United States Department of Agriculture

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SUBJECT: SOI – Geophysical Assistance

April 8, 2010

TO: Kevin D. Norton
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File Code: 330-7

Purpose:
The principal objective of this study was to use ground-penetrating radar (GPR) to assess the presence, depth, and continuity of ironstone layers in areas mapped as Darley soils in Claiborne and Webster Parishes. In addition, comparative field studies were conducted using the Dualem-1s and the EM38MK2-2 meters in Vermillion Parish.

Participants:
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Gerald Trahan, MLRA Project Leader, USDA-NRCS, Carencro, LA
David Weindorf, Assistant Professor, Louisiana State University, Baton Rouge, LA

Activities:
Field studies were completed during the period of March 22-26, 2010.

Summary:
1. Ground-penetrating radar provided satisfactory penetration depths and resolution of subsurface features, and helped characterize ironstone layers in areas of Darley soils. In general, multiple ironstone layers were observed in most areas of Darley soils. These layers appear highly fractured and discontinuous with spheroid features intermixed. Ironstone layers were associated with higher-lying, convex surfaces and were generally absent on lower-lying, plane or concave surfaces. However, faulting and incongruent surfaces and formations have fostered inconsistent and jumbled patterns across some landscapes.

2. Sixteen radar traverses of varying lengths were completed within two open areas of Darley soils in Claiborne Parish. These traverses provided 111,068 observations. Ironstone layers were interpreted to be present at 50% of these observation points. The percent of soils with ironstone layers was variable along each traverse and ranged from 0 to 100 %.

3. In comparative studies using the Dualem-1s and the EM38MK2-2 meters at the Live Oaks Plantation in Vermillion Parish, spatial EC_a patterns were remarkably similar with each meter. Differences are attributed to the slightly different intercoil spacing and effective penetration depths of the meters. In general, slightly higher and more variable EC_a was recorded with the Dualem-1s meter across the survey area.

4. At the Live Oaks Plantation, using the ESAP software program's *Deterministic Model*, both the Dualem-1s and the EM38MK2-2 meters characterized the 0 to 30 cm soil depth interval across the survey area as being dominantly very slightly (2 to < 4 dS/m) and slightly (4 to < 8 dS/m) saline. For both meters, the model estimated that soil salinity increases with increasing soil depths. Both meters characterized the 30 to 60 cm soil depth interval across the survey area as being dominantly slightly and moderately (8 to < 16 dS/m) saline.

5. Instrument drift test demonstrated that the Dualem-1s was slightly more stable than the EM38MK2-2 meter. Over a single location and a period of 33 minutes, the Dualem-1s meter recorded lower ranges in apparent conductivity (EC_a) (2.10 and 1.40 mS/m) in its two coil geometries, than the EM38MK2-2 meter (3.16 and 4.84 mS/m) in its two intercoil spacings. These test revealed that the Dualem-1s meter, which is owned by the NRCS Soil Staff in Louisiana, has slightly greater instrument stability than the EM38MK2-2 meter.

It was the pleasure of Jim Doolittle and the National Soil Survey Center to work with and be of assistance to your fine staff in this study.

JONATHAN W. HEMPEL
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Technical Report on the use of Ground-Penetrating Radar (GPR) to assess the presence, depth, and continuity of ironstone layers in Western Coastal Plains soils of Louisiana on 22 to 26March 2010.

Jim Doolittle

Background:
In a joint project with Dr. David Weindorf of Louisiana State University, several type locations of soils described as having ironstone layers were investigated with GPR in Claiborne, Vernon, and Webster Parishes. One of these soils, Darley, is a benchmark soil series that contains layers of ironstone fragments and fractured ironstone layers. Ironstone is an *in situ* concentration of iron oxides that is at least weakly cemented (Soil Science Society of America, 1996). Where continuous, ironstone can form root and water restricting layers (see Figure 1). In this study, GPR was used to assess the presence, depth, and continuity of ironstone layers in areas mapped principally as Darley soils. Results from this investigation are expected to influence series concepts and affect map unit interpretations. In addition, an area in Vernon Parish that has ironstone layers, which manifest many of the properties defined for *placic horizons*, was investigated with GPR.

Figure 1. Marc Bordelon, Jerry Daigle, and Charles Guillory inspect ironstone layers in a road cut of Darley soil.

Equipment:
The radar unit is the TerraSIRch Subsurface Interface Radar (SIR) System-3000 (here after referred to as the SIR-3000), manufactured by Geophysical Survey Systems, Inc. (GSSI; Salem, NH).[1] The SIR-3000 consists of a digital control unit (DC-3000) with keypad, SVGA video screen, and connector panel. A 10.8-volt lithium-ion rechargeable battery powers the system. The SIR-3000 weighs about 4.1 kg (9 lbs) and is backpack portable. With an antenna, the SIR-3000 requires two people to operate. Jol (2009) and

[1] Trade names are used for specific references and do not constitute endorsement.

Daniels (2004) discuss the use and operation of GPR. The 400 and 200 MHz antennas were used in this study.

The RADAN for Windows (version 6.6) software program (GSSI; here after referred to as RADAN) was used to process the radar records shown in this report.[2] Processing included: header editing, setting the initial pulse to time zero, color table and transformation selection, range gain adjustments, signal stacking, migration, and high-pass filtration (refer to Jol (2009) and Daniels (2004) for discussions of these techniques).

Using the *Interactive 3D Module* of the RADAN, depths to ironstone layers were automatically and reasonably accurately picked, and outputted to a worksheet (X, Y, Z format; including latitude, longitude, depths to interface or layer, and other useful data).

Recent technical developments allow the integration of GPR and GPS data. The SIR-3000 system provides a setup for the use of a GPS receiver with a serial data recorder (SDR). A Pathfinder ProXT GPS receiver with Hurricane antenna (Trimble, Sunnyvale, CA) was used to georeferenced GPR data.[2] With this setup, each scan of the radar can be georeferenced (position/time matched). Following data collection, a subprogram within the RADAN is used to proportionally adjust the position of each radar scan according to the time stamp of the two nearest positions recorded with the GPS receiver. Position data were recorded with the GPS receiver at a time interval of one second.

Field Methods:
Traverses were conducted using the SIR-3000 with either a 200 or 400 MHz antenna. Traverses were completed by towing an antenna by hand along a traverse line. The Pathfinder ProXT GPS receiver with Hurricane antenna was used to georeference each radar scan along most traverse lines.

Calibration:
Ground-penetrating radar is a time scaled system. The system measures the time that it takes electromagnetic energy to travel from an antenna to an interface (e.g., soil horizon, stratigraphic layer) 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 (from Daniels, 2004):

$$v = 2D/T \qquad [1]$$

The velocity of propagation is principally affected by the relative dielectric permittivity (E_r) of the profiled material(s) according to the equation (from Daniels, 2004):

$$E_r = (C/ v)^2 \qquad [2]$$

where C is the velocity of propagation in a vacuum (0.298 m/ns). Typically, velocity is expressed in meters per nanosecond (ns). In soils, the amount and physical state (temperature dependent) of water have the greatest effect on the E_r and v.

As different antennas were used, separate calibrations were performed with each antenna. Both antennas were calibrated based on the measured depths to a known, buried reflector. Based on the two-way travel time, depth to a shallowly (50 cm) buried, metallic (30 cm diameter) reflector, and equations [1] and [2],

[2] Trade names are used for specific references and do not constitute endorsement.

the E_r of the upper part of Darley soil was estimated to be 6.22 and 6.18 for the 200 and 400 MHz antennas, respectively. These E_r resulted in v of 0.1195 and 0.1199 m/ns for the 200 and 400 MHz antennas, respectively.

Study Sites:
Sites were located principally in areas of Darley soils in Claiborne and Webster Parishes. The well drained, highly weathered and leached Darley soils have formed on uplands of the Western Coastal Plains. Darley is a member of the fine, kaolinitic, thermic Typic Hapludults taxonomic family. Darley soils have low base status throughout. Although Darley soils have relatively high clay content, their low base status and dominance of low activity clays makes them suited to GPR.

