A study of nitrate and atrazine concentrations in groundwater from agricultural use on a sandy, irrigated corn field in the Lower Wisconsin River Valley. [DNR-081] 1997?

Madison, Frederick William, 1937-
Madison, Wisconsin: Wisconsin Department of Natural Resources, 1997?

35 1265

A STUDY OF NITRATE AND ATRAZINE CONCENTRATIONS IN GROUNDWATER FROM AGRICULTURAL USE ON A SANDY, IRRIGATED CORN FIELD IN THE LOWER WISCONSIN RIVER VALLEY

INTRODUCTION

The Lower Wisconsin River Valley (LWRV), from Prairie du Sac to Boscobel, is a broad level valley consisting of sandy soils over deep, coarse textured unlithified subsurface materials. This area represents one of the most hydrogeologically vulnerable settings in the state: a shallow sand and gravel aquifer under irrigated, coarse-textured soils.

The LWRV is an intensively farmed area consisting of irrigated and non-irrigated fields. Because of this high degree of agricultural use combined with the physical characteristics of the area, numerous studies have been conducted in the recent past years to determine the nature and extent of groundwater contamination.

-In 1989, the Department of Natural Resources (DNR) sampled approximately 50 domestic wells (mostly shallow sandpoints) from Arena to Lone Rock and found atrazine in about half of the wells and concentrations of nitrate (NO3-N) often exceeding the drinking water standard of 10 ppm.

-Ciba Geigy (the manufacturer of atrazine) conducted a study in July, 1989 in the same area of the river valley using 27 irrigation wells where the screened interval was usually

60-100 feet below the land surface. Atrazine was detected in 25 of the 27 wells, metalachlor in 13 and nitrate concentrations were over the drinking water standard in all 27 samples (Yeary, 1990).

-The Department of Agriculture, Trade and Consumer Protection (DATCP) installed nests of monitoring wells downgradient from irrigated fields on sandy soil at 15 sites in the LWRV from Prairie du Sac to Bosbobel. The Preventive Action Limit (PAL) for atrazine (0.35 ppb at the time) was exceeded at 13 of the 15 sites and the Enforcement Standard (ES) of 3.5 ppb at 7 of the 15 sites (Postle, 1989). Since this initial study new groundwater standards were implented in 1991. The wells were resampled several times from April to August, 1991. Out of 100 samples taken, 33% of the samples exceeded the new PAL (0.30 ppb) while 19% exceeded the new enforcement standard (3.0 ppb). In addition 23% of these samples had metabolite detects but no parent compound (Postle, 1991).

-The Wisconsin Geological and Natural History Survey, with funding from the DNR, tested 78 wells (mostly domestic wells) from Prairie du Sac to Boscobel (Cates, et al, 1991). Of the 66 samples for which both parent atrazine and metabolites were determined, 28 (43%) had detects. Atrazine metabolites were found in 11 (17%) of the samples when the parent compound was not present. Other pesticides were also detected including metolachlor, alachlor and simazine (Princep). Nitrate concentrations exceeded the drinking water standard in 27 of the 78 (33%) samples taken.

-The University of Wisconsin-Madison Soil Science department has conducted numerous studies on the Sparta loamy fine sand at a research site near Arena, in the LWRV. Soil-column studies showed herbicide movement through the root zone of this soil to be 15 to

100 times greater than a similar, well-drained, sandy soil from the Central Sands (CS) area of Wisconsin (Fermanich, 1994). It was also determined that after 12 hours a 1" rainfall could leach water beyond the root zone in the Sparta soil thus it was concluded that large rainstorm events (> 1") are the driving force for leaching. It was suggested that the well-sorted, uniform sand, a lack of significant morphologic discontinuities and the small organic matter and clay contents, greatly affect the leaching rate of the Sparta loamy fine sand and also that the attenuation of atrazine and nitrogen which are limited at this site.

It's clear from the above studies that atrazine and nitrate are a groundwater quality problem from agricultural use in the LWRV. But what isn't clear is the impact on groundwater quality from different management practices such as reduced inputs of nitrogen and atrazine. Therefore this study proposed to look at atrazine and nitrate concentrations in groundwater by using in-field monitoring wells, at a Nutrient and Pest Management (NPM) demonstration site near Muscoda, Wisconsin. The management practices used on the field were determined by the NPM staff and the farmer.

The proposed study was initially designed for the 1990 and 1991 growing seasons. However, due to the interest in the use and fate of atrazine the study was first extended through June, 1994 and then to June, 1995. During this time (1990-1995) several changes occurred concerning the regulation and use of atrazine.

1. The Atrazine Rule

The DATCP began regulating atrazine use in the state by use of its administrative rules. In 1990, atrazine was prohibited from use around 5 private wells including some in the LWRV. By the 1991 growing season, atrazine was banned from use on all irrigated fields, including those in the LWRV and in 1993 it could not be used anywhere in the LWRV as well as other selected areas in the state.

2. Atrazine analysis

In 1990 only parent atrazine was being analyzed by The State Lab of Hygiene. In 1991, 2 metabolites of atrazine, deethylatrazine and deisopropylatrazine, were added to the analysis and included in total atrazine concentrations. By 1993, another metabolite, diaminoatrazine was added to the analysis.

3. Health standards for atrazine

In 1991 the PAL for atrazine was lowered from 0.35 ppb to 0.3 ppb and the ES was lowered from 3.5 ppb to 3.0 ppb. These standards were to include metabolite concentrations as numerical results became available.

METHODS

Six monitoring wells were installed in April 1990 under a demonstration field site at the Studnicka Brothers Farm in Grant County, near Muscoda. This site was chosen because it was a demonstration site for the UW-Extension Nutrient and Pest Management Program (NPM) which had been selected to show different management practices for irrigated corn production on the sandy soils in the LWRV. In addition, the Studnicka family had expressed concerns about the impacts of agriculture on groundwater quality.

