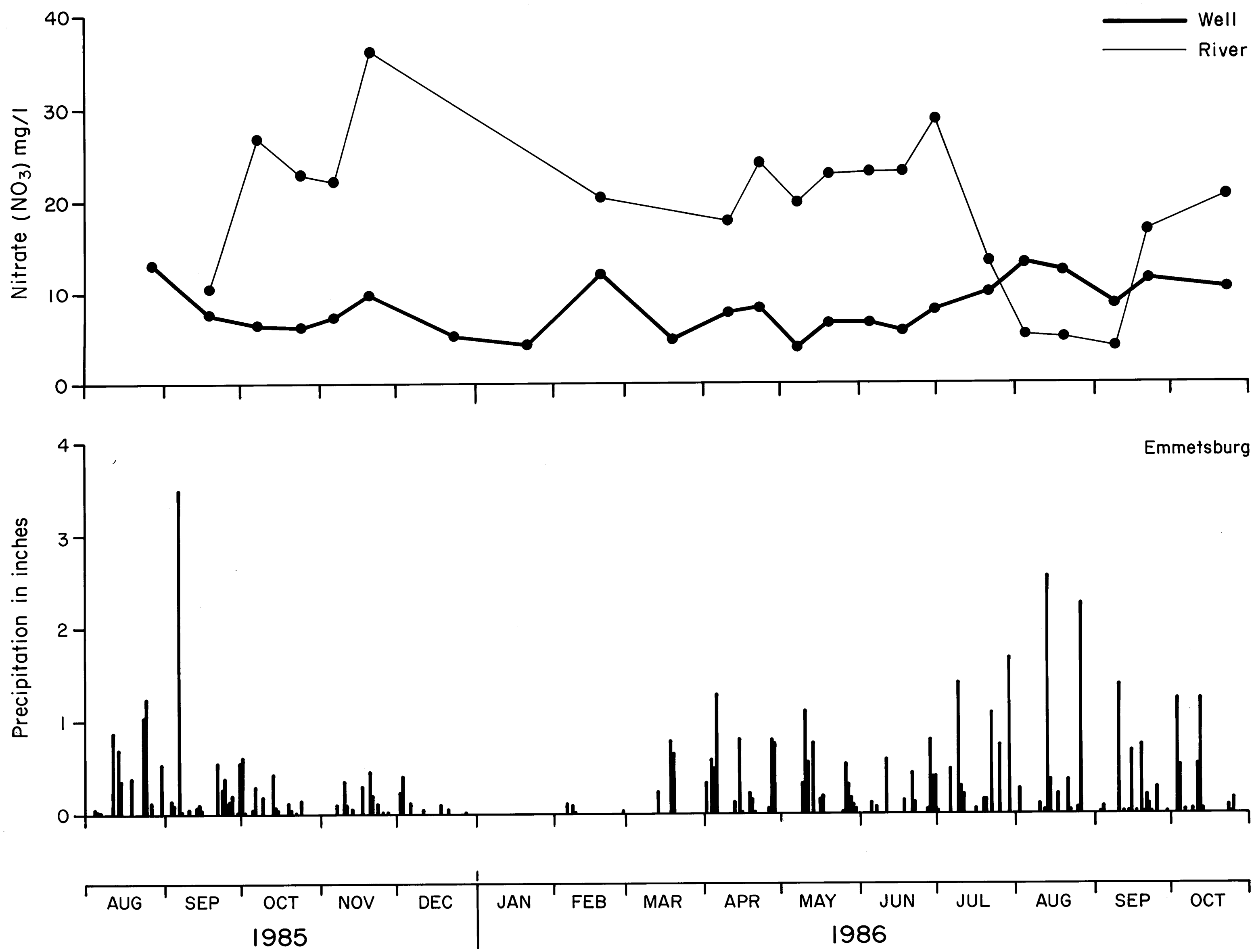

Figure 2. Temporal trends in average nitrate concentrations for all groundwater sites and all river sites and precipitation at Emmetsburg.

Table 3. Tritium analyses of groundwater in alluvial wells.

WELL	SCREENED INTERVAL (ft.)	VALUE (tritium units)
WD6U	6-10	18.4 ±1.5
		18.2 ±1.5
WD6M	16-20	44.5 ±3.0
WD6L	24-26.5	48.4 ±3.3
WD9U	3-8	22.5 ± 1.8
		20.9 ± 1.7
WD9MU	15-17	32.1 ± 2.3
WWD9ML	30-33	60.0 ± 4.1
WD9L	43-47	70.9 ± 4.8

and that some of the water recharged to the aquifer must have moved to lower levels of the aquifer during the past thirty-five years. The nitrate stratification may be a function of this age stratification. Water with high nitrate concentrations may not yet have reached lower parts of the aquifer.

Recharge to Alluvial Aquifers from Other Sources

Another cause for the observed vertical changes in nitrate concentration may be recharge to the aquifer from a source lower in nitrate. Water levels indicate recharge from the glacial materials into the alluvium. The shallow parts of the alluvial aquifer are characterized by dominant lateral flowpaths and high infiltration rates. Flow from the glacial materials, may not be a significant percentage of total flow in the upper part of the aquifer, but in deeper parts of the aquifer, recharge through the glacial materials could be important. Slug tests (Freeze and Cherry, 1979) on the three wells installed in the surrounding uplands and below the alluvium established higher than expected conductivities ranging from 1.4 x 10^{-4} cm/sec to 3.9 x 10^{-5} cm/sec. The reasons for these higher values were not investigated, but could be caused by fractures or sand lenses in the fine-grained glacial materials.

Major ion concentrations were analyzed to determine whether groundwater from the glacial materials is entering the alluvium (Table 4). All of the chemical constituents measured are within range of those previously found in the alluvium (Thompson, 1984), and therefore, none are particularly useful as a chemical tracer. The wells in the glacial materials, however, do show low concentrations of nitrate. Discharge of groundwater from the glacial materials could explain the lower concentrations of nitrate in the deeper part of the aquifer. Without being able to positively identify water coming from the glacial materials, however, no direct conclusions can be made.

Denitrification in Alluvial Aquifers

Denitrification appears to be an important factor in reducing nitrate delivered to the alluvial groundwater system, providing a suitable explanation for the distribution of nitrate in the shallowest wells. Nitrate concentrations are consistently below 5 mg/l in many of the shallowest wells. At one of these sites (WD9), pesticides have been detected even in the absence of nitrate. If the pesticides reached the aquifer via infiltration, it might be expected that nitrate would also be present. Other studies have also noted sharp declines in nitrate concentrations just below the water table (Hendry et al., 1983; Trudell et al., 1986). This decline in nitrate has been attributed to denitrification occurring in the aquifer.

Denitrification is the transformation of nitrate to nitrogen gas by denitrifying, facultative bacteria. These bacteria use nitrate as an oxygen source when anaerobic conditions exist. A source of organic carbon is necessary as a food source. The greatest potential for denitrification occurs in

Table 4. Water analyses from wells installed in glacial materials. All analyses in milligrams per liter (mg/l) except for conductance which is in micromhos per centimeter (μMHOS/cm).

Site	ORT-2	ORT-3	ORT-1	ORT-4[1]
Screened Interval (ft.)	55-60	36-41	54.5-60	36-41
Date	8/3/87	8/4/87	8/3/87	8/4/87
Specific Conductance	1500	550	1100	750
Total Alkalinity	429	273	541	288
Total Hardness	735	287	678	375
Dissolved Solids	992	334	672	450
Silica	22	30	22	23
Calcium	190	72	180	91
Magnesium	62	26	55	36
Sodium	75	37	47	3.8
Potassium	5.4	9.0	4.9	3.9
Bicarbonate	523	333	660	351
Chloride	35	12	5.0	9.0
Flouride	0.4	0.45	0.35	0.35
$No_2 + NO_3$ as Nitrate	0.1	<0.1	0.8	<0.1
Sulfate	380	54	220	91
Manganese	1.3	0.33	0.70	0.26
Soluble Iron	0.34	0.06	0.33	0.18
Diss. Organic Carbon	22	2.9	5.3	1.6

[1] well completed in sand lens within glacial materials

oxygen-deficient, water-saturated soils (Rolston, 1981).

Several tests were done to establish if conditions conducive to denitrification exist in the aquifer. Cultures were done to establish the presence of denitrifying organisms. Soil cores were examined for further information on reducing conditions. Since carbon supplies the necessary substrate for growth of denitrifying organisms, carbon concentrations in both soil and water were measured. Dissolved-oxygen measurements were done to establish if anaerobic conditions exist within the zone of available carbon.

Denitrifying bacteria were found in all water samples from all depths of the aquifer and in all soil types tested. Denitrifying bacteria would thus seem to be ubiquitous in their distribution in this alluvial setting. However, some of these settings show high concentrations of nitrate while others do not. There are obviously other factors which may be more important in determining whether denitrification will occur.

Soil cores from sites where denitrification is suspected exhibit organic matter dispersed through the matrix possibly providing a source of carbon, and gleyed soil colors indicative of reducing conditions (Buol et al., 1973).

The denitrification process is dependent on an available supply of biodegradable organic carbon. Concentrations of dissolved carbon in alluvial wells ranged from 0.8 to 3.8 mg/l (Table 5). If all this carbon were used by the bacteria, 3.3 to 15.6 mg of nitrate could be denitrified per liter. Measurements of total soil organic carbon (Table 5) range from 1,300 to 46,600 mg/kg. Percentages of total carbon range from 0.86 to 9.75 percent. If 100 percent of this carbon could be used by the bacteria, an additional 8.2 to 258 mg of nitrate could be denitrified for each cubic centimeter of soil. For the process to be sustainable, a renewable source of carbon would have to be available commensurate with the rate of denitrification.

Table 6 shows the mean dissolved oxygen concentration for each of three nitrate classes for all alluvial wells. There is a statistically significant correlation between nitrate concentrations and dissolved oxygen concentrations: low oxygen concentrations are associated with low nitrate concentrations. However, low nitrate or dissolved oxygen concentrations in the deeper wells may be unrelated to denitrification, possibly providing spurious correlations between the two. To account for any possible effects caused by vertical stratification, only shallow wells less than ten feet in

Table 5. Organic carbon concentrations in groundwater and soil.

