Results from the new Indiana Geothermal Monitoring Network: Implications for how and where soil modifications can improve the performance and affordability of geothermal heat pumps

Kevin Ellett, Shawn Naylor, Andrew Gustin and Connor Waldoch

Indiana Geological Survey 1837
Indiana University

Center for Geospatial Data Analysis
Indiana University

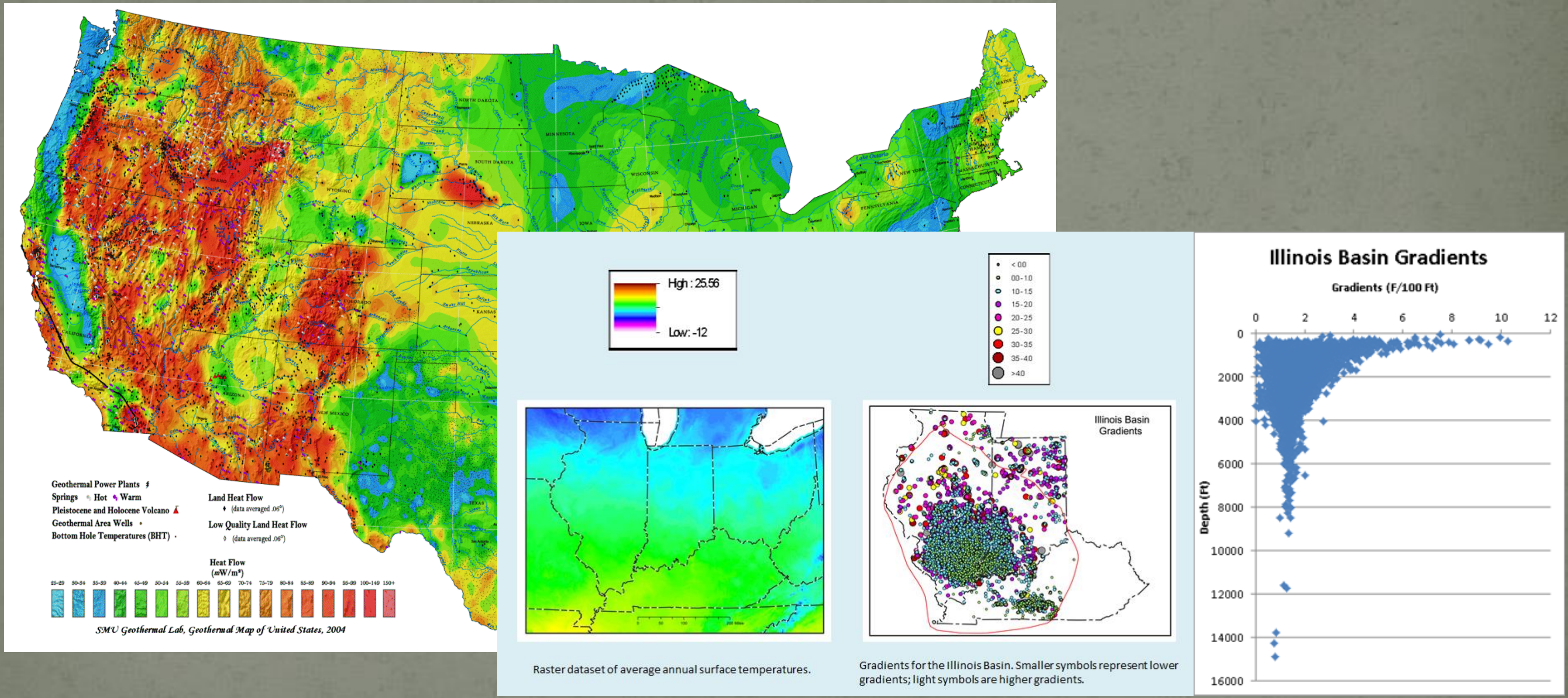
Research funding acknowledgement

U.S. Department of Energy

NGDS
National Geothermal Data System

Background

- USDOE national-scale study is focused largely on evaluating high-temperature geothermal resources– deep geologic systems



Raster dataset of average annual surface temperatures.

Gradients for the Illinois Basin. Smaller symbols represent lower gradients; light symbols are higher gradients.

Proffitt et al., 2013, AAPG

Rationale

•High-temperature geothermal resources are fairly limited compared to low-temperature resources– i.e., **harnessing the potential of geothermal (ground-source) heat pump technology**

