

IMPACT OF AGRICULTURAL
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PLEISTOCENE LACUSTRINE
DEPOSITS, DAVIESS AND HOPKINS
COUNTIES, KENTUCKY: INTERIM
FINDINGS

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**Philip G. Conrad¹, James S. Dinger¹,
Lyle V.A. Sendlein², and Jeffrey D. Snell³**

ABSTRACT

Two sites in the Western Kentucky Coal Field were instrumented and monitored during 1992 and 1993 for the occurrence of agricultural chemicals in ground water. Both sites are located in broad valley floors that owe their topography to Pleistocene lacustrine deposits. The lacustrine deposits are at least 20 feet thick at the main nests of monitoring wells and are dominantly composed of silt and clay. Shallow ground-water flow is principally lateral toward local drainage ditches. The monitored sites are in or near groundwater discharge zones, and shallow ground water at the sites does not enter deeper ground-water systems. Both sites are tile drained at a depth of approximately 3 feet, and the piezometric surface seldom reaches 6 feet in depth at the sites.

Corn has been grown annually at the Hopkins County site for most of the last 40 years with conventional tillage practices. Atrazine has been applied to this field during most years for over three decades. Atrazine, simazine, and 2,4-D were applied at this site during the time of study. Nitrogen was applied as urea and anhydrous ammonia.

Soybeans were grown using no-till and minimum-till practices at the Daviess County site during the time of study. Metolachlor, 2,4-D, and imazaquin were applied during 1992 and 1993. No nitrogen fertilizers were applied at the site during the time of study.

Tile-drain effluent contained the highest concentrations of the pesticides applied. Below the tile drains, ground water in the upper 10 feet of the deposits contained the highest pesticide concentrations. There were few detections of the applied pesticides at both sites at a depth of 20 feet, and these detections were at trace concentrations. The clay-rich lacustrine deposits impede the downward movement of pesticides where they are not perforated by deep macropores in the form of shrinkage cracks and deep root casts.

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Measurements of nitrate-N at the Daviess County site were below 1.5 mg/L at all depths. Concentrations in shallow ground water at the Hopkins County site usually measured over 8 mg/L from the water table to approximately 25 feet in depth. The dichotomy between the sites is attributed to better conditions for denitrification at the Daviess County site.

INTRODUCTION

The U.S. Environmental Protection Agency, the Kentucky Cabinet for Natural Resources and Environmental Protection, and many farming and environmental groups have expressed concern about the effect of agricultural practices on ground water. Of particular interest is the fate of agricultural chemicals that are applied over large areas in the course of raising crops, and the effect of livestock-related activities on ground water. To address this concern, the 1990 Kentucky General Assembly passed Senate Bill 271, which mandated an assessment of the impact of these activities on the ground water of Kentucky. Ten study sites in different physiographic regions of the State were chosen for general assessment. Research on the movement and causes of agricultural chemicals in both shallow and deeper ground water was also a focus at six of the sites. These efforts are supported by the University of Kentucky College of Agriculture, the Kentucky Geological Survey, and the Kentucky Water Resources Research Institute.

This interim report focuses on two of the six research sites. These two sites represent the topographically flat valleys of the Western Kentucky Coal Field. The research began in early 1992, and is focused on defining the groundwater flow systems, monitoring for the presence or absence of agricultural chemicals in these systems, and determining mechanisms that control their occurrence. This report will be followed by a more detailed KGS Report of Investigations.

Physiography and Geomorphology

Figure 1 shows the location of the two counties and the distribution of lacustrine and alluvial deposits within the Western Kentucky Coal Field. The lacustrine sediments of the Western Kentucky Coal Field partially fill the larger stream valleys, and overlie alluvium at the base of the buried valleys and Pennsylvanian bedrock. Soil types reflect the lacustrine parent material. Lacustrine and alluvial sediments fill the valley floors of many tributaries of the Ohio River in Indiana, Ohio, Kentucky, and Illinois (McFarlan, 1943; Thornbury, 1950; Walker,

1965; Campbell and others, 1974; Ryder, 1974; Teller and Last, 1981).

The very low gradient of the land surface prevents soil erosion, but flooding is common in many of these areas during late winter and spring. Hills surrounding the lacustrine deposits are composed of Pennsylvanian bedrock and are mantled by loess and silty loessal soils. Many of these low-gradient slopes are formed in the region.

Adjacent to the Green River, alluvium consists of sand and gravel underlying 30 or more feet of fine-grained deposits (Ryder, 1974). In the flat tributary valleys to the Green River, however, coarse alluvium is less abundant below the finer grained lacustrine deposits.

The uppermost units at both monitoring sites consist of Pleistocene lacustrine deposits and more recent alluvium, which combined generally total over 20 feet of sediments above bedrock. Over 90 percent of these sediments is silty or argillaceous in nature, and the sediments are underlain by Pennsylvanian sandstone, shale, and coal.

The upper 7 feet of sediments are more silty at the Hopkins County site than the Daviess County site, but both sites include clay-rich lacustrine deposits from approximately 10 to 25 feet below the ground surface. The sites are each tile-drained with perforated pipe at a depth of approximately 3 feet to shorten the period of seasonally high water tables in late winter and spring when the fields are too saturated for planting.

Ground-Water System Characterization

Information used to delineate and characterize the ground-water flow systems was collected from April 1992 to September 1993. This characterization was derived from existing geologic and topographic maps, logs of geologic materials encountered during drilling for monitoring wells, rainfall events recorded on site with a tipping bucket rain gage and data logger, measurements of well elevations above mean sea level, 381 water-level measurements from monitoring wells at both sites over 1.5 years, water-level measurements of nearby streams,

water-well logs on record with the State of Kentucky, various geologic publications, county soil-survey publications, and major-ion analyses of ground water at different depths.

HOPKINS COUNTY SITE

Soil and Geology

Belknap silt-loam in the Belknap-Waverly soil association is the predominant soil type at the study site. This soil is moderately permeable, and is acid to strongly acid in the surface layer unless limed (Fehr and others, 1977).

The geology of the county is mapped on the Slaughters (Kehn, 1964b), Hanson (Franklin, 1965), Coiltown (Franklin, 1967), Madisonville West (Kelm, 1964a), Madisonville East (Kehn, 1963), Dawson Springs (Trace, 1967), St. Charles (Palmer, 1967), and Nortonville (Palmer, 1968) geologic quadrangle maps.

Stratigraphy of sediments and bedrock at this site was logged during drilling of monitoring wells. The upper 7 feet of sediments are composed of silt (Figs. 2-3). These silty sediments were derived from Pleistocene loess from the surrounding hilly terrain (Fehr and others, 1977). From 7 to 12 feet, silt and clay are interbedded. Below 12 feet, sediments are dominated by silty clay. Weathered sandstone bedrock was encountered during drilling at 26 feet deep, and competent bedrock is below 27 feet. Shallow bedrock is part of the Middle Pennsylvanian Patoka Formation (Greb and others, 1992). Alluvium was not encountered at the base of the lacustrine sediments. Elevation of the ground surface at all wells is within 1 foot of 390 feet.

Land Use

Corn has been grown annually at this site for over four decades, and atrazine has been used annually for over 30 years. An exception was in 1991, when soybeans were grown and atrazine was not applied.

Agricultural chemicals were applied in spring and summer during the time of study. Atrazine, simazine, and nitrogen fertilizer were applied in 1992. Nitrogen was applied as part of a 9-28-30 fertilizer mixture in April of 1992 at a rate of 18 lbs./acre nitrogen (the fertilizer included phosphorus and potassium). Corn rows were side dressed with anhydrous ammonia as a post-emergent soil injection approximately 6 weeks after planting, at a rate of 200 units/acre (200 lbs./acre nitrogen). The two triazine

herbicides were simultaneously broadcast and disked in on about May 2, very shortly before planting. Atrazine was applied at a rate of 1.1 lbs./acre (Aatrex Nine-0; 90 percent atrazine), and simazine was applied at a rate of 1.8 lbs./acre (Princep Caliber 90; 90 percent simazine).

In 1993, nitrogen was again applied at a rate of 18 lbs./acre as part of a 9-28-30 fertilizer mixture. Anhydrous ammonia was side-dressed in 1993 as a post-emergent soil injection on June 28 at a rate of 100 units/acre. Application rates of the triazine herbicides were increased in 1993, and 2,4-D ester was also applied. Atrazine and simazine were broadcast and disked in on May at rates of 1.25 lbs./acre (Aatrex Nine-O), and 2.5 lbs./acre (Princep Caliber 90). On July 19, 2,4-D ester was applied at a rate of 1 pint/acre.

Monitoring Methods

Seven monitoring wells, one piezometer, and one suction lysimeter were installed at the Hopkins County site to monitor water quality in the lacustrine deposits and the underlying bedrock (Fig. 2). Wells were constructed to different depths at increments of 5 feet down to bedrock. The screen of most wells was 2.5 feet long, and the screen of the deepest well crossed the interface between clay-rich lacustrine deposits and underlying sandstone bedrock. Figure 3 is a schematic cross section that shows the screened intervals of the well nest and two wells adjacent to a large drainage ditch at the southern boundary of the monitored field. Monitoring wells were constructed in separate boreholes, and are not actually stacked, as implied on the cross section. One suction lysimeter was installed at the well nest to a depth of 5 feet. The elevation of the ground surface at all wells and the lysimeter was approximately 390 feet. Appendix A gives details of well construction and installation of other monitoring equipment.

The well nest consisted of five wells (H01, H02, H03, H05, and H06) and the suction lysimeter (H07), and was installed 50 feet from and parallel to the edge of the drainage ditch. Two additional wells were located adjacent to the drainage ditch at the edge of the field (Fig. 3). These two wells were installed approximately 100 feet apart to prevent the long screen interval of well H09 from influencing the hydrologic setting of well H08. The screen interval of well H08, near the ditch, was constructed at the same elevation as the interval for well H03, at the well

nest, for comparison of piezometric level and water quality.

Ground-water samples were collected during two growing seasons from April 1992 to September 1993 (Table 1). The 115 samples collected from the site were analyzed for pesticides and nitrate-N (nitrate-nitrogen). Samples were collected more frequently in the spring after application of chemicals.

Table 1. Sources of water-quality and water-level data for the Hopkins County site (April 1992–September 1993).

<i>Sources</i>	<i>Number at Site</i>
Monitoring wells	8
Suction lysimeters	1
Monitoring-well samples	102
Lysimeter samples	13
Field-chemistry measurements	91
Water-level measurements	125

Pesticides were analyzed by two methods. The results here were determined using enzyme-linked immunosorbent assay (ELISA) unless otherwise stated. Some of the samples were also analyzed by gas chromatography (GC).

Nitrate-nitrogen was measured using a cadmium-reduction method. Concentrations of nitrate-nitrogen (in mg/L) can be converted to concentrations of nitrate (in mg/L) by multiplying the values in this report by 4.43. Appendix B provides details on the analysis methods used in this study.

A rain gage and data logger were installed next to the field to record rainfall. Water levels in wells were measured using an electronic probe with a graduated cable. Measurements were made before purging wells prior to sampling. The level of water in the ditch was also measured.

RESULTS AND DISCUSSION

Physical Hydrogeology

The water table at the monitoring-well nest was generally between 387 and 384 feet (3 to 6 feet in depth). It was slightly higher farther from the ditch, where it was somewhat controlled by the 3-foot-deep drainage tiles when the water table rose in late winter and early spring. The tiles had an elevation of approximately 387 feet in most of the field. Figure 4 shows the fluctuation of potentiometric water levels in the wells over two growing seasons. The water level of the shallowest well (H06) approximated the water table height at the monitoring well nest. The nearby ditch periodically became dry or stagnant during the summer, when precipitation was infrequent.

The potentiometric levels of deeper wells of the monitoring nest (H02, H03, and H08) were generally deeper, indicating a slight downward

gradient near the well nest. Also, the water level in the 20-foot well near the ditch (H08) was approximately 2 feet lower than the 20-foot well at the well nest (H03). These differences in water level indicate that ground-water flow is dominantly horizontal from the monitoring-well nest toward the ditch. The potentiometric gradient from the well nest was 0.04.

