

INVITED HYDROGEPHYSICS PAPERS FROM SAGEEP  
NGWA Summit - Oral • Monday 11:10 AM – 11:30 AM

**CHARACTERIZING THE SPIRITWOOD VALLEY AQUIFER USING HELICOPTER TIME-DOMAIN ELECTROMAGNETICS**

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## OUTLINE

- Introduction
- VTEM™ System
- Spiritwood Valley Aquifer Project
  - HTEM Survey Results
  - 1D Layered-Earth Inversions
    - Resistivity-Depth Plans
    - LEI Sections
- Conclusions

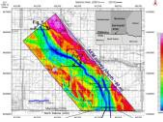


## INTRODUCTION

- 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 shallow 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.

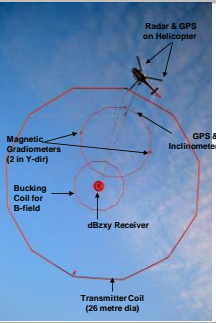


## INTRODUCTION (continued)

- 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 resist.).
- 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 (45channels from 0.021-8.083msec.) are collected for H<sub>z</sub>-H<sub>y</sub>-H<sub>x</sub> 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.

**SPIRITWOOD-JT VTEM SURVEY LINE LOCATION MAP**

**GENEAL LOCATION OF SPIRITWOOD-JT PROJECT**



VTEM survey  
1950 line-km  
400m line-spacing  
5km tie-line spacing

### SPIRITWOOD VALLEY VTEM SURVEY

VTEM Flight Lines over Mapped Spiritwood Aquifer

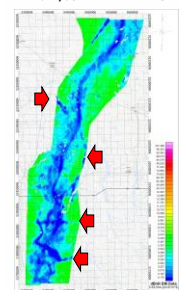


- Prior to the survey the Spiritwood Aquifer system (shown in blue) was mapped from a series of well logs used to derive the current extents of the aquifer system.
- Shown left are State Wells & Test Holes, but there are likely an equal number of private wells present that also helped map the Spiritwood Aquifer system.
- The objective of the survey was to collect high resolution HTEM 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.



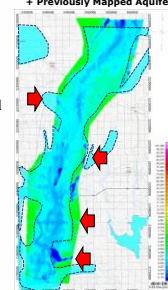
### SPIRITWOOD VALLEY VTEM SURVEY

VTEM dBz/dt - LATE TIME DECAY



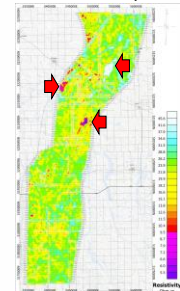
- Preliminary analysis of the raw VTEM data indicated a strong correlation with the known Spiritwood Aquifer system
- From the raw survey results the main channel aquifer is observed but also there are areas with complex structure
- The VTEM data were modelled using the Geoscience Australia 1D Layered Earth Inversion algorithm (GALEISBSTEM) producing a series of resistivity-depth slices and cross sections through the survey area.

VTEM dBz/dt - LATE TIME DECAY + Previously Mapped Aquifer

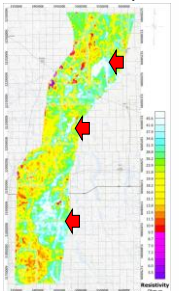


### SPIRITWOOD VALLEY VTEM SURVEY - DEPTH SLICES

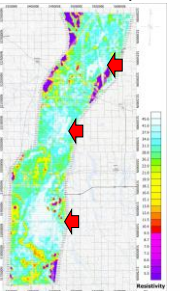
VTEM Inverted Resistivity - 20m



VTEM Inverted Resistivity - 40m



VTEM Inverted Resistivity - 50m

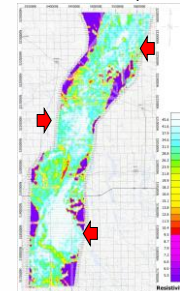


- At shallowest depths mixed soils appear to dominate EM response.
- At moderate depths, sand & gravel have greater influence on EM response.

