Methods for Reassessing Potential Soil Salinity Changes Adjacent to the Devils Lake Outlet Channel

By
W. M. Schuh
(Soil Salinity Maps by M. H. Hove)

Water Resources Investigation No. 39
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1.0 Introduction: Potential Soil Salinity Reassessment for the Devils Lake Outlet

Landowners adjacent to the Devils Lake Outlet channel have expressed concern over potential salinization of their lands. In order to provide a basis for evaluating and quantifying possible degradation, an initial baseline assessment of soil salinity was needed. A method for assessing soil salinization on a field scale must be capable of strong spatial representation, it must be mapable, and it must be cost effective. Methods requiring laboratory procedures on soil samples collected at discrete points, while valuable and rigorous, would be time, labor and cost prohibitive. There are, however, methods for measuring bulk soil electrical conductivity (EC_a) that are mapable, capable of providing suitable data density, and cost and labor effective.

Two common methods for measuring soil EC_a are electromagnetic induction (EMI) and direct contact (Lund and others 1999). Both methods are commonly used and have comparable results (Lund and others 1999). Both are capable of focused measurements of shallower or deeper soil units.

Veris™ has developed a direct contact method which employs a Wenner array. Electrical contact with the soil is accomplished through metal discs. Disc distances are designed to provide two arrays which measure soil EC_a to 25 cm (approx. 1 foot) and 75 (approx. 3 ft.) depths. When used with 15 to 20 m (50 to 66 ft.) swaths at speeds up to 12 k/h (20 mph), 40 to 100 samples per ha (100 to 250 samples per acre) can be measured (Lund and others 1999). This is equivalent to measurements about every eight to ten feet (two and a half to three meters). Readings are geo-referenced and mapable.

While soil EC_a is highly correlated with salinity, the relationship is not exclusive. Rather it depends on various electrical conductors and pathways and their interaction. Conductors include solid matrix, water between and in films along the matrix, and free water. Salinity is related only to changes in the water portion(s). EC_a is significantly related to clay content, saturation percentage, cation exchange capacity, and some other soil properties. The Veris™ method, in fact, is used to map soils for precision agriculture, and there is substantial literature relating Veris™ measurements to soil texture. Some soil physical properties are relatively stable. To assess salinity changes we are concerned primarily with changes in the soil-water fraction.

The standard parameter for assessing soil salinity has been the electrical conductivity of the soil saturation extract (USDA 1954, Hoffman 1981). In this report we will label the conductivity of the saturation extract EC_e. While there has been considerable discussion of the appropriateness of EC_e as a standard measure of salinity effects (Corwin and Lesch 2003), there are several reasons for using it as the standard of assessment for the Outlet impact on adjacent soils. Among these are: (1) It is a common parameter that can be measured relatively simply, and is available at reasonable cost in most commercial soil laboratories; (2) It has been a commonly accepted and used standard, and there is a substantial body of literature explaining its use and application; and (3) There are a substantial body of literature and several mathematical models relating EC_e to EC_a.

The Veris™ method was selected for evaluating soil salinity along the Outlet channel. Veris™ work was performed in October of 2005 by TotalCrop Inc. subcontracted under Western Plains Consulting (WPC). Measurements were made for four transects on both sides of the channel in each field for which landowner permission was obtained. Target locations for transects were 100, 160, 220 and 600 feet from the edge of the channel, although some variance was allowed for local circumstances. Increments were based on work by Skarie and others (1986) in Grand Forks County which indicated that salinization occurred mostly within 300 feet of a drainage ditch in an area with a shallow water table. The 600 foot measurement was intended as a "control" transect beyond likely early influence from the channel. Its purpose was to serve as a relative indicator of natural salinization.

Western Plains Consulting Inc. classified and sampled soil on 25 calibration sites. Measurements collected included soil temperature, % sand, % silt, % clay, soil organic matter, sodium adsorption ratio (SAR), dissolved calcium, magnesium and sodium, saturation percentage (SP) and EC_e for the soil saturation extract. Each of the calibration sites were surveyed for precise geo-reference. These were then compared with Veris™ EC_a measurements. The measurements were made in later October, 2005, with moist soil conditions. Laboratory data, soil classification for calibration sites, Veris™ data corresponding to calibration sites and analysis, including the relationship between Veris™ EC_a and laboratory EC_e are published in a WPC report by Prochnow and Loken (2006). The report also includes an appendicized compact disc containing geo-referenced field Veris™ data. Results indicated a very strong correlation ($R^2 > 0.88$) for both topsoil (0 to 1 foot) and subsoil (1 to 3 foot) between Veris™ EC_a and laboratory EC_e measurements.

Should future conditions indicate possible soil salinization, repeated measurements would be required to discern changes caused by Outlet channel operation. The purpose of this report is to examine the data and findings of Prochnow and Loken (2006), and explore the usefulness of various published models for estimating EC_e from EC_a, and propose a general procedure for re-sampling and comparing baseline and later field measurements. In addition, this report includes in appendix: (1) a map showing the location of the Devils Lake Outlet channel (Appendix 1); (2) Maps of the field EC_a measurements (Appendix 2) for data published by Prochnow and Loken (2006); and (3) Data tables that include saturation percentage and saturation extract chemistry and parameters, which were unavailable at the time of publication of the WPC report (Appendix 3). This report is intended as a "first approach" for comparison, and later changes and adjustment from consultants making actual field comparisons would be both expected and welcome.

2.0 Models and Procedures for Evaluating Soil Saturation Extract Specific Conductance (EC_e) from Soil Conductivity (EC_a) Measured Using Veris™

Soil electrical conductivity as measured in the field using Veris™ has several components which are related to the composition of the solid matrix, the amount, salinity and salt composition of soil water, the temperature of the soil, and the interaction of soil matrix and water and the state of water as related to the flow of electricity. Considerable research has been conducted and several models have been published for interpreting this relationship. This section reviews some of the models in relation to Devils Lake Outlet data, and their potential usefulness for future comparison of baseline and post-operational soil salinity.

2.1. Two-Element Model

The earliest conceptual and analytical scheme for interpreting the specific conductance of soil water, EC_w, from soil electrical conductivity, EC_a, was based on a "two-conductor in parallel" model of Rhoades and Ingvalson (1971). These are:

(1) a *continuous liquid phase* (the soil solution), and

(2) a *continuous soil phase* (soil-to-soil contact).

The model is:

$$EC_a = EC_s^{'} + EC_w \theta T \qquad (2.1)$$

where $EC_s^{'}$ is specific conductance of the solid-to-solid phase, and EC_w is the specific conductance of the continuous liquid phase. θ is the soil water content by volume, and T is the transmission coefficient of the soil (Shainberg and others 1980), accounting for the longer path lengths of electrical current due to bending and discontinuity of pores. Rhoades and others (1989) described T as "simply the fraction of the total soil water that is mobile, ie., in the large pore system."

Rhoades and Ingvalson (1971) and Shainberg and others (1980) concluded that EC_a can be used to assess soil solution salinity (EC_w) ***when the soil is near field capacity.*** They further concluded that "***small deviations from field capacity water***

content did not interfere with the salinity diagnosis because the salt concentration of the soil water would increase as the volume of soil water decreased by evapotranspiration; hence, the current carrying capacity would not appreciably decrease by such relatively small variations in water content" (Shainberg and others 1980). Rhoades and others (1989) stated that ***T was approximately equal to one*** in their application**.**

Researchers found experimentally that the linear equation (Eq. 2.1) could be ***applied in the approximate range of 2 to 4 dS/m*** EC_w, which is the range of concern with respect to crop growth. Below this range, or in some cases at somewhat lower EC_a, EC_w vs. EC_a was curvilinear and the linear model (Eq. 2.1) could not be applied. Shainberg and others (1980) examined the non-linearity of EC_w vs. EC_a and found that:

(1) The deviation from linearity increases with increased clay content of the soil. A soil with 8% clay reached linearity at EC_a greater than 1.5 dS/m, while a soil with 35% clay reached linearity at EC_a greater than 3.0 dS/m.

(2) The deviation from linearity increases with increased exchangeable sodium percentage (ESP) in the soil.

At higher ESP or higher clay content, "the deviation from linearity begins at higher soil solution concentration and the departure (indicated by the linear intercept $EC_s^{'}$***) is greater***.

2.2. Three-Element Model

Shainberg and others (1980), based on theoretical work of Sauer and others, (1955) determined that a three-element model could be used to better predict the curvilinear EC_w vs. EC_a in the lower EC_a range. The three elements are:

(1) Conductance through alternating layers of soil particles and interstitial soil solution; named the *liquid-solid series-coupled element;*

(2) Conductance through or along the surfaces of the soil particles (a *solid-solid element*); and

(3) Conductance through the interstitial soil solution (a *liquid element*.)

Rhoades and others (1989) developed the following application of the model employing the three elements. The left term of the right-hand of the equation describes the *liquid-solid series-coupled element*. This series element is treated in parallel with the middle (*solid-solid element*) and the right (*continuous liquid element*).

$$EC_a = \left[\frac{(\theta_{ss} + \theta_{ws})^2 \bullet EC_{ws} \bullet EC_{ss}}{(\theta_{ss} \bullet EC_{ws}) + (\theta_{ws} \bullet EC_s)} \right] + \theta_{sc} \bullet EC_s + \theta_{wc} \bullet EC_{wc} \qquad (2.2)$$

EC_{wc} is the specific conductance of the continuous liquid element.

EC_{ws} is the specific conductance of the water that is series coupling with the solid particles.

EC_{ss} is the specific conductance of the series-coupled (coupled with interstitial water) soil particles.

EC_{sc} is the specific conductance of the solid-to-solid (continuous-solid) soil particles.

EC_s is a combined value representing $EC_s = EC_{sc} = EC_{sc}$, since according to Rhoades and others (1989), EC_{ss} and EC_{sc} should be identical.

θ_{ws} is the volumetric water content in the soil-water series-coupled pathway. This is viewed as water in fine pores occupying and electrically bridging the interstitial areas between particles.

θ_{wc} is the volumetric water content of the separate continuous liquid pathway. This is viewed as water in large pores.

θ_{ss} is the volume of soil particles.

Rhoades and others (1989) determined that the solid-solid soil particle element is negligible. So the three-element model is reduced to two elements.

$$EC_a = \left[\frac{(\theta_{ss} + \theta_{ws})^2 \bullet EC_{ws} \bullet EC_{ss}}{(\theta_{ss} \bullet EC_{ws}) + (\theta_{ws} \bullet EC_s)} \right] + (\theta_w - \theta_{ws}) \bullet EC_{wc} \qquad (2.3)$$

Where $(\theta_w - \theta_{ws})$ is substituted for θ_{wc}, and θ_w is the ambient soil volumetric water content.

For the linear range (EC_a greater than 1.5 to 4 dS/m, or EC_s greater than approx. 1.5 dS/m, depending on the soil), Rhoades and others (1989) further simplify Eq. (2.3) to:

$$EC_a = \left[\frac{(\theta_s + \theta_{ws})^2}{(\theta_s)} EC_s \right] + (\theta_w - \theta_{ws}) \bullet EC_{wc} \qquad (2.4)$$

because the product $\theta_{ss} \bullet EC_{ws}$ is so much larger than $\theta_{ws} \bullet EC_s$. This is equivalent to Eq. (2.1) where $T = \frac{(\theta_w - \theta_{ws})}{\theta_w}$. According to Rhoades and others (1989) $\frac{(\theta_s + \theta_{ws})^2}{(\theta_s)}$ is approximately equal to 1, so that $EC_s \approx EC_s^{'}$ from Eq. (2.1).

Solutions to Equations (2) through (4)

Rhoades and others (1989) and Corwin and Lesch (2003) have published empirical relations to simplify use of Equations (2) through (4). These include:

$EC_s = 0.0247 \bullet \%Clay - 0.0236$ (Rhoades and others, 1989) (2.2.a)

$\theta_w = \frac{(PW \bullet BD)}{100}$ (Corwin and Lesch, 2003) (2.2.b)

$\theta_{ws} = 0.6390 \bullet \theta_w + 0.011$ (Corwin and Lesch, 2003) (2.2.c)

$\theta_{ss} = \frac{BD}{2.65}$ (Corwin and Lesch, 2003) (2.2.d)

$EC_a = \left[\frac{(\theta_s + \theta_{ws})^2}{(\theta_s)} EC_s \right] + (\theta_w - \theta_{ws}) \bullet EC_{wc}$ (Corwin and Lesch, 2003) (2.2.e)

$EC_w = \left[\frac{EC_e \bullet BD \bullet SP}{100 \bullet \theta_w} \right]$ (Corwin and Lesch, 2003) (2.2.f)

$EC_w = \left[\frac{EC_e \bullet SP}{PW} \right]$ (2.2.b and 2.2.f combined) (2.2.g)

$$EC_w = EC_{ws} = EC_{wc} \qquad \text{(Rhoades and others, 1989)} \qquad (2.2.g)$$

Required Data is:

BD = bulk density,

% Clay = percent clay content,

EC_e = specific conductance of the saturation extract,

PW = gravimetric water percentage,

SP = saturation percentage of the saturation extract.

2.3. Linear Determination of EC_e

For EC_a in the linear range (greater than the critical value 2 to 5 dS/m) and where soils are near field capacity, a simplified approach for determining EC_e based on Equation 2.1 was presented by Rhoades and others (1989) as :

$$EC_e = m\left(EC_s^{'} - EC_a\right) \qquad (2.3)$$

Where the slope, m, is determined empirically from bulk density and saturation percentage as:

$$m = 0.01375x^2 + 4.1156x - 1.5021 \qquad (2.3.a)$$

Where

$$x = \frac{100}{SP \bullet BD} \qquad (2.3.b)$$

$EC_s^{'}$ is approximately equal to EC_s (Rhoades and others 1989, p435) and can be estimated using equation 2.2a.