The deepest wells (H02, H03, and H09) had water levels that were usually above the base of the ditch. Dry conditions in September 1993 created an exception (Fig. 4). Ground water below the ditch had an upward component of flow toward discharge to the ditch. During most of the study period, the apparent discharge area for ground water at all monitored depths was the nearby ditch.

The chemistry of ground water in bedrock was different than in more shallow ground water. Water from bedrock was a sodium-calcium bicarbonate type with a small amount of chloride, whereas ground water from the shallowest well during the summer of 1992 was a calcium chloride type. This implies that a large component of the deeper ground water monitored at the site was derived from below the lacustrine deposits.

Ground-Water Quality Nitrate

Nitrate-N concentration in the shallowest monitoring well, H06 (screened from 5 to 7.5 feet in depth), ranged from 13.5 to 24 mg/L. Concentrations in the lacustrine deposits generally decreased with depth, and ranged from 7 to 13 mg/L in most wells below 8 feet in depth (Fig. 5).

The deepest well (H02), partly screened across sandstone bedrock, consistently yielded ground water with less than 3 mg/L nitrate-N, and often less than 2 mg/L. Likewise, ground water from 20- and 22.5-foot-deep wells screened in lacustrine deposits near the ditch had nitrate-N concentrations below 1 mg/L. This low-nitrate-N water is similar to that in the bedrock well at the well nest, and provides evidence that ground water from bedrock below the ditch is flowing upward toward discharge to the ditch. Conversely, the U.S. Environmental Protection Agency maximum contaminant level (MCL) of 10 mg/L for nitrate-N was often exceeded at all depths within the lacustrine deposits.

The lower concentrations of nitrate-N at the bedrock/lacustrine-deposit interface are consistent

with those measured in other private wells in the region. Information on record with the Kentucky Ground-Water Data Repository showed a 1.1 mg/L average concentration of nitrate-N for 17 private wells in the Western Kentucky Coal Field. The median nitrate-N concentration for these coal field wells was 0.17 mg/L.

Triazine Herbicides

The first sample drawn from each of the monitoring wells in mid-April 1992 had triazine concentrations between 0.1 and 0.4 micro-g/L (Appendix B). These concentrations are attributed to temporary contamination directly resulting from the disruption of sediments and vertical mixing of ground water during well construction. Herbicide concentrations in samples collected 2 weeks later were all below the detection level.

The highest concentrations of herbicides for 1992 samples were from the shallowest monitoring well (H06), screened between 5 and 7.5 feet in depth. The maximum concentrations were in samples collected on June 4, 1 month after application. Atrazine was detected by GC at 1.8 micro-g/L, and simazine was detected by GC at 1.6 micro-g/L (Fig.5). The graph showing concentration over time for the shallowest well (H06) indicates that herbicides did not reach a depth of 5 feet until 2 to 4 weeks after application (Fig. 6). None of the samples exceeded the atrazine MCL of 3 micro-g/L. Concentrations remained above 1 micro-g/L at this depth for approximately 3 weeks. Triazines were not detected in any deeper wells until over 5 weeks after application, and these concentrations were all below 0.3 micro-g/L.

Triazine detections resulting from application in the spring of 1993 were fewer and lower in concentration than those from 1992, despite application at a higher rate in 1993. Concentrations at a depth of 5 to 7.5 feet (well H06) reached a maximum of 0.55 micro-g/L in 1993, according to GC analysis, and were below 0.3 micro-g/L in samples collected in August and September (Fig. 6). There were no detections in any deeper wells in 1993.

The fewer detections and lower concentrations in the shallowest ground water during 1993 were likely caused by a lack of rainfall events over 0.5 inch for nearly 6 weeks after application that year. In comparison, four rainfalls over 0.5 inch occurred in the 6 weeks after 1992 application (Fig. 6). The initial detection of pesticides in both years

coincided with the first recorded rise in ground-water level after application (Fig. 6).

This indicates that sufficient rainfall to recharge ground water is necessary for pesticides to reach shallow ground water in detectable concentrations.

Dry weather after application allows the herbicides a longer residence time in the soil zone, where conditions are best for degradation into other compounds and sorption onto organic matter. The longer time before significant rainfall in 1993 was the likely cause of lower herbicide concentrations in shallow ground water that year.

2,4-D

On July 19, 1993, 2,4-D was applied, and samples were collected 16 days after application (August 4). There were no detectable concentrations in these samples or the following samples collected on September 15. Rainfall records indicate that conditions were wetter during application of 2,4-D than during application of the triazine herbicides. If detectable concentrations were present at sampled depths, they occurred for less than 2 weeks.

Suction Lysimeter

Triazine pesticide concentrations in the suction lysimeter (H07, 5 feet deep) were usually below detection, whereas the well screened from 5 to 7.5 feet in depth often had detectable concentrations. Nitrate-N concentrations in well water and lysimeter water were more similar, but often lower in the lysimeter by 20 to 35 percent. In this study, the water quality from the shallow well was used to represent ground water at this depth, and results from the suction lysimeter were not used.

Site Summary

Shallow ground-water flow at the study site was toward the drainage ditch. Very shallow ground water flowed laterally to the ditch, and there was little downward flow in the upper 10 feet of sediments. Shallow ground water below the level of the ditch also apparently discharged into the ditch except in very dry weather, when the potentiometric level dropped below the stream bed.

The fewer detections and lower concentrations of triazine herbicides in shallow ground water during 1993 compared to 1992 were likely caused by a lack of enough rainfall to recharge ground water for nearly 6 weeks after application that year. In comparison, there were four rainfalls

each over 0.5 inch during the 6 weeks after the 1992 application. As a result, herbicides were detected in shallow ground water sooner in 1992, and concentrations were appreciably higher than in the following year.

Concentrations of nitrate-N decreased with depth from the ground surface. Consistent concentrations greater than 7 mg/L were found most often at the well nest in the lacustrine deposits, which indicates that denitrification is inefficient within 20 feet of the ground surface. The application of nitrogen fertilizers where denitrification occurs at a slow rate presumably raises the nitrate-N concentration above natural concentrations.

Ground water from the deepest well has nitrate-N concentrations closer to the 1.1 mg/L average (and 0.17 mg/L median) measured for 17 wells in the Western Kentucky Coal Field. Local ground-water flow toward discharge at the local surface drainage prevented higher nitrate-N in shallow ground water from raising the nitrate-N concentration of ground water below the lacustrine deposits.

DAVIESS COUNTY SITE Soil and Geology

Figure 1 shows the location of Daviess County in the Western Kentucky Coal Field. Like the Hopkins County site, the Daviess County site lies in a broad, flat valley bottom, as indicated on a map of the study area (Fig. 7).

Soil at the Daviess County site is a Karnak silty clay of the Belknap-Karnak-Waverly association. The soil is sticky and plastic when wet, and wide cracks form in the soil when it is dry. Cracks in soil at the study site were common over 1/4 inch in width at the ground surface, and these cracks can extend over 3 feet in depth in very dry conditions. The parent material of the Karnak silty clay is lacustrine deposits of Pleistocene age (Cox, 1974). This soil is much less silty than soil at the Hopkins County site.

The geology of the county is mapped on the Owensboro West (Goudarzi and Smith, 1971), Owensboro East (Johnson and Smith, 1968), Maceo (Calvert, 1966), Curdsville (Fairer and Norris, 1966), Panther (Goudarzi, 1971), Sutherland (Johnson and Smith, 1969), Philpot (Calvert, 1964), Glenville (Johnson and Smith, 1972a), and Utica (Johnson and Smith, 1972b).

Stratigraphy of sediments and bedrock was logged during drilling of monitoring wells. Sediments above bedrock at the monitoring site

are lacustrine clays, silt, or alluvial deposits. A silty clay extends from the ground surface to approximately 8.5 feet in depth, and is underlain by a gravel zone approximately 1.5 feet thick. A clay unit extends from the gravel to bedrock at both monitoring-nest locations (Fig. 8). The bedrock surface is weathered and gravel is present at this surface in some locations. The only variation in this lithologic sequence was at well DA1, where the usually thick clay unit is not present below the upper gravel zone. Instead, sandy clay and gravel extend from the upper gravel zone to bedrock (Fig. 8).

Bedrock consists of interbedded sandstone, shale, siltstone, limestone, and coal. The beds have a southerly dip in this location, and there is no known faulting in the immediate area. The Davis coal of the Carbondale Formation (Greb and others, 1992) lies from 58 to over 70 feet in depth at the site, and is approximately 2 feet thick. The Yeargins Chapel Limestone was found below the Davis coal during drilling.

Land Use

The farm field was wooded until logged and cleared for farming in the early 1970's. The field was no-till farmed for at least 4 years prior to this study, including during the 1992 growing season. The field was tilled in the spring of 1993. One oil well was in service in the field.

The adjacent wooded lot has been selectively logged; most smaller trees remain. Several oil wells have been drilled in the woods, and some of them were in operation during the study.

Soybeans were grown during both 1992 and 1993 in the western two-thirds of the monitored farm field, where the wells are located. In 1991, prior to well installation, corn was grown on the monitored part of the field, and atrazine and simazine were applied.

Metolachlor, 2,4-D, and imazaquin were applied during monitoring in 1992, and imazaquin was again applied in 1993. No nitrogen fertilizers were used either year. The primary source of nitrogen for crops during the study was from the fixation of atmospheric nitrogen by soybean plants.

Metolachlor and 2,4-D were both applied on June 15 and June 17, 1992. On June 15, application of metolachlor and 2,4-D was interrupted by a localized "very hard rain," according to a witness. The rain immediately followed approximately 30 minutes of herbicide application on part of the field. This area of partial application

included the locations of all monitoring wells of the crop site. On June 17, the same pesticides were applied to the whole field. Metolachlor (Dual) was applied at a rate of 2 lbs./acre active ingredient, and 2,4-D was applied at a rate of 0.5 lb./acre active ingredient.

Earlier in June 1992, metolachlor was detected in water samples from tile drains that cross the field. The tile drains trend north-south, and discharge into ditch 2, along the northern border of the field. The early June metolachlor was not applied by the landowner, and may have been blown onto part of the monitored field from aerial spraying to the adjacent farm to the south. Metolachlor was not applied in 1992 at the monitoring-well locations before the mid-June dates previously mentioned.

On July 14, 1992, imazaquin was applied as part of the pesticide combination Squadron at a rate of 56 grams (approximately 1/8 lb.) per acre. Analyses for imazaquin began in early June 1993.

In 1993, imazaquin was the only pesticide applied at the site for which there was analytical capability in this study. Imazaquin was applied to the field on June 19, at a rate of 56 grams/acre. Five sets of ground-water samples were collected from shortly before application until one month after application. The detection limit for imazaquin is 5 micro-g/L, which is considerably higher than for the other pesticides studied (Appendix B).

Monitoring Methods

Figure 7 shows the location of monitoring points, which include a nest of monitoring wells constructed in a no-till farm field and two individual wells in outlying locations of the same field. In addition, a nest of monitoring wells was constructed in an adjacent wooded lot, and two individual wells were installed in separate outlying locations within the woods. Each of the four individual wells at the site, along with one well at each well nest, was screened at similar elevations. This allowed comparison of the potentiometric surface over a broad area, and assessment of the direction of lateral ground-water flow.

Figure 8 shows the screened intervals of the two well nests and one of the outlying wells (DAI). The monitoring wells at the nest sites were constructed in separate boreholes a few feet apart, and were not actually stacked, as the cross section implies. Most wells had a 2.5-foot screen near their base to collect ground water from that interval. Wells at each nest were constructed to different depths at increments of 5 feet to the bedrock

surface. Five wells were screened in bedrock. The deepest well in each nest was screened to retrieve ground water from the Davis coal, since the cleats in coal beds provide permeability for ground-water flow. The elevation of the ground surface is approximately 389 feet at all well locations, except at well DA1, where the elevation is closer to 390 feet.

Ground-water samples were collected from April 1992 to July 1993, a span of time that included two growing seasons (Table 2). One hundred fifteen samples were collected from the site, and all were analyzed for pesticides and nitrate-N. Samples were collected more frequently in the spring after application of chemicals. Analyses of major ions were performed on water samples collected in July 1992.

