United States Department of Agriculture

Natural Resources Conservation Service

11 Campus Boulevard, Suite 200 Newtown Square, PA 19073

Subject: Soil - Geophysical Assistance-EMI **Date:** 26 February 2009

To: Juan A. Martínez
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Purpose:
An electromagnetic induction (EMI) survey was completed of agricultural fields included in the Jobos Bay Special Emphasis Watershed Conservation Effects Assessment Project near Salinas, Puerto Rico. The purpose of the project is to identify and reduce the causes of soil contamination. Maps of apparent conductivity (EC_a) identified spatial patterns related to physiochemical soil properties. Using the ESAP Software Suite for Windows measured EC_a values were used to develop two different optimal soil sampling plans.

Participants:
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Activities:
All field activities were completed during the period of 18 to 26 February 2009.

Summary:
Electromagnetic induction surveys were complete of the selected fields with an EM38 meter. Measured apparent conductivity was found to be relatively high across the surveyed area and representative of the fine-textured and sodic soils. Based on 50636 measurements, EC_a averaged 89.1 mS/m and ranged from about 8 to 301 mS/m. Areas of higher EC_a are associated with higher amounts of soluble salts and Cartagena soils.

Using the *Response Surface Sampling Design* (RSSD) of the ESAP Software Suite, two different directed-sampling plans (6 and 12 sample sites) were developed to direct the scheduled soil sampling by Dr. Ellis Benham of the National Soil Survey Center later this spring. For each sampling plan, sites were selected to optimize the estimation of regression models and to simultaneously maximize the average separation distance among the sampling sites. Sites are representative of the total variation in EC_a and should reflect the variations in soils and soil property within these cultivated fields. If twenty sampling sites are desired, a suitable directed-sampling plan will be developed, upon request.

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

With kind regards,

James A. Doolittle
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Equipment:
An EM38 meter, manufactured by Geonics Limited (Mississauga, Ontario), was used in this investigation.[1] The meter weighs about 1.4 kg (3.1 lbs) and needs only one person to operate. No ground contact is required with this instrument. The EM38 meter has a 1-m intercoil spacing and operates at a frequency of 14,600 Hz. When placed on the soil surface, it has effective penetration depths of about 0.75 m and 1.5 m in the horizontal and vertical dipole orientation, respectively (Geonics Limited, 1998). The EM38 meter measures the EC_a of earthen materials, which is expressed in milliSiemens/meter (mS/m).

Study Site:
The study site consists of about 256 acres of irrigated fields. These fields are located about 3.5 miles east-southeast of Salinas. The boundaries of the site conform to those of a center-pivot irrigation system (see Figure 1). Soil polygons identified within these fields include Cartagena clay (Ce); Fraternidad clay, 2 to 5 % slopes (FrB); Ponceña clay (Po), and small areas of Pozo Blanco clay loam, 5 to 12 % slopes, eroded (PrC2), and Tidal flats (TF). The very deep, somewhat poorly drained Cartagena, and moderately well drained. Fraternidad and Ponceña soils formed in clayey sediments weathered form volcanic rocks and limestone on the semiarid coastal plains of southern Puerto Rico. Cartagena soils are on lower-lying areas and are sodium-affected. Ponceña and Fraternidad soils are on higher-lying areas and are moderately well drained. In addition, Ponceña and Pozo Blanco soils have a calcic horizon. The very deep, well drained Pozo Blanco soils formed in alluvium and colluvium over residuum that derived from soft limestone. In addition, Pozo Blanco soils have lower clay contents. The taxonomic classifications of the named soils are listed in Table 1.

