August 1993

Atrazine in the Platte River and Lincoln Municipal Water

James D. Carr
University of Nebraska - Lincoln, jcarr1@unl.edu

Great Plains Research 3 (August 1993):167-88

ATRAZINE IN THE PLATTE RIVER AND LINCOLN MUNICIPAL WATER

James D. Carr

Department of Chemistry
University of Nebraska–Lincoln
Lincoln, NE 68588-0304

Abstract. *The City of Lincoln draws water from a well field along the banks of the Platte River near Ashland. Since 1989 we have monitored the infusion of atrazine into this well field via recharge from the Platte River. Samples of water from the river, several monitoring wells and production wells were analyzed by gas chromatography coupled to mass spectrometer following solid phase extraction. Atrazine concentrations were found to be less than 0.1 ppb before the growing season every year through 1989-1992. Atrazine in the Platte reached maximum concentrations of 5, 11, 19, and 19 ppb respectively in these years. These increases corresponded to precipitation events and agricultural practices in the Platte River basin. Following a time delay, high concentrations were observable in the well water samples and ultimately in Lincoln municipal tap water.*

The initial purpose of this research was to use atrazine as a tracer of water recharging an aquifer from a river source. The system selected is located within the Lincoln municipal well field located along the banks of the Platte River near Ashland, NE. The river acts as a line source of induced recharge, thus allowing contaminants in the river to be used as tracers of induced recharge. The amount of recharge water and the speed at which it enters the Lincoln well field ultimately determine the amount of water that can be withdrawn by the city for municipal use. Our study determined the rate of movement of induced recharge by tracing atrazine from the river through a system of monitoring wells located in a line roughly perpendicular to the course of the river.

Atrazine was chosen because it is present in detectable quantities due to agricultural applications. Widely used in the Platte river valley as a herbicide, atrazine has been detected in the Platte River for years. Other researchers have attempted to quantify the ability of this aquifer to supply future water demands and the role the Platte river plays in recharging the aquifer (Black 1964; Layne-Western 1974). All studies have shown that induced recharge is a major source of water withdrawn from the well field.

Federal regulations limit the concentration of atrazine in drinking water to 3 parts per billion (ppb). The hazards of atrazine to human health and the biosphere have been studied frequently without reaching definite conclusions. Diminished diversity of organisms in stream ecosystems have been shown at levels of atrazine above 50 ppb. This is thought to be due to its herbicidal activity on aquatic plants and therefore on the other organisms which depend on these plants.

Description of Study Area

The study area, three miles northeast of the town of Ashland, Nebraska is located in the southeast corner of Saunders County (Fig. 1). The Platte River in this region is braided and its discharge levels are dependent upon season and precipitation. In the southern part of the well field, the main channel of the river is near the east side of the river but in the northern part, the main channel is up against the west bank of the river.

Lincoln is approximately 35 miles to the southwest of the site. The well field provides the principal source of water for Lincoln and supplies 97% of the water used in the metropolitan area. Since the demand for water created by urban growth is expected to increase, two more large capacity horizontal wells are now under construction on an island in the river adjacent to the present well field. Forty-four wells extract water from the alluvial aquifer in the Lincoln Municipal well field. Each of these 44 production wells are capable of producing between 1,200 and 3,000 gallons per minute. Pumpage creates a localized area of depression in the water table with ground-water levels in pumping wells averaging 20 feet below river stage (Gary DeFoil, personal communication). Induced recharge from the river into the aquifer results from this localized depression.

The alluvial aquifer, composed of sands and gravels, ranges in thickness from 70 to 100 feet in this area (Souders 1967). The aquifer is in direct hydraulic connection with the river in the well field (Chu 1988; Marlette 1952; Brogden 1972). The static water table outside the well field is relatively shallow ranging from 5 to 15 feet below the surface and slopes less than 5 feet per mile toward the Platte River (Souders 1967; G.M.I. 1984-1987) except in the immediate vicinity of the well field.

Model of Atrazine Movement

Atrazine ($C_8H_{14}N_5Cl$) (Fig. 2) is a herbicide used extensively in Nebraska for broadleaf weed control in crops such as corn and sorghum. It is typically

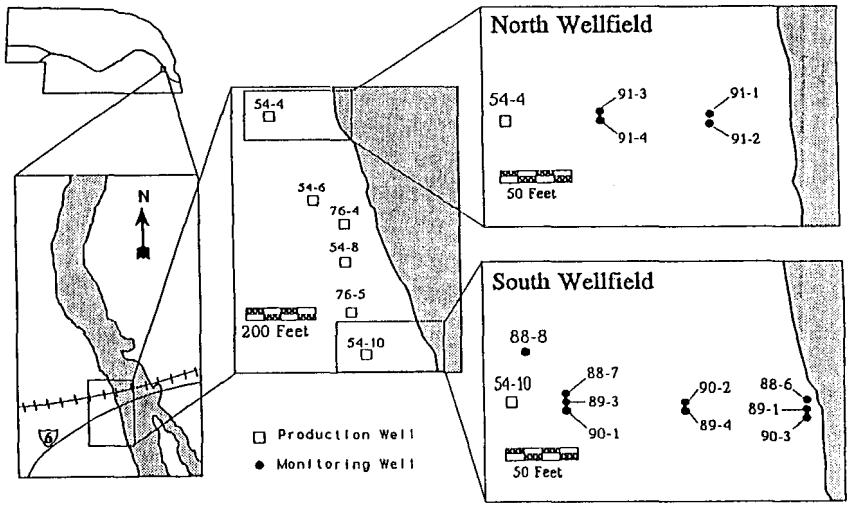

Figure 1. Map of well field area near Ashland, Nebraska (Blum 1993).

applied in early May. After its application, precipitation runoff events causes some of the atrazine to enter the surface water system of small streams. From there, the atrazine is carried downstream in the flow and, under the influence of induced recharge, some enters the aquifer under the well field. The amount of atrazine induced into the well field is related to the concentration of atrazine in the river and the volume of recharge water. All atrazine in the sampled wells is assumed to have come from the induced river recharge since the herbicide is not applied in the immediate area of the well field.