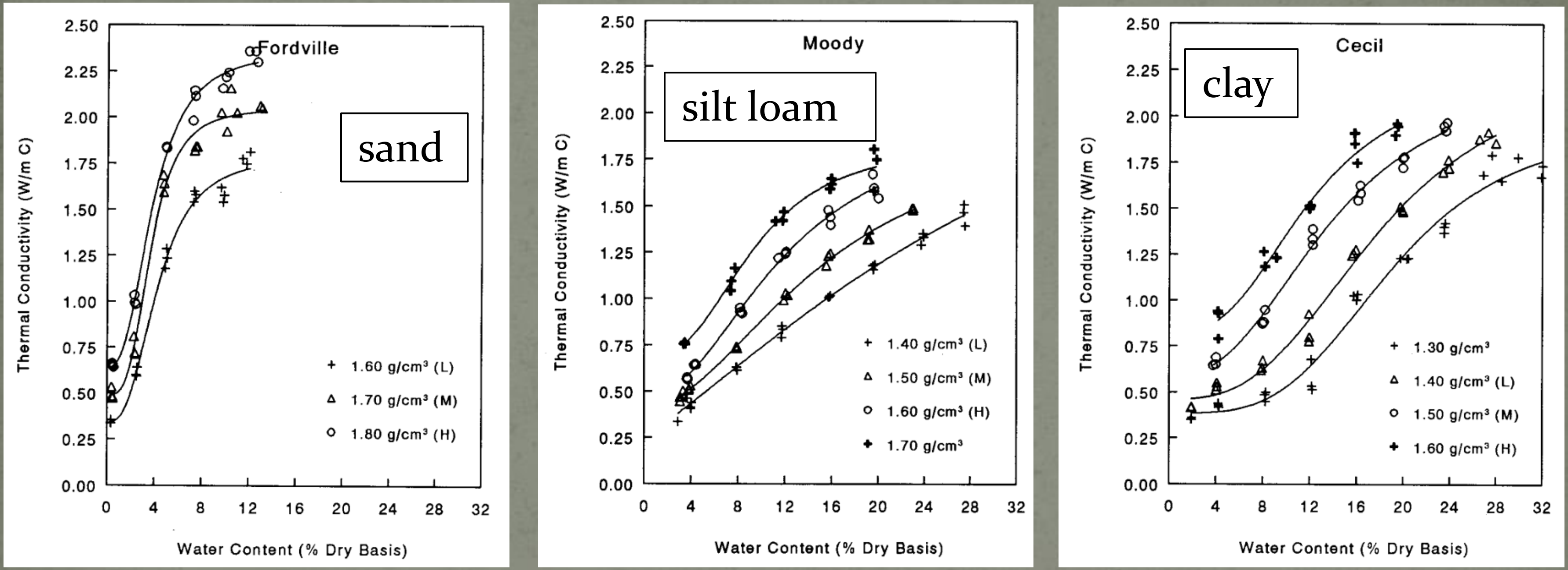
•Optimal design of geothermal heat pump (GHP) systems requires better handling of uncertainty in key parameters of ground heat exchange: **soil thermal properties/states and dynamic variability**

•Preliminary investigation suggested that variability in geotechnical parameters can lead to

  - Design trench lengths from 100 to 400 feet per ton of capacity (1 ton = 12,000 BTU/hr heating or cooling)
  - •Land area requirements between 1,500 and 3,000 ft^2 per ton

Key soil properties/states affecting ground heat exchange (GHE)

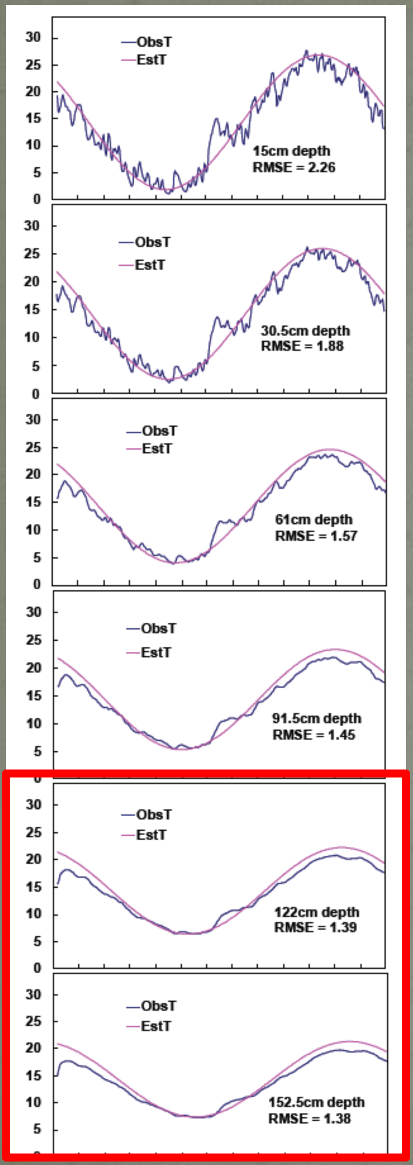
Water content, soil texture (particle size/composition) and bulk density are primary controls on thermal conductivity and diffusivity of unconsolidated materials



(Source: Remund, 1994)

A three-fold increase in thermal conductivity (e.g., dry to saturated sands) can result in a 30% reduction in required earth-coupled loop lengths

Additional uncertainty from dynamic processes



•Actual soil temperature can vary by several degrees from seasonal model prediction, and 5 to 10 degrees C colder/warmer than annual mean during peak heating/cooling loads.

•Recent discussion with residential-scale, GHP installers suggests that industry practices for GHE sizing varies from rules-of-thumb, look-up tables and nomograms to simplified analytical solutions for heat transport by conduction only (Kelvin line-source theory or cylindrical source model): **too simple to achieve optimal design**

•More sophisticated approaches using numerical models are not applied in industry (i.e., research models)

•The goal of our study is to develop **a rare network of in-situ observations to evaluate**

- **•the importance of dynamic soil processes**
- **•performance/validation of GHE design approaches**
- **•GIS approaches for State-wide mapping of salient parameters for GHP installations**