Monitoring wells were established in-field along 2 rows, parallel to the irrigation road (Figure 1). A 3-foot well screen was located just below the water table. The wells were fitted with below-ground couplings so that they could be disconnected at a depth of 18" below the soil surface and tillage operations could proceed normally. When disconnected, wells were capped and iron plates were placed over the wells so they could be located with a ground penetrating radar unit. Once tillage was complete, the above ground sections of the well were reattached to ease sampling throughout the remainder of the year. The wells were surveyed to determine water table elevations; those elevations were then used to determine the direction of groundwater flow. Depth to groundwater was determined on most sampling dates to determine fluccuations in water table elevations (Table 1).

Over the duration of the study, eighteen water samples were collected from each well for nitrate analysis. Nitrate-nitrogen concentrations as well as those of organic and ammonium nitrogen and chlorides were analyzed by a lab in the UW-Madison Soil Science Department.

Sixteen samples from each well were collected and analyzed for atrazine concentrations by the State Lab of Hygiene. Samples taken before 10/25/90 were analyzed for parent atrazine only. From 11/26/90 - 2/4/91 detects of the atrazine metabolites, deethy and deisopropylatrazine were recognized. After 2/4/91, numerical results were reported for these two metabolites. By 3/23/93, a third metabolite, diaminoatrazine was added to the analysis.

The level of detection (LOD) for analysis of parent atrazine and its metabolites and the level of quantitation (LOQ) used by the State Lab of Hygiene are listed below.

State Lab of Hygiene	LOD (ppb)	LOQ (ppb)
Parent Atrazine	0.10	0.40
Deethylatrazine	0.30	0.90
Deisopropylatrazine	0.50	1.70
Diaminoatrazine	0.50	1.60

RESULTS AND DISCUSSION

Soil, subsurface materials and depth to groundwater

Site conditions which include soil, subsurface materials and depth to groundwater all affect the attenuation of potential contaminants. Some soil is better able to attenuate contaminants than others. The soil at the Studnicka site is a Sparta loamy fine sand, 0 - 2% slope. The soil is mostly a well sorted, uniform sand. NPM soil test results indicate organic matter content between 1.2 - 1.8%

Subsurface geological material and depth to groundwater affect contaminant attenuation below the rooting zone. At the Studnicka site depth to groundwater at the monitoring wells ranged from 4.3 feet to 10.4 feet, depending on the well being sampled and time of year (Table 1). When the irrigation well was drilled in 1977, the well drillers log indicated that the depth to water was 10 ft. and that sand was encountered the entire length of the drill hole (115 ft.).

Groundwater flow direction was determined to be in a north-northwesterly direction (figure 1) - moving towards the Wisconsin River, which is a regional discharge area. The monitoring wells were screened across the top of the water table in order to intercept groundwater being recharged from above, in the immediate area of the monitoring well.

Nitrate-Nitrogen

The first samples taken for nitrogen analysis on 4/27/90 indicated nitrate concentrations ranging from 15-27 ppm (Tables 4-9), which are well above the drinking water standard of 10 ppm. One of the goals of the NPM study was to determine the affect on crop yield from different nitrogen application rates. Two of the rates affected the zone of contribution to the 6 monitoring wells in this study. In the zone of contribution to monitoring wells 2, 4, and 6, the recommended application rate of 185 lbs. of available nitrogen (corn yield goal of 141-160 bu/A with < 21 T/A organic matter concent) was applied. Manure and whey permeate were credited with 46 lb. of available N/A and the balance of available nitrogen was applied as commercial fertilizer (anhydrous ammonia, preplant). NPM data indicate that corn yields at this rate averaged 59 bu/A which is well below the corn yield goal. This meant that those nitrates not utilized for crop production were available for leaching. Nitrate leaching did occur as maximum nitrate concentrations increased at these wells (2, 4, and 6) to 37, 49, and 37 ppm during the year following application (4/90 - 4/91). In the zone of contribution to wells 1, 3, and 5, 251 lbs/A of total available N (as manure, whey permeate and commercial fertilizer) was applied. Corn yields averaged 96 bu/A at this rate of application which is also below the expected goal. Maximum nitrate concentrations in wells 1, 3, and 5 reached 64, 56, and 64 ppm during the testing period. There was a clear difference in nitrate concentrations from the 2 different application rates (64, 56, and 64 at 251 lbs N/A vs. 37, 49, and 37 at 185 lbs N/A) although all wells indicate that excess nitrates were reaching the groundwater. Research from the Arena site in the LWRV indicates that large rainfall events (>1") can move water beyond the root zone and a 2 inch event can move water up to 5 feet in 12 hours (Fermanich, 1994). There were 5 rainfall events during the 1990 growing season which exceeded 1 inch/day. Two of these storms exceeded 4 inches/day. Water table elevations increased 2 feet in June (Table 2) as rapid recharge occurred from 10.8 inches of rain during that month (Table 3).

The 1991 growing season was drier than normal (Table 3). Total available nitrogen was applied at a rate of 185 lbs/A for the entire study area and credits were taken for manure and whey. Anhydrous ammonia was side-dressed and a nitrogen inhibitor (N-Serve) was used in the zone contributing recharge to wells 1, 3, and 5 while anhydrous ammonia preplant and N-Serve were used near wells 2, 4, and 6. Corn yields of 150 bu/A were obtained from the side-dress application while 119 bu/A was harvested from the preplant application. Yields from the side-dress application fell within the yield goal range while the preplant application treatment was below the range. Plant and soil samples taken in June indicated a nemotode pressure above the threshold levels at this demostration site which could have affected the yields. Nitrate concentrations decreased by 30-50 ppm at all 6 wells during and immediately after this growing season. Five of the 6 wells went below the drinking water standard by 10/8/91. The data does not indicate any differences in nitrate concentations from the two different applications of nitrogen. It does indicate that high nitrates in the groundwater from the 1990 growing season moved out of the area around the well screen and that the nitrogen applied in the spring of 1991, stayed in the soil profile and was utilized for plant growth. This could be from the use of a nitrogen inhibitor as well as fewer large rainfall events that could leach nitrates to the groundwater.

