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CONTAMINATION OF THE SANDSTONE AQUIFER OF PRINCE EDWARD ISLAND, CANADA BY ALDICARB AND NITROGEN RESIDUES

by

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ABSTRACT

Prince Edward Island is wholly dependent upon ground water from a highly permeable fractured sandstone aquifer for all industrial, domestic, agricultural and potable uses. The contamination of this aquifer by agricultural residues, principally aldicarb and nitrate, has caused concern among Islanders. Ground water quality has been monitored during 1985-1988 beneath three potato fields to which aldicarb (Temik) had been applied at planting once or twice between 1983 and 1986. In May of 1988, 10% of all the monitoring well samples exceeded the drinking water guideline of 9 µg/L. Furthermore 50% of all samples exceeded the nitrate guideline of 10 mg/L. Aldicarb persistence appears related to its application at planting when soil temperatures are low and recharge is high and to the inhibiting pH effect that ammonium (from fertilizers and soil organic nitrogen) oxidation has on its degradation. It is therefore recommended that aldicarb be applied at plant emergence.

RÉSUMÉ

Pour tous ses besoins en eau potable et en eau destinée aux usages industriel, domestique et agricole, l'Île-du-Prince-Édouard dépend totalement de l'eau souterraine d'un réservoir aquifère de grès facturé hautement perméable. La population s'inquiète donc beaucoup de la contamination de ce réservoir par les produits chimiques utilisés en agriculture, en particulier l'aldicarbe et les nitrates. On a contrôlé, de 1985 à 1988, la qualité de l'eau souterraine en dessous de trois champs de pomme de terre qui avaient, à une ou deux reprises entre 1983 et 1986, été traités à l'aldicarbe (Temik) au moment de la plantation. En mai 1988, 10 % de tous les échantillons des puits de contrôle dépassaient la directive de 9 µg/l pour l'eau potable. Qui plus est, 50 % de tous les échantillons dépassaient la directive de 10 mg/l de nitrates. La persistance de l'aldicarbe semble liée, d'une part, au fait qu'il ait été appliqué à la plantation, alors que la température du sol est basse et l'apport en eau élevé, et, d'autre part, à l'effet de pH inhibiteur qu'a sur sa dégradation l'oxydation de l'ammonium (venant des engrais et de l'azote organique du sol). On recommande donc d'appliquer l'aldicarbe au moment de la levée des plants.

MANAGEMENT PERSPECTIVE

Prince Edward Island is wholly dependent upon ground water for all domestic, agricultural, industrial and potable uses. The "sole source aquifer" is a fractured sandstone of high permeability, which yields ground water of otherwise good quality. The contamination of this aquifer by agricultural residues, principally aldicarb and nitrate, has caused much concern among Islanders. Beginning in 1985, hydrogeologists from NHRI and then NWRI have been monitoring ground water quality beneath three potato fields to which aldicarb (Temik) had been applied once or twice from 1983 to 1986 together with the seed potatoes. Ground water monitoring in May, 1988 indicated that 10% of all samples from these three fields exceeded the NH&W drinking water guideline of 9 ppb. However, 50% of all samples had nitrate concentrations exceeding drinking water guidelines.

PERSPECTIVE DE GESTION

Pour tous ses besoins en eau potable et en eau destinée aux usages industriel, domestique et agricole, l'Île-du-Prince-Édouard dépend totalement de l'eau souterraine. Son seul réservoir aquifère est un grès facturé très perméable, qui donne une eau souterraine par ailleurs de bonne qualité. La population s'inquiète donc beaucoup de la contamination de ce réservoir par les produits chimiques utilisés en agriculture, en particulier l'aldicarbe et les nitrates. Depuis 1985, les hydrogéologues de l'INRH puis de l'INRE ont contrôlé la qualité de l'eau souterraine sous trois champs de pomme de terre qui avaient, à deux ou trois reprises entre 1983 et 1986, été traités à l'aldicarbe au moment de la plantation. Le contrôle effectué en mai 1988 a montré que 10 % de tous les échantillons de ces trois champs dépassaient la directive de 9 parties par milliard fixée par le ministère de la Santé nationale et du bien-être social pour l'eau potable. De plus, 50 % de tous les échantillons présentaient des concentrations de nitrates supérieures aux directives pour l'eau potable.

INTRODUCTION

Pesticide contamination of ground water is an environmental and public health concern throughout Canada, particularly in the Maritime provinces (Fig. 1) where ground water is a major source of water for all uses. Surveys of farm wells on Prince Edward Island (PEI) indicated that low levels (1-6 µg/L) of the toxic insecticide aldicarb were present in 18% of high-risk wells around potato fields (Matheson *et al.*, 1987). Aldicarb residues have also been found in drinking water wells as a result of application to potatoes in the Northeastern United States (especially Long Island, NY) and Wisconsin (Moye and Miles, 1988).

Aldicarb is an extremely toxic carbamate insecticide (oral LD_{50} (rats) = 0.9 mg/kg) with an aqueous solubility of 6000 mg/L and a hydrolysis half-life ranging from a few weeks to years (Lightfoot *et al.*, 1987). Because of its toxicity, aldicarb is applied in Canada in granular form (as Temik 10G - 10% aldicarb) during spring planting of potatoes. The granules dissolve and the insecticide undergoes rapid microbially catalyzed oxidation to the sulfoxide, which can then undergo either hydrolysis to relatively non-toxic oximes and nitriles or further oxidation to the sulfone and then similar hydrolytic degradation. Health and Welfare Canada has issued a maximum acceptable concentration for total aldicarb (aldicarb, aldicarb sulfoxide, aldicarb sulfone) in drinking water of 9 µg/L.

The migration and fate of aldicarb in ground water has been extensively studied at various sites under a wide variety of conditions (see Moye and Miles, 1988). The objective of this study was to gain an understanding of the transport and transformations of aldicarb under the particular conditions of the fractured sandstone aquifer of PEI which is the sole source supply of water for the Island (127,000 population; 2185 sq. miles). The supplementary chemical data acquired during this project provides insight into nitrate contamination of the aquifer as well. From this study information will be gained in order to refine guidelines on the use of Temik in Canada.

A detailed examination of the chemical and hydraulic properties of the aquifer beneath three fields on PEI is being undertaken. In this paper these conditions are described and ground water quality monitoring data for aldicarb and nitrogen residues are summarized.

FIELD SITES

Three sites on PEI were chosen to conduct field assessments of aldicarb persistence. These sites were selected because there had been accurate documentation of pesticide and fertilizer use over the last few years and evidence of aldicarb residues in nearby farm wells (at two sites). All three of these fields are located in the main potato growing area of eastern Prince County, PEI. The hydrostratigraphy usually consists of 6 to 10 feet (2-3 m) of till underlain by fractured fine-grained sandstone red-beds of Permo-Carboniferous age (van de Poll, 1983). The sandstone aquifer is basically unconfined and, due to the decreasing number of fractures and their decreasing aperture, the hydraulic conductivity decreases with depth. Therefore the most productive zones are also the most easily contaminated (Francis, 1981).

Ground water monitoring was conducted using 2 inch (5.08 cm), schedule 40 PVC piezometers that were installed using an air rotary drilling rig. Screens (#6 slot) were either 3 or 5 feet (1 or 1.5 m) long and a sand-pack (#2 silica sand) was used with a three foot (1 m) bentonite seal placed above it. The hole was backfilled with native material produced during the drilling of the borehole (see Fig. 2).

In 1985 and 1986, a total of 25 piezometers were installed in a 32 acre (13 ha) field near Augustine Cove (Fig. 3). In 1987, three deep boreholes were drilled and hydraulically tested prior to installing a four or five port Solinst multilevel in each. The site at Mill Valley (Fig. 4) is a much larger potato field located along the Wilmot River. Due to both its size and access problems it has not been studied in as much detail. The third site is located at New Annan (Fig. 5) adjacent to a large food processing plant. It was instrumented in late 1986 and has not been sampled as frequently.