Precipitation soon after atrazine application results in high concentrations in the runoff and thus high concentrations in the river. Atrazine is more mobile when it is at the surface immediately after application and is thus more susceptible to transport (Shea 1989). Runoff from precipitation acts as the major transporter of atrazine from farmland into the river. The greater the amount of precipitation, the greater the amount transported (Shea 1989). Very high concentrations have been detected in small streams in the midst of agricultural areas. In May 1992, we found atrazine concentration to be 40 ppb

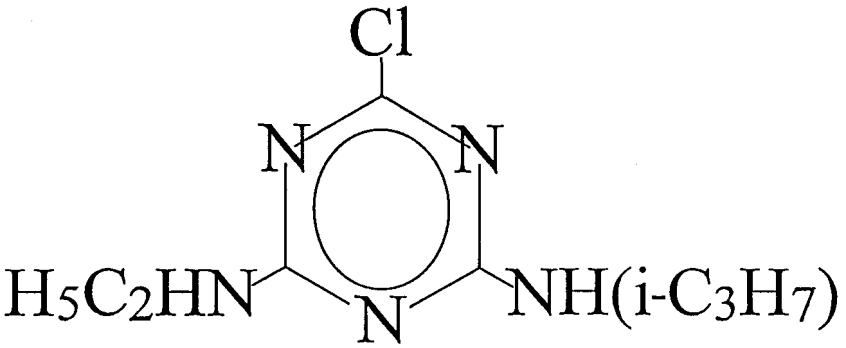

Figure 2. Chemical structure of atrazine.

in Maple Creek in Colfax County. Our data show that the amount of atrazine in the river increases during normal precipitation events and decreases during periods of less rain. The atrazine concentration depends upon both the amount of available atrazine and the volume of water, both of which increase immediately after an upstream rainfall. The Platte River discharge increases substantially in response to runoff during precipitation events in the contributing basin of 84,200 mi^2 (Boohar et al. 1990). A maximum flow of 80,600 ft^3/s occurred on June 17, 1990 and a minimum flow of 840 ft^3/s on December 14, 1989 during the study period (Boohar et al. 1990).

Methods of Analysis

This study utilized several monitoring wells in both the north and south parts of the well field (Fig. 1 and Table 1). Production well 54-10 is typical and has 40 feet of screen at the bottom with the top part of the screen at the same level as the screens of the deeper monitoring wells. The concentration of atrazine in the water recharging the aquifer was assumed to be the same as that

TABLE 1

DEPTH AND LOCATION OF MONITORING WELLS

Well	Depth (ft)	Distance to River (ft)
91-1	50	50
91-2	36	50
91-3	50	135
91-4	36	135
88-6	50	10
89-1	16	10
90-3	25	10
89-4	18	75
90-2	25	75
88-7	50	160
89-3	18	160
90-1	25	160

in the sample taken at the river's edge directly adjacent to the well field but we recognize the possibility of error in this assumption.

All water samples were collected in 500 mL amber glass reagent bottles washed with distilled water. Collection was accomplished by pumping air from the sample bottle and allowing it to fill via a 30 foot non-collapsible polyethylene tube inserted below the water level of the well. The sample bottle was filled three times prior to retention of a sample. Samples from production wells were taken from the spigot attached to the discharge pipe inside the well house. A 100% teflon (Isco, Inc. series 3600 system) bailer was used to collect samples when the water table dipped below the lifting ability of the pump.

Samples were taken approximately three times a week during May through August and less frequently earlier and later in the year. Sampling frequency was increased following rainfall events. Blanks and duplicates were taken in order to identify any error of procedure. Duplicate samples of river were taken at every collection time.

The herbicide was extracted from 10 mL of the sample using a C-18 solid phase extraction resin (100 mg in 1 mL syringe) and eluted using two 250 μ aliquots of ethyl acetate. This eluent was blown to dryness and redissolved in 50 μ of ethyl acetate. This was reduced to 5-7 μ by a flow of dry nitrogen before injection into the gas chromatograph/mass spectrometer. An internal standard of terbuthylazine was used in this method to compensate for variables in the extraction process. Terbuthylazine is a triazine herbicide not licensed for use in the United States, and does not otherwise appear in the samples. Details of this procedure are reported in our earlier paper (Shepherd et al. 1990).

Results and Interpretations

Important differences, attributed to rainfall patterns during the growing seasons, have been measured in this four year study. The summer of 1989 proved to be dry with infrequent but heavy precipitation events and low river stage. The Platte River discharge increased substantially in response to runoff during the few times that widespread precipitation occurred in the contributing basin. During drier periods the river discharge dropped significantly. The summers of 1990 and 1991 were much wetter but hot whereas 1992 was a wet and cool summer. In 1989 the Platte nearly dried up due to insufficient rainfall, in 1990 the river was temporarily dewatered to allow installation of a pipeline to carry water from the new wells on the island to the treatment plant in Ashland, in 1991 the river did not dry up as much as it had in 1989, and in 1992 it stayed bankful nearly all summer. In all four years, the concentration of atrazine in the river increased dramatically immediately after the first rainfall following the application of atrazine during corn planting in early May (Fig. 3).

In all four years, the concentration of atrazine in wells close to the river increased sharply a few days after the concentration in the river had peaked. Monitoring well 88-6, located just ten feet from the river bank, showed a maximum atrazine concentration about 22 days after the corresponding maximum river concentration (Fig. 4). The time spans between the peaks in the river and the peaks in the levels of atrazine in well 88-6 are reasonably consistent (Table 2). The point of induced recharge in the river bed for water sampled in this well is not known but is most certainly not from the immediate adjacent river bed.

Monitoring well 88-8, located slightly northeast of production well 54-10, is approximately 200 feet further west from the river than well 88-6. A line drawn from 88-6 to 88-8 is roughly perpendicular to the river. The linear

