Characterizing the Hydrostratigraphic Controls on Groundwater Discharge: A Methodological Investigation for the Harpeth River, Nashville, TN

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MOTIVATION

The hydrostratigraphic structure of the subsurface informs groundwater flow paths and partly controls the rate at which groundwater enters surface water bodies. When a contaminant moves into the subsurface, its movements are often dictated by groundwater flow. Previously, researchers have used labor and time intensive techniques such as well installation, borehole geophysics, automated samplers and tracer experiments to investigate groundwater flow. While thermal anomalies, electromagnetic (EM) induction and flow models cannot directly replace these methods, they can serve as a preliminary technique when the basic lithology is known. This research aims to generate simple and efficient methodologies for investigating the controls on shallow groundwater movement.

THERMAL SIGNATURE

As water flows through the ground it equilibrates to the relatively constant temperature of the shallow subsurface. This important thermal property allows heat to be used as a groundwater tracer. In the winter months (when pictures below were taken), the surface water is cooler than the groundwater and temperature variations can delineate groundwater inflows in the hyporheic zone. These temperature differences are easy to locate using an infrared camera.

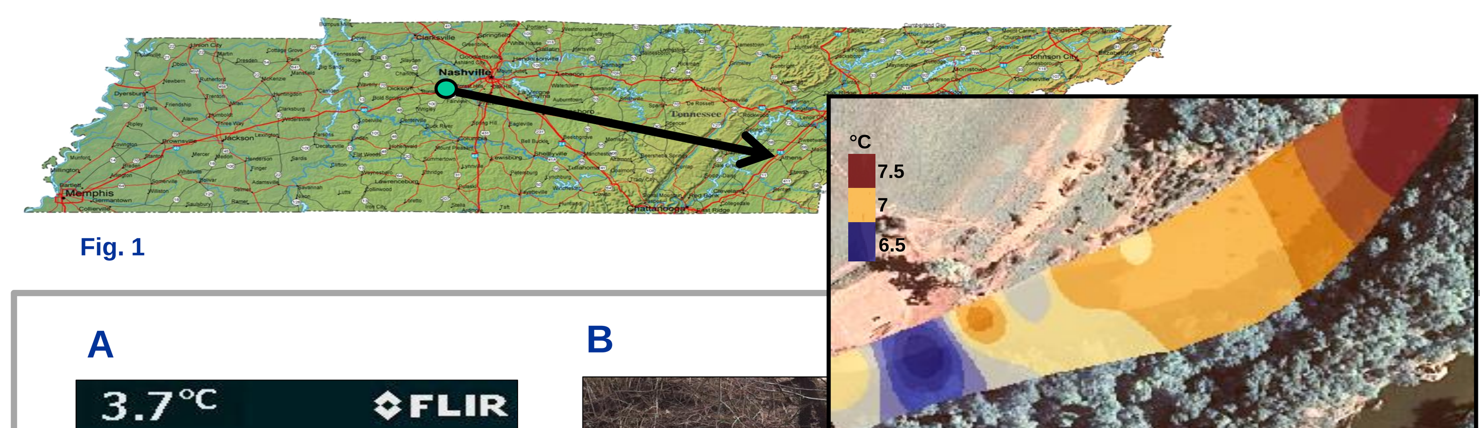


Fig. 1

Fig 1: Study site location and an interpolated temperature profile down a ~300 meter reach of the Harpeth river (interpolated using inverse distance weights in ArcGIS).

