An Evaluation of the USDA ESAP Program for Converting EM Data to Electrical Conductivity at Goodale Research Farm Using a GEM2 and an EM38

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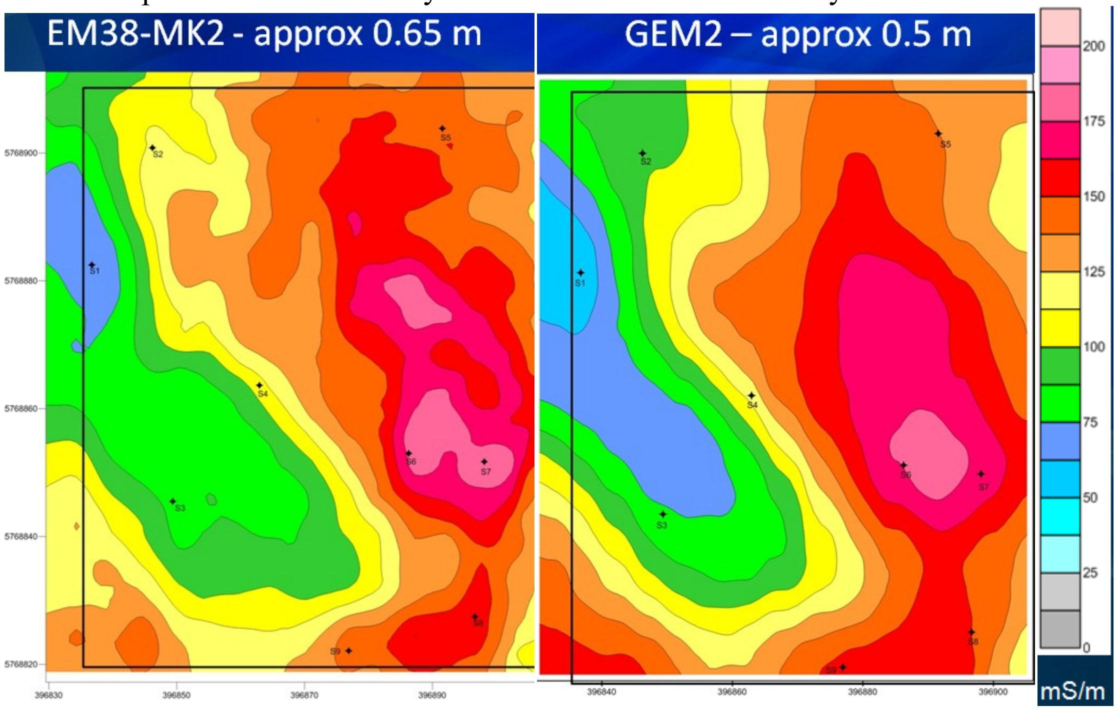
Background

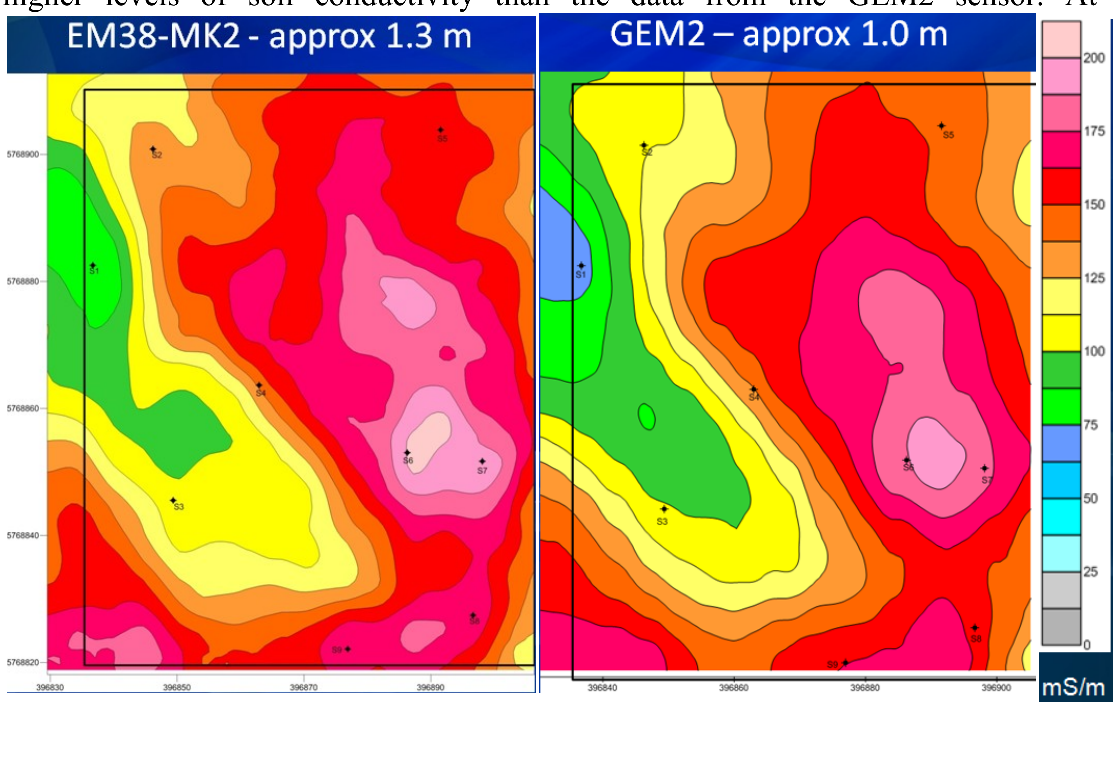
Soil salinity mapping used to be really hard work. But then in the late 60's, Jim Rhoades, a soil scientist with the USDA Salinity Lab in Riverside, CA, came up with what was to be known as the Rhoades conductivity probe. It was actually a modified Wenner array and it could be mounted on a hydraulic cylinder and slung under a tractor. The tractor was driven to a spot in the field, stopped, the hydraulic arm pushed the probe into the soil and a conductivity reading was taken and the process was repeated at other spots across the field. This was the first mechanized conductivity survey and it became the norm for almost 10 years, as it freed soil scientists from the work of soil sampling and physically pushing the probe into the soil. Then in the late 70's, Geonics introduced portable EM induction technology with the EM31 in 1977 and the EM38 in 1980. With these instruments, you could simply carry the sensor and walk through the field collecting conductivity data and it revolutionized soil salinity mapping. Federally through PFRA and provincially through the departments of Agriculture, large areas of southern Saskatchewan and Alberta were mapped for Dryland salinity and seepage along irrigation canals. This work continued until funding began to dry up in the late 80's. But these two technologies also created a huge problem. Now there was a large database of conductivity collected with a Rhoades conductivity probe, as well as another equally large database of conductivity data collected with Geonics EM sensors with no way to compare the two sets of data directly. Colin McKenzie from the Brooks Research Station was the first to publish a paper that allowed EM data to be converted to a saturated paste extract electrical conductivity (EC) through the use of a series of soil moisture, temperature and texture curves. At about the same time, scientists from the USDA Salinity Lab were developing a software program designed to do the same thing. It appears that they incorporated most of McKenzie's curves into this software program that was called Electromagnetic Sampling Analysis Design or ESAP for short. The software contained modules to convert Rhoades conductivity probe data to EC as well as Geonics EM data to EC using either stochastic (statistical) or deterministic models.

