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Purpose:
To estimate depths to bedrock beneath two (spring and fall), long-term range sites using electromagnetic techniques at the USDA-ARS Sheep Experiment Station near Dubois, Idaho.

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Activities:
I arrived at the ARS Sheep Station on the morning of 17 July 1995. Grids (30-m intervals) were established across the long-term fall and long-term spring range sites during the afternoon and morning of 17 and 18 July, respectively. Four, smaller, 5-m interval grids were established within selected areas of the two larger (30-m) grids on 19 and 20 July. A topographic survey of the 30-m grids was completed on 19 July. Coordinates of selected grid and sample locations were compiled using GPS on 20 and 21 July. Electromagnetic induction surveys of the grids were begun on 18 July and completed on 20 July. I began my returned to Chester, Pennsylvania, on the afternoon of 21 July.

Introduction:
Electromagnetic induction is a non-invasive geophysical technique which uses electromagnetic energy to measure the apparent conductivity of earthen materials. Apparent conductivity is a weighted average measurement for a column of earthen materials to a specified observational depth (Greenhouse and Slaine, 1983). Variations in apparent conductivity are caused by changes in the electrical

conductivity of soils and other earthen materials. The electrical conductivity of soils is influenced by the (i) volumetric water content, (ii) type and concentration of ions in solution, (iii) temperature and phase of the soil water, and (iv) amount and type of clays in the soil matrix (McNeill, 1980). The apparent conductivity of soils increases with increases in the exchange capacity, water content, and clay content (Kachanoski et al., 1988; Rhoades et al., 1976).

Soil scientists have used EM techniques principally to identify, map, and monitor soil salinity (Cook and Walker, 1992; Corwin and Rhoades, 1982, 1984, and 1990; Rhoades and Corwin, 1981; Rhoades et al., 1989; Slavich and Petterson, 1990; Williams and Baker, 1982; and Wollenhaupt et al., 1986). Recently, the use of this technology has been expanded to included the assessment and delineation of sodium-affected soils (Ammons et al., 1989; Nettleton et al., 1994), depths to claypans (Stroh et al., 1993; Sudduth and Kitchen, 1993; and Doolittle et al., 1994), and edaphic properties important to forest site productivity (McBride et al., 1990).

Electromagnetic induction (EM) methods can provide a relatively inexpensive, fast, and comprehensive means for mapping the depths to bedrock. This technique has been used to determine depths to bedrock (Palacky and Stephens, 1990; Zalasiewicz et al., 1985) and to locate water-bearing fault or fracture zones in bedrock (Beeson and Jones, 1988; Edet, 1990; Hazell et al., 1988; McNeill, 1991; Olayinka, 1990). In areas of karst, EM techniques have been used to detect anomalous subsurface patterns indicative of solution features (Canace and Dalton, 1984; Pazuniak, 1989; Robinson-Poteet, 1989; Rumbens, 1990). These studies have documented that this noninvasive technique is facile, can provide large quantities of data for site characterization and assessments, and can be applied over broad areas and soils.

STUDY SITE

The study site was located at the USDA-ARS Sheep Experiment Station, near Dubois in northeastern Idaho. A 24.8 hectare study site was selected for this investigation. The study site was located in the W1/2 of Section 27, T. 11 N., R. 36. E. The coordinates for the southwest corner of the study site were 44° 14′ 44.12" N. Lat., 112° 12′ 47.39" W. Long.

Figure 1 is a two-dimensional contour plot of the study site. The study site consisted of two enclosed areas of sagebrush steppe vegetation. Each area was managed differently. The horizontal (east-west) line extending across the central portion of Figure 1 is a fence line. This fence separates a long-term fall grazing area (south) from a long-term spring grazing area (north).

In Figure 1, the contour interval is 0.5 m. The average elevation of the study site is about 1648 m. Relief is about 12.1 m. The long-term fall grazing area (southern portion of site) has slightly more relief (12.6 m) than the long-term spring grazing area (10.6).

In general, the surface slopes towards the west and southwest. Higher-lying areas are located in the southeastern and eastern portions of the study site. Several parallel ridge lines extend in a southwesterly direction from the uplands. These subdued ridge lines are believed to represent elevated portions of the bedrock surface. The ridge lines are apparent in Figure 1. The ridges are separated by lower-lying areas. Some of the lower-lying areas appear to be small ephemeral drainageways.

Soils recognized within the study site belong to two taxonomic orders and are members of the Calcixerollic Xerochrepts, Aridic Calcixerolls, Lithic Calcixerolls, Lithic Haploxerolls, and Calcic Haploxerolls taxonomic subgroups. Principal soil delineations included areas of the Eaglecone-Mike complex, 0 to 12 percent slopes, and the Eaglecone very stony loam, 0 to 12 percent slopes. Areas of the Eaglecone-Mike complex, 0 to 12 percent slopes, were restricted to the uplands in the southern portion of the site. Areas of the Eaglecone very stony loam, 0 to 12 percent slopes, occurred throughout the site, but were most extensive in the northern portions.

The moderately deep (50 to 100 cm) Eaglecone soils are members of the fine-loamy, mixed, frigid Typic Calcixerolls family. The shallow (0 to 50 cm) Mike soils are members of the loamy, mixed, frigid Lithic Calcixerolls family. These soils formed in calcareous alluvium overlying basalt. Textures of the fine earth fraction were loam or silt loam. Depth to and concentration of carbonates were variable.

