Subject: **PV-SWW Mobilized Salinity Assessment Survey Results**

Project: Palo Verde Demonstration Field #1
Date: April, 2001
Location: Palo Verde

1. Survey Data

EM-38 horizontal and vertical survey readings were collected at 1777 survey locations across 25 distinct transects within this field. EM-38 vertical signal readings ranged from 30 mS/m to 304 mS/m, with a median level of 96.3 mS/m. EM-38 horizontal signal readings ranged from 17 mS/m to 207 mS/m, with a median level of 70.5 mS/m. The vertical / horizontal signal correlation was extremely high (r = 0.979: log EM scale).

Maps of the vertical and horizontal spatial signal patterns are shown in figures 1.1 and 1.2, respectively. In a relative sense, these two maps are nearly identical (only the scales differ). Both maps show the presence of a distinct "finger" of high conductance extending down vertically from the northern field boundary. This feature then seems to fan-out into a swath of moderately high conductance, which sweeps over towards the eastern boundary. A distinctly low conductance zone is also obvious along the western boundary, and the transition between zones seems especially sharp (at least within the western half of the field).

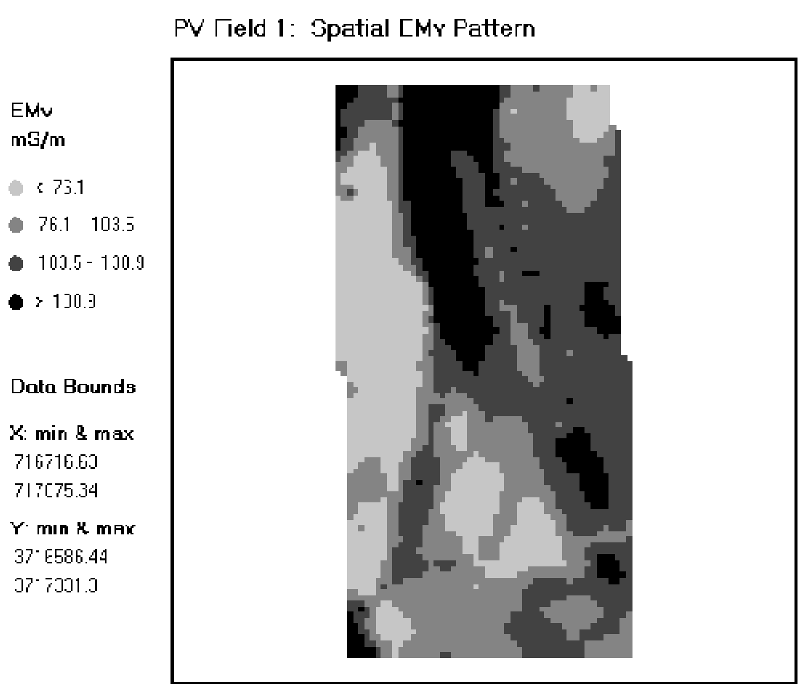

Figure 1.1: Observed spatial EMv signal pattern.