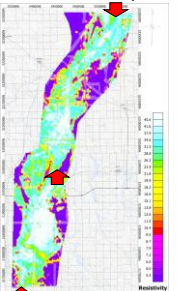


### SPIRITWOOD VALLEY VTEM SURVEY - DEPTH SLICES

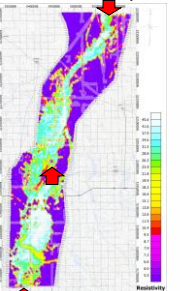
VTEM Inverted Resistivity - 60m



VTEM Inverted Resistivity - 70m



VTEM Inverted Resistivity - 80m

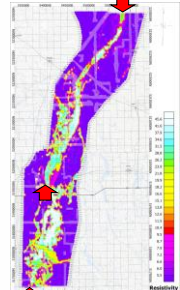


- At moderate depths sand & gravels of Spiritwood aquifer are widest
- At greater depths, buried channels within Spiritwood are becoming more visible.

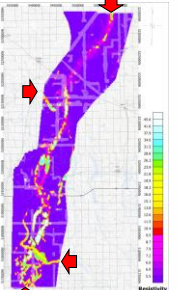


### SPIRITWOOD VALLEY VTEM SURVEY - DEPTH SLICES

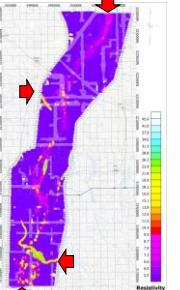
VTEM Inverted Resistivity - 90m



VTEM Inverted Resistivity - 100m



VTEM Inverted Resistivity - 110m

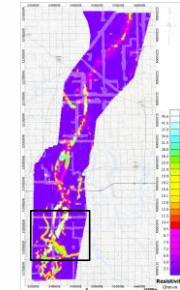


- At greater depths buried channels in Spiritwood aquifer are most prominent
- At greatest depths, cross-cutting channels become more visible, particularly in south.

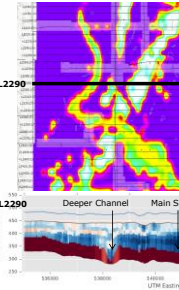


### SPIRITWOOD VALLEY VTEM SURVEY

VTEM Inverted Resistivity - 100m



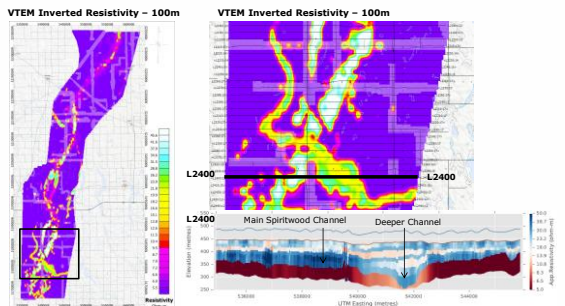
VTEM Inverted Resistivity - 100m



- Highlighting a secondary aquifer that cross-cuts/branches-off the Spiritwood Aquifer. On L2290 the secondary channel is deeper and parallels the main Spiritwood Aquifer.



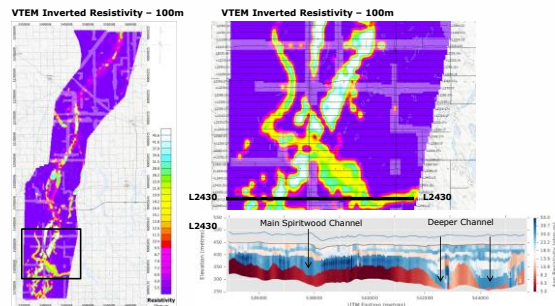
### SPIRITWOOD VALLEY VTEM SURVEY



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



### SPIRITWOOD VALLEY VTEM SURVEY

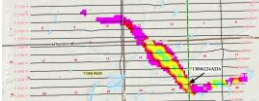


• Furthest south, we observe the cross-cutting channel exiting to the east.  
 • On L2430 the deeper secondary channel is observed as two separate features.



### SPIRITWOOD VALLEY - FOLLOW-UP

#### L2430 - VTEM 1D Resistivity + Well Hole Location



Sent: 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 400P borehole geophysical tool to provide 16" and 64" resistivity along with SP, GAMMA, and Resistance. We also have their 25NA tool.

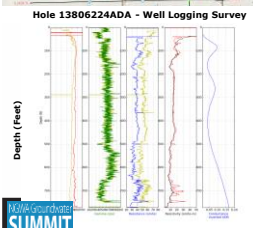
The attached files show the location of the deeper channel test hole 13806224ADA, along with the borehole geophysics, one includes the inverted conductance from the final blocky inversion.

