pUnited States
Department of
Agriculture

Soil
Conservation
Service

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Subject: Joint USDA-Soil Conservation Service USDOT Advanced Concept Division salinity survey, Utah: 3 to 8 June 1990

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To: Francis T. Holt
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**Purpose:**
To test the feasibility of conducting reconnaissance soil salinity surveys using electromagnetic induction (EM) techniques over broad areas. Field data and locations were collected and plotted using the INTRANSIT (INternational TRANSportation Information Tracking) developed by the USDOT Advanced Concept Division (ACD).

**Participants:**
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**Activities:**
William O'Keefe an I held a preliminary planning meeting at the USDOT, Advanced Concept Division office in Cambridge, Massachusetts, on 1 June 1990. We arrived in Salt Lake City, Utah, on 3 June 1990. Reconnaissance soil salinity surveys using electromagnetic induction (EM) techniques with INTRANSIT and global positioning system (GPS) were carried out in Salt Lake County (Soil Survey Atlas Sheets 4, 8, and 9) on 4 June; at the Bear River Migratory Bird Refuge in Box Elder County (Soil Survey Atlas Sheets 121 and 122) on 5 June; near Corrine in Box Elder County (Soil Survey Atlas Sheet 113) on 6 June; and near Randolph in Rich County (Soil Survey Atlas Sheet 28) on 7 June 1990. On July 10, 1990, the INTRANSIT plots of the survey areas were reviewed at the ACD facility in Cambridge, Massachusetts.

**Results:**
This study brought together several agencies and technologies to solve a common problem. The field objectives of this study were satisfied. It is recommended that NHQ explore the use of the INTRANSIT system in other geographic areas. The rapid scanning, plotting and annotation capabilities of this system appear to have significant and benefital applications in areas of soil and national resource inventories.

With the exception of the Rich County site, the field crew was in direct communications (cellular phone) with the ACD facility in Cambridge, Massachusetts. Personnel assigned to ACD are most talented, and are commended for the excellent services and the long hours rendered during this field operation.

An EM-38 manufactured by GEONICS, Ltd., was used to measure the bulk or apparent soil conductivity. Within each study site, random observations were made with the EM-38 at intervals ranging from about 100 to 1700 feet. At each observation site, two measurements were made with the EM-38 meter. These measurements represented the integration of soil conductivities over response depths of 75 and 150 cm.

Soil samples were collected at 11 observation sites. The sample correlation coefficient, r, between EM measurements and averaged salinity measurements was 0.905343. The high correlation between EM measurements and sampled, averaged salinity values attests to the utility of using EM techniques to rapidly map or assess soil salinity in Utah. In the areas studied, EM values can be corrected to reflected the measured soil salinity value by the equation:

$$EM(H) = 109.0314 + 7.1693(X)$$

where X is the averaged soil salinity measurement of the upper 50 cm of the soil profile, and EM(H) is the horizontal electromagnetic induction measurement.

A key pad was used to transmit and record: (i) the EM measurements, (ii) the latitude and longitude of each site, and (iii) field notes. Enclosure 1 (pages 1 to 33) is a copy of all recorded transmissions made by the INTRANSIT system during the field study. Some field data was missed (observe the omission of sites 1 through 10 on June 4, 1990). It is believed that the missing data is in the system, but its retreaval would require an extensive search through the data files.

Using a LORAN-C unit with the INTRANSIT system, locational data was recorded, transmitted, and plotted on soil field sheets or topographic maps. Enclosures 2 through 7 are copies of the plotted LORAN-C positional data. Several sheets contain examples of the annotations possible with the INTRANSIT system (enclosures 2, 4, 5, and 6). Enclosure 3, illustrates the high resolution and accurate "zoom-in" capabilities of the INTRANSIT system. Enclosure 3 contains the study area which was initially plotted on Enclosure 2.

As many of the soil atlas sheets contain inaccuracies in the photo map scale, the positional data plotted with LORAN-C or GPS appear to be in error and do not match the imagery (see enclosure 4).

Position data should be plotted on only rectified imagery and the use of standard 7.5 minute topographic quadrangles and 7.5 minute orthophotoquads meeting national map accuracy standards is encouraged.

The low frequency (100KHz) transmissions of LORAN-C have an approximate range of about 800 to 1400 miles from a master or slave station. LORAN transmissions were received from stations located in San Diego, San Fransisco, and Seattle. The study sites and much of the interior of the United States are located near or beyond the maximum range of the system. As a consequence, positional data plotted on Enclosures 6 and 7, while relatively accurate contain errors in absolute measurements. In mountainous areas, errors in positional data caused by interference and topographic bounces of the sky wave were observed. On many plots, extraneous signals, not related to the survey, were observed.

