Subject: **EM-38 Salinity Assessment Survey Results**
Ag 20/20 Project

Date: March 2000

Location: Sheely Farms: fields 6.2 & 6.3, Central CA

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1. Summary

The following report documents the results of two EM-38 surveys carried out in two adjacent central California agricultural fields. These surveys were performed in order to describe and predict the spatial soil salinity conditions within each field at the time of the survey, and to also quantify and predict the existing spatial SAR, Boron, and soil texture (SP) conditions.

The ESAP-95 software package was used to process and analyze this conductivity survey and soil sample data, including the development of the calibration equations and the creation of the predicted soil variable maps. The ESAP-95 package contains three integrated programs: ESAP-RSSD, ESAP-Calibrate, and ESAP-SaltMapper. These programs are designed to generate optimal sampling designs from conductivity survey information (RSSD), estimate optional conductivity to salinity calibration models (Calibrate), and produce observed conductivity and/or predicted soil salinity maps (SaltMapper). For these two fields, excellent predictive relationships were established between the EM-38 conductivity readings and depth specific soil salinity data collected from the two fields. Excellent predictive relationships were also established between the EM-38 conductivity readings and the bulk average SAR, Boron, and SP data collected from these fields.

2. Survey Data

EM-38 horizontal and vertical survey readings were collected from 195 sites in each field on an approximate 200 x 200 foot grid spacing. In field 6.2, EM-38 horizontal (H) and vertical (V) readings ranged from 66 to 314 mS/m (H) and 151 to 429 mS/m (V), with median values of 184 and 240 mS/m, respectively. In field 6.3, EM-38 horizontal (H) and vertical (V) readings ranged from 148 to 294 mS/m (H) and 180 to 365 mS/m (V), with median values of 203 and 252 mS/m, respectively. The log transformed horizontal / vertical correlation statistics in both fields were quite high: $r = 0.989$ (field 6.2) and $r = 0.941$ (field 6.3).

Maps of the horizontal and vertical signal patterns are shown in figures 1 and 2 for both fields, respectively. (Note: field 6.2 is located directly north of field 6.3 in all the figures shown in this report.) The spatial conductivity patterns are markedly different between these two fields, and suggest a combination of both natural (soil induced) and management induced influences.

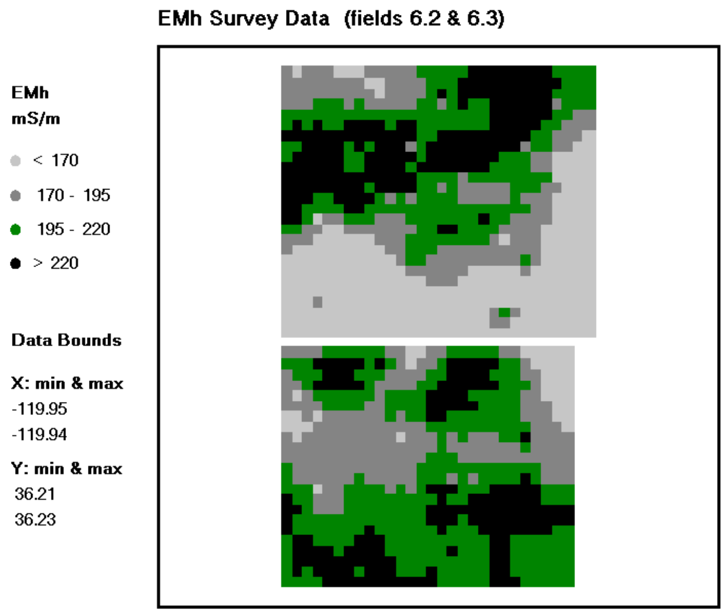

Figure 1. Spatial map of EM-38 horizontal signal data in fields 6.2 & 6.3.

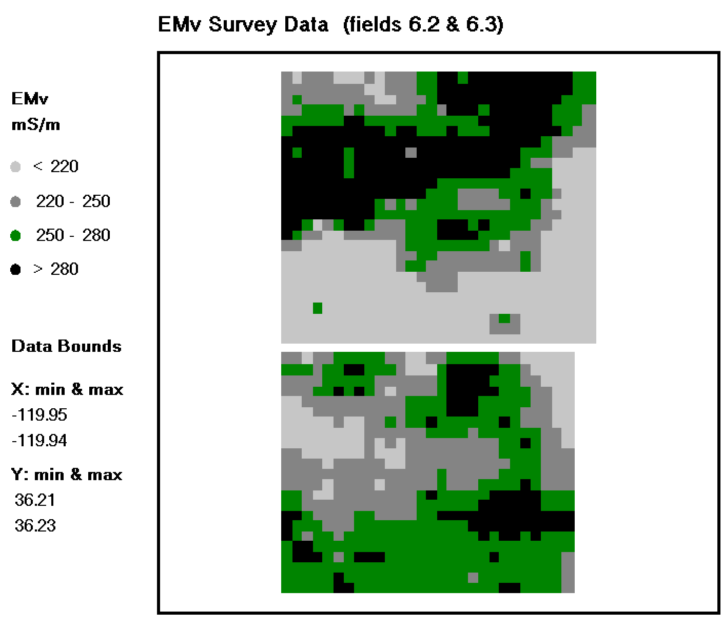

Figure 2. Spatial map of EM-38 vertical signal data in fields 6.2 & 6.3.