The hydraulic properties of the aquifer are controlled by the fracture spacing, orientations and apertures. The bulk hydraulic conductivity of the sandstone varies from 10^{-4} ft/s (4×10^{-5} m/s) in the shallow bedrock to 10^{-5} ft/s (5×10^{-6} m/s) below the first 15 ft

(5 m) at Augustine Cove (Lapcevic and Novakowski, 1988). By contrast, Francis (1981) measured values of 10^{-7} ft/s (5×10^{-8} m/s) in the matrix which is unaffected by fracturing. Matrix porosity ranged from 12 to 20%. Lapcevic and Novakowski estimated the transmissivity of the bedrock to be of the order of 0.01 ft^2/s (6×10^{-4} m^2/s) with a storativity of 2×10^{-4}.

Measurements of soil organic carbon content have been made on samples from all sites. Except for one sample, taken at a depth of 6 in (15 cm) in the field at Mill Valley, the fraction of organic carbon in all samples was less than 2%. Organic carbon content decreases rapidly below the root zone. At 2.5 ft (70 cm), levels were below 0.2% and a sample of sandstone cuttings from just above the water table at Augustine Cove contained no detectable organic carbon (i.e., <0.004%). Column experiments using material from the unsaturated zones of these sites have shown that aldicarb sulfoxide and sulfone move about 25% slower than an unretarded tracer. Consequently aldicarb may be considered as an almost conservative tracer.

METHODS OF SAMPLING AND ANALYSIS

Samples were collected from the two inch (5.08 cm) monitoring wells using either an all Teflon or a Teflon/stainless steel bladder pump (QED Systems, Ann Arbor, MI, U.S.A.). These pumps were not dedicated and had to be cleaned by flushing with distilled water between wells. After about two well volumes were removed from each well, flow cell analyses were begun. These parameters include E_H and pH using combination platinum and glass electrodes, respectively (Orion, Cambridge, MA, U.S.A.). An Orbishpere Model 2606 Oxygen meter (Orbishere Labs, Geneva, Switzerland) was used to measure dissolved oxygen. Samples were also titrated to determine alkalinity (as HCO_3^-) and in some cases ammonia measurements were made with an Orion gas-sensing electrode. Conductivity and temperature were also measured in the field.

After field analyses were completed, samples for aldicarb were filtered, acidified to pH 5 and stored at about 40°F (4°C) in amber glass bottles until analysis. Field blanks of distilled water and water from the pump cleaning procedure were taken and stored in a similar fashion. Samples for inorganic parameters were collected in plastic bottles and stored at about 40°F (4°C) until analysis. Cation samples were collected separately and acidified to pH 3 with nitric acid to prevent possible mineral precipitation.

Aldicarb analysis was initially conducted using the method of Chaput (1986). Since only aldicarb sulfoxide and aldicarb sulfone were detected in the samples from 1985 and 1986, subsequent samples (i.e., 1987 and 1988) were analyzed using a simpler method similar to that of Lesage (1989) which did not analyze for the parent compound. These two compounds are hereafter referred to as total aldicarb.

ALDICARB AND NITROGEN CHEMISTRY

The environmental chemistry of aldicarb, whose degradation pathways are shown in Figure 6, has been studied in detail by numerous workers (see Moye and Miles, 1988). Much of this research was conducted on a post-mortem basis as cases of ground water contamination arose in various parts of the U.S.A. and Canada. Information from these studies and accompanying laboratory tests have been used to understand more fully the migration and fate of aldicarb in the subsurface (soil and ground water). Modifications to agricultural practices to minimize contamination of ground water in problem areas have been developed from this work (e.g., Jones et al., 1986).

Two of the most important variables affecting the degradation of total aldicarb to less toxic products are pH and temperature (Moye and Miles, 1988). The chemical hydrolysis reactions that degrade aldicarb (sulfoxide and sulfone) proceed slowest in the pH range of 5 to 6. Outside of this range acid and base hydrolysis are more pronounced. Temperature also has a significant effect on the degradation of the three toxic products. Typically, the rate of most chemical reactions is doubled with a 18°F (10°C) rise in temperature, however, these hydrolysis reactions are about 3 to 5 times as fast with a similar change in temperature (Lightfoot et al., 1987). Lightfoot et al. also show that soil surface catalysis is an important factor although not yet fully understood.

Since the parent aldicarb is oxidized so rapidly to aldicarb sulfoxide, it is rarely detected in ground water. The oxidation of the sulfoxide proceeds at a much slower rate, therefore total aldicarb is typically comprised of only the two oxidized species. The proportions of these two compounds in the subsurface may vary within or between different sites.

The geochemistry of soil nitrogen has also been studied in detail. The transformation of concern in this study is the oxidation of ammonium (NH_4^+) to nitrate (NO_3^-), i.e., nitrification. Nitrification is prevalent in oxygenated soil moisture beneath fields that have been treated with ammoniacal fertilizers. Soil organic nitrogen is also readily converted to nitrate via ammonium. The reaction:

$$(1/2)NH_4^+ + O_2 = (1/2)NO_3^- + (1/2)H_2O + H^+$$

produces protons (acidity) and nitrate. Optimal conditions vary quite widely (see Schmidt, 1982), but, under conditions such as those found on PEI, nitrification is relatively rapid and a significant proportion of the ammonium applied at spring planting will be nitrified within 60 days (John MacLeod, Agriculture Canada, Charlottetown, PEI, pers. comm.).

GROUND WATER QUALITY

Prince Edward Island is a rich farming province located on Canada's east coast. Its soils, being cool, sandy and well-drained are particularly suited to the cultivation of potatoes. This also presents conditions conducive to aldicarb leaching and persistence. The pH of rainfall is low (<5) and the soils are acidic. Six soil samples from Mill Valley and Augustine Cove all contained less than 0.1% (w/w) inorganic carbon. The soil temperatures (at 6 in. (15 cm)) reach a maximum of 63°F (17°C) during July or August (Macdougall et al., 1981).

A summary of chemical data from 5 wells at Augustine Cove is presented in Table 1. Observation well #27 is located in an area that is affected by the losing stream, consequently its chemical composition reflects reducing conditions. Apart from the monitoring points close to the stream, the ground water contains abundant dissolved oxygen (8-10 mg/L) and is low in dissolved organic carbon. The other four wells in Table 1 are all completed to a depth of 2 to 6 ft. (1-3 m) in the aquifer and are all located away from the edges of the fields. They are shown here because they represent conditions beneath the field of interest without influences from the stream and inputs to adjacent fields.

Table 2 shows similar data for three representative wells at Mill Valley. The most striking difference is that, despite Temik applications in both 1985 and 1986 (Table 3), there is very little contamination of the ground water beneath this field. The 9.3 µg total aldicarb/L detected at MV-17 was the highest level at any well at this site during any sampling period. Nitrate levels are also lower in most wells compared to both Augustine Cove and New Annan. The only peculiar sampling point at this site has been the spring at the bottom of the field that discharges into the Wilmot River. It has had an average total aldicarb concentration of 5.5 µg/L over a four year period. The fracture zone supplying this spring probably acts much like a tile drain in transporting residues to the discharge zone.

Detectable levels of total aldicarb (0.6-4.3 µg/L) were found in 9 of the 10 wells beneath the field at New Annan in May, 1988. This is a full five years after the last application of aldicarb to this field (Table 3). Although sampling at this site has been less frequent, in general it seems that NO_3-N levels are relatively high. In May 1988, wells 1A, 2C, 5A and 5B (see Fig. 5) had NO_3-N concentrations between 22 and 30 mg/L.

CORRELATION OF ALDICARB AND NITROGEN RESIDUES

In contrast with results from other research sites (e.g., Harkin et al., 1986), the PEI data show a good correlation between aldicarb and nitrogen residues in the saturated zone (Fig. 7). This may of course be due strictly to physical reasons - both aldicarb and nitrate are essentially mobile and unretarded in the subsurface, hence their leaching characteristics are similar. Since favourable conditions exist for both aldicarb persistence and nitrification, there may also be a chemical reason for the observed trend. Given that the oxidation of ammonium lowers pH and produces nitrate ions, the logical conclusion is that ground waters that inhibit aldicarb degradation (low pH) would also be high in nitrate as a result of this oxidation reaction. In previous papers, Priddle et al. (1987 and 1988) have discussed the pH effect of nitrification in greater detail.

