Estimating Water Quality Along the Southwest Florida Coast for Hydrologic Models Using Helicopter Electromagnetic Surveys

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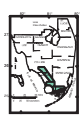
Introduction

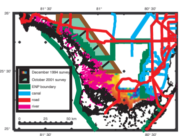
Modern, three-dimensional hydrologic models are valuable tools for understanding and managing ground-water resources. They are also beasts that need to be fed great quantities of data in the form of hydrologic properties. Throw solute transport into the model and you have a beast on steroids requiring thousands of estimates of water quality. Traditional approaches relying upon water quality measured in wells and then interpolated or extrapolated across the model can be woefully inadequate, especially when well data are sparse.

Helicopter electromagnetic (HEM) surveys rapidly collect high density data about subsurface conditions. Combining well information with HEM results provides a way of satisfying the data hungry beast. The well information is used to determine the relationship between geophysical parameters and physical quantities of interest to hydrologic modellers, such as aquifer geometry and water quality.

We previously used this approach in Everglades National Park to map saltwater intrusion (see maps below). We have extended HEM coverage to the northwest along the coast near Everglades National Park and Big Cypress National Preserve. This survey has 2,692 line-kilometers of flight lines covering an area of approximately 1020 sq-km.



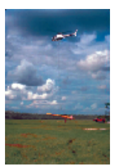
Index map showing location of study area in south Florida.



Map showing location of Everglades and Big Cypress HEM surveys

How HEM Works

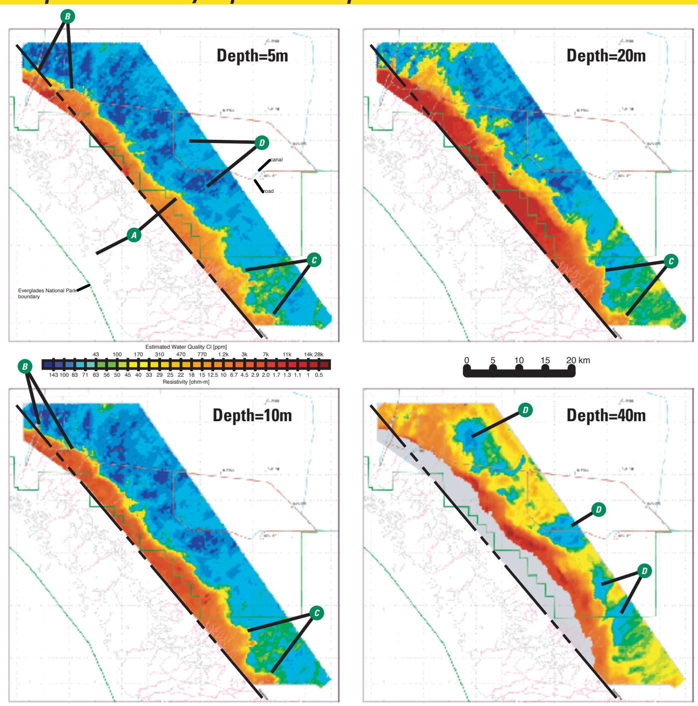
Helicopter electromagnetic (HEM) surveys measure the electrical conductivity of the ground at multiple frequencies using an instrument pod slung beneath a helicopter. A measurement is made every 0.2 s corresponding to a distance of 5-10 m depending upon flight speed. Flight-line spacing is typically 400 m. The depth of exploration, which varies with the transmitted electromagnetic signal frequency and the conductivity of the underlying geologic units, is typically 20-80 m. Five transmitter-receiver frequencies are used to vary exploration depth. In more conductive zones, such as those saturated with seawater or brine, the exploration depth is diminished, while in freshwater saturated zones deeper exploration is possible. The HEM data are used to estimate a layered-earth electrical resistivity model at every measurement point. (Resistivity is the reciprocal of conductivity.) The interpreted resistivity values can then be interpolated to create a three-dimensional grid of electrical properties.



Helicopter taking off with electromagnetic bird on 30-m long sling.