3. Soil Sample Data

The ESAP-RSSD program was used to process the EM survey data and generate the soil sampling plans. Twelve (12) optimal sampling locations were identified in each field, based on the EM horizontal and vertical survey data. Soil samples were collected from each site at 0-1, 1-2, and 2-3 foot sampling depths. These 36 soil samples from each field were then shipped to a commercial soil laboratory and analyzed for the following chemical and physical variables:

1. ECe, dS/m
2. Cations (Ca, Mg, Na), meq/l
3. SAR
4. Boron, ppm
5. SP (saturation percentage, %)
6. gravimetric soil water content, %

The gravimetric water content data was then converted into estimated volumetric water content data, using standard assumptions about the expected relationship between the (non-sampled) bulk density and SP.

Summary statistics for all variables other than the cations are shown in tables 1 and 2 for fields 6.2 and 6.3, respectively.

Table 1. Summary statistics, by sampling depth, for soil sample data from field 6.2.

Soil Variable	depth level	mean	std.dev	min	max
ECe	0.50	2.906	1.795	1.210	6.320
	1.50	3.463	2.550	1.130	9.250
	2.50	4.649	3.933	0.940	11.900
SP	0.50	46.833	6.631	35.000	59.000
	1.50	48.250	10.323	32.000	64.000
	2.50	49.833	14.522	28.000	73.000
Vol H2o	0.50	0.353	0.028	0.302	0.403
(estimated)	1.50	0.343	0.035	0.286	0.402
	2.50	0.339	0.027	0.280	0.391
SAR	0.50	10.258	3.696	5.600	15.800
	1.50	10.450	4.904	5.800	21.400
	2.50	12.525	5.301	4.400	21.300
Boron	0.50	2.218	1.040	0.970	4.630
	1.50	2.878	1.483	1.130	5.950
	2.50	3.556	2.042	1.270	7.360

Table 2. Summary statistics, by sampling depth, for soil sample data from field 6.3.

Soil Variable	depth level	mean	std.dev	min	max
ECe	0.50	4.353	2.202	2.070	10.600
	1.50	4.483	2.634	1.890	11.800
	2.50	5.155	1.958	3.230	9.060
SP	0.50	47.583	4.852	40.000	55.000
	1.50	43.500	8.350	30.000	60.000
	2.50	42.167	8.579	33.000	63.000
Vol H2o	0.50	0.312	0.040	0.276	0.425
(estimated)	1.50	0.343	0.027	0.289	0.378
	2.50	0.365	0.066	0.227	0.470
SAR	0.50	8.867	4.476	4.600	20.300
	1.50	12.767	7.198	6.000	32.400
	2.50	15.367	6.844	8.400	28.600
Boron	0.50	2.027	1.151	1.120	5.150
	1.50	2.304	1.683	1.000	6.970
	2.50	2.812	1.488	1.180	6.070

The observed range in the sample salinity (ECe) data in both fields is from about 1 to 2 dS/m to above 10 dS/m. These higher end values are sufficiently elevated to be considered limiting to tomatoes, and to a lesser extent, most varieties of wheat. The average salinity levels in each field range from about 3 to 5 dS/m by depth, but appear to be higher in field 6.3 for each depth zone. The range in SP values suggests that the soils in both fields represent a mixture of sands and loams. The correlation statistics between the log transformed, bulk average salinity and log transformed, bulk average SAR and Boron levels were quite high in both fields. The correlation statistic between the log transformed, bulk average salinity and bulk average SP levels was also high in field 6.2, as shown in table 3 below.

Table 3. Correlation statistics between log transformed, bulk average salinity and bulk average SP, SAR (log transformed), and Boron (log transformed) for fields 6.2 and 6.3.

log(ECe, average) versus:	Field 6.2	Field 6.3
SP, average	0.828	0.499
log(SAR, average)	0.920	0.876
log(Boron, average)	0.835	0.848

In general, all of the soil sample data passed a preliminary QA/QC analysis, except for the sample data from one site (site 174) in field 6.3. This latter site had an abnormally low salinity value associated with the 1-2 foot sample, which appeared to be in error with respect to the corresponding cation, SAR, and boron sample levels. Because the salinity data associated with this sample core appeared to be erroneous, this data was excluded from all subsequent analyses and calibration modeling exercises.

4. Survey Reliability & Preliminary Conductivity / Soil Data Correlation Statistics

The reason for the collection of soil sample data during a conductivity survey is so that accurate conductivity to salinity (and/or secondary sample variable) calibration equations can be developed and exploited. When the calibration sample data includes measurements of salinity (ECe), texture (SP or % clay data), and water content values, the ESAP-Calibrate program can convert this data into calculated conductivity readings and compare these readings to the measured conductivity (EM-38 or four-electrode) data. Determining the correlation between the calculated and measured conductivity readings yields an estimate of the "survey reliability".