Lines showing maximum acceptable concentrations for both total aldicarb and nitrate have been included in Figure 7. Note that, with only one exception, all the points with total aldicarb concentrations that are greater than 9 μg/L also contain greater than 10 mg nitrate-N/L. This suggests that it may be possible to use nitrate as an indicator of wells susceptible to pesticide contamination. Only domestic wells with high nitrate levels would have to be sampled in a pesticide survey. During the aldicarb surveys on Prince Edward Island in 1983/84, it was found that wells containing aldicarb residues generally had higher nitrate concentrations than those without residues (Matheson et al., 1987).

If one assumes that nitrification conditions are similar at both Augustine Cove and Mill Valley and therefore equal amounts of nitrate are being produced by fertilizer application, then the effects should be the same. In the last six years (1983-1988), more nitrogen has been applied to the field at Augustine Cove than at Mill Valley (Table 3). This seems to be reflected in the lower NO_3-N levels in ground water at Mill Valley. Total aldicarb levels are also lower but seem to be rising in the period after the 1985 and 1986 applications.

The May 1988 data obtained from all three sites provides strong evidence that both nitrate and aldicarb residues are stored in the unsaturated zone and then transported to the water table during periods of high recharge. Overall higher concentrations of total aldicarb and nitrate were detected during this Spring sampling period than at any other time. This is surprising when the application timetable for aldicarb and nitrogen fertilizers (Table 3) is examined. Pacenka et al., (1987) observed similar slow leaching of aldicarb residues following cessation of aldicarb use on Long Island, NY. Furthermore, Geake and Foster (1989) have shown that slow transport of nitrate through the British Chalk has lead to a build up in the unsaturated zone.

Similar storage of residues in the saturated zone may be occurring. Since ground water flow is predominantly through the fractures, it is possible that solutes diffuse into the sandstone matrix and when concentrations in the fracture decrease they diffuse back out ("matrix diffusion"). This phenomenon explains the relatively steady total aldicarb concentrations over time.

At New Annan, despite aldicarb being last applied in 1983, average ground water residues were higher in May 1988 than in September 1986 and July 1987. Nitrate values were also exceptionally high in the spring of 1988.

Sampling and analysis of unsaturated zone material showed that low concentrations of total aldicarb (1 µg/kg) were present from 15-25 ft (5-8 m) below ground surface at the Augustine Cove site

(September, 1988). Although no unsaturated zone sampling has been done at Mill Valley this situation is probable because of the two consecutive years of Temik application and the thicker unsaturated zone. This hypothesis is supported by the concentrations of total aldicarb found in the spring (Table 2).

During May of 1988 four wells at Augustine Cove were sampled and analyzed nine times for total aldicarb and nitrate. Water level and precipitation data were also collected over this period and the data for one well (#6) are displayed as a time series in Figure 8. The figures for the other three wells are similar (different magnitudes but steady concentrations of total aldicarb and nitrate) and it is evident that short term variations are relatively minor. Relative standard deviations (RSD) for total aldicarb concentrations were calculated for the May data at the four wells giving values of 6-19% with an average of about 10%. This compares with an RSD of 3.8% for a 10 µg/L standard of aldicarb sulfoxide and aldicarb sulfone analyzed 4 times.

The water table - and therefore recharge - is usually highest in late April or early May following the Spring snowmelt. As shown by the head data in Figure 8, the water levels decrease during the month of May. The higher than average overall concentrations are indicative of this recharge transporting solutes from the unsaturated zone and/or diffusion of sources from the sandstone matrix of those parts of the aquifer that were normally above the water table.

In general, aldicarb residues are highest in areas where the water table is shallow and concentrations decrease rapidly with depth in the aquifer (Fig. 9a). It should be noted, however, that total alidcarb residues of 1.1 and 1.5 µg/L were found in intervals of the deep boreholes corresponding to about 60 ft (18 metres) below the water table. Nitrate residues are far more pervasive, being found at high concentrations throughout the monitoring well networks of the three fields (Fig. 9a). These observations relate to the fact that nitrogen fertilizers are used more frequently and over a larger area (i.e., adjacent fields) than Temik. Furthermore nitrate is very stable in oxygenated ground water whereas aldicarb residues may undergo hydrolytic degradation.

Jones et al. (1987) have reported the rapid infiltration of aldicarb residues to a shallow water table before degradation could occur even under the warm conditions of Florida soils. Similarly at Augustine Cove, total aldicarb concentrations are highest where the water table is shallowest (Fig. 9b). The importance of a thick unsaturated zone is also noticed when the pH values from Mill Valley and Augustine Cove are compared. At Mill Valley no wells have had a pH below 7.3 whereas there are several wells at Augustine Cove that are consistently below 7.0. Recharge water, that is acidic both from rainfall and nitrification, has therefore had more time to be neutralized before reaching the water table at Mill Valley.

PESTICIDE MANAGEMENT IMPLICATIONS

Presently, the application of Temik to potatoes in Canada is only permitted at planting. Experience in the U.S. has shown that this practice is conducive to ground water contamination and that application should be postponed until plant emergence (Wyman et al., 1985 and Jones et al., 1986). Soil temperatures at planting are very low (40-50°F [5-10°C]) in the potato growing regions of Eastern Canada inhibiting the hydrolysis (i.e., detoxification) of the toxic aldicarb species. At the same time spring rains (having low pH) and low evapotranspiration increase recharge while uptake of aldicarb residues is minimal because root systems have not developed.

The state of Wisconsin partially remedied this problem by passing legislation in 1982 that only permitted the application of Temik at plant emergence (Moye and Miles, 1988). This occurs about one month after planting, when the plant is actively growing, recharge is lower and soil temperatures are higher. Research in Maine (Jones et al., 1986) and Wisconsin (Wyman et al., 1985) has shown that this practice, in combination with other site specific regulations, have much reduced ground water contamination. It is recommended that it be adopted throughout Canada.

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FIGURES

Table 1. Selected ground water quality data, Augustine Cove, PEI, showing sampling date (m/y), pH, dissolved oxygen, nitrate-nitrogen and total aldicarb (sum of aldicarb sulfoxide and sulfone). With the observation well number, screen refers to the depth to mid-screen below grade; vadose is the approximate thickness of the unsaturated zone. Blank - parameter not measured.

Date	pH	DO (mg/L)	NO_3^--N (mg/L)	Total Ald. (µg/L)
Well #4 (Screen - 37.5 ft (11.4 m), vadose - 33 ft (10 m))				
7/85	7.5	9.0	7.6	4.0
9/85			2.8	0.2
9/86	7.0	8.7	7.6	3.6
6/87	7.1	10.0	11.0	3.1
8/87				1.4
5/88	7.0		13.4	4.6
10/88			7.2	2.7
Average	7.2	9.2	8.3	2.8
Well #6 (Screen - 20 ft (6.1 m), vadose - 13 ft (4 m))				
7/85	6.3	2.8	14.0	12.0
9/85			5.0	3.9
9/86	6.4	5.7	8.4	7.1
6/87	6.3	9.0	12.0	6.9
8/87				7.1
5/88	6.3		9.8	10.3
10/88			8.5	3.6
Average	6.3	5.8	9.6	7.3

Table 1. (cont'd)

Date	pH	DO (mg/L)	NO_3^--N (mg/L)	Total Ald. (μg/L)
Well #7 (Screen - 17.5 ft (5.3 m), vadose - 10 ft (3 m))				
7/85	6.4	9.0	12.0	10.8
9/85			11.0	5.9
9/86	5.6		8.0	4.7
7/87	6.6	8.0	11.0	3.7
8/87				4.8
5/88	6.7		11.4	4.5
10/88				2.8
Average	6.3	8.5	10.7	5.3
Well #9 (Screen - 14 ft (4.2 m), vadose - 10 ft (3 m))				
7/85			14.0	14.2
9/85			12.0	12.3
9/86	6.6		13.6	12.8
7/87	7.5	6.0	13.0	15.0
8/87				12.8
5/88	7.6		10.6	9.7
10/88			10.3	7.2
Average	7.2	6.0	12.3	12.0
Well #27 (Screen - 23 ft (7 m), vadose - 3 ft (1 m))				
9/86	6.8	0.3	<0.05	<0.1
7/87	6.8	0.4	<0.05	0.6
8/87				0.4
5/88			1.6	<0.1
Average	6.8	0.4	0.5	0.3

Table 2. Selected ground water quality data, Mill Valley, PEI, showing sampling date (m/y), pH, dissolved oxygen, nitrate-nitrogen and total aldicarb (sum of aldicarb sulfoxide and sulfone). With the observation well number, screen refers to the depth to mid-screen below grade; vadose is the approximate thickness of the unsaturated zone. Blank - parameter not measured.

