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FINAL REPORT TO

WISCONSIN DEPARTMENT OF AGRICULTURE, TRADE AND CONSUMER PROTECTION

AND THE WISCONSIN DEPARTMENT OF NATURAL RESOURCES

SOURCES AND EXTENT OF ATRAZINE CONTAMINATION OF GROUNDWATER AT GRADE A DAIRY FARMS IN DANE COUNTY, WI

by

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I. JUSTIFICATION

In 1988 and 1989, the Wisconsin Department of Agriculture, Trade and Consumer Protection (WDATCP) conducted a survey of the water quality in private drinking water wells on Grade A dairy farms across Wisconsin. Water samples were analyzed for many commonly used pesticides and nitrate-nitrogen. The WDATCP determined with 95% confidence that between 9 and 15% of the state's Grade A dairy farm wells contain detectable amounts of atrazine. The South Central Agricultural Statistics District had the highest number of atrazine detects and the WDATCP determined with 95% confidence that between 19 and 39% of wells from that district have water contaminated with atrazine. In early 1990, a second survey was conducted in which residents voluntarily sent water samples to the WDATCP for analysis. Although the sampling was not random, rough agreement was found with the Grade A survey, helping to confirm the extent of atrazine contamination in the state.

In 1984, comprehensive groundwater legislation was enacted in Wisconsin, establishing a system for setting groundwater quality standards and laying out the responsibilities of regulatory agencies if standards were violated. In this two-tier system, an enforcement standard (ES) of 3.5 ppb and a preventive action limit (PAL) of 0.35 ppb were promulgated for atrazine in October 1988. When an ES is exceeded, the WDATCP must prohibit the activity or practice that caused the violation. In the case of pesticides, ES violations usually dictate a use prohibition. In response to a PAL violation, the WDATCP can take a variety of actions including promulgation of administrative rules to ensure that the ES will not be violated. In the Grade A survey, 39 of 534 wells had atrazine concentrations above the PAL; three had concentrations above the ES. Consequently, in April 1991 the WDATCP promulgated chapter AG 30, Wisconsin Administrative Code, restricting atrazine use and reducing maximum allowable application rates. The restrictions are controversial because atrazine is the most widely used herbicide in Wisconsin. The groundwater legislation had never before been applied to such a widely-used substance.

Public hearings regarding the proposed rule in October 1990 attracted many farmers, university faculty, environmentalists and pesticide manufacturers and distributors. Many objections centered on technical issues yet to be resolved by research. The question was raised whether atrazine contamination resulted from point or nonpoint sources. If the widespread contamination is largely a point source problem, then the proposed restrictions will not alleviate the problem. In addition, new regulations have recently been enacted to control such point sources as pesticide mixing and loading sites. Some who testified against the rule urged the WDATCP to wait and see if the point-source rules effectively reduce atrazine concentrations in groundwater. They also questioned whether atrazine residues found in groundwater result from 30 years of use and not from seasonal leaching to groundwater. The residues might date back to previous years when atrazine use was more widespread and application rates were higher than presently allowed. Finally, those in opposition suggested that further investigations be conducted to determine the true extent (in time and space) of atrazine contamination of groundwater before reacting with restrictions that might impose undue economic hardship on Wisconsin farmers.

Since initiation of the research project described here, the presence in groundwater of potentially harmful atrazine metabolites has become an issue. At this study's field site in Waunakee, WI, metabolite residues have been found in groundwater, often at concentrations exceeding those of the parent compound. Little is currently known of their toxicological significance or their extent in groundwater. The ES of 3.5 ppb and PAL of 0.35 ppb were established solely for the parent compound. Until now, no standard has been established which includes atrazine metabolites. The Wisconsin Department of Health and Social Services (WDHSS) is responsible for recommending ES values to the Wisconsin Department of Natural Resources (WDNR). Based on toxicological studies reviewed by the WDHSS, it was concluded that little difference exists in the biological effects from exposure to atrazine or its chlorinated metabolites (Anderson et al., 1990). The WDHSS therefore recommended that a standard be established for the sum of atrazine and its toxicologically significant, chlorinated metabolites:

desethylated atrazine, desisopropylated atrazine, and diamino-chloro-*s*-triazine. Since more toxicological information is available on the parent compound, the numerical standard will be based on a risk assessment of exposure to the parent compound alone, and applied to the sum of the concentrations of the four compounds. Based on an expected federal maximum contaminant level of 3.0, the WDHSS recommended an ES and PAL of 3.0 and 0.3 ppb. The proposed standards have been approved by the Natural Resources Board and are awaiting approval from the legislature. If the standards are included in chapter NR 140, Wisconsin Administrative Code, the WDATCP may have to strengthen AG 30 to ensure that the new standards are not violated. The inclusion of metabolites in the proposed 3.0 ppb standard might substantially increase restriction on atrazine use in Wisconsin, especially if the patterns observed at the Waunakee site are typical.

Such pesticide-use rules as AG 30 are partly based on groundwater monitoring data. Site-specific restrictions are based on frequency and/or magnitude of pesticide detections in that area. For example, in AG 30, atrazine application is limited to a maximum rate of 0.75 lb/acre (0.84 kg/ha) in the lower Wisconsin River valley Atrazine Management Area due to the high incidence of detections exceeding the PAL. Prohibition areas also are established for quarter-quarter sections of townships that are within a groundwater basin in which atrazine residues have been detected in excess of the ES. It is likely that more wells will violate the ES than currently do once metabolites are included in the standard. More standard violations may lead to establishment of additional Atrazine Management Areas with severely restricted use. The WDATCP and WDNR have expanded their monitoring programs to include analysis for atrazine metabolites. More data are needed to assess the impact of metabolites on regulations and agricultural management practices.

Although large-scale monitoring surveys answer some questions of regulatory significance, smaller-scale, detailed studies such as the Waunakee project are needed to identify the extent (temporal and spatial) and sources of contamination. Only in this way can the effectiveness of a given pesticide restriction or prohibition be assessed.

II. STUDY OBJECTIVES

Emphasis was on the fate and transport of atrazine and its metabolites in the soil and the unlithified deposits overlying the bedrock aquifer that serves as the source of drinking water for most area residents. The investigation of unlithified deposits determines to what extent movement of residues through these deposits can serve as the source of contamination of the bedrock aquifer. Although some private bedrock wells were sampled occasionally, a thorough investigation of the bedrock system was beyond the scope of this study. Objectives were to gain insights into pesticide transport in the soil and unlithified deposits and to assess the temporal and spatial sources of the contamination. Specific objectives were:

1. Investigate and characterize the extent and distribution of atrazine residue concentrations in soil and shallow groundwater and over a 2-yr period, observe their temporal and spatial patterns.
2. Determine whether the concentrations show a seasonal variability that can help establish the time of transport through the unsaturated zone.
3. Characterize rates and amounts of atrazine residue leaching through the unsaturated zone and describe the relative mobilities of the compounds.
4. Predict the likely zones of contribution for specific monitoring wells and relate the concentrations at those wells to the characteristics of the zones. Use these predictions to assess the importance of point and nonpoint sources.
5. Predict the time of transport of atrazine residues through the groundwater system to selected monitoring wells and relate concentrations of the compounds to predicted residence times.
6. Predict contaminant impact on the bedrock aquifer based on observed rates of movement and extent of contamination in the unlithified deposits.

7. Discuss the implications of the findings of this study on Wisconsin's atrazine regulations.

III. BACKGROUND

A. Atrazine and Formation of its Metabolites

Atrazine [2-chloro-4-ethylamino-6-isopropylamino-*s*-triazine] was released in 1953 and is now the most widely used herbicide in Wisconsin and the United States (Wehtje et al., 1984). In Wisconsin it is used to control annual broadleaf and grassy weeds in corn and sorghum and in 1985, was applied to 77% of all Wisconsin corn fields. By 1989 it had declined to 52% (USDA Economic Research Service, 1990). Atrazine inhibits photosynthetic electron transport in target plants. Resistant species like corn have the ability to rapidly metabolize and detoxify atrazine (Wehtje et al., 1984). In the environment, atrazine is transformed by chemical and biological means. Names of the metabolites and degradation pathways of atrazine are shown in Fig. 1 and Table 1.

Chemical degradation of atrazine occurs by hydrolysis to hydroxyatrazine (Fig. 1, compound 2) in which the Cl is replaced by a OH group; hydroxyatrazine is less phytotoxic than atrazine and is taken-up by plants less readily than atrazine (Jones and Winchell, 1984; Jones et al., 1982). If the reaction is sufficiently rapid, carryover problems are not encountered. Hydroxyatrazine was not included in the proposed new standard since it was considered less of a threat to human health by the WDHSS than the chlorinated metabolites (Anderson et al., 1990). Based on the narrow differences between atrazine degradation rates in sterile and nonsterile soils, chemical degradation of atrazine appears to be the dominant, but not sole transformation mechanism (Chesters et al., 1988; Junk et al., 1984; Saltzman and Mingelgrin, 1984; Armstrong et al., 1967; Harris, 1967). Chesters et al. (1988) assuming first-order kinetics, found half-life ($t_{1/2}$) increases of 36 to 78 d, 53 to 67 d and 48 to 79 d in a loam, silt-loam and sand, respectively after sterilization. In a ^{14}C-labeled atrazine column transport study Green et al. (1968) found that about 35% of the activity recovered from the column after 10 weeks was identified as

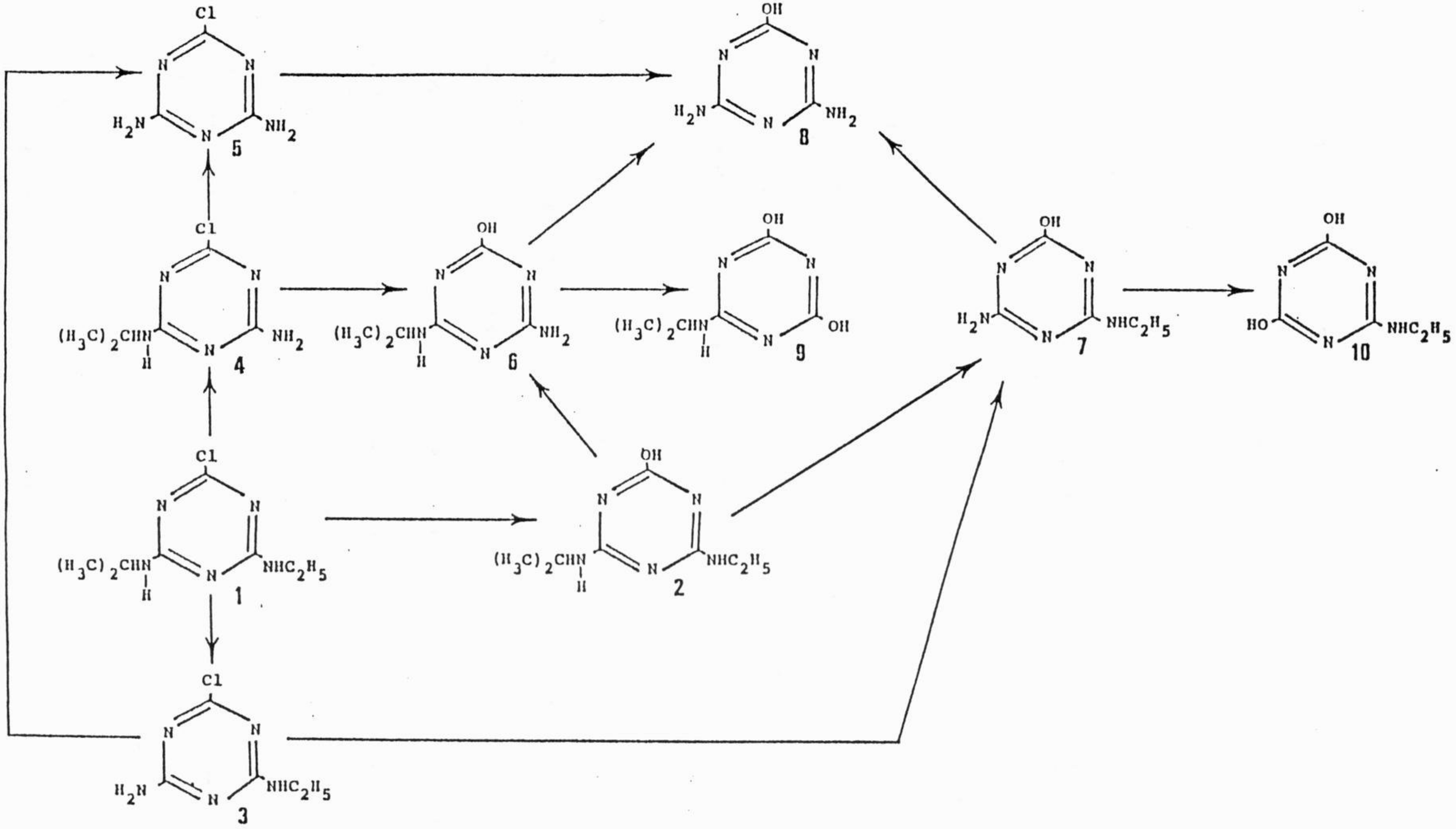

Figure 1. Degradation pathways of atrazine (1) and its metabolites (2 - 10).

Table 1. Atrazine and metabolites likely to be found in soils.

Compound code[a]	Chemical name	Common name
1	2-Chloro-4-ethylamino-6-isopropylamino-*s*-triazine	Atrazine
2	2-Hydroxy-4-ethylamino-6-isopropylamino-*s*-triazine	Hydroxyatrazine
3	2-Chloro-4-ethylamino-6-amino-*s*-triazine	Desisopropylated atrazine
4	2-Chloro-4-amino-6-isopropylamino-*s*-triazine	Desethylated atrazine
5	2-Chloro-4,6-diamino-*s*-triazine	Diamino-chloro-*s*-triazine
6	2-Hydroxy-4-amino-6-isopropylamino-s-triazine	Desethylated hydroxyatrazine
7	2-Hydroxy-4-ethylamino-6-amino-*s*-triazine	Desisopropylated hydroxyatrazine
8	2-Hydroxy-4,6-diamino-*s*-triazine	Diamino-hydroxy-*s*-triazine
9	2,4-Dihydroxy-6-isopropylamino-*s*-triazine	
10	2,6-Dihydroxy-4-ethylamino-*s*-triazine	

[a] Refers to compounds in Fig. 1.

hydroxyatrazine. Skipper and Volk (1972) added ^{14}C-labeled atrazine to three Oregon soils and found that after 28 d about 40% of the recovered activity from a silt-loam soil was hydroxyatrazine, but hydroxyatrazine accounted for only 10-12% of the activity recovered from a clay and loam soil. It was hypothesized that the lower pH of the clay or organic matter surfaces of the silt loam soil accounted for the difference. After 12 months under field conditions hydroxyatrazine accounted for 77% of the total atrazine residues detected in the top 40 cm of soil (Muir and Baker, 1978). Dao (1977) also found hydrolysis to be the major atrazine degradation pathway and calculated a hydrolysis half-life ($t_{1/2}$) of 48 d at 30 C over 240 d. The $t_{1/2}$ of a pesticide is calculated when the degradation process follows first-order kinetics. In general, a degradation rate constant can be derived from the power law:

$$-\frac{dC}{dt}=kC^{n} \tag{1}$$

where C is concentration of the compound,

t is time,

k is the degradation rate constant and

n is the order of the reaction.

For first-order kinetics, $n=1$, and through integration:

$$\ln\frac{C_0}{C}=kt \tag{2}$$

where C_0 is the initial concentration.

Degradation rates can then be expressed either by the rate constant or with a $t_{1/2}$ equal to ln(2)/k. First-order kinetics often are assumed when simulating pesticide degradation.

Atrazine hydrolysis is accelerated the farther the soil pH is from neutral. Armstrong et al. (1967) assumed first-order kinetics and found that for acid systems:

$$\log t_{1/2} = 0.62(\mathrm{pH}) - 0.1 \tag{3}$$

and for alkaline systems:

$$\log t_{1/2} = 5.64 - 0.9(\mathrm{pH}-7) \tag{4}$$

where $t_{1/2}$ is for the hydrolysis of atrazine.

Under acid conditions, protonation of the triazine ring N atoms weaken the C-Cl bond. Under alkaline conditions, direct displacement of the Cl with the OH is enhanced. Hydrolysis reactions are also enhanced when the atrazine molecule is sorbed at soil particle surfaces (Armstrong and Chesters, 1968). Much like in acidic conditions, sorption due to H bonding between adsorbents and the triazine ring N atoms causes further electron withdrawal from the electron deficient C atom, which allows the C-Cl bond to be attacked by water.

The rate of atrazine hydrolysis also increases with increase in temperature (Bacci et al., 1989; Armstrong et al., 1967).

Although most investigations of atrazine degradation have been performed in soil, Wehtje et al. (1984) found that in saturated aquifer sand (12 C, pH = 6.2), atrazine was converted to hydroxyatrazine at the rate of 3% every 90 d and concluded that it was the only major atrazine degradation product in the aquifer.

In the presence of microorganisms, atrazine is transformed by desalkylation at one or both of the alkyl groups. Removal of the ethyl group, the isopropyl group or both results in the formation of desethylated atrazine, desisopropylated atrazine or diamino-chloro-*s*-triazine (Fig. 1, Table 1, compounds 4, 3 and 5). Together atrazine and the three metabolites comprise the chlorinated compounds thought to pose a risk to human health (Anderson et al., 1990). The chlorinated metabolites can also undergo hydrolysis to less phytotoxic compounds (Fig. 1, Table 1, compounds 6, 7 and 8).

When atrazine was applied to sandy loam soil field plots of pH 4.6 for three consecutive years, Muir and Baker (1978) observed the appearance of small amounts of desethylated atrazine within 1 week of application. In the first year, soil concentrations of desethylated atrazine increased to about 0.05 ppm and steadily declined during the following 5 weeks. In the following 2 years, concentrations reached a maximum of about 0.08 ppm and remained relatively constant. Twelve months after the 1974 application, it accounted for 4.2% of the total residues detected (compared with 76.6% for hydroxyatrazine). The same general behavior was true of desethylated hydroxyatrazine which accounted for 8.2% of the total residues. Small amounts of desisopropylated atrazine were also found, accounting for only 0.4% of the total residues, while 9.4% of the total residue in the soil profile was parent compound at the end of the study period. Similarly, Jones et al. (1982) studied the degradation of atrazine in estuarine water/sediment systems and found that after 80 d, 6, 92 and 2% of the extracted residues were desethylated atrazine, hydroxyatrazine and the parent compound, respectively.

Bowman (1990) investigated atrazine fate in field lysimeters of a sand and silt loam soil. Eight weeks after application on the sand, 8.7 and 9.5% of the atrazine were transformed to desethylated atrazine in lysimeters with moisture regimes reflecting natural and irrigated conditions. In the silt loam, 8 weeks after application, desethylated atrazine concentrations increased to 23 and 16% of the applied atrazine in natural and irrigated regimes, after which they steadily declined. The percentages compare well to the amounts and rate of appearance found in a clay loam soil by Sirons et al. (1973).

Frank and Sirons (1985) measured the $t_{1/2}$ of atrazine in the field for a wide range of soils collected from many locations. They extracted atrazine and desethylated atrazine and found an average of 3.3, 8.7, 15, 21, 22 and 22% of the extracted residues were desethylated atrazine after 0.12, 1.0, 2.5, 5.0, 8.0 and 12 months.

Skipper and Volk (1972) applied ^{14}C-labeled atrazine and hydroxyatrazine to soil and measured evolution of $^{14}CO_2$. Experiments were performed with the ^{14}C label on the ethyl group, the isopropyl group and the triazine ring for atrazine and on the triazine ring for hydroxyatrazine. Based on greater $^{14}CO_2$ evolution from the ethyl-labeled atrazine than from the isopropyl-labeled atrazine, they concluded that microbial attack predominates at the ethyl chain. In 3 weeks, approximately 1.0 and 0.3% of the isopropyl-labeled chain was respired in samples from the A and C horizons of a loam soil, whereas about 8 and 12 times as much ethyl-labeled chain was respired. Microbial breakdown of the *s*-triazine ring of atrazine was very low amounting to only 0.1% in 2 weeks. Breakdown of the *s*-triazine ring of hydroxyatrazine was 25 times greater in a silt loam soil and 40 times greater in the A horizon of the loam soil than the breakdown of the *s*-triazine ring of atrazine.

Microbial degradation rates increase with increasing temperature up to a certain temperature. For example, Roethe et al. (1969) concluded that the rate of atrazine degradation increased 2 to 3 times with each 10^{o}C increase in incubation temperature up to 35 C. Soil pH, clay content, moisture content and organic matter content have also been shown to affect atrazine $t_{1/2}$. The interactions between these factors are complicated, especially because chemical hydrolysis and microbial desalkylation are affected differently and sometimes inversely. Levy (1989) summarized the laboratory and field experiments relating atrazine degradation rates to soil parameter values and derived multiple regression equations quantifying those relationships. The summary and regression equations can be used to help determine proper degradation rate values for unsaturated-zone modeling of atrazine, but estimation of metabolite-specific degradation rates will be more difficult. The degradation investigations above may prove useful in choosing reasonable degradation parameter values for computer simulations.

B. Atrazine Leaching and Contamination of Groundwater

Atrazine has been detected in groundwater in 13 states usually at concentrations below 2 μg/L (Isensee et al., 1990). Most of the contamination is thought to originate from normal field use rather than from direct contamination of wells or from point-source spills or mishandling. Evidence indicating nonpoint-source origin includes the widespread nature of the detections, the greater concentrations in shallow versus the deeper wells (as opposed to greater concentrations at depth due to back-siphoning), the greater concentrations downgradient of corn fields and soil studies indicating that such amounts as 0.05% of the applied atrazine commonly leaches past the root zone into the subsoil (Wehtje et al., 1983). Contamination is especially prominent in areas with shallow depths to groundwater, coarse-textured soils, planted in continuous corn and undergoing heavy irrigation. Wehtje et al. (1984), for example, reported concentrations of 2 μg/L in 1.5 m deep monitoring wells beneath fields with such characteristics. In similar conditions in the lower Wisconsin River valley, the WDATCP detected atrazine in groundwater at 25 of 35 sites; violations of the PAL (0.35 μg/L) were detected at 19 of those sites, and violations of the ES (3.5 μg/L) at eight sites (WDATCP, 1991). The highest concentration detected was 35 μg/L.

That the highest atrazine concentrations in the state were found at these sites was not surprising given the combination of shallow depth to groundwater, sandy soil and irrigated corn. In similar conditions in the sand plain region of central Wisconsin the WDATCP detected much lower concentrations of atrazine in groundwater. Daniel et al. (1989) compared the movement of atrazine through soil columns representing the lower Wisconsin River valley (Sparta sand soil) and the sand plain region (Plainfield sand soil) and found atrazine was leached more readily through the Sparta soil. The Plainfield sand has more silt and slightly more clay than the Sparta soil in the upper horizon giving rise to lower hydraulic conductivities and greater atrazine sorption.

Evidence is accumulating that atrazine leaching also occurs in finer-textured soils. Hall and Hartwig (1978), for example, detected atrazine concentrations from 10 to 20 μg/L in water extracted from silty clay and clay loam soils at a depth of 1.2 m. The results of the WDATCP's Grade A Dairy Farm Well Survey indicated that atrazine contamination of groundwater was widespread and that there was no clear association between the number and levels of detections and such environmental factors as soil organic matter content, depth to groundwater, soil texture and depth to bedrock. Widespread atrazine residue contamination of shallow groundwater was discovered in a Pennsylvania watershed with predominantly loam and silt loam agricultural soils (Pionke and Glotfelty, 1989).

One mechanism that might account for atrazine leaching through medium- and fine-textured soils is transport through macropores (Isensee et al., 1990; Starr and Glotfelty, 1990; Isensee et al., 1988). Studies have shown that substantial water can flow through macropores into and below the soil root zone soon after a precipitation event (Isensee et al., 1990; Isensee et al., 1988). When such rapid movement occurs, dissolved pesticide can move to the groundwater bypassing much of the soil matrix where retardation from sorption usually takes place. Less time of retention in the soil profile also results in less degradation. Conservation tillage results in greater preservation and enhancement of soil (and macropore) structure and can cause enhanced pesticide leaching (Isensee et al., 1990; Starr and Glotfelty, 1990). In a study comparing leaching patterns on conventional and no-tillage field plots (Isensee et al., 1990), much more atrazine was leached into groundwater under no-tillage. Atrazine was detected in soil below the root zone in only 2 d after application and in groundwater within 14 d. Starr and Glotfelty (1990) measured the movement of water, Br and atrazine in the top 60 to 90 cm of a silt loam soil under Maryland field conditions. Neutron probe access tubes (5-cm diameter) were pushed to about 90 cm or until a gravel layer was encountered to determine water content of the soil profiles. Double-ring infiltrometers were pushed to a depth of 10 cm to pond 10 cm of water, generating an intense leaching event. On average 43, 42 and 36% of the applied water, Br and atrazine was lost through the bottom of the soil profiles. The fact that the percentages were similar for all three indicates the bypassing of the soil matrix through macropore flow. One would not expect such flow to be so dominant, however, with a less intense leaching event. Distributions of Br and atrazine were compared with simulated distributions using LEACHMP, a one-dimensional convection-dispersion unsaturated flow and contaminant transport computer model. The lack of agreement and the model's underprediction of atrazine leaching was further indication of macropore flow.

Bowman (1989) detected maximum atrazine movement through 75-cm deep field lysimeters in Plainfield sand to be 30 cm after 21 weeks with natural rainfall. Atrazine moved through the whole lysimeter with natural rainfall supplemented by 70 cm of water. However, atrazine appeared in the effluent collected at the lysimeter bottom on day 2 after a 5 cm water application, long before it was detectable (> 2 to 3 ng/g soil) in the lower segments of the lysimeters. Once again, a certain percentage of applied atrazine seems to be bypassing the soil matrix through macropore flow. Such results imply that the amount of precipitation in the first week or two after pesticide application may have a dramatic impact on the amount of pesticide leached to groundwater. Bowman found that leaching was diminished when pesticides were given a longer time to equilibrate with the soil before water application indicating a non-instantaneous sorption process or conversion to hydroxyatrazine. Such studies as those by Bowman

(1989) and Starr and Glotfelty (1990) indicate that macropore and soil-matrix flow can take place simultaneously and might account for the double-peak patterns sometimes observed in contaminant breakthrough curves. In his silt loam soil-column experiments, Schiavon (1988a) notes that although the movement of most of the compounds studied was retarded by sorption, a small amount of the applied residues were present in even the first percolation water to exit the columns.

Pionke et al. (1988) used PO_4 as a possible indicator of macropore flow contamination of groundwater in an agricultural Pennsylvania watershed. PO_4 sorbs strongly onto soil particles and would not ordinarily be expected to leach to groundwater. Non-macropore leaching of PO_4 from P-rich surface soils to groundwater would be difficult since subsoils are normally P-starved and thus strongly sorb PO_4. Transport of weakly sorbed organic P and subsequent transformation to PO_4 in groundwater was not considered likely since organic P was not found in groundwater samples. However, it was found that no correlation exists between atrazine and PO_4 groundwater contamination and therefore unsaturated flow short-circuiting through macropores was not considered to be a major contributor to atrazine contamination in this watershed.

Pionke et al. (1988) also compared distribution of atrazine concentrations to those of NO_3-N and Cl. Relations established between these groundwater quality parameters are useful since NO_3-N and Cl are more leachable contaminants and analysis is less costly. Regulatory control would be easier if these parameters could be used as indicators of atrazine contamination potential. Pionke et al. (1988) found that when NO_3-N and Cl concentrations were high, the probability of an atrazine detection was increased. Junk et al. (1980) also observed correlations between NO_3-N and atrazine concentrations in bottomland shallow- and medium-depth wells that were influenced by upgradient corn cultivation and irrigation. The similar concentrations suggest similar transport times in groundwater.

Junk et al. (1980) also detected atrazine concentrations in three shallow wells near a river that were almost identical to those in the river water. The river bottom sediments in this case had high permeability. Spalding et al. (1979) reported a sharp contrast in concentrations when the river bottom sediments were finely textured.

Atrazine contamination of groundwater might also result from its long use history and slow movement to groundwater with little degradation occurring once the residues have been leached beyond the biologically active root zone. In Wisconsin, atrazine has been detected in groundwater beneath fields that probably serve as the source area even though atrazine has not been applied for at least 2 yr (McGrath, 1991). It was detected in soil beneath fields in Maryland where it had not been applied in 2 to 3 yr (Isensee et al., 1990). Capriel et al. (1985) applied ^{14}C-labeled atrazine to field plots and detected about 83% of the applied activity in the soil profile 9 yr after application, about 50% of which was in the bound or nonextractable form. They removed bound residues by high temperature distillation and collected them in various traps containing suitable solvents. Of the bound residues collected, about 27, 25, 32, and 17% were atrazine, hydroxyatrazine, desethylated hydroxyatrazine, and desisopropylated hydroxyatrazine. Desethylated atrazine and desisopropylated atrazine were found in only trace amounts and may have been leached from the soil profiles. Of the 50% nonbound residues (extracted with methanol), 81% was parent compound. Atrazine residues in soil so long after application are not commonly reported in the literature, but the data imply that, through desorption, atrazine residues in soil could act as a long-term low-level source of contamination to groundwater. Likewise, atrazine residues sorbed by aquifer particles could continue to contaminate groundwater long after leaching has stopped. Wehtje et al. (1983) calculated a sorption coefficient (K_d) for aquifer sands in Nebraska of 0.40 to 0.46 ml/g. Such coefficients indicate that at saturation, 68 to 71% of the atrazine in groundwater would remain in solution. The rest could serve as a low-level contamination source. Wehtje et al. (1983) hypothesize that the accumulated atrazine residue in groundwater can be computed given the yearly input (A) and the yearly fraction that remains in solution after sorption, degradation, and dilution through dispersion (X). Over n years, the accumulated atrazine residue in groundwater would be:

$$AX + AX^2 + AX^3 + \ldots + AX^n \qquad (5)$$

which simplifies to:

$$\frac{AX\left(1-X^n\right)}{1-X} \qquad (6)$$

Atrazine residue mass can be converted to a groundwater concentration given aquifer thickness and porosity. This model indicates that an aquifer-averaged equilibrium concentration should be reached within 5 to 10 years with a dissipation factor of around 50% or even sooner if there is more dissipation. With such a model, it would be expected that atrazine concentrations in groundwater would remain fairly stable and exhibit little or no seasonal fluctuation. Decreases in equilibrium concentrations with distance downgradient of the fields of application can indicate degradation along the flow paths and can be used to estimate degradation rates within the saturated zone.

C. Occurrence in groundwater and leaching of atrazine and its metabolites.

While there have been numerous studies on the leaching of atrazine, studies examining the behavior of atrazine and its metabolites are more limited. Their relative mobilities have been investigated by comparing leaching patterns and relative sorption coefficients (Bowman, 1990; Brouwer et al., 1990; Schiavon, 1988a; Schiavon, 1988b; Best and Weber, 1974; Armstrong and Chesters, 1968; and Green et al., 1968).

Pesticide sorption is perhaps the most important factor determining pesticide mobility in porous media and is most often described by the Freundlich isotherm in which the equilibrium concentration of pesticide in solution (C in μg/L) is related to the equilibrium concentration of sorbed pesticide (X in μg/g of soil) by the equation:

$$X = K_F C^n \tag{7}$$

where K_F (L^n/g) and n are the empirical Freundlich constants.

If n is considered equal to 1, then the equation reduces to a linear isotherm:

$$X = K_d C \tag{8}$$

where K_d is the linear distribution coefficient (L/g).

Most unsaturated-zone contaminant-transport computer models assume a linear sorption isotherm. Since soil organic matter is thought to be the major factor controlling pesticide sorption, distribution coefficients are sometimes expressed in terms of the more soil-independent K_{om}:

$$K_d = f_{om} K_{om} \tag{9}$$

where f_{om} is the organic matter fraction of soil.

Brouwer et al. (1990) studied the relative sorption of atrazine, desethylated atrazine, desisopropylated atrazine and hydroxyatrazine in the surface soils (0 to 20 cm) of four soils -- two sands, a loam and a loamy sand. K_d values were calculated because "n" in the Freundlich isotherm was, in most cases, close to 1. Sorption was highly dependent on organic matter content, but not in a strictly linear manner, since K_{om} of the compounds varied from soil to soil. Relative K_d values and K_{om} values were consistently in the order hydroxyatrazine > atrazine > desisopropylated atrazine > desethylated atrazine in ratios of 3.5 : 1 : 0.63 : 0.44, averaged for the four soils. Although sorption coefficients were not calculated, hydroxyatrazine was only slightly more sorptive than atrazine in a study by Armstrong and Chesters (1968). Green et al. (1968) found similar relative sorption to Armstrong and Chesters (1968) in a latosolic soil. Data agree with a laboratory study by Best and Weber (1974) in which atrazine and hydroxyatrazine were leached to similar degrees in a silt loam soil. As soil pH decreases from neutral, more sorption of hydroxyatrazine is expected since it has a higher pK for protonation of the amino group than the chloro-compounds.

The order of mobility expected from the sorption experiments above -- desethylated atrazine > desisopropylated atrazine > atrazine > hydroxyatrazine -- compares well with findings by Schiavon (1988b) in which ^{14}C-labeled atrazine and metabolites were individually applied to clay loam soil columns which where buried in the field. Schiavon (1988b) showed that percent radioactivity remaining in the top 24 cm of the 60-cm long columns at the end of the study were: hydroxyatrazine (99.6%) > desisopropylated atrazine (88.9%) > atrazine (87.0%) > diamino-chloro-*s*-triazine (86.5%) > desethylated atrazine (83.4%). Leachate throughout the study period (Schiavon, 1988a) showed that the quantities and percent of applied, undegraded compounds collected through a 90-d period were in the order desethylated atrazine (11.5%) > diamino-chloro-*s*-triazine (4.2%) > atrazine (1.9%) > desisopropylated atrazine (1.3%) > hydroxyatrazine (0.06%). This order reflects a combination of a compound's mobility and degradation rate. Leaching of the applied compound plus its metabolites might be a better indicator of relative contamination potential. From the column to which ^{14}C-atrazine alone was applied, Schiavon (1988a) found that the leachate over 90 d contained 33 to 50% desethylated atrazine, 10 to 28% diamino-chloro-*s*-triazine, 11 to 24% atrazine, 4 to 7.5% desisopropylated atrazine, 3 to 9.5% desethylated hydroxyatrazine, 3 to 6% hydroxyatrazine, 0.5 to 4% diamino-hydroxy-*s*-triazine, and 1 to 3.5% desisopropylated hydroxyatrazine. Unidentified residues made up 3 to 36% of leached radioactivity.

Bowman (1990) measured the sorption coefficients of atrazine and desethylated atrazine in a sand and a silt loam soil. The Freundlich isotherm was not perfectly linear, with n ranging from 0.77 to 0.91. Desethylated atrazine consistently had a lower K_F than atrazine. In the sand, K_F values for atrazine and desethylated atrazine were 0.84 and 0.49. Bowman divided the silt loam soil into two horizons, 0 to 15 cm and 15 to 100 cm. In the surface horizon, the atrazine and desethylated atrazine K_F values were 1.3 and 0.86. In the subsoil they were 0.67 and 0.33.

Jones and Winchell (1984) studied plant uptake and phytotoxicity of atrazine and its metabolites. Plant uptake is related in part to the degree of sorption of a compound. They found that the order of uptake was atrazine > desethylated atrazine > desisopropylated atrazine > hydroxyatrazine.

Only a few previous studies have examined the occurrence of atrazine and its metabolites in groundwater systems (Isensee et al., 1990; Pionke and Glotfelty, 1990, 1989; Pionke et al., 1988; Muir and Baker, 1976). Isensee et al. (1990) measured atrazine residue concentrations in shallow groundwater (< 1.5 m deep) beneath silt loam soils under conventional and no-tillage systems in Maryland for three growing seasons, 1986 to 1988. In 1986 and 1987, they detected desethylated atrazine in every water sample that contained atrazine. They apparently detected seasonal variation as concentrations were approximately equal for the first 5 to 6 months after application and desethylated atrazine concentrations gradually increased to twice those of atrazine before the next treatment. In 1988 concentrations of desethylated atrazine were less than those of atrazine.

Muir and Baker (1976) monitored atrazine residue concentrations in tile-drain water from a 1.75 ha field under corn production. The field was composed of sandy loam soil and the tile drain was set at a depth of 1.2 m. Average desethylated atrazine, atrazine and desisopropylated atrazine residue concentrations in the tile-drain water (April through December) were 1.3, 1.2 and 0.17 μg/L, respectively.

Pionke et al. (1988) studied the nature and extent of atrazine residue concentrations in a nonirrigated, agricultural watershed with medium-textured soils in Pennsylvania. Distribution of residues in the watershed indicated that the most important factor controlling groundwater contamination was corn production intensity (CPI), a number that accounts for the percent of land and years of a rotation that a near-well area is planted to corn. When wells had a CPI < 50%, little or no atrazine was found. The highest concentrations were detected at wells with a CPI between 75 and 100%. Such figures indicate that the atrazine contamination of groundwater is likely due to nonpoint sources and that corn rotations reduce the potential for such contamination. Depth to the water table, aquifer rock type, well position in the flow system and general soil characteristics had no discernable effect on detected residue concentrations. The majority of wells in the watershed yielded water of higher concentrations of atrazine residues for low flow or discharge periods and lower concentrations for recharge periods indicating that dilution was a major factor. The seasonal patterns reported, however, are based only on two late-summer and two late-winter samplings and are somewhat inconsistent. While the two winter results are similar, the late summer results are quite different. In all wells where corn-rotation land was dominant, concentrations of desethylated atrazine were greater than those of atrazine which, in turn, were much greater than concentrations of desisopropylated atrazine. No other metabolites were identified. Desethylated atrazine dominance was less in wells in recharge areas than in discharge areas indicating some atrazine degradation to desethylated atrazine while the residues moved along a groundwater flow path. Desethylated concentrations also did not decrease seasonally as much as those of atrazine and desisopropylated atrazine indicating either continued degradation of atrazine or longer persistence of desethylated atrazine.

Perry (1990) detected residues of atrazine in a Kansas domestic well ranging from 21 to 46 μg/L over a 2-yr period. Soil analyses and the distribution of herbicide residue concentrations in groundwater around the domestic well indicated the contamination source was back-siphonage from a sprayer tank to a freeze-proof hydrant, down the sand-filled trench of the water supply line to the annular space of the domestic well and to the water table. After pumping the domestic well continuously for > 3 months, atrazine concentrations in the domestic well decreased to 11 μg/L and continued to decrease over the next year to 2.7 μg/L. Perry (1990) also detected desethylated atrazine and desisopropylated atrazine residues in groundwater at concentrations that were small compared to the parent compound. Ratios of desethylated atrazine to atrazine concentrations ranged from 0.001 to 0.008; ratios of desisopropylated atrazine to atrazine concentrations ranged from 0.017 to 0.04. Such low ratios are indicative of point-source contamination since much higher ratios would be expected from atrazine degradation typical of that in the soil root zone.

Degradation, sorption, and transport of atrazine and metabolite residues in soil and groundwater are complex processes. Absolute amounts of the compounds remaining in soil columns and profiles or leached out of a soil column varied with investigation, making it difficult to predict residue concentrations in groundwater at specific locations. A further complicating factor is that large precipitation events and preferential flow paths in the unsaturated zone increase the likelihood of groundwater contamination. From a summation of all the investigations, it is fair to suggest that atrazine parent and desethylated atrazine are the most likely compounds to be detected in groundwater. Because of its high sorbability, hydroxyatrazine is unlikely to be detected in groundwater, but the residues are expected to appear in highest concentrations in the surface soils.

IV. SITE SELECTION

The Grade A dairy farm selected for the study was chosen in conjunction with the WDATCP. Selection criteria included soils that were typical of glaciated areas in Dane County, evidence of groundwater contamination from atrazine, and landowner cooperation. The private well (belonging to Farmer X) on the selected site was part of the WDATCP's Grade A Dairy Farm Well Survey and, in fact, was the well with the highest recorded atrazine residue concentration in Dane County (2.8 ppb). The field site is located in Section 12 of T8N, R8E, just west of the Village of Waunakee in Dane County, Wisconsin (Fig. 2). The study area is approximately 1.6 mi^2 (4.1 km^2) and includes land mostly north of Woodland Rd. and south of Sixmile Creek within Section 12. Surface topography is gently rolling to somewhat steep grades on one drumlin.

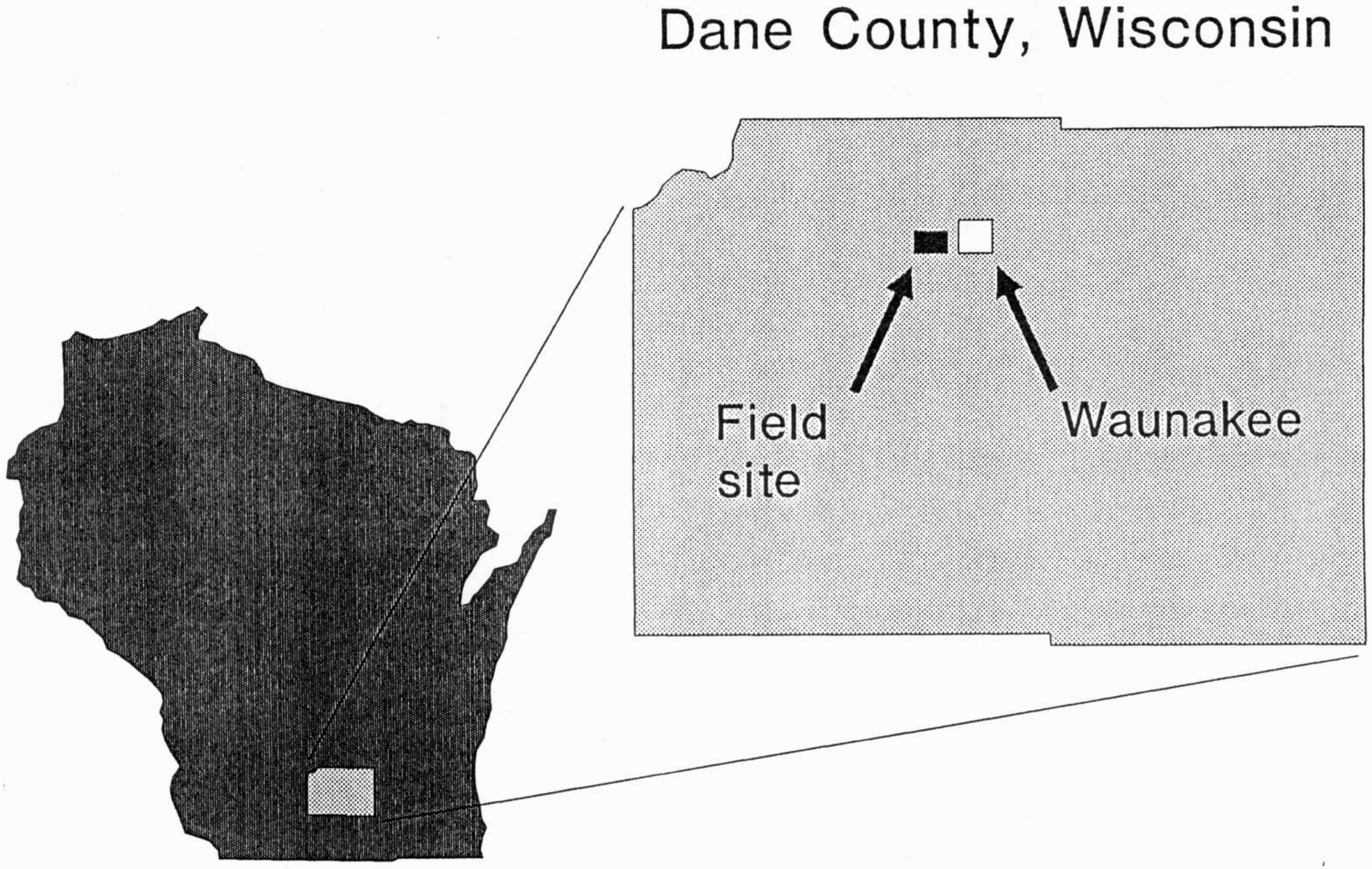

Figure 2. Waunakee field site location.

V. WELL INSTALLATION AND BOREHOLE SAMPLING

Wells were installed at 24 locations (Fig. 3). Four wells, K1 through K4, are multilevel samplers and were drilled using air-rotary techniques and 6- to 8-in diameter augers. During drilling, geologic material was sampled at various intervals for description of site stratigraphy and atrazine analysis. The sampling was completed using a 3.0-in (7.6-cm) O.D. split spoon equipped with polycarbonate liners in 6.0-in (15-cm) segments. The augers and split spoon sampler were steam-cleaned prior to and between each sample for each location to avoid cross-contamination. During drilling, a boring log was kept and samples were characterized. Each bore sample was later split in the laboratory. Half was saved for future atrazine and metabolite residue extraction, half was sent to the University of Wisconsin - Extension Soil and Plant Analysis Laboratory for grain-size, pH and organic matter content determination. On completion of each boring, the multilevel sampling assembly was installed approximately 30 ft (9.1 m) into groundwater. These assemblies consist of a 1.25-in (3.2-cm) I.D. flush-threaded PVC pipe with a 1-ft-long (0.30-m) screen surrounded by seven polypropylene 0.50-in (1.3-cm) O.D. x 0.38-in (0.95-cm) I.D. sampling tubes. The tubes terminate at various depths below the water table at intervals of 3 or 5 ft (0.91 or 1.5 m). At the end of each tube is a 3-in-long (7.6-cm) screen of Style 3401 Typar® spunbonded polypropylene. The whole assembly was sand-packed to about 2 ft (0.61 m) above the water table and sealed with bentonite. Due to the small volumes and low recharge rates of the multi-level samplers at K1 and K2, sampling for atrazine analysis is not practical. The PVC well is still used for potentiometric levels and sampling. K3 and K4 are fully functioning multi-level sampling wells. The lack of a bentonite seal between sampling ports, however, brings into question the extent to which water pumped from a particular sampling port represents the water quality at that depth in the aquifer. The hydraulic conductivity of the sand pack separating the ports is probably greater than the surrounding aquifer, and with the downward hydraulic gradients at K3, water entering the sand pack near the water table will move to deeper sampling ports faster than water moves downward in the surrounding aquifer.