Table 2. Sources of water-quality and water-level data for the Daviess County site (April 1992–September 1993).

<i>Sources</i>	<i>Number at Site</i>
Monitoring wells	16
Suction lysimeters	2
Monitoring-well samples	203
Lysimeter samples	15
Field-chemistry measurements	157
Water-level measurements	256

Pesticides were analyzed by two methods. The results reported here were determined using an ELISA method unless stated otherwise. A portion of the samples were also regularly analyzed by GC. Greater detail on the analysis methods is in Appendix B.

Two local drainage ditches were sampled during the study period by personnel from the University of Kentucky Department of Agronomy. Pesticide analyses were performed on these samples by the Department of Agronomy.

Rainfall information is a composite of records from Calhoun, Ky., 6 miles southwest of the site, and a rain gage installed at the study site. Calhoun records extend to June 17, 1992. A local rainfall not included in the Calhoun station record was witnessed at the study site on June 15, 1992. This "very hard rain" was estimated to be a 1-inch event, and is shown as such on rainfall graphs. Measurements after June 17, 1992, were made by a recording rain gage installed at the

study site. Water levels in wells were measured (Table 2) before purging prior to sampling.

RESULTS AND DISCUSSION

Physical Hydrogeology

The water table at the crop monitoring nest was usually between an elevation of 388 and 386 feet (1 to 3 feet in depth), but was lower when precipitation was infrequent (Fig. 9). The potentiometric levels measured in the five shallowest wells at the crop nest were very similar, indicating that the vertical component of flow in the lacustrine deposits was very small.

The most hydraulically conductive zone in the lacustrine/alluvial deposits above bedrock was the gravelly zone below the silty clay. The gravelly zone is at an elevation of approximately 380 feet, which is approximately 9 feet from the ground surface. Ground water in the lacustrine deposits had a very small gradient toward the east-northeast, as determined by water levels measured in wells screened at similar elevations across the site. The discharge area for this shallow ground water was probably ditch 3, which is at least 4 feet deeper than ditches 1 and 2, and has a bottom elevation of approximately 381 feet (Fig. 7).

Water levels in the two deepest bedrock wells (DA8 and DA9) were lower than in the shallower wells, indicating a downward gradient in the Pennsylvanian bedrock. The water level in well DA8 was often lower than in all other wells because it recharged much more slowly after purging. When given ample time to recharge, the water level of well DA8 was between that of the deeper wells and those shallower than DA8. Normal water levels for well DA8 were recorded during the first half of 1993, when it was not purged or sampled (Fig. 9).

Major-ion chemistry of ground water from bedrock was different than that of more shallow ground water. Ground water from the Davis coal bed was a sodium bicarbonate type, whereas ground water from the lacustrine deposits was a calcium-magnesium bicarbonate.

Properties of the Karnac silty clay soil in the upper few feet of deposits at the study site create shrinkage cracks in dry conditions. Such cracks serve as efficient macropores for transmission of water from the ground surface.

A deeper set of macropores was derived from remnant tree roots in the form of well-preserved root casts and rotting root material.

These were observed during well construction to extend from the soil zone, through the underlying silty clay, to the underlying gravelly zone (approximately 8 to 10 feet deep). The root material was not observed below the gravelly material. At the location of well DA1, root casts were abundant at greater depth, down to the level of bedrock. During well construction, ground water was seen moving through the root material into recently drilled boreholes. Water was seen entering boreholes from these conduits as deep as 7 feet from the ground surface. The abundant root material in the gravelly zone suggests that many of these macropores extend to that depth. The remnant tree roots are efficient macropores for the transmission of ground water, and serve as avenues of preferential flow through the clay. Ground water from precipitation causes a preferential vertical displacement of water in the root macropores instead of a more uniform piston type displacement of ground water throughout the silty clay. These macropores effectively direct ground water to the gravel zone underlying the clay unit.

Ground-Water Quality

Nitrate

Nitrate-N concentrations in ground water were consistently low for all wells at the site, and far below the MCL of 10 mg/L. All samples had concentrations below 1.5 mg/L, except for the first sample collected from well DA14 at the woods well nest (April 1992), which had a concentration of 4.5 mg/L. This initial high concentration was not approached by future samples, and was apparently caused by temporary contamination of the screened interval during well construction. Consistently low nitrate-N concentrations were probably caused by efficient denitrification in the saturated zone.

Initial Herbicide Concentrations

On the initial day of application of metolachlor and 2,4-D near the wells, the application was halted by heavy rainfall. This partial application area included the monitored portions of the field. Rainfall within 30 minutes after application would have allowed little time for adsorption, degradation, or volatilization (in the case of 2,4-D) of the pesticides. A second application occurred 2 days later, on June 17. Groundwater samples were collected from monitoring

wells the following day (June 18), 3 days after the initial application of metolachlor and 2,4-D.

In the first samples collected after application adjacent to the wells, pesticides were detected in six wells in the crop field (DA1, DA3, DA4, DA5, DA6, and DA10), which monitored the regolith from 3 feet to 17.5 feet in depth. This rapid downward movement was likely caused by the short period between application and rainfall, and by preferential flow paths (root casts) through the silty clay unit.

At the crop nest, the well screened in the lower portion of the gravel zone at a depth of 10 feet (DA5) had the highest metolachlor and 2,4D concentrations measured at the site. These high concentrations occurred 3 days after pesticide application. Metolachlor concentration was 5.1 micro-g/L (GQ and 2,4-D concentration was 12 micro-g/L. Also on this date, two wells that are shallower than the gravel zone (DA3 and DA4) had respective metolachlor concentrations of 0.84 and 3.5 micro-g/L (Fig. 8), but 2,4-D was below the detection limit.

Three other wells in the same field, each with the same screened intervals (15 to 17.5 feet in depth), also indicate the important role that root macropores and the gravelly zone play in movement of ground water and pesticides. Wells DA1 (south of the well nest), DA6 (at the crop nest), and DA10 (at the northern boundary of the field) were each installed more than 1,000 feet apart (Fig. 7). At the location of well DA1, the clay below 10 feet deep is more gravelly or sandy, and bedrock is more shallow than at the other wells in the field. Tree root material extends to bedrock at approximately 14 feet in depth (Fig. 8). Three days after application, both herbicides were detected at this location. Metolachlor concentration was measured at a high of 3.6 micro-g/L (GC), and 2,4-D concentration reached 3.9 micro-g/L. However, concentrations of metolachlor at the same depth at two other wells were an order of magnitude lower on this date, and 2,4-D was not detected. Metolachlor concentrations measured 0.35 micro-g/L (GQ in well DA10 and 0.27 micro-g/L in well DA6 (GC). The lower concentrations at the latter two locations are attributed to a somewhat shallower macropore network and a clay unit below the gravel zone.

Metolachlor with Depth

Figure 10 shows the concentration of metolachlor with depth for the seven monitoring wells at the crop nest. Depths on the graph are

generally midpoints of the screened intervals. Concentrations are shown for two different 1992 sampling dates (June 18 and October 14).

Detectable concentrations of metolachlor were found for varying lengths of time among wells of the crop well nest. Metolachlor concentration remained above 1 micro-g/L at 5 to 7.5 feet in depth (well DA4) for up to 2 weeks after application near the wells, after which it was below detectable concentrations by both GC and ELISA analytical methods. In the gravel zone (well DA5), metolachlor concentration reached a high of 5.1 micro-g/L. Metolachlor concentration in the gravel remained above 1 micro-g/L for approximately 2.5 months after application and was detectable at that depth for the remainder of 1993 below 0.3 micro-g/L. In samples from 15 to 17.5 feet in depth (well DA6), concentrations did not peak until August 6, at 0.61 micro-g/L. Metolachlor was detected at this depth in June 1993 at concentrations less than 0.3 micro-g/L, but was not detected in the last sample collected on July 20, 1993. In ground water from 20 to 22.5 feet in depth (well DA7), metolachlor was detected once (less than 0.3 micro-g/L), on July 16, 1992. Metolachlor was not detected in samples from this depth thereafter. Metolachlor was not detected in the two deepest bedrock wells of the crop nest (DA8 and DA9) after initial detections attributed to temporary well-construction contamination.

The three wells screened from 15 to 17.5 feet in depth contained detectable concentrations of metolachlor for very different periods of time. Metolachlor in samples from well DA1, where deeper macropores and less clay were encountered, reached a peak concentration of 3.6 micro-g/L (GQ 3 days after the June 15 application of herbicides. Concentrations in this well remained above 1 micro-g/L for 7 to 8 weeks after application, and there were two detections below 0.3 micro-g/L reported from ELISA analyses in June and July 1993. Conversely, the highest concentrations in two wells constructed to the same depth in other locations were 0.61 and 0.27 micro-g/L. Metolachlor was below detection in DA10 samples by August 6 of 1992, but DA6 concentrations peaked later, on August 6, at 0.61 micro-g/L. Metolachlor remained detectable in DA6 samples for the first half of 1993. All of the 1993 detections in this well were below 0.3 micro-g/L. The lower concentrations and later peaks in these latter two wells suggest that there was a poorer hydraulic connection extending downward from the gravel zone than where bedrock was more shallow.

2,4-D with Depth

The herbicide 2,4-D was detected in fewer wells than metolachlor was, and for a much shorter period of time. At the crop nest, 2,4-D was never detected in the two shallowest wells (DA3 and DA4). The peak concentration in the gravel zone (well DA5) was 12 micro-g/L in the sample collected on June 18, 3 days after application. The July 2 sample from the gravel zone had a 2,4-D concentration of 1.5 micro-g/L, but 2,4-D was not detected in the July 16 samples or thereafter. It was never detected at or below 15 feet in depth at the crop nest (Fig. 11).

2,4-D was only found at a depth of 15 feet where bedrock is shallower, macropores are deeper, and the clay is sandier (well DA1). At this location, the peak concentration was 3.9 micro-g/L, measured 3 days after the June 15 application. The sample from July 2 had a concentration of 1.1 micro-g/L, and 2,4-D was undetected in the well from July 16, 1992, through 1993.

Ground water collected from a 15-foot-deep well at the northern boundary of the field (DA10) never had detectable concentrations of 2,4-D. Detectable concentrations of 2,4-D were found only in the most permeable sediments, and were present for less than one month.

Imazaquin

Imazaquin was the only herbicide applied at the site in 1993 for which the laboratory had analytical capability. The detection limit for the ELISA method used was 5.0 micro-g/L, much higher than for other pesticides in this study.

Imazaquin was applied on June 18, 1993, at a rate of 56 g/acre. Wells ranging from 3 to 22.5 feet in depth (wells DA4, DA5, DA6, and DA7) at the crop nest were sampled twice shortly before application and three times during the following month. None of the samples had detectable concentrations of imazaquin. The negative results for monitoring-well samples were not used to make inferences regarding the presence of imazaquin at the site because of the high detection limit.

Woods Monitoring Wells

Samples were collected from the woods monitoring wells from April to July 16, 1992. The well nearest the monitored crop site (DA11) was the only woods well sampled in 1993.

Nitrate-N concentrations in the wood monitoring wells were similar to those at the crop

monitoring nest. All concentrations were below 1.5 mg/L.

Pesticides were not detected in most samples from the woods monitoring wells. Detections of metolachlor and triazines in initial samples collected in April 1992 were attributed to temporary contamination during well construction. Subsequent samples showed no detectable levels of pesticides, or had concentrations below 0.3 micro-g/L. The cause of the low concentrations of metolachlor and triazine pesticides detected in these wells was probably flooding of the wooded land by overflowing local drainage ditches. During 1992, 1 to 6 inches of drainage-ditch water flooded the woods and crop monitoring sites for a few days in late March, and on July 3 and 4. Puddles of water resulting from late March flooding remained near the well locations during the time of well construction.

