Electromagnetic Surveying in the Mangrove Lakes Region of Everglades National Park

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1. Introduction:

The Mangrove Lakes are an interconnected set of shallow (~ 1m), brackish lake and creek systems on the southern margin of the Everglades adjacent to Florida Bay. This system has experienced significant changes in water quality over the past century as a result of reduced freshwater flows in the Everglades. Current efforts associated with the Comprehensive Everglades Restoration Plan (CERP) aim to increase these flows. This study describes preliminary results of geophysical surveys in the lakes conducted to assess changes in the groundwater chemistry as part of a larger hydrologic and geochemical study in the Everglades Lakes region.

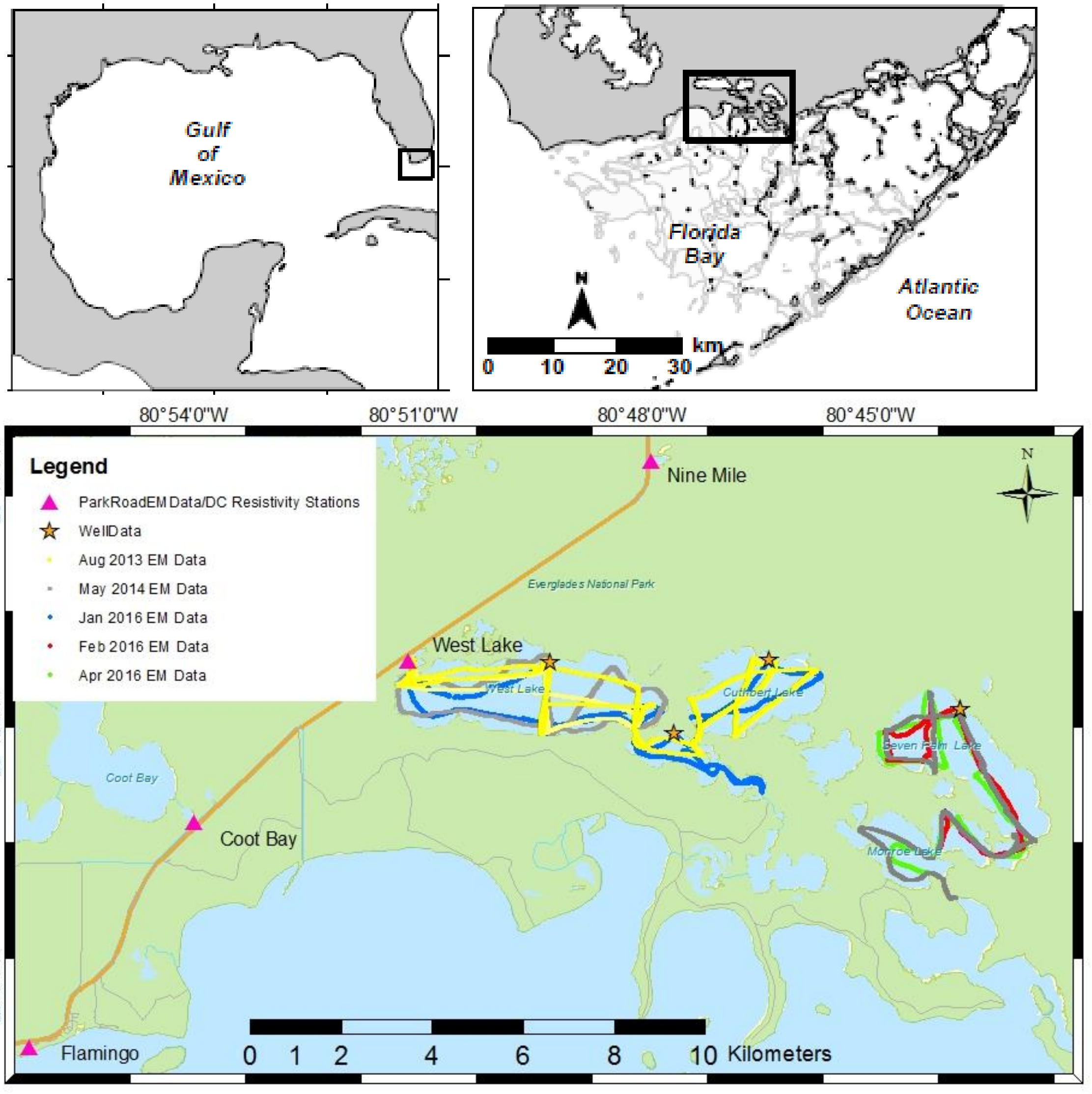


Figure 1. Map showing location of shallow groundwater wells and geophysical surveys