Field Methods and Data

The Goodale Farm test site was located on the U of S Research Farm, just southeast of Saskatoon, off Highway 16. At the farm, there is a Dryland saline seep that has been used extensively as a test site for sampling and for the past 5 years by PENSERV for EM surveys. The white pin flags marked soil sampling locations and the site was about 1 acre in size. EM surveys were conducted manually with GPS using a Geonics EM38-MK2 and two Geophex GEM2 EM sensors. The EM38 had depths of penetration of 0.75 and 1.5 m at ground level, but since the sensor was carried above the canola stubble, the effective depth of penetration was closer to 0.65 and 1.3 m. The GEM2 sensors used frequencies that roughly corresponded to depths of 0.5 and 1.0 m, so the two sensors were more or less comparable in depth capabilities. The survey path of the first EM survey was used as a template for the 2nd and 3rd surveys and in this respect, it was reasonably successful. In total there were between 1374 and 1392 data points for all 3 surveys. The data for the EM surveys indicated that the EM38 had



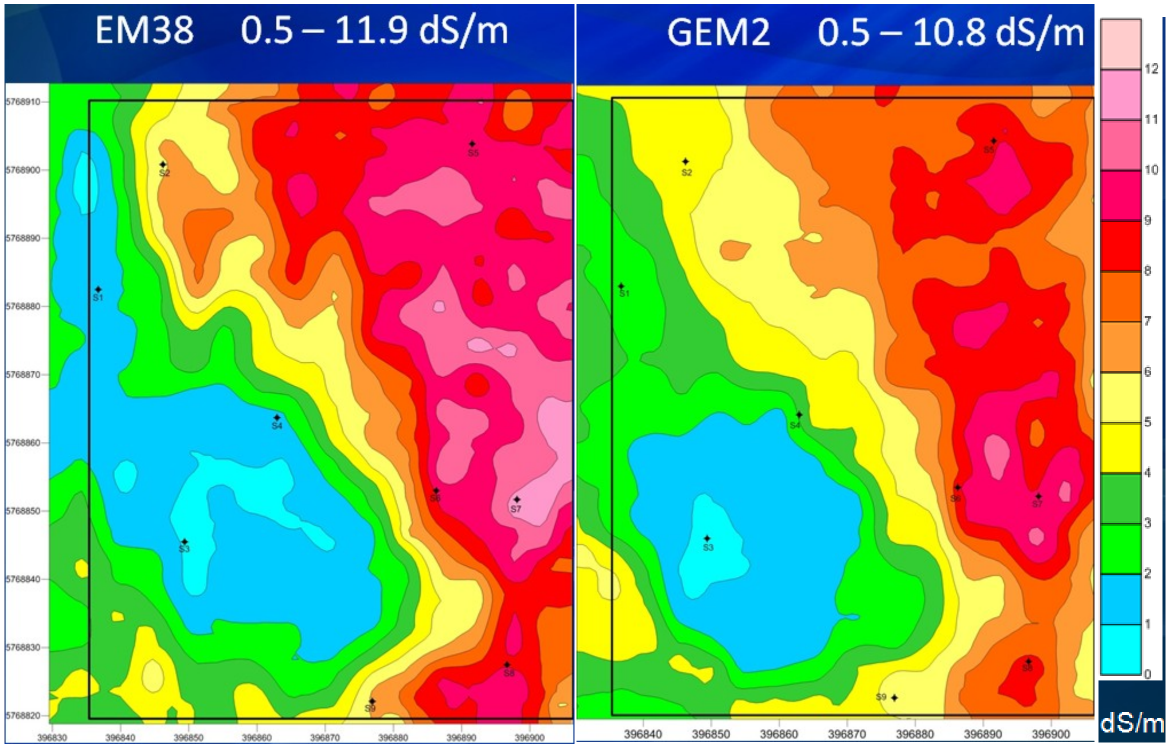
slightly higher levels of soil conductivity than the data from the GEM2 sensor. At the lower



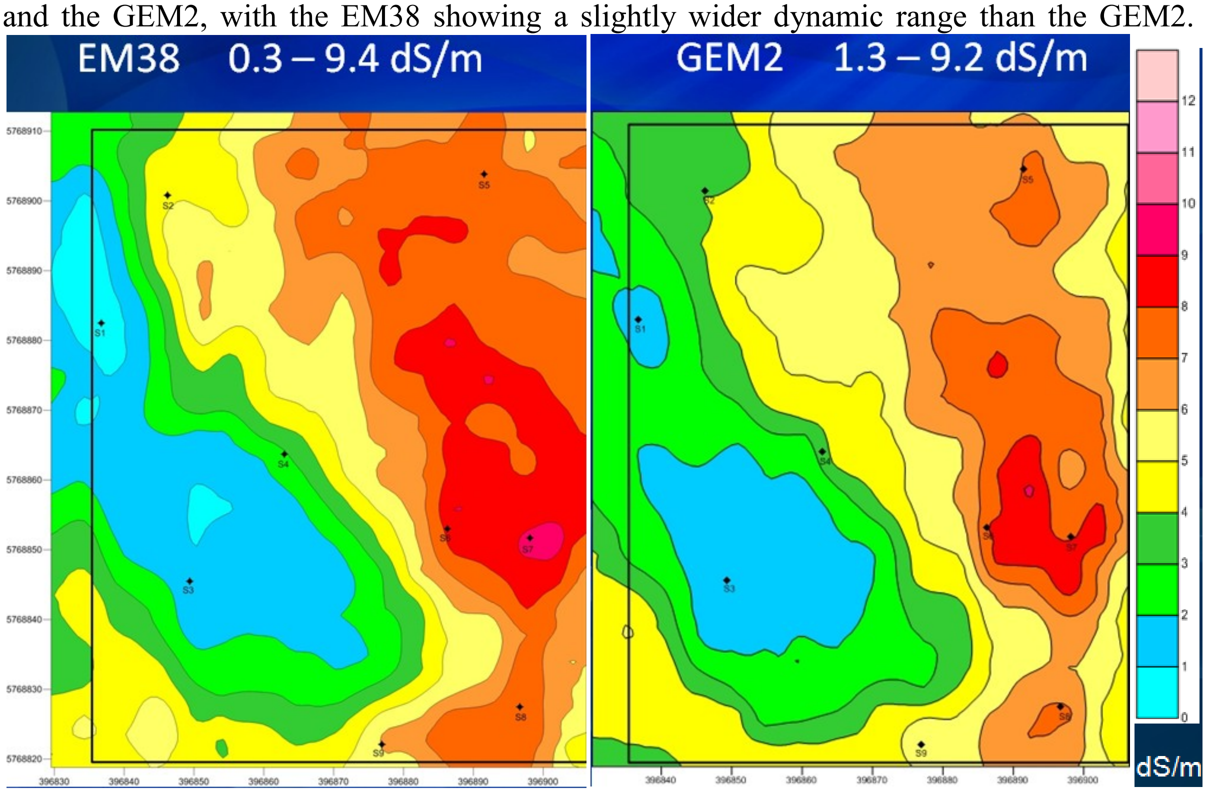
depths, the EM38 also showed slightly higher levels of conductivity, probably because it was imaging through a greater volume of soil as it was penetrating to slightly greater depth than the GEM2. The corollary of this is that the frequencies chosen for the GEM2 did appear to be reasonable approximations of the depths of penetration with respect to the EM38.

