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INTRODUCTION

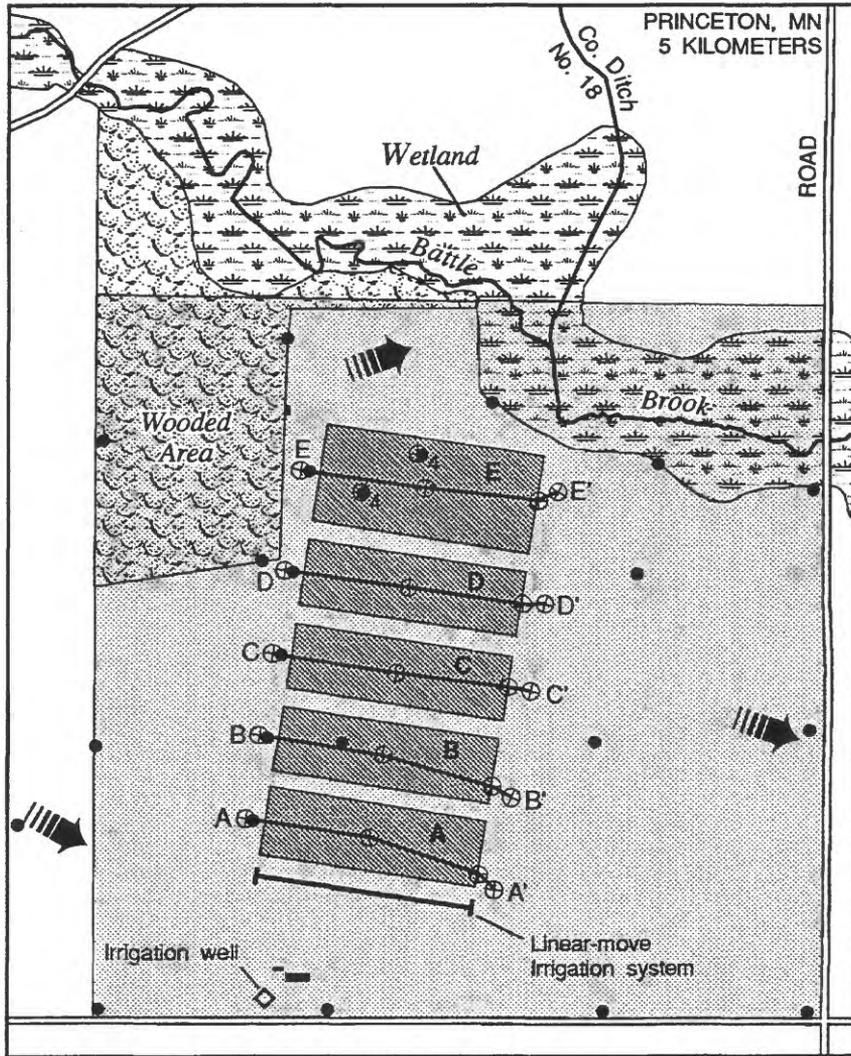
The northern cornbelt sand-plains Management Systems Evaluation Area (MSEA) program is a multiagency, multistate initiative to evaluate the effects of modified and prevailing farming systems on water quality in a sand-plain area in Minnesota and at satellite areas in North and South Dakota, and Wisconsin (Delin and others, 1992). The primary objective of the northern cornbelt sand-plains MSEA is to evaluate the effects of ridge-tillage practices in a corn and soybean farming system on ground-water quality. The Minnesota MSEA program is a cooperative study primarily between the U.S. Department of Agriculture-Agricultural Research Service, the University of Minnesota Soil Science Department, and the U.S. Geological Survey. The Minnesota Pollution Control Agency and the Department of Geology and Geophysics at the University of Minnesota are also cooperating in the evaluation of ground-water quality at the MSEA.