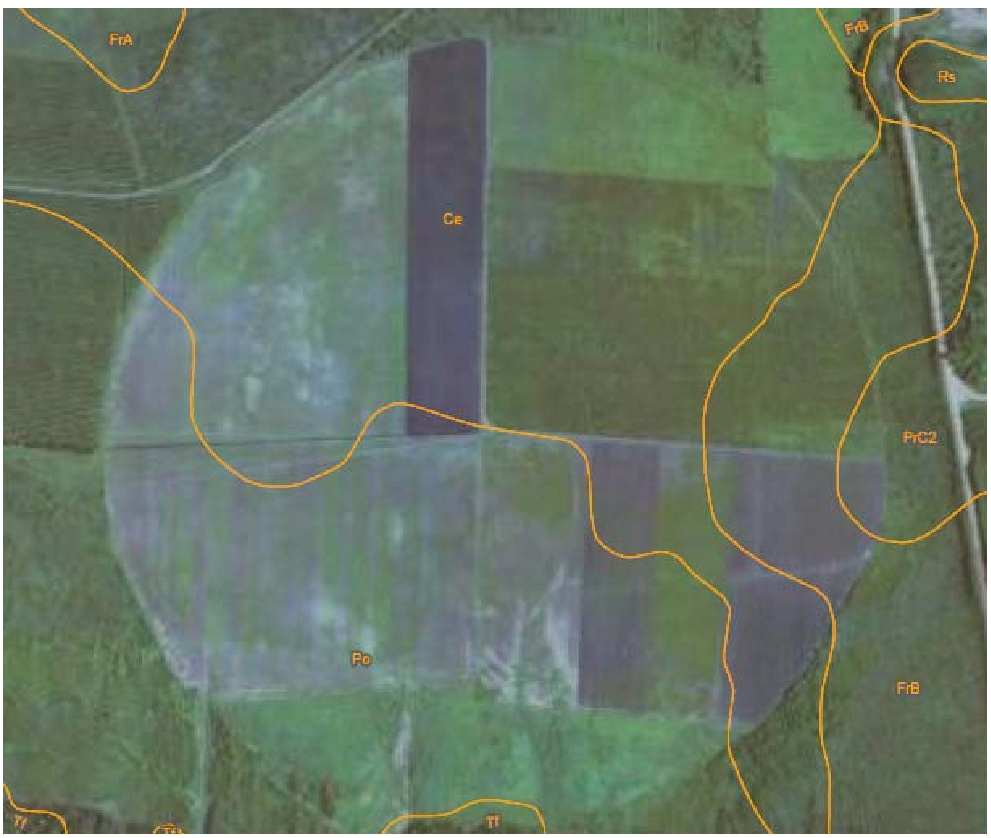

Figure 1. This soil map of the Jobos Bay site is from the Web Soil Survey.

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

Table 1. Taxonomic classifications of the soil series recognized in Jobos Bay Project area.

Soil Series	Taxonomic Classification
Cartagena	Fine, mixed, superactive, isohyperthermic Sodic Haplusterts
Fraternidad	Fine, smectitic, isohyperthermic Typic Haplusterts
Ponceña	Fine, mixed, superactive, isohyperthermic Typic Calciusterts
Pozo Blanco	Fine-loamy, mixed, superactive, isohyperthermic Aridic Calciustolls

Survey Procedures:
Depending on the presence of cultivated crops, either pedestrian or mobile EMI surveys were conducted across the different units of management within the site. Mobile EMI survey provides more comprehensive site coverage, in a shorter period of time, and with less effort than the pedestrian surveys. For mobile surveys, the EM38 meter was towed in a plastic sled behind a probe truck at speeds of 2 to 4 m/sec. Pedestrian surveys were completed by walking along crop rows, with the EM38 suspended above the ground surface. In general, traverse lines conformed to the board, semicircular planting patterns of these centered-pivot irrigated fields. Using the RTM38 program developed by Geomar Software, Inc. (Mississauga, Ontario), both GPS and EC_a data were simultaneously recorded and displayed on an Allegro CX field computer (Juniper Systems, North Logan, UT)[2]. The coordinates of each EC_a measurement were recorded with a Trimble AgGPS114 L-band DGPS (differential GPS) antenna (Trimble, Sunnyvale, CA).[2]

To help summarize the results, the SURFER for Windows (version 8.0) software, developed by Golden Software, Inc., was used to construct the two-dimensional simulation shown in this report.[1] Grids were created using kriging methods with an octant search. The ESAP Software Suite for Windows (Version 2.35R) developed by the USDA-ARS, Salinity Laboratory (Riverside, CA) was used to create two optimal soil sampling schemes based on EC_a data. The *Response Surface Sampling Design* (RSSD) of ESAP was used to generate these optimal sampling plans and to identify the locations of sampling sites.

Results:
Apparent conductivity is relatively high across the surveyed area. The high EC_a is associated with relatively high clay, moisture, and soluble salt contents of the soils. Based on 50636 measurements, EC_a averaged 89.1 mS/m and ranged from about 8 to 301 mS/m. One-half of the EC_a measurements were between 65.8 and 104.2 mS/m. Areas of noticeably higher EC_a are principally associated with higher amounts of soluble salts and Cartagena soils.

