Viability of the Use of Electromagnetic Induction to Predict Streambed Properties

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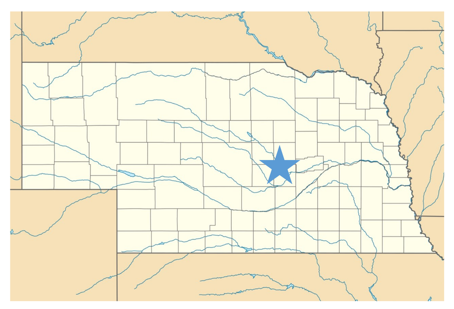
Introduction



This study examined **streambed hydraulic conductivity (*K*), water temperature, water conductivity, and field apparent conductivity (σ_a)** in the **North Loup River** in Nebraska. If there is a correlation between any of the variables and σ_a, it would allow for quick and non-invasive determination of the streambed property using electromagnetic induction. This information can then be used to prepare for possible human or natural developments. We expect *K* to be the primary control of electrical conductivity; however, measurements of water conductivity and temperature will allow us to examine the effect of other parameters on electrical conductivity values.

This location was chosen based on accessibility and water depth.

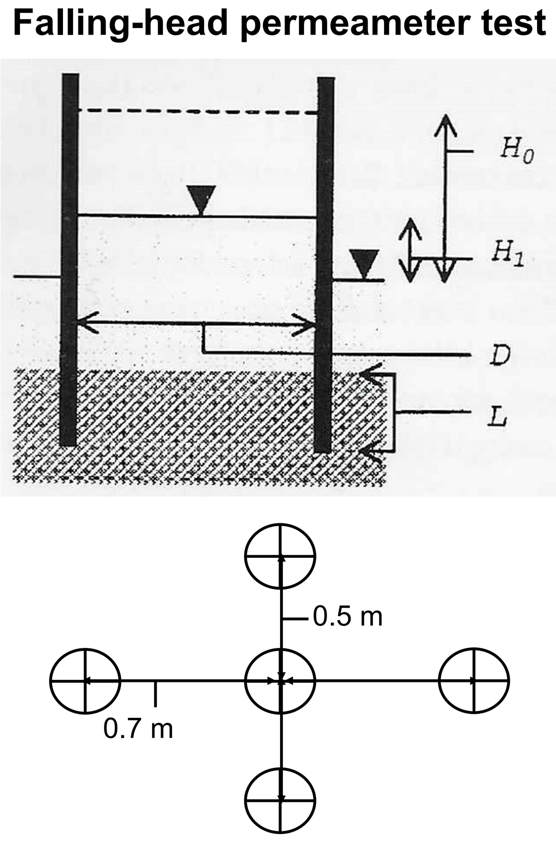
Methods

The **electromagnetic induction (EM) test** measures σ_a of the subsurface, which is controlled by water and sediment properties such as mineral content, chemistry, temperature, and pore volume and structure (Bernard, 2003). We used the EMP-400 field portable, multi-frequency EMI tool manufactured by Geophysical Survey System, Inc. The value given by the EMP-400 represents an average of the conductive properties of a volume of material underlying the site.

The **falling-head permeameter test** is used to measure K_v, vertical hydraulic conductivity. Transparent plastic tubes with an inside diameter of 5.1 cm were pushed vertically into the sediment to depths of 0.5 m. The tests were clustered (see diagram below) to ensure that similar volumes were measured in the falling head permeameter tests and the EM test. Water is added to the tube, and the time is recorded each time the water level drops 0.5 cm. This data is then translated into a K_v value using the Hvorslev equation (Landon et al., 2001).

