EFFECTS OF FOCUSED RECHARGE ON THE TRANSPORT OF AGRICULTURAL CHEMICALS AT THE PRINCETON, MINNESOTA MANAGEMENT SYSTEMS EVALUATION AREA, 1991-92

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Dallas L. Peck, Director

For additional information write to:

District Chief
U.S. Geological Survey
2280 Woodale Drive
Mounds View, MN 55112

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EFFECTS OF FOCUSED RECHARGE ON THE TRANSPORT OF AGRICULTURAL CHEMICALS AT THE PRINCETON, MINNESOTA MANAGEMENT SYSTEMS EVALUATION AREA, 1991-92

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INTRODUCTION

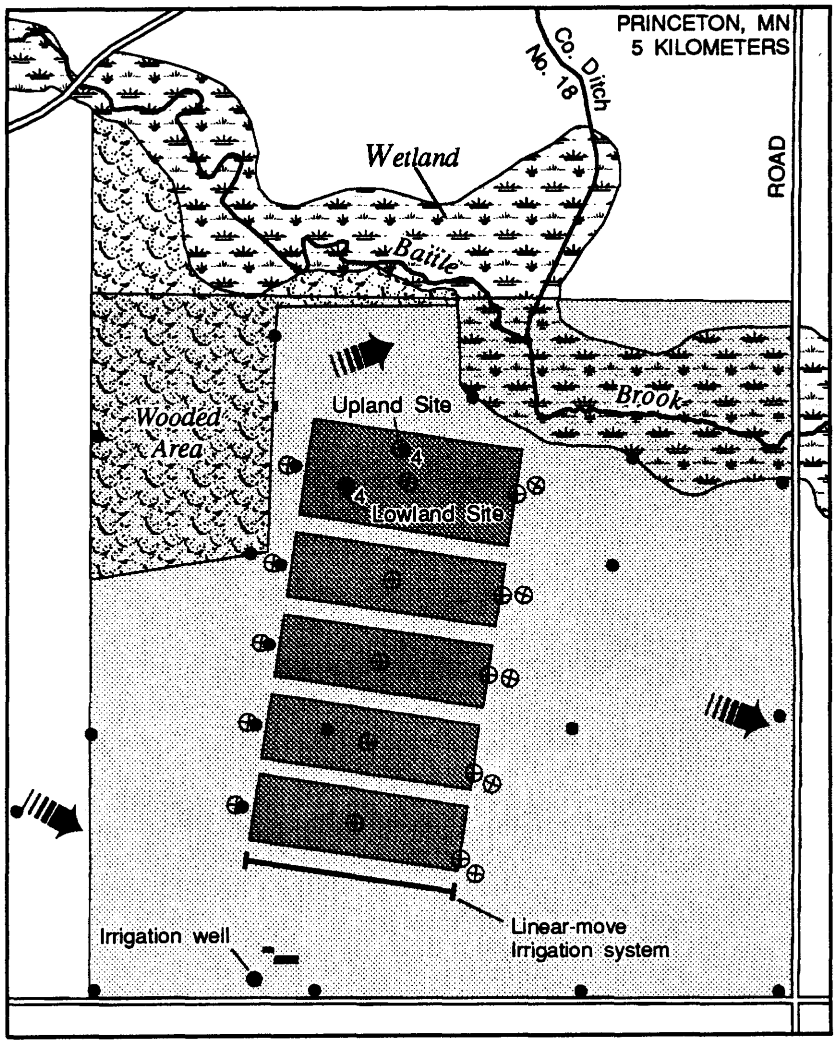
Rates of water movement through the unsaturated zone greatly affect the amount and concentrations of agricultural chemicals that may reach the water table. For example, recharge can flush chemicals to the water table which have accumulated in the unsaturated zone during dry periods. A better understanding of how topography influences recharge and the movement of agricultural chemicals is needed. In 1991, the U.S. Geological Survey (USGS), with funding from the USGS Toxic Substances Hydrology Program, began studying the movement of water and agricultural chemicals to the water table at the Management Systems Evaluation Area (MSEA) near Princeton, Minnesota.

