United States Department of Agriculture

Natural Resources Conservation Service

11 Campus Boulevard, Suite 200 Newtown Square, PA 19073

Subject: SOI – Geophysical Field Assistance **Date:** 8 October 2002

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Purpose: To provide site assessment assistance using electromagnetic induction (EMI) and ground-penetrating radar (GPR) techniques and to provide training on the use and operation of the GEM300 sensor.

Participants:
Jim Boyd, Resource Conservationist, USDA-NRCS, Norwood, CO
Joe Brummer, Soil Scientist, USBR, Denver, CO
Bill Cone, Irrigation Specialist, Ute Mountain Ute Tribe, Towaoc, CO
Dave Deerstyne, Soil Survey Project Leader, Montrose, CO
Mike Deluzio, Project Engineer, USDA-NRCS, Grand Junction, CO
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Doug Ramsey, Soil Survey Project Leader, USDA-NRCS, Cortez, CO
Valerie Slyter, Student Intern, USDA-NRCS, Cortez, CO

Activities:
All field activities were completed on 23-26 September 2002.

Summary of Results:

1. GPR and EMI surveys of a portion of Buckeye Reservoir did not reveal any evidence of a fault or additional solution features. It is possible that these features exist but are too small and/or do not produce a sufficient electromagnetic contrast to be detect with EMI. GPR was extremely depth restricted and provided little meaningful subsurface information; its use is considered inappropriate at this site.

2. Training was provided on the operation of the GEM300 sensor and the interpretation of EMI data.

3. In an area of Battlerock loam, saline-sodic phase, 0 to 3 percent slopes, EMI effectively mapped areas of higher sodicity adjacent to Greasewood plants. These higher responses were attributed to increased sodium salt and moisture contents adjacent to these plants. Soils were moister and had higher pH's (9.6 adjacent to greasewood and 8.2 in open areas) in surface layers.

4. In an irrigated area of Mack soils, higher values (> 16 mS/m) of apparent conductivity were associated with the fine-loamy Mack soil, while lower values (< 12 mS/m) were associated with a coarse-loamy inclusion. The distribution of fine- and coarse-loamy soils within this irrigated area is important to

management. Areas of finer-textured materials will retain more moisture and crop response will better under similar water management than areas of coarser-textured soil materials.

5. Data obtained when the GEM300 sensor is operated at different frequencies and dipole orientations is often similar. In general, sufficient information is obtained when the GEM300 sensor is operated at one frequency and two dipole orientations, than at multiple frequencies and two dipole orientations. Soil scientists preferred operating the GEM300 sensor in the vertical dipole orientation. At the Gypsey soil site, as little additional information was gained by operating at different frequency and dipole orientations, this survey could be as efficiently completed using only one frequency and one dipole orientation.

6. A slight discrepancy (.005 %) exists between the clocks of the Garmin Map 76 receiver and the GEM300 sensor. These clocks are used to assign time-stamps to waypoints and EMI measurements. Following surveys, this data set are typically merged in an Excel spreadsheet. The time error, while noted, is slight and should not compromise the accuracy of data collected for soil survey quality control

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

With kind regards,

Wes Tuttle
Soil Scientist (Geophysical)

cc:
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Equipment:
Electromagnetic induction (EMI) instruments used in this study were the GEM3000 sensor and the EM31and EM38DD meters. For each device, values of apparent conductivity are expressed in milliSiemens per meter (mS/m).

The GEM300 multifrequency sensor is manufactured by Geophysical Survey Systems, Inc. [1] Won and others (1996) describe the use and operation of this sensor. This sensor is configured to simultaneously measure up to 16 frequencies between 330 and 20,000 Hz with a fixed coil separation. With the GEM300 sensor, the penetration depth is considered "skin depth limited" rather than "geometry limited." The skin-depth represents the maximum depth of penetration and is frequency and soil dependent: low frequency signals travel farther through conductive mediums than high frequency signals. Theoretical penetration depths of the GEM300 sensor are dependent upon the bulk conductivity of the profiled earthen material(s) and the operating frequencies. Multifrequency sounding with the GEM300 theoretically allows multiple depths to be profiled with one pass of the sensor. The sensor is keypad operated and measurements can either be automatically or manually triggered.