2.4 Direct Regression

All of the field samples were collected and interpreted by Norman Prochnow of Western Plains Consulting, Inc. (Prochnow and Loken 2006). Prochnow approached the problem as a simple regression of EC_e vs. EC_a:

$$EC_e = A + B \bullet EC_a \qquad 2.4$$

This approach is very similar to Equation 2.1 , except that EC_w , while closely related to EC_e, is not identical to it. Prochnow's regressions were very highly correlated ($R^2 \sim 0.9$) for both topsoil and subsoil.

3.0 Data Requirements

3.1 The Main Objective

To compare base-line and later soil salinity we must clearly delineate the key parameter for comparison. In the literature for soil salinity analysis the main parameter used is usually the specific conductance of the soil solution extract (EC_e) at a 25^oC standard temperature. **The objective of all field measurements is thus to estimate EC_e.**

The main mapped parameter is the soil electrical conductivity EC_a. Because EC_a is a function of three elements discussed above (continuous water, continuous soil, and soil and water in series), and because EC_e constitutes a portion of the water elements, sufficient data to extract EC_e from the EC_a measurements must be obtained and used. Thus, **the objective is to obtain sufficient data to relate EC_e to the key mapped parameter, EC_a.**

3.2 Soil Temperature Adjustment

EC_a varies with soil temperature. For this **reason field EC_a must be adjusted for soil temperature at the time of mapping in order for a relationship to EC_e to be transferable to other times and conditions.** Corwin and Lesch (2003) observed that "electrical conductivity increases at a rate of approximately 1.9% per degree centigrade increase in temperature, and that a standard temperature of 25^oC is usually applied. Handbook 60 of the U.S Salinity Laboratory (USDA, 1954) described the relation as:

$$EC_{25} = EC_t \bullet f_t \qquad 3.1$$

where f_t varies with soil temperature. Handbook 60 (Table 15) presents f_t in tabular form. Corwin and Lesch (2003) cite a functional description from Sheets and Hendrickx (1995):

$$f_t = 0.4470 + 1.4034 \bullet e^{-t/26.815} \qquad 3.2$$

3.3 Utility of Model Variables

3.3.1. **% Clay** *Percent Clay Content (%)* is used as an empirical transfer function for estimating EC_s (Eq. 2.2.a).

3.3.2 **BD** *Dry Bulk Density* (Mg/m^3) is used to calculate θ_w (Eq. 2.2.b), θ_s (Eq. 2.2.d) and EC_w (Eq. 2.2.f) and also EC_{wc} and EC_{wc} (Eq. 2.2.g) at equilibrium moisture . It can be measured in a laboratory using undisturbed cores samples. Good bulk density samples can be difficult to obtain, and in relation to the problems of interpreting mapped data estimated values will be sufficient. This will be discussed later.

3.3.3 **PW** *Percent Water by Weight (*$\frac{g_{water}}{g_{soil}} \bullet 100$*)* is used to calculate θ_w (Eq. 2.2.b) and EC_{wc}(Eq. 2.2.f). It can be measured in a laboratory using disturbed field samples.

3.3.4 **SAR** *The Sodium Adsorption Ratio*, is not used directly in any of the models discussed above. However, the Exchangeable Sodium Percentage (ESP) is known to be related to the *threshold of linearity* for EC_e **vs.** EC_a **(the minimum** EC_a **value at which** EC_e **vs.** EC_a **becomes linear). The threshold** EC_a **and the degree of deviation from linearity are higher with higher ESP (Shainberg and others 1980).** Thus, additional correlation can be expected using ESP, or by proxy Sodium Adsorption Ratio (SAR) of the saturation extract. According to Handbook 60 (USDA 1954, p26) SAR is strongly correlated with ESP as:

$$ESP = \frac{100(-.0126 + 0.01475 \bullet SAR)}{1 + 100(-.0126 + 0.01475 \bullet SAR)} \qquad 3.3$$

ESP or SAR are not intrinsic model parameters. SAR will, however, be considered as a supporting variable for the Devils Lake assessment correlations.

3.3.5 **SP** *Saturation Percentage of the Saturation Extract* $(\frac{g_{water}}{g_{soil}} x100)$ is used to calculate EC_{wc}(Eq. 2.2.f) and also EC_{ws} and EC_{wc} (Eq. 2.2.g), and can also be used in a transfer function for EC_s.

Table 3.1. List of data requirements for field calibration of EC_a assessment of soil salinity. R is required, NR is not required, U is not required but empirically useful, and * indicates that for this model it is required if the m parameter is not empirically calculated using local data.

Models / Parameters	Model 2.1	Model 2.2	Model 2.3	Model 2.4
Soil Temperature (t)	R	R	R	R
Bulk Density (BD)	R	R	R*	NR
% Clay	R	R	R	U
Percent Water PW	R	R	NR	NR
Saturation Percentage (SP)	R	R	R	NR
Sodium Adsorption Ratio SAR	U	U	U	U

3.4 Sensitivity of EC_a vs. EC_e to Bulk Density

Bulk density is a key parameter for applying the full three-element model (2.2) and the linear model (2.3) with the published slope (m). It is a semi-stable property in that it does not normally fluctuate widely with climate. In the long term it is subject to many forces of change: including faunal effects (gophers, ants, earthworms), frost heaving, root packing or root separation, slaking from crop oils and others. The main short-term effect would be mechanical compaction from farm operations or other activities involving heavy equipment. It is arguable that changes due to introduction of new faunal influence are not likely to be substantial within a time-frame of a few years. Frost, mechanical, and root effects are likely to be limited in the subsoil. Main short-term effects of changing BD would be expected in the topsoil. While local and situational variation may be large, field measurements for a wide range of North Dakota soil series by Cassel and Sweeney (1974), and other measurements by Schuh, Cline and Sweeney (1991) indicate that for soils of similar or associated series and texture, topsoil and subsoil bulk densities tend to vary within a generally limited range. Bulk-density related problems in applying model 2.2 include:

(1) Bulk density may change somewhat between measurements at a given site, particularly within the topsoil.

(2) Bulk density can only be practically measured at limited discrete sites, unlike Veris™ EC_a which is measured on a continuous and repeated interval every few feet. Point-for-point matching of EC_a measurements with field bulk density is both physically and economically infeasible.

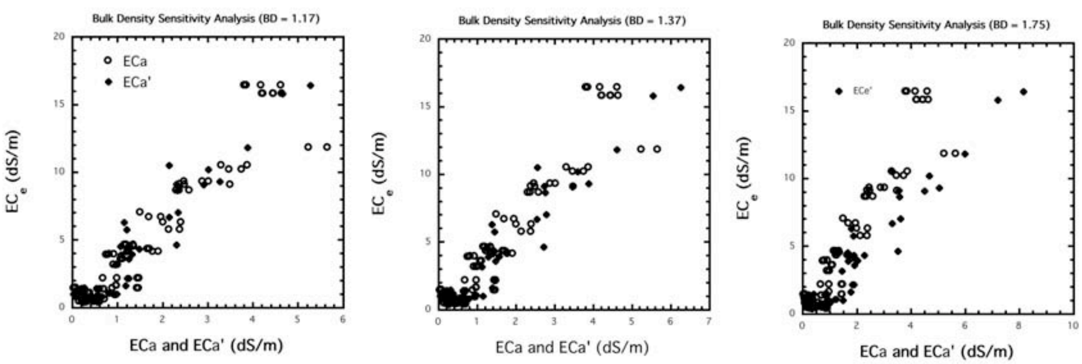

Figure 3.1. Results of sensitivity test for Bulk Density (BD). Figures compare EC_a predicted using three (minimum, median and maximum BD) with field measured EC_a' EC_e' predicted using the full model (2.1) and for the linear model (2.3).

In applying models 2.1 and 2.3 topsoil and subsoil BD were estimated based on soil series and associated soil series, and texture and organic matter similarities using data from Cassel and Sweeney (1974) and Schuh, Cline and Sweeney (1991). The results of Model 2.2 predicted measured field EC_a with a precision of about 88%. Because BD may vary, it is important that we understand the sensitivity of predicted EC_a to changes in BD. Model 2 simulations were reapplied using the minimum (1.17 g/cm3), median

(1.37 g/cm3) and maximum (1.75 g/cm3) bulk densities uniformly for all data in three separate sets of computations. Results are shown on Fig. 3.1. Use of minimum and median BD resulted in little change in the match with measured EC_a. Use of the maximum BD resulted in a larger change.

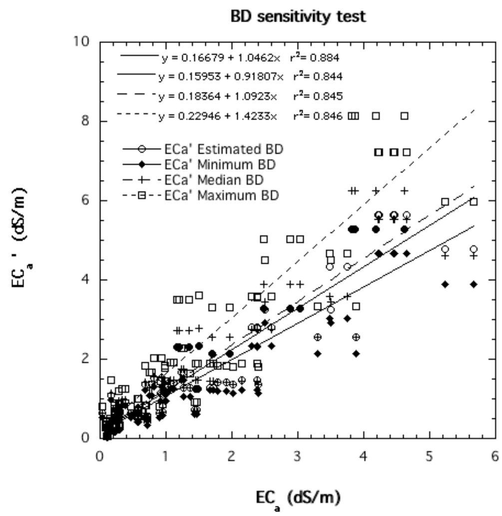

Figure 3.2. Comparison of EC_a measured using Veris™ with predicted EC_a' (from EC_e) using a distributed bulk density assigned by soil series, association, texture and bulk density; and uniform bulk densities using minimum, median, and maximum bulk density values applied to the full data set.

Regression of EC_a' vs. EC_a for the four cases examined (distributed BD based on soil type, uniform minimum BD, uniform median BD, and uniform maximum BD) indicates that the correlation is only slightly higher (accounting for 88% of the variability) for the distributed BD compared with the uniform BD scenarios (all accounting for about 85% of variability). The intercepts of all converge near zero and do not differ significantly from zero with respect to the problem of field measurement we are concerned with. The slopes of the relationship is closest (within 0.04) to one (identity) for the distributed BD, but are very close to one (within 0.1) for the minimum and median uniform BD values. The uniform maximum BD value, while highly correlated, has a slope ~50% larger than 1, which means that calculated EC_a' values using maximum uniform BD would substantially and increasingly overestimate actual EC_a with increasing EC_a. Minimum and median uniform BD assumptions would have slightly overestimate and underestimate, respectively, with increasing EC_a, but the effect would be small (Fig. 3.2). Use of the median value would be almost indiscernible from the distributed BD values.

These indicate that EC_a' are not highly sensitive to BD. A distributed BD assigned to soil types in general mapping classifications, or a single median value applied to all soils in the Devils Lake area would suffice for comparisons of salinity changes. This is particularly true if they are applied as relative measurements over the same transects and for grouped soil measurement units.

3.5 Data Stability and Variability

Of the required data discussed above (3.3), % Clay and saturation percentage (SP) should be relatively stable. Temporal repetition of measurements should not be required at control sites.

Bulk Density (BD) is semi-stable and should not change appreciably in the subsoil in a few-year time interval. A statistical mean of BD in a given representative surface area of topsoil should also be relatively stable. While recognizing that local changes due to compaction or tillage may strongly affect the topsoil layer, the models discussed are reasonably robust with respect to variable BD, and it seems likely that samples taken at the same time of year and representing the mean of several positions on the landscape will be sufficient. In fact, as stated above, use of a single BD of about 1.35 g/cm^3 for all sites seems to give reasonably good results.

Gravimetric water percentage (PW) is highly variable both temporally and spatially. In the fall 2005 measurement, PW varied from as little as 5 % to as much as 25%. It depends spatially on texture, organic matter and landscape position, and temporally on antecedent climate. Some control measurement of this property is needed at the time of sampling.

Spatial variability of all properties is considerable over the entire landscape of the Outlet channel, ranging from sandy, stony and coarse-loamy moraine materials in the northern portion, to loamy and fine-loamy materials in the south. Assessment of properties will need to be sub-divided by soil types and general areas.

The addition of sodium adsorption ratio (SAR) has been shown to improve most models for EC_e vs. EC_a'. It has been demonstrated that all models can be improved to almost perfect precision (r^2>0.99) by adding Ca, Mg and Na (mg/L) as regression variables. If SAR is to be used, these cations might as well be added because they compose the computational elements of SAR. However, exchangeable or soil-solution chemical properties are extremely unstable. Moreover, they comprise a major component of the salinity, which is what we are trying to measure. Increased EC_e implies an increase in one or more of these cations. For this reason they are not independent and constitute an alternative means for measuring EC_e rather than a supplement to EC_a measurements. They are, moreover, an expensive and impractical parameter set for measuring field EC_e on an extensive basis. Direct measurement of changes in soil cation composition is therefore impractical and inappropriate as a parameter for assessing field changes in salinity.

Parameters used in models should be limited to those that are: (1) stable (ex. % Clay, SP) or semi-stable (BD); or (2) which can be characterized for representative field units (PW, BD). Soil chemical parameters are not likely to be useful indicators for use in comparing EC_e vs. EC_a.