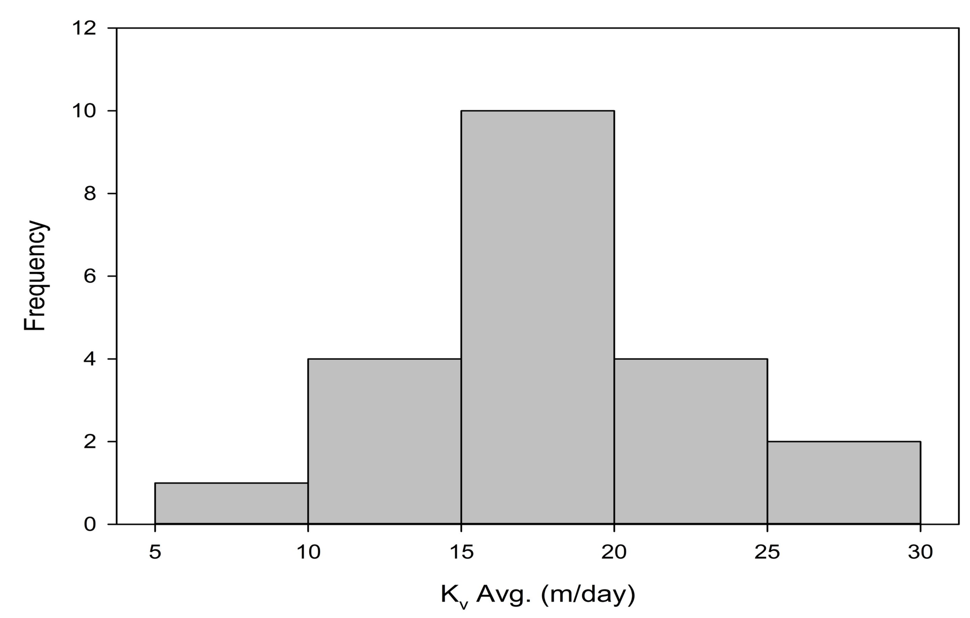
Water conductivity and **water temperature** were measured at the middle tube at depths of 0.5 m using a hand-held conductivity and temperature meter. Per USGS protocol, the water was purged using a flowthrough cell/chamber and a hand vacuum pump. This insured that the meter was adequately rinsed with the water sample and any air bubbles or non-hydrological properties, such as sediment or biological matter, did not affect the readings (Wilde, 2015).