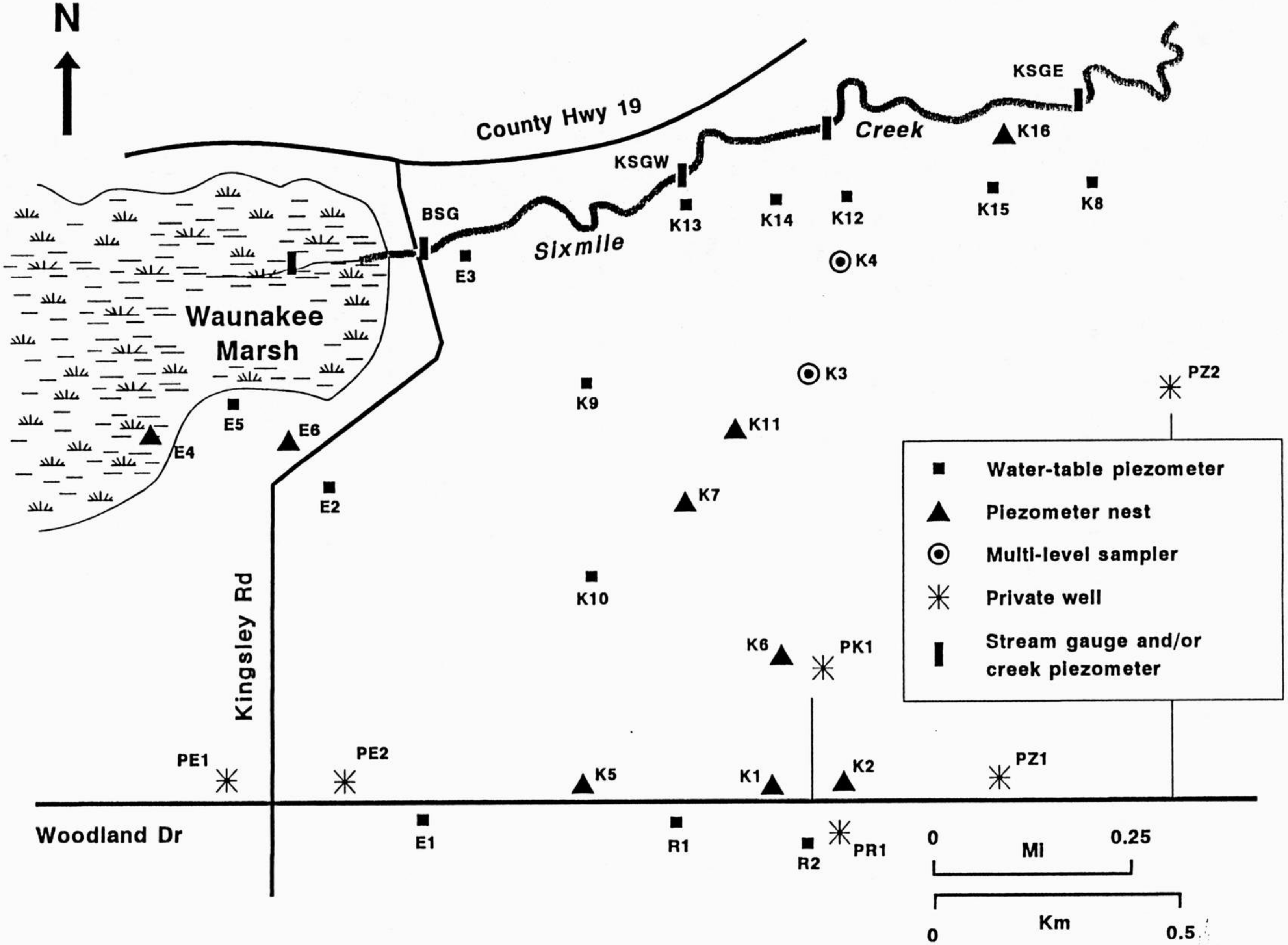

Figure 3. Location of wells at the Waunakee field site.

The quality of water pumped from an individual port reflects the quality of water from that elevation and, to some extent, water from shallower depths. Data regarding the vertical distribution of water quality at K3 and K4 may therefore be misleading. The data collected from all the sampling ports at a well, however, adequately represents the water quality at that well location. In future, multilevel samplers should not be used in fine- to medium-grained aquifers unless a seal can be installed between ports or unless vertical gradients are small.

In addition to the multi-level samplers, 22 water-table wells have been installed. These wells allow water-table mapping and determination of local groundwater flow direction and gradient magnitude. Most of the water-table wells are 2-in (5.1-cm) I.D. flush-threaded PVC with 5-ft-long (1.5-m) screens intersecting the water table. Where the depth to groundwater is < 7 ft (2.1 m), holes were hand-augured and 0.5-in (1.3-cm) I.D. water-table wells with 5-ft (1.5-m) long screens were installed. Water-table elevation declines in the winter caused some wells to go dry; the water table did not rise above the well bottom again until snowmelt the following spring. Nine of the water-table wells are nested with either 1, 2 or 3 other piezometers with varying-length screens set deeper in the groundwater system. Nested piezometers allow determination of vertical hydraulic gradients and vertical distribution of atrazine residues and other groundwater quality and chemistry information. All screens were sand-packed unless the natural material collapsed above the top of the screen. Holes were sealed with bentonite to within 1 or 2 ft (0.30 or 0.61 m) of the ground surface. During well installation, drilling samples were peeled off the augers at 5 ft (1.5 m) intervals. Samples were characterized and sent to the University of Wisconsin - Extension Soil and Plant Analysis Laboratory for grain-size, organic matter content, and pH determination. Well construction information is summarized in Table 2. Note that all wells have been assigned unique Wisconsin well numbers, supplied by the WDNR.

Polypropylene 0.50-in (1.3-cm) O.D. x 0.38-in (0.95-cm) I.D. piezometers with 4-in (10-cm) screens were installed at four locations in Sixmile Creek to determine whether groundwater is discharging

Table 2. Waunakee site well construction data.

Well	Wis. Unique Well #	Date Installed or Last Altered	Elevation of Top (ft)	Total Depth (ft)	Elevation of Bottom (ft)	Screen Length (ft)	Inner Well Diameter (ft)	Ground Elevation (ft)
K1-Main	EC871	07/27/89	945.59	55.61	889.98	1.00	0.11	942.89
K1.B	EC872	05/03/90	943.21	35.14	908.07	5.00	0.18	943.03
K1.C	EC873	08/13/90	944.47	25.11	919.36	5.00	0.18	942.87
K2-Main	EC874	07/28/89	946.74	42.57	904.17	1.00	0.11	944.04
K2.B	EC875	07/13/90	945.23	30.11	915.12	5.00	0.18	943.81
K3.1	EC876	07/30/89	932.59	20.51	912.08[1]	0.36	0.03	929.78
K3.2	EC877	07/30/89	932.62	23.54	909.08[1]	0.36	0.03	929.78
K3.3	EC878	07/30/89	932.57	26.49	906.08[1]	0.36	0.03	929.78
K3.4	EC879	07/30/89	932.62	31.54	901.08[1]	0.36	0.03	929.78
K3.5	EC880	07/30/89	932.56	36.48	896.08[1]	0.36	0.03	929.78
K3.6	EC881	07/30/89	932.55	41.47	891.08[1]	0.36	0.03	929.78
K3.7	EC882	07/30/89	932.53	46.45	886.08[1]	0.36	0.03	929.78
K3-Main	EC883	07/30/89	932.44	48.11	884.33	1.00	0.11	929.78
K3.B	EC884	07/13/90	932.58	20.07	912.51	5.00	0.18	930.08
K4.1	EC885	07/31/89	927.59	18.04	909.55[1]	0.36	0.03	924.39
K4.2	EC886	07/31/89	927.50	20.95	906.55[1]	0.36	0.03	924.40
K4.3	EC887	07/31/89	927.50	23.95	903.55[1]	0.36	0.03	924.40
K4.4	EC888	07/31/89	927.52	28.97	898.55[1]	0.36	0.03	924.32
K4.5	EC889	07/31/89	927.52	33.97	893.55[1]	0.36	0.03	925.42
K4.6	EC890	07/31/89	927.44	38.89	888.55[1]	0.36	0.03	924.34
K4.7	EC891	07/31/89	927.59	44.04	883.55[1]	0.36	0.03	924.39
K4-Main	EC892	07/31/89	927.45	45.65	881.80	1.00	0.11	924.35
K4.B	EC893	07/13/90	925.97	11.57	914.40	5.00	0.18	924.57
K5.A	EC894	03/23/90	946.64	45.15	901.49	5.00	0.18	944.20
K5.B	EC895	05/21/90	944.67	35.37	909.30	5.00	0.18	944.09
K5.C	EC896	07/13/90	945.17	30.32	914.85	5.00	0.18	943.96
K6.A	EC897	03/23/90	947.41	39.46	907.95	5.00	0.18	947.60
K6.B	EC898	05/22/90	947.54	52.49	895.05	5.00	0.18	947.60
K6.C	EC899	05/25/90	947.53	69.66	877.87	5.00	0.18	947.60
K6.D	EC900	08/10/90	947.47	32.25	915.22	5.00	0.18	947.60
K7.A	EC901	04/24/91	936.05	20.31	915.74	5.00	0.13	933.30
K7.B	EC827	11/02/90	934.62	23.87	910.75	5.00	0.18	933.30
K8	EC902	07/23/90	932.53	21.51	911.02	5.00	0.18	930.54
K9	EC903	04/07/90	959.84	48.46	911.38	5.00	0.18	959.09
K10	EC904	07/18/90	941.53	27.67	913.86	5.00	0.18	938.82
K11.B	EC906	11/02/90	931.36	20.14	911.22	5.00	0.18	932.33
K11.C	EC905	02/12/91	931.47	52.25	879.22	1.00	0.18	932.33

[1] Total depth and bottom elevation for multi-level ports are approximate.

Table 2. Continued.

Well	Wis. Unique Well #	Date Installed or Last Altered	Elevation of Top (ft)	Total Depth (ft)	Elevation of Bottom (ft)	Screen Length (ft)	Inner Well Diameter (ft)	Ground Elevation (ft)
K12	EC907	07/10/90	923.27	10.00	913.27	5.00	0.0508	920.46
K13	EC908	07/11/90	925.90	10.00	915.90	5.00	0.0508	923.20
K14	EC909	07/11/90	928.66	12.12	916.54	5.00	0.0508	924.24
K15	EC910	07/12/90	924.46	12.56	911.90	5.00	0.0508	920.31
K16.A	EF661	02/12/91	920.61	17.33	903.28	5.00	0.13	917.87
K16.B	EF662	02/12/91	920.62	23.49	897.13	1.00	0.18	917.89
K16.C	EF663	02/12/91	920.65	29.95	890.70	1.00	0.18	917.95
K16.D	EC826	04/03/91	920.48	9.86	910.62	5.00	0.11	917.73
R01	EC821	07/13/90	949.97	38.48	911.49	5.00	0.18	946.19
R02	EC822	02/04/91	943.57	25.11	918.46	5.00	0.18	941.79
E01	EF664	08/13/90	953.57	41.19	912.38	5.00	0.18	948.86
E02	EF665	04/08/91	946.29	33.19	913.10	5.00	0.13	941.71
E03	EF666	09/17/90	923.83	11.28	912.55	5.00	0.0508	920.08
E04	EF667	09/19/90	921.36	10.57	910.79	0.43	0.0508	918.01
E05	EF668	09/19/90	926.81	11.75	915.06	4.20	0.0508	923.06
E06.A	EF669	09/21/90	925.21	13.08	912.13	4.82	0.0508	922.01
E06.B	EF670	09/21/90	922.90	14.71	908.19	1.19	0.0508	922.00

to the creek or the creek is recharging the aquifer. Locations were just north of K8, K12, K13 and in the creek within Waunakee Marsh about 840 ft (250 m) west of Kingsley Rd. Piezometers were installed by first pounding steel pipe with a loose fitting plug on the bottom into the creek bed. The polypropylene tubing was then inserted into the pipe and the pipe was slipped over the tubing. Creek bottom sediment collapsed around the tubing anchoring the piezometer. At each location, two piezometers were nested so that their screens were vertically separated by between about 2 and 6 ft. Water rising in the piezometers above the surface-water level of the creek indicates the aquifer discharges to the creek. Stream gauges were also installed in Sixmile Creek just north of K8 and K13 to monitor the water-level elevation in the creek. The elevation of the Kingsley Rd. bridge over the creek was measured so that the bridge could also be used as a stream gauge.

VI. SITE DESCRIPTION

The site is within the Yahara River system, a tributary of the Rock River system (Cline, 1965). The Yahara River system drains about 40% of Dane County and originates just north of the Dane County border. The Yahara River valley has an irregular topography, flat and rolling to hummocky and hilly. Lowlands are generally marshy, uplands are well drained. Drumlins are common and are usually aligned in a northeast-southwest direction.

A. Landuse

Area landuse is primarily dairy farms, typically with rotations of corn and alfalfa. Most of the land area has received pesticide application at some time. Wells are located on three farms with most of the wells on one of the farms (Farm X), the primary focus of the study. Farm X comprises about 160 acres of corn and alfalfa. Lower lying fields with poor drainage have been kept in continual corn production while the other areas have undergone rotation between corn and alfalfa for at least the last 10 yr. Typically, an area stays in corn production for 2 or 3 yr and in alfalfa for 4 yr. Oats are usually planted with alfalfa during alfalfa's first year in the rotation. Atrazine has been applied on the corn on Farm X for at least 20 yr. Typically, atrazine was applied at 3 lb/acre (2.7 lb/acre a.i.) on corn in its first year out of alfalfa and 2 lb/acre (1.8 lb/acre a.i.) after that. In 1990 Farmer X applied atrazine at 1 and 0.5 lb/acre (0.45 lb/acre a.i.) on first year and non-first year corn. In 1991, Farmer X applied either 0.5 lb/acre (0.45 lb/acre a.i.) or 0.75 lb/acre (0.68 lb/acre a.i.) on some of the corn and did not use atrazine on other corn. Other herbicides used by Farmer X include alachlor and cyanazine. Most of the remaining wells are located on Farm Y, to the west of Farm X. Farmer Y has not used atrazine for at least the past 2 yr and grows peas in addition to corn and alfalfa.

B. Soils

Soils at the field site (shown and listed in Fig. 4 and Table 3) are medium-textured, predominantly Plano, Ringwood, St. Charles and Dodge silt loams. They are generally deep, well drained or moderately well drained, nearly level to sloping on glaciated uplands, have high fertility and available water capacity and moderate permeability (Glocker and Patzer, 1978). Most of Farm X consists of Plano soils which typically have a 6- to 20-in silt loam, A horizon, underlain by a 30- to 60-in B horizon of clayier material (silty clay loam, clay loam, or clay). The clayey horizon is underlain by coarse material ranging from sandy loam to gravelly sand. Soil pH is generally between 7.0 and 7.5 in the plow layer, falls to as low as 5.5 at a depth of 4 ft, after which it increases with depth to over 8.0 at 6 ft. Organic matter content ranges from 2.0 to 5.8% in the first 1 ft, typically decreasing to 1.0% or less by 4 ft.

Table 3. Soil types found at the Waunakee site

Ad - Adrian muck
DnB - Dodge silt loam, 2 to 6% slopes
DnC2 - Dodge silt loam, 6 to 12% slopes
DpB - Dodgeville silt loam, 2 to 6% slopes
EfB - Elburn silt loam, 1 to 4% slopes
Ev - Elvers silt loam
GwB - Griswold loam, 2 to 6% slopes
GwC - Griswold loam, 2 to 6% slopes
GwD2 - Griswold loam, 12 to 20% slopes
Mc - Marshan silt loam
MdC2 - McHenry silt loam, 6 to 12% slopes
MdD2 - McHenry silt loam, 12 to 20% slopes
Pa - Palms muck
PnA - Plano silt loam, 0 to 2% slopes
PnB - Plano silt loam, 2 to 6% slopes
PnC2 - Plano silt loam, 6 to 12% slopes
RnB - Ringwood silt loam, 2 to 6% slopes
RnC2 - Ringwood silt loam, 6 to 12% slopes
ScA - St. Charles silt loam, 0 to 2% slopes
ScB - St. Charles silt loam, 2 to 6% slopes
VrB - Virgil silt loam, 1 to 4% slopes
VwA - Virgil silt loam, gravelly substratum, 0 to 3% slopes
Wa - Wacousta silty clay loam

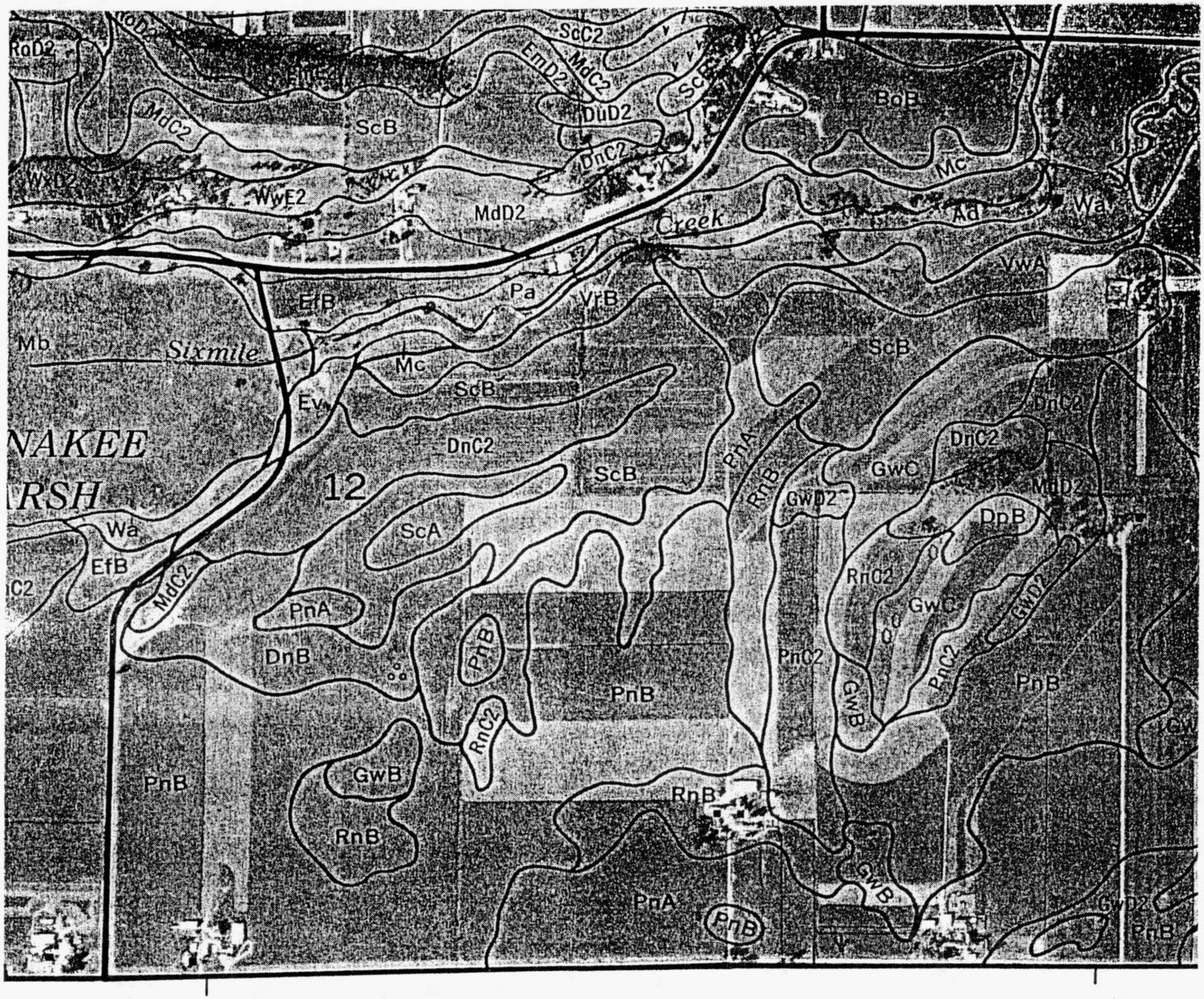

Figure 4. Soil series map of Waunakee field site (from Glocher and Patzer, 1978).

C. Geology

Geology was investigated by examination of well-drilling samples, grain-size analysis on drilling samples, private-well log interpretation, and interpretation of geologic maps from Cline (1965). Underlying the soil throughout most of the study site is a glacial drift. The undifferentiated Quaternary deposits are part of the Horicon formation laid down by the Green Bay Lobe during late Wisconsin time (13,000 to 19,000 yr ago) (Michelson et al., 1984). The deposits are of sandy loam or loamy sand till (according to soil classification) and are calcareous, yellow-brown in color and include clay, silt, sand, and gravel. Gravel was found as large as 5 to 6 cm in diameter. No bedding planes were observed in the split-spoon cores. Typical grain-size distribution of the till is 65 to 75% sand, 15 to 30% silt, and 1 to 15% clay. At wells R2, K2, K3 and K9, lenses of sandier material were also observed. At R2, material containing as much as 92% sand was encountered between 7 and 13 ft below ground surface. At K2, material ranging from 81 to 89% sand (loamy sand to sand) was found between 7 and 16 ft below ground surface. At K3, material containing up to 97% sand was found between 7 and 9 ft below ground surface. At K9, loamy sand, containing 80 to 84% sand was found from 29 to 38 ft below ground surface. In all cases, the sand lenses were above the water table and probably represent glacial outwash deposits. The sand lenses at K2 and R2 are likely correlated. The connectedness and lateral extents of the other outwash deposits are unknown. Mickelson (1983) identifies more glacial outwash along Sixmile Creek on the northern border of the study site. Till pH increases with depth, generally from 8.2 near the soil-till interface to between 8.5 and 9.0 about 30 ft below ground surface. Till organic matter content decreases with depth, from 0.1 to 0.4% near the soil interface to <0.1 to 0.2% at depth. During the course of the drilling, bedrock was reached only on one of the drumlins in the area, about 150-ft west of private well PZ2 (Fig. 3). Throughout most of the study area, the till extends to at least 50 ft below ground surface and to at least 90 ft at well K6 (Fig. 3). According to area well logs and to Cline (1965), till thickness ranges from 15 to 100 ft (4.6 to 30 m).

Underlying the till through most of the study area is Cambrian sandstone, typically containing some dolomite and shale (Cline, 1965). The Cambrian sandstone has a regional dip to the south of 10 to 15 ft/mi (1.9 to 2.9 m/km). The upper Cambrian component is the Trempealeau formation which can be subdivided into an upper, middle and lower component. The upper component is composed of fine- to medium-grained locally dolomitic sandstone. The middle section has more siltstone and is dolomitic to very dolomitic. The lower component is locally very dolomitic sandstone. Underlying the Trempealeau formation is Franconia sandstone. Its upper component is glauconitic, very fine- to fine-grained dolomitic sandstone, and the lower component is fine- to coarse grained and is only locally dolomitic and glauconitic. The next layer down is the Dresback group, composed of the Mt. Simon, Eau Clair and Galesville sandstones. Underlying the Cambrian sandstones is Precambrian rhyolite, granite, and basalt. Thickness of the Cambrian sandstone is about 700 ft.

Within the study area are two drumlins (Mickelson and McCartney, 1979), both aligned southwest-northeast. The larger of the two, underlying private well PZ2 (Fig. 3) rises to over 1,010 ft (308 m) above mean sea level (msl) and is topped with 20 to 25 ft (6.1 to 7.6 m) of soil and till over Prairie du Chien group dolomite. It is the only place within the study area where the Ordovician Prairie du Chien bedrock remains. Within the study area, surface elevations above msl range from 1,015 ft (310 m) on the drumlin top to 914 ft (279 m) at Sixmile Creek. Horizontally, the distance between this high and low is only 0.33 mi (0.53 km). The smaller drumlin, underlying piezometer K9, rises to only 965 ft (294 m) above msl and is composed of till over Cambrian sandstone. On the north side of Sixmile Creek, another drumlin rises very steeply to over 1,100 ft (335 m) above msl and its bedrock is of the Prairie du Chien group.

D. Hydrology

Potentiometric-surface and water-table maps of Dane County have been made by Cline (1965) and by Olcott (1973), but they may not be independent sources as there is little difference in their configurations near the study area. Both indicate that a regional groundwater divide runs northward through Middleton and Springfield townships and turns to the northeast near Springfield Corners. The divide separates water flowing east and south into the Yahara River basin and water flowing north and west to the Wisconsin River. It is located 3 to 4 mi (4.8 to 6.4 km) northwest of the field site. Regional flow through the bedrock aquifer in the study area is southeasterly with a gradient of about 0.0025 ft/ft (m/m). Water-table mapping has indicated a local flow system of a more complex nature. The local flow system, as mapped in the shallow groundwater in the till, is much more affected by surface topography and drainage features. Water-table maps are shown for April and August 1991 in Figs. 5a and 5b. A groundwater divide runs through the study area that very roughly corresponds to a surface divide. Water to the north and east of the divide flows toward Waunakee Marsh and Sixmile Creek. Water to the southwest of the divide flows toward Dorn Creek. Both creeks eventually run south to Lake Mendota. Locally, water recharges the groundwater through most of the study area as indicated by a downward vertical hydraulic gradient at piezometer nests. Near and in Sixmile Creek and Waunakee Marsh, groundwater gradients are generally upward, indicative of groundwater discharge areas. The water-table high to the immediate east of well K2 is caused by permanently standing surface water and might be contributing to the water table high at R2 and K1. The surface water results from drainage ditches from barns and barnyards at the two adjacent farms. A polypropylene 0.50-in (1.3-cm) O.D. x 0.38-in (0.95-cm) I.D. piezometer with a 4-in (10-cm) screen was placed in the standing water and driven about 3 ft into the bottom sediments. The water level in the piezometer is below the level of the standing water indicating a strong downward gradient and sediment saturation to at least 3 ft below ground surface. If the surface water is hydraulically connected to the groundwater, the water-table elevation is about 22 ft higher than at well K2, 300 ft to the west. Even if the surface water is perched, it probably still represents a significant recharge zone and the water-table elevation beneath it is probably still high

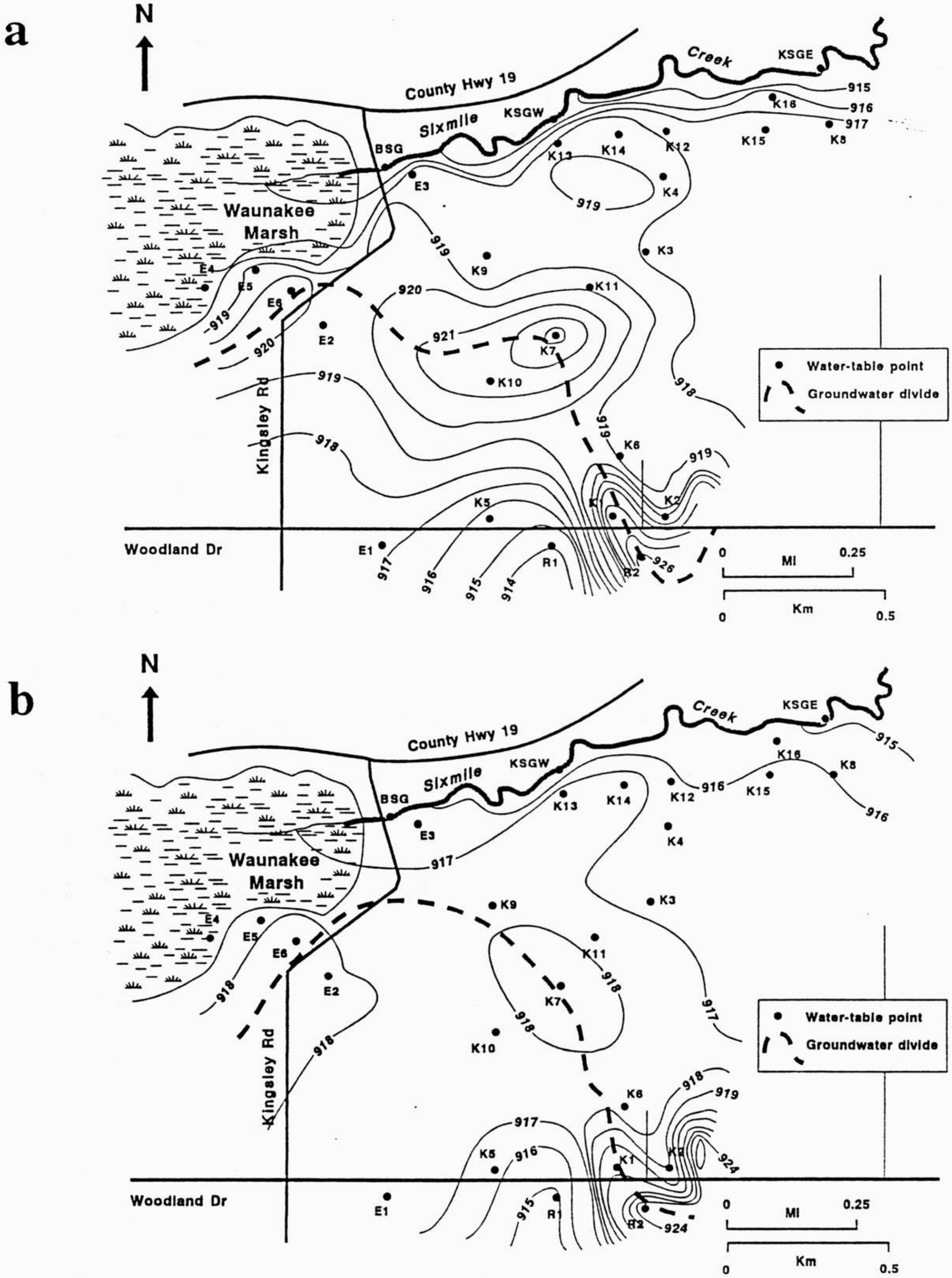

Figure 5. Water-table elevations in ft above mean sea level on April 22 (a) and August 5 (b), 1991.

compared to the surrounding area. The potential impact of this surface water on the groundwater quality will be considered later.

During the past 2 yr, water levels throughout the study area rose during snowmelt (end of February in 1991) and peaked around April or May. Water levels then steadily declined until the next snowmelt. Examples of hydrographs are shown in Figures 6a and 6b. Figure 6a shows water-table elevations at piezometer K12, located near Sixmile Creek. Weekly precipitation, measured on site with a universal rain gauge, is also shown for the non-winter months. Wells throughout the site show a response to precipitation within a few days to 2 weeks. Figure 6b shows water levels and precipitation in four nested piezometers at well location K6 where downward hydraulic gradients dominate. Vertical gradients between different pairs of wells at K6 are shown in Figure 7a which indicates that the strongest gradients are between piezometers K6.A (screened 3 to 8 ft below the water table) and K6.B (screened 16 to 21 ft below the water table. The strongest vertical gradients were found at well K1 (Fig. 7b), between K1.B (screened between 7 and 12 ft below the water table) and K1-Main (screened 30 to 31 ft below the water table). The water-table elevation at K1 is higher than at K6, engendering groundwater flow in the northerly direction (Fig. 5). The stronger downward hydraulic gradients at K1 causes a horizontal flow direction change at some elevation below the water table, i.e., the heads at K1 fall faster with depth than those at K6. Figure 8 shows that this flow reversal probably occurs around 890 ft above mean sea level (msl), 53 to 57 ft below ground surface and 27 to 30 ft below water table. This flow direction reversal is taking place over much of the field area so that in areas where shallow flow is toward the north and Sixmile Creek, deeper flow is toward the south and Lake Mendota.

Vertical hydraulic gradients are dependent on water-table elevations. Figure 9, for example, shows the effect of the water-level elevation (left-hand side Y-axis) at K11.B (screened just below the water table) on the vertical gradient (right-hand side Y-axis) between K11.B and K11.C (screened about 37 ft below water table). Potentiometric heads deeper in the till aquifer respond less to recharge events

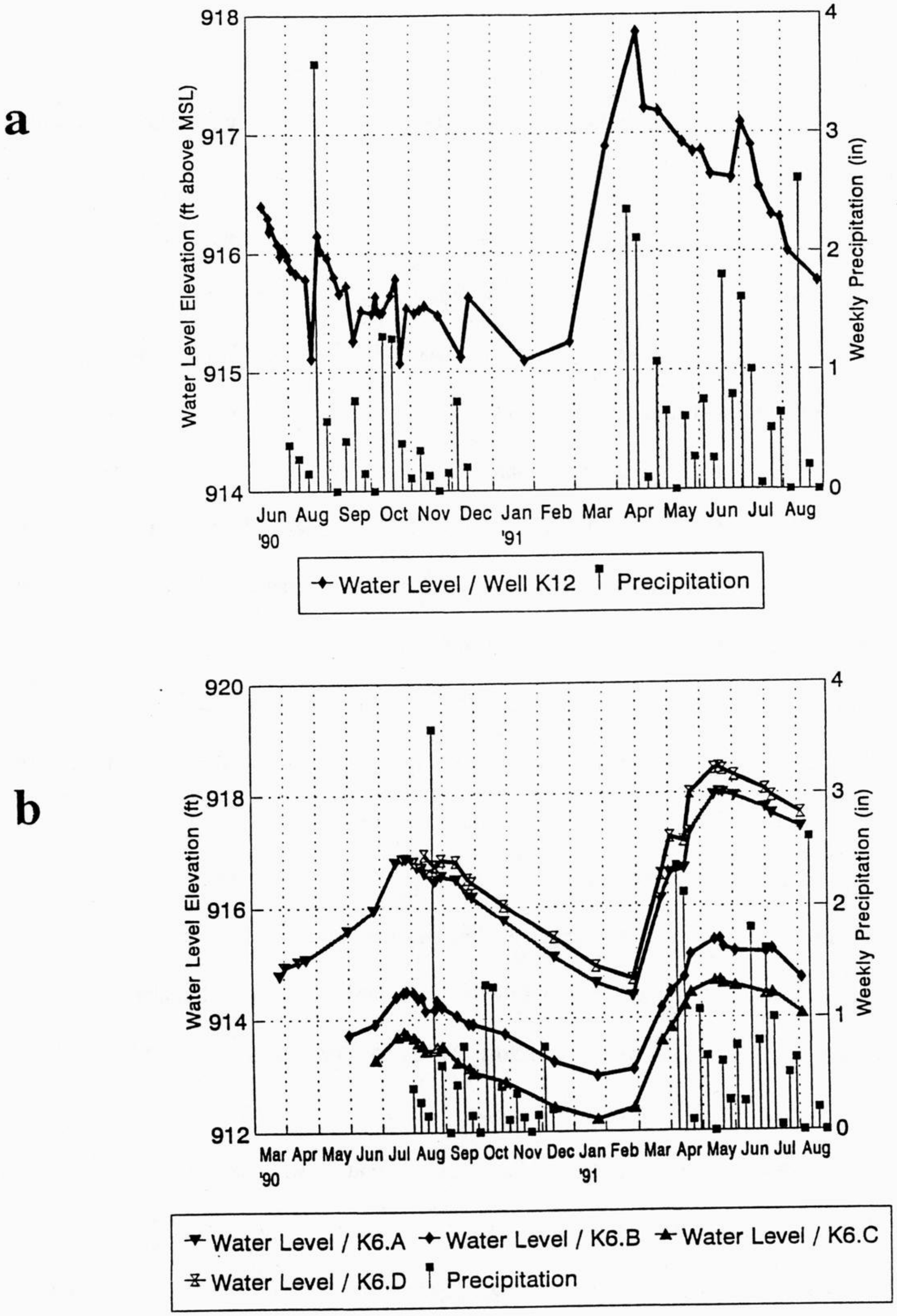

Figure 6. Water levels and precipitation at wells K12 (a) and K6 (b).

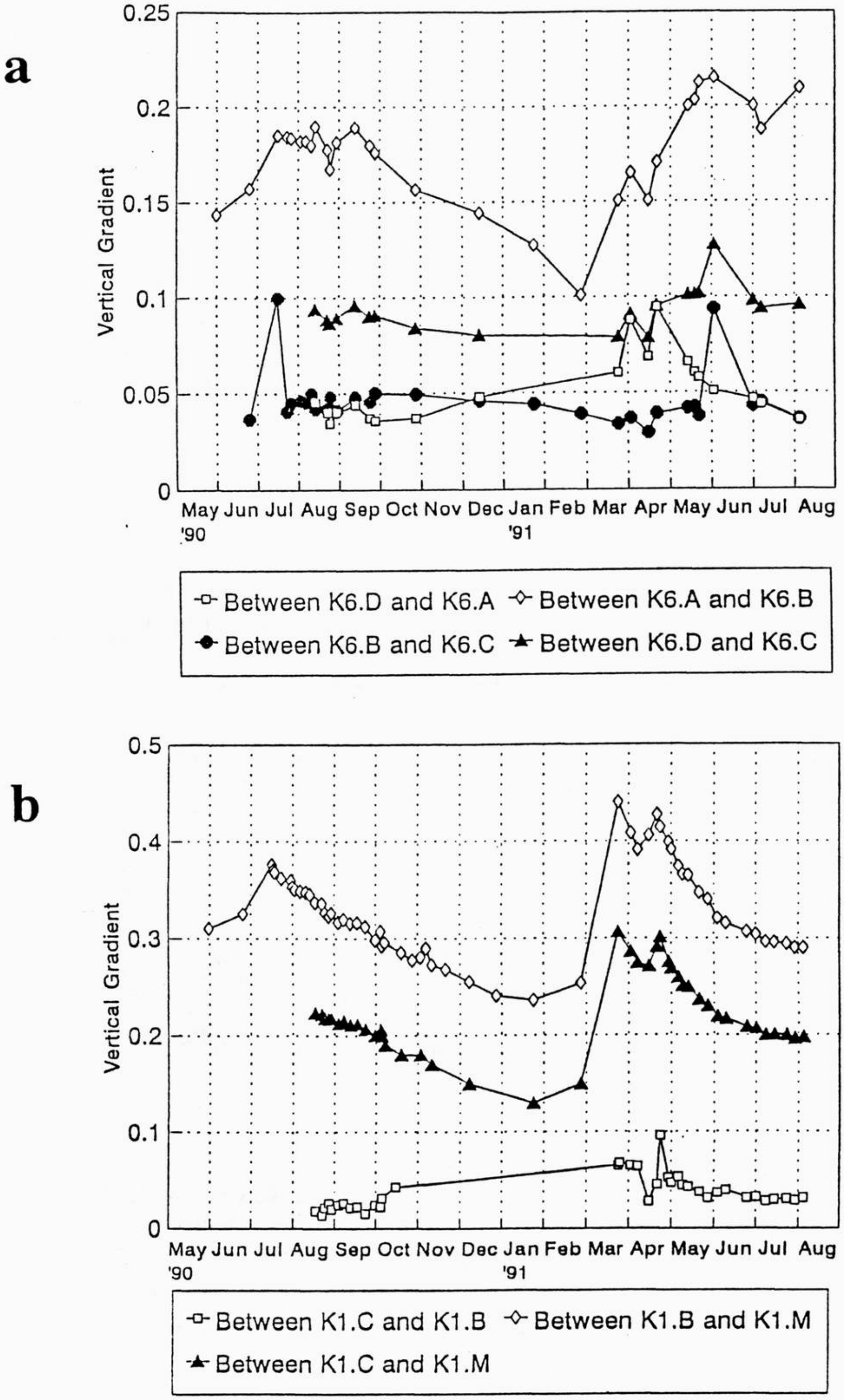

Figure 7. Vertical hydraulic gradients at well K6 (a) and well K1 (b).

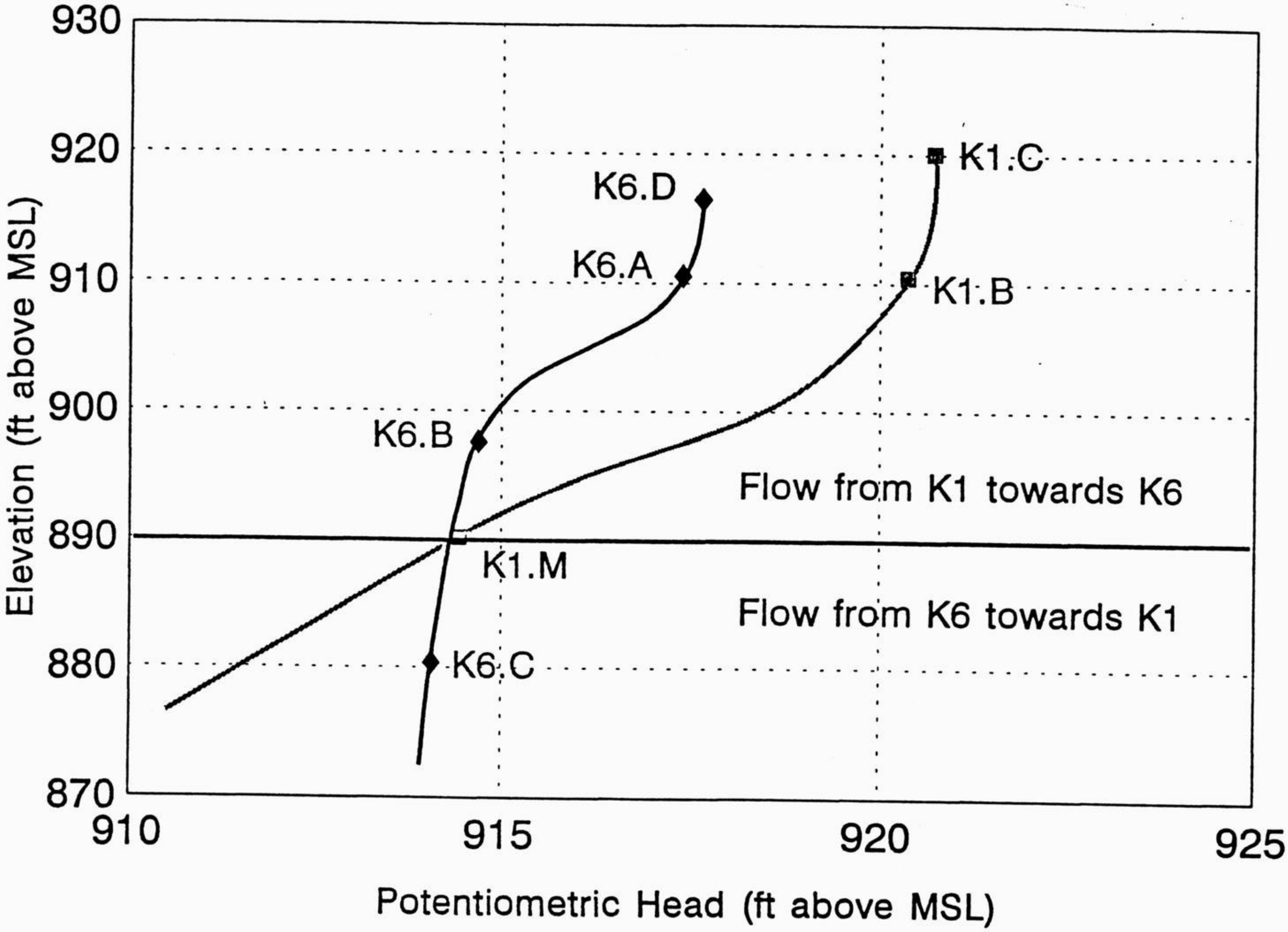

Figure 8. Potentiometric head, elevation relationship at wells K1 and K6 (August 5, 1991), indicating direction of horizontal groundwater flow.

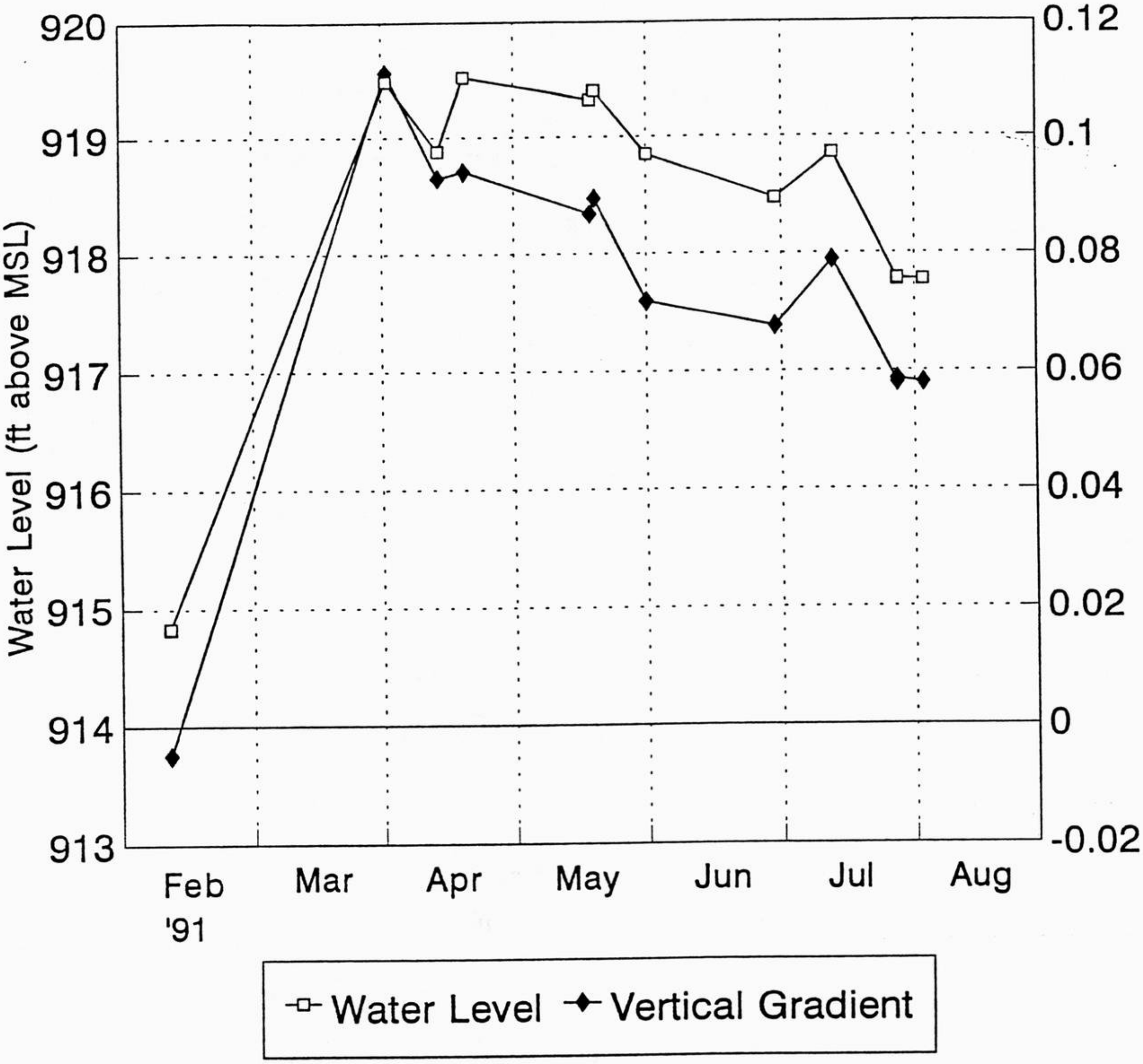

Figure 9. Water level and vertical hydraulic gradient at well K11.

than do the shallower heads. At wells K4, K16 and E6, located near Sixmile Creek and Waunakee Marsh, vertical hydraulic gradients have reversed from downward in periods of high water table to upward as the water table lowered. The response to recharge events in the upper aquifer account for the differences seen in the water-table configurations throughout the year. The April 1991 water-table map (Fig. 5a), when water levels at most wells were peaking, shows the effects of localized surface ponding and, therefore, increased recharge near wells K7, R2, E6, and south of K13 and K14. The August water-table map (Fig. 5b) shows a less complex water-table configuration as such mounds as those at K7 and south of K13 and K14 decrease. It is expected that the mounding will continue to decrease until the next snowmelt, as it did in the winter of 1990-1991.