Geonics Limited manufactures the EM31 and EM38DD meters.[1] These meters are portable and require only one person to operate. No ground contact is required with these meters. McNeill (1980) described the principles of operation of the EM31 meter. The EM31 meter provides limited vertical resolution and depth information. Lateral resolution is approximately equal to the intercoil spacing (about 3.9 m). The EM31 meter operates at a frequency of 9,800 Hz and has theoretical observation depths of about 3 and 6 m in the horizontal and vertical dipole orientations, respectively (McNeill, 1980).

The EM38DD operates at a frequency of 14,600 Hz. It has effective penetration depths of about 0.75 and 1.5 m in the horizontal and vertical dipole orientations, respectively (Geonics Limited, 2000). The EM38DD meter consists of two EM38 meters bolted together and electronically coupled. One unit acts as a master unit (meter that is positioned in the vertical dipole orientation and having both transmitter and receiver activated) and one unit acts as a slave unit (meter that is positioned in the horizontal dipole orientation with only the receiver switched on). The Geonics EM38Dpro Data Logging System was used to record and store both EMI and GPS data. [1] The logging system consists of an EM38DD meter, Allegro field computer, Trimble AG114 GPS receiver, backpack and frame for GPS, and associated cables. With the logging system, the EM38DD meter is keypad operated and measurements can either be automatically or manually triggered.

The ground-penetrating radar (GPR) unit is the Subsurface Interface Radar (SIR) System-2000, manufactured by Geophysical Survey Systems, Inc.[1] Morey (1974) and Doolittle (1987) have discussed the use and operation of GPR. The SIR System-2000 consists of a digital control unit (DC-2000) with keypad, VGA video screen, and connector panel. A 12-volt battery powered the system. This unit is backpack portable and, with an antenna, requires two people to operate. A 200 MHz antenna was used in this study.

A Garmin GPS Map 76 receiver was used to collect the coordinates of observation points. To help summarize the results of this study, the SURFER for Windows (version 8.0) program, developed by Golden Software, Inc., [1] was used to construct two- and three-dimensional simulations[1]. Grids were created using kriging methods with an octant search.

Buckeye Reservoir:
Buckeye Reservoir will not hold water. A fault line is believed to underlie a portion of the reservoir and be responsible for a solution cavity. The cavity has been plugged with bentonite clays and a concrete plug. A 180 by 122 m grid was established across a portion of the reservoir that included this filled solution cavity. It was hoped that either ground-penetrating radar or electromagnetic induction would provide subsurface information on the location and extent of this fault line and the presence of other solution features.

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[1] Manufacturer's names are provided for specific information; use does not constitute endorsement.

Several traverses were completed with GPR across the reservoir bottom. Because of the clay and salt contents of these sediments, the GPR was depth restricted, and provided little meaningful subsurface information. The use of GPR is considered inappropriate at this site.

Two parallel lines defined an area to be surveyed with EMI. Each line was 180 m long. The two lines were 122 m apart. Along each line, survey flags were inserted in the ground at intervals of 20 m. These flags served as traverse line end points and provided ground control. Walking at a fairly uniform pace between similarly numbered flags on opposing sets of parallel lines in a back and forth pattern completed an EMI survey. Both the EM31 meter and the GEM300 sensor were operated in the continuous mode with measurements recorded at a 1-sec interval. Software packages were later used to adjust the location of each measurement and to provide a uniform interval between observation points.

When operated in the continuous mode, the EM31 meter and the GEM300 sensor cannot be rotated to record measurements in both dipole orientations. As a consequence, two separate surveys were required with each device. Data collected with the EM31 meter in the horizontal dipole orientation contained high levels of noise that made the data ineffectual. Surveys were completed with the GEM300 sensor and the EM31 meter held at hip height with its long axis parallel to the direction of traverse.