The correlation statistics between the log transformed, bulk average calculated and measured conductivity data were r = 0.922 and r = 0.891 in fields 6.2 and 6.3, respectively. These correlation statistics suggest a high degree of survey reliability for both fields, given that the sample calibration data was only collected down to 3 feet.[1]

The raw correlation statistics between the log transformed, average EM-38 conductivity data (log(H)+log(V) / 2) and various soil parameters were also generally very good to excellent, as shown in table 4 on the next page. With the single exception of the log conductivity / average SP correlation estimate for field 6.3, all correlation statistics exceed 0.75. Additionally, many of the conductivity / salinity correlation statistics were near or above 0.9. Overall, these statistics suggest that accurate calibrations can be established between the EM-38 survey conductivity data and previously discussed target soil variables (depth specific salinity and bulk average SP, SAR, and Boron).

[1] Calibration soil samples associated with a conductivity survey are typically collected down to 4 feet, and sometimes as deep as 6 feet. In general, deeper sampling yields higher survey reliability statistics, since the EM-38 typically responds to the apparent conductivity within the first four to six feet of topsoil.

Table 4. Correlation statistics between log transformed, average conductivity and depth specific salinity (ECe, 0-1, 1-2, and 2-3 feet, log transformed), bulk average salinity (ECe, 0-3 feet, log transformed), bulk average SP, SAR (log transformed), and boron (log transformed) for fields 6.2 and 6.3.

log conductivity: (log(H)+log(V) / 2)
versus:

	Field 6.2	Field 6.3
log(ECe, 0-1 ft)	0.771	0.915
log(ECe, 1-2 ft)	0.884	0.898
log(ECe, 2-3 ft)	0.929	0.905
log(ECe, average)	0.923	0.953
SP, average	0.814	0.467
log(SAR, average)	0.934	0.764
log(Boron, average)	0.896	0.829

5. Calibration Data Modeling

The ESAP-Calibrate program can be used to automatically determine, select, and estimate an optimal spatial regression model which describes the relationship(s) between survey conductivity data and sample soil salinity data. These models attempt to predict the salinity levels from a linear combination of co-located conductivity readings, while simultaneously adjusting for any drift effects via the use of additional trend surface parameters.[2] This modeling approach can also be used to calibrate soil conductivity to other soil variables (such as soil texture, SAR, Boron, etc.), provided measurements of such secondary data is acquired during the survey process.

This automatic model fitting procedure was used to determine and estimate all of the calibration regression equations developed for these two fields. For these surveys, regression equations were identified that could accurately predict both depth specific soil salinity and bulk average salinity, SAR, boron, and SP levels within each field. A brief listing of summary statistics for each estimated regression model is shown in table 5. These statistics document the degree of prediction accuracy obtained using each equation. Additionally, plots of the observed versus depth specific predicted salinity levels in fields 6.2 and 6.3 are shown in figures 3 and 4, respectively.

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[2] The optimization criteria employed by ESAP is the minimization of the regression model PRESS statistic. The PRESS statistic represents a type of "jack-knife" statistic that can be used to help determine a robust form of regression model which should in turn minimize the errors associated with future predictions (i.e., predictions at all non-sampled survey locations). Model fitting techniques which minimize the PRESS statistic rarely maximize R-square statistics.

Table 5. Regression model summary statistics for log(ECe), SP, log(SAR), and log(boron) calibration equations associated with fields 6.2 and 6.3.

Field	Prediction Variable	Model R-square	Obs v.s Prd Correlation
6.2	log(ECe, 0-1 ft)	0.904	0.951
	log(ECe, 1-2 ft)	0.899	0.948
	log(ECe, 2-3 ft)	0.914	0.956
	log(ECe, average)	0.964	0.982
	SP(average)	0.895	0.946
	log(SAR, average)	0.964	0.982
	log(boron, average)	0.874	0.935
6.3	log(ECe, 0-1 ft)	0.864	0.930
	log(ECe, 1-2 ft)	0.900	0.949
	log(ECe, 2-3 ft)	0.929	0.964
	log(ECe, average)	0.931	0.965
	SP(average)	0.796	0.892
	log(SAR, average)	0.819	0.905
	log(boron, average)	0.873	0.935