4.0 Model Assessment for Use at Devils Lake

4.1 Model 2.1 (Two-element Linear Model)

The two-element linear model of Rhoades (Rhoades and Ingvaldson 1971, and Rhoades and others 1989) has no practical advantage over the local linear calibration model of Prochnow and Loken (2006) in the Devils Lake area. Its theoretical validity is limited to the upper EC_a range (above the linear threshold EC_a value). While it contains a θ_w term accounting for moisture, this term is eliminated when using the empirical formulae presented by Corwin and Lesch to determine $\theta_w EC_w$. Specifically, applying Equation 2.2.f , $EC_w = \left[\frac{EC_e \bullet BD \bullet SP}{100 \bullet \theta_w}\right]$, it can be seen that θ_w is eliminated when multiplying by θ_w. Inverse application of this equation is needed to solve for EC_e as:

$$\frac{\left(EC_a - EC_s^{'}\right) \bullet 100}{BD \bullet SP} = T \bullet EC_e \qquad (4.1)$$

EC_a is measured using Veris™, $EC_s^{'}$ is estimated using the empirical relation 2.2.a above, and T is determined by regression of the left term on measured EC_e. T is thus empirically determined. Regression for the Devils Lake data yield a T value of 0.275 for combined data, about 0.29 for topsoil data, and about 0.26 for subsoil data.

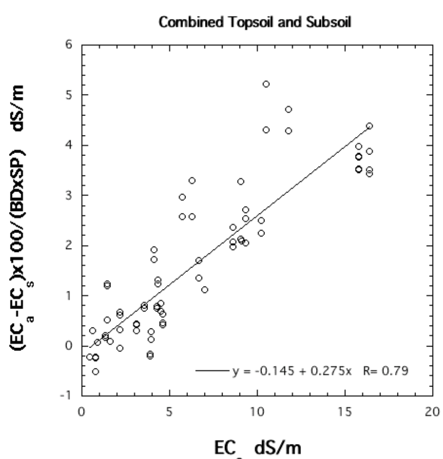

Figure 4.1. Model 1; T calibration for combined data.

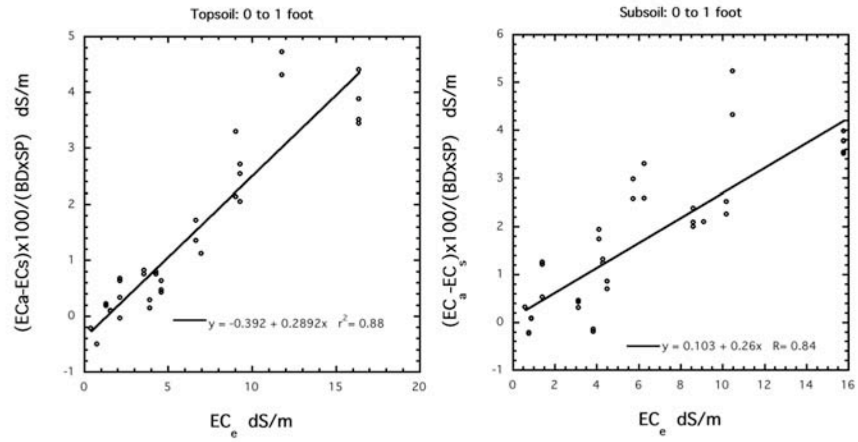

Figure 4.2. Model 1; T calibration for topsoil and subsoil data.

T values are fractional and less than one and represent the effect of path length on electrical conductivity. Rhoades and others (1989) estimated that in many cases T should be close to 1. A 'T' value of approx. 0.3 does not seem to be an unreasonable number. **However, given that T is an empirical derivation of measured EC_e; that several other parameters are needed, and empirical fitting is still required; that Model 3.2.1 applied using the empirical $EC_s^{'}$ and θ_w cannot really account for changes in soil moisture; that Model 2.1 is also confined to the range above the threshold of linearity; and that there is no apparent better fit using Model 2.1, there is really no practical advantage of employing Model 1 over the precalibrated regression approach (Model 2.3) or the direct regression approach (Model 2.4).**

4.2 Model 2.2.2 (The Full Three-Element Model)

Theoretically, and in published literature, Model 2.2 should be capable of assessing EC_e in the curvilinear range (below the threshold of linearity). It should also be capable of better adjusting for changes in moisture. The comparison of the relationship between field measured EC_a and lab EC_e, and estimated EC_a (labeled EC_a') calculated from lab EC_e, % clay, PW, SP, and estimated BD using Model 2.2 is shown for composite topsoil and subsoil data (Figure 4.3) and for individual topsoil and subsoil data sets (Figure 4.4). Lines shown are polynomial least-squares fits for the calculated data EC_a'. Fits are good for all data sets. Direct regression of EC_a' vs. EC_a accounted for 88% of variability on the composite comparison, 92% of the variability for the topsoil, and 88 % of the variability for the subsoil. Linear coefficients were 0.84, 0.79 and 0.91 for the comparisons respectively, all reasonably close to one, or identity. Intercept coefficients were 0.03, 0.25 and 0.26 respectively; all very close to 0. Generally the fits were quite good.

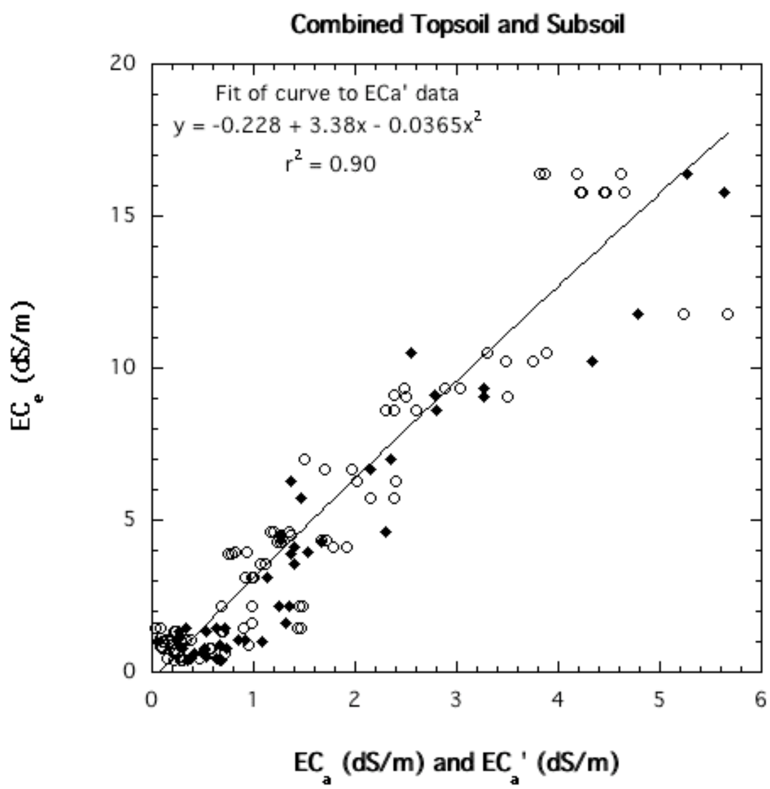

Figure 4.3. Comparison of field EC_a and EC_a' estimated using the three-element model (Model 2.2.2) for predicting lab EC_e using composite topsoil and subsoil data.

These indicate that reasonably good estimates of EC_e should be attainable using Model 2.2. The reverse computation process would be somewhat more complicated than the forward comparison used here. EC_a would be measured using Veris™. SP, estimated BD, and % clay should be relatively stable within the error of the method. PW would have to be re-measured at selected sites and assigned to soil units within fields. EC_e should also be re-measured at selected sites for comparison with calculated EC_e.

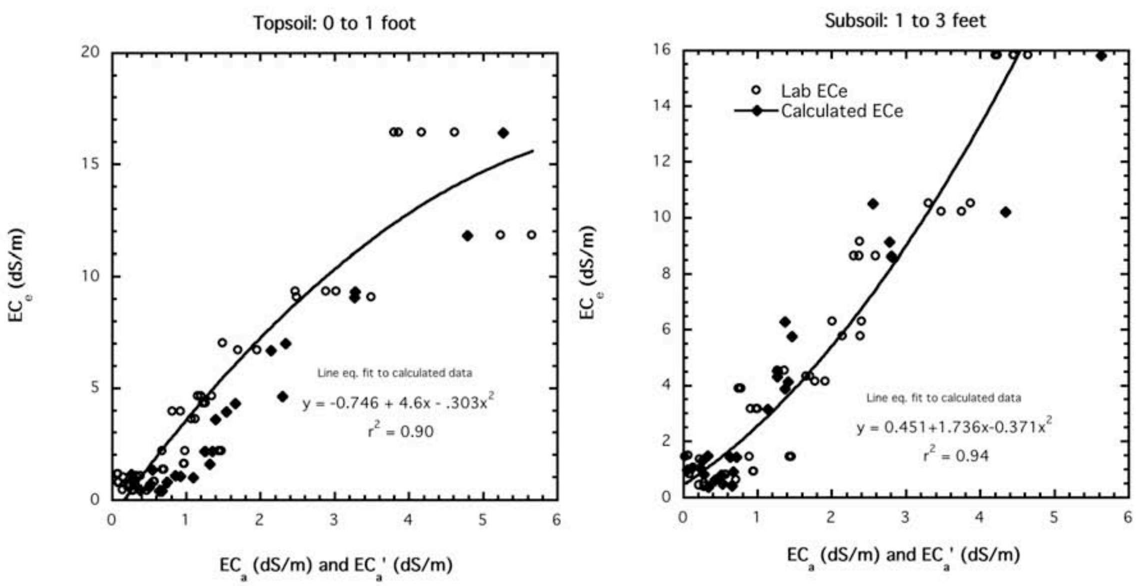

Figure 4.4. Comparison of field EC_a and EC_a' estimated using the three-element model (Model 2.2.2) for predicting lab EC_e using individual topsoil and subsoil data.

The Computation algorithm would consist of:

(1) Assigning an estimated initial EC_e';

(2) Use the initial estimated EC_e to calculate EC_w (Eq. 2.2.g)

(3) Apply the relation $EC_w = EC_{ws} = EC_{wc}$ (Eq. 2.2.h)

(4) Determine all other parameters using Eq. 2.2a through 2.2f.

(5) Estimate EC_a' using Model 2.2.2.

(6) Determine the residual (EC_a' - EC_a) and desired direction of EC_e to decrease the residual.

(7) Adjust a new estimate of EC_e'.

(8) Continue steps (1) through (7) until the residual is within a desired error tolerance *x*.

This procedure could be easily and quickly accomplished with a computer algorithm applying the eight steps in iterative succession.

Sodium adsorption ratio (SAR) is known to affect the relationship between EC_e and EC_a. Higher SAR is related to elevated "threshold of linearity", and also to higher EC_e. We examined the benefit of empirical adjustment for predicting EC_a' using several variables, including BD, PW, SP, % Clay, % Sa and % Si in multiple regression equations was examined. The model used was:

$$EC_e = a + b\ EC_a' + c\ SAR \qquad (4.2)$$

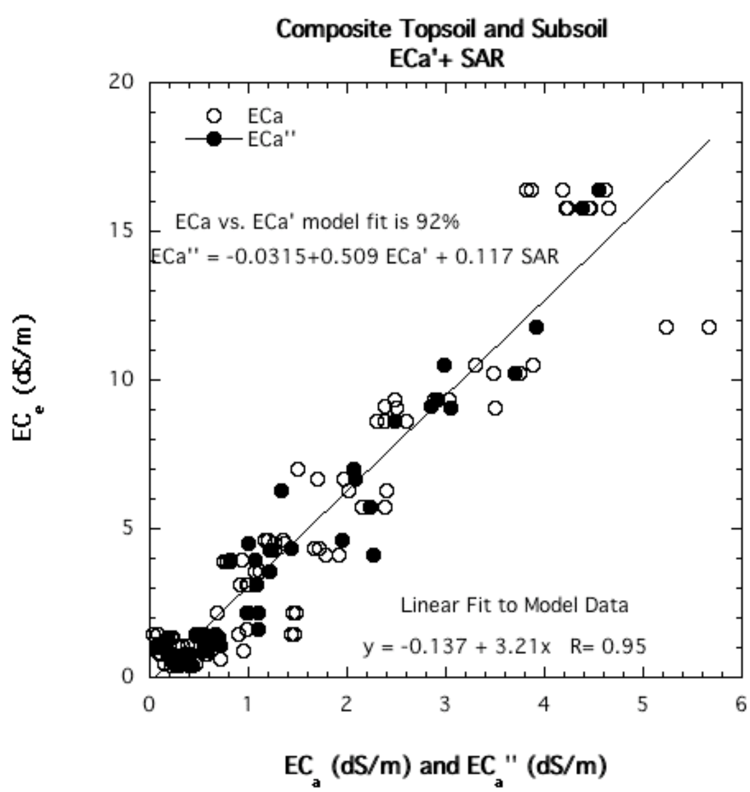

Figure 4.5. Comparison of field EC_a and EC_a' estimated using the three-element model (Model 2.2.2) with empirical adjustment for SAR to predict lab EC_e using composite topsoil and subsoil data.