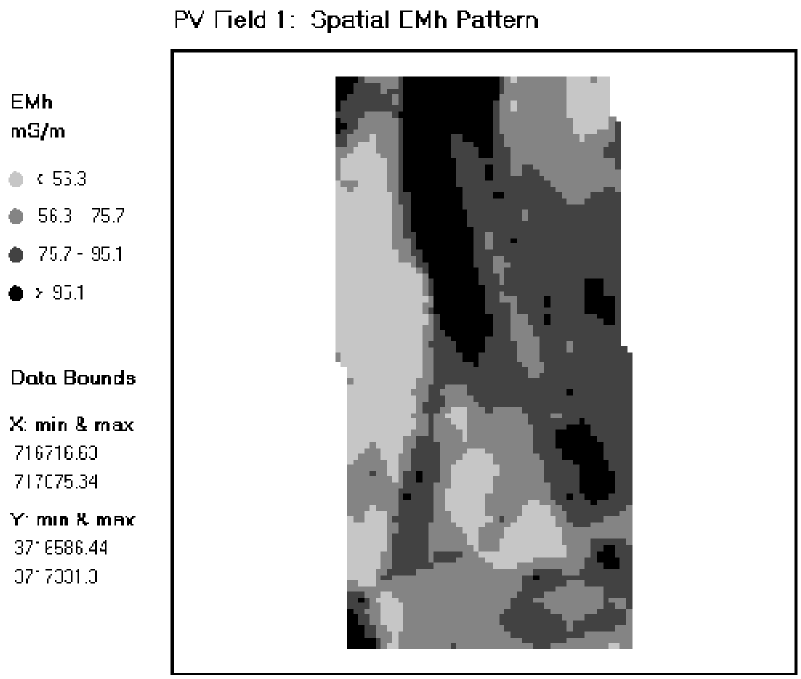

Figure 1.2: Observed spatial EMh signal pattern.

2. Soil Sample Data

The ESAP-95 software package was used to process the EM survey data and generate the soil sampling plan. Twelve (12) optimal sampling locations were identified, based on the EM survey data. At each sampling location, soil samples were acquired using a hand auger in 1-foot intervals down to a depth of 3 feet. These 36 soil samples were then analyzed for the following four soil chemical and physical properties:

Property	Description
ECe	Salinity (dS/m)
SP	Saturation Percentage (%)
Vol H2o	Volumetric water content (ratio, estimated)
H2o | FC	Water content relative to field capacity (%, estimated)

The ECe (salinity), SP (texture), and H2o |FC (water content relative to field capacity) were of particular interest to the farmer, since this field had displayed some evidence of reduced yields in recent years. (The farmer felt that this yield loss was possibly due to either salinity or permeability problems in the field.)

Some basic summary statistics pertaining to the analyzed laboratory soil samples are shown below. Additionally, figures 2.1 through 2.4 show the observed profile shapes for each of these four soil variables.

Soil Variable	depth level	mean	std.dev	min	max
ECe	0.50	2.159	2.372	0.850	9.570
	1.50	3.589	2.786	1.240	10.780
	2.50	3.308	2.569	1.470	11.010
SP	0.50	75.942	11.242	57.500	90.900
	1.50	67.200	20.644	29.800	93.100
	2.50	59.308	26.390	28.600	97.600
Vol H2o	0.50	0.285	0.027	0.248	0.333
	1.50	0.285	0.044	0.192	0.326
	2.50	0.259	0.092	0.114	0.350
%H2o | FC	0.50	62.179	4.676	55.034	71.343
	1.50	70.230	10.086	52.404	84.094
	2.50	69.086	12.938	51.818	98.901

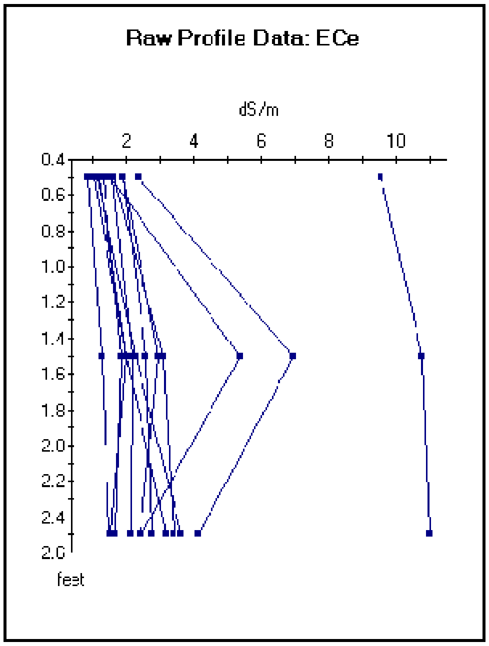

Figure 2.1: ECe profile data.

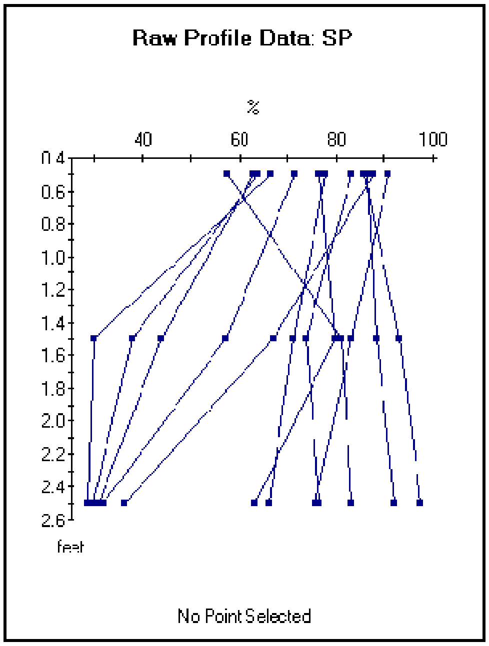

Figure 2.2: SP profile data.