A plot of EC_a data shows intricate spatial patterns (see Figure 2), which can be visualized as three noticeable zones (low, medium, and high EC_a) that are believed to constitute major and contrasting soil polygons. The southern (lower) half of the site contains relatively large areas of noticeably higher (>100 mS/m) EC_a. As visible salt flecks were observed along some tram lines and on the soil surface in these areas, the higher conductivity is attributed to greater concentrations of soluble salts. As this area is nearest to Jobos Bay, the higher EC_a can reflect the affects of salt water intrusion. As additional areas of moderately high (60 to 100 mS/m) EC_a are located near roadways or along some tram lines, they are assumed to reflect increased levels of soluble salts caused by imperfect drainage and/or the application of contaminated irrigation water. It is possible, that the waters used for irrigation has a high-soluble salt content and its application has resulted in salinization of the soils. In general, the lowest EC_a is found in peripheral areas, where soils are higher-lying, better drained, less intensively irrigated and/or coarser textured. As the center of the pivot is approached, the general trend is for EC_a to increase.

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In Figure 2, some broadly curved, narrow, linear spatial EC_a patterns conform to plant rows and irrigation tram lines. These patterns are assumed to reflect differences in soil compaction, soil moisture and or soluble salt contents.

Figure 3 provides a comparison of the soil and EC_a maps. Results from the high-intensity EC_a survey and future, directed, soil sampling may warrant revisions to the soil map. Apparent conductivity maps can be used to visually correlate EC_a with soil patterns, determine map unit composition, and the placement of soil boundaries. In many instances, zones on EC_a maps correspond with soil polygons shown on soil maps. Frogbottom and Oliver (2007) used EC_a, elevation, and yield data to identify relatively homogenous areas at field scales. Shaner et al. (2008) determined that, if transition zones are avoided, EC_a -directed zone sampling is a cost effective alternative methods to prepare grid soil sampling. They noted that EC_a zone maps in combination with order 2 soil survey maps could be used as an alternative to high-intensity (order 1) soil maps and delineate management zones.