We have also drilled another 3 holes, and are finishing up a deeper hole on the "deep" NW anomaly south of Wimbledon, ND.

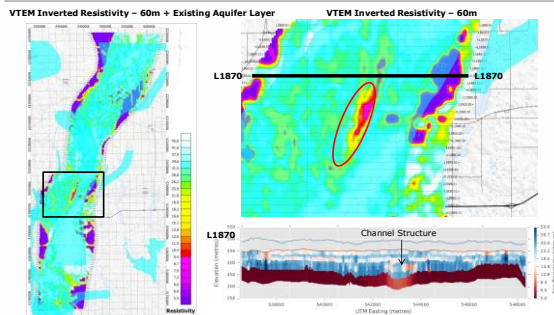
Thought you might be interested in this data before presenting at the conference next month.

Cheers,  
 Dave

David Hisz  
 Hydrologist - Water Appropriations  
 ND State Water Commission



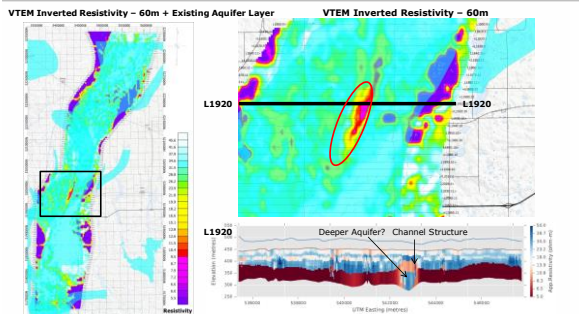
### SPIRITWOOD VALLEY VTEM SURVEY



• 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.



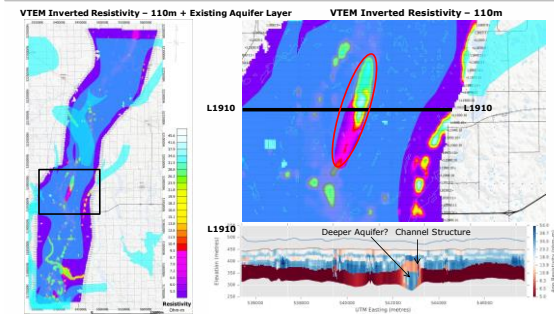
### SPIRITWOOD VALLEY VTEM SURVEY



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



### SPIRITWOOD VALLEY VTEM SURVEY

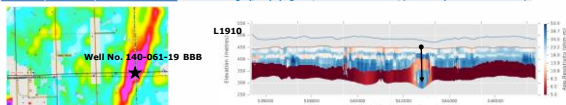


• Looking at a deeper resistivity depth slide above center of channel feature (resistive!).  
 • North-south extend of deeper inferred channel aquifer is now better highlighted.

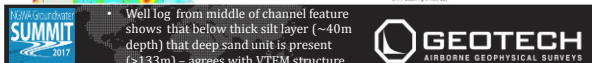


## SPIRITWOOD VALLEY VTEM SURVEY

Interval (feet)	Unit	Description
0 - 20 (0 - 6m)	TILL	buff, calcareous, sandy, oxidized
20 - 23 (6 - 9m)	TILL	gray, unoxidized
23 - 40 (9 - 12m)	SAND	medium to coarse, well sorted, gravelly
40 - 46 (12 - 14m)	GRAVEL	fine to medium
46 - 103 (14 - 31m)	TILL	gray, sandy
103 - 105 (31 - 32m)	GRAVEL	fine to coarse
105 - 142 (32 - 43m)	TILL	gray
142 - 386 (43 - 118m)	SILT	gray, clayey, calcareous, lignitic, minor amounts light gray clay laminae, Pierre Shale
386 - 435 (118 - 129m)	SILT	gray to black, clayey to silty, lignitic, moderate sorting, Niobrara Formation
435 - 437 (129 - 130m)	CLAY	light gray, highly calcareous, pyritiferous, Niobrara Formation
437 - 483 (133 - 147m)	SAND	gray, clayey lignitic, Niobrara Formation, (Poor samples below 320 feet)



Well log from middle of channel feature shows that below thick silt-layer (~40m depth) that deep sand unit is present (>133m) - agrees with VTEM structure.



## 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.



## 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.

Presented at NGWA Groundwater Summit 2017  
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