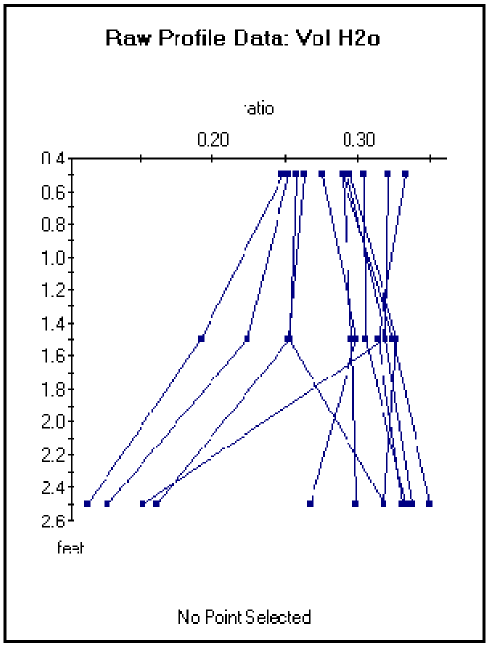

Figure 2.3: Vol H2o profile data.

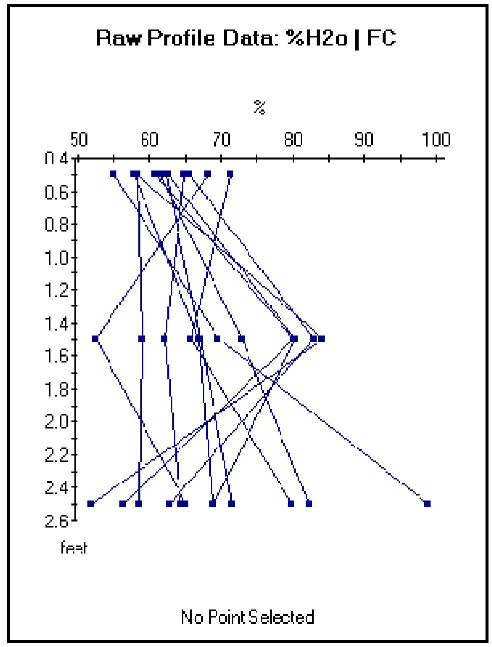

Figure 2.4: %H2o|FC profile data.

The mean sample salinity level was about 2 dS/m in the first foot, and about 3.5 dS/m in the second and third foot. The range estimates (from 1 to 10 dS/m) suggest significant salinity variation, but it is clear from the profile plot (figure 2.1) that this is not the case. Nine of the 12 sample cores had salinity levels less than 3 dS/m throughout the profile, and only one core appears to have particularly elevated salinity levels.

The mean SP levels through the first three feet (76%, 67%, and 59%, respectively) suggest that the soil texture is becoming lighter with depth. The SP range estimates for the 1-2 and 2-3 foot depths suggest extreme textural variation (min < 30%, max > 90%). The SP profile data suggest that possibly two distinct texture profiles exist in this field: heavy clay profiles (which appear to be apparently uniform with depth) and stratified loamy clay-to-sand profiles. The estimated volumetric water content levels and profile shapes reflect these textural differences. However, the estimated average percent water content relative to field capacity data appears to be much more uniform, and this latter water content data also appears to be somewhat less variable.

3. DPPC Correlation Assessment & Data Analysis Results

A DPPC (dual pathway parallel conductance) correlation assessment was performed on the combined survey and soil sample data, using the DPPC correlation modeling procedure contained within the ESAP-Calibrate program. The observed correlation between the (log transformed) average EM signal data and (log transformed) bulk average calculated conductivity data was a very respectable 0.910, suggesting good agreement between the measured and calculated conductivity levels. However, the calculated EM signal deterioration (due to texture and water content variation) was 44.1%, implying that our ability to accurately map the spatial salinity pattern from the EM survey data might be significantly impaired. The correlation estimate between the observed, bulk average texture (SP) and volumetric water content data was quite high ® = 0.894), but all remaining pair-wise correlation estimates (between the salinity, SP, vol H2o, and %H2o data) were low.