The Indiana Geothermal Monitoring Network

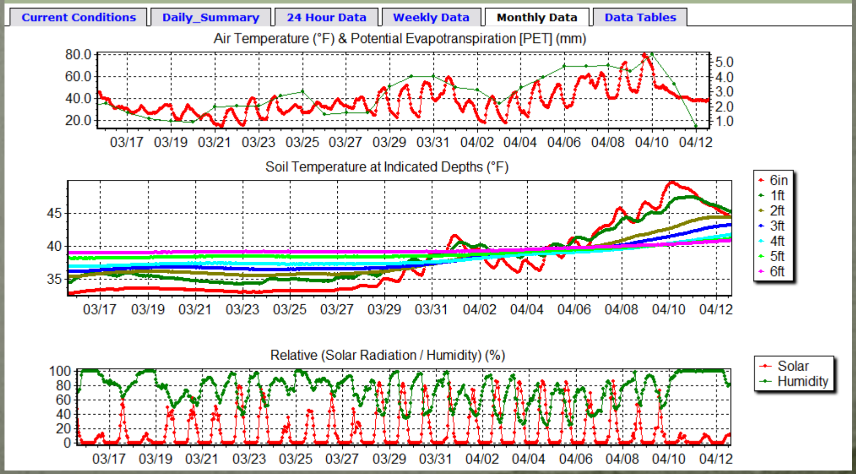
Trenches excavated to 2 m/6 ft depth at six locations across the State

Full suite of land-surface energy and water flux instrumentation

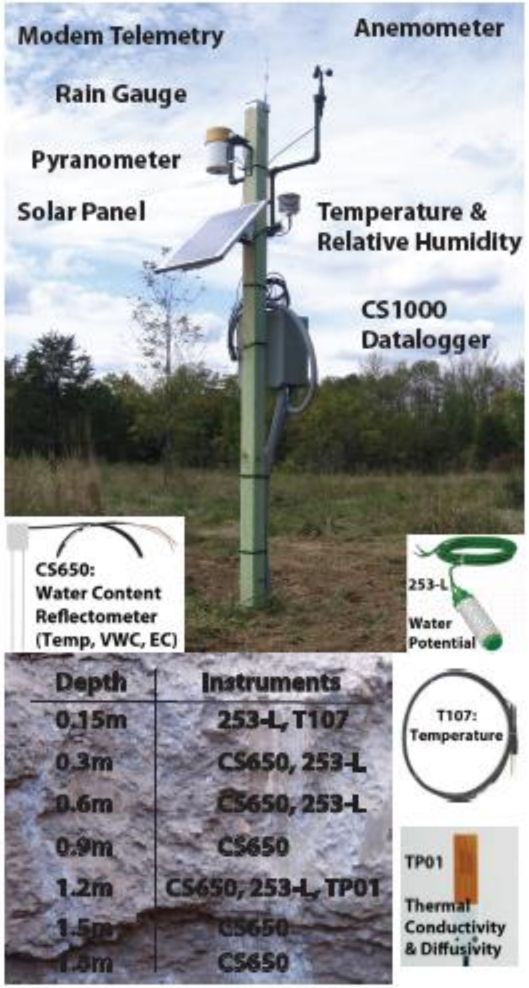
The Indiana Geothermal Monitoring Network

Extensive core sampling for analysis of physical and thermal properties

Automated data logging and cellular telemetry for real-time data acquisition



The Indiana Geothermal Monitoring Network



Depth	Instruments
0.15m	253-L, T107
0.3m	CS650, 253-L
0.6m	CS650, 253-L
0.9m	CS650
1.2m	CS650, 253-L, TP01
1.5m	CS650
1.8m	CS650

Figure 4. Meteorological and vadose-zone instruments installed at each site.

Figure 5. Photograph showing installation of subsurface instruments into trench face.

Monitoring sites

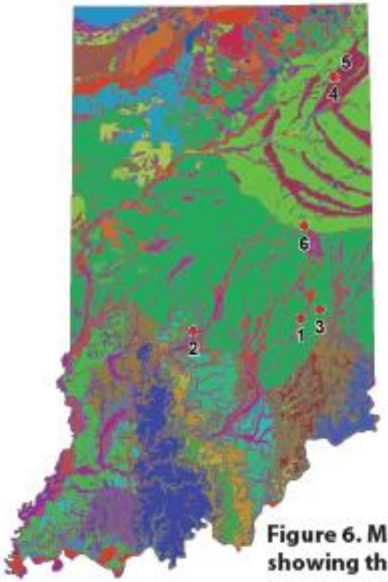


Figure 6. Map showing the location of six monitoring sites and the diversity of surficial geology in Indiana.

Table 1. Geologic settings and sedimentologic details for each monitoring site. Deep horizon soil texture and bulk density from the Soil Survey Geographic Database (SSURGO) are also shown for each location.

Site #	*Site name*	*Geologic setting*	*Deep horizon texture*	*Deep horizon bulk density (g/cm^2)*	*SSURGO deep horizon texture*	*SSURGO deep horizon bulk density (g/cm3)*
1	Flatrock	low-level outwash terrace	sandy clay loam	TBD	stratified coarse sand to gravelly sand	2.06
2	Bradford	alluvial terrace	silt loam	1.39	stratified sandy loam to silt loam	1.62
3	Shelbyville	moraine crest	silty clay loam	1.71	loam	1.90
4	Eel River	high-level outwash terrace	sandy loam	1.69	stratified sand to silt loam	1.68
5	Wabash	moraine crest	clay loam	1.91	clay loam	2.06
6	Ball State	ground moraine	TBD	TBD	clay loam	2.07