2. Geophysical Assessment of Groundwater Quality

The project has installed shallow groundwater wells along the northern shores of West, Cuthbert, Long, and Seven Palm lakes to monitor changes in salinity, nutrients and geochemical tracers (Figure 1; Allen and Price, this conference). The relatively sparse distribution of these wells is insufficient to characterize spatial variations in the groundwater salinity. The objective of this study is to use geophysical techniques to map surface and groundwater salinity in the lakes.

Electromagnetic (EM) methods use the principle of electromagnetic induction to map variations in the electrical conductivity, σ (or its reciprocal resistivity, $\rho = 1/\sigma$) (Figure 2). EM waves from a transmitting coil induce eddy currents in the subsurface which resulting in a secondary field detected in a receiving coil. In porous media, currents are carried by electrolytic conduction of ions in pore waters. The pore fluid conductivity, σ_{GW}, and the bulk conductivity of the rock σ_{rock} are related by $\sigma_{GW} = F\sigma_{rock}$ where *F* is the formation factor.

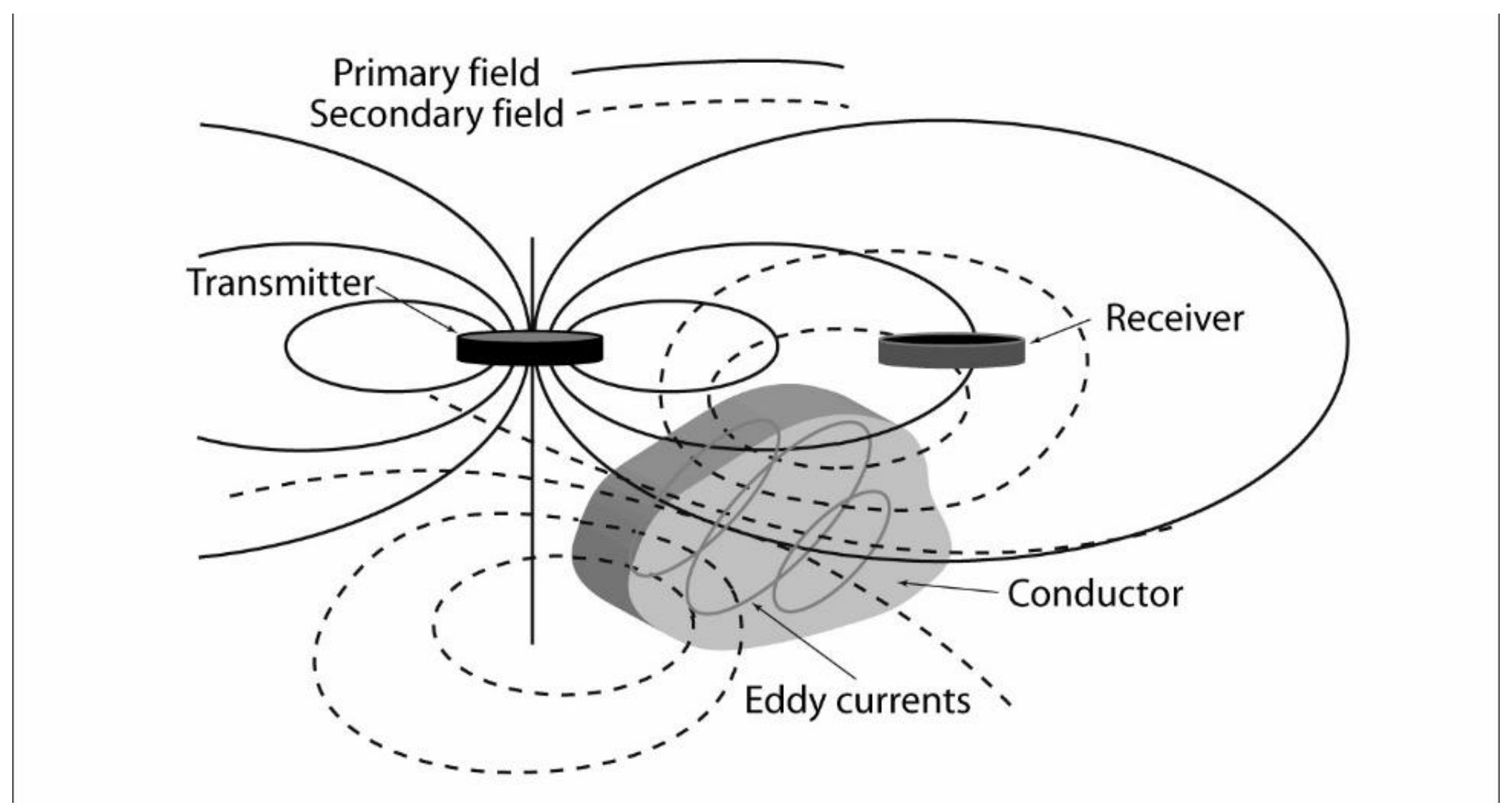


Figure 2. Electromagnetic method. From Burger et. al, 2006, *Introduction to Applied Geophysics*

3. Experimental setup

A GSSI Profiler EMP-400, multi-frequency EM conductivity meter was deployed in a flat bottomed plastic kayak towed behind a motorized skiff (Figure 3). Lake water depth, water temperatures and GPS locations were continuously measured with a sounder/chart plotter which was calibrated with periodic sounding rod measurements. At periodic intervals during the survey, the profiling was stopped and surface water conductivity, temperature and salinity were recorded with a portable YSI probe on the tow boat.