In March 1992, the water in two local ditches had detectable concentrations of alachlor, metolachlor, and triazine pesticides. In ditch 1, located approximately 50 feet from the woods monitoring nest (Fig. 7), mid-March samples contained the following pesticide concentrations: 0.38 micro-g/L alachlor, 0.53 micro-g/L triazines, and 0.53 micro-g/L metolachlor. Samples collected the day before flooding on July 3, 1992, contained 8.3 micro-g/L alachlor, 1.16 micro-g/L triazines, and 1.0 micro-g/L metolachlor. Concentrations of pesticides in the drainage ditch water very during the year, and become temporarily higher than the above listed concentrations during the days and weeks following application of pesticides on farms in the area. Pesticides remaining in surface sediments after the late March 1992 flooding of the woods was the apparent cause of pesticides entering the woods wells during their construction approximately one week after the flooding.

Suction Lysimeters

Metolachlor concentrations in the crop-nest suction lysimeter (5 feet deep) were similar to those in the well screened from 5 to 7.5 feet in depth (well DA4). Neither the well nor the lysimeter yielded metolachlor concentrations above 0.3 micro-g/L during the 1992 growing season, when metolachlor and 2,4-D were applied. Likewise, 2,4-D was not detected. Nitrate concentrations were often not detectable in water from both of the suction lysimeters (woods and crop locations), whereas wells constructed near each of these lysimeters at similar depths generally contained detectable concentrations. Concentrations

of nitrate-N in these wells were usually below 0.3 mg/L. Concentrations of pesticides and nitrate-N at a depth of 5 feet were too low to adequately assess the reliability of the lysimeter samples.

Site Summary

Nitrate-N concentrations in ground water are consistently below 1.5 mg/L at the site, far below the MCL of 10 mg/L. The greatest cause of these low concentrations is probably efficient denitrification in the saturated zone. Any release of nitrate by decomposition of soybean plant stubble left on the field during 1992 and 1993 did not elevate the concentration of nitrate in ground water. Therefore, application of nitrogen fertilizer at the site is unlikely to substantially elevate nitrate-N concentrations in ground water.

Deep soil cracks and deeper macropores derived from tree roots allow pesticides to move quickly to the gravel zone at approximately 8 to 10 feet in depth. The downward movement of pesticides was much slower below this gravel zone in most of the crop field, as evidenced by three crop wells with screens from 15 to 17.5 feet deep. However, where root macropores are abundant a few feet deeper, and the clay is thinner, sandy, and gravelly in nature, as is the case near well DA1, pesticides moved deeper at readily detectable levels. Considering that metolachlor concentration reached a high of 3.6 micro-g/L at this location, pesticides with similar properties and that have a low MCL (such as atrazine, 3 micro-g/L) could periodically exceed the MCL under these conditions. The silty clay in the upper 8 to 9 feet of sediments would better impede the downward movement of the pesticides if not for the deep macropores. More detailed study is necessary to quantify the effects of these macropores on pesticide movement in the subsurface.

Pesticide concentrations remained under 1 micro-g/L below the tree-root zone during the two growing seasons studied. Where there are thick clay deposits below root-cast macropores, agriculture on these flat-lying deposits contributed only very small amounts of pesticides to ground water below the former root zone.

SUMMARY AND CONCLUSIONS

At both sites, the unconsolidated, clay-rich Pleistocene lacustrine deposits below the root

zone impeded the downward movement of pesticides and caused the residual pesticides to move laterally along local, shallow flow patterns to local drainage ditches. The clay-rich sediments below 7 feet at the Hopkins County site and those below 10 feet deep at the Daviess County site greatly hinder downward movement of the analyzed pesticides.

At the Daviess County site, soil cracks and tree-root macropores 10 feet deep extend through the upper clay unit to the underlying gravel zone. Water quality evidence strongly suggests that these macropores preferentially transmit ground water and agricultural chemicals from the soil zone, through the silty clay, into the gravel. There was no evidence of deep macropores of any origin at the Hopkins County site.

The first sample drawn from the monitoring wells at both sites in mid-April 1992 had triazine concentrations as high as 1.2 micro-g/L. These pesticide detections are attributed to temporary contamination during well construction, caused by the temporary disruption of sediments and vertical mixing of ground water in the borehole. The origin of pesticides at well locations in the woods was probably the overflow of the nearby drainage ditch approximately 1 week before well construction. Analyses of water from the local ditches indicate that pesticides were present in ditch water at that time.

Pesticide MCL's were not exceeded at either site. This includes atrazine at the Hopkins County site and metolachlor and 2,4-D at the Daviess County site. There is no MCL for simazine or imazaquin.

Dry weather during and after pesticide application reduced pesticide infiltration to ground water at the Hopkins County site. Infrequent and low rainfall after pesticide application resulted in little percolation of soil water and pesticides to the water table. The dry conditions allowed pesticides more residence time in the soil zone, which resulted in greater pesticide sorption and degradation.

No nitrate-N concentrations exceeded the MCL in Daviess County monitoring wells. The low concentrations are probably caused by efficient denitrification in the saturated zone. Release of nitrogen from soybean plants in 1992 and 1993 did not elevate the nitrate-N concentrations in ground water. Therefore, application of nitrogen fertilizer at the Daviess County site would probably not elevate the nitrate-N concentration.

Denitrification was apparently less efficient at the Hopkins County site than at the Daviess County site. Application of nitrogen fertilizer at the Hopkins county site likely increased the concentration of nitrogen in shallow ground water beyond natural concentrations. However, the area near the ditch is a ground-water discharge zone, and therefore deeper ground water was not affected at the study site.

The highest concentrations of most pesticides in the shallowest ground water occurred during the first 2 months after chemical application. These applications are most common during spring, are less common during summer months, and less common still during the fall.

Dug and shallow bored wells are recharged by very shallow ground water and can be contaminated by application of agricultural chemicals in similar areas. Drilled wells with a properly sealed casing in the borehole should not be significantly contaminated by agricultural chemicals.

RECOMMENDATION

Farming is common on the low-gradient slopes surrounding the flat-lying deposits that are the focus of this report. The occurrence of agricultural chemicals in ground water below these slopes should be a subject of future research in the coal field.

REFERENCES CITED

- Calvert, R.H., 1964, Geology of the Philpot Quadrangle, Kentucky: U.S. Geological Survey Geologic Quadrangle Map GQ-297.
- Calvert, R.H., 1966, Geologic map of the Maceo Quadrangle, Daviess and Hancock Counties, Kentucky: U.S. Geological Survey Geologic Quadrangle Map GQ-570.
- Campbell, L.J., Bleuer, N.K., Gray, H.H., Powell, R.L., and Swadley, W C, 1974, Late Cenozoic geologic features of the Middle Ohio River Valley (roadlog for Geological Society of Kentucky 1974 Field Conference): Kentucky Geological Survey, Series 10, 25 p.
- Cox, F.R., 1974, Soil survey of Daviess and Hancock Counties, Kentucky: U.S. Department of Agriculture, Soil Conservation Service, 108 p.
- Fairer, G.M., and Norris, R.L., 1972, Geologic map of the Curdsville Quadrangle, western Kentucky: U.S. Geological Survey Geologic Quadrangle Map GQ-1039.
- Fehr, J.P., Jacobs, E.H., and Converse, H.T., 1977, Soil survey of Hopkins County, Kentucky: U.S. Department of Agriculture, Soil Conservation Service, 62 p.
- Franklin, G.J., 1965, Geology of the Hanson Quadrangle, Kentucky: U.S. Geological Survey Geologic Quadrangle Map GQ-365.
- Franklin, G.J., 1967, Geology of the Coiltown Quadrangle, Hopkins County, Kentucky: U.S. Geological Survey Geologic Quadrangle Map GQ-629.
- Goudarzi, G.H., 1971, Geologic map of the Panther Quadrangle, Daviess County, Kentucky: U.S. Geological Survey Geologic Quadrangle Map GQ-866.
- Goudarzi, G.H., and Smith, A.E., 1971, Geologic map of part of the Owensboro West Quadrangle in Daviess County, Kentucky: U.S. Geological Survey Geologic Quadrangle Map GQ-890.
- Greb, S.F., Williams, D.A., and Williamson, A.D., 1992, Geology and stratigraphy of the Western Kentucky Coal Field: Kentucky Geological Survey, ser. 11, Bulletin 2, 77 p.
- Johnson, W.D., and Smith, A.E., 1968, Geologic map of part of the Owensboro East Quadrangle in Daviess County, Kentucky: U.S. Geological Survey Geologic Quadrangle Map GQ-751.
- Johnson, W.D., and Smith, A.E., 1969, Geologic map of the Sutherland Quadrangle, Daviess County, Kentucky: U.S. Geological Survey Geologic Quadrangle Map GQ-839.
- Johnson, W.D., and Smith, A.E., 1972a, Geologic map of the Glenville Quadrangle, McLean and Daviess Counties, Kentucky: U.S. Geological Survey Geologic Quadrangle Map GQ-1046.
- Johnson, W.D., and Smith, A.E., 1972b, Geologic map of the Utica Quadrangle, western Kentucky: U.S. Geological Survey Geologic Quadrangle Map GQ-995.
- Kehn, T.M., 1963, Geology of the Madisonville East Quadrangle, Kentucky: U.S. Geological Survey Geologic Quadrangle Map GQ-252.
- Kehn, T.M., 1964a, Geology of the Madisonville West Quadrangle, Kentucky: U.S. Geological Survey Geologic Quadrangle Map GQ-346.

- Kelm, T.M., 1964b, Geology of the Slaughters Quadrangle, Kentucky: U.S. Geological Survey Geologic Quadrangle Map GQ-360.
- McFarlan, A.C., 1943, Geology of Kentucky: Lexington, University of Kentucky, 531 p.
- Palmer, J.E., 1967, Geology of the St. Charles Quadrangle, Hopkins and Christian Counties, Kentucky: U.S. Geological Survey Geologic Quadrangle Map GQ-674.
- Palmer, J.E., 1968, Geology of the Nortonville Quadrangle, Hopkins and Christian Counties, Kentucky: U.S. Geological Survey Geologic Quadrangle Map GQ-672.
- Ray, L.L., 1965, Geomorphology and Quaternary geology of the Owensboro Quadrangle, Indiana and Kentucky: U.S. Geological Survey Professional Paper 488, 72 p.
- Ryder, P.D., 1974, Ground water in the alluvium along the Green River between its mouth and Woodbury, Kentucky: U.S. Geological Survey Water Resources Investigations Report 53-73, 5 p.
- Teller, U., and Last, W.M., 1981, The Claryville Clay and early glacial drainage in the Cincinnati, Ohio, region: Palaeogeography, Palaeoclimatology, Palaeoecology, v. 33, p. 347-367.
- Thornbury, W.D., 1950, Glacial sluiceways and lacustrine plains of southern Indiana: Indiana Department of Conservation, Division of Geology, Bulletin 4, 21 p.
- Trace, R.D., 1977, Geology of the Dawson Springs Southeast Quadrangle, Christian and Hopkins Counties, Kentucky: U.S. Geological Survey Geologic Quadrangle Map GQ-1365.
- Walker, E.H., 1957, The deep channel and alluvial deposits of the Ohio Valley in Kentucky: U.S. Geological Survey Water-Supply Paper 1411, 24 p.

APPENDIX A: CONSTRUCTION AND SAMPLING PROTOCOLS Well and Lysimeter Installation

Most wells were constructed with 2-inch-diameter schedule-40 PVC pipe, and three wells were constructed with 4-inch-diameter schedule-40 PVC pipe. Boreholes for most 2-inch-diameter wells were 6 inches in diameter, and boreholes for 4-inch-diameter wells were 10 inches in diameter. Each well was constructed in a separate borehole. Two-inch wells had 2.5-foot screens near their bases, with 0.010-inch slots. Also, a 2.5-foot, plugged, PVC extension below screen level was added for increased sample volume. Quartz sand was placed around each bottom extension and screen, and Holeplug (Baroid, Inc.) bentonite gravel was used to backfill from the sand pack to the ground surface. The screen interval of each well is shown in Figures 3 and 8.

Three suction lysimeters were installed, each to a depth of 5 feet at each site, in order to correspond to the depth of the 5-7.5-foot well at each site, and to compare data from the lysimeters. Water was collected from the lysimeters through a ceramic cup at the base when a vacuum was applied; vacuums were installed to collect pore water if the water table dropped below the level of the shallowest well. Samples could usually be obtained whether the water table was above or below the level of the ceramic cup.