Naylor et al., 2012, AGU

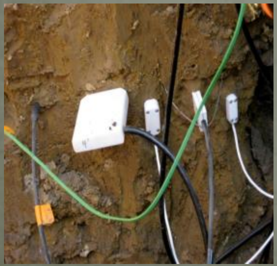
Initial Results: Evaluation of Hukseflux sensor

Hukseflux TP01 Thermal Properties Sensor

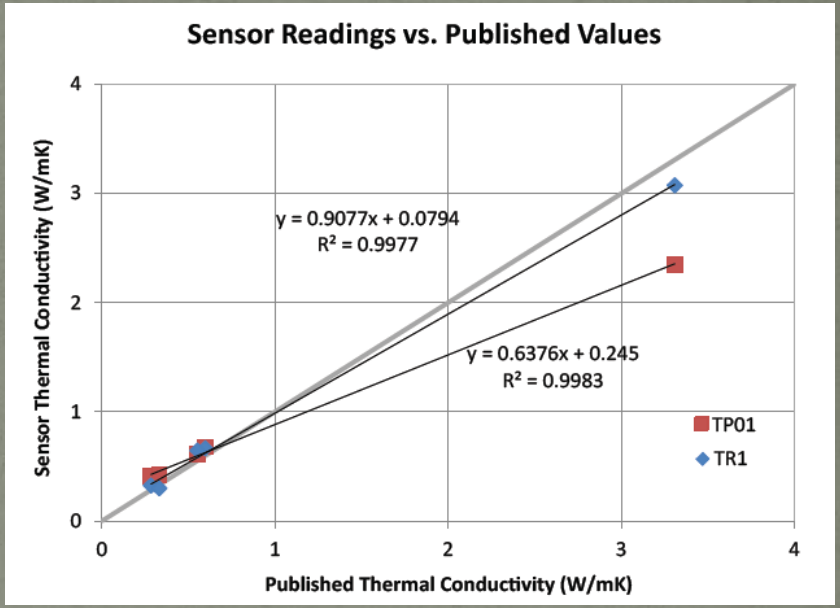
- Measures radial diff. temp. around heating wire using 2 thermopiles

Decagon KD2 Pro Thermal Properties Sensor

- Measures thermal props. using transient line heat source

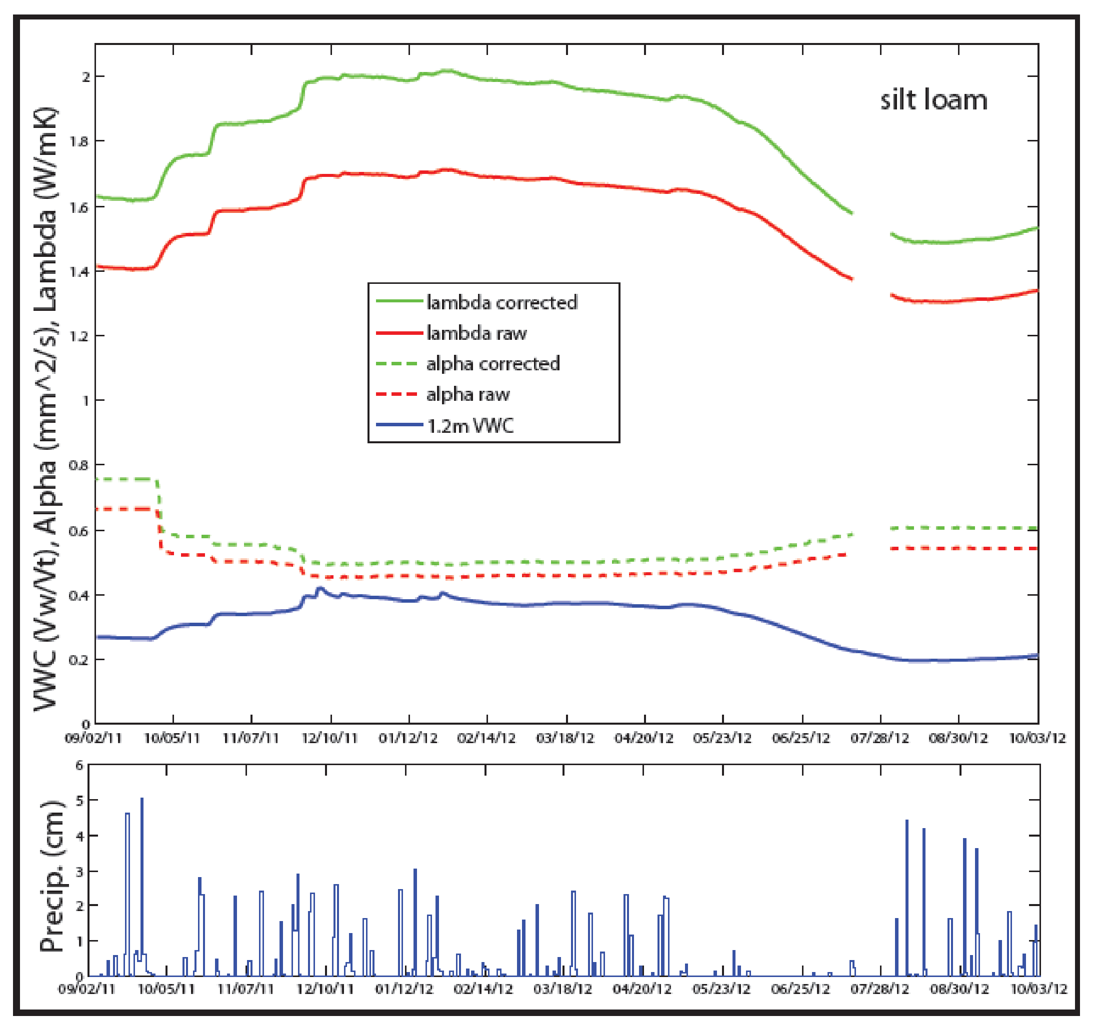


In-situ evaluation and lab calibration of Hukseflux using standards (glycerin, agar gell, Ottawa sand)