A total of 966 measurements were recorded with the EM31 meter. Apparent conductivity averaged 19.0 mS/m with a range of 12 to 36.9 mS/m for measurements collected with the EM31 meter in the vertical dipole orientation. Half of these observations had values of apparent conductivity between 15.9 and 21.6 mS/m. Figure 1 is a two-dimensional plot of the apparent conductivity data collected with the EM31 meter in the vertical dipole orientation. In Figure 1, the concrete plug used to seal the solution feature produced a weakly expressed anomaly at "A." In addition to this cultural feature, several noteworthy anomalies were detected with the EM31 meter. An anomalous area of higher apparent conductivity is evident surrounding "B" in Figure 1. A soil boring in this area revealed shallower depths to bedrock. A conspicuous finger of lower (14 to 16 mS/m) extends from the left-hand margin of the survey area into the reservoir. Soil borings near "C" revealed an extensive area of more resistive, coarser-textured materials in this area. Based on a soil boring near "D," the prominent zone of high apparent conductivity in the right hand portion of the survey area was associated with finer-textured soil materials and slightly higher levels of salinity. The orientation of this zone was orthogonal and did not conform to the probable trend of the fault line.

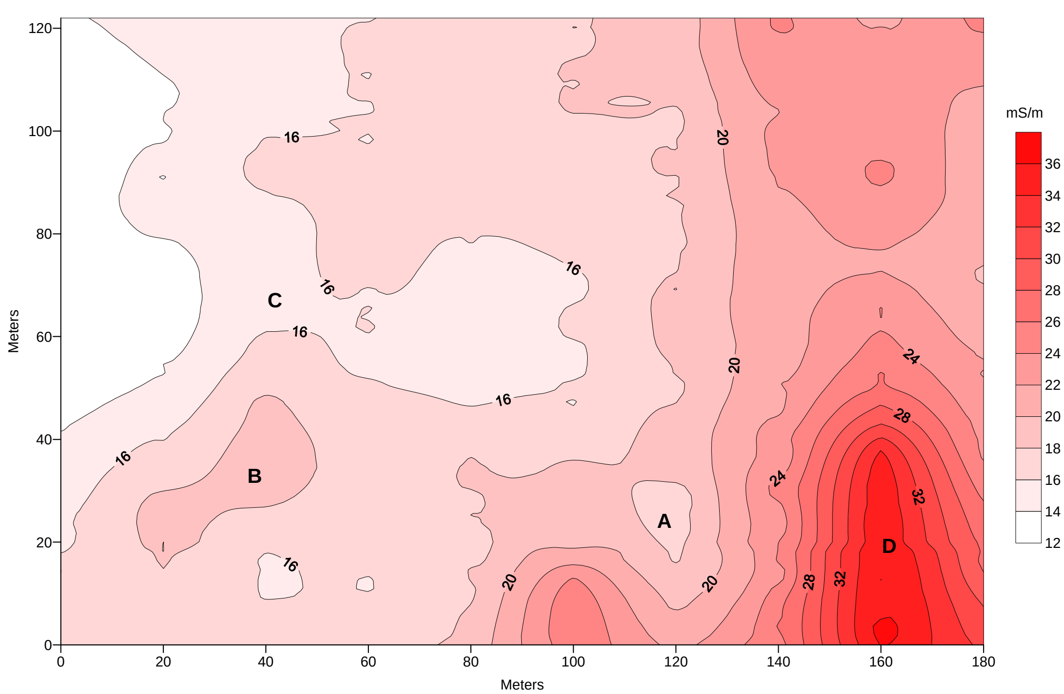

Figure 1 – Spatial pattern of apparent conductivity measured with the EM31 meter in the vertical dipole orientation.

The EMI survey of a portion of Buckeye Reservoir did not reveal any evidence of the fault or addition solution features. It is possible that both features exist but are too small and/or do not produce a sufficient electromagnetic contrast to be detect with EMI.

Ute Mountain Ute Tribe Farm and Ranch Enterprise

The Ute Mountain Ute Tribe Farm and Ranch Enterprise is a seven-year-old 7,800-acre irrigation project in the desert. This market-oriented project provides year-round employment for tribal members. EMI training and soil investigations were conducted on three mapped soil delineations within the Ute Mountain Ute Tribe Farm and Ranch Enterprise.

Area of Battlerock loam, saline-sodic phase, 0 to 3 % slopes:

A 50 by 50 m grid was established across an area of Battlerock loam, saline-sodic phase, 0 to 3 percent slopes. The very deep, well drained Battlerock soil formed in stratified alluvium derived from mixed sources on flood plains. Battlerock is a member of the fine-loamy, mixed, superactive, calcareous, mesic Typic Torrifluvent family. The average composition of this map unit is about 70 percent Battlerock soil and 30 percent included soils. The survey site was in rangeland.