By 3/25/92, nitrate concentrations increased again to levels above the drinking water standard in 4 of 6 wells. It's not entirely clear why this happened except manure and whey (46 lbs/A available N) were applied very early this year before canning peas were planted on April 8th. Nitrates, from these sources, could have leached to the groundwater during the period of frost melt and spring recharge. After the pea harvest on June 17th, 200 lbs/A of bulk urea (138 lbs/A available N) was applied. A short season corn crop for silage was planted 2 days later. Overall the 1992 growing season was slightly wetter than normal. A second set of samples taken in 1992, after the growing season (12/3/92) indicated all 6 wells had nitrate concentrations above the drinking water standard again, wirh values ranging from 11.9 to 27.7 ppm.

In the spring of 1993, 210 lbs available nitrogen/A was applied for corn production. Forty six lbs/A were credited from manure and whey and 164 lbs available N from anhydrous ammonia. A nitrogen inhibitor was not used. When the wells were sampled on 3/23/93, two of the 6 wells (wells 3 and 4) had a very strong odor (like sour milk), and a pale yellow color. Whey permeate had been applied to this field prior to this date and must have leached very rapidly to the groundwater near these wells during the spring thaw/recharge. Chloride concentrations increased approximately 200 ppm and nitrate concentrations were 0.05 ppm in each well while ammonium was 11.4 and 12.1 ppm and organic nitrogen was 20 and 20.5 ppm. There was no odor or color difference in the other 4 wells and nitrate concentrations ranged from 14.9-25.6 ppm while ammonium and organic nitrogen were usually less than 1 ppm each.

Another round of samples were taken two months later (5/20/93) and although chloride concentrations decreased 150-200 ppm in the sour smelling wells, nitrate concentrations remained about the same. Several months later (8/19/93), the impact from the whey permeate on the 2 monitoring wells was diminishing but still apparent. Nitrate concentrations at these 2 wells were < 5ppm while 3 of the other 4 wells were above 15 ppm. The 1993 growing season was the year of the floods and rainfall amounts far exceeded normal (Table 3). Irrigation was not necessary as rainfall events provided more than enough water for crop growth.

Corn yields for this year were well below the expected yield goal. Harvests were

116 bu/A near wells 1, 3, and 5 and 92 bu/A near wells 2, 4, and 6. This meant excess nitrogen was available for leaching during and after this growing season and there were numerous large rainstorms to move excess nitrates below the root zone and to the groundwater (Table 2). Although nitrate levels were above the drinking water standard in 3 of the 6 wells on 8/19/93, nitrate levels never approached the high levels reached in 1990. This may be due to denitrification from the wet soils and/or dilution from all the water.

After the 1993 growing season, the NPM program was no longer involved with field demonstations on this site. However, monitoring of these groundwater wells continued. By 5/3/94, the affects of the whey on wells 3 and 4 were no longer apparent. Nitrate concentrations ranged from 2.0 to 17.8 ppm with 3 of the wells above the drinking water standard.

One water sample was taken from the irrigation well on 9/25/90. The nitrate concentration was 11 ppm (Table 10). Although the well is screened from 88-113 feet, large capacity wells usually produce a cone of depression when pumping which means some groundwater is pulled into the well from above. Even so, it seems clear that nitrates have moved beyond the surface of the aquifer and have the potential to impact alot of groundwater.

It is clear from the analyzed data that nitrate concentrations at the water table in a rapid flow-through site vary greatly. Better management practices such as nitrogen application rates that reflect realistic yield goals, manure and legume crediting, timing and choice of nitrogen, use of a nitrogen inhibitor, and irrigation scheduling can help reduce nitrate leaching to the groundwater. However even with most of these practices in place at this demonstration site, nitrate levels still remained above the drinking water standard throughout much of the study period. Although better management of nitrogen is helpful in reducing nitrate input to groundwater there are other factors, such as frequency and size of rainfall events, that influence nitrate leaching.

Atrazine

Atrazine was applied for 2 growing seasons (1990 and 1991) using 2 different rates. On 4/29/90 1 lb/A atrazine was applied in the zone of contribution to wells 1, 3, and 5 while 0.5 lbs/A was applied to the recharge area of wells 2, 4, and 6. In 1991, the DATCP initiated the Atrazine Rule which banned atrazine from irrigated fields in the LWRV. However because this study was in place, permission was given to apply atrazine at similar rates to the previous year; it should be noted that these rates were well below the label rate for atrazine application at that time.

The first samples taken for atrazine anaylsis on 8/21/90 showed no detects of parent atrazine. Metabolites or break down products of atrazine were not being anaylzed by the State Lab of Hygiene at this time. However 7 months after the initial application deethyl and deisoproplyatrazine detects were reported. At that time (11/26/90), deethylatrazine was detected (no numerical results) in most of the monitoring wells (4 out of 6) while parent atrazine was present in one well at 0.14 ppb (Tables 4 - 9). By 2/4/91, parent atrazine was found in two of the wells and by 3/25/91, about 11 months after the first application, parent atrazine was found in 4 of the 6 wells. Numerical results were available for the two metabolites, deethyl and deisoproplyatrazine by 3/25/91. On this date 5 of the 6 wells had deethylatrazine concentrations ranging from 0.73 ppb to 1.5 ppb while parent atrazine was usually less than half the levels of deethylatrazine. There was no deisoproplyatrazine in any of the wells. Not one of the wells exceeded the ES although 5 of the wells exceeded the PAL. The highest total atrazine concentration (parent atrazine and 2 metabolites) was 2.17 ppb for well 5. This was reached less than 1 year after the initial application. There wasn't any clear connection between the 2 different application rates and the atrazine concentrations found in the groundwater samples. Additionally there wasn't any clear connection between atrazine levels in groundwater and deep percolation events. Under conditions at the study site, deethylatrazine, although the most leachable, still took about 7 months to reach the groundwater even with numerous large rainfall events (Table 1) which increased the water table elevation by at least 2 feet.