A

B

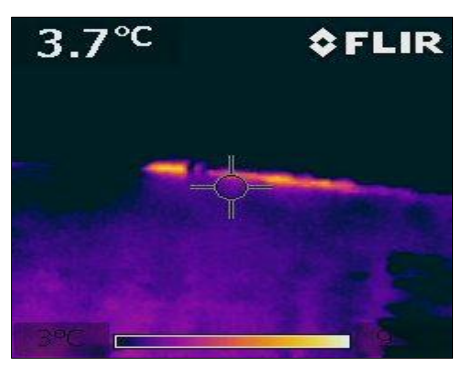


Fig. 2

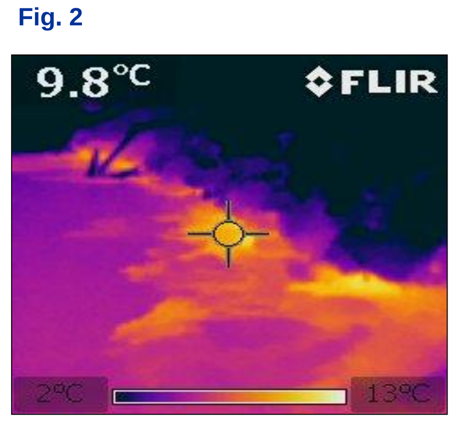
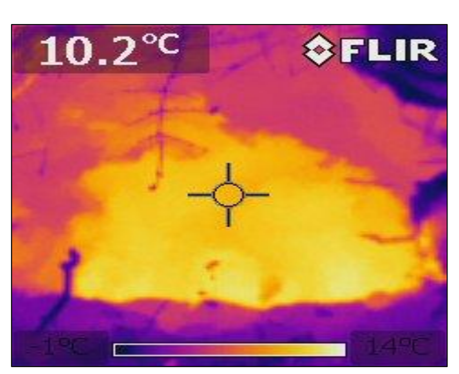


Fig. 3



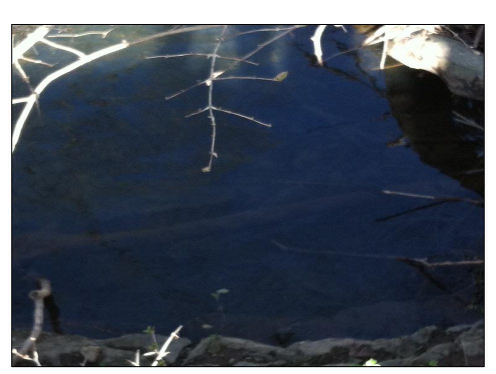


Fig. 4

Fig. 5

Fig 2-4a: pictures taken with an IR camera in the Little Harpeth River.

Fig 2-4b: Pictures taken with regular camera at same locations as 2-4a

.Fig 5: Me using IR camera in the Little Harpeth River.