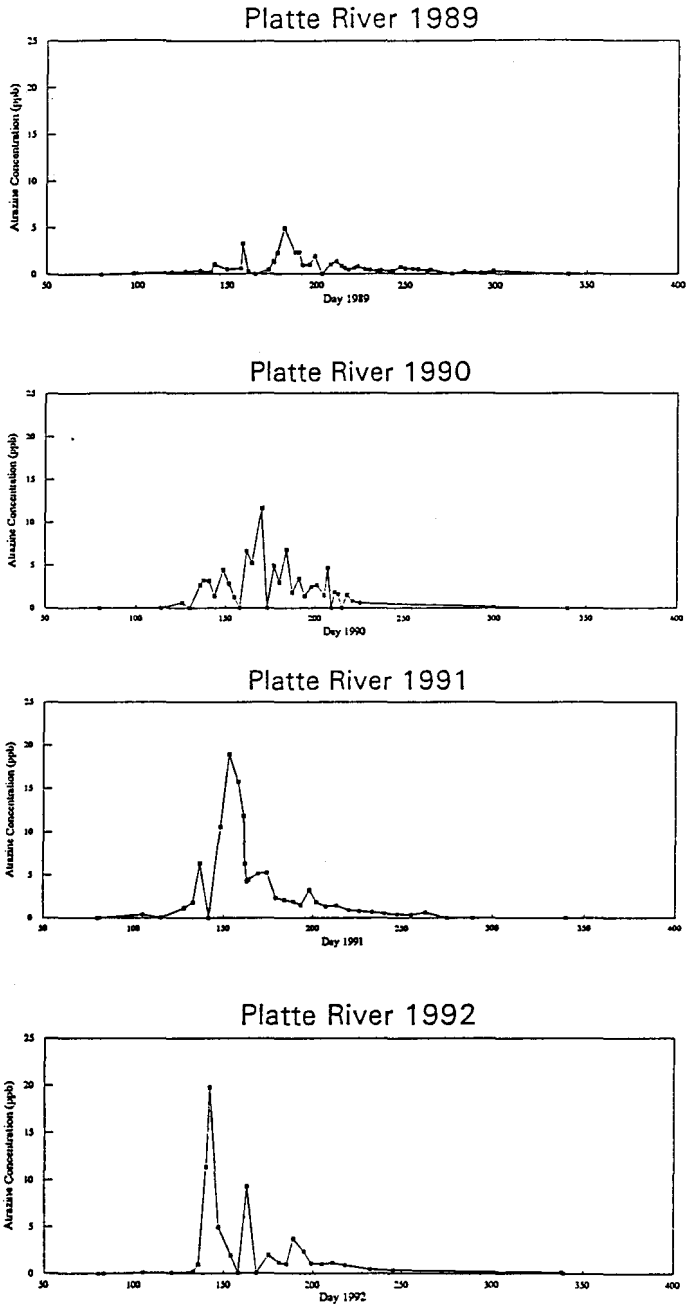

Figure 3. Atrazine concentration in the Platte River in 1989, 1990, 1991, and 1992. Compilation of (Blum 1993) and (Duncan 1991).

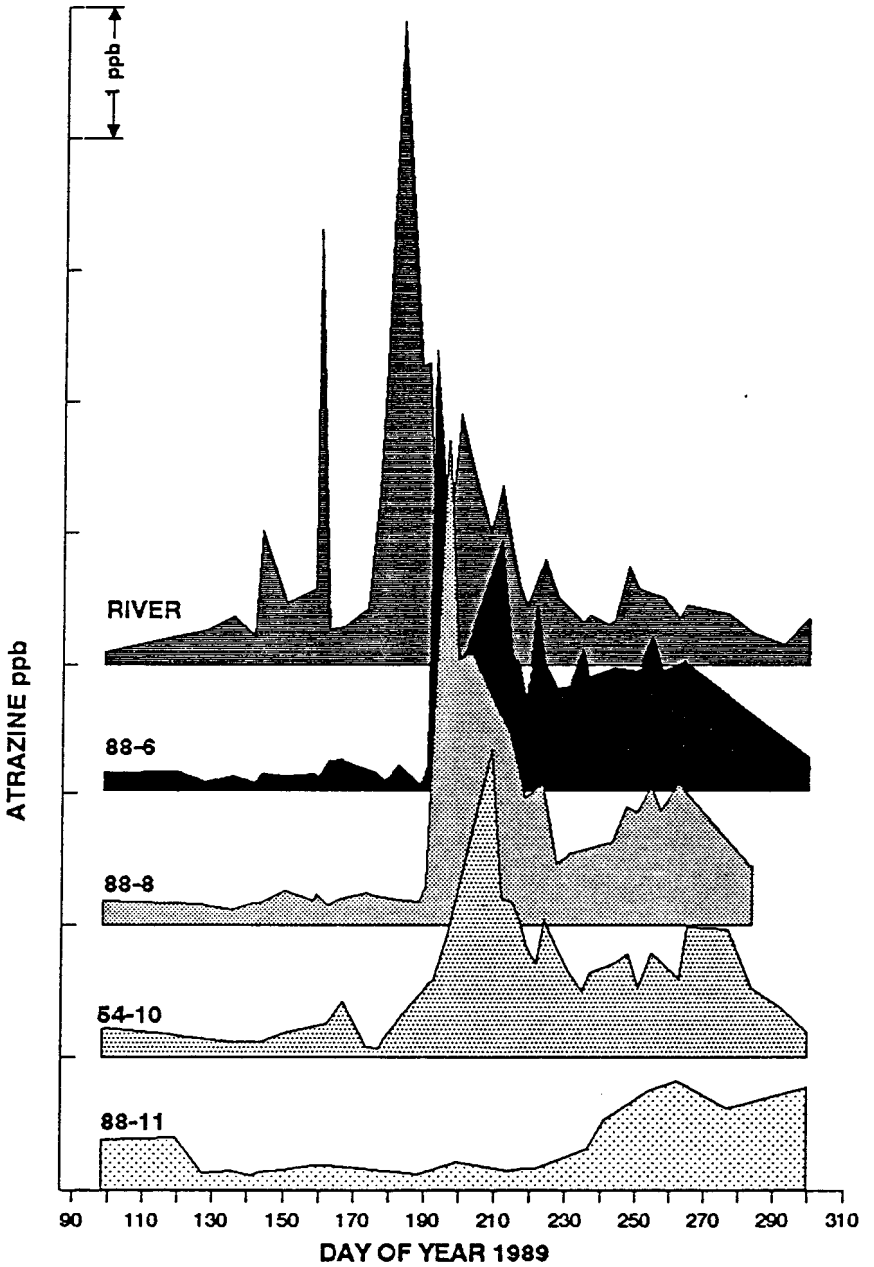

Figure 4. Concentration of atrazine in monitoring wells in the south well field in 1989 (Duncan 1991).

TABLE 2

CONCENTRATION OF ATRAZINE IN PLATTE RIVER AND MONITORING WELLS

Date 1992	Day 1992	91-1	91-2	91-3	91-4	54-4	54-10	River 1	River 2	River 3	River 4	Tap	88-6
Mar 23	83	0.11			0.03	0.05		0.02		0.02			0.06
Apr 14	105	0.16	0.14	0.28	0.14	0.13		0.12	0.17	0.16		0.06	0.13
Apr 30	121	0.12	0.11	0.11	0.14			0.13	0.14	0.14	0.14		0.13
May 12	133							0.23	0.31	0.34	0.39	0.32	
May 15	136	0.12	0.21	0.17	0.22	0.15	0.16	0.99	1.58	2.11	2.91		0.12
May 19	140							11.36	10.61	10.42	10.48	0.39	
May 21	142	0.21	0.36	0.30	0.34			19.79	19.65	19.32	19.06		0.22
May 26	147	0.30	9.68	0.40	0.85	0.24		4.94	4.54	4.05	3.93		0.57
June 2	154	0.17	19.29	0.47	15.47			1.94				0.61	4.19
June 8	158	1.89	16.13	0.52	16.38			2.10					6.85
June 11	163	3.18	11.72	0.63	18.75		2.88	9.33				1.76	11.47
June 16	168	5.64	6.31	0.64	6.59		3.83	4.00				2.28	4.64
June 23	175							2.03				1.53	4.16
June 29	181	6.01	5.52	0.71	6.12			1.15					3.12
July 3	185	5.79	3.89	0.99	5.41			1.02					2.83
July 7	189	4.37	1.10	1.47	4.02		0.95	3.74				0.83	4.31
July 13	195	2.59	2.74	3.23	1.41	1.08		2.35					3.70
July 17	199	2.46	2.22	2.39	2.29	2.09	2.61	1.08					3.53
July 23	205	2.57	1.21	2.41	1.75	2.22		1.03	0.89	0.80	0.64	0.79	3.44
July 29	211	2.20	0.82	1.89	1.04	1.59		1.17					2.48
Aug 5	218	1.20	1.21	1.30	1.16	1.66	2.1	0.92	0.89	0.73	0.78		2.33
Aug 19	232					1.09		0.44					1.51
Sept 1	245							0.36					0.86
Dec 3	338							0.16					0.23

movement of atrazine from the river to the production well is demonstrated by a difference in the time lag for the maximum concentration of atrazine between the river and these two wells (Fig 3).