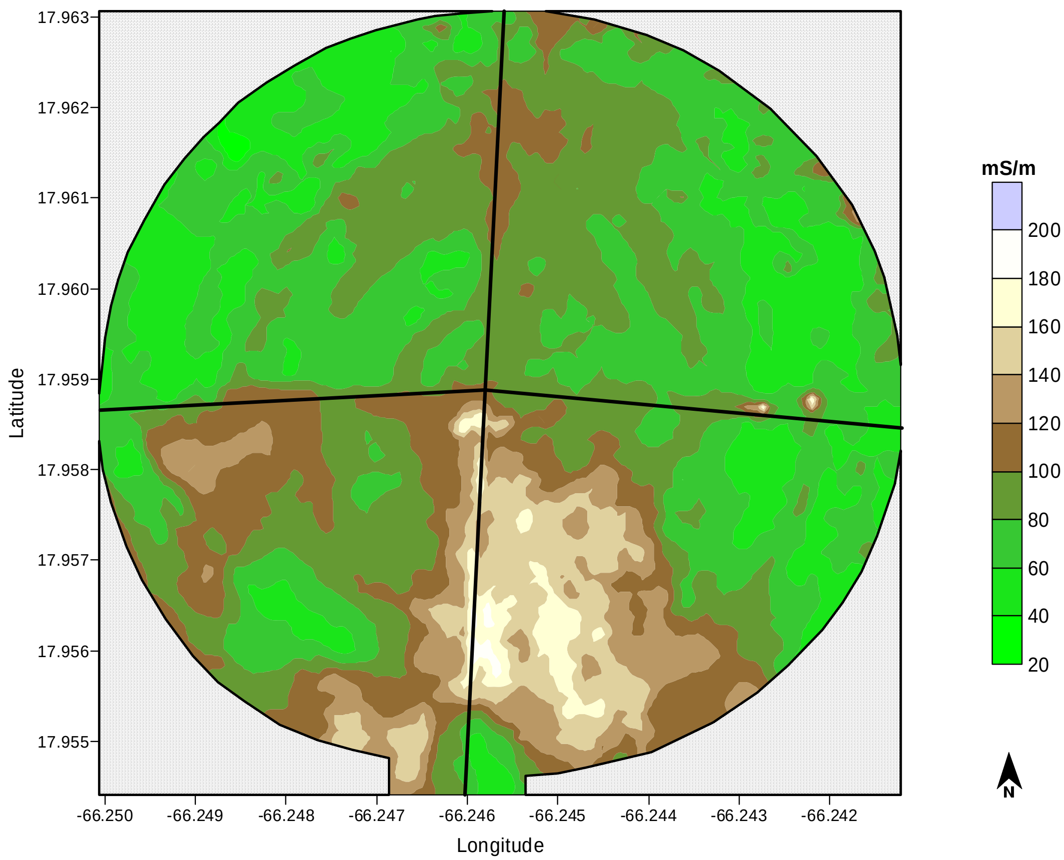

Figure 2. This EC_a map of the Jobos Bay Site was prepared with data collected with the EM38 meter in the vertical dipole orientation.

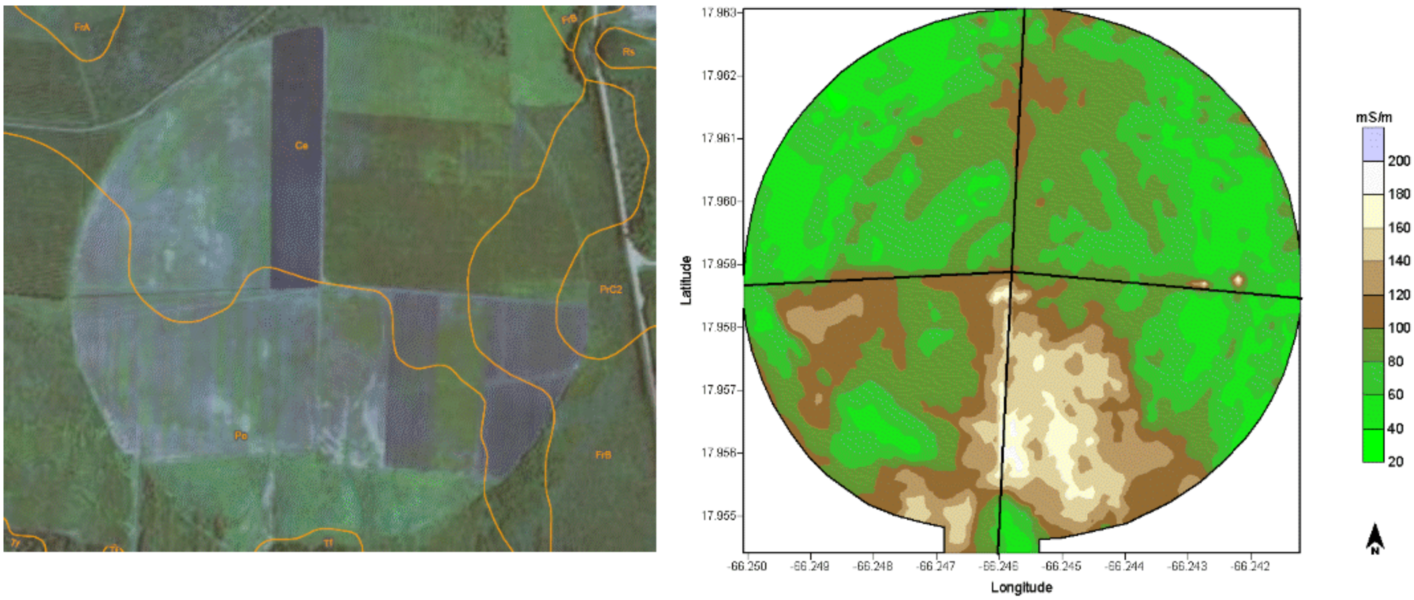

Figure 3. The soil and EC_a maps of the Jobos Bay Site are compared these plots.

Directed Sampling:
As a tool for precision agriculture and high intensity soil surveys, EC_a data can be used as an ancillary measure for a spatially varying soil property that is not easily sensed or mapped, to direct soil sampling, and to refine maps (Jaynes, 1995; Stafford, 2000). With EMI, EC_a data are quickly and efficiently collected at field-scales. In precision agriculture, with EMI, units of management are partitioned into zones based on spatial EC_a patterns and sparse sampling is conducted in each zone. Zone sampling reduces the costs of sampling while maintaining information on soil variability (Shaner et al., 2008).