The extreme SP variation and strong SP / vol H2o apparent correlation implies that the EM survey data should respond most strongly to changes in the soil texture and (volumetric) water content. Not surprisingly, this appeared to be the case, as shown by the correlation estimates between the (log transformed) average EM signal data and bulk average soil data:

Variables	Correlation
log(EM) / log(ECe)	0.547
log(EM) / SP	0.890
log(EM) / vol H2o	0.794
log(EM) / %H2o	-0.283

These initial correlation estimates suggest that the EM survey data can be used to effectively map the variation in SP (texture) data, and most of the variation in the estimated volumetric water content data (if desired). The percent water content data (relative to field capacity) appears to be unrelated to the EM data (and thus can not be mapped). The EM / salinity correlation is dangerously low.

4. Soil SP and ECe Maps

The initial, raw correlation between the measured average log(EM) conductivity and SP was quite good, (r = 0.890), while the log(EM) / log(ECe) correlation was weak (r = 0.547). However, both correlation estimates greatly improved after the EM signal data was adjusted using the ESAP-95 spatial regression modeling procedure. The final predicted correlations between the trend-adjusted log(EM) conductivity data and bulk average soil variables discussed above were as follows:

Soil Variable	Model R^2	CV%	Root MSE	Corr(Obs,Prd)
ECe (dS/m)	0.717	39.1	*n/a*	0.847
SP (%)	0.934	*n/a*	5.32	0.966

Note that the inclusion of significant east-west trend surface effects substantially improved the accuracy of both spatial regression models, as demonstrated by the final observed versus predicted data plots shown in figures 4.1 (ECe) and 4.2 (SP).

When fit to the depth specific SP and log(ECe) sample data, these same trend adjusted regression models produced the following statistics:

Soil Variable	Depth	Model R^2	CV%	Corr(Obs,Prd)
ECe (dS/m)	0-1 ft	0.895	25.6	0.946
	1-2 ft	0.643	49.2	0.802
	2-3 ft	0.616	44.6	0.785

Soil Variable	Depth	Model R^2	Root MSE	Corr(Obs,Prd)
SP	0-1 ft	0.457	9.71	0.676
	1-2 ft	0.862	9.01	0.928
	2-3 ft	0.872	11.09	0.934

The above statistics indicate that accurate field mean and range interval estimates can be constructed for both variables, but that the spatial accuracy associated with 3 of the 6 depth specific maps will be less than satisfactory (i.e., $R^2 < 0.7$).

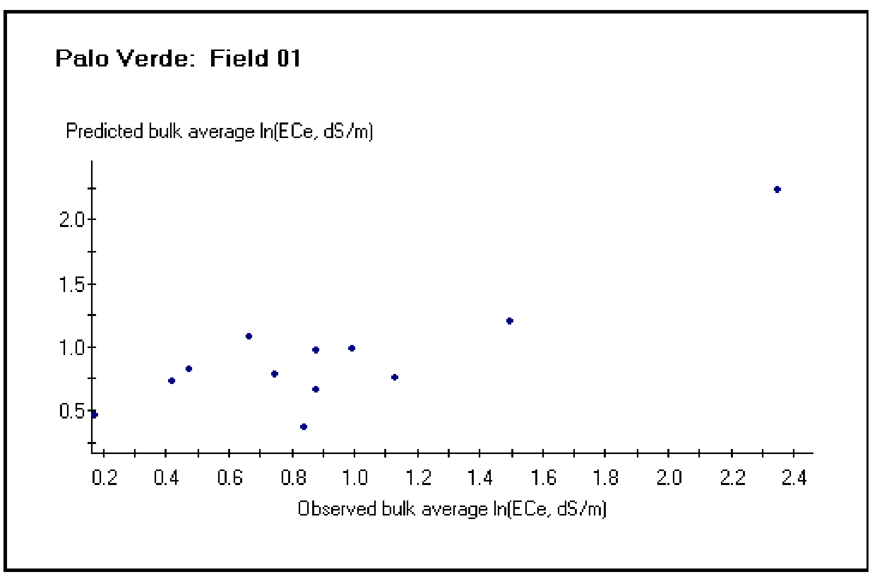

Figure 4.1: Regression model predicted v.s. observed bulk average log(ECe) sample data.