GROUNDWATER - Dissolved organic carbon

LOCATION	DATE	CONCENTRATION (mg/l)
WD30U	8/05/87	1.1
WD6U	5/20/87	2.6
	8/05/87	0.83
WD6M	5/20/86	1.4
WD6L	5/20/87	1.4
	8/05/87	1.2
WD9U	5/19/86	2.6
	8/04/87	3.8
WD9MU	5/19/87	1.8
WD9ML	5/19/87	1.7
WD11U	8/05/87	1.8

SOILS - Total organic carbon (TOC)

SOIL SERIES	DEPTH INCREMENT (inches)	DATE	CONCENTRATION (mg/kg)	TOC% OF SAMPLE PASSING 100-MESH SIEVE
Linder loam	1-9	3/13/87	41,000	9.75
	9-16.5		18,000	4.6
	16.5-21		3,600	1.37
	21-28		1,300	0.86
Estherville sandy loam	1-9	3/13/87	19,000	5.73
	9-15		8,600	3.24
Estherville loam	0-12	7/23/87	23,700	3.8
Spillville loam	0-12	7/23/87	19,200	3.8
Cylinder loam	0-12	7/23/87	31,200	5.3
	12-21		7,000	1.5
Wabash silty clay	0-15	7/23/87	28,500	7.6
Biscay clay loam	1-9	7/23/87	46,600	8.0
	9-32		15,700	5.6

depth were examined. Again, low oxygen concentrations are associated with low nitrate concentrations. Using oxygen concentrations as an indicator of reducing conditions, it would seem that nitrate concentrations are low in a reducing environment even at very shallow depths.

The presence or absence of nitrate also appears to relate to the position of the water table. There is a statistically significant correlation between nitrate concentration and water level in the shallowest wells (Table 7). When water levels are less than five feet below ground surface, nitrate concentrations are low. High water tables increase soil moisture and reduce dissolved oxygen levels by

Table 6. Relationship between dissolved oxygen and nitrate concentration.

NO_3 (mg/l)	MEAN D.O. (mg/l)	NO. OF SAMPLES
	For All Depths	
<5	0.63	204
5-45	2.4	53
>45	7.1	15
	Wells Less Than Ten Feet Deep	
<5	1.44	38
5-45	4.55	23
>45	7.56	14

Table 7. Relationship between nitrate concentration and water level in the alluvium.

WATER LEVEL BELOW LAND SURFACE (ft.)	NO. OF SAMPLES	MEAN NITRATE (mg/l)
<5	105	9.33
>5	62	30.85

decreasing oxygen diffusion (Gambrell et al., 1975). When these anoxic conditions occur in the presence of a carbon supply, as is the case with a high water table in the soil zone, denitrification can occur.

Conditions appropriate for the occurrence of denitrification are prevalent along the Des Moines River alluvial aquifer from south of Emmetsburg to the southern border of Palo Alto County. This area is characterized by a broad, flat valley with a water table generally less than five feet below ground surface. Nitrate levels are consistently below 5 mg/l NO_3 (<1 mg/l NO_3-N), with few exceptions. Some shallow private wells in this area do show elevated concentrations, >5 mg/l NO_3 (>1 mg/l NO_3-N), of nitrate. Some of these wells sit on higher ground where the water table is lower and where denitrification would not be expected to occur. Another possible explanation for the increased nitrate concentrations in these private wells is the effect of pumping on groundwater flow. Even at low rates, pumping may induce downward flow to the well. Nitrate in the water may not have adequate contact time in the zone of denitrification for any transformations to occur.

Higher nitrate concentrations may be expected both south of this area to Bradgate in Humboldt County, and north of Emmetsburg. In these areas, low terraces cover much of the valley bottom. The water table is deeper and reducing conditions are not achieved until lower in the aquifer out of the zone of available carbon. Denitrification apparently does not occur; rather, nitrate infiltrates the aquifer where flow-dominated processes then control its distribution. Since vertical flow paths are not evident, the nitrate-enriched water follows shallow lateral flow paths, eventually recharging the Des Moines River.

Table 8. Tentative standards for pesticides in drinking water (U.S. Environmental Protection Agency, 1987a, b, 1989). All analyses in parts per billion (ppb).

	HEALTH ADVISORIES (ppb)	RISK ASSESSMENT CONCENTRATION (ppb)
alachlor	0.0	0.15 - 1.5
atrazine	3.0	
cyanazine	9.0	
metolachlor	10.0	

PESTICIDE DISTRIBUTION

There is increasing concern about pesticides in drinking water because of the possible health effects. The U.S. Environmental Protection Agency is still reviewing many of the commonly found compounds. Table 8 lists the health advisories and risk-assessment concentrations which have been proposed. Risk-assessment concentrations correspond to a one-in-a-million risk for carcinogenic (cancer-causing) chemicals. Health advisories are proposed values, still under review. They are guidelines and are not legally enforceable.

Pesticides were sampled at four well sites and one river-water site (Table 9). In addition two analyses were available from these sites from a previous monitoring. Atrazine was detected in groundwater at two sites (3 wells). Alachlor (Lasso) was the only other pesticide detected and was found in the upper and middle wells at one site (WD6). The presence of alachlor in the middle well at site WD6 is unusual. A downward movement of nitrate had been observed at these wells during the previous sampling period, two weeks prior. It may have been related to increased precipitation and leaching since there were several moderate rainstorms preceding the sampling. In general, pesticide concentrations detected in the study area have been below the proposed standards, but alachlor (Lasso) concentrations in two of the monitoring wells were within the range of the proposed standards

River sampling at Bridge 3 (Table 9), detected four pesticides: atrazine, cyanazine (Bladex), metolachlor (Dual), and alachlor (Lasso). Higher concentrations and detection of all four pesticides in May might be related to application time. This is similar to the pattern of detection in other western Iowa rivers (Thompson, 1986, 1987; Kelley, 1988; Kelley and Wnuk, 1986).

DISCUSSION AND SUMMARY

The study has yielded several insights into the occurrence and distribution of agricultural chemicals in alluvial aquifers. Nitrate distribution within the Des Moines River alluvial aquifer is not uniform. Concentrations vary from well to well, in addition to varying through time. Overall, the nitrate concentrations are low and increase in response to precipitation and decrease as infiltration decreases. Changes in nitrate distribution are caused by both flow-related processes and denitrification.

Nitrate concentration usually decreases with depth. This decrease may be related to the flow regime. Vertical gradients are small to non-existent, and contaminants reaching the water table will tend to move horizontally in the shallow part of the aquifer, eventually discharging to the Des Moines River. Based on the tritium data, groundwater recharge to the aquifer originated as precipitation in the last 35 years. This implies that either slow recharge is occurring or that water from a source low in nitrate recharges deeper parts of the aquifer.

Part of the observed nitrate distribution may also be attributable to denitrification. Denitrification occurs in areas where a high water table persists, allowing anaerobic conditions to exist in the zone of enriched carbon. However, it is unknown whether the system can continue generating the requisite conditions for removal of nitrate from the groundwater.

Two pesticides were detected in alluvial groundwater; four compounds were found in river water. Concentrations were similar in both river water and groundwater, except for alachlor which occurred at a higher concentration in groundwater. Alachlor concentrations in groundwater were within the range of the proposed risk-assessment concentration.

Table 9. Pesticide monitoring results in micrograms per liter (µg/l). Positive detections are underlined.

LOCATION	DATE	atrazine	cyanazine (Bladex)	metolachlor (Dual)	alachlor (Lasso)	metribuzin (Sencor)	butylate (Sutan)	trifluralin (Treflan)	fonofos (Dyfonate)	carbofuran (Furadan)
WD-6U	10/30/84	0.11	ND	ND	ND	ND	ND	ND	ND	ND
	5/20/86	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
	6/17/86	<0.2	<0.2	<0.5	1.1	<0.2	<0.2	<0.2	<0.2	<0.2
	7/22/86	0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
	8/20/86	0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
WD-6M	5/21/86	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
	6/17/86	<0.2	<0.2	<0.5	0.99	<0.2	<0.2	<0.2	<0.2	<0.2
	7/22/86	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
WD-9U	5/19/86	0.18	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
	6/17/86	0.36	<0.2	<0.5	<0.5	<0.2	<0.2	<0.2	<0.2	<0.2
	7/21/86	0.25	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
	8/20/86	0.33	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
WD-9MU	10/24/84	0.14	ND	ND	ND	ND	ND	ND	ND	ND
	5/19/86	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
	6/17/86	<0.2	<0.2	<0.5	<0.5	<0.2	<0.2	<0.2	<0.2	<0.2
	7/21/86	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
WD-9ML										
	5/19/86	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
	6/17/86	<0.2	<0.2	<0.5	<0.5	<0.2	<0.2	<0.2	<0.2	<0.2
Bridge-3	5/19/86	0.27	0.15	0.67	0.25	<0.1	<0.1	<0.1	<0.1	<0.1
	6/17/86	0.2	<0.2	0.56	<0.5	<0.2	<0.2	<0.2	<0.2	<0.2
	7/21/86	0.28	0.15	0.26	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
	8/20/86	0.19	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
WD-14U	7/21/86	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
WD-14M	7/21/86	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
WD-16U	8/20/86	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
WD-16L	8/20/86	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1

ND = non-detected
< = detection limit

Alluvial aquifers are becoming increasingly important as water sources. Understanding the mechanisms controlling the distribution of agricultural chemicals in alluvial aquifers will allow better management of these important resources. The possibility of future water-quality degradation cannot be ruled out. Continued monitoring of these systems is essential to ascertain long-term trends.

ACKNOWLEDGEMENTS

This study was funded with assistance from the Environmental Protection Division of the Iowa Department of Natural Resources.

Darwin Evans and Mike Tietjens installed the wells for the project and collected some water samples. Additional water-quality sampling was done by Roger Bruner, Donivan Gordon, Jean Prior, and Paul VanDorpe. Michael Bounk logged the well samples. Bob Pyle and Michael Farmer provided assistance with the sampling equipment.

The University of Iowa Hygienic Laboratory provided excellent support. They performed all the water quality analytical work and provided answers to many questions which arose during the study. The special efforts of Nancy Hall, Jack Kennedy, John Kempf, and Roger Splinter are appreciated.

Data entry was done by Steve Gates, Lynette Seigley, and Nancy Hancock. Graphics were prepared by Kay Irelan and Pat Lohmann.

Roger Bruner, Donivan Gordon, and Robert Libra have provided ideas and valuable discussion throughout the course of this research.

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APPENDIX I.

PROCEDURES

WELL INSTALLATION

A total of nineteen new alluvial wells were installed at eight locations with a mud-rotary drill rig and developed by pumping (Driscoll, 1986). In order to assess vertical variability in the aquifer, two to four nested wells were installed at each location dependent on aquifer thickness at the site (Fig. AI-1). Generally, wells were set in the aquifer near the top of the water table, near the middle, and one at the bottom. Wells were constructed of two-inch, schedule 40 PVC pipe. Slots were cut in the lower two to four feet of the pipe bottom. Integrity of each well was checked after installation with regard to preservation of head conditions and prevention of water movement between wells.

Four wells, designated as ORT1-ORT4 (Fig. AI-2) were installed in the glacial materials underlying or adjacent to the alluvium. ORT-1 and ORT-3 were completed in fine-grained glacial drift in the uplands. ORT-4 was an upland well finished in a sand layer within the fine-grained glacial drift. ORT-2 was finished in fine-grained glacial drift underlying the alluvium. Two-inch PVC pipe was used for the well casings.