Boreholes for lysimeters were hand-augured and were 3 inches in diameter. Silica silt ("silica flour") was placed around the ceramic cup at the bottom of the borehole. The borehole was backfilled with Benseal (Baroid, Inc.) bentonite

pebbles. Two tubes extended from a sealed gasket in the lysimeter to the ground surface.

Well and Lysimeter Sampling

Sample collection protocols were the same for both sites. Prior to well purging and sampling, water levels were measured using an electronic water-level probe with a graduated cable. Two-inch-diameter wells were purged using a PVC bailer dedicated to each well. Between sampling events, bailers were hung in the top of the well casing, above the water table. Most wells were bailed until empty, because of their generally slow recharge. Wells with adequate recharge were purged of three well volumes and allowed to recharge prior to sampling. Four-inch-diameter wells were purged using a Fultz pump with a Teflon hose and Teflon impellers. Likewise, the wells were either emptied and allowed to recharge, or purged of three well volumes before sampling. Samples were collected within 24 hours of purging. A portion of the well water was used to measure temperature, pH, and conductivity during sampling.

Lysimeters were first purged of any water that may have accumulated prior to applying a vacuum to the unit. A 25- to 30-psi vacuum was then placed on lysimeters to draw water through the ceramic cup. A pressure pump was then used to evacuate the water sample.

APPENDIX B: METHODS OF ANALYSIS

All well samples were analyzed by an enzyme-linked immunosorbent assay (ELISA) method, and some of the samples were also analyzed by gas chromatography (GQ). ELISA analyses were performed for the following pesticides: triazines, metolachlor, 2,4-D, and alachlor. The triazine analysis was designed to be most sensitive to atrazine, which it measures above a detection limit of 0.046 micro-g/L, but it also detects simazine (above 0.34 micro-g/L) and cyanazine (above 1.0 micro-g/L), according to the manufacturer, Ohmicron Corporation. This analysis also detects some degradation compounds of the pesticides. Therefore, the ELISA triazine results represent the total of triazine compounds detectable in water samples. The ELISA analysis for 2,4-D has a detection limit of 0.9 micro-g/L. It also detects the herbicide 2,4-DB above 3.95 micro-g/L, and other related compounds. The other ELISA analyses similarly react to a small group of compounds, and are generally most sensitive to the pesticide targeted in the analysis (e.g., metolachlor in the metolachlor analysis). Detection limits reported by the Kentucky Geological Survey Computer and Laboratory Services Section for the ELISA methods are the following (in micro-g/L: triazines, 0.06; metolachlor, 0.06; alachlor, 0.018; and 2,4-D, 0.90. Results below detection are plotted on graphs in this report along the axis labeled "ND" (not detected).

Selected samples from Daviess County were also analyzed for imazaquin using an AgriDiagnostic Corp. ELISA method. This analysis had a detection limit of 5 micro-g/L. Pesticides applied at the site that could not be detected by the laboratory are not discussed in this report.

Selected samples from both locations were also analyzed by gas chromatography (GQ) for five of the above pesticides: atrazine, simazine, cyanazine, alachlor, and metolachlor. Detection

limits for GC methods are (in micro-g/L): atrazine, 0.23; simazine, 0.026; cyanazine, 0.024; alachlor, 0.018; and metolachlor, 0.031. Some of the 1992 GC analyses had a slightly lower detection limit.

The GC method detects each target compound individually, but is expensive and therefore used less often. A preliminary comparison of the two methods using split samples indicated that the precision of the ELISA triazine and metolachlor results greatly diminishes below 1 micro-g/L.

Alachlor results by ELISA were found to be far less precise than either the atrazine or metolachlor results by ELISA. The alachlor ELISA analysis apparently detects a common metabolite of alachlor as well as alachlor itself, and the majority of results were not similar to GC results. Alachlor concentrations in ground water are therefore not assessed in this report. There was not analytical capability to detect imazaquin and 2,4-D by GC, and the relative precision of ELISA results for these compounds is unknown.

Two local drainage ditches were sampled by the University of Kentucky Department of Agronomy. Pesticide analyses of these samples were performed by the Department of Agronomy using Agri-Diagnostics Corporation ELISA methods.

Nitrate-N was measured by a cadmium reduction method with a detection limit of 0.05 mg/L by the Department of Agronomy. Nitrate concentrations can be determined by multiplying reported nitrate-N measurements by 4.43.

The U.S. Environmental Protection Agency has established a maximum contaminant level for three of the pesticides in this study: atrazine (0.7 micro-g/L), alachlor (2 micro-g/L), and 2,4-D (70 micro-g/L). The MCL for nitrate-N is 10 mg/L.

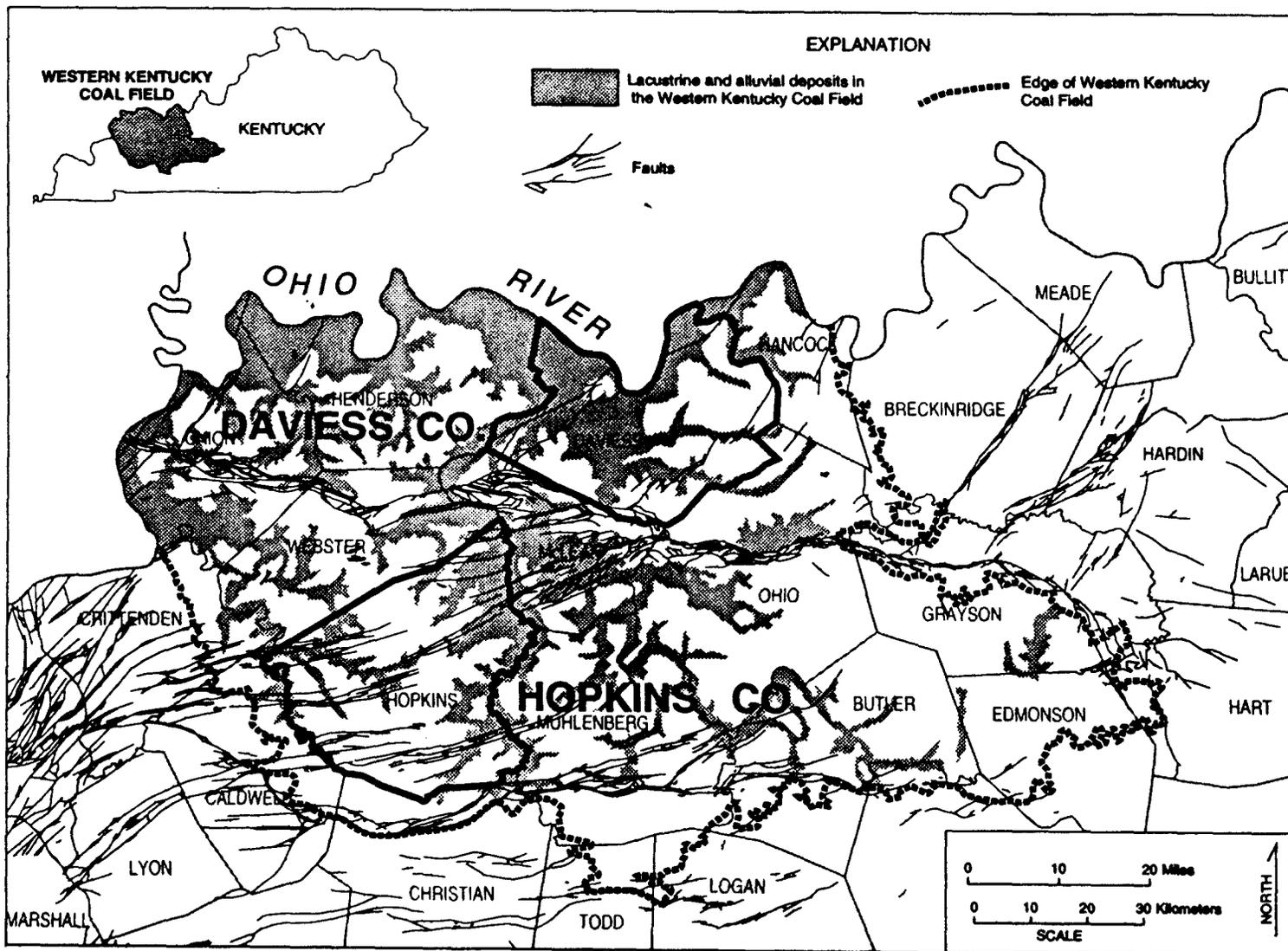


Figure 1. Location of Hopkins and Daviess Counties in western Kentucky, showing the distribution of lacustrine and alluvial deposits. The map explanation above applies only within the Western Kentucky Coal Field portion of the map.

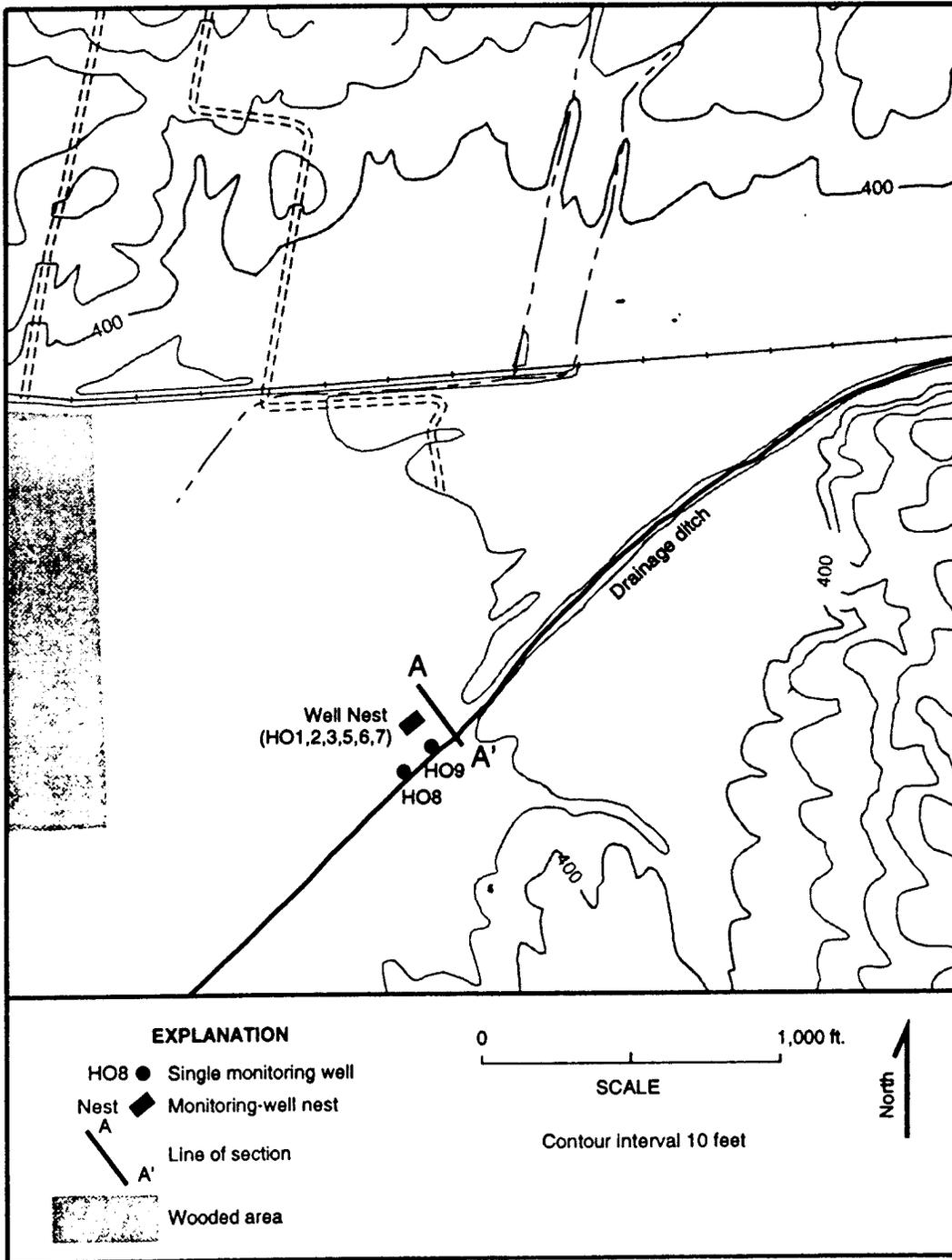
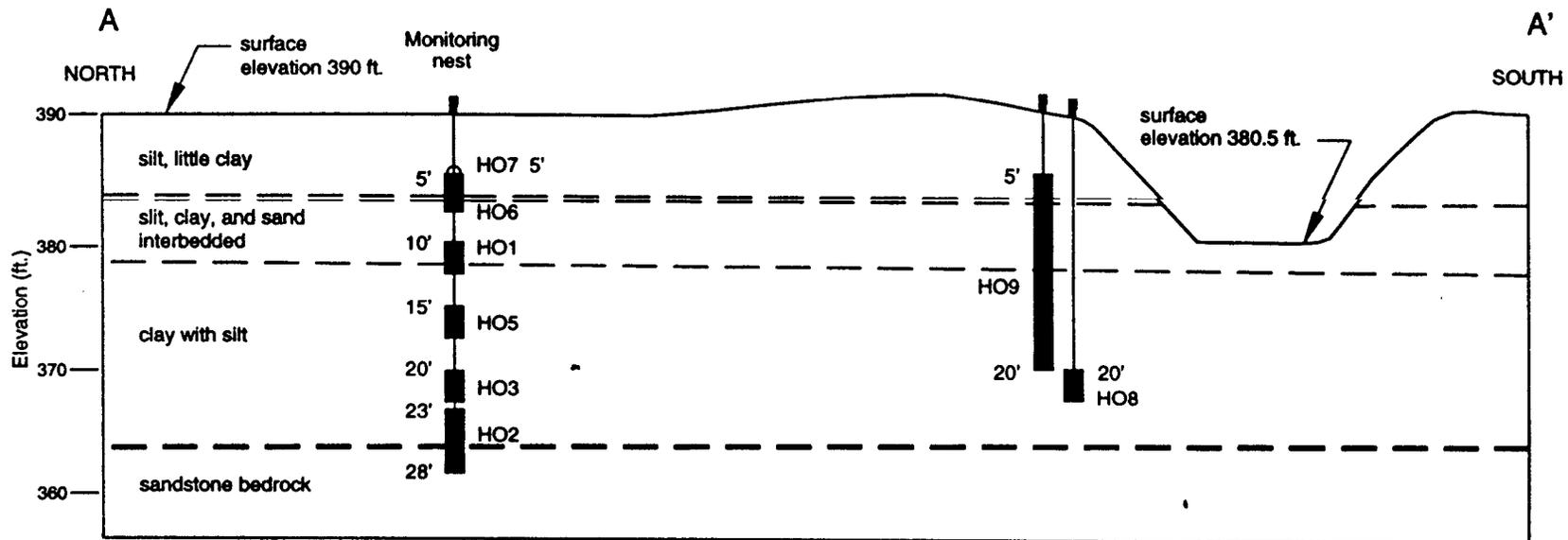