ESAP Software Program

The ESAP software program consists of 5 modules. The two that are used for EM data are the RSSD and Calibrate modules. The Salt Mapper module is a graphics package, but I prefer to use Surfer for contour map creation. SigDPA module is used to transform the signal from a Trimble GPS and I had no use for that module. The DPPC module is what you would use if you had data from a Rhoades conductivity probe. The RSSD module stands for Response Surface Sampling Design and its function is to generate a sampling design. The EM data is imported in a specific format and basic statistics can be generated to assess the quality of the data, Scatter plots and histograms of the data can also be viewed. The sampling design can be automatic with options for 6, 12 or 20 sampling points or user-generated with any number of sampling sites. The only stipulation is that each sampling point must be tied to a specific EM data point. The Calibrate module is where the conversion of EM data into EC takes place. The EM survey data from the RSSD module is imported along with the soil analytical data from soil samples, if the statistical model is the option of choice. The Calibrate module chooses the most appropriate model for the data. As mentioned, the statistical or stochastic model requires that soil samples be taken and soil analytical data of at least EC and Saturation Percentage be present. The deterministic model can be utilized without analytical data, with merely some assumptions about the soils. In my opinion, one of the reasons that the ESAP software has not been as widely accepted as its authors originally envisioned is that the deterministic model is one of the pathways. This model is heavily biased to a Southern California climate or at least a Southern US climate. For example, soil temperature is limited to the range of 10°C to 35°C. When the surveys at Goodale Farm were conducted on 10 October 2011, the soil temperatures at 15 cm were uniformly 8°C and at 30 cm, 7°C, which is lower than the given range, thus the deterministic pathway would not be available for late season EM survey data conversion. Another problem is the manner in which ESAP deals with soil moisture, which is expressed as a percentage of field capacity with a range of 50% to 125%. Again, in my opinion, this range is unrealistic for Western Canada, although I did find that soil moisture does not greatly influence the calculated values. The predicted EC values were approximately 3 times higher than those predicted for the statistical model. The inability of the deterministic model to provide reasonable predictions of EC is probably one of the reasons that this program is not used more extensively. With the statistical model, the model and the form of the model is chosen automatically by the software program. While there are 12 variations of the model available, in all cases the form chosen was z1, z2 and the accompanying manual states that this is then the preferred model to use. The user is not exposed to the values used in the model other than knowing it is a multiple factor regression analysis that uses both EC and saturation percentage values (as an estimate of soil texture). From my own experimentation, I can vouch that the regression is not linear. The Calibrate module outputs a table of predicted EC values for each sampling depth that can be used in Surfer to generate maps of predicted EC values.



The maps of predicted EC values for the 0-30 cm depth were quite similar between the EM 38 and the GEM2, with the EM38 showing a slightly wider dynamic range than the GEM2. For the depths of 30-60 cm, the predicted EC values were closer, but the EM38 still showed a slightly wider dynamic range than the GEM2. One of the reasons for this variability between the two EM sensors might be that the sampling depths of 30 cm increments down to 1.2 m were closer to the



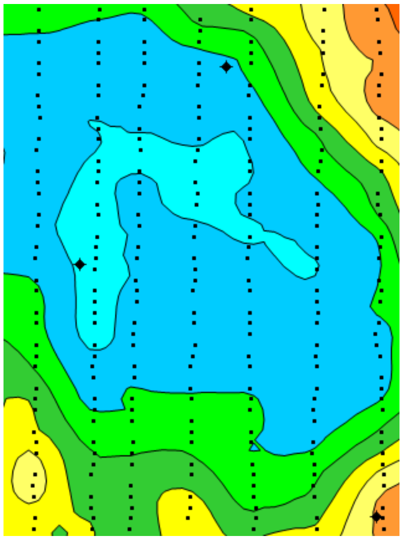
depth of penetration of the EM38. If 25 cm increments down to 1 m had been used, the predicted values of EC might have shown a better correlation for the GEM2. However the magnitude of the variability did not appear to be significant. Two trends were noticeable in the data. Both sensors tended to show more variability at lower EC and tended to be more accurate at higher EC. This may be one of the tradeoffs for working with an EM induction sensor. The signal to noise ratio tends to be lower at low conductivity, meaning there is more noise, which translates to more variability in predicted EC. In the table of predicted EC values for the 0-30 cm depth,

Sample	Lab EC	EM38 EC	GEM2 EC
S1	1.3	1.8	2.7
S2	5.4	5.9	4.7
S3	1.8	0.9	0.3
S4	1.7	1.8	2.5
S5	9.8	9.3	9.3
S6	9.0	9.2	8.3
S7	10.5	11.3	9.3
S8	8.6	8.9	8.2
S9	6.2	6.1	5.1

some of this variability can be seen. When the lab EC is less than 2, predicted values of EC for either the EM38 or GEM2 can both be lower than the lab EC (S3, S4) or higher than lab EC (S1). Similarly, at high lab EC, the predicted values tend to be closer to the lab values (S5-S9). Although not shown, maps of predicted EC values were also derived for the other sampling depths of 60-90 and 90-120 cm.

Application of ESAP

Potentially the ESAP conversion software could be applied to any site that has sufficient analytical data to allow use of the statistical model. In an agricultural scenario, the application might be limited to research plots in the same manner that I have applied it to the test site at Goodale Farm. For environmental applications, the techniques might have a wider use for reclaimed or abandoned well sites, where a number of soil samples are already taken for chemical analysis for the development of Phase II programs or the final reclamation of a site. In these cases, the sampling design would be user generated and while some of the sampling locations would be dependent on values delineated by the EM survey, other sampling locations would be dictated by cultural features such as the former locations of the wellhead, production tanks or flare stack. As long as the sampling locations are geo-referenced with reasonable



accuracy, they can be overlain on an EM survey and tied to specific EM data points. Typically, the line spacing on well sites is about 5 m, which means that even when a sampling point lies between two lines of EM data, the maximum distance it would have to be moved would be on the order of 2-3 m, which would not be expected to seriously degrade the accuracy of the predicted EC values. This also means that the user generated sampling design can be determined before or after the EM survey. The analytical data is required by regulators and now it can be used in an additional manner, to provide a means of converting EM data to EC by using soil samples that are representative of that particular site. The final EM maps are then output in EC values in units that are already familiar to regulatory agencies, a fact that might lead to even greater acceptance for the use of EM surveys.

Conclusions

As a result of these experiments at Goodale Farm, the following conclusions can be drawn:

1. EM survey data from the EM38-MK2 and the GEM2 are virtually identical, even though the detecting paradigms of both sensors are vastly different.
2. The ESAP software program appeared to calculate reasonable predictions of EC values when used with soil sample data and run through the multiple factor regression model.
3. The soil sampling design can be independent of the ESAP software and the predictions will still be valid, which makes the technique particularly well suited to well site reclamation projects.

Acknowledgements

The author wishes to acknowledge the contributions of Access Analytical labs in Calgary for providing the analysis of soil samples, Dr. Les Henry, who is mostly retired, for getting me involved in research at Goodale Farm and Kevin Yemoto, who was my contact at the USDA Salinity lab in Riverside, California. The ESAP software program can be downloaded at the USDA website:

http://www.ars.usda.gov/Services/docs.htm?docid=8918

Conversion of EM Data to EC

Using USDA ESAP Program to Convert EM Data to Electrical Conductivity at Goodale Research Farm Using EM38-MK2 and GEM2