Recently, the United States Salinity Laboratory (Riverside, California) has developed software to select optimal soil sampling points based on EC_a data (Lesch et al., 1995a, 1995b; Lesch et al., 2000; Lesch, 2005). The USDA-ARS's ESAP (Sampling, Assessment, and Prediction) software was designed to predict soil salinity (EC_e) from EC_a data. This software, however, can be used to predict other soil properties as well. Prediction-based sampling and modeling approaches are embraced in this program as a cost-effective alternative to geostatistical modeling techniques, which are often more sample-intensive (Eigenberg et al., 2008). The ESAP software is designed to combine high-intensity EC_a data with sparse, low-density soil sampling in order to calibrate a suitable predictive equation. A goal of this prediction-based sampling approach is to reduce the number and optimize the collection of sampling data.

The ESAP- *Response Surface Sampling Design* (RSSD) program can generate three different directed-sampling plans (6, 12, and 20 sample sites). The selection of the most suitable sampling design will depend on the availability of resources and the intensity and use of the survey. The RSSD program determines sampling sites based on the magnitude and spatial locations of the collected EC_a data. In this directed-sampling approach, a minimum number of calibration samples sites are selected based on the observed magnitudes and spatial location of EC_a data (Eigenberg et al., 2008). The sampling sites are selected to optimize the estimation of a regression model and to simultaneously maximize the average separation distance among sampling sites. Sample locations are representative of the total variation of EC_a and, hopefully, the targeted soil property (Corwin et al., 2006). The directed-sampling approach has been described as a hybrid blend of a response surface sampling design with a space-filling algorithm (Eigenberg et al., 2008; Lesch, 2005).

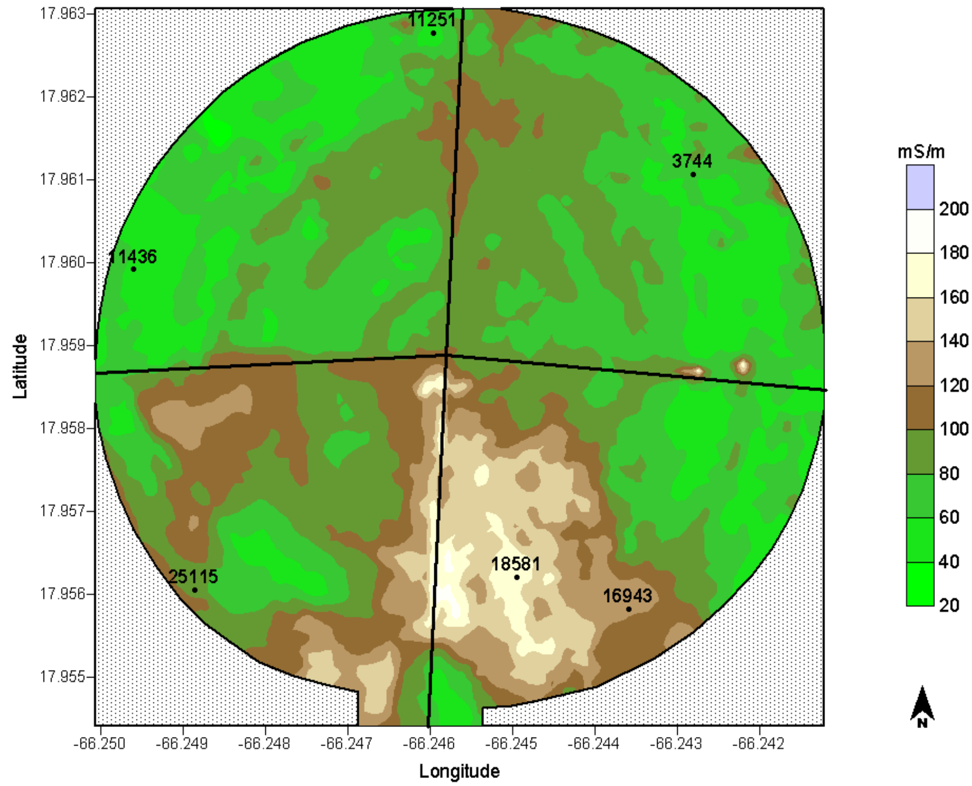

Figure 4. This plot of spatial EC_a patterns identifies the locations of six optimal sampling sites generated by the RSSD program of the ESAP Software Suite.

