United States Department of Agriculture **Chester, PA 19013**
Soil Conservation Service **610-490-6042**

Subject: Ground-Penetrating Radar (GPR) study of recent splay deposits along the Missouri River; 6 - 9 June 1994.

Date: 19 July 1994

To: Bruce W. Thompson
State Soil Scientist
USDA- Soil Conservation Service
Parkade Center, Suite 250
601 Business Loop 70 West
Columbia, Missouri 65203

Purpose:
To assess the feasibility of using GPR and computer graphic techniques to investigate and map the thickness of coarse-textured materials deposited during the summer floods of 1993 along the Missouri River.

Participants:
Terry Barney, Resource Inventory Specialist, SCS, Columbia, MO
Elizabeth Cook, GIS Analyst, Lincoln University, Jefferson City, MO
Mike Cook, Area Resource Soil Scientist, SCS, Washington, MO
Jim Doolittle, Soil Specialist, SCS, Chester, PA
Richard Fenwick, Consultant, Kansas City, MO
Darlene Johnson, Soil Conservationist, SCS, Richmond, MO
Dennis Hoffman, Civil Engineer, SCS, Fulton, MO
David Howard, Area Resource Soil Scientist, SCS, Warrensburg, MO
Walter Lane, Soil Conservationist, SCS, Columbia, MO
Caryl Radatz, Soil Scientist Project Leader, Columbia, MO
Jim Rehmsmeyer, District Conservationist, SCS, Richmond, MO
Rickey Schwieter, District Conservationist, SCS, Fulton, MO
Melvin Simmons, Soil Scientist, SCS, Columbia, MO
Bruce Thompson, State Soil Scientist, SCS, Columbia, Mo
Ken Vogt, Assistant State Soil Scientist, SCS, Columbia, MO
Donald Williams, Geologist, SCS, Columbia, MO
Jerry Zimmerman, Area Resource Soil Scientist, SCS, St. Joseph, MO

Activities:
On 6 June, a flood-plain splay deposit was examined with GPR near Jefferson City, in Calloway County, Missouri. This was a trial and equipment calibration site where equipment and survey procedures were developed. On 7 June, three closely neighboring sites were surveyed in Saline County, near Glasgow, Missouri. On June 8 June, a site was surveyed near Orrick in Ray County.

Equipment:
The radar unit used in this study was the Subsurface Interface Radar (SIR) System-8 manufactured by Geophysical Survey Systems, Inc. The system was powered by a 12-volt deep-cycle, marine battery. The model 3110 (120 mHz) antenna with a model 705DA transceiver was used in this investigation. The unit was mounted on a John Deere Gator.

Two-dimensional plots of splay deposit thicknesses within each survey site were prepared using SURFER software developed by Golden Software,

Inc. Data used to construct these simulations were kriged and the resulting matrices smoothed using cubic spline techniques.

Survey Procedures:
The control and recording units were mounted on a Gator. The antenna was placed in a sled which was towed behind the Gator. Along each grid line, the Gator operator maintained course and speed between the flagged end points.

At each site, survey grids were formed from parallel lines spaced at 300 foot intervals. The GPR survey was conducted by towing the 120 mHz antenna along each line. Surveys were conducted in only one, and not orthogonal directions. A hand-held survey wheel was dragged alongside the Gator and used to measure distances along the grid lines. This procedure required three people: a driver, a radar operator, and a person operating the survey wheel. Survey wheels are available from manufacturers which simplify the "gridding" process by automatically superimposing distance marks on radar profiles. A mounted survey wheel would reduce the number of people needed to conduct a survey to two.

Along each line, at an interval of 100 feet, the radar operator impressed a segmented line, or distance mark, on the radar profile. The segmented line indicated the location of an observation point. Though the radar provides a continuous record of subsurface conditions, interpretations of splay deposits thicknesses were restricted to these observation points. At each observation point, the thickness of the recent splay deposits was interpreted from the radar imagery.

Calibration:
Calibration trials consisted of multiple traverses conducted within the Calloway County site. A scanning time of 40 nanoseconds (ns) was established on the control unit. As part of the calibration trials, a metallic reflector was buried at a depth of 10.5 inches (27 cm). Based on the scaled depth to this reflector, the calculated dielectric constant of the relatively dry, sand deposit was 5.9. The velocity of propagation was 0.408 ft/ns (0.128 m/ns). With a scanning time of 40 ns, the maximum observation depth was about 8.4 feet (2.56 m).

During the course of the GPR investigations, at each survey site and at twenty-five observation points, a soil auger was used to determine the thickness of the splay deposit. This information was used to confirm radar interpretations. The correlation between auger observations and scaled radar depths was exceptionally high. Based on 25 observations, the coefficient of determination (r^2) between the observed auger and the interpreted radar thicknesses of splay deposits was 0.9466 (see Figure 1). The average difference between soil auger and radar measurements of splay deposit thicknesses was 2.46 inches.