In this investigation, the study site was characterized as consisting of a relatively thin (0 to 2 m) mantle of medium textured, calcareous alluvium overlying basalt bedrock. The medium-textured alluvium, having higher clay and soluble salt contents, was presumed to have higher conductivities than the underlying basalt.

MATERIALS AND METHODS

Equipment

The electromagnetic induction meters are the EM38 and EM31, manufactured by Geonics Limited*. These meters are portable and requires only one person to operate. Principles of operation have been described by McNeill (1980, 1986). The observation depth of an EM meter is dependent upon intercoil spacing, transmission frequency, and coil orientation relative to the ground surface. The EM38 meter has a fixed intercoil spacing of about 1.0 m. It operates at a frequency of 13.2 kHz. The EM38 meter has effective observation depths of about 0.75 and 1.5 m in the horizontal and vertical dipole orientations, respectively (McNeill, 1986). The EM31 meter has a fixed intercoil spacing of 3.66 m. It operates at a frequency of 9.8 kHz. The EM31 meter has effective observation depths of about 3.0 and 6.0 m in the horizontal and vertical dipole orientations, respectively (McNeill, 1980). For each meter, lateral resolution is approximately equal to the intercoil spacing. Values of apparent conductivity are expressed in milliSiemens per meter (mS/m).

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

Field Methods

The study site contained two enclosed areas of rangeland. A 330 by 750 m grid was established across the site. The grid covered about 24.8 hectares. Grid lines and intersections were established with a compass and measuring tapes. The grid interval was about 30 m. Survey flags were inserted in the ground at each grid intersection. This procedure provided 312 observation points. At each grid intersection, measurements were taken with an EM38 and an EM31 meter placed on the ground surface in both the horizontal and vertical dipole orientations.

At each observation point, the relative elevation of the surface was determined using a level and stadia rod. Elevations were not tied to an elevation benchmark; the lowest recorded observation point corresponded with the approximate location of the 1643 m (5390 ft) contour line.

The study site contained four additional grids. The locations of these grids were selected based on observed EM responses. Each grid had dimensions of about 30 by 30 m (0.1 ha). Grid lines were referenced and measured into the larger grid which had been previously established across the study site. The grid interval for the four detailed grids was 5.0 m. Survey flags were inserted in the ground at each grid intersection. This provided 49 observation points for each grid. At each grid intersection, measurements were taken with the EM38 meter placed on the ground surface in both the horizontal and vertical dipole orientations.

During the course of this study, depths to basalt were determined at 38 observation points. This information was used to help confirm the EM interpretations and to develop predictive equations. Within the study site, depths to basalt were observed to range from 10 to more than 152 cm. Typically, the basalt was overlain by a cobble line. Bedrock was identified by its resistance to hand-excavations. At some observation points, probings were halted by the cobble line and depths to bedrock had to be estimated.

DISCUSSION

EM38 Survey

Figures 2 and 3 are two-dimensional plots of the data collected with the EM38 meter in the horizontal and vertical dipole orientations, respectively. In each plot, the isoline interval is 2 mS/m. Also, in each figure, the locations of the four 5-m grids have been shown.

The patterns appearing in figures 2 and 3 are intricate and remarkably similar. The intricate pattern is due, in part, to variations in soil properties and to the narrow isoline interval used.

Within the site, values of apparent conductivity were relatively low. Apparent conductivity averaged 6.42 and 6.43 mS/m in the horizontal and vertical dipole orientations, respectively. One-half of the observations had values of apparent conductivity between 4.0 and 8.3 mS/m and between 2.9 and 9.2 mS/m in the horizontal and vertical dipole orientations, respectively.

Within the site, with the EM38 meter, values of apparent conductivity

However, fifteen measurements taken near the encompassing sheep fence were obviously affected by the metal wires. All observation points susceptible to this interference had EM responses greater than 12 mS/m. In addition, small metallic objects scattered throughout the site were believed to have influenced some of the EM measurements.

Excluding those measurements suspected of interference (values greater than 12 mS/m and located near fence lines), the isolines appearing in figures 2 and 3 are assumed to reflect changes in soils, soil properties, and soil depth. Acknowledging the comparatively small proportion of site actually observed (30-m interval, 312 observations) and the relatively narrow interquartile range of apparent conductivity values (4.3 and 6.3 mS/m), these patterns appear highly complex and variable over short distances. These spatial patterns were attributed to variations in the depths to basalt and carbonates.

In each plot (figures 2 and 3), spatial patterns are similar and have a conspicuous northeast to southwest trend. This trend appears to closely mimic the pattern of low subdued ridges extending outwards from the uplands as seen in Figure 1.

Comparing Figure 1 with figures 2 and 3, apparent conductivity values are lower and iso-conductivity lines are more widely spaced on upland areas in the eastern and the southeastern portions of the site. In general, on uplands, areas of exposed basalt were more conspicuous and observed depths to basalt were generally less than on lower-lying areas. Customarily, with the EM38 meter, areas of rock outcrop had values of less than 4 mS/m in both orientations. On lower-lying areas in the western portions of the site, iso-conductivity lines appear further apart and soil properties were assumed to be more homogeneous or less variable than on upland areas.

EM 31 Survey

Figures 4 and 5 are two-dimensional plots of the data collected with the EM31 meter in the horizontal and vertical dipole orientations, respectively. In each plot, the isoline interval is 2 mS/m. Also, in each figure, the locations of the four 5-m grids have been shown.