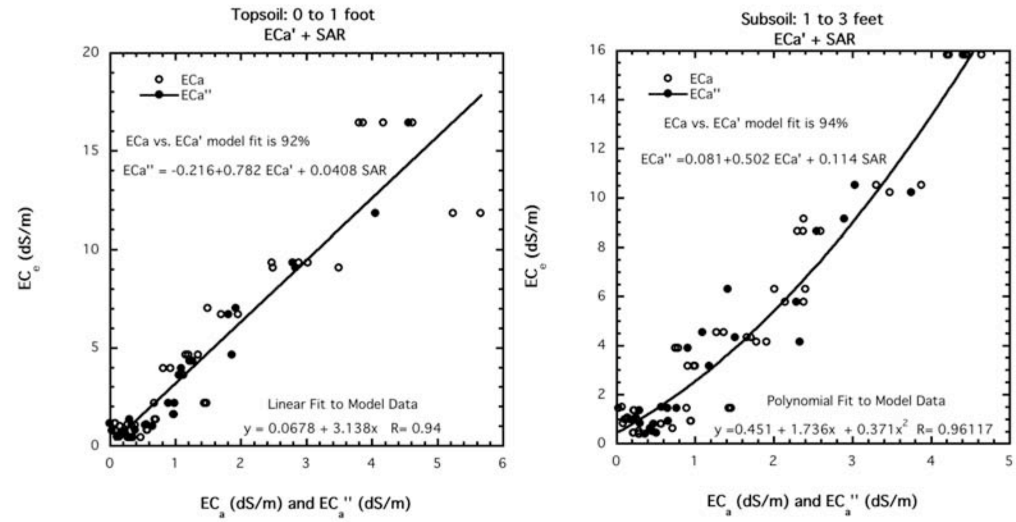

Figure 4.6. Comparison of field EC_a and EC_a' estimated using the three-element model (Model 2.2.2) with empirical adjustment for SAR to predict lab EC_e using individually correlated topsoil and subsoil data.

Results indicated a significant improvement in predicting EC_e. This application would be applied as an adjustment after determining an optimized EC_e and EC_a using the eight steps described above.

While optimal application of the Veris^{TM} for predicting EC_e should always attempt to approaching field capacity, and primary stress should be on the linear (higher EC) range, **the three-element model is theoretically more capable adapting to lower moisture contents and to the curvilinear (low EC) range.** The fits of the three-element model have been remarkably good (Figures 4.4 and 4.5) considering that there is no local empirical adjustment of fits with EC_e. EC_a' was calculated entirely using the theoretical model and on empirical transfer functions derived from the literature. This indicates that the model should be robust in field applications.

4.3 Model 2.3. Linear Determination of EC_e

The slope, *m*, for the linear model of EC_e vs. (EC_a - $EC_s^{'}$) and the value of $EC_s^{'}$ were determined from empirical relations based on BD, % Cl, and SP using transfer functions 2.2a and 2.3b. A composite comparison with EC_e is shown on Figure 4.7. Comparisons with measured EC_e is shown on Figure 4.8. Fits are reasonably good for predictive models calibrated in other areas of the country, and without calibration to local EC_e. As would be expected, weakest fits tend to be in the lower EC_a range. The slope coefficient for direct regression of EC_e vs. EC_e' using the composite data is 0.9, very close to 1. The linear intercept is 2.18. The standard error is 4.9.

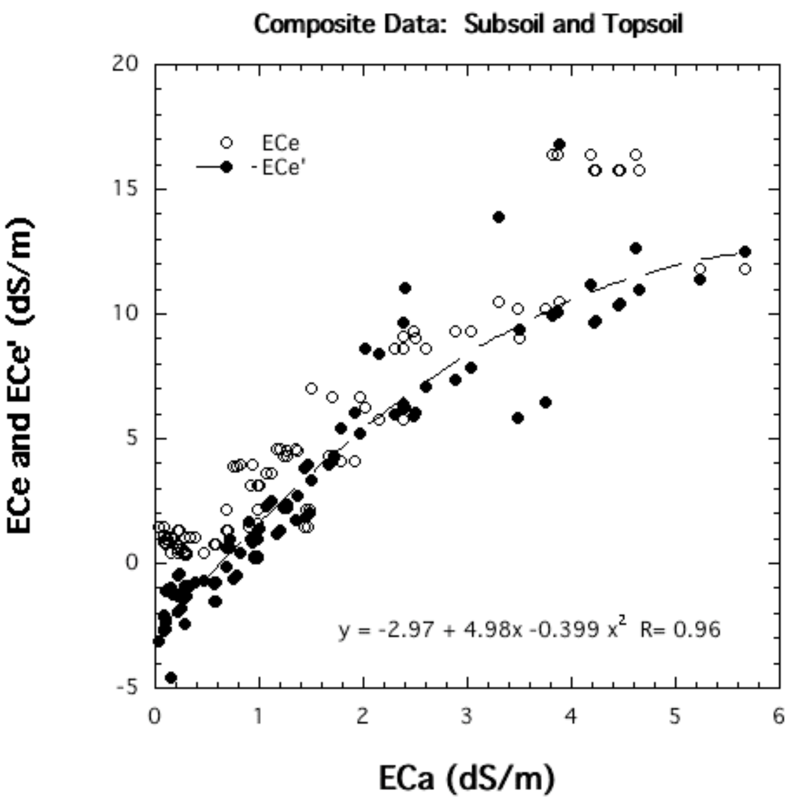

Figure 4.7. Comparison of field EC_a and EC_a' estimated using the linear model of Rhoades and others (1989) (Model 2.3) to predict lab EC_e using individually composite topsoil and subsoil data.

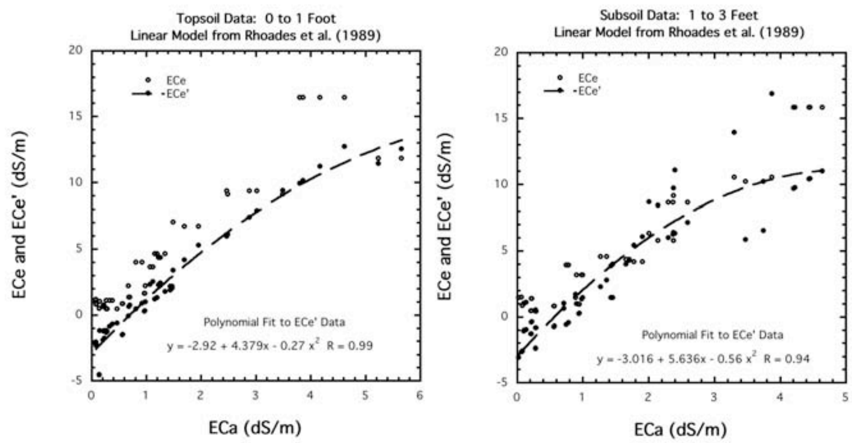

Figure 4.8. Comparison of field EC_a and EC_a' estimated using the linear model of Rhoades and others (1989) (Model 2.3) to predict lab EC_e using individually correlated topsoil and subsoil data.

Empirical adjustment for topsoil alone (EC_e vs. EC_e') is a linear constant of 2.3 and a slope of 1.02, having a standard error of 2.3, R^2 = 0.91. For subsoil, the linear constant is 0.16, the slope is 0.92 and the standard error is 4.57.

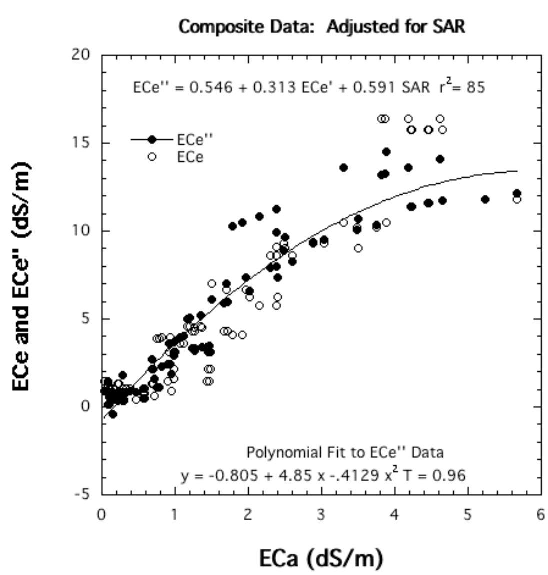

Figure 4.9. Comparison of field EC_a and EC_e' estimated using the linear model of Rhoades and others (1989) (Model 2.2.3) with empirical adjustment for SAR to predict lab EC_e using composite topsoil and subsoil data.

A multiple regression using SAR [EC_e'' =f(EC_e' and SAR)] is shown for composite data on Fig. 4.9. Fig. 4.10 shows the EC_e' and SAR combined models calibrated for individual topsoil and subsoil units. Correlations are generally very good. The exceptionally high predicted values are all from the subsoil of two sites (Site 19 and Site 21). These two sites all have exceptionally high SAR (13 and 14.7 respectively). For both models the probability of a significant relationship between SAR and EC_e was significant at P<0.001. It was also more highly significant than EC_e' as a predictive variable.

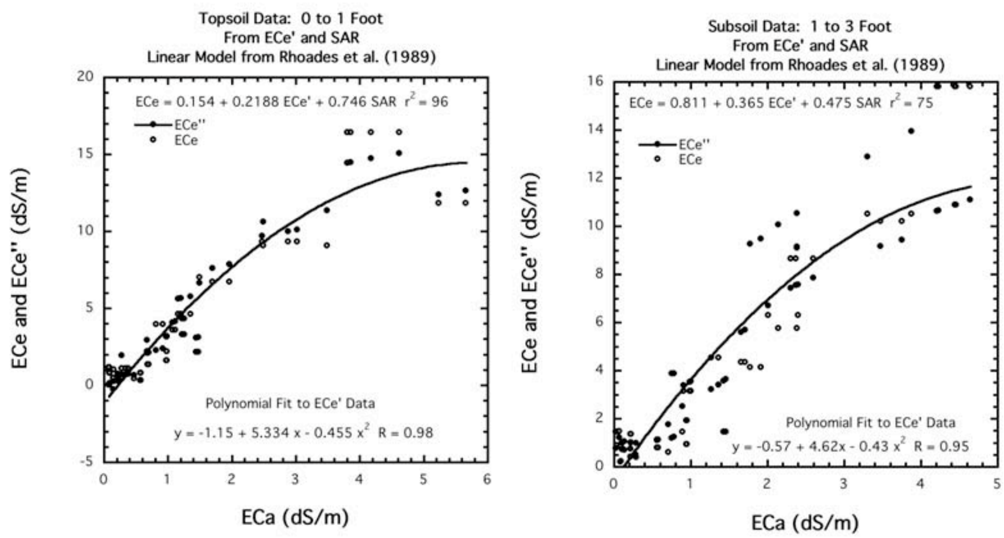

Figure 4.10. Comparison of field EC_a and EC_e' estimated using the linear model of Rhoades and others (1989) (Model 2.2.3) with empirical adjustment for SAR to predict lab EC_e using individual topsoil and subsoil data.

The Rhoades linear model shares the advantage of independently generated input parameters with the three-element model. That is, it does not require local calibration. Fits are good considering the independent derivation. As with the regression model, however, this model is limited in application to near field capacity, and to higher ranges of EC_a. While SAR improves predictive capability significantly, SAR is a dynamic property that must be measured for each field position at each application, and its application would likely not be practical under field conditions.

4.4. Local Regression Model

Prochnow and Loken (2006) used a direct regression approach for examining the relationship between EC_a and EC_e in their report on baseline salinity along the Devils Lake Outlet. They found that EC_a estimated using Veris™ were capable of predicting 88% of the variability of laboratory EC_e in the subsoil and 92% of the variability in the topsoil, with no further data requirements. Field conditions at the time of measurement were moist and measurements were made in mid October with minimal active evapotranspiration. We can therefore assume that despite differences in soil moisture due to differences in soil texture (gravelly sand through loam) field conditions were close to field capacity. Correlation for the composite topsoil and subsoil (adjusted to dS/m units) and using temperature normalized Veris™ data are shown on Fig. 4.11. Correlations for individual topsoil and subsoil layers are shown on Fig. 4.12. Advantages of the direct regression approach are: (1) simplicity of use, it is by far the simplest method to apply; and (2) local calibration which ties it directly to local soils. Disadvantages are the same as the two-element model (Model 2.1) and the linear model (2.3), requiring application near field capacity and above the threshold of linearity. The threshold of linearity on these data seem lower (approx. 1 dS/m EC_a) than those documented in the literature (2 to 5 dS/m EC_a).

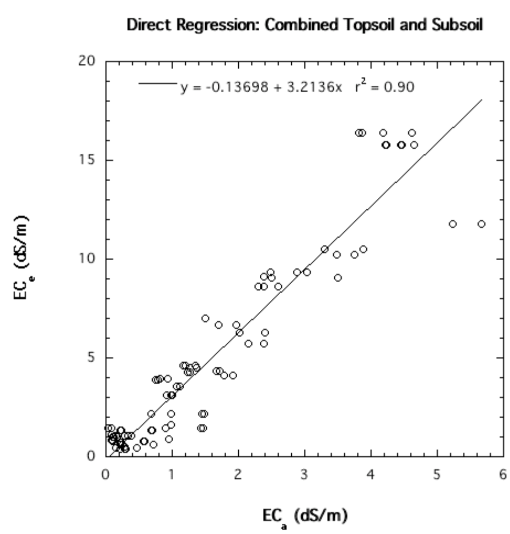

Figure 4.11. Comparison of field EC_a and EC_e correlated using the direct regression model of Prochnow and Loken (2006) for composite topsoil and subsoil data.

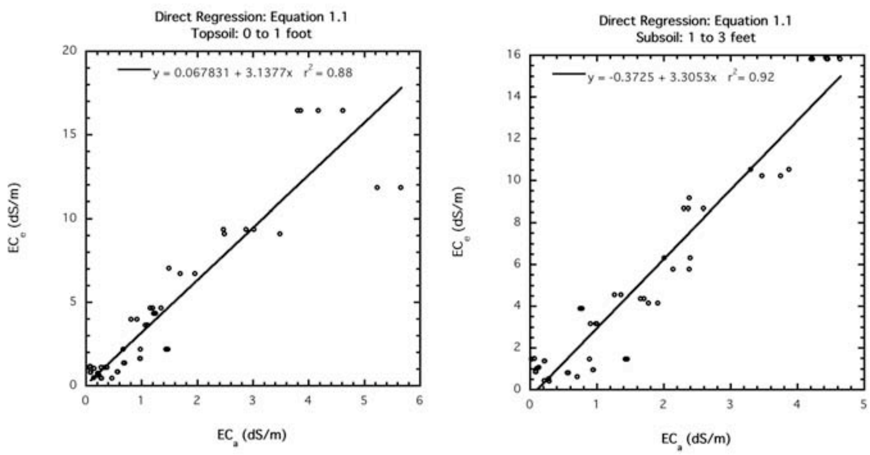

Figure 4.12. Comparison of field EC_a and EC_e correlated using the direct regression model of Prochnow and Loken (2006) for individual topsoil and subsoil data.