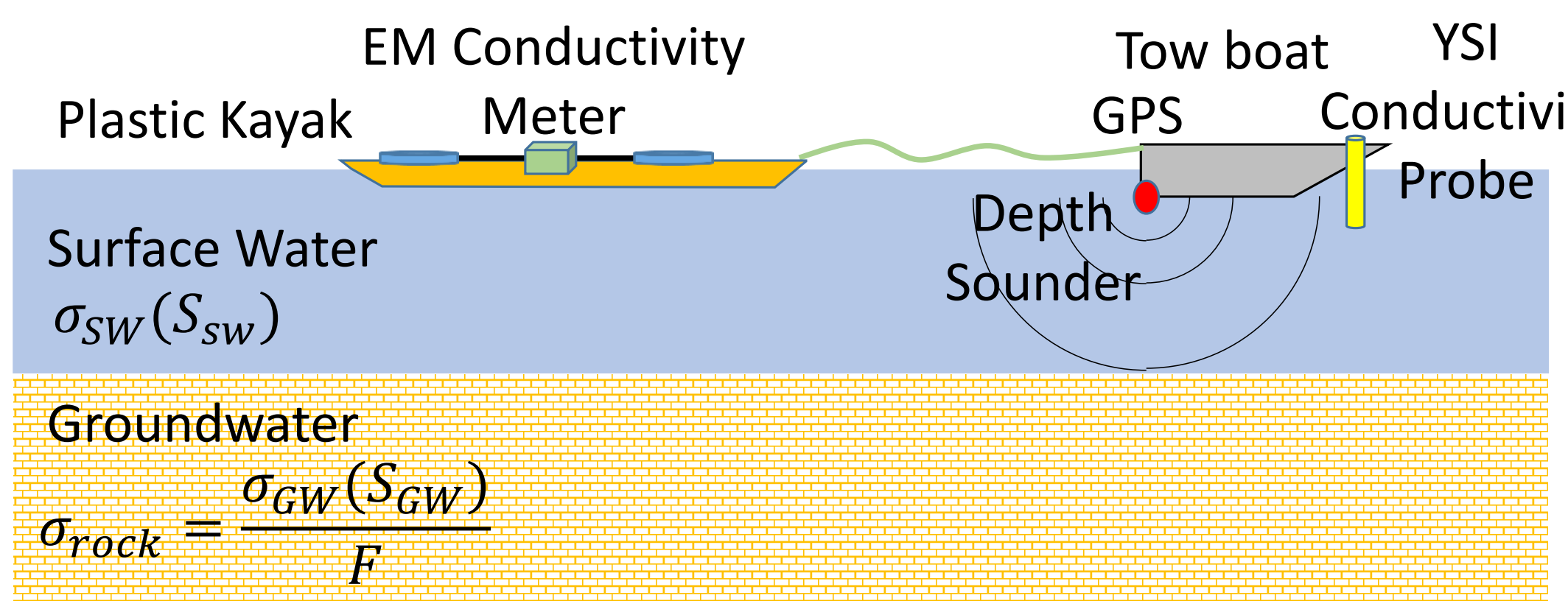


Figure 3. Experimental setup

4. Data

EM profiles were conducted in Alligator Creek (West Lake) and McCormick Creek (Seven Palm Lake) systems in August 2013, May, 2014, and the winter of 2016 (Figure 1). EMP-400 conductivity meter continuously recorded in-phase and quadrature field components at three discrete frequencies between 1 and 16 KHz. In total, over 100,000 discrete measurements were recorded.

Figure 4 shows the field components converted to apparent conductivity, the conductivity of an equivalent 1 layer earth, for the 2016 data. The 16 KHz data has the lowest penetration depth and reflects the conductivity of surface water whereas the 1 KHz data has the greatest penetration depth and measures an average of the surface water, the nonconductive lake bottom formations, and groundwater. This is demonstrated by the generally higher conductivities at the high frequencies. The data also show the general increase in conductivity from February to April demonstrating the increase in salinity during the dry season.