In general, apparent conductivity became slightly higher and more variable with increasing observation depths. As the basalt is less conductive than the overlying alluvium, no persuasive explanation for these trends can be offered at this time. However, this trend suggests and would support the presence of horizontal and variable sheets of basalt.

With the EM31 meter, apparent conductivity averaged 4.46 and 5.75 mS/m in the horizontal and vertical dipole orientations, respectively. One-half of the observations had values of apparent conductivity between 2.9 and 5.6 mS/m and between 3.6 and 7.2 mS/m in the horizontal and vertical dipole orientations, respectively. Within the study site, values of apparent conductivity ranged from 1.1 to 11.7 mS/m and from 1.5 to 30.0 mS/m in the horizontal and vertical dipole orientations, respectively. However, several measurements were obviously affected by the metal wires of the enclosing fence. All observation points susceptible to this interference had EM responses greater than 12 mS/m. In addition, small metallic objects scattered throughout the site were believed to have influenced some of the EM measurements.

In figures 4 and 5, linear patterns appear to extend in a northeast to southwest direction across the site. These pattern extends from the eastern uplands across the site. In a study conducted by Olayinka (1990) in Nigeria, areas of high electrical conductivity were identified and associated with zones of deep weathering and/or fracture zones in crystalline bedrock. The linear patterns recognized in figures 4 and 5, though reflecting near-surface conditions, could reflect not only changes in soil types, but zones of shallower and deeper depths to bedrock, and/or fracture traces in the underlying bedrock.

Comparison of EM31 and EM38 Data

The spatial patterns evident in figures 2 to 5 were assumed to principally reflect the influence and the variable depths to the more electrically resistive basalt. However, these patterns also reflect changes in soils and soil properties (depths to carbonates, rock fragments, texture) and thicknesses of alluvial deposits.

Spatial patterns evident in the simulated plots of the EM31 data (figures 4 and 5) were similar to those simulated from EM38 data (figure 2 and 3) and conformed with observable components of the landscape (figure 1). However, compared with the measurements collected with the EM38 meter, measurements obtained with the EM31 meter were generally lower and less variable. This relationship was attributed to the greater depth and volume of earthen materials measured with the EM31 meter and the increased influence of the more resistive basalt with greater depths of observation.

Table 1
Dubois Study Site, Idaho
(all values are in mS/m)

				Quartiles			
Meter	Orientation	Minimum	Maximum	1st	Median	3rd	Average
EM38	Horizontal	0.2	29.6	4.0	6.4	8.3	6.42
EM38	Vertical	0.2	34.1	2.9	6.3	9.2	6.43
EM31	Horizontal	1.1	11.7	2.9	4.2	5.6	4.46
EM31	Vertical	1.5	30.0	3.6	4.9	7.2	5.75

Basic statistics for the EM data collected at the Dubois site are displayed in Table 1. Variations in each meters response can be related to differences in soil type, landscape position, and depth to and thickness of contrasting materials (alluvium or basalt).

The general decrease in EM responses with depth conforms with the basic conceptual model of the site. For the purpose of this investigation, the site was assumed to consist of two principal layers: alluvium and basalt. The medium-textured alluvium has higher clay and carbonate contents and was presumed to have higher apparent conductivity values than the underlying basalt.

Estimation of Depths to Basalt

The thickness of alluvium and the depth to basalt varied across the site because of differences in erosion, deposition, and landscape position. Because of differences in clay, soluble salt, and water contents among the soil horizons and between the alluvium and the underlying basalt, vertical contrasts in electrical conductivity were assumed to exist. It was assumed that variations in the magnitude of the EM response could be used to provide estimates of the thickness of the alluvium and/or the depth to basalt bedrock.

Table 2

Relationship Among EM Measurements and Depth to Basalt
(38 observations)

Meter and Orientation	r
EM38 Meter (Horizontal Dipole Orientation)	0.612
EM38 Meter (Vertical Dipole Orientation)	0.769
EM31 Meter (Horizontal Dipole Orientation)	0.594
EM31 Meter (Vertical Dipole Orientation)	0.492

At thirty-eight observation points, the depth to basalt was observed or estimated from spade and auger observations. Observed depths to bedrock averaged 70.8 cm and ranged from about 10 to 152 cm. A comparison of soil probe and EM data collected at the thirty-eighty observation points (see Table 2) revealed a positive correlation between depth to basalt and EM response. These relationships conform with the basic conceptual model of the site. The medium-textured alluvium was presumed to have higher clay, moisture, and soluble salt contents and to be more conductive than the underlying basalt. Areas having greater thicknesses of alluvium and depths to basalt generally had higher EM responses.

Electromagnetic induction is an imperfect tool and is not equally suitable for use in all soil investigations. Generally, the use of EM techniques has been most successful in areas where subsurface properties are reasonably homogeneous, the effects of one factor (clay, water, or salt content) dominates over the other factors, and variations in EM response can be related to changes in the dominant factor (Cook et al., 1989). In such areas, information is gathered on the dominant factor, and assumptions are made concerning the behavior of the other factors (Cook and Walker, 1992). Within the Dubois site, several factors (clay, rock fragments, and carbonate contents) varied across the site. Variations in these factors weakened the strengths of the desired relationships and made it difficult to attribute variation in the EM response to the depth to basalt alone.