4.5. Comparison with Other Soil Electrical Conductance Work in North Dakota

Several scientists have worked with salinity assessment using soil electrical conductance measurements in North Dakota. Mike Ulmer of the Natural Resources Conservation Service in Bismarck, ND, has reported poor correlations in some instances for EC_a measured using electromagnetic induction to estimate EC_e in the Red River valley. He is currently collaborating with Drs. Corwin and Lesch of the USDA-NRCS to identify the sources of poor results in calibration, and has stated that the EC_e vs. EC_a relationship is very complex. Ulmer has suggested that comparison of direct Veris^{TM} measurements may be more productive than attempting to compare EC_e. Dr. David Franzen of North Dakota State University Soil Science Department, has worked extensively with Veris^{TM}, but like Ulmer he considers calibration to be extremely complex and prefers to use it for relative comparisons. He has pointed out the need for soil moisture measurements, which can affect the calibration, and has observed that actual measured depth can vary with soil and moisture and can be problematic. Dr. Franzen has suggested that normalized comparisons of Veris^{TM} measurements may provide the best approach. Dr. David Hopkins of the North Dakota State University Soil

Science Department has also employed Veris™ in his research. Dr. Hopkins provided the following topsoil data from Richland County, in southeast North Dakota. The Richland County data are plotted with the Devils Lake Outlet data on Figure 4.13. The Richland County data occupy a range similar to the Outlet data and are consistent with the same population, but the Richland County data are more scattered, particularly in the EC_a range above 1 dS/m. The scatter of data in Richland County may reflect greater variability in soil moisture conditions at the time of measurement, compared with relatively uniform high moisture conditions for the Devils Lake measurements. Alternately they may reflect some of the difficulties encountered by Ulmer. Additional work using Veris™ is being conducted near Devils Lake by one of Dr. Hopkins' graduate students and will be useful for further comparison with the data discussed in this report.

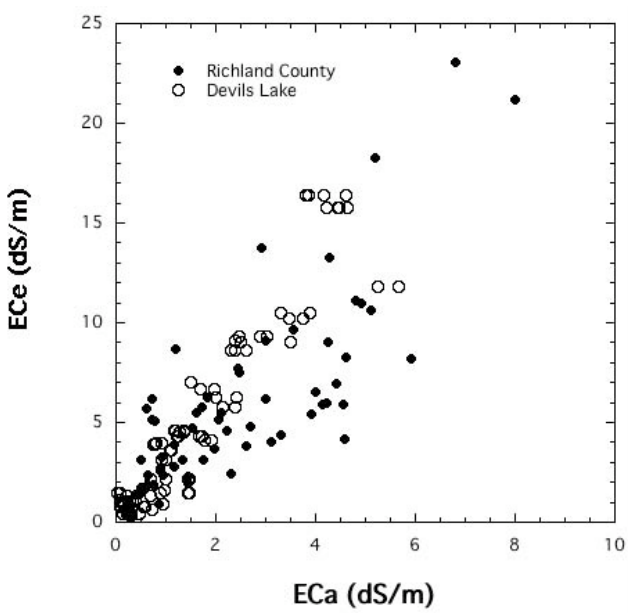

Figure 4.13. Comparison of Devils Lake Outlet EC_e vs. EC_a measurements with measurements made in Richland County (Richland County data with permission from Dr. David Hopkins, NDSU).

Mike Ulmer's suggestion of a direct comparison of Veris™ has merit and is worth consideration for resampling soils adjacent to the Outlet. Since non-salinity variables affecting EC_a (such as % Clay and SP) do not change at a given location, changes in salt content of the soil solution should dominate the changes in measured EC_a provided measurements are made under moist conditions (approaching field capacity) over the Outlet area. Effects of other large factors, including moisture, could be minimized by normalization as suggested by Dr. Franzen. This would be accomplished by treating changes near the channel as ratios of the readings at 600-foot distance from the channel. Ulmer has further suggested dividing units for comparison by soil type to maximize uniformity of conditions.

Direct comparison of Veris™ EC_a should be considered for discernment of temporal changes in salinity. However, the problem of interpretation still remains. If change is established, there still remains the problem of evaluating what that change means in terms of potential crop productivity impairment. Assessment of potential productivity impairment from salinization is almost entirely based on EC_e assessment in the literature. Thus, at some point it becomes necessary to estimate EC_e. The procedural question at that point becomes one of stress and focus. That is, direct comparison using Veris™ places more stress on simply establishing the fact of change, and uses the calibration models to help interpret the meaning of that change; whereas use of EC_e determinations from calibrated models themselves places more stress on changes in EC_e per se. A potential advantage of using pre-calibrated parameters is that use of the three-parameter model may help to filter effects due to moisture. Conversely, use of models may massage the data somewhat and mask or skew some of the variation. Both approaches will need to be carefully considered if field reassessment becomes necessary.

5.0 Recommendations

The following recommendations are offered as initial proposals for assessing changes in field salinity using Veris™ measurements. They are intended to provide a basis for discussion and polishing of field procedures. Other approaches, unidentified here, may prove to be appropriate as well.

5.1 The objective is to estimate and compare EC_e. Use EC_a from Veris™ with complimentary data to determine EC_e using appropriate models. Alternately, assessment of difference employing the same metrics could be performed using the Veris™ measurements directly, and the models could be used after change assessment to interpret the degree of potential productivity impairment implied by the measured differences.

5.1.1 Repeat the Veris™ transects, matching the original as closely as possible. Some possible approaches are:

(a) Use previous geo-referenced location data to direct the Veris™ as close as possible to original transect;

(b) Use the Veris™ coordinates to flag the original transect at visual intervals; or

(c) Combine (a) and (b). For example, flag the Control transect and the first pass near the channel and use the Veris™ orientation system to repeat the 60' spacings to the next three.

5.1.2 Use digitized soil survey maps and geographical-information system (GIS) software to divide fields into computation units (u) according to soil series. A number of individual readings (for example 12 readings at 8 foot intervals for approximate 96-foot computation units) should be established as a minimum representative sample volume.

5.1.3 Use the Data of Prochnow and Loken to provide required data (SP, % Clay) for each soil series. If multiple data is available for a given series use the closest data point, or average data, whichever seems most appropriate for local conditions. These parameters, and BD should be relatively stable within the range of significant effect on the model outcome.

5.1.4 Sample the control locations for PW and temperature and apply as above. If variability is large, additional samples may be necessary to provide a good statistical distribution.

5.1.5. Sample when field conditions are as close to field capacity as possible. Best results would be expected after an extended rainfall period, or following winter thaw and before crop emergence, with good subsoil moisture. Slight variance should not be a serious problem because ionic strength increases with loss of water, therefore partially compensating for depletion of the continuous water pathway (Shainberg and others 1980). However, large variance will affect the dependability of results and increase uncertainty. Model 2.2 (the three-element model) would likely have higher reliability than other models with increasing departure from field capacity. However, all models are most reliable near field capacity.

5.1.6. Apply appropriate models to estimate EC_e from EC_a (Veris™). *This step may be applied alternatively after assessment of change.*

5.1.7. Use normalized metrics. Error factors include location, equipment, weather, variability of physical properties, model random error, operator differences, moisture conditions, and the range of EC_e application in relation to curvilinearity of the EC_e vs. EC_e relationship. Use of normalized metrics can minimize many of these error factors. Equipment, weather, and operator differences can likely be nearly eliminated. Physical properties and moisture conditions, and model bias can also be minimized. There are three relative degrees of freedom that can be employed. These are:

5.1.7.1. Comparison of field (F) measurements of EC_e near the outlet channel with control measurements (C) measured more distant (approx. 600 feet) from the outlet channel;

5.1.7.2. Comparison of initial (i) baseline measurements before or early in outlet channel operation with later (f) measurements after channel operation for a defined period of time: and

5.1.7.3. Combined application of *5.1.7.1* and *5.1.7.2.*

5.1.8 Two metrics are proposed.

5.1.8.1 Additive and Semi-proportional metric:

Determine the ratio (R_u) of field (*F*) EC_e (or alternately EC_a for direct comparison) near the outlet channel to EC_e *(alt.* EC_a***)*** in the control (*C*) transect for the same field measurement unit (*u*) in the initial (*i*) pre-operational period.

$$R_u = \left(\frac{EC_{e-F,i}}{EC_{e-C,i}} \right)_u \qquad 5.1$$

Estimate (*) the expected $EC^*_{e-F,f}$ near the channel (F) after outlet operation (f) using the EC_e calculated from Veris™ EC_a measurements for the control (C) transect after outlet operation (f) and R_u determined from initial measurements (Eq. 5.1).

$$\left(EC^*_{e-F,f} \right)_u = R_u \bullet EC_{e-C,f} \qquad 5.2$$

Measure and calculate $EC_{e-C,f}$ for field (F) transects near the outlet using Veris™ EC_a measurements for the field transects after outlet operation. Then calculate the difference as:

$$\Delta = EC^*_{e-F,f} - EC_{e-F,f} \quad (5.3)$$

Calculate the mean $\overline{\Delta}_u$ for each land unit; and use a student's t-test

$$\overline{\Delta}_u \pm t_p \sigma_u \neq 0 \qquad 5.4$$

(or a non parametric alternative, if appropriate) to determine if $\overline{\Delta}_u$ differs significantly from 0 at probability *p*. Likely *p* used to discriminate significance will have to be relatively low (*ex. 60 or 70 %*) because of variability. This would be to say, in effect, that there is better than a 50/50 chance that change caused by the Outlet has occurred. While this is low when compared with research standards (usually 95% or better), expectations of statistical certainty for field assessment under conditions that cannot be carefully controlled must be lower than those for controlled conditions.

5.1.8.2 Fully Proportional Metric:

Using appropriate models calculate EC_e for control (C) and field (F) transects adjacent to the outlet. Determine the field to control ratios for initial pre-operational conditions as:

$$R_i = \frac{EC_{e-F,i}}{EC_{e-C,i}} \qquad 5.5$$

and for post-operational conditions as

$$R_f = \frac{EC_{e-F,f}}{EC_{e-C,f}} \qquad 5.6$$

To compare the proportional difference (d) between pre-and post-operational scaled EC_e use the corresponding ratios as:

$$R_d = \frac{R_f}{R_i} \qquad 5.6$$

determine the mean $\overline{R}_{d-u}$ and standard error for each land unit (u) and test for difference from one using the Student's t-test (or a non parametric alternative, if appropriate).

$$\overline{R}_{d-u} \pm t_p \sigma_{d-u} \neq 1 \qquad 5.7$$

Likely p used to discriminate significance will have to be relatively low (*ex.60 to 70%*) because of variability.

5.2. Use Multiple Models

Calculating EC_e using more than one model is recommended. The data set is essentially the same for all, and each model has certain comparative advantages. Computation is simple and inexpensive compared with data acquisition and field Veris™ measurements.

5.2.1 The direct regression model of Prochnow and Loken (Model 2.4) has the advantage of entirely local calibration and simplicity. It will likely be effective in the range near field capacity and at higher EC_a values (approx. EC_a > 1,000 μs/m) on local data*.

5.2.2. The linear model of Rhoades and others (Model 2.3) has the advantage of general calibration of research and data, and, though slightly more complex than direct regression, is reasonably simple. Its range of applicability is similar to Model 2.4 (i.e. near field capacity and EC_e > 1,000 μS/cm or 1 dS/m) on local data**.

5.2.3. The three-element model (Model 2.2) is the most complex and difficult to use. It shares independent development and calibration advantages with Model 2.3. In addition it is the most rigorous from a theoretical standpoint, and would likely provide better results with larger departures of soil moisture from the proximity of field capacity, and would likely function better in the curvilinear EC_e vs EC_a range (EC_a > 1,000 μS/cm or 1 dS/m). Computations of EC_e will require numerical algorithms for iterative approximation.

** The threshold of linearity is generally reported to be in the range of 2 to 4 dS/m, but varies with texture and SAR, generally being higher with finer textured soils and higher SAR. Most of the Devils Lake maintain at least an approximation of linear behavior as low as 1 dS/m. Slight curvature can be observed below that level.

Final interpretations should be weighted based on model appropriateness for ambient conditions. Limitations of models, and the approximate nature of the EC_e conversion used for impact assessment should be clearly recognized.

6.0 Citations

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APPENDIX 1: Map of Outlet Channel Location

Figure A.1. Map showing the location of the Devils Lake Outlet in relation to Devils Lake and nearby communities.

APPENDIX 2:

Salinity Maps for Devils Lake Outlet

Baseline Measurements Using Veris™ in Fall 2006

The following six pages provide maps of baseline salinity in fields adjacent to the Devils Lake Outlet measured using Veris™ and field samples in October of 2006. They are divided into three groups (North, Middle and South) of two maps each (shallow and deep), and are presented in the order: North Shallow, North Deep, Middle Shallow, Middle Deep, South Shallow, South Deep.

The interpretive table below can be used to convert map key groupings to equivalent numerical Veris™ EC_a values, or Laboratory EC_e values. The table and its sources are presented and described in Prochnow and Loken (2006).

