Geothermal Sinks: Time to Reach Steady State and Soil Thermal Properties in Minnesota

1 Introduction

A geothermal system is a heating or cooling system that uses the earth as a heat source or heat sink. In Minnesota, the earth's temperature ranges anywhere from 40–50 °F at a depth of 50 feet throughout the year. Minnesota's surface weather is known for its wide seasonal swings and sometimes unpredictable daily variations. For example, in the Twin Cities, the average January high is around 21–22 °F (with lows near 4 °F), while in July the highs average about 83 °F (and lows around 63 °F). The region's climate is classified as hot-summer humid continental (Köppen Dfa), meaning that Minnesota experiences very cold winters—often with record lows reaching −41 °F—and hot summers, with historical record highs near 108 °F.

2 Heat Transfer Fluids and Regulations

Heat transfer fluids used in BGHE (Borehole Ground Heat Exchanger) systems must be propylene glycol or ethanol, as required by Minnesota Rules, Part 4725.7050. These rules are set in place to minimize potential groundwater contamination and related drinking water concerns in the event of a system leak. More information can be found at the Minnesota Department of Health website on Geothermal Heating and Cooling Systems. A geothermal heat exchanger must be installed by a well contractor or a licensed geothermal heat exchanger contractor.

3 Long-Term Temperature Changes in Geothermal Heat Pump Systems

Long-term temperature changes caused by a geothermal heat pump (GHP) system in Korea were measured. The temperature was shown to increase at a rate of 0.135 °C/year at a depth of 10 m and 0.118 °C/year at a depth of 50 m over approximately 10 years.

Figure 1: Groundwater temperatures measured at 10 m and 50 m depths in a 300 m deep monitoring well over approximately 10 years. The blue and red dots represent the temperatures at depths of 10 m and 50 m, respectively. The green triangular and yellow circular marks are the annual mean temperatures at these depths. The green and yellow dotted lines show the results of linear regression analysis of the annual mean temperatures. (Adapted from *Evaluation of Ground Temperature Changes by the Operation of the Geothermal Heat Pump System and Climate Change in Korea* by Seoung-Kyun Kkim and Youngmin Lee.)

4 Temperature Variation in Minnesota's Subsurface

There aren't many readily published continuous temperature profiles for Minnesota's subsurface down to 150 feet. However, some older USGS reports do include measured temperature data from deep wells in Minnesota. For example, in the USGS report *Geothermal Data of the United States* (USGS Bulletin 701), a 467-foot well in Winona was reported to yield water at about 54 °F, while another well in Sibley County (707 feet deep) showed temperatures around 50 °F. Although these points do not form a continuous profile from the surface to 150 feet, they imply that—once below the shallow seasonal layer—the geothermal gradient in Minnesota is very low (roughly 0.013–0.014 °F per foot). Over 150 feet this increase might be only around 2 °F.

5 Subsurface Soil Types and Thermal Properties in Minnesota

In Minnesota, especially in the metropolitan areas such as the Twin Cities region, the near-surface geology is dominated by glacial deposits. For depths from the surface down to about 150 feet, the soils are typically composed of:

- **Glacial Till:** An unsorted mixture of clay, silt, sand, and gravel.
- **Glacial Outwash Deposits:** Sorted sands and gravels deposited by meltwater.
- **Lake Sediments:** Fine-grained lacustrine deposits in some areas.

The thermal properties of these soils depend strongly on their composition, density, and moisture content. Table 1 summarizes typical values for soils found in Minnesota under field-moisture conditions.

Table 1: Typical Thermal Properties of Minnesota Soils (at Field Moisture Conditions)

Soil Type	**Thermal Conductivity (W/m·K)**	**Volumetric Heat Capa**
Glacial Till (silt/clay loam)	1.5–2.5	1.8–2.5
Glacial Outwash (sandy soil)	1.2–2.0	1.5–2.0
Lake Sediments (fine-grained)	1.0–1.8	1.6–2.2

Notes:

- **Thermal conductivity** increases with moisture content and compaction.
- **Volumetric heat capacity** is influenced by the soil's mineral composition and organic matter.
- **Thermal diffusivity** is calculated as the ratio of thermal conductivity to volumetric heat capacity, indicating how quickly temperature changes propagate through the soil.

For depths around 80 to 150 feet, the soils are typically well-consolidated glacial till or lake sediments. These conditions, together with the low geothermal gradient (about 0.013–0.014 °F per foot), result in an overall temperature increase of roughly 2 °F over 150 feet.

6 References

- Geothermal Heating and Cooling Systems, Minnesota Department of Health
- MDPI: Water (12, 10, 2931)
- USGS Bulletin 701: Geothermal Data of the United States
- Ground Source Heat Pumps (Wikipedia)