United States Department of Agriculture

Natural Resources Conservation Service

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Subject: Geophysical Assistance

Date: 9 September 1998

To: Richard J. Gooby
State Conservationist
USDA - NRCS
Federal Building, Room 443
10 East Badcock Street
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Purpose:
To provide ground-penetrating radar (GPR) and electromagnetic induction (EMI) field assistance.

Participants:
Wade Botts, Soil Specialist, MLRA 4, USDA-NRCS, Bozeman, MT
Jim Doolittle, Research Soil Scientist, NSSC, USDA-NRCS, Radnor, PA
Bob Lienard, Plant Ecologist, Riparian/Wetland Team, USDA-NRCS, Bozeman, MT
Chris Noble, Soil Scientist, Riparian/Wetland Team, USDA-NRCS, Bozeman, MT

Activities:
All field activities were completed during the period of 24 to 28 August 1998.

Equipment:
The radar unit used was the Subsurface Interface Radar (SIR) System-2, manufactured by Geophysical Survey Systems, Inc.* The SIR System-2 consists of a digital control unit (DC-2) with keypad, VGA video screen, and connector panel. The models 5103 (400 mHz) and 5106 (200 mHz) antennas were used in this study. The system was powered by a 12-VDC battery. The use and operation of GPR have been discussed by Morey (1974), Doolittle (1987), and Daniels and others (1988).

The electromagnetic induction meter used was the EM38, manufactured by Geonics Limited*. This meter is portable and requires only one person to operate. Principles of operation have been described by McNeill (1986). No ground contact is required with this meter. This meter provides limited vertical resolution and depth information. Lateral resolution is approximately equal to the intercoil spacing. The EM38 meter operates at a frequency of 14,600 Hz. It has theoretical observation depths of about 0.75 and 1.5 meters in the horizontal and vertical dipole orientations, respectively (McNeill, 1986). Values of apparent conductivity are expressed in milliSiemens per meter (mS/m).

The position of observation points was obtained with a Rockwell Precision Lightweight GPS Receiver (PLGR)*. The receiver was operated in the continuous mode using an external power source (portable

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9 volt battery). The Universal Transverse Mercator (UTM) coordinate system was used.

To help summarize the results of this study, the SURFER for Windows program, developed by Golden Software, Inc.,* was used to construct two-dimensional simulations. Grids were created using kriging methods with an octant search. All grids were smoothed using a cubic spline interpolation.

Results:

1. In the selected riparian areas of Beaverhead County, ground-penetrating radar provided unacceptable depths of observation and poor resolution of soil and stratigraphic features. High rates of signal attenuation limited observation depths to about 1.25 meters in areas of fine-loamy, Typic and Cumulic Cryaquolls. Principal factors restricting observation depths were the concentrations of soluble salts and bases, and clay content and mineralogy (smectitic). While concentrations of soluble salts and clays were comparatively low, they were sufficient to limit the use of GPR for soil investigations

2. Electromagnetic induction appears to be an effective tool for the mapping riparian areas. The use of this tool should be explored more thoroughly and the knowledge learned during this field period should be expanded upon during my second visit to Montana (September 28 to October 2, 1998).

3. Chris Noble received training on the use and operation of the EM38 meter.

4. EMI survey procedures for riparian areas have been refined during this field trip. The necessity of some soil sampling is understood by participants. Participants realize the need for geo-referencing stream channels and zones of vegetation. Topographic surveys of sites may improve interpretations.

5. At the Price Creek Site, several soil borings were obtained. Soil's information was compared with apparent conductivity measurements. Excluding a sample taken within the seepage area, a strong correlation ($r = 0.9936$) was obtained by relating apparent conductivity to water table depth. This relationship is based on a very limited sample and should be examined more thoroughly during my next visit.

6. Geophysical interpretations are considered preliminary estimates of site conditions. The results of geophysical site investigations do not substitute for direct observations, but rather reduce their number, direct their placement, and supplement their interpretations. Interpretations contained in this report should be verified by ground-truth observations.

It was my pleasure to work in Montana and with members of your fine staff.

With kind regards,

James A. Doolittle
James A. Doolittle
Research Soil Scientist

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1. Ground-penetrating Radar

In Montana, GPR has been used to investigate the morphology of point-bar deposits (Alexander et al., 1994) and to map buried paleochannels and water tables (Poole et. al., 1997). In both studies, results were "soil dependent." In studies conducted along the Flathead River, near Kalispell and West Glacier (Poole et. al., 1997), GPR was successful in soils with low clay contents and water saturation. Discussed transects completed by Alexander and others (1994) along the Madison River near Hebgen Lake, were principally restricted to coarse-textured, point bar deposits.

Studies were conducted to evaluate the use of GPR to map the depth and extent of diagnostic soil horizons and gravel layers within riparian areas in southwestern Montana. Sites were located in Beaverhead County, Montana.