Soil Great-Group classifications are provided for comparison with salinity classification data on each of the maps.

Table A.2.1. Map key for Outlet salinity maps on the following pages. Veris™ EC_a are presented in units (mS/m) of actual implement readout, with corresponding EC_e (dS/m) for laboratory saturation extracts. The relationships on this table were calculated using the transfer functions of Prochnow and Loken (2006) for field data obtained in the fall of 2005. Map classes can be converted to either Veris™ EC_a or laboratory EC_e using this table.

Salinity Classes	Laboratory EC_e (dS/m)	Veris™ EC_a (0 to 1 foot) (mS/m)	Veris™ EC_a (1 to 1 feet) (mS/m)
Non-Saline	0-2	< 39.66	< 46.34
Very Slightly Saline	>=2 to 4	>= 39.66 to 83.14	>= 46.34 to 87.58
Slightly Saline	>=4 to 8	>= 83.14 to 170.1	>= 87.58 to 170.05
Moderately Saline	>=8 to 16	>= 170.1 to 344.01	>= 170.05 to 335.00
Strongly Saline	>=16	> 344.01	> 335.00

Figure A.2.1. Shallow (0 to 1 foot depth) Veris™ : North Area

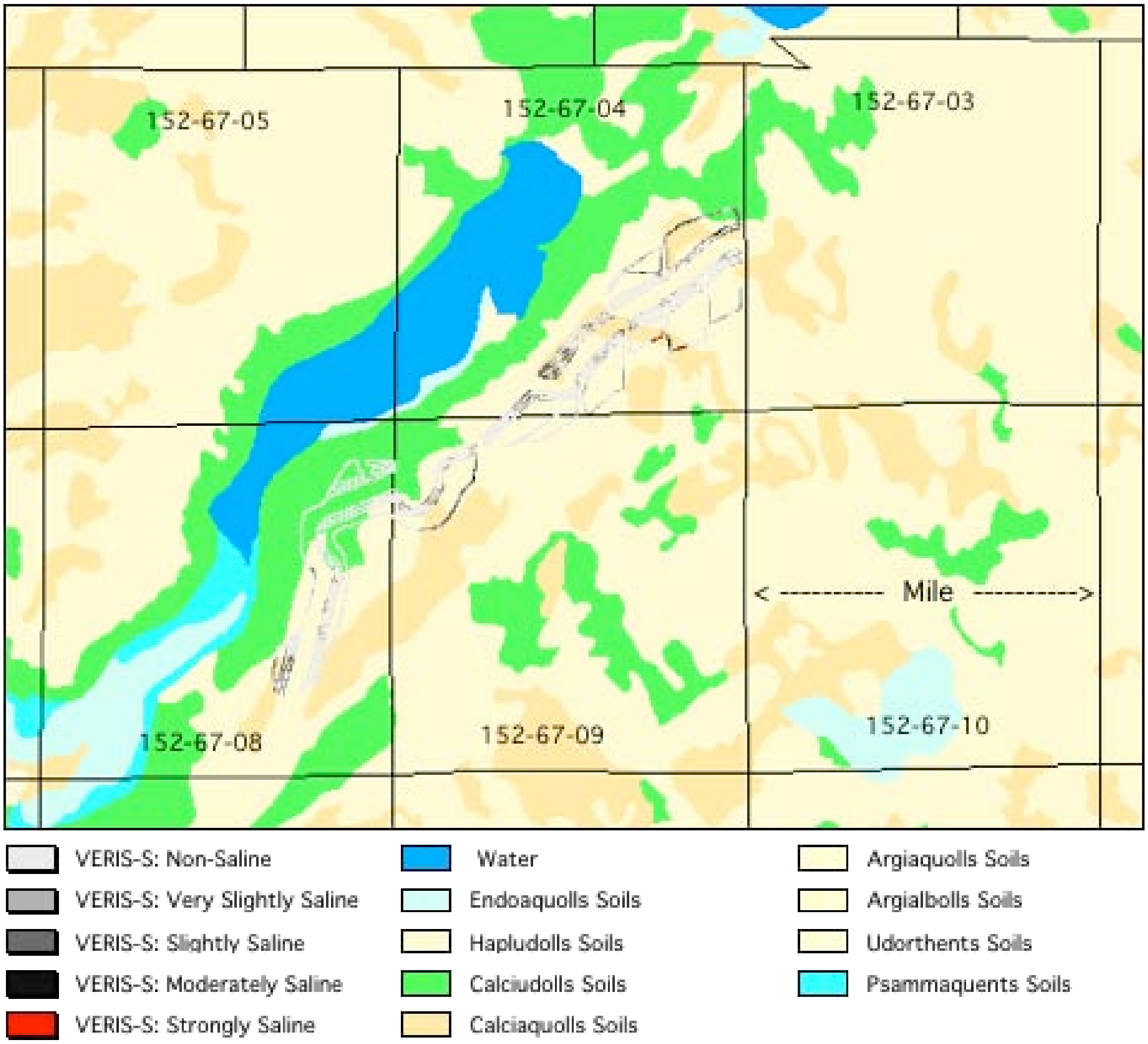


Figure A.2.2 Deep (1 to 3 feet depth) Veris™ : North Area

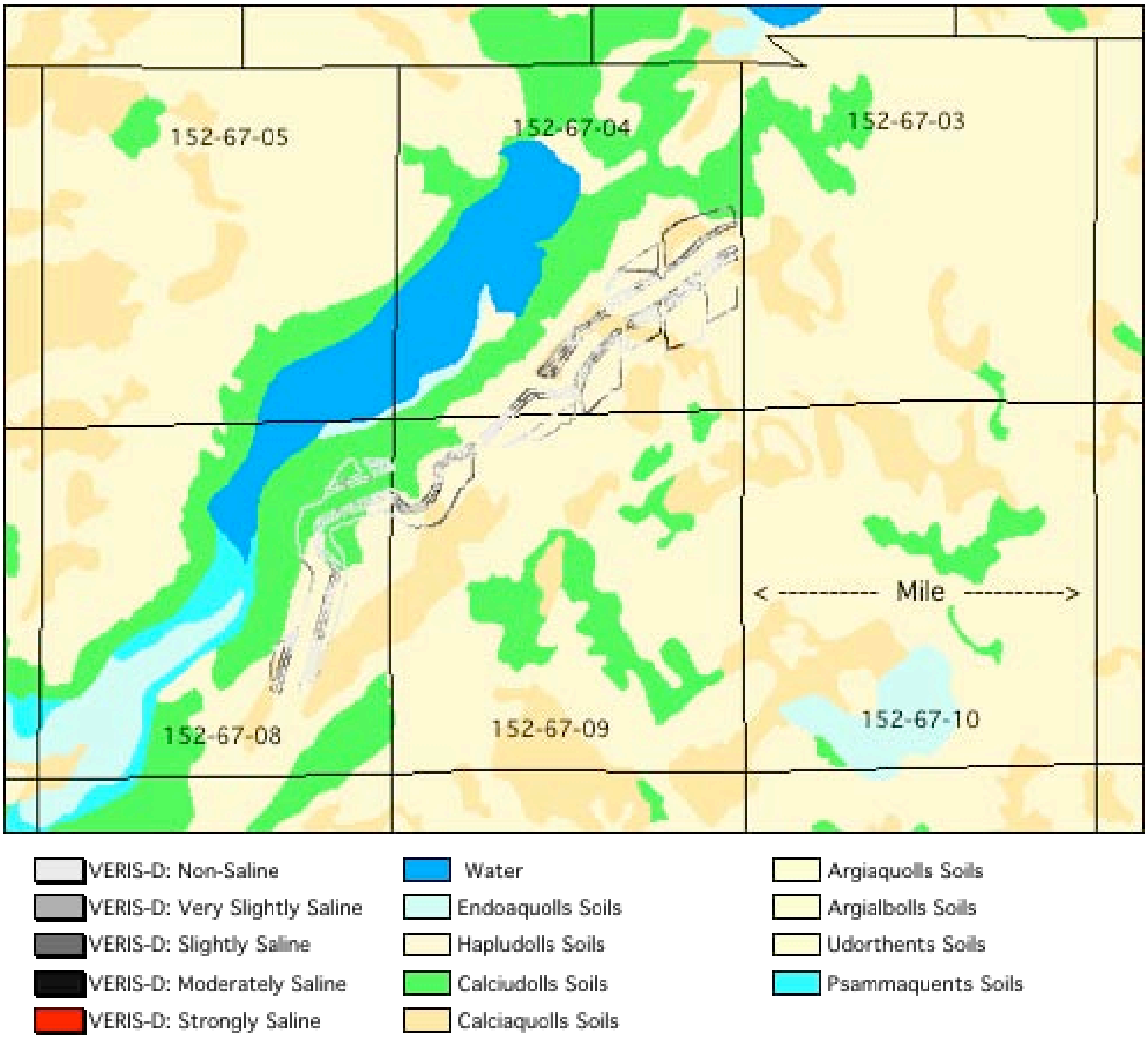


Figure A.2.3 Shallow (0 to 1 foot depth) Veris™ : Middle Area

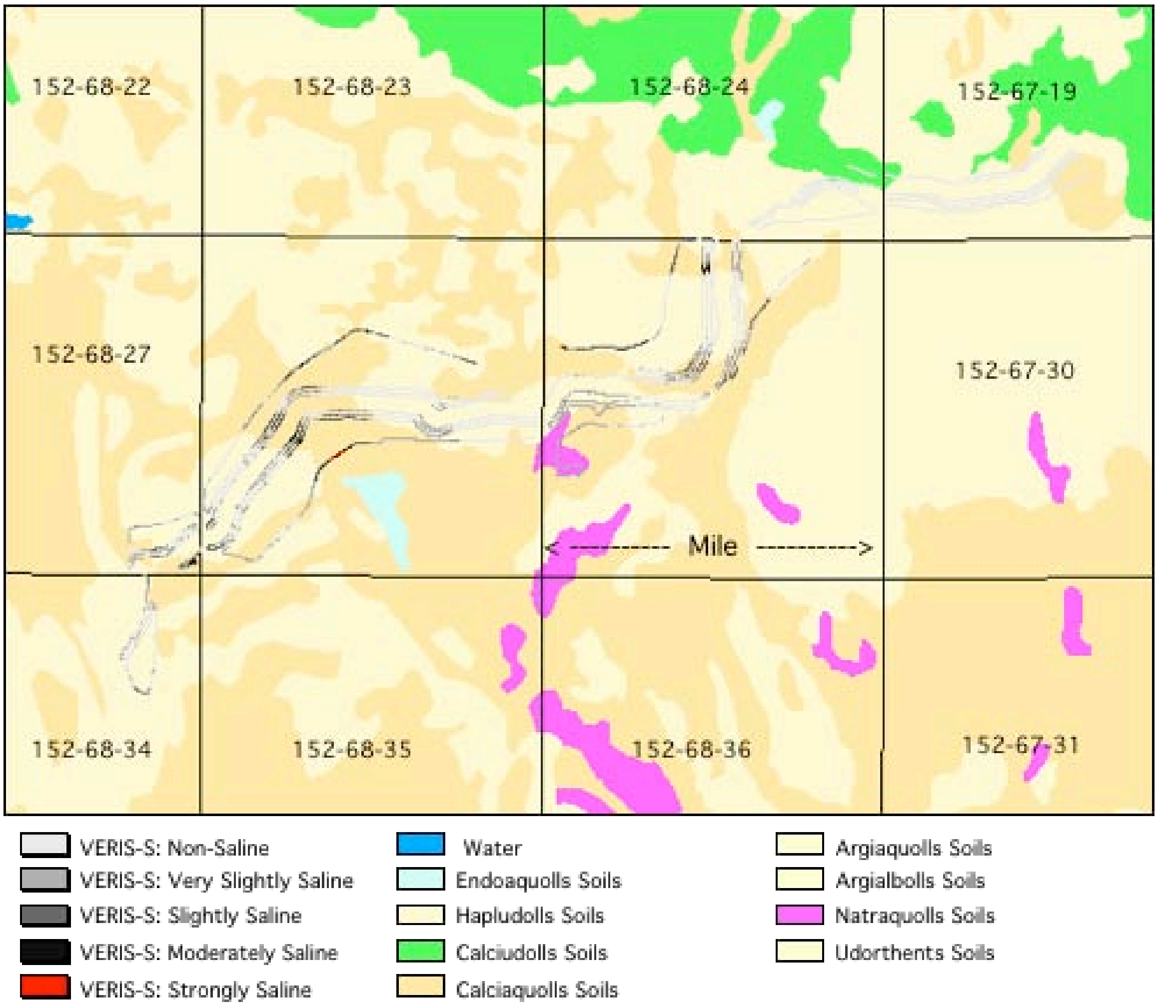


Figure A.2.4 Deep (1 to 3 feet depth) Veris™ : Middle Area

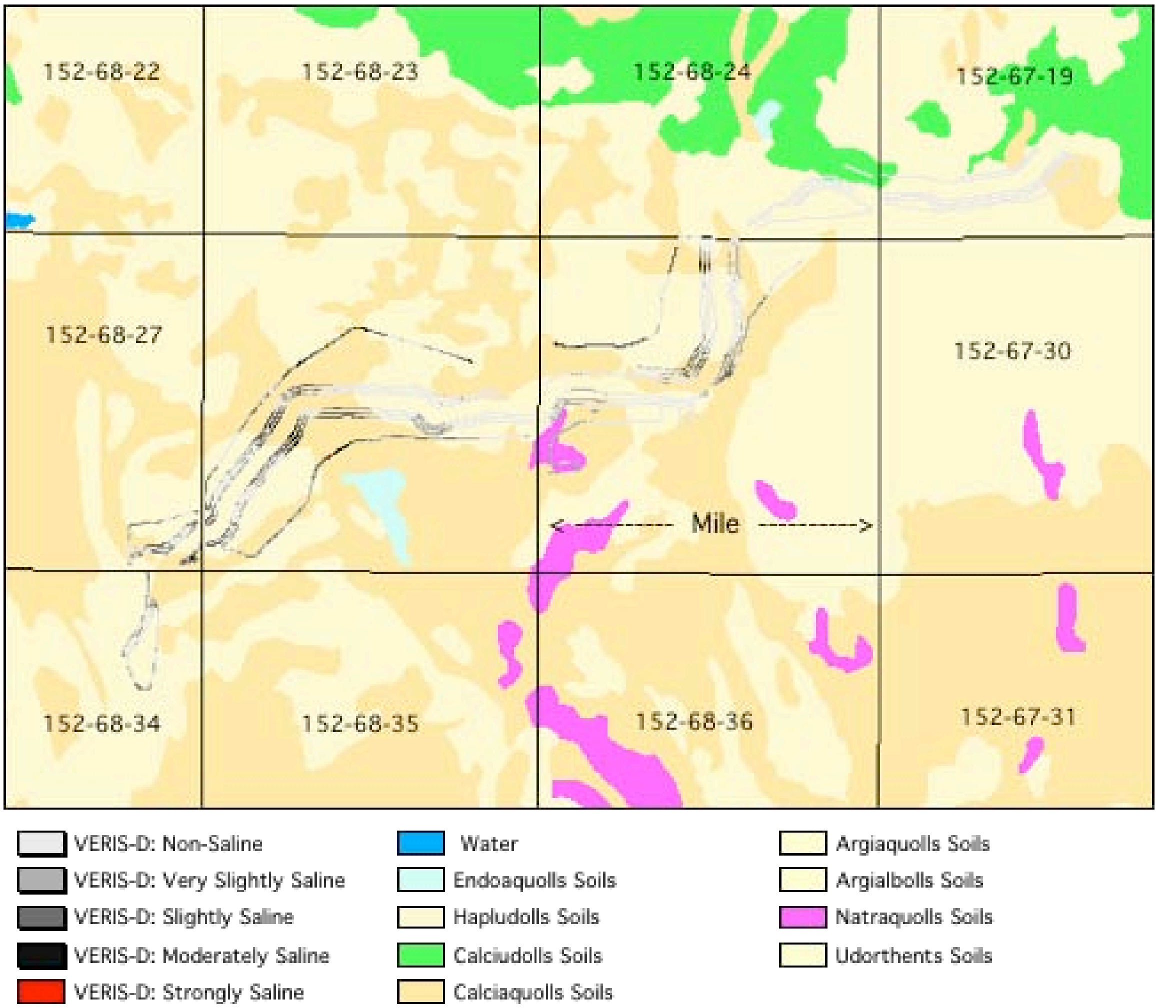


Figure A.2.5. Shallow (0 to 1 foot depth) Veris™ : South Area

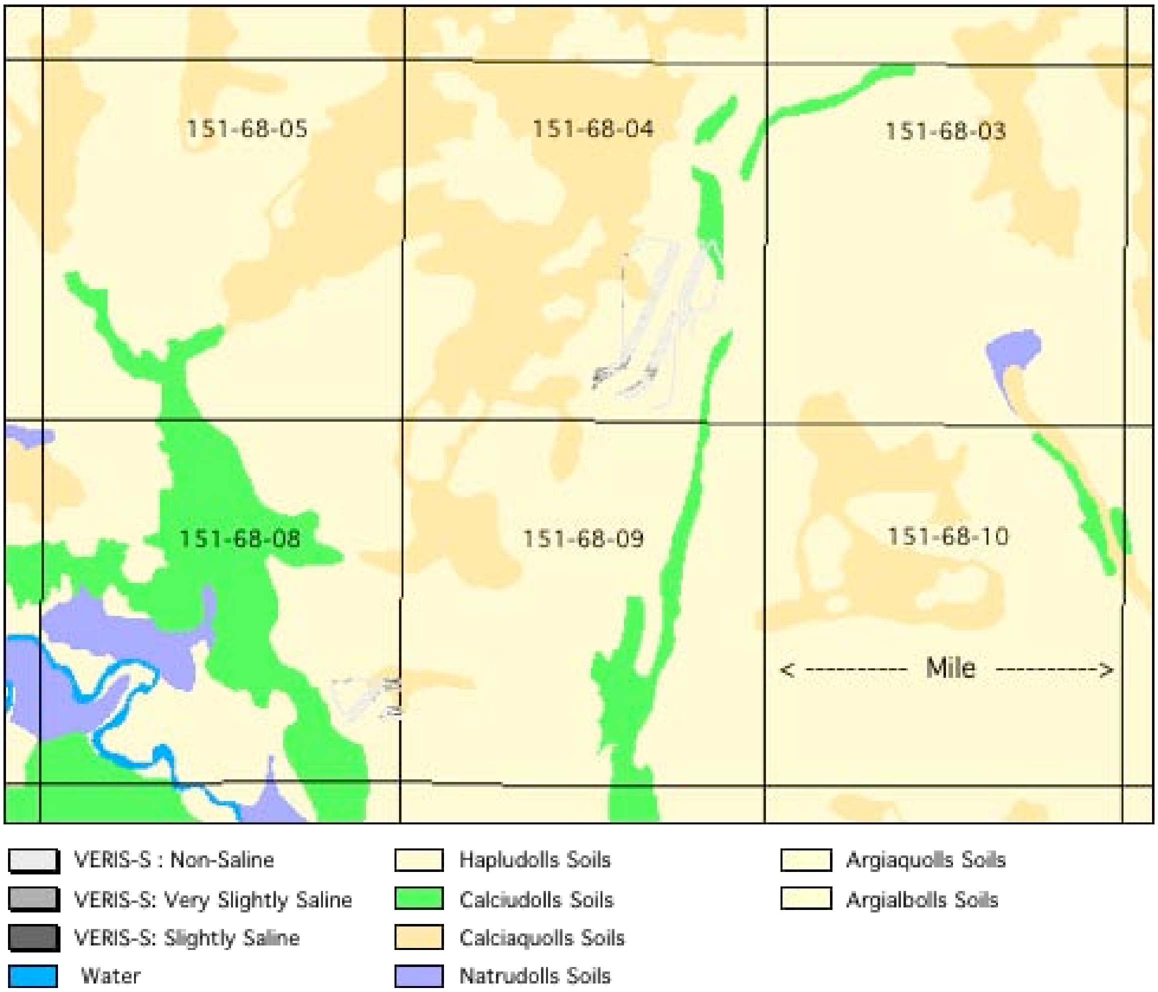
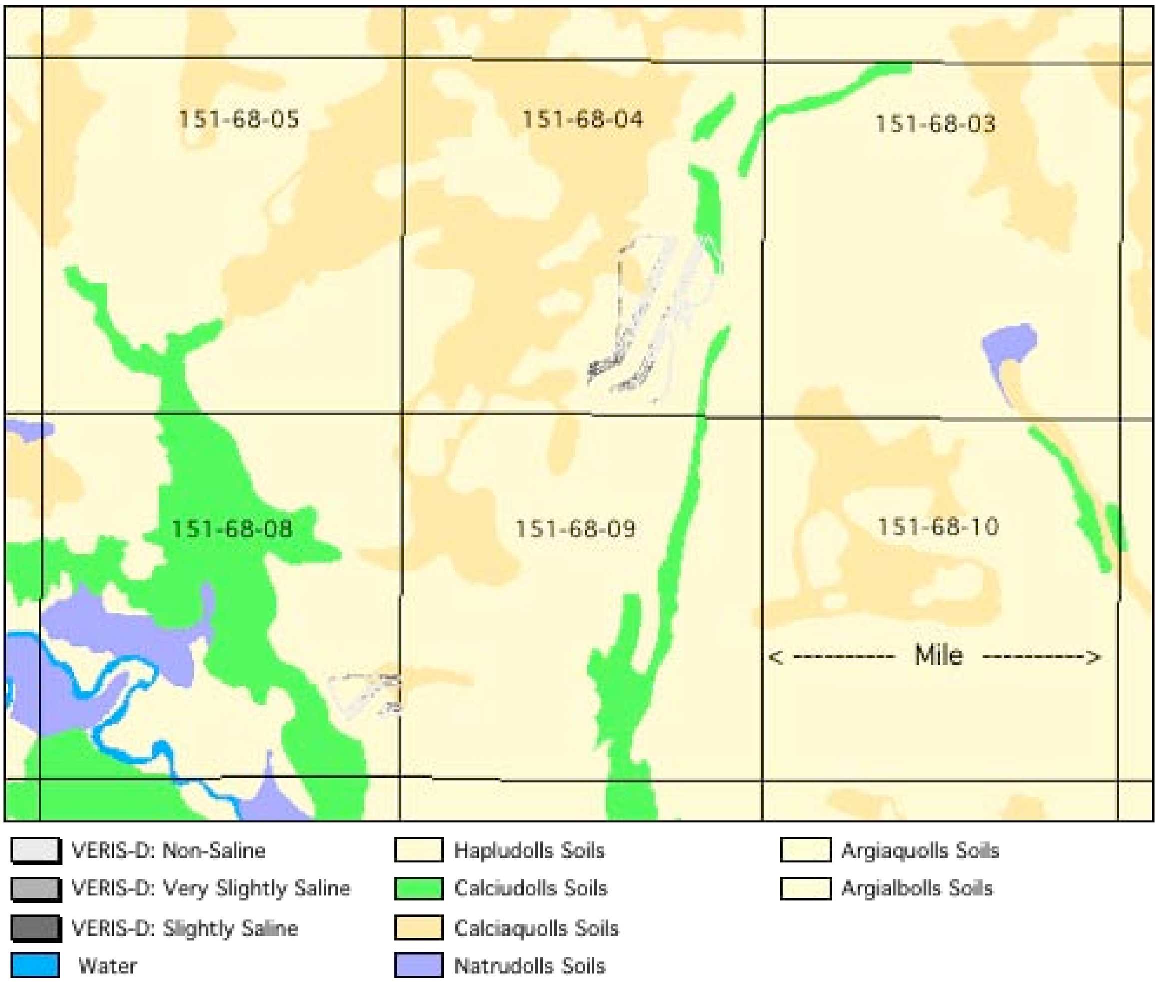


Figure A.2.6. Deep (1 to 3 feet depth) Veris™ : South Area



APPENDIX 3:

Data for Control Sites Used to Calculate EC_e from Veris™ EC_a

Table A.3.1. Shallow (0 to 1 foot) Veris™ EC_a, and laboratory data for Control Sites.