In comparing levels of atrazine in the river and in the monitoring well 88-8 the first peak in the atrazine concentration in the monitoring well occurred on July 15, 1989 (day 196), four days later than the first peak in well 88-6 on July 11 (day 192). Similar delay times between these monitoring wells were seen in subsequent years. The peaks of atrazine concentration in well 88-8 are more difficult to correlate to the peaks in the river (Fig. 3). The only peak that can be correlated with confidence is river peak 1, which causes the peak seen in well 88-8 on July 15. The later increases in levels of atrazine concen-

tration in monitoring well 88-8 were not significant, distinct or consistent enough to match with confidence to the four following peaks in the concentration pattern seen in the river.

Monitoring well 88-11, located 150 feet west of production well 54-10, does not reflect river atrazine levels. Rather, after weeks of no change there begins a slow, consistent increase in atrazine concentrations (Fig.3). This monitoring well is some distance from the river and one would expect damping of peaks. Additionally, production well 54-10 lies between the river and this monitoring well so more peak smoothing would be expected because of mixing. The lack of peaks in 88-11 illustrate that the peaks seen in the other wells are not reflections of rainfall at the well site or other non-river-related phenomena. A definite trend (Fig. 3) can be seen in response time as a function of distance from the river. Well 88-6, closest to the river, reacts first, followed by well 88-8 and well 54-10. The gradual rise in 88-11 in October probably represents the eventual arrival of induced recharge at this site from the river, with the modifying effects of the production well in the vicinity. Well 88-11 was destroyed during the construction of the pipeline through the well field during 1990.

The four north well field monitoring wells (91-1, 91-2, 91-3, and 91-4) were installed to learn about recharge as a function of well depth. Well 91-2, shallow (screen depth 12.0m) and close to the river (18.5m), showed an atrazine level of 19.3 ppb on June 2nd 12 days after the river's peak of 19.8 ppb (Fig 5.). Well 91-4, the same depth, is situated 41.5 meters from the river. It showed a high atrazine concentration of 18.7 ppb on June 11th, 21 days after the river's peak. The two deep wells (91-1 and 91-3) are screened at 18.5 meters and showed much later and lower peak atrazine levels although they are the same distance from the river as wells 91-2 and 91-4 respectively. Well 91-1 showed a peak concentration of 6.0 ppb on June 29th (39 day delay from river peak) and 91-3 exhibited a peak concentration of 3.2 ppb on July 13.

The source for the atrazine in the well field was clearly the river because:

1. Atrazine is not applied to the surface in the immediate area of the study.
2. The patterns of concentration highs and lows evident in the river are traceable to some extent in the wells.
3. Wells closer to the source show response sooner than those further from it.

4. The lack of concentration peaks in well 88-11 indicates that the concentration maxima in the response of the other wells are not linked to local precipitation events.

Atrazine in Production Wells

Production well samples were gathered systematically three times during 1991 (July 12, September 10, and October 30) and five times during 1992 (May 27, July 6, August 3 or 10, September 17, and December 3). Values of atrazine concentrations were generally much lower in 1992 than in 1991 even though the concentration in the river was similar. Figure 6 shows production well locations. Atrazine slowly moves from the Platte River through the well field into the more distant wells. The closest wells to the river display atrazine peak concentrations early in the season while the more distant wells peak much later in the year (Table 3). This is thought to be due to the longer time needed for the water to move from the river to the well affording more time for natural degradation processes, dispersion, and mixing to reduce the atrazine concentration. Concentrations in 1992 were thought to be lower than in 1991 because the cooler summer required less water to be withdrawn from the well field and the effect of induced recharge was diminished.

Implications of Recharge Rate Measurements

Knowledge of the atrazine intrusion rate into the well field has allowed the city to pump wells which have low concentrations at any given time during the summer and thereby minimize the concentration of atrazine in municipal drinking water. Knowledge of the rate of recharge and the connection of river water to well field water is involved in water rights issues confronting Nebraskans now and in the future.

It had been suggested that since the Elkhorn River joins the Platte about 7 miles upstream of our sampling point, the mixing of the Platte and Elkhorn water may not be complete, thus causing different portions of the river to experience different concentrations of atrazine at different times. To study this possibility, simultaneous collection and measurement were performed on 4 different river sites (points A-D on Fig. 6). The results of the study (Fig. 7) suggest that the river is relatively homogeneous (Table 2). At no time during sampling was an important difference in atrazine concentration recorded. This testing will also be periodically performed in 1993 at times of dry weather as well as after intense runoff conditions.