Figure 2. Location of the monitoring-well nest, two wells adjacent to the ditch, and cross section A-A' at the Hopkins County site.



EXPLANATION

- Depth of screen top 15' ■ HO1 Screen of monitoring well
- Depth of sampling cup 15' ○ HO7 Sampling cup of suction lysimeter
- — — — — Bedrock surface

Figure 3. Schematic cross section A-A' at the Hopkins County site. The location of the cross section is shown on Figure 2.

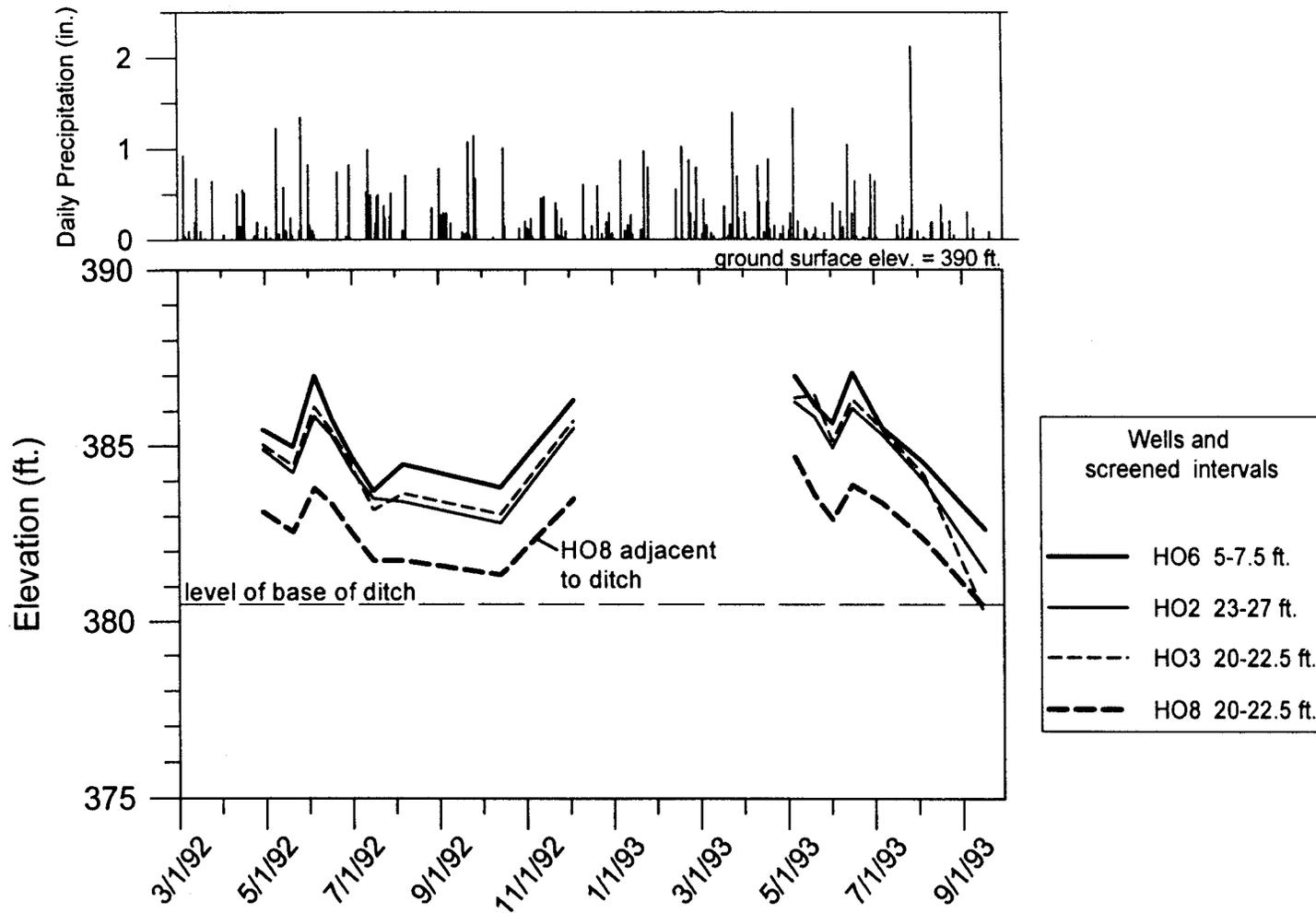


Figure 4. Water levels in selected Hopkins County monitoring wells. Screened intervals listed are in feet below ground surface.

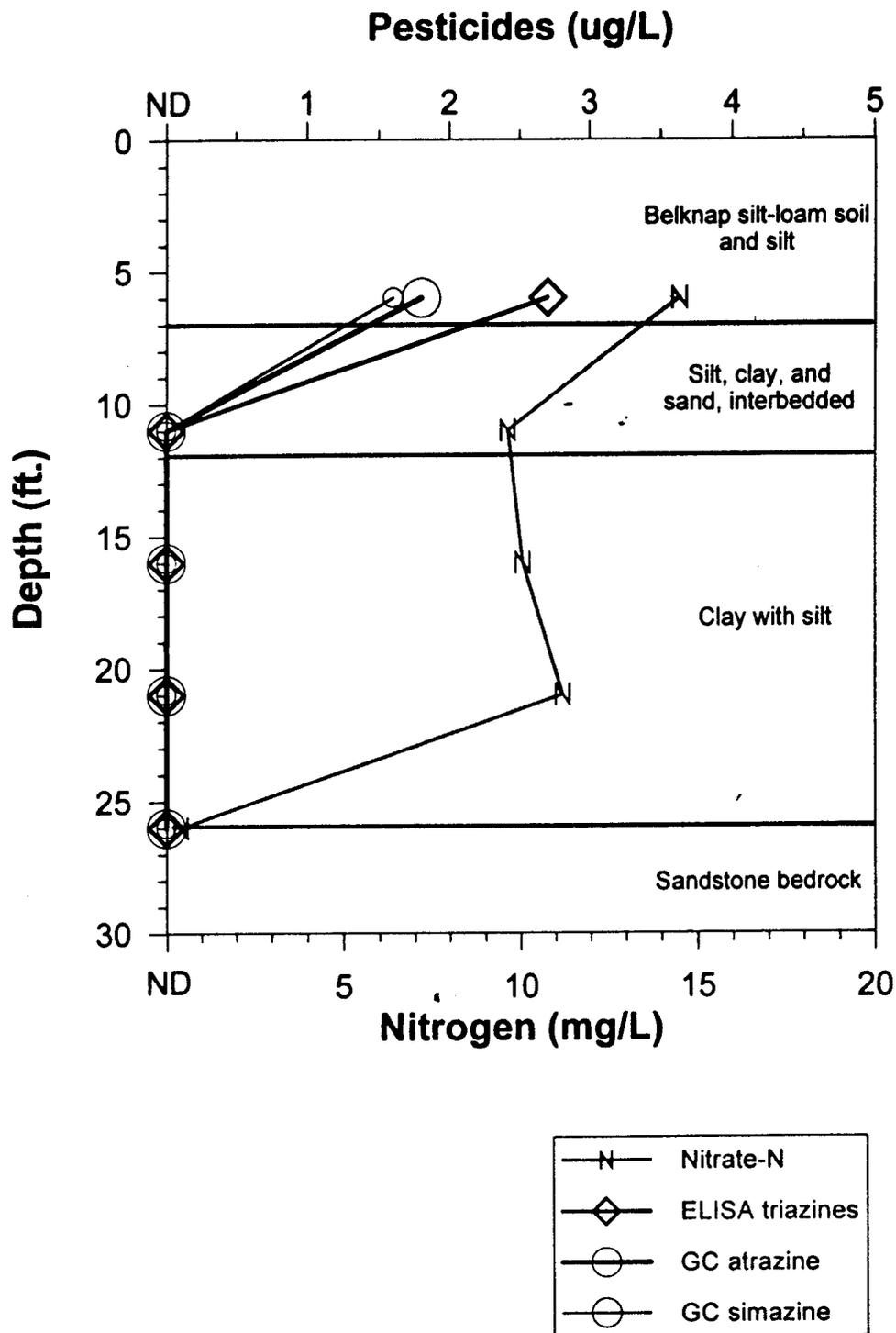


Figure 5. Pesticide and nitrate-nitrogen concentrations with depth at the Hopkins County site (from top to bottom: wells HO6, HO1, HO5, HO3, and HO2).