DESCRIPTION OF THE PRINCETON, MINNESOTA MSEA

The Minnesota research area is located in the Anoka Sand Plain near the town of Princeton. Topographic relief at the 65-hectare Princeton MSEA is less than 3 meters (m). Generally, the unsaturated zone consists of fine-to-medium-grained sand and the saturated zone consists of medium-to-coarse-grained sand. There are discontinuous layers of silt and very-fine-grained sand as thick as 20 centimeters (cm) in both the unsaturated and saturated zones. A predominantly clayey till underlies the surficial aquifer (the till is less permeable than the aquifer). During 1991, the average depth to the water table was about 3.6 m below land surface and the saturated thickness ranged from 4 to 16 m. The average saturated hydraulic conductivity is about 0.04 cm per second. The direction of ground-water flow generally is from west to east at an average rate of about 8 cm per day. Ground-water recharge rates generally range from 10 to 20 cm per year.

Five 1.8- to 2.6-hectare cropped areas are aligned with the predominant direction of ground-water movement at the Princeton MSEA (fig. 1). The following three cropping systems are being evaluated: (1) a corn-soybean rotation under ridge (conservation) tillage, split nitrogen (N) application, N credit for legumes, and banding of herbicides (application of herbicide only over row; banded application amount is one-third of broadcast application amount) (cropped areas A and C), (2) a sweet corn-potato rotation with conventional full-width (disk or chisel) tillage and banding of herbicides for sweet corn and conventional full-width tillage and broadcast application of herbicides for potatoes (cropped areas B and D), and (3) corn in consecutive years under conventional full-width tillage and broadcast application of herbicides (cropped area E) (Anderson and others, 1991). The buffer area around the cropped areas (fig. 1) was planted with a mixture of timothy and smooth brome grass where agricultural chemicals were not applied. Prior to the implementation of the MSEA farming systems in spring 1991, the entire 65-hectare field was planted in alfalfa from 1981 to 1989 and in corn during 1990.

The ground-water-quality sampling network at the Princeton MSEA consists of 29 observation wells and 22 multilevel piezometers (fig. 1). In addition, 14 observation wells are located off the 65-hectare field and are not shown in figure 1. The observation wells were used to measure water levels and to determine background concentrations of agricultural chemicals. The observation wells are constructed of 5.1-cm diameter galvanized steel or polyvinyl chloride (PVC) casing with 0.6-m long screens installed at the water table or 0.15-m long screens installed deeper in the aquifer. The multilevel piezometers are located 21 m upgradient, in the middle, immediately downgradient, and 25 m downgradient (which approximates the distance ground water travels in 1 year) of each cropped area (fig. 1). Each multilevel piezometer consists of six 0.6-cm diameter stainless-steel tubes housed in a 5.1-cm diameter PVC casing; each stainless-steel tube has a 3-cm long screened interval (port) which is external to the PVC casing. The sampling ports were installed at 0.5-m intervals. A port was installed 0.5 m above the water table, in order to allow sample collection if the water table rose.



Base from U.S. Geological Survey
Princeton 1:24,000 quadrangle, 1982

0 250 500 750 1000 FEET
0 100 200 300 METERS

EXPLANATION

-  Cropped area and identifier
-  Research area
-  Direction of ground-water flow, January, 1991
- A—A' Line of Section
-  Observation well, number indicates number of wells at site
-  Multilevel Piezometer
-  Building

The research area is located in the northeast quarter of section 18, township T35N, range R26W.

Figure 1.--Layout of the Princeton, Minnesota Management Systems Evaluation Area.