Radar Interpretations:
Figure 2 is a processed radar profile from the Ray County Site near the town of Orrick. This profile has been processed through the RADAN software package. The amplitudes of the reflected signals have been transformed to a color index and modified. The horizontal and vertical scales measure distances along the transect line and depths, respectively. These scales are in meters.

In Figure 2, the lower-most, continuous interface represents the boundary separating the coarse-textured splay deposits from the medium-textured, buried soil materials. This interface consists of two or three, dark, sub-parallel bands. It ranges in depth from about 10 to 95 inches. Exceptionally high rates of attenuation in the medium-textured materials limited signal penetration beyond this interface. Stratified, often segmented and more steeply inclined layers of coarser-textured splay deposits are evident in the upper part of the radar profile.

Discussion:

Jefferson City Site:

A 1600 by 700 foot grid was established at the Calloway County site. The grid was formed from two, parallel lines spaced 700 feet apart. Each line was 1600 feet. Along each of these two lines, survey flags were inserted in the ground at a 100 foot interval. The radar survey was conducted by towing the 120 mHz antenna orthogonal to the two parallel lines, along the seventeen, 700-foot lines. This procedure provided 136 observation points. At each observation point, the thickness of the sand deposits was interpreted from the radar imagery.

The survey area covered about 25.7 acres. The survey, consisting of 2.2 miles of continuous radar records, was completed in about one hour.

Based on radar interpretations at 136 observation points, the thickness of the sand deposits ranged from about 3.5 to 22 inches. The average thickness was 9.3 inches. One-half of the observations had splay deposits between 5.3 and 11.7 inches. Seventy-six percent of the observation points had deposits less than 12 inches. Twenty-one percent of the observation points had deposits between 12 and 18 inches. The estimated volume of recently deposited coarse-textured materials within the site is **32,506** cubic yards (approximated from data using the trapezoidal rule).

Figure 3 is a two-dimensional plot of splay deposits within the site. The break in the levee occurred to the west (left-hand side) of the survey site. Generally, the thickness of the splay deposits was greater in the western half of the survey site and appears to decrease with increasing distance from the break in the levee. The deepest splay deposits are located nearest to the break in the levee (see the upper left-hand corner of Figure 3).

The splay deposits were dominantly shallow (less than 20 inches) over buried soil materials. This site contained thinner than anticipated deposits of sands. Though the 120 mHz antenna was used, the relatively low resolution of this antenna at shallow depths hampered interpretations. The use of the higher frequency 300 or 500 mHz antennas would be more appropriate at this site.

Saline County - Site 1:

An irregularly-shaped, 900 by 4800 foot rectangular grid was established at this site. The grid was formed from four, parallel lines spaced 300 feet apart. Along each of these lines, survey flags were inserted in the ground at a 100 foot interval. This procedure

provided 166 observation points. At each observation point, the thickness of the sand deposits was interpreted from the radar imagery.

The survey area covered about 88.8 acres. The survey, consisting of 2.81 miles of continuous radar records, was completed in about one hour.

Based on radar interpretations at 166 observation points, the thickness of the splay deposits ranged from about 0 to 56 inches. The average thickness was 22.9 inches. One-half of the observations had deposits between 14 and 30 inches. Twenty percent of the observation points had deposits less than 12 inches. Thirteen percent of the observation points had deposits between 12 and 18 inches. Twenty-two percent of the observation points had deposits between 18 and 24 inches. Thirty-five percent of the observation points had deposits between 24 and 36 inches. Nine percent of the observation points had deposits greater than 36 inches. The estimated volume of recently deposited coarse-textured materials within the site is **325,691** cubic yards (approximated from data using the trapezoidal rule).

Figure 4 is a two-dimensional plot of the splay deposits within this site. The break in the levee occurred to the north (upper margin of plot) of the survey site. Generally, the thickness of the splay deposits was variable across the survey site.

Saline County - Site 2:
A 1500 by 1500 foot grid was established at this site. The grid was formed from six, parallel lines spaced 300 feet apart. Along each of these lines, survey flags were inserted in the ground at a 100 foot interval. This procedure provided 156 observation points. At each observation point, the thickness of the sand deposits was interpreted from the radar imagery.

The survey site covered about 51.6 acres. The survey, consisting of 1.70 miles of continuous radar records, was completed in less than one hour.

Based on radar interpretations at 156 observation points, the thickness of the splay deposits ranged from about 5 to 42 inches. The average thickness was 24.6 inches. One-half of the observations had deposits between 11 and 23 inches. Forty-one percent of the observation points had deposits less than 12 inches. Fifteen percent of the observation points had deposits between 12 and 18 inches. Twenty-four percent of the observation points had deposits between 18 and 24 inches. Fifteen percent of the observation points had deposits between 24 and 36 inches. Five percent of the observation points had deposits greater than 36 inches. The estimated volume of recently deposited coarse-textured materials within the site is **113,387** cubic yards (approximated from data using the trapezoidal rule).

Figure 5 is a two-dimensional plot of the splay deposits within Site 2 in Saline County. The break in the levee occurred to the northwest (upper left-hand corner) of the survey site. Other than a noticeable sand ridge in the northeast corner (upper right-hand corner of Figure 5), the site was relatively featureless with splay deposits of moderately uniform thicknesses.

Saline County - Site 3:
A 1200 by 900 foot grid was established at this site. The grid was formed from five, parallel lines spaced 300 feet apart. Along each of these lines, survey flags were inserted in the ground at a 100 foot interval. This procedure provided 50 observation points. At each observation point, the thickness of the sand deposits was interpreted from the radar imagery or measured with a soil auger.

The survey site covered about 24.8 acres. The survey was restricted because of wet and impassable soil conditions in the swales and depressions. Most observations were obtained with a soil auger.

Based on 50 observation points, the thickness of the splay deposits ranged from about 2 to 47 inches. The average thickness was 19 inches. One-half of the observations had deposits between 10 and 26 inches. Thirty-two percent of the observation points had deposits less than 12 inches. Twenty-two percent of the observation points had deposits between 12 and 18 inches. Eighteen percent of the observation points had deposits between 18 and 24 inches. Ten percent of the observation points had deposits between 24 and 36 inches. The estimated volume of recently deposited coarse-textured materials within the site is **67,909** cubic yards (approximated from data using the trapezoidal rule).

Figure 6 is a two-dimensional plot of the splay deposits within this site. The break in the levee occurred to the north (upper margin of plot) of the survey site. Generally, the thickness of the splay deposits was variable across the survey site. Two sand ridges are evident in the southwest and northeast corners of the site.

Ray County - Site 1:
An irregularly-shaped, 2100 by 7200 foot rectangular grid was established at this site. The grid was formed from eight, parallel lines of variable lengths, spaced 300 feet apart. Along each of these lines, survey flags were inserted in the ground at a 1000 foot interval. Using a survey wheel, distance marks were impressed on the radar profiles at 100 foot intervals. This procedure provided 464 observation points. At each observation point, the thickness of the sand deposits was interpreted from the radar imagery.

The survey site covered about 264.6 acres. The radar survey, consisting of 8.64 miles of continuous radar records, was completed in 2.08 hours.

Based on radar interpretations at 464 observation points, the thickness of the splay deposits ranged from about 0 to 91 inches. The average thickness was 24.7 inches. One-half of the observations had deposits between 8 and 35 inches. Thirty-one percent of the observation points had deposits less than 12 inches. Eleven percent of the observation points had deposits between 12 and 18 inches. Ten percent of the observation points had deposits between 18 and 24 inches. Twenty-five percent of the observation points had deposits between 24 and 36 inches. Twenty-two percent of the observation points had deposits greater than 36 inches. The estimated volume of recently deposited coarse-textured materials within the site is **1,092,830** cubic yards (approximated from data using the trapezoidal rule).

Figure 7 is a two-dimensional plot of the splay deposits within this site. The break in the levee occurred to the west and north-west (upper margin of plot) of the survey site. Generally, the thickness of the splay deposits was variable across the survey site. Areas containing relatively thick and thin sand deposits are evident in the south-central and northern portions of the survey site, respectively.

Results:

Based on this study, GPR appears to be a most appropriate tool for determining the thickness of splay deposits along the Missouri River. Ground-penetrating radar and computer-graphic techniques can be used to rapidly quantify, characterize, and display the thicknesses of splay deposits across large areas. This information can be used to assess the volume of recently deposited sands within individual units of management or landscapes. In addition, GPR can provide the data needed to support digital remote sensing interpretations across larger areas of the Missouri River Basin.

Ground-penetrating radar provides highly interpretable images of the interface separating the surficial coarse-textured deposits from the underlying buried, medium-textured soil materials. However, because of the strong surface reflection and the resolution of the 120 mHz antenna, interfaces within the upper 12 to 14 inches of the soil profile were difficult to resolve. Twenty-five auger observations confirmed the accuracy of GPR interpretations. With a limited number of auger observations, radar profiles can be properly interpreted, scaled and verified to yield large amounts of data on the thickness of splay deposits.

With a suitable platform and vehicle for traversing areas with recent splay deposits, GPR techniques can be effectively used to quickly cover large areas and provide continuous, highly-resolved profiles of the subsurface. With suitable equipment and survey procedures, areas of 320 acres or more can be examined with GPR in a day. Based on this study, parallel radar traverses spaced at intervals of 300 feet with observations points spaced at 100 foot intervals along each traverse appear reasonable. Radar data must be verified in the field and properly interpreted (in terms of thickness of splay deposits). For each management unit, basis statistics and two-dimensional plots (as illustrated in this report) can be prepared from the radar data.

The costs of a radar survey will vary with consulting companies. Radar consultant fee range from $900 to $2000/day (personal communication with Stan Smith of Geophysical Survey Systems, Inc.). Transportation, shipping, travel, and equipment expenses (rentals or purchase of suitable survey vehicle) must be added to this fee (an additional $200/day). In addition, for each day in the field, two days are required in the office to analyze the data and prepare reports. Generally, consultant interpretation fees range from $400 to $500/day. Assuming a consultant fee of $1500/day, travel and related expenses of $200/day, and interpretation fees of $900/day (for each day in the field, two days in office at @ $450/day); the costs of a radar survey would average about $2600/field day. This would work out to be about $8.12/acre surveyed (assuming a production rate of 320 acres/day).

A disc containing the data collected in this study has been forwarded to Ken Vogt under a separate cover letter. This data may be useful to the state's GIS staff. If I can be of any further assistance, please do not hesitate to ask. It was my pleasure to work in Missouri and with Ken, Richard and other members of your fine staff.

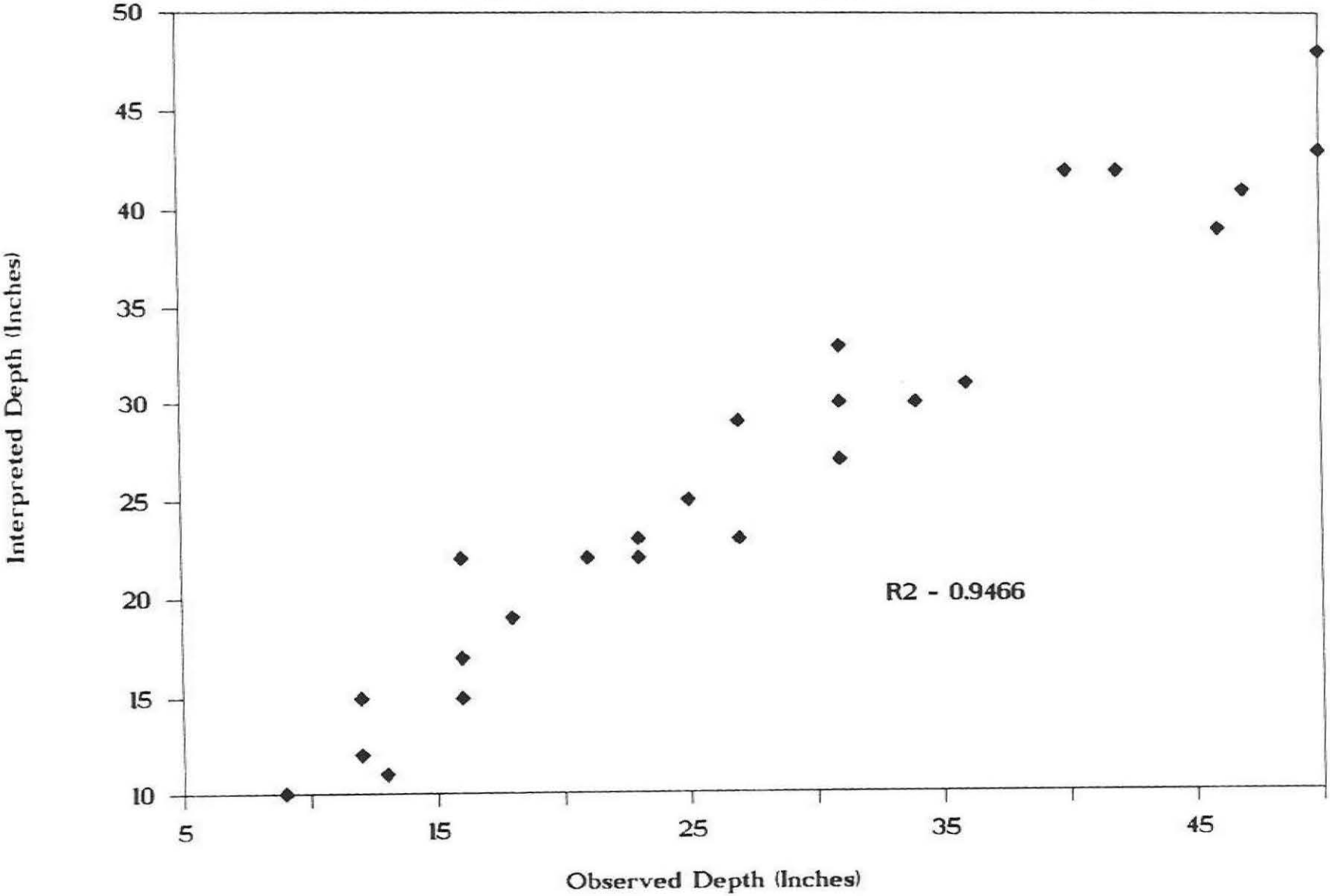
With kind regards

James A. Doolittle
Soil Specialist

cc:
Russell C. Mills, STC, SCS, Columbia, Missouri
James Culver, Assistant Director, NSSC, MWNTC, SCS, Lincoln, NE
Richard Fenwick, 12717 East 64th Ct., Kansas City, Missouri 64133
Steve Holzhey, Assistant Director, NSSC, MWNTC, SCS, Lincoln, NE

FIGURE 1

COMPARISON OF OBSERVED AND INTERPRETED THICKNESSES OF SAND LAYERS FOR SPLAY DEPOSITS ALONG THE MISSOURI RIVER



MO2 Created Jun 14,1994 11:51 Modified Jun 14,1994 12:56

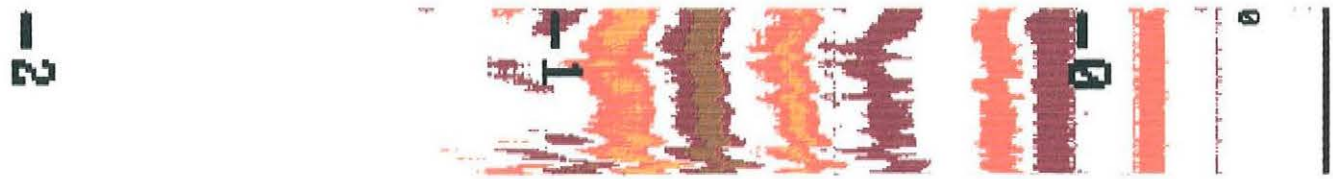
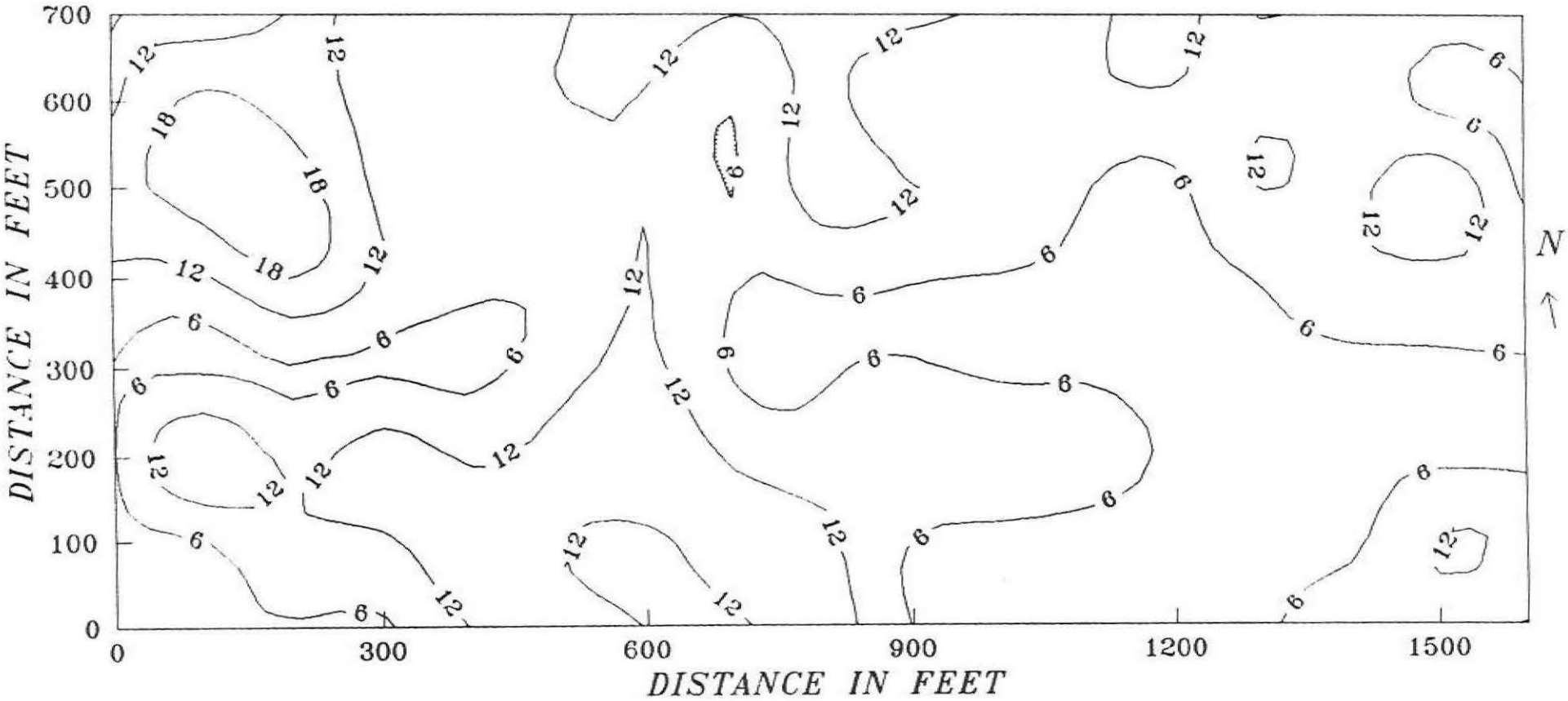


FIGURE 3

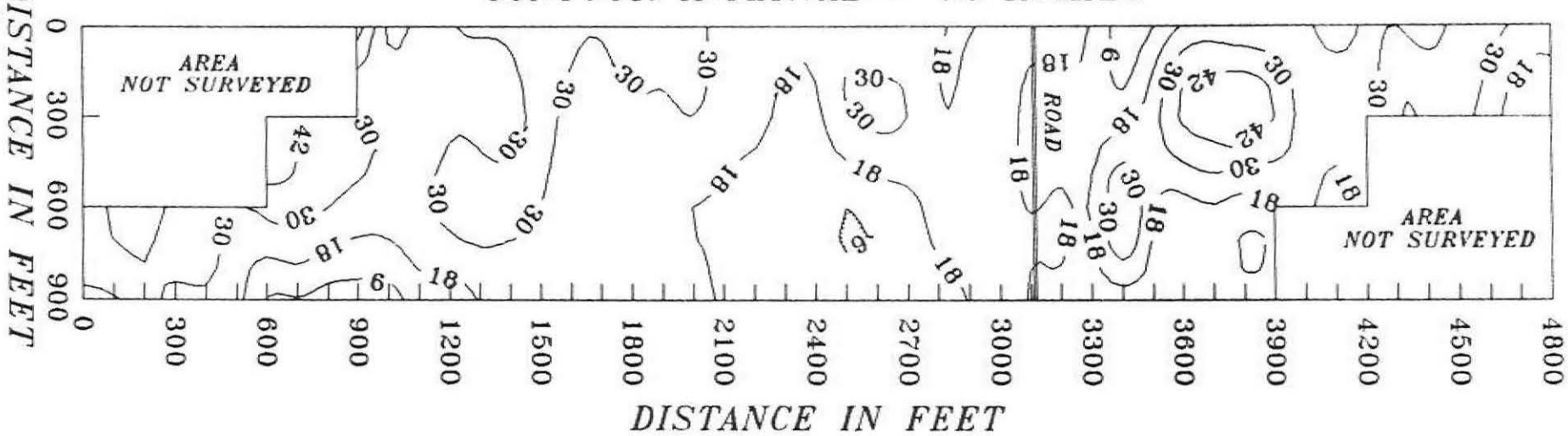
THICKNESS OF SPLAY DEPOSITS, SITE 1 – CALLOWAY COUNTY, MO

CONTOUR INTERVAL = 6 INCHES



THICKNESS OF SPLAY DEPOSITS, SITE 1 - SALINE COUNTY, MO

CONTOUR INTERVAL = 12 INCHES

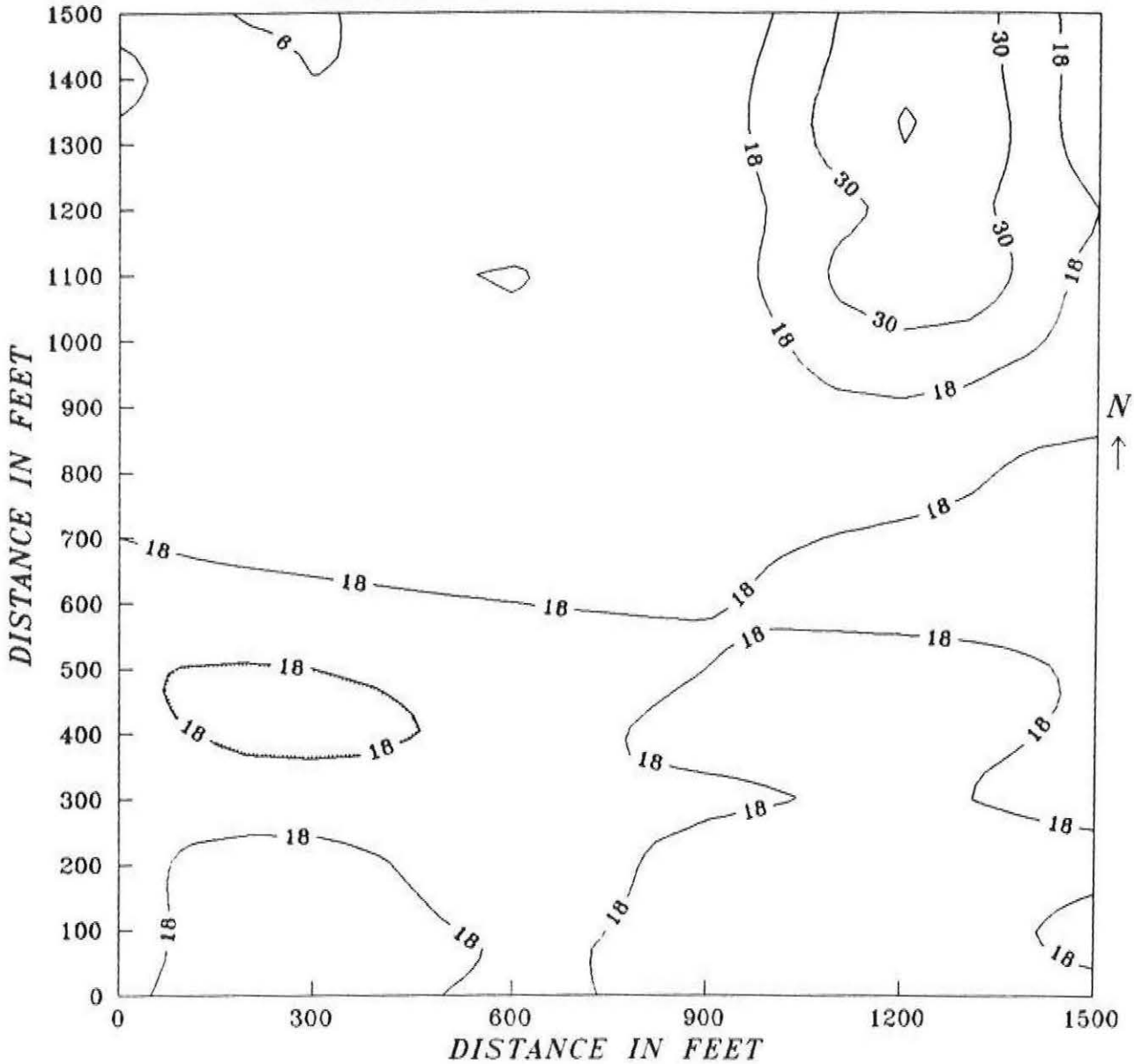


$N \leftarrow$

FIGURE 4

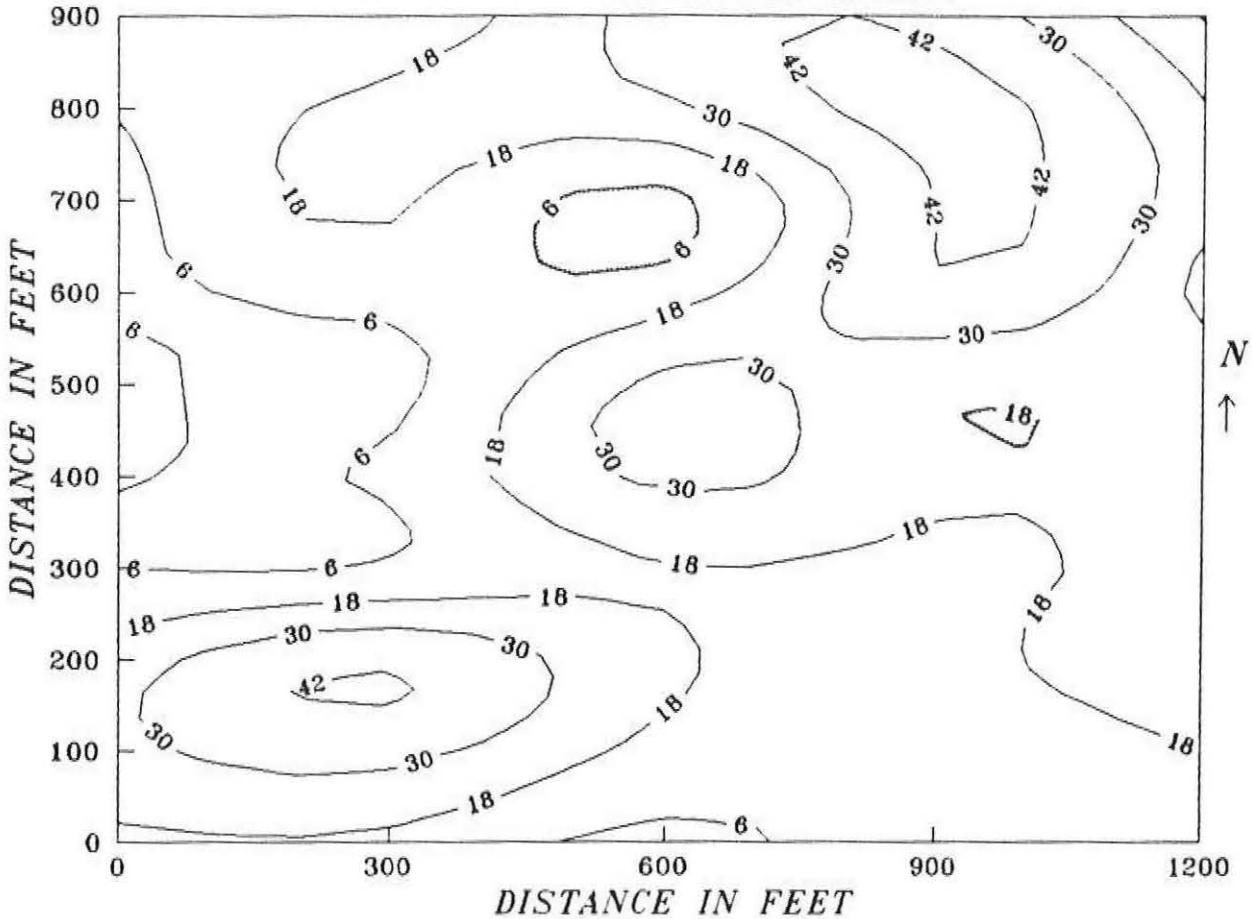
THICKNESS OF SPLAY DEPOSITS, SITE 2 – SALINE COUNTY

CONTOUR INTERVAL = 12 INCHES



THICKNESS OF SPLAY DEPOSITS, SITE 3 - SALINE COUNTY, MO

CONTOUR INTERVAL = 12 INCHES



THICKNESS OF SPLAY DEPOSITS, SITE 1 – RAY COUNTY, MO

CONTOUR INTERVAL = 12 INCHES

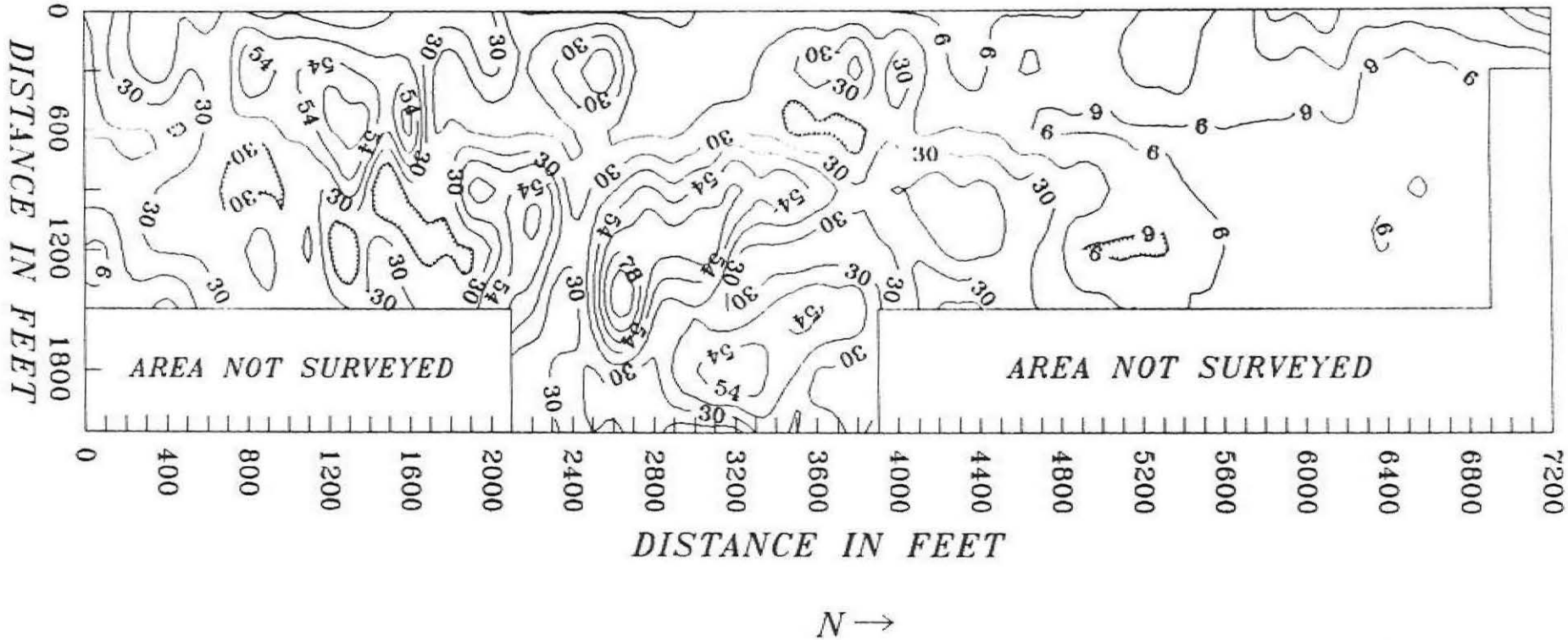


FIGURE 7