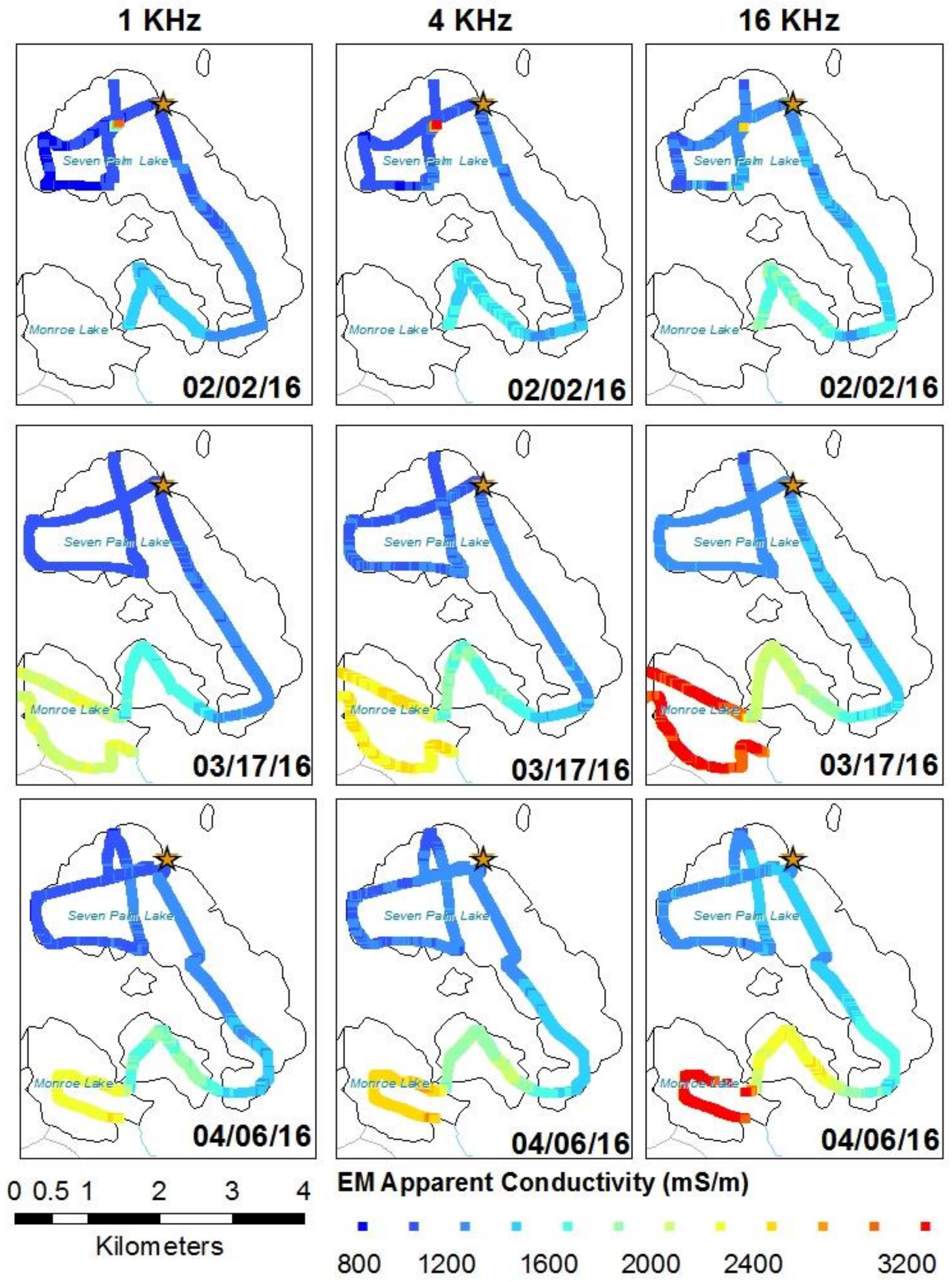