Darley soils formed in iron-rich, clayey, Tertiary age sediments. Darley soils form in the Cook Mountain Formation of the Claiborne Group. This formation consists of bedded marine sediments composed of mostly sideritic and glauconitic clays and fossiliferous marl (in lower part) (Kilpatrick et al., 1998; Kilpatrick and Henry, 1989). The weathering of sideritic and glauconitic clays results in the accumulation of iron oxide and the formation of "continuous ironstone layers" in many upland soils (Kilpatrick et al., 1998). Kilpatrick et al. (1998) noted that although ironstone layers are common in many upland soils, these layers are most evident in Darley, Mahan (fine, kaolinitic, thermic Typic Hapludults) and Ruple (fine, parasesquic, thermic Typic Rhodudults) soils. The official series description for Darley soils notes:

> *"The depth to ironstone layers typically ranges from 20 to 40 inches and can range from 10 to 40 inches. Angular and flattened fragments of ironstone make up from 15 to 35 percent of the volume in the A and E horizons. The number of fractured, nearly continuous ironstone layers typically ranges from 1 to 4 within the solum. Thickness of ironstone layers ranges from 1/2-inch to 12 inches. The average lateral distance between fractures in the ironstone ranges from 2 to 20 inches and averages 4 to 8 inches."*
>
> *"The Bt/Bsm horizon consists of alternating layers of ironstone and sandy clay or clay. Ironstone fragments, including fragments that make up the ironstone layers, make up from 20 to 60 percent of the volume of the horizon. The ironstone layers are fractured and range in thickness from 1/2-inch to 12 inches. The lateral distance between fractures ranges from 2 to 20 inches and averages 4 to 8 inches. Typically, the ironstone layers are continuous for several feet; but in some pedons they are intermittent and extend only a few feet horizontally. In some pedons, the layers are parts of the large spheroidal configurations that are separated from one another by vertical flows of red clay, sandy clay or clay loam."*

Over the years, soil scientists have observed similar layers of fractured ironstone in exposures of Darley soils. Figure 2 is an image of an exposed area of Darley soil. As described in the official series description, the ironstone layers are intermittent and extend only a few meters horizontally. Here, the ironstone layers are composed of several large spherical forms (see "A" in Figure 2). These laminated, globular or sphere-shaped features suggest fossilized organic features deposited in shallow water environments. These layered, accretionary, sphere-shaped structures may have formed in shallow water by the trapping and cementation of sedimentary grains by microorganisms. In Figure 2, vertical flows of darker red colored soil materials indicate the presence of former root channels.

Figure 2. This exposure of Darley soil contains several ironstone layers and spheroid masses. Fractured, discontinuous ironstone layers are evident below depths of 60 to 80 cm. Several spheroid configurations are evident to the left of the letter "A". White horizontal lenses in Bt horizon are reduced clays and segregated pockets of kaolin

Results:

Processing and Display:

Most radar records shown in this report are imaged as two-dimensional (2D) diagrams with all scales expressed in meters. The X is distance. The Z axis is depth. For display purposes, the vertical scales have been exaggerated. High-amplitude reflections are shown in shades of white, pink, and blue; intermediate-amplitude reflections are shown in shades of yellow and green; and low-amplitude reflections are shown in shades of red and black.

Site 1 - Claiborne Parish:

This hay land site (32.7684 N. latitude, 92.8781 W. longitude) is mapped as Darley-Sacul complex on 12 to 30 percent slopes (Dy). The very deep, moderately well drained Sacul soils formed in acid, loamy and clayey marine sediments on uplands of the Western Coastal Plains. Sacul is a member of the fine, mixed, active, thermic Aquic Hapludults family. Sacul soils contain fragments of ironstone.

Figure 3 contains a processed radar record from an area of Darley soils at this study site. Processing techniques included migration, signal stacking, vertical high pass filtration, and range gain adjustments. These processing procedures were applied to improve the clarity and interpretability of the ironstone layers. Ironstone layers form a distinct and easily identifiable zone or radar *facies* on this and most radar records. On this radar record, individual ironstone layers are difficult to identify and trace laterally. This suggests that the ironstone layers are highly fractured, convoluted, and discontinuous over short distances. Variations in signal amplitude suggest differences in degree of induration and contrast with the encompassing soil materials. Reflections not only vary in amplitude but in form, ranging from point to planar reflectors. In different parts of this radar record, arrangements of reflectors can be described as chaotic, wavy, parallel, or hummocky. Although an overriding slightly incline (vertical scale has been exaggerated) linearity is apparent, the lack of clearly-expressed parallel, linear reflectors suggest highly fractured, closely spaced, intertwining layers, and the presence of convoluted structures; possibly the spherical forms evident in Figure 2.

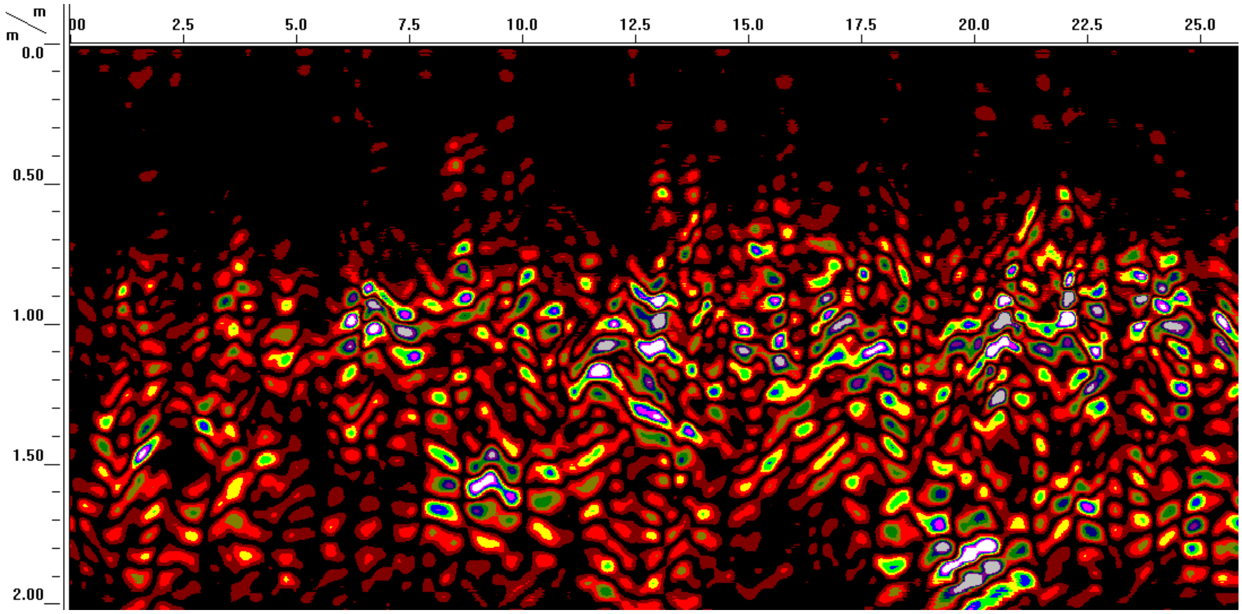

Figure 3. A processed radar record from an area of Darley soils at Site 1 in Claiborne Parish. The ironstone evident in the processed radar record appears highly fractured and discontinuous over short distances. Variations in signal amplitude suggest differences in degree of induration and contrast with the encompassing soil materials.

Seven radar traverses were completed at Site 1 and provided a total of 55,244 observations. Ironstone layers were interpreted to be present at 64 % of these observation points. However, the percent of observation points with ironstone layers in each traverse was variable and ranged from 10 to 100 % (see Table 1). Ironstone layers were more common along radar traverses conducted on higher-lying, convex summit and shoulder slope positions. Ironstone layers were less common or absent along radar traverses conducted on lower-lying, plain and concave surfaces.

Table 1
Composition of radar traverses according to the presence or absence of ironstone layers at Site 1, Claiborne Parish.

Traverse	Observations	ironstone	none
1	9581	1.00	0.00
2	6689	1.00	0.00
3	11022	0.77	0.23
4	6969	0.14	0.86
5	4549	0.80	0.20
6	6832	0.72	0.28
7	9602	0.10	0.90

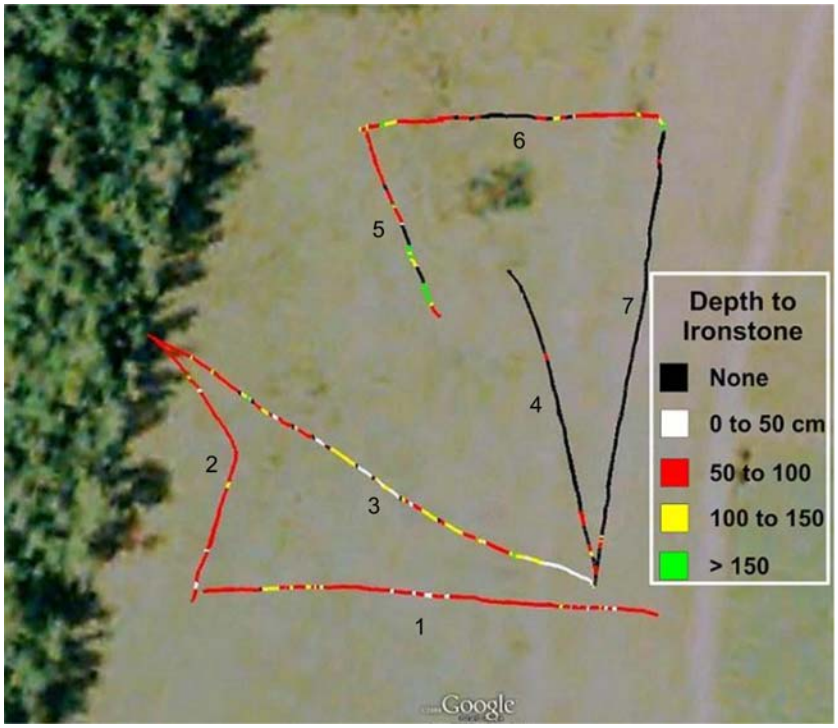

Figure 4. This Google Earth image shows the location of GPR traverse lines, presence or absence of ironstone, and the relative depths to ironstone layers within Site 1, Claiborne Parish. Numbers are used to identify the traverse lines.