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Background to ESAP

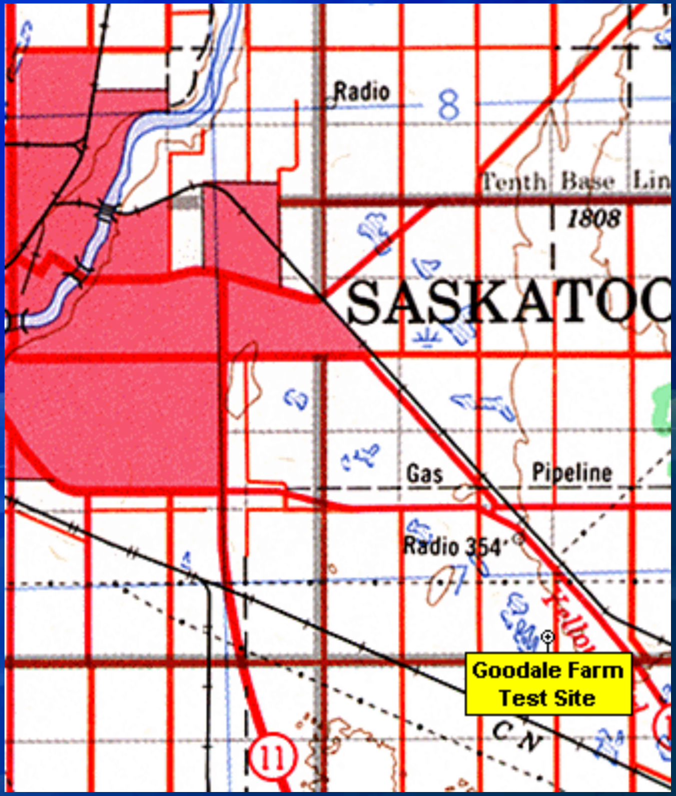
- Soil salinity mapping
  - Mechanized surveys - early to mid 70’s
  - Rhoades - conductivity probe (1950 - 1980)
    - Modified Wenner array
- EM Induction technology
  - Geonics introduced EM 31 - 1977; EM 38 - 1980
  - PFRA, Ag Depts - salinity surveys in AB and SK
    - Dryland salinity and seepage along irrigation canals
    - Late 70’s and mid 80’s

Drivers for ESAP

- Conversion of EM Data to EC
  - Rhoades conductivity probe and EM 38/31 data
  - McKenzie - soil temperature, texture equations
- USDA Salinity Lab ESAP Program (1995-2005)
  - Software to convert EM 38 data to EC
  - Conversion of Rhoades data to EC
  - Deterministic and Stochastic (statistical) models

Goodale Farm Test Site

- U of S research farm
  - Approx 1 ac site



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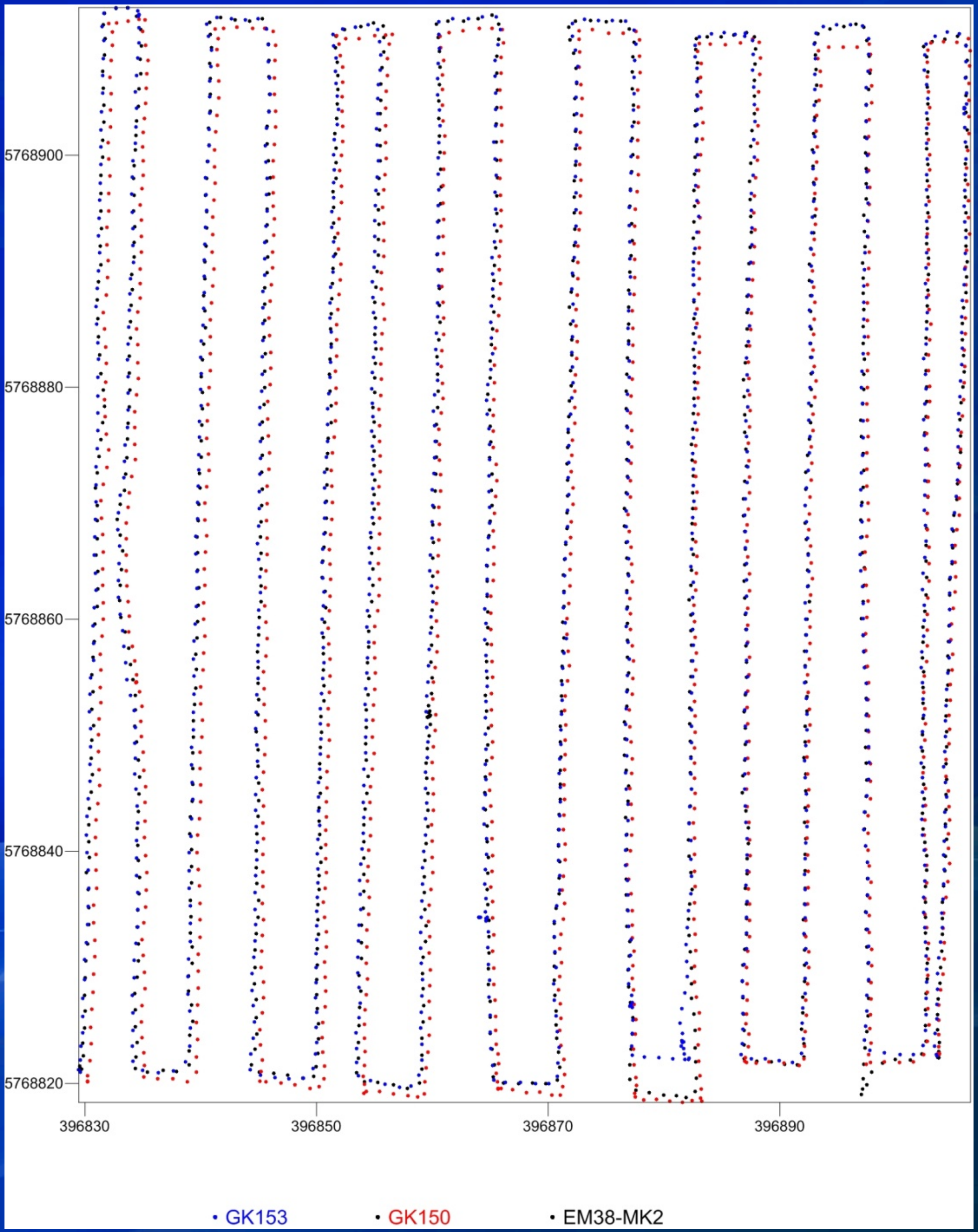
EM Surveys

- Manual surveys with GPS
- EM38-MK2
  - 0.65, 1.3 m
- GEM2
  - 0.5, 1.0 m
- Same survey path
  - Path of 1st survey used as template for other surveys