Acknowledgments

Greg George, Yi Mei, Vanderbilt EES department, and always- Bonnie Worland

CONCEPTUAL MODEL

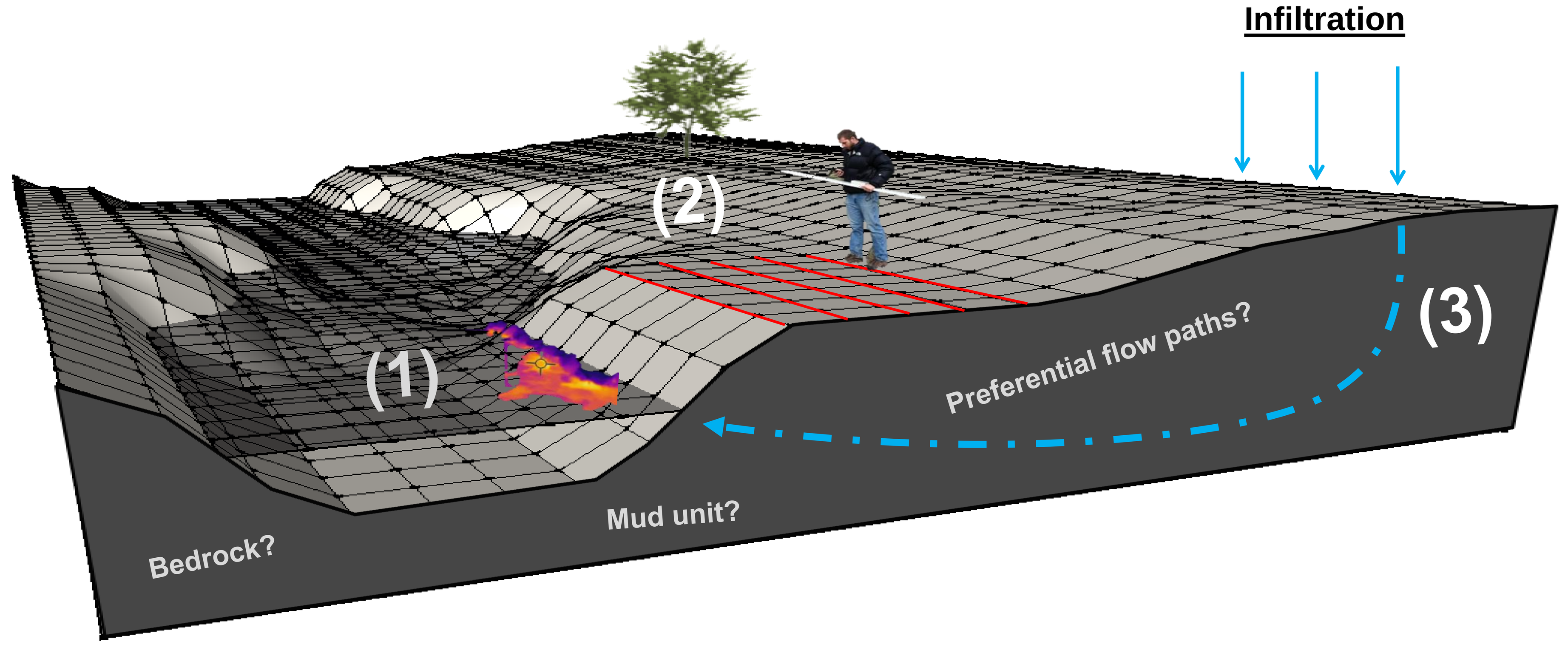


Fig.6

Fig 6: The conceptual model demonstrates the combined processes involved in determining the input parameters for flow models. (1) The thermal signatures inform the locations of groundwater inflow along the stream bank. (2) Once inflow is located, EM induction can be used to explore the structure and properties of the lithology adjacent to the groundwater inflow. (3) The EM output serves as constraints (potential recharge locations, varying hydraulic conductivity, water table level, contaminant plume size, and location) for flow models.