SCREEN 5-7.5 ft TRIAZINES

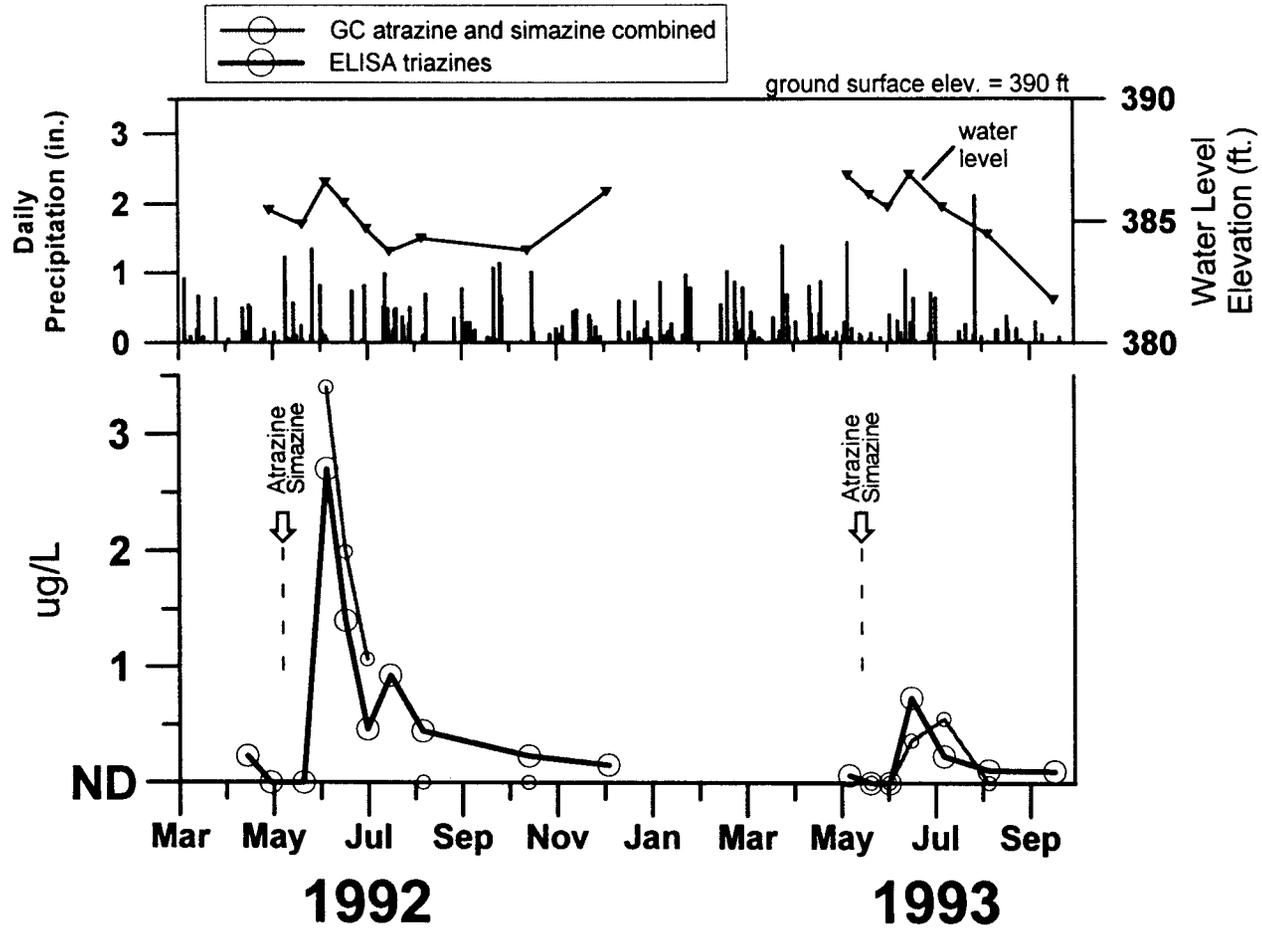


Figure 6. Pesticide concentration in Hopkins County at a depth of 5 to 7.5 feet during 1992 and 1993. The time of pesticide application and daily precipitation are also shown.

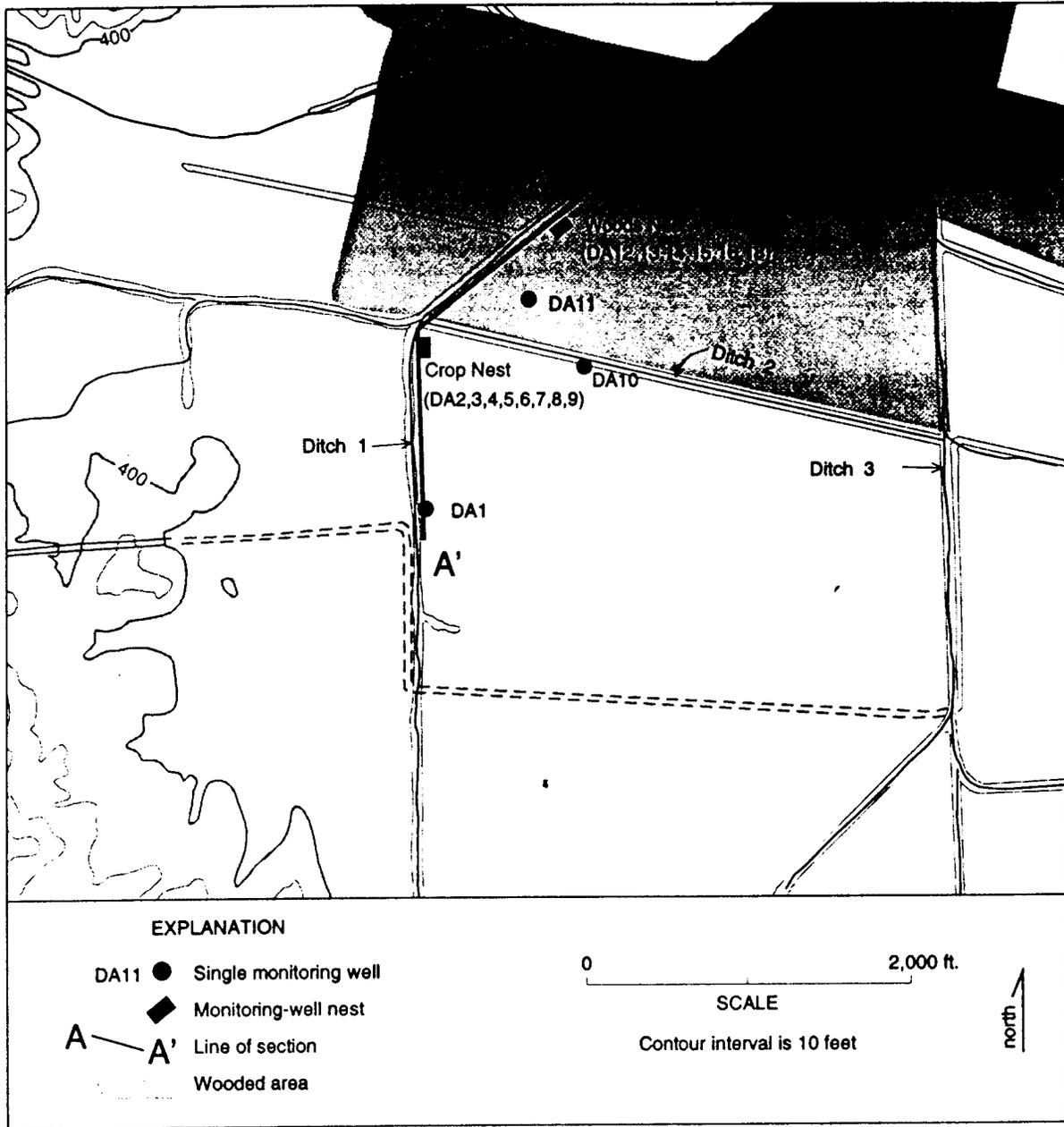


Figure 7. Location of two monitoring-well nests, individual monitoring wells, local ditches, and cross section A-A' at the Daviess County site.

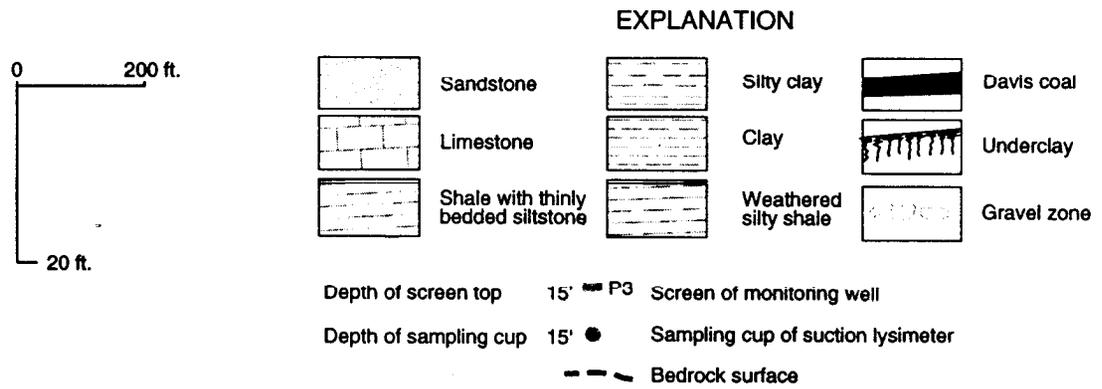
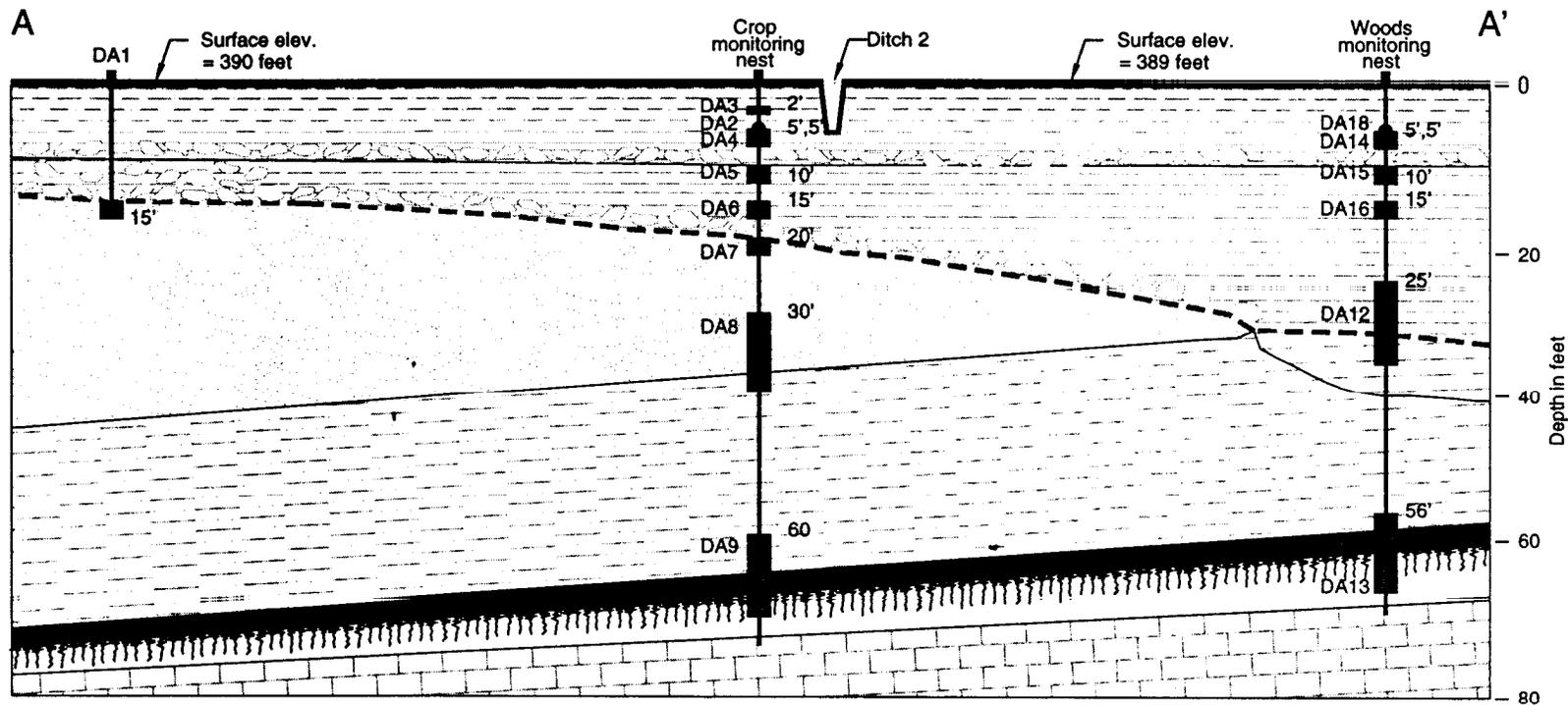


Figure 8. Schematic cross section A-A' at the Daviess County site. The location of the cross section is shown on Figure 7.

