CHARACTERIZING THE SPIRITWOOD VALLEY AQUIFER USING HELICOPTER TIME-DOMAIN ELECTROMAGNETICS

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Presented at NGWA Groundwater Summit 2017, March 26-29, 2017, North Palm Beach, FL, USA

INTRODUCTION

Buried valley aquifers are important sources of groundwater supply in many regions of the USA consisting of permeable sand and gravel deposits in eroded bedrock valleys.

Buried valley aquifers have been difficult to define because they are often partially eroded, have complex lithology and are hidden amongst other shallower sand and gravel aquifers within thick glacial overburden.

In the Drift Plains District of North and South Dakota, glacial drift of various thickness unconformably overlies shale of the Cretaceous Pierre Formation.

The pre-glacial and glacial history has resulted in a complex geologic landscape, with ancient rivers carving deep valleys into the Pierre shale. Sand & gravel deposited within these drainage networks as well as outwash from glacial processes now form major aquifers in the area.

INTRODUCTION (continued)

The Spiritwood aquifer system is a complex network of glacially deposited sand and gravel bodies that are interbedded with till and clay, which are relatively impermeable.

The Spiritwood Aquifer is an important supply of water both in the United States and Canada where, in particular, it has been successfully mapped and studied using helicopter time-domain EM.

Recent investigations of the Spiritwood Valley aquifer in southern Manitoba by the Geological Survey of Canada and other workers, have demonstrated the value of helicopter time domain electromagnetic surveys in aquifer mapping and characterization (Oldenborger et al., 2010; 2011; 2012; 2013) using the contrasts between sand-gravels (high resistivity) and clay-tills (low resistivity).

This provided the impetus for the North Dakota Water Commission to fly a VTEM helicopter EM survey in the Jamestown ND region in October, 2016.

THE VTEM PLUS SYSTEM

The VTEM™ (Versatile-Time domain – Electromagnetic) system is known for its high signal-to-noise resulting in the high quality EM data and large depth of investigation (>150m to +750m).

Its Full Waveform technology allows for reliable early-time data (0.018msec min.) which is essential for resolving near-surface geology (top 25 meters / 80 feet).

Survey speed is typically 80 km/h (50 mph) with Transmitter/Receiver clearance of 35 meters (115 feet).

Off-time time-domain EM decays for (45 channels from 0.021-0.083msec.) are collected for H_x H_y H_z, with Magnetic-Gradiometer data at approx. 3m stations.

SPIRITWOOD VALLEY VTEM SURVEY

In October 2016 Geotech Ltd. carried out a helicopter-borne geophysical survey over the Spiritwood-JT block situated near Jamestown, North Dakota.

A total of 1950 line-kilometres of geophysical data were acquired in eleven (11) survey days from October 12-22, 2016.

OUTLINE

• Introduction
• VTEM™ System
• Spiritwood Valley Aquifer Project
  • HTEM Survey Results
  • 1D Layered-Earth Inversions
    • Resistivity-Depth Plans
    • LEI Sections
• Conclusions
Prior to the survey the Spiritwood Aquifer system (shown in blue) was mapped from a series of well logs used to derive the current extents of the aquifer system.

Shown left are State Wells & Test Holes, but there are likely an equal number of private wells present that also helped map the Spiritwood Aquifer system.

The objective of the survey was to collect high resolution VTEM data to 1) better characterize the aquifer boundary and geometry of the deeper Spiritwood channels; and 2) to better understand possible transverse till aquifers that cross-cut the main Spiritwood Aquifer.

Preliminary analysis of the raw VTEM data indicated a strong correlation with the known Spiritwood Aquifer system.

From the raw survey results the main channel aquifer is observed but also there are areas with complex structure.

The VTEM data were modelled using the Geoscience Australia 1D Layered Earth Inversion algorithm (GALEISBSTDEM) producing a series of resistivity-depth slices and cross sections through the survey area.

At shallowest depths mixed soils appear to dominate EM response.

At moderate depths, sand & gravel have greater influence on EM response.

At greater depths, buried channels within Spiritwood are becoming more visible.

Highlighting a secondary aquifer that cross-cuts/bypasses the Spiritwood Aquifer.

On L2290 the secondary channel is deeper and parallel to the main Spiritwood Aquifer.
SPIRITWOOD VALLEY VTEM SURVEY

VTEM Inverted Resistivity – 100m

- As the secondary aquifer continues south it turns eastward.
- On L2400 the secondary channel is deeper and also broader than Spiritwood aquifer.

 SPIRITWOOD VALLEY VTEM SURVEY

VTEM Inverted Resistivity – 100m

- Further south, we observe a cross-cutting channel exiting to the east.
- On L2450 the deeper secondary channel is observed as two separate features.

SPIRITWOOD VALLEY – FOLLOW-UP

L2400 – VTEM 1D Resistivity + Well Hole Location

Hole 13806224ADA – Well Logging Survey

Date: Monday, August 14, 2017 4:48 PM
Subject: Spiritwood test drilling results from L2430

We have been drilling for a few months throughout the Spiritwood study area. Please find attached some quick information from test drilling on L2430. It appears the deeper channel is real!!