Date	pH	DO (mg/L)	NO_3^--N (mg/L)	Total Ald. (µg/L)
Well #12 (Screen - 58 ft (17.7 m), vadose - 40 ft (12 m))				
7/85			3.5	<0.1
9/85			4.3	<0.1
9/86				<0.1
6/87	7.8	10.0	4.7	<0.1
8/87				<0.1
5/88			5.0	<0.1
Average			4.4	<0.1
Well #14 (Screen - 59 ft (18.1 m), vadose - 30 ft (9 m))				
7/85			5.4	
9/85			6.0	<0.1
9/86				<0.1
6/87	7.3	10.0	6.1	3.7
8/87				0.7
5/88			7.0	0.1
Average			6.1	0.9

Table 2. (cont'd)

Date	pH	DO (mg/L)	NO_3^--N (mg/L)	Total Ald. (µg/L)
Well #17 (Screen - 16.5 ft (5 m), vadose - 8 ft (2.5 m))				
7/85	7.9	5.3	5.4	0.1
9/85			4.3	
9/86				1.1
6/87	7.3	9.0	12.0	7.7
8/87				0.7
5/88			13.8	9.3
Average			8.9	3.8
Spring near Wilmot River				
7/85			8.3	4.7
9/85			8.0	4.6
6/87	7.2	9.0		4.8
8/87				3.4
5/88				9.8
Average			8.2	5.5

Table 3. Fertilizer and aldicarb application (1983-1988). All values expressed as kg nitrogen/ha. (1 kg/ha = 0.9 lb/acre).

Fertilizer or Pesticide	Year	Amount Applied (kg/ha)		
		Augustine Cove	Mill Valley	New Annan
ammonium nitrate	1988			175
ammonium nitrate	1987	52		175
Aldicarb	1986	2.0	2.0	
ammonium nitrate		210	206	
urea			82	
Aldicarb	1985		2.2	
ammonium nitrate			27	
ammonium nitrate	1984		27	175
diammonium phosphate		54		
Aldicarb	1983	2.0		2.2
ammonium nitrate		190	27	175
urea		5.9		