The locations of the optimal sampling sites are shown in Figures 4 and 5. The sites shown in Figures 4 and 5 are optimized based on 6 and 12 point sampling schemes, respectively. In each plot, the locations and identity of the optimal sampling sites are provided. Tables 2 and 3 provide essential data for the sampling points generated by the response surface sampling design program for six and twelve sample sites, respectively.

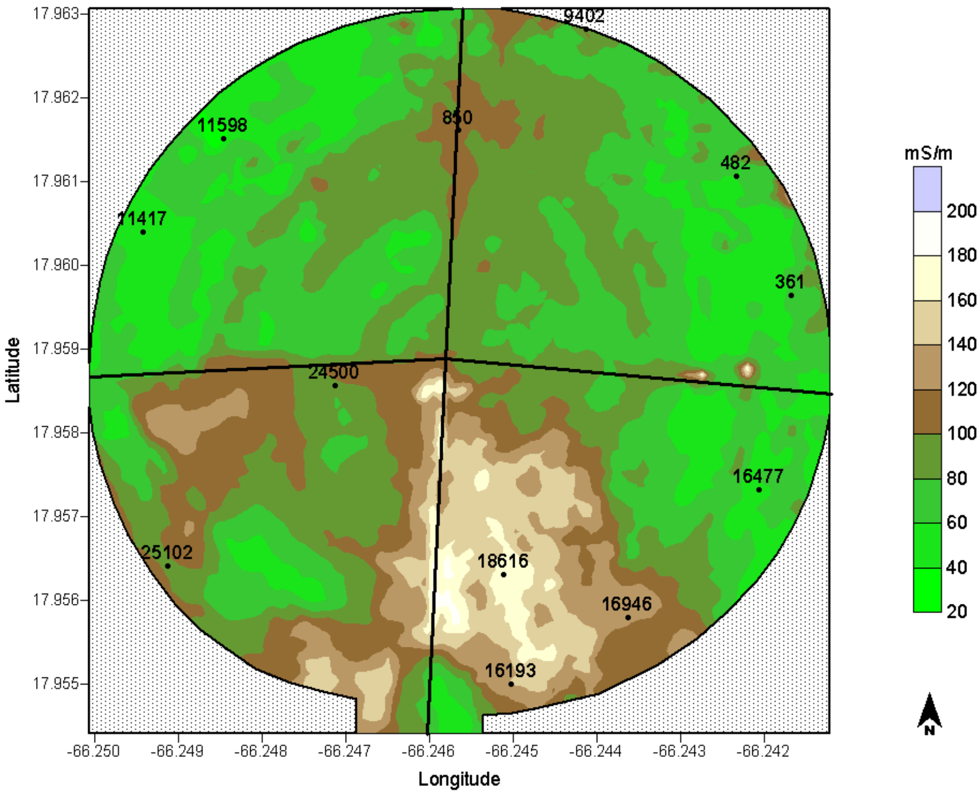

Figure 5. This plot of spatial EC_a patterns identifies the locations of twelve optimal sampling sites generated by the RSSD program of the ESAP Software Suite.

Table 2. The identity, location and EC_a of six sample sites based on a response surface sampling design.

Obs.	Longitude	Latitude	mS/m
3744	-66.24280	17.96107	89.3
11251	-66.24596	17.96277	36.0
11436	-66.24960	17.95992	42.4
16943	-66.24359	17.95582	136.0
18581	-66.24494	17.95621	167.3
25115	-66.24886	17.95605	88.6

Table 3. The identity, location and EC_a of twelve sample sites based on a response surface sampling design.

Obs.	Longitude	Latitude	mS/m
361	-66.24167	17.95964	65.8
482	-66.24233	17.96107	58.0
850	-66.24565	17.96161	107.8
9402	-66.24413	17.96282	112.6
11417	-66.24942	17.96040	42.4
11598	-66.24846	17.96151	36.0
16193	-66.24502	17.95500	151.6
16477	-66.24206	17.95732	36.4
16946	-66.24363	17.95579	136.0
18616	-66.24511	17.95631	167.3
24500	-66.24713	17.95856	93.0
25102	-66.24912	17.95641	90.5

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