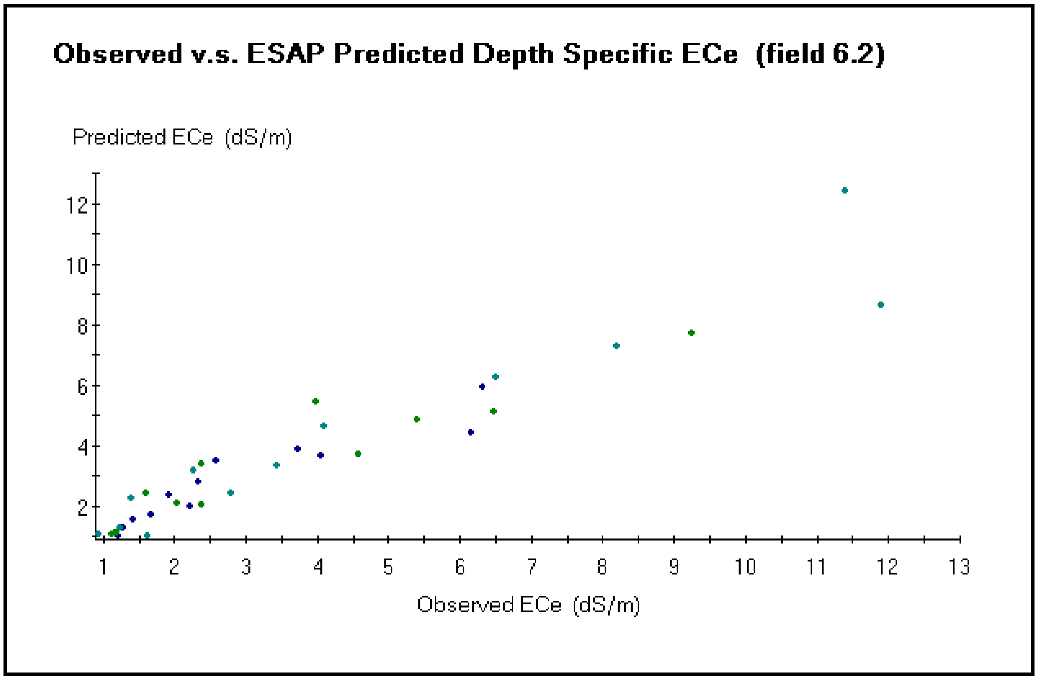

Figure 3. Observed versus regression model predicted salinity data for field 6.2

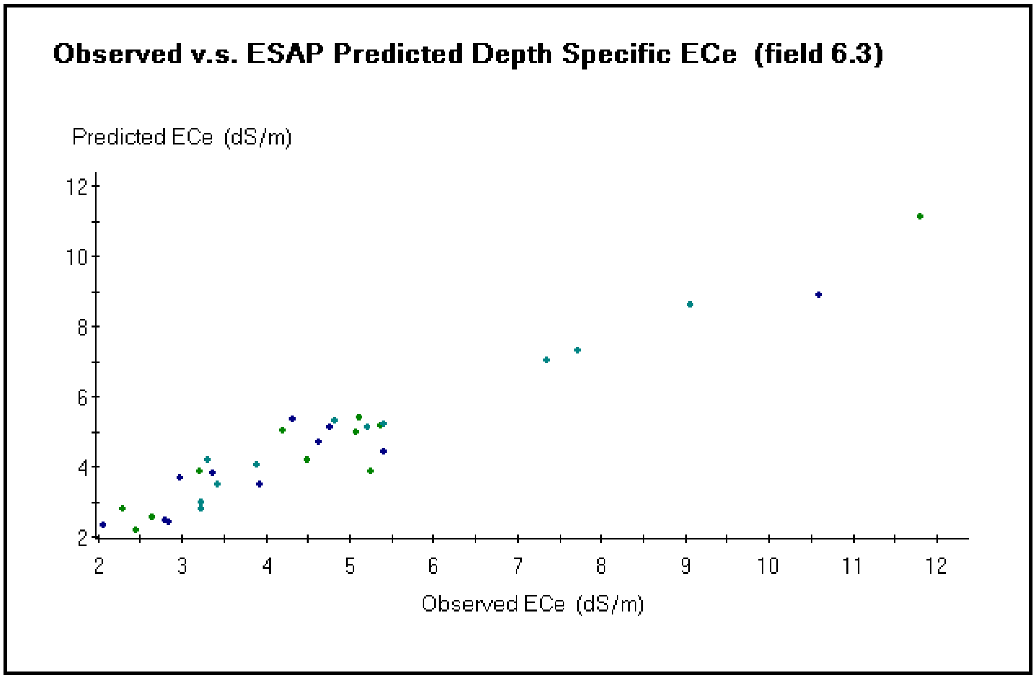

Figure 4. Observed versus regression model predicted salinity data for field 6.3

6.0 Prediction Results & Statistics: Soil Salinity

Once the regression models have been estimated, these models can in turn be used to produce both field average summary statistics (via ESAP-Calibrate) and spatial prediction maps (via ESAP-SaltMapper). Since depth specific soil salinity models were estimated in each of these surveys, both depth specific and bulk average soil salinity statistics and maps have been produced in this report.

Tables 6 and 7 show the type of summary statistics produced by the ESAP-Calibrate program. These statistics include estimates and confidence intervals for the field median salinity levels by depth, in addition to the bulk average statistics. For field 6.2 (table 6), the 0-1, 1-2, 2-3, and 0-3 estimated median salinity levels were 2.42, 2.61, 3.14, and 2.79 dS/m. For field 6.3 (table 7), the same depth interval estimates were 4.25, 4.61, 5.12, and 4.70 dS/m, respectively.

In addition to field median estimates, a set of statistics called "range interval estimates" are produced. These represent depth specific estimates of the percent area of the field falling into pre-determined ranges of salinity. For these two fields, these ranges were defined to be 0-2, 2-4, 4-6, 6-8, and > 8 dS/m, respectively. Note that 60 to 75% of the area in field 6.2 is estimated to be below 4 dS/m (for each depth), but only 25 to 40% of the area in field 6.3 lies below this same threshold.

Table 6. Salinity (ECe, dS/m) summary statistics for field 6.2

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

depth	median	95% Confidence Interval
0-1 ft	2.42	2.09 to 2.79
1-2 ft	2.61	2.17 to 3.14
2-3 ft	3.14	2.55 to 3.87
average	2.79	2.50 to 3.12

II. Field Range Interval Estimates

depth	range 1	range 2	range 3	range 4	range 5
0-1 ft	37.69	41.92	16.55	3.10	0.73
1-2 ft	35.76	35.74	18.46	6.73	3.31
2-3 ft	30.07	30.49	18.18	10.06	11.20
average	32.85	34.79	22.00	8.05	2.31

range[1]: < 2.000
range[2]: 2.000 to 4.000
range[3]: 4.000 to 6.000
range[4]: 6.000 to 8.000
range[5]: > 8.000

Table 7. Salinity (ECe, dS/m) summary statistics for field 6.3.