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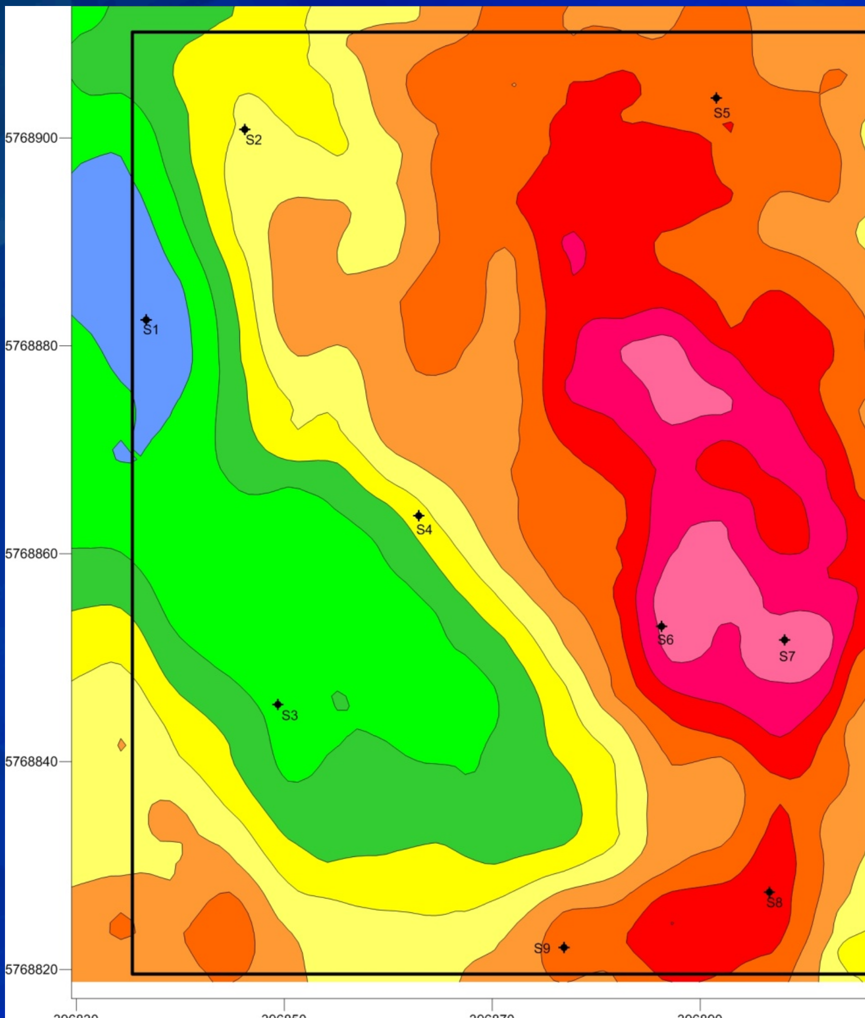
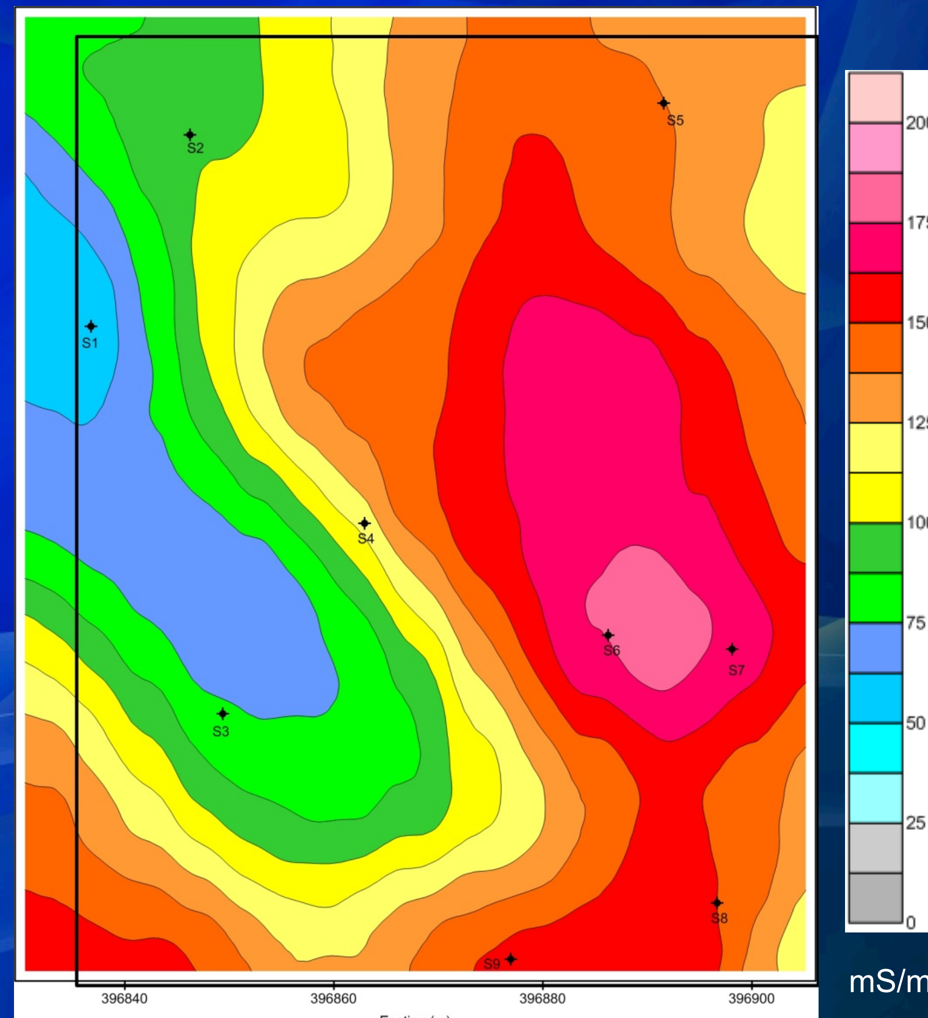
EM Survey – Shallow Depth

EM38-MK2 - approx 0.65 m



GEM2 – approx 0.5 m



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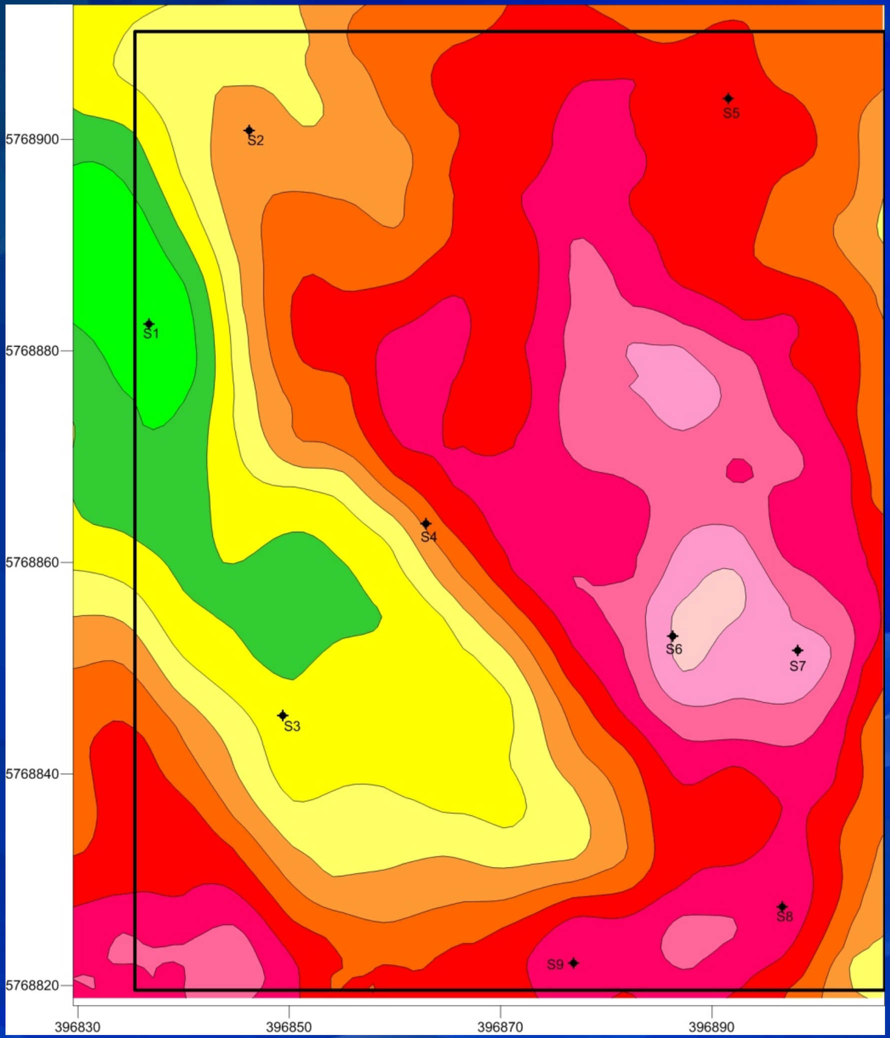
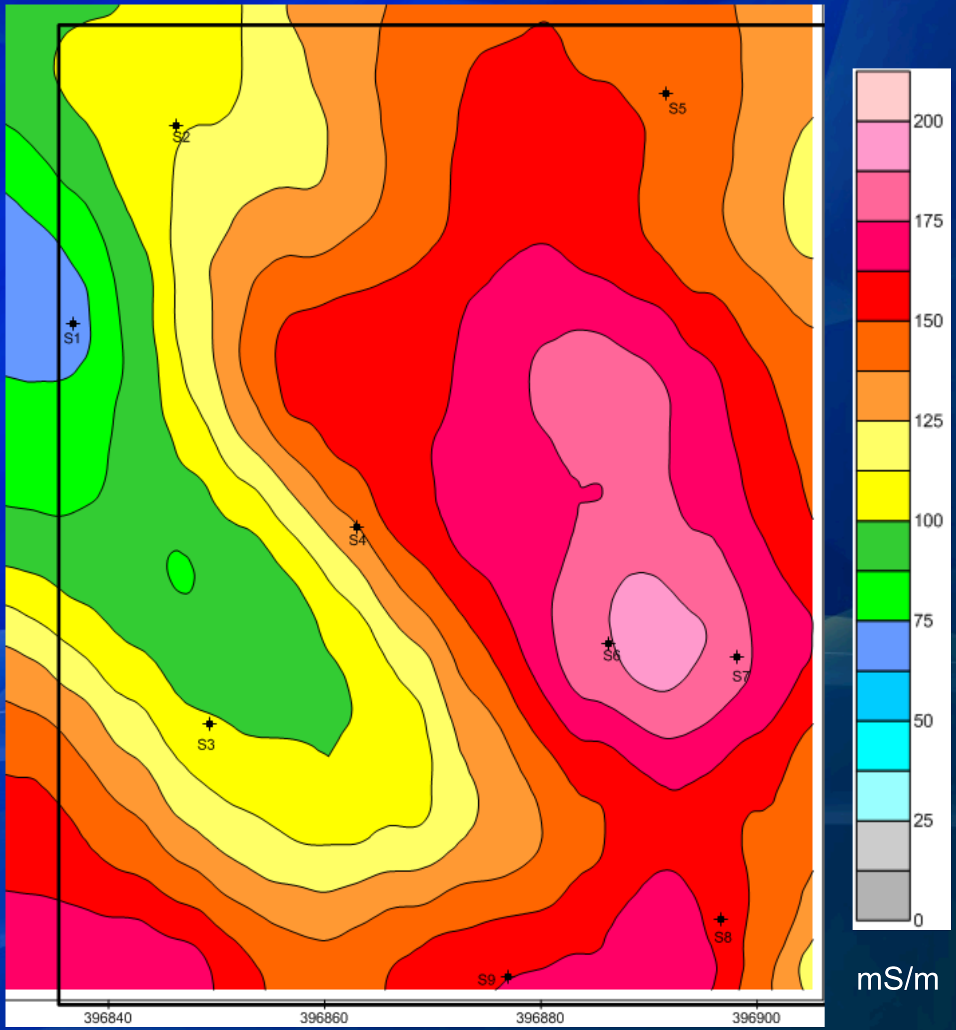
EM Survey – Deeper Depth