The primary objective of this four-year research study is to evaluate the effects of transient recharge, topography, and subsurface heterogeneities on the flux of water and agricultural chemicals to ground water. To achieve this objective the approach was to (1) install instruments to sample and measure the movement of water through the unsaturated zone beneath topographically high and low areas of a corn field; (2) conduct recharge and tracer tests in the field to evaluate the movement of water and agricultural chemicals at both topographic settings; and (3) simulate the field recharge and tracer tests in the laboratory. The primary research hypothesis was that the vertical flux of water and agricultural chemicals is greater in topographically low areas than in topographically high areas.

DESCRIPTION OF RESEARCH SITES

The research is being conducted in an upland area (topographically high) and a lowland area (topographically low) within the northernmost cropped area at the 65-hectare Princeton MSEA (fig. 1). The upland and lowland sites are about 78 meters (m) apart and the difference in elevation between the sites is 1.4 m. Generally, the unsaturated zone consists of fine-to-medium-grained sand and the saturated zone consists of medium-to-coarse-grained sand (Delin and others, 1992a). The upper meter of the unsaturated zone at the upland site is slightly coarser, better sorted, and has a smaller percentage of silt- and clay-sized particles than the upper meter of the unsaturated zone at the lowland site. Organic carbon content in the upper 20 centimeters (cm) of topsoil is about 1.0 percent at the lowland site and about 0.6 percent at the upland site. There are discontinuous layers of silt and very-fine sand as thick as 20 cm in the unsaturated and saturated zones. The water table was about 4 m below land surface at the upland site and about 2.8 m below land surface at the lowland site during October 1991. Saturated hydraulic conductivities generally range between 0.004 and 0.08 cm per second. Based on well hydrograph analyses, ground-water recharge rates generally range from 10 to 20 cm per year. Ground-water flow is generally from southwest to northeast beneath the upland and lowland sites at about 8 cm per day. Ground-water-flow gradients varied between 0.0009 and 0.002 m per m during 1991.

The herbicides atrazine and alachlor were applied to the research sites at broadcast rates of 1.7 kilograms per hectare (kg/ha) and 2.25 kg/ha, respectively, during both May 1991 and May 1992. Nitrogen fertilizer was applied during April to June 1991 and during June 1992 at rates of 157 kg/ha and 123 kg/ha, respectively. Herbicides and fertilizers were not applied to the field from 1981-89, prior to the implementation of the MSEA farming systems, when the site was planted in alfalfa.



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

Research area

Direction of ground-water flow, January, 1991

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.

DYE-TRACING/TRENCHING STUDY AND INSTALLATION OF INSTRUMENTATION

Before the unsaturated-zone instruments were installed, a dye-tracing/trenching study was conducted at the upland and lowland sites to identify zones of preferential and retarded flow (Delin and others, 1992b). Water flow through unsaturated porous media is controlled to a large extent by grain size, differences in soil density, and macropores. Macropores and zones of reduced soil density are caused by climatic and geologic factors, animals, or plants and may permit rapid movement of water and chemicals through the unsaturated zone. Unsaturated-zone instrumentation commonly is installed horizontally in the walls of a trench, minimizing disturbances of the unsaturated zone above the instruments and allowing for identification of soil heterogeneities. Although gross soil heterogeneities may be visible within a trench, more subtle grain-size differences that affect water movement are typically difficult to identify. Thus, it may be impossible to identify whether the unsaturated-zone instrumentation is being installed in a homogeneous or in a heterogeneous part of the unsaturated zone. Installation of instrumentation in a heterogeneous zone of soil-moisture movement may result in collection of data that does not represent typical unsaturated flow for the site. Water samples collected from a suction sampler intercepting a rodent burrow filled with coarse sand, for example, will represent a different flow regime than will samples collected from a suction sampler installed in silt.