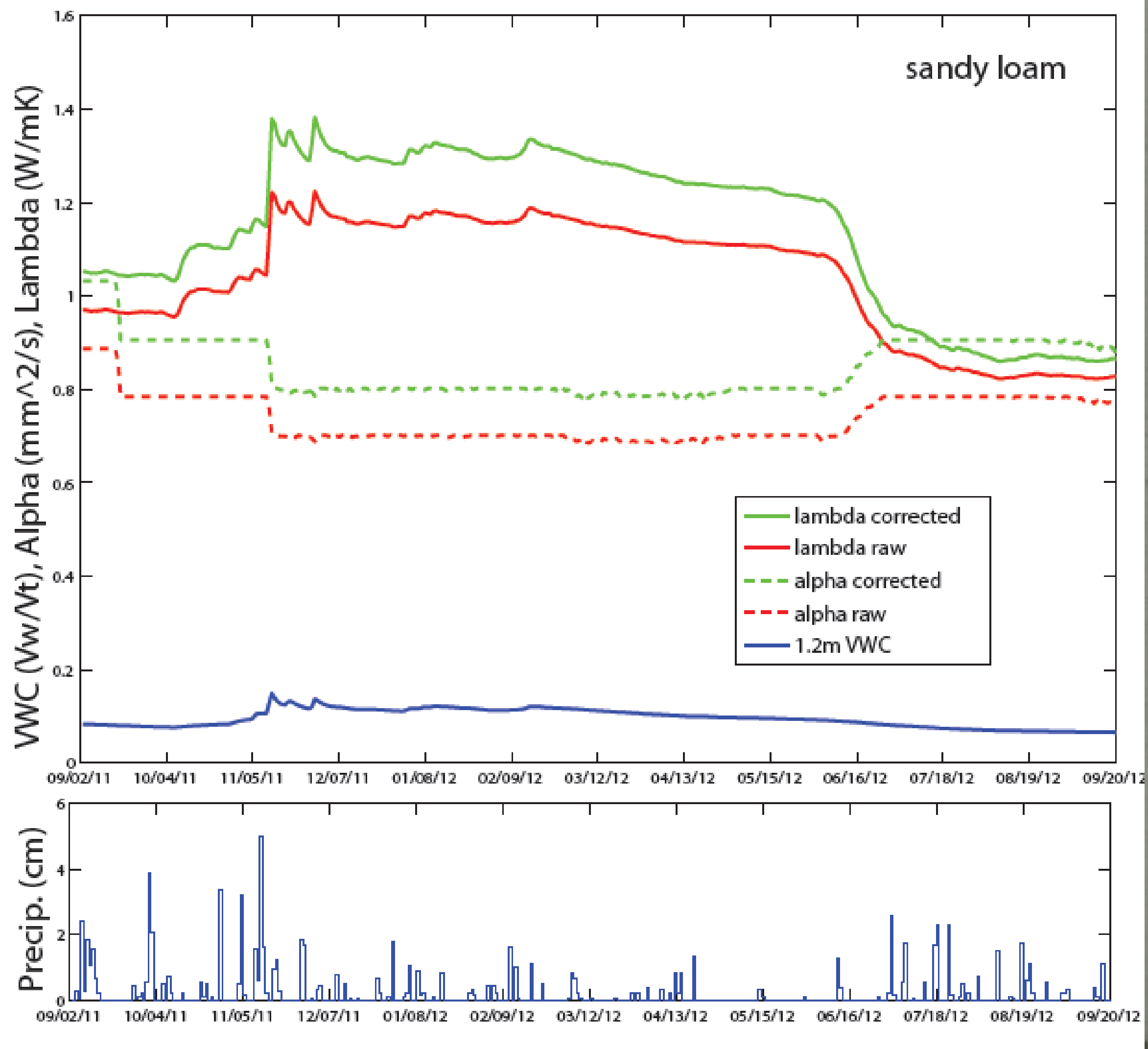


Hukseflux may underestimate thermal conductivity by up to 30% but transform equation allows correction to +/- 10% error specification