Figure 4 is a Google Earth image that shows the location of GPR traverse lines, presence or absence of ironstone, and the relative depths to ironstone layers along each traverse line within Site 1, Claiborne Parish. Traverse lines 1, 2, 3 and 5 are located on convex summit and shoulder slopes. These traverse lines have soils with large amounts of ironstone (see Table 1). Traverse line 6 spans from one convex shoulder slope to another and cross a swale. Traverse line 4 is located along the center line of a swale. Traverse line 7 is located on a plane side slope. Traverse lines 4 and 7 have soils with very low amounts of ironstone.

Table 2
Frequency distribution (%) of ironstone layers according to soil depth classes along the seven traverse lines in Site 1.

Traverse	None	Shallow	Mod Deep	Deep	Very Deep
1	.03	.08	.80	.08	.00
2	.00	.04	.94	.03	.00
3	.23	.00	.49	.28	.00
4	.86	.00	.10	.04	.00
5	.20	.01	.53	.11	.15
6	.28	.02	.61	.09	.01
7	.90	.00	.06	.03	.01

The Google Earth image shown in Figure 4 also indicates the relative depths to ironstone layers along each traverse line. While the presence and depth to ironstone is quite variable along these traverse lines and landscape components, the ironstone is shallow at 2 %, moderately deep at 50 %, deep at 9 %, very deep at 2 % and absent at 36 % of the 55,244 observation points. Table 2 summarizes the distribution of ironstone according to soil depth classes for the seven traverses that were conducted across Site 1.

Detailed grid survey of Darley soil:

An emerging approach to GPR interpretations is three-dimensional (3D) visualization of GPR data (3D GPR). Three-dimensional GPR provides images that can improve our understanding of the structure and geometry of many subsurface features. Recently, with the advent of digital GPR outputs and advanced data processing software, it has become a more routine practice to analyze the structure or configuration of subsurface features from a three-dimensional perspective. Grasmueck and Green (1996) noted that compared with the information provided by single 2D radar records, 3D GPR pseudo-images can provide "unrivaled resolution and detail of subsurface features". Three-dimensional GPR pseudo-images allow the rapid viewing of the data volume from different cross-sections and directions (Beres et al., 1999).

Unavoidably, the acquisition of data for 3D GPR pseudo-images requires greater expenditures of time and other resources than the collection of 2D radar records. To construct 3D GPR pseudo-images, a relatively small area (generally < 50 m^2) is intensively surveyed with closely spaced (typically 0.1 to 0.5 m), parallel GPR traverse lines. The relatively dense network of traverse lines is necessary to resolve the geometries and sizes of different subsurface features and to prevent spatially *aliasing* of the data (Grasmueck and Green, 1996). The additional resources needed to collect and process GPR data for 3D imaging is often compensated for by more detailed spatial coverage and higher resolution of subsurface features (Grasmueck and Green, 1996).

In 3D GPR, data from closely-spaced, parallel lines are processed into a 3D GPR pseudo-image using software such as *RADAN*. Once processed, arbitrary cross-sections, insets, and time slices can be extracted from the 3D data set. Three-dimensional GPR imaging enables users to view the subsurface from nearly any perspective (Junck and Jol, 2000). Some software packages, allow the observer to rapidly travel through the entire data volume with animated imagery (Grasmueck, 1996). Interactive software packages permit the rapid display of any sub-section or block within the surveyed grid. The flexibility of 3D visualizations can greatly facilitate the interpretation of many spatial relationships and the analysis of lithologic and stratigraphic features. Lehmann and Green (1999) discuss considerations that are important for 3D GPR surveys. As noted by Szerbiak et al. (2001), all 3D GPR pseudo-images require correct velocity analysis (for reliable travel times to interfaces) and depth migration.

With 2D and 3D imaging of radar data, because of often limited ground-truth observations, interpretations rest with the investigator's knowledge concerning the feature of interest. As noted by Regli et al. (2002) cores, outcrops, and geophysical information represents data of different quality and scale. Relationships between GPR patterns and subsurface structures are often ambiguous (Regli et al., 2002). Being more ambiguous than boring or outcrop data, 2D radar records and 3D GPR pseudo-images are considered soft data (Regli et al., 2002), which is interpretive and must be used with a caution.

To collect the data required for construction of a 3D GPR pseudo-image of an area of Darley soil, a survey grid was established on a fairly level summit at Site 1. The grid had dimensions of 5.0 by 5.0 m. Along the two parallel Y-axis lines, survey flags were inserted into the ground at a spacing of 25 cm. A reference line was stretched between matching survey flags on opposing sides of the grid using a distance-graduated rope. GPR traverses were conducted along this reference line. Each radar traverse was 5-m long. The 400 MHz antenna was towed along the graduated rope on the soil surface and, as it passed each 100-cm graduation, a mark was impressed on the radar record. Following data collection along a line, the reference line was sequentially displaced 25-cm to the next pair of survey flags to repeat the process. A total of 21 traverses were required to complete the GPR survey of the grid site.

Figure 5 is a 3D pseudo-image of the grid site with a 300 by 300 by 150 cm inset cube removed. Radar traverses were conducted parallel with the x-axis (right foreground). Data were continuously recorded in this direction. Along the y-axis (left foreground), data were interpreted between adjoining radar traverse lines, which were spaced 25 cm apart. Spatial aliasing and some smudging of data are noticeable along the y-axis.

In this 3D pseudo-image, a sequence of ironstone layers is evident within the soil column. This 3D pseudo-image does provide a means of visualizing and interpreting the 3D continuity of these layers. These layers contain noticeable gaps, which are interpreted as breaks in their continuity. Along the base of the cutout cube, the dimensions of these breaks are more apparent. Here, the base of the cutout cube approximates the seemingly level (along x- and y-axes) upper contact of an ironstone layer. Areas of no noticeable reflections are colored black. Black colored areas occupy a large portion of this base and are inferred to represent breaks and the uneven micro-topography of this ironstone layer.

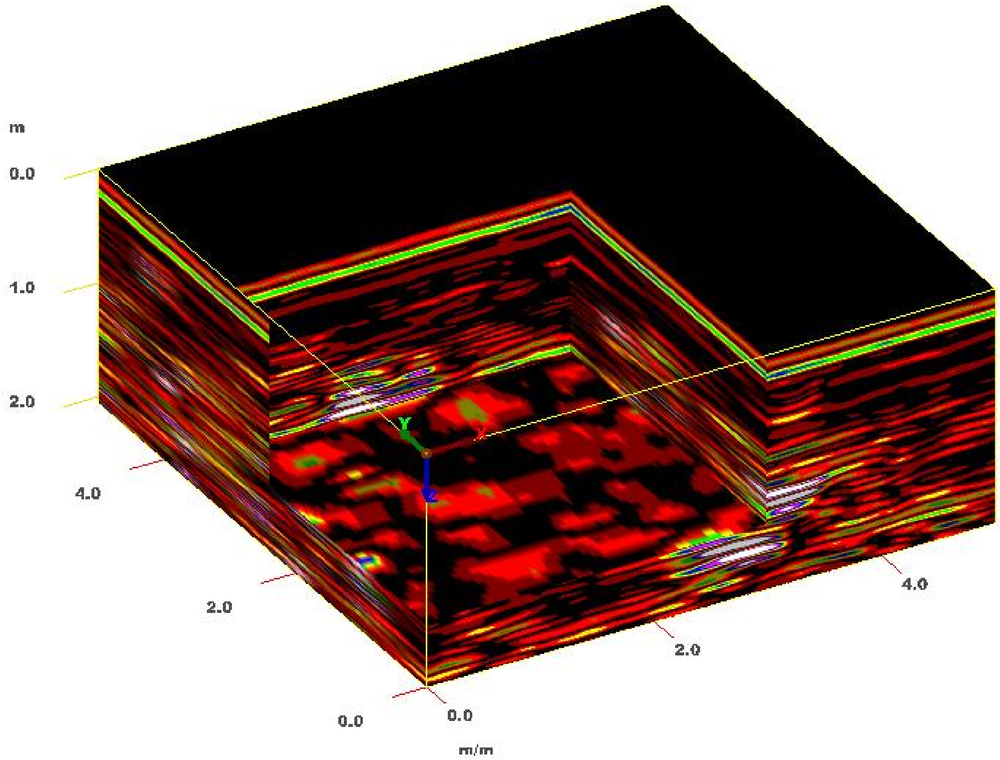

Figure 5. A 3D pseudo image of the Darley Grid Site with a 300 by 300 by 150 cm inset cube removed. This grid was created from GPR traverses run parallel to X axis (right foreground).