Horizontal hydraulic gradients in the glacial till throughout the study area are generally much less than are the vertical gradients at most wells not located near Sixmile Creek or Waunakee Marsh. Groundwater flow is therefore primarily vertical in the shallow aquifer throughout most of the study area, probably turning horizontal at depth. The horizontal gradients are also affected by seasonal recharge and water-table elevation fluctuations. Figure 10a shows the water-table elevations at wells K3, K7, and K11; Figure 10b shows the horizontal gradients between those wells at the water table. Because the area around K7 accumulates more surface ponding and recharge, the gradient between it and K11 responds more to the water-table fluctuations. Water-table fluctuations and subsequent changes in horizontal gradients are less between K3 and K11. The average horizontal gradient between K7 and K11 is about 0.004 while the average vertical gradients at K7 and K11 are 0.3 and 0.05. The average horizontal gradient between K11 and K3 is about 0.002 while the average vertical gradient at K3 is about 0.025. In this area vertical gradients are roughly between 1 and 2 orders of magnitude higher than the horizontal gradients. Unless there is strong horizontal to vertical anisotropy in the hydraulic conductivities, one would expect vertical groundwater flow paths to dominate in this area and around K1, K2, and K6.

Hydraulic conductivities of the glacial till aquifer and of the creek bed in Sixmile Creek were

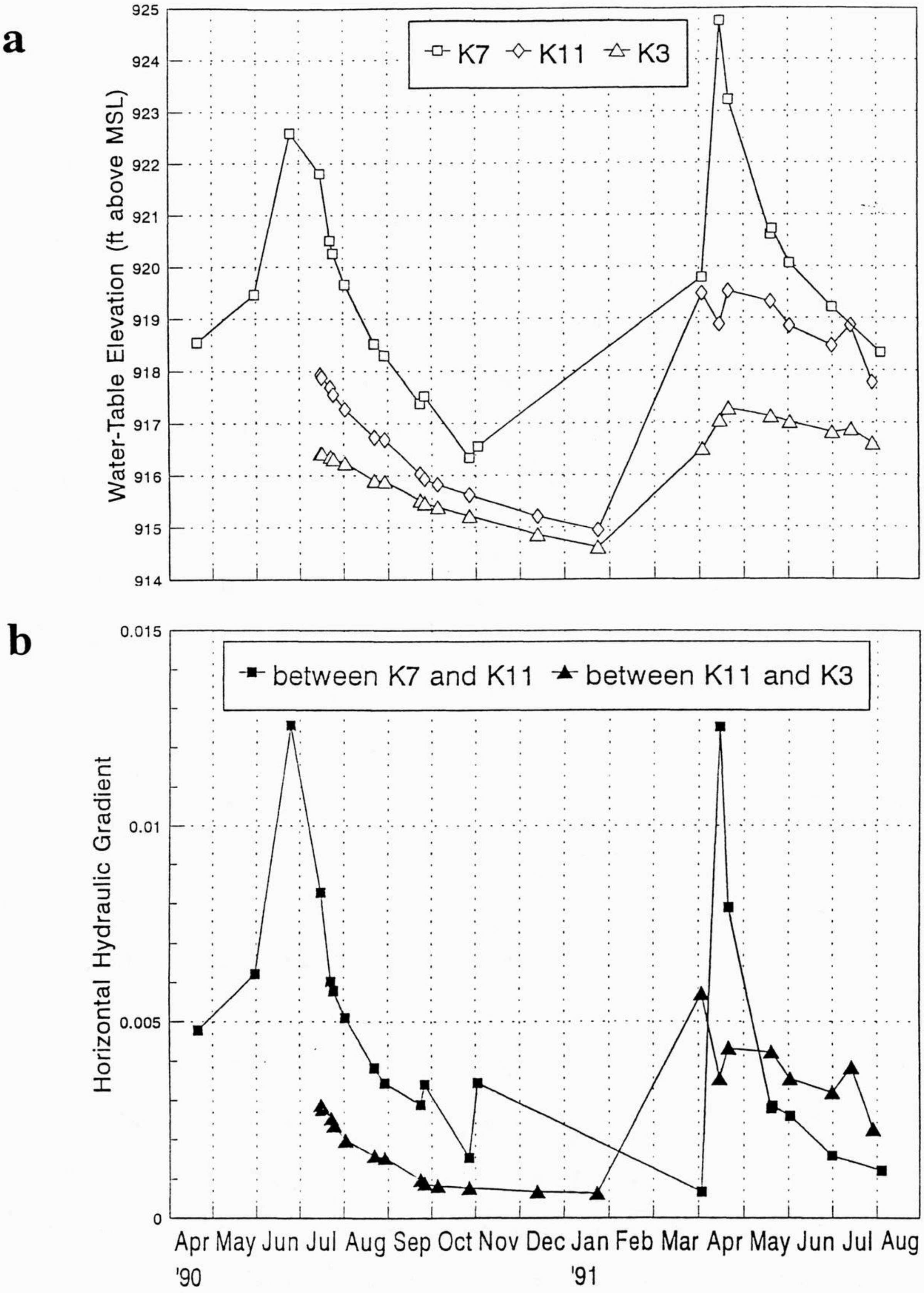

Figure 10. Water-table elevation at wells K3, K7, K11 (a) and horizontal hydraulic gradients between K7 and K11 and between K11 and K3 (b).

measured using piezometer slug tests in which water in the piezometers is instantaneously displaced by dropping (a falling slug test) or pulling out (a rising slug test) a solid object or slug into or from the piezometer and measuring the rate of recovery of the water level to equilibrium. Creek piezometer slug tests were also performed by adding water to the piezometers (falling tests only). Slug tests were analyzed using the method described by Bouwer and Rice (1976) and Bouwer (1989). Results of 64 till and the six creek piezometer slug tests are presented in Tables 4 and 5; their distributions are shown in Figure 11 in both the normal and log scale and indicate the data are log-normal. For water-table piezometers the rising tests are more accurate (Bouwer, 1989) and the rising test results were chosen to best represent the hydraulic conductivity at the well. All falling and rising test results were examined for reliability based on the straight-line fit of plots of the log of water displacement versus time, and the better test was chosen to represent the well. When both tests were equally satisfactory, the geometric mean of the tests was chosen. The arithmetic and geometric mean of all measured hydraulic conductivities of the glacial till aquifer were 0.69 and 0.30 ft/day ($2.4x10^{-4}$ and $1.1x10^{-4}$ cm/sec). The arithmetic and geometric mean of the hydraulic conductivities of the creek bed were 0.12 and 0.099 ft/day ($4.2x10^{-5}$ and $3.5x10^{-5}$ cm/sec).

Although the shallow groundwater system within the till unit is the primary unit of investigation, it might be considered a confining unit to the more permeable sandstone aquifer beneath. Hydraulic conductivity of the sandstone aquifer was estimated using specific capacity data from private well logs obtained from the Wisconsin Geological and Natural History Survey (WGNHS). A computer program called TGUESS (Bradbury and Rothschild, 1985) was used for the calculations. Non-field-based estimates of the storage and well loss coefficients were made for the calculation. The geometric and arithmetic means of the hydraulic conductivities calculated from 10 such logs close to the field site were 10 and 14 ft/day ($3.6x10^{-3}$ and $4.8x10^{-3}$ cm/sec), more than an order of magnitude greater than the mean

Table 4. Hydraulic Conductivity of the Horicon till as calculated from slug tests.

	Falling Tests		Rising Tests		Average or Best	
Well ID	K (ft/day)	K (cm/sec)	K (ft/day)	K (cm/sec)	K (ft/day)	K (cm/sec)
K1-Main	0.13	$4.6x10^{-5}$	0.11	$3.8x10^{-5}$	0.12	$4.2x10^{-5}$
K1.B	0.20	$7.0x10^{-5}$	0.21	$7.3x10^{-5}$	0.20	$7.2x10^{-5}$
K1.C	0.13	$4.5x10^{-5}$	0.035	$1.2x10^{-5}$	0.035	$1.2x10^{-5}$
K2-Main	0.045	$1.6x10^{-5}$	0.0094	$3.3x10^{-6}$	0.021	$7.2x10^{-6}$
K2.B	0.17	$5.9x10^{-5}$	0.28	$9.8x10^{-5}$	0.28	$9.8x10^{-5}$
K3-Main	2.6	$9.3x10^{-4}$	2.2	$7.6x10^{-4}$	2.4	$8.4x10^{-4}$
K3.B	0.71	$2.5x10^{-4}$	0.79	$2.8x10^{-4}$	0.79	$2.8x10^{-4}$
K4-Main	-	-	3.2	$1.1x10^{-3}$	3.2	$1.1x10^{-3}$
K4.B	0.039	$1.4x10^{-5}$	0.018	$6.5x10^{-6}$	0.018	$6.5x10^{-6}$
K5.A	0.34	$1.2x10^{-4}$	-	-	0.34	$1.2x10^{-4}$
K5.B	0.46	$1.6x10^{-4}$	0.30	$1.1x10^{-4}$	0.37	$1.3x10^{-4}$
K5.C	0.33	$1.2x10^{-4}$	0.22	$7.6x10^{-5}$	0.22	$7.6x10^{-5}$
K6.A	0.97	$3.4x10^{-4}$	0.31	$1.9x10^{-4}$	0.55	$1.9x10^{-4}$
K6.B	0.89	$3.1x10^{-4}$	2.1	$7.4x10^{-4}$	0.89	$3.1x10^{-4}$
K6.C	0.89	$3.1x10^{-4}$	0.58	$2.0x10^{-4}$	0.89	$3.1x10^{-4}$
K6.D	0.13	$4.6x10^{-5}$	0.13	$4.6x10^{-5}$	0.13	$4.6x10^{-5}$
K7.A	0.010	$3.6x10^{-6}$	0.0033	$1.2x10^{-6}$	0.0033	$1.2x10^{-6}$
K7.B	0.13	$4.7x10^{-5}$	0.11	$3.8x10^{-5}$	0.12	$4.2x10^{-5}$
K8	1.3	$4.5x10^{-4}$	1.1	$3.8x10^{-4}$	1.1	$3.8x10^{-4}$
K8	0.55	$1.9x10^{-4}$	2.4	$8.5x10^{-4}$	2.4	$8.5x10^{-4}$
K9	0.38	$1.3x10^{-4}$	0.23	$8.8x10^{-5}$	0.30	$1.1x10^{-4}$
K10	1.2	$4.3x10^{-4}$	0.56	$2.0x10^{-4}$	0.82	$2.9x10^{-4}$
K10	0.78	$2.8x10^{-4}$	0.90	$3.2x10^{-4}$	0.84	$3.0x10^{-4}$
K11.B	0.031	$1.1x10^{-5}$	0.022	$7.7x10^{-6}$	0.031	$1.1x10^{-5}$
K11.C	-	-	0.68	$2.4x10^{-4}$	0.68	$2.4x10^{-4}$
K16.A	0.13	$4.5x10^{-5}$	0.035	$1.2x10^{-5}$	0.067	$2.4x10^{-5}$
K16.B	0.068	$2.4x10^{-5}$	0.15	$5.3x10^{-5}$	0.15	$5.3x10^{-5}$
K16.C	0.78	$2.7x10^{-4}$	1.6	$5.6x10^{-4}$	1.6	$5.6x10^{-4}$
K16.D	1.3	$4.5x10^{-4}$	1.1	$4.0x10^{-4}$	1.1	$4.0x10^{-4}$
R01	1.0	$3.5x10^{-4}$	0.76	$2.7x10^{-4}$	0.76	$2.7x10^{-4}$
R02	0.28	$9.9x10^{-5}$	0.13	$4.5x10^{-5}$	0.13	$4.5x10^{-5}$
E01	1.7	$5.9x10^{-4}$	1.7	$5.9x10^{-4}$	1.7	$5.9x10^{-4}$
E02	0.52	$1.8x10^{-4}$	0.61	$2.2x10^{-4}$	0.61	$2.2x10^{-4}$
Arithmetic Mean					0.69	$2.4x10^{-4}$
Geometric Mean					0.30	$1.1x10^{-4}$

Table 5. Hydraulic conductivity of creek bed as calculated from slug tests on creek piezometers.

Creek Piezometer	K (ft/day)	K (cm/sec)
CPW1	0.070	2.5×10^{-5}
CPW2	0.12	4.2×10^{-5}
CPC1	0.18	6.3×10^{-5}
CPC2	0.029	1.0×10^{-5}
CPE1	0.093	3.3×10^{-5}
CPE2	0.23	8.0×10^{-5}
Arithmetic Mean	0.12	4.2×10^{-5}
Geometric Mean	0.099	3.5×10^{-5}

hydraulic conductivities of the till. It is not known as of yet to what extent water is exchanged between the two units, i.e., at what rate water from the till recharges the sandstone and whether any water from the sandstone discharges to Sixmile Creek. Mapping of the potentiometric surface within the sandstone and computer simulation of the system should provide realistic estimates.

The piezometers installed in Sixmile Creek consistently showed upward gradients indicating groundwater discharge into the creek. Water-level differences between pairs of piezometers indicates an average upward gradient of about 0.11. On rare occasions, Sixmile Creek would rise above the water level in one or more of the piezometers.

Computer modeling of the groundwater flow system at the Waunakee site has yet to be performed, but will be started in the fall of 1991. Attempts were made in spring 1991 to measure groundwater discharge into Sixmile Creek for use in such modeling. Sixmile Creek will be a model boundary for at least the upper part of the till aquifer. Groundwater discharge rates to model boundaries are important model parameters, especially given the uncertainty in recharge rate estimation. Groundwater discharge to a stream segment can be measured by taking the difference between an upgradient and downgradient

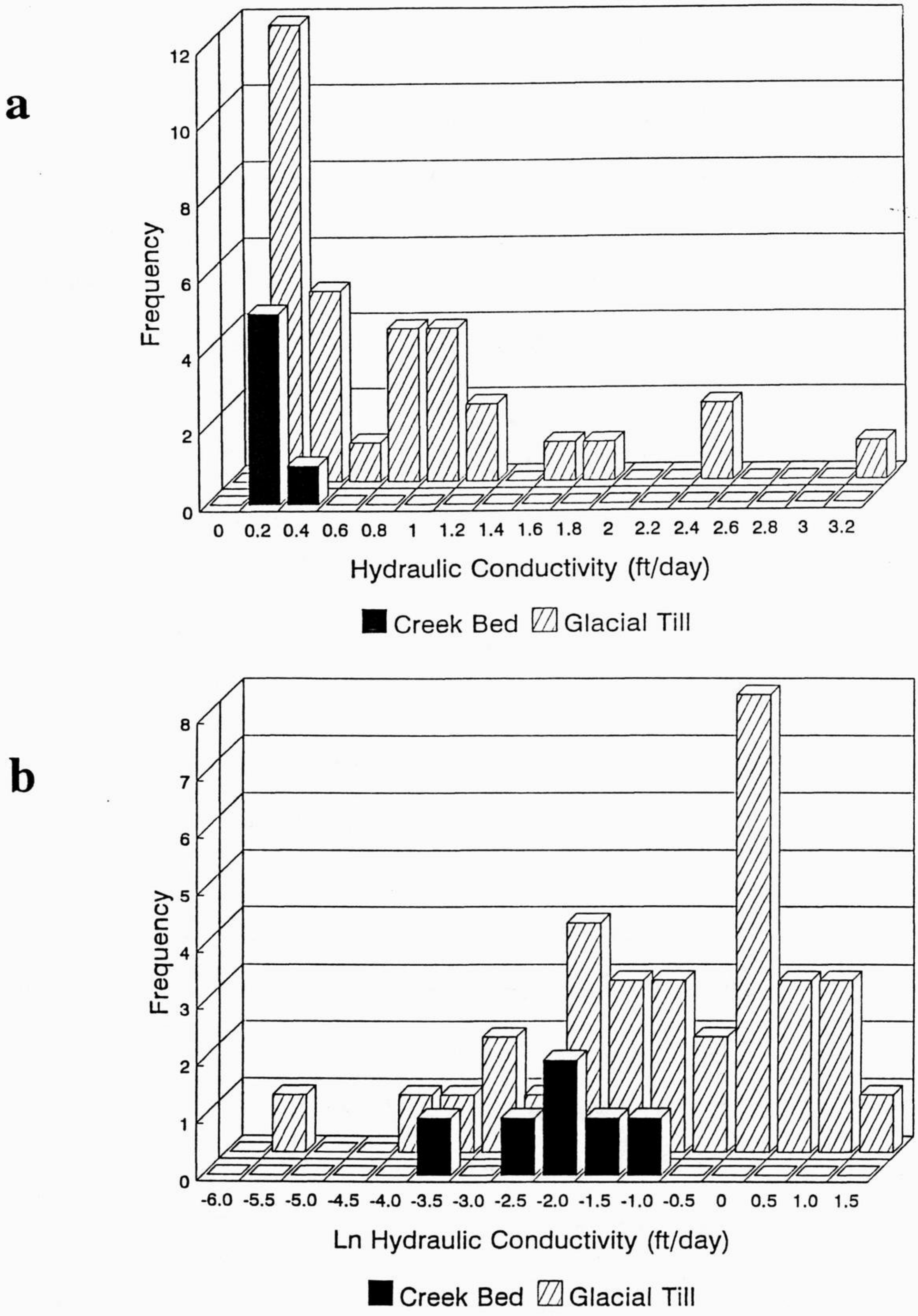

Figure 11. Distribution of hydraulic conductivities (a) and the natural logs of hydraulic conductivities (b) of the till and the creek bed as measured by piezometer slug tests.

stream-flow measurement during low-flow conditions when contributions to the stream are primarily due to groundwater. Stream-flow was measured in Sixmile Creek, since the main area of concern was between there and the groundwater divides shown in Figures 5a and 5b. Flow in Sixmile Creek was too slow to measure with Price or pygmy flow meters; instead dilution gauging was attempted. In this method, a NaCl tracer with known electrical conductivity (EC) is injected in the creek at a constant rate. Downstream, EC is measured as it increases over background and stabilizes. Relationships between EC and NaCl concentration are established in the laboratory and EC measurements are converted to concentrations. The relation between the injection concentration (C_1), background concentration (C_0), downstream concentration (C_2), rate of tracer injection (q) and stream discharge (Q) is:

$$QC_0 + qC_1 = (Q + q)C_2 \tag{10}$$

with Q as the only unknown (Water Research Association , 1970). The dilution gauging method requires that the NaCl solution be evenly mixed across the creek width. Despite many attempts at stirring and moving the measuring point farther downstream from the injection, the overall slow creek-flow velocity and the higher velocity of the creek middle than the sides prohibited even mixing. Instead, the velocity-area method was employed using plastic bottles to measure flow velocity. Plastic bottles were filled with water and sediment so that they floated almost totally submerged to better represent flow velocity at depth and minimize wind and surface flow effects. Due to the shallow creek depths (maximum of 1.5 ft, 45 cm) the mostly submerged bottles usually extended to over half of the creek depth. Creek cross sections were divided into 10 0.5-m sections. Depth and flow velocity within each section were measured. The product of flow velocity and cross sectional area of a segment gives the volumetric flow rate of that section. The sum of these volumetric flow rates gives the total volumetric flow rate of the creek at the measurement point. Creek flow was measured near KSGE and just east of BSG (Fig. 3). The method was slightly improved on and repeated 2 weeks later and the results of both trials are shown in Table 5.

The positive difference indicates that Sixmile Creek is losing water to the aquifer as it flows which

Table 6. Sixmile Creek stream-flow measurements.

	Flow Rate (L/sec)	
	Trial 1	Trial 2
Upstream, near BSG	92.4	61.2
Downstream, near KSGE	89.4	60.3
Difference	3.0	0.9

contradicts the upward gradients observed in the creek piezometers. In actuality, the small differences of 3.0 and 0.9 L/sec are probably insignificant compared with the measurement error associated with the method. In other words, the method used may provide reliable estimates of flow ratesin Sixmile Creek, but the rates upstream and downstream are too similar to measure a reliable difference. Assuming a 10% error with each flow measurement, one can conclude that the groundwater discharge to Sixmile Creek along this stretch is < 11 L/sec, and probably appreciably less.

VII. WATER AND SOIL SAMPLING PROCEDURES AND ANALYSES

A. Water

Water sampling allows collection of information on extent and distribution of pesticide contamination of the shallow groundwater system. The distribution of atrazine residue concentrations may also suggest sources of contamination. Wells and multi-level ports were sampled monthly or bimonthly during winter months from October 1989 through July 1991. Not every well was sampled each time. Monthly sampling will continue through October 1991 to observe water quality through the end of the 1991 farming season. Although the bedrock aquifer is not the focus of the study, water was sampled twice from four area private wells and analyzed for atrazine residues.

A peristaltic pump was used for sampling multi-level ports at K3 and K4 and at the 0.5-in (1.3-cm) I.D. wells. Each multi-level port had dedicated tubing permanently to attach it to the pump. The dedicated tubing was flushed with *in situ* water before sampling. All tubing associated with the pump was rinsed with distilled water between each use. The wells recharge quickly and about four well volumes were removed from each polypropylene sampling tube before sampling to ensure the water is characteristic of water from the aquifer and not water left sitting in the well. Samples were collected in 1 L amber bottles and kept on ice for transport to the laboratory where they remained refrigerated until extraction within 7 d of sampling.

Sampling of most of the 2- and 1.25-in (5.1- and 3.2-cm) I.D. PVC wells was done with stainless steel bailers. All bailing equipment was rinsed with distilled water between each use. Most of the wells recharge slowly enough to be bailed dry and sampled later. Some wells had to be sampled the following day to allow enough time for recharge. Four well volumes were removed before sampling from wells that could not be bailed dry. A submersible bladder pump was used to remove four well volumes from two deeper wells that recharge more quickly. Other sampling procedures are the same as for the multi-level wells. Occasionally, rinse blanks were collected by passing distilled water through sampling equipment after routine sampling and cleaning. At least one blank was collected for each type of sampling equipment used after the equipment was exposed to the wells known to be the most contaminated. Analysis of blanks indicated that no detectable cross contamination from sampling procedures was occurring.

For the first 10 sampling rounds and in April 1991 water samples were also taken for analyses of NO_3-N, NH_4-N, alkalinity, P, K, Ca, Mg, S, Zn, B, Mn, Fe, Cu, Al, Na, and Cl. Samples were filtered in the field to remove suspended solids and HNO_3 was added to prevent precipitation. Separate samples were taken for NO_3-N and NH_4-N analyses to which acid was not added. Analyses were conducted by the University of Wisconsin - Extension Soil and Plant Analysis Laboratory. It was hoped that analytical results might indicate groundwater sources and flow patterns. Measurements of water pH, electrical conductivity, temperature and dissolved oxygen were taken in the field during water sampling.

Determination of atrazine in groundwater samples consisted of preparation of concentrated extracts which were then subjected to chromatographic analysis. The samples were extracted by passing them through solid phase extraction (SPE) tubes packed with silica particles linked to straight-chain octadecyl hydrocarbon molecules (C_{18}). The hydrocarbons create a phase to which hydrophobic contaminants partition from water. Atrazine and some of its metabolites are retained by these columns and can be stripped off by passing methanol through the SPE cartridge. In this way, extraction and cleanup are carried out in one step. The extract in most cases is suitable for analysis by gas chromatography (GC) and high pressure liquid chromatography (HPLC). HPLC has been used as the primary analytical method in this study, while GC has served as a confirmatory method.

HPLC separation involved using a column packed with silica linked to a mixture of octyl hydrocarbon (C_8) and cation exchanger, a mobile phase of methanol, and water buffered with phosphate and an ultraviolet detector. The ratio of methanol to buffer was varied in response to changes in the characteristics of the column as it aged. This scheme exploits both the hydrophobic and weak base characteristics of triazines. Instrument and materials characteristics are described in earlier progress reports.

GC analysis was accomplished using capillary columns. Initial work was done using a 10-meter column and an electron capture detector. Incomplete separation of sample components led to the adoption of a longer (30-meter) column. Sensitivity to and specificity for the analytes was improved by switching to a nitrogen phosphorous (NP) detector. Problems with reproducibility of results were dealt with by adding terbuthylazine (TBA) to the extracts as an internal standard. TBA is identical to atrazine with the exception that a tertiary butyl group substitutes for the isopropyl group. GC analysis has been delayed by the need for further development of the method and by frequent problems with the instrument. GC analysis of extracts prepared in 1991 will be completed this fall.

In 1991, a change in the extraction method was adopted. Spike and recovery experiments indicated that extraction efficiency for DEAT and DIAT is improved by the addition of 50 g/L sodium chloride to the samples prior to extraction and by using SPE cartridges containing 1 g versus 0.5 g of packing material. To compare results of the old and new extraction methods, twelve samples collected in February, 1991 were split and extracted using both methods. The data appear Table 7.

Table 7. Comparison of old (0.5 g SPE packing) and new (1 g SPE packing + NaCl) extraction methods for selected monitoring wells.

	DEAT[1] conc. (ppb)		Atrazine conc. (ppb)	
Well ID	0.5 g	1 g+NaCl	0.5 g	1 g+NaCl
K3-Main	ND[2]	0.43	ND	Trace
K3.1	0.98	1.63	1.01	0.66
K3.2	0.86	1.43	0.91	0.61
K3.3	0.58	1.52	0.86	1.06
K3.4	0.37	0.88	0.46	0.44
K3.5	0.38	0.73	0.37	0.29
K3.6	0.37	0.89	0.34	0.35
K3.7	0.46	1.04	0.42	0.32
K6.A	0.72	1.50	2.93	1.60
K6.B	0.14	0.33	0.88	0.64
K6.C	0.12	ND	0.19	0.37
K6.D	0.52	1.23	0.98	1.48

[1] DEAT is desethylated atrazine.
[2] ND is not detected.

Reproducibility and detection limits for the extraction method were determined by collecting a 4 L sample from well K6A and extracting 7-500 mL portions of it. The results appear in Table 8. The limit of detection (LOD) was calculated from these data as 3 times the standard deviation of the 7 replicate assays. For samples measured at the LOD, there is a 99% probability that the analyte is in fact present (not zero). These data indicate that the method is reasonably sensitive and reproducible. A degree of caution should be exercised in extending these limits to all wells at the site; certain well waters yield extracts having a chromatographic background against which the peaks of interest must be quantified. This complicates interpretation of the results and indicates that for these samples, an additional cleanup step should be incorporated. The large number of samples analyzed in this study necessitated application of a relatively simple extraction technique. If errors due to inadequate cleanup or incomplete extraction have occurred, they will have resulted in underestimation of atrazine residues.

Table 8. Analyses of seven replicate extractions of water from Well K6A. Average of two HPLC analyses.

	Desethylated atrazine (ppb)	Atrazine (ppb)
	1.94	2.78
	1.86	2.81
	1.90	2.63
	1.91	2.71
	1.92	2.70
	1.95	2.72
	1.85	2.66
Standard deviation	0.0397	0.0623
Detection limit	0.119	0.187

Chromatographic data from analysis of groundwater routinely revealed the presence of components having retention times that did not correspond to any atrazine or atrazine metabolite standard used in the analysis. While it is common to observe unidentified peaks during any environmental analysis, the large size of certain chromatographic peaks and their appearance in several wells suggest that it would be worthwhile to identify them. Analysis of a selection of wellwater extracts by GC-mass spectroscopy is planned and should reveal whether residues of other pesticides are present.

B. Soil

The goals of soil sampling are to track the movement and dissipation of atrazine residues in the soil profile; to characterize the spatial variability of the observed rates of movement and degradation of the compounds; to obtain data on soil characteristics (soil pH, organic matter, grain-size distribution and bulk density) for future unsaturated-zone modeling; to relate pesticide movement and fate to soil characteristics; and to calibrate the unsaturated-zone model with the pesticide residue concentrations determined in the samples. On Farm X, two main fields were planted to corn and received atrazine application in 1990. The fields were divided into blocks of approximately equal area (4 to 5 acres or 1.6 to 2 ha) to evenly distribute soil sampling (Fig. 12). The north field was planted to corn and received atrazine treatment in the 1989 growing season as well as in 1990. The south field was planted to alfalfa from 1986 through 1989. In 1991, the north half of the north field was planted to oats and alfalfa. The south field and the other half of the north field were planted to corn as in 1990, except in 1991 the south field received no atrazine application. The north field provides two field seasons' data with atrazine application while the south field provides a longer period of persistence and mobility observations without the complication of an additional application.

1990 samples were taken prior to atrazine application and at 3, 6, 12 and 20 weeks post-application. 1991 samples have so far been taken prior to atrazine application, one day after atrazine application on the north field, and 11 weeks after application. Soil will be sampled once more at the end of October 1991, 24 to 25 weeks after atrazine application. Within each soil-sampling block, one set of soil cores was taken on each sampling date. On all but one sampling date, samples were taken approximately at the center of the blocks which were marked with flags. Soil cores were taken using 0.75-in (1.9-cm) and 1.25-in (3.2-cm) Oakfield soil sampling tubes. Successive 1-ft-long (0.30-m) soil cores were taken to a depth of 6 ft (1.8 m) on the first sampling date, to 3 ft (0.91 m) on the second and

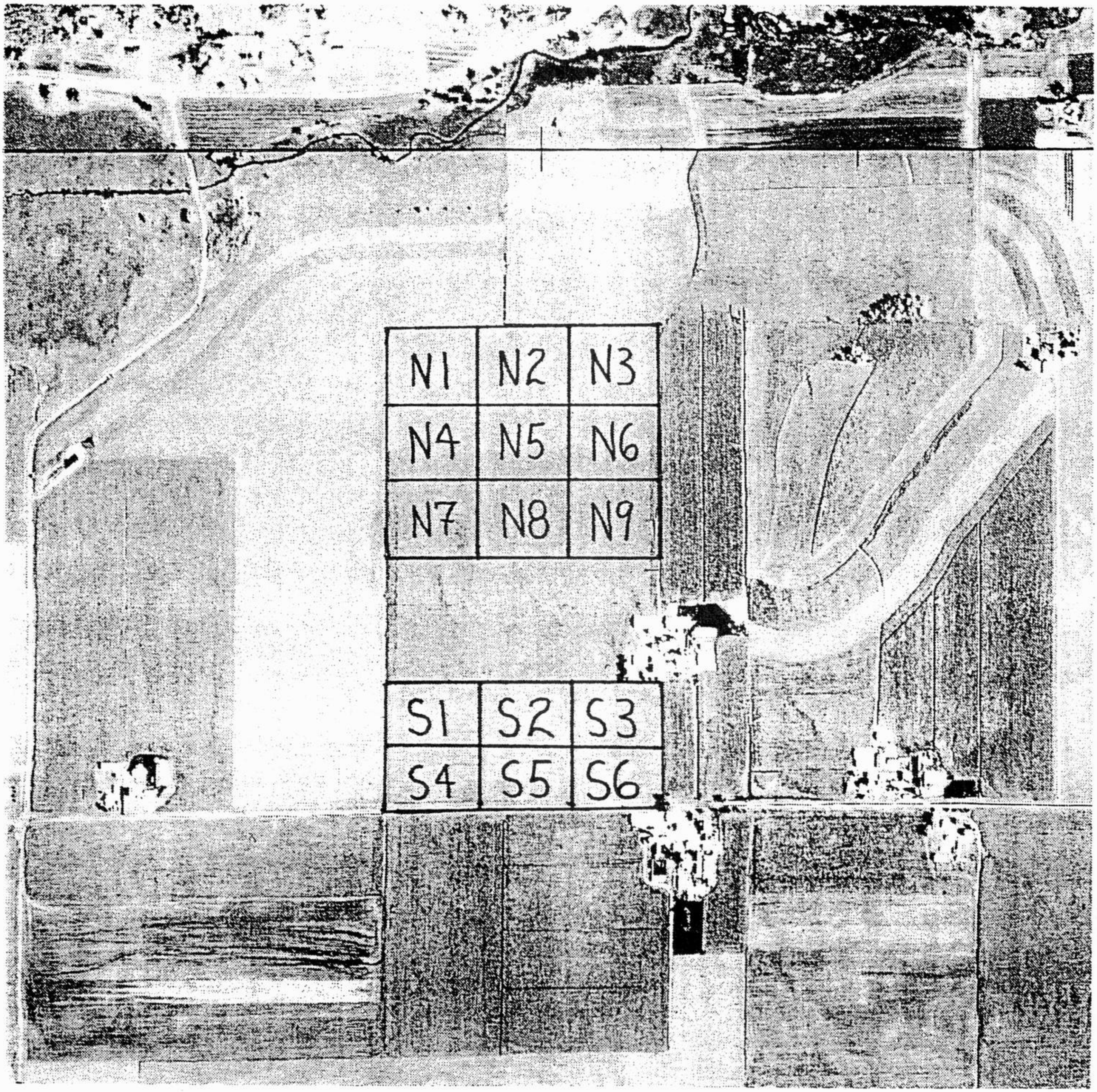

Figure 12. Grid design for soil sampling at the Waunakee field site. N and S stand for the north and south units.

to 6 ft (1.8 m) during subsequent samplings. Gravel layers in some of the blocks prevented sampling past 4 or 5 ft (1.2 or 1.5 m). When the larger sampling tubes were used, 1 core-ft was taken, while two cores of the same layer of soil were taken when the smaller tubes were used. After removal of the sample, a 3.5-in (8.9-cm) diameter bucket auger was used to bore a hole facilitating access to the next deeper layer of soil and reducing the danger of cross-contamination. To further reduce this risk, the top inch and the side of the core exposed in the sampling tube were cut off and discarded. Between uses, the sampling tubes were washed with Alconox and rinsed with water, distilled water and ethanol. The soil samples were transferred to new, steel food cans; each can was covered with clean aluminum foil and the foil was secured with a rubber band. Samples were kept on ice until they were stored in a freezer to await analysis.

To avoid creating new preferential flow pathways, the holes created by auguring were backfilled with the excavated soil in the order in which it was removed, and packed with a wooden tamping rod. This practice was not used in the three blocks during the first sampling.

Soil samples collected from the Waunakee field site will be analyzed this fall. The method is derived from work done with Plano silt loam that had been treated with 14C-labeled atrazine and described in the fourth quarterly report for this project. The procedure involves 3-serial extractions of soil samples with 4:1 acetonitrile/water with 0.25 N HCl, with centrifugation between each step. Modifications of the extraction protocol may be made to optimize extraction efficiencies from the samples collected from the Waunakee field site. Cleanup will be carried out in the following manner:

1. Acetonitrile is removed with rotary evaporation, leaving an aqueous solution.
2. The pH is adjusted by diluting 1:1 with 0.01 M monobasic potassium phosphate buffered at pH 2.0.
3. Particulate material is removed by passing extract through a 0.45 μm filter.
4. The extract is then passed through an SPE cartridge containing strong cation exchange (SCX)

packing preconditioned with methanol and phosphate buffer (pH 2.0). The SCX packing is silica linked to benzene sulfonic acid and retains atrazine residues positively charged in the acidified medium.

5. The packing is washed with 2 mL 1% acetic acid, followed by 2-3 mL methanol.
6. Atrazine and metabolite residues are eluted from the packing by passing 5-7 mL 3% ammonium hydroxide in methanol and then subjected to chromatographic analysis.

VIII. GROUNDWATER-SAMPLE ANALYTICAL RESULTS

Results of the groundwater sampling and analysis are shown in Tables 9-24. Only atrazine and desethylated atrazine were found in any quantifiable amounts. Trace amounts of desisopropylated atrazine were found rarely and at few wells. HPLC results are shown for every sampling period while GC results are shown for only April, May and June 1990 when the GC was working properly. Note that desethylated atrazine concentrations are also shown as modified metabolite, so as to correct for the lower molecular weight of the metabolite. The ratio of modified metabolite to atrazine residue concentrations would be the same as the ratio of the molar concentrations of atrazine and desethylated atrazine. That ratio (DAR: desethylated atrazine / atrazine concentration ratio) is also shown in Tables 9-24. For the HPLC data, when a "no detect" (ND) is reported for atrazine or desethylated atrazine, the HPLC limit of detection is substituted so that a reasonable DAR can be calculated. When ND is reported for atrazine and desethylated atrazine, no DAR is given. Since the GC limits of detection have not as yet been calculated, when a ND is reported for either atrazine or desethylated atrazine, no DAR is given.

Table 9. HPLC results from sampling during October, 1989.

Well ID	WI Unique Well Number	Depth Below WT[1] (ft)	Atrazine Conc. (ppb)	DEAT[2] Conc. (ppb)	Modified Metab.[3] (ppb)	Total (ppb)	DAR[4]
K3.1	EC 876	3.30	1.30	2.80	3.22	4.52	2.48
K3.2	EC 877	6.30	0.80	2.10	2.41	3.21	3.02
K3.3	EC 878	9.30	1.10	1.80	2.07	3.17	1.88
K3.4	EC 879	14.30	0.40	0.80	0.92	1.32	2.30
K3.5	EC 880	19.30	0.20	0.50	0.57	0.77	2.87
K3.6	EC 881	24.30	ND[5]	0.24	0.28	0.28	1.48
K3.7	EC 882	29.30	ND	0.30	0.34	0.34	1.84
K4.1	EC 885	6.83	ND	0.10	0.11	0.11	*[6]
K4.2	EC 886	9.83	ND	0.10	0.11	0.11	*
K4.3	EC 887	12.83	ND	ND	ND	0.00	*
K4.4	EC 888	17.83	ND	ND	ND	0.00	*
K4.5	EC 889	22.83	ND	ND	ND	0.00	*
K4.6	EC 890	27.83	ND	ND	ND	0.00	*
K4.7	EC 891	32.83	ND	ND	ND	0.00	*
P[7]K1-unsoftened	CK 227	-	0.60	0.60	0.69	1.29	1.15
PK1-softened	CK 227	-	0.70	0.80	0.92	1.62	1.31

[1] WT is water table.

[2] DEAT is desethylated atrazine.

[3] Modified metabolite concentration is desethylated atrazine concentration corrected to reflect the lower molecular weight of the metabolite.

[4] DAR is the modified metabolite : atrazine concentration ratio.

[5] ND is not detected.

[6] * indicates the DAR cannot be computed due to residue concentrations < the detection limit.

[7] P signifies a farmer's domestic well.

Table 10. HPLC results from sampling during December, 1989.

Well ID	WI Unique Well Number	Depth Below WT[1] (ft)	Atrazine Conc. (ppb)	DEAT[2] Conc. (ppb)	Modified Metab.[3] (ppb)	Total (ppb)	DAR[4]
K1-Main	EC 871	29.88	ND[5]	0.10	0.11	0.11	*[6]
K2-Main	EC 874	12.09	ND	0.10	0.11	0.11	*
K3.1	EC 876	3.30	0.80	2.40	2.76	3.56	3.45
K3.2	EC 877	6.30	0.90	1.90	2.18	3.08	2.43
K3.3	EC 878	9.30	1.10	1.00	1.15	2.25	1.05
K3.4	EC 879	14.30	1.00	0.70	0.80	1.80	0.80
K3.5	EC 880	19.30	ND	0.30	0.34	0.34	1.84
K3.6	EC 881	24.30	ND	0.30	0.34	0.34	1.84
K3.7	EC 882	29.30	ND	0.30	0.34	0.34	1.84
K3-Main	EC 883	30.67	ND	0.40	0.46	0.46	2.46
K4.1	EC 885	6.68	ND	0.30	0.34	0.34	1.84
K4.2	EC 886	9.68	ND	0.40	0.46	0.46	2.46
K4.3	EC 887	12.68	ND	0.40	0.46	0.46	2.46
K4.4	EC 888	17.68	ND	0.30	0.34	0.34	1.84
K4.5	EC 889	22.68	ND	0.30	0.34	0.34	1.84
K4.6	EC 890	27.68	ND	0.30	0.34	0.34	1.84
K4.7	EC 891	32.68	ND	0.50	0.57	0.57	3.07
K4-Main	EC 892	34.05	ND	ND	ND	0.00	*

[1] WT is water table.

[2] DEAT is desethylated atrazine.

[3] Modified metabolite concentration is desethylated atrazine concentration corrected to reflect the lower molecular weight of the metabolite.

[4] DAR is the modified metabolite : atrazine concentration ratio.

[5] ND is not detected.

[6] * indicates the DAR cannot be computed due to residue concentrations < the detection limit.

Table 11. HPLC results from sampling during late January and mid-February, 1990.

Well ID	WI Unique Well Number	Depth Below WT[1] (ft)	Atrazine Conc. (ppb)	DEAT[2] Conc. (ppb)	Modified Metab.[3] (ppb)	Total (ppb)	DAR[4]
K1-Main	EC 871	29.08	0.38	1.00	1.15	1.53	3.03
K2-Main	EC 874	11.39	ND[5]	0.13	0.15	0.15	0.80
K3.1	EC 876	3.00	1.30	3.50	4.02	5.32	3.10
K3.2	EC 877	6.00	1.10	2.90	3.33	4.43	3.03
K3.3	EC 878	9.00	0.71	2.50	2.87	3.58	4.05
K3.4	EC 879	14.00	0.29	1.40	1.61	1.90	5.55
K3.5	EC 880	19.00	0.13	0.78	0.90	1.03	4.81
K3.6	EC 881	24.00	ND	0.87	1.00	1.00	5.35
K3.7	EC 882	29.00	ND	0.53	0.61	0.61	3.26
K3-Main	EC 883	30.37	0.14	0.72	0.83	0.97	4.44
K4.1	EC 885	6.73	0.09	0.68	0.78	0.87	4.17
K4.2	EC 886	9.73	0.07	0.82	0.94	1.01	5.03
K4.3	EC 887	12.73	0.03	0.64	0.74	0.77	3.95
K4.4	EC 888	17.73	0.07	0.61	0.70	0.77	3.74
K4.5	EC 889	22.73	ND	0.79	0.91	0.91	4.86
K4.6	EC 890	27.73	0.28	0.78	0.90	1.18	3.20
K4.7	EC 891	32.73	0.06	0.45	0.52	0.58	2.78
K4-Main	EC 892	34.10	ND	0.60	0.69	0.69	3.69
PK1-unsoftened[6]	CK 227	-	0.63	0.97	1.12	1.75	1.77
PK1-softened	CK 227	-	0.75	0.65	0.75	1.50	1.00

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[1] WT is water table.

[2] DEAT is desethylated atrazine.

[3] Modified metabolite concentration is desethylated atrazine concentration corrected to reflect the lower molecular weight of the metabolite.

[4] DAR is the modified metabolite : atrazine concentration ratio.

[5] ND is not detected.

[6] P signifies a farmer's domestic well.

Table 12. HPLC results from sampling week of March 20, 1990.

Well ID	WI Unique Well Number	Depth Below WT[1] (ft)	Atrazine Conc. (ppb)	DEAT[2] Conc. (ppb)	Modified Metab.[3] (ppb)	Total (ppb)	DAR[4]
K1-Main	EC 871	29.78	0.17	0.42	0.48	0.65	2.84
K2-Main	EC 874	11.99	ND[5]	ND	ND	0.00	*[6]
K3.1	EC 876	3.76	0.72	1.58	1.82	2.54	2.52
K3.2	EC 877	6.76	0.81	2.18	2.51	3.32	3.09
K3.3	EC 878	9.76	0.42	1.04	1.20	1.62	2.85
K3.4	EC 879	14.76	0.22	0.77	0.89	1.11	4.02
K3.5	EC 880	19.76	0.15	0.49	0.56	0.71	2.99
K3.6	EC 881	24.76	0.19	0.37	0.43	0.62	2.24
K3.7	EC 882	29.76	0.14	0.32	0.37	0.51	2.63
K3-Main	EC 883	31.13	0.15	0.31	0.36	0.51	2.38
K4.1	EC 885	7.43	0.12	0.58	0.67	0.79	3.58
K4.2	EC 886	10.43	0.75	0.86	0.99	1.74	1.32
K4.3	EC 887	13.43	0.14	0.62	0.71	0.85	3.80
K4.4	EC 888	18.43	0.30	0.71	0.82	1.12	2.72
K4.5	EC 889	23.43	0.12	0.51	0.59	0.71	3.16
K4.6	EC 890	28.43	0.88	1.01	1.16	2.04	1.32
K4.7	EC 891	33.43	0.13	0.52	0.60	0.73	3.21
K4-Main	EC 892	34.80	0.16	0.80	0.92	1.08	4.92
P[7]K1-unsoftened	CK 227	-	0.72	0.91	1.05	1.77	1.45
PK1-softened	CK 227	-	0.51	1.04	1.20	1.71	2.34
Drain Pit	-	-	0.09	0.12	0.14	0.23	*

[1] WT is water table.