The four depth-slice maps in the center panel show the interpreted formation resistivity at depths of 5, 10, 20, and 40 m. The maps show a transition from high resistivities (>30 ohm-m) to low resistivity (<10 ohm-m) as the shore line is approached. This transition is caused by saltwater intrusion, and we call it the freshwater/saltwater interface (FWSWI). The transition is fairly abrupt, though smooth in the direction parallel the transition. In places the FWSWI is found between 15 and 20 km inland. The influence of canals and streams on the FWSWI is evident in several locations and depths.

Interpreted Resistivity Depth-Slice Maps



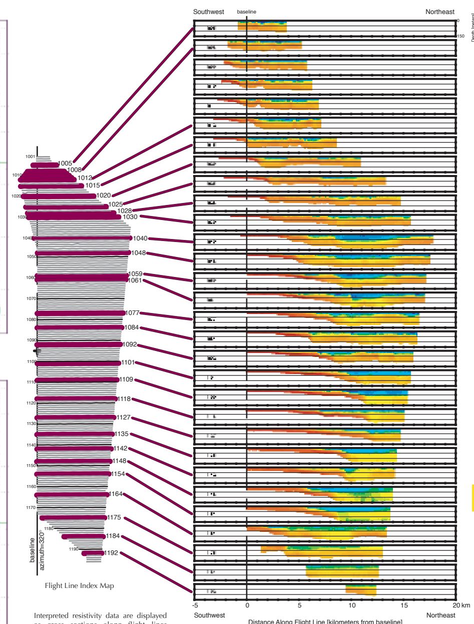
A — Saltwater intrudes aquifer 15-20 km from coast.

B — Canal along road influences FWSWI geometry.

C — Streams lower hydrologic head and control location of FWSWI.

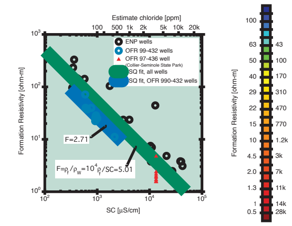
D — Deep resistive zone may reflect bedrock erosional features.

Interpreted Resistivity Cross Sections



Interpreted resistivity data are displayed as cross sections along flight lines perpendicular to baseline. Vertical exaggeration is 10:1. Color scale is the same as for the depth-slice maps.

Estimating Water Quality



The HEM measurements provide estimates of formation resistivity, which is a function of the specific conductivity (SC) of the pore water, the amount of pore space, the degree of saturation, and the presence of clay minerals. For hydrologic modelling purposes information about the quality of the pore water, such as salinity or chloride content, is required. Establishing this relationship is involved. A simpler task is to establish a relationship between formation resistivity and the specific conductance (SC) of the pore water. Using scatter plots of formation resistivity from geophysical logs against SC measured downhole or on pumped water samples the correlation can be established.

The figure above shows data from wells in Collier and Monroe Counties in the study area (Weedman et al., 1997, 1999) and from wells in Everglades National Park (Fitterman and Deszcz-Pan, 2001). Two correlation lines are shown, one for the combined data sets and the other for just the eastern Collier and northern Monroe Counties data (Weedman et al., 1999). The difference between the two correlations gives an idea of the uncertainty in the SC estimates derived from the HEM data. We have used the composite correlation because it spans a wider range of environments. Also shown on the figure is an estimated chloride concentration scale derived for aquifers near the study area (Reese and Cunningham, 2000).

References

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Summary & Conclusions

Helicopter electromagnetic (HEM) data provide a very detailed image of subsurface resistivity conditions. Because of the strong influence of ground-water specific conductance on the formation resistivity in south Florida, the HEM data are being used to estimate chloride content to match against 3-D solute transport model results. This task could not be accomplished using only well data due to the sparcity of wells and severe access limitations.

The HEM data display the effects of canals and natural drainages on saltwater intrusion. The shape of the interface is seen to be complex and spatially variable.

The use of HEM data combined with water quality information from selected wells is a new approach for meeting the data demands of three-dimensional hydrologic models. The relatively flat lying geology in south Florida justifies the use of one-dimensional interpretation of the HEM data. The lackof clay minerals in the aquifer makes establishing the relationship between water quality and formation resistivity relatively straight forward. The combined use of well and HEM data could be used to sate the bestial data requirements of modern hydrologic models in other study areas.

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