<u>Site 2 - Claiborne Parish:</u>
This hay land site (32.79011 N. latitude, 92.8745 W. longitude) is mapped principally as Darley gravelly loamy fine sand on 1 to 5 % slopes (De), with a small area of Darley-Sacul complex on 12 to 30 percent slopes (Dy). Traverses were conducted across two separate hills located within this site (see Figure 6). Traverse lines 1 to 5 were conducted along the eastern hill top. Traverse lines 6 to 9 were conducted along the western hill top and adjoining side slopes (line 7). These two separate hills were found to have dissimilar distributions of ironstone; the eastern hill contained little ironstone whereas ironstone was more abundant on the western hill. The presence of faults and the unpredictability of the soils-landscape in this portion of Louisiana were discussed during fieldwork and may have contributed to these noticeable differences.

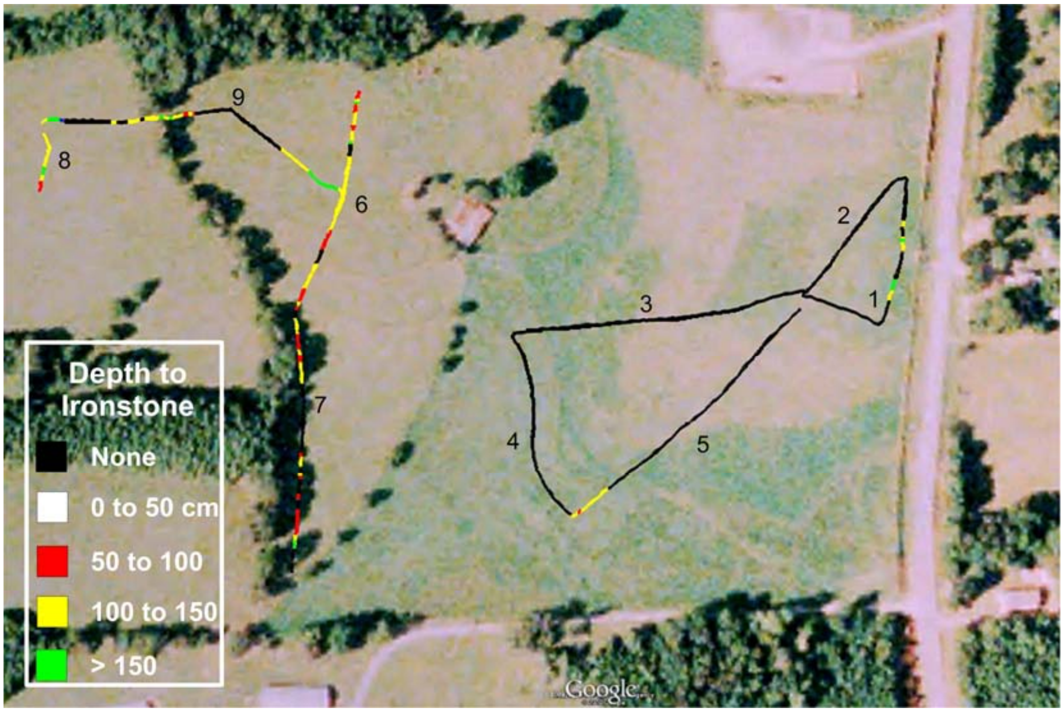

Figure 6. This Google Earth image shows the location of GPR traverse lines, presence or absence of ironstone, and the relative depths to ironstone layers within Site 2, Claiborne Parish. Numbers are used to identify the traverse lines.

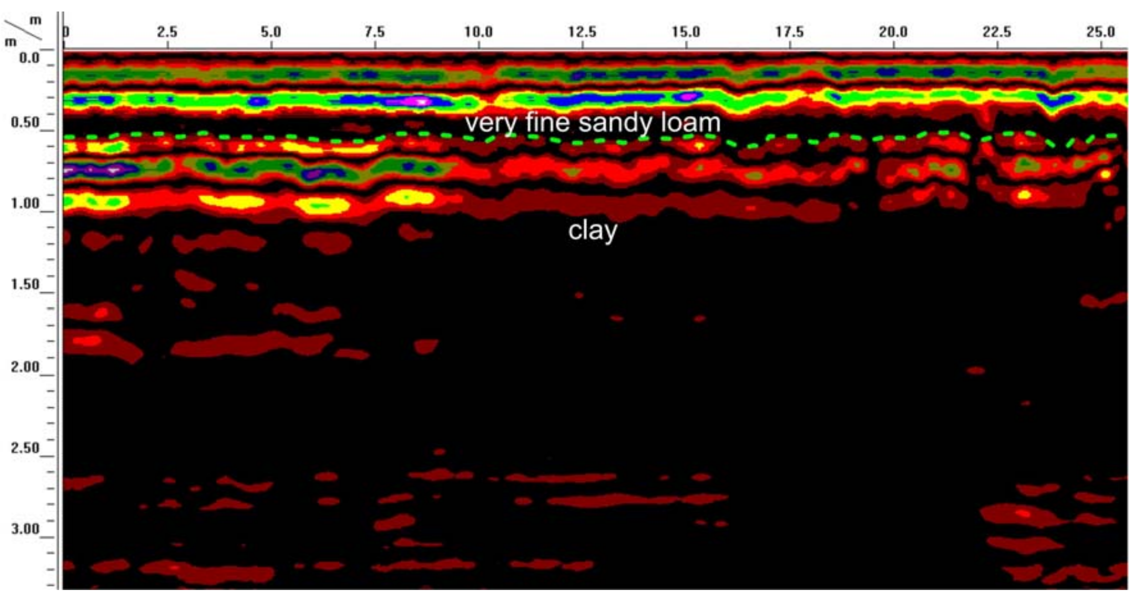

Figure 7. A representative radar record of Mahan soils from Site 2 that lacks ironstone

Figure 7 is a representative radar record of a well drained soil that lacks ironstone from Site 2. The soil is most likely Mahan fine sandy loam. Mahan is a member of the fine, kaolinitic, thermic Typic Hapludults family. The horizontal and vertical scales on this radar record are expressed in meters. A green-colored segmented line has been used to emphasize the contact between the very fine sandy loam surface layers and the underlying clayey subsoil. In contrast with the radar record shown in Figure 3, no ironstone can be identified on the radar record of Mahan soils. In Figure 7, the low amplitude and segmented horizontal bands in the lower part of the radar record represents system and background noise.

Nine radar traverses were completed at this site and provided a total of 55,824 observations. Ironstone layers were interpreted to be present at only 37 % of these observation points. However, for each traverse at Site 2, the percent of observation points with ironstone layers was exceedingly variable and ranged from 0 to 100 % (see Table 3). The most perplexing anomaly at Site 2 was the dissimilarity existing between the two hills; ironstone was common on the western hill, but not on the eastern hill. Though not as true as at Site 1, ironstone layers were again found to be more common on higher-lying, convex summit and shoulder slopes and more absent on lower-lying, plain and concave surfaces.

Table 3
Composition of radar traverses according to the presence or absence of ironstone layers at Site 2.

Traverse	Observations	ironstone	none
1	9077	0.12	0.88
2	1906	0.00	1.00
3	5727	0.00	1.00
4	4965	0.00	1.00
5	6863	0.17	0.83
6	5910	0.85	0.15
7	10789	0.64	0.36
8	1509	1.00	0.00
9	9078	0.52	0.48

The Google Earth image shown in Figure 6 indicates the presence or absence of ironstone, and the relative depths to ironstone layers along each traverse line. The presence and depth to ironstone is quite variable along these traverse lines and landscape components. Ironstone is moderately deep at 9 %, deep at 24 %, very deep at 5 % and absent at 63% of the 55, 824 observation points. Compared with Site 1, where ironstone was mostly moderately deep, a larger proportion of the ironstone layers were deep at Site 2. Table 4 summarizes the distribution of ironstone according to soil depth classes for the seven traverses that were conducted across Site 2.