[2] DEAT is desethylated atrazine.

[3] Modified metabolite concentration is desethylated atrazine concentration corrected to reflect the lower molecular weight of the metabolite.

[4] DAR is the modified metabolite : atrazine concentration ratio.

[5] ND is not detected.

[6] * indicates the DAR cannot be computed due to residue concentrations < the detection limit.

[7] P signifies a farmer's domestic well.

Table 13. HPLC and GC results from sampling week of April 29, 1990.

		HPLC						GC				
Well ID	WI Unique Well Number	Depth Below WT[1] (ft)	Atrazine Conc. (ppb)	DEAT[2] Conc. (ppb)	Modified Metab.[3] (ppb)	Total (ppb)	DAR[4]	Atrazine Conc. (ppb)	DEAT Conc. (ppb)	Modified Metab. (ppb)	Total (ppb)	DAR
K1-Main	EC 871	29.88	0.17	0.42	0.48	0.65	2.84	0.61	ND	ND	0.61	*
K2-Main	EC 874	13.29	ND[5]	ND	ND	0.00	*[6]	ND	ND	ND	0.00	*
K3.1	EC 876	3.55	0.58	1.20	1.38	1.96	2.38	0.99	1.36	1.56	2.55	1.58
K3.2	EC 877	6.55	1.01	1.17	1.35	2.36	1.33	0.85	1.19	1.37	2.22	1.61
K3.3	EC 878	9.55	0.79	1.23	1.41	2.20	1.79	0.82	1.31	1.51	2.33	1.84
K3.4	EC 879	14.55	0.29	0.82	0.94	1.23	3.25	0.36	0.72	0.83	1.19	2.30
K3.5	EC 880	19.55	0.19	0.45	0.52	0.71	2.72	0.29	0.48	0.55	0.84	1.90
K3.6	EC 881	24.55	0.21	0.66	0.76	0.97	3.61	0.23	0.47	0.54	0.77	2.35
K3.7	EC 882	29.55	0.23	0.39	0.45	0.68	1.95	0.23	0.57	0.66	0.89	2.85
K3-Main	EC 883	30.92	0.16	0.21	0.24	0.40	1.28	0.28	0.28	0.32	0.60	1.15
K4.1	EC 885	7.03	0.10	0.42	0.48	0.58	2.56	0.19	0.49	0.56	0.75	2.97
K4.2	EC 886	10.03	0.21	0.45	0.52	0.73	2.46	0.24	0.65	0.75	0.99	3.11
K4.3	EC 887	13.03	0.09	0.47	0.54	0.63	2.89	0.21	0.46	0.53	0.74	2.52
K4.4	EC 888	18.03	0.08	0.24	0.28	0.36	1.50	0.17	0.35	0.40	0.57	2.37
K4.5	EC 889	23.03	0.05	0.24	0.28	0.33	1.50	0.16	0.26	0.30	0.46	1.87
K4.6	EC 890	28.03	0.29	0.43	0.49	0.78	1.70	0.18	0.47	0.54	0.72	3.00
K4.7	EC 891	33.03	0.16	0.33	0.38	0.54	2.89	0.15	0.35	0.40	0.55	2.68
K4-Main	EC 892	34.40	0.02	0.32	0.37	0.39	1.98	0.09	0.43	0.49	0.58	5.49
K5.A	EC 894	10.93	ND	ND	ND	0.00	*	ND	ND	ND	0.00	*
K6.A	EC 897	4.61	3.88	3.51	4.04	7.92	1.04	3.42	3.58	4.12	7.54	1.20
K7.A	EC 901	0.68	0.10	0.49	0.56	0.66	2.99	0.15	0.45	0.52	0.67	3.45

Table 13. Continued.

			HPLC					GC				
Well ID	WI Unique Well Number	Depth Below WT (ft)	Atrazine Conc. (ppb)	DEAT Conc. (ppb)	Modified Metab. (ppb)	Total (ppb)	DAR	Atrazine Conc. (ppb)	DEAT Conc. (ppb)	Modified Metab. (ppb)	Total (ppb)	DAR
K8	EC 902	2.97	ND	0.30	0.34	0.34	1.84	ND	0.35	0.40	0.40	2.15
K9	EC 903	2.86	0.07	ND	ND	0.07	*	0.16	ND	ND	0.16	*
K10	EC 904	5.98	0.26	0.13	0.15	0.41	0.57	0.44	ND	ND	0.44	*
K11.A	EC 906	3.76	ND	0.33	0.38	0.38	2.03	ND	0.52	0.60	0.60	*
P[7]K1 unsoftened	CK 227	-	0.50	0.55	0.63	1.13	1.26	0.79	0.87	1.00	1.79	1.27
PK1 softened	CK 227	-	0.71	0.71	0.82	1.53	1.15	0.82	1.15	1.32	2.14	1.61
Drain Pit	-	-	ND	0.16	0.18	0.18	0.98	ND	0.23	0.26	0.26	1.41
Sixmile Creek	-	-	ND	ND	ND	0.00	*	ND	ND	ND	0.00	*

[1] WT is water table.

[2] DEAT is desethylated atrazine.

[3] Modified metabolite concentration is desethylated atrazine concentration corrected to reflect the lower molecular weight of the metabolite.

[4] DAR is the modified metabolite : atrazine concentration ratio.

[5] ND is not detected.

[6] * indicates the DAR cannot be computed due to residue concentrations < the detection limit.

[7] P signifies a farmer's domestic well.

Table 14. HPLC and GC results from sampling week of May 31, 1990.

		HPLC						GC				
Well ID	WI Unique Well Number	Depth Below WT[1] (ft)	Atrazine Conc. (ppb)	DEAT[2] Conc. (ppb)	Modified Metab.[3] (ppb)	Total (ppb)	DAR[4]	Atrazine Conc. (ppb)	DEAT Conc. (ppb)	Modified Metab. (ppb)	Total (ppb)	DAR
K1-Main	EC 871	29.38	0.31	0.40	0.46	0.77	1.48	0.66	ND[5]	ND	0.66	*[6]
K1.B	EC 872	8.95	0.24	0.36	0.41	0.65	1.72	0.40	1.02	1.17	1.57	2.93
K2-Main	EC 874	13.69	ND	ND	ND	0.00	*	ND	ND	ND	0.00	*
K3.1	EC 876	3.66	1.14	1.53	1.76	2.90	1.54	1.17	1.55	1.78	2.95	1.52
K3.2	EC 877	6.66	0.68	0.65	0.75	1.43	1.10	0.92	1.15	1.32	2.24	1.44
K3.3	EC 878	9.66	0.98	1.47	1.69	2.67	1.72	1.03	1.02	1.17	2.20	1.14
K3.4	EC 879	14.66	0.32	0.47	0.54	0.86	1.69	0.62	0.88	1.01	1.63	1.63
K3.5	EC 880	19.66	0.16	0.26	0.30	0.46	1.60	0.37	0.57	0.66	1.03	1.77
K3.6	EC 881	24.66	0.24	0.31	0.36	0.60	1.49	0.33	1.07	1.23	1.56	3.73
K3.7	EC 882	29.66	0.37	0.66	0.76	1.13	2.05	0.43	0.66	0.76	1.19	1.76
K3-Main	EC 883	31.03	0.45	0.38	0.44	0.89	0.97	0.53	0.99	1.14	1.67	2.15
K4.1	EC 885	7.63	0.19	0.41	0.47	0.66	2.48	0.22	0.84	0.97	1.19	4.39
K4.2	EC 886	10.63	0.20	0.53	0.61	0.81	3.05	0.25	0.96	1.10	1.35	4.41
K4.3	EC 887	13.63	0.15	0.25	0.29	0.44	1.55	0.21	0.82	0.94	1.15	4.49
K4.4	EC 888	18.63	0.17	0.28	0.32	0.49	1.71	0.24	1.14	1.31	1.55	5.46
K4.5	EC 889	23.63	0.15	0.41	0.47	0.62	2.51	0.22	1.05	1.21	1.43	5.49
K4.6	EC 890	28.63	0.23	0.36	0.41	0.64	1.80	0.27	1.33	1.53	1.80	5.66
K4.7	EC 891	33.63	0.15	0.26	0.30	0.45	1.60	0.20	1.06	1.22	1.42	6.09
K4-Main	EC 892	35.00	0.23	0.30	0.34	0.57	1.50	0.40	1.73	1.99	2.39	4.97
K5.A	EC 894	10.85	ND	ND	ND	0.00	*	ND	ND	ND	0.00	*
K5.B	EC 895	3.04	ND	ND	ND	0.00	*	ND	ND	ND	0.00	*

Table 14. Continued.

		HPLC						GC				
Well ID	WI Unique Well Number	Depth Below WT (ft)	Atrazine Conc. (ppb)	DEAT Conc. (ppb)	Modified Metab. (ppb)	Total (ppb)	DAR	Atrazine Conc. (ppb)	DEAT Conc. (ppb)	Modified Metab. (ppb)	Total (ppb)	DAR
K6.A	EC 897	5.12	3.68	2.02	2.32	6.00	0.63	3.42	3.44	3.96	7.38	1.16
K6.B	EC 898	18.02	0.93	ND	ND	0.93	0.15	1.14	ND	ND	1.14	*
K7.A	EC 901	at WT	0.09	0.28	0.32	0.41	1.71	0.16	0.71	0.82	0.98	5.10
K8	EC 902	3.30	ND	0.13	0.15	0.15	0.80	ND	0.25	0.29	0.29	*
K9	EC 903	3.04	0.06	0.14	0.16	0.22	0.86	0.19	1.47	1.69	1.88	8.90
K10	EC 904	6.13	0.28	0.14	0.16	0.44	0.57	0.25	0.46	0.53	0.78	2.12
K11.A	EC 906	4.01	ND	0.12	0.14	0.14	0.74	ND	ND	ND	0.00	*
P[7]K1 unsoftened	CK 227	-	1.01	0.66	0.76	1.77	0.75	0.98	1.16	1.33	2.31	1.36
PK1 softened	CK 227	-	0.61	0.37	0.43	1.04	0.70	0.77	0.99	1.14	1.91	1.48
Drain Pit	-	-	0.19	0.09	0.10	0.29	0.72	0.26	0.48	0.55	0.81	2.12
Sixmile Creek	-	-	ND	ND	ND	0.00	*	ND	ND	ND	0.00	*

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[1] WT is water table.

[2] DEAT is desethylated atrazine.

[3] Modified metabolite concentration is desethylated atrazine concentration corrected to reflect the lower molecular weight of the metabolite.

[4] DAR is the modified metabolite : atrazine concentration ratio.

[5] ND is not detected.

[6] * indicates the DAR cannot be computed due to residue concentrations < the detection limit.

[7] P signifies a farmer's domestic well.

Table 15. HPLC and GC results from sampling week of June 25, 1990.

		HPLC						GC				
Well ID	WI Unique Well Number	Depth Below WT[1] (ft)	Atrazine Conc. (ppb)	DEAT[2] Conc. (ppb)	Modified Metab.[3] (ppb)	Total (ppb)	DAR[4]	Atrazine Conc. (ppb)	DEAT Conc. (ppb)	Modified Metab. (ppb)	Total (ppb)	DAR
K1-Main	EC 871	29.89	0.39	0.27	0.31	0.70	0.80	1.56	1.66	1.91	3.47	1.22
K1.B	EC 872	9.46	0.36	0.94	1.08	1.44	3.00	0.50	1.29	1.48	1.98	2.97
K2-Main	EC 874	13.76	ND[5]	ND	ND	0.00	*[6]	ND	ND	ND	0.00	*
K3.1	EC 876	3.63	0.98	1.20	1.38	2.36	1.41	1.43	1.33	1.53	2.96	1.07
K3.2	EC 877	6.63	0.91	1.38	1.59	2.50	1.74	1.31	1.40	1.61	2.92	1.23
K3.3	EC 878	9.63	1.10	1.43	1.64	2.74	1.49	1.47	1.55	1.78	3.25	1.21
K3.4	EC 879	14.63	0.97	0.76	0.87	1.84	0.90	0.65	0.64	0.74	1.39	1.13
K3.5	EC 880	19.63	0.39	0.61	0.70	1.09	1.80	0.54	0.64	0.74	1.28	1.36
K3.6	EC 881	24.63	ND	0.43	0.49	0.49	2.64	0.45	0.60	0.69	1.14	1.53
K3.7	EC 882	29.63	ND	0.39	0.45	0.45	2.40	0.38	0.43	0.49	0.87	1.30
K3-Main	EC 883	31.00	0.20	0.34	0.39	0.59	1.95	0.86	0.80	0.92	1.78	1.07
K4.1	EC 885	7.02	0.37	0.42	0.48	0.85	1.31	0.48	0.60	0.69	1.17	1.44
K4.2	EC 886	10.02	0.07	0.52	0.60	0.67	3.21	0.37	0.69	0.79	1.16	2.14
K4.3	EC 887	13.02	ND	0.41	0.47	0.47	2.52	0.40	0.74	0.85	1.25	2.13
K4.4	EC 888	18.02	0.07	0.33	0.38	0.45	2.03	0.34	0.55	0.63	0.97	1.86
K4.5	EC 889	23.02	0.07	0.34	0.39	0.46	2.09	0.37	0.66	0.76	1.13	2.05
K4.6	EC 890	28.02	ND	0.42	0.48	0.48	2.58	0.39	0.83	0.95	1.34	2.45
K4.7	EC 891	33.02	ND	0.41	0.47	0.47	2.52	0.39	0.71	0.82	1.21	2.09
K4-Main	EC 892	34.39	0.24	0.19	0.22	0.46	0.91	0.31	0.48	0.55	0.86	1.78
K5.A	EC 894	10.65	ND	ND	ND	0.00	*	0.74	1.07	1.23	1.97	1.66
K5.B	EC 895	2.84	ND	ND	ND	0.00	*	-	-	-	-	-

Table 15. Continued.

		HPLC						GC				
Well ID	WI Unique Well Number	Depth Below WT (ft)	Atrazine Conc. (ppb)	DEAT Conc. (ppb)	Modified Metab. (ppb)	Total (ppb)	DAR	Atrazine Conc. (ppb)	DEAT Conc. (ppb)	Modified Metab. (ppb)	Total (ppb)	DAR
K6.A	EC 897	5.22	3.48	1.17	1.35	4.83	0.39	3.20	2.61	3.00	6.20	0.94
K6.B	EC 898	18.12	1.16	0.26	0.30	1.46	0.26	1.08	0.84	0.97	2.05	0.89
K6.C	EC 899	35.30	0.77	0.30	0.34	1.11	0.45	1.07	1.05	1.21	2.28	1.13
K7.A	EC 901	4.72	ND	0.32	0.37	0.37	1.97	0.10	0.60	0.69	0.79	6.90
K8	EC 902	3.36	ND	0.34	0.39	0.39	2.09	ND	0.52	0.60	0.60	*
K9	EC 903	3.35	ND	0.15	0.17	0.17	0.92	0.34	0.53	0.61	0.95	1.79
K10	EC 904	6.38	ND	0.24	0.28	0.28	1.48	0.72	0.44	0.51	1.23	0.70
K11.A	EC 906	4.15	ND	0.35	0.40	0.40	2.15	ND	2.32	2.67	2.67	*
P[7]K1 unsoftened	CK 227	-	0.78	1.10	1.26	2.04	1.62	0.85	0.97	1.12	1.97	1.31
PK1 softened	CK 227	-	0.84	0.71	0.82	1.66	0.97	0.90	1.07	1.23	2.13	1.37
Drain Pit	-	-	0.46	ND	ND	0.46	0.30	0.86	0.47	0.54	1.40	0.63
Sixmile Creek	-	-	ND	ND	ND	0.00	*	ND	ND	ND	0.00	*

[1] WT is water table.
[2] DEAT is desethylated atrazine.
[3] Modified metabolite concentration is desethylated atrazine concentration corrected to reflect the lower molecular weight of the metabolite.
[4] DAR is the modified metabolite : atrazine concentration ratio.
[5] ND is not detected.
[6] * indicates the DAR cannot be computed due to residue concentrations < the detection limit.
[7] P signifies a farmer's domestic well.

Table 16. HPLC results from sampling week of July 25, 1990.

Well ID	WI Unique Well Number	Depth Below WT[1] (ft)	Atrazine Conc. (ppb)	DEAT[2] Conc. (ppb)	Modified Metab.[3] (ppb)	Total (ppb)	DAR[4]
K1-Main	EC 871	31.36	ND[5]	0.31	0.36	0.36	1.91
K1.B	EC 872	10.93	0.09	0.38	0.44	0.53	2.35
K2-Main	EC 874	15.07	ND	ND	ND	0.00	*[6]
K2.B	EC 875	at WT	ND	ND	ND	0.00	*
K3.1	EC 876	4.12	1.48	1.07	1.23	2.71	0.83
K3.2	EC 877	7.12	1.43	1.14	1.31	2.74	0.92
K3.3	EC 878	10.12	1.27	1.03	1.18	2.45	0.93
K3.4	EC 879	15.12	0.64	0.65	0.75	1.39	1.17
K3.5	EC 880	20.12	ND	0.35	0.40	0.40	2.15
K3.6	EC 881	25.12	0.07	0.22	0.25	0.32	1.33
K3.7	EC 882	30.12	0.37	0.29	0.33	0.70	0.90
K3-Main	EC 883	31.49	ND	0.19	0.22	0.22	1.17
K3.B	EC 884	at WT	-	0.84	0.97	0.97	*
K4.1	EC 885	7.04	ND	0.12	0.14	0.14	0.74
K4.2	EC 886	10.04	ND	0.14	0.16	0.16	0.86
K4.3	EC 887	13.04	ND	0.12	0.14	0.14	0.74
K4.4	EC 888	18.04	ND	0.16	0.18	0.18	0.98
K4.5	EC 889	23.04	ND	0.13	0.15	0.15	0.80
K4.6	EC 890	28.04	ND	0.17	0.20	0.20	1.05
K4.7	EC 891	33.04	ND	0.15	0.17	0.17	0.92
K4-Main	EC 892	34.41	ND	0.07	0.08	0.08	*
K4.B	EC 893	at WT	1.00	ND	ND	1.00	0.14
K5.A	EC 894	11.90	ND	ND	ND	0.00	*
K5.B	EC 895	4.09	ND	ND	ND	0.00	*
K6.A	EC 897	6.41	1.73	1.15	1.32	3.05	0.76
K6.B	EC 898	19.31	0.87	0.37	0.43	1.30	0.49
K6.C	EC 899	36.49	0.75	0.19	0.22	0.97	0.29
K7.A	EC 901	at WT	ND	0.12	0.14	0.14	0.75
K8	EC 902	at WT	ND	0.11	0.13	0.13	*
K9	EC 903	3.41	ND	0.11	0.13	0.13	*
K10	EC 904	at WT	ND	0.02	0.02	0.02	*
K11.A	EC 906	at WT	ND	0.19	0.22	0.22	1.17
K12	EC 907	at WT	0.24	0.15	0.17	0.41	0.72
K13	EC 908	at WT	ND	0.61	0.70	0.70	3.75
K15	EC 910	at WT	ND	ND	ND	0.00	*
PK1[7]	CK 227	-	0.84	0.37	0.43	1.27	0.51

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[1] WT is water table.

[2] DEAT is desethylated atrazine.

[3] Modified metabolite concentration is desethylated atrazine concentration corrected to reflect the lower molecular weight of the metabolite.

[4] DAR is the modified metabolite : atrazine concentration ratio.

[5] ND is not detected.

[6] * indicates the DAR cannot be computed due to residue concentrations < the detection limit.

[7] P signifies a farmer's domestic well.

Table 17. HPLC results from sampling week of August 29, 1990.

Well ID	WI Unique Well Number	Depth Below WT[1] (ft)	Atrazine Conc. (ppb)	DEAT[2] Conc. (ppb)	Modified Metab.[3] (ppb)	Total (ppb)	DAR[4]
K1-Main	EC 871	30.65	0.74	0.33	0.38	1.12	0.51
K1.B	EC 872	10.22	ND[5]	0.64	0.74	0.74	3.93
K1.C	EC 873	at WT	2.30	0.75	0.86	3.16	0.37
K2-Main	EC 874	13.80	0.40	0.07	0.07	0.47	0.19
K2.B	EC 875	at WT	ND	ND	ND	0.00	*[6]
K3.1	EC 876	3.69	1.65	1.48	1.70	3.35	1.03
K3.2	EC 877	6.69	1.05	1.15	1.32	2.37	1.26
K3.3	EC 878	9.69	1.36	1.80	2.07	3.43	1.52
K3.4	EC 879	14.69	0.66	1.25	1.44	2.10	2.18
K3.5	EC 880	19.69	0.34	0.70	0.80	1.14	2.37
K3.6	EC 881	24.69	0.31	0.72	0.83	1.14	2.67
K3.7	EC 882	29.69	0.27	0.76	0.87	1.14	3.24
K3-Main	EC 883	31.06	0.44	0.53	0.61	1.05	1.38
K3.B	EC 884	at WT	0.57	1.24	1.43	2.00	2.50
K4.1	EC 885	6.04	0.18	0.55	0.63	0.81	3.36
K4.2	EC 886	9.04	0.19	0.28	0.32	0.51	1.69
K4.3	EC 887	12.04	0.22	0.65	0.75	0.97	3.40
K4.4	EC 888	17.04	0.10	0.26	0.30	0.40	1.60
K4.5	EC 889	22.04	0.13	0.37	0.43	0.56	2.30
K4.6	EC 890	27.04	0.17	0.45	0.52	0.69	2.78
K4.7	EC 891	32.04	0.14	0.48	0.55	0.69	2.94
K4-Main	EC 892	33.41	0.16	0.37	0.43	0.59	2.30
K5.A	EC 894	11.65	ND	ND	ND	0.00	*
K5.B	EC 895	3.84	ND	ND	ND	0.00	*
K6.A	EC 897	6.39	3.25	1.72	1.98	5.23	0.61
K6.B	EC 898	19.29	1.10	0.32	0.37	1.47	0.33
K6.C	EC 899	36.47	0.84	0.38	0.44	1.28	0.52
K6.D	EC 900	at WT	2.50	1.07	1.23	3.73	0.49
K7.A	EC 901	at WT	0.23	0.38	0.44	0.67	1.90
K8	EC 902	at WT	0.04	0.18	0.21	0.25	1.12
K9	EC 903	3.25	0.25	0.39	0.45	0.70	1.79
K10	EC 904	at WT	0.48	0.21	0.24	0.72	0.50
K11.A	EC 906	at WT	ND	0.34	0.39	0.39	2.09
K12	EC 907	at WT	0.50	0.97	1.12	1.62	2.23
K13	EC 908	at WT	0.80	0.90	1.03	1.83	1.29
K15	EC 910	at WT	ND	ND	ND	0.00	*
PK1[7]	CK 227	-	1.45	0.88	1.01	2.46	0.70

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[1] WT is water table.

[2] DEAT is desethylated atrazine.

[3] Modified metabolite concentration is desethylated atrazine concentration corrected to reflect the lower molecular weight of the metabolite.

[4] DAR is the modified metabolite : atrazine concentration ratio.

[5] ND is not detected.

[6] * indicates the DAR cannot be computed due to residue concentrations < the detection limit.

[7] P signifies a farmer's domestic well.

Table 18. HPLC results from sampling week of September 26, 1990.

Well ID	WI Unique Well Number	Depth Below WT[1] (ft)	Atrazine Conc. (ppb)	DEAT[2] Conc. (ppb)	Modified Metab.[3] (ppb)	Total (ppb)	DAR[4]
K1-Main	EC 871	29.92	0.45	0.59	0.68	1.13	1.51
K1.B	EC 872	9.49	ND[5]	0.52	0.60	0.60	3.20
K2-Main	EC 874	13.25	0.26	ND	ND	0.26	0.53
K2.B	EC 875	at WT	ND	ND	ND	0.00	*[6]
K3.1	EC 876	3.32	1.32	1.39	1.60	2.92	1.21
K3.2	EC 877	6.32	1.34	1.35	1.55	2.89	1.16
K3.3	EC 878	9.32	1.10	1.88	2.16	3.26	1.96
K3.4	EC 879	14.32	0.65	0.88	1.01	1.66	1.56
K3.5	EC 880	19.32	0.40	0.52	0.60	1.00	1.49
K3.6	EC 881	24.32	0.30	0.43	0.49	0.79	1.65
K3.7	EC 882	29.32	0.30	0.47	0.54	0.84	1.80
K3-Main	EC 883	30.69	0.30	0.48	0.55	0.85	1.84
K4.1	EC 885	5.69	0.25	0.29	0.33	0.58	1.33
K4.2	EC 886	8.69	0.12	0.32	0.37	0.49	1.98
K4.3	EC 887	11.69	0.18	0.33	0.38	0.56	2.03
K4.4	EC 888	16.69	0.18	0.57	0.66	0.84	3.52
K4.5	EC 889	21.69	0.21	0.52	0.60	0.81	2.85
K4.6	EC 890	26.69	0.12	0.39	0.45	0.57	2.41
K4.7	EC 891	31.69	0.12	0.28	0.32	0.44	1.71
K4-Main	EC 892	33.06	0.15	0.35	0.40	0.55	2.13
K5.A	EC 894	11.38	ND	ND	ND	0.00	*
K5.B	EC 895	3.57	ND	ND	ND	0.00	*
K6.A	EC 897	6.05	3.03	1.46	1.68	4.71	0.55
K6.B	EC 898	18.95	1.75	1.06	1.22	2.97	0.70
K6.C	EC 899	36.13	0.80	0.44	0.51	1.31	0.63
K6.D	EC 900	at WT	2.94	1.85	2.13	5.07	0.72
K7.A	EC 901	at WT	1.10	0.95	1.09	2.19	0.99
K8	EC 902	at WT	ND	0.22	0.25	0.25	1.35
K9	EC 903	2.88	ND	0.50	0.57	0.57	3.07
K10	EC 904	at WT	0.58	0.19	0.22	0.80	0.38
K11.A	EC 906	at WT	ND	0.39	0.45	0.45	2.40
K12	EC 907	at WT	0.92	0.97	1.12	2.04	1.21
K13	EC 908	at WT	0.68	0.93	1.07	1.75	1.57
K15	EC 910	at WT	0.14	0.16	0.18	0.32	1.31
PK1	CK 227	-	1.40	0.92	1.06	2.46	0.76

Table 18. Continued.

Well ID	WI Unique Well Number	Depth Below WT (ft)	Atrazine Conc. (ppb)	DEAT Conc. (ppb)	Modified Metab. (ppb)	Total (ppb)	DAR
E1	EF 664	at WT	ND	0.17	0.20	0.20	1.05
E2	EF 665	at WT	0.18	ND	ND	0.18	*
E3	EF 666	at WT	ND	0.22	0.25	0.25	1.35
E4	EF 667	6.98	ND	ND	ND	0.00	*
E5	EF 668	at WT	0.47	ND	ND	0.47	0.29
E6.A	EF 669	2.82	ND	ND	ND	0.00	*
E6.B	EF 670	8.58	ND	ND	ND	0.00	*

[1] WT is water table.

[2] DEAT is desethylated atrazine.

[3] Modified metabolite concentration is desethylated atrazine concentration corrected to reflect the lower molecular weight of the metabolite.

[4] DAR is the modified metabolite : atrazine concentration ratio.

[5] ND is not detected.

[6] * indicates the DAR cannot be computed due to residue concentrations < the detection limit.

[7] P signifies a farmer's domestic well.

Table 19. HPLC results from sampling week of October 28, 1990.

Well ID	WI Unique Well Number	Depth Below WT[1] (ft)	Atrazine Conc. (ppb)	DEAT[2] Conc. (ppb)	Modified Metab.[3] (ppb)	Total (ppb)	DAR[4]
K1-Main	EC 871	29.20	trace	0.24	0.28	0.28	1.48
K1.B	EC 872	8.77	ND[5]	0.37	0.43	0.43	2.27
K2-Main	EC 874	12.62	ND	ND	ND	0.00	*[6]
K2.B	EC 875	at WT	ND	ND	ND	0.00	*
K3.1	EC 876	3.02	1.52	1.51	1.74	3.26	1.14
K3.2	EC 877	6.02	1.43	1.48	1.70	3.13	1.19
K3.3	EC 878	9.02	0.91	1.22	1.40	2.31	1.54
K3.4	EC 879	14.02	0.60	0.92	1.06	1.66	1.76
K3.5	EC 880	19.02	0.43	0.50	0.57	1.00	1.34
K3.6	EC 881	24.02	trace	0.30	0.34	0.34	1.84
K3.7	EC 882	29.02	0.37	0.42	0.48	0.85	1.31
K3-Main	EC 883	30.39	0.19	0.25	0.29	0.48	1.51
K3.B	EC 884	at WT	0.37	1.14	1.31	1.68	3.54
K4.1	EC 885	5.34	0.04	0.28	0.32	0.36	1.71
K4.2	EC 886	8.34	ND	0.20	0.23	0.23	1.23
K4.3	EC 887	11.34	ND	0.21	0.24	0.24	1.29
K4.4	EC 888	16.34	ND	0.21	0.24	0.24	1.29
K4.5	EC 889	21.34	ND	0.22	0.25	0.25	1.35
K4.6	EC 890	26.34	0.08	0.19	0.22	0.30	1.18
K4.7	EC 891	31.34	ND	0.24	0.28	0.28	1.48
K4-Main	EC 892	32.71	ND	0.18	0.21	0.21	1.11
K5.A	EC 894	10.99	ND	0.10	0.11	0.11	0.61
K5.B	EC 895	3.18	ND	ND	ND	0.00	*
K6.A	EC 897	5.57	3.00	1.39	1.60	4.60	0.53
K6.B	EC 898	18.47	0.55	0.29	0.33	0.88	0.61
K6.C	EC 899	35.65	0.26	0.24	0.28	0.54	1.06
K8	EC 902	at WT	ND	0.17	0.20	0.20	1.05
K9	EC 903	2.77	ND	0.27	0.31	0.31	1.66
K10	EC 904	at WT	ND	ND	ND	0.00	*
K11.B	EC 906	at WT	trace	0.28	0.32	0.32	1.72
K13	EC 908	at WT	ND	0.82	0.94	0.94	5.04
K15	EC 910	at WT	trace	ND	ND	0.00	*
P[7]K1	CK 227	-	1.24	0.66	0.76	2.00	0.61

Table 19. Continued.

Well ID	WI Unique Well Number	Depth Below WT (ft)	Atrazine Conc. (ppb)	DEAT Conc. (ppb)	Modified Metab. (ppb)	Total (ppb)	DAR
E1	EF 664	at WT	ND	ND	ND	0.00	*
E2	EF 665	at WT	ND	ND	ND	0.00	*
E6.A	EF 669	4.03	ND	ND	ND	0.00	*

[1] WT is water table.

[2] DEAT is desethylated atrazine.

[3] Modified metabolite concentration is desethylated atrazine concentration corrected to reflect the lower molecular weight of the metabolite.

[4] DAR is the modified metabolite : atrazine concentration ratio.

[5] ND is not detected.

[6] * indicates the DAR cannot be computed due to residue concentrations < the detection limit.

[7] P signifies a farmer's domestic well.

Table 20. HPLC results from sampling week of December 15, 1990.

Well ID	WI Unique Well Number	Depth Below WT[1] (ft)	Atrazine Conc. (ppb)	DEAT[2] Conc. (ppb)	Modified Metab.[3] (ppb)	Total (ppb)	DAR[4]
K1-Main	EC 871	28.38	0.57	0.85	0.98	1.55	1.71
K1.B	EC 872	7.95	0.03	trace	ND	0.03	*[5]
K2-Main	EC 874	11.54	trace	ND[6]	ND	0.00	*
K3.1	EC 876	2.66	1.26	1.42	1.63	2.89	1.30
K3.2	EC 877	5.66	1.25	1.45	1.67	2.92	1.33
K3.3	EC 878	8.66	0.86	1.35	1.55	2.41	1.80
K3.4	EC 879	13.66	0.60	0.92	1.06	1.66	1.76
K3.5	EC 880	18.66	0.10	0.38	0.44	0.54	2.35
K3.6	EC 881	23.66	0.08	0.34	0.39	0.47	2.09
K3.7	EC 882	28.66	0.15	0.32	0.37	0.52	1.98
K3-Main	EC 883	30.03	trace	0.34	0.39	0.39	2.09
K3.B	EC 884	at WT	0.25	1.14	1.31	1.56	5.24
K4.1	EC 885	6.24	ND	0.28	0.32	0.32	1.72
K4.2	EC 886	9.24	ND	0.48	0.55	0.55	2.95
K4.3	EC 887	12.24	ND	0.30	0.34	0.34	1.84
K4.4	EC 888	17.24	ND	0.33	0.38	0.38	2.03
K4.5	EC 889	22.24	0.05	0.31	0.36	0.41	1.93
K4.6	EC 890	27.24	0.03	0.27	0.31	0.34	1.66
K4.7	EC 891	32.24	0.06	0.32	0.37	0.43	2.30
K4-Main	EC 892	33.61	0.07	0.22	0.25	0.32	1.34
K4.B	EC 893	at WT	1.10	0.75	0.86	1.96	0.78
K5.A	EC 894	10.53	ND	ND	ND	0.00	*
K5.B	EC 895	2.72	ND	ND	ND	0.00	*
K6.A	EC 897	4.99	2.69	1.32	1.52	4.21	0.56
K6.B	EC 898	17.89	2.35	0.61	0.70	3.05	0.30
K6.C	EC 899	35.07	1.16	ND	ND	1.16	0.00
K7.B	EC 827	2.68	ND	0.65	0.75	0.75	4.00
K9	EC 903	2.56	trace	0.40	0.45	0.45	2.43
K10	EC 904	at WT	0.67	ND	ND	0.67	0.21
K11.B	EC 906	at WT	ND	0.28	0.32	0.32	1.72
K12	EC 907	at WT	0.93	0.34	0.39	1.32	0.42
K13	EC 908	at WT	ND	0.57	0.66	0.66	3.50
K15	EC 910	at WT	ND	ND	ND	0.00	*

Table 20. Continued.

Well ID	WI Unique Well Number	Depth Below WT (ft)	Atrazine Conc. (ppb)	DEAT Conc. (ppb)	Modified Metab. (ppb)	Total (ppb)	DAR
E1	EF 664	at WT	ND	ND	ND	0.00	*
E3	EF 666	2.31	ND	ND	ND	0.00	*
E5	EF 668	at WT	0.05	0.22	0.25	0.30	1.34
E6.A	EF 669	4.38	ND	ND	ND	0.00	*
P[7]K1	CK 227	-	1.30	0.69	0.79	2.09	0.61

[1] WT is water table.

[2] DEAT is desethylated atrazine.

[3] Modified metabolite concentration is desethylated atrazine concentration corrected to reflect the lower molecular weight of the metabolite.

[4] DAR is the modified metabolite : atrazine concentration ratio.

[5] * indicates the DAR cannot be computed due to residue concentrations < the detection limit.

[6] ND is not detected.

[7] P signifies a farmer's domestic well.

Table 21. HPLC results from sampling week of February 27, 1991.

Well ID	WI Unique Well Number	Depth Below WT[1] (ft)	Atrazine Conc. (ppb)	DEAT[2] Conc. (ppb)	Modified Metab.[3] (ppb)	Total (ppb)	DAR[4]
K1-Main	EC 871	27.38	ND[5]	0.57	0.66	0.66	3.50
K1.B	EC 872	6.95	ND	0.39	0.45	0.45	2.40
K2.B	EC 875	at WT	ND	ND	ND	0.00	*[6]
K3.2	EC 877	5.63	0.29	1.32	1.52	1.81	5.23
K3.3	EC 878	8.63	0.90	1.45	1.67	2.57	1.85
K3.4	EC 879	13.63	0.28	0.78	0.90	1.18	3.20
K3.5	EC 880	18.63	0.19	0.42	0.48	0.67	2.54
K3.6	EC 881	23.63	0.15	0.37	0.43	0.58	2.84
K3.7	EC 882	28.63	0.25	0.37	0.43	0.68	1.70
K3-Main	EC 883	30.00	ND	0.38	0.44	0.44	3.50
K4.1	EC 885	6.83	trace	0.43	0.49	0.49	3.50
K4.2	EC 886	9.83	ND	0.29	0.33	0.33	3.50
K4.3	EC 887	12.83	ND	0.34	0.39	0.39	3.50
K4.4	EC 888	17.83	0.92	0.34	0.39	1.31	0.42
K4.5	EC 889	22.83	trace	0.30	0.34	0.34	3.50
K4.6	EC 890	27.83	ND	0.31	0.36	0.36	3.50
K4.7	EC 891	32.83	trace	0.30	0.34	0.34	3.50
K4-Main	EC 892	34.20	trace	0.21	0.24	0.24	3.50
K4.B	EC 893	at WT	ND	ND	ND	0.00	*
K5.A	EC 894	10.14	ND	ND	ND	0.00	*
K5.B	EC 895	2.33	ND	0.07	0.08	0.08	*
K6.A	EC 897	4.45	2.47	1.75	2.01	4.48	0.81
K6.B	EC 898	17.35	0.89	0.49	0.56	1.45	0.63
K6.C	EC 899	34.53	0.36	0.33	0.38	0.74	1.05
K7.B	EC 827	3.39	ND	ND	ND	0.00	*
K8	EC 902	at WT	ND	0.17	0.20	0.20	3.50
K9	EC 903	2.58	0.19	0.31	0.36	0.55	1.88
K10	EC 904	at WT	0.38	0.10	0.11	0.49	0.30
K11.B	EC 906	at WT	ND	ND	ND	0.00	*
K11.C	EC 905	35.11	ND	0.07	0.08	0.08	*
K12	EC 907	at WT	ND	0.27	0.31	0.31	3.50
K13	EC 908	at WT	ND	ND	ND	0.00	*
K16.A	EF 661	10.22	0.14	0.49	0.56	0.70	4.02
K16.C	EF 663	24.80	trace	0.27	0.31	0.31	3.50
P[7]K1	CK 227	-	0.45	0.58	0.67	1.12	1.48
Surface water near K7		-	ND	ND	ND	0.00	*

Table 21. Continued.

Well ID	WI Unique Well Number	Depth Below WT (ft)	Atrazine Conc. (ppb)	DEAT Conc. (ppb)	Modified Metab. (ppb)	Total (ppb)	DAR
E1	EF 664	at WT	0.06	ND	ND	0.06	*
E3	EF 666	3.06	ND	ND	ND	0.00	*
E6.A	EF 669	5.80	ND	ND	ND	0.00	*
E6.B	EF 670	11.56	ND	ND	ND	0.00	*

[1] WT is water table.

[2] DEAT is desethylated atrazine.

[3] Modified metabolite concentration is desethylated atrazine concentration corrected to reflect the lower molecular weight of the metabolite.

[4] DAR is the modified metabolite : atrazine concentration ratio.

[5] ND is not detected.

[6] * indicates the DAR cannot be computed due to residue concentrations < the detection limit.

[7] P signifies a farmer's domestic well.

Table 22. HPLC results from sampling week of April 16-22, 1991.

Well ID	WI Unique Well Number	Depth Below WT[1] (ft)	Atrazine Conc. (ppb)	DEAT[2] Conc. (ppb)	Modified Metab.[3] (ppb)	Total (ppb)	DAR[4]
K1-Main	EC 871	33.15	trace	0.58	0.66	0.66	3.53
K1.B	EC 872	12.72	ND[5]	0.48	0.55	0.55	2.96
K1.C	EC 873	at WT	ND	ND	ND	ND	*[6]
K2-Main	EC 874	16.11	ND	-	-	-	*
K2.B	EC 875	2.80	ND	ND	ND	ND	*
K3.1	EC 876	4.84	0.73	1.52	1.74	2.47	2.39
K3.2	EC 877	7.84	0.62	1.30	1.49	2.11	2.41
K3.3	EC 878	10.84	1.01	1.56	1.79	2.80	1.78
K3.4	EC 879	15.84	0.43	0.94	1.08	1.50	2.51
K3.5	EC 880	20.84	0.27	0.65	0.75	1.02	2.77
K3.6	EC 881	25.84	0.39	0.80	0.91	1.30	2.34
K3.7	EC 882	30.84	0.35	0.94	1.08	1.43	3.09
K3-Main	EC 883	32.21	0.18	0.39	0.45	0.63	2.39
K3.B	EC 884	at WT	ND	ND	ND	ND	*
K4.1	EC 885	9.13	0.13	0.31	0.36	0.49	1.91
K4.2	EC 886	12.13	ND	0.31	0.36	0.36	1.91
K4.3	EC 887	15.13	0.19	0.18	0.21	0.40	1.09
K4.4	EC 888	20.13	trace	0.14	0.16	0.16	0.86
K4.5	EC 889	25.13	0.20	0.18	0.21	0.41	1.04
K4.6	EC 890	30.13	0.09	0.32	0.37	0.46	1.97
K4.7	EC 891	35.13	0.06	0.43	0.49	0.55	2.65
K4-Main	EC 892	36.50	0.06	0.34	0.39	0.45	2.09
K4.B	EC 893	at WT	ND	0.61	0.70	0.70	3.75
K5.A	EC 894	12.57	ND	ND	ND	ND	*
K5.B	EC 895	4.76	ND	ND	ND	ND	*
K5.C	EC 896	at WT	trace	ND	ND	ND	*
K6.A	EC 897	6.71	2.53	1.52	1.75	4.27	0.69
K6.B	EC 898	19.61	0.66	0.33	0.38	1.04	0.57
K6.C	EC 899	36.79	0.18	trace	ND	0.18	*
K6.D	EC 900	at WT	1.40	1.18	1.36	2.76	0.97
K7.A	EC 901	6.07	ND	0.17	0.20	0.20	1.05
K7.B	EC 827	11.50	ND	0.10	0.11	0.11	0.62
K8	EC 902	3.07	ND	ND	ND	ND	*
K9	EC 903	4.24	0.06	trace	ND	0.06	*
K10	EC 904	6.08	0.20	ND	ND	0.20	0.68
K11.B	EC 906	5.16	0.13	0.11	0.13	0.26	0.68
K11.C	EC 905	39.16	ND	ND	ND	ND	*
K12	EC 907	at WT	ND	0.45	0.52	0.52	2.77
K13	EC 908	at WT	ND	ND	ND	ND	*
K14	EC 909	at WT	ND	trace	ND	ND	*
K15	EC 910	2.98	0.19	0.18	0.21	0.40	1.09

Table 22. Continued.

Well	WI Unique Well Number	Depth Below WT (ft)	Atrazine Conc. (ppb)	DEAT Conc. (ppb)	Modified Metab. (ppb)	Total (ppb)	DAR
K16.A	EF 661	11.36	ND	0.27	0.31	0.31	1.66
K16.B	EF 662	19.51	0.09	0.16	0.18	0.27	0.98
K16.C	EF 663	25.94	ND	trace	ND	ND	*
K16.D	EC 826	4.02	ND	ND	ND	ND	*
R1	EC 821	at WT	ND	ND	ND	ND	*
R2	EC 822	4.07	0.69	ND	ND	0.69	0.20
E1	EF 664	at WT	ND	ND	ND	ND	*
E2	EF 665	at WT	ND	ND	ND	ND	*
E3	EF 666	3.66	ND	ND	ND	ND	*
E4	EF 667	7.24	ND	ND	ND	ND	*
E5	EF 668	at WT	ND	ND	ND	ND	*
E6.A	EF 669	6.59	ND	ND	ND	ND	*
E6.B	EF 670	12.35	ND	ND	ND	ND	*
P[7]K1	CK 227	-	0.78	0.63	0.72	1.50	0.93
Creek	-	-	ND	ND	ND	ND	*
CPW2[8]	-	7.18	0.07	0.23	0.26	0.33	1.45

[1] WT is water table.
[2] DEAT is desethylated atrazine.
[3] Modified metabolite concentration is desethylated atrazine concentration corrected to reflect the lower molecular weight of the metabolite.
[4] DAR is the modified metabolite : atrazine concentration ratio.
[5] ND is not detected.
[6] * indicates the DAR cannot be computed due to residue concentrations < the detection limit.
[7] P signifies a farmer's domestic well.
[8] CPW2 is a creek piezometer located north of K13.

Table 23. HPLC results from sampling week of June 3-6, 1991.

Well	WI Unique Well Number	Depth Below WT[1] (ft)	Atrazine Conc. (ppb)	DEAT[2] Conc. (ppb)	Modified Metab.[3] (ppb)	Total (ppb)	DAR[4]
K1.B	EC 872	11.51	ND[5]	ND	ND	ND	*[6]
K1.C	EC 873	0.20	ND	ND	ND	ND	*
K2.B	EC 875	2.07	ND	ND	ND	ND	*
K3.1	EC 876	4.81	0.42	1.36	1.56	1.98	3.71
K3.2	EC 877	7.81	0.17	1.42	1.63	1.80	8.74
K3.3	EC 878	10.81	0.60	1.31	1.50	2.10	2.50
K3.4	EC 879	15.81	0.24	0.94	1.08	1.32	4.60
K3.5	EC 880	20.81	0.07	0.58	0.67	0.73	3.57
K3.6	EC 881	25.81	0.13	0.55	0.63	0.76	3.38
K3.7	EC 882	30.81	0.06	0.53	0.61	0.66	3.26
K3-Main	EC 883	32.18	0.39	0.74	0.85	1.23	2.19
K3.B	EC 884	2.00	0.13	1.32	1.51	1.64	8.09
K4.1	EC 885	8.33	0.10	0.23	0.26	0.36	1.42
K4.2	EC 886	11.33	0.05	0.21	0.24	0.28	1.26
K4.3	EC 887	14.33	0.03	0.22	0.25	0.28	1.35
K4.4	EC 888	19.33	ND	0.06	0.07	0.07	0.37
K4.5	EC 889	24.33	0.08	0.08	0.09	0.17	0.49
K4.6	EC 890	29.33	ND	0.22	0.25	0.25	1.35
K4.7	EC 891	34.33	0.07	0.21	0.24	0.31	1.26
K4-Main	EC 892	35.70	0.07	0.23	0.26	0.33	1.42
K4.B	EC 893	1.10	ND	ND	ND	ND	*
K5.A	EC 894	13.06	ND	ND	ND	ND	*
K5.B	EC 895	5.25	ND	ND	ND	ND	*
K5.C	EC 896	0.15	ND	ND	ND	ND	*
K6.A	EC 897	7.87	1.70	1.54	1.77	3.47	1.04
K6.B	EC 898	20.77	0.42	0.33	0.38	0.79	0.91
K6.C	EC 899	37.95	0.17	ND	ND	0.17	*
K6.D	EC 900	0.60	1.32	0.86	0.98	2.30	0.75
K7.A	EC 901	1.82	ND	ND	ND	ND	*
K7.B	EC 827	6.81	ND	0.48	0.55	0.55	2.95
K8	EC 902	3.03	ND	0.14	0.16	0.16	0.83
K9	EC 902	4.02	0.06	0.34	0.39	0.45	2.06
K10	EC 903	2.19	0.23	0.12	0.14	0.36	0.61
K11.B	EC 906	5.13	ND	0.33	0.38	0.38	2.03
K11.C	EC 905	39.13	ND	0.22	0.25	0.25	1.35
K12	EC 907	1.08	trace	0.33	0.37	0.37	2.00
K16.A	EF 661	10.46	trace	0.31	0.35	0.35	1.88
K16.B	EF 662	18.79	trace	0.38	0.43	0.43	2.31
K16.C	EF 663	25.29	ND	0.18	0.21	0.21	1.11
K16.D	EC 826	2.54	ND	ND	ND	ND	*

Table 23. Continued.