A three-percent solution of rhodamine WT dye was applied uniformly as a tracer to a 3.5- by 6-m area of land at both sites. The dye was applied at 10-day intervals from July 5 through September 13, 1991 to ensure complete coverage of the entire unsaturated zone with dye. Total rainfall from July 5 through October 22, 1991 was about 30 cm. Beginning October 22, 1991, a 3- by 2-m trench was dug in the middle of each dye-application area in 0.5-m stages of depth to a total depth of 2.0 m to locate the dye and characterize soil properties in the unsaturated zone. Photographs of the sides and bottom of each trench were taken to document the visible distribution of dye in the unsaturated zone. Soil samples collected from the sides and bottom of each trench were analyzed for grain-size distribution, hydraulic conductivity, bulk density, organic content, moisture retention, moisture content, and dye fluorescence.

The distribution of dye through the unsaturated zone was highly variable at both sites. Dye movement, as expected, was greatest beneath the furrows and least beneath the corn rows. The depth of visible dye at the upland site was typically about 0.4 m beneath the furrows and 0.1 m beneath the rows. At the lowland site, the depth of visible dye was typically about 0.2 m beneath the furrows and 0.01 m beneath the rows. The difference in visible dye between the upland and lowland sites likely is due to the higher organic content and finer-textured soil at the lowland site. The maximum depth of visible dye at both sites was about 1.0 m. Dye was visible along plant roots as deep as 1 m and visibly moved around coarser-grained heterogeneities in the unsaturated zone.

A fluorometer was used to quantify dye concentrations in water elutions of soil samples collected from the trenches. Concentrations at both topographic settings generally were greater than 400 micrograms per liter (μg/L) at land surface, less than 100 μg/L at the 0.2-m depth, and less than 1 μg/L below the 0.5-m depth. Preliminary results from analyses of soil bulk density, saturated hydraulic conductivity, moisture-retention characteristics, and moisture content suggest minimal correlation with visible dye distribution. Results suggest the dye moved preferentially in response to tillage patterns, microtopography, presence of plant roots, and differences in grain size.

Based on the relative presence or absence of dye, two vertical profiles at each site were instrumented with (1) suction lysimeter samplers, at depths of 0.8, 1.8, and 2.4 m, (2) thermocouples and time-domain reflectometry (TDR) probes, at depths of 0.2, 0.4, 0.6, 0.8, 1.0, 1.5, 2.0, 2.5, and 3.0 m, and (3) tensiometers, at depths of 0.5, 1.0, 1.5, 2.0, and 2.5 m. A water-table well was installed upgradient of each trench so that concentrations of agricultural chemicals reaching the water table could be determined. Precipitation and ground-water levels were continuously recorded at both sites. TDR is a process of sending electronic pulses through a coaxial cable that is attached to a fixed-length probe embedded in the soil (Topp and others, 1980). The waveform is influenced by the moisture content of the soil surrounding the probe. Because the dielectric constant of water is much higher than that of most other materials, a signal in moist soil will propagate more slowly than in the same soil when dry. Thus, the moisture content can be calculated by measuring the waveform propagation time over the fixed-length probe.

WATER INFILTRATION AT THE UPLAND AND LOWLAND SITES

Infiltration tests at the upland and lowland sites were conducted during 1992 by applying about 2.5 cm of water from a linear-move sprinkler irrigation system. The movement of wetting fronts through the unsaturated zone to the water table were then evaluated with TDR. For the purpose of this study, a wetting front generally was defined as about a 2 percent increase in volumetric moisture content.

The movement of wetting fronts was highly variable at the upland and lowland sites during 1992. Wetting fronts typically moved more rapidly and penetrated deeper into the unsaturated zone at the lowland site than at the upland site. About 24 hours after 2.5 cm of irrigation water was applied on June 9, for example, the wetting front at the upland site had moved to a maximum depth of only about 0.8 m below land surface (fig. 2). By comparison, the wetting front at the lowland site reached the water table (about 2.8 meters below land surface) after the same 24-hour period, resulting in ground-water recharge. The increased moisture contents at the 2.5- and 3.0-m depths at the lowland site resulted from the water table being about 2.8 m below land surface on June 9 (fig. 2). The increase in the amount of water in the soil from June 9 to June 10 at the lowland site (3.7 cm) was greater than the amount at the upland site (2.3 cm). These results indicate that the lowland site was an area of preferential or funneled flow of water because the increase in water storage (3.7 cm) exceeded the amount of water applied (2.5 cm).