Table 4
Frequency distribution (%) of ironstone layers according to soil depth classes along the seven traverse lines in Site 2.

Traverse	None	Shallow	Mod Deep	Deep	Very Deep
1	0.88	0.00	0.00	0.09	0.03
2	1.00	0.00	0.00	0.00	0.00
3	1.00	0.00	0.00	0.00	0.00
4	1.00	0.00	0.00	0.00	0.00
5	0.83	0.00	0.01	0.16	0.00
6	0.15	0.00	0.29	0.53	0.03
7	0.36	0.00	0.29	0.34	0.02
8	0.00	0.00	0.16	0.70	0.14
9	0.48	0.00	0.02	0.31	0.19

Exposures, Webster and Claiborne Parishes:

Multiple road-side cuts and soil exposures were examined during the course of this investigation. Most radar records collected at these sites showed discontinuous, highly fractured layers of ironstone with areas of more chaotic reflection patterns associated with spherical features. One of the most informative exposures was in a borrow area (32.7630 N. latitude, 92.8072 W. longitude) in Claiborne Parish. The exposure is located in an area of Darley gravelly loamy fine sands on 1 to 5 % slopes (De). The exposure, which is shown in Figures 2 and 8, contains several well expressed ironstone layers. The ironstone layers are essentially parallel with the soil surface, but have wavy to broken topographies. These ironstone layers are highly fractured, discontinuous, and often bifurcate. Several spheroid masses (see Figure 2) are included within the ironstone layers. The ironstone layers are generally thin (< 4 to 6 inches) and display different degrees of indurations and wetness.

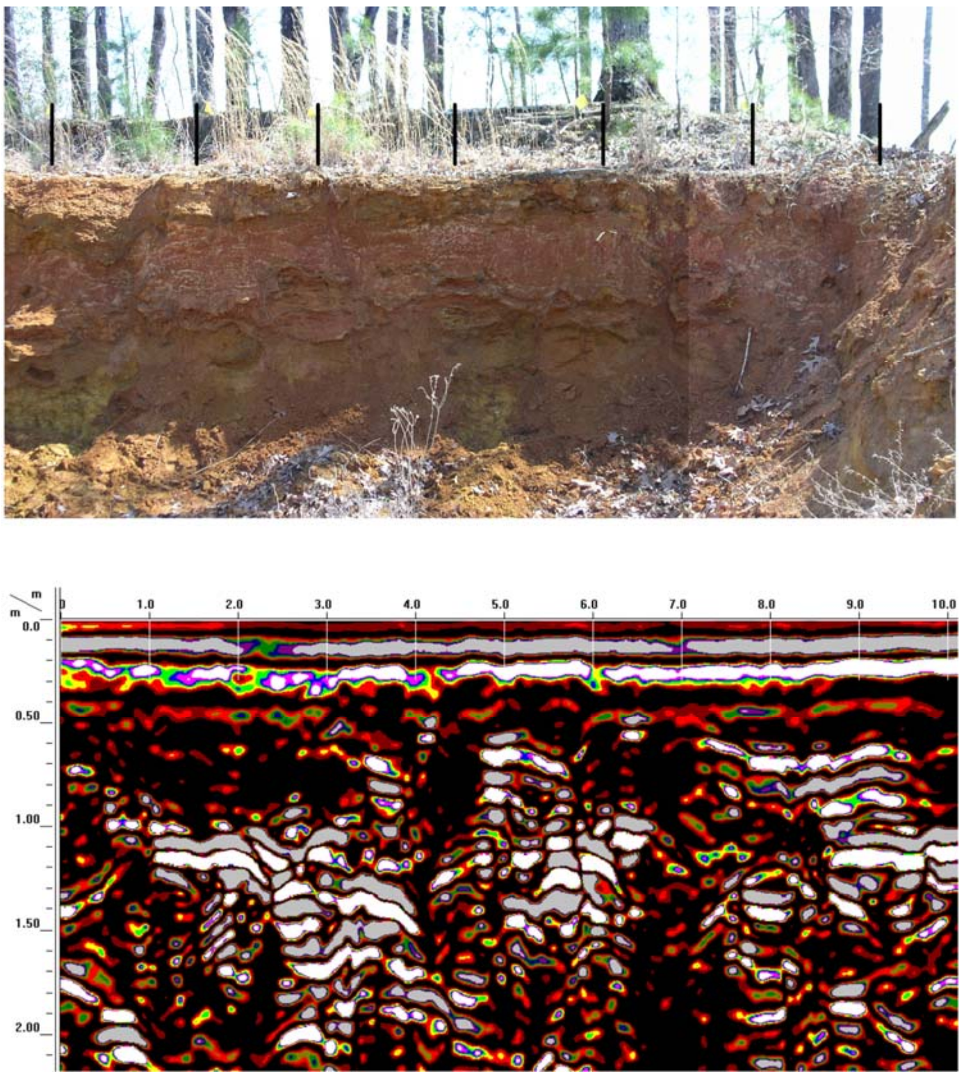

Figure 8. Cut bank exposure and radar record from an area of Darley gravelly loamy fine sands on 1 to 5 % slopes (De) in Claiborne Parish

At this exposure, ten survey flags, each spaced 1 m apart, were place along the top of the cut bank. In Figure 8, black-colored, vertical lines have been inserted on the upper image to mark the locations of seven of these flags, which are not clearly evident. The radar record (Figure 8, lower image) was collected with the 400 MHz antenna and shows the complete traverse line. The radar record captures the characteristics of the ironstone layers well and shows their fundamental linearity and parallelism with the soil surface, their discontinuous and highly fractured makeup, and their bifurcation into and presence of spheroid features.

The radar record shown in Figure 8 is considered representative of the larger number of radar records collected in areas of Darley soils. In general, though multiple ironstone layers were observed in Darley soils, these layers are highly fractured and discontinuous with spheroid features intermixed. While ironstone layers are commonly associated with higher-lying, convex surfaces than lower-lying, plane or concave surfaces, faulting and incongruent surfaces and formations have fostered inconsistent and perplexing patterns within some landscapes.

Dr. David Weindorf's Site near Leesburg, Vernon Parish:
The site (31.0601 N latitude, 92.8954 W longitude) is located in a borrow pit on Fort Polk Army Base in Vernon Parish. The area was originally mapped as Malbis fine sandy loam, 3 to 5 percent slopes (MaC). The very deep, well drained and moderately well drained Malbis soils formed in loamy marine or alluvial deposits on uplands of the Western Coastal Plains. Malbis is a member of the fine-loamy, siliceous, subactive, thermic Plinthic Paleudults family. Malbis soils contain nodules of plinthite, (by volume, ranging from 5 to 25 percent) in the lower part of the Btv horizon.

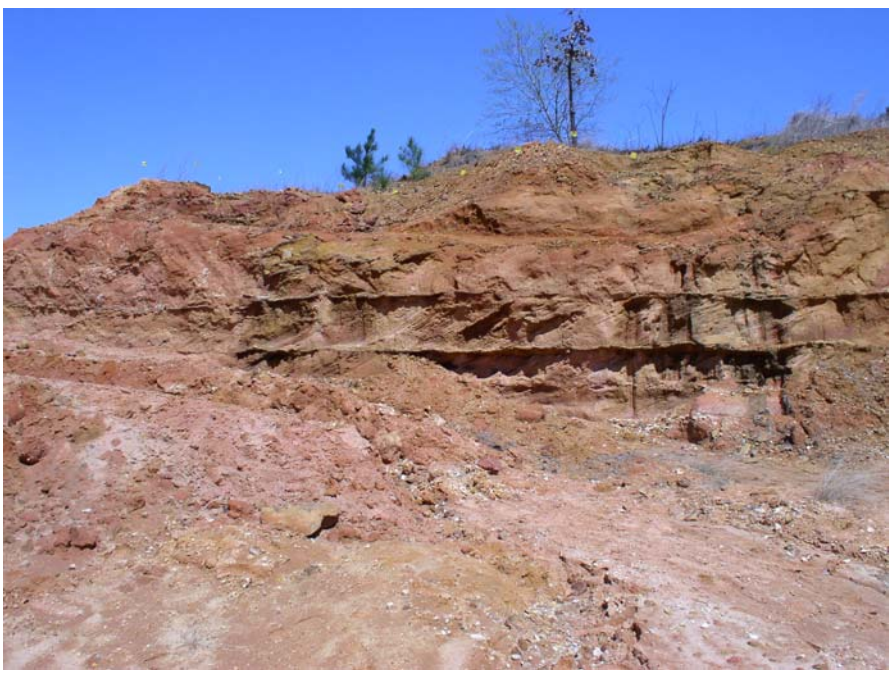

Figure 9. A radar traverse was conducted over this side wall of a borrow pit at the Fort Polk site.

