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Quantitative Hydrogeological Framework Interpretations from Modeling Helicopter Electromagnetic Survey Data, Nebraska Panhandle

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Introduction

Background

- North Platte River Valley in western Nebraska
- Critical section of the North Platte River for cooperative agreement
- Major groundwater and surface-water management issues
- Data will be used in the COHYST and Western Nebraska Optimization Model
- Three-year study (2-year data collection, 3rd year report writing)

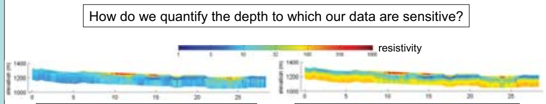
Airborne Electromagnetic Surveys

- A method of collecting information about changes in electrical resistivity beneath the land surface that can be related to lithology in a geospatially-referenced dataset
- Non-invasive
- Cost-effective compared to drilling alone
- Designed to cover large areas quickly
- Effective where sands and gravel overlie silt and clay

Typical helicopter electromagnetic survey system showing helicopter towing instrumentation package

Inversion, Depth of Investigation, and Image Display

How do we quantify the depth to which our data are sensitive?

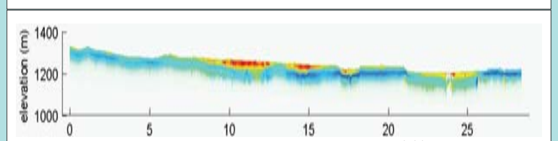


At depth, where the data are no longer sensitive to the model (*rho*), resistivity values tend towards the reference value (rho_{high} or rho_{low})

$$0 \leq ß = \frac{m_{high} - m_{low}}{ref_{high} - ref_{low}} \leq 1 \qquad m = \log(rho)$$

$ß \rightarrow 0$: $m_{high} = m_{low}$ ***i.e. inversion strongly controlled by the data***

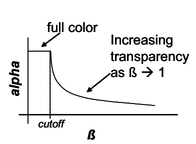
$ß \rightarrow 1$: $m_{high} = ref_{high}$ and $m_{low} = ref_{low}$ ***i.e. inversion strongly controlled by the reference model***



Apply a transparency mask to the final image based on the DOI:

$$alpha = \begin{cases} 1 & ß < ß_{cutoff} \\ e^{-(ß - ß_{cutoff})} & ß > ß_{cutoff} \end{cases}$$

($ß_{cutoff}$ is a user-specified parameter, often ~ 0.1 to 0.2)



1-D Inversion

- UBC EM1DFM – Farquharson, Oldenburg and Routh, Geophysics, 2003

Depth of Investigation (DOI)

– Based on Oldenburg and Li, Geophysics, 1999

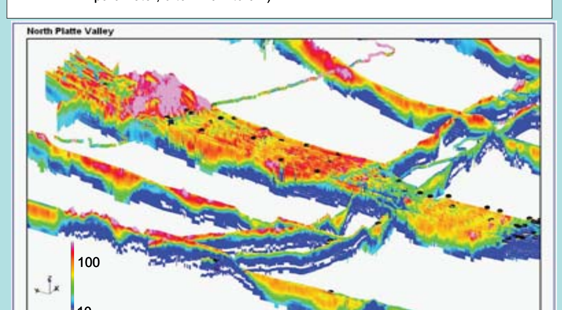
- The index, *ß*, quantifies where the data are sensitive to the model

Image Display

- Select a user-specified *ß* cutoff and then apply an increasing transparency value to the resistivity color scale as *ß* increases.