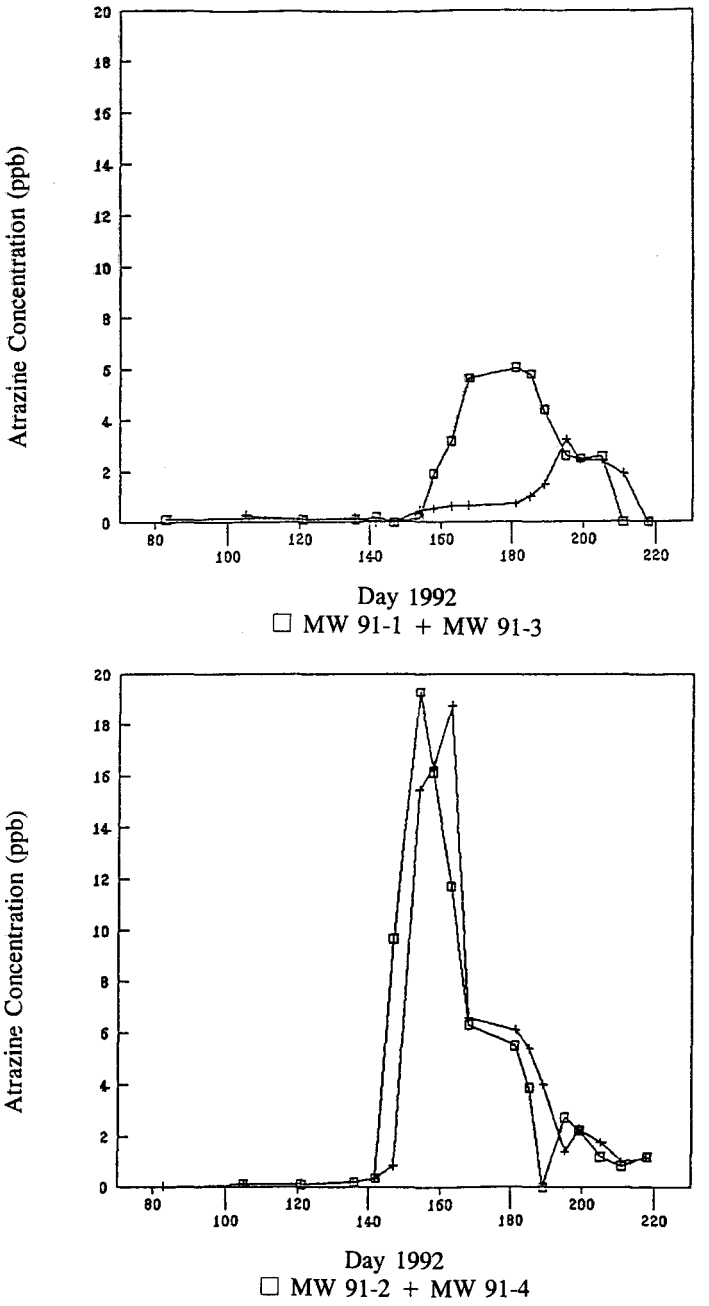

Figure 5. Concentration of atrazine in monitoring wells in the north wellfield in 1992 (Blum 1993).

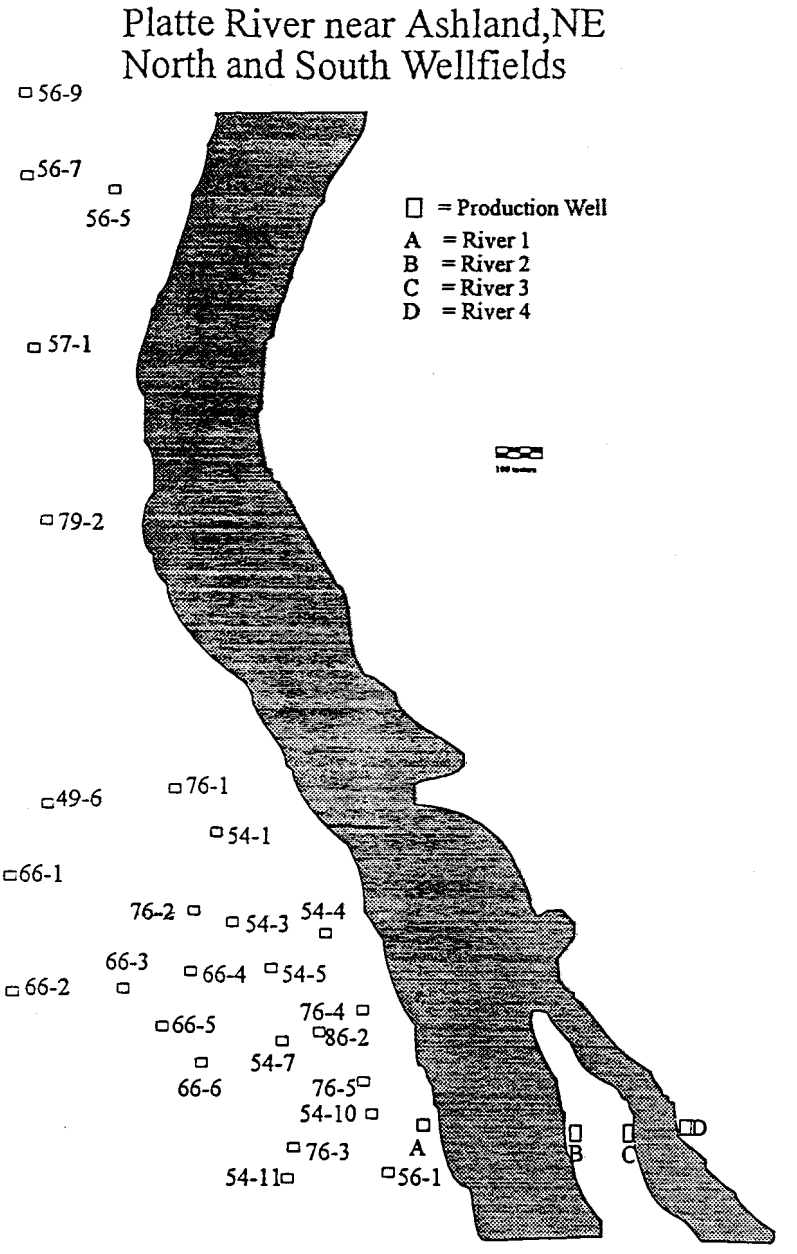

Figure 6. Map of production wells and sites for river homogeneity study.

TABLE 3

CONCENTRATION OF ATRAZINE IN PRODUCTION WELLS
1991 AND 1992

		May 27	July 6	Aug 3	Aug 10	Sept 17	Dec 3	July 12	Sept 10	Oct 31
Production Well	River Distance (in feet)	1992 Day 148	1992 Day 188	1992 Day 216	1992 Day 223	1992 Day 261	1992 Day 338	1992 Day 193	1991 Day 253	1991 Day 304
76-4	50	2.48	2.34	1.80		0.68		6.97	1.03	0.39
76-5	75	0.35	3.27	1.81		0.77		5.53	1.02	
56-5	125	0.15	2.37		1.51	0.93		4.12	1.62	0.32
56-1	150	0.10	0.31	1.05		2.14		2.88	2.03	1.09
54-1	150	0.09	0.07		1.00	2.89		0.18	5.43	0.62
54-4	200	0.18	1.72		1.30	0.67		6.04	1.24	0.36
54-10	200	0.08	0.35	2.24		0.75		5.52	1.85	
57-1	225	0.66	0.56		0.39	0.42		0.54	2.32	
79-2	225	0.12	0.13	0.78		1.26		0.36	1.96	0.89
86-2	350	0.11	4.09		3.60	1.93	0.52	4.76		0.81
54-11	550	0.47	0.59	0.78		0.50	0.63	1.84	1.68	0.6
76-3	600	0.44	0.70	0.92		1.76		1.47	1.57	
54-5	650	0.11	0.47		0.49	2.81	0.86	1.96	5.43	1.3
54-7	700	0.39	2.91		1.51	0.64		0.05	0.8	1.92
54-3	700	0.08	0.18		1.66	2.40		0.53	1.9	
56-7	750	0.56	0.52	0.55		0.43		0.96	0.09	
76-1	850	0.16	0.24		0.44	1.35		0.27	3.13	
76-2	850	0.47	0.43	0.43		1.12	1.28	0.53	4.47	0.70
66-4	1175	1.13	0.63		0.55	0.54		0.43	0.66	
56-9	1200	0.03	0.07		0.14	0.10	0.09	0.73	0.39	0.11
49-6	1200	0.31	0.04		0.05	0.10	0.20	0.33	0.45	
66-6	1350	0.23	0.34	0.62		0.33		0.24	0.32	
66-5	1550	0.03	0.03		0.06	0.19		<.05		
66-3	1675	0.03	0.07	0.08					0.08	
66-1	2150		0.37	0.37		0.56		0.16	0.19	

Compilation of this research and (Blum 1993).

