Proceedings of the
Latin-American Geothermal Congress 2025
LGC 2025
San Salvador, El Salvador
22–26 Sept. 2025

Use of fiber optics to evaluate the terrestrial heat flow and de-risk geothermal exploration

Fiona Chapman*[1], Jasmin Raymond*[2], Nina Rman[3], Karlo Borko[4], Andrej Vidmar[5]
1, 2 Institut national de la recherche scientifique, CANADA
(E-mail: fiona.chapman@inrs.ca, jasmin.raymond@inrs.ca)
3, 4 Geological Survey of Slovenia, SLOVENIA
(E-mail: karlo.borko@geo-zs.si, nina.rman@geo-zs.si)
5 Faculty of Civil and Geodetic Engineering, University of Ljubljana, SLOVENIA
(E-mail: andrej.vidmar@fgg.uni-lj.si)

Keywords: active distributed temperature sensing, high-resolution, international collaboration, thermal conductivity, groundwater flow, existing boreholes

Abstract: An accurate knowledge of terrestrial heat flow is critical to assess geothermal resources. The Earth's natural heat flow can be evaluated using the geothermal gradient, thermal conductivity, and where applicable, radiogenic heat production. Thermal conductivity is typically estimated based on lithology or measured on core in the laboratory. However, core material is often unavailable, so resultant heat flow assessments are low-quality. The objective of this presentation is to illustrate how a high spatial resolution method for in situ evaluation of ground thermal conductivity allows for accurate heat flow assessment in existing boreholes.

In Canada, active distributed temperature sensing (ADTS) was used to conduct heat injection tests in groundwater wells and measure the ground thermal response with a spatial resolution of 0.25 m using a composite fiber optic and copper heating cable. In Slovenia, distributed temperature sensing is currently used with conventional thermal response test in a single U-tube borehole heat exchanger. In both cases, the recovery period following the heat injection is analyzed to infer an accurate ground thermal conductivity profile and identify borehole sections where heat transfer is dominated by conduction. The geothermal gradient is corrected for topography and paleoclimates prior to being combined with thermal conductivity to calculate heat flow.

This presentation will provide examples of measurements made in Canada and in Slovenia to assess the Earth natural heat flow with ADTS in boreholes up to 385 m depth. This method could potentially be used elsewhere, for example in Latin America, to better quantify geothermal resources without the need of drilling new boreholes.

Introduction: Thermal characterization of the subsurface is essential to support the development of geothermal resources. Knowledge of dominant heat transfer mechanisms and an accurate evaluation of local heat flux are essential to evaluate moderate to deep geothermal potential [1].

Heat flux is commonly calculated based on a knowledge of the geothermal gradient, thermal conductivity, and radiogenic heat production. The geothermal gradient is measured in situ, whereas the thermal conductivity can be estimated based on local lithology, measured in the laboratory on core samples, or measured in situ. Deriving thermal conductivity from heat injection tests in pre-existing boreholes provides reliable values at low cost.

Heating cables can be used to disturb the ground temperature for thermal response tests. In 2011, Raymond et al. demonstrated that thermal properties around boreholes can then be evaluated based on thermal recovery [2]. However, tests made with punctual data loggers to monitored temperature have a poor spatial resolution. High-resolution measurements are better suited to identify dominant heat transfer mechanisms over long borehole sections and calculate the terrestrial heat flux [3].

Herein, we demonstrate the advantages of using distributed temperature sensing with fiber optic to increase the spatial resolution of thermal response tests (up to 25 cm), herby referred to as active distributed temperature sensing (ADTS) [e.g. 4, 5]

Methods
ADTS was used for geothermal exploration in existing boreholes filled with groundwater in Canada and Slovenia. The method put forward (Figure 1) allowed to evaluate the ground thermal conductivity, the terrestrial heat flux and the groundwater flow