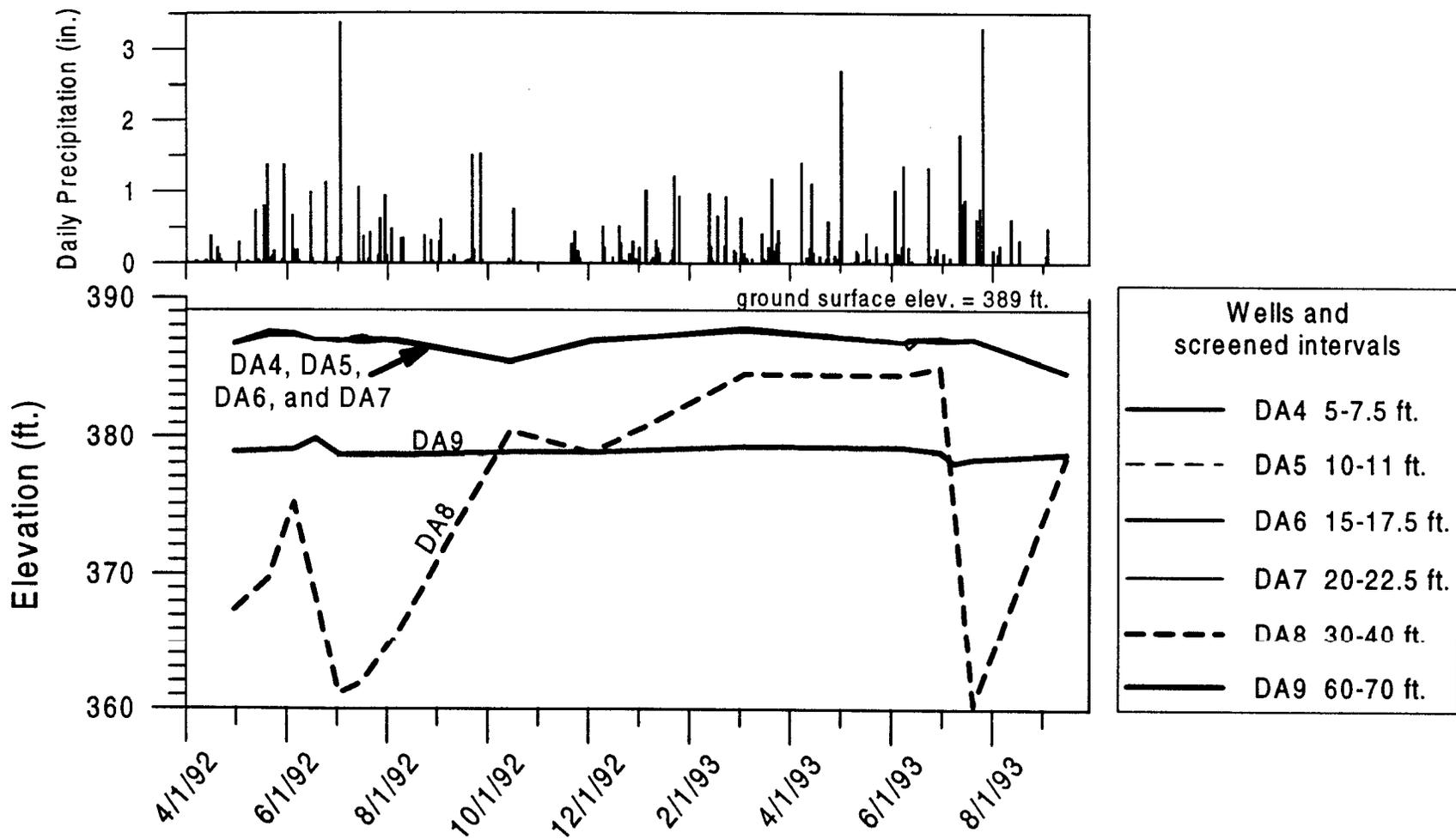


Figure 9. Water levels in crop-nest wells and daily precipitation at the Daviess County site. Screened intervals listed are in feet below the ground surface.

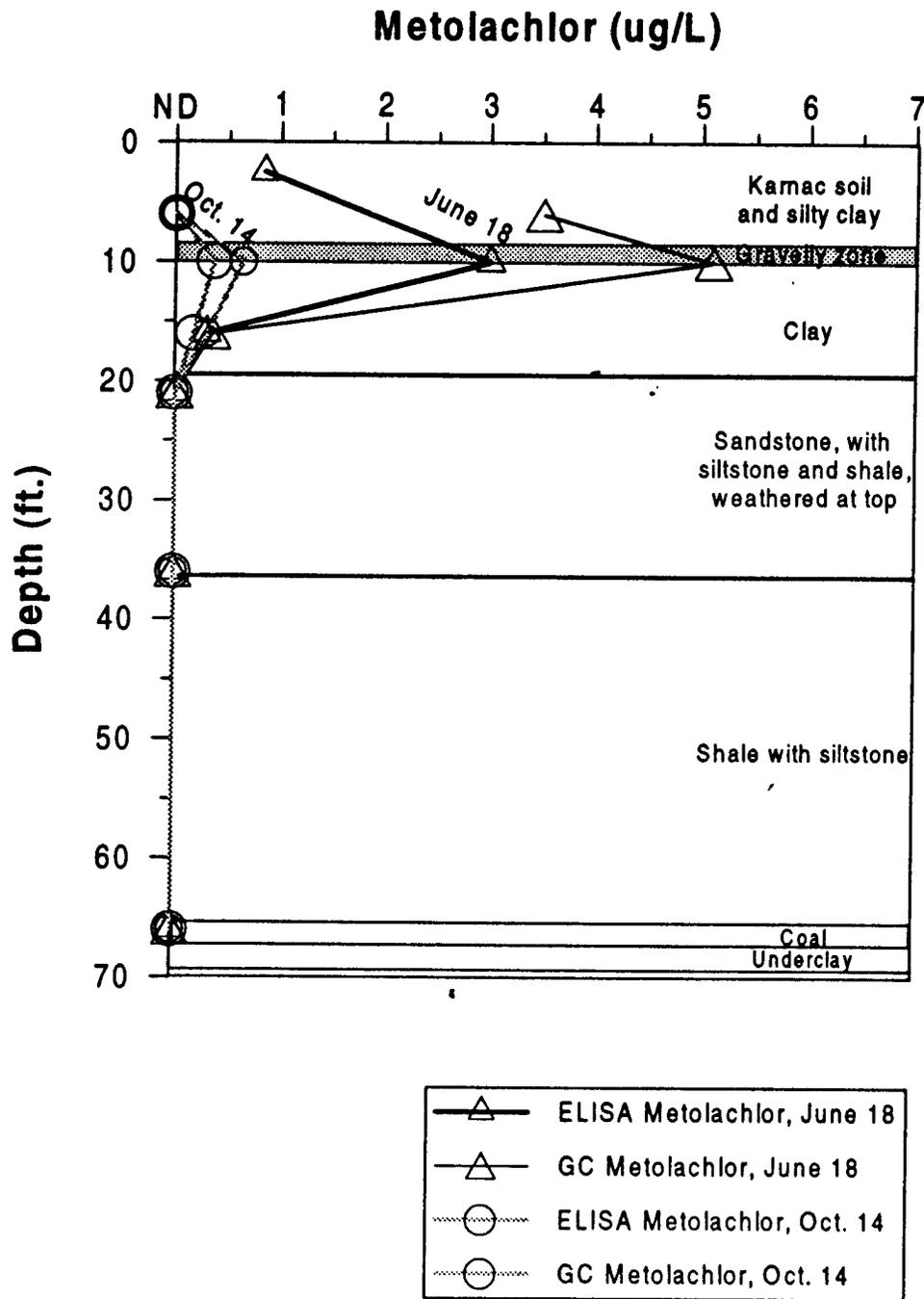


Figure 10. Metolachlor concentration with depth at the Daviess County crop monitoring nest (from top to bottom: wells DA3, DA4, DA5, DA6, DA7, DA8, and DA9). Data from June and October 1992 sampling dates are shown.

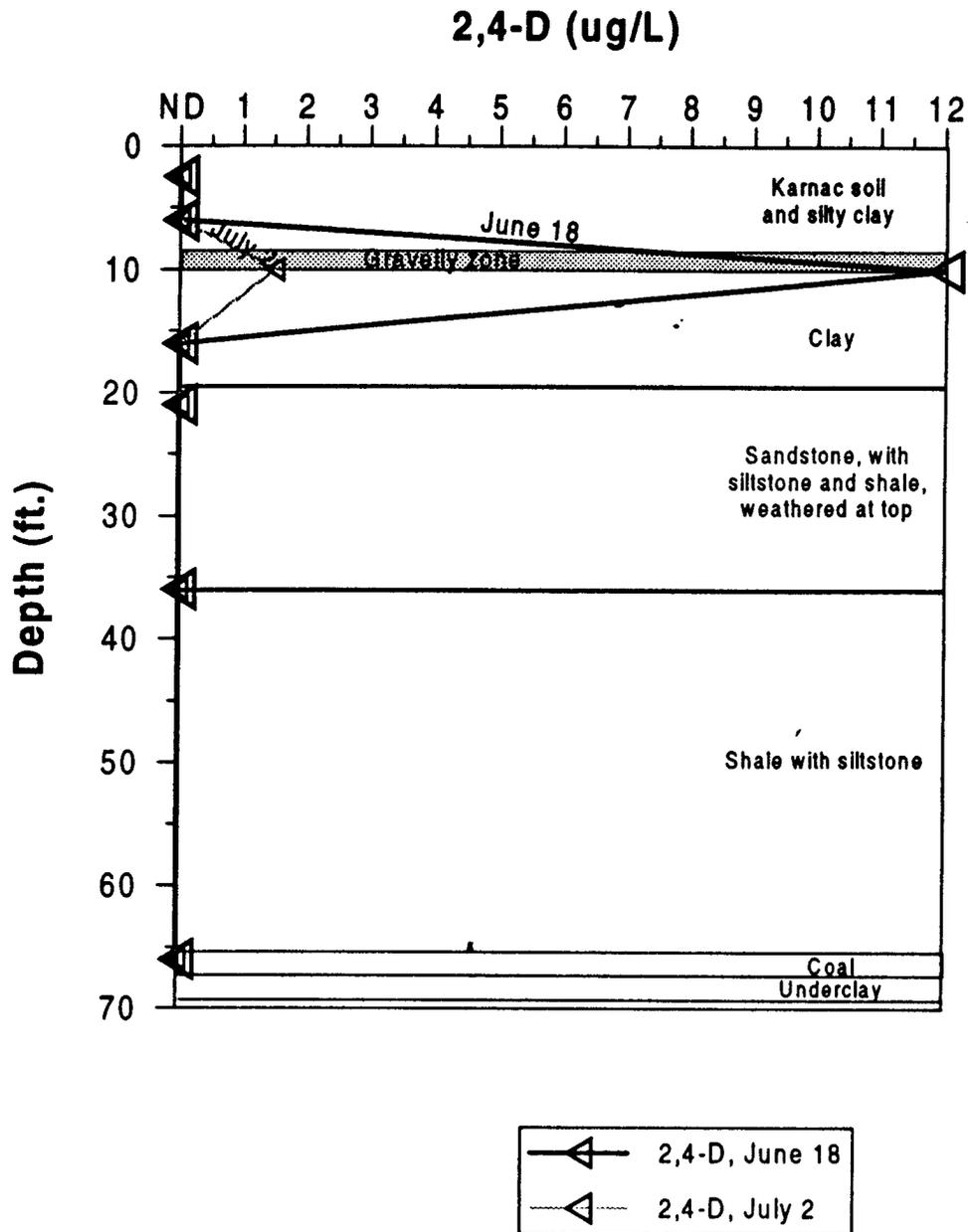


Figure 11. Concentration of 2,4-D with depth at the Daviess County crop monitoring nest (from top to bottom: wells DA3, DA4, DA5, DA6, DA7, DA8, and DA9).