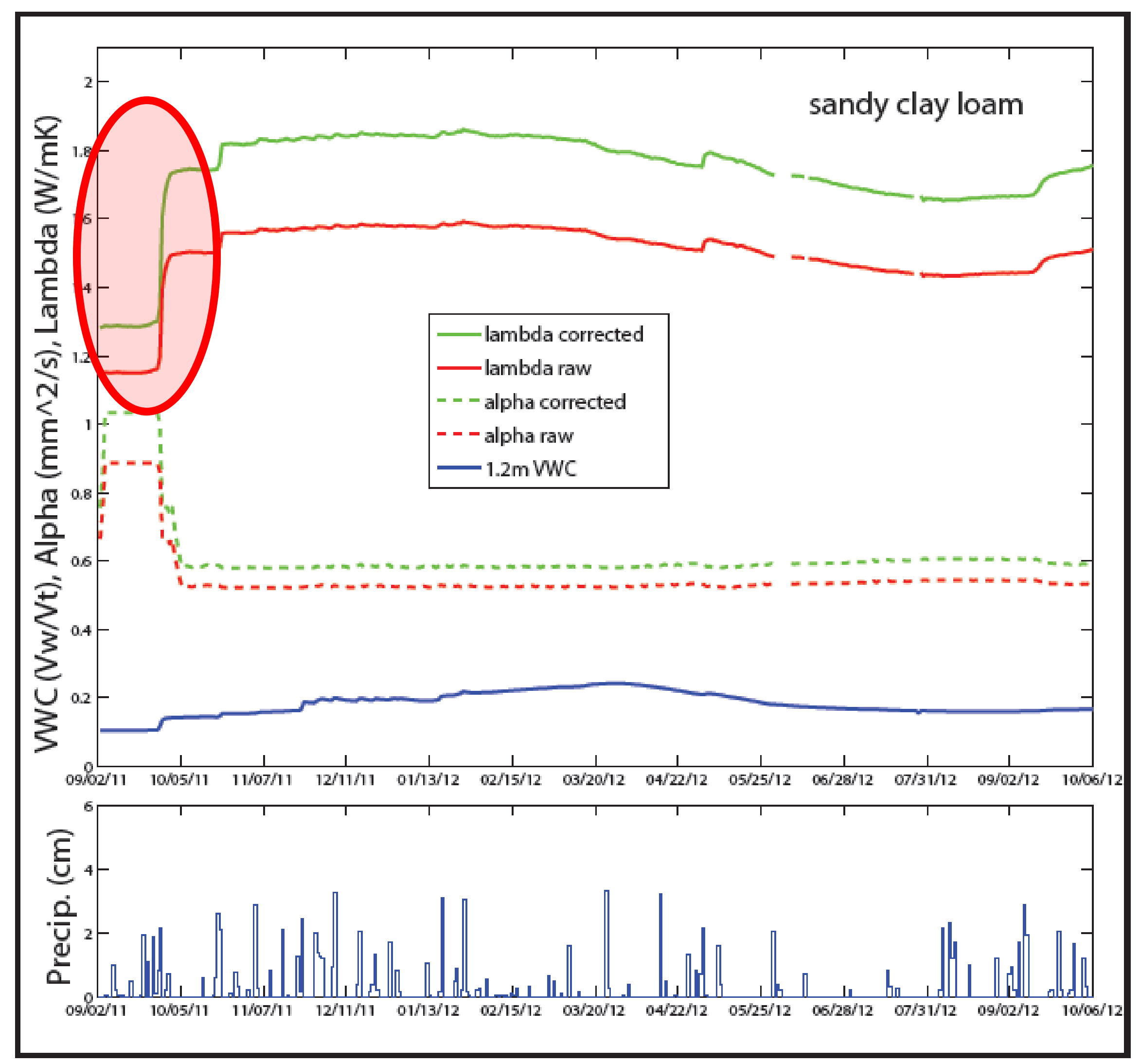
Monitoring results (silt loam site): thermal conductivity variability from 1.6 to 2 W/mK driven by soil moisture



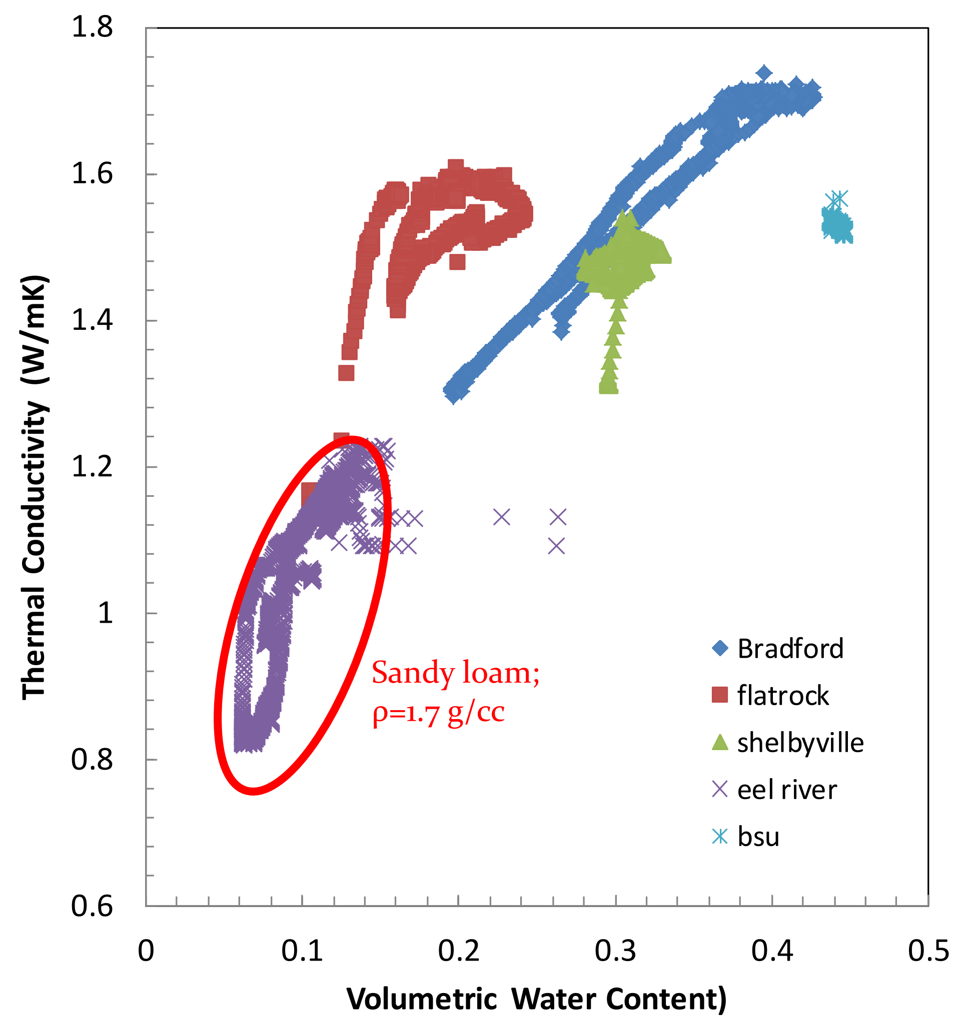
Results from sandy loam site: thermal conductivity variability from ~0.8 to 1.4 W/mK driven by soil moisture