Atrazine was applied for the second growing season on 5/8/91 at similar rates to 1990 (1 lb/A by wells 1, 3, and 5 and 0.5 lbs/A near wells 2, 4, and 5). By 8/28/91, 5 of the 6 wells had total atrazine concentrations exceeding 2 ppb. Well 1 exceeded the ES at 8.8 ppb. (for unexplained reasons atrazine concentrations were often much higher in this well). By 10/8/91, 3 of the wells exceeded the ES. After this time total atrazine concentrations dropped slowly over the next year or so and by 3/25/92 only well 1 exceeded the ES. However, total atrazine concentrations began increasing again and by 5/20/93 deisoproplyatrazine began appearing in the wells (except well 1 where it had been present since 10/8/91) and a third metabolite, diaminoatrazine which had been added to the analysis, was also present. Diaminoatrazine exceeded PAL in all 6 wells and 4 of these wells had total atrazine concentrations exceeding the ES. However it is necessary to add that in 1993 and 1995 other triazine products were used at this study site (Cyanazine (Bladex), 1993; Simazine (Princep) and Cyanazine (Bladex), 1995). Diamino and Deisopropylatrazine are also metabolites of these 2 products. Concentrations of diamino and deisopropylatrazine peak in 1993 and 1995 which may be attributed to the application of these other triazine products.

The data from the last sample set taken on 5/17/95 indicate that well 1 and 5 exceeded the ES, wells 2, 3, and 4 exceeded the PAL, and well 6 has no detect of atrazine or metabolites.

Conclusions

The study site near Muscoda in the LWRV is one of the most vulnerable settings in the state of Wisconsin. The Sparta loamy fine sand overlays a shallow aquifer which ranges from 4 to 10 feet below the ground surface. With irrigation scheduling, water is applied at rates to meet the needs of the crop. However, large rainfall events and rainfall that occurs soon after irrigating causes water movement beyond the root zone, and leachable materials in the soil, such as nitrates, move with it.

Nitrate concentrations fluccuated greatly in the 6 monitoring wells throughout the study period. The highest concentrations in the groundwater occurred from over application of nitrogen from manure, whey permeate, and commercial fertilizer (at 254 lbs/A) in a year with several heavy rainfall events. However even when nitrogen was applied at rates to meet crop needs, deep percolation from these rainstorms moved nitrates beyond the root zone before it could be utilized by the crop. The lowest nitrate concentrations (below the drinking water standard) were achieved in a drier year and with better management practices for sandy soils that included use of a nitrogen inhibitor and side-dress application of nitrogen. Thus it seems that nitrate leaching seems strongly related to the amount and timing of rainfall/irrigation with respect to the time and amount of available nitrogen application in the upper root zone. This means that even with the best management practices large or unpredicatable rainstorm events can leach nitrates through these sandy soils to the groundwater thus making it difficult to meet groundwater quality standards immediately below this field.

Parent atrazine and its metabolites are not nearly as leachable as nitrates. The study area, with uniform sand particles and small organic matter and clay content had relatively little capacity to sorb atrazine but nevertheless it's movement was retarded. Even with several rainfall events in 1990, which caused deep percolation it took about a year for parent atrazine to reach the water table. If the results of this study had been based on parent atrazine only, not one of the well samples would have exceeded the ES and only a few samples from each of the wells would have exceeded the PAL. However with the addition of metabolite analysis, total atrazine concentrations often exceeded

PAL and at times, the ES. Deethylatrazine appeared to be the most mobile compound. It was detected sooner, showed up in more samples, stayed around longer and was at higher concentrations than parent atrazine. The other 2 metabolites (diamino and deisopropylatrazine) were not detected until at least 3 years after initial application of atrazine. However these 2 metabolites are also breakdown products of 2 other frequently used triazine herbicides, namely Cyanazine (Bladex) and Simazine (Pricep). The State Lab of Hygiene does not differentiate the source of these metabolites. This potentially affects the results of this study as these herbidices were used on the study site in 1993 and 1995. This suggests that the concentrations of diamino and deisopropylatrazine may not be attibuted to atrazine alone. However approximately 1.5 years after the initial application of atrazine, 4 of the 6 wells exceeded the ES. This occurred prior to the application of the other triazine products.

Four years after the last application of atrazine (but which also includes the applications from cyanazine (Bladex) and simazine (Princep)) total atrazine concentrations (parent atrazine plus 3 metabolites) were over 2 ppb in 4 of the 6 wells (wells 1, 3, 4, and 5). Only one well (well 6) had no detectable level of parent atrazine or any metabolites. There seems to be a relationship to application rates of atrazine over time however this may be questionable if the use of these other triazine products affects the metabolite concentrations. Regardless of use of other triazine products, this study does suggests that atrazine stays in the soil and is released slowly over time. How long it stays and is available for leaching has yet to be determined.

Recommendations

In order to reduce the quantity of nitrate reaching the groundwater in the LWRV, nitrogen should be applied at amounts that meet realistic yield goals. Management practices to minimize nitrogen application should include nitrogen crediting from manure, legumes, whey and other sources. Other recommended practices to reduce nitrate leaching and increase plant usage include ridge-placed N in a ridge-tillage system, (Dolan, et al, 1994) band-application, split-N applications and use of a nitrogen inhibitor. Although heavy rainstorms can not be controlled, precipitation forecasting along with irrigation scheduling can help reduce large water inputs.