Ground-penetrating radar is a time scaled system. This system measures the time that it takes electromagnetic energy to travel from an antenna to an interface (e.g., soil horizon, stratigraphic layer, water table) and back. To convert the travel time into a depth scale, either the velocity of pulse propagation or the depth to a reflector must be known. The relationships among depth (d), two-way pulse travel time (t), and velocity of propagation (v) are described in the following equation (Morey, 1974):

$$v = 2d/t$$

The velocity of propagation is principally affected by the dielectric permittivity (e) of the profiled earthen material(s) according to the equation:

$$e = (c/v)^2$$

Where c is the velocity of propagation in a vacuum (0.3 m/nanosecond). The amount and physical state of water (temperature dependent) have the greatest effect on the dielectric permittivity of earthen materials.

Calibration trials were conducted at each site. The purposes of these trials were to assess the suitability of GPR and the interpretive quality of radar profiles. At each site, a shovel bladed was buried in the ground. This buried reflector was identified on radar profiles. The depth to this reflector was scaled and used to estimate the velocity of propagation through the upper part of the soil profile and the maximum depth of observation.

At the Basin Creek site (UTM: 0388617 Easting, 4956220 Northing), traversed soils belong to the Haplocryolls subgroup and the fine-loamy textural class. A shovel blade was buried at a depth of 0.40 m (16 inches). Based on the round-trip travel time to this reflector, the velocity of propagation through the upper part of the soil was estimated to be 0.0998 m/ns with the 200 mHz antenna. The dielectric permittivity was estimated to be 9.0. A scanning time of 40 ns provided a maximum potential depth of observation of about 2 m. However, observation depths were restricted by the rapid rates of signal attenuation. Reflections on radar profiles were discontinuous and very poorly expressed below depths of about 1.25 m.

At the Price Creek site (UTM: 0410785 Easting, 4935968 Northing), traversed soils belong to the fine-loamy, mixed, Cumulic Cryaquolls family. A shovel blade was buried at a depth of 0.40 m (16 inches). Based on the round-trip travel time to the buried shovel blade, the velocity of propagation through the upper part of the soil was estimated to be 0.1145 m/ns with the 200 mHz antenna. The dielectric permittivity was estimated to be 6.9. A scanning time of 50 ns provided a maximum potential depth of observation of about 2.9 m. However, observation depths were restricted by rapid rates of signal attenuation. The maximum observation depth was about 0.90 m.

At the Red Rock River site (UTM: 0409821 Easting, 4943255 Northing), traversed soils consisted of stratified layers of sands and sandy loams. Soils belong to the coarse-loamy, mixed, Cumulic Cryaquolls family. These were the coarsest textured soils traversed with GPR. A shovel blade was buried at a depth of 0.50 m (20 inches). Based on the round-trip travel time to the buried shovel blade, the velocity of propagation through the upper part of the soil was estimated to be 0.1097 m/ns with the 200 mHz antenna. The dielectric permittivity was estimated to be 7.5. A scanning time of 50 ns provided a maximum potential depth of observation of about 2.7 m. Once more, observation depths were restricted by rapid rates of signal attenuation. The maximum observation depth was about 0.60 m.

Soils at the Watson Creek site (UTM: 0329227 Easting, 4998340 Northing) had been mapped as a sandy textural class. Several soil probings were made at this site. The soils observed in these exposures were members of the fine-loamy, mixed, Typic or Cumulic Cryaquolls families.

After investigating the Watson Creek site, it was concluded that a representative range of soils and sites had been investigated. A large portion of the riparian areas consists of soils having superactive cation-exchange activity class, a prevalence of smectitic clays, and fine-loamy or finer textural classes (at least in the upper part of the control section). These soils are highly attenuating and restrict the penetration depth of GPR. Within each site, it is probable that small included areas having thin soil mantles overlying sands and gravel deposits could be found. These areas would be more suited to GPR. However, in most areas, radar profiles would be too depth restricted and the interpretive quality of the radar profiles would be too poor to be helpful to investigators. In Montana, while exceptions to this rule can be found, GPR is considered an inappropriate tool for soil investigations in most riparian areas.

2. Electromagnetic Induction

Background

Electromagnetic induction is a noninvasive geophysical tool that has been used in high intensity surveys and detailed site assessments. Electromagnetic induction uses electromagnetic energy to measure the bulk electrical conductivity of the soil below the transmitter and receiver coils. This apparent conductivity is a weighted, average conductivity measurement for a column of earthen materials to a specific observation depth (Greenhouse and Slaine, 1983).

Variations in apparent conductivity are produced by changes in the electrical conductivity of earthen materials. The electrical conductivity of soils is influenced by the types and concentration of ions in solution, the amount and types of clays in the soil matrix, the volumetric water content, and the temperature and phase of the soil water (McNeill, 1980). The apparent conductivity of soils increases with increases in soluble salts, water, and clay contents (Kachanoski et al., 1988; Rhoades et al., 1976). Apparent conductivity is principally affected by changes in the electrolyte concentration of the soil water and the soil water content (Johnston, 1997). However, at low soil moisture contents, EMI is relatively insensitive to changes in soil-water content. At high soil moisture contents, EMI is more sensitive to changes in soil-water content (Hanson, 1997).