Well	WI Unique Well Number	Depth Below WT (ft)	Atrazine Conc. (ppb)	DEAT Conc. (ppb)	Modified Metab. (ppb)	Total (ppb)	DAR
R1	EC 821	0.81	ND	ND	ND	ND	*
R2	EC 822	5.74	ND	ND	ND	ND	*
E1	EF 664	3.15	ND	ND	ND	ND	*
E2	EF 665	3.00	ND	ND	ND	ND	*
E6.A	EF 669	5.24	ND	ND	ND	ND	*
E6.B	EF 670	11.00	ND	ND	ND	ND	*
P[7]K1	CK 227	-	0.77	0.89	1.02	1.78	1.33

[1] WT is water table.

[2] DEAT is desethylated atrazine.

[3] Modified metabolite concentration is desethylated atrazine concentration corrected to reflect the lower molecular weight of the metabolite.

[4] DAR is the modified metabolite : atrazine concentration ratio.

[5] ND is not detected.

[6] * indicates the DAR cannot be computed due to residue concentrations < the detection limit.

[7] P signifies a farmer's domestic well.

Table 24. HPLC results from sampling week of July 8-12, 1991.

Well	WI Unique Well Number	Depth Below WT[1] (ft)	Atrazine Conc. (ppb)	DEAT[2] Conc. (ppb)	Modified Metab.[3] (ppb)	Total (ppb)	DAR[4]
K1-Main	EC 871	31.12	0.10	0.64	0.74	0.84	3.95
K1.B	EC 872	10.69	trace	0.25	0.29	0.29	1.56
K1.C	EC 873	at WT	trace	trace	ND[5]	ND	*[6]
K2-Main	EC 874	14.82	0.09	0.17	0.20	0.28	1.05
K2.B	EC 875	at WT	ND	ND	ND	ND	*
K3.1	EC 876	4.64	1.29	2.09	2.41	3.69	1.87
K3.2	EC 877	7.64	1.01	1.87	2.14	3.15	2.12
K3.3	EC 878	10.64	1.05	1.75	2.01	3.06	1.90
K3.4	EC 879	15.64	0.63	1.21	1.39	2.02	2.20
K3.5	EC 880	20.64	0.56	0.92	1.06	1.62	1.90
K3.6	EC 881	25.64	0.51	0.89	1.02	1.53	1.99
K3.7	EC 882	30.64	0.46	0.90	1.03	1.49	2.24
K3-Main	EC 883	32.01	0.39	0.85	0.98	1.37	2.48
K3.B	EC 884	at WT	0.77	1.98	2.28	3.05	2.95
K4.1	EC 885	7.85	0.47	0.37	0.42	0.89	0.89
K4.2	EC 886	10.85	0.15	0.45	0.51	0.66	2.74
K4.3	EC 887	13.85	0.29	0.40	0.46	0.75	1.58
K4.4	EC 888	18.85	0.30	0.42	0.48	0.78	1.59
K4.5	EC 889	23.85	0.32	0.40	0.47	0.79	1.45
K4.6	EC 890	28.85	0.31	0.47	0.54	0.85	1.72
K4.7	EC 891	33.85	ND	0.43	0.50	0.50	2.68
K4-Main	EC 892	35.22	0.13	0.45	0.51	0.64	2.74
K4.B	EC 893	at WT	0.99	1.22	1.41	2.39	1.42
K5.A	EC 894	12.84	ND	ND	ND	0.00	*
K5.B	EC 895	5.03	ND	ND	ND	0.00	*
K5.C	EC 896	at WT	ND	ND	ND	0.00	*
K6.A	EC 897	7.50	2.85	1.95	2.24	5.10	0.79
K6.B	EC 898	20.40	2.50	0.71	0.82	3.32	0.33
K6.C	EC 899	37.58	0.84	ND	ND	0.84	0.16
K6.D	EC 900	at WT	1.45	0.93	1.07	2.52	0.74
K7.A	EC 901	at WT	ND	0.14	0.16	0.16	0.86
K7.B	EC 827	5.96	ND	0.63	0.72	0.72	3.87
K8	EC 902	2.84	ND	0.07	0.08	0.08	*
K9	EC 903	3.88	0.22	0.50	0.58	0.79	2.68
K10	EC 904	at WT	0.32	0.15	0.17	0.49	0.54
K11.B	EC 906	4.75	ND	0.39	0.44	0.44	2.38
K11.C	EC 905	38.75	ND	ND	ND	0.00	*
K12	EC 907	at WT	0.18	0.46	0.53	0.71	2.85
K13	EC 908	at WT	0.21	0.46	0.53	0.73	2.52
K14	EC 909	at WT	0.48	ND	ND	0.48	0.29
K15	EC 910	3.20	0.15	ND	ND	0.15	*

Table 24. Continued.

Well	WI Unique Well Number	Depth Below WT (ft)	Atrazine Conc. (ppb)	DEAT Conc. (ppb)	Modified Metab (ppb)	Total (ppb)	DAR
K16.A	EF 661	9.98	0.13	0.45	0.52	0.66	2.80
K16.B	EF 662	18.13	ND	0.29	0.33	0.33	1.78
K16.C	EF 663	24.56	ND	0.13	0.15	0.15	0.82
K16.D	EC 826	2.64	ND	0.07	0.08	0.08	*
R1	EC 821	at WT	ND	ND	ND	0.00	*
R2	EC 822	5.59	0.43	0.16	0.19	0.61	0.44
E1	EF 664	2.97	ND	ND	ND	0.00	*
E2	EF 665	2.91	ND	ND	ND	0.00	*
E3	EF 666	3.66	ND	trace	ND	0.00	*
E6.A	EF 669	6.33	ND	ND	ND	0.00	*
E6.B	EF 670	12.09	ND	ND	ND	0.00	*
P[7]K1	CK 227	-	1.14	0.97	1.12	2.26	0.98

[1] WT is water table.
[2] DEAT is desethylated atrazine.
[3] Modified metabolite concentration is desethylated atrazine concentration corrected to reflect the lower molecular weight of the metabolite.
[4] DAR is the modified metabolite : atrazine concentration ratio.
[5] ND is not detected.
[6] * indicates the DAR cannot be computed due to residue concentrations < the detection limit.
[7] P signifies a farmer's domestic well.

Figures 13 and 14 show the atrazine, modified desethylated atrazine and total residue concentrations versus depth at multi-level sampling wells K3 and K4 for each of the 16 sampling rounds. Concentrations at K3 tend to peak 3 to 11 ft below the water table and then decrease with depth. Because of the way K3 was constructed, the concentration gradient measured may not reflect the actual gradient in the aquifer. (See the discussion on page 23, this report.) Data suggest, however, that atrazine and desethylated atrazine residues are entering the well area near the surface more than at depth. The uppermost point at around 2 ft below the water table (missing from the February 1991 sampling) represents K3.B, a water table well independent of the multi-level sampling unit. Concentrations shown at well K4 show no concentration trend with depth and generally lower atrazine and metabolite residue concentrations than at K3, especially near the water table. The uppermost point on the graphs in Fig. 14 represent concentrations at K4.B, again independent of the multi-level sampling unit. The difference between the K3 and K4 may reflect land use. Corn was planted upgradient of K4 in 1991, but before that, not since 1985. Corn was planted upgradient of K3 in 1988, 1989 and 1990. As discussed later, due to the slow groundwater velocity in the shallow aquifer, one would expect recent cropping patterns to be discernable in concentrations from only the shallowest sampling points. Water reaching deeper sampling points may have originated from long enough ago that it would have significantly mixed with water from other growing seasons.

Throughout the study period, the point of highest atrazine and desethylated atrazine concentrations was at well site K6. Figure 15a and 15b show the concentrations of atrazine and desethylated atrazine over time at each of the four piezometers nested at K6. Concentrations at the 2 deepest wells (K6.B and K6.C) indicate decreasing contamination with depth; surprisingly, however, concentrations at K6.A, screened 3 to 8 ft below the water table, are usually higher than at K6.D, screened at the water table. Concentrations of atrazine relative to desethylated atrazine were especially high at K6, resulting in some of the lowest DAR values observed. The low DAR values may be due to the nature of the source and/or

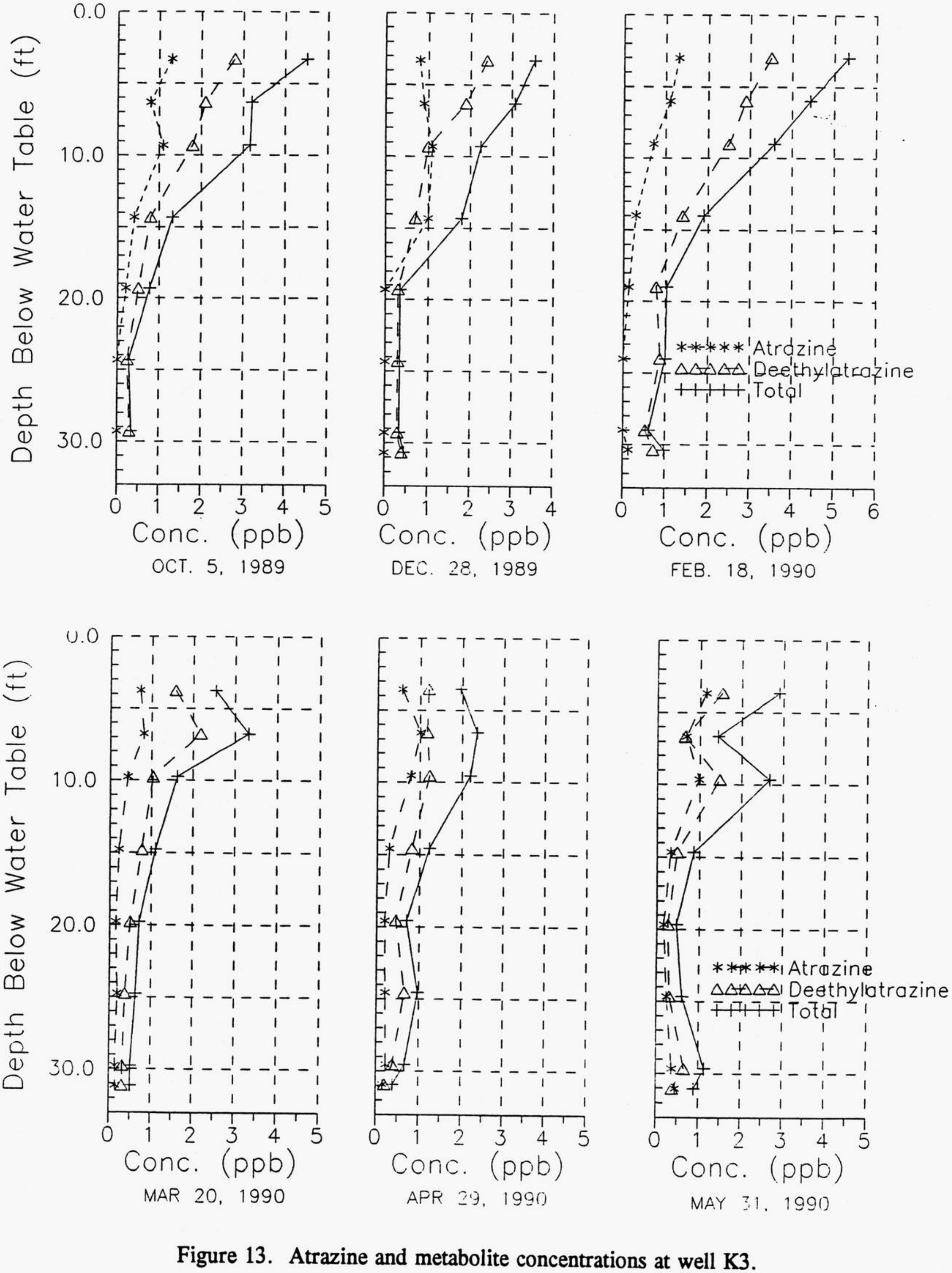

Figure 13. Atrazine and metabolite concentrations at well K3.

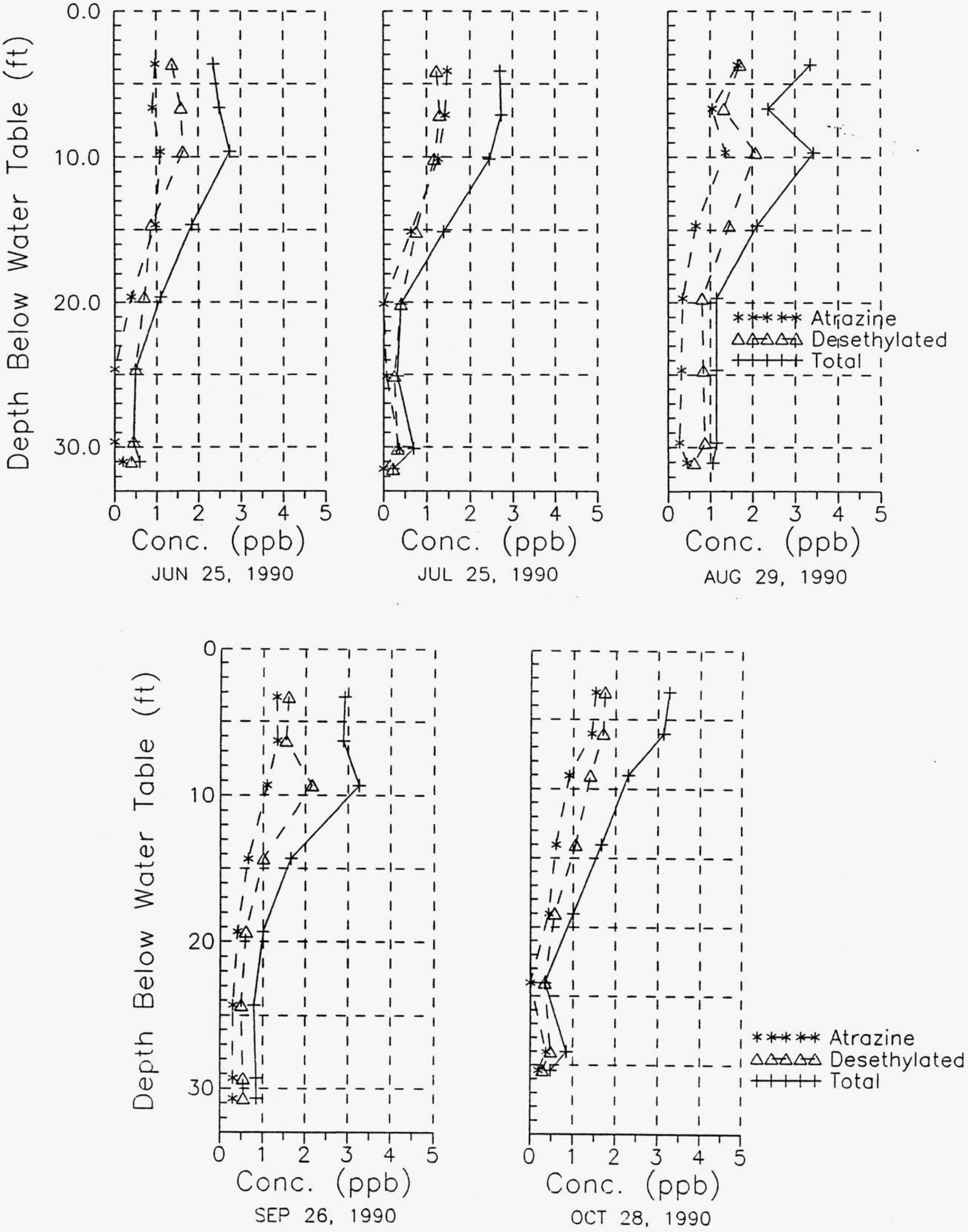

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Figure 13. Continued.

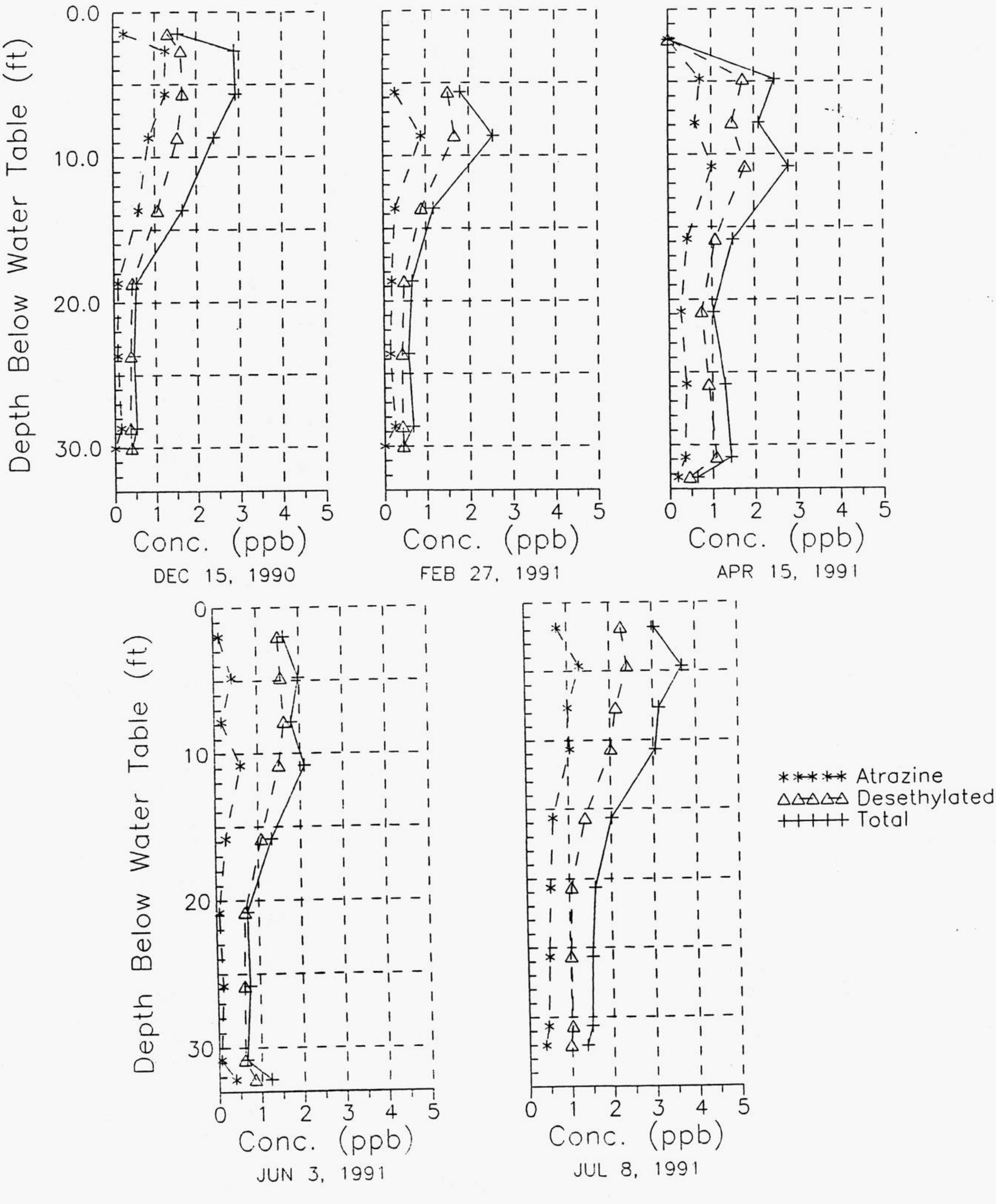

Figure 13. Continued.

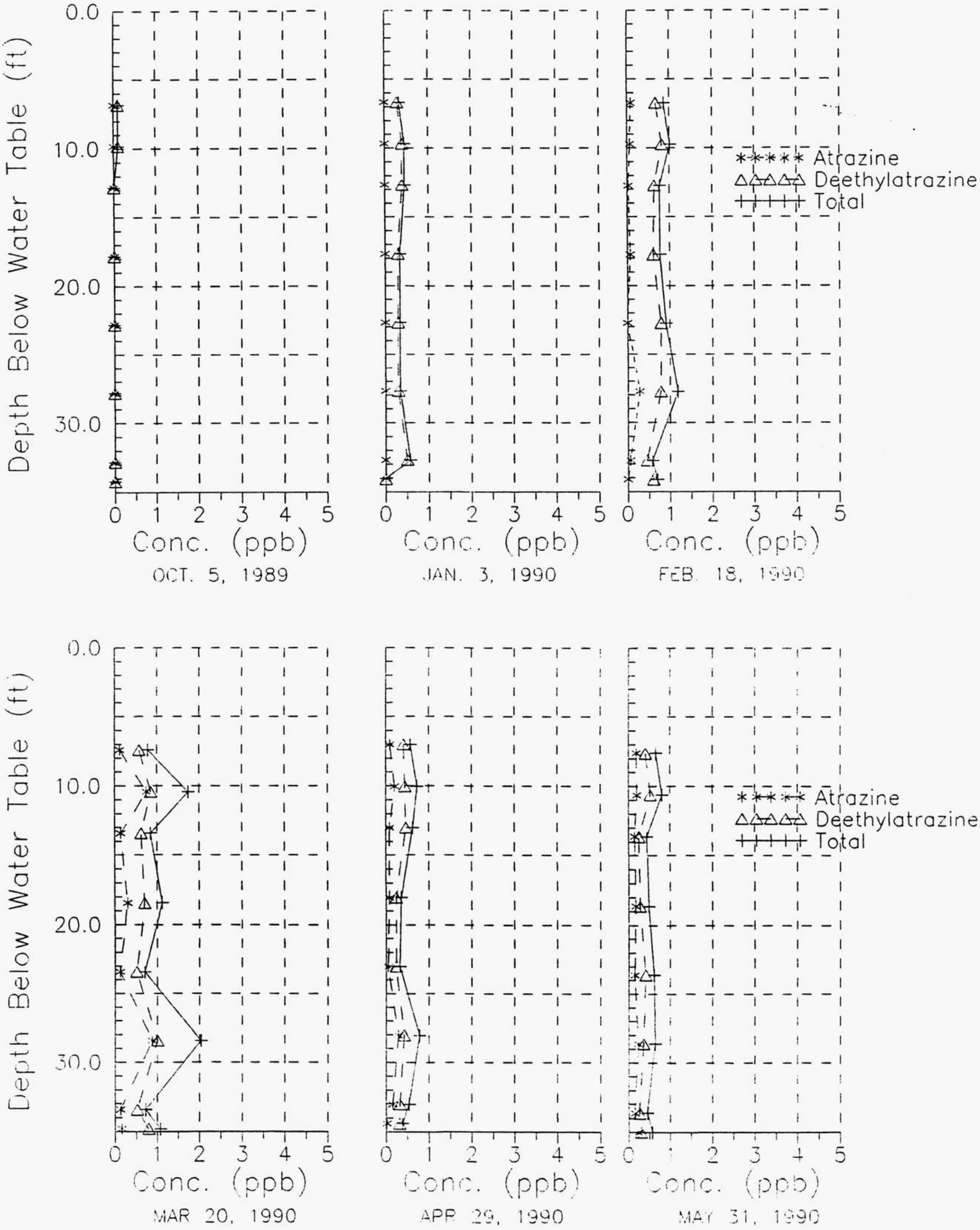

Figure 14. Atrazine and metabolite concentrations at well K4.

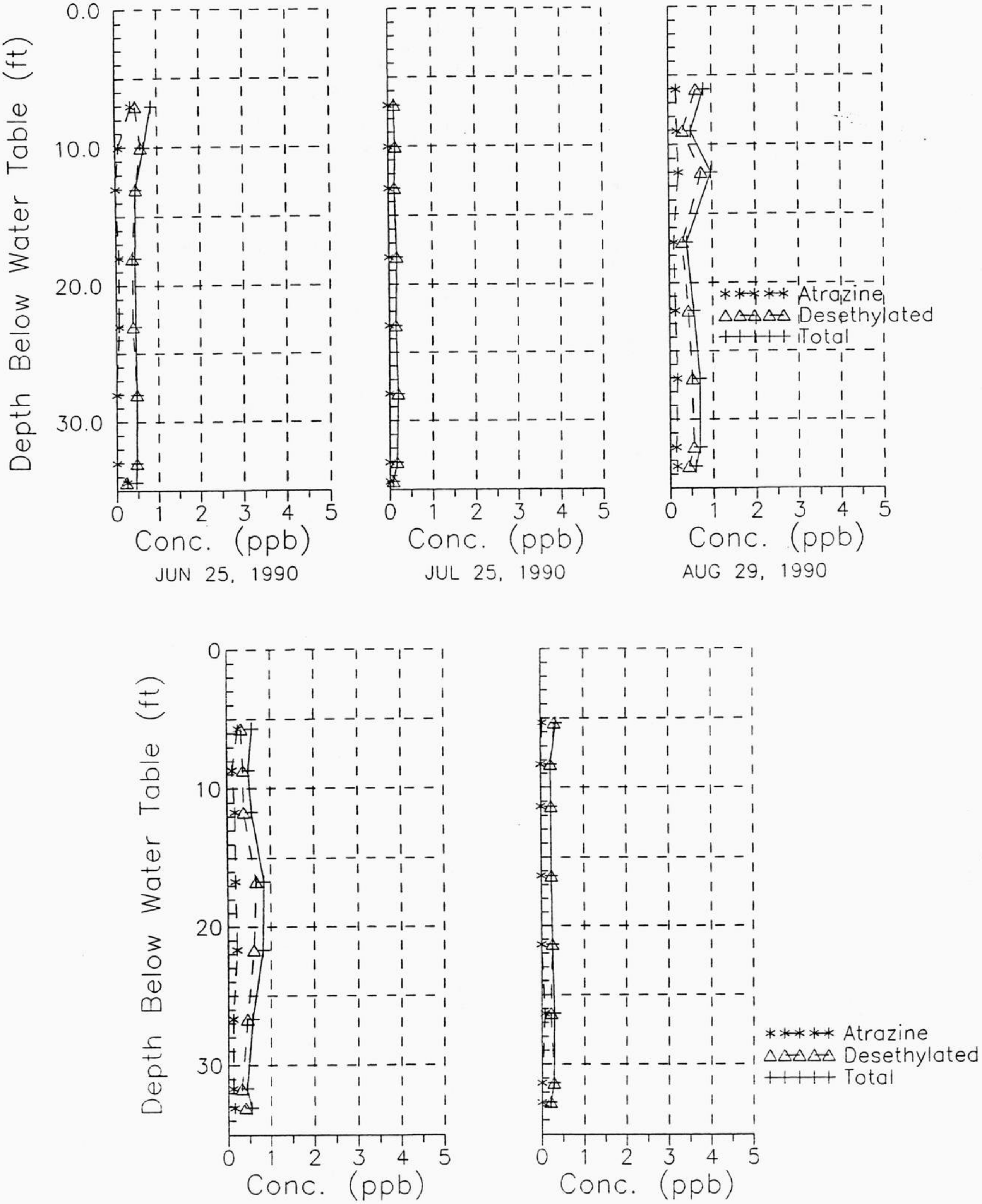

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Figure 14. Continued.

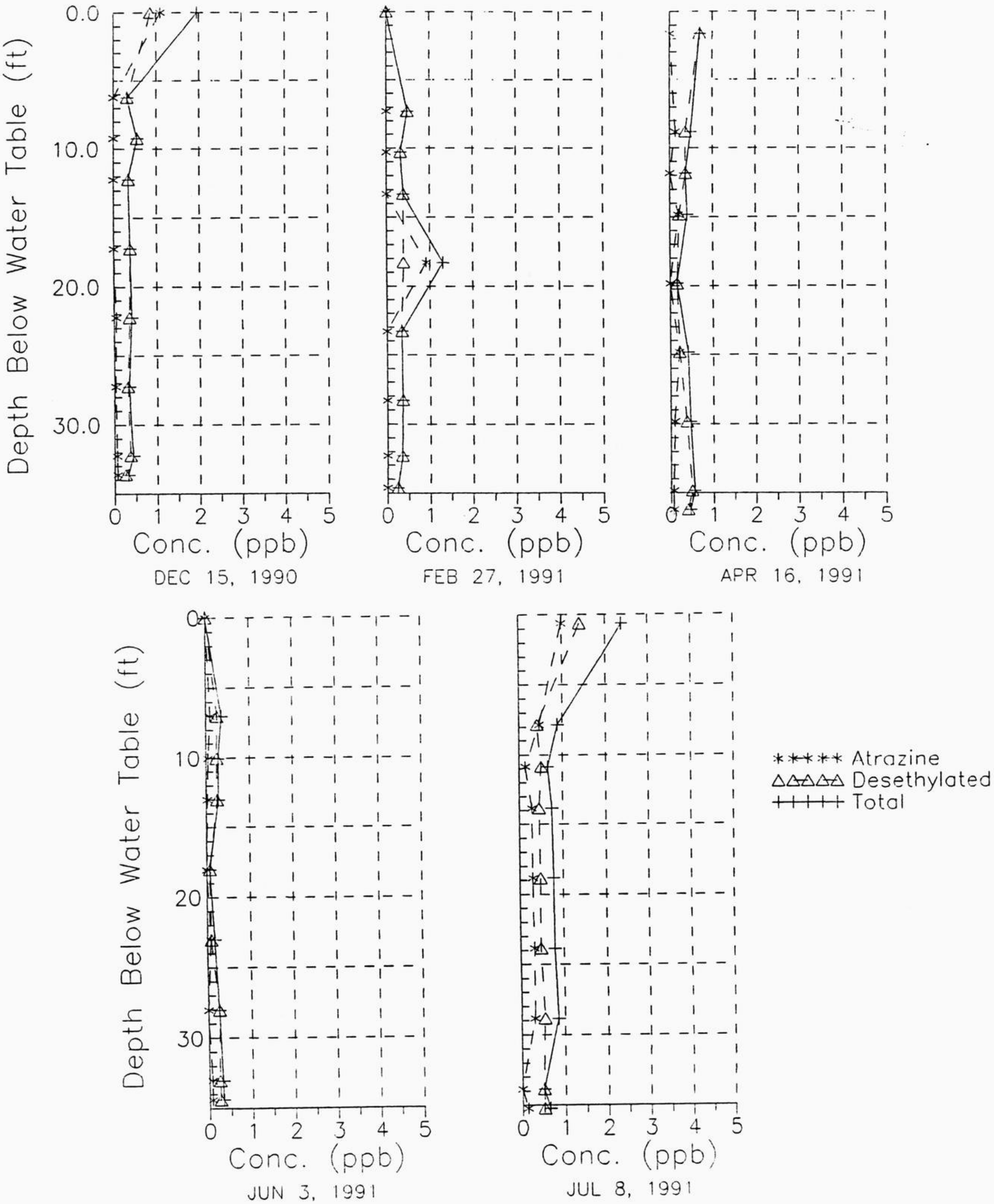


Figure 14. Continued.

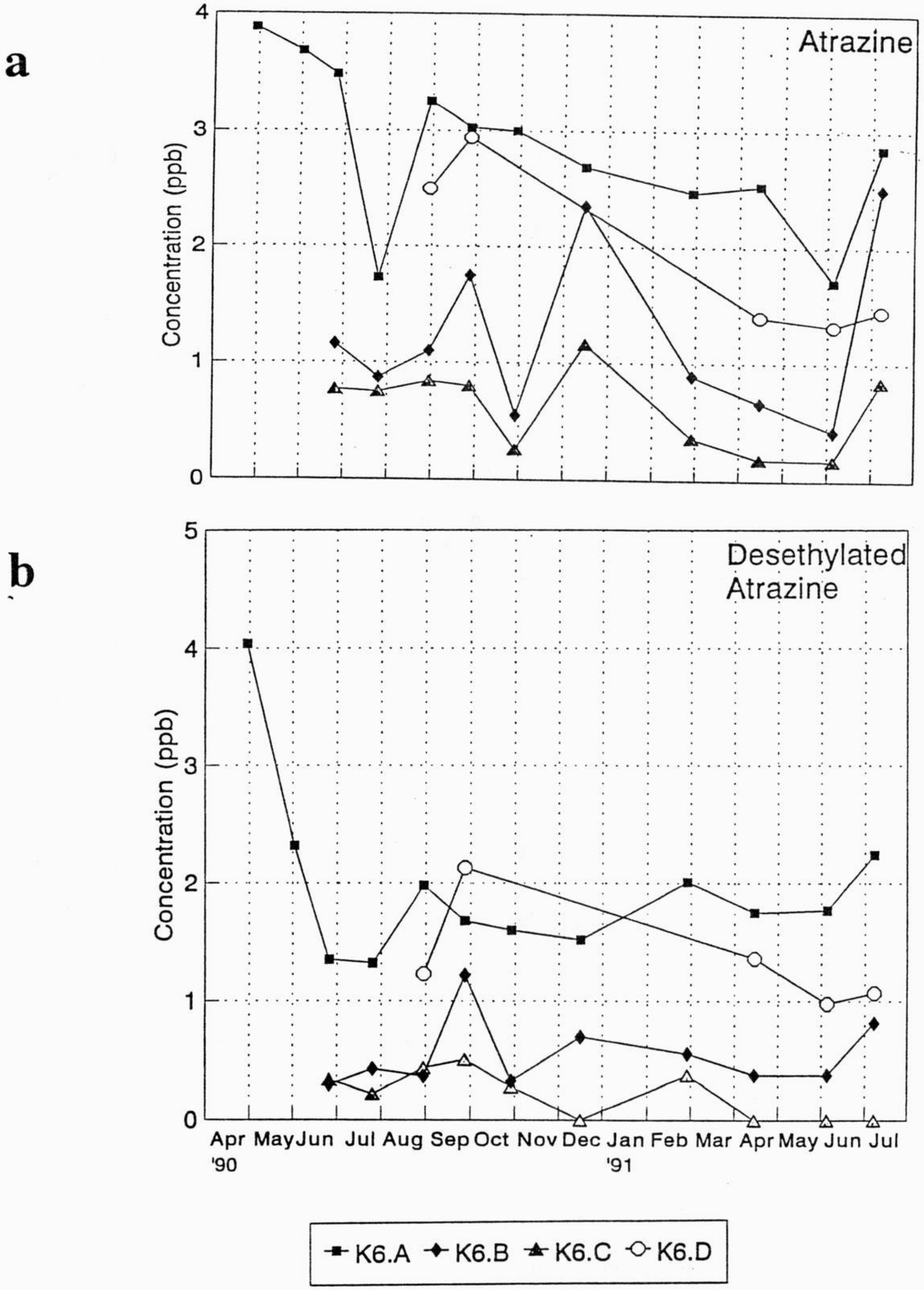


Figure 15. Atrazine (a) and metabolite (b) concentrations in water from K6.D, screened at the water table, and K6.A, K6.B, and K6.C, screened an average of 5.8, 18.5, and 36.0 ft below the water table.

the time of transport to the well. The proximity of K6 to pesticide handling areas suggests that the high concentrations might have resulted from minor accidental spills and may reflect point-source origin. Lower DAR values are expected to be associated with point-source contamination if the contaminants are entering the aquifer through a natural or artificial conduit or are somehow driven to the water table so that they bypass the soil microorganisms responsible for the transformation of atrazine to desethylated atrazine (Adams and Thurman, 1991; Perry, 1990). Point-source contamination by atrazine at high enough concentrations might also decrease soil microbial populations, again resulting in lower DAR values. K6 is located adjacent to a septic field that could provide an additional driving force for atrazine residues reaching the water table more quickly than at other wells.

Except for K6, highest atrazine and desethylated atrazine concentrations were found at K3.1. The DAR values there, however, are substantially higher than at K6, possibly representing a difference between point and non-point source contamination. Over the study period, the DAR at K3.1 averaged 2.02, compared with 0.70 at K6.A and 0.73 at K6.D. DAR values at K6.B were even lower, averaging 0.48 over the study period. DAR values at K6 and at K3 are shown in Fig. 16. It should be noted, however, that Perry (1990) reported atrazine and desethylated atrazine concentrations at three wells resulting in DAR values < 0.04 in a shallow aquifer believed to be contaminated by point sources. Low average DAR values were also found at K2-Main and R2 both of which are located near standing water from barnyard runoff, possibly accelerating the leaching of atrazine residues through the soil. Low DAR values were consistently found at K10, near where snowmelt ponds, however, just as much ponding occurs at K7 where DAR values are higher. The low DAR values might indicate point sources and/or accelerated leaching due to ponding, but other factors are also involved.

PK1 was the private well that was originally part of the WDATCP Grade A dairy farm well survey. No well log has been found for PK1. Total depth, obtained by slipping a weight past the well pump and feeling the bottom, was measured at 70 ft below ground surface. It is possible that the weight

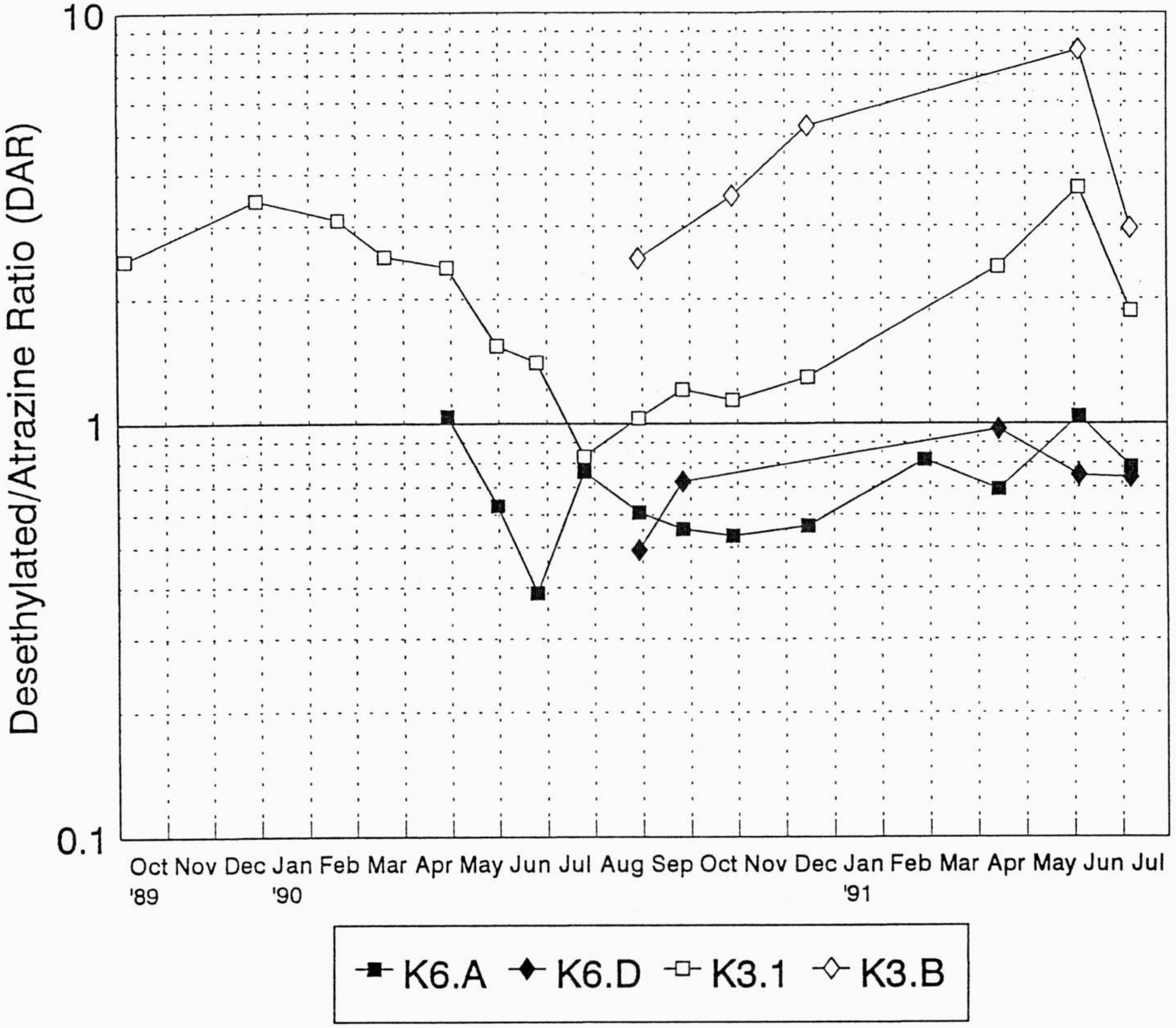


Figure 16. Desethylated atrazine to atrazine concentration ratio (DAR) at wells K6 and K3.

got hung up on something other than the well bottom, although the weight was bobbed up and down to ensure its progress to the bottom. PK1 is therefore approximated to be as deep as well K6.C, and is probably developed in the till, not bedrock. PK1's depth of casing and, therefore, its open interval is unknown. Assuming the casing length is at least 40 ft (according to code which did not apply when this well was drilled), PK1 is open from approximately 10 to 33 ft below the water table. Pesticide residue concentrations, representing the average over that depth interval, were monitored at PK1 and data are shown in Fig. 17. Atrazine concentrations during the study period are well below the 2.8 ppb reported by the WDATCP in the Grade A survey, but it should be kept in mind that the results shown in Fig. 17 are from a different laboratory and using a different technique (HPLC versus GC). Total atrazine residue concentrations have consistently remained below the proposed 3.0 ppb ES, but above the proposed 0.3 PAL.

The horizontal distributions of atrazine and desethylated atrazine in water-table wells during the April and July 1991 sampling periods are presented in Figs. 18 and 19. The maps show lines of equal concentration at contour intervals of 0.5 ppb and the wells that were used in their generation. Since the concentration variability is probably large compared to the well density, caution should be employed in interpreting these maps, especially in predicting concentrations between wells. The maps do visually summarize much of the data presented in Tables 22 and 24. Figures 18 and 19 indicate that contamination by desethylated atrazine residues is somewhat more widespread than contamination by atrazine, possibly a result of low-level nonpoint source contamination over much of the area. Lack of atrazine use by Farmer Y is apparent from the low concentrations shown at the E-labeled wells and at K5, all down gradient of Farmer Y's property. (See water-table elevation maps Figs. 5a and 5b.)

To include more wells and, therefore, more information in the concentration contour maps, the maps were redrawn to show average concentrations from wells between the water table and 15 ft below the water table. Concentrations from different wells were weighted according to their screen lengths.

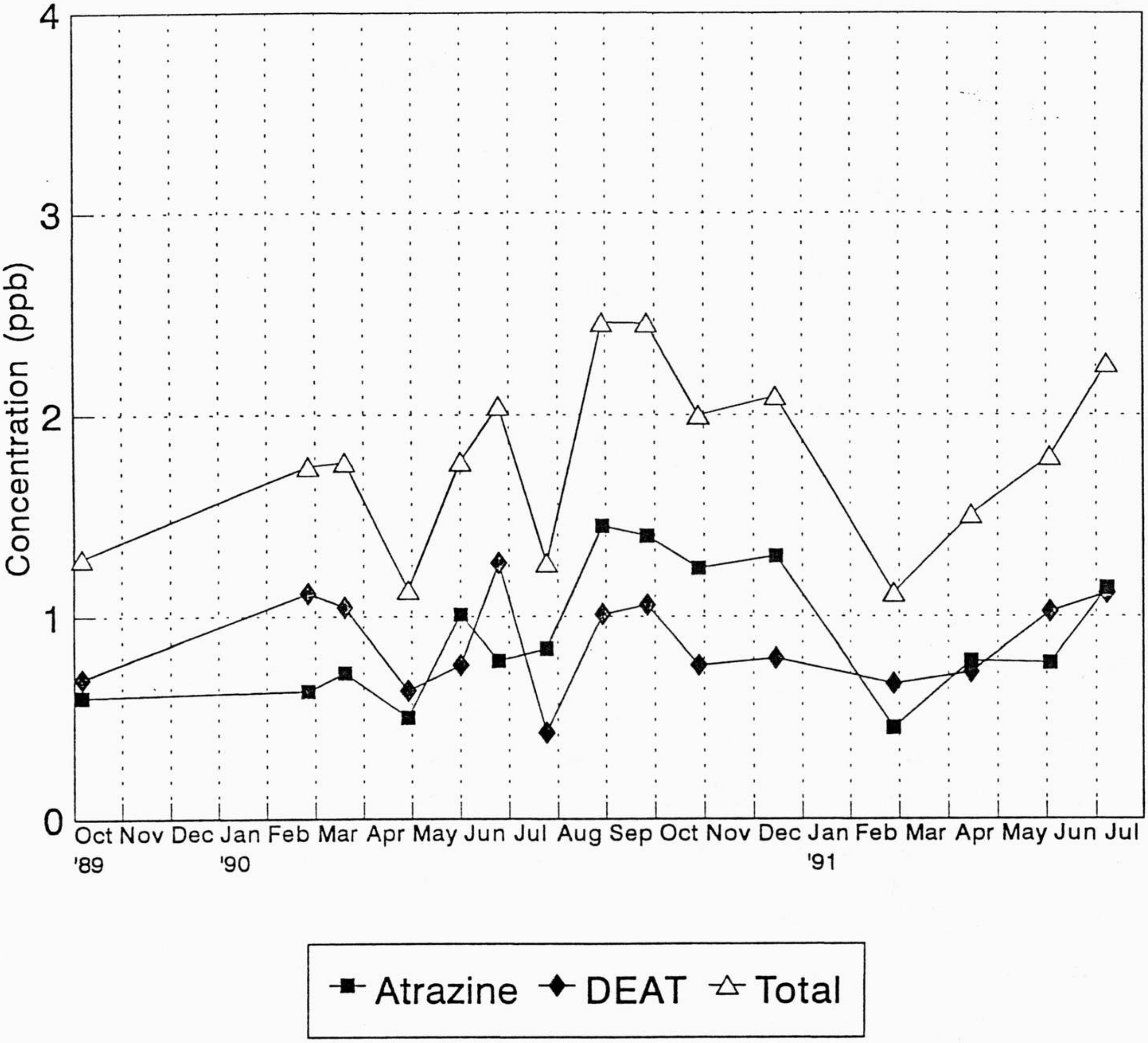


Figure 17. Atrazine and metabolite concentrations in water from PK1, a private well.