Atrazine was banned from the LWRV by the DATCP in 1991. Data from this study show that after 2 years of applying atrazine at a reduced rate of 0.5 lbs/A, total atrazine concentrations exceeded the PAL at all 3 wells located within the zone of contribution and exceeded the ES in 1 well, within 1.5 years after initial application. After this time total atrazine concentrations began declining however there were significant peaks in 1993 and again in 1995. These were the years when other triazine herbicides are applied on this field. These herbicides break down into metabolites which are not differentiated to source by the current analytic methods used by the State Lab of Hygiene. Because of the peaks in metabolites after the application of these other triazines these results may raise questions concerning the atrazine standard. Further study is needed.

Table 4. Studnicka Monitoring Well #1

Well ID	Date	P Atraz ppb	Deethyl ppb	Deisop ppb	Diamino ppb	Total Atr ppb	NO3-N ppm	NH4 ppm	Org N ppm	Total N ppm	Cl mg/l
1	04/27/90	NC	NC	NC	NC	NC	20	NC	NC	NC	NC
1	07/17/90	NC	NC	NC	NC	NC	24.3	1	2	27	13
1	08/21/90	<D	ND	ND	ND	<D	NC	NC	NC	NC	NC
1	09/25/90	<D	ND	ND	ND	<D	57.2	0.8	0.1	58	21
1	10/25/90	NC	NC	NC	NC	NC	44.6	0.9	0.1	46	17
1	11/26/90	<D	D	<D	ND	D	61.9	2.2	0.1	64	16
1	02/04/91	<D	D	<D	ND	D	52.9	0.8	5.7	59	23
1	03/25/91	<D	0.7	<D	ND	0.7	48.3	0.9	0.05	49	18
1	08/28/91	1.3	7.5	<D	ND	8.8	10.4	0.4	1.4	12	59
1	10/08/91	1.9	8.9	0.8	ND	11.6	18.3	0.2	2.1	21	54
1	12/10/91	1.3	6.7	1	ND	9	28.3	0.6	2.1	31	39
1	03/25/92	1.1	8.6	<D	ND	9.7	32.5	0.6	9.8	43	33
1	12/03/92	1	4.9	0.9	ND	6.8	27.7	0.3	0.7	29	22
1	03/23/93	0.7	4.5	0.9	1.2	7.3	25.6	0.6	1.3	28	19
1	05/20/93	0.6	3	1.2	1.2	6	25.5	1.1	0.8	27	16
1	08/19/93	0.4	2.6	3.3	2.4	8.7	22.6	0.3	4.3	27	10
1	03/01/94	0.2	1	1.8	1.5	4.5	13.9	0.1	1.6	16	8
1	05/03/94	0.2	1	1.8	1.6	4.6	14.9	0.1	1.2	16	7
1	05/17/95	0.1	0.7	5.1	2.6	8.5					

NC - No sample collected
ND - Not determined
D - Detect
<D - Less than detectable level

Table 5. Studnicka Monitoring Well #2

Well ID	Date	P Atraz ppb	Deethyl ppb	Deisop ppb	Diamino ppb	Total Atr ppb	NO3-N ppm	NH4 ppm	Org N ppm	Total N ppm	Cl mg/l
2	04/27/90	NC	NC	NC	NC	NC	23	NC	NC	NC	NC
2	07/17/90	NC	NC	NC	NC	NC	24.5	1.8	0.1	26	10
2	08/21/90	<D	ND	ND	ND	0	NC	NC	NC	NC	NC
2	09/25/90	<D	ND	ND	ND	0	36	0.9	0.1	37	20
2	10/25/90	NC	NC	NC	NC	NC	33.6	0.7	0.1	34	18
2	11/26/90	<D	D	<D	ND	D	33.1	0.8	0.1	34	20
2	02/04/91	<D	D	<D	ND	D	36.2	0.9	0.05	37	35
2	03/25/91	0.1	0.8	<D	ND	0.9	33.4	0.4	0.05	34	53
2	08/28/91	0.3	2.5	<D	ND	2.8	11.1	0.4	0.7	12	44
2	10/08/91	0.5	3.3	<D	ND	3.8	0.4	1.3	0.05	2	73
2	12/10/91	0.5	2.6	<D	ND	3.1	1.4	0.3	0.6	2	73
2	03/25/92	0.3	2.2	<D	ND	2.5	3.6	1.1	0.05	5	52
2	12/03/92	0.2	1.5	<D	ND	1.7	19.8	0.3	0.05	20	11
2	03/23/93	0.2	0.9	<D	<D	1.1	14.9	0.3	1	16	7
2	05/20/93	0.2	1	1.2	0.8	3.2	20.7	0.5	0.01	21	12
2	08/19/93	0.1	0.7	2.5	1	4.3	19.2	0.2	0.7	20	11
2	03/01/94	<D	<D	1.8	1.1	2.9	12	0.3	0.3	13	8
2	05/03/94	<D	<D	1.5	0.8	2.3	11.9	0.05	1.7	14	7
2	05/17/95	<D	<D	0.8	0.6	1.4					

NC - No sample collected
ND - Not determined
D - Detect
<D - Less than detectable level