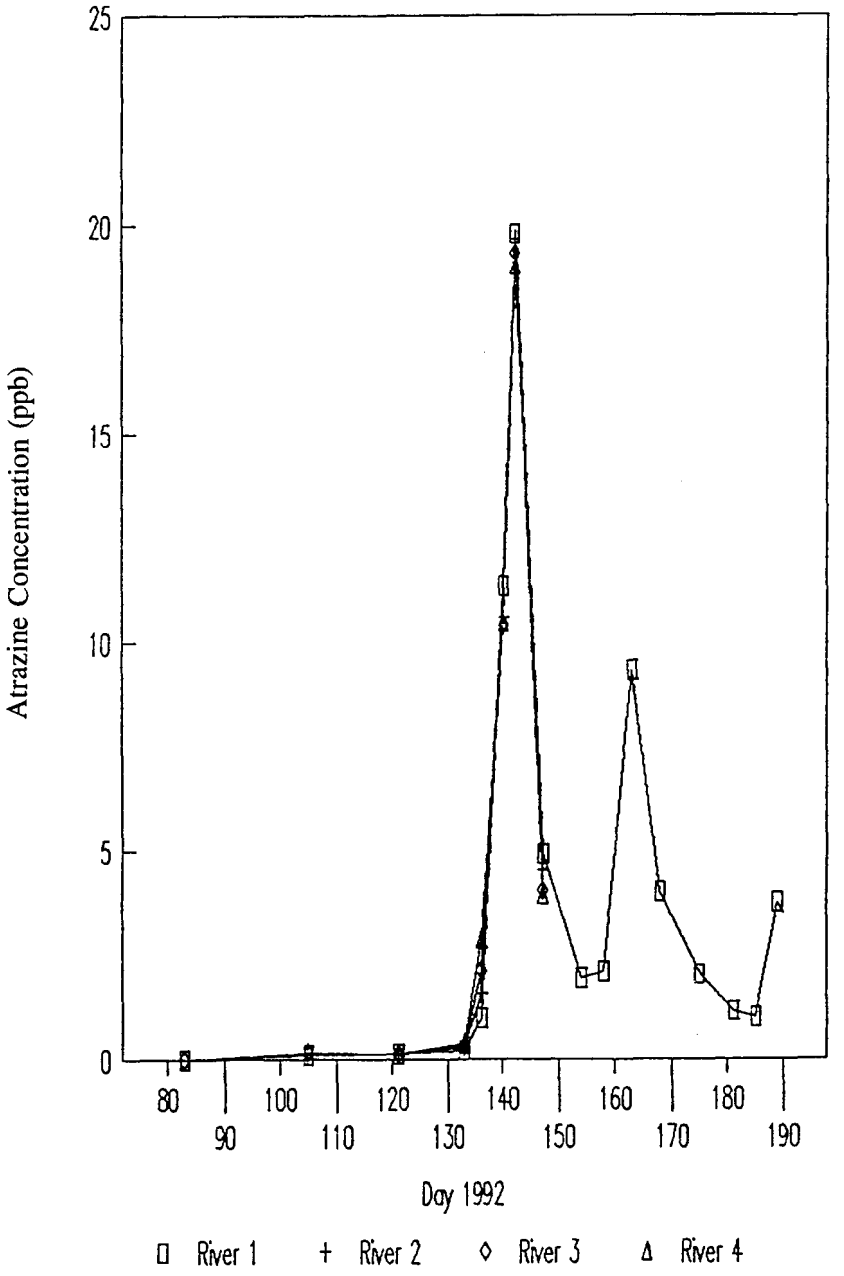

Figure 7. Concentration of atrazine in four locations of Platte River for river homogeneity study in 1992 (Blum 1992).

Knowledge of the daily atrazine concentration and the daily river flow allows calculation of the amount of atrazine during any time period. A total of 1,400 kilograms of atrazine washed down the river in 1989. The corresponding numbers for 1990, 1991, and 1992 of 10,100, 15,000, and 49,000 kilograms respectively were calculated by multiplying the daily concentration of atrazine in the Platte by the known volume of water flowing per day and summing over the year. Approximately five million kilograms of atrazine are applied annually in the drainage basin, so only a small fraction of the applied atrazine moves down the Platte River as the intact molecule.

Some of the lost atrazine has undergone chemical change either in the field or in the river before sampling. Suspected degradation products are hydroxyatrazine (HYA), deethylatrazine (DEA), and deisopropylatrazine (DIA). These compounds have been detected in soil but a trustworthy method for determining DEA and DIA has only recently been available and we have developed a method for determining HYA in water. Too few measurements have been completed to make specific statements, but we find smaller amounts of DEA and DIA than of atrazine and amounts of HYA parallel atrazine levels in Platte River water. Concentrations of DIA were generally lower than DEA by about a factor of three with DEA being typically around one half the atrazine concentration.

1993 will be the first year for a comprehensive evaluation of atrazine degradation products. It is likely that the formation of degradation products of atrazine may contribute to a better overall picture of atrazine in the environment. From soil studies it is understood that hydroxyatrazine is formed via a chemical hydrolysis process in the environment while deethyl and deisopropyl atrazine are formed by fungal mediated cleavage of the alkyl chains on the amine nitrogens.

Rainfall measurements of atrazine levels were conducted in the Lincoln area throughout 1991 and 1992 with a peak concentration of 1.8 ppb on June 16, 1991 and 1.2 ppb on June 5, 1992 (Fig. 8). The increase and decrease in rainfall atrazine paralleled that in the Platte River, both of which are interpreted in terms of agricultural practices and weather patterns.

Atrazine was monitored in Lincoln tap water taken in Hamilton Hall from a tap far distant from any atrazine in the building. Water was allowed to run for 20 minutes before collecting the sample. In each year studied, the atrazine concentration showed very low values (< 0.2 ppb) early in the year to higher values in midsummer (Fig. 9). Concentrations were greater than 1 ppb from June 14 - July 30 in 1990, from June 7 - October 2 in 1991, and June 11 - June 23 in 1992. Maximum concentrations detected were 0.7 (Sept 4, 1989), 3.1 (July 6, 1990), 2.1 (June 23, 1991), and 2.3 ppb (June 16, 1992).