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

depth	median	95% Confidence Interval
0-1 ft	4.25	3.68 to 4.90
1-2 ft	4.61	4.04 to 5.27
2-3 ft	5.12	4.68 to 5.61
average	4.70	4.27 to 5.18

II. Field Range Interval Estimates

depth	range 1	range 2	range 3	range 4	range 5
0-1 ft	3.48	39.84	36.99	14.01	5.68
1-2 ft	2.68	34.06	36.22	17.28	9.76
2-3 ft	0.12	22.73	47.52	19.12	10.52
average	0.71	32.21	42.36	17.91	6.81

range[1]: < 2.000
range[2]: 2.000 to 4.000
range[3]: 4.000 to 6.000
range[4]: 6.000 to 8.000
range[5]: > 8.000

Figures 5, 6, 7, and 8 display the combined, predicted soil salinity maps for both fields. For comparative purposes, in each map the salinity classes have been defined to be < 2.5, 2.5-4.0, 4.0-5.5, and > 5.5 dS/m. Figure 5 shows the bulk average (0-3 foot) predicted salinity patterns in both fields, while figures 6, 7, and 8 display the depth specific predicted patterns (0-1, 1-2, and 2-3 feet, respectively).

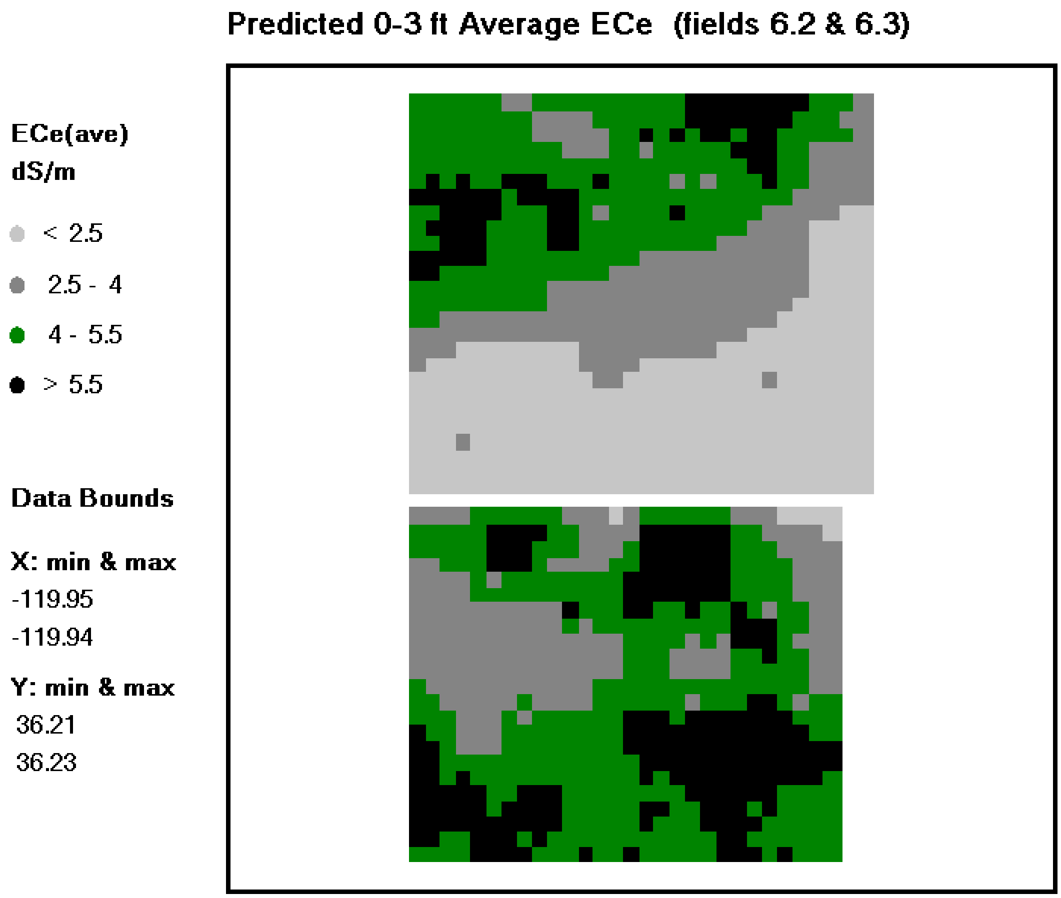

Figure 5. Predicted 0-3 foot bulk average salinity maps for fields 6.2 and 6.3.