The grid interval used in this survey was 10 m. At each grid intersection a survey flag was inserted in the ground and served as an observation point. This procedure produced 36 observation points. The grid area was surveyed with the GEM300 sensor operating at frequencies of 9810 and 14790 Hz. The GEM300 sensor was held at hip height. Data were collected in both the horizontal and vertical dipole orientations. Two surveys were completed of the grid area: a station-to-station, and a continuous survey.

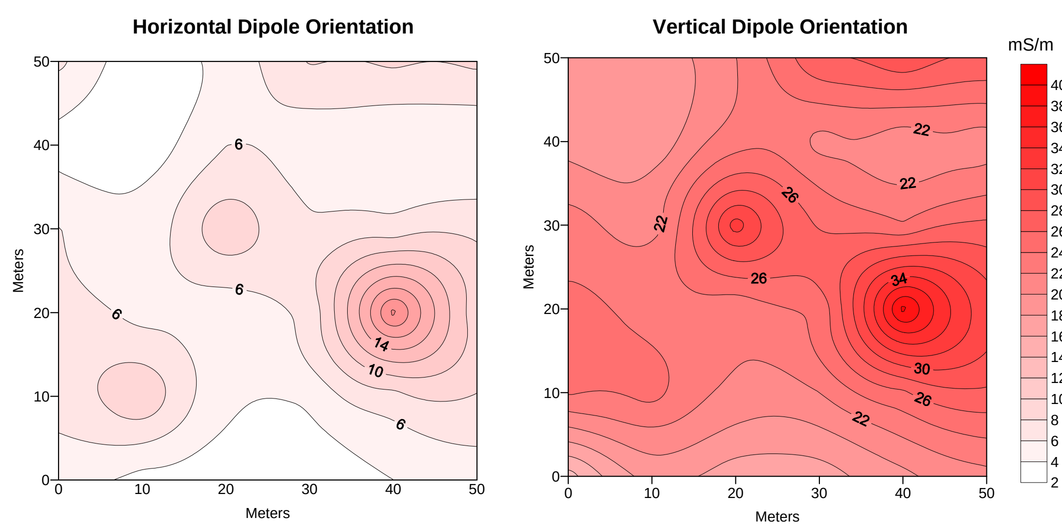

Figure 2 – Spatial pattern of apparent conductivity in an area of Battlerock loam, saline-sodic phase, 0 to 3 percent slopes, measured with the GEM300 sensor at a frequency of 14790 Hz.

A total of 36 measurements were recorded with the GEM300 sensor in the station-to-station survey. Figure 2 shows the spatial distribution of apparent conductivity measured with the GEM300 sensor operating at a frequency of 14790 Hz within the surveyed area. Apparent conductivity increased with increase soil depth (measurements obtained in the shallower-sensing, horizontal dipole orientation were lower and less variable than those obtained in the deeper-sensing vertical dipole orientation). Apparent conductivity averaged 6.1 mS/m with a range of 2.3 to 20.6 mS/m for measurements collected with the GEM300 sensor in the horizontal dipole orientation. Half of these observations had values of apparent conductivity between 4.1

and 7.5 mS/m. Apparent conductivity averaged 23.3 mS/m with a range of 13 to 40.6 mS/m for measurements collected with the GEM300 sensor in the vertical dipole orientation. Half of these observations had values of apparent conductivity between 20.7 and 25.8 mS/m.

In Figure 2, the two conspicuously high areas of apparent conductivity are near greasewood plants. Greasewood plants are known to cycle and deposit sodium in the upper part of the soil profile. Higher EMI responses were recorded adjacent to Greasewood plants. These higher responses were attributed to increased sodium salt and moisture contents adjacent to these plants. Soils were moister and had higher pHs (9.6 adjacent to greasewood and 8.2 in open areas) in surface layers.

Mack fine sandy loam, 1 to 3 percent slopes:
The study site was located in the northeast corner of center pivot area 4020. The irrigated area is planted to alfalfa. The area has been mapped as Mack fine sandy loam, 1 to 3 percent slopes. The very deep, well drained Mack soil formed in alluvium and eolian deposits derived from sandstone on alluvial fans, mesas, and terraces. Mack is a member of the fine-loamy, mixed, superactive, mesic Typic Calciargid family. The average composition of this unit is 80 percent Mack soil and 20 percent included soils.