Multiple radar traverses were conducted with the 200 and 400 MHz antennas along the top of the cut bank shown in Figure 9. Nine survey flags, which were spaced at 1-m intervals along the radar traverse line, are evident in this photograph. On this photo, the two, thin, prominent ironstone layers each provided a highly contrasting interface with the adjoining non-indurated materials and produced easily recognizable, high-amplitude radar reflections with each antenna. These reflections form the continuous, planar bands that are evident on the radar record shown in Figure 10. The radar record shown in Figure 10 was collected with the 200 MHz antenna. The radar record has been *surface normalized* in an attempt to recreate the topography of the site. All scales shown in Figure 10 are expressed in meters. On this radar record, the ironstone layers, though continuous, vary spatially in signal amplitudes. Variations in signal amplitude suggest lateral differences in degrees of induration. In Figure 10, in several places along each interface, steeply inclined breaks (colored white) suggest vertical gaps in the ironstone layers. Though varying in signal amplitude, these ironstone layers provided the most continuous lateral expression of this investigation. Perhaps the coarser nature of the parent materials at this site contributed to the more continuous, less fractured expression of ironstone layers.

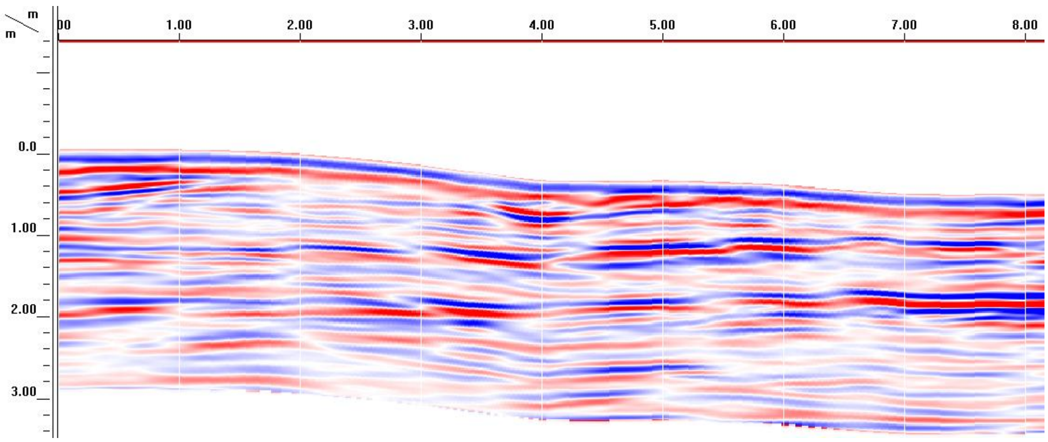

Figure 10. This representative radar record was collected with the 200 MHz antenna in an area of Malbis fine sandy loam, 3 to 5 percent slopes at the Fort Polk site. This radar record has been surface normalized to account for changes in elevation.

<u>EMI survey at Live Oaks Plantation, Vermillion Parish:</u>
In recent years, disastrous floods from hurricanes have devasted portions of the Gulf Coastal Chenier Marsh. In many coastal areas, because of salt water inundation, salinity has become a major concern on soils formed in both fresh-water organic and mineral soil materials. Electromagnetic induction (EMI) surveys have been conducted by the NRCS Soil Staff located in Carencro, Louisiana, to assess spatial and temporal patterns of salt concentrations across these affected soils. During the present fieldwork, comparative studies using the EM38MK2-2 and Dualem-1s meters were performed at the Live Oaks Plantation in Vermillion Parish. The study site is located approximately 3 miles southeast of the community of Esther and had been flooded by saline waters during recent hurricanes. The purposes of this survey were to compare data collected with the two meters, evaluate instrument stability and drift over time, and assess soil salinity using the *ESAP Calibrate* program developed by the USDA-ARS, Salinity Laboratory in Riverside, California.

The study site is in pasture. Delineated soil map units include Crowley-Patoutville silt loam (Cy) and Jeanerette silt loam (Ja) (see Figure 11). These soils formed on Pleistocene terraces. The very deep, somewhat poorly drained Crowley soils formed in clayey sediments. The very deep, somewhat poorly drained Patoutville and Jeanerette soils formed in medium-textured loess. The taxonomic classifications of these soils are listed in Table 5.

Table 5.
Taxonomic classifications of the soils recognized at the Live Oaks Plantation, Vermillion Parish

Soil Series	Taxonomic Classification
Crowley	Fine, smectitic, thermic Typic Albaqualfs
Jeanerette	Fine-silty, mixed, superactive, thermic Typic Argiaquolls
Patoutville	Fine-silty, mixed, superactive, thermic Aeric Epiaqualfs

Figure 11. This soil map of the Live Oaks site in Vermillion Parish is from the Web Soil Survey.

Equipment:
An EM38-MK2-2 (Geonics Limited; Mississauga, Ontario) and the Dualem-1s (Dualem Inc., Milton, Ontario) meters were used in this investigation[3]. These meters require no ground contact and only one person to operate. Both meters are designed to simultaneously record two depths of penetration. The depths of penetration are "*geometry limited*" and dependent upon the intercoil spacing, coil orientation or geometry, and the conductivity of the soil.

The EM38-MK2-2 meter operates at a frequency of 14,500 Hz and weighs about 5.4 kg (11.9 lbs). The meter has one transmitter coil and two receiver coils. The receiver coils are separated from the transmitter coil by distances of 1.0 and 0.5 m. This configuration provides nominal penetration depths of about 1.5 and 0.75 m in the vertical, and about 0.75 and 0.40 m in the horizontal dipole orientations. In either dipole orientation, the EM38-MK2-2 meter provides measurements of both the quadrature-phase (apparent conductivity; EC_a) and the in-phase (susceptibility) components for two depth ranges. Apparent conductivity is typically expressed in milliSiemens/meter (mS/m). Susceptibility is expressed parts per thousand (ppt). Operating procedures for the EM38-MK2-2 meter are described by Geonics Limited (2007).

The Dualem-1s meters consist of one transmitter and two receiver coils. One receiver coil and the transmitter coil provide perpendicular (PRP) geometry. The other receiver coil provides a horizontal co-planar (HCP) geometry with the transmitter coil. The Dualem-1s meters operate at a frequency of about 9000 Hz. The Dualem-1s meter has a 1-m intercoil spacing and provides nominal penetration depths of about 50 and 150 cm in the PRP and HCP geometries, respectively. Taylor (2008) describes the principles of operation of this meter.

Allegro CX field computers (Juniper Systems, North Logan, UT) were used with the meters to record and store both GPS and EMI data[3]. Data collected with the Dualem-1s meter was geo-referenced with a GR-

[3] Trade names are used for specific references and do not constitute endorsement.

213 GPS receiver manufactured by HOLUX Technology, Inc.[3] A Pathfinder ProXT GPS receiver with Hurricane antenna (Trimble, Sunnyvale, CA) was used to georeferenced EMI data collected with the EM38-MK2-2 meter.[4] The RTmap38 program (Geomar Software, Inc., Mississauga, Ontario) was used with the EM38-MK2-2 meter to record both GPS and EC_a on the Allegro CX field computer.[4]

The ESAP (*EC_e Sampling, Assessment, and Prediction*) Software Suite for Windows (Version 2.35R) developed by the USDA-ARS, Salinity Laboratory (Riverside, CA) was used to create optimal soil sampling schemes based on EC_a data and to estimate soil salinity (EC_e) (Lesch et al., 2000). The *ESAP-RSSD* (*Response Surface Sampling Design*) software was used to generate optimal sampling schemes and identify sampling locations. The *ESAP-Calibrate* software was used to estimate EC_e from the collected EC_a survey data base on Rhoades *Dual Pathway Conductance Model* (Lesch et al., 2000).

To help summarize the results of the EMI surveys, the SURFER for Windows (version 9.0) software (Golden Software, Inc., Golden, CO) was used to construct the two-dimensional simulations shown in this report.[4] Grids were created using kriging methods with an octant search.

Survey Procedures:
Pedestrian and mobile EMI surveys were conducted with the EM38MK2-2 and Dualem-1s meters, respectively. For the mobile survey, the Dualem-1s meter was towed in a plastic sled behind an all-terrain vehicle at speeds of 2 to 4 m/sec. Pedestrian surveys were completed by walking with the EM38-MK2-2 meter suspended above the ground surface in the vertical dipole orientation. For each survey, measurements were made at 1 second intervals. Because of the faster speeds of the mobile Dualem-1s survey, fewer measurements were recorded with the Dualem-1s meter (1250) than with the EM38MK2-2 meter (2344).