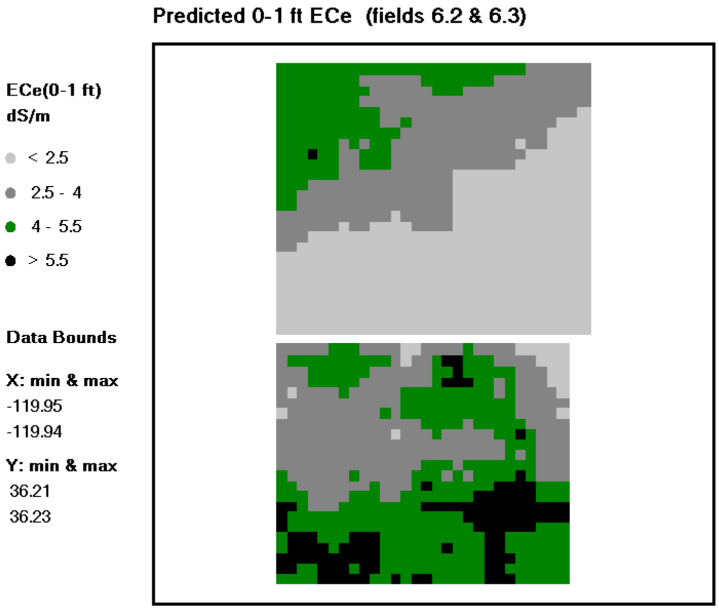

Figure 6. Predicted 0-1 foot salinity maps for fields 6.2 and 6.3.

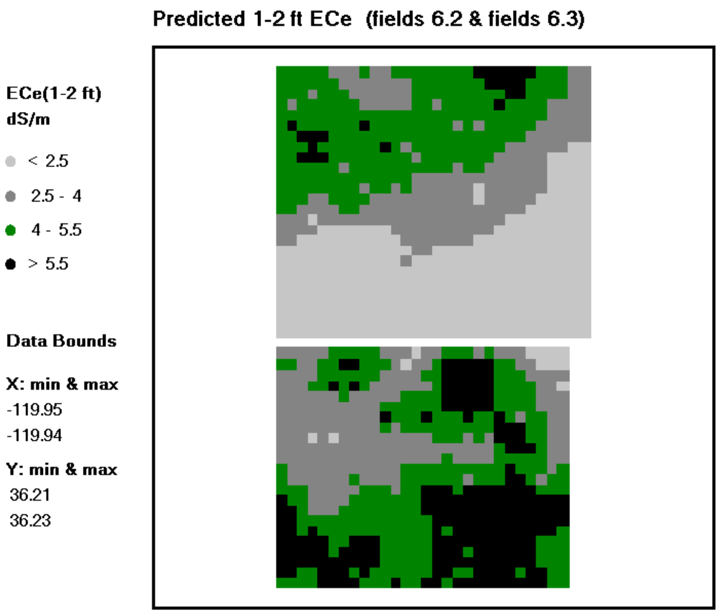

Figure 7. Predicted 1-2 foot salinity maps for fields 6.2 and 6.3.

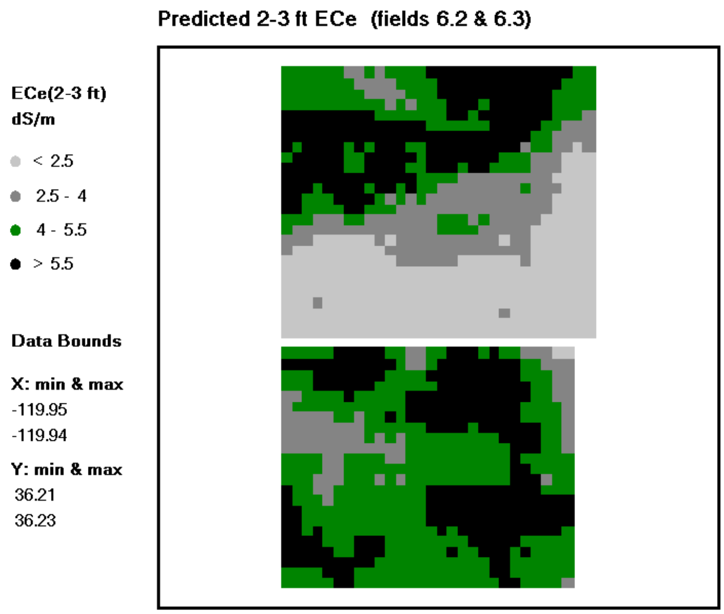

Figure 8. Predicted 2-3 foot salinity maps for fields 6.2 and 6.3.

For the most part, the predicted spatial salinity patterns in each field tend to follow the observed EM-38 conductivity patterns. Additionally, it is clear from figures 6 through 8 that the soil salinity levels increase with depth in both fields, and that the salinity pattern in field 6.3 appears to be more spatially complex (with high spots occurring throughout the field). In contrast, the dominant salinity buildup in field 6.2 is clearly occurring along the northern half of the field.

One additional feature available in the ESAP-Calibrate program is the option to calculate hypothetical yield loss estimates for specific crops, based on the predicted salinity patterns. In fields 6.2 and 6.3, yield loss calculations were computed for cotton, wheat, and tomatoes. Using these predicted salinity patterns in conjunction with standard salt tolerance curves, ESAP estimated the hypothetical yield losses to be 0.7% for cotton, 1.7% for wheat, and 11.7% for tomatoes in field 6.2. In field 6.3, these same crops showed hypothetical losses of 1.4%, 4.0%, and 24.6% (for cotton, wheat, and tomatoes, respectively). These calculations suggest that some degree of reclamation might be in order if tomatoes are to be grown (particularly in field 6.3).