The EM38 meter in the vertical dipole orientation explained more of the variations in the depths to basalt than any other meter or orientation. In Table 2, the highest correlation is found between depths to basalt and measurements of apparent conductivity collected with the EM38 meter in the vertical dipole orientation. This relationship appears to weaken with decreased (EM38 meter in the horizontal dipole orientation) or increased (EM31 meter) observation depths. Expectedly, the observation depth of the EM38 meter in the vertical dipole orientation (0 to 150 cm) most closely bracketed the observed range in depths to basalt (10 to 152 cm).

Data collected with the EM38 meter in the vertical dipole orientations were used to develop a predictive regression equation:

$$D = 19.53975 + (8.93625 * EM38V) \qquad [1]$$

where "D" is depth to basalt (cm) and "EM38V" is the apparent conductivity (mS/m) measured by the EM38 meter in the vertical dipole orientation.

This empirical relationship shown in Equation [1] is site specific. Additional observations are needed to transfer the results of this study to other sites. The coefficients used in Equation [1] are relatively large. These large coefficients will magnify small measurement errors. In addition, as negative values were not observed nor anticipated within the study site, according to Equation [1], the shallowest possible estimated depth to basalt is 19.5 cm.

Equation [1] was used to estimate the depth to basalt at each observation point. Based on 312 EM38 measurements and the predictive Equation [1], the average depth to basalt was estimated to be 77.0 cm with a range of 21.3 to 324.3 cm. One-half of the observations had depths to basalt between 24.4 and 101.8 cm. The basalt was shallow (<50 cm) at 31 percent, moderately deep (50 to 100 cm) at 43 percent, deep (100 to 150 cm) at 24 percent, and very deep (>150 cm) at 2 percent of the observation points. The preponderance of moderately deep and shallow soils is in accord with the soils and map units delineated within the study site.

Figure 6 is a two-dimensional simulation showing the distribution of depths to basalt across the study site. The spatial patterns indicate that the depths to basalt are dominantly moderately-deep across the site. Included areas of shallow soils occur principally as irregularly shaped patterns. Areas of deep and very deep soils occur mainly as elongated linear patterns. In Figure 6, these manifested patterns correspond with the aforementioned, sub-parallel orientation of the landforms.

Figure 7 is a three-dimensional surface net diagram of soil surface with depths to basalt superimposed. Depths to basalt appear to be fairly predictable from the landscape. In general, areas of shallow soils occur on slightly higher-lying convex surfaces. Areas of deep and very deep soils are more prevalent on lower-lying, concave surfaces. In Figure 6, on concave surfaces, several linear "channel-like" areas of deep and very deep soils are evident. Here, it is assumed that thicker deposits of alluvium have blanketed and buried several channels or fracture traces in the basalt. These channels or fracture traces appear disjointed or segmented. Their segmentation could represent an artifact from the relatively coarse sampling interval (30 m) and computer simulation processes used.

<u>Analysis of Variance</u>

One of the goals of this investigation was to compare EM responses and estimated depths to bedrock between a long-term fall and a long-term spring grazing area. The 312 observation points were grouped according to their locations within areas of either a long-term fall or a long-term spring grazing area. Each area of rangeland contained one hundred and fifty-six observation sites. As similar soils and depths to bedrock were assumed to occur within each unit of management, it was hypothesized that no difference would exist in the EM responses between the two rangelands.

Measurements obtained with the EM38 and the EM31 meters in both the horizontal and vertical dipole orientations were assessed by means of a one-way analysis of variance. The results are summarized in Table 3. With the exception of measurements obtained with the EM31 meter in the vertical dipole orientation, no significant differences appear to exist between the two rangelands in terms of EM response and presumably, soils, soil properties, and depths to bedrock.

Table 3

Analysis of Variance
for EM Measurements
on long-term fall and long-term spring rangelands

Source of Variation	d. f.	Sum of Squares	Mean Square	F-value	Probability
EM38 meter - Horizontal Dipole Orientation					
Between	1	2.35	2.35	0.21	
Within	310	3481.08	11.23		
EM38 meter - Vertical Dipole Orientation					
Between	1	26.25	26.25	1.46	0.227
Within	310	5561.03	17.94		
EM31 meter - Horizontal Dipole Orientation					
Between	1	10.01	10.02	2.53	0.113
Within	310	1229.44	3.97		
EM31 meter - Vertical Dipole Orientation					
Between	1	119.64	119.64	11.66	0.000
Within	310	3182.03	10.26		

As the EM31 meter in the vertical dipole orientation was more susceptible to interference from the surrounding metal fence, higher measurements (>12.0 mS/m) were questioned. When the suspect responses (14 observations) were removed, and the revised data set (296 observations) was reevaluated, the F-value was reduced to 5.81 and the probability to 0.016. This analysis reveals that, when the upper 0 to 6 m (measurements obtained with the EM31 meter, vertical dipole orientation) are compared, a significant difference exists between the two grazing areas. These measurements are assumed to reflect differences in properties of the underlying basalt. Differences suggest the possible occurrence of superposed sheets of lava and perhaps even intercalated sheets of tuff.