- The DOI is defined by the range of depths along the profile where *ß < ßcutoff*

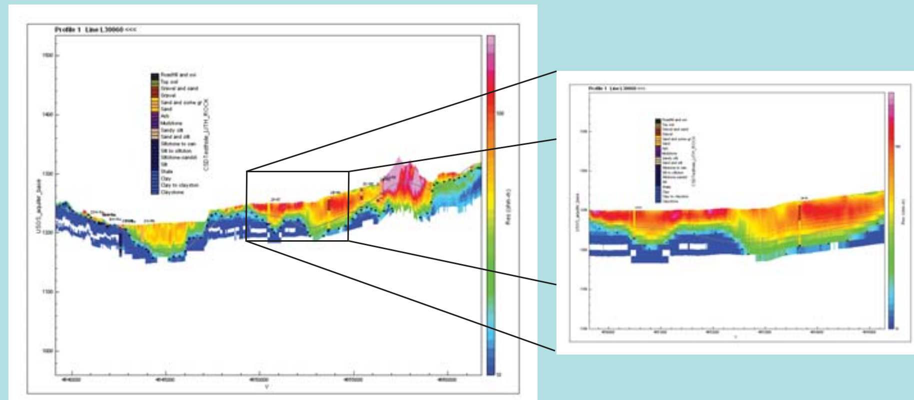
- The transparency allows for more robust interpretations as not all the data are removed at the cutoff point, but are preserved as a transparent color reflecting the decreasing sensitivity of the data to the model.



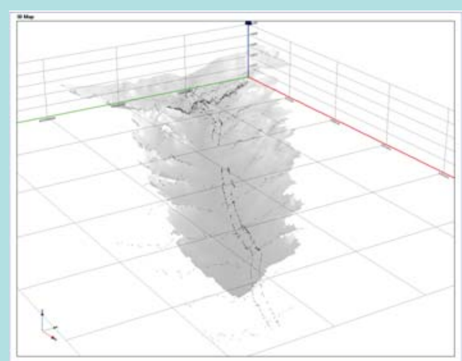
3-D Imaging

Fence diagram of the resistivity values in a portion of the project area. This illustrates the complex nature of the geology of the subsurface. Hydrogeologic frameworks are greatly enhanced by this information by using it to draw new bedrock elevation contours (shown as the top of the dark blue layer) and mapping the changes in lithology related to resistivity values. A set *ß* and no transparency has been used.

Interpretation and Pick Confidence



A selected 2-D resistivity image section (with zoom) showing location of test holes with lithology (vertical color bars), interpreted bedrock (black dots), and pre-HEM bedrock contour (gray line). The HEM data provided a better solution to the bedrock surface than just the test holes alone. All of the test hole data are correctly fitted with the HEM depth images. A set *ß* and no transpanrency has been used.

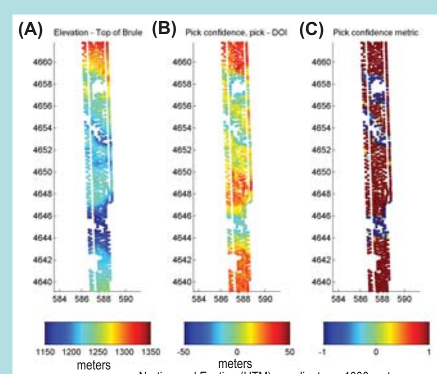


Interpreted Picks

3-D image of the area of the groundwater model in the North Platte valley (gray surface) and the black dots representing the interpreted pick of the bedrock surface.

Resulting interpreted picks constitute 6000 virtual test holes in the North Platte valley from the 2008 HEM data. This compares to $8M worth of drilling required to provide the same sampling of the bedrock.

The bedrock picks that are provided to the groundwater model need to be quantified and classified based on the confidence in the geophysical data.