GROUND-WATER QUALITY, 1991

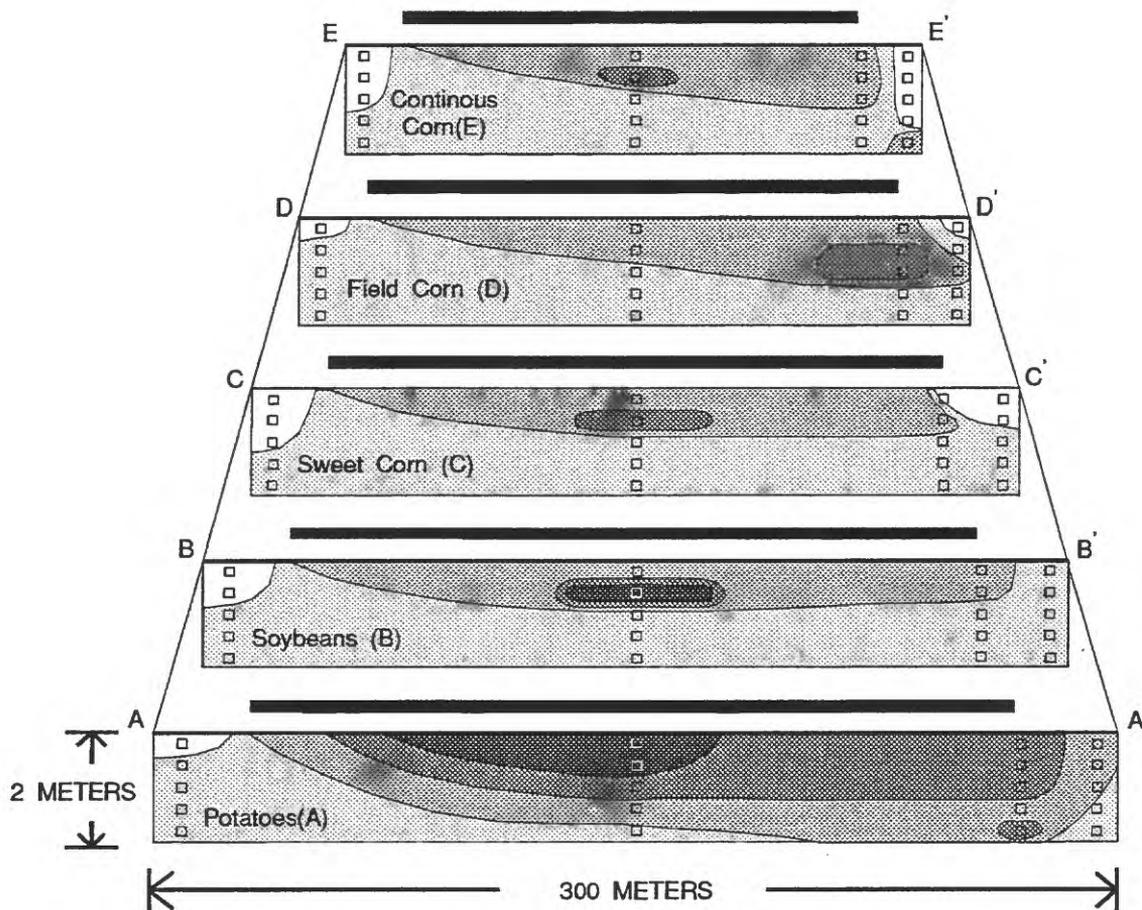
During 1991, water samples were collected from all multilevel piezometers, selected on-site observation wells, and Battle Brook (fig. 1) four times: once before agricultural chemicals were applied (April), twice during the growing season (May-June and August), and once during late fall after crops were harvested (December). Strict sample collection and laboratory analysis Quality Assurance/Quality Control (QA/QC) protocols were followed. Field pH, specific conductivity, temperature, dissolved oxygen, and oxidation-reduction potential were measured at each sampling site prior to sample collection. Alkalinity titrations were performed the same day in the field. Water samples were collected and analyzed for dissolved major cations and anions, nutrients, and selected herbicides and herbicide metabolites (atrazine, de-ethylatrazine, de-isopropylatrazine, alachlor, chloroalachlor, 2,6-diethylalanine, metolachlor, and metribuzin). Gas chromatography/mass spectroscopy (GC/MS) was used to determine herbicide concentrations.

CHLORIDE — Potassium chloride (potash) fertilizer (0-0-60) was applied to the cropped areas during late April 1991 to provide potassium for the crops. The application rate was 504 kilograms per hectare (kg/ha) on the potatoes (cropped area A) and 112 kg/ha on the other cropped areas (corn, sweet corn, and soybeans). Chloride was used as a tracer for water recharging through the MSEA cropped areas because the potash fertilizer was applied only to the cropped areas and chloride moves conservatively with ground water.