A 300 by 250 m grid was established across the study area. Two parallel lines defined the study area. Each line was 300 m long. The lines were 250 m apart. Along each line, survey flags were inserted in the ground at intervals of 25 m. These flags served as grid line end points and provided ground control. Walking at a fairly uniform pace between similarly numbered flags on opposing sets of parallel lines in a back and forth pattern across the grid area completed a survey. Surveys were completed with both the EM38DD meter and the GEM300 sensor.

The EM38DD meter was carried about 3 inches above the ground surface. The meter was operated in the continuous mode with measurements recorded at a 1-sec interval. The Geonics EM38Dpro Data Logging System was used to record and store both EMI and GPS data.

A total of 2054 measurements were recorded with the EM38DD meter. Apparent conductivity increased with increase soil depth (measurements obtained in the shallower-sensing, horizontal dipole orientation were lower and less variable than those obtained in the deeper-sensing vertical dipole orientation). Apparent conductivity averaged 14.5 mS/m with a range of 5.13 to 31.9 mS/m for measurements collected with the EM38DD meter in the vertical dipole orientation. Half of these observations had values of apparent conductivity between 12.3 and 16.3 mS/m. Apparent conductivity averaged 6.6 mS/m with a range of 0.05 to 21.6 mS/m for measurements collected with the EM38DD meter in the horizontal dipole orientation. Half of these observations had values of apparent conductivity between 5.0 and 8.0 mS/m.

In Figure 3, the upper and lower plots show the distribution of apparent conductivity measured with the EM38DD meter in the shallower-sensing, horizontal dipole and the deeper-sensing vertical dipole orientations, respectively. In each plot the isoline interval is 2 mS/m. The location of observation points and the traverse tracks are also shown in each plot.

Soil borings revealed an association between apparent conductivity and the clay content of the soils. In general, areas with apparent conductivity values greater than 16 mS/m in the vertical dipole orientation were associated with fine-loamy Mack soils. Areas with apparent conductivity values less than 12 mS/m in the vertical dipole orientation were associated with a coarse-loamy inclusion. The distribution of fine- and coarse-loamy soils within this irrigated area is important to management. Areas of finer-textured materials will retain more moisture and crop response will better under similar water management than areas of coarser-textured soil materials.

The area of anomalously high apparent conductivity in the extreme northeast corner of the survey area is associated with a road and culvert. Here, higher values of apparent conductivity may be related to the accumulation of carbonates and soluble salts.