Based on measurements obtained with the EM38 meter, no significant differences existed between the two grazing areas. Based on 156 EM38 measurements taken in the vertical dipole orientation within each management area and predictive Equation [1], the depths to basalt were remarkably similar between the long term fall and spring grazing areas. Within the long-term fall grazing area, the average depth to basalt was estimated to be 79.6 cm with a range of 21.3 to 191.1 cm. One-half of the observations had depths to basalt between 45.5 and 105.3 cm. Within the long-term fall grazing area, the basalt was shallow (<50 cm) at 29 percent, moderately deep (50 to 100 cm) at 41 percent, deep (100 to 150 cm) at 26 percent, and very deep (>150 cm) at 4 percent of the observation points.

Within the long-term spring grazing area, the average depth to basalt was estimated to be 74.4 cm with a range of 21.3 to 324.3 cm. One-half of the observations had depths to basalt between 44.6 and 98.2 cm. Within the long-term spring grazing area, the basalt was shallow (<50 cm) at 33 percent, moderately deep (50 to 100 cm) at 44 percent, deep (100 to 150 cm) at 22 percent, and very deep (>150 cm) at 1 percent of the observation points.

Assessment of 5-m grid sites

The locations of the four, 5-m grid sites were selected based on management practices and the observed responses of the EM38 meter. Two sites were chosen within the long-term fall (subgrids 1 and 2) and within the long-term spring (subgrids 3 and 4) grazing areas. Within each unit of management, one site was selected as typifying an area of low EM responses (subgrids 1 and 4) and one site was selected as typifying an area of high EM responses (subgrids 2 and 3). It was assumed that areas of high EM responses would represent areas of deeper soils while areas of lower EM responses would represent areas of shallower soils.

The basic statistics for each of these subgrids are listed in Table 4. This data supports the assumptions underlying the selection of these sites based on EM data and inferred depths to basalt.

Table 4
5-m Grid Sites
(all values are in cm)

			Quartiles			
Subgrid Site	Minimum	Maximum	1st	Median	3rd	Average
1	30.3	110.7	41.0	67.4	82.6	64.62
2	25.8	166.1	47.2	95.9	145.3	98.23
3	30.3	137.5	56.2	67.4	89.9	74.54
4	23.15	119.60	39.2	53.0	74.7	60.10

Computer simulated, two-dimensional plots of subgrid sites 1, 2 , 3, and 4 are displayed in figures 8, 9, 10, and 11, respectively. The general patterns simulated in these plots corresponds favorably with the patterns generated from the coarser 30-m grid sites (see figures 2, 3, and 6). This agreement among data set collected on different days and by different operators helps to substantiate the repeatability of measurements collected with EM meters. The more intricate patterns and varied depths to bedrock shown in figures 8, 9, 10, and 11, helps to emphasize the short-range variability in EM responses and soil depths. Based on the results of this study, in areas of moderately deep and shallow soils, a 30-m grid interval appears appropriate for showing gross spatial bedrock patterns. However, small areas of rock outcrop and narrow linear features such as ridge lines or fracture traces are not adequately displayed with this interval. Smaller intervals (5 to 15 m) may be necessary to adequately define these features.

RESULTS

1. The study provided training on the use of EM techniques for conducting soil and site assessments. The techniques discussed in this report appear most applicable for use in areas of the Snake River Plain.

2. Positive correlations were found between EM measurements and depths to basalt. In this area of Idaho, and for areas of predominantly moderately deep and shallow soils, the EM38 meter in the vertical dipole orientation provided the best correlation between EM response and depth to basalt. While in light of other correlations made in the field of soil science, this correlation ($r = 0.769$) may appear weak, it demonstrated the underlying truths of our hypothesis concerning these soils and earthen materials. Perceived shortcomings attest to the inherent variability of soil properties within the overlying alluvium.

3. A predictive equations can be developed to estimate depths to basalt from EM data. Electromagnetic induction techniques appear to be best suited to studies requiring a large number of observations and to depths beyond the limits of most conventional surveying tools.

4. No significant difference in the measured responses of an EM38 meter was found to exist between a long term spring and a long-term fall grazing area. It was inferred that soil properties and the depths to bedrock were similar between the two rangelands. However, measurements obtained with an EM31 meter in the vertical dipole orientation (observation depth of 0 to 6 m) were significantly different. It was assumed that this difference in the underlying sheets of basalt.

I wish to express my thanks to members of your staff who assisted this project. It was my pleasure to work with these knowledgeable and hard-working individuals.