Figure 1

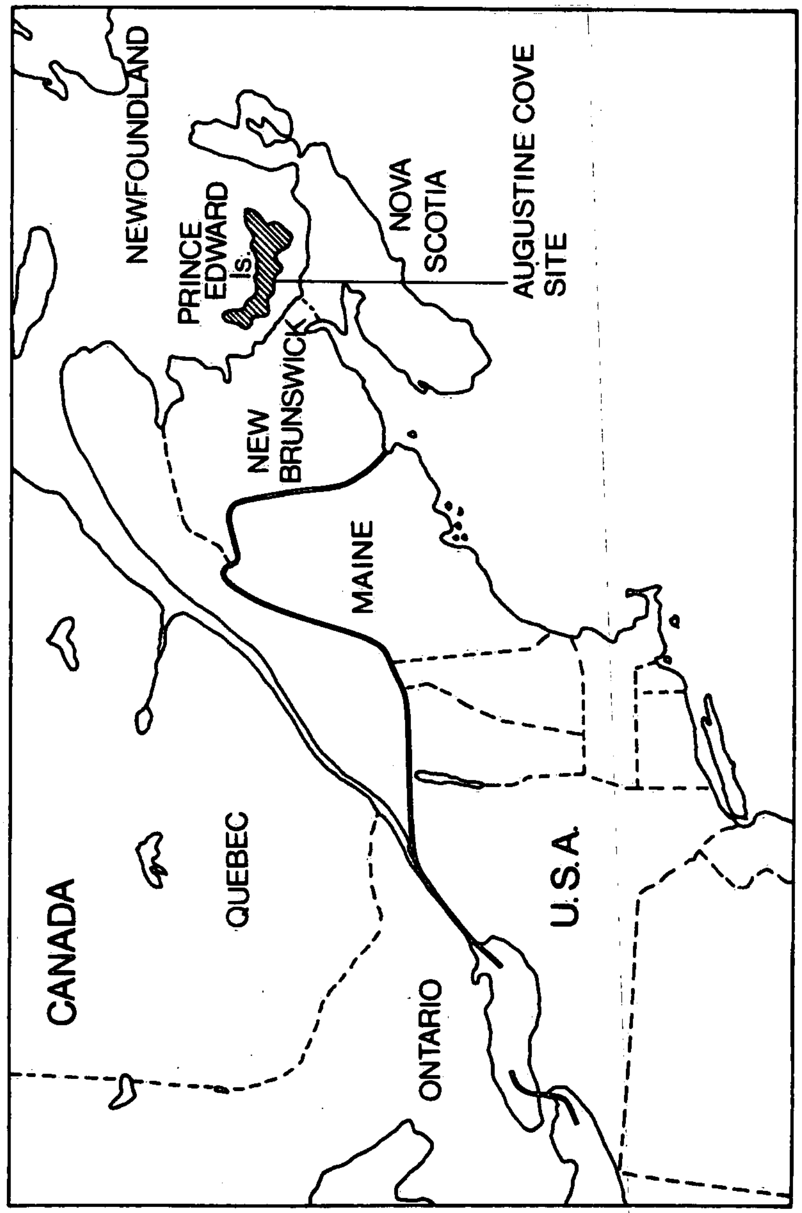

NEWFOUNDLAND
PRINCE EDWARD Is.
NOVA SCOTIA
AUGUSTINE COVE SITE
NEW BRUNSWICK
MAINE
CANADA
QUEBEC
U.S.A.
ONTARIO

Figure 2

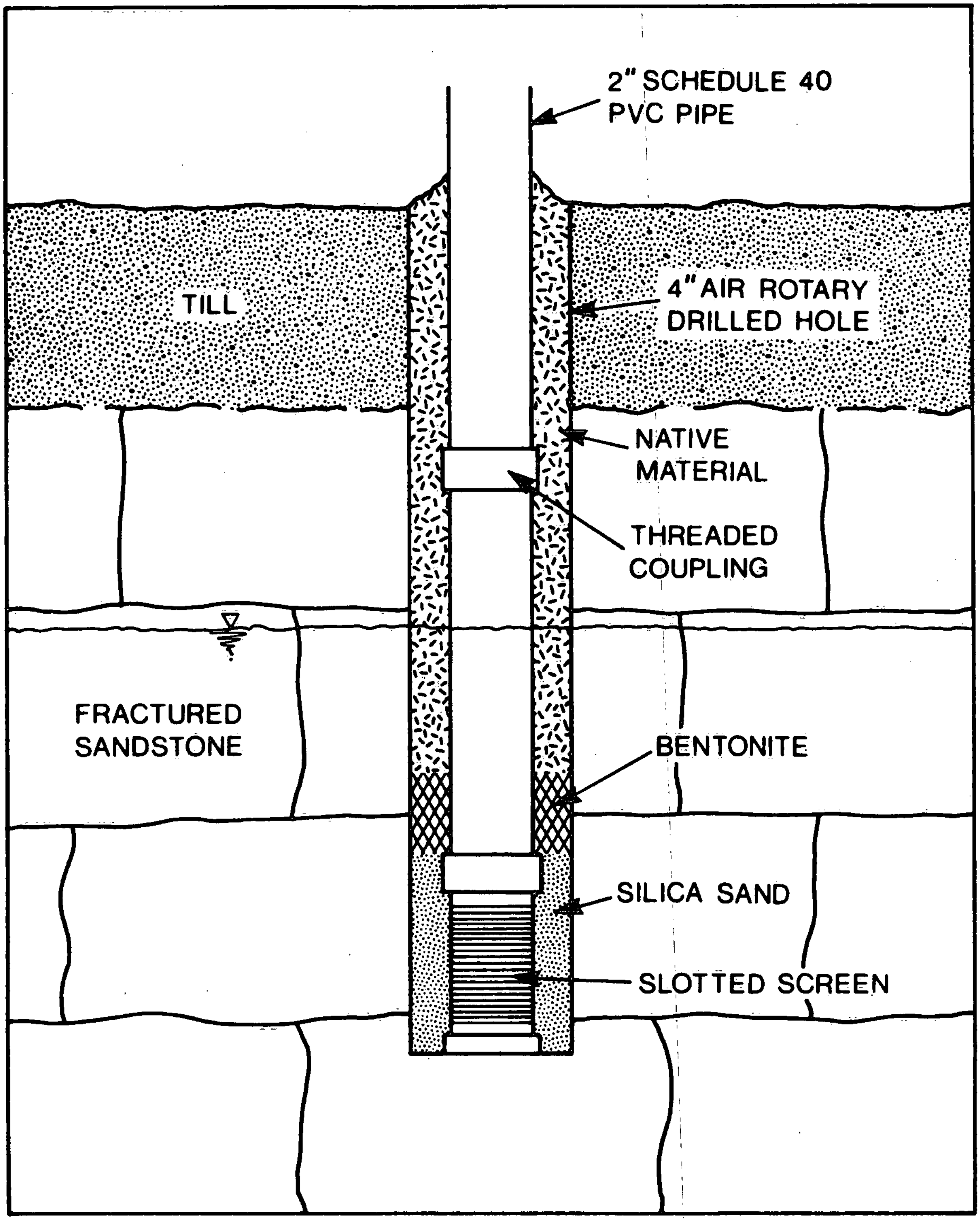
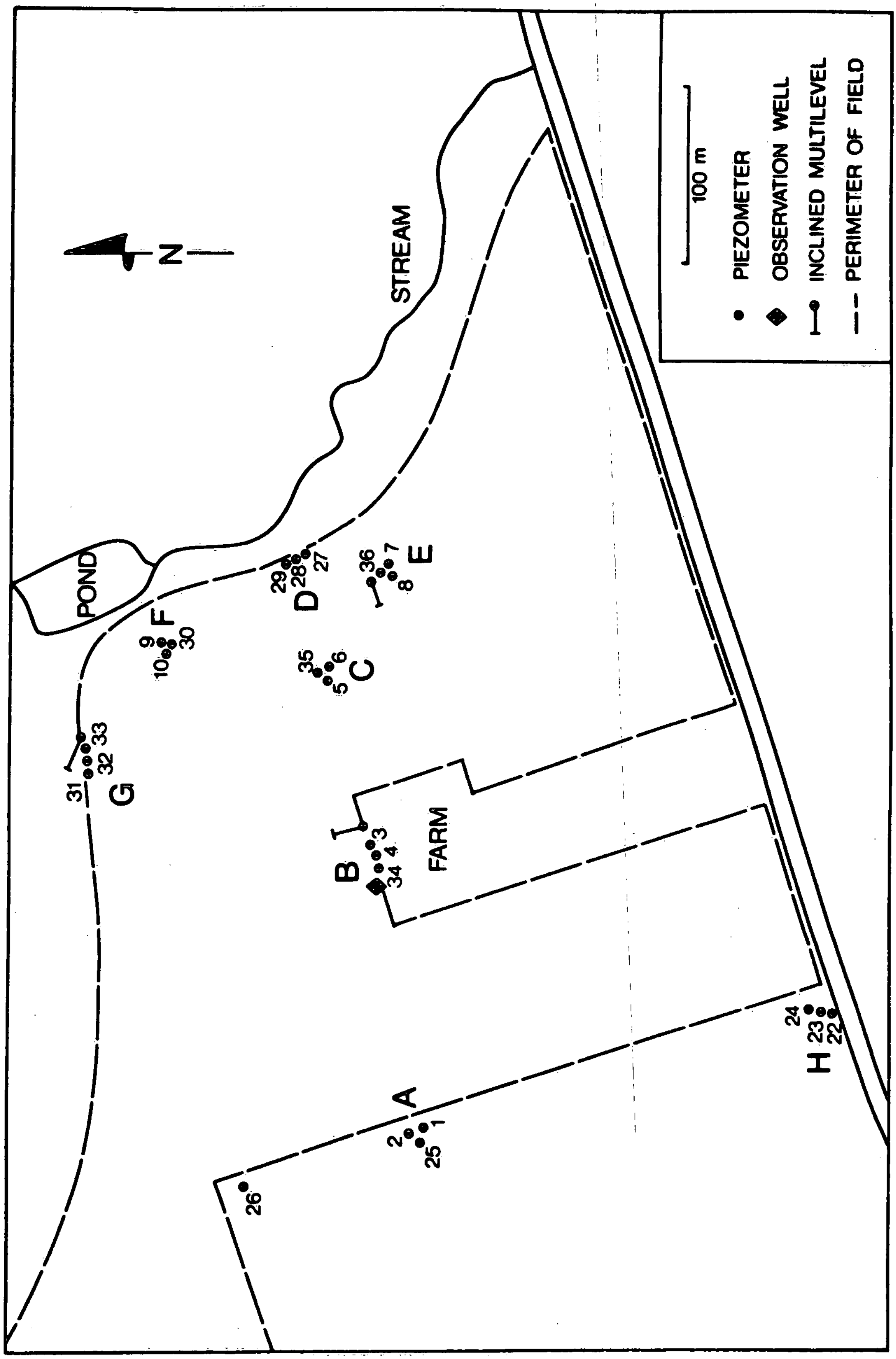
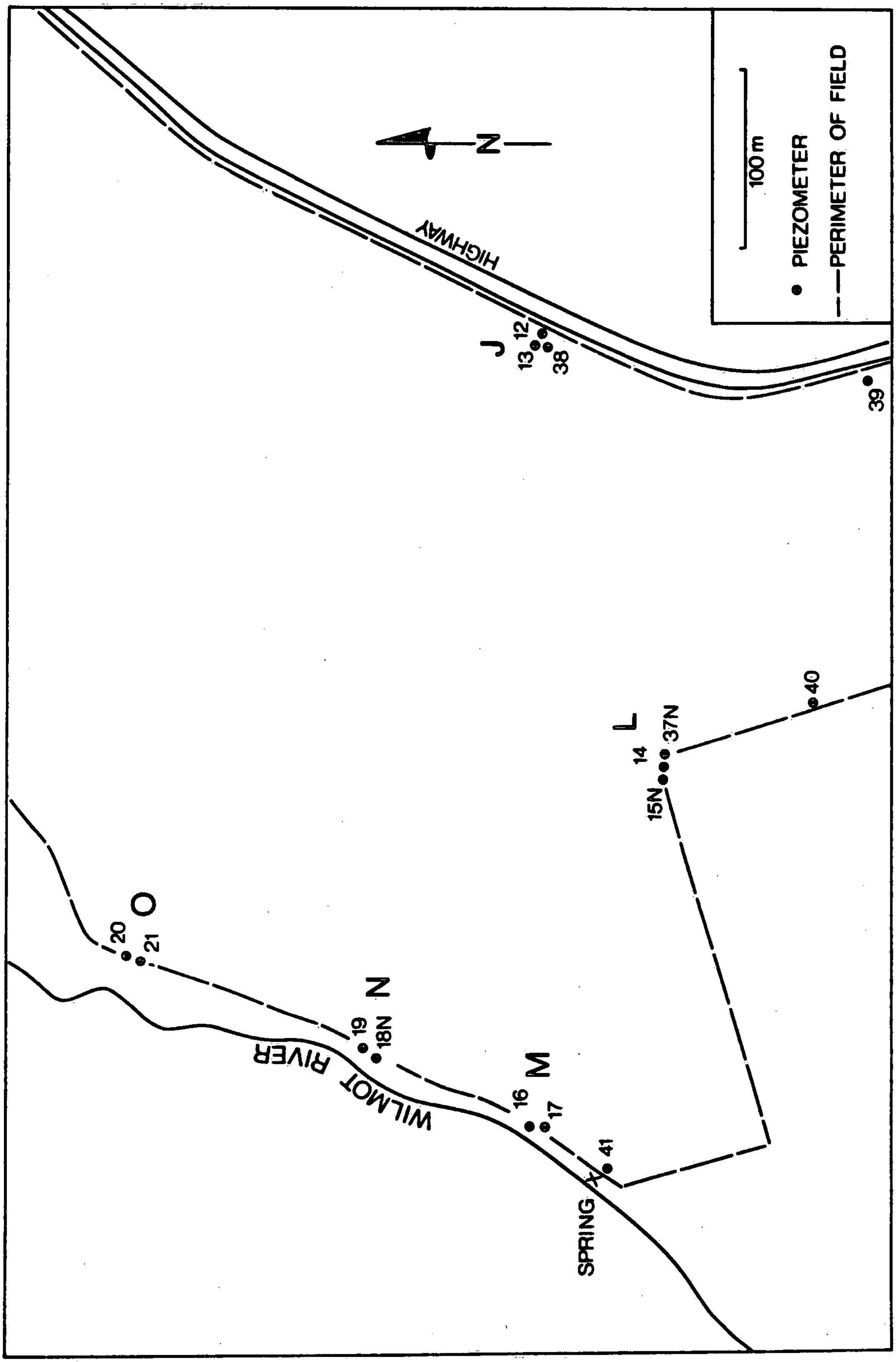