Site No.	EC_a mS/m	T °C	EC_a 25° C* mS/m	EC_e mS/m	PW %	SP %	Clay %	Sand %	Silt %	pH	O.M. g/cm³	Ca mg/L	Mg mg/L	Na mg/L	SAR	Sulfate mg/L	BD* g/cm³
1	15	9	21.754	59	15.8	52.5	25	47.5	27.5	7.7	3.11	4.1	1.3	1.2	0.73	-	1.19
1	16.9	9	24.51	59	15.8	52.5	25	47.5	27.5	7.7	3.11	4.1	1.3	1.2	0.73	-	1.19
2	6.3	8.5	9.2557	76	10.69	39.3	17.5	62.5	20	7.7	2.05	5	1.5	1.1	0.61	-	1.19
2	6.8	8.5	9.9902	76	10.69	39.3	17.5	62.5	20	7.7	2.05	5	1.5	1.1	0.61	-	1.19
3	55.6	8.5	81.685	394	20.5	55.8	30	35	35	7.3	3.62	23.8	22.4	13	2.7	-	1.35
3	63.3	8.5	92.997	394	20.5	55.8	30	35	35	7.3	3.62	23.8	22.4	13	2.7	-	1.35
4	100.9	8	150.18	700	20.68	65.1	27.5	42.5	30	7.7	1.09	23.6	38.8	43	7.7	-	1.17
5	38.6	8	57.452	79	18.47	58.8	40	27.5	32.5	7.2	3.53	3.7	3	1.2	0.66	-	1.3
5	38.9	8	57.898	79	18.47	58.8	40	27.5	32.5	7.2	3.53	3.7	3	1.2	0.66	-	1.3
6	385.3	8.5	566.06	1180	22.9	70.1	40	30	30	7.2	4.15	23.3	77	92	13	-	1.42
6	356.8	8.5	524.19	1180	22.9	70.1	40	30	30	7.2	4.15	23.3	77	92	13	-	1.42
7	9.3	5	14.989	45	14.34	44.3	40	42.5	17.5	6.6	1.35	2.3	1.1	1	0.77	-	1.32
7	9.4	5	15.15	45	14.34	44.3	40	42.5	17.5	6.6	1.35	2.3	1.1	1	0.77	-	1.32
8	9.9	5	15.956	99	18.51	74.3	25	45	30	7.4	5.14	6.7	2	0.9	0.43	-	1.3
8	9.9	5	15.956	99	18.51	74.3	25	45	30	7.4	5.14	6.7	2	0.9	0.43	-	1.3
9	4.9	5	7.8972	113	9.25	32.9	15	65	20	7.2	2.25	9.5	1.4	1	0.43	-	1.32
9	5.6	5	9.0253	113	9.25	32.9	15	65	20	7.2	2.25	9.5	1.4	1	0.43	-	1.32
10	17.1	4.5	27.934	40	24.59	61.4	27.5	37.5	35	6.6	5.51	1.8	0.7	1.2	1.07	-	1.32
10	18	4.5	29.405	40	24.59	61.4	27.5	37.5	35	6.6	5.51	1.8	0.7	1.2	1.07	-	1.32
11	17.9	6	28.086	107	20.24	61	25	45	30	7.5	3.82	3.8	2.9	5	2.73	-	1.26
12	42.4	5	68.335	216	25.2	64.3	30	37.5	32.5	7.8	1.88	4.2	11.4	10.4	3.72	-	1.3
12	61.4	5	98.956	216	25.2	64.3	30	37.5	32.5	7.8	1.88	4.2	11.4	10.4	3.72	-	1.3
13	76	7	116.12	461	24.65	78.3	32.5	35	32.5	7.8	5.5	8.9	24.4	28.4	6.96	-	1.17
13	88.7	7	135.53	461	24.65	78.3	32.5	35	32.5	7.8	5.5	8.9	24.4	28.4	6.96	-	1.17
13	78.9	7	120.56	461	24.65	78.3	32.5	35	32.5	7.8	5.5	8.9	24.4	28.4	6.96	-	1.17
14	102.2	9	148.22	215	24.82	66.2	40	27.5	32.5	7.9	3.83	4.9	11.5	9.6	3.35	-	1.17
14	99.7	9	144.59	215	24.82	66.246	40	27.5	32.5	7.9	3.83	4.9	11.5	9.6	3.35	-	1.17
15	179.2	5	288.81	932	22.72	71.1	32.5	32.5	35	7.6	3.72	21.7	52	67	11	-	1.17
15	153.9	5	248.04	932	22.72	71.1	32.5	32.5	35	7.6	3.72	21.7	52	67	11	-	1.17
15	188	5	302.99	932	22.72	71.1	32.5	32.5	35	7.6	3.72	21.7	52	67	11	-	1.17
16	47.6	8	70.847	132	15.95	46.7	25	47.5	27.5	8.1	2.19	2.7	6.4	5.1	2.39	-	1.17
16	47.5	8	70.699	132	15.95	46.7	25	47.5	27.5	8.1	2.19	2.7	6.4	5.1	2.39	-	1.17
16	46.4	8	69.061	132	15.95	46.7	25	47.5	27.5	8.1	2.19	2.7	6.4	5.1	2.39	-	1.17
17	29.9	5.5	47.546	42	19.11	58	27.5	45	27.5	7.6	4.05	2.1	1.4	1.1	0.83	-	1.37
18	68.9	4.5	112.55	358	20.42	56	22.5	45	32.5	7.9	2.06	13.4	16.4	17.6	4.56	-	1.3
18	65.8	4.5	107.49	358	20.42	56	22.5	45	32.5	7.9	2.06	13.4	16.4	17.6	4.56	-	1.3
19	108.4	6	170.08	668	20.38	62.3	30	45	25	7.7	3.34	22.2	26.3	43	8.73	-	1.17
19	125.2	6	196.44	668	20.38	62.3	30	45	25	7.7	3.34	22.2	26.3	43	8.73	-	1.17
20	66.3	8	98.68	160	26.84	68.6	37.5	35	27.5	8	3.73	3.6	6.2	8.7	3.93	-	1.3
20	65.7	8	97.787	160	26.84	68.6	37.5	35	27.5	8	3.73	3.6	6.2	8.7	3.93	-	1.3
21	161.2	6.5	249.59	906	20.66	66.5	27.5	35	37.5	7.8	1.39	20.8	40.9	68	12.2	-	1.3
21	225.8	6.5	349.61	906	20.66	66.5	27.5	35	37.5	7.8	1.39	20.8	40.9	68	12.2	-	1.3
22	82.7	7	126.36	430	19.83	59	27.5	32.5	40	7.8	2.49	22.4	21.1	16.3	3.5	-	1.3
22	80.4	7	122.85	430	19.83	59	27.5	32.5	40	7.8	2.49	22.4	21.1	16.3	3.5	-	1.3
23	16.4	9.5	23.48	71	17.99	47.4	20	45	35	7.7	2.31	4.3	1.5	1.1	0.65	-	1.32
23	15.7	9.5	22.478	71	17.99	47.4	20	45	35	7.7	2.31	4.3	1.5	1.1	0.65	-	1.32
24	266.1	9.5	380.99	1640	23.13	72.3	37.5	27.5	35	7.9	3.85	24.6	116	136	16.2	-	1.17
24	292	9.5	418.07	1640	23.13	72.3	37.5	27.5	35	7.9	3.85	24.6	116	136	16.2	-	1.17
24	270	9.5	386.57	1640	23.13	72.3	37.5	27.5	35	7.9	3.85	24.6	116	136	16.2	-	1.17
24	322.8	9.5	462.16	1640	23.13	72.3	37.5	27.5	35	7.9	3.85	24.6	116	136	16.2	-	1.17
24	322.8	9.5	462.16	1640	23.13	72.3	37.5	27.5	35	7.9	3.85	24.6	116	136	16.2	-	1.17
25	21.2	5	34.167	105	19.99	63.3	25	30	45	7.5	4.42	6	3.5	2.1	0.96	-	1.3
25	24	5	38.68	105	19.99	63.3	25	30	45	7.5	4.42	6	3.5	2.1	0.96	-	1.3

*BD was estimated from published data as described in the report.

Table A.3.1. Deep (1 to 3 feet) Veris[TM] EC_a, and laboratory data for Control Sites.

Site No.	EC_a mS/m	T °C	EC_a 25° C* mS/m	EC_e mS/m	PW %	SP %	Clay %	Sand %	Silt %	pH	O.M. g/cm^3	Ca mg/L	Mg mg/L	Na mg/L	SAR	Sulfate mg/L	BD* g/cm^3
1	19.9	9	28.86	50	15.86	50.7	35	42.5	22.5	8.3	1.59	1.2	2.8	1.4	0.99	44.4	1.39
1	20	9	29.005	50	15.86	50.7	35	42.5	22.5	8.3	1.59	1.2	2.8	1.4	0.99	44.4	1.39
2	5.9	8.5	8.668	82	8.27	35.7	20	57.5	22.5	7.9	0.71	3.1	3.2	1.3	0.73	37	1.39
2	6.3	8.5	9.2557	82	8.27	35.7	20	57.5	22.5	7.9	0.71	3.1	3.2	1.3	0.73	37	1.39
3	113.2	8.5	166.31	432	18.38	51.2	37.5	27.5	35	8	1.21	7.5	23.1	27.4	7	2760	1.21
3	116.6	8.5	171.3	432	18.38	51.2	37.5	27.5	35	8	1.21	7.5	23.1	27.4	7	2760	1.21
4	160.4	8	238.74	912	22.1	53.2	35	37.5	27.5	7.9	0.7	20.9	49.1	74	12.5	6940	1.39
5	53	8	78.885	387	15.1	51.2	37.5	27.5	35	7.8	1.09	24.5	29.9	6.5	1.25	2920	1.45
5	50.7	8	75.461	387	15.1	51.2	37.5	27.5	35	7.8	1.09	24.5	29.9	6.5	1.25	2920	1.45
6	237	8.5	348.19	1020	19.98	63.7	47.5	25	27.5	7.7	1.4	23.5	49.6	79	13.1	7280	1.63
6	255.6	8.5	375.52	1020	19.98	63.7	47.5	25	27.5	7.7	1.4	23.5	49.6	79	13.1	7280	1.63
7	6.7	5	10.798	98	4.96	21.1	10	72.5	17.5	7.6	0.5	4.6	3.3	1.3	0.65	21.4	1.75
7	7.2	5	11.604	98	4.96	21.1	10	72.5	17.5	7.6	0.5	4.6	3.3	1.3	0.65	21.4	1.75
8	13.5	5	21.758	41	19.48	59.7	25	37.5	37.5	7.5	3.54	2.3	0.9	1.1	0.87	31.5	1.37
8	13.8	5	22.241	41	19.48	59.7	25	37.5	37.5	7.5	3.54	2.3	0.9	1.1	0.87	31.5	1.37
9	8.9	5	14.344	105	7.68	27.9	12.5	70	17.5	7.5	1.04	6.2	2.6	1.1	0.52	22.8	1.75
9	8.9	5	14.344	105	7.68	27.9	12.5	70	17.5	7.5	1.04	6.2	2.6	1.1	0.52	22.8	1.75
10	17.9	4.5	29.241	38	14.46	37.1	20	55	25	6.1	0.53	1.6	0.8	1.1	1	61.6	1.75
10	18	4.5	29.405	38	14.46	37.1	20	55	25	6.1	0.53	1.6	0.8	1.1	1	61.6	1.75
11	4.9	6	7.6883	147	16.41	30.4	17.5	67.5	15	7.7	2.14	4.4	3.9	5.9	2.9	150	1.43
12	2.1	5	3.3845	143	20.87	43	25	27.5	47.5	8.1	0.69	3.1	7.5	5.2	2.26	415	1.37
12	55.6	5	89.609	143	20.87	43	25	27.5	47.5	8.1	0.69	3.1	7.5	5.2	2.26	415	1.37
13	59.8	7	91.372	314	22.59	47.3	30	27.5	42.5	8.1	1.01	6.1	18.2	16.2	4.65	1760	1.39
13	64.8	7	99.012	314	22.59	47.3	30	27.5	42.5	8.1	1.01	6.1	18.2	16.2	4.65	1760	1.39
13	66	7	100.85	314	22.59	47.3	30	27.5	42.5	8.1	1.01	6.1	18.2	16.2	4.65	1760	1.39
14	99.1	9	143.72	143	19.65	46.9	27.5	30	42.5	8.1	1.23	3.6	6.7	6.5	2.86	530	1.39
14	101.1	9	146.62	143	19.65	46.9	27.5	30	42.5	8.1	1.23	3.6	6.7	6.5	2.86	530	1.39
15	143.2	5	230.79	863	22.74	55.4	32.5	25	42.5	7.9	0.68	21.7	52.7	57	9.35	6400	1.39
15	147.5	5	237.72	863	22.74	55.4	32.5	25	42.5	7.9	0.68	21.7	52.7	57	9.35	6400	1.39
15	161.4	5	260.12	863	22.74	55.4	32.5	25	42.5	7.9	0.68	21.7	52.7	57	9.35	6400	1.39
16	38.2	8	56.857	78	20.56	43.7	30	37.5	32.5	8.3	1.31	1.7	4.9	2.2	1.21	131	1.39
16	38.3	8	57.005	78	20.56	43.7	30	37.5	32.5	8.3	1.31	1.7	4.9	2.2	1.21	131	1.39
16	38.9	8	57.898	78	20.56	43.7	30	37.5	32.5	8.3	1.31	1.7	4.9	2.2	1.21	131	1.39
17	45.1	5.5	71.716	60	14.51	42.9	22.5	47.5	30	8.2	1.18	1.8	2.6	1.8	1.21	52.8	1.42
18	109.1	4.5	178.22	413	20.52	50.2	25	42.5	32.5	8.4	0.84	2.9	9.6	34	13.6	1860	1.37
18	117.4	4.5	191.78	413	20.52	50.2	25	42.5	32.5	8.4	0.84	2.9	9.6	34	13.6	1860	1.37
19	136.9	6	214.8	575	18.17	43.5	25	52.5	22.5	8.1	1.01	6.5	17.4	45	13	3180	1.39
19	152.2	6	238.81	575	18.17	43.5	25	52.5	22.5	8.1	1.01	6.5	17.4	45	13	3180	1.39
20	63.7	8	94.811	91	24.71	48.9	37.5	35	27.5	8.1	0.86	3	3	3.7	2.14	291	1.37
20	64.2	8	95.555	91	24.71	48.9	37.5	35	27.5	8.1	0.86	3	3	3.7	2.14	291	1.37
21	213.7	6.5	330.87	1050	20.89	45.9	25	32.5	42.5	8.1	0.99	9.6	56	84	14.7	7300	1.37
21	250.7	6.5	388.16	1050	20.89	45.9	25	32.5	42.5	8.1	0.99	9.6	56	84	14.7	7300	1.37
22	131.7	7	201.23	628	17.09	40.1	25	50	25	8	0.47	14.8	45.8	31.4	5.7	4200	1.37
22	157.4	7	240.5	628	17.09	40.1	25	50	25	8	0.47	14.8	45.8	31.4	5.7	4200	1.37
23	15.6	9.5	22.335	134	11.36	27	12.5	72.5	15	8	0.96	4.9	6.5	1.7	0.71	33.2	1.75
23	16	9.5	22.908	134	11.36	27	12.5	72.5	15	8	0.96	4.9	6.5	1.7	0.71	33.2	1.75
24	294.3	9.5	421.36	1580	22.59	66.7	40	22.5	37.5	8.2	1.34	22.5	144	120	13.2	13700	1.39
24	295.8	9.5	423.51	1580	22.59	66.7	40	22.5	37.5	8.2	1.34	22.5	144	120	13.2	13700	1.39
24	310.8	9.5	444.98	1580	22.59	66.7	40	22.5	37.5	8.2	1.34	22.5	144	120	13.2	13700	1.39
24	311.8	9.5	446.42	1580	22.59	66.7	40	22.5	37.5	8.2	1.34	22.5	144	120	13.2	13700	1.39
24	324.7	9.5	464.88	1580	22.59	66.7	40	22.5	37.5	8.2	1.34	22.5	144	120	13.2	13700	1.39
25	79.1	5	127.48	452	16.75	45.8	35	30	35	7.9	1.27	14.9	32.2	16.2	3.34	2540	1.37
25	85.1	5	137.15	452	16.75	45.8	35	30	35	7.9	1.27	14.9	32.2	16.2	3.34	2540	1.37

*BD was estimated from published data as described in the report.