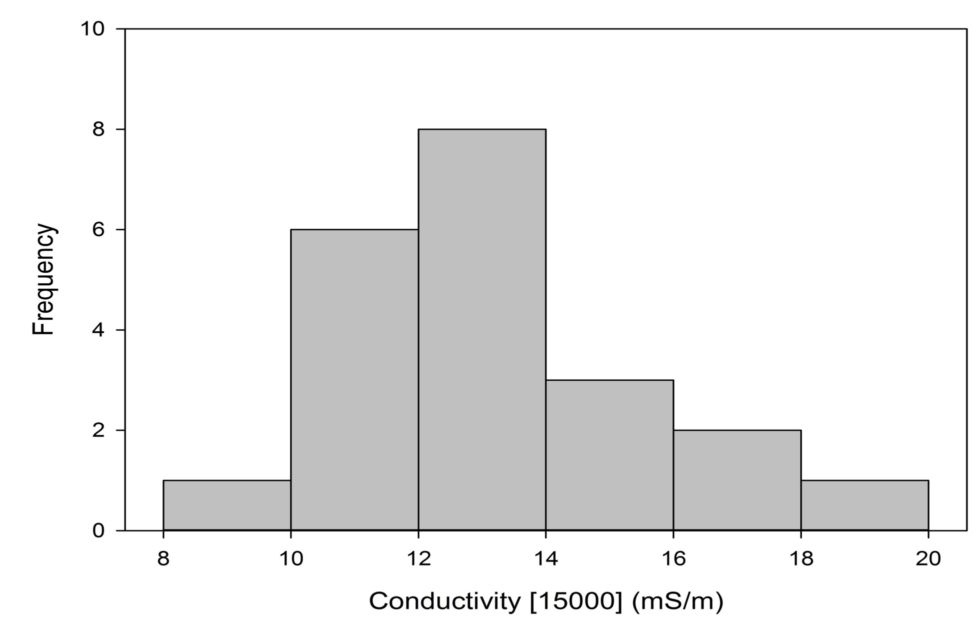
Falling-head permeameter test

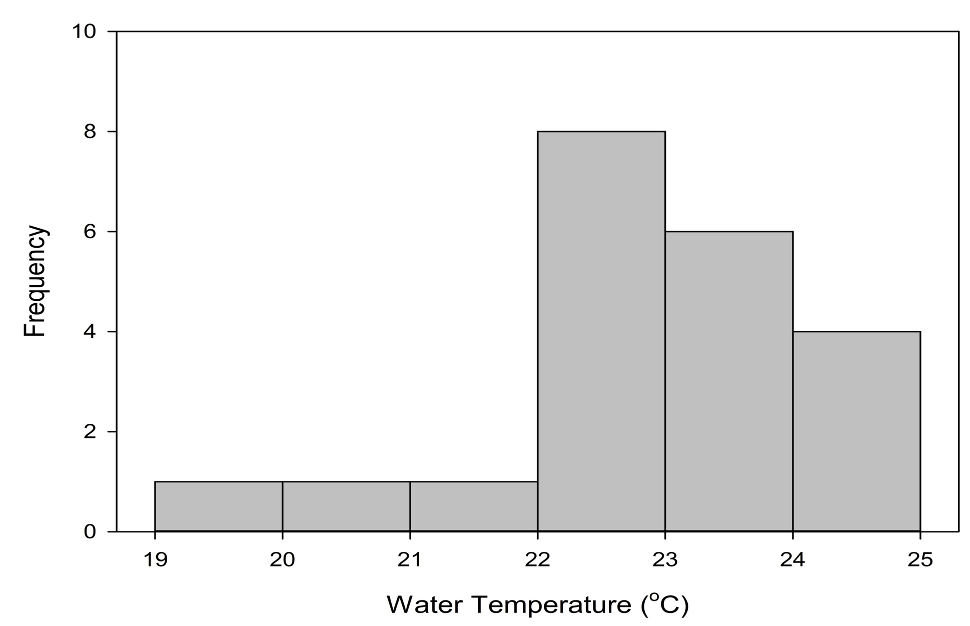


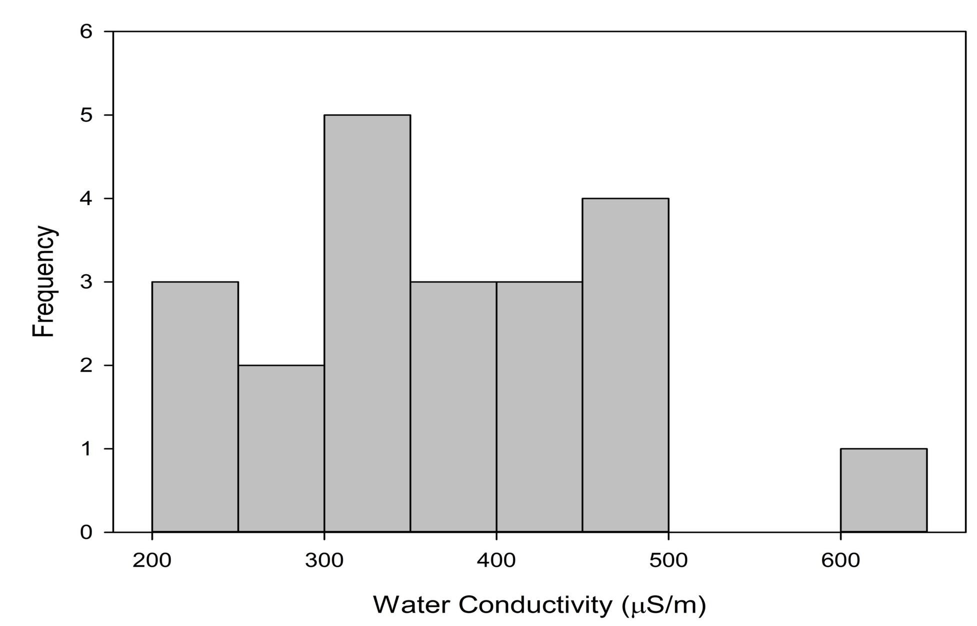
Electromagnetic induction (EM) test

Results & Discussion

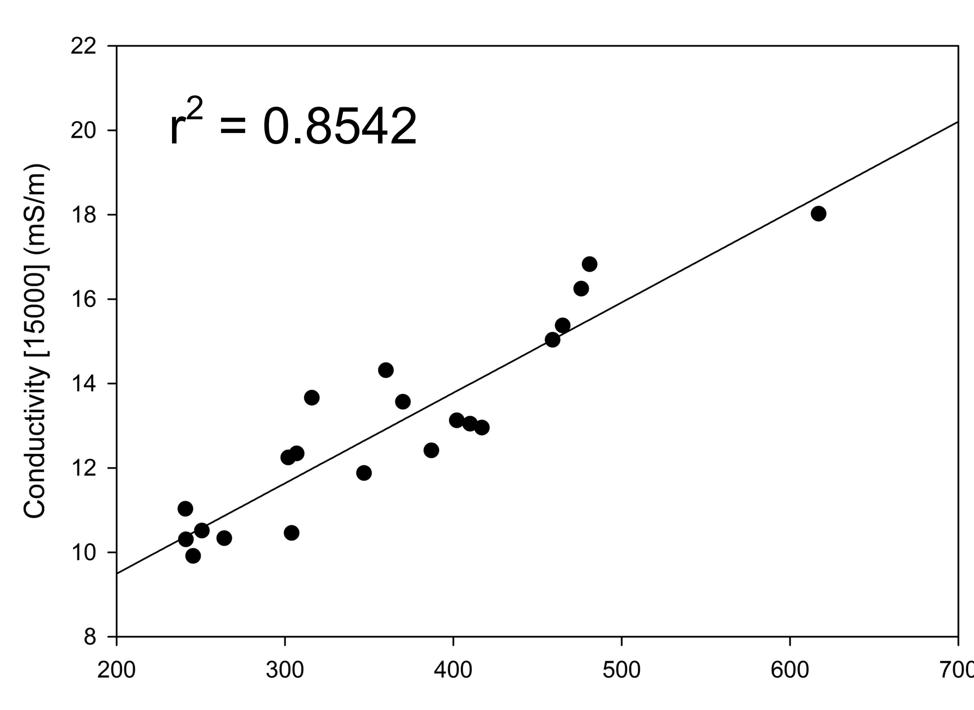


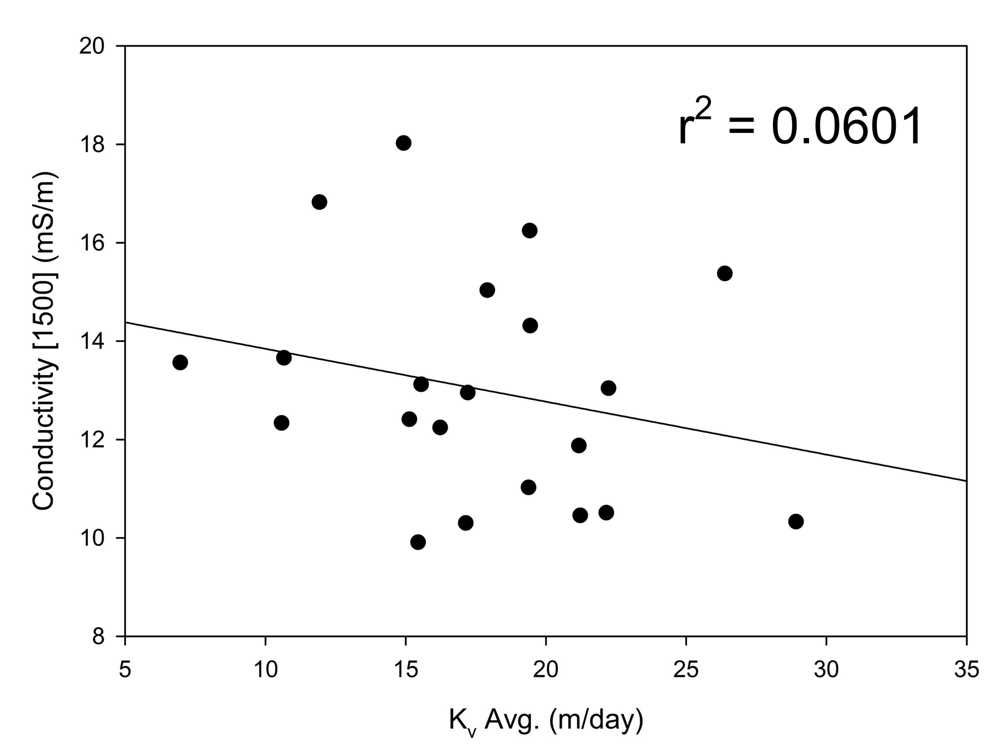


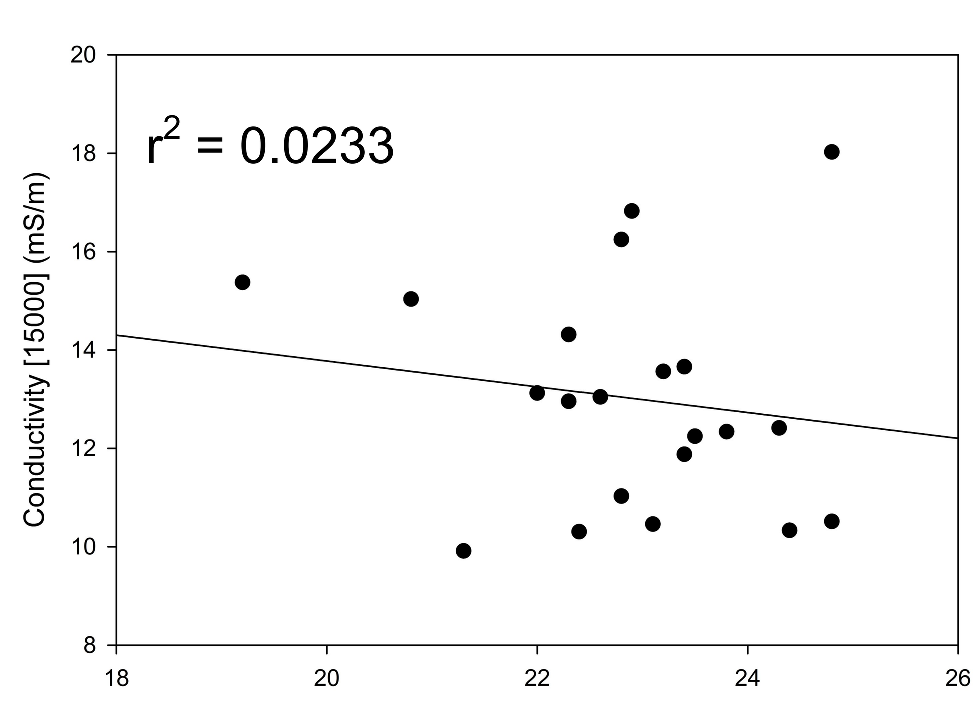




The vertical hydraulic conductivity values were averaged for each site from the five clustered tests. The data show a **normal distribution of K_v values**, with a mean of 17.62 m/day. This is similar to the results of Xunhong Chen's permeameter tests along the Platte River from south-central to eastern Nebraska in 2000 and 2005 (Cheng et al., 2011). Measured at a frequency of 15kHz, **conductivity yielded a positively skewed distribution** and a mean value of 13.03 milliSiemens/m. **Water temperature values presented a negatively skewed distribution** with a mean value of 22.9 °C, and **water conductivity had a multimodal distribution** with a mean value of 365 microSiemens/m.