Electromagnetic induction methods map spatial variations in apparent electrical conductivity. Though seldom diagnostic in themselves, lateral and vertical variations in apparent conductivity have been used to infer changes in soils and soil properties. Electromagnetic induction has been extensively used by soil scientists to identify, map, and monitor soil salinity (Cook and Walker, 1992; Corwin and Rhoades, 1982 and 1990; Rhoades and Corwin, 1981; Rhoades et al., 1989a and 1989b; Slavich and Peterson, 1990; and Wollenhaupt et al., 1986). This technology has also been used to assess and map sodium-affected soils (Ammons et al., 1989; Nettleton et al., 1994), depths to claypans (Doolittle et al., 1994; Stroh et al., 1993; Sudduth and Kitchen, 1993; and Sudduth et al., 1995), regional differences in soil mineralogy (Doolittle et al., 1995), and edaphic properties important to forest site productivity (McBride et al., 1990). In addition, electromagnetic induction has been used to measure soil water contents (Kachanoski et al., 1988), cation exchange capacity (McBride et al., 1990), and leaching rates of solutes (Jaynes et al., 1995b).

Apparent conductivity can be used to assess the within-field variability of soils and soil properties. At low total soluble salt levels, EMI maps soil types (Cook et al., 1992). Apparent conductivity has been associated with changes in soils and soil map units (Hoekstra et al., 1992; Jaynes et al., 1993, Doolittle et al., 1996). Electromagnetic induction integrates the bulk physical and chemical properties of soils into a single value for a defined observation depth. The inherent physical and chemical properties of each soil, as well as temporal variations in soil water and temperature, establish a unique and characteristic range of apparent conductivity values. This range can be influenced by differences in use or management practices (Sudduth and Kitchen, 1993, Sudduth et al., 1995).

Electromagnetic induction is ideally suited to high intensity soil surveys. Apparent conductivity has been used as a surrogate for soil and soil properties. Spatial patterns of apparent conductivity have been used to prepare soil attribute maps (Doolittle et al., 1996). Results from EMI surveys have been used to map soils and soil properties, guide sampling, and facilitate site assessments. Recently, EMI has been used in the Midwest to map soil attributes for precision farming (Jaynes, 1995; Jaynes et al., 1995a; Sudduth et al., 1995).

Generally, the use of EMI has been most successful in areas where soils and subsurface properties are reasonably homogeneous. This technique has been most effective in areas where the effects of one property (e.g., clay, water, or salt content) dominate over the other properties. In these areas, variations in EMI response can be directly related to changes in the dominant property (Cook et al., 1989).

Electromagnetic induction is not suitable for use in all soils. The use of EMI is often inappropriate in areas having varied soils with complex and highly changeable properties or spatial distributions. In these areas, relationships are weakened and results are more ambiguous. The predictive accuracy of EMI data decreases with increasing numbers of subsurface layers. In addition, an EMI meter must be sensitive to the differences existing between soil layers. In other words, a meter must be able to detect differences in electromagnetic properties between the layers.

Some dissimilar materials have similar values of apparent conductivity and therefore produce non-unique (equivalent) solutions. This occurs where differences in apparent conductivity caused by changes in one property (e.g., layer thickness; soluble salt, clay, or water contents) are offset by variations in another property. Many soils have subsurface layers that vary in thickness and in chemical and physical properties, but have closely similar conductivity values. Where these dissimilar layers occur in the same landscape, they can produce equivalent solutions or measurements. Equivalent solutions are caused by the simultaneous change in two or more properties (e.g., layer thickness; soluble salt, clay or water contents). Equivalent solutions obscured results and limited the effectiveness of EMI. In studies conducted by Jaynes and others (1995, 1995b) in Iowa, coexistent changes in the moisture, clay, and carbonate contents weakened relationships between apparent conductivity and moisture stress or drainage classes.

Preliminary EMI surveys in Beaverhead County:

Multiple riparian areas and soil map units were traversed or gridded with EMI during the latter part of the week. The purpose of systematic EMI surveys is to identify the distribution and extent of soil and geologic patterns within riparian areas and to assess changes in soil properties within and among these patterns.

Price Creek Site

Six random traverses were conducted across the Price Creek Site. Survey flags were inserted at irregular intervals along each traverse line. Generally, intervals conform with observed divisions in landscape or vegetative units. This procedure produced fifty-eight observation points. The locations of these observation points are shown in the left-hand plot in Figure 1. Also shown in Figure 1 is the location of Price Creek (segmented, blue line). At each survey flag, measurements were obtained with the EM38 meter in both the horizontal and vertical dipole orientations. For each measurement, the meter was placed on the ground surface. The coordinates of each observation point were obtained with a Rockwell Precision Lightweight GPS receiver.

Figure 1 contains two-dimensional plots of data collected with the EM38 meter in the horizontal (left-hand plot) and vertical (right-hand plot) dipole orientations. In Figure 1, the left-hand plot represents the spatial distribution of apparent conductivity within the upper 30 inches of the soil profile. The right-hand plot represents the spatial distribution of apparent conductivity within the upper 60 inches of the soil profile. In each plot, the isoline interval is 5 mS/m.