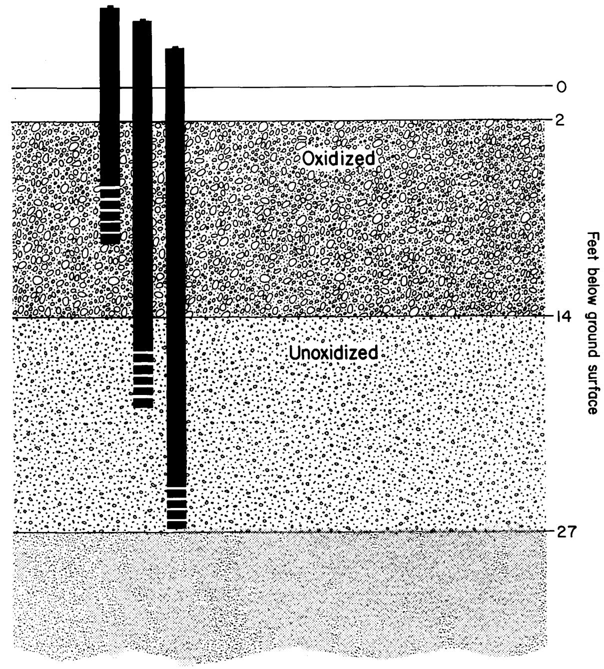

Figure AI-1. Schematic diagram of nested monitoring wells.

WATER-QUALITY SAMPLING

Water-quality sampling was done at all 23 alluvial wells (8 sites) and three river-water sites. Figure AI-2 shows the locations of the monitoring sites. Complete results for each monitoring site can be found in Appendix II.

Three casing volumes of water were removed with a submersible pump before each sampling which has proven more than adequate to stabilize temperature and conductivity values and to assure a representative sample from this highly transmissive aquifer. Samples were collected with a PVC bailer.

Field Analyses

Parameters measured in the field included temperature, conductivity, pH, and dissolved oxygen. Temperature was measured with a standard laboratory thermometer. Conductivity was measured in micromhos/cm using a Fisher Model 152 conductivity meter automatically corrected to 25° C. A Sargent-Welch pH meter, Model 2050, with automatic temperature compensation, coupled with a glass-combination electrode, was used to determine pH. Dissolved-oxygen measurements were made using a YSI Model 57B dissolved-oxygen meter and a self-stirring BOD bottle probe. Additional dissolved-oxygen measurements were done by titration using the azide modification of the Winkler method (APHA-AWWA-WPCF, 1976). Tests for the presence of denitrifying bacteria were done using a technique which relies on the appearance of a gas in a culture tube (Wehmeyer, 1988). Cultures were prepared with the assistance of the UHL staff and were inoculated in the field.

Laboratory Analyses

All laboratory analyses of water samples, except for tritium, were performed by the University of Iowa Hygienic Laboratory (UHL). Table AI-1 indicates the analytical methods and quality-control/quality-assurance procedures used by UHL for pesticides and nitrate analyses. Total

Table AI-1. Analytical methods and quality-assurance/quality-control procedures (from UHL, written communication).

	NITRATE - NITRATE (as NO3)	COMMON AG HERBICIDE
Sample Matrix	Water	Water
Analytical Method	EPA Method 353.2	EPA Method 619
Sample Preservation	Cool, 4°C	Cool, 4°C
Maximum Holding Time	48 hours	7 days, 40 days after extraction
Estimated Detection Limit	1 mg/l	0.1 µg/l
Practical Quantitation Limit	1 mg/l	0.1 µg/l
Estimated Accuacy[1]	94% (9%)	114%
Accuracy Protocol	sample spike	spike[2]
Estimated Precision	0.9 (0.9) mg/l[3]	46%[4]
Precision Protocol	replicate	spike[2]

1 mean percent recovery (1 standard deviation)
2 mean difference (1 standard deviation)
3 percent recovery (standard deviation)
4 in-house (UHL) spike of natural groundwater

coliform bacteria were determined using the most probable number (MPN) method (U.S. EPA, 1978). Fecal coliforms were also analyzed by the MPN method.

Total organic carbon was analyzed using a Dohrman TOC analyzer. Samples were acidized to remove inorganic carbon and purged with nitrogen gas. Results are reported in milligrams per liter (mg/l). All samples were chilled until delivery to UHL.

Samples for tritium analysis were collected in tightly capped 500-milliliter bottles to prevent evaporation. The samples were analyzed using enriched scintillation counting which has an accuracy of ±2 Tritium Units (T.U.) by the Environmental Isotope Laboratory, Department of Earth Sciences, University of Waterloo, Waterloo, Ontario, Canada.

Tritium (^3H) is a radioactive isotope of hydrogen which is produced by the interaction of nitrogen gas and cosmic rays (Freeze and Cherry, 1979). It has a half-life of 12.4 years. Concentrations of tritium in water are reported in Tritium Units (T.U.), where 1 T.U. is equal to 1 tritium atom in 1018 hydrogen atoms. Natural tritium levels are low, 10-15 T.U. (Payne, 1972), but atomic testing from the mid-1950s through the early 1960s introduced large amounts of tritium into the atmosphere. Tritium data collected from shallow groundwater sources in Iowa--shallow wells and tile lines--indicate the current tritium content of precipitation is approximately 15 to 30 tritium units, higher than natural background values (Thompson, 1986; IDNR-GSB unpublished data).

The short half-life and the low natural concentrations of tritium in pre-1953 precipitation can be used to estimate groundwater age. Waters introduced into the aquifer prior to the 1950s would currently have very low (<5 T.U.) tritium concentrations. In contrast, recharge water from the mid-1960s would currently have tritium levels of 250 to 500 T.U. In general, a relationship between tritium concentration and time can be used to estimate groundwater age (Payne, 1972). However, tritium displays seasonal variation and mixing of different age water can occur and change the observed tritium concentrations. Nevertheless, useful estimates can still be made.

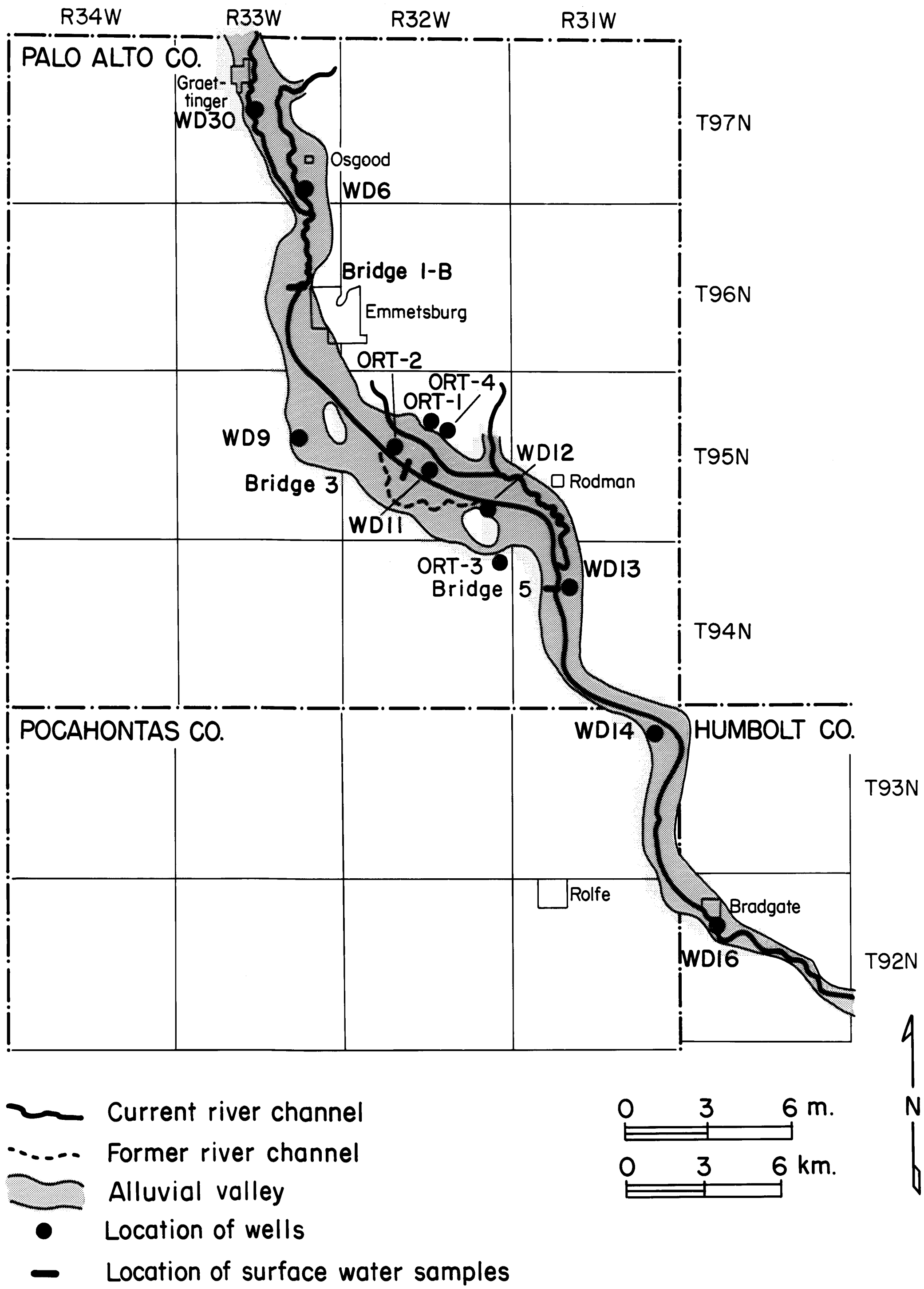

Figure AI-2. Location of monitoring sites.

APPENDIX II

MONITORING NETWORK DATA

ABBREVIATIONS USED IN THIS APPENDIX

mp, MP	measuring point (top of casing)
NGVD	national geodetic vertical datum (a geologic datum derived from a general adjustmant of the first-order level nets of both the United States and Canada, formerly called "mean sea level")
gs	ground surface
Ht.	height
mg/l	milligrams per liter
Cond	conductivity
DO	dissolved oxygen
NO_3	nitrate

Water levels are measured in feet
Water level elevation is measured in feet above mean sea level (NGVD)

Well locations are shown on Figure 1

SITE DATA

Well WD-30 Date Installed 8/21/85 NE, NW, NE, sec. 22, T97N, R33W

Screened Interval 9-12 ft. MP Elevation 1231.7 NGVD Casing Ht. 2.2 ft.