With kind regards

James A. Doolittle

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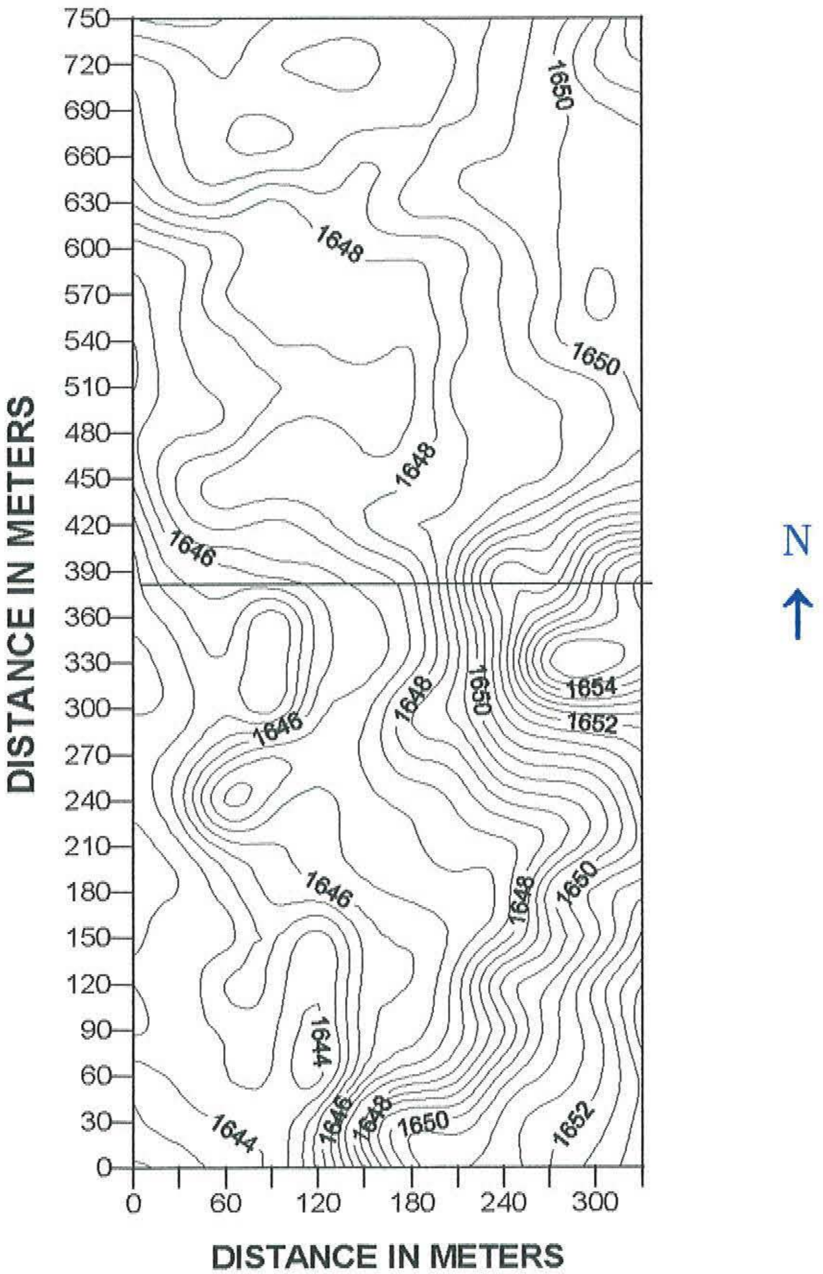
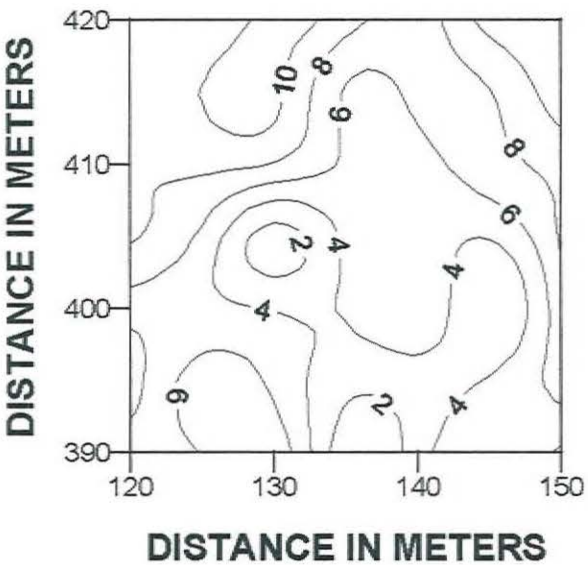
USDA-ARS SHEEP EXPERIMENT STATION
DUBOIS, IDAHO
LONG-TERM RANGE SITES