At the Price Creek Site, the dominant soils are members of the fine-loamy, mixed, Cumulic Cryaquolls family. Apparent conductivity of the upper 30 inches (measured with the EM38 meter in the horizontal dipole orientation) averaged 15.6 mS/m. One-half of the observations had an apparent conductivity between 7.75 and 20.0 mS/m. The apparent conductivity of the upper 60 inches (measured with the EM38 meter in the vertical dipole orientation) averaged 21.2 mS/m. One-half of the observations had an apparent conductivity between 12.0 and 28.0 mS/m. The increased conductivity with depth was attributed to increased moisture at greater soil depths. Of the three sites surveyed with the EM38 meter, Price Creek was the most variable in terms of apparent conductivity. The lowest (2.0 mS/m) and highest (51.0 ,mS/m) apparent conductivity measurements were recorded at the Price Creek Site. The inclusion of different soils and landscape components (terraces, upland) within the survey area explains some of this variability. In addition, a seep area on a sideslope (see area of highest conductivity near the lower right-hand corner of each plot in Figure 1) contributed to the complexity to this site.

The spatial patterns evident in Figure 1 are believed to represent the distribution of soils and/or soil properties. Soils were observed at four observation points. These soils differed in the arrangement, thickness, and texture of soil horizons, depth to redoximorphic features, water table, and gravel layers. Excluding the sample taken in the seep area and although sampling was restricted (N = 3), a strong correlation (r = 0.9936) was obtained by relating apparent conductivity to water table depth. This relationships should be examined more thoroughly.

Red Rock River Site

A grid survey was completed at the Red Rock River Site. This procedure produced twenty-four observation points. The locations of these observation points are shown in the left-hand plot in Figure 2. Unfortunately the location of Red Rock River and a tributary were not recorded with the GPS receiver. As a consequence, it is difficult to interpret these plots and to understand the spatial patterns.

At each survey flag, measurements were obtained with the EM38 meter in both the horizontal and vertical dipole orientations. For each measurement, the meter was placed on the ground surface. The coordinates of these observation points were obtained with a Rockwell Precision Lightweight GPS receiver.

Figure 2 contains two-dimensional plots of data collected with the EM38 meter in the horizontal (left-hand plot) and vertical (right-hand plot) dipole orientations. In Figure 2, the left-hand plot represents the spatial distribution of apparent conductivity within the upper 30 inches of the soil profile. The right-hand plot represents the spatial distribution of apparent conductivity within the upper 60 inches of the soil profile. In each plot, the isoline interval is 10 mS/m.

At the Red Rock River Site, the observed soils belong to the coarse-loamy, mixed, Cumulic Cryaquolls family. Apparent conductivity of the upper 30 inches (measured with the EM38 meter in the horizontal dipole orientation) averaged 36.6 mS/m. One-half of the observations had an apparent conductivity between 32.0 and 39.5 mS/m. The apparent conductivity of the upper 60 inches (measured with the EM38 meter in the vertical dipole orientation) averaged 35.5 mS/m. One-half of the observations had an apparent conductivity between 31.0 and 39.0 mS/m. Apparent conductivity remained essentially constant with depth.

Compared with the Price Creek Site, soils at the Red Rock River Site were coarser textured. If all other factors (moisture and salt contents) are equal, the lower clay content of soils at the Red Rock River Site should have resulted in slightly lower measurements of apparent conductivity. This was not the case. Averaged values of apparent conductivity measured with the EM38 meter in both orientations were higher, though less variable, at the Red Rock River Site. Differences in apparent conductivity are assumed to reflect differences in the concentration of moisture and soluble salts in soil profiles. However, these observations are conjectural and require verification by soil probe sampling.

Long Creek Site

Three random traverses were conducted across the Long Creek Site. Survey flags were inserted at irregular intervals along each traverse line. Generally, intervals conform with observed divisions in landscape or vegetative units. This procedure produced twenty-five observation points. The locations of these observation points are shown in the left-hand plot in Figure 3.

At each survey flag, measurements were obtained with the EM38 meter in both the horizontal and vertical dipole orientations. For each measurement, the meter was placed on the ground surface. The coordinates of these observation points were obtained with a Rockwell Precision Lightweight GPS receiver. Long Creek traversed the site in a sinuous pattern. Unfortunately the location of Long Creek was not recorded with the GPS receiver. As a consequence, it is difficult to interpret these plots and to understand the spatial patterns.

Figure 3 contains two-dimensional plots of data collected with the EM38 meter in the horizontal (left-hand plot) and vertical (right-hand plot) dipole orientations. In Figure 3, the left-hand plot represents the spatial distribution of apparent conductivity within the upper 30 inches of the soil profile. The right-hand plot represents the spatial distribution of apparent conductivity within the upper 60 inches of the soil profile. In each plot, the isoline interval is 10 mS/m.

Because of the shortage of available time, no soil borings were possible at the Long Creek Site. Apparent conductivity of the upper 30 inches (measured with the EM38 meter in the horizontal dipole orientation) averaged 26.4 mS/m. One-half of the observations had an apparent conductivity between 19.5 and 31.0 mS/m. The apparent conductivity of the upper 60 inches (measured with the EM38 meter in the vertical dipole orientation) averaged 31.7 mS/m. One-half of the observations had an apparent conductivity between 28.0 and 34.8 mS/m. The greater conductivity with increased observation depth was attributed to increased moisture at greater soil depths.