Table 6. Studnicka Monitoring Well #3

Well ID	Date	P Atraz ppb	Deethyl ppb	Deisop ppb	Diamino ppb	Total Atr ppb	NO3-N ppm	NH4-N ppm	Org N ppm	Total N ppm	Cl mg/l
3	04/27/90	NC	NC	NC	NC	NC	22	NC	NC	NC	NC
3	07/17/90	NC	NC	NC	NC	NC	32.2	0.7	2.5	35	13
3	08/21/90	<D	ND	ND	ND	<D	NC	NC	NC	NC	NC
3	09/25/90	<D	ND	ND	ND	<D	49.2	2.1	0.1	51	17
3	10/25/90	NC	NC	NC	NC	NC	39.5	2.1	0.1	42	13
3	11/26/90	<D	<D	<D	ND	<D	48.2	1.5	0.1	50	20
3	02/04/91	<D	<D	<D	ND	<D	54.8	1.5	0.05	56	39
3	03/25/91	<D	<D	<D	ND	<D	41.5	1.2	0.05	43	31
3	08/28/91	0.2	1.8	<D	ND	2	17.9	0.4	0.6	19	23
3	10/08/91	0.2	2.2	<D	ND	2.4	8.7	0.8	0.8	10	43
3	12/10/91	0.2	3.1	<D	ND	3.3	7.7	0.2	0.7	9	67
3	03/25/92	<D	2.4	<D	ND	2.4	24.3	0.3	0.05	25	28
3	12/03/92	<D	1.4	<D	ND	1.4	20.9	0.3	0.6	22	47
3	03/23/93	*	<D	<D	*	*	0.05	12.1	20	32	257
3	05/20/93	<D	0.5	<D	0.6	1.1	0.1	2.4	48	51	68
3	08/19/93	<D	0.5	1.9	1.1	3.5	4.3	1	2.5	8	40
3	03/01/94	<D	<D	0.6	<D	0.6	7.5	0.6	3.1	11	11
3	05/03/94	<D	<D	0.7	<D	0.7	2	0.6	1.7	4	12
3	05/17/95	<D	<D	1.3	1.1	2.4					

NC - No sample collected
ND - Not determined
* - Contaminated sample
<D - Less than detectable level

Table 7. Studnicka Monitoring Well #4

Well ID	Date	P Atraz ppb	Deethyl ppb	Deisop ppb	Diamino ppb	Total Atr ppb	NO3-N ppm	NH4-N ppm	Org N ppm	Total N ppm	Cl mg/l
4	04/27/90	NC	NC	NC	NC	NC	15	NC	NC	NC	NC
4	07/17/90	NC	NC	NC	NC	NC	24.5	1	2	27	13
4	08/21/90	<D	ND	ND	ND	<D	NC	NC	NC	NC	NC
4	09/25/90	<D	ND	ND	ND	<D	48.1	1	0.1	49	18
4	10/25/90	NC	NC	NC	NC	NC	41.3	0.8	0.1	42	17
4	11/26/90	<D	<D	<D	ND	<D	35.9	1	0.1	37	14
4	02/04/91	<D	D	<D	ND	D	13.9	0.9	3	18	20
4	03/25/91	0.2	1.1	<D	ND	1.3	15	0.3	0.8	16	16
4	08/28/91	<D	0.9	<D	ND	0.9	6.7	0.2	0.4	7	40
4	10/08/91	<D	0.6	<D	ND	0.6	0.4	0.5	0.9	2	77
4	12/10/91	<D	0.8	<D	ND	0.8	0.2	0.3	1.6	2	80
4	03/25/92	<D	0.7	<D	ND	0.7	15	0.6	0.05	16	47
4	12/03/92	<D	0.5	<D	ND	0.5	13.8	0.5	0.05	14	53
4	03/23/93	*	<D	<D	*	*	0.05	11.4	20.5	32	241
4	05/20/93	<D	0.8	0.6	0.7	2.1	0.23	4.3	6.9	12	41
4	08/19/93	<D	<D	0.5	<D	0.5	0.4	1.2	1.2	3	14
4	03/01/94	<D	<D	<D	<D	<D	6.4	0.3	1.2	8	15
4	05/03/94	<D	<D	<D	<D	<D	7	0.3	2	9	10
4	05/17/95	<D	<D	1.6	0.8	2.4					

NC - No sample collected
ND - Not determined
D - Detect
* - Contaminated sample
<D - Less than detectable level

Table 8. Studnicka Monitoring Well #5

Well ID	Date	P Atraz ppb	Deethyl ppb	Deisop ppb	Diamino ppb	Total Atr ppb	NO3-N ppm	NH4 ppm	Org N ppm	Total N ppm	Cl mg/l
5	04/27/90	NC	NC	NC	NC	NC	27	NC	NC	NC	NC
5	07/17/90	NC	NC	NC	NC	NC	29	0.8	0.9	31	16
5	08/21/90	<D	ND	ND	ND	<D	NC	NC	NC	NC	NC
5	09/25/90	<D	ND	ND	ND	<D	49.4	1.1	0.1	51	22
5	10/25/90	NC	NC	NC	NC	NC	40.1	1.7	0.1	42	25
5	11/26/90	<D	D	<D	ND	D	62	1.4	0.5	64	27
5	02/04/91	0.5	D	<D	ND	0.5	57.8	0.5	0.05	58	44
5	03/25/91	1	1.2	<D	ND	2.2	49.4	0.4	0.05	50	39
5	08/28/91	0.4	2.3	<D	ND	2.7	9.1	0.6	0.6	10	36
5	10/08/91	0.5	3.4	<D	ND	3.9	5.9	0.1	0.5	7	54
5	12/10/91	0.2	2.4	<D	ND	2.6	8.4	0.5	17.3	26	33
5	03/25/92	0.3	1.9	<D	ND	2.2	31.9	0.05	0.05	32	7
5	12/03/92	0.2	2.6	<D	ND	2.8	25.3	0.2	3.3	29	22
5	03/23/93	0.2	2.1	<D	0.6	2.9	24	0.05	1.3	25	36
5	05/20/93	0.2	1.7	1.3	1	4.2	29.8	0.2	0.01	30	40
5	08/19/93	0.1	0.8	3.3	1.1	5.4	15.2	0.2	0.9	16	11
5	03/01/94	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC
5	05/03/94	<D	0.4	1.6	0.8	2.8	17.8	0.05	1.1	19	9
5	05/17/95	<D	<D	7.1	1.5	8.6					