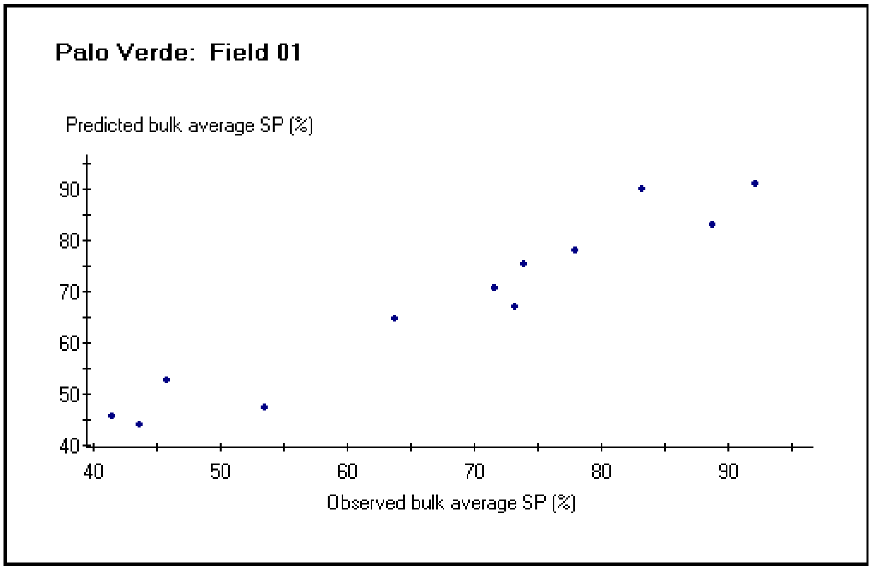

Figure 4.2: Regression model predicted v.s. observed bulk average SP sample data.

Depth specific and bulk average prediction summary statistics for the predicted soil salinity levels are shown in Table 4.1. These statistics refer to the 0-1, 1-2, 2-3, and 0-3 foot sampling depths, and include both the predicted median levels for the entire field and range interval estimates (i.e., the percent area of the field containing salinity levels within the given ranges). Depth specific and bulk average prediction summary statistics for the predicted SP levels are shown in Table 4.2. These statistics also refer to the 0-1, 1-2, 2-3, and 0-3 foot sampling depths, and include both the predicted mean levels for the entire field and SP range interval estimates.

Table 4.1. Field salinity (ECe, dS/m) summary prediction statistics.

I. Back-Transformed Field Median Point Estimates [ECe]

depth	median	95% Confidence Interval
0.50	1.781	1.49 to 2.13
1.50	3.016	2.17 to 4.20
2.50	2.912	2.15 to 3.94
bulk average	2.618	2.00 to 3.43

Table 4.1 continued...

II. Field Range Interval Estimates

depth	range 1	range 2	range 3	range 4
0.50	61.04	28.20	8.54	2.22
1.50	30.37	35.50	22.99	11.14
2.50	28.44	41.00	23.21	7.35
bulk average	34.89	40.26	18.92	5.94

range[1]: < 2.000
range[2]: 2.000 to 4.000
range[3]: 4.000 to 8.000
range[4]: > 8.000

Table 4.2. Field texture (SP, %) summary prediction statistics.