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PINE CREEK SITE:

WAYPOINT	EASTING	NORTHING	EM38H	EM38V
WP001	410671	4936161	5.0	9.0
WP002	410680	4936163	20.0	27.0
WP003	410687	4936167	25.5	32.0
WP004	410694	4936171	24.0	31.0
WP005	410704	4936173	18.0	18.0
WP006	410707	4936177	25.5	28.0
WP007	410714	4936180	33.0	40.0
WP008	410721	4936180	30.5	42.0
WP009	410731	4936184	11.0	18.5
WP010	410739	4936185	12.0	21.0
WP011	410732	4936216	12.5	11.0
WP012	410723	4936214	7.0	12.0
WP013	410716	4936214	10.0	18.0
WP014	410709	4936211	45.0	50.0
WP015	410700	4936213	27.0	29.0
WP016	410695	4936211	20.0	24.5
WP017	410687	4936209	16.5	16.0
WP018	410682	4936206	14.5	22.0
WP019	410672	4936204	18.0	27.0
WP020	410655	4936200	9.0	17.0
WP021	410647	4936196	4.0	8.0
WP022	410641	4936223	4.0	8.0
WP023	410651	4936227	20.0	32.0
WP024	410660	4936232	17.5	29.0
WP025	410668	4936235	32.5	36.0
WP026	410681	4936236	21.0	32.0
WP027	410688	4936235	21.0	22.0
WP028	410703	4936235	32.0	30.0
WP029	410711	4936235	48.0	51.0
WP030	410719	4936237	8.5	15.0
WP031	410728	4936238	5.5	11.5
WP032	410719	4936268	6.0	10.0
WP033	410702	4936264	6.0	10.0
WP034	410694	4936261	17.5	29.0
WP035	410682	4936258	13.0	17.0
WP036	410669	4936257	20.5	28.0
WP037	410651	4936257	19.5	28.0
WP038	410641	4936256	9.5	15.5
WP039	410632	4936255	5.0	9.0
WP040	410627	4936282	2.5	9.0
WP041	410636	4936285	7.5	12.0
WP042	410641	4936286	16.0	25.5
WP043	410652	4936289	16.0	27.5
WP044	410659	4936293	25.0	25.0
WP045	410668	4936297	17.0	18.5
WP046	410681	4936300	9.0	14.0
WP047	410687	4936302	4.5	8.0
WP048	410694	4936305	2.2	9.0
WP049	410710	4936305	7.0	2.0
WP050	410710	4936333	8.5	12.5
WP051	410701	4936336	9.0	13.0
WP052	410692	4936334	15.0	26.0
WP053	410680	4936335	16.0	18.5
WP054	410671	4936335	15.0	22.0
WP055	410653	4936334	13.0	22.0
WP056	410635	4936330	16.5	27.0
WP057	410633	4936324	8.0	13.0
WP058	410617	4936328	4.5	8.0

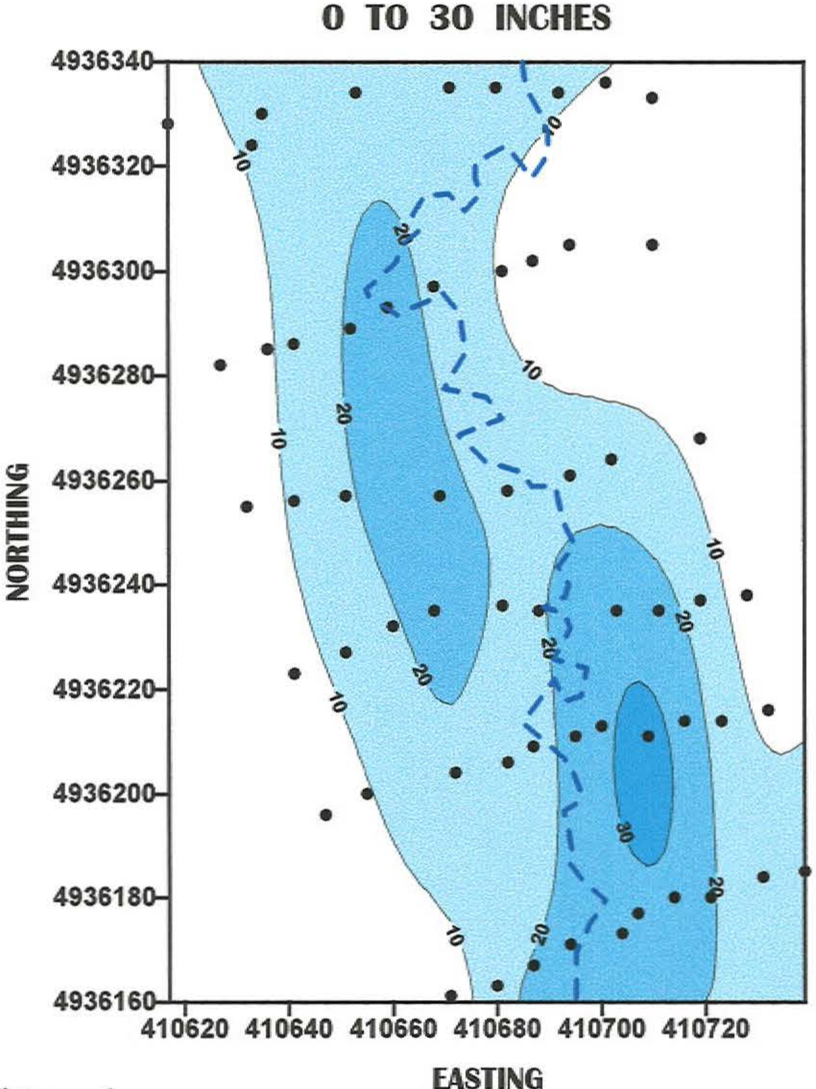
RED ROCK RIVER SITE:

WAYPOINT	EASTING	NORTHING	EM38H	EM38V
WP122	409823	4943250	34.0	31.0
WP123	409828	4943248	29.0	29.0
WP124	409836	4943245	32.0	32.0
WP125	409844	4943243	28.0	30.5
WP126	409847	4943250	35.0	34.0
WP127	409838	4943252	31.0	31.0
WP128	409830	4943255	31.0	33.0
WP129	409824	4943255	41.0	36.0
WP130	409826	4943264	37.0	34.5
WP131	409833	4943263	35.0	34.5
WP132	409842	4943263	40.0	38.0
WP133	409850	4943260	38.0	39.0
WP134	409855	4943267	39.0	39.5
WP135	409846	4943269	39.5	40.0
WP136	409835	4943271	39.0	34.0
WP137	409827	4943273	31.0	31.0
WP138	409830	4943280	35.0	36.0
WP139	409838	4943279	38.0	28.0
WP140	409849	4943275	44.0	44.0
WP141	409857	4943271	43.0	39.0
WP142	409860	4943280	46.0	39.0
WP143	409853	4943283	47.0	41.0
WP144	409844	4943287	32.0	32.5
WP145	409834	4943290	34.0	37.0

PRICE CREEK SITE

WAYPOINT	EASTING	NORTHING	EM38H	EM38V
WP146	417210	4953114	37.0	34.0
WP147	417211	4953122	35.0	38.0
WP148	417212	4953137	35.0	39.0
WP149	417213	4953150	32.0	38.0
WP150	417215	4953164	28.0	34.0
WP151	417216	4953172	18.0	25.0
WP152	417215	4953181	15.0	19.0
WP153	417208	4953196	19.0	26.0
WP154	417204	4953184	18.0	28.0
WP155	417205	4953168	26.0	32.0
WP156	417204	4953163	29.0	36.0
WP157	417204	4953155	31.0	34.0
WP158	417203	4953152	38.0	45.0
WP159	417202	4953142	29.0	32.0
WP160	417201	4953130	28.0	29.0
WP161	417201	4953118	22.0	28.0
WP162	417199	4953110	21.0	28.0
WP163	417189	4953109	27.0	32.0
WP164	417188	4953131	17.0	20.0
WP165	417191	4953139	26.0	32.0
WP166	417190	4953142	31.0	35.0
WP167	417192	4953148	33.0	42.0
WP168	417193	4953153	27.0	32.0
WP169	417192	4953173	21.0	29.0
WP170	417194	4953189	17.0	25.0