RELATIVE TOPOGRAPHY
CONTOUR INTERVAL = 0.5 M

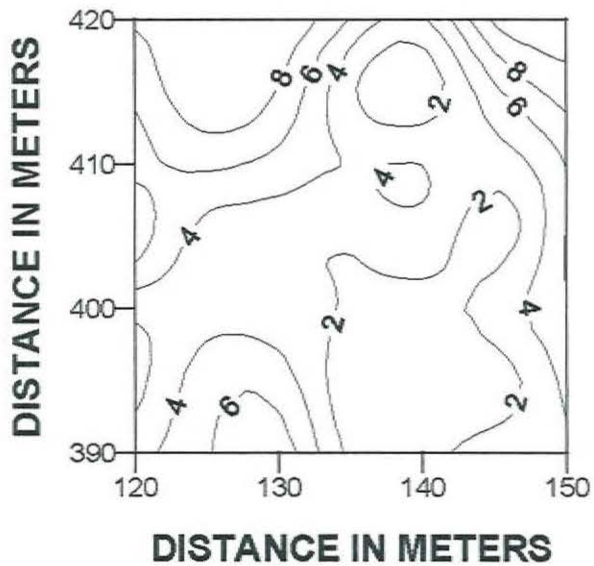


SUBGRID 4
LONG-TERM RANGE SITE - SPRING

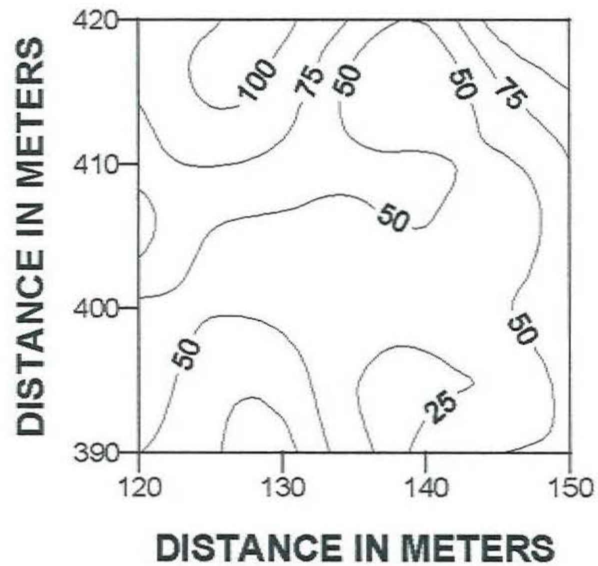
EM38 METER
HORIZONTAL DIPOLE ORIENTATION



EM38 METER
VERTICAL DIPOLE ORIENTATION

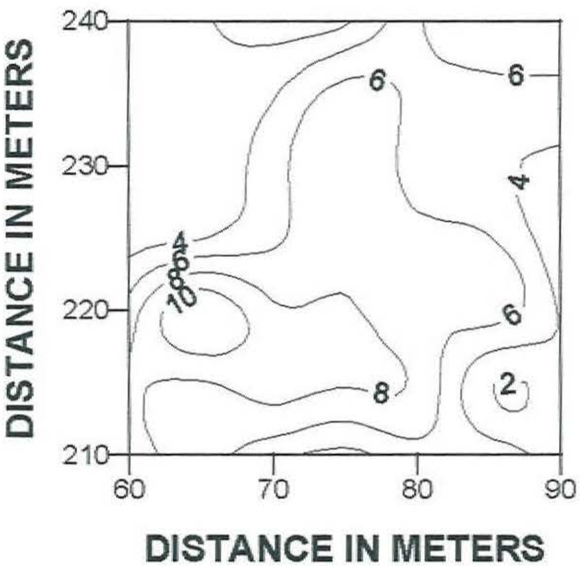


SOIL DEPTH

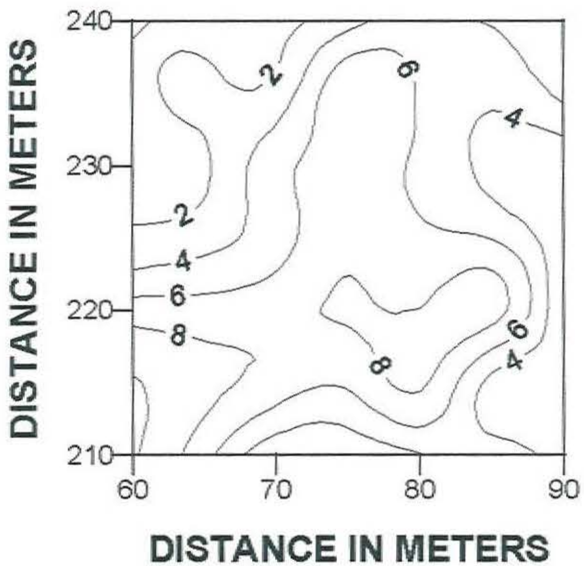


SUBGRID 1
LONG-TERM RANGE SITE - FALL

EM38 METER
HORIZONTAL DIPOLE ORIENTATION



EM38 METER
VERTICAL DIPOLE ORIENTATION



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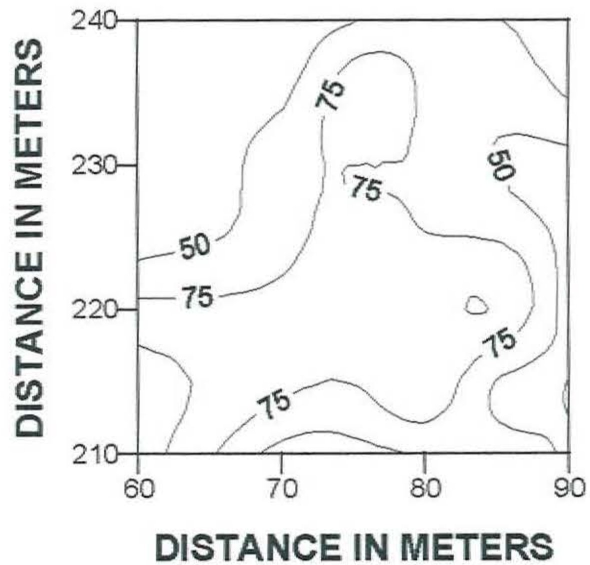
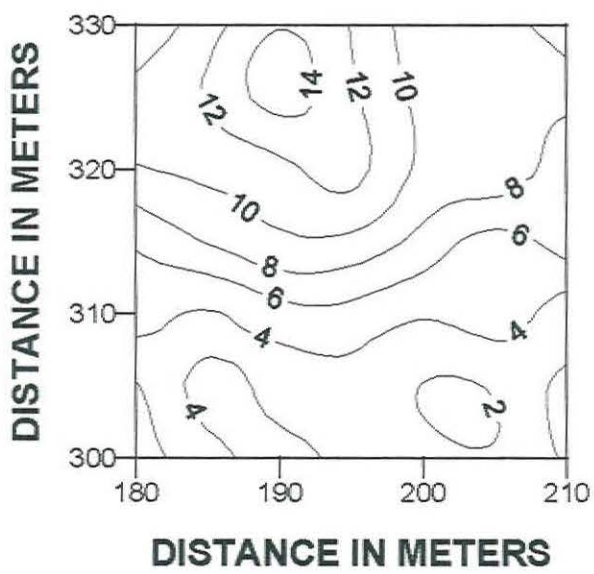
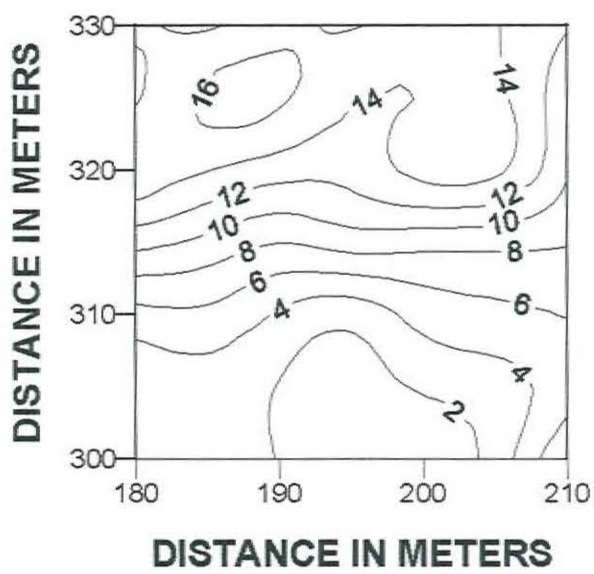