2" SCHEDULE 40
PVC PIPE
TILL
4" AIR ROTARY
DRILLED HOLE
NATIVE
MATERIAL
THREADED
COUPLING
FRACTURED
SANDSTONE
BENTONITE
SILICA SAND
SLOTTED SCREEN

Figure 3



N
STREAM
POND
FARM
A
B
C
D
E
F
G
H
1
2
3
4
5
6
7
8
9
10
22
23
24
25
26
27
28
29
30
31
32
33
34
35
36
100 m
PIEZOMETER
OBSERVATION WELL
INCLINED MULTILEVEL
PERIMETER OF FIELD

Figure 4



N
100 m
• PIEZOMETER
PERIMETER OF FIELD
HIGHWAY
J
12
13
38
39
40
L
14
37N
15N
O
20
21
N
19
18N
M
16
17
41
WILMOT RIVER
SPRING

Figure 5

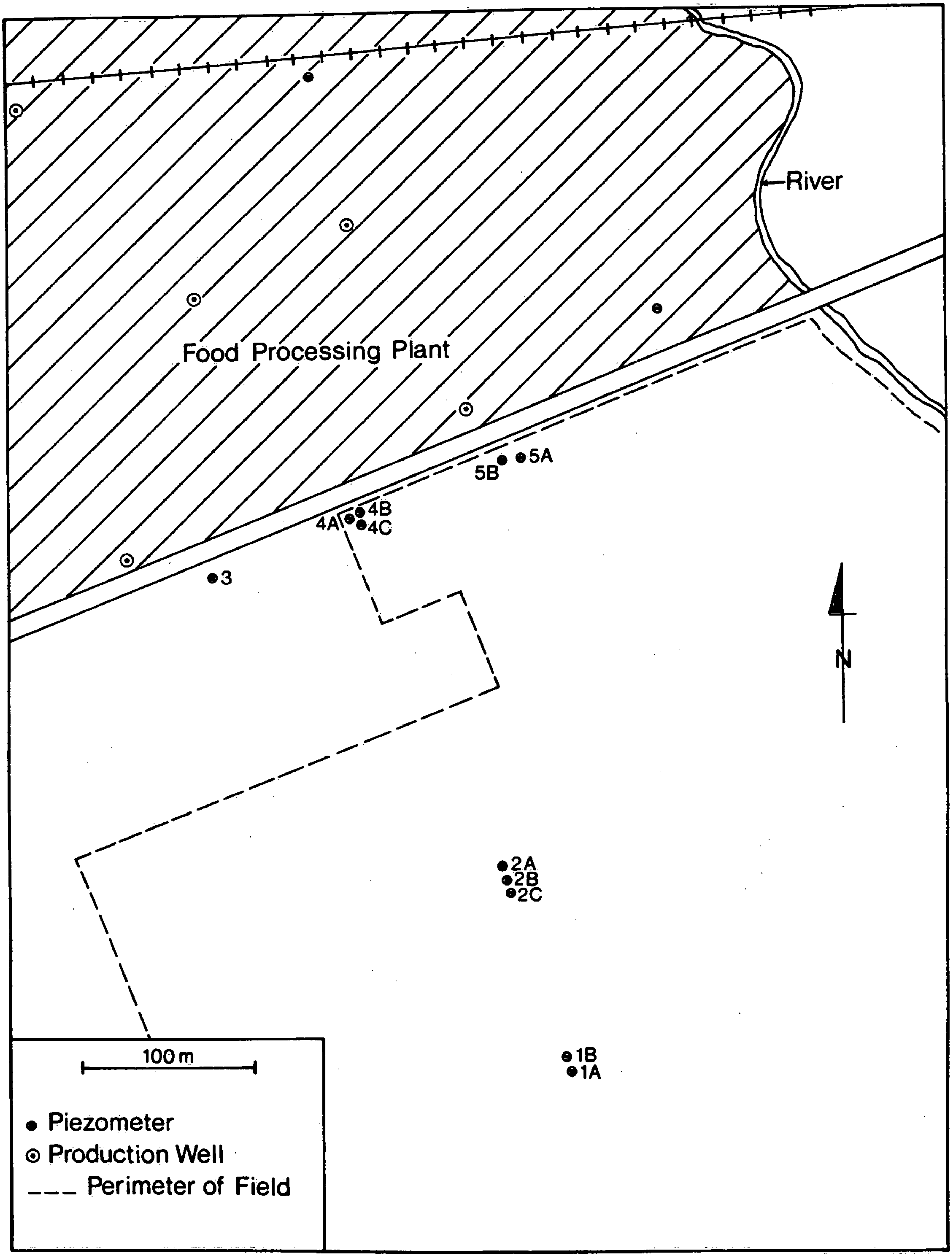

River
Food Processing Plant
5A
5B
4B
4A
4C
3
N
2A
2B
2C
1B
1A
100 m
Piezometer
Production Well
Perimeter of Field