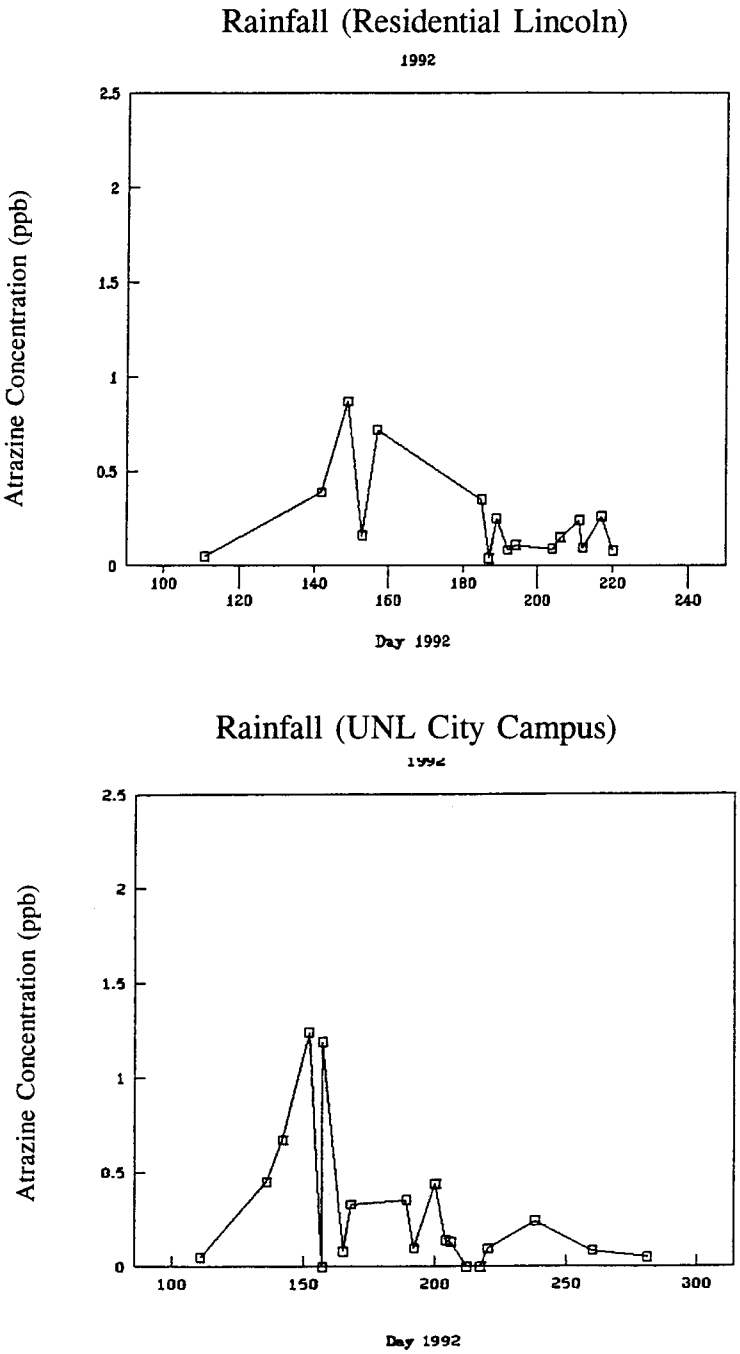

Figure 8. Concentration of atrazine in rainfall during 1992.

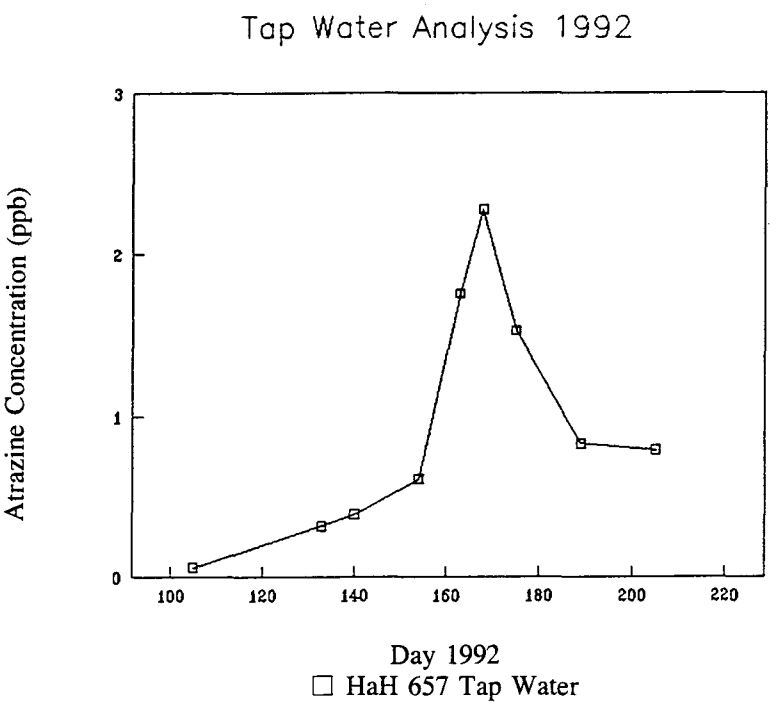

Figure 9. Concentration of atrazine in Lincoln tap water during 1992.

Measurements of atrazine in dry air were completed in 1992 with more testing expected in spring 1993. Analysis for airborne atrazine was performed by collecting dry air on May 4th (the first day of application of atrazine) at a farm located 12 miles north of Schuyler, NE and 1 mile east of Highway 15. Samples were gathered before, during, and after application in the field, on a tractor, and on a planter. The sampling apparatus consisted of a large gas-tight syringe to draw in air connected to a preconditioned C-18 solid phase extraction tube. For other samples the technique was modified by adding a filter (0.45 micron) to collect suspended particles while allowing intact molecules to pass through. These measurements were intended to help answer questions relating to the pathway by which atrazine reaches the atmosphere and produces considerable concentrations in rainfall. After sample collection, internal standard TBZ was added after which atrazine and TBZ were eluted from

TABLE 4

CONCENTRATION OF ATRAZINE IN DRY AIR AND MAPLE CREEK DURING 1992

	Before filter	During filter	During no filter
Field	0.1	4.0	
Tractor		53.0	228
Planter		113	359
Maple Creek	Date	Day	(Atz)
	5-6	127	0.22
	5-13	134	0.58
	5-16	137	10.23
	5-17	138	39.67
	5-24	145	3.15
	5-25	146	3.29
	5-28	149	1.02
	6-1	153	6.00
	6-6	158	0.97
	6-16	168	12.74
	6-17	169	7.26
	6-30	182	4.44
	7-12	194	1.24

(Blum 1992)

the solid phase extraction tube with ethyl acetate which is evaporated to approximately 5 ul and injected onto the GC/MS system. This test showed very low concentrations of atrazine before application (0.1 ppb) and a large increase to over 200 ppb on the tractor and over 350 ppb on the planter in the air samples collected without the filter attached. Samples collected with the filter attached show that approximately half of the atrazine collected was on the 0.45 micron filter paper while the other half passed through the filter. The technique used to determine the atrazine concentration of the filter included an extra step of washing the filter and then extracting (Table 4). Runoff studies at nearby Maple Creek showed atrazine levels that reached nearly 40 ppb on May 17, 1992 (Table 4).