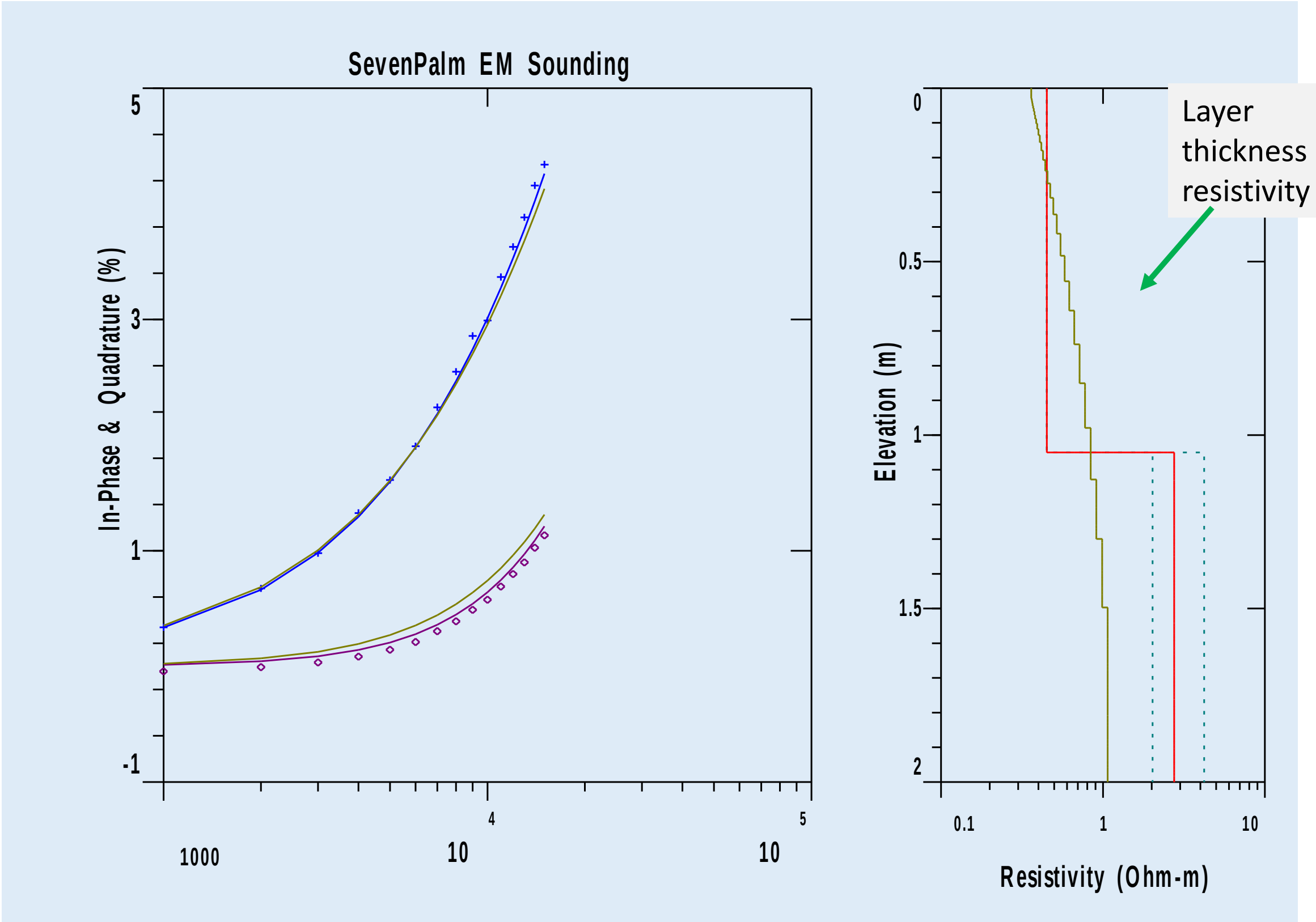