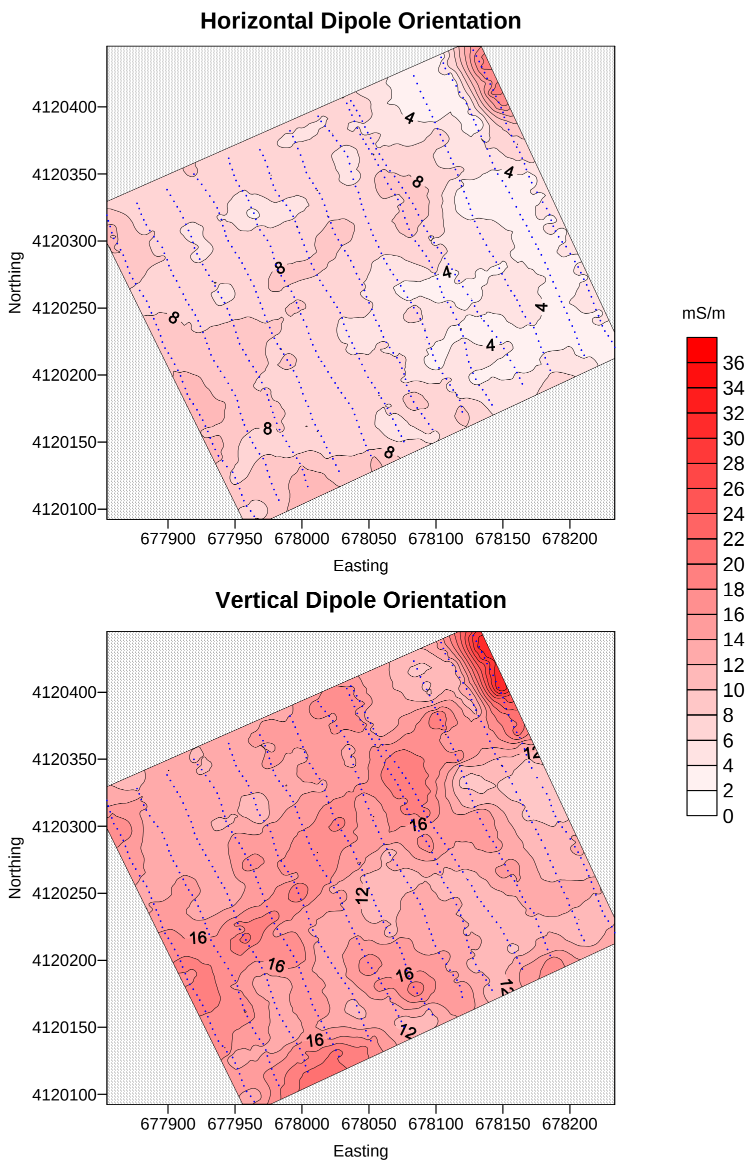

Figure 3 – Spatial pattern of apparent conductivity in an area of Mack fine sandy loam, 1 to 3 percent slopes, measured with the EM38DD meter.

Gypsey loam, 3 to 6 percent slopes:
Transects were conducted with the GEM300 sensor in an area of Gypsey loam, 3 to 6 percent slopes. The moderately deep to paralithic material, well drained Gypsey soil formed in residuum weathered from calcareous shale on pediments. Gypsey is a member of the fine-loamy, mixed, carbonatic, mesic Typic Calcigypsid family. The average composition of this unit is 80 percent Gypsey soil and 20 percent included soils.

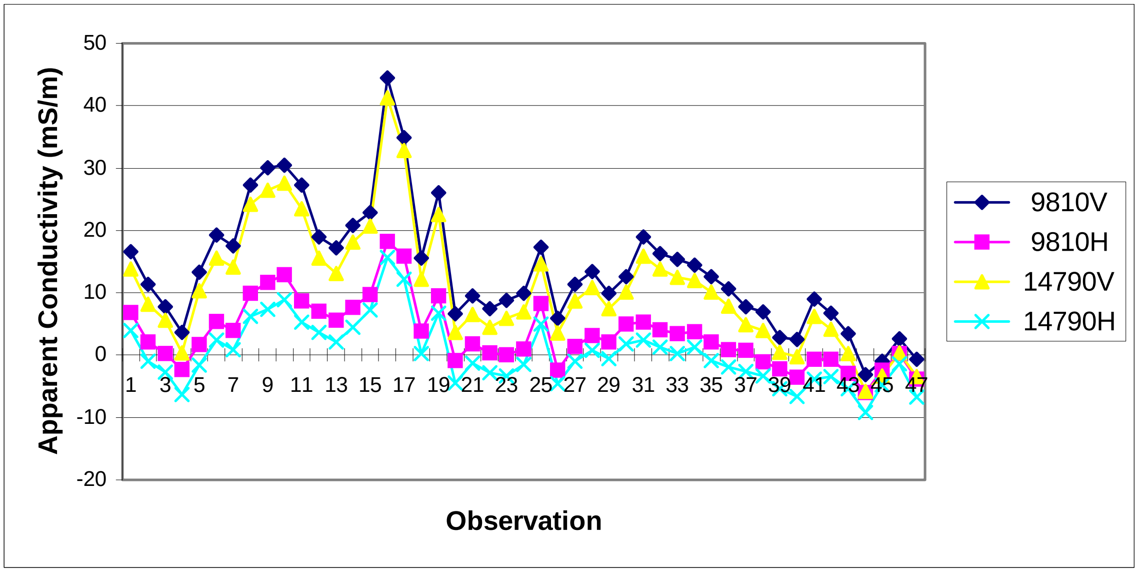

Figure 4 – Spatial pattern of apparent conductivity in an area of Gypsey loam, 3 to 6 percent slopes, measured with the GEM300 sensor operating at a frequency of 9810 and 14790 Hz in the horizontal and vertical dipole orientations.