Figure 6

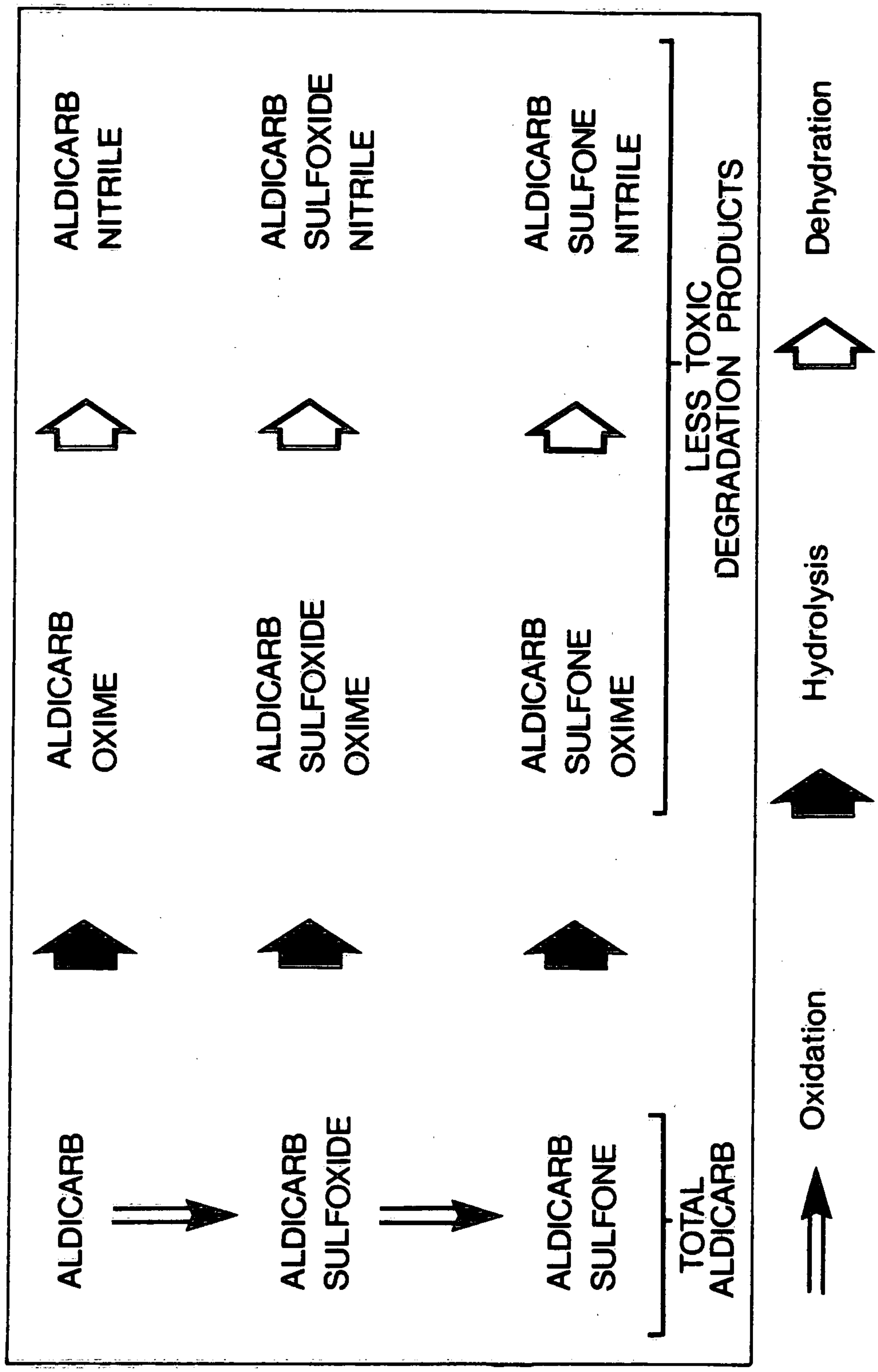

ALDICARB
ALDICARB SULFOXIDE
ALDICARB SULFONE
TOTAL ALDICARB
ALDICARB OXIME
ALDICARB SULFOXIDE OXIME
ALDICARB SULFONE OXIME
ALDICARB NITRILE
ALDICARB SULFOXIDE NITRILE
ALDICARB SULFONE NITRILE
LESS TOXIC DEGRADATION PRODUCTS
Oxidation
Hydrolysis
Dehydration