Date	Water Level (mp)	Water Level (gs)	Water Level Elevation	pH	Temp (°C)	Cond (umhos)	DO (mg/l)	NO_3 (mg/l)	Bacteria
8/27/85								19	0
9/19/85	12.01	9.81	1219.7		18.1	840		8	0
10/08/85	11.70	9.50	1220.0		12.8	770		17	16+
10/24/85	11.60	9.40	1220.1		12.5	540	1.3	<5	16+
11/07/85	11.66	9.46	1220.0		12.5	780	1.6	12/10	16+/16
11/21/85	11.77	9.57	1219.9		10.0	820	1.1	13	9.2
12/23/85	11.80	9.60	1219.9					20	
1/22/86	12.20	10.00	1219.5					<5	9.2
2/19/86	12.65	10.45	1219.0	7.3	5.0	660		16/16	5.1/16
3/19/86	11.64	9.44	1220.1	7.7				<5/<5	
4/10/86	10.59	8.39	1221.1	7.7	7.0	795		7	9.2
4/22/86	10.38	8.18	1221.3		5.0	760		<5	9.2
5/07/86	10.02	7.82	1221.7		9.0	640		<5	9.2
5/19/86	9.65	7.45	1221.0	7.5	9.0	650		5	9.2
6/04/86	9.96	7.76	1221.7	7.4	10.0	770	0.7	11	16+
6/17/86	10.35	8.15	1221.3	7.4	10.5	750	0.3	19	16
6/30/86	10.61	8.41	1221.1	7.3	11.0	640		17/18	5.1/2.2
7/21/86	11.59	9.39	1220.1	6.9	14.0	670	0.4	13/13	16+/16+
8/04/86	11.58	9.38	1220.1	7.2	14.0	720	0.7	20	0
8/19/86	11.97	9.77	1219.7		17.0	680		16	9.2
9/08/86	11.81	9.61	1219.9	7.2	14.0	705	0.8		
9/21/86	12.01	9.81	1219.7	7.4	14.0	730		17/18	16+/16+
10/22/86	10.90	8.70	1220.8	7.4	13.0	700	1.2	7	

WELL WD-30L Date Installed 8/21/85 NE, NW, NE, sec. 22, T97N, R33W

Screened Interval 13-15 ft. MP Elevation 1231.5 NGVD Casing Ht. 2.0 ft.

Date	Water Level (mp)	Water Level (gs)	Water Level Elevation	pH	Temp (°C)	Cond (µmhos)	DO (mg/l)	NO_3 (mg/l)	Bacteria
8/27/85								17	0
9/19/85	11.79	9.79	1219.7		17.6	890		5	0
10/08/85	11.50	9.50	1220.0		11.7	800		<5	0
10/24/85	11.40	9.40	1220.1		12.0	750	0.5	<5	9.2
11/07/85	11.46	9.46	1220.0		12.0	660	0.4	<5	16+
11/21/85	11.58	9.58	1219.9		10.0	780	0.1	<5	16
12/23/85	11.70	9.70	1219.8					<5	
1/22/86	12.10	10.10	1219.4					<5	16
2/19/86	12.45	10.45	1219.0	7.6	7.0	740	0.2	6	5.1
3/19/86	11.46	9.46	1220.0					<5	
4/10/86	10.36	8.36	1221.1	7.8	7.5	620		<5	0
4/22/86	10.19	8.19	1221.3		5.0	760		<5	2.2
5/07/86	9.82	7.82	1221.7		9.0	680		<5	2.2
5/19/86	9.43	7.43	1221.1	7.5	9.5	640	0.0	<5	16+
6/04/86	9.77	7.77	1221.7	7.5	11.0	710	0.2	<5	16+
6/17/86	10.13	8.13	1221.4	7.4	10.0	740	0.3	<5/<5	16+/16+
6/30/86	10.89	8.89	1220.6	7.4	11.0	700		5	2.2
7/21/86	11.38	9.38	1220.1	6.9	13.0	460	0.4	<5	16+
8/04/86	11.34	9.34	1220.2	7.1	13.0	720	0.6	<5	16+
8/19/86	11.78	9.78	1219.7		15.0	590	0.5	<5	16+
9/08/86	11.61	9.61	1219.9	7.1	13.5	690	0.4	<5	
9/21/86	11.79	9.79	1219.7	7.3	14.0	710		<5	16+
10/22/86	10.69	8.69	1220.8	7.3	13.0	730	2.0		

WELL WD-6U Date Installed 8/21/85 NW, SW, NW, sec. 36, T97N, R33W

Screened Interval 6-10 ft. MP Elevation 1224.9 NGVD Casing Ht. 2.3 ft.

Date	Water Level (mp)	Water Level (gs)	Water Level Elevation	pH	Temp (°C)	Cond (µmhos)	DO (mg/l)	NO_3 (mg/l)	Bacteria
8/27/85								60	0
9/19/85	10.12	7.82	1214.8		18.6	460		63	16+
10/08/85	8.53	6.23	1216.4		13.3	610		75	16+
10/24/85	8.49	6.19	1216.4		12.0	640	7.2	<5	16+
11/07/85	8.75	6.45	1216.1		12.5	610	9.2	74	16+
11/21/85	8.50	6.20	1216.4		8.0	700	7.1	85/87	16/16
12/23/85	9.20	6.90	1215.7					62	
1/22/86	9.60	7.30	1215.3					7	16+
2/19/86	10.20	7.90	1214.7	7.7	6.0	600	5.3	100	16

3/19/86	8.06	5.76	1216.8					45	
4/10/86	7.18	4.88	1217.7	7.1	7.0	410		75	9.2
4/22/86	7.30	5.00	1217.6		8.0	570	7.8	90	5.1
5/07/86	7.29	4.99	1217.6		9.0	580		<5	16+
5/19/86	7.01	4.71	1217.9	7.7	9.5	590	8.4	99	9.2
6/04/86	7.40	5.10	1217.5	7.5	11.0	580	8.1	101	16+
6/17/86	7.75	5.45	1217.1	7.7	10.5	620	8.4	100	16
6/30/86	7.80	5.50	1217.1	7.6	12.0	620		98	16
7/21/86	8.58	6.28	1216.3	7.2	13.0	630	8.1	97/97	16+/16+
8/04/86	8.18	5.88	1216.7	7.4	15.0	660	8.5	88	16
8/19/86	8.42	6.12	1216.5		17.0	600	8.0	105	9.2
9/08/86	8.53	6.23	1216.4	7.3	15.0	590	8.6	127/121	
9/21/86	8.24	5.94	1216.7	7.6	15.0	660		101	16+
10/22/86	7.46	5.16	1217.4	7.5	12.0	680	8.1	110/111	

WD-6M Date Installed 8/21/85 NW, SW , NW, sec. 36, T97N, R33W

Screened Interval 16-20 ft. MP Elevation 1224.7 NGVD Casing Ht. 2.2 ft.

Date	Water Level (mp)	Water Level (gs)	Water Level Elevation	pH	Temp (°C)	Cond (μmhos)	DO (mg/l)	NO_3 (mg/l)	Bacteria
8/27/85								<5	16+
9/19/85	9.00	6.80	1215.7		17.9	600		<5	16
10/08/85	8.42	6.22	1216.3		12.8	590		<5	0
10/24/85	8.38	6.18	1216.3		11.0	600	0.4	<5	0
11/07/85	8.58	6.38	1216.1		12.0	590	0.6	<5	9.2
11/21/85	8.40	6.20	1216.3		8.0	660	0.1	<5/<5	16/16+
12/23/85	9.10	6.90	1215.6					<5	
1/22/86	9.30	7.10	1215.4					<5	9.2
2/19/86	10.10	7.90	1214.6	7.5	9.0	620	0.3	<5	0
3/19/86	7.93	5.73	1216.8					<5	
4/10/86	7.06	4.86	1217.6	7.1	9.0	430		<5	16+
4/22/86	7.18	4.98	1217.5		9.5	590	0.0	<5	16+
5/07/86	7.18	4.98	1217.5		10.0	590		<5	16+
5/19/86	6.89	4.69	1217.8	7.5	10.0	540	0.0	<5/<5	9.2/9.2
6/04/86	7.30	5.10	1217.4	7.5	10.5	610	0.3	5	16+
6/17/86	7.63	5.43	1217.1	7.3	10.0	590	0.3	<5	16+
6/30/86	7.67	5.47	1217.0	7.5	11.0	575		<5	16+
7/21/86	8.47	6.27	1216.2	7.6	11.0	590	0.3	<5	16+
8/04/86	8.07	5.87	1216.6	7.3	12.0	550	0.4	<5	16+
8/19/86	8.31	6.11	1216.4		14.0	410	0.6	<5	16
9/08/86	8.43	6.23	1216.3	7.4	12.5	580	0.4	<5	
9/21/86	8.12	5.92	1216.6	7.5	13.0	560		<5/<5	16+/16+
10/22/86	7.35	5.15	1217.3	7.4	11.0	590	0.8	<5	

WELL WD-6L **Date Installed 9/1/83** **NW, SW, NW, sec. 36, T97N, R33W**

Screened Interval 24-26.5 ft. **MP Elevation 1224.3 NGVD** **Casing Ht. 1.8 ft.**

Date	Water Level (mp)	Water Level (gs)	Water Level Elevation	pH	Temp (°C)	Cond (μmhos)	DO (mg/l)	NO_3 (mg/l)	Bacteria
7/16/85	9.74	7.94	1214.6						
9/19/85	8.49	6.69	1215.8		18.2	465		<5	5.1
10/08/85	7.92	6.12	1216.4		11.4	160		<5	0
10/24/85	7.87	6.07	1216.4		10.0	605	0.4	11	0
11/07/85	8.19	6.39	1216.1		11.0	580	0.6	<5	2.2
11/21/85	7.91	6.11	1216.4		7.0	660	0.0	<5	0
12/23/85	8.60	6.80	1215.7					<5	
1/22/86	9.00	7.20	1215.3					<5	0
2/19/86	9.60	7.80	1214.7	7.5	9.0	700		<5	0
3/19/86	7.38	5.58	1216.9					<5	
4/10/86	6.53	4.73	1217.8	7.0	9.5	410		<5	0
4/22/86	6.67	4.87	1217.6		10.0	610	0.0	<5	0
5/07/86	6.66	4.86	1217.6		11.0	530		<5	2.2
5/19/86	6.37	4.57	1217.9	7.4	11.0	590	0.0	<5	2.2
6/04/86	6.76	4.96	1217.5	7.5	11.0	580	0.4	<5	16+
6/17/86	6.11	4.31	1218.2	7.5	10.5	590	0.3	<5/<5	16+/16+
6/30/86	7.15	5.35	1217.1	7.4	11.0	580		<5	16+
7/21/86	8.91	7.11	1215.4	7.5	11.5	580	0.3	<5	16+
8/04/86	7.56	5.76	1216.7	7.3	12.0	700	0.4	<5	9.2
8/19/86	7.79	5.99	1216.5		14.0	400	0.4	<5	16
9/08/86	7.91	6.11	1216.4	7.4	12.0	580	0.4	<5	
9/21/86	7.55	5.75	1216.7	7.6	12.0	560		<5	16+

SURFACE BRIDGE-1B **MP ELEVATION 1196.0 NGVD** **Sec 14/24, T96N, R33W**

Date	Water Level (mp)	Water Level Elevation	PH	Temp (°C)	Cond (μmhos)	NO_3 (mg/l)
9/19/85	2.20	1198.2		23.2	875	10
10/08/85	3.30	1199.3			920	27
10/24/85	3.00	1199.0		12.0	790	23
11/06/85	2.20	1198.2		7.0	960	22
11/21/85	3.00	1196.0		1.0	820	39
2/19/86			7.8	3.0	1200	22
4/10/86			7.2	11.0	530	17
4/22/86	7.30	1203.3		5.0	840	24
5/07/86	8.30	1204.3		19.0	720	20
5/19/86	7.40	1203.4	8.4	17.0	980	23
6/04/86	5.00	1201.0	8.1	22.0	820	23
6/17/86	4.09	1200.1	8.2	21.0	880	23
6/30/86	6.55	1202.6	8.1	20.0	590	7

7/21/86	4.13	1200.1	7.7	25.0	770	13
8/04/86	2.77	1198.8	8.5	24.0	760	<5
8/19/86	1.75	1197.8		23.0	690	<5
9/08/86	1.52	1197.5	8.5	20.0	785	<5
9/21/86	4.81	1191.1	8.2	19.0	680	17
10/22/86	5.00	1201.0	8.2	12.0	810	19

WELL WD-9U Date Installed 8/14/85 SE, SW, SE, sec. 14, T95N, R33W

Screened Interval 3-8 ft. MP Elevation 1191.9 NGVD Casing Ht. 2.2 ft.