EM38-MK2 - approx 1.3 m



GEM2 – approx 1.0 m



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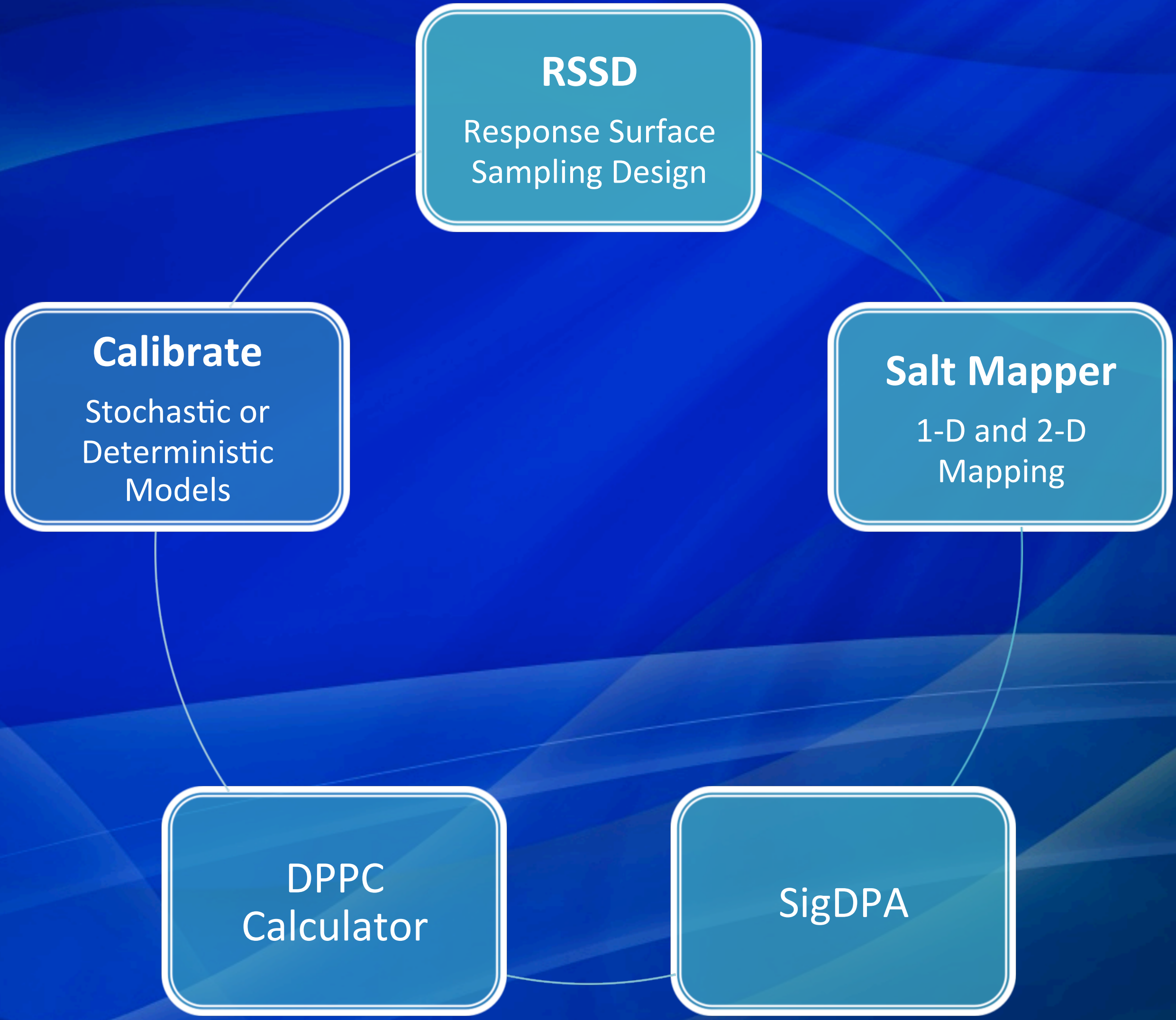
ESAP Software Program