Prior to drilling, we purchased a Mount Sopris 40GRP borehole geophysical tool to provide 16” and 64” resistivity along with IP, GAMMA, and Resistivity. We also have their 2SNA tool.

The attached file shows the location of the deeper channel test hole on L2430. The channel is located just north of the channel from the VTEM survey. We have also drilled a total of 3 holes, and are finishing up a deeper hole on the “deep” NW anomaly south of Wimbledon, ND.

Thought you might be interested in this data before presenting at the conference next month.

Cheers,
Dave

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David Hisz
Geologist – Water Appropriations
ND State Water Commission

SPIRITWOOD VALLEY VTEM SURVEY

VTEM Inverted Resistivity – 60m + Existing Aquifer Layer

- Looking at a conductive feature in mid-survey that divides the Spiritwood in two.
- On L1870, the channel structure appears as a mid-depth clay rich conductive layer.

SPIRITWOOD VALLEY VTEM SURVEY

VTEM Inverted Resistivity – 60m + Existing Aquifer Layer

- Looking at a center of conductive feature.
- On L1920, the channel structure resembles a basement horst, which overlies a deeper resistive feature in basement.

SPIRITWOOD VALLEY VTEM SURVEY

VTEM Inverted Resistivity – 60m + Existing Aquifer Layer

- Looking at a deeper resistivity depth slide above center of channel feature (resistive).
- Northsouth instead of deeper inferred channel aquifer, a deeper inferred aquifer is now better highlighted.

SPIRITWOOD VALLEY VTEM SURVEY

VTEM Inverted Resistivity – 110m + Existing Aquifer Layer

- Looking at a deeper resistivity depth slide above center of channel feature (resistive)
**SPIRITWOOD VALLEY VTEM SURVEY**

<table>
<thead>
<tr>
<th>Interval (feet)</th>
<th>Unit</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 – 20</td>
<td>TILL</td>
<td>buff, calcareous, sandy, oxidized</td>
</tr>
<tr>
<td>20 – 29</td>
<td>TILL</td>
<td>gray, unoxidized</td>
</tr>
<tr>
<td>29 – 40</td>
<td>SAND</td>
<td>medium to coarse, well-cemented, gravelly</td>
</tr>
<tr>
<td>40 – 46</td>
<td>GRAVEL</td>
<td>fine to medium</td>
</tr>
<tr>
<td>46 – 103</td>
<td>TILL</td>
<td>gray, sandy</td>
</tr>
<tr>
<td>103 – 105</td>
<td>GRAVEL</td>
<td>fine to coarse</td>
</tr>
<tr>
<td>105 – 142</td>
<td>TILL</td>
<td>gray</td>
</tr>
<tr>
<td>142 – 386</td>
<td>SILT</td>
<td>gray, clayey, calcareous, lignitic, minor amounts light gray clay laminae, Niobrara Formation</td>
</tr>
<tr>
<td>386 – 435</td>
<td>SILT</td>
<td>gray to black, clayey to silty, moderate sorting, Niobrara Formation</td>
</tr>
<tr>
<td>435 – 437</td>
<td>CLAY</td>
<td>light gray, highly calcareous, pyritiferous, Niobrara Formation</td>
</tr>
<tr>
<td>437 – 483</td>
<td>SAND</td>
<td>gray, clayey, lignitic, Niobrara Formation, (Poor samples below 320 feet)</td>
</tr>
</tbody>
</table>

**CONCLUSIONS**

- The VTEM data collected over the Spiritwood-JT block were of high quality, which allowed for geological mapping from near surface to depth, in spite of relatively weak resistivity contrasts (<10X).
- These data were inverted with the 1D GALEISBSTDEM algorithm to produce resistivity-depth models.
- These models were able to resolve the location and depths to the top and bottom of the Spiritwood aquifer throughout the central portion of the block providing more detailed pictures of the aquifer’s geometry.
- In addition to resolving the main Spiritwood aquifer as well as its deeper channels, the VTEM data and models highlighted several smaller aquifers which cross-cut/branch-off from Spiritwood.
- These are interpreted as probable glacial outbursts that segmented the main Spiritwood channel and were later filled with sand and gravel.

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**CONCLUSIONS**

- An area of interest was located in the southern portion of the survey block where a secondary aquifer appears to initially run parallel to Spiritwood then turns and dips underneath before exit the block eastward. It represents a potentially newly discovered buried aquifer.
- In addition to the southern area of interest, the VTEM data and inversion models displayed other smaller aquifers and aquitards to the main Spiritwood aquifer channel that shows the aquifer system contains more character than initially thought within the survey block.
- The North Dakota Water Commission have concluded that the Spiritwood JT VTEM helicopter TDEM survey successfully achieved both its survey goals of: 1) better characterizing the deeper channels within the Spiritwood aquifer systems, and 2) better understanding the transverse systems that were previously unknown but were apparent from their existing well studies of the Spiritwood Valley Aquifer.

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**ACKNOWLEDGEMENTS**

Our sincerest thanks to the North Dakota State Water Commission for allowing us to present these VTEM Survey results.