The ability to FAX from a remote facility in Cambridge, Massachusetts, to the state office in Salt Lake City, Utah, base maps containing the plotted information was demonstrated. Communication error resulted in selection of the wrong scale USGS base map. However, this error does not detract from the accomplishment of the systems objectives to plot and FAX plotted data to field offices.

A more detailed report on the results of the EM and LORAN-C survey will be prepared. The EM data will be plotted on topographic maps. Contour maps having isolines of equal soil conductivity will be prepared to show the distribution and variability of soil salinities across each study site.

Your staff is commended for the excellent preparation and excution of this pilot survey. With kind regards.

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**Discussion:**
Salinity surveys were carried out in areas affected by flooding from the Great Salt Lake in Salt Lake and Box Elder counties or by the Bear River in Rich County. Farm operators and land managers need to know the amount and variability of soil salinity across these inundated areas. This information is needed to determine what type of salt-tolerant grasses to plant. A reconnaissance soil salinity survey was carried out using EM techniques to measure soil conductivity (in mS/m) and LORAN-C and GPS to record, locate, and plot this data on suitable imagery.

ELECTROMAGNETIC (EM) SURVEY
Soil scientists, agronomists, engineers, and land use planners have recognized the need for a device for rapid, routine detection and mapping of salt affected areas. Resistivity meters (four-electrodes arranged in a Wenner arrays or soil salinity probes) require good soil contact, are often time consuming to set-up in the field, and produce poor results in dry or fragmental soils Rhoades, 1976; Rhoades and Corwin 1981).

The EM-38 electromagnetic ground conductivity meter was developed specifically as a rapid, non-contact tool or measuring soil conductivity within the root zone (McNeill, 1986a). The meter has been used extensively to measure the apparent electrical conductivity of saline (Corwin and Rhoades, 1982 and 1984; De Jong, 1979; Kingston, 1985; Rhoades and Corwin, 1981; Rhoades and Halvorson, 1977; Slavich and Read, 1985; Williams, 1983; Williams and Baker, 1982; William and Hoey, 1987; and Wollenhaupt et al., 1986) and sodic (Ammons et al., 1989) soils. In many of these investigations EM measurements were used to locate, identify and categorize areas of salt affect soils.

The operation of the EM-38 meter is described in detail by McNeill (1986b). Electromagnetic (EM) methods measure the electrical conductivity between the receiver and transmitter coils. Measurements are made by placing the EM-38 meter on the ground surface. An oscillating dipolar magnetic field is produced by the transmitter coil. This primary magnetic field induces an electrical current in the ground which generates a secondary magnetic field in a manner that the amplitude of the induced current is proportional to the electrical conductivity of the scanned earthen materials. The magnitude of this current is measured at the receiver coil and is a function of the apparent electrical conductivity of the soil.

Electromagnetic methods measure the apparent electrical conductivity of earthen materials. Factors influencing the conductivity of earthen materials include (i) the volumetric water content, (ii) amount and type of salts in solution, (iii) the amount and type of clays in the soil matrix, and (iv) the soil temperature.

Soil conductivities measured with the EM-38 represent an integration of the apparent conductivity (ECa) over the meters response depth. Response depth varies with transmission frequency, intercoil spacing and orientation.

A Geonic Limited EM-38 electromagnetic induction soil conductivity meter was used in this study. The EM-38 weights about 2.5 Kg. It has a intercoil spacing of 1 m and an operating frequency of 13.2 KHz. With the EM-38 meter placed on the surface and orientated in a vertical dipole position, the response depth is about 150 cm. With the EM-38 meter placed on the surface and orientated in a horizontal dipole position, the response depth is about 75 cm.

In areas of saline soils, salinity accounts for about 70 % of the variance in measured ECa values (Williams and Baker, 1982). These measurements reflect the cumulative relative contributions from horizons occurring above the meters response depth. For salinity appraisals, the distribution of ECa with depth and its relation to saturated paste extract salinity are needed. Regression equations have been used to relate EM measurements to saturated paste extract conductivity ( Rhoades and Corwin 1981; Corwin and Rhoades, 1982 and 1984; and Rhoades et al. 1989). However, these equations often have a limited to a particular geographic area as multiple regression coefficients are affected by differences in mineralogy and parent materials (Rhoades and Corwin, 1981).