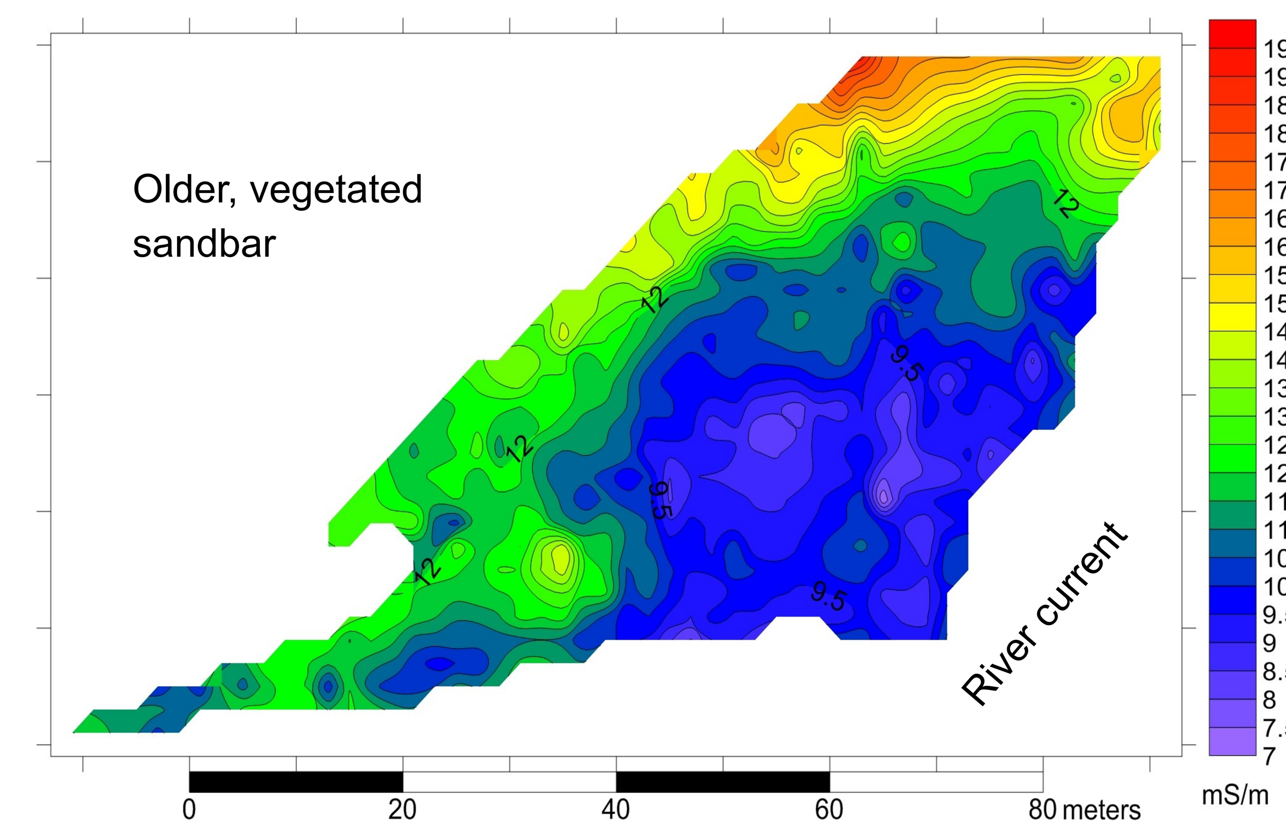




The data produce a **strong positive correlation between water conductivity and electrical conductivity**. This is consistent with existing studies showing that electromagnetic induction can be used in agriculture to measure soil water salinity (Shanahan et al., 2015; Herrero et al., 2011). Although we expected the K_v and σ_a values to show a relationship, we found **no correlation between vertical hydraulic conductivity and electrical conductivity** at our site. There also was **no correlation between water temperature and electrical conductivity**.

Conclusions

Electrical Conductivity Contour Map of Test Location



This study documents a **strong positive correlation between water conductivity and apparent electrical conductivity measured by electromagnetic induction** at the North Loup River test site. One the basis of this relationship, **EM was used to rapidly (0.5 hours) prepare a high-resolution map of water conductivity variability across the test site (see above)**. The map shows that the distribution of water conductivity is closely related to its position with respect to the vegetated sandbar on the top border and the river channel on the bottom border, which provides evidence of variable groundwater/surface water interaction at the site. The bottom edge of the site is exposed to the current, where groundwater is readily able to exchange water with the low-conductivity stream water. The upper edge, however, is comparatively less connected with the stream, creating a zone of hydrologically isolated, electrically conductive water containing high concentrations of solutes. **A suggestion for future studies is to examine hypotheses concerning the controls on temporal and spatial patterns of water conductivity in streambed sandbars.**

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Acknowledgements

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