I. Field Average Point Estimates [SP]

depth	mean	variance	95% Confidence Interval
0.50	75.35746	11.51688	67.532 to 83.183
1.50	68.38271	9.91123	61.123 to 75.642
2.50	58.11099	15.01708	49.175 to 67.047
bulk average	67.2837	3.45693	62.996 to 71.571

II. Field Range Interval Estimates

depth	range 1	range 2	range 3	range 4
0.50	2.25	11.18	34.96	51.60
1.50	11.57	19.66	30.53	38.25
2.50	30.04	21.78	22.76	25.41
bulk average	7.95	23.71	35.64	32.69

range[1]: < 45.000
range[2]: 45.000 to 60.000
range[3]: 60.000 to 75.000
range[4]: > 75.000

The field median salinity estimates (table 4.1) were calculated to be 1.78, 3.02, 2.91, and 2.62 dS/m for the 0-1, 1-2, 2-3, and 0-3 foot depths, respectively. The range interval estimates indicate that about 10% of the 0-1 foot field salinity levels exceed 4 dS/m, and about 30% of the 1-2 and 2-3 foot levels exceed 4 dS/m. Overall, the majority of the field salinity levels appear to be quite low, especially given the average EM-38 signal levels.

The field mean SP estimates (table 4.2) indicate that the average saturation percentage levels decrease with depth (75, 68, and 58% for the 0-1, 1-2, and 2-3 foot depths, respectively).

The range interval estimates indicate that substantial variation in the soil SP levels exists throughout the field, especially at the deeper depths.

The final predicted bulk average salinity map is shown in figure 4.3 below. This map clearly shows a build up of soil salinity towards the western side of the field, in addition to an apparent salinity incursion coinciding with the high conductance finger (extending down vertically from the northern field boundary).

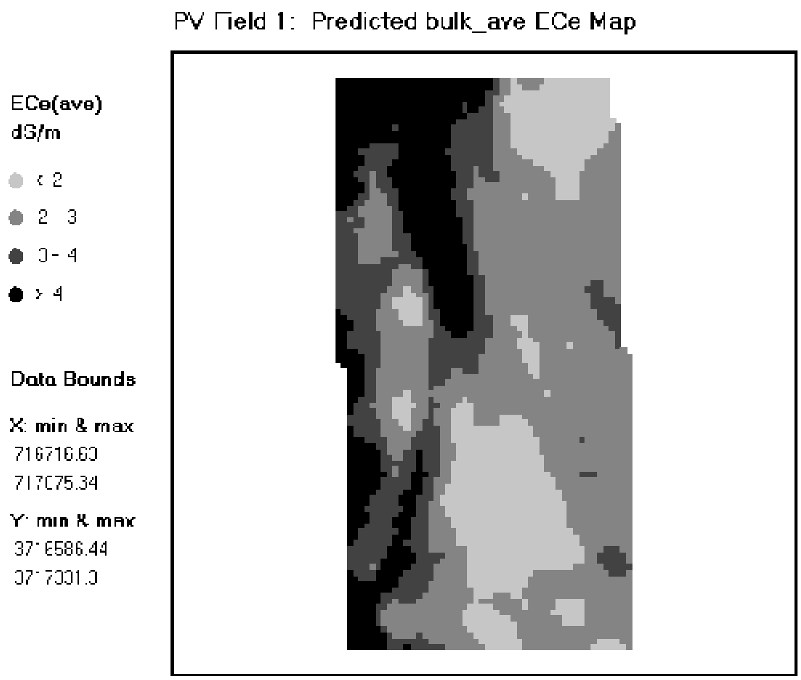

Figure 4.3: Final prediction bulk average (0-3 ft) salinity map.

The final predicted bulk average SP map is shown in figure 4.4 on the next page. In contrast to the salinity pattern, this map shows that the heaviest soil texture occurs on the eastern side of the field. Note that the high conductance finger is still partially visible within the textural pattern, although it is not as pronounced in this second map.