ELECTROMAGNETIC INDUCTION

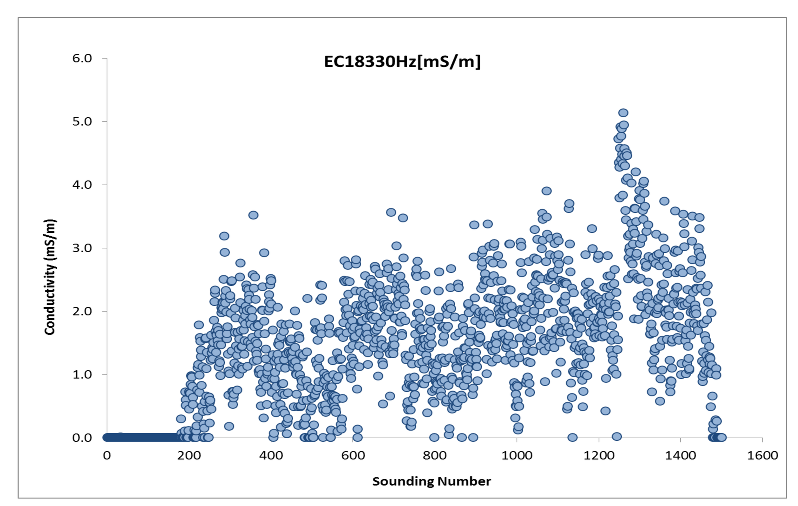


Fig. 7

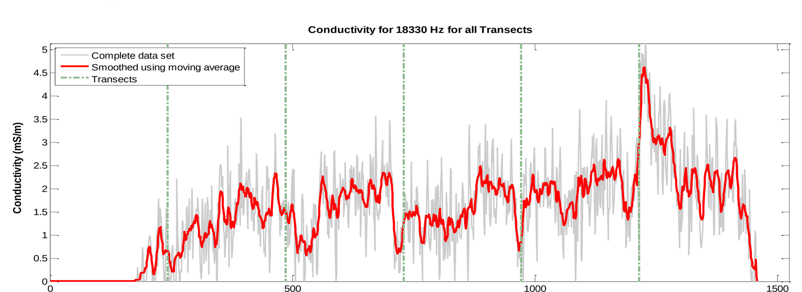


Fig. 8

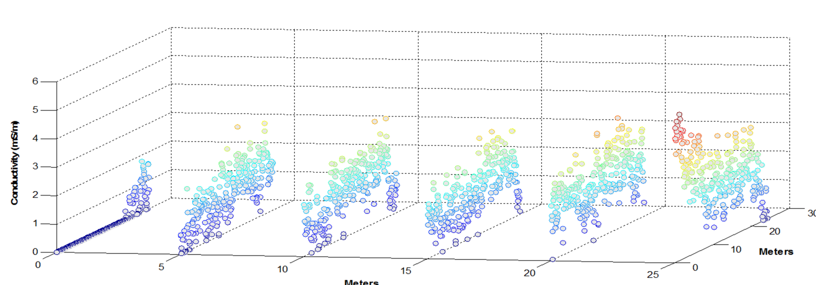


Fig. 9

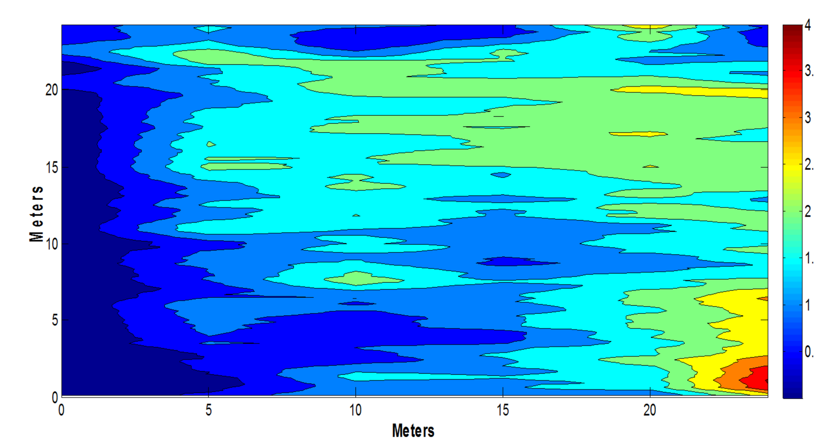


Fig. 10

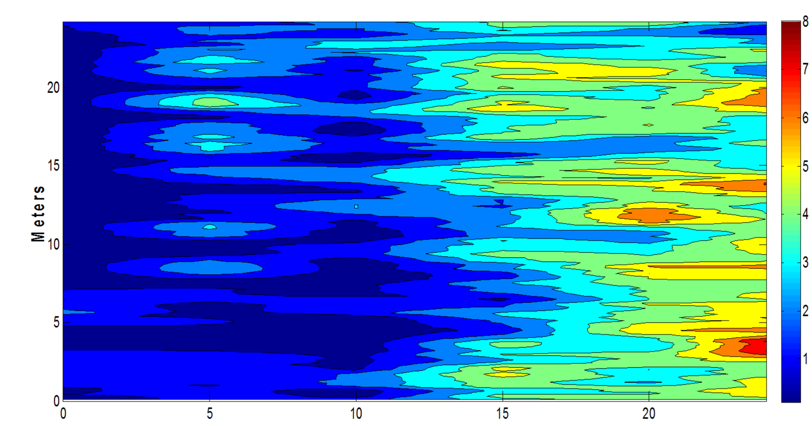


Fig. 11

Fig 7: Raw output of electrical conductivity data for 18330 Hz.

Fig 8: Smoothed conductivity data using a 12 point moving average for 18330 Hz.

Fig 9: Scatter plot of smoothed conductivity data long transects.

Fig 10: Filled contour plot for 18330 Hz.

Fig 11: Filled contour plot for 5310 Hz.

Fig 12: Stacked surface plots of smoothed and interpolated conductivity measurements.