Figure 4. Apparent conductivities at 1, 4, and 16 KHz in the McCormick Creek system measured in 2016

5. Inverse Modeling

The field component data were inverted to 2-layer models representing the water layer thickness and conductivity and the lake bottom conductivity. At spot locations, models were constrained with water depth soundings and surface water conductivity measurements (Figure 5). At other locations along the profiles, the water depth and conductivity were allowed to be free, but the free models were generally consistent with the constrained models.

An example of the inversion from the May, 2014 data is shown in Figure 6. In West Lake, sub-bottom conductivities decreased from 400 mS/m in the west to 200 mS/m in the east indicating a general W to E decrease in groundwater salinity. In the McCormick Creek system, sub-bottom conductivities increased from 200 mS/m at the north end of Seven Palm Lake to over 650 mS/m at the southern end of Monroe Lake.



Layer thickness and resistivity fixed

Figure 5. Two-layer modeling results of from the multi-frequency sounding performed in Seven Palm Lake in May, 2014. The left hand plot shows the fit between the observed and calculated quadrature (blue) and in-phase (purple) components. The right hand plot shows the best fit inverted resistivity-depth model (red) and upper and lower range of acceptable models (green dashed lines) as determined by an equivalence analysis.

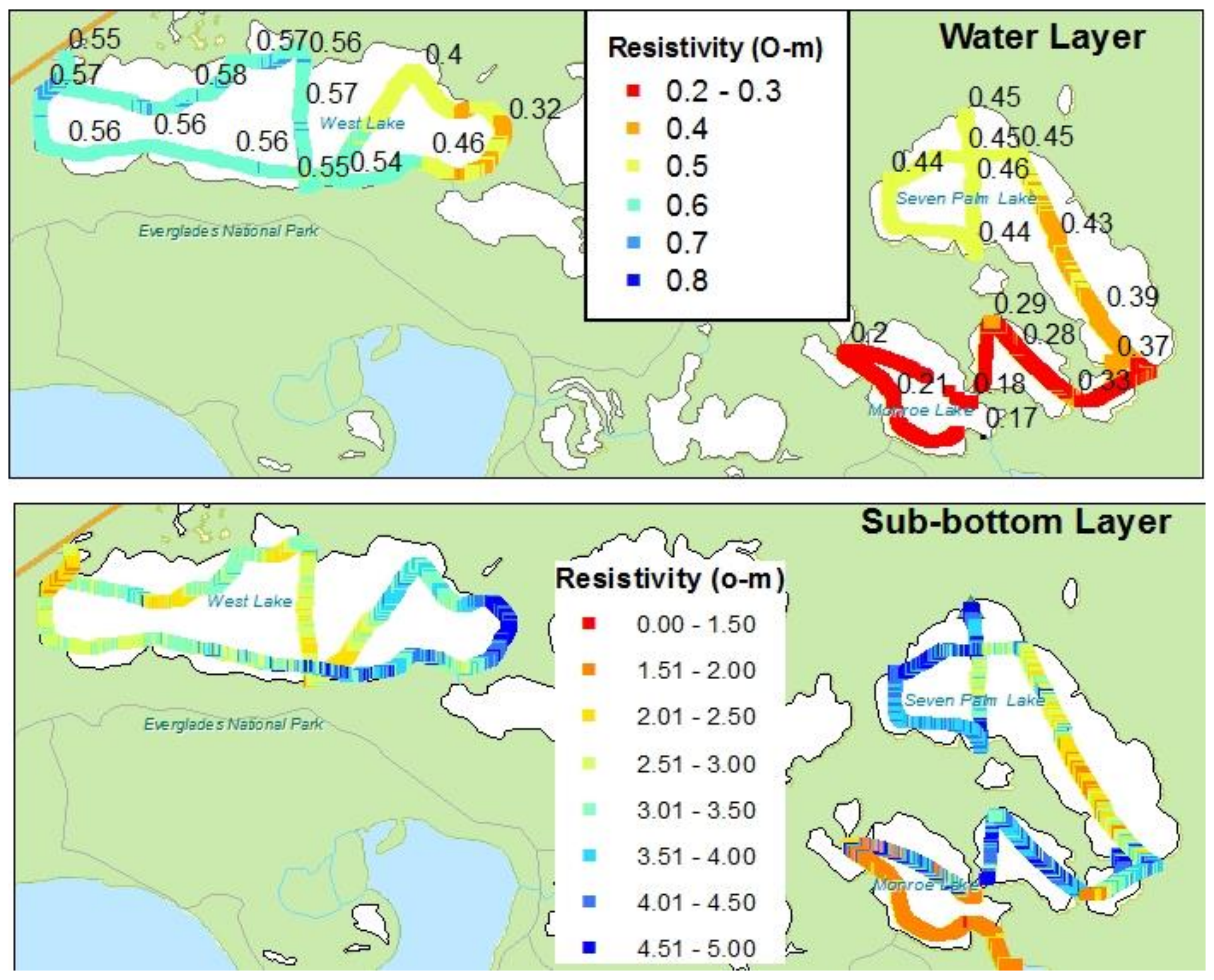


Figure 6. Two-layer modeling results of the data collected in May, 2014. Numbers in the top map are resistivity as determined from spot YSI conductivity probe measurements.

6. Salinity Analysis

Pore fluid resistivity was estimated by assuming a formation factor of 5.1 (Fitterman and Deszcs-Pan, 2004). Salinity is estimated from standard relations between salinity and specific conductance.

An example of this analysis from the May, 2014 data is shown in Figure 7. In the Seven Palm Lake system, the salinity of both the surface and groundwater decreases from north to south. In addition, the salinity of the surface water is generally higher than the groundwater. This difference is greatest in the southern portions of the system. In West Lake, the salinity of the surface water decreases from east to west whereas the salinity of the groundwater increases from east to west.

