Hydrogeologic considerations for designing ground-source heat pump installations in Indiana

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NGDS
National Geothermal Data System

Project overview

- Funded by American Recovery and Reinvestment Act
- Develop distributed network of databases
- Acquire, manage, and maintain data related to geothermal resources for all 50 states
- Indiana Geological Survey project team is responsible for providing existing data and compiling new datasets that support geothermal resource development in Indiana

Outcome = Centralized datasets for the geothermal industry

U.S. DEPARTMENT OF ENERGY

ARIZONA GEOLOGICAL SURVEY AZGS

AASG Association of American State Geologists

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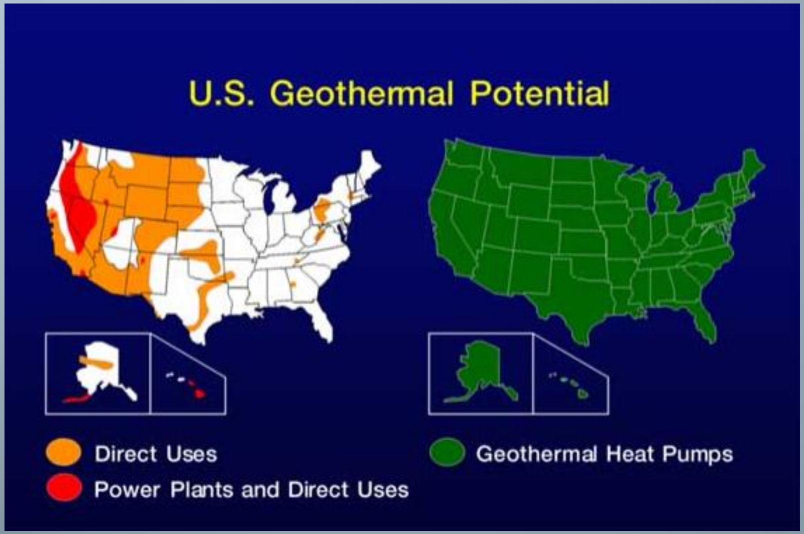
Geothermal power capacity in the U.S.



Geothermal Education Office

Megawatts electric (MW_e):

- 3086 MW_e capacity in 2010 (Jennejohn, 2010)
  -0.3% of US power production
- 7057 MW_e capacity in development
- CA, NV, UT, HI, ID, AK, OR, WY, NM

Resource classification:

- High temp. (>150 C)
- Medium temp. (90-150 C)
- Low temp. (<90 C)

Direct uses, megawatts thermal (MW_t):

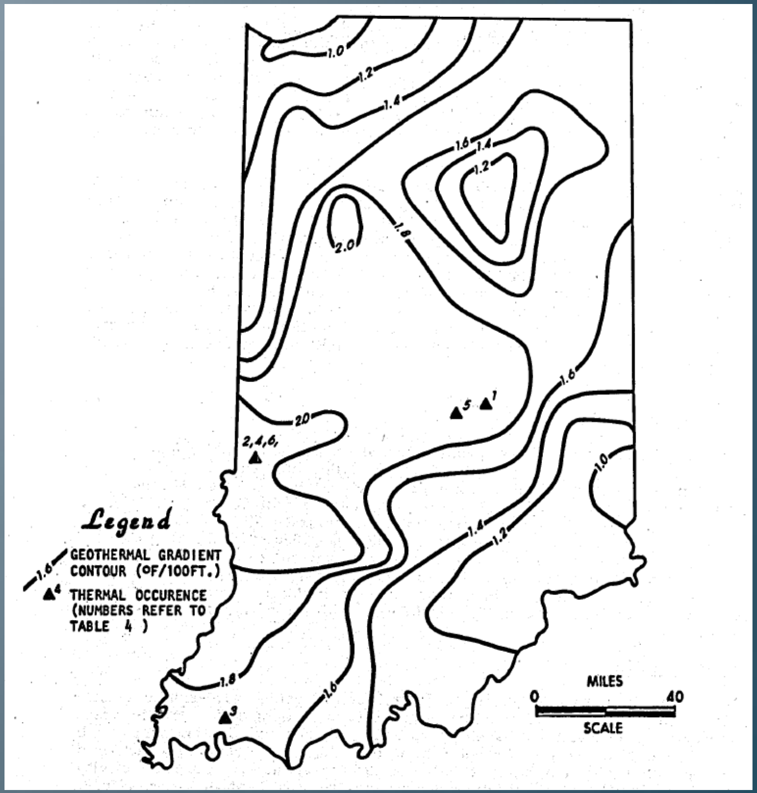
- 7817 MW_t capacity in 2005 (Lund, 2007)
- 57% comes from ground-source heat pumps

Realities of living in a low-temperature state

- Highest temperature recorded at depth is 167 F for an 11,752′ well

- Binary power generation is possible for low and moderate temperatures resources, but Rafferty (2000) calculated that, for a 210 F system, the cost to produce electricity from a 3,000 foot well is $0.48 per kWh

electric power is a long-shot but…..