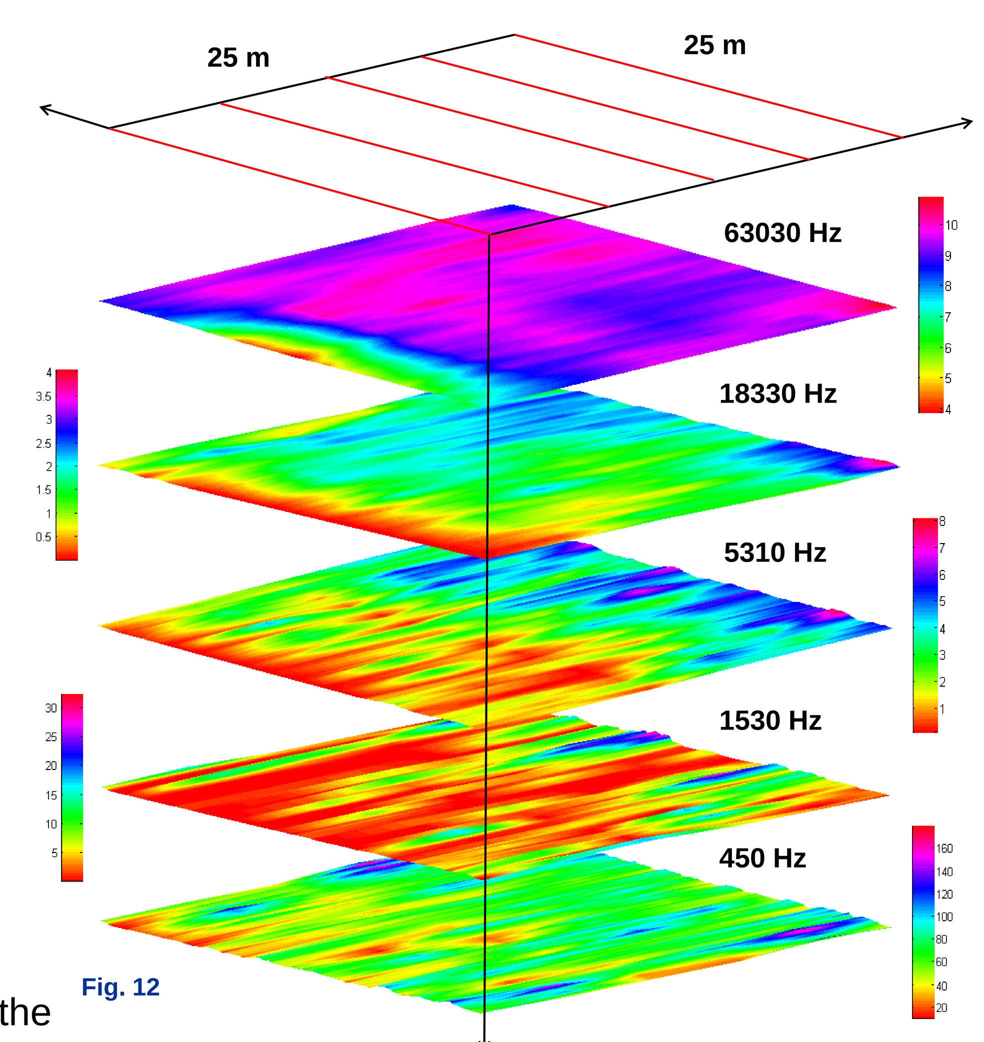


Fig. 12

EM induction measures the electrical conductivity of the subsurface. The instrument (GEM-2) generates electromagnetic fields in the ground which create secondary, quadrature phase, fields which vary in magnitude depending on the magnetic field generated by the subsurface material through which the current propagates. The GEM-2 allows the generation of multiple frequencies simultaneously. Higher frequencies depict shallower depths while lower frequencies records conductivities at deeper depths. This allows the usage of multiple post processing techniques to visualize the shallow subsurface. Electrical conductivity is inversely related to hydraulic conductivity, and continuing efforts are being made to better constrain EM data to hydrostratigraphic properties. Depending on the local geology, the groundwater table is easily detectable after an inversion of the data is completed. With further analysis, the EM data can be used as baseline data to construct subsurface maps.

FLOW MODELS

$$\nabla^2 \rho q = 0$$

$$\frac{\partial}{\partial x}\left(K_x \frac{\partial h}{\partial x}\right) + \frac{\partial}{\partial z}\left(K_z \frac{\partial h}{z}\right) = 0$$

MATLAB Model parameters

1. Two dimensional finite element method
2. Implicitly solved
3. Fixed head boundary conditions
4. Galerkin weighted residual method
5. Variable hydraulic conductivity