As seen in Figure 4, similar data were obtained when the GEM300 sensor was operated at different frequencies (9810 or 14790 Hz) and dipole orientations (H – horizontal, or V – vertical). While following similar spatial trends, variations in the strength of the electromagnetic response can be observed in the two dipole orientations. At all sites, apparent conductivity obtained in the shallower-sensing, horizontal dipole orientation was lower than the conductivity obtained in the deeper-sensing, vertical dipole orientation. This could reflect lower conductivity at shallower observation depths or the greater relative contribution from the column of air beneath the sensor (sensor held at hip height). Soil scientists preferred operating the GEM300 sensor in the vertical dipole orientation. As little additional information is gained by operating at different frequency and dipole orientations, this survey could be as efficiently completed using only one frequency and one dipole orientation.

During this field exercise, both the Garmin GPS Map 76 and the Trimble AG114 receivers were set to record waypoints at 1 sec intervals. The Garmin GPS Map 76 receiver collected differentially corrected signals while the Trimble AG114 collected autonomous signal. The Garmin unit recorded signals from two more satellites than the Trimble unit. In spite of these differences, the relative tracks of the waypoints were closely similar (see Figure 5). Either receiver appears to provide reasonably accuracy for the location of EMI observation points used in soil mapping.

A slight error was noted in the clock of the GEM300 sensor. This clock is used to provide a time-stamp for each EMI measurements. Following the survey, GPS and EMI data are joined according to matching time stamps. The time for the transect shown in Figure 5 was 10 min 21 sec for the GEM300 sensor, and 10 min 24 sec for the GPS. This difference represents a 0.005 percent error. It is presumed that the error is in the GEM300's clock.

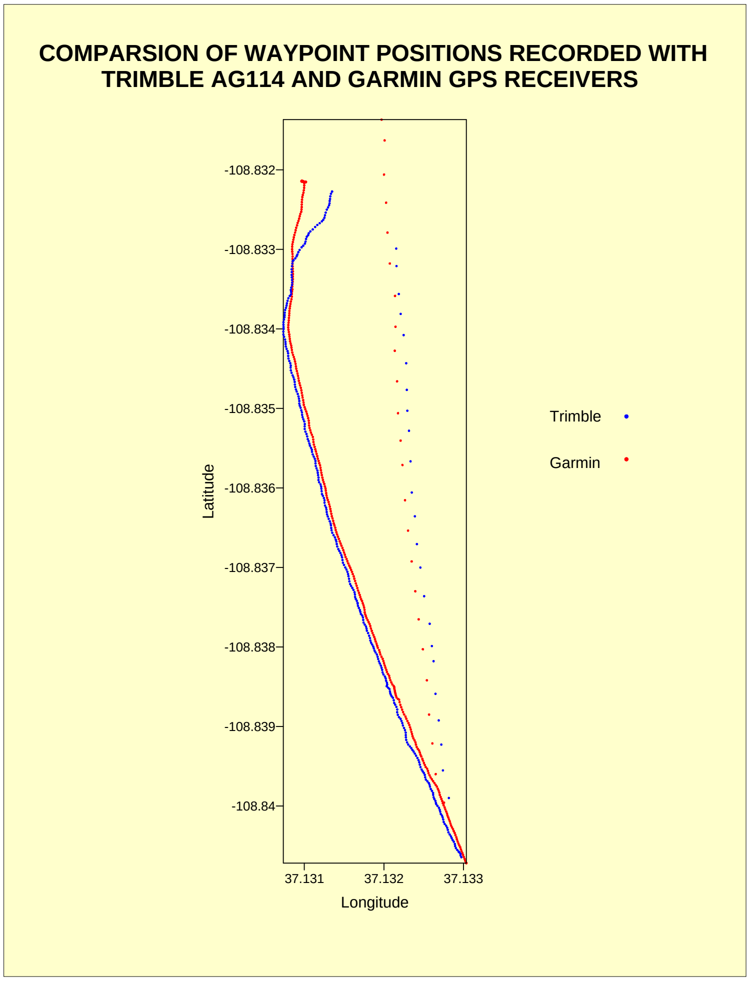

Figure 5 – Comparison of relative positioning of waypoints obtained with a Garmin GPS Map 76 and Trimble AG114 GPS receivers in an area of Gypsey loam, 3 to 6 percent.

References:

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