Chloride concentrations greater than background were first detected during the August 1991 sampling period beneath the potatoes (cropped area A) and soybeans (cropped area B). By the December 1991 sampling period, chloride concentrations greater than background were detected beneath all of the cropped areas. It is likely that water with chloride concentrations greater than background reached the water table during a 2.5-cm recharge event that occurred from late October to early November. Additional inputs of chloride, and continued spread of chloride through the aquifer, occurred during spring 1992; during this time there was approximately 6.4-cm of recharge to the aquifer.

Figure 2 illustrates the contoured chloride concentrations in the upper two meters of the saturated zone along cross-sections beneath each of the five cropped areas during April 1992. Results from this sampling period show the effects of agricultural practices prior to 1992 because application of agricultural chemicals and planting for the 1992 growing season had not occurred prior to April 1992. Chloride concentrations in the upper meter of the saturated zone beneath the cropped areas ranged from 20 to 50 milligrams per liter (mg/L) compared with concentrations of less than 20 mg/L in areas up-gradient of the cropped areas and deeper in the saturated zone. Beneath areas upgradient and downgradient of the cropped areas, chloride concentrations near the water table (less than 10 mg/L) were less than concentrations deeper in the saturated zone (10 to 20 mg/L). Ground water near the water table beneath these buffer areas probably was recharged to ground water during 1991. This recharge water had lower chloride concentrations compared to shallow ground water beneath the MSEA cropped areas because potassium chloride was not applied in the buffer areas during 1991. Chloride concentrations of between 10 and 20 mg/L in water 1 to 2 m below the water table beneath the entire area probably represent ground water affected by agricultural practices not associated with the MSEA study. Chloride concentrations were greatest beneath the potatoes (cropped area A) because the potassium chloride application rate on the potatoes was greater than on any other crop.

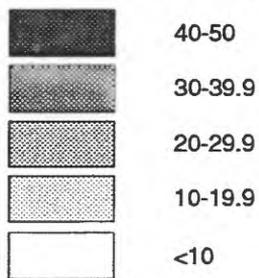
NITRATE-NITROGEN — Nitrogen was applied during April to June 1991 at a rate of 224 kg/ha on the potatoes (cropped area A) and 157 kg/ha on the corn (cropped areas C, D, and E). None was applied on the soybeans (cropped area B). Nitrate-nitrogen (nitrate-N) concentrations greater than those measured upgradient and 1 to 2 meters below the water table were first detected at the water table beneath the potatoes (cropped area A) in December 1991. Nitrate-N concentrations in the ground water increased beneath the potatoes during spring 1992. Although relatively small amounts of recharge occurred during fall 1991 (2.5 cm) and spring 1992 (6.4 cm), concentrations of chloride and nitrate in the ground water increased. Concentrations of these chemicals during early summer 1991 appeared to be diluted by large amounts of recharge (12.5 to 20 cm). Nitrate-N concentrations were similar upgradient, beneath, and downgradient of the other cropped areas such that additions of nitrate as a result of MSEA activity were difficult to distinguish above background levels. Nitrate-N concentrations were greatest beneath the potatoes (cropped area A) because the nitrogen application rate on the potatoes was greater than on any other crop.



Trace of sections shown on figure 1.

EXPLANATION

Chloride concentration, in milligrams per liter



Cropped area

A _____ A' Water table

Sweet Corn (C) 1991 crop and cropped area identifier

Data point

Figure 2.--Chloride concentrations along cross sections beneath cropped areas at the Princeton, Minnesota Management Systems Evaluation Area, April, 1992.