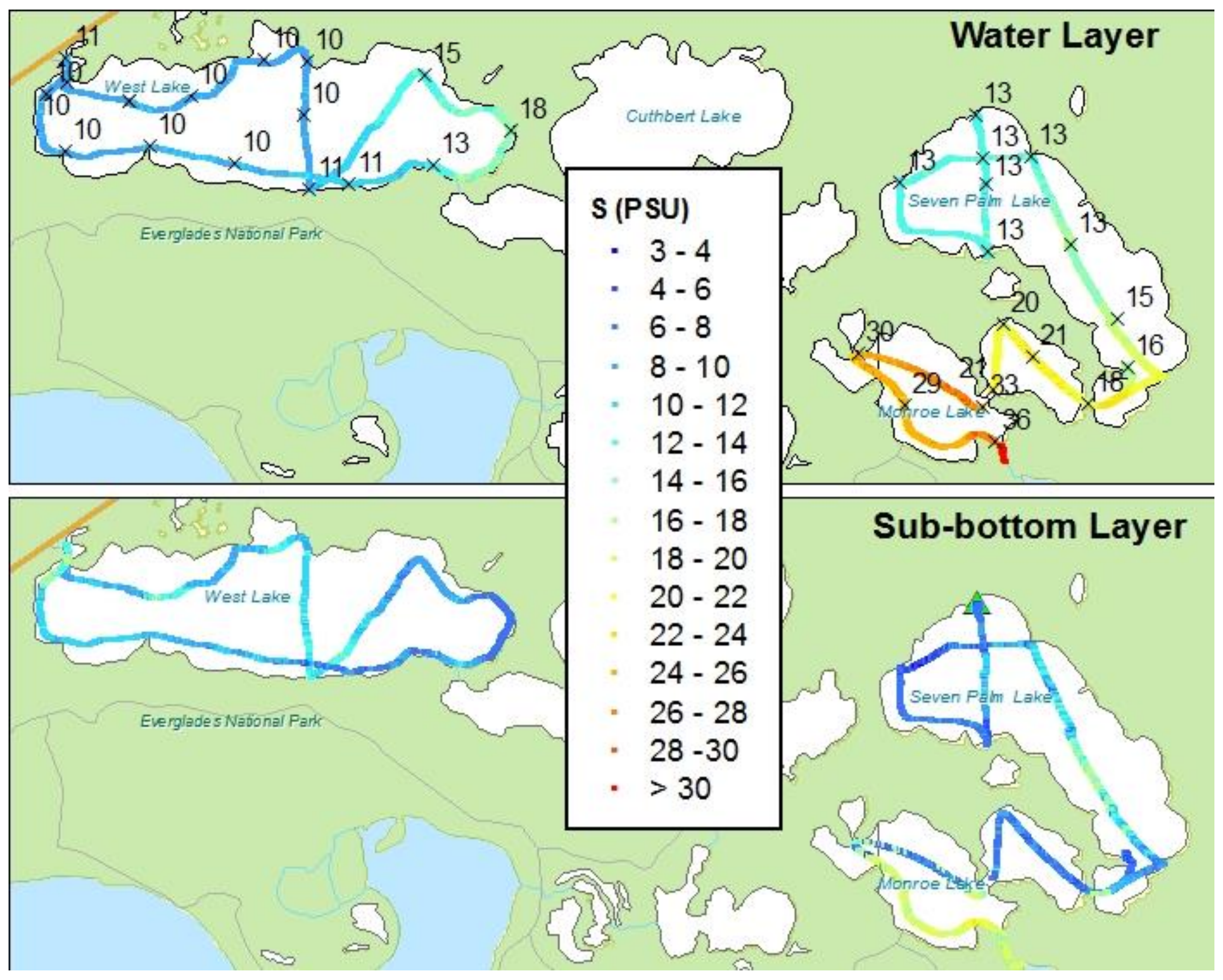


Figure 7. Interpreted salinity in May, 2014. Numbers in the top map are salinity as determined from spot YSI conductivity probe measurements.

7. Future Work

Future work will include refinement of the modeling procedures to better constrain the models. EM surveys will be repeated in May, August and November and an experiment using DC resistivity methods will be attempted in the Lakes. Finally, a deeper groundwater monitoring well is planned for the West Lake parking lot. Water samples from this well will be combined with a surface electrical survey to independently determine a formation factor for the site. This will allow us to better determine the salinity from the geophysical profiles

8. Acknowledgements

We wish to thank the South Florida Water Management District for funding this project. Josh Allen and Michael Kiflai contributed to the data acquisition.