MATLAB

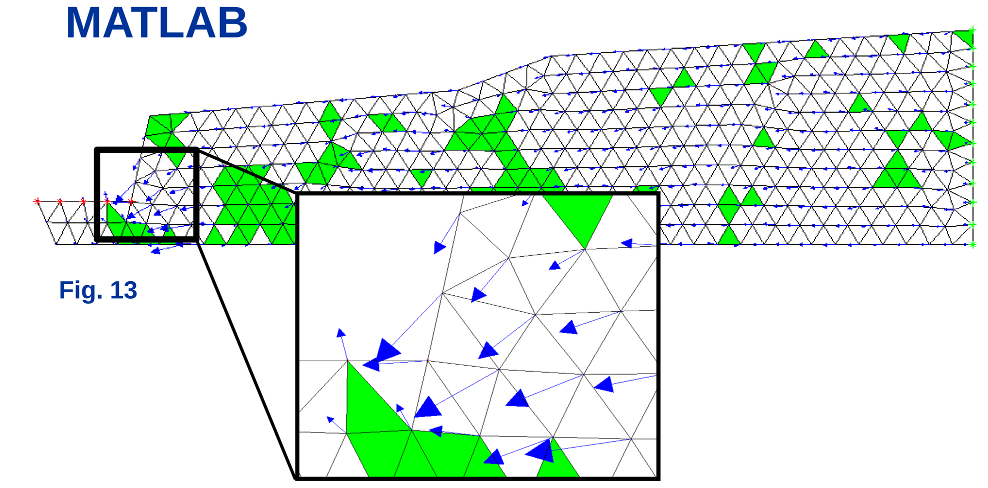


Fig. 13

TOPODRIVE

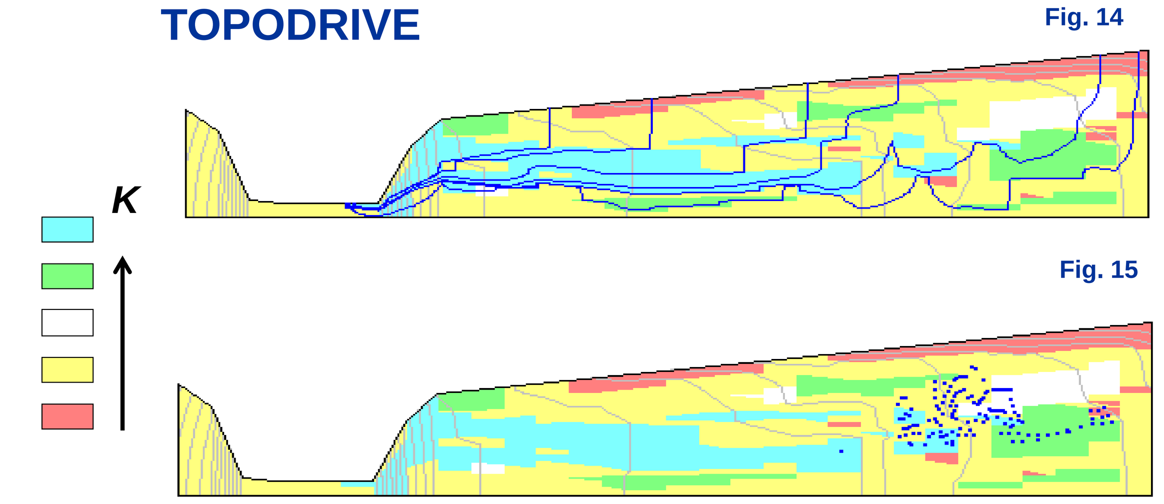


Fig. 14

Fig. 15

Fig 13-15: Demonstrate the possible applications of flow models based on acquired field data. Note that the specifics of the flow models are not necessarily important for this current research, as they are only displayed for illustrative purposes. Nevertheless, TOPODRIVE was intentionally designed for modeling at the exploratory or conceptual level and does serve as a good first order approximation to flow contours and possible paths for solute transport.

DISCUSSION

This approach has many applications, ranging from leachate source identification to the simple characterization of the hydrogeological mechanics involved in local groundwater flow. The results are quantitative, informative and visually appealing. Generating optimal earth models using sounding data is a complex task. Not only do the models need to be mathematically acceptable, but the result must also be geologically and geophysically plausible. EM induction is an advancing field with much effort being focused on the post-processing steps. When basic shallow lithology is approximately known, the data analysis is well constrained and can be considered an accurate depiction of the subsurface. The combination of infrared imaging and EM induction offers a remarkably efficient technique to characterizing subsurface structure and probable groundwater flow vectors.

References

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