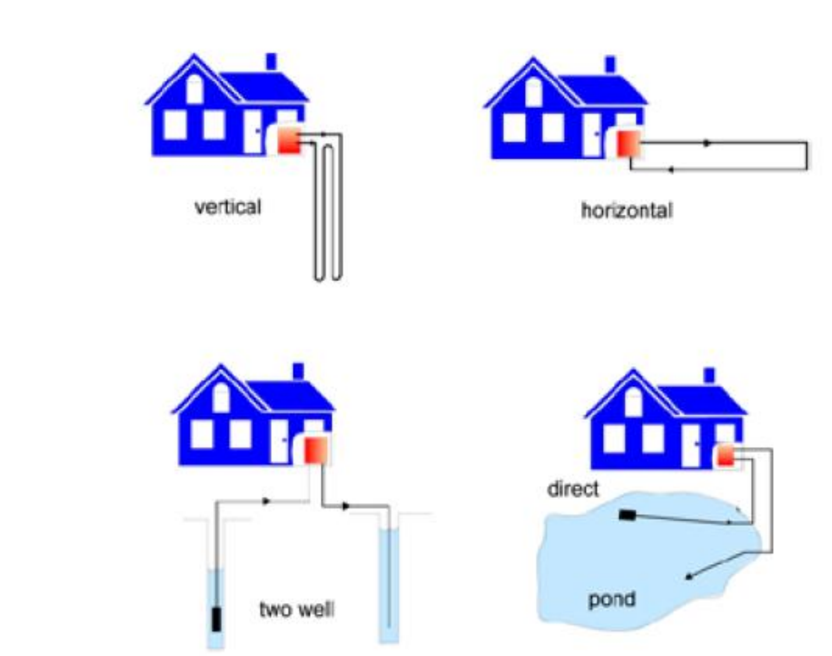


Geothermal gradient in Indiana (from AAPG and USGS, 1976)

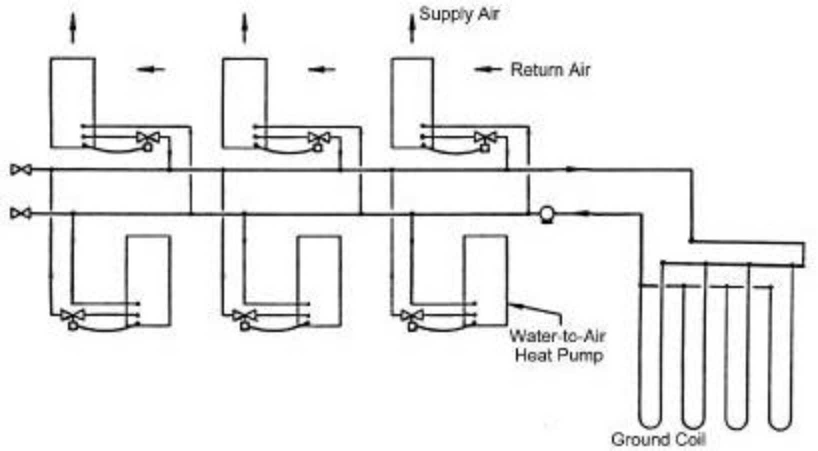
…we have (geo) thermal mass that can be exchanged via ground-source heat pumps (GSHPs)

700,000 GSHP units installed in U.S. (most in midwest and eastern states)

15% annual growth (Lund, 2007)