SUBGRID 2
LONG-TERM RANGE SITE - FALL

EM38 METER
HORIZONTAL DIPOLE ORIENTATION



EM38 METER
VERTICAL DIPOLE ORIENTATION



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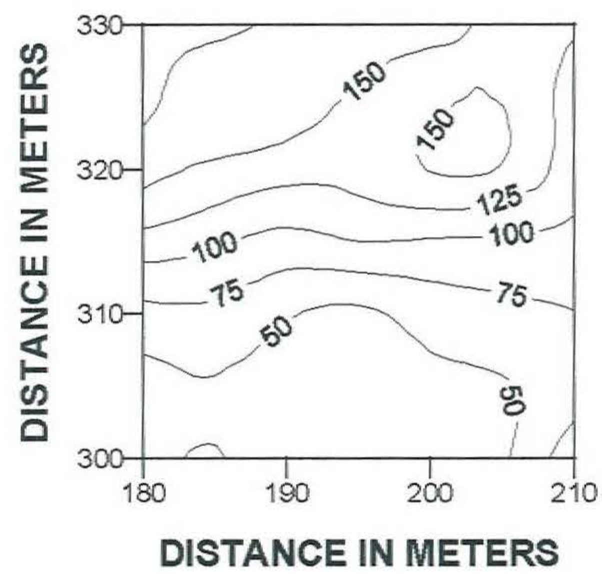
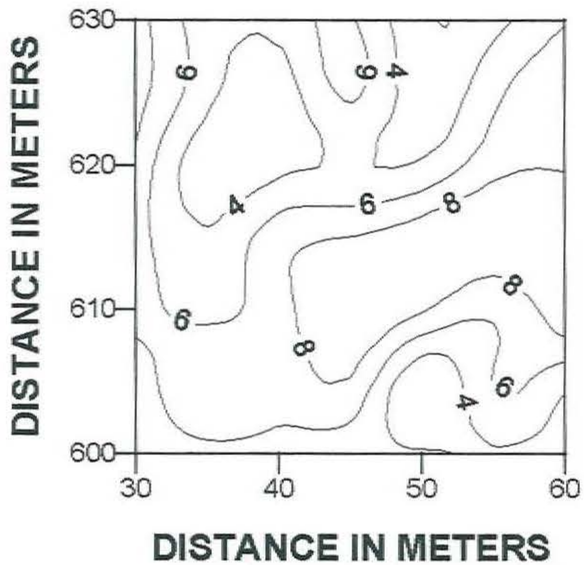
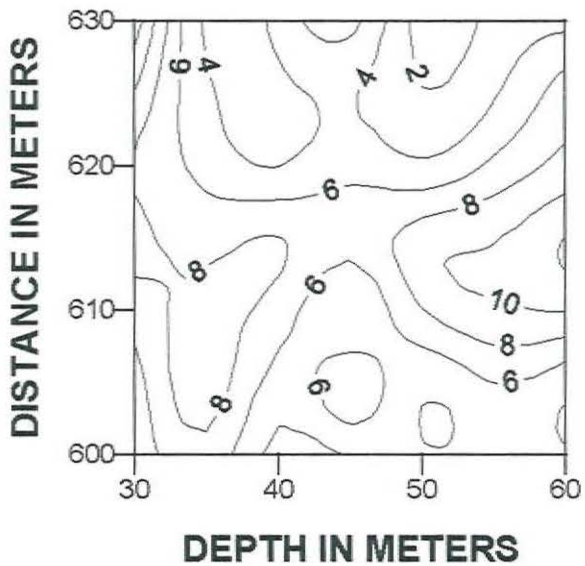


SUBGRID 3
LONG-TERM RANGE SITE - SPRING

EM38 METER
HORIZONTAL DIPOLE ORIENTATION



EM38 METER
VERTICAL DIPOLE ORIENTATION



SOIL DEPTH