Results from sandy clay loam site: thermal conductivity variability affected by installation (contact resistance)



Summary of important dynamic variability and soil properties



Initial look at impact of observed variability on GHE sizing in design modeling (LoopLink software)

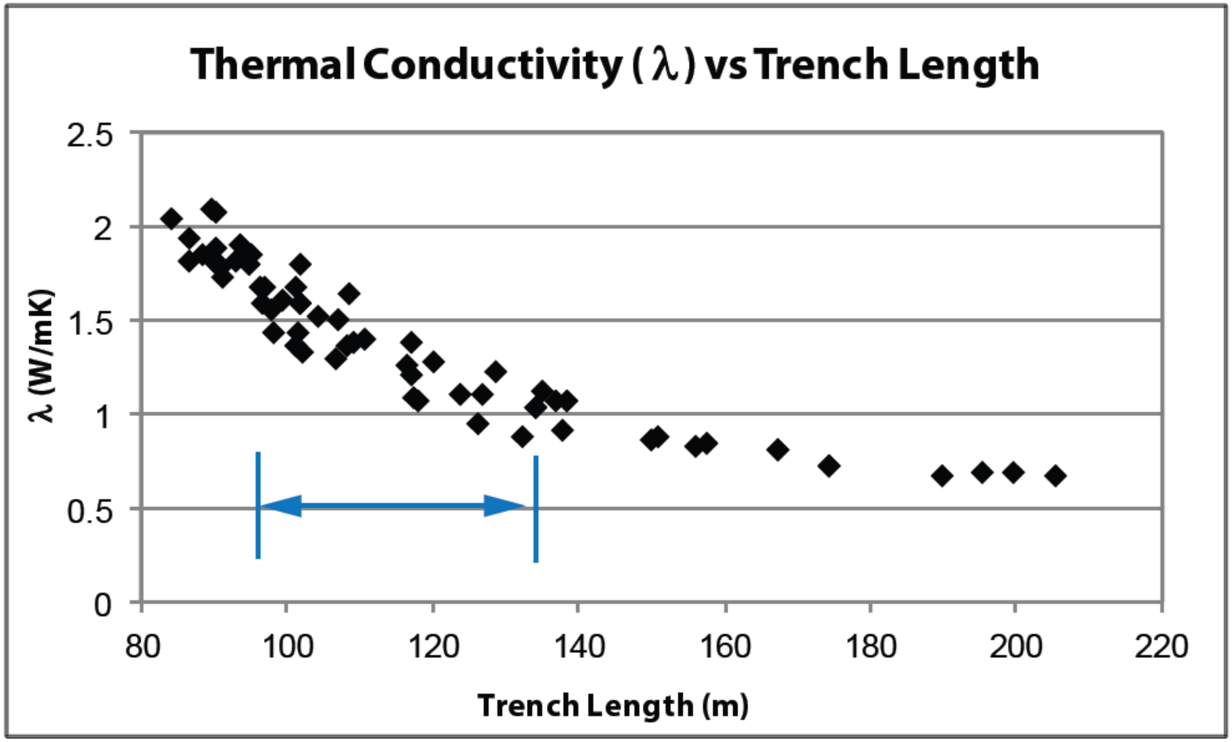


Figure 1. Thermal conductivity of unconsolidated sediments plotted vs. calculated horizontal trench length for a 1.25-ton system capacity in heating mode. Trench lengths determined using LoopLink ground-source heat pump design software. Arrows indicate the range of trench lengths that would result from thermal conductivities measured at site #4.