GSHP configurations



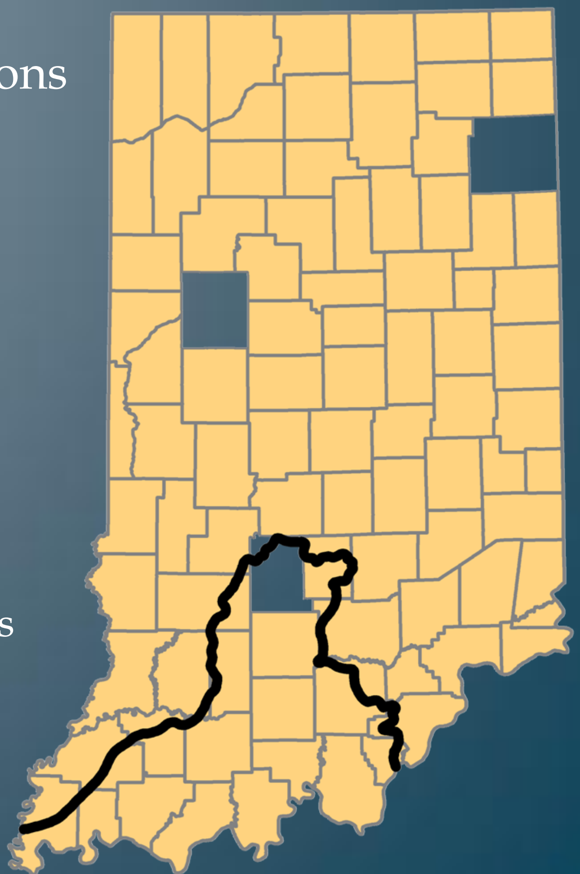
Commercial ground-coupled (closed loop) heat pump system

Most GSHPs in Indiana are:

•Vertical closed loops (VCL)
•Vertical open loops (VOL)
•Horizontal closed loops (HCL)

Data needs for GSHP design

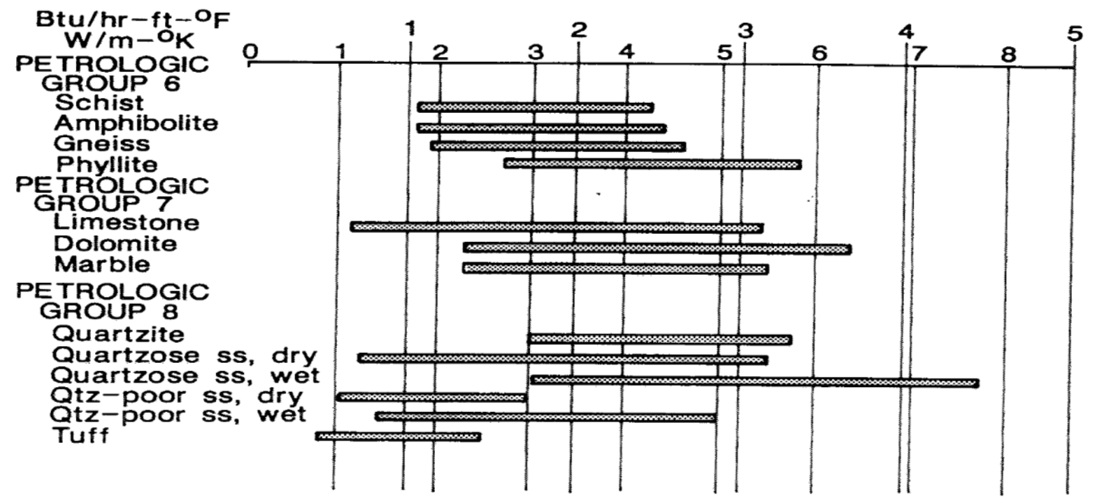
- Thermal conductivity of rocks and unconsolidated sediments (soils)
  - Lithologies and structural contours for formations
- Data related to degree of saturation for geologic formations
  - Depth to GW / potentiometric surface maps
  - Drainage characteristics of soils
- Thermal gradients and GW temperatures
  - Bottom hole temperature data from petroleum well logs
  - Temperature profiles from petroleum well logs
  - GW temperature data from monitoring studies
- Other datasets that can assist with design and site investigations
  - Depth to bedrock / thickness of unconsolidated sediments
  - Hydraulic conductivity / transmissivity of local aquifers



Importance of formation thermal conductivity – VCL applications

•Knowing the thermal conductivity of a geologic formation(s) is important in order to develop a properly sized ground loop for a particular application

•The thermal conductivity of the formation determines how easily heat can be conducted to and from the circulating fluid in the heat exchanger piping (i.e., the heat flux rate of the system)