Date	Water Level (mp)	Water Level (gs)	Water Level Elevation	pH	Temp (°C)	Cond (μmhos)	DO (mg/l)	NO_3 (mg/l)	Bacteria
8/27/85								<5	16+
9/19/85	5.23	3.03	1186.7		19.8	690		<5	16+
10/08/85	4.60	2.40	1187.3		13.3	540		<5	9.2
10/24/85	4.66	2.46	1187.2		13.5	450	0.4	<5	0
11/07/85	4.85	2.65	1187.0		12.0	640	0.6	<5	9.2
11/21/85	4.36	2.16	1187.5		7.0	760	0.1	<5/<5	0/9.2
2/19/86	5.20	3.00	1186.7	7.4	6.0	560	0.2	<5	0
3/19/86	3.08	0.88	1188.8					<5	
4/10/86	3.06	0.86	1188.8	7.1	8.0	670		<5	16+
4/22/86	3.50	1.30	1188.4		8.5	620	0.0	<5	16
5/07/86	3.87	1.67	1188.0		10.1	640		<5	2.2
5/19/86	3.18	0.98	1188.7	7.4	11.0	411	0.0	<5	5.1
6/04/86	3.90	1.70	1188.0	7.4	12.0	490	0.2	<5	2.2
6/17/86	4.25	2.05	1187.6	7.5	13.0	680	0.2	<5	16+
6/30/86	3.93	1.73	1188.0	7.3	15.0	610		<5/<5	5.1/5.1
7/21/86	4.70	2.50	1187.2	7.3	15.0	620	0.2	<5	16+
8/04/86	4.24	2.04	1187.7	7.2	17.0	650	0.5	<5	16+
8/19/86	3.58	1.38	1188.3		17.0	650	0.4	<5	16+
9/08/86	4.14	1.94	1187.8	7.3	16.0	615	0.5	<5/<5	
9/21/86	2.78	0.58	1189.1	7.4	16.0	615	0.9	<5	16+
10/22/86	2.76	0.56	1189.1	7.5	13.0	650	0.8	<5	

WELL WD-9MU Date Installed 8/14/85 SE, SW, SE, sec. 14, T95N, R33W

Screened Interval 15-17 ft. MP Elevation 1191.3 NGVD Casing Ht. 1.6

Date	Water Level (mp)	Water Level (gs)	Water Level Elevation	pH	Temp (°C)	Cond (μmhos)	DO (mg/l)	NO_3 (mg/l)	Bacteria
7/16/85	4.45	2.85	1186.8						
9/19/85	4.33	2.73	1187.0		18.7	480		<5	16+
10/08/85	3.78	2.18	1187.5		11.7	620		<5	9.2
10/24/85	3.85	2.25	1187.4		13.0	460	0.4	<5	0

11/07/85	4.00	2.40	1187.3		12.0	610	0.6	<5	
11/21/85	3.49	1.89	1187.8		7.0	720	0.1	<5	0
2/19/86	4.30	2.70	1187.0	7.5	8.5	700	0.1	<5	0
3/19/86	2.17	0.57	1189.1					<5	
4/10/86	2.22	0.62	1189.1	7.1	9.0	720		<5	2.2
4/22/86	2.64	1.04	1188.7		10.0	630	0.0	<5	0
5/07/86	3.02	1.42	1188.3		10.0	620		<5	9.2
5/19/86	2.30	0.70	1189.0	7.4	9.5	410	0.0	<5/<5	0/9.2
6/04/86	3.04	1.44	1188.3	7.4	10.0	450	0.2	<5	16+
6/17/86	3.40	1.80	1187.9	7.5	10.5	630	0.1	<5	16+
6/30/86	3.08	1.48	1188.2	7.5	11.0	415		<5	9.2
7/21/86	3.85	2.25	1187.4	7.4	11.0	610	0.3	<5	16+
8/04/86	3.40	1.80	1187.9	7.4	12.0	580	0.5	<5/<5	16+/16+
8/19/86	2.75	1.15	1188.5		13.0	580	0.4	<5	16+
9/08/86	3.38	1.78	1187.9	7.3	12.0	640	0.5	<5	
9/21/86	1.94	0.34	1189.4	7.3	13.0	610	1.0	<5	16+
10/22/86	1.82	0.22	1189.5	7.5	12.0	580	0.9	<5	

WELL WD-9ML Date Installed 8/14/85 SE, SW, SE, sec. 14, T95N, R33W

Screned Interval 30-33 ft. MP Elevation 1191.1 NGVD Casing Ht. 1.4 ft.

Date	Water Level (mp)	Water Level (gs)	Water Level Elevation	pH	Temp (°C)	Cond (µmhos)	DO (mg/l)	NO_3 (mg/l)	Bacteria
7/16/85	4.28	2.88	1186.8						
9/19/85	4.24	2.84	1186.9		18.6	490		<5	16+
10/08/85	3.61	2.21	1187.5		10.0	620		<5	9.2
10/24/85	3.66	2.26	1187.4		11.5	460	0.4	<5	9.2
11/07/85	3.84	2.44	1187.3		11.0	625	0.6	<5	
11/21/85	3.33	1.93	1187.8		7.0	720	0.0	<5	0
2/19/86	4.20	2.80	1186.9	7.5	9.0	680		<5/<5	0/0
3/19/86	2.03	0.63	1189.1					<5	
4/10/86	2.06	0.66	1189.0	7.1	10.5	720		<5	2.2
4/22/86	2.49	1.09	1188.6		11.0	620		<5	0
5/07/86	2.88	1.48	1188.2		12.0	620		<5	9.2
5/19/86	2.14	0.74	1189.0	7.5	11.0	415	0.0	<5	9.2
6/04/86	2.90	1.50	1188.2	7.5	11.0	590	0.4	<5	16+
6/17/86	3.25	1.85	1187.8	7.4	11.5	600	0.3	<5	16
6/30/86	2.92	1.52	1188.2	7.5	12.0	570		<5	16+
7/21/86	3.72	2.32	1187.4	7.4	11.0	590	1.5	<5	16+
8/04/86	3.12	1.72	1188.0	7.4	11.5	600	0.4	<5	
8/19/86	2.56	1.16	1188.5		12.0	420	0.6	<5	16+
9/08/86	3.13	1.73	1188.0	7.2	11.0	565	0.6	<5	
9/21/86	1.78	0.38	1189.3	7.5	13.0	550	1.1	<5	16+

WELL WD-9L Date Installed 9/6/83 SE, SW, SE, sec. 14, T95N, R33W

Screened Interval 43-47 ft. Mp Elevation 1191.6 NGVD Casing Ht. 1.9 ft.

Date	Water Level (mp)	Water Level (gs)	Water Level Elevation	pH	Temp (°C)	Cond (μmhos)	DO (mg/l)	NO_3 (mg/l)	Bacteria
7/16/85	4.80	2.90	1186.8						
9/19/85	4.79	2.89	1186.8		18.1	575		<5	16+
10/08/85	4.19	2.29	1187.4		12.2	600		<5	16+
10/24/85	4.23	2.33	1187.4		11.0	575	0.4	83	16+
11/06/85	4.38	2.48	1187.2		10.0	570	0.6	<5	
11/21/85	3.89	1.99	1187.7		8.0	680	0.0	<5	0
2/19/86	4.80	2.90	1186.8	7.1	9.0	620		<5	0
3/19/86	2.59	0.69	1189.0					<5	
4/10/86	2.62	0.72	1189.0	7.0	10.5	550		<5	2.2
4/22/86	3.08	1.18	1188.5		11.0	600		<5	2.2
5/07/86	3.43	1.53	1188.2		12.0	580		<5	5.1
5/19/86	2.73	0.83	1188.9	7.3	11.0	410	0.0	<5	16+
6/04/86	3.47	1.57	1188.1	7.5	12.0	595	0.4	<5	16+
6/17/86	3.81	1.91	1187.8	7.4	12.0	595	0.2	<5	16+
6/30/86	3.47	1.57	1188.1	7.5	12.0	600		<5	16+
7/21/86	4.25	2.35	1187.3	7.4	12.0	580	0.9	<5/<5	16+/16+
8/04/86	3.81	1.91	1187.8	7.5	12.0	565	0.2	<5	
8/19/86	3.18	1.28	1188.4		12.0	460	0.9	<5	16+
9/08/86	3.71	1.81	1187.9	7.4	11.5	505	0.5	<5	
9/21/86	2.34	0.44	1189.3	7.5	13.0	460	2.0	<5	16+

SURFACE BRIDGE-3 MP ELEVATION 1188.8 NGVD C., sec. 21, T95N, R32W

Date	Water Level (mp)	Water Level Elevation	PH	Temp (°C)	Cond (μmhos)	NO_3 (mg/l)
7/16/85	14.56	1174.2				
9/19/85				23.7	845	11
10/08/85	13.80	1175.0				27
10/24/85	13.40	1174.4		14.0	920	23
11/06/85	14.73	1174.1		7.0	905	23
11/21/85	14.71	1174.1		0.0	760	35
4/10/86			7.0	13.5	470	18
4/22/86	8.58	1180.2		11.0	810	25
5/07/86	9.83	1179.0		17.5	770	20
5/19/86	10.20	1178.6	8.4	19.0	710	23
6/04/86	12.28	1176.5	8.3	21.5	860	24
6/17/86	14.45	1174.3	8.2	24.5		23
6/30/86	11.15	1200.0	8.1	20.0	720	40

7/21/86	13.03	1175.8	8.2	27.0	780	13
8/04/86	14.38	1174.4	8.5	23.0	690	6
8/19/86	15.13	1173.3		23.0	720	5/7
9/08/86	15.77	1173.0	8.5	18.0	840	<5
9/21/86	12.66	1176.1	8.1	19.0	700	17
10/22/86	11.90	1176.9	8.3	13.0	770	19/19

WELL WD-11U Date Installed 8/14/85 C, sec. 22, T95N, R32W

Screened Interval 3-8 ft. MP Elevation 1177.9 NGVD Casing Ht. 2.2 ft.