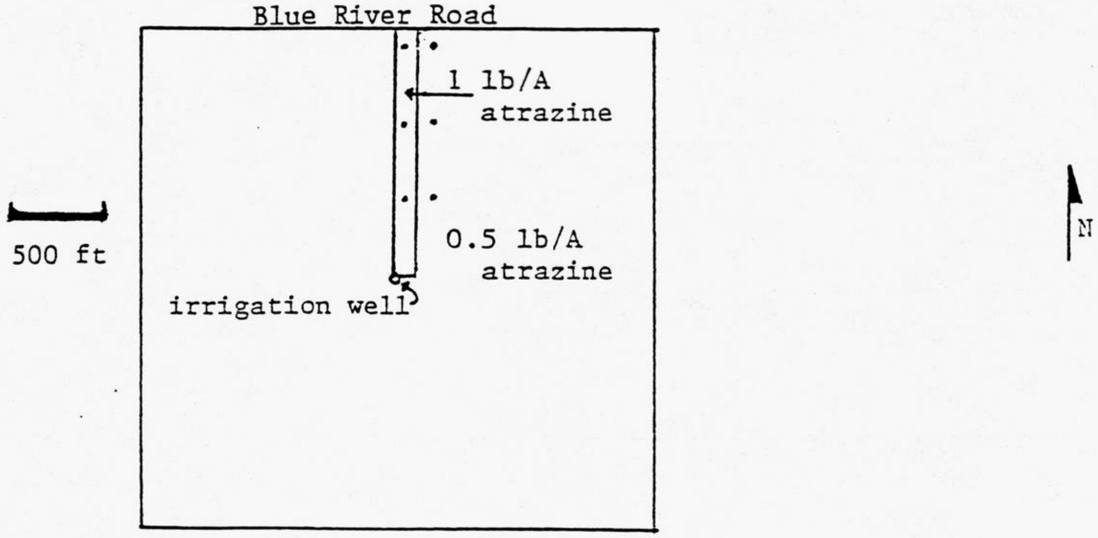
NC - No sample collected
ND - Not determined
<D - Less than detectable level

Table 9. Studnicka Monitoring Well #6

Well ID	Date	P Atraz ppb	Deethyl ppb	Deisop ppb	Diamino ppb	Total Atr ppb	NO3-N ppm	NH4 ppm	Org N ppm	Total N ppm	CL mg/l
6	04/27/90	NC	NC	NC	NC	NC	27	NC	NC	NC	NC
6	07/17/90	NC	NC	NC	NC	NC	25.2	1	1.3	27	13
6	08/21/90	<D	ND	ND	ND	<D	NC	NC	NC	NC	NC
6	09/25/90	<D	ND	ND	ND	<D	29.3	1.5	0.1	31	11
6	10/25/90	NC	NC	NC	NC	NC	36.1	1.1	0.1	37	16
6	11/26/90	0.1	D	<D	ND	0.1	33.3	0.8	0.1	34	15
6	02/04/91	0.2	D	<D	ND	0.2	31.7	1.9	0.05	34	21
6	03/25/91	0.3	1.5	<D	ND	1.8	29.4	0.3	0.05	30	23
6	08/28/91	0.8	2	<D	ND	2.8	0.6	0.3	0.5	1	115
6	10/08/91	0.6	1.9	<D	ND	2.5	0.1	0.2	0.6	1	89
6	12/10/91	0.5	2.2	<D	ND	2.7	1.1	1.1	2.5	5	95
6	03/25/92	0.3	1.5	<D	ND	1.8	3.2	0.3	0.3	4	61
6	12/03/92	0.4	1.1	<D	ND	1.5	11.9	0.7	1	14	50
6	03/23/93	0.2	1	1	<D	2.2	23	0.05	0.6	24	63
6	05/20/93	0.2	0.6	2.4	0.9	4.1	17.1	0.1	2.2	19	57
6	08/19/93	<D	<D	1	<D	1	0.6	0.2	0.9	2	57
6	03/01/94	<D	<D	<D	<D	<D	16.9	3.6	0.05	21	13
6	05/03/94	<D	<D	<D	<D	<D	8.3	2.8	2	13	9
6	05/17/95	<D	<D	<D	<D	<D					

NC - No sample collected
ND - Not determined
D - Detect
<D - Less than detectable level