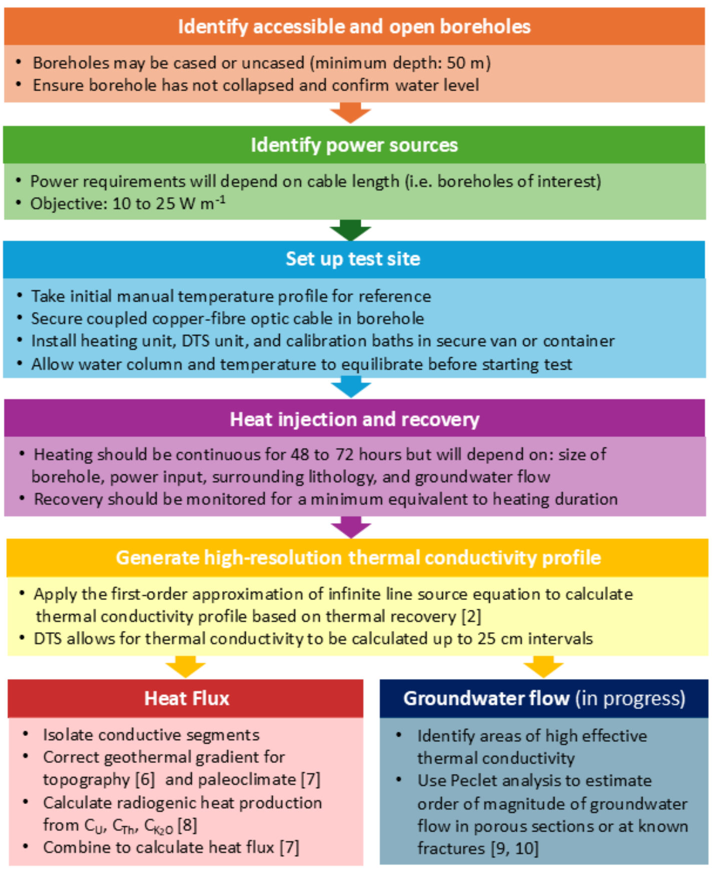

Figure 1: Steps for heat flux estimation and groundwater flow interpretation using ADTS.

Results: Five thermal response tests with ADTS were completed in 80 to 387 m boreholes (two in Yukon, Canada, and three in Slovenia). Effective thermal conductivity profiles were generated for each site. Figure 2 provides an example of results at Yukon site 1. The conductive-dominant segment used to evaluate heat flux is identified by a red box and sections with significant groundwater flow are identified by blue arrows [2]. For Yukon site 1, the heat flux value is 89 mW m^{-2} and groundwater flow was estimated at 2.3×10^{-7} and 1.2×10^{-7} m s^{-1} for the upper and lower peaks, respectively (Figure 2). The initial profiles for the Slovenian sites have been generated but data analysis is ongoing. These sites are located in uncased boreholes across three different lithologies.

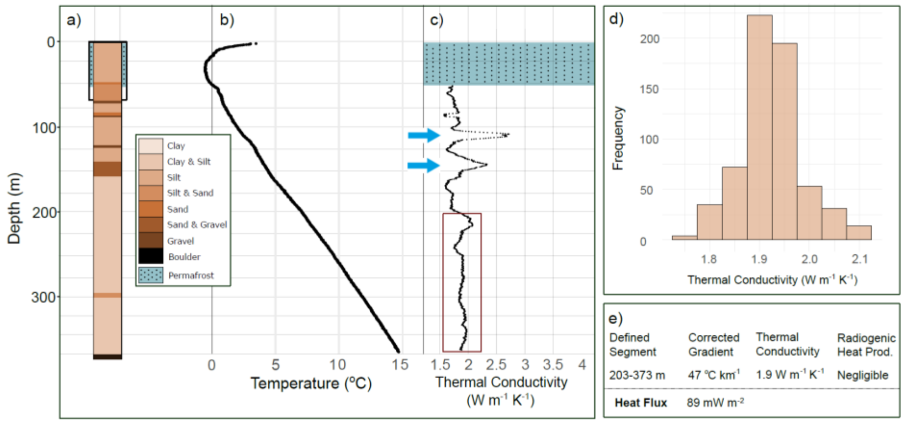

Figure 2: ADTS results used to evaluate heat flux around Burwash Landing, Yukon [2].

Discussion: ADTS provides reliable in situ values for heat flux estimation and mitigates costs associated with core recovery. In Yukon, Canada, ADTS allowed for two new local heat flux evaluations to be added to a data scarce region. These values will help de-risk further geothermal efforts in Yukon, Canada. In Slovenia, the information will primarily be used to optimise borehole and aquifer thermal energy storage projects [11].