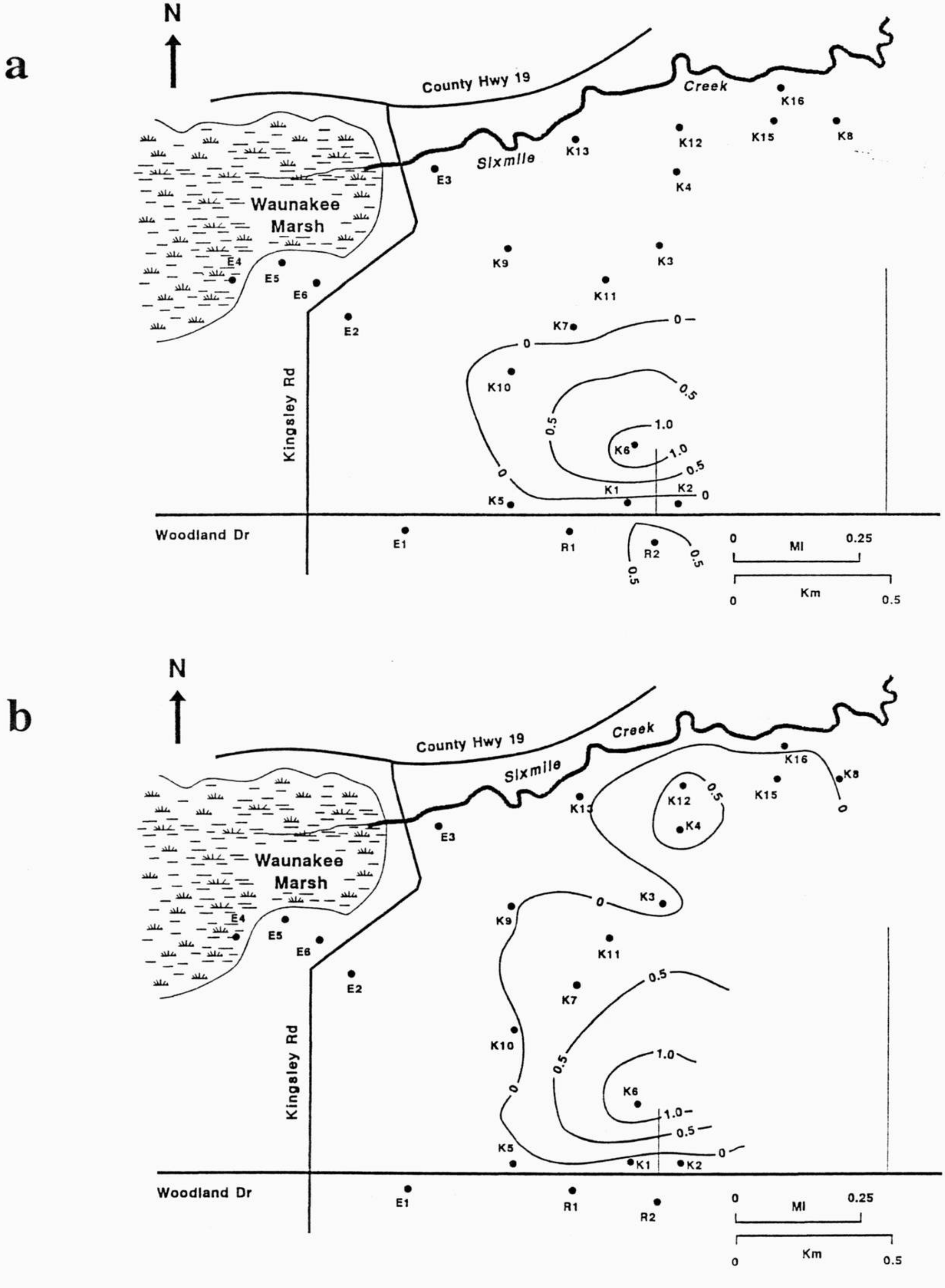
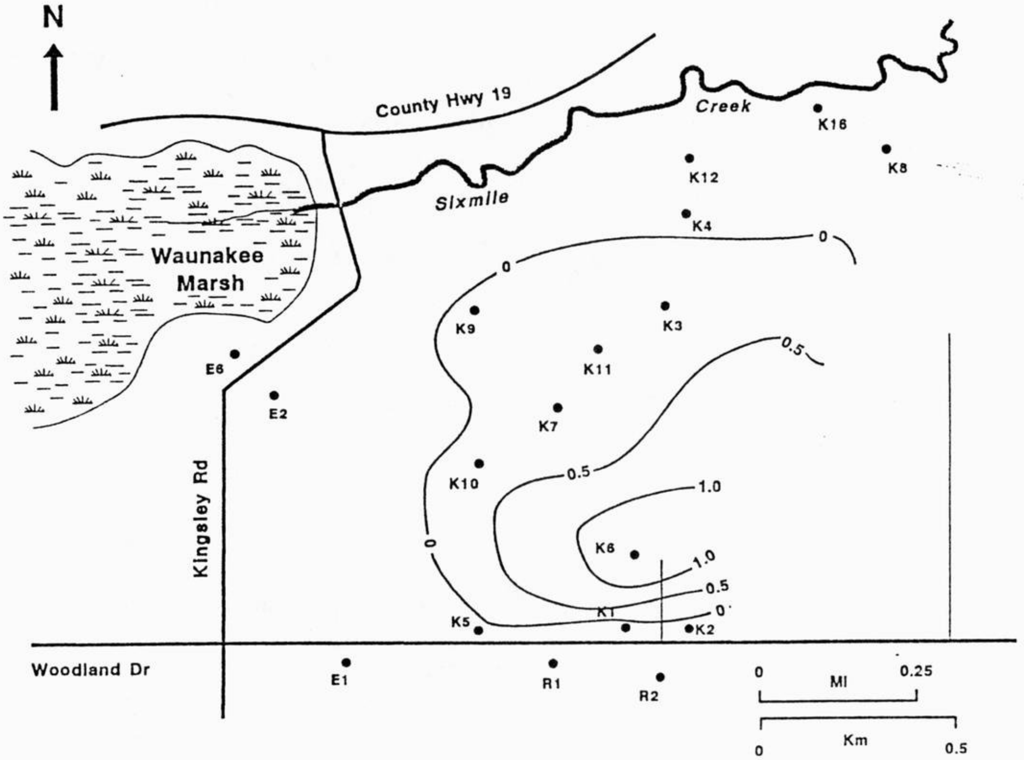


Figure 18. Concentrations (ppb) of atrazine (a) and desethylated atrazine (b) at the water table on April 16 to 22, 1991.

a



b

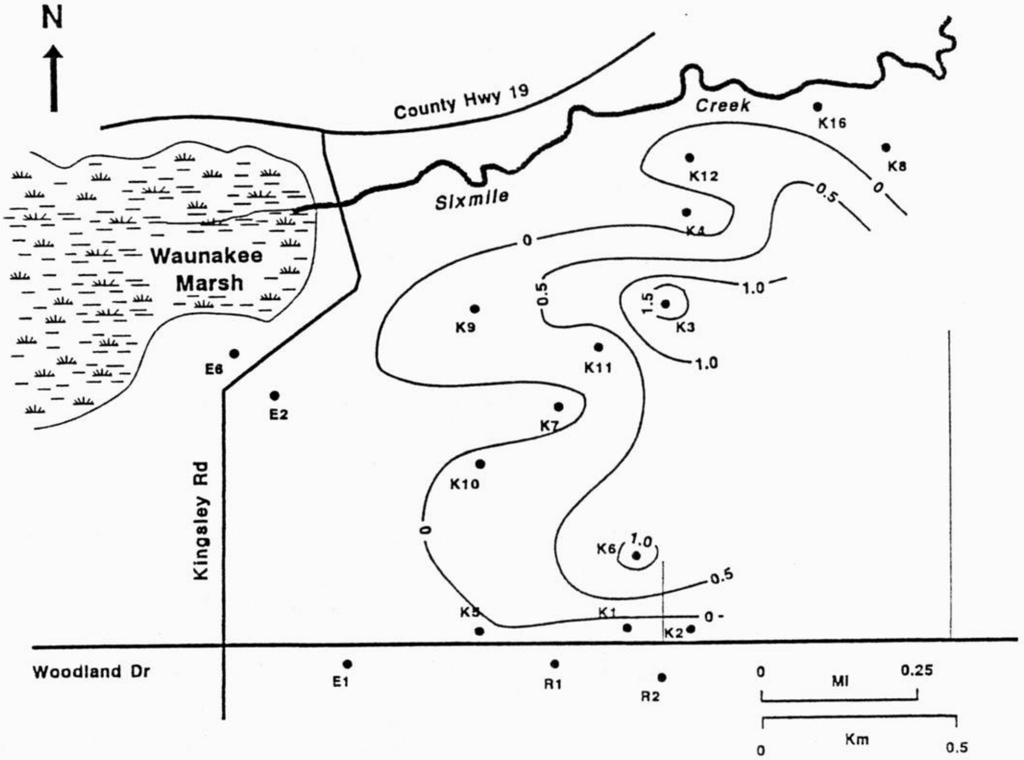


Figure 19. Concentrations (ppb) of atrazine (a) and desethylated atrazine (b) at the water table on June 3 to 6, 1991.

Note the somewhat arbitrary depth cutoff of 15 ft excludes data from PK1. This may present a more representative picture since it includes information from those piezometer nests where the highest concentrations were not at the water-table. In these representations -- Figs. 20 and 21 -- the difference between desethylated atrazine and atrazine concentration distributions is present, but not as pronounced as in Figs. 18 and 19.

The spatial distributions of concentrations did not vary much from month to month over the study period, possibly due to a combination of the slow movement of groundwater and continual desorption and leaching of residues from the soil to the groundwater. When concentrations from one sampling period are correlated with another sampling period, the correlation factor indicates how stable the spatial distribution of concentrations is. Beginning with April 1990, when there were more data to work with, the lowest such correlation factor for atrazine when all sampling periods are correlated against all other periods is 0.70. Most correlations coefficients are over 0.88. This means that the atrazine concentration at a given well for any one sampling during the study period provides a good prediction for the concentration at any other sampling period. The same is true for desethylated atrazine. The average of all correlation factor of all samplings compared against all other sampling from April 1990 through July 1991 was 0.87 for atrazine and 0.85 for desethylated atrazine. For the purpose of these correlation computations, no detects were treated as 0 ppb.

One objective of the study is to determine whether atrazine or metabolite residue concentrations show any seasonal periodicity that might provide clues to the time of residue transport through the unsaturated zone. The water-table wells with shallow depth to groundwater are the most likely place to observe residue arrivals since the time of transport to deeper wells through the saturated zone is likely to be very long and the greater the depth to groundwater, the more diffuse the breakthrough curve is likely to be. Data are too sparse for definite conclusions at most of the water-table wells, but graphs of concentration against time at wells K3.B, K7.A, K12, and K13 (Figs. 22a, 22b, 22c, and 22d) show peak

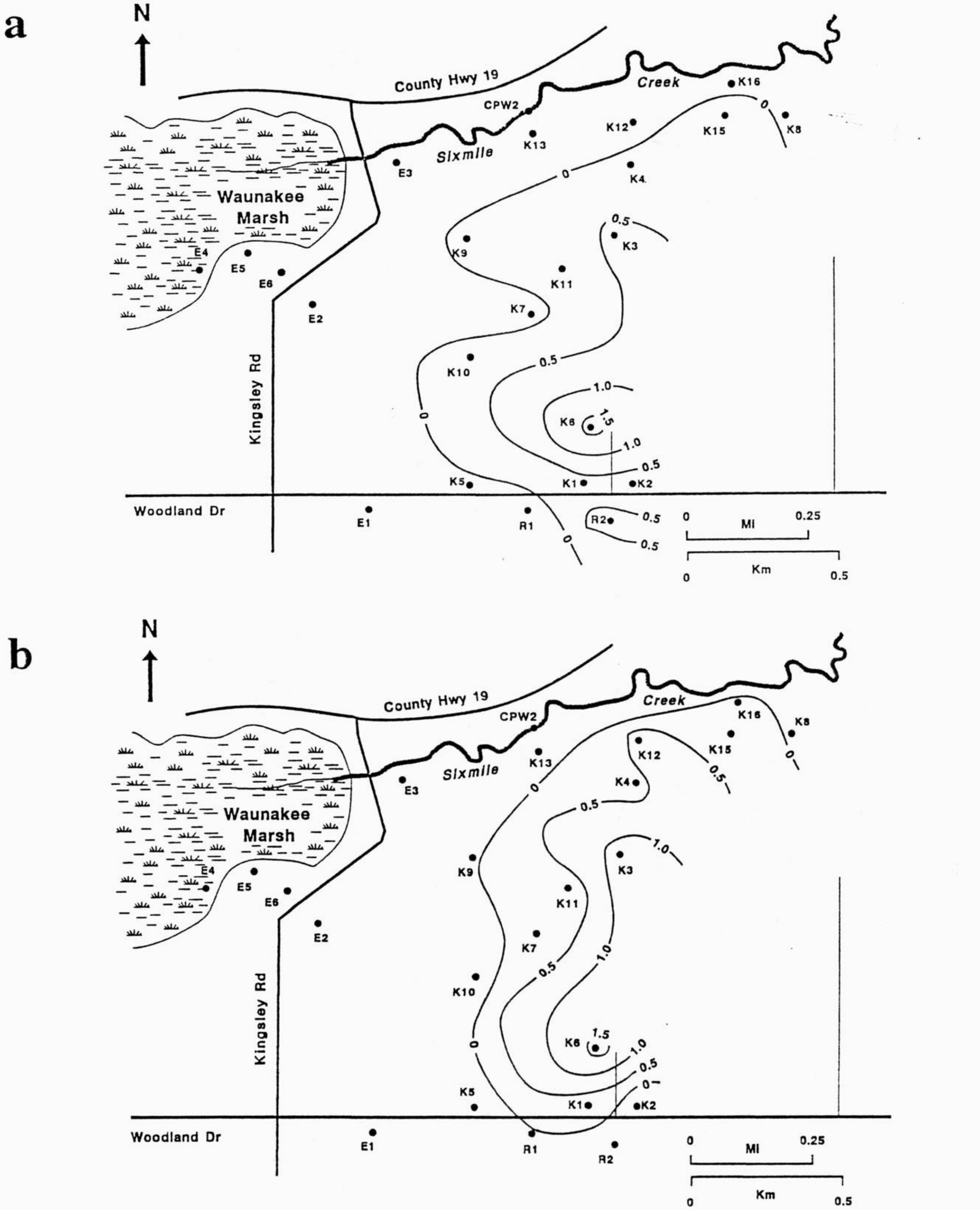


Figure 20. Average concentrations (ppb) of atrazine (a) and desethylated atrazine (b) from 0 to 15 ft below the water table on April 16 to 22, 1991.

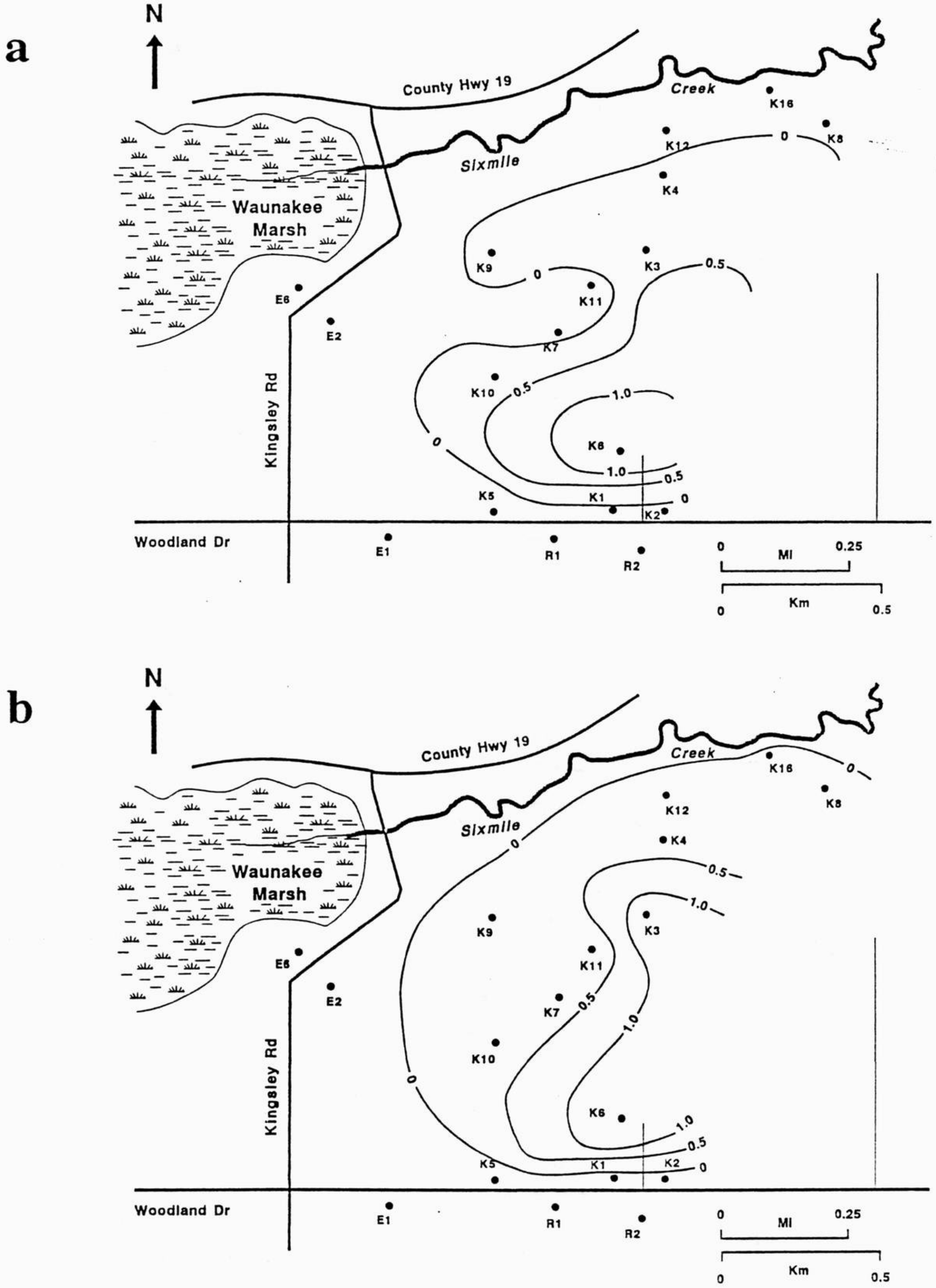


Figure 21. Average concentrations (ppb) of atrazine (a) and desethylated atrazine (b) from 0 to 15 ft below the water table on June 3 to 6, 1991.

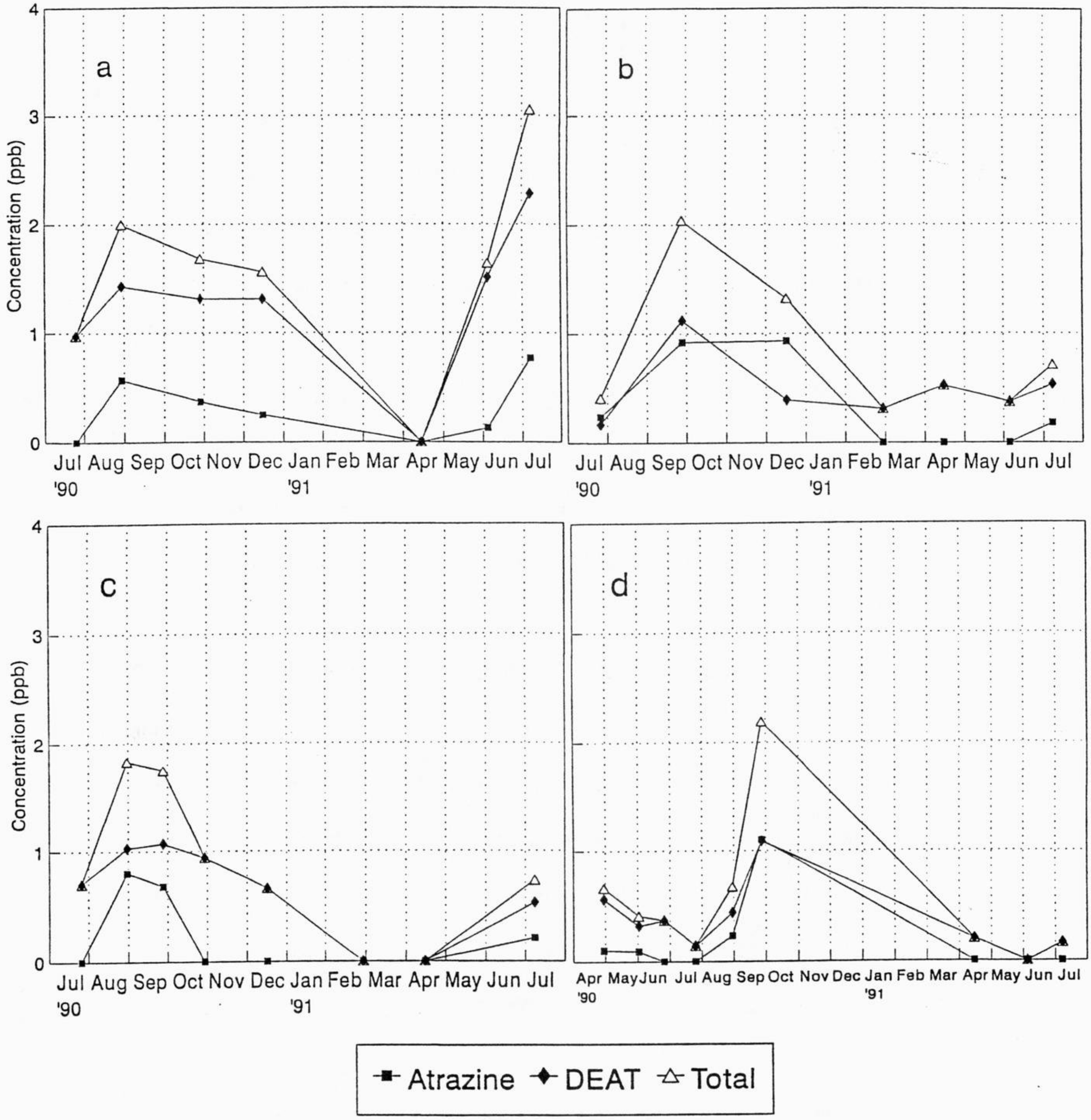


Figure 22. Atrazine and metabolite concentrations at water-table wells K3.B (a), K12 (b), K13 (c), and K7.A (d).

concentrations occurring 3 to 4 months after atrazine application in 1990 (or possibly 15 to 16 months after atrazine application in 1989) and, with the exception of K7.A, might be rising again as of July 1991. Discounting the early data from well K3.1, concentrations rose to a peak around August 1990 and appear to be rising again as of July 1991 (Fig. 23a). Not much atrazine was applied near water-table well K4.B in 1990 and no definite peak occurred, but in 1991, atrazine was applied upgradient from K4 and concentrations of atrazine and desethylated atrazine increased dramatically in July 1991, only 2 months after the 1991 atrazine application (or possibly 14 months after the 1990 application) (Fig. 23b). Depth to groundwater at K4 averages about 7 ft. Concentrations at K11.B, K14, K15 and piezometer nest K16 (Fig. 24) have yet to show evidence of pesticide residue front arrivals despite the fact that they are water-table wells in areas of corn where depths to groundwater are < 15 ft. Pesticide arrivals might be found in subsequent samplings.

Atrazine and metabolite residue concentrations in four private bedrock wells -- PE1, PE2, PZ1, and PZ2 -- were measured in August 1990 and April 1991; a fifth bedrock well, PR1, was sampled in April 1991 (Table 25). Concentrations were generally low, but residues were detected at all wells except PE1 during at least one sampling. Of the nine total samplings, the highest total atrazine residue concentration found was 0.57 ppb at PZ2 in August 1990. In April 1991, neither atrazine nor desethylated atrazine was detected in PE1, PE2, and PZ1. Pesticide-use history of the all the area surrounding the private wells is unknown, but the area around PE1 has not received atrazine application since at least 1986.

From October 1989 through September 1990 and again in April 1991, water samples were taken and analyzed for cations, anions and NO3-N at the University of Wisconsin - Extension Soil and Plant Analysis Laboratory and the results are presented in Appendix A. Although some fluctuation in concentrations occurs over time, the patterns of wells containing high levels of particular constituents remained constant over time. Data for the latest water chemistry sampling, from April 1991, are

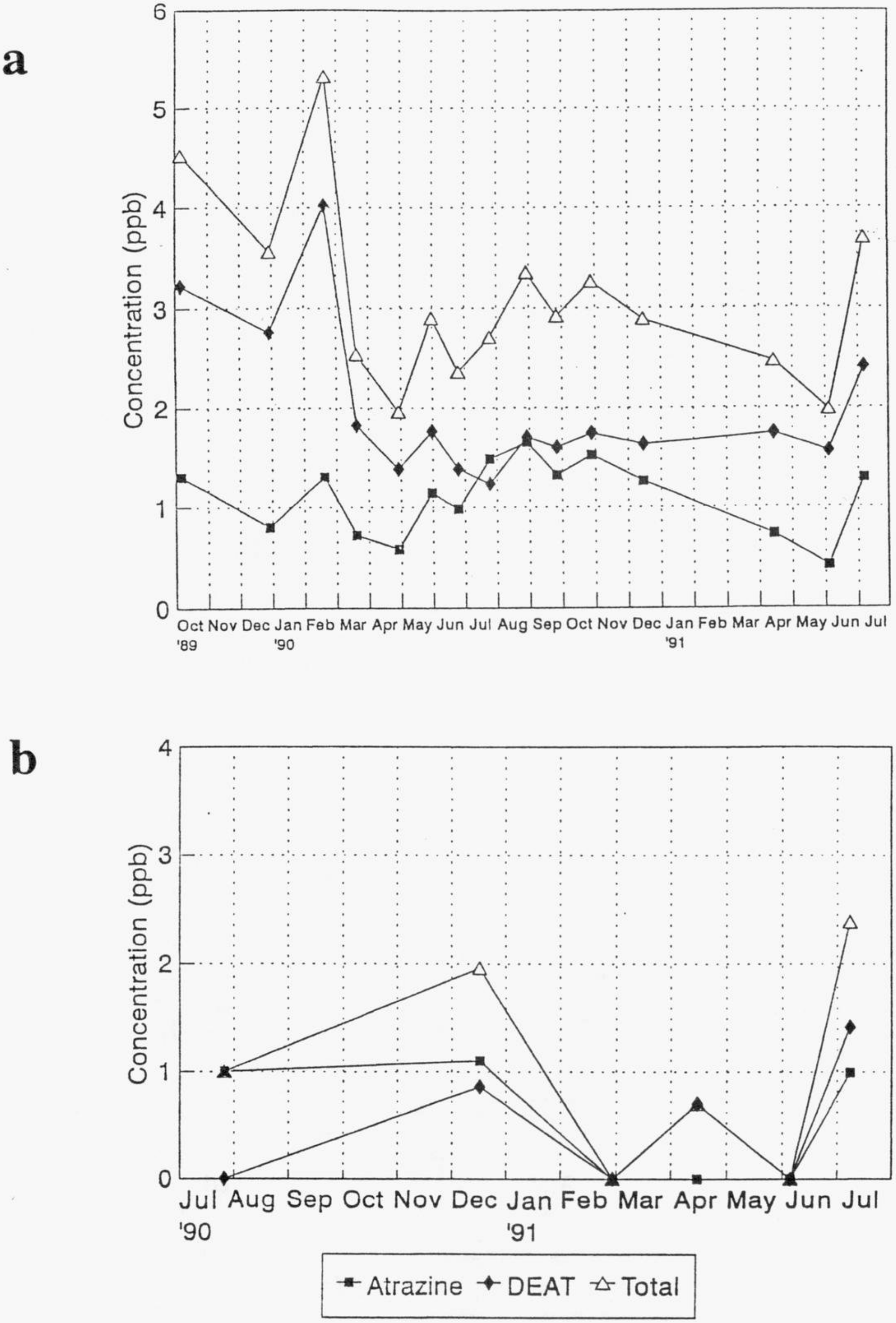


Figure 23. Atrazine and metabolite concentrations at multi-level sampler K3.1 (a) and water-table well K4.B (b).

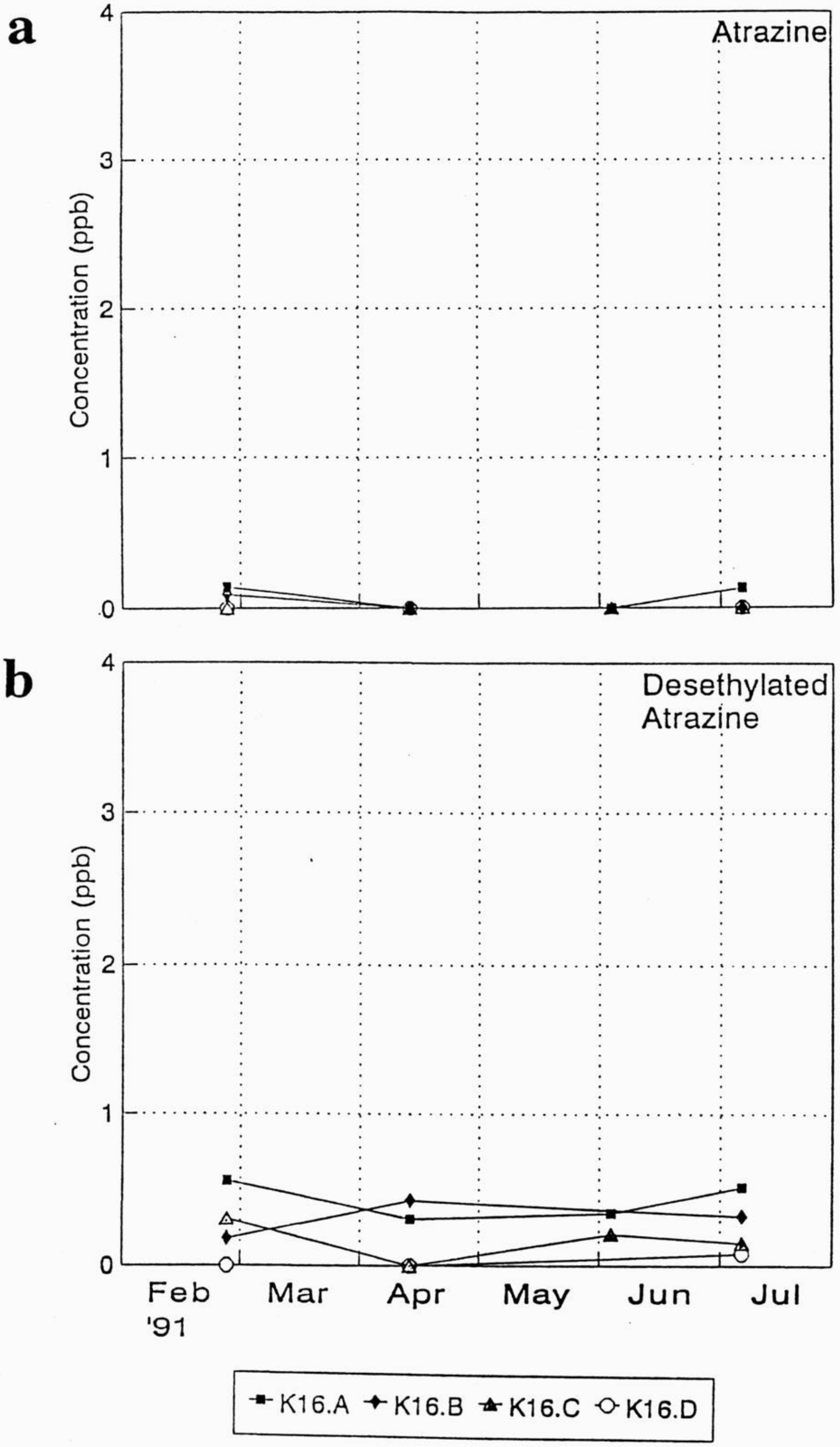


Figure 24. Atrazine (a) and metabolite (b) concentrations in water from K16.D, screened at the water table, and K16.A, K16.B, and K16.C, screened an average of 10.7, 18.9, and 25.3 ft below the water table.

Table 25. HPLC Results for private bedrock wells.

Well	Wis. Unique Well #	Open Interval (ft BWT[1])	Atrazine Conc. (ppb)	Modified Metab.[2] (ppb)	Total (ppb)	DAR[3]	Cl (ppm)	NO_3-N (ppm)
August 1990								
PE1	EC 823	88 to 124	ND[4]	ND	ND	*[5]	17.0	1.5
PE2	EC 824	105 to 121	0.22	0.17	0.39	0.77	93.5	7.5
PZ1	DL 497	78 to 132	0.21	0.39	0.60	1.86	54.5	24.0
PZ2	EC 825	-	0.13	0.44	0.57	2.35	40.0	10.0
April 1991								
PE1	EC 823	88 to 124	ND	ND	ND	*	22.0	<0.5
PE2	EC 824	105 to 121	ND	ND	ND	*	159	7.5
PZ1	DL 497	78 to 132	ND	ND	ND	*	59.0	24.5
PZ2	EC 825	-	0.05	0.23	0.28	1.23	42.0	9.5
PR1	AM 529	15 to 94	0.40	ND	0.40	0.34	144	22.5

[1] BWT is below water table.

[2] Modified metabolite is desethylated atrazine concentration corrected to reflect the lower molecular weight of the metabolite.

[3] DAR is the modified metabolite : atrazine concentration ratio.

[4] ND is not detected.

[5] * indicates the ratio cannot be computed due to atrazine and desethylated concentrations < the limit of detection.

presented as Table 26.

Note the similar chemical signatures of water-table well K2.B and the perennially-ponded surface water just to the east of K2 that results from barnyard runoff collection ditches of Farmers X and Z. Both have high concentrations of K and NO_3-N. The similarity suggests the surface water may be a partial source of water to K2. K2.B also contains high Na and Cl concentrations that might result from road salt because of proximity to Woodland Rd, although no other water-table wells along Woodland Rd. (K1.C, R1, K5.C, E1) have such high concentrations of Na and Cl. High Na and Cl concentrations could also result from cow urine in the runoff water, water softener discharge, or chemicals used to clean

Table 26. Water chemistry during sampling week of April 16-22, 1991.

Well	Temp. (°C)	Elec. Cond. (μmhos)	Dis. Oxy. (mg/L)	(ppm)													
				P	K	Ca	Mg	S	Zn	B	Mn	Fe	Cu	Al	Na	Cl	NO3-N
K1-Main	9.0	730	3.1	<0.217	3.337	110.3	61.82	14.45	0.190	0.033	0.064	0.134	0.225	<0.352	13.88	55.0	30.5
K1.B	9.8	610	4.2	<0.217	0.816	106.6	54.48	7.58	0.047	0.041	0.003	0.039	0.081	<0.352	10.07	58.5	6.5
K1.C	8.5	650	10.2	<0.217	5.009	102.7	51.48	12.08	0.042	0.056	0.060	0.123	0.095	<0.352	10.76	54.0	17.5
K2-Main	9.4	1070	4.7	<0.217	7.858	160.0	98.10	14.08	0.291	0.068	0.247	0.052	0.061	<0.352	50.96	126.5	13.0
K2.B	8.9	2290	7.4	<0.217	275.4	298.5	104.2	31.35	0.055	0.227	0.639	0.350	0.056	<0.352	116.3	472.0	50.0
K3.1	10.3	700	7.6	<0.217	<0.621	112.1	62.31	12.32	0.029	<0.029	<0.003	<0.011	<0.025	<0.352	10.61	36.0	2.5
K3.2	10.7	700	9.6	<0.217	<0.621	113.5	62.15	13.76	0.054	<0.029	<0.003	0.011	0.065	<0.352	12.67	36.0	1.5
K3.3	10.0	680	9.2	<0.217	<0.621	135.9	62.85	13.04	0.046	<0.029	<0.003	<0.011	0.069	<0.352	11.23	37.0	1.5
K3.4	10.6	620	9.6	<0.217	<0.621	105.8	58.71	12.49	<0.01	<0.029	<0.003	<0.011	<0.025	<0.352	11.15	36.0	1.5
K3.5	10.6	800	8.4	<0.217	<0.621	107.9	52.68	11.41	0.091	<0.029	0.003	0.020	0.033	<0.352	11.99	35.5	5.5
K3.6	10.6	630	10.1	<0.217	<0.621	103.9	54.71	12.17	0.047	<0.029	<0.003	0.055	0.049	<0.352	12.97	35.5	5.0
K3.7	10.4	830	8.6	<0.217	<0.621	104.2	55.63	12.04	<0.01	<0.029	<0.003	<0.011	<0.025	<0.352	13.40	36.0	5.0
K3-Main	8.0	590	11.5	<0.217	<0.621	104.2	52.16	10.83	0.099	<0.029	0.012	0.044	0.033	<0.352	11.74	35.0	7.0
K3.B	8.0	600	10.1	<0.217	<0.621	114.0	58.96	13.41	0.269	<0.029	0.007	0.015	0.086	<0.352	9.77	26.5	1.5
K4.1	8.0	630	10.6	<0.217	0.969	111.6	61.11	11.63	0.017	<0.029	0.226	<0.011	0.030	<0.352	11.28	71.5	1.5
K4.2	8.2	660	3.7	<0.217	0.853	115.6	62.74	11.63	0.021	<0.029	0.195	<0.011	0.027	<0.352	7.33	76.5	3.5
K4.3	8.2	670	1.8	<0.217	0.733	111.0	60.89	11.56	<0.01	<0.029	0.196	<0.011	<0.025	<0.352	7.18	74.5	3.0
K4.4	7.9	680	2.9	<0.217	0.633	111.0	60.67	10.87	0.018	<0.029	0.151	<0.011	<0.025	<0.352	7.01	76.5	3.0
K4.5	8.1	650	1.39	<0.217	0.854	111.2	61.00	11.50	0.041	<0.029	0.173	<0.011	<0.025	<0.352	7.17	74.0	3.0
K4.6	8.9	680	1.1	<0.217	0.754	109.5	59.88	11.45	0.020	0.030	0.145	<0.011	0.029	<0.352	7.50	76.5	2.5
K4.7	9.1	980	1.2	<0.217	0.704	112.0	61.13	11.14	0.037	<0.029	0.166	<0.011	<0.025	<0.352	7.56	75.5	2.5
K4-Main	7.6	640	1.3	<0.217	0.758	112.1	61.44	11.67	0.016	<0.029	0.154	0.049	<0.025	<0.352	7.70	76.0	3.0
K4.B	6.8	880	4.8	<0.217	4.238	113.4	42.00	10.55	0.042	0.058	2.283	0.134	0.036	<0.352	16.70	59.5	3.5
K5.A	9.7	480	10.2	<0.217	<0.621	84.0	40.04	2.52	0.059	<0.029	0.011	0.071	<0.025	<0.352	6.08	15.0	1.0
K5.B	9.4	410	11.2	<0.217	<0.621	98.4	46.05	3.42	0.056	<0.029	0.170	0.533	<0.025	<0.352	6.46	5.5	1.0
K5.C	9.2	580	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
K6.A	9.3	1050	6.4	<0.217	0.665	179.2	82.12	16.06	0.128	0.088	0.010	0.049	<0.025	<0.352	30.25	98.5	34.0
K6.B	9.8	2830	4.7	<0.217	1.414	196.6	97.52	18.45	0.057	0.062	0.075	0.021	<0.025	<0.352	550.9	941.0	13.0
K6.C	8.9	1590	3.6	<0.217	2.480	143.1	71.38	19.08	0.037	0.032	0.326	0.048	<0.025	<0.352	220.2	308.5	23.5
K6.D	9.1	790	3.3	<0.217	2.495	143.8	62.15	13.14	0.065	0.040	0.031	0.221	0.028	<0.352	16.49	35.5	17.5

Table 26. Continued.

Well	Temp	EC	DO	P	K	Ca	Mg	S	Zn	B	Mn	Fe	Cu	Al	Na	Cl	NO3-N
K7.A	7.3	465	3.3	0.292	13.000	101.0	24.51	6.73	0.099	<0.029	0.586	0.096	0.072	<0.352	13.98	56.0	25.5
K7.B	8.0	420	8.1	<0.217	5.579	65.4	30.98	6.01	0.091	<0.029	0.038	0.114	0.125	<0.352	9.53	41.0	18.5
K8	7.0	430	8.6	<0.217	<0.621	81.7	43.50	7.91	0.017	<0.029	0.033	0.115	0.108	<0.352	7.29	6.0	3.0
K9	9.2	530	7.7	<0.217	1.458	83.4	44.82	6.33	0.182	<0.029	0.016	0.152	0.095	<0.352	8.81	29.0	5.5
K10	8.0	490	11.5	<0.217	1.099	88.3	35.14	13.43	0.080	<0.029	0.061	0.467	0.074	<0.352	22.81	12.0	4.5
K11.B	7.3	550	7.1	<0.217	4.184	137.8	50.21	10.39	0.117	<0.029	0.304	0.265	0.058	<0.352	14.07	49.5	5.0
K11.C	9.0	480	3.3	<0.217	7.157	69.8	48.48	16.45	0.048	<0.029	0.060	0.067	0.039	<0.352	7.79	38.0	8.5
K12	-	-	-	<0.217	<0.621	86.5	47.76	16.95	0.015	<0.029	0.557	0.065	0.057	<0.352	10.27	68.0	0.5
K14	-	-	-	0.639	22.13	150.0	70.89	19.24	0.254	0.061	2.562	0.832	0.137	0.493	32.13	170.5	4.5
K15	-	-	-	<0.217	0.714	104.1	42.94	20.80	0.053	<0.029	0.165	0.226	0.095	<0.352	12.11	68.0	10.5
K16.A	6.2	600	5.1	<0.217	1.314	120.9	55.10	15.98	0.098	<0.029	0.061	0.133	0.133	<0.352	20.77	51.0	12.0
K16.B	7.0	520	6.7	<0.217	1.130	90.4	46.98	9.32	0.028	<0.029	0.081	0.055	<0.025	<0.352	8.18	37.0	11.0
K16.C	7.6	460	3.3	<0.217	7.620	64.6	42.77	7.76	0.022	<0.029	0.166	0.032	<0.025	<0.352	5.57	25.5	6.0
K16.D	6.3	390	3.1	<0.217	<0.621	86.5	36.02	13.70	0.193	<0.029	0.053	0.321	0.039	<0.352	6.75	27.0	1.0
E1	9.6	590	9.2	<0.217	1.131	69.7	35.31	4.10	0.023	<0.029	0.004	0.026	<0.025	<0.352	68.18	62.0	1.5
E2	8.9	1390	3.1	<0.217	1.335	190.4	158.5	26.46	0.040	0.050	0.724	<0.011	<0.025	<0.352	35.09	50.5	25.5
E3	6.8	350	5.5	<0.217	<0.621	59.0	30.54	3.97	<0.01	<0.029	0.069	0.086	0.030	<0.352	4.13	6.0	1.5
E4	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
E5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
E6.A	-	-	-	<0.217	2.091	208.5	111.6	14.62	0.060	<0.029	1.311	0.084	0.058	<0.352	15.82	147.5	20.5
E6.B	-	-	-	0.261	1.824	199.6	114.9	5.44	0.083	<0.029	0.077	8.366	<0.025	<0.352	14.32	238.0	0.5
R1	9.5	670	7.9	0.403	1.523	108.5	47.26	5.21	0.097	<0.029	0.161	0.092	0.067	<0.352	19.20	63.0	1.5
R2	8.8	1100	3.1	<0.217	101.9	154.4	72.10	20.66	0.073	0.079	1.048	0.074	0.110	<0.352	27.48	109.5	3.0
PK1	10.9	970	7	<0.217	8.148	141.2	69.03	15.27	0.166	<0.029	0.016	0.105	<0.025	<0.352	29.80	-	-
PE1	10.7	500	1.6	<0.217	1.110	83.8	48.45	14.68	0.230	<0.029	0.311	0.279	<0.025	<0.352	7.04	22.0	<0.5
PE2	10.9	930	7.8	<0.217	1.887	126.8	78.94	22.75	0.091	<0.029	0.073	0.049	<0.025	<0.352	27.17	159.0	7.5
PZ1	9.6	650	7.9	<0.217	2.519	109.8	58.28	12.41	0.168	<0.029	0.004	0.078	0.030	<0.352	20.02	59.0	24.5
PZ2	9.9	600	9.1	<0.217	<0.621	95.8	49.67	10.37	0.067	<0.029	<0.003	0.072	0.069	<0.352	7.59	42.0	9.5
PR1	10.1	1050	6.5	<0.217	8.711	139.9	72.96	14.64	0.055	0.030	<0.003	0.080	<0.025	<0.352	52.30	144.0	22.5
Surface water near K2	8.1	820	1.3	30.67	185.6	42.0	21.44	5.79	0.411	0.124	0.609	1.749	0.040	<0.352	23.25	65.0	39.0

milk pipelines that are often discharged to drainage ditches. Na and Cl concentrations were relatively high at K2-Main, butless than at K2.B. K2-Main is screened over a 1-ft interval about 14 ft below the water table, although like K3-Main and K4-Main, it is within a sandpack that extends to the water table. Atrazine and metabolite residues have typically not been detected at wells K2.B and K2-Main.