Potential impact from engineering of soils

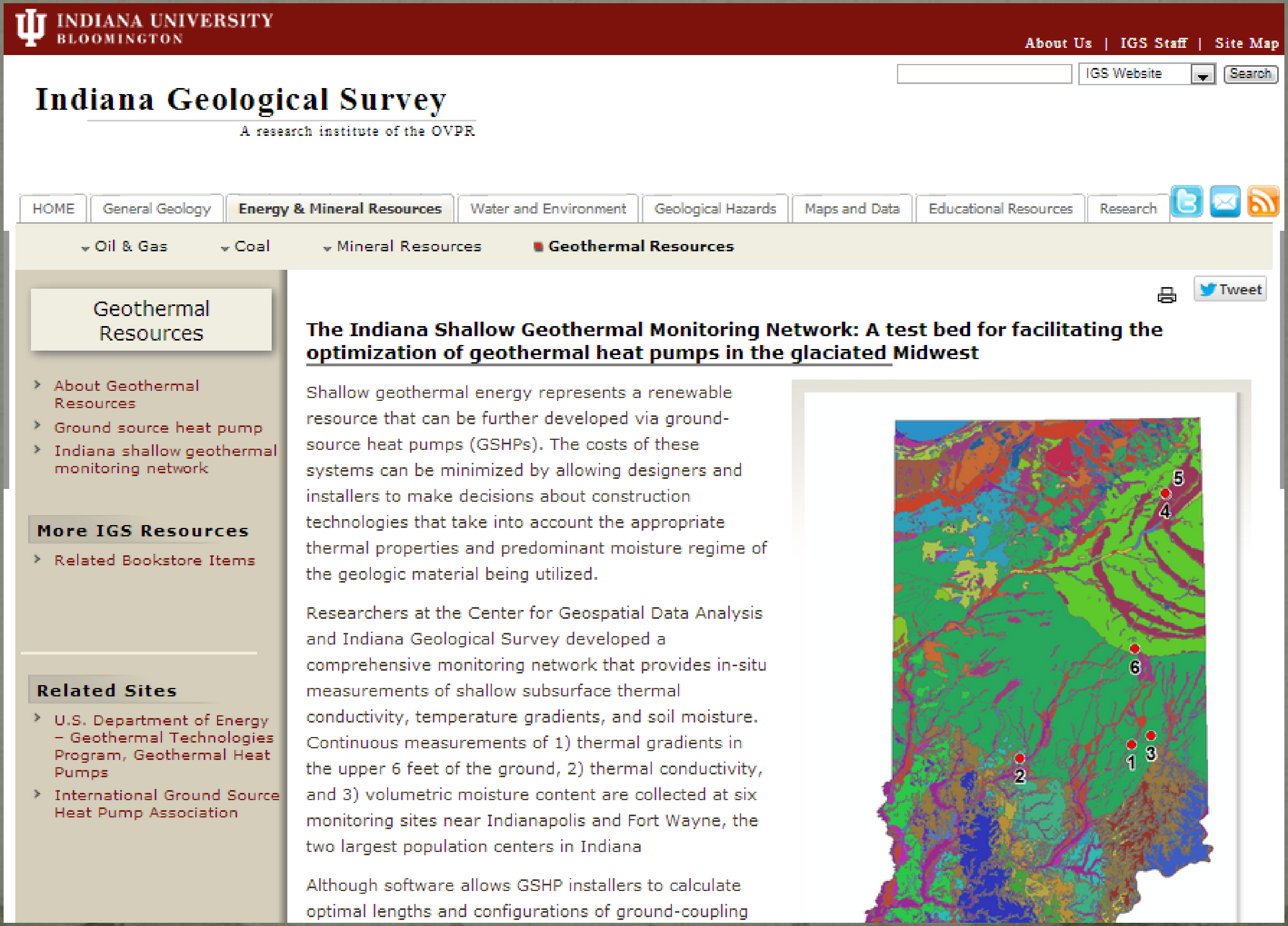
- Prior research and theoretical considerations suggest areas with low Kt soils could be improved by engineering soil properties (texture, mineralogy, bulk density)
  - Addition of quartz-rich sand in backfill
  - Compaction of backfill to increase bulk density

- Results from this study indicate that soil moisture is the dominant control on Kt (even for annual mean)
  - In-situ observations suggest modeling Kt from static soil properties is challenging
  - Irrigating soils may be the most beneficial engineering approach

Conclusions

- Results demonstrate the importance of including dynamic variability in GHE/GHP design
  - Thermal properties and soil temperature exhibit large variability at GHE installation depths across a range of different soil types in Indiana
  - Variability is strongly correlated to soil moisture states
  - IGSHPA approach suggests cooling load based calculations for design trench lengths are likely to have the largest errors
    - **Thermal conductivity can be 0.3 W/mK or more below the mean value**
    - **Soil temperature can be 8 deg C or more above the mean**
- Work to be completed in 2013 will quantify the impact of these results on standard GHP design approaches
- New state-wide maps of key geothermal parameters will be developed from a GIS analysis combining IGMN results with the SSURGO database

For more details visit: http://igs.indiana.edu/Geothermal/



The Indiana Shallow Geothermal Monitoring Network: A test bed for facilitating the optimization of geothermal heat pumps in the glaciated Midwest

Shallow geothermal energy represents a renewable resource that can be further developed via ground-source heat pumps (GSHPs). The costs of these systems can be minimized by allowing designers and installers to make decisions about construction technologies that take into account the appropriate thermal properties and predominant moisture regime of the geologic material being utilized.

Researchers at the Center for Geospatial Data Analysis and Indiana Geological Survey developed a comprehensive monitoring network that provides in-situ measurements of shallow subsurface thermal conductivity, temperature gradients, and soil moisture. Continuous measurements of 1) thermal gradients in the upper 6 feet of the ground, 2) thermal conductivity, and 3) volumetric moisture content are collected at six monitoring sites near Indianapolis and Fort Wayne, the two largest population centers in Indiana.

Although software allows GSHP installers to calculate optimal lengths and configurations of ground-coupling