Figure 1. Groundwater Monitoring Wells



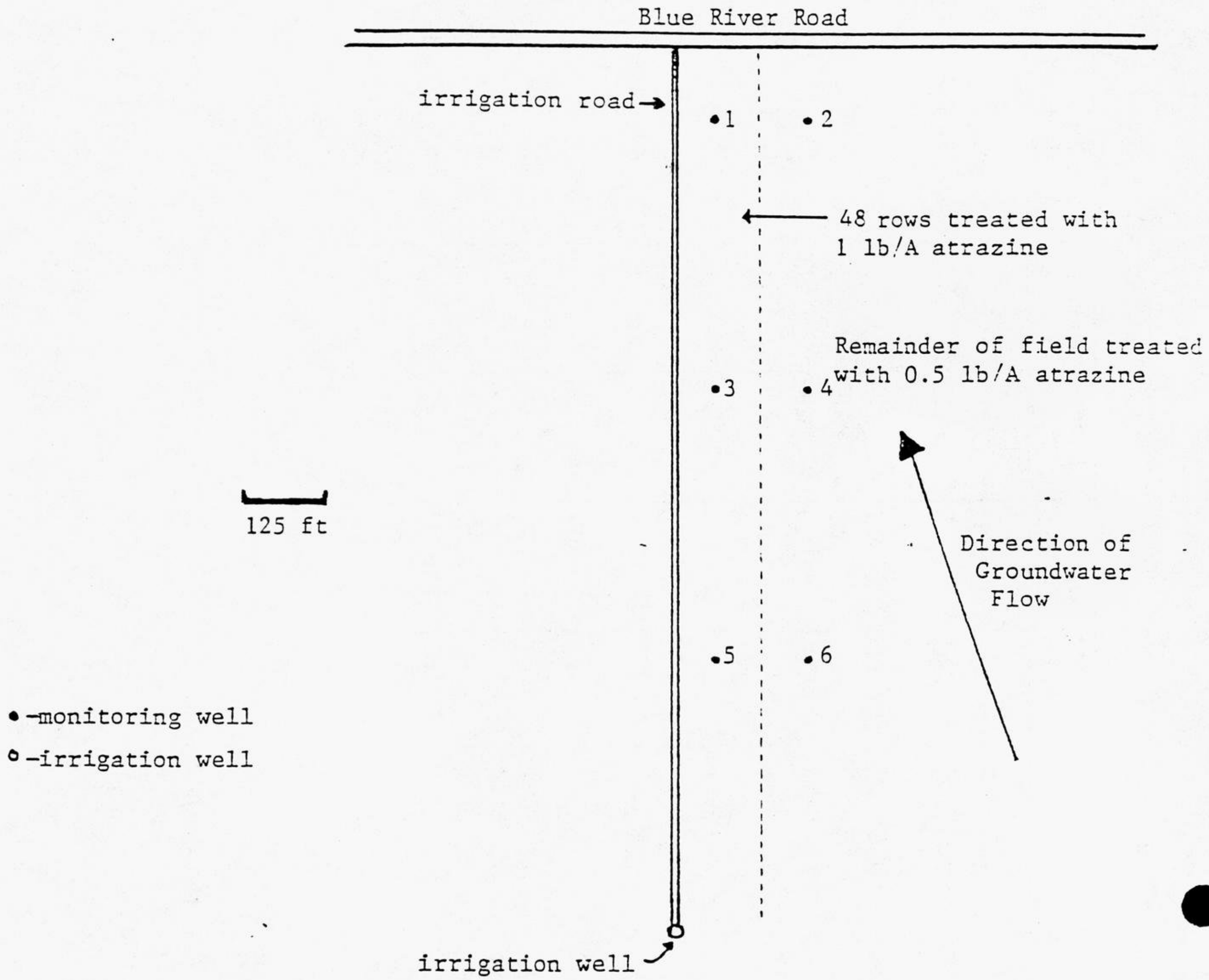


Table 1: Depth to Groundwater

	Well 1	Well 2	Well 3	Well 4	Well 5	Well 6
04/27/90	9.05	8.82	9.33	8.66	10.40	-
07/11/90	6.97	6.72	-	-	-	-
07/17/90	-	-	7.57	6.87	8.88	8.23
08/21/90	7.33	7.07	7.62	6.94	8.68	8.00
09/25/90	7.44	7.18	7.25	7.05	8.75	8.13
10/25/90	7.88	7.64	8.20	7.50	9.19	8.57
11/26/90	8.25	7.97	8.56	7.85	9.59	8.93
02/04/91	8.92	8.60	9.16	8.48	10.16	9.53
08/28/91	8.04	7.85	8.41	7.72	9.35	8.71
10/08/91	8.09	7.82	8.38	7.67	*	8.74
12/10/91	7.03	6.76	7.31	6.61	*	7.68
03/25/92	7.16	6.88	7.44	6.76	8.35	7.82
03/23/93	7.17	6.92	7.46	6.72	*	7.73
05/20/93	4.69	4.44	5.02	4.28	*	5.28
03/01/94	6.34	6.07	6.59	5.34	*	6.81

- depth to water was not measured
* broken well casing

Table 2: Rainfall events > 1" for May-September, 1990-1993

	May	June	July	August	Sept.
1990 (1)	1.1	2.5		4.5	
		4.9		1.2	
1991 (1)		2.4		1.7	1.4
		1.5			1.8
1992 (2)		1.1	1.4	1.3	1.1
			1.4		1.8
					1.1
1993 (2)	1.5	1.5	2.4	3.2	
			1.0	1.5	
			1.6		
			1.4		

Table 3: Rainfall for May-September, 1990-1993

Total Rainfall Amounts (inches)

	May	June	July	August	Sept.	Total
1990 (1)	2.1	10.8	1.8			= 23.1
1991 (1)	3.6	5.0	0.7	2.3	5.7	= 17.3
1992 (2)	1.6	1.5	5.8	3.0	7.3	= 19.2
1993 (2)	5.3	5.4	9.4	6.2	2.4	= 28.7
Normal	3.14	3.61	3.49	3.91	3.87	= 18.01

(data from NOAA 30 year average from Lone Rock and Prairie du Sac)

(1) Muscoda weather station data

(2) Arena weather station data

Table 10. Studnicka Irrigation Well

Well ID	Date	P.Atraz. ppb	Deethyl ppb	Deisop ppb	Diamino ppb	Total Atr ppb	NO3-N ppm	NH4 ppm	Org N ppm	Total N ppm	Cl mg/l
irrigation	09/25/90	0.24	NA	NA	NA	0.24	11.2	1.2	0.1	12	12

Postle, Jeffrey K., 1989. Results of the WDATCP Groundwater Monitoring for Pesticides. (memo report, Agricultural Resource Management division, Department of Agriculture, Trade and Consumer Protection)

Postle, Jeffrey K., 1991. Groundwater Monitoring Project for Pesticides. Results from 1991 Atrazine and Metabolite testing. (Memo report, Agricultural Resource Management division, Department of Agriculture, Trade and Consumer Protection.

Yeary, JoAnne, 1990. Sampling Irrigation Wells for Atrazine and Metolachlor in the Lower Wisconsin River Valley. Giba Geigy Corporation, Document #CG02846.2.1.

Cates, Kim J., Dr. Fred Madison and Jeffrey Postle, 1992. Drinking water and Groundwate Quality in the Lower Wisconsin River Valley. Wisconsin Department of Natural Resources final report.

Dolan, P.W., et al., 1993. Nitrogen Placement and Leaching in a Ridge-Tillage System. Pp 176-183. In: Proceedings from Agricultural Research to Protect Water Quality Conference. Feb. 1993, Minneapolis, MN.

Fermanich, Kevin, 1994. Herbicide and nitrate movement in a sandy soil in the Lower Wisconsin River Valley near Arena, WI. Field day summary July 19, 1994.