ADTS tests typically take between five and seven days to complete as it is essential to monitor the recovery period [2]. Previous research suggested not to exceed 20 W m^{-1} in boreholes with variable lithologies as this may create natural convection within cased boreholes [5]. However, the Canadian tests presented herein use a power input up to 28 W m^{-1} and natural convection was not generated [2]. Previous research has also identified complexities related to the influence of vertical flow in uncased boreholes during ADTS [12]. Previous flow and geophysics research at sites in Slovenia will be used to understand the influence of vertical flow and identify ADTS limitations related to groundwater velocity for open boreholes.

Conclusion: ADTS was applied in existing boreholes for geothermal exploration in Canada (Yukon, GeoDirect project) and Slovenia (ARIS DEP project Geo-OPT). The high-resolution effective thermal conductivity profiles allow for differentiation between convection and conduction dominated horizons of the subsurface to identify dominant heat transfer mechanisms, groundwater velocity, and calculate heat flux. This method could be applied elsewhere, such as in Latin America, to better quantify geothermal resources without drilling new boreholes.

Acknowledgement: Research in Canada was funded by NSERC under a CGS and a MSFSS given to F. Chapman as well as an Alliance Grant (14460163) with collaboration of the Yukon Geological Survey. Research in Slovenia was funded by the SRIA in the frame of the young researcher program of K. Borko, the research core funding No. P1-0020, and the Target research program No. V1-2213. Collaboration between Canada and Slovenia was facilitated by the UNESCO IGCP group 636.

References:

[1] Stefansson, V. (2005). World Geothermal Assessment. Proceedings World Geothermal Congress.

[2] Raymond, J., Therrien, R., & Gosselin, L. (2011). Borehole temperature evolution during thermal response tests. Geothermics, 40(1), 69–78. https://doi.org/10.1016/j.geothermics.2010.12.002

[3] Chapman, F. M., Klepikova, M., Bour, O., Miranda, M., Soucy La Roche, R., & Raymond, J. (2025). Heat flux evaluation based on active fiber optic distributed temperature sensing tests in southwestern Yukon, Canada. Geothermics, 131, 103354. https://doi.org/10.1016/j.geothermics.2025.103354

[4] Hakala, P., Vallin, S., Arola, T., & Martinkauppi, I. (2022). Novel use of the enhanced thermal response test in crystalline bedrock. Renewable Energy, 182, 467–482. https://doi.org/10.1016/j.renene.2021.10.020

[5] Márquez, M. I. V., Raymond, J., Blessent, D., Philippe, M., Simon, N., Bour, O., & Lamarche, L. (2018). Distributed Thermal Response Tests Using a Heating Cable and Fiber Optic Temperature Sensing. Energies, 11(11), Article 11. https://doi.org/10.3390/en11113059

[6] Lee, T.-C. (1991). On terrain corrections in terrestrial heat flow. 135.

[7] Jessop. (1990). Analysis and Correction of Heat Flow on Land. In Developments in Solid Earth Geophysics (Vol. 17, pp. 57–85). Elsevier. https://doi.org/10.1016/B978-0-444-88309-4.50007-5

[8] Rybach, L. (1988). Determination of heat production rate. In Handbook of Terrestrial Heat-flow Density Determination (pp. 125–142). Kluwer Academic Press.

[9] Koubikana Pambou, C. H., Raymond, J., & Lamarche, L. (2019). Improving thermal response tests with wireline temperature logs to evaluate ground thermal conductivity profiles and groundwater fluxes. Heat and Mass Transfer, 55(6), 1829–1843. https://doi.org/10.1007/s00231-018-2532-y

[10] Lehr C, Sass I (2014) Thermo-optical parameter acquisition and characterization of geologic properties: a 400-m deep BHE in a karstic alpine marble aquifer. Environ Earth Sci 72:1403–1419

[11] Borko, K., Brenčič, M., Savšek, Z., Knez, J., Vozelj, A., Kisel, G., & Rman, N. (2025). Insights into Aquifer and Borehole Thermal Energy Storage Systems for Slovenia's Energy Transition. Energies, 18(5), 1019.https://doi.org/10.3390/en18051019

[12] Kyrkou, K., Booth, A., Loveridge, F., Kelly, J., Jackson, M., Hough, E., & Boon, D. (2025, March 15). Distributed thermal response testing in a fractured chalk aquifer with high groundwater flow. https://doi.org/10.5194/egusphere-egu25-16436