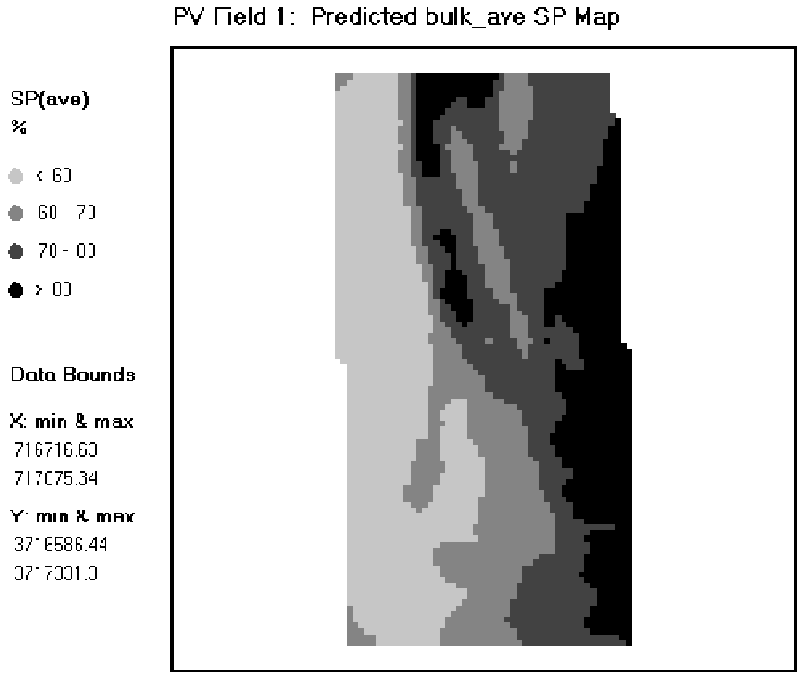

Figure 4.4: Final predicted bulk average (0-3 ft) SP map.

5.0 Yield Loss Calculations & General Field Assessment

Projected salt tolerance yield losses for three representative crops (alfalfa, cotton, and red clover) were estimated using the ESAP-Calibrate program. Based on the previously discussed ECe predictions, the yield loss estimates were calculated to be 12% for alfalfa, 2% for cotton, and 20% for red clover. Alfalfa represents a moderately salt sensitive crop, and the dominant crop throughout the Palo Verde region. Likewise, cotton was chosen because it represents a reasonably salt tolerant crop, and red clover represents a salt sensitive crop. These yield loss estimates suggest that economically significant yield losses would possibly occur only if one attempted to cultivate a salt sensitive crop in this field.

The overall spatial pattern of the apparent salinity levels may very well be due in part simply to the irrigation direction (furrow irrigated from east to west). Although the runs are not especially long (approximately 340 meters), the repetitive application of head-to-tail water flow over many years can still easily lead to a tail end salinity build-up. The spatial complexity of the salinity pattern within the western half of the field is most likely due to the interaction of this water flow with the highly variable near-surface soil texture.

In many respects, the salinity levels are surprisingly low in this field (especially for the heaviest soil texture areas). Additionally, the current irrigation practice (i.e., water-flow direction) is actually fortuitous. If this field was irrigated from west to east, then the tail end of the furrow runs would coincide with the heaviest soil textures (rather than the lightest). In such a scenario, the tail end build-up in salinity could be substantially worse.

On a final, purely scientific note: we were actually quite fortunate to be able to distinguish both the spatial soil texture (SP) and salinity (ECe) pattern in this field. EM-38 survey data can often be used to map both texture and salinity in saline fields, when these properties are highly correlated. However, it is rather unusual to be able to map both properties in a marginally saline field where these properties are poorly correlated. Our ability to successfully accomplish such a breakout in this field is primarily due to the pronounced spatial trends apparent in both properties. The ability to detect and incorporate such trends (using spatial regression equations) is one of the most important features inherent in the stochastic modeling approach.

6.0 Additional Comments

Approximately one year before this survey took place, the owner had dug (and refilled) a series of trenches along the northern edge of this field (apparently in an attempt to improve the soil permeability). Not surprisingly, he was interested if the EM survey data could detect these trenches, and/or possibly shed some light on their effectiveness.

Figure 6.1 shows both the EM vertical and horizontal signal data along a single, detailed transect (located about 50 feet in from the northern edge of the field), collected immediately after the primary survey was finished. Although the field was fallow during the time of the EM survey, there was no visual evidence indicating the locations of the previous trenching operations. However, the recorded EM-38 data obviously shows sudden, abrupt disturbances in the transect pattern (as indicated by the sudden drops in conductivity readings). Figure 6.2 shows the locations of these disturbances even more sharply, via a plot of the ratio of the EMh versus (EMh+EMv) data. The abrupt drops in this ratio plot represent sudden changes in on or more soil properties (which manifest themselves more strongly in the surface weighted horizontal readings than the depth weighted vertical readings).