Figure 7

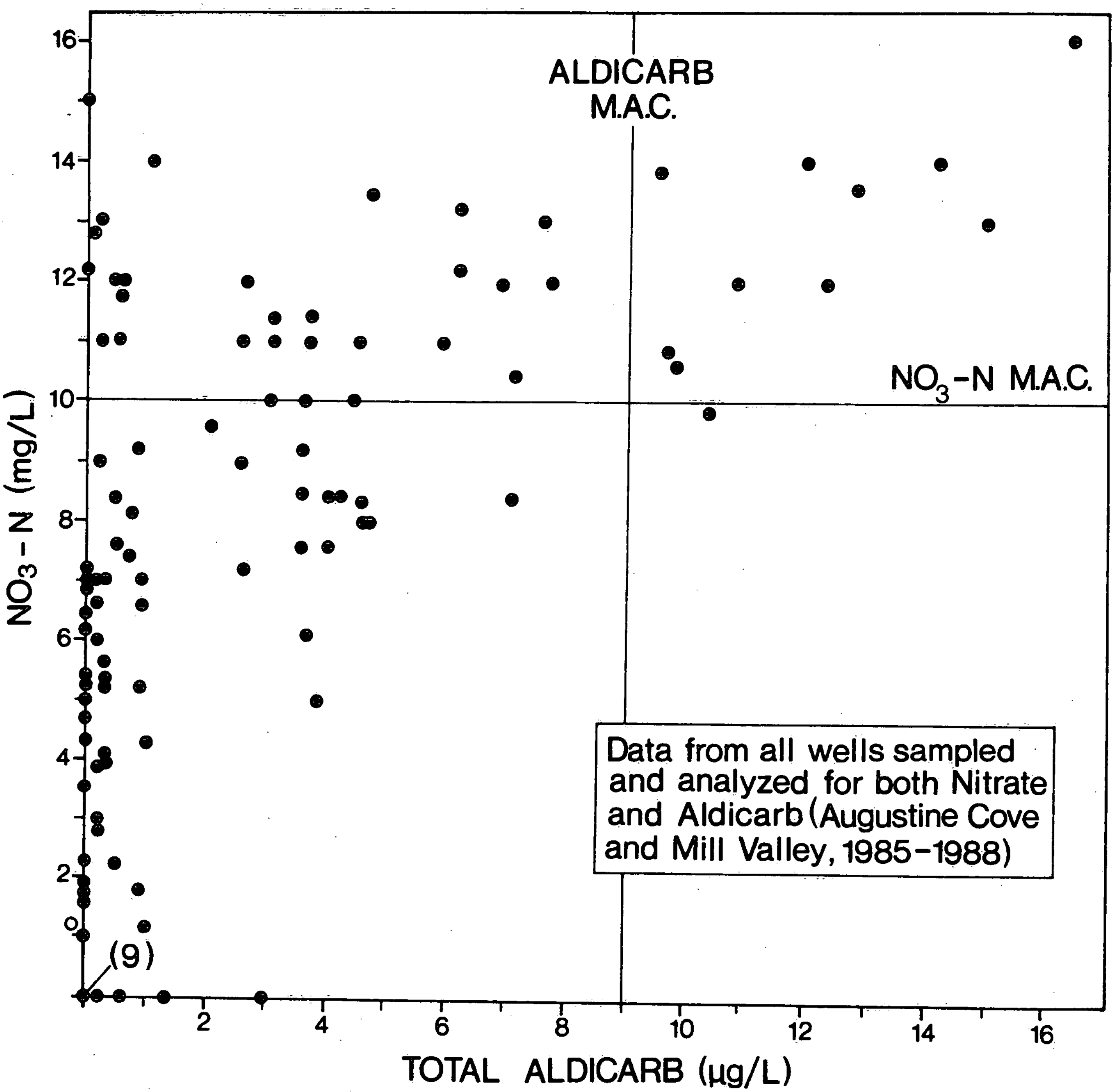
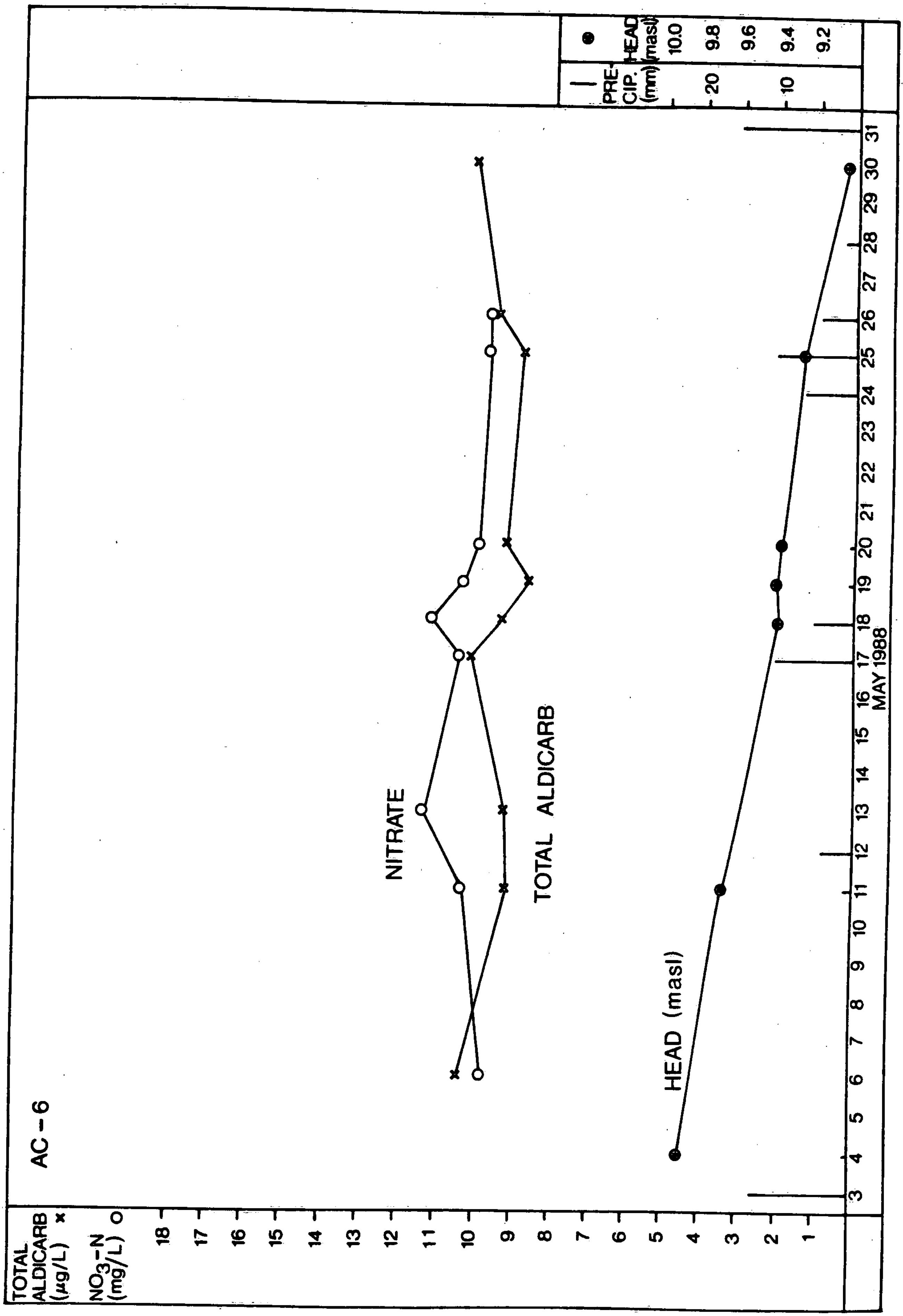
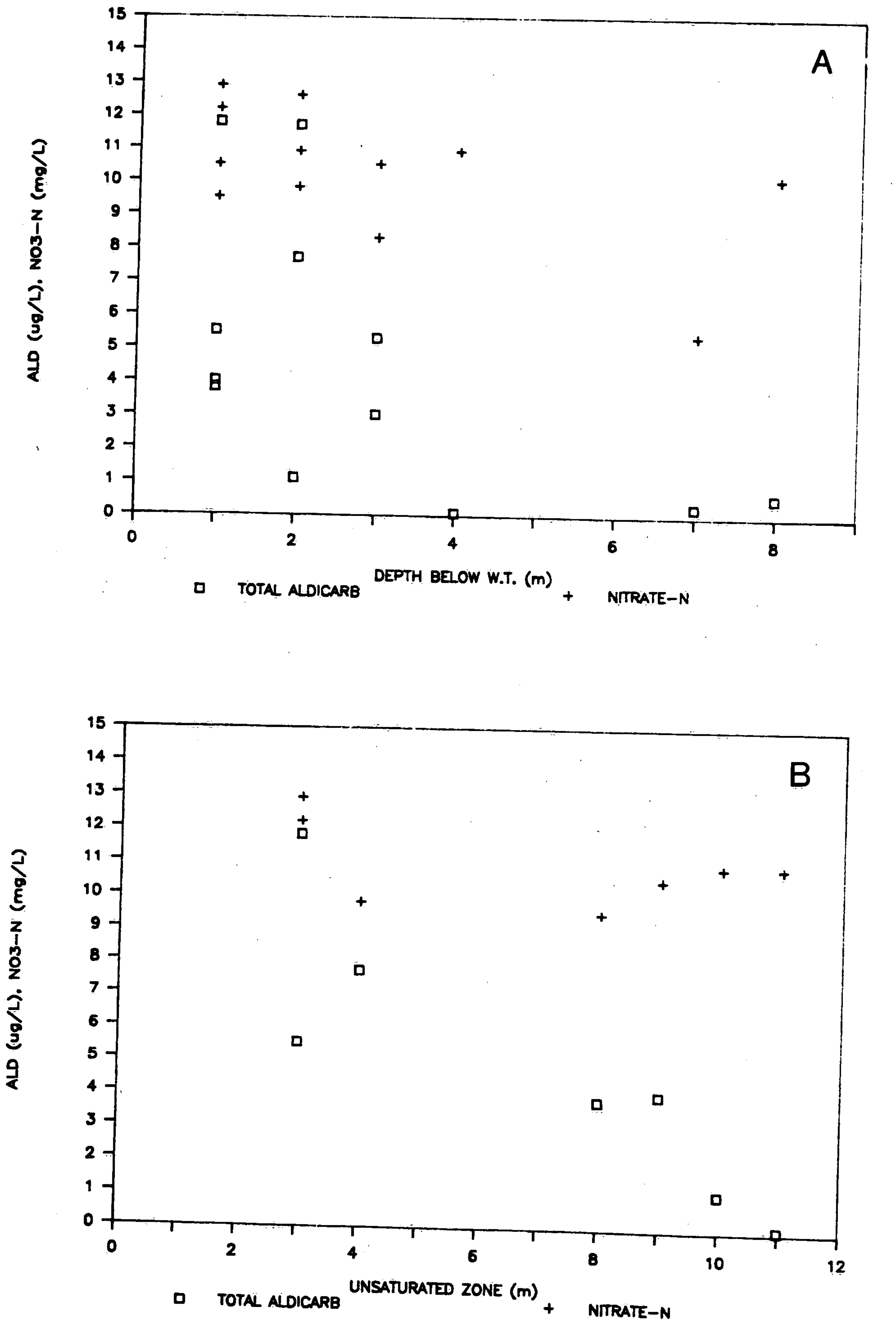

ALDICARB
M.A.C.
NO_3-N M.A.C.
NO_3 - N (mg/L)
TOTAL ALDICARB (μg/L)
(9)
0
2
4
6
8
10
12
14
16
Data from all wells sampled and analyzed for both Nitrate and Aldicarb (Augustine Cove and Mill Valley, 1985–1988)

Figure 8



AC – 6
NITRATE
TOTAL ALDICARB
HEAD (masl)
TOTAL ALDICARB (µg/L) x
NO_3-N (mg/L) O
MAY 1988
PRE-CIP. (mm)
HEAD (masl)


A
ALD (ug/L), NO3-N (mg/L)
DEPTH BELOW W.T. (m)
TOTAL ALDICARB
NITRATE-N
B
ALD (ug/L), NO3-N (mg/L)
UNSATURATED ZONE (m)
TOTAL ALDICARB
NITRATE-N