7.0 Prediction Results and Statistics: SP, SAR, and Boron

Figures 9, 10, and 11 show the predicted (0-3 foot bulk) average spatial SP, SAR, and boron maps for fields 6.2 and 6.3. Tables 8, 9, and 10 show the corresponding summary statistics for these same variables, respectively.

The bulk average SP maps shown in figure 9 displays a clearly contiguous soil structure spanning both fields. A heavier (loam) textured region is clearly apparent in the north west zone of field 6.2. A lighter (sand) textured region cuts across the south west zone of field 6.2 into the north west zone of field 6.3. This SP (texture) map appears reasonably similar to the bulk average salinity map shown in figure 5, suggesting that the soil texture is partially influencing the spatial distribution of salinity levels in both fields. The summary statistics shown in table 8 confirm that the average SP level is higher in field 6.2, and that the texture distribution in this field includes more loam type soils.

The bulk average SAR maps shown in figure 10 exhibit spatial patterns which are extremely similar to the salinity maps shown earlier. Additionally, the median SAR levels are quite similar between the two fields (10.62 versus 11.51). However, the range interval statistics shown in table 9 suggest that the spatial SAR levels exhibit more variability in field 6.3.

The bulk average boron maps shown in figure 11 show a spatial structure that looks similar to the SP maps shown in figure 9. This is perhaps not that surprising, since it is well known that boron retention is directly influenced by the amount of clay present in the soil (and the SP level is directly related to the % clay content of the soil). The summary statistics shown in table 10 suggest that the boron levels are, on the average, somewhat more elevated in field 6.2. This result is most likely due to the higher percentage of heavier textured soil in this field.

Table 8. Bulk average SP (%) summary statistics for fields 6.2 and 6.3.

I. Field Average Point Estimates [SP]

depth	mean	variance	95% Confidence Interval
average (6.2)	49.69	1.576	46.80 to 52.59
average (6.3)	44.50	1.112	42.07 to 46.93

II. Field Range Interval Estimates

depth	range 1	range 2	range 3	range 4
average (6.2)	14.53	33.86	40.61	11.00
average (6.3)	23.41	57.18	18.55	0.87

range[1]: < 40.000
range[2]: 40.000 to 50.000
range[3]: 50.000 to 60.000
range[4]: > 60.000

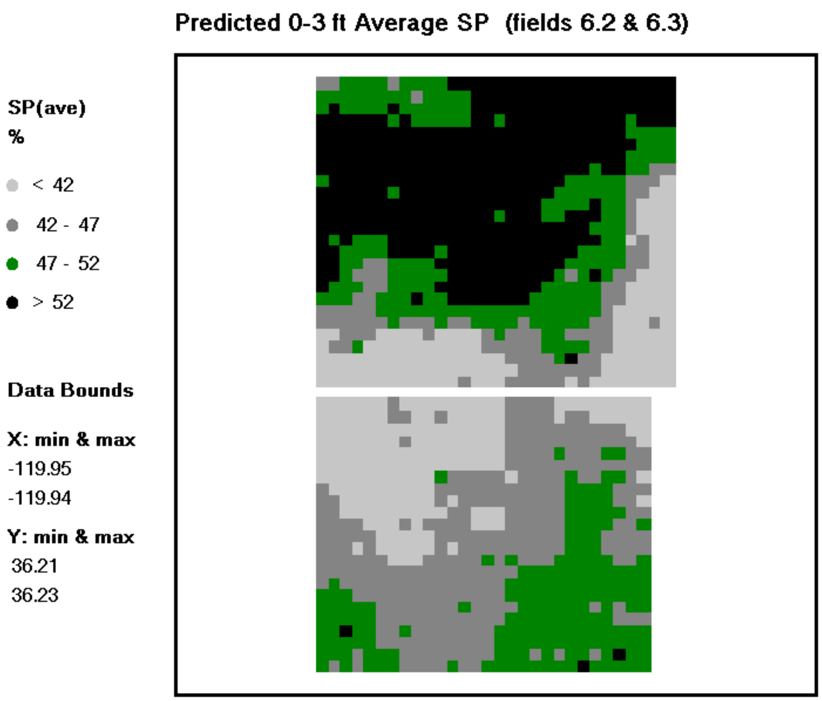

Figure 9. Predicted 0-3 foot bulk average SP maps for fields 6.2 and 6.3.

Table 9. Bulk average SAR summary statistics for fields 6.2 and 6.3.