Saturated rocks have higher thermal conductivities

Increasing porosity decreases thermal conductivity

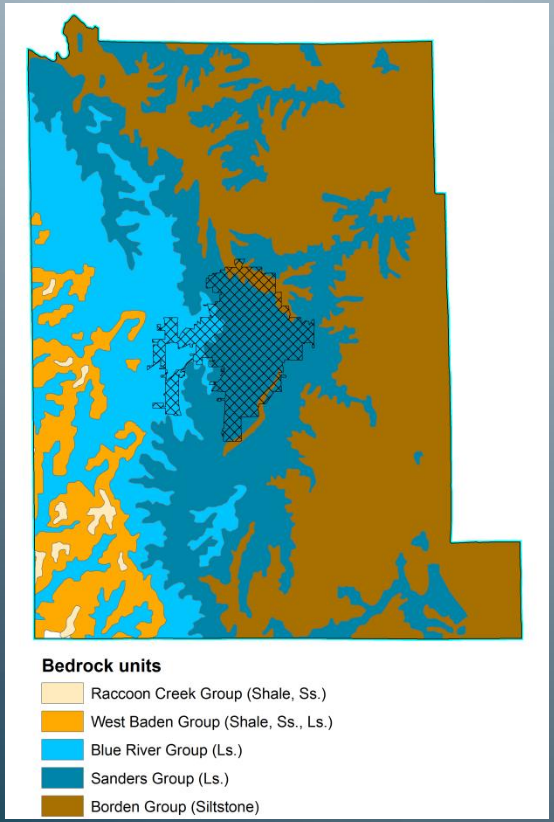
Mineralogy matters – higher quartz content yields higher K_t

Thermal conductivity values for common rock types (from Salomone and Marlowe, 1989)

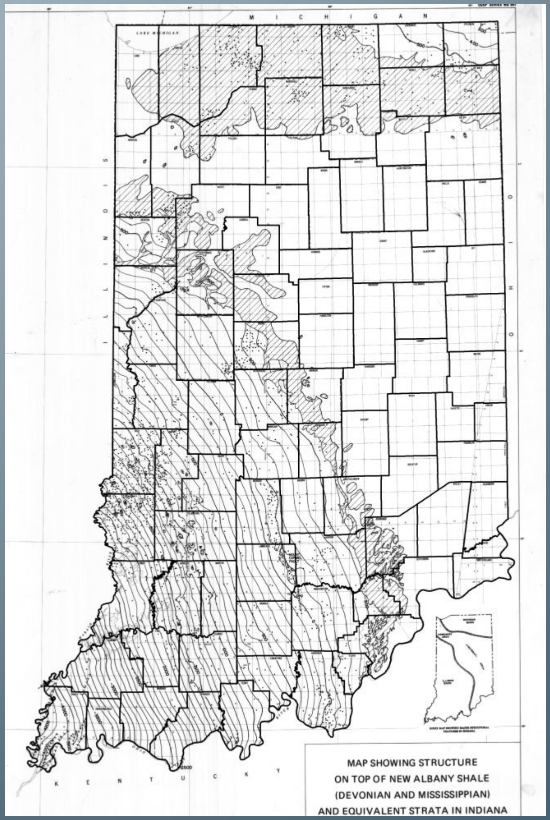
Datasets related to rock type – VCL applications

Vertical GSHPs systems installed at depths greater than 200′ can encounter several rock formations with varying thermal properties

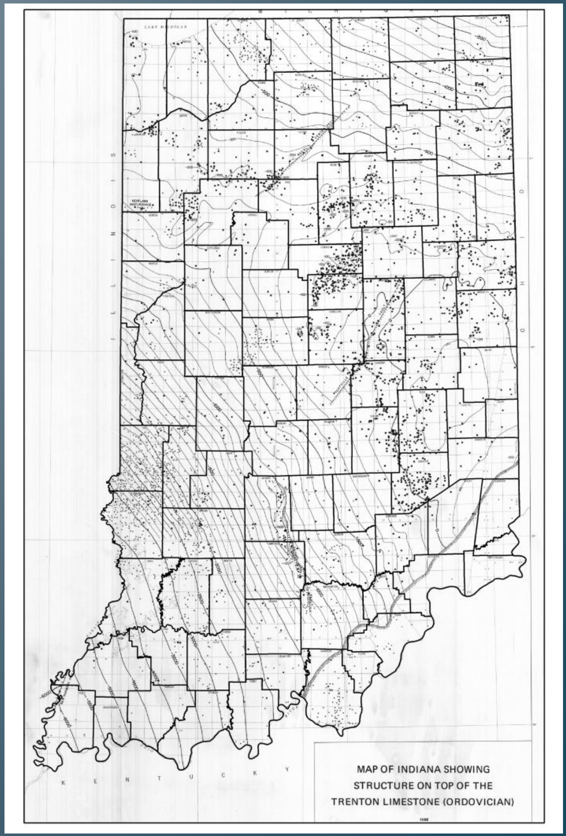
Bedrock geology of Monroe County



Elevation of the top of the New Albany Shale