The apparent conductivity (ECa) of the soil has been related to the paste extract conductivity (ECe) by the relationship ECa=5ECa (McNeill, 1986a). Table 1 (from McNeill, 1986a) illustrates this general relationship. Measurements are expressed in millisiemens/meter (mS/m).

As discussed by Benson and others (1984), the absolute values are not necessarily diagnostic in themselves, but lateral and vertical variations in conductivity are significant. Interpretations of the EM data are based on the identification of spatial patterns in the data set.

**Table 1**

**Soil Conductivity vs Salinity (from McNeill, 1986a)**

| Salinity | ECe(mS/cm) | ECa(mS/m) |
|---|---|---|
| Slight | 0-4 | 0-80 |
| Moderate | 4-8 | 80-160 |
| High | 8-12 | 160-240 |
| Extreme | >12 | >240 |

Global Positioning System

Global Positioning systems (GPS) offers a rapid and accurate means for recording or locating soil sampling sites, plotting soil boundaries, and updating or revising soil maps. GPS requires less time and field costs than triangulation or surveys conducted with transit or compass and tape or electronic distance measuring devices. The accuracy of traditional methods of positioning often depends on map scale and image quality, terrain conditions, and the skill and aptitude of soil surveyor.

The USDA-Forest Service has evaluated GPS for delineating and mapping trails, forest stands, and fire boundaries under diverse terrain conditions (Sears et al., 1987). GPS has been used to collect geo-referencing data needed to create, update, and maintain GIS data bases (Lange, 1989; Stenberg and Lange, 1989).

## Theory

NAVSTAR GPS is an acronym for **Nav**igation **S**atellite **T**iming and **R**anging **G**lobal **P**ositioning **S**ystem. This system is commonly referred to as GPS. GPS is a satellite-based positioning and navigation system. This system consists of a constellation of orbiting satellites, ground stations which monitor and control the satellites, and user receivers.

When fully deployed in the 1990's, GPS will consist of 24 satellites (3 are in-orbit spares) in six orbital planes. The satellites have an altitude of about 12,000 miles and an orbital period of 12 hours. The satellites will provide 24 hour world-wide coverage with three-dimension positioning services accurate to within 25 meters in autonomous mode and within 5 meters in differential mode (Lange and Kruczynski, 1989). The differential mode requires two GPS receivers tracking the same GPS signals. One GPS receiver remains stationary at a known location while a mobile GPS receiver is used to record field positions. A correction is applied to positions recorded at field locations.

Control of the GPS system is administered by the U.S. Department of Defense (DOD). Five ground stations track and control the altitude, position, and speed of the satellites. On March 25, 1990, DOD implemented selectivity availability (SA) which degraded the accuracy of GPS. Selective availability introduces errors into the clock and emphemeris (predictions of current satellite position) data transmitted to GPS receivers from satellites. This has caused substantial degradation in the accuracy of positions recorded over moderate distances (up to several 100 meters).

GPS receivers obtain the coded signals radiated from satellites. Assuming good satellite/ receiver geometry, a GPS receiver decodes signals, determines the distance to each satellite, and calculates the earth surface position by triangulating the distance to three or more satellites. Terrain conditions (steep slope, aspect, vegetation, etc.) can interfere with signal reception and adverse the reliability of GPS. Following data collection, data is downloaded, processed, and differentially corrected to remove common GPS errors. GPS receivers can provide direct digital data entry into GIS.

Signals from three satellites are required to obtain two-dimensional position data and four satellites are needed for a three-dimensional position data (latitude, longitude, altitude).

Position data can be continuously updated on the receiver's display. GPS receivers can record field positions at a rate of one position per second. However, by remaining at a location for longer periods of time (three minutes or more), position accuracy is increased as more signals are averaged.

For soil survey operations, a portable, all weather, economical receiver is needed. GPS receivers are sufficiently accurate to plot soil boundaries to within 30 m of their actual positions. The GPS system can be used in the field to navigate to or record the location of National Resource Inventories (NRI) or soil sampling sites. Additional uses include verifying features appearing on soil maps, positioning and navigating along traverses, and digitizing and plotting of soil boundaries.

## REFERENCES

Ammons, J. T., M. E. Timpson, and D. L. Newton. 1989. Application of an aboveground electromagnetic conductivity meter to separate Natraqualfs and Ochraqualfs in Gibson County, Tennessee. Soil Surv. Horiz. 30(3):66-70.