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

depth	median	95% Confidence Interval
average (6.2)	10.62	10.00 to 11.29
average (6.3)	11.51	10.09 to 13.12

II. Field Range Interval Estimates

depth	range 1	range 2	range 3	range 4	range 5
average (6.2)	1.54	28.54	31.46	29.45	9.00
average (6.3)	3.96	21.65	29.60	20.95	23.85

range[1]: < 6.000
range[2]: 6.000 to 9.000
range[3]: 9.000 to 12.000
range[4]: 12.000 to 15.000
range[5]: > 15.000

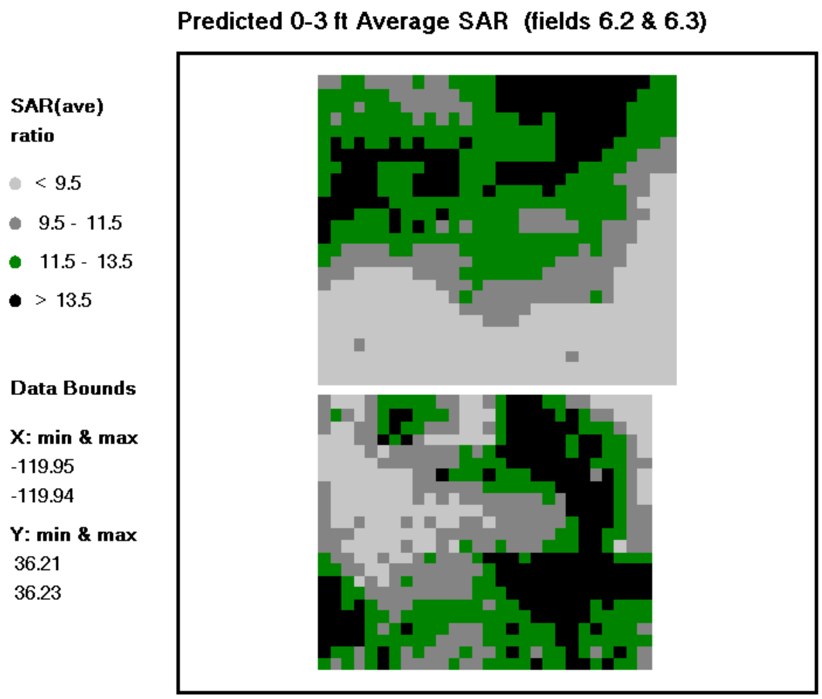

Figure 10. Predicted 0-3 foot bulk average SAR maps for fields 6.2 and 6.3.

Table 10. Bulk average Boron (ppm) summary statistics for fields 6.2 and 6.3.

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

depth	median	95% Confidence Interval
average (6.2)	2.68	2.31 to 3.10
average (6.3)	2.08	1.79 to 2.41

II. Field Range Interval Estimates

depth	range 1	range 2	range 3	range 4	range 5
average (6.2)	9.97	32.25	28.32	18.65	10.82
average (6.3)	22.69	46.22	20.28	6.48	4.33

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range[4]: 3.500 to 4.500
range[5]: > 4.500

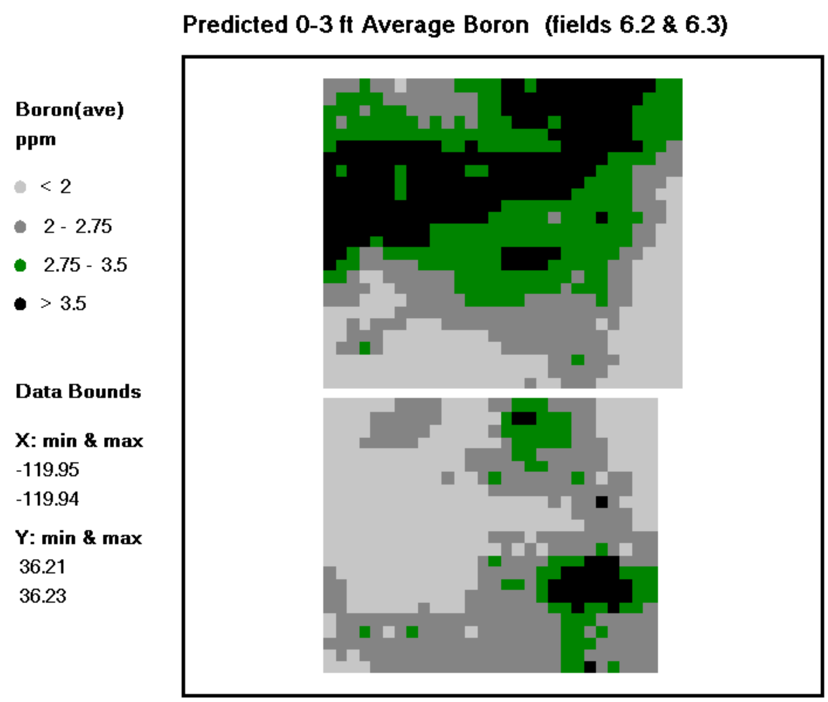

Figure 11. Predicted 0-3 foot bulk average Boron maps for fields 6.2 and 6.3.

8.0 Concluding Remarks

This report has documented the results from two agricultural EM-38 surveys which were highly effective at predicting the 0-3 foot bulk average spatial SP, SAR, and boron levels, in addition to accurately estimating the depth specific (0-1, 1-2, and 2-3 foot) spatial salinity distributions. The ability to use soil conductivity survey information to predict these types of soil variables has been well documented in the soil and environmental science literature (Rhoades et. al., 1999; Lesch et. al. 1995a,b).

All of the calibration modeling and prediction analyses discussed in this report were performed using the ESAP-95 software package. This software package was specifically designed for analyzing and interpreting soil conductivity survey data, and is available free of charge from the George E. Brown Jr. Salinity Laboratory (Lesch et. al., 2000). More information about ESAP-95 can be obtained from the Salinity Laboratory web site (*www.ussl.ars.usda.gov*).

9.0 References

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