Well R2, where the water-table elevation is the highest of any well measured at the field site, is a water-table well adjacent to a small barnyard-runoff collection pit south of Woodland Rd. As at K2.B, concentrations of K, Na, and Cl are elevated relative to most of the wells. Na and Cl concentrations were also elevated at well K6, the well site with the highest atrazine and metabolite residue concentrations. The high concentrations probably result from the wells' proximity to Farmer X's septic field and his use of softened water. Interestingly, the highest Na and Cl concentrations occur at K6.B and K6.C, the deepest wells of the piezometer nest, where atrazine and metabolite residue concentrations were lowest. It would appear that water from the septic field moves vertically and spreads out so that the most concentrated part of the septic plume bypasses K6.D and K6.A, contradicting the hypothesis that the septic field is somehow responsible for high residue atrazine and desethylated atrazine residue concentrations. NO_3-N concentrations are also high at K6, with the highest concentration occurring at K6.A, screened 3 to 8 ft below the water table, where atrazine and metabolite residue concentrations were also highest.

The similarity of atrazine and NO_3-N concentrations at K6 suggests that there might be a general relationship between them across the whole field site. No relationship was found, however, as correlation coefficients between NO_3-N and atrazine and between NO_3-N and desethylated atrazine during April 1991 were 0.21 and 0.05. In fact no correlation coefficient in excess of 0.4 was found between atrazine or desethylated atrazine and any other chemical constituent. Correlations from April 1991 are discussed here since that data set was the most complete one collected, however, correlation analyses from previous months were similar.

IX. GROUNDWATER VELOCITIES, TRAVEL TIMES, WELL ZONES OF CONTRIBUTION AND THEIR RELATIONSHIP TO PESTICIDE RESIDUE CONCENTRATIONS

A. Analytical Predictions

As derived from Darcy's law, average linear groundwater velocity (v) is expressed as:

$$\bar{v} = \frac{Q}{nA} = -\frac{K}{n}\frac{\partial h}{\partial l} \tag{11}$$

where Q is the volumetric flux (m^3/sec);

n is porosity (unitless);

A is the cross-sectional area of flow (m^2);

K is the hydraulic conductivity (m/sec);

and $\partial h/\partial l$ is the hydraulic gradient (unitless) (Freeze and Cherry, 1975).

Hydraulic conductivity and hydraulic gradient were measured in the field. For the purposes of these calculations, porosity of the till aquifer was estimated at 0.3. Even though it is an estimate, its uncertainty is probably less than that of hydraulic conductivity calculated from slug tests.

At piezometer nests K1, K2, K3, K6, K7, and K11, downward hydraulic gradients are much greater than horizontal gradients. Barring a high horizontal to vertical hydraulic conductivity anisotropy ratio, vertical groundwater flow probably dominates near these wells. At K6, for example, the vertical gradient between K6.D (at the water table) and K6.A (average of 5.8 ft below the water table) averaged 0.060. From the water table to the middle of the K6.D screen (average of 0.64 ft below the water table), a vertical groundwater velocity of 0.026 ft/d (9.2×10^{-6} cm/sec) was computed by multiplying the vertical gradient between K6.D and K6.A by the hydraulic conductivity at K6.D and dividing by porosity. The horizontal hydraulic gradient at the water table between K1 (the nearest upgradient well to K6) and K6 averaged 0.023. During the 24.6 d that water would take to get to the depth of the middle of K6.D's screen it would move 0.25 ft horizontally. While the horizontal gradient decreases and even reverses with depth (Fig. 8) the vertical gradient increases to 0.17 between 5.8 and 18.5 ft below the water table and then drops to 0.050 between K6.B and K6.C (average of 36.0 ft below the water table). To compute groundwater velocities between wells, the geometric mean of the hydraulic conductivities measured at those wells was used. The mean hydraulic conductivity between K6.D and K6.A was 0.39 ft/d. Multiplying by the vertical hydraulic gradient and dividing by the porosity and assuming an anisotropy ratio of 1 (vertical hydraulic conductivity = horizontal hydraulic conductivity) yields a vertical groundwater velocity estimate of 0.78 ft/d (2.8×10^{-5} cm/sec). Using the same method, vertical groundwater velocity would be 0.43 ft/d (1.5×10^{-4} cm/sec) and 0.15 ft/day (5.2×10^{-5} cm/sec) from K6.A to K6.B and from K6.B to K6.C, respectively. At these velocities, water traveling the 5.4 ft from mid-screen K6.D to mid-screen K6.A would take about 70 d during which time it would travel only about 1.6 ft horizontally. Time of water travel (TOT) between the depths of the middle of K6.A and K6.B would be about 31 d during which time it would move about 1.4 ft horizontally. From the K6.B to the K6.C depth, the TOT and subsequent horizontal distance travelled would be about 116 d and 5.9 ft. If water travelled from the water table near K6 to K6.C its total TOT and horizontal distance would be 218 d and 8.9 ft meaning that water starting at the water table about 8.9 ft upgradient (towards K1) from well nest K6 would reach the middle of the well screen of K6.C in about 218 d. The horizontal distance in effect defines the zone of contribution (ZOC) to the monitoring well nest. If the glacial till aquifer has horizontal beds or some type of structure, the anisotropy ratio ($K_{horizontal}/K_{vertical}$) might be > 1. If, for example the anisotropy ratio is = 5, then the TOT and ZOC of well K6.C become 1,090 d and 27 ft. In either case, the ZOC is small enough that any pesticide residue concentrations present probably resulted from pesticide application (or spills) near the well. It should be noted that there are many sources of uncertainty involved in these calculations. Compared with aquifer pumping tests, slug tests measure hydraulic conductivity in relatively small areas around a well screen. Depending on the degree of aquifer heterogeneity, the values used may not be applicable to areas away from or between well screens. Horizontal gradients may vary locally in ways that can only be clarified by drilling many more wells. The anisotropy ratio and porosity are estimated with no field data to back them up. Nonetheless, the velocity estimates and resultant TOT- and ZOC-values represent the best estimates possible at this time. Calculations similar to those made at K6 also were made at any well nest where the average vertical hydraulic gradient was downward -- at K1, K2, K3, K4, K5, K7, and K11 -- and the results are presented in Table 27 for anisotropy ratios of 1 and 5. For other monitoring wells TOT and ZOC predictions are more difficult and require the use of groundwater-flow, particle-tracking models. The small horizontal distances shown indicate that the ZOC-values for all wells (Table 27) are small and the water quality of those wells should reflect the land use and farm practices in their near vicinities. Note that no ZOC-values are given for K7 since it is near a water table divide and has no upgradient wells for computation of horizontal gradient.

Due to sorption, pesticide residues move through the soil and aquifer more slowly than water. However, one would still expect that the total residence time of water in the soil and the aquifer would be related to overall pesticide residue concentrations and the ratio of metabolite to parent compound concentrations. The longer the residence time, the longer the residues have to undergo degradation and dilution through dispersion. The time of travel for water through the unsaturated zone is related to the thicknesses, texture, and structure of the surface soil and vadose zone horizons. These factors can be incorporated into unsaturated zone models for prediction of residence times, but even then preferential flow paths can render such predictions invalid. For now, in lieu of such modeling efforts, the simplifying assumption has been made that residence times of water and pesticide residues in the unsaturated zone are related to the total thickness of that zone, i.e., the average depth to groundwater shown in Table 27. The residence time of water and pesticide residues in groundwater should be related to the predicted TOTs in Table 27. Correlation and regression analyses were performed to explore the relationships of

Table 27. Predicted water time of travel (TOT) to and maximum zones of contributions (ZOC) of monitoring wells.

Well	Depth to ground-water (ft)	Depth below water Table (ft)	TOT from water table (d)		TOT from water table (yr)		Max. ZOC (ft)	
			Kh/Kv=1	Kh/Kv=5	Kh/Kv=1	Kh/Kv=5	Kh/Kv=1	Kh/Kv=5
K1.C	21.1	1.2	260	1,300	0.71	3.5	0.15	0.76
K1.B	21.1	11.2	1,200	5,800	3.2	16	0.14	0.70
K1-Main	21.1	31.7	1,300	6,400	3.5	18	1.7	8.6
K2.B	25.6	1.6	47	240	0.13	0.65	3.3	16
K2-Main	25.6	13.5	1,400	6,900	3.8	19	29	140
K3.B	14.7	1.4	22	110	0.060	0.30	0.12	0.58
K3-Main	14.7	30.6	870	4,300	2.4	12	7.9	39
K4.B	7.1	1.5	860	4,300	2.3	12	0.13	0.64
K4-Main	7.1	35.2	2,300	11,300	6.2	31	2.9	15
K5.C	28.8	0.2	44	220	0.12	0.60	0.083	0.42
K5.B	28.8	3.4	720	3,600	2.0	9.8	1.7	8.7
K5.A	28.8	11.2	2,000	10,000	5.6	28	5.8	29
K6.D	31.1	0.6	25	120	0.067	0.34	0.25	1.2
K6.A	31.1	6.1	130	630	0.34	1.7	2.3	12
K6.B	31.1	19.0	160	790	0.43	2.2	4.1	20
K6.C	31.1	36.1	270	1,400	0.75	3.7	12	60
K7.A	14.8	1.4	420	2,100	1.1	5.7	-	-
K7.B	14.8	5.3	610	3,100	1.7	8.4	-	-
K11.A	14.8	2.1	400	2,000	1.1	5.4	0.16	0.82
K11.B	14.8	3.8	740	3,700	2.0	10	0.31	1.5
K11.C	14.8	37.8	2,100	11,000	5.9	29	3.0	15

atrazine and desethylated atrazine concentrations and the ratio of those concentrations (DAR) to depth to groundwater and TOT predictions. Correlation coefficients and regressions were computed between data sets of concentrations from particular sampling periods and the depths to groundwater and TOT predictions from Table 27. Correlation and regression analyses were also performed on the natural logs values of concentrations, DARs, depths to groundwater, and aquifer TOTs to see whether log models provided better fits.

Atrazine concentrations measured at specific wells were negatively correlated with the predicted

TOT to that well indicating that concentrations decrease with increased residence time in the aquifer. Correlation coefficients ranged from -0.35 in April 1991 to -0.55 in September 1990. The natural log of the atrazine residue concentration was better correlated with the log of the TOT, ranging from -0.31 in October 1990 to -0.93 in September 1990. Of particular interest is whether the average concentration at a given well over time is correlated to the predicted TOT to that well. The correlation coefficient between the logs of average atrazine residue concentrations and logs of the TOT-values was -0.68. The regression equation describing this relationship was:

$$\ln(\text{Avg. ATRA}) = 2.6 - 0.66 \ln(\text{TOT}),\ R2=0.42 \text{ on } 12 \text{ df}$$

where Avg. ATRA is the average atrazine residue concentration over time at a well (ppb),

TOT is the time of travel in the saturated zone (d),

and df is the degrees of freedom of the regression equation.

Although, as indicated by the low R^2 value, TOT does not account for the major portion of the variability of the concentrations, the relationship is significant at $p<0.01$, with a t of -3.21 for the slope term. (This corresponds to an F value of 10 for the regression model on 1/12 df.) The log-log regression model provided a better fit than either the semi-log or non-log model. When depth to groundwater was added to the equation in either the log or non-log form, the regression was not significantly improved.

The average desethylated atrazine residue concentration at a well was negatively correlated to TOT predictions (-0.39) and positively correlated to average depth to groundwater (0.04). Again, log-log models provided better fits and the log of average concentration was negatively correlated to the log of the depth to groundwater. A regression model was found where:

$$\ln(\text{Avg. DEAT}) = 6.4 - 1.2 \ln(\text{DTG}) - 0.67 \ln(\text{TOT}),\ R^2=0.32 \text{ on } 15 \text{ df}$$

where Avg. DEAT is the average desethylated atrazine concentration,

and DTG is average depth to groundwater.

DTG was only significant at $p<0.1$ with $t=-1.89$, while TOT was significant at $p<0.01$ with $t=-3.08$.

The full regression model was significant at $p<0.05$ on 2/15 df with $F= 5.0$. When DTG is omitted from the regression model, the equation becomes:

$$\ln (\text{Avg. DEAT}) = 1.9 - 0.50 \ln (\text{TOT}),\ R^2=0.21 \text{ on } 16 \text{ df.}$$

In this equation, TOT is significant at $p<0.05$ with $t=-2.4$ and F for the regression model = 5.5 on 1/16 df. The fit is improved by removing well K5.B from the data as a potential outlier. The regression equation becomes:

$$\ln (\text{Avg. DEAT}) = 1.7 - 0.44 \ln (\text{TOT}),\ R^2=0.35 \text{ on } 15 \text{ df.}$$

Now TOT is significant at $p<0.01$ with $t=-3.12$ and the regression model $F=9.7$ on 1/15 df.

Average total atrazine residue concentrations at a well (Avg. Total = atrazine + desethylated atrazine) were the most strongly related to the TOT:

$$\ln (\text{Avg. Total}) = 3.0 - 0.57 \ln (\text{TOT}),\ R^2=0.51 \text{ on } 15 \text{ df}$$

TOT in this equation is significant at $p<0.001$ with $t=-4.18$. The regression model $F=17$ on 1/15 df. A plot of the logs of average total concentrations against the logs of predicted TOT-values is shown in Fig. 25. Again, adding DTG to the model does not significantly improve the fit.

As time increases in the aquifer, one might expect that the DAR would increase as atrazine is degraded to desethylated atrazine. However, no strong relationships between DAR, TOT, or DTG were observed. Again, the best fit was a log-log model between the average DAR at a well over time and the predicted TOT-values:

$$\ln (\text{DAR}) = -1.8 + 0.33 \ln (\text{TOT}),\ R^2=0.30 \text{ on } 14 \text{ df.}$$

Well K3.B was omitted as a potential outlier from the data resulting in this model. TOT was significant at $p<0.02$ with $t=2.72$ (and regression model $F=7.4$ on 1/14 df). Note the model predicts that the desethylated concentration at a well increases with respect to the parent compound concentration as time of travel to the well increases. The relationship is significant but weak (Fig. 26). TOT-values explain only a portion of the DAR variability.

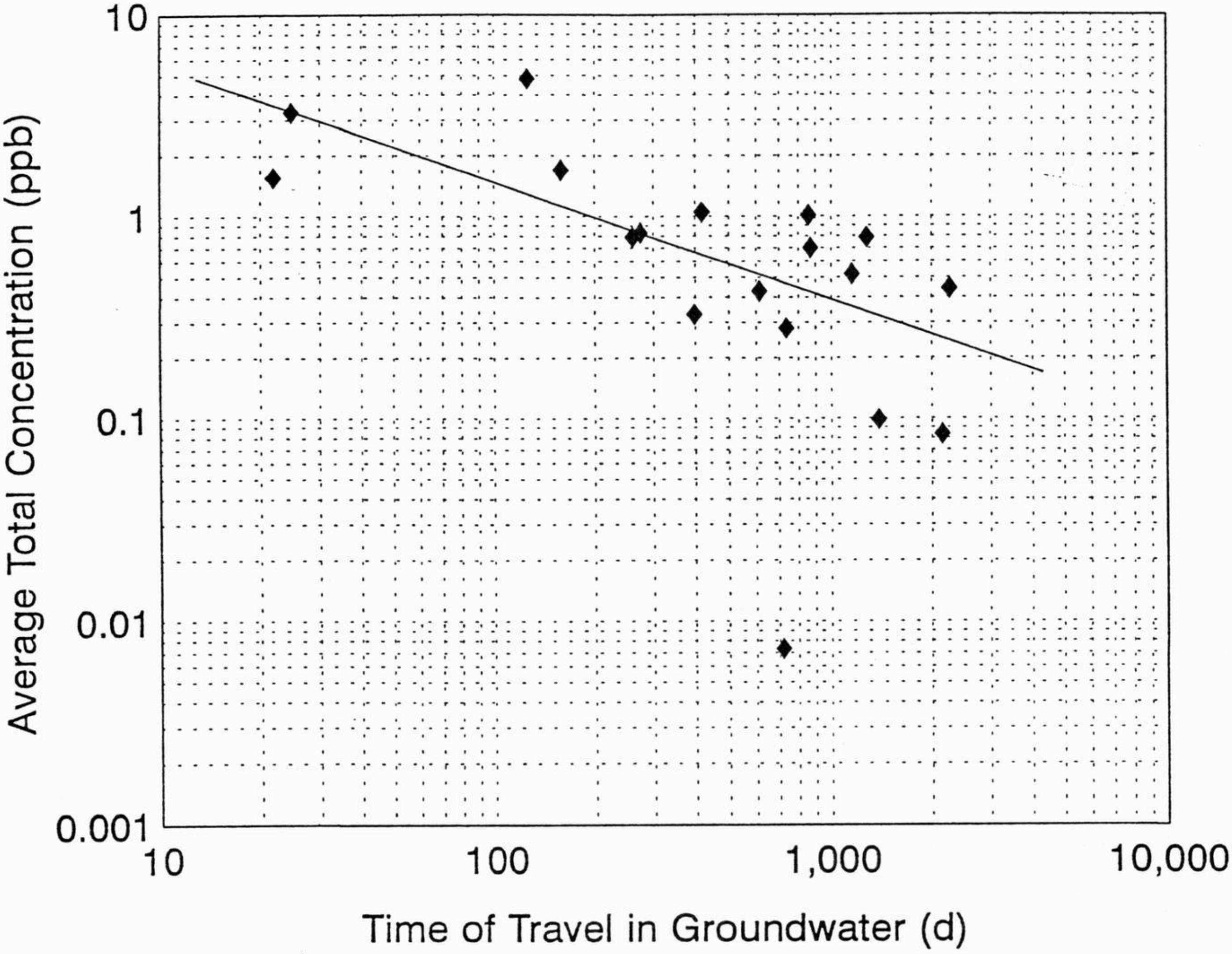


Figure 25. **Relationship between the average total atrazine and metabolite concentrations and predicted times of travel in groundwater at selected wells.**

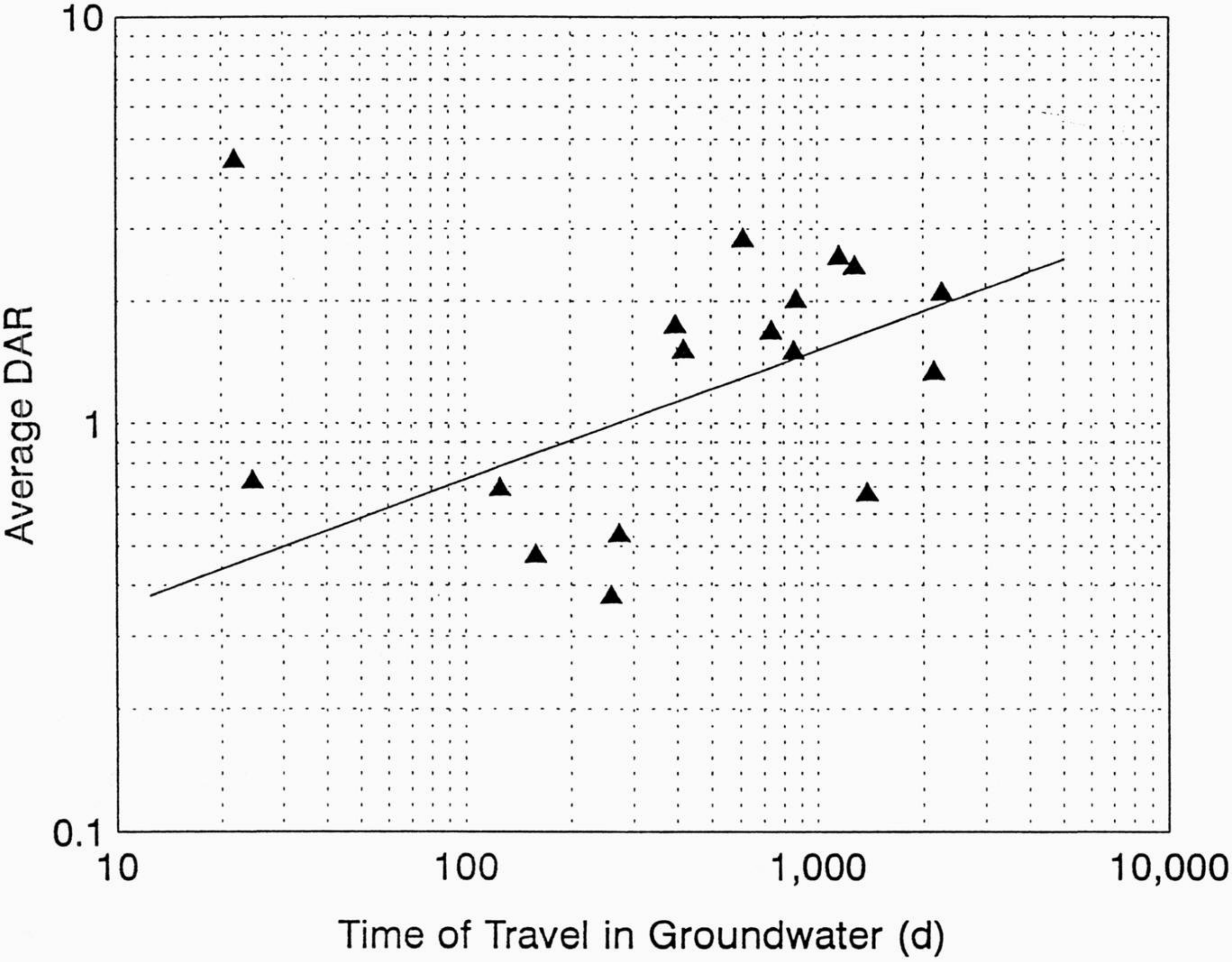


Figure 26. Relationship between the ratio of desethylated atrazine to atrazine concentrations (DAR) and times of travel in groundwater at selected wells.

The regression models indicate that atrazine and metabolite concentrations decrease with time in the aquifer while no other metabolites were detected indicating that dilution due to dispersion is the major dissipation pathway. There appears to be some conversion from parent to desethylated atrazine occurring in the aquifer as indicated by the relationship between the DAR and the TOT, however, the low R^2 values of this regression model indicate that the relative amounts of the compounds are more fully explained by factors not accounted for by these regression models. Depth to groundwater was not a significant factor in determining either the absolute or relative concentrations of atrazine or desethylated atrazine.

B. Tritium Sampling and Analysis

To some extent, travel-time estimates can be verified with measurement of tritium (^3H) concentrations in groundwater. ^3H is a radioactive isotope of hydrogen that is naturally present at low levels in the earth's atmosphere. Atmospheric nuclear weapons testing dramatically increased the ^3H levels from 1952 through the mid-1960s. The amount of ^3H in groundwater or soil water is related to the year of precipitation of the water in question, and relative amounts can give clues to the relative ages of groundwater samples (Bradbury, 1991). ^3H has a half-life of 12.3 yr, making it a good indicator of recent groundwater recharge (Bradbury, 1991). Tritium amounts are given in tritium units (TU), a ratio of the number of ^3H:^1H atoms. One TU equals one ^3H atom/10^{18} ^1H atoms. Matching ^3H levels in groundwater to a curve of atmospheric ^3H concentrations, corrected for radioactive decay, provides an estimate of groundwater age, though most ^3H levels can correspond to more than one age and must be interpreted cautiously. Very low levels of ^3H (<2.0 TU) are found in water from precipitation before the mid-1950s, i.e., before atmospheric testing of atomic weapons. ^3H levels <0.2 TU indicate water from precipitation $>$ 50 yr ago in which substantial radioactive decay has occurred. ^3H levels rose steeply to a peak around 1963 to 1964 and have declined since. Levels $>$ 100 TU indicate the water recharged somewhere between 1960 and 1965. Levels between 10 and 100 TU indicate an average groundwater age of < 35 yr. Samples for ^3H analysis were taken from 10 wells at five well sites of the study area and were analyzed at the University of Waterloo, Canada. Analytical data and interpretations are shown in Table 28. All wells sampled contained water of 17 to 54 TU indicating minimum ages of 8.5 to 20 yr. The interpreted ages at well nest K6 are obtained by accepting the minimum age at K6.A and making sure that K6.B and K6.C have older ages that still correspond to the amount of ^3H present. At K3, water sampled may not come from the depth of the sampling port, making interpretation impossible, however, it is still significant that nowhere in K3 was water sampled that was younger than 9 yr. Water from K11.C is probably older than water from the other wells sampled. If the interpreted ages are correct, the Darcy TOT estimates at K6, PK1, and probably K3 are low and the discrepancy may indicate that a K_h/K_v ratio larger than 5 is warranted. Maximum ZOCs shown in Table 27 are underestimated by the same factor as the TOT-values. TOT and ^3H age estimates are closer at K11, however, less is known there about the the hydraulic conductivity between the water table and the deep well than at K6. The discrepancies may be due in part to the fact that TOT estimates do not take into account travel time through the unsaturated zone. The ^3H amounts indicate that even the relatively high atrazine and desethylated atrazine residue concentrations at K6, K3.1, and PK1 resulted from pesticide applications and handling more occurring from 8 to 14 yr ago and probably that minimal atrazine degradation is occurring over much of that time. Desethylated atrazine residue detections at K11.C indicate that the degradation pathway from parent, to desethylated atrazine, to a non-triazine can take > 20 yr. Probably, the desethylated atrazine concentrations at K11.C indicate that compounds persistence in the saturated zone. Tritium concentrations presented represent an average of the water collected at a given well; it is reasonable to assume that water of younger and older age is present in the well.

Table 28. Results and interpretations of tritium analyses.

Well	Sampling Date	Depth below water table (ft)	Tritium amount (TU)	Minimum age (yr)	Interpreted age (yr)	Darcy TOT[1] estimate (yr)
K3.1	9/12/90	3.12	29.4 ± 2.2	10.0	-	0.62
K3.4	9/12/90	14.1	34.9 ± 2.5	10.5	-	1.8
K3-Main	9/12/90	30.6	28.3 ± 2.2	8.5	-	11.8
K6.A	9/12/90	6.05	17.3 ± 1.5	8.5	8.5	1.7
K6.B	9/12/90	19.0	36.0 ± 2.6	10.5	10.5	2.2
K6.C	9/12/90	3.12	32.6 ± 2.3	10.5	13.5	3.7
K11.C	4/15/91	37.8	53.6 ± 3.6	20.0	20.0	29.3
K16.C	4/15/91	24.4	33.1 ± 2.3	10.5	10.5	-
K16.D	4/15/91	2.51	20.3 ± 1.5	9.0	9.0	-
PK1	4/15/91	10 to 33	24.3 ± 1.8	10.0	10.0	1.9 to 3.5

[1] TOT is the time of travel estimate made assuming that $K_h/K_v=5$.

X. SUMMARY AND CONCLUSIONS

Atrazine contamination was originally discovered in water from private well PK1 as part of the WDATCP Grade A Dairy Farm Well Water Quality Survey. The Waunakee field study was initiated in the area around that well to investigate the sources and extent of atrazine contamination and contamination from atrazine metabolites in the shallow glacial till aquifer. Residues of atrazine were detected at some depth at 19 of the 25 locations monitored with single or nested piezometers. Atrazine residues were also detected at five of the six private wells in the immediate area. Of all the atrazine metabolites determined, only desethylated atrazine was detected in quantifiable amounts. Other metabolites are either sorbed more strongly by soil particles or are not the products of major atrazine degradation pathways in these media. Desethylated atrazine groundwater contamination was as widespread as that of atrazine, also occurring at 19 of the 25 locations monitored (all depths included) and at 4 of the 6 private wells sampled. At 36 of the 56 individual monitoring piezometers and multilevel sampling ports, average concentrations of desethylated atrazine exceeded those of the parent compound (average DAR > 1). The average DAR was < 1 at 10 of the 56 wells and ports, and neither compound was ever detected at concentrations > the limit of detection at 10 of the 56 wells and ports. These numbers include all the sampling ports at K3 and K4 (all with DARs > 1) when really, the independence of the samples from those ports is questionable. Treating the multilevel samplers as one well means that of the 42 wells sampled, 22, 10, and 10 had DARs > 1, < 1, or no DAR, respectively. In any case, desethylated atrazine was the dominant contaminant.

Much of the field area is dominated by downward vertical hydraulic gradients. Where such gradients exist, it is possible to predict the TOT- and ZOC-values to various monitoring wells. Such predictions indicate that the ZOC-values to many of the wells are very small (although the 3H data indicate they are probably bigger than shown in Table 27), and the atrazine concentrations measured at those wells are the result of pesticide applications and handling in the near vicinity. TOT predictions and ^{3}H analyses indicate that water at many contaminated wells may be a decade or more old and that little atrazine and metabolite degradation is occurring in the aquifer. Concentrations of atrazine and desethylated atrazine decrease with time spent in the aquifer. The DAR-values are increasing with time, although the relationship is weak, indicating that some atrazine is being degraded to desethylated atrazine in groundwater, but dilution through dispersion is probably the dominant cause of atrazine (and metabolite) dissipation.

Although atrazine and desethylated atrazine residues are widely spread through much of the study area, they are highest at K6, near PK1. The high atrazine and metabolite concentrations and low DAR-values relative to most of the other wells may indicate a point versus nonpoint source contamination. If the contamination is the result of some spill or mishandling, water ages from ^{3}H analysis at K6 would indicate that the event happened at least 8 yr ago. The anion and cation concentrations at K6.B and K6.C indicate that the septic field near K6 could be responsible for high concentrations if additional leachate from the septic field moved residues out of the unsaturated zones where substantial degradation would have otherwise occurred. Whatever is responsible for the high concentrations at K6 is probably also responsible for the contamination at PK1, the well which led to the choice of this study site. PK1 is shallower than other private wells in the area and may be finished in the till, not the bedrock aquifer, probably accounting for its relatively high atrazine and desethylated atrazine concentrations.

Although some evidence of point-source pollution exists, most groundwater residues probably result from normal field applications; total concentrations are generally < 1.0 ppb, with DAR-values generally > 1. Contamination distribution reflects different pesticide application practices by the three farmers in the study area. At some water-table wells with shallow depths to groundwater, evidence exists of pesticide front arrivals from 3 to 7 months after pesticide application (or possibly 15 to 19 months after the previous year's application). Future analyses of the soil samples collected during 1990 and 1991 should provide much more information regarding atrazine and metabolite residue transport through the unsaturated zone, as well as the fate of other atrazine metabolites.

Monitoring has only occurred over a 2-yr period, but thus far, PAL violations do not predict future ES violations. Of the 61 monitoring and private wells sampled throughout the study period, 13 (including four multi-levels from K3) showed average atrazine concentrations in excess of the current PAL of 0.35 ppb while none had average concentrations in excess of the current ES of 3.5 ppb; 26 wells (including nine of the multi-levels of K3 and K4) had PAL violations at one or more sampling dates. K6.A was the only well with ES violations which occurred during the April and May 1990 samplings. Should the proposed 3.0 and 0.3 ppb ES and PAL for total atrazine and metabolite concentrations be accepted by the legislature, the number of violations would increase dramatically. Forty of the wells (16 from multi-level samplers K3 and K4) had average total concentrations in excess of the proposed PAL and 3 had average total concentrations greater than the proposed ES (including K3.1); 46 (16 from multi-level samplers K3 and K4) and seven wells (four from multi-level sampler K3) violated the proposed PAL and ES on one or more sampling dates. During the two samplings of private bedrock wells, there was one violation of the current PAL and no violations of the ES, while there were four and zero violations of the proposed standards. If the wells in this area are at all indicative of other areas in Wisconsin, the change in atrazine standards will lead to a greatly increased number of violations. Regulatory agencies should be prepared to take appropriate action. It should be kept in mind, however, given the age of the water and residues at some monitoring wells, that it may be many years before the effect of reduced application rates or atrazine bans will be noticeable. The efficacy of atrazine-use restrictions cannot be measured in the first few years after policy implementation at sites such as the one studied here.

A more complete analysis will be conducted in the next several months through continued field work and computer modeling of the groundwater flow system. Field work will include further collection of water and soil samples, soil analyses, investigation of bedrock depth and measurements of groundwater discharge rates to Sixmile Creek. While the soil sampling and analysis will give insight into atrazine's fate in the unsaturated zone, the other field efforts in combination with computer modeling should increase our understanding of the relationship between the shallow and bedrock groundwater flow systems. Together, the research efforts should provide a more complete picture of atrazine residue fate and transport from the ground surface to the bedrock aquifer.

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APPENDIX A -- WATER CHEMISTRY RESULTS

Table A1. Water chemistry during October 1989.

	(ppm)														
Well	P	K	Ca	Mg	S	Zn	B	Mn	Fe	Cu	Al	Na	Cl	NH_4-N	NO_3-N
K3.1	<0.217	<0.621	102.5	64.54	12.83	<0.010	0.044	0.040	0.012	<0.025	<0.352	3.945	43.5	2.5	2.5
K3.2	<0.217	<0.621	125.8	65.37	13.05	<0.010	0.044	0.020	<0.011	<0.025	<0.352	6.304	43.5	1.5	2.5
K3.3	<0.217	<0.621	124.4	64.10	12.76	<0.010	0.039	0.024	0.011	<0.025	<0.352	8.266	43.5	<0.5	2.5
K3.4	<0.217	<0.621	122.1	60.25	13.35	<0.010	0.034	0.015	<0.011	<0.025	<0.352	3.365	39.5	0.5	3.5
K3.5	<0.217	3.959	100.2	53.47	11.83	<0.010	<0.029	0.013	0.018	<0.025	<0.352	3.277	34.0	2.0	6.5
K3.6	<0.217	<0.621	110.3	52.17	11.53	<0.010	<0.029	0.010	0.013	<0.025	<0.352	3.328	33.0	1.0	9.0
K3.7	<0.217	<0.621	102.3	52.29	11.37	<0.010	<0.029	0.011	0.016	<0.025	<0.352	3.387	33.5	0.5	9.0
K4.5	<0.217	0.650	63.53	39.21	6.104	<0.010	<0.029	0.010	0.019	<0.025	<0.352	<0.611	10.5	1.5	6.5
K4.7	<0.217	0.798	55.04	34.50	2.213	<0.010	<0.029	0.008	0.048	<0.025	<0.352	3.645	3.0	2.5	4.5
PK1	<0.217	10.76	179.7	78.00	22.14	<0.010	0.042	0.012	0.013	<0.025	<0.352	21.17	107.0	1.0	28.5

Table A2. Water chemistry during December 1989.

	(ppm)														
Well	P	K	Ca	Mg	S	Zn	B	Mn	Fe	Cu	Al	Na	Cl	NH_4-N	NO_3-N
K1-Main	<0.217	12.97	86.37	88.50	17.08	<0.010	0.174	0.210	0.013	0.028	<0.352	48.47	161.0	1.0	5.5
K2-Main	<0.217	14.98	83.70	89.99	19.55	<0.010	0.206	0.223	0.014	0.031	<0.352	47.40	230.5	0.5	5.0
K3.1	<0.217	<0.621	78.16	64.22	12.47	<0.010	0.039	0.012	<0.011	<0.025	<0.352	4.798	44.5	<0.5	2.0
K3.2	<0.217	<0.621	44.25	63.26	12.06	<0.010	0.037	0.008	<0.011	<0.025	<0.352	4.884	43.5	1.5	1.5
K3.3	<0.217	<0.621	128.30	64.11	12.53	<0.010	0.040	0.014	0.011	<0.025	<0.352	4.710	44.0	0.5	2.0
K3.4	<0.217	<0.621	36.50	58.85	12.65	<0.010	0.030	0.008	<0.011	<0.025	<0.352	5.075	40.5	1.0	2.5
K3.5	<0.217	<0.621	103.70	52.11	11.34	<0.010	<0.029	0.007	<0.011	<0.025	<0.352	4.572	32.5	0.5	7.5
K3.6	<0.217	3.690	37.33	49.57	10.56	<0.010	<0.029	0.012	0.013	<0.025	<0.352	4.647	32.0	1.0	7.5
K3.7	<0.217	<0.621	71.69	50.35	10.88	<0.010	<0.029	0.014	0.039	<0.025	<0.352	4.271	33.0	0.5	7.5
K3-Main	<0.217	1.348	112.7	54.67	12.03	<0.010	0.033	0.009	<0.011	0.025	<0.352	5.828	38.5	1.5	8.0
K4.1	<0.217	0.897	57.25	43.44	10.01	<0.010	<0.029	0.024	0.165	<0.025	<0.352	2.005	31.0	1.0	7.0
K4.2	<0.217	<0.621	101.1	48.65	31.47	<0.010	<0.029	0.021	<0.011	<0.025	<0.352	2.264	34.5	1.0	8.5
K4.3	<0.217	<0.621	64.73	49.01	11.09	<0.010	<0.029	0.018	<0.011	<0.025	<0.352	2.266	35.0	0.5	8.0
K4.4	<0.217	<0.621	99.46	50.65	11.60	<0.010	<0.029	0.014	<0.011	<0.025	<0.352	2.408	35.0	<0.5	8.5
K4.5	<0.217	<0.621	96.34	50.40	11.45	<0.010	<0.029	0.012	0.015	<0.025	<0.352	2.534	35.0	0.5	7.5
K4.6	<0.217	<0.621	84.57	49.96	11.35	<0.010	<0.029	0.011	<0.011	<0.025	<0.352	2.475	35.5	<0.5	7.5
K4.7	<0.217	0.724	75.02	47.85	10.30	<0.010	<0.029	0.010	<0.011	<0.025	<0.352	1.958	30.0	1.0	7.5
K4-Main	<0.217	3.113	56.81	41.12	5.328	<0.010	0.034	0.009	<0.011	<0.025	<0.352	1.080	14.5	0.5	5.0

Table A3. Water chemistry during late January and mid-February 1990.

Well	P	K	Ca	Mg	S	Zn	B	Mn	Fe	Cu	Al	Na	Cl	NH_4-N	NO_3-N	Alkalinity (mg/L)
	(ppm)															
	P	K	Ca	Mg	S	Zn	B	Mn	Fe	Cu	Al	Na	Cl	NH_4-N	NO_3-N	$CaCO_3$
K1-Main	<0.217	14.33	72.34	80.68	16.63	<0.010	0.083	0.085	<0.011	<0.025	<0.352	14.06	78.0	1.0	25.5	267
K2.B	<0.217	8.750	82.69	81.99	13.86	<0.010	0.107	0.038	<0.011	<0.025	<0.352	33.29	-	-	-	-
K3.1	<0.217	<0.621	108.8	62.39	11.08	<0.010	<0.029	<0.003	<0.011	<0.025	<0.352	8.899	45.5	<0.5	1.0	310
K3.2	<0.217	0.774	107.2	61.46	10.77	<0.010	<0.029	<0.003	0.012	<0.025	<0.352	8.897	46.5	<0.5	0.0	210
K3.3	<0.217	0.913	103.0	59.05	10.48	<0.010	<0.029	<0.003	<0.011	<0.025	<0.352	8.582	43.0	<0.5	1.0	342
K3.4	<0.217	0.973	95.08	52.97	10.42	<0.010	<0.029	<0.003	0.014	<0.025	<0.352	8.744	36.0	<0.5	4.5	296
K3.5	<0.217	1.045	90.04	47.33	9.335	<0.010	<0.029	<0.003	0.077	<0.025	<0.352	9.090	31.0	<0.5	6.0	246
K3.6	<0.217	1.005	91.20	48.04	9.426	<0.010	<0.029	<0.003	0.020	<0.025	<0.352	9.113	31.5	<0.5	6.5	257
K3.7	<0.217	1.232	89.72	47.55	9.525	<0.010	<0.029	0.007	0.312	<0.025	<0.352	9.675	31.0	<0.5	5.5	175
K3-Main	<0.217	1.260	90.46	47.39	9.318	<0.010	<0.029	0.003	0.219	<0.025	<0.352	9.049	31.0	<0.5	5.5	274
K4.1	<0.217	1.992	87.89	49.06	11.38	<0.010	<0.029	0.021	0.140	<0.025	<0.352	7.753	-	<0.5	5.0	-
K4.2	<0.217	1.246	92.18	50.59	11.64	<0.010	<0.029	0.004	0.071	<0.025	<0.352	5.908	60.0	<0.5	6.0	-
K4.3	<0.217	1.197	91.12	49.90	11.55	<0.010	<0.029	<0.003	0.041	<0.025	<0.352	5.830	56.0	<0.5	6.0	-
K4.4	<0.217	1.175	91.31	49.82	11.50	<0.010	<0.029	<0.003	0.027	<0.025	<0.352	5.863	55.0	<0.5	6.0	-
K4.5	<0.217	1.143	90.78	49.27	11.17	<0.010	<0.029	0.003	0.087	<0.025	<0.352	6.000	50.0	<0.5	6.5	-
K4.6	<0.217	1.140	91.19	49.70	11.32	<0.010	<0.029	0.003	0.032	<0.025	<0.352	5.950	52.5	<0.5	5.0	-
K4.7	<0.217	1.230	87.73	47.58	10.53	<0.010	<0.029	0.005	0.067	<0.025	<0.352	5.630	51.0	<0.5	5.5	-
K4-Main	<0.217	1.739	88.22	47.99	10.54	<0.010	<0.029	0.007	0.900	<0.025	0.521	5.638	47.5	<0.5	5.5	-

Table A4. Water chemistry during sampling week of March 20, 1990.

Well	(ppm)													
	P	K	Ca	Mg	S	Zn	B	Mn	Fe	Cu	Al	Na	Cl	NO3-N
K1-Main	0.380	15.08	77.36	80.34	15.59	<0.010	0.045	0.148	<0.011	<0.025	<0.352	17.28	64.0	28.5
K2-Main	2.047	18.61	88.36	82.12	14.20	<0.010	0.101	0.169	<0.011	0.043	<0.352	45.27	116	1.5
K3.1	<0.217	<0.621	110.1	63.28	11.78	<0.010	<0.029	0.013	<0.011	<0.025	<0.352	9.888	45.0	<0.5
K3.2	<0.217	<0.621	108.2	62.55	11.48	<0.010	<0.029	0.012	0.012	<0.025	<0.352	9.918	43.0	1.0
K3.3	<0.217	<0.621	102.1	59.21	11.00	<0.010	<0.029	<0.003	<0.011	<0.025	<0.352	9.315	42.0	1.5
K3.4	<0.217	<0.621	99.82	56.62	12.49	<0.010	<0.029	<0.003	<0.011	<0.025	<0.352	9.009	39.0	1.5
K3.5	<0.217	<0.621	92.00	49.57	10.49	<0.010	<0.029	<0.003	0.023	<0.025	<0.352	10.08	32.5	4.0
K3.6	<0.217	<0.621	90.93	48.42	10.13	<0.010	<0.029	<0.003	0.012	<0.025	<0.352	10.04	32.0	4.5
K3.7	<0.217	<0.621	92.11	49.44	10.46	<0.010	<0.029	<0.003	0.018	<0.025	<0.352	9.946	33.0	5.0
K3-Main	<0.217	0.863	92.42	48.52	10.05	<0.010	<0.029	0.003	0.021	<0.025	<0.352	10.25	31.5	5.5
K4.1	<0.217	2.443	76.77	51.05	16.21	<0.010	<0.029	0.026	<0.011	<0.025	<0.352	24.26	44.5	3.5
K4.2	<0.217	0.969	88.69	49.65	10.95	<0.010	<0.029	<0.003	<0.011	<0.025	<0.352	7.084	44.5	2.0
K4.3	<0.217	0.937	88.82	49.77	11.14	<0.010	<0.029	<0.003	0.028	<0.025	<0.352	7.362	46.5	3.5
K4.4	<0.217	0.978	89.18	49.70	14.14	<0.010	<0.029	<0.003	<0.011	<0.025	<0.352	7.259	46.5	3.5
K4.5	<0.217	0.977	88.45	49.32	11.09	<0.010	<0.029	<0.003	<0.011	<0.025	<0.352	7.399	45.5	4.0
K4.6	<0.217	0.970	88.72	49.41	11.17	<0.010	<0.029	0.003	0.044	<0.025	<0.352	6.971	46.5	4.0
K4.7	<0.217	1.018	88.27	49.30	11.18	<0.010	<0.029	0.004	0.051	<0.025	<0.352	7.271	46.5	4.0
K4-Main	<0.217	1.346	88.64	49.54	11.15	<0.010	<0.029	0.013	0.042	<0.025	<0.352	7.714	45.5	3.0
PK1	<0.217	8.193	137.1	68.90	18.13	0.019	<0.029	0.009	<0.011	<0.025	<0.352	22.54	85.0	18.5
PK1 softened	<0.217	0.839	0.432	0.217	17.69	<0.010	<0.029	<0.003	<0.011	<0.025	<0.352	328.5	87.0	21.0
Drainage pit	0.885	22.14	67.73	36.85	12.10	0.010	0.059	0.156	1.168	0.031	2.066	10.46	78.0	17.0

Table A5. Water chemistry during sampling week of April 29, 1990.