While the apparent locations of the trenching operations clearly stand out, the resulting effect on the soil is much harder to determine. Since the trenching process would be expected to significantly disturb the natural soil structure, it is difficult to infer exactly how much of the drop in soil conductivity is due to a reduction in soil salinity (versus a change in bulk density, volumetric soil water content, and/or an inversion of the textural profile, etc.). None the less, their overall effectiveness seems rather marginal. These reductions in conductivity seem to be extremely localized, which implies that there has been little (if any) effect on the immediately surrounding, non-trenched soil.

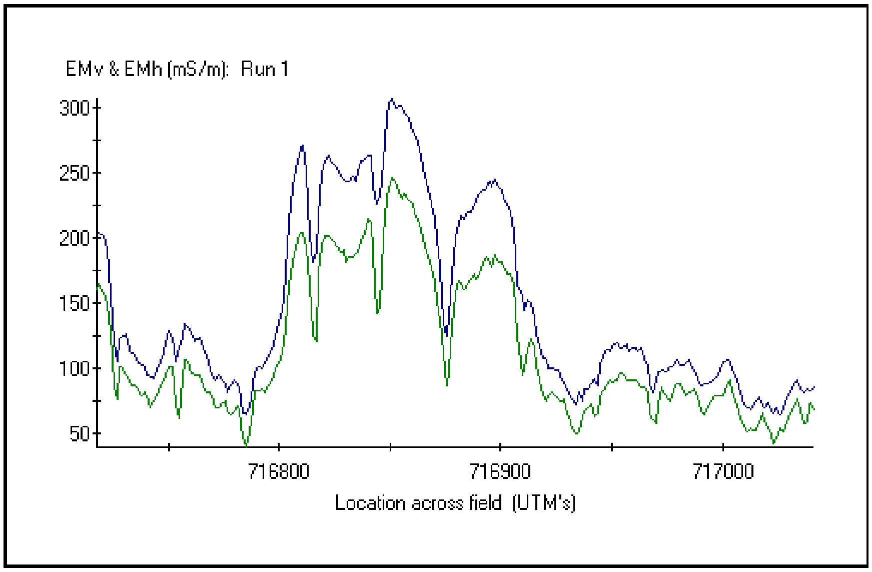

Figure 6.1: Detailed EM transect run showing probable locations of previous trenching operations.

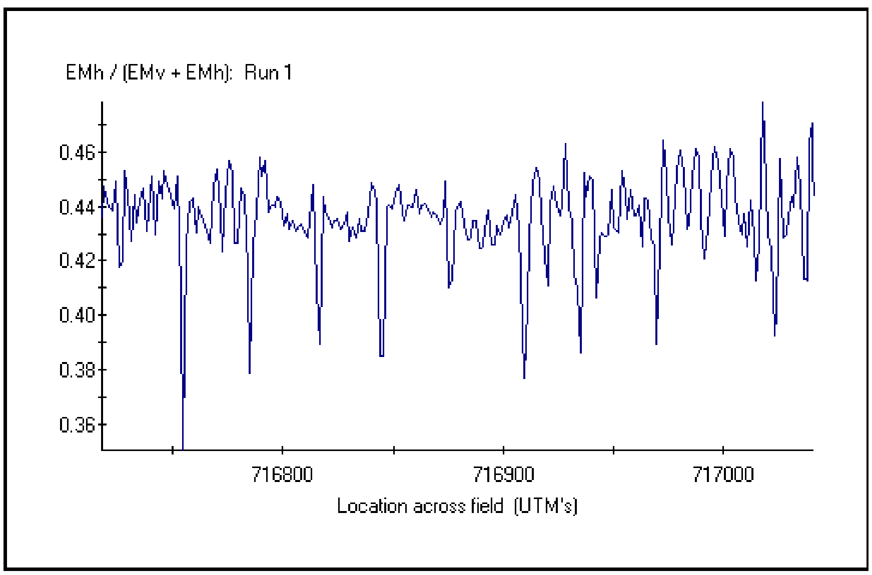

Figure 6.2: EM ratio plot (EMh / [EMh+EMv]) which clearly displays the exact locations of disturbed EM signal readings.

Survey work performed by

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Note: *All spatial maps shown in this document were produced using the ESAP-SaltMapper program, beta version 2.11. A general user version of this program is due to be released by the Salinity Laboratory in October, 2001.*

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