The apparent pattern of soil-moisture movement as indicated by rhodamine WT adsorption in the unsaturated zone did not reflect measured soil-moisture distributions during 1992. Soil-moisture movement in what was identified as a retarded flow zone during the dye-trace study was actually measured as accelerated (preferred). This difference likely indicates that the preferred flow zones observed on the trench walls did not extend much beyond the face of the trench, or encompass the entire length of the installed TDR probes. In addition, it is likely that the probes that were installed in an apparent preferential flow zone must have actually penetrated an adjacent zone of retarded flow.

WATER QUALITY AT THE UPLAND AND LOWLAND SITES

Water samples were collected from each sampling location (including precipitation, irrigation water, suction lysimeter samplers, and the water-table well) prior to the start of each infiltration test to determine pre-test concentrations of the agricultural chemicals. Following the application of irrigation water, water samples were collected from the suction lysimeter samplers as the wetting front passed a given sampler elevation, and from the water table after the wetting front reached the saturated zone. The water samples were analyzed for dissolved major anions (nitrate-nitrogen, chloride, sulfate, bromide) using ion chromatography and analyzed for selected herbicides and herbicide metabolites (atrazine, de-ethylatrazine (DEA), de-isopropylatrazine (DIA), alachlor, chloroalachlor, 2,6-diethylanaline, metolachlor, and metribuzin) using gas chromatography/mass spectroscopy.

Nitrate-nitrogen (nitrate-N) concentrations in water samples collected from unsaturated-zone at the lowland site were greater than concentrations at the upland site during 1992. The median nitrate-N concentration in the unsaturated zone at the lowland site was 35.4 mg/L (10 samples) compared to a median of 19.5 mg/L (8 samples) at the upland site. Whereas nitrate-N concentrations at the lowland site were similar throughout the unsaturated zone, nitrate-N concentrations in the upper meter of the unsaturated zone at the upland site (median of 5.3 mg/L) were much less than deeper in the profile (median of 22.5 mg/L). The median nitrate-N concentration from the water table at the lowland site (16.6 mg/L) was also greater than the median concentration of 13.5 mg/L at the upland site. Nitrate-N concentrations changed little throughout the spring and summer of 1992 at both sites.