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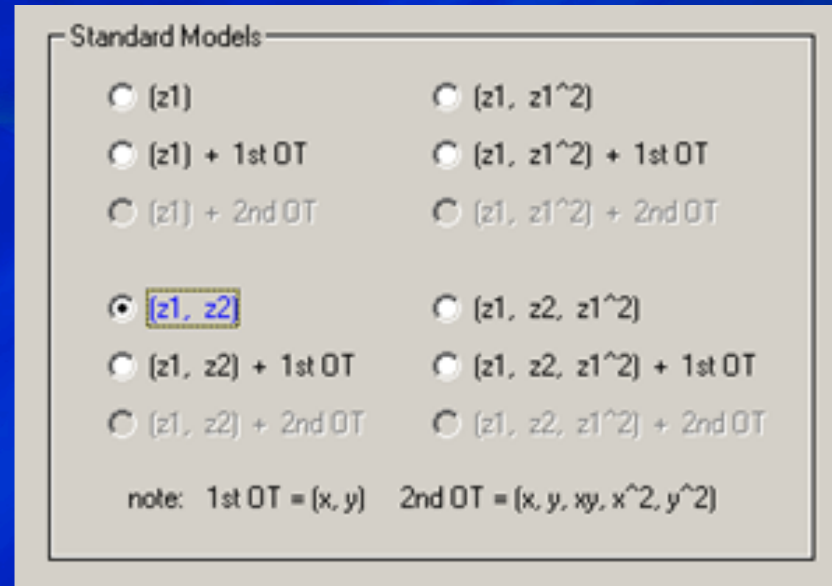
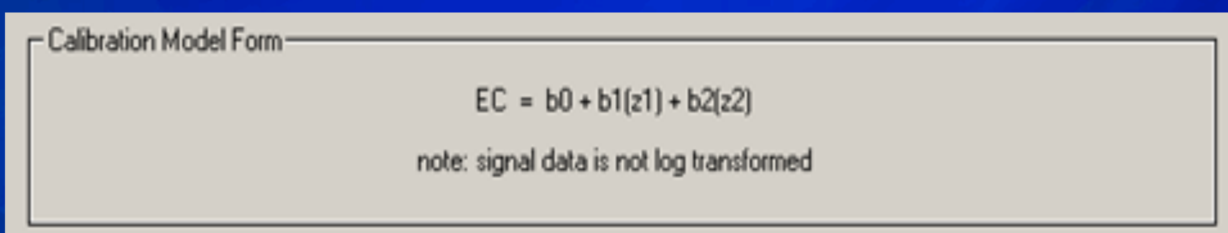
Deterministic Model

- Biased towards Southern California
- Soil temperature will only go down to 10°C
  - Actual soil temperatures - 10 October 2011
    - 8°C at 15 cm and 7°C at 30 cm
- Moisture content as % of field capacity
  - Range is 50% to 125%
  - Unrealistic for Western Canada
- Predicted EC values about 300% higher than statistical method

Spatial Regression Model

- Program will select appropriate model



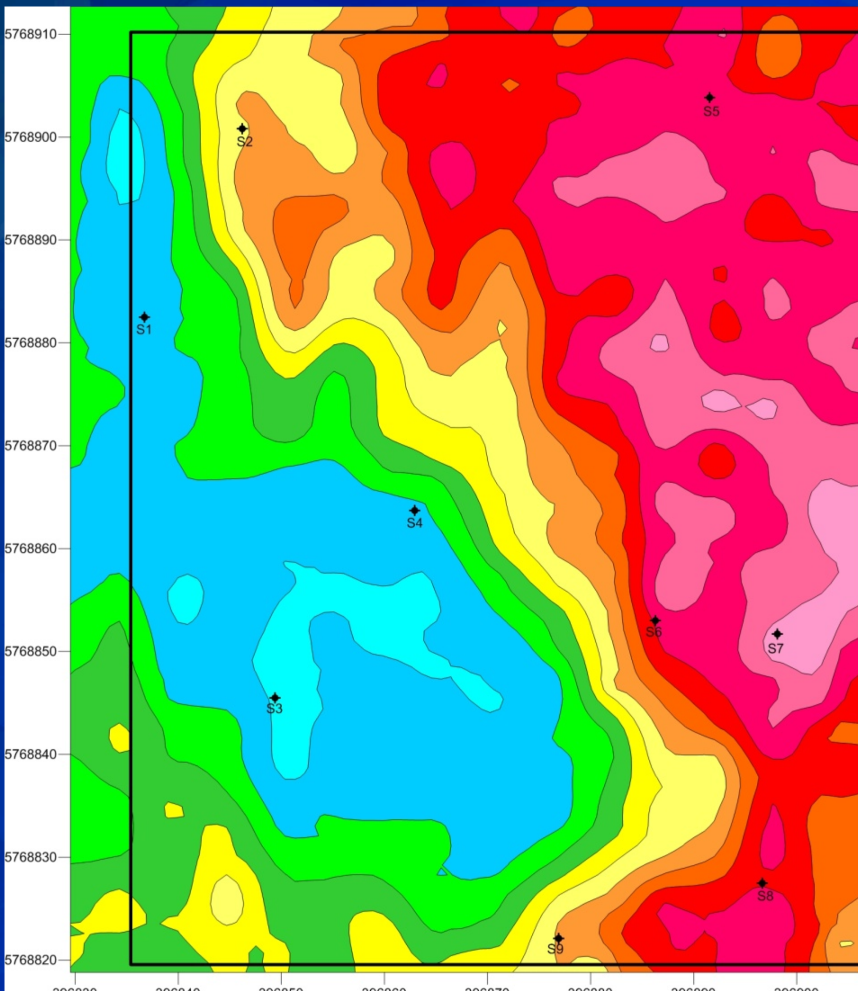


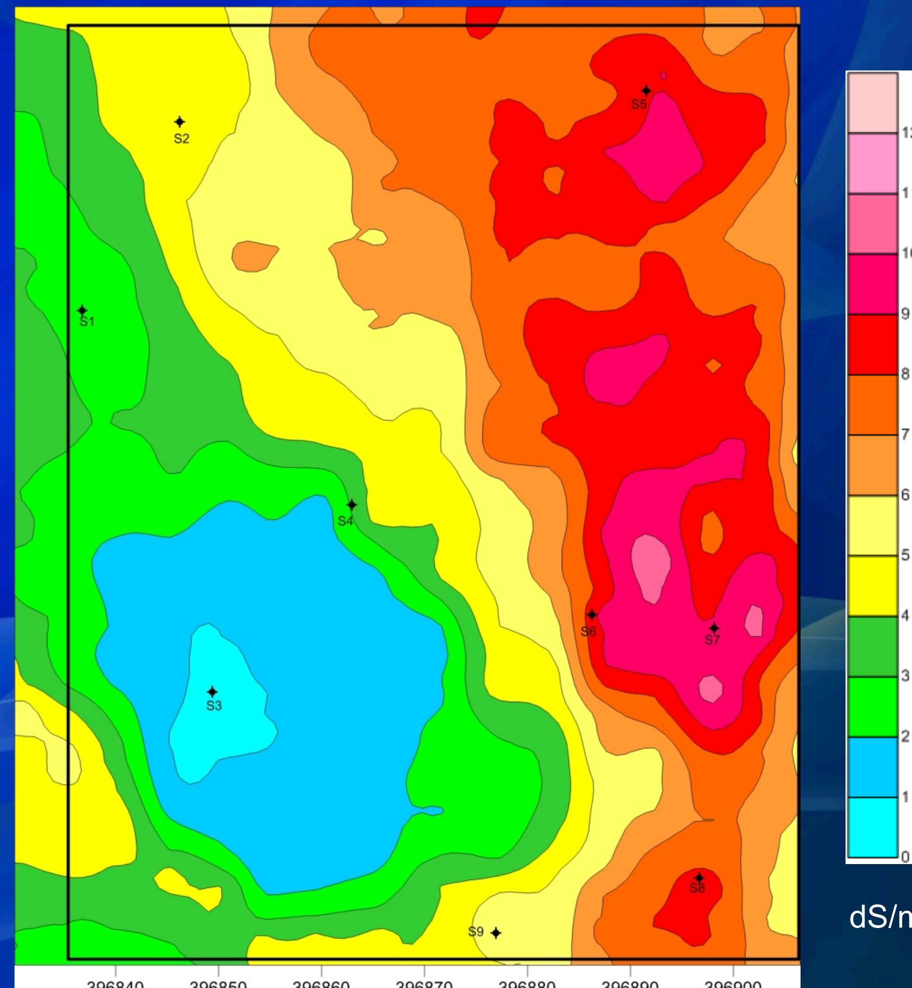
Calculated table of predicted Electrical Conductivity values