Benson, R. C., R. A. Glaccum, and M. R. Noel. 1984. Geophysical techniques for sensing buried wastes and waste migration: an application review. IN: D. M. Nielsen and M. Curl (eds.) Surface and Borehole Geophysical Methods in Ground Water Investigations. NWWA/EPA Conference, San Antonio, Texas, p. 533-566.

Corwin, D. L., and J. D. Rhoades. 1982. An improved technique for determining soil electrical conductivity-depth relations from above-ground electromagnetic measurements. Soil Sci. Soc. Am. J. 46:517-520.

Corwin, D. L., and J. D. Rhoades. 1984. Measurement of inverted electrical conductivity profiles using electromagnetic induction. Soil Sci. Soc. Am. J. 48:288-291.

De Jong, E., A. K. Ballantyne, D. R. Cameron, and D. W. L. Read. 1979. Measurement of apparent electrical conductivity of soils by an electromagnetic induction probe to aid salinity surveys. Soil Sci. Soc. Am. J. 43:810-812.

Kingston, G. 1985. Electromagnetic inductive instruments for use in surveys of soil salinity. Proc. Australian Soc. Sugar Cane Tech. Bisbane, Queensland. p. 74-84.

Lange, A. F. and L. R. Kruczynski, 1989. Global positioning system applications to geographic information systems. ARC/INFO Users Conference, Palm Springs, CA. May 22-25, 1989. pp. 7.

McNeill, J.D. 1980. Electrical conductivity of soils and rocks. Geonics Ltd. Mississauga, Canada. Technical Note TN-5. 22 pp.

McNeill, J. D. 1986a. Rapid, accurate mapping of soil salinity using electromagnetic ground conductivity meters. Geonics Ltd., Mississauga, Ontario. Tech. Note TN-18. pp. 15.

McNeill, J. D. 1986b. GEONICS EM38 ground conductivity meter operating instruction and survey interpretation techniques. Geonics Ltd., Mississauga, Ontario. Tech. Note TN-21. pp. 15.

Rhoades, J. D. 1976. Measuring, mapping and monitoring field salinity and water table depths with soil resistance measurements. FAO Soil Bull. 31:159-186.

Rhoades, J. D. and D. L. Corwin. 1981. Determining soil electrical conductivity-depth relations using an inductive electromagnetic soil conductivity meter. Soil Sci. Soc. Am. J. 45:255-260.

Rhoades, J. D. and A. D. Halvorson. 1977. Electrical conductivity methods for detecting and delineating saline seeps and measuring salinity in northern Great Plains soils. USDA-ARS Rept. ARS W-42.

Rhoades, J. D. S. M. Lesch, P. J. Shouse, and W. J. Alves. 1989. New calibrations for determining soil electrical conductivity-depth relations from electromagnetic measurements. Soil Sci Soc. Am. J. 53: 74-79.

Sears, N., F. L. Frederick, and R. G. Hallman. 1987. A field facility for evaluating satellite-based automatic position and navigation instruments. 1987 Winter Meetings American Society of Agricultural Engineers. Chicago, IL. December 15-18, 1987. Paper no. 87-1561. pp.12.

Slavich, P. G. and B. J. Read. 1985. Assessment of electromagnetic induction measurements of soil salinity for indication of crop response. IN: Muirhead, W. A. and E. Humphreys (eds) Root zone limitation to crop production on clay soils: Symposium of the Australian Soc. Soil Sci. Griffith, N.S.W. Sept. 1988. p. 33-40.

Stenberg, J. and A. F. Lange. 1989. GPS, GRASS-GIS and the Everglades National Park. GRASS-GIS User's Group Conference, Alexander, VA. November 6-9, 1989. pp.6.

Williams, B. G. 1983. Electromagnetic induction as an aid to salinity investigations in north east Thailand. CSIRO Inst. Biological Resources, Div. Water and Land Res. Canberra, Australia. Tech. Memo. 83/27.

Williams, B. G. and G. C. Baker. 1982. An electromagnetic induction technique for reconnaissance surveys of soil salinity hazards. Australian J. Soil Res. 20(2):107-118.

William, B. G. and D. Hoey. 1987. The use of electromagnetic induction to detect the spatial variability of the salt and clay contents of soils. Aust. J. Soil Res. 25:21-27.

Wollenhaupt, N. C., J. L. Richardson, J. E. Foss, and E. C. Doll. 1986. A rapid method for estimating weighted soil salinity from apparent soil electrical conductivity measured with an aboveground electromagnetic induction meter. Can. J. Soil Sci. 66:315-321.