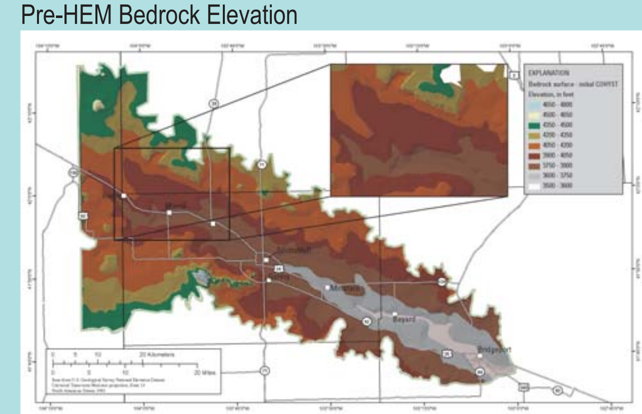


Pick Confidence

Plot of the picked HEM survey block collected in the North Platte Valley showing from left to right
(A) Color plot of the interpreted pick elevation in meters
(B) Color plot of the pick elevation with the maximum depth of investigation (DOImax) subtracted (meters). This is a measure of how far above or below the pick is from the elevation that corresponds to ßcutoff. Negative values indicate little resolution or confidence.
(C) Color plot of the plot (B) scaled from -1 to +1. This is a pick metric for each interpreted pick of the bedrock elevation (Brule part of the Tertiary White River Group). Negative is less confident and positive is more confident.
The groundwater modeler is provided each individual pick with a pick confidence metric. This allows qualification of the geophysical data that are supplied to the groundwater model.

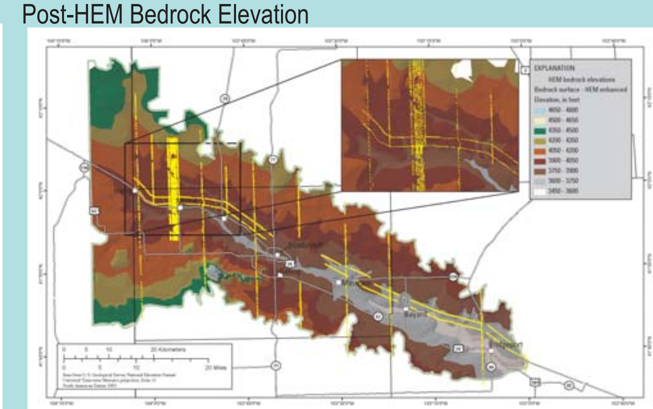
Improvements to Hydrogeologic Framework

Pre-HEM Bedrock Elevation



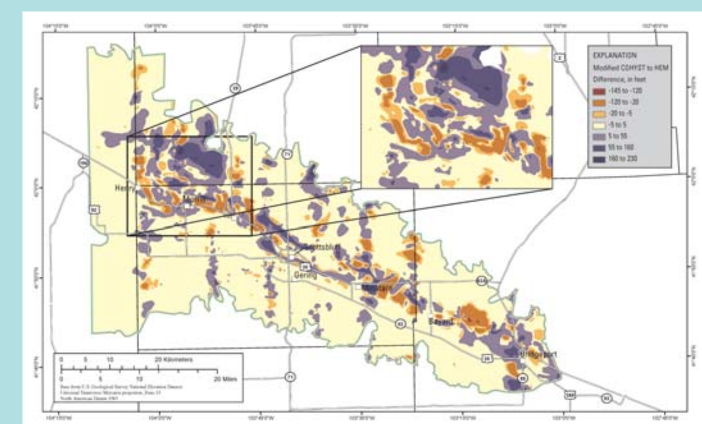
Pre-HEM top of bedrock map constructed from data provided by borehole and surficial geologic mapping. There are large distances between boreholes (lithologic logs from the Nebraska Dept. of Natural Resources database) and in many cases miles between Conservation and Survey Division test holes, which are included in the county test-hole log books.

Post-HEM Bedrock Elevation



Bedrock elevation based on new data provided by the HEM flights. The flight lines are yellow. Analysis of these data generated substantial changes in the bedrock elevation compared to the original.

Modification to Bedrock Elevation



Calculated difference between the pre-HEM and post-HEM bedrock elevation. Considerable changes exist showing the enhancements to the hydrogeologic framework because of the additional knowledge provided by HEM data.

Impact on Groundwater Model

The creation of the refined hydrogeologic framework resulted in a redistribution of flow path orientation (redefining the location of paleochannels).
The improved groundwater models represent actual hydrogeology at a level of accuracy not achievable using previous data sets.
Combining the water table elevation data with the HEM derived hydrogeological framework provides an accurate saturated thickness map. The saturated thickness times the estimated porosity of the aquifer from hydrologic tests determines the best available estimate of water in storage.

Project Partners
North Platte Natural Resources District, South Platte Natural Resources District, Nebraska Environmental Trust Fund, University of Nebraska Conservation Survey Division, U.S. Geological Survey

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