	(ppm)															Alkalinity (mg/L)
Well	P	K	Ca	Mg	S	Zn	B	Mn	Fe	Cu	Al	Na	Cl	NH_4-N	NO_3-N	$CaCO_3$
K1-Main	<0.217	9.684	98.85	77.01	15.88	0.189	<0.029	0.138	<0.011	<0.025	<0.352	14.85	59.0	<0.5	10.4	290
K2-Main	0.448	13.39	91.35	83.89	14.64	0.015	0.099	3.610	<0.011	<0.025	<0.352	45.82	115.5	<0.5	1.6	330
K3.1	<0.217	1.499	115.5	64.45	11.98	<0.010	<0.029	0.014	<0.011	<0.025	<0.352	9.235	42.0	<0.5	1.0	365
K3.2	<0.217	<0.621	113.8	64.33	12.07	<0.010	<0.029	0.012	<0.011	<0.025	<0.352	12.49	41.5	<0.5	1.2	380
K3.3	<0.217	<0.621	11.00	63.01	43.02	<0.010	<0.029	0.010	<0.011	<0.025	<0.352	9.196	42.0	<0.5	1.4	390
K3.4	<0.217	<0.621	106.9	59.31	12.44	<0.010	<0.029	0.009	<0.011	<0.025	<0.352	8.671	38.5	<0.5	1.8	380
K3.5	<0.217	1.682	96.44	50.46	10.53	<0.010	<0.029	0.010	<0.011	<0.025	<0.352	9.603	31.5	<0.5	5.7	290
K3.6	<0.217	0.811	96.78	50.33	10.49	<0.010	<0.029	0.012	<0.011	<0.025	<0.352	9.568	31.5	<0.5	5.9	290
K3.7	<0.217	0.807	99.18	51.94	10.96	<0.010	<0.029	0.010	<0.011	<0.025	<0.352	9.740	32.5	<0.5	4.9	320
K3-Main	<0.217	1.108	96.19	49.90	10.42	<0.010	<0.029	0.021	<0.011	<0.025	<0.352	9.729	31.5	<0.5	6.4	320
K4.1	<0.217	2.104	91.20	52.56	13.09	<0.010	<0.029	0.030	<0.011	<0.025	<0.352	11.67	47.0	<0.5	4.2	280
K4.2	<0.217	1.110	98.63	53.42	12.87	<0.010	<0.029	0.031	<0.011	<0.025	<0.352	6.650	52.0	<0.5	7.1	270
K4.3	<0.217	1.243	97.81	52.76	12.91	<0.010	<0.029	0.021	<0.011	<0.025	<0.352	6.740	57.0	<0.5	5.8	270
K4.4	<0.217	1.038	97.54	52.56	12.87	<0.010	<0.029	0.012	<0.011	<0.025	<0.352	6.488	54.5	<0.5	6.1	280
K4.5	<0.217	1.045	96.37	51.66	12.14	<0.010	<0.029	0.019	<0.011	<0.025	<0.352	6.787	47.0	<0.5	6.2	290
K4.6	<0.217	1.032	97.53	52.58	12.84	<0.010	<0.029	0.009	<0.011	<0.025	<0.352	6.546	55.0	<0.5	6.3	280
K4.7	<0.217	1.017	98.40	52.93	12.89	<0.010	<0.029	0.009	<0.011	<0.025	<0.352	6.463	55.5	<0.5	6.0	300
K4-Main	<0.217	1.312	95.35	52.12	12.76	<0.010	<0.029	0.164	<0.011	<0.025	<0.352	6.889	53.5	<0.5	6.5	270
K5.A	<0.217	0.933	80.72	39.17	2.679	0.015	<0.029	0.042	<0.011	<0.025	<0.352	6.298	10.5	0.5	<0.5	280
K6.A	<0.217	2.940	170.9	88.29	15.16	0.101	0.053	0.383	<0.011	<0.025	<0.352	169.0	342.0	0.6	17.4	435
K7.A	<0.217	11.45	73.13	36.57	30.58	<0.010	<0.029	0.062	<0.011	<0.025	<0.352	8.856	39.5	<0.5	5.7	180
K8	<0.217	2.404	70.16	45.19	9.698	<0.010	<0.029	0.194	<0.011	<0.025	<0.352	6.176	17.0	<0.5	3.4	270
K9	<0.217	73.06	21.08	61.78	10.43	0.049	0.063	0.218	<0.011	<0.025	<0.352	15.13	47.0	1.4	0.6	285
K10	<0.217	6.216	57.33	50.57	32.09	0.212	<0.029	0.122	<0.011	<0.025	<0.352	10.97	32.5	0.8	3.1	220
K11.A	<0.217	3.443	90.99	44.37	9.578	<0.010	<0.029	0.389	<0.011	<0.025	<0.352	9.252	45.0	<0.5	0.9	270
PK1	<0.217	11.08	156.5	75.54	19.60	<0.010	<0.029	0.036	<0.011	<0.025	0.382	34.59	94.0	<0.5	12.4	365
PK1 softened	<0.217	0.945	0.87	0.344	18.52	<0.010	<0.029	0.023	<0.011	<0.025	<0.352	351.4	98.5	<0.5	17.1	400
Drainage pit	<0.217	2.423	94.56	48.28	19.34	<0.010	<0.029	0.065	<0.011	<0.025	<0.352	6.921	45.5	<0.5	3.5	255

Table A6. Water chemistry during sampling week of May 31, 1990.

Well	(ppm)															Alkalinity (mg/L) $CaCO_3$
	P	K	Ca	Mg	S	Zn	B	Mn	Fe	Cu	Al	Na	Cl	NH4-N	NO_3-N	
K1-Main	<0.217	4.511	124.7	65.30	15.95	0.016	0.267	0.065	0.012	0.042	<0.352	10.440	58.5	<0.5	24.0	278
K1.B	<0.217	9.167	104.4	61.39	15.81	<0.010	0.037	0.178	<0.011	<0.025	<0.352	9.397	45.5	1.0	22.0	286
K2-Main	<0.217	11.10	89.33	83.58	13.87	<0.010	0.109	0.046	0.013	<0.025	<0.352	36.60	99.0	<0.5	5.0	507
K3.1	<0.217	1.193	106.1	65.45	13.13	<0.010	<0.029	0.015	<0.011	<0.025	<0.352	7.258	42.5	<0.5	1.5	378
K3.2	<0.217	<0.621	110.3	64.44	13.24	<0.010	<0.029	0.008	<0.011	<0.025	<0.352	7.304	41.0	<0.5	1.5	457
K3.3	<0.217	<0.621	127.4	65.59	12.88	<0.010	<0.029	0.023	<0.011	<0.025	<0.352	6.991	43.0	<0.5	1.0	368
K3.4	<0.217	<0.621	118.8	60.72	13.16	<0.010	<0.029	0.004	0.015	<0.025	<0.352	6.604	40.0	<0.5	2.0	475
K3.5	<0.217	0.821	109.4	53.61	11.46	<0.010	<0.029	0.003	<0.011	<0.025	<0.352	7.102	34.5	<0.5	5.5	332
K3.6	<0.217	0.825	110.3	53.95	11.46	<0.010	<0.029	0.028	<0.011	<0.025	<0.352	7.172	34.5	<0.5	4.5	357
K3.7	<0.217	0.791	112.3	55.05	11.76	<0.010	<0.029	<0.003	<0.011	<0.025	<0.352	7.096	34.5	0.5	4.5	339
K3-Main	<0.217	1.292	109.4	53.77	11.38	<0.010	<0.029	0.117	0.012	<0.025	<0.352	8.049	36.5	<0.5	5.5	382
K4.1	<0.217	2.207	97.48	51.57	12.58	<0.010	<0.029	<0.003	<0.011	<0.025	<0.352	11.91	37.0	<0.5	2.5	343
K4.2	<0.217	1.137	105.6	53.10	13.30	<0.010	<0.029	<0.003	<0.011	<0.025	<0.352	4.715	48.5	<0.5	4.5	321
K4.3	<0.217	1.120	105.2	52.73	11.80	<0.010	<0.029	<0.003	<0.011	<0.025	<0.352	4.719	19.0	<0.5	4.0	332
K4.4	<0.217	1.188	106.0	53.20	11.74	<0.010	<0.029	<0.003	<0.011	<0.025	<0.352	4.766	19.0	<0.5	4.5	318
K4.5	<0.217	1.165	106.1	53.19	11.91	<0.010	<0.029	<0.003	<0.011	<0.025	<0.352	4.771	19.5	<0.5	4.0	325
K4.6	<0.217	1.099	106.4	53.50	41.86	<0.010	<0.029	<0.003	<0.011	<0.025	<0.352	8.965	19.5	0.5	4.0	303
K4.7	<0.217	1.167	105.7	53.15	12.05	<0.010	<0.029	<0.003	<0.011	<0.025	<0.352	8.324	50.0	<0.5	4.0	321
K4-Main	0.258	1.798	104.3	52.63	12.03	<0.010	<0.029	0.019	0.018	0.030	<0.352	5.819	51.0	<0.5	6.5	286
K5.A	<0.217	1.120	88.59	40.02	2.799	<0.010	<0.029	0.021	0.012	<0.025	<0.352	5.076	16.0	1.0	<0.5	307
K5.B	<0.217	1.021	83.07	39.50	4.303	<0.010	<0.029	0.010	<0.011	<0.025	<0.352	5.229	9.0	<0.5	<0.5	539
K6.A	<0.217	1.579	167.9	87.52	17.00	<0.010	0.092	0.100	0.013	<0.025	<0.352	39.74	144.0	<0.5	18.5	407
K6.B	<0.217	22.76	158.4	128.80	16.84	<0.010	0.128	0.078	0.012	<0.025	<0.352	535.7	1008	1.0	9.5	614
K7.A	<0.217	10.07	85.16	39.96	6.786	<0.010	<0.029	0.026	<0.011	<0.025	<0.352	5.755	39.0	<0.5	11.5	236
K8	<0.217	2.141	74.39	44.00	9.568	<0.010	<0.029	0.151	<0.011	<0.025	<0.352	4.050	10.5	<0.5	1.5	303
K9	<0.217	54.25	17.23	59.02	9.795	<0.010	0.090	0.132	<0.011	<0.025	<0.352	8.916	31.5	<0.5	1.0	289
K10	<0.217	3.257	70.92	41.74	6.355	<0.010	0.037	0.085	<0.011	<0.025	<0.352	4.872	16.0	0.5	3.5	257
K11.A	<0.217	2.729	101.7	47.62	9.193	<0.010	<0.029	0.255	<0.011	<0.025	<0.352	6.505	46.5	<0.5	1.5	314

Table A6. Continued.

Well	(ppm)															Alka-linity (mg/L) $CaCO_3$
	P	K	Ca	Mg	S	Zn	B	Mn	Fe	Cu	Al	Na	Cl	NH4-N	NO_3-N	
PK1	<0.217	1.471	2.740	0.443	17.28	<0.010	<0.029	<0.003	<0.011	<0.025	<0.352	318.2	85.0	<0.5	25.0	382
PK1 softened	<0.217	10.78	153.3	69.50	18.33	<0.010	<0.029	0.030	<0.011	<0.025	<0.352	20.04	85.0	<0.5	23.0	389
Drainage pit	<0.217	1.552	116.6	53.31	18.89	<0.010	<0.029	0.070	<0.011	<0.025	<0.352	5.557	57.0	<0.5	7.5	282
Sixmile Creek	<0.217	5.115	69.76	32.74	2.392	<0.010	<0.029	0.019	0.130	<0.025	<0.352	5.829	18.5	<0.5	1.0	246

Table A7. Water chemistry during sampling week of June 25, 1990.

Well	(ppm)															Alkalinity (mg/L)
	P	K	Ca	Mg	S	Zn	B	Mn	Fe	Cu	Al	Na	Cl	NH4-N	NO_3-N	$CaCO_3$
K1-Main	<0.217	5.067	123.5	68.23	16.82	<0.010	0.149	0.088	0.014	0.044	<0.352	8.288	57.0	1.0	26.5	282
K1.B	<0.217	7.744	106.9	60.62	15.51	<0.010	0.054	0.169	<0.011	<0.025	<0.352	6.099	44.0	1.0	20.5	293
K2-Main	<0.217	10.89	107.2	87.43	15.45	<0.010	0.146	0.347	0.013	0.029	<0.352	48.39	117.0	1.0	7.5	443
K3.1	<0.217	<0.621	132.1	65.89	13.34	<0.010	0.039	0.015	0.016	<0.025	<0.352	4.357	39.5	0.5	1.5	386
K3.2	<0.217	<0.621	130.5	65.17	45.50	<0.010	0.033	0.011	0.013	<0.025	<0.352	8.799	38.5	<0.5	1.5	425
K3.3	<0.217	<0.621	129.5	64.78	13.38	<0.010	0.040	0.010	0.012	<0.025	<0.352	4.697	40.0	<0.5	1.5	428
K3.4	<0.217	<0.621	123.1	61.34	13.58	<0.010	0.034	0.009	0.011	<0.025	<0.352	4.254	38.0	<0.5	2.5	411
K3.5	<0.217	<0.621	113.2	53.96	36.88	<0.010	<0.029	0.009	0.012	<0.025	<0.352	4.580	33.0	<0.5	6.5	371
K3.6	<0.217	<0.621	111.9	53.51	11.78	<0.010	<0.029	0.008	0.012	<0.025	<0.352	4.523	32.5	0.5	6.0	354
K3.7	<0.217	<0.621	111.9	53.12	11.77	<0.010	0.031	0.008	0.018	<0.025	<0.352	4.517	33.5	0.5	6.0	350
K3-Main	<0.217	0.860	113.0	53.78	11.82	<0.010	0.031	0.065	0.051	<0.025	<0.352	7.160	33.5	<0.5	7.5	350
K4.1	<0.217	5.546	103.0	51.06	14.43	<0.010	0.046	0.028	0.020	0.025	<0.352	12.41	37.0	<0.5	2.5	357
K4.2	<0.217	0.746	113.8	55.09	12.71	<0.010	0.034	0.009	0.021	<0.025	<0.352	3.295	54.0	<0.5	5.0	318
K4.3	<0.217	0.804	112.1	54.27	12.79	<0.010	0.036	0.009	0.012	<0.025	<0.352	2.018	56.0	<0.5	6.0	307
K4.4	<0.217	0.770	116.3	55.59	13.26	<0.010	0.035	0.010	0.018	<0.025	<0.352	2.153	56.5			318
K4.5	<0.217	0.708	115.6	56.05	13.40	<0.010	0.037	0.009	0.012	<0.025	<0.352	2.111	57.5		6.5	307
K4.6	<0.217	0.772	117.3	56.70	13.58	<0.010	0.039	0.009	0.013	<0.025	<0.352	2.156	57.5	<0.5		300
K4.7	<0.217	0.752	115.2	55.93	13.40	<0.010	0.036	0.008	0.015	<0.025	<0.352	1.995	57.5	<0.5	5.0	293
K4-Main	<0.217	0.732	115.6	55.99	13.44	<0.010	0.033	0.010	0.022	<0.025	<0.352	2.136	57.5	<0.5	6.0	325
K5.A	<0.217	1.985	88.94	39.14	2.677	<0.010	<0.029	0.045	<0.011	<0.025	<0.352	1.360	10.0	-	-	321
K5.B	<0.217	0.678	87.12	39.46	4.324	<0.010	<0.029	0.021	<0.011	<0.025	<0.352	1.314	7.0	<0.5	<0.5	304
K6.A	<0.217	0.736	200.0	88.63	18.50	<0.010	0.107	0.202	0.015	<0.025	<0.352	43.32	150.5	<0.5	20.0	478
K6.B	<0.217	5.941	192.1	98.76	20.56	<0.010	0.083	0.238	0.048	<0.025	<0.352	610.2	893.5	1.0	12.5	564
K6.C	<0.217	15.53	105.6	78.51	26.74	<0.010	0.081	0.300	0.017	<0.025	<0.352	221.1	408.5	4.0	4.5	364
K7.A	<0.217	8.240	80.22	22.13	6.177	<0.010	0.034	0.076	0.012	<0.025	<0.352	2.317	45.5	1.0	17.0	121
K8	<0.217	1.706	78.46	44.77	10.18	<0.010	0.038	0.212	0.029	<0.025	<0.352	1.042	9.0	1.0	5.5	271
K9	<0.217	36.83	31.30	62.05	8.823	<0.010	0.084	0.211	0.012	<0.025	<0.352	4.244	23.0	1.0	2.0	321
K10	<0.217	1.597	80.43	38.24	6.449	<0.010	0.047	0.065	0.012	0.027	<0.352	0.997	11.0	0.5	4.5	268
K11.A	<0.217	2.090	104.9	49.31	9.104	<0.010	0.042	0.203	0.014	<0.025	<0.352	3.365	47.5	1.0	2.0	321

Table A7. Continued.

	(ppm)															Alkalinity (mg/L)
Well	P	K	Ca	Mg	S	Zn	B	Mn	Fe	Cu	Al	Na	Cl	NH4-N	NO_3-N	$CaCO_3$
PK1	<0.217	8.689	164.3	72.13	18.84	<0.010	0.042	0.069	<0.011	<0.025	<0.352	18.16	86.5	0.5	22.5	364
PK1 softened	<0.217	0.725	1.218	0.346	37.57	<0.010	0.033	0.007	<0.011	<0.025	<0.352	341.8	88.0	0.5	23.5	400
Drainage pit	<0.217	1.431	124.8	54.56	21.73	<0.010	0.031	0.063	0.019	<0.025	<0.352	3.220	62.5	0.5	14.0	271
Sixmile Creek	0.231	2.778	75.82	33.31	1.714	<0.010	0.033	0.045	0.187	<0.025	<0.352	1.929	14.0	0.5	1.0	261

Table A8. Water chemistry during sampling week of July 25, 1990.

	(ppm)															Alkalinity (mg/L)
Well	P	K	Ca	Mg	S	Zn	B	Mn	Fe	Cu	Al	Na	Cl	NH4-N	NO_3-N	$CaCO_3$
K1-Main	<0.217	5.434	101.0	62.60	16.27	<0.010	<0.029	0.057	<0.011	<0.025	<0.352	14.51	55.0	<0.5	30.5	205
K1.B	<0.217	7.012	94.31	55.47	14.98	<0.010	<0.029	0.126	<0.011	<0.025	<0.352	11.19	44.0	<0.5	19.0	265
K2-Main	<0.217	10.78	88.93	84.29	14.68	<0.010	0.091	0.245	<0.011	<0.025	<0.352	46.92	110.5	0.5	5.0	430
K2.B	<0.217	191.8	309.5	117.5	40.00	0.093	0.104	1.255	<0.011	<0.025	<0.352	77.78	452.5	<0.5	52.5	625
K3.1	<0.217	1.029	106.0	61.15	12.79	<0.010	<0.029	0.011	<0.011	<0.025	<0.352	10.08	38.0	<0.5	1.0	405
K3.2	<0.217	1.033	109.7	60.38	13.97	<0.010	<0.029	<0.003	<0.011	<0.025	<0.352	12.88	37.0	<0.5	1.0	445
K3.3	<0.217	1.012	109.7	60.67	12.89	<0.010	<0.029	<0.003	<0.011	<0.025	<0.352	10.25	38.5	<0.5	1.5	420
K3.4	<0.217	1.142	104.7	57.24	13.11	0.113	<0.029	0.004	<0.011	<0.025	<0.352	10.14	37.5	<0.5	2.0	395
K3.5	<0.217	1.210	96.43	50.83	11.74	<0.010	<0.029	<0.003	<0.011	<0.025	<0.352	10.63	32.0	<0.5	5.0	330
K3.6	<0.217	1.427	101.5	47.14	10.77	<0.010	<0.029	<0.003	<0.011	<0.025	<0.352	9.763	32.0	<0.5	6.5	300
K3.7	<0.217	1.209	94.17	49.41	11.03	<0.010	<0.029	<0.003	<0.011	<0.025	<0.352	10.04	32.0	<0.5	6.5	290
K3-Main	<0.217	1.536	94.35	49.38	11.37	<0.010	<0.029	0.007	<0.011	<0.025	<0.352	10.33	33.0	<0.5	8.0	305
K3.B	<0.217	1.924	113.2	61.03	11.15	<0.010	<0.029	0.013	<0.011	<0.025	<0.352	9.246	31.5	<0.5	1.0	400
K4.1	<0.217	1.861	87.48	52.86	12.98	<0.010	<0.029	0.007	<0.011	<0.025	<0.352	8.783	56.0	0.5	5.5	245
K4.2	<0.217	1.357	98.40	53.05	12.96	<0.010	<0.029	0.003	<0.011	<0.025	<0.352	6.597	60.0	<0.5	6.0	305
K4.3	<0.217	1.426	100.8	54.23	13.82	<0.010	<0.029	<0.003	<0.011	<0.025	<0.352	6.718	64.0	0.5	6.0	305
K4.4	<0.217	1.301	98.08	52.85	13.36	<0.010	<0.029	<0.003	<0.011	<0.025	<0.352	6.562	62.0	<0.5	6.0	305
K4.5	<0.217	1.248	99.74	53.60	13.56	<0.010	<0.029	<0.003	<0.011	<0.025	<0.352	6.608	62.0	<0.5	7.0	295
K4.6	<0.217	1.437	101.2	54.26	13.89	<0.010	<0.029	<0.003	<0.011	<0.025	<0.352	6.892	63.5	<0.5	7.0	285
K4.7	<0.217	1.372	100.3	53.84	13.73	<0.010	<0.029	<0.003	<0.011	<0.025	<0.352	6.720	64.5	<0.5	6.5	270
K4-Main	<0.217	1.773	100.5	53.93	13.82	<0.010	<0.029	<0.003	<0.011	<0.025	<0.352	7.097	63.5	<0.5	7.5	270
K4.B	<0.217	4.008	94.07	55.87	8.086	<0.010	<0.029	0.038	<0.011	<0.025	<0.352	7.578	31.5	<0.5	3.0	345
K5.A	<0.217	0.870	75.64	36.68	2.960	<0.010	<0.029	0.025	<0.011	<0.025	<0.352	6.589	10.5	0.5	0.5	295
K5.B	<0.217	1.085	71.78	34.19	3.231	<0.010	<0.029	0.007	<0.011	<0.025	<0.352	6.722	6.0	<0.5	0.5	270
K5.C	<0.217	0.852	75.30	36.58	2.885	<0.010	<0.029	0.011	<0.011	<0.025	<0.352	6.342	9.5	1.0	0.5	-
K6.A	<0.217	1.542	192.1	90.41	18.86	<0.010	0.046	0.227	<0.011	<0.025	<0.352	65.95	222.0	0.5	24.0	460
K6.B	<0.217	3.152	186.9	94.59	20.83	<0.010	<0.029	0.261	<0.011	<0.025	<0.352	624.5	940.0	<0.5	15.0	590
K6.C	<0.217	9.768	136.1	82.65	22.49	<0.010	<0.029	0.273	<0.011	<0.025	<0.352	313.3	502.5	0.5	16.0	455

Table A8. Continued.

Well	(ppm)															Alkalinity (mg/L)
	P	K	Ca	Mg	S	Zn	B	Mn	Fe	Cu	Al	Na	Cl	NH4-N	NO_3-N	$CaCO_3$
K7.A	<0.217	8.854	74.39	27.42	6.230	<0.010	<0.029	0.017	<0.011	<0.025	<0.352	7.116	44.5	0.5	22.0	145
K8	<0.217	0.836	69.90	37.71	9.742	<0.010	<0.029	0.045	<0.011	<0.025	<0.352	4.018	5.5	<0.5	2.5	250
K9	<0.217	23.04	48.48	57.44	8.060	<0.010	<0.029	0.107	<0.011	<0.025	<0.352	7.808	18.0	<0.5	4.0	330
K10	<0.217	2.992	49.93	22.42	17.08	<0.010	<0.029	0.069	<0.011	<0.025	<0.352	83.52	36.0	0.5	2.5	270
K11.A	<0.217	2.458	84.79	48.24	7.994	<0.010	<0.029	0.008	<0.011	<0.025	<0.352	8.327	47.0	<0.5	1.5	305
PK1	<0.217	9.314	137.3	66.82	17.53	<0.010	<0.029	0.073	<0.011	<0.025	<0.352	28.34	84.5	<0.5	23.0	390
Sixmile Creek	<0.217	2.162	74.46	37.86	3.835	<0.010	<0.029	0.008	<0.011	<0.025	<0.352	8.718	19.5	<0.5	2.0	255

Table A9. Water chemistry during sampling week of August 29, 1990.

	(ppm)															Alkalinity (mg/L) CaCO$_3$
Well	P	K	Ca	Mg	S	Zn	B	Mn	Fe	Cu	Al	Na	Cl	NH4-N	NO$_3$-N	
K1-Main	<0.217	4.195	114.8	62.73	16.06	0.035	<0.029	0.059	<0.011	<0.025	<0.352	11.94	56.5	<0.5	34.0	270
K1.B	<0.217	5.031	93.55	53.41	13.96	<0.010	<0.029	0.169	<0.011	<0.025	<0.352	8.642	-	1.0	16.0	305
K2-Main	<0.217	10.59	81.71	86.87	13.72	<0.010	0.130	0.318	<0.011	<0.025	<0.352	45.36	115.0	<0.5	6.5	470
K2.B	<0.217	194.6	284.0	118.2	34.61	0.083	0.152	1.227	<0.011	<0.025	<0.352	78.29	370.5	0.5	67.0	390
K3.1	<0.217	<0.621	104.8	60.52	11.58	<0.010	<0.029	<0.003	<0.011	<0.025	<0.352	6.812	39.5	<0.5	1.0	380
K3.2	<0.217	<0.621	104.4	60.03	11.91	0.099	<0.029	<0.003	<0.011	<0.025	<0.352	7.798	-	<0.5	1.5	405
K3.3	<0.217	<0.621	105.8	59.85	11.51	<0.010	<0.029	0.006	<0.011	<0.025	<0.352	6.835	40.0	<0.5	1.5	430
K3.4	<0.217	<0.621	100.7	56.62	11.84	<0.010	<0.029	0.100	<0.011	<0.025	<0.352	6.647	37.5	<0.5	2.5	360
K3.5	<0.217	<0.621	89.36	48.77	10.23	0.062	<0.029	0.004	<0.011	<0.025	<0.352	6.917	33.0	<0.5	6.5	335
K3.6	<0.217	<0.621	85.76	46.10	9.510	<0.010	<0.029	<0.003	<0.011	<0.025	<0.352	6.717	31.5	0.5	9.0	310
K3.7	<0.217	<0.621	98.77	48.13	10.16	<0.010	<0.029	0.004	<0.011	<0.025	<0.352	6.863	33.0	0.5	7.0	350
K3-Main	<0.217	<0.621	87.80	48.33	10.05	<0.010	<0.029	0.003	<0.011	<0.025	<0.352	7.423	32.0	1.0	9.0	325
K4.1	<0.217	<0.621	76.79	46.59	10.16	<0.010	<0.029	0.021	<0.011	<0.025	<0.352	5.093	36.0	<0.5	8.0	240
K4.2	<0.217	<0.621	86.20	47.07	10.35	<0.010	<0.029	0.004	<0.011	<0.025	<0.352	4.332	37.5	<0.5	7.5	260
K4.3	<0.217	<0.621	83.09	45.64	9.581	<0.010	<0.029	<0.003	<0.011	<0.025	<0.352	3.427	36.0	0.5	6.5	255
K4.4	<0.217	<0.621	89.07	47.02	10.23	<0.010	<0.029	<0.003	<0.011	<0.025	<0.352	4.163	37.5	1.0	8.5	300
K4.5	<0.217	<0.621	87.16	47.62	10.38	<0.010	<0.029	<0.003	<0.011	<0.025	<0.352	4.438	38.5	0.5	8.0	300
K4.6	<0.217	<0.621	82.23	45.58	9.446	<0.010	<0.029	<0.003	<0.011	<0.025	<0.352	3.455	36.0	<0.5	6.5	280
K4.7	<0.217	<0.621	79.13	43.95	9.084	<0.010	<0.029	<0.003	<0.011	<0.025	<0.352	3.273	34.5	0.5	6.0	270
K4-Main	<0.217	<0.621	81.47	45.37	9.856	<0.010	<0.029	0.003	<0.011	<0.025	<0.352	3.945	41.0	0.5	6.0	290
K5.A	<0.217	<0.621	74.75	37.21	2.586	<0.010	<0.029	0.037	<0.011	<0.025	<0.352	5.447	14.5	0.5	1.0	315
K5.B	<0.217	<0.621	70.60	34.61	2.859	<0.010	<0.029	0.011	<0.011	<0.025	<0.352	4.226	7.5	0.5	1.0	220
K6.A	<0.217	<0.621	177.1	86.61	18.21	<0.010	0.079	0.025	<0.011	<0.025	<0.352	95.99	235.5	<0.5	29.5	480
K6.B	<0.217	1.446	206.5	93.45	19.59	<0.010	0.051	0.144	<0.011	<0.025	<0.352	584.7	799.5	1.0	15.0	660
K6.C	<0.217	7.670	145.9	83.36	20.20	<0.010	0.045	0.441	<0.011	<0.025	<0.352	303.3	409.0	1.5	17.5	480
K6.D	<0.217	11.27	55.64	63.45	12.53	0.015	0.051	0.324	0.613	<0.025	<0.352	24.46	68.5	1.0	13.0	-
K7.A	<0.217	6.830	83.56	28.30	4.772	<0.010	0.053	0.060	0.040	<0.025	<0.352	7.902	36.5	-	15.5	185
K8	<0.217	<0.621	103.2	58.92	9.550	<0.010	0.035	0.362	0.462	<0.025	<0.352	5.613	6.5	0.5	3.0	285
K9	<0.217	14.30	81.17	56.33	7.810	<0.010	<0.029	0.139	<0.011	<0.025	<0.352	4.701	17.5	1.0	6.0	290
K10	<0.217	1.565	58.29	30.79	9.872	<0.010	0.062	0.213	<0.011	0.038	<0.352	43.65	29.5	0.5	3.0	250
K11.A	<0.217	1.362	94.13	51.84	7.261	<0.010	0.076	0.125	0.297	<0.025	<0.352	11.44	49.0	0.5	2.0	-
PK1	<0.217	8.827	136.7	69.44	18.10	0.253	<0.029	0.004	<0.011	<0.025	<0.352	29.60	95.5	-	25.5	420

Table A10. Water chemistry during sampling week of September 26, 1990.

	(ppm)															Alkalinity (mg/L)
Well	P	K	Ca	Mg	S	Zn	B	Mn	Fe	Cu	Al	Na	Cl	NH4-N	NO_3-N	$CaCO_3$
K1-Main	<0.217	4.596	99.20	58.54	15.01	<0.010	<0.029	0.041	0.036	0.028	<0.352	12.74	51.5	-	-	240
K1.B	<0.217	5.786	92.43	51.25	13.29	<0.010	<0.029	0.159	<0.011	<0.025	<0.352	10.49	47.0	0.5	12.5	310
K2-Main	<0.217	12.80	117.0	104.4	18.30	<0.010	0.127	0.396	0.090	<0.025	<0.352	53.33	161.5	1.0	11.5	515
K2.B	<0.217	186.2	276.1	123.0	34.65	<0.010	0.156	1.114	<0.011	<0.025	<0.352	78.48	430.0	0.5	73.5	440
K3.1	<0.217	<0.621	108.6	60.72	11.47	<0.010	0.043	<0.003	<0.011	<0.025	<0.352	8.376	36.0	<0.5	1.0	380
K3.2	<0.217	0.654	109.6	60.32	11.43	<0.010	<0.029	<0.003	<0.011	<0.025	<0.352	8.313	37.5	<0.5	1.5	405
K3.3	<0.217	0.710	110.8	59.64	11.30	<0.010	0.032	0.021	<0.011	0.091	<0.352	7.899	39.0	<0.5	1.5	430
K3.4	<0.217	0.938	100.8	56.34	11.63	<0.010	<0.029	<0.003	<0.011	<0.025	<0.352	7.616	38.0	<0.5	2.5	360
K3.5	<0.217	1.033	91.96	48.98	10.03	<0.010	<0.029	<0.003	<0.011	<0.025	<0.352	8.252	31.0	<0.5	6.5	335
K3.6	<0.217	1.080	88.57	46.76	9.494	<0.010	<0.029	0.004	0.028	<0.025	<0.352	8.248	30.5	0.5	9.0	310
K3.7	<0.217	1.058	91.61	48.32	9.959	<0.010	<0.029	<0.003	<0.011	<0.025	<0.352	8.321	30.5	0.5	7.0	350
K3-Main	<0.217	1.235	89.69	47.28	9.845	0.031	<0.029	<0.003	0.026	<0.025	<0.352	8.355	31.5	1.0	9.0	325
K4.1	<0.217	1.099	87.13	47.12	10.43	<0.010	<0.029	<0.003	<0.011	<0.025	<0.352	5.900	33.0	1.0	9.0	300
K4.1 rep.	<0.217	1.424	87.42	46.49	10.47	<0.010	<0.029	0.005	<0.011	<0.025	<0.352	6.036	33.5	<0.5	8.0	240
K4.2	<0.217	1.182	93.10	47.72	10.58	<0.010	<0.029	<0.003	0.020	<0.025	<0.352	6.214	35.5	<0.5	7.5	260
K4.3	<0.217	1.175	91.05	47.60	10.46	0.014	<0.029	<0.003	<0.011	<0.025	<0.352	5.988	-	0.5	6.5	255
K4.4	<0.217	1.060	90.81	48.19	10.59	<0.010	<0.029	<0.003	<0.011	<0.025	<0.352	6.321	35.0	1.0	8.5	300
K4.5	<0.217	1.250	90.06	47.79	10.56	<0.010	<0.029	<0.003	0.078	<0.025	<0.352	6.237	35.5	0.5	8.0	300
K4.6	<0.217	1.218	86.34	44.71	9.391	<0.010	<0.029	<0.003	0.022	<0.025	<0.352	4.324	31.0	<0.5	6.5	280
K4.7	<0.217	1.152	82.33	44.92	9.473	<0.010	<0.029	<0.003	0.027	<0.025	<0.352	4.186	32.5	0.5	6.0	270
K4-Main	<0.217	2.084	87.54	47.81	10.79	0.060	<0.029	0.013	0.023	0.332	0.529	6.285	43.5	0.5	6.0	290
K5.A	<0.217	0.920	73.82	34.19	2.990	<0.010	<0.029	0.021	0.013	<0.025	<0.352	5.118	7.0	<0.5	0.5	230
K5.B	<0.217	0.893	74.74	35.76	2.445	<0.010	<0.029	0.010	<0.011	<0.025	<0.352	4.527	11.5	1.0	1.1	215
K6.A	<0.217	1.169	180.9	84.46	16.96	0.049	0.076	0.232	0.076	<0.025	<0.352	86.75	202.5	<0.5	31.0	485
K6.B	<0.217	2.962	184.9	94.19	18.59	0.036	0.058	0.189	0.024	<0.025	<0.352	539.7	958.0	0.5	15.5	630
K6.C	<0.217	7.851	139.0	79.29	18.16	<0.010	0.036	0.534	<0.011	<0.025	<0.352	289.1	454.0	1.0	18.5	560
K6.D	<0.217	5.328	103.4	75.12	16.05	<0.010	0.054	0.345	0.033	<0.025	<0.352	17.20	59.5	3.5	19.5	390
K8	<0.217	2.593	79.83	44.37	9.701	<0.010	<0.029	0.210	0.168	<0.025	0.374	5.456	6.5	0.5	3.0	270
K9	<0.217	8.022	80.46	50.39	8.846	<0.010	<0.029	0.066	<0.011	<0.025	<0.352	6.938	13.0	1.0	4.5	375
K10	<0.217	2.821	60.40	31.36	8.266	0.119	0.032	0.101	0.043	<0.025	<0.352	21.01	25.0	1.0	3.0	220
K11.A	<0.217	2.363	84.73	47.09	7.997	2.546	<0.029	0.016	0.260	<0.025	<0.352	7.807	44.0	1.0	3.0	190
K15	<0.217	0.868	83.03	34.24	10.33	<0.010	<0.029	0.276	<0.011	<0.025	<0.352	7.533	27.0	1.0	2.0	235

Table A10. Continued.

Well	(ppm)															Alka-linity (mg/L)
	P	K	Ca	Mg	S	Zn	B	Mn	Fe	Cu	Al	Na	Cl	NH4-N	NO_3-N	$CaCO_3$
E1	<0.217	1.739	63.75	32.78	4.124	0.039	<0.029	0.152	0.020	<0.025	<0.352	34.45	-	-	-	-
E2	<0.217	3.671	175.80	177.8	42.76	0.018	0.045	1.028	<0.011	<0.025	<0.352	50.51	-	-	-	-
E6.A	<0.217	1.880	170.60	93.45	5.736	<0.010	<0.029	0.295	1.382	<0.025	<0.352	14.58	179.0	1.0	0.5	555
PE1	<0.217	1.657	71.41	44.67	14.70	<0.010	<0.029	0.230	0.136	<0.025	<0.352	5.481	17.0	1.0	1.5	280
PE2	<0.217	2.244	108.6	68.54	23.64	0.016	<0.029	0.079	0.013	<0.025	<0.352	17.73	93.5	1.5	7.5	335
PZ1	<0.217	3.304	173.0	60.93	14.51	0.077	<0.029	<0.003	0.032	<0.025	<0.352	20.43	54.5	0.5	24.0	330
PZ2	<0.217	0.938	97.32	52.29	11.65	<0.010	<0.029	<0.003	0.033	<0.025	<0.352	6.869	40.0	2.0	10.0	265
PK1	<0.217	10.81	147.3	72.47	18.95	<0.010	<0.029	<0.003	<0.011	<0.025	<0.352	32.42	94.0	0.5	28.5	400

Table A11. Water chemistry during sampling week of April 16-22, 1991.

Well	P	K	Ca	Mg	S	Zn	B	Mn	Fe	Cu	Al	Na	Cl	NO_3-N
	(ppm)													
K1-Main	<0.217	3.337	110.3	61.82	14.45	0.190	0.033	0.064	0.134	0.225	<0.352	13.88	55.0	30.5
K1.B	<0.217	0.816	106.6	54.48	7.58	0.047	0.041	0.003	0.039	0.081	<0.352	10.07	58.5	6.5
K1.C	<0.217	5.009	102.7	51.48	12.08	0.042	0.056	0.060	0.123	0.095	<0.352	10.76	54.0	17.5
K2-Main	<0.217	7.858	160.0	98.10	14.08	0.291	0.068	0.247	0.052	0.061	<0.352	50.96	126.5	13.0
K2.B	<0.217	275.4	298.5	104.2	31.35	0.055	0.227	0.639	0.350	0.056	<0.352	116.3	472.0	50.0
K3.1	<0.217	<0.621	112.1	62.31	12.32	0.029	<0.029	<0.003	<0.011	<0.025	<0.352	10.61	36.0	2.5
K3.2	<0.217	<0.621	113.5	62.15	13.76	0.054	<0.029	<0.003	0.011	0.065	<0.352	12.67	36.0	1.5
K3.3	<0.217	<0.621	135.9	62.85	13.04	0.046	<0.029	<0.003	<0.011	0.069	<0.352	11.23	37.0	1.5
K3.4	<0.217	<0.621	105.8	58.71	12.49	<0.010	<0.029	<0.003	<0.011	<0.025	<0.352	11.15	36.0	1.5
K3.5	<0.217	<0.621	107.9	52.68	11.41	0.091	<0.029	0.003	0.020	0.033	<0.352	11.99	35.5	5.5
K3.6	<0.217	<0.621	103.9	54.71	12.17	0.047	<0.029	<0.003	0.055	0.049	<0.352	12.97	35.5	5.0
K3.7	<0.217	<0.621	104.2	55.63	12.04	<0.010	<0.029	<0.003	<0.011	<0.025	<0.352	13.40	36.0	5.0
K3-Main	<0.217	<0.621	104.2	52.16	10.83	0.099	<0.029	0.012	0.044	0.033	<0.352	11.74	35.0	7.0
K3.B	<0.217	<0.621	114.0	58.96	13.41	0.269	<0.029	0.007	0.015	0.086	<0.352	9.77	26.5	1.5
K4.1	<0.217	0.969	111.6	61.11	11.63	0.017	<0.029	0.226	<0.011	0.030	<0.352	11.28	71.5	1.5
K4.2	<0.217	0.853	115.6	62.74	11.63	0.021	<0.029	0.195	<0.011	0.027	<0.352	7.33	76.5	3.5
K4.3	<0.217	0.733	111.0	60.89	11.56	<0.010	<0.029	0.196	<0.011	<0.025	<0.352	7.18	74.5	3.0
K4.4	<0.217	0.633	111.0	60.67	10.87	0.018	<0.029	0.151	<0.011	<0.025	<0.352	7.01	76.5	3.0
K4.5	<0.217	0.854	111.2	61.00	11.50	0.041	<0.029	0.173	<0.011	<0.025	<0.352	7.17	74.0	3.0
K4.6	<0.217	0.754	109.5	59.88	11.45	0.020	0.030	0.145	<0.011	0.029	<0.352	7.50	76.5	2.5
K4.7	<0.217	0.704	112.0	61.13	11.14	0.037	<0.029	0.166	<0.011	<0.025	<0.352	7.56	75.5	2.5
K4-Main	<0.217	0.758	112.1	61.44	11.67	0.016	<0.029	0.154	0.049	<0.025	<0.352	7.70	76.0	3.0
K4.B	<0.217	4.238	113.4	42.00	10.55	0.042	0.058	2.283	0.134	0.036	<0.352	16.70	59.5	3.5
K5.A	<0.217	<0.621	84.0	40.04	2.52	0.059	<0.029	0.011	0.071	<0.025	<0.352	6.08	15.0	1.0
K5.B	<0.217	<0.621	98.4	46.05	3.42	0.056	<0.029	0.170	0.533	<0.025	<0.352	6.46	5.5	1.0
K5.C	-	-	-	-	-	-	-	-	-	-	-	-	-	-
K6.A	<0.217	0.665	179.2	82.12	16.06	0.128	0.088	0.010	0.049	<0.025	<0.352	30.25	98.5	34.0
K6.B	<0.217	1.414	196.6	97.52	18.45	0.057	0.062	0.075	0.021	<0.025	<0.352	550.9	941.0	13.0
K6.C	<0.217	2.480	143.1	71.38	19.08	0.037	0.032	0.326	0.048	<0.025	<0.352	220.2	308.5	23.5
K6.D	<0.217	2.495	143.8	62.15	13.14	0.065	0.040	0.031	0.221	0.028	<0.352	16.49	35.5	17.5

Table A11. Continued.

	(ppm)													
Well	P	K	Ca	Mg	S	Zn	B	Mn	Fe	Cu	Al	Na	Cl	NO_3-N
K7.A	0.292	13.00	101.0	24.51	6.73	0.099	<0.029	0.586	0.096	0.072	<0.352	13.98	56.0	25.5
K7.B	<0.217	5.579	65.4	30.98	6.01	0.091	<0.029	0.038	0.114	0.125	<0.352	9.53	41.0	18.5
K8	<0.217	<0.621	81.7	43.50	7.91	0.017	<0.029	0.033	0.115	0.108	<0.352	7.29	6.0	3.0
K9	<0.217	1.458	83.4	44.82	6.33	0.182	<0.029	0.016	0.152	0.095	<0.352	8.81	29.0	5.5
K10	<0.217	1.099	88.3	35.14	13.43	0.080	<0.029	0.061	0.467	0.074	<0.352	22.81	12.0	4.5
K11.B	<0.217	4.184	137.8	50.21	10.39	0.117	<0.029	0.304	0.265	0.058	<0.352	14.07	49.5	5.0
K11.C	<0.217	7.157	69.8	48.48	16.45	0.048	<0.029	0.060	0.067	0.039	<0.352	7.79	38.0	8.5
K12	<0.217	<0.621	86.5	47.76	16.95	0.015	<0.029	0.557	0.065	0.057	<0.352	10.27	68.0	0.5
K14	0.639	22.13	150.0	70.89	19.24	0.254	0.061	2.562	0.832	0.137	0.493	32.13	170.5	4.5
K15	<0.217	0.714	104.1	42.94	20.80	0.053	<0.029	0.165	0.226	0.095	<0.352	12.11	68.0	10.5
K16.A	<0.217	1.314	120.9	55.10	15.98	0.098	<0.029	0.061	0.133	0.133	<0.352	20.77	51.0	12.0
K16.B	<0.217	1.130	90.4	46.98	9.32	0.028	<0.029	0.081	0.055	<0.025	<0.352	8.18	37.0	11.0
K16.C	<0.217	7.620	64.6	42.77	7.76	0.022	<0.029	0.166	0.032	<0.025	<0.352	5.57	25.5	6.0
K16.D	<0.217	<0.621	86.5	36.02	13.70	0.193	<0.029	0.053	0.321	0.039	<0.352	6.75	27.0	1.0
E1	<0.217	1.131	69.7	35.31	4.10	0.023	<0.029	0.004	0.026	<0.025	<0.352	68.18	62.0	1.5
E2	<0.217	1.335	190.4	158.5	26.46	0.040	0.050	0.724	<0.011	<0.025	<0.352	35.09	50.5	25.5
E3	<0.217	<0.621	59.0	30.54	3.97	<0.010	<0.029	0.069	0.086	0.030	<0.352	4.13	6.0	1.5
E6.A	<0.217	2.091	208.5	111.6	14.62	0.060	<0.029	1.311	0.084	0.058	<0.352	15.82	147.5	20.5
E6.B	0.261	1.824	199.6	114.9	5.44	0.083	<0.029	0.077	8.366	<0.025	<0.352	14.32	238.0	0.5
R1	0.403	1.523	108.5	47.26	5.21	0.097	<0.029	0.161	0.092	0.067	<0.352	19.20	63.0	1.5
R2	<0.217	101.9	154.4	72.10	20.66	0.073	0.079	1.048	0.074	0.110	<0.352	27.48	109.5	3.0
PK1	<0.217	8.148	141.2	69.03	15.27	0.166	<0.029	0.016	0.105	<0.025	<0.352	29.80	-	-
PE1	<0.217	1.110	83.8	48.45	14.68	0.230	<0.029	0.311	0.279	<0.025	<0.352	7.04	22.0	<0.5
PE2	<0.217	1.887	126.8	78.94	22.75	0.091	<0.029	0.073	0.049	<0.025	<0.352	27.17	159.0	7.5
PZ1	<0.217	2.519	109.8	58.28	12.41	0.168	<0.029	0.004	0.078	0.030	<0.352	20.02	59.0	24.5
PZ2	<0.217	<0.621	95.8	49.67	10.37	0.067	<0.029	<0.003	0.072	0.069	<0.352	7.59	42.0	9.5
PR1	<0.217	8.711	139.9	72.96	14.64	0.055	0.030	<0.003	0.080	<0.025	<0.352	52.30	144.0	22.5
Surface water near K2	30.67	185.6	42.0	21.44	5.79	0.411	0.124	0.609	1.749	0.040	<0.352	23.25	65.0	39.0

Sources and Extent of Atrazine Contamination of Groundwater at Grade A Dairy Farms in Dane County, Wisconsin

DATE	ISSUED TO