Date	Water Level (mp)	Water Level (gs)	Water Level Elevation	pH	Temp (°C)	Cond (µmhos)	DO (mg/l)	NO_3 (mg/l)	Bacteria
8/27/85								<5	16+
9/19/85	6.48	4.28	1171.4		16.9	840		<5	16+
10/08/85	5.87	3.67	1172.0		12.8	745		6	16+
10/24/85	5.75	3.55	1172.1		13.2	805	0.4	7	16+
11/06/85	5.85	3.65	1172.0		10.0	820	1.0	5	16
11/21/85	5.46	3.26	1172.4		7.0	1400	0.6	6	5.1
12/23/85	5.60	3.40	1172.3					<5	
1/22/86	5.70	3.50	1172.2					<5	9.2
2/19/86	6.10	3.90	1171.8	7.5	6.0	780	1.5	12/12	0/0
3/19/86	4.20	2.00	1173.7					<5	
4/10/86	2.16	-0.04	1175.7	7.1	8.0	540		<5/<5	9.2/16
4/22/86	2.44	0.24	1175.5		9.0	790	4.1	<5	16+
5/07/86	3.54	1.34	1174.4		12.0	760		<5	5.1
5/19/86	2.34	0.14	1175.6	7.4	14.0	1080	0.0	<5	16+
6/04/86	3.89	1.69	1174.0	7.3	12.5	790	0.3	<5/<5	16+/16
6/17/86	4.30	1.99	1173.6	7.4	14.0	740	0.2	<5	16+
6/30/86	4.19	1.97	1173.7	7.4	13.0	620		<5	16+
7/21/86	5.00	2.80	1172.9	7.3	15.0	720	1.0	<5	16+
8/04/86	4.83	2.63	1173.1	7.2	15.5	780	0.5	<5	16+
8/19/86	4.84	2.64	1173.1		15.0	740	0.5	<5	16+
9/08/86	5.35	3.15	1172.5	7.2	15.0	820	0.2	<5	
9/21/86	4.92	2.72	1173.0	7.5	17.0	810	0.3	<5/<5	16+/16+
10/22/86	2.54	0.34	1175.4	7.6	13.0	650	1.0		

WELL WD-11M Date Installed 8/14/85 C, sec. 22, T95N, R32W

Screened Interval 15-19 ft. MP Elevation 1177.7 NGVD Casing Ht. 2.0 ft.

Date	Water Level (mp)	Water Level (gs)	Water Level Elevation	pH	Temp (°C)	Cond (µmhos)	DO (mg/l)	NO_3 (mg/l)	Bacteria
8/27/85								<5	16+

9/19/85	6.30	4.30	1171.4		17.1	1050		<5	16+
10/08/85	5.66	3.66	1172.0		11.1	1050		<5	16+
10/24/85	5.51	3.51	1172.2		12.0	1500	0.4	<5	5.1
11/06/85	5.63	5.63	1172.1		10.0	1100	0.7	<5	9.2
11/21/85	5.20	3.20	1172.5		7.0	1600	0.0	<5	2.2
12/23/85	5.40	3.40	1172.3					<5	
1/22/86	5.50	3.50	1172.2					<5	0
2/19/86	5.90	3.90	1171.8	7.2	9.0	1200	0.1	<5	0
3/19/86	3.96	1.96	1173.7					<5	
4/10/86	1.95	-0.05	1175.7	7.0	9.5	870		<5	0
4/22/86	2.22	0.22	1175.5		9.0	1200	0.0	<5	0
5/07/86	3.36	1.36	1174.3		10.0	980		<5	0
5/19/86	2.13	0.13	1175.6	7.4	11.0	1080	0.0	<5	16+
6/04/86	3.63	1.63	1174.1	7.3	11.0	560	0.2	<5	16
6/17/86	4.05	2.05	1173.6	7.5	11.0	700	0.4	<5	16+
6/30/86	4.01	2.01	1173.7	7.4	10.5	460		<5	16+
7/21/86	4.76	2.76	1172.9	7.3	11.5	760	1.7	<5/<5	16+/16+
8/04/86	4.63	2.62	1173.1	7.2	12.0	740	0.6		
8/19/86	4.63	2.63	1173.1		11.5	740	0.4	<5	16+
9/08/86	5.12	3.12	1172.6	7.2	11.0	1050	0.4	<5	
9/21/86	4.67	2.67	1173.0	7.5	14.0	1000	1.0	<5	16+
10/22/86	2.33	0.33	1175.4	7.4	13.0	900	0.6	<5	

WELL WD-11L Date Installed 9/7/83 C, sec. 22, T95N, R32W

Screened Interval 31-34 ft. MP Elevation 1177.4 NGVD Casing Ht. 1.7 ft.

Date	Water Level (mp)	Water Level (gs)	Water Level Elevation	pH	Temp (°C)	Cond (μmhos)	DO (mg/l)	NO_3 (mg/l)	Bacteria
7/16/85	4.40	2.70	1173.0						
9/19/85	6.01	4.31	1171.4		17.6	945		<5	5.1
10/08/85	5.34	3.64	1172.1		10.0	980		<5	0
10/24/85	5.19	3.49	1172.2		11.8	800	0.5	<5	9.2
11/06/85	5.32	3.62	1172.1		8.0	1100	0.7	<5	0
11/21/85	4.91	3.21	1172.5		7.0	1600	0.0	<5	5.1
12/23/85	5.20	3.50	1172.2					<5	
1/22/86	5.20	3.50	1172.2					<5	0
2/19/86	5.60	3.90	1171.8	6.9	10.0	1100		<5	0
3/19/86	3.69	1.99	1173.7					<5	
4/10/86	1.65	-0.05	1175.7	7.0	11.0	920		<5	5.1
4/22/86	1.96	0.26	1175.4		10.0	1200		<5	0
5/07/86	3.07	1.37	1174.3		11.0	1100		<5	0
5/19/86	1.93	0.23	1175.5	7.4	13.0	1100	0.0	<5	16+
6/04/86	3.32	1.62	1174.1	7.2	11.0	1050	0.2	<5	16
6/17/86	3.74	2.04	1173.7	7.3	12.0	970	0.2	<5	16+
6/30/86	3.73	2.03	1173.7	7.2	11.0	800		<5	16+
7/21/86	4.46	2.76	1172.9	7.3	12.0	1000	2.2	<5	16

8/04/86	4.29	2.59	1173.1	7.2	12.0	1050	0.6		
8/19/86	4.36	2.66	1173.0		11.0	980	0.4	<5	16+
9/08/86	4.83	3.13	1172.6	7.4	11.0	780	0.6	<5	
9/21/86	4.40	2.70	1173.0	7.6	12.0	1000	0.9	<5	16

WELL WD-12U Date Installed 8/21/85 SE, SW, SE, sec. 25, T95N, R32W

Screened Interval 5-8 ft. MP Elevation 1170.2 NGVD Casing Ht. 2.9 ft.

Date	Water Level (mp)	Water Level (gs)	Water Level Elevation	pH	Temp (°C)	Cond (µmhos)	DO (mg/l)	NO_3 (mg/l)	Bacteria
7/16/85	6.38	3.48	1163.8						
9/19/86	7.84	4.94	1162.4		18.6	785		<5	16+
10/08/85	7.64	4.74	1162.6		13.3	940		<5	16+
10/24/85	6.92	4.02	1163.3		13.5	810	7.8	<5	16+
11/06/85	6.88	3.98	1163.3		10.5	905	1.0	<5	16+
11/21/85	6.81	3.91	1163.4		9.0	830	0.9	36	16+
12/23/85	6.40	3.50	1163.8					<5	
1/22/86	6.80	3.90	1163.4					25	16+
2/19/86	7.10	4.20	1163.1	7.6	6.0	600	3.1	21	16+
3/19/86	5.51	2.61	1164.7					<5/<5	
4/10/86	1.60	-1.30	1168.6						
4/22/86	2.95	0.05	1167.2		8.5	560	0.0	<5	16+
5/07/86	3.20	0.30	1167.0		10.0	600		<5/<5	16+/16+
5/19/86	2.53	-0.37	1167.7	7.4	11.0	470	0.0	<5/<5	16+/16+
6/04/86	4.04	1.14	1166.2	7.3	11.0	610	0.3	<5/<5	16+/16+
6/17/86	6.77	3.87	1163.4	7.4	14.0	600	1.2	<5/<5	16/16
6/30/86	5.34	2.44	1164.9	7.3	13.0	320		<5	16+
7/21/86	5.73	2.83	1164.5	7.2	14.0	470	1.1	<5	16+
8/04/86	5.65	2.75	1164.5	7.2	15.5	630	0.6		
8/19/86	6.10	3.20	1164.1		17.0	580	1.2	<5	16+
9/08/86	6.43	3.53	1163.8	7.0	15.0	550	0.5	<5	
9/21/86	6.27	3.87	1163.9	7.2	16.0	615		<5	16+
10/22/86	3.56	0.66	1166.6	7.5	14.0	470	1.8	<5	

WELL WD-12M Date Installed 8/14/85 SE, SW, SE, sec. 25, T95N, R32W

Screened Interval 14-16.5 ft. MP Elevation 1170.1 NGVD Casing Ht. 2.8 ft.

Date	Water Level (mp)	Water Level (gs)	Water Level Elevation	pH	Temp (°C)	Cond (µmhos)	DO (mg/l)	NO_3 (mg/l)	Bacteria
8/27/85								<5	0
9/18/85	7.73	4.93	1162.4		18.0	520		<5	9.2
10/07/85	6.20	4.40	1163.9		12.2	750		<5	16+

10/23/85	6.86	4.06	1163.2		13.0	710	0.4	<5	9.2
11/06/85	6.81	4.01	1163.3		11.0	750	0.6	<5	9.2
11/20/85	6.80	4.00	1163.3		9.0	800	0.1	<5	16+
12/23/85	6.30	3.50	1163.8					<5	
1/22/86	6.80	4.00	1163.3					<5	16+
2/19/86	7.20	4.40	1162.9	7.5	9.0	900	0.0	<5	9.2
3/19/86	5.45	2.65	1164.6					<5	
4/10/86		FLOODED							
4/22/86	2.87	0.07	1167.2		9.0	690	0.0	<5	16+
5/07/86	3.12	0.32	1167.0		10.0	620		11	16+
5/19/86	2.48	-0.32	1166.6	7.5	11.0	460	0.0	<5	16
6/04/86	3.95	1.15	1166.1	7.5	10.0	730	0.3	<5	16+
6/17/86	6.88	4.08	1163.2	7.6	11.0	620	0.2	<5	16+
6/30/86	5.24	2.44	1164.8	7.6	10.0	420		<5	16+
7/21/86	5.61	2.81	1164.5	7.5	10.5	610	1.1	<5	16
8/04/86	5.57	2.77	1164.5	7.4	11.0	640	0.8		
8/19/86	5.99	3.19	1164.1		12.0	540	3.1	<5/<5	16+/16+
9/08/86	6.33	3.53	1163.8	7.4	11.5	580	0.2	<5	
9/21/86	6.20	3.40	1163.9	7.6	16.0	660		<5	16+
10/22/86	3.46	0.66	1166.6	7.6	14.0	600	0.5	<5	

WELL WD-12L Date Installed 9/8/83 SE, SW, SE, sec. 25, T95N, R32W

Screened Interval 28-32 ft. MP Elevation 1168.6 NGVD Casing Ht. 1.3 ft.