Results:
Apparent Conductivity (EC_a):
Apparent conductivity is relatively high across the surveyed area confirming the inundation of the study site by salty waters. The high EC_a is also associated with the relatively high clay and moisture contents of the soils. Based on 1250 HCP measurements made with the Dualem-1s meter, EC_a averaged 144.6 mS/m and ranged from about 42.0 to 321.1 mS/m within the upper 150 cm of the soils. One-half of the HCP measurements were between 116.1 and 162.7 mS/m. Based on 2344 measurements made with the 100-cm intercoil spacing on the EM38MK2-2 meter, EC_a averaged 131.78 mS/m and ranged from about 50.7 to 281.5 mS/m within the upper 150 cm of the soils. One-half of these EC_a measurements were between 107.0 and 145.63 mS/m. Data collected by the two meters were similar. However, EC_a recorded with the EM38MK2-2 meter was slightly lower and less variable than the data recorded with the Dualem-1s meter.

Based on 1250 PRP measurements collected with the Dualem-1s meter, EC_a averaged 105.9 mS/m and ranged from about 35.8 to 307.9 mS/m within the upper 50 cm of the soils. One-half of the EC_a measurements were between 84.9 and 115.5 mS/m. Based on 2344 measurements collected with the 50-cm intercoil spacing of the EM38MK2-2 meter, EC_a averaged 96.24 mS/m and ranged from about -125.7 to 241.6 mS/m within the upper 75 cm of the soils. Negative values presumably represent metallic artifacts either buried or scattered across the site and crossed over with the meter. One-half of the EC_a measurements were between 77.03 and 105.3 mS/m. Once again, the EM38MK2-2 meter had slightly lower values and a less variable (excluding 3 points believed to be influenced by metallic artifacts, the minimum value is 27.6 mS/m) range in EC_a than the Dualem-1s meter. Differences are attributed to the number of measurements obtained with each instruments, instrument calibrations, and disparities in effective penetration depths of the two meters.

[4] Trade names are used for specific references and do not constitute endorsement.

Figure 12 contains plots of EC_a data collected with the Dualem-1s (upper) and EM38MK2-2 (lower) meters in the shallower-sensing (left) and deeper-sensing (right) coil geometries or intercoil spacings. The same color ramp and scale are used in all plots. Slightly different areas were surveyed with each meter. For each depth interval, spatial EC_a patterns look remarkably similar for comparable depth intervals. Differences are attributed to the meters slightly different intercoil spacing, instrument calibrations and effective penetration depths. In general, spatial patterns are similar, but EC_a is slightly higher with the Dualem-1s meter.

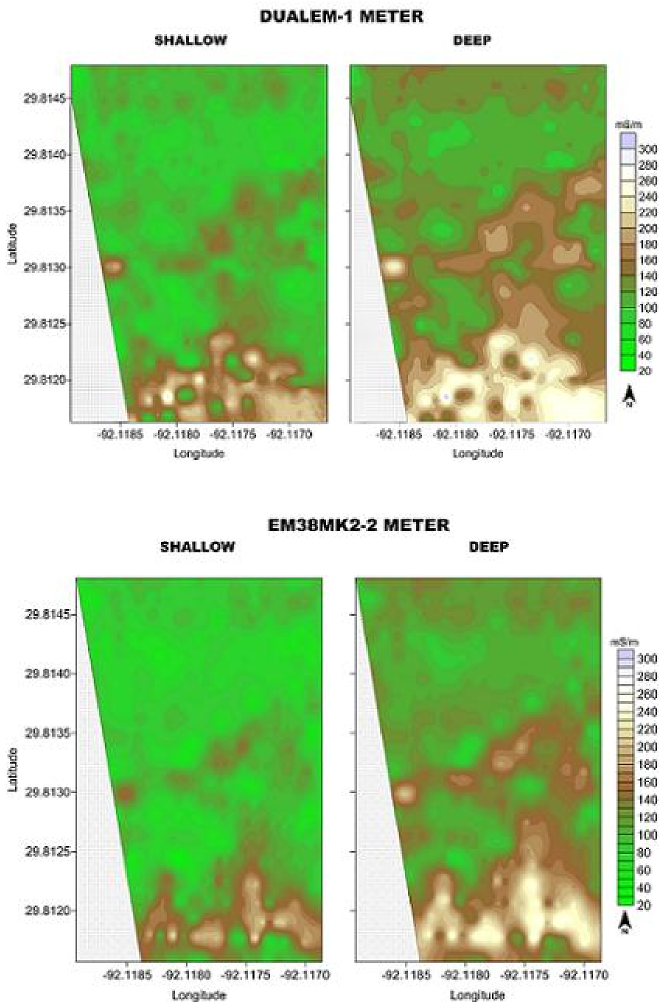

Figure 12. These plots of EC_a were collected at Live Oaks Plantation in Vermillion Parish. The upper and lower plots show data recorded with the Dualem-1s and EM38MK2-2 meters, respectively. The left-hand and right-hand plots show the spatial distribution of EC_a recorded in the shallower- and deeper-sensing intercoil spacings or geometries, respectively.

<u>Salinity Assessments:</u>

All collected EC_a data were entered into an Excel spreadsheet and processed thru the ESAP (version 2.35) software program (Lesch, 2000). The *Response Surface Sampling Design* software program of ESAP was used to generate optimal sampling designs for the study site based on the EC_a data collected with each meter. Based on the results of the RSSD program, six, twelve, and twenty optimal sampling design schemes and points were selected from the EC_a data collected with each meter. The six, twelve, and twenty optimal sampling schemes that were generated from data collected with the Dualem-1s and EM38MK2-2 meters are shown in Figure 13.

Apparent soil electrical conductivity can be correlated with any soil property that significantly influences the EC_a measurements (Corwin and Lesch, 2005). The ESAP-Calibrate program is designed to estimate calibration equations that can be used to predict values of a soil attribute from the EC_a survey data. Two models are available in ESAP-Calibrate: a *deterministic* and a *stochastic model*. The deterministic model does not require (as does the stochastic model) soil sample data, but can only be used to estimate soil salinity (EC_e) from EC_a survey data. The deterministic model also requires the collection of EC_a data in two dipole orientations, geometries, or intercoil spacings. The stochastic model requires the collection and analysis of soil sample data (from sample locations selected by RSSD program), but can be used to predict soil attributes other than EC_e. In addition, the stochastic model can use EC_a data collected in only one dipole orientation.

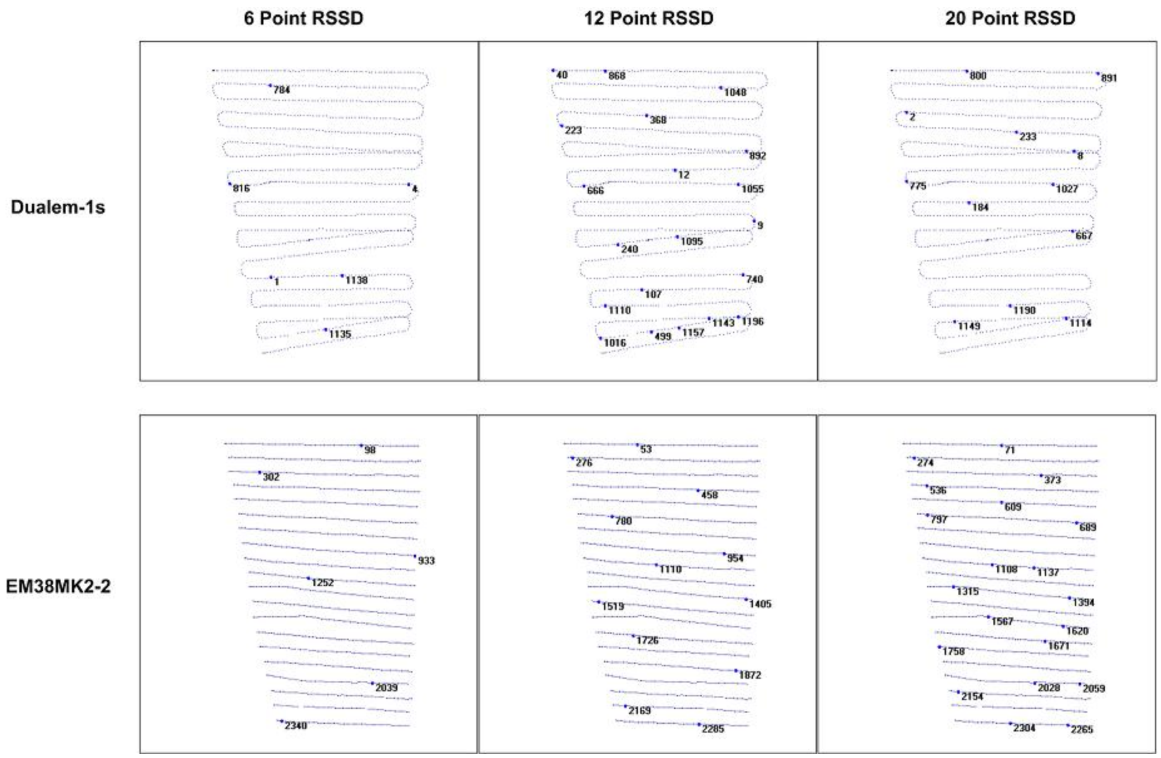

Figure 13. Six (left plots), twelve (center plots) and twenty (right plots) sampling point, selected by the Response Surface Sampling Design program of ESAP for the Dualem-1s (upper plots) and EM38MK2-2 (lower plots) meters. Sample locations are identified by their observation numbers. Also shown in these plots are the locations of measurement points and the tracks of the EMI meters.