Nitrate-N concentrations decreased from 15 to 25 mg/L near the water table to 5 to 10 mg/L at 2 m below the water table upgradient, beneath, and downgradient of the cropped areas. Concentrations of nitrate-N at 7 m below the water table were less than 0.2 mg/L, indicating that the vertical gradient in nitrate-N concentrations continued between 2 and 7 m below the water table. Nitrate-N concentrations typically were 15 to 25 mg/L at the water table beneath the buffer areas upgradient and downgradient of the cropped areas throughout the year. Because nitrogen fertilizer was not applied to these buffer areas it is likely that the nitrate-N in the ground water was the result of nitrogen fixation by the legume alfalfa that was grown on the MSEA from 1981 through 1989. Nitrate-N concentrations in ground water beneath and immediately downgradient of the woodlands (fig. 1) were generally less than 1 mg/L as compared with average concentrations of about 15 mg/L at the water table beneath agricultural areas. Because nitrate-N concentrations in ground water decreased along the edge of the wetlands near Battle Brook and were less than 0.2 mg/L in Battle Brook, nitrate-N in ground water discharging into the wetlands/stream system appears to have been retained or consumed in the wetlands/stream sediments.

OTHER INORGANIC CONSTITUENTS — Sharp vertical gradients in the concentrations of dissolved oxygen, pH, alkalinity, calcium, magnesium, and sulfate in the upper two meters of the saturated zone were also measured at the MSEA. While most water-quality constituents varied over time and space, concentrations of dissolved oxygen decreased with depth and pH, alkalinity, calcium, magnesium, and sulfate increased with depth.

HERBICIDES — Atrazine and its metabolites de-ethylatrazine and de-isopropylatrazine were detected in ground-water samples collected from observation wells throughout the 65-hectare MSEA during April 1991 (before the implementation of the MSEA farming systems). Atrazine and alachlor were applied in bands (banded) to the sweet corn and field corn (cropped areas C and D) and broadcast on the continuous corn (cropped area E) during May 1991 at broadcast rates of 1.7 kg/ha and 2.25 kg/ha, respectively. During May 1991, metribuzin and metolachlor were broadcast on the potatoes (cropped area A) at rates of 0.56 kg/ha and 1.12 kg/ha, respectively. During May 1991, metribuzin and alachlor were banded on the soybeans (cropped area B) at broadcast rates of 0.56 kg/ha and 2.25 kg/ha, respectively.

Atrazine was detected above the quantitative reporting limit of 0.04 micrograms per liter (mg/L) in 21 percent of the 322 samples collected during the May-June 1991, August 1991, December 1991, and April 1992, sampling periods. Atrazine was detected at trace levels (concentrations between the quantitative reporting limit and qualitative detection limit of 0.01 mg/L) in 31 percent of the samples. The median atrazine concentration was 0.01 mg/L. Detections of atrazine and atrazine metabolites beneath the buffer areas and beneath the cropped areas where the atrazine was not applied (the potatoes and soybeans) indicate that there are persistent background levels of these compounds which are unrelated to the MSEA farming practices.

De-ethylatrazine was the most frequently detected of either the herbicides or the herbicide metabolites. It was detected above the quantitative reporting limit of 0.06 mg/L in 62 percent of the 322 samples collected and was detected at trace levels (concentrations between the reporting limit and the qualitative detection limit of 0.03 mg/L) in 12 percent of the samples. The median concentration of de-ethylatrazine was 0.08 mg/L. During the April 1992 sampling period, de-ethylatrazine concentrations were at trace levels (or not detected) near the water table and at 0.08 to 0.30 mg/L between 1 and 2 m below the water table. This vertical zonation, which was not evident before the April 1992 sampling period, likely indicates that water recharged through the MSEA cropped areas during 1991 had lower de-ethylatrazine concentrations compared with older ground water. De-isopropylatrazine was detected above the quantitative reporting limit of 0.08 mg/L in 8 percent of the samples and at trace levels (above 0.06 mg/L) in 2 percent of the samples.

Alachlor and its metabolites chloralachlor and 2,6-diethylaniline, were detected above the qualitative detection limits of 0.01, 0.06, and 0.01 mg/L, respectively, in 3, 2, and 0 percent of the samples, respectively. Metolachlor and metribuzin were detected above their qualitative detection limits of 0.01 and 0.03 mg/L, respectively, in 1 percent of the samples. None of the detections of herbicides or herbicide metabolites can be clearly linked to the MSEA farming systems.

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