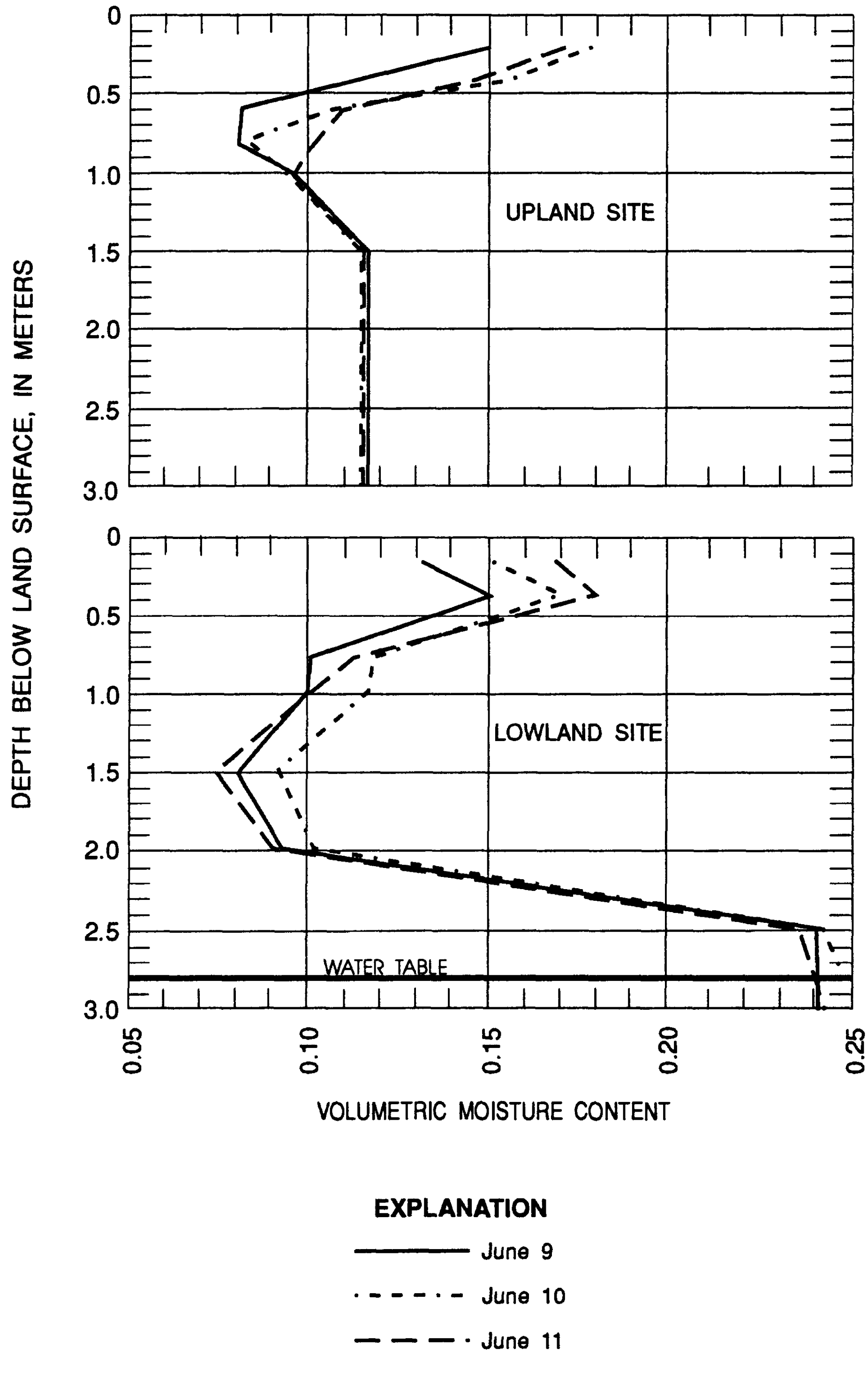


Figure 2.--Soil moisture at the upland and lowland sites, following application of 2.5 centimeters of irrigation water on June 9, 1992.

Atrazine and DIA concentrations in water samples collected from the unsaturated zone at the lowland site were generally greater than concentrations at the upland site during 1992. Atrazine concentrations at the lowland site ranged from 0.07 to 0.42 µg/L with a median of 0.09 µg/L (5 samples) compared to a range of 0.04 to 0.20 µg/L and a median of 0.07 µg/L (4 samples) at the upland site. Similarly, DIA concentrations at the lowland site ranged from 0.0 to 0.49 µg/L with a median of 0.09 µg/L compared to a range of 0.06 to 0.25 µg/L and a median below the reporting limit of 0.08 µg/L at the upland site. DEA concentrations at the lowland site ranged from 0.0 to 1.43 µg/L with a median of 0.06 µg/L compared to a range of 0.08 to 0.35 µg/L and a median of 0.18 µg/L at the upland site. Similarly, the concentration of atrazine in samples from the water table at the lowland site (median of 0.05 µg/L for 4 samples) were also slightly greater than concentrations at the upland site (median below the reporting limit of 0.04 µg/L for 3 samples). Because the detection limit of 5 nanograms per gram for atrazine in soil samples is too large to detect these herbicide concentrations, these results indicate that full evaluation of the movement of atrazine to ground water may require analysis of water samples from the unsaturated zone.

Differences in the movement of wetting fronts, agricultural chemicals, and tracers at the upland and lowland sites likely result from a combination of factors including differences in organic content, grain size, macropores and sedimentary heterogeneities, antecedent moisture conditions, and topographic relief. These results support the hypothesis that the vertical flux of water and agricultural chemicals is increased in lowland sites compared to upland sites.

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