In the deterministic model, the *dual pathway parallel conductance* (DPPC) *model* (Rhoades et al., 1989a, 1989b, 1990; Corwin and Lesch, 2003) is used to convert EC_a to EC_e with knowledge of other associated soil properties. The DPPC model is based on the theory that soil electrical conductivity can be modeled by a multi-pathway, parallel electrical conductance equation. In this model, soil electrical conductivity is reduced to a nonlinear function of five soil physiochemical properties: EC_e, saturation potential, volumetric soil water content, bulk density, and soil temperature (Corwin and Lesch, 2005). The deterministic modeling approach is the preferred approach when significant localized variations in soils and soil properties exist in a survey area (Corwin and Lesch, 2005). This approach, however, requires knowledge of soil properties (e.g., soil water content, saturation potential or clay content, bulk density, and temperature) (Corwin and Lesch, 2005). Errors in the estimation of any one of these soil properties will produce inaccuracies in the predictive model. In this study, when using the deterministic model, unease was felt concerning the selection of the averaged soil's clay and soil water contents, which varied both vertically and spatially across the study site.

Figures 14 show the spatial and depth distributions of EC_e that were predicted using EC_a data collected with the Dualem-1s (upper plots) and the EM38MK2-2 (lower plots) meters and the deterministic model at Live Oaks Plantation. The left- and right-hand plots show the modeled EC_e data for the 0 to 30 and the 30 to 60 cm depth intervals, respectively. The estimated inputs for the DPPC model included: an average soil temperature of 15.6^{o} C, an average clay content of 35 %, an assumed water content at 100 % field capacity, and a bulk density of 1.369. Errors undoubtedly occurred in these estimates and variable soil properties across the site affected the accuracy of predictions.

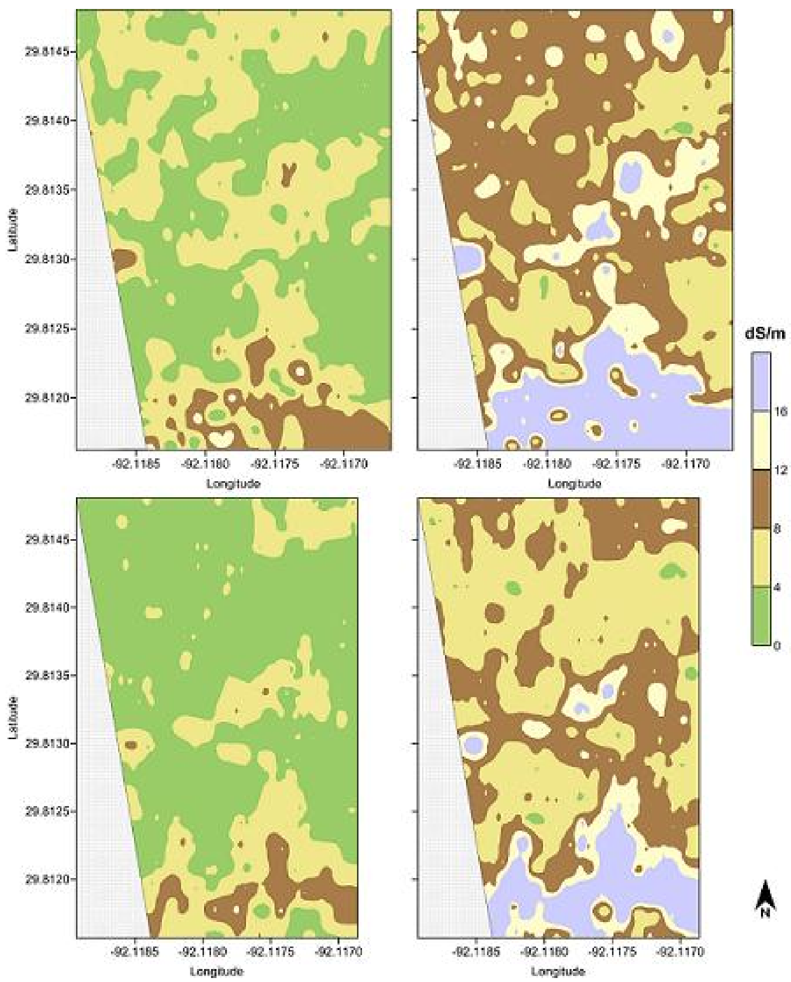

Figure 14. These plots of spatial EC_e data from Live Oaks Plantation were derived using the deterministic model in the ESAP-Calibrate program and EC_a data collected with two EMI meters. Shown are spatial EC_e patterns for the Dualem-1s (upper plots) and EM38MK2-2 (lower plots) meters for the 0 to 30 cm (right-hand plots) and 30 to 60 cm (left-hand plots) depth intervals. Soil electrical conductivity (EC_e) is expressed in dS/m.

Both meters characterized the 0 to 30 cm depth interval as being dominantly very slightly (2 to < 4 dS/m) and slightly (4 to < 8 dS/m) saline. Based on data collected with the Dualem-1s meter, for the 0 to 30 cm depth interval, soils are 11 % non-saline (< 2 dS/m), 41 % very slightly saline, and 40 % slightly saline. Based on data collected with the EM38MK2-2 meter, for the 0 to 30 cm depth interval, soils are 4 % non-saline, 52 % very slightly saline, and 27 % slightly saline.

For both meters, the deterministic model predicted that soil salinity increases with increasing soil depths. This *normal salinity profile* seems incorrect for this site, where recent flooding by saline waters should produce an *inverted salinity profile* (salinity decreasing with increasing soil depths). A *normal salinity profile* would be correct if salts are leached or are intruded from lower soil depths (e.g., water table). Both meters characterized the 30 to 60 cm depth interval as being dominantly slightly and moderately (8 to < 16 dS/m) saline. Based on data collected with the Dualem-1s meter, for the 30 to 60 cm depth interval, soils are 27 % slightly saline and 58 % moderately saline. Based on data collected with the EM38MK2-2 meter, for the 30 to 60 cm depth interval, soils are 43 % slightly saline and 43 % moderately saline.

It is sensed that the DPPC model did not work well at Live Oaks Plantation. As information concerning the soils and their variability was lacking, errors were expected in some or most of the predicted EC_e values. More work needs to be completed in testing both the stochastic and deterministic models that are available in ESAP Calibrate program to estimate soil salinity from apparent conductivity data.

<u>Comparative Drift Tests:</u>
Tests were also performed to evaluate instrument drift with the two meters. Each meter was placed on the ground surface an allowed to collect 2000 EC_a measurements over a 33 minute period. Both meters were placed on the ground surface and separated at a distance of about 15 m. For the EM38MK2-2 meter, EC_a averaged 131.19 and 107.11 mS/m for the deeper-sensing, 100 cm, and the shallower-sensing, 50 cm intercoil spacings, respectively. Measurements ranged from 129.49 to 132.66 mS/m and from 104.65 to 109.49 mS/m for the 100 cm and the 50 cm intercoil spacings, respectively. For the Dualem-1s meter, EC_a averaged 145.41 and 119.18 mS/m for the HCP and the PRP geometries, respectively. Measurements ranged from 144.1 to 146.2 mS/m and from 118.8 to 120.2 mS/m for the HCP and the PRP geometries, respectively.

The Dualem-1s appears to be slight more stable with less instrument drift than the EM38MK2-2 meter. In summary, the Dualem-1s meter had a range of 2.10 and 1.40 mS/m for the HCP and the PRP geometries, respectively. The EM38MK2-2 meter had a range of 3.16 and 4.84 mS/m for the 100 cm and the 50 cm intercoil spacings, respectively.

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