Date	Water Level (mp)	Water Level (gs)	Water Level Elevation	pH	Temp (°C)	Cond (µmhos)	DO (mg/l)	NO_3 (mg/l)	Bacteria
7/16/85	6.15	4.85	1162.4						
9/18/85	6.20	4.90	1162.4		18.7	810		<5	9.2
10/07/85	5.78	4.48	1162.8		10.6	1410		<5	2.2
10/23/85	5.28	3.98	1163.3		12.0	1400	0.5	<5	2.2
11/06/85	5.26	3.96	1163.3		10.0	1200	0.5	<5	5.1
11/20/85	5.23	3.93	1163.4		7.0	1600	0.1	<5	9.2
12/23/85	4.80	3.50	1163.8					<5	
1/22/86	5.20	3.90	1163.4					<5	0
2/19/86	5.60	4.30	1163.0	7.5	9.0	1500		<5	0
3/19/86	3.91	2.61	1164.7					<5	
4/10/86		FLOODED							
4/22/86	1.29	-0.01	1167.3		11.5	1200		<5	16+
5/07/86	1.51	0.21	1167.1		12.0	1300		<5/<5	0/0
5/19/86								<5/<5	0/0
6/04/86	2.36	1.06	1166.2	7.0	11.5	1000	0.2	<5	9.2
6/17/86	5.33	4.03	1163.3	7.3	13.0	950	0.3	<5	9.2
6/30/86	3.67	2.37	1164.9	7.2	11.0	1100		<5/<5	16+/16+
7/21/86	4.07	2.77	1164.5	7.1	12.0	1130	1.1	<5	9.2

8/04/86	4.00	2.70	1164.6	7.2	11.5	1300	0.7		
8/19/86	4.43	3.13	1164.2		13.0	1300	0.4	<5	16+
9/08/86	4.76	3.46	1163.8	7.2	11.5	1350	0.4	<5	
9/21/86				7.5	14.0	1200		<5	16+

SURFACE BRIDGE-5 MP Elevation 1163.6 NGVD Sec 5/8, T94N, R31W

Date	Water Level (mp)	Water Level Elevation	PH	Temp (°C)	Cond (µmhos)	NO_3 (mg/l)
9/18/85	12.22	1151.4		23.6	810	11
10/07/85	11.51	1152.1				27
10/23/85	11.54	1152.0		15.0	940	23
11/06/85	12.08	1151.5		7.3	955	22
11/20/85	11.75	1151.8		0.0	760	35
2/19/86			8.0	2.0	940	19
4/10/86			8.5	12.0	700	19
4/22/86				12.0	780	24
5/07/86				19.0	745	20
5/19/86	9.10	1154.5	8.4	19.0	720	23
6/04/86	9.73	1153.9	8.3	19.5	860	23
6/17/86	11.67	1151.9	8.3	24.0	805	23/25
6/30/86	8.98	1154.6	8.2	20.0	650	40
7/21/86	10.60	1153.0	8.2	26.0	810	15
8/04/86	11.67	1151.9	8.4	21.0	750	6
8/19/86	13.31	1150.3		24.0	700	5
9/08/86	12.69	1150.9	8.5	17.0	640	<5
9/21/86	11.65	1152.0	8.5	20.0	570	17/17
10/22/86	10.78		8.3	15.0	740	24

WELL WD-13U Date Installed 8/14/85 SW, SE, SW, sec. 4, T94N, R31W

Screened Interval 12-16 ft. MP Elevation 1161.5 NGVD Casing Ht. 2.6 ft.

Date	Water Level (mp)	Water Level (gs)	Water Level Elevation	pH	Temp (°C)	Cond (µmhos)	DO (mg/l)	NO_3 (mg/l)	Bacteria
8/27/85								<5	16
9/18/85	9.84	7.24	1151.7		18.5	600		<5	16+
10/07/85	8.47	5.87	1153.1		13.9	825		<5	16+
10/23/85	8.93	6.33	1152.6		14.8	600	0.4	<5	16+
11/06/85	9.42	6.82	1152.1		13.0	760	0.5	<5	9.2
11/20/85	8.49	5.89	1153.0		9.5	815	0.1	<5	9.2
12/23/85	9.10	6.50	1152.4					<5	
1/22/86	9.40	6.80	1152.1					<5	16
2/19/86	10.00	7.40	1151.5	7.4	8.0	700	0.1	<5	0

3/19/86	5.91	3.31	1155.6					<5	
4/10/86	5.27	2.67	1156.2	7.7	7.0	680		<5	5.1
4/22/86	6.60	4.00	1154.9		8.0	680	0.0	<5	16
5/07/86	6.61	4.01	1154.9		8.5	680		<5	5.1
5/19/86	6.29	3.69	1155.2	7.7	10.5	420	0.0	<5	16+
6/04/86	8.26	5.66	1153.2	7.5	11.0	690	0.4	<5/<5	16/16+
6/17/86	8.45	5.85	1153.0	7.6	11.2	615	0.2	<5	16+
6/30/86	8.67	6.07	1152.8	7.5	11.0	530		<5	16+
7/21/86	9.35	6.75	1152.1	7.4	13.0	690	1.8	<5	16+
8/04/86	9.40	6.80	1152.1	7.3	13.0	715	0.3	<5	16+
8/19/86	9.36	6.76	1152.1		15.0	570	0.5	<5	16+
9/09/86	9.90	7.30	1151.6	7.3	14.0	690	0.3	<5/<5	
9/21/86	9.28	6.68	1152.2	7.6	15.0	715		<5	16+
10/22/86	7.23	4.63	1154.3	7.5	15.0	620	0.6	<5	

WELL WD-13M Date Installed 8/14/85 SW, SE, SW, sec. 4, T94N, R31W

Screened Interval 21-25 ft. MP Elevation 1161.3 NGVD Casing Ht. 2.4 ft.

Date	Water Level (mp)	Water Level (gs)	Water Level Elevation	pH	Temp (°C)	Cond (µmhos)	DO (mg/l)	NO_3 (mg/l)	Bacteria
8/27/85								<5	16+
9/18/85	9.53	7.13	1151.8		18.8	540		<5	16+
10/07/85	8.20	5.80	1153.1		11.7	820		<5	16+
10/23/85	8.63	6.23	1152.7		13.0	430	0.4	<5	9.2
11/06/85	9.11	6.71	1152.2		11.5	780	0.5	<5	0
11/20/85	8.24	5.84	1153.1		8.0	840	0.1	<5	16
12/23/85	8.80	6.40	1152.5					<5	
1/22/86	9.10	6.70	1152.2					<5	16+
2/19/86	9.70	7.30	1151.6	7.5	10.0	760	0.0	<5/<5	0/0
3/19/86	5.61	3.21	1155.7					<5	
4/10/86	5.02	2.62	1156.3	7.6	10.0	765		<5	2.2
4/22/86	6.33	3.93	1155.0		10.5	630	0.0	<5	9.2
5/07/86	6.31	3.91	1155.0		10.5	750		<5	2.2
5/19/86	6.01	3.61	1155.3	7.4	11.5	420	0.0	<5	0
6/04/86	7.96	5.56	1153.3	7.4	10.5	560	0.4	<5	16
6/17/86	8.67	6.27	1152.6	7.5	11.5	680	0.2	<5	16
6/30/86	8.38	5.98	1152.9	7.5	10.0	575		<5	16+
7/21/86	9.08	6.68	1152.2	7.3	11.5	740	1.1	<5	16+
8/04/86	9.13	6.73	1152.2	7.3	11.0	660	0.4	<5	16+
8/19/86	9.08	6.68	1152.2		12.0	540	0.2	<5	16+
9/09/86	9.60	7.20	1151.7	7.3	11.0	650	0.4	<5	
9/21/86	8.99	6.59	1152.3	7.6	12.5	700		<5	16+
10/22/86	6.93	4.53	1154.4	7.5	14.0	660	1.6	<5	

WELL WD-13L Date Installed 9/8/83 SW, SE, SW, sec. 4, T94N, R31W

Screened Interval 33-35.5 ft. MP Elevation 1160.9 NGVD Casing Ht. 2.0 ft.

Date	Water Level (mp)	Water Level (gs)	Water Level Elevation	pH	Temp (°C)	Cond (µmhos)	DO (mg/l)	NO_3 (mg/l)	Bacteria
7/16/85	6.46	4.46	1154.4						
8/27/85								<5	5.1
9/18/85	9.22	7.22	1151.7		18.6	605		<5	2.2
10/07/85	7.88	5.88	1153.0		11.1	825		<5	2.2
10/23/85	8.30	6.30	1152.6		12.2	640	0.5	<5	2.2
11/06/85	8.79	6.79	1152.1		11.0	780	0.5	<5	2.2
11/20/85	7.93	5.93	1153.0		6.0	835	0.0	<5	0
12/23/85	8.50	6.50	1152.4					<5	
1/22/86	8.80	6.80	1152.1					<5	0
2/19/86	9.40	7.40	1151.5	7.3	9.0	900		<5	0
3/19/86	5.32	3.32	1155.6					<5	
4/10/86	4.71	2.71	1156.2	7.5	11.0	785		<5	0
4/22/86	6.01	4.01	1154.9		12.0	750		<5	16+
5/07/86	6.02	4.02	1154.9		11.0	760		<5	16+
5/19/86	5.70	3.70	1155.2	7.4	14.0	420	0.0	<5	16+
6/04/86	7.68	5.68	1153.2	7.4	10.0	570	0.4	<5	16
6/17/86	8.97	6.97	1151.9	7.4	12.5	760	0.2	<5	5.1
6/30/86	8.08	6.08	1152.8	7.4	11.0	590		<5	16
7/21/86	8.78	6.78	1152.1	7.2	12.0	750	2.5	<5	16+
8/04/86	8.82	6.82	1152.1	7.3	11.3	740	0.5	<5	16+
8/19/86	8.79	6.79	1152.1		12.0	690	0.2	<5	16+
9/09/86	9.28	7.28	1151.6	7.2	11.0	600	0.5	<5	
9/21/86	8.69	6.69	1152.2	7.6	12.0	720		<5	16+

WELL WD-14U Date Installed 8/13/85 NW, NE, NW, sec. 12, T93N, R31W

Screened Interval 5 9 ft. MP Elevation 1140.7 NGVD Casing Ht. 2.2 ft.