Predicted EC at 0-30 cm

EM38 0.5 – 11.9 dS/m

GEM2 0.5 – 10.8 dS/m





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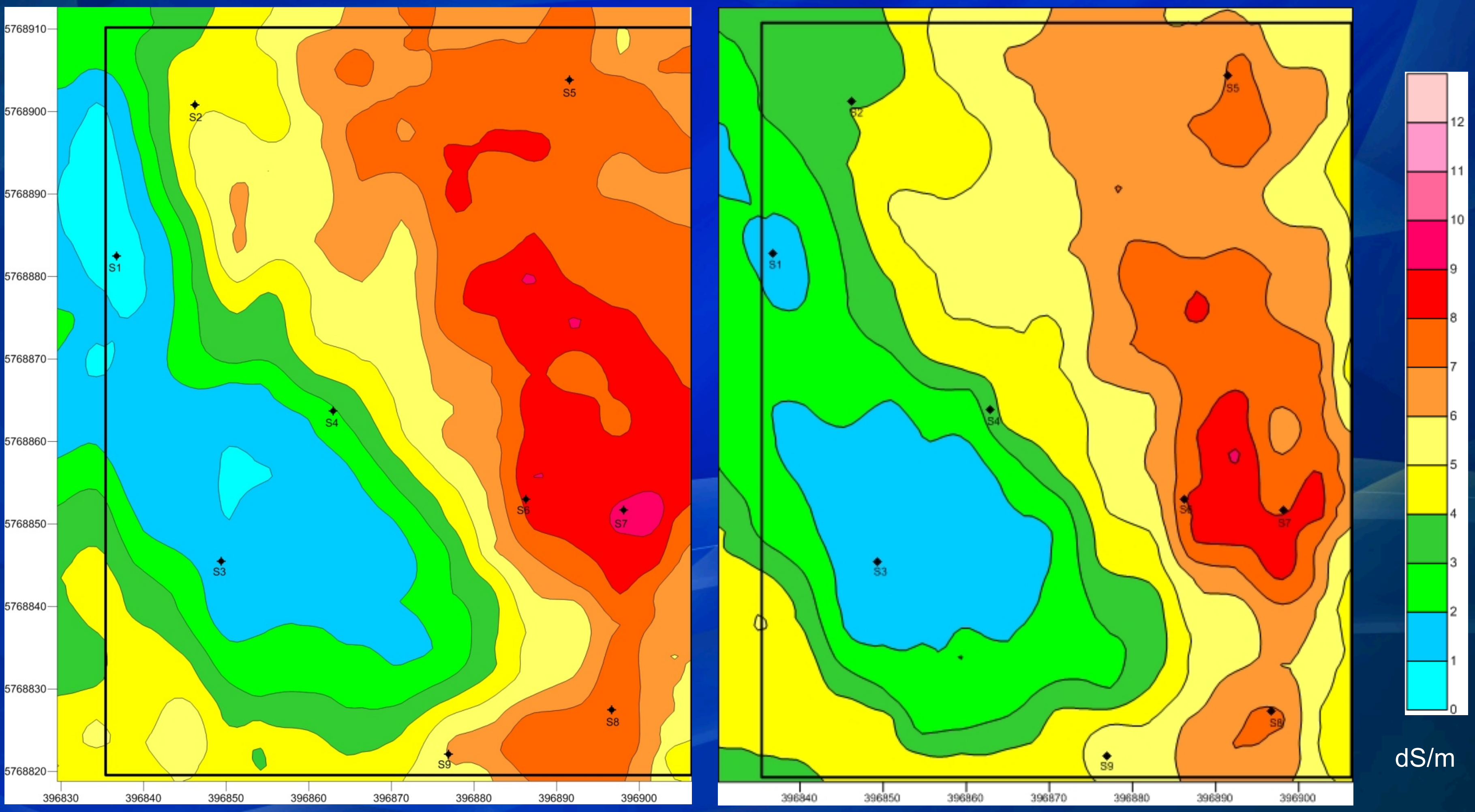
Predicted EC at 30-60 cm

EM38 0.3 – 9.4 dS/m

GEM2 1.3 – 9.2 dS/m



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Variability in Predicted EC Maps

- GEM2 Predicted EC values more variable
  - Related to depths of sampling
  - 30 cm increments down to 120 cm
    - 25 cm increments down to 100 cm better range for GEM2
- Magnitude of Variability Not Significant
  - Both EM sensors tended to be more variable at lower EC
  - Both were more accurate at higher EC

Comparison of Predicted EC Values

0 – 30 cm depths

Sample	Lab EC	EM38 EC	GEM2 EC
S1	1.3	1.8	2.7
S2	5.4	5.9	4.7
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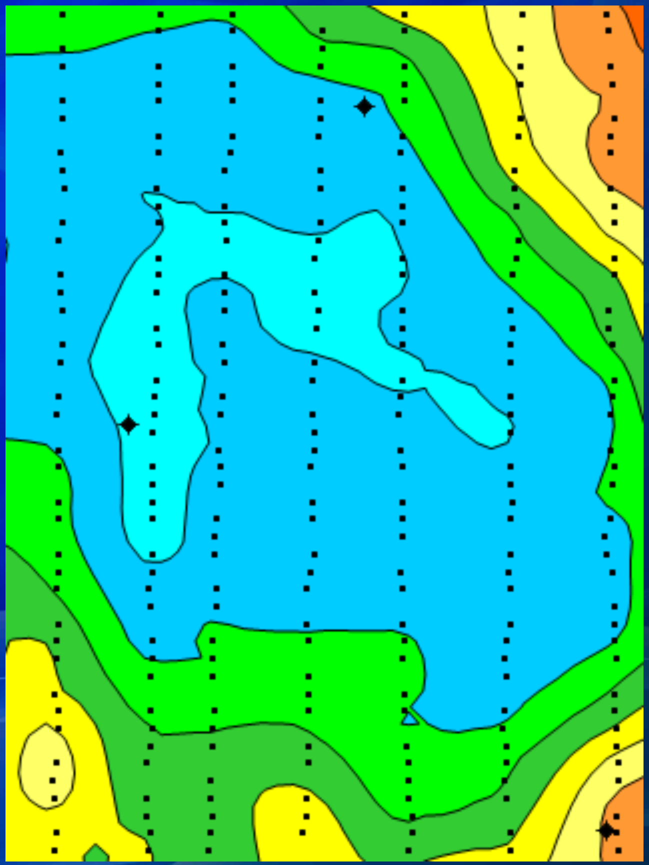
S7	10.5	11.3	9.3
S8	8.6	8.9	8.2
S9	6.2	6.1	5.1

Potential Application of ESAP

- Any site with sufficient analytical data
- Reclamation site
  - EM survey before or after
  - Soil samples collected - GPS to mark locations
  - Overlay sampling sites on EM survey
- Visual map of EC (dS/m)
  - Enhance understanding by regulators



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Conclusions

- EM data from EM38 and GEM2 virtually the same
- ESAP program calculated reasonable prediction of EC
- Sampling design can be independent of ESAP
  - Predictions still valid
  - Well suited to reclamation projects

Acknowledgements

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- http://www.ars.usda.gov/Services/docs.htm?docid=8918