Conclusions

1. **The river is the source of atrazine detected in the well field.** The pattern of atrazine concentration unique to the river was found to be repeated with a high degree of similarity in the well field. Induced recharge transports the atrazine. Other agricultural chemicals also enter the well field via recharge from the river.

2. **The highest river atrazine concentrations occurred in late spring and early summer.** This has been attributed to two factors: the time of herbicide application to the fields located in the Platte River's drainage area; and the amount of precipitation following this application. It is logical that the nearer the rainfall is to the period of application, and the greater the amount of this rainfall, the greater the amount of atrazine carried by runoff into the river. At some point, with increasing precipitation, the amount of runoff will exceed the available mobile atrazine. Consequently, dilution of the atrazine in the runoff and eventually the river will occur.

3. **The rate of ground-water movement is represented by the time lag between high atrazine concentration levels in the river and adjacent monitoring wells.** The time lag between the high concentration of atrazine that occurs in the river to the corollary peak in concentration in the monitoring well increases as distance from the river increases (Fig. 4).

4. **Atrazine movement may be used to study contaminate dispersion in the aquifer.** The increased lack of pattern replication of the atrazine highs and lows as the distance from the river increases is attributed to the hydraulic dispersion of the induced recharge. Additionally, mixing due to pumping from several production wells may effect wells 88-11 and 88-8.

5. **Atrazine in the river water can be used as a tracer of induced recharge.** The ground-water movement at this site in the well field is the movement of induced recharge from the river to the well field.

6. **Atrazine enters the air both as free molecules and adsorbed on dust particles during planting.** This material can move many miles through the air before falling in rain.

7. **Recognizable degradation products of atrazine are also present in water samples.** The sum of these substances is of the same approximate concentration as the atrazine itself.

Acknowledgments

I would like to express my gratitude to the Nebraska Governors Research Initiative Fund and The City of Lincoln, Nebraska for financial support. Special thanks Dr. Darrel Pederson, Geology Department, University of Nebraska–Lincoln, and to Darryl Blum, T.R. Shepherd, Robert Morris, Patrick Gronland, Mike Gerdes, Doug Hagerman, Julie Brown, James Bond, Amy Neben, Diana Duncan, and Ralph Davis for their long hours in the field and the lab that made this report possible.

References

Black and Veatch. 1964. *Report on Water Works Improvements for Lincoln, NE.* Kansas City, MO: Black and Veatch.

Boohar, J. A., C. G. Hoy, and G. V. Steele. 1990. *Water Resources Nebraska: Water Year 1990.* U.S.G.S. Water-Data Report NE-90-1.

Blum, D. A. 1992. The transport of Atrazine and its environmental impact near Ashland, Nebraska. Master's Thesis. Department of Chemistry, University of Nebraska–Lincoln.

Blum, D. A., J. D. Carr, R. K. Davis, and D. T. Pederson. 1993. Atrazine in a stream-aquifer system: Transport of Atrazine and its environmental impact near Ashland, Nebraska. *Groundwater Monitoring and Remediation* 13: 125-33.

Brogden, R. E. 1972. A model of a Platte-Elkhorn Valley aquifer. Masters Thesis. Department of Civil Engineering, University of Nebraska–Lincoln.

Chu, T. M. 1988. Investigation of the thermal regime in a river-aquifer system near Ashland, Nebraska. Master's Thesis. Department of Geology, University of Nebraska–Lincoln.

Cohen, S. Z., R. F. Carsel, S. M. Creeger, and C. G. Enfield. 1984. *Potential Pesticide Contamination of Groundwater from Agricultural Uses in Treatment and Disposal of Pesticide Wastes.* ACS Symposium Series 259, 297-325. Washington, DC: American Chemical Society.

Dao, T. H., T. L. Lavy, and R. C. Sorensen. 1979. Atrazine degradation and residue distribution in soil. *Soil Science Society American Journal* 43: 1129-34.

Davis, R. K., D. T. Pederson, D. A. Blum, and J. D. Carr. Atrazine in a stream-aquifer system: Estimation of aquifer properties from aquifer concentration profiles. *Groundwater Monitoring and Remediation* 13: 134-41.

Davis, S. N., G. M. Thompson, H. W. Bentley, and G. Stiles. 1980. Groundwater tracers—a short review. *Ground Water* 18: 14-22.

Duncan D. 1991. Atrazine used as a marker of induced recharge. *Groundwater Monitoring Review* 11:144-50.

Freeze, R. A. and J. A. Cherry. 1979. *Groundwater.* Englewood Cliffs, NJ: Prentice-Hall, Inc.

G.M.I. 1984-1987. *Ashland Project Reports, the Comprehensive Development Plan.* Kansas City, KS: Groundwater Management Inc.

Layne-Western Co., Inc. 1974. *Lincoln Hydrology Study-Ashland Well Field Area, Platte River Valley, Nebraska.* Kansas City, KS: Layne-Western Co., Inc.

Layne-Western Co., Inc. 1986. *Seismic Refraction Survey, Ashland, NE.* Kansas City, KS: Layne-Western Co., Inc.

Marlette, R.R. 1952. Fields determinations of the transmissibility and storage coefficients of the Platte Valley Aquifer near Ashland, Nebraska. Masters thesis. Department of Civil Engineering, University of Nebraska-Lincoln.

Shepherd T. R., J. D. Carr, D. Duncan, and D. T. Pederson. 1992. A simple resin extraction technique for triazine herbicides in surface and ground waters at pptr levels. *Journal of the Association of Official Analytical Chemists* 75: 581-83.

Shea, P. 1989. Pesticide management practices and ground water quality. *1989 Spring Semester Water Seminar Series*, 77-84.

Snow D. D. and R. F. Spaulding. 1988. *Soluble Pesticide Levels in the Platte River Basin of Nebraska.* 211-33. Conservation and Survey Division, University of Nebraska–Lincoln.

Souders, V. L. 1967. Availability of water in Eastern Saunders County, Nebraska. In *Hydrology Investigations Atlas* HA-266. Conservation and Survey Division, University of Nebraska-Lincoln.

Spaulding, R. F., M. E. Burbach, and M. E. Exner. 1989. Pesticides in Nebraska's ground water. *Ground Water Monitoring Review* 9:126-33.