Date	Water Level (mp)	Water Level (gs)	Water Level Elevation	pH	Temp (°C)	Cond (µmhos)	DO (mg/l)	NO_3 (mg/l)	Bacteria
8/27/85								18	0
9/18/85	7.44	5.24	1133.3		19.4	610		14	16+
10/07/85	6.64	4.44	1134.1		13.9	640		11	16+
10/23/85	6.36	4.16	1134.3		14.5	545	3.5	8	16+
11/06/85	6.40	4.20	1134.3		11.5	520	5.5	10	9.2
11/20/85	6.06	3.86	1134.6		9.0	610	5.0	5	16
12/23/85	6.40	4.20	1134.3					<5	
1/22/86	6.90	4.70	1133.8					<5	16+

2/19/86	7.20	5.00	1133.5	7.5	7.0	690	4.1	28	9.2
3/19/86	6.09	3.89	1134.6					14	
4/10/86	4.72	2.52	1136.0	7.5	8.0	635		30/31	5.1/2.2
4/22/86	4.27	2.07	1136.4		10.0	580	7.0	33	2.2
5/07/86	4.14	1.94	1136.6		10.5	700		25	0
5/19/86	2.99	0.79	1137.7	7.6	13.0	525	6.0	15	0
6/04/86	3.60	1.40	1137.1	7.5	12.0	420	6.2	<5/<5	16+/16+
6/17/86	4.39	2.19	1136.3	7.5	14.0	590	5.5	8	16+
6/30/86	4.27	2.07	1136.4	7.4	14.0	520		25	16+
7/21/86	4.77	2.57	1135.9	7.3	16.0	620	8.1	20	16+
8/04/86	5.23	3.03	1135.5	7.2	15.5	660	6.5	21	16+
8/19/86	5.71	3.51	1135.0		15.0	620	7.2	25	16+
9/09/86	6.24	4.04	1134.5	7.3	16.0	690	6.0	10/8	
9/21/86	6.20	4.00	1134.5	7.4	17.0	640		14	16+
10/22/86	4.63	2.43	1136.1	7.5	16.0	580	5.8	7/7	

WELL WD-14M Date Installed 8/13/85 NW, NE, NW, sec. 12, T93N, R31W

Screened Interval 14-18 ft. MP Elevation 1140.5 NGVD Casing Ht. 2.0 ft.

Date	Water Level (mp)	Water Level (gs)	Water Level Elevation	pH	Temp (°C)	Cond (µmhos)	DO (mg/l)	NO_3 (mg/l)	Bacteria
8/27/85								34	16
9/18/85	7.54	5.54	1133.0		18.2	510		34	9.2
10/07/85	6.48	4.48	1134.0		13.3	600		8	5.1
10/23/85	6.20	4.20	1134.3		14.0	540	0.4	10	9.2
11/06/85	6.20	4.20	1134.3		12.0	570	0.6	8	0
11/20/85	6.12	4.12	1134.4		8.0	410	0.2	28/37	0/0
12/23/85	6.30	4.30	1134.2					<5	
1/22/86	6.70	4.70	1133.8					29	0
2/19/86	7.00	5.00	1133.5	7.2	9.0	650	0.7	44	0
3/19/86	5.84	3.84	1134.7					42	
4/10/86	4.51	2.51	1136.0	7.6	9.5	520		31	0
4/22/86	4.14	2.14	1136.4		11.0	580	0.0	31	0
5/07/86	3.93	1.93	1136.6		10.5	560		23	0
5/19/86	2.77	0.77	1137.7	7.6	12.0	555	0.0	35	0
6/04/86	3.39	1.39	1137.1	7.4	11.5	440		17	16
6/17/86	4.17	2.17	1136.3	7.5	11.5	560	0.3		
6/30/86	4.07	2.07	1136.4	7.6	11.0	455		<5	16+
7/21/86	4.56	2.56	1135.9	7.4	13.5	560	1.2	30	16+
8/04/86	5.02	3.02	1135.5	7.4	12.5	540	0.5		
8/19/86	5.51	3.51	1135.0		15.0	380	0.6	67/75	16+/16
9/09/86	6.02	4.02	1134.5	7.3	12.5	565	0.4	10	
9/21/86	5.99	3.99	1134.5	7.6	15.0	600		62	16+
10/22/86	4.43	2.43	1136.1	7.9	15.0	370	2.0	7	

WELL WD-14L Date Installed 8/12/83 NW, NE, NW, sec.12, T93N, R31W

Screened Interval 28-31 ft. MP Elevation 1140.3 NGVD Casing Ht. 1.8 ft.

Date	Water Level (mp)	Water Level (gs)	Water Level Elevation	pH	Temp (°C)	Cond (μmhos)	DO (mg/l)	NO_3 (mg/l)	Bacteria
7/16/85	6.73	4.93	1133.6						
8/27/85								<5	0
9/18/85	7.46	5.66	1132.8		18.9	730		<5	0
10/07/85	6.40	4.60	1133.9		13.3	820		<5	16
10/23/85	6.10	4.30	1134.2		13.0	720	0.5	<5	2.2
11/06/85	6.09	4.29	1134.2		11.0	780	0.6	<5	0
11/20/85	6.40	4.60	1133.9		8.0	840	0.1	<5	0
12/23/85	6.20	4.40	1134.1					<5	
1/22/86	6.60	4.80	1133.7					<5	0
2/19/86	6.90	5.10	1133.4	7.6	9.0	840		<5	0
3/19/86	5.78	3.98	1134.5						<5
4/10/86	4.45	2.65	1135.8	7.4	11.0	530		<5/<5	0/0
4/22/86	4.08	2.28	1136.2		12.0	740		<5	5.1
5/07/86	3.86	2.06	1136.4		12.0	730		<5	2.2
5/19/86	2.47	0.67	1137.8	7.5	12.5	700	0.0	<5	0
6/04/86	3.32	1.52	1137.0	7.3	12.0	580	0.4	<5	16
6/17/86	4.10	2.30	1136.2	6.9	14.5	710	0.0	<5	16
6/30/86	3.98	2.18	1136.3	7.4	11.0	585		15	9.2
7/21/86	4.49	2.69	1135.8	7.2	13.0	690	1.5	<5	2.2
8/04/86	4.93	3.13	1135.4	7.2	12.0	725	0.6	<5	16+
8/19/86	5.44	3.64	1134.9		16.0	680	0.2	<5	5.1
9/09/86	5.95	4.25	1134.3	7.3	11.0	740	0.4	<5	
9/21/86	5.91	4.11	1134.4	7.7	13.0	610		<5	16+

WELL WD-16U Date Installed 8/13/85 NE, SE, SW, sec. 8, T92N, R30W

Screened Interval 5-8 FT. MP Elevation 1119.4 NGVD Casing Ht. 2.8 ft.

Date	Water Level (mp)	Water Level (gs)	Water Level Elevation	pH	Temp (°C)	Cond (μmhos)	DO (mg/l)	NO_3 (mg/l)	Bacteria
8/27/85								46	16+
9/18/85	8.77	5.97	1110.6		23.4	680		21	5.1
10/07/85	8.35	5.55	1111.0		19.0	800		15	2.2
10/23/85	8.23	5.43	1111.2		14.0	595		18	2.2
11/06/85	8.50	5.70	1110.9		12.0	595		23/24	0/2.2
11/20/85	8.46	5.66	1110.9		7.0	600	5.5	21	0
12/23/85		FROZEN							

1/22/86	9.00	6.20	1110.4					<5	16+
2/19/86	9.20	6.40	1110.2	7.5	2.5	580		15	16
3/19/86	7.18	4.38	1112.2					<5	
4/10/86	4.70	1.90	1114.7	7.6	7.0	465		18	16+
4/22/86	5.29	2.49	1114.1		8.0	480	5.8	16	16+
5/07/86	5.29	2.49	1114.1		11.0	490		25/22	16+/9.2
5/19/86	4.63	1.83	1114.8	7.3	12.5	530	3.9	<5	16
6/04/86	5.34	2.54	1114.1	7.4	13.0	390	5.8	11	16+
6/17/86	6.16	3.36	1113.2	7.4	16.5	435	5.0	<5	16+
6/30/86	6.16	3.36	1113.2	7.4	15.0	435		28/14	16+/16+
7/21/86	6.31	3.51	1113.1	7.1	17.0	520	4.8	15	16
8/04/86	6.61	3.81	1112.8	7.1	18.0	590	4.6	42	16+
8/19/86	7.33	4.53	1112.1		14.0		6.0	62	16+
9/09/86	8.05	5.25	1111.3	7.2	17.0	640	4.2	68	
9/21/86	7.81	5.01	1111.6	7.3	18.0	590		52	16+
10/22/86	5.14	2.34	1114.3	7.5	16.0	500	4.0	17	

WELL WD-16L Date Installed 9/12/83 NE, SE, SW, sec. 8, T92N, R30W

Screened Interval 13-14.5 ft. MP Elevation 1119.2 NGVD Casing Ht. 2.6 ft.

Date	Water Level (mp)	Water Level (gs)	Water Level Elevation	pH	Temp (°C)	Cond (µmhos)	DO (mg/l)	NO_3 (mg/l)	Bacteria
7/16/85	8.19	5.59	1111.0						
8/27/85								32	0
9/18/85	8.56	5.96	1110.6		20.4	500		32	0
10/07/85	8.06	5.46	1111.1		15.0	437		17	16
10/23/85	8.04	5.44	1111.2		15.5	610	1.8	8	0
11/06/85	8.30	5.70	1110.9		12.0	670	1.8	39	0
11/20/85	8.28	5.68	1110.9		8.0	725	0.6	36	0
12/23/85	8.40	5.80	1110.8					11	
1/22/86	8.80	6.20	1110.4					21	0
2/19/86	9.00	6.40	1110.2	7.1	4.0	670	0.8	40	0
3/19/86	6.95	4.35	1112.0					11	
4/10/86	4.52	1.92	1114.7	7.7	8.0	380		21	0
4/22/86	5.10	2.50	1114.1		9.5	580	0.0	25	0
5/07/86	5.08	2.48	1114.1		10.0	740		6/6	2.2/0
5/19/86	4.42	1.82	1114.8	7.5	12.0	610	0.0	5/6	5.1/2.2
6/04/86	5.15	2.55	1114.0	7.8	10.5	420	0.4	10	16
6/17/86	6.36	3.76	1112.8		12.5	570	1.0	9	16+
6/30/86	5.98	3.38	1113.2	7.6	11.0	440		26	16+
7/21/86	6.09	3.49	1113.1	7.4	13.0	380	1.5	11	
8/04/86	6.41	3.81	1112.8	7.4	13.0	520	1.5	32/25	16+/16
8/19/86	7.12	4.52	1112.1		14.0	370	3.1	15/15	16+/16+
9/09/86	7.86	5.26	1111.3	7.4	14.0	560	2.0	<5	
9/21/86	7.62	5.02	1111.6	7.7	15.0	470		20	16+
10/22/86	7.95	5.35	1111.2	7.6	16.0	480	1.6	21	

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