EMI SURVEY
PRICE CREEK SITE
EM38 METER



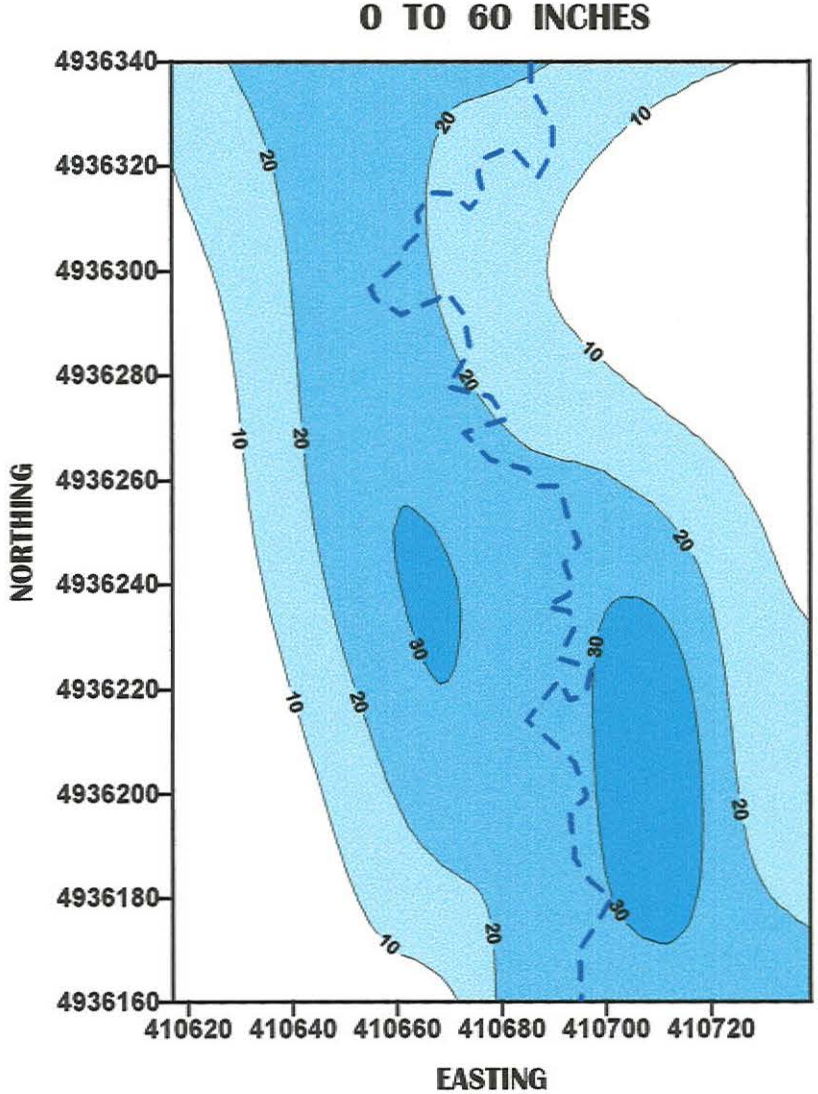


Figure 1

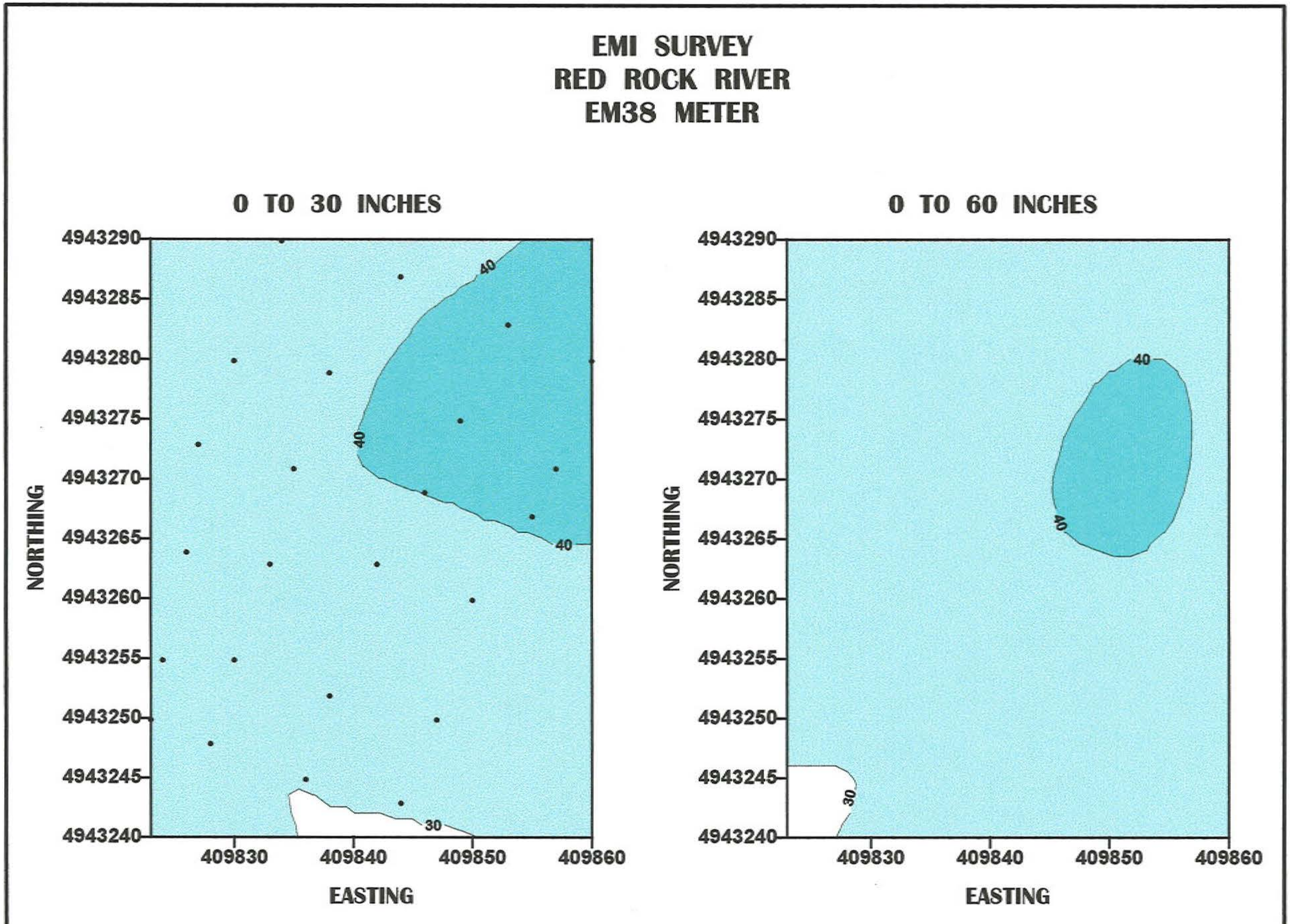
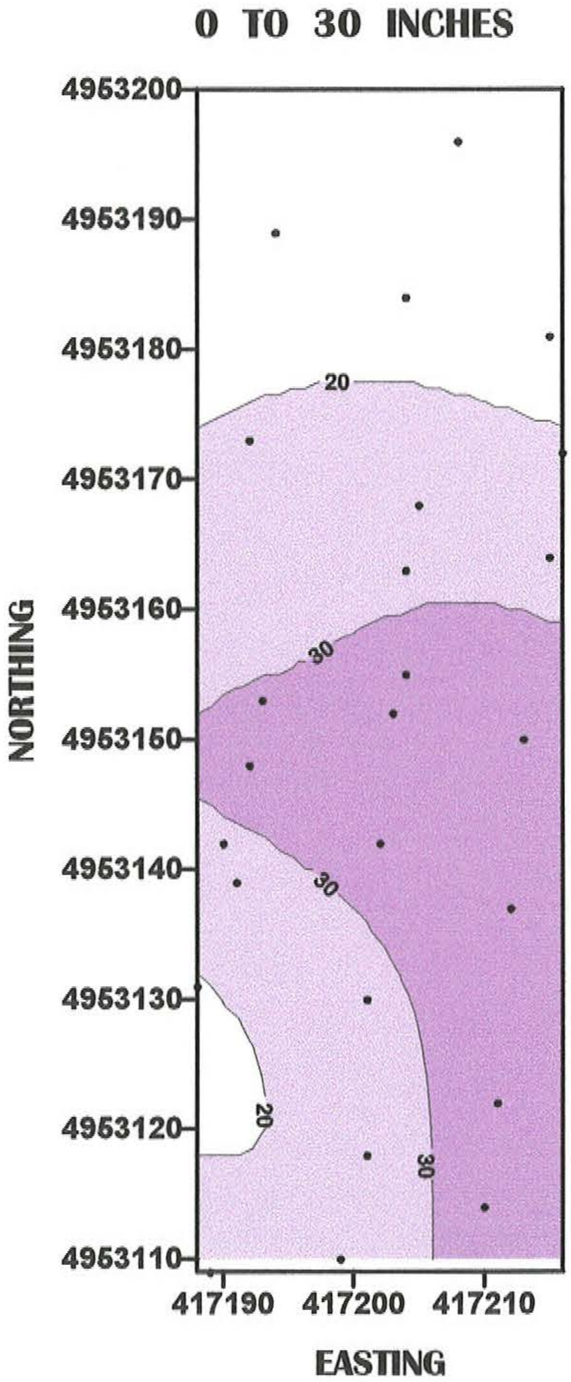
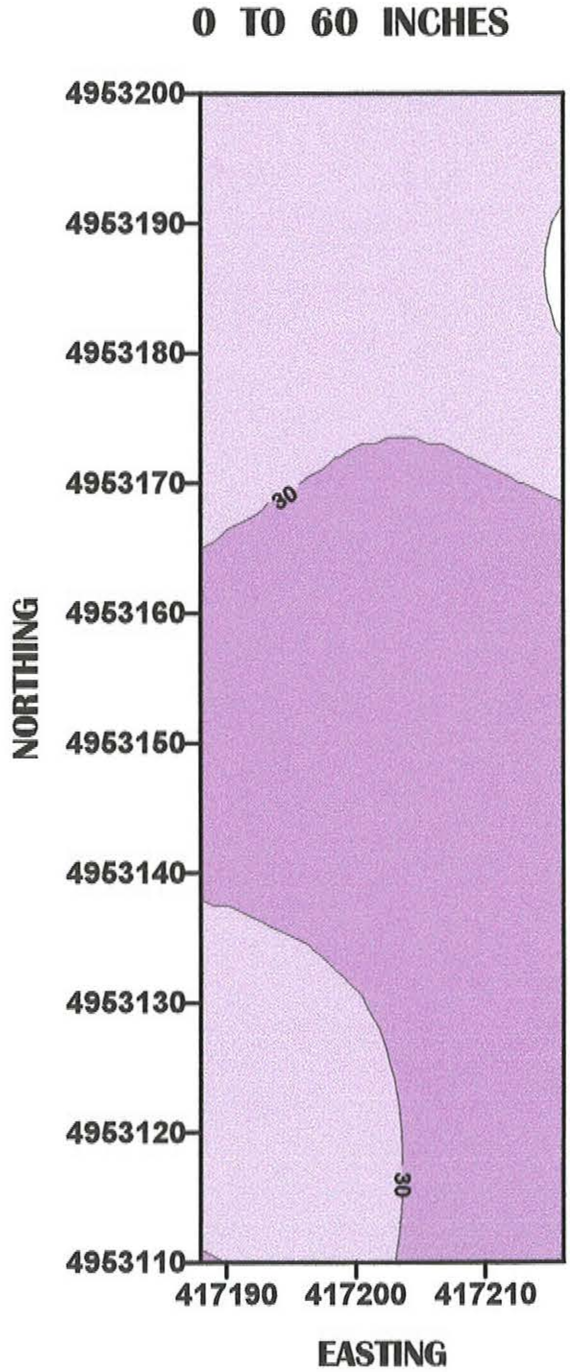

EMI SURVEY
RED ROCK RIVER
EM38 METER
0 TO 30 INCHES
0 TO 60 INCHES
4943290
4943285
4943280
4943275
4943270
4943265
4943260
4943255
4943250
4943245
4943240
NORTHING
409830
409840
409850
409860
EASTING
40
30
Observation Point

Figure 2

EMI SURVEY
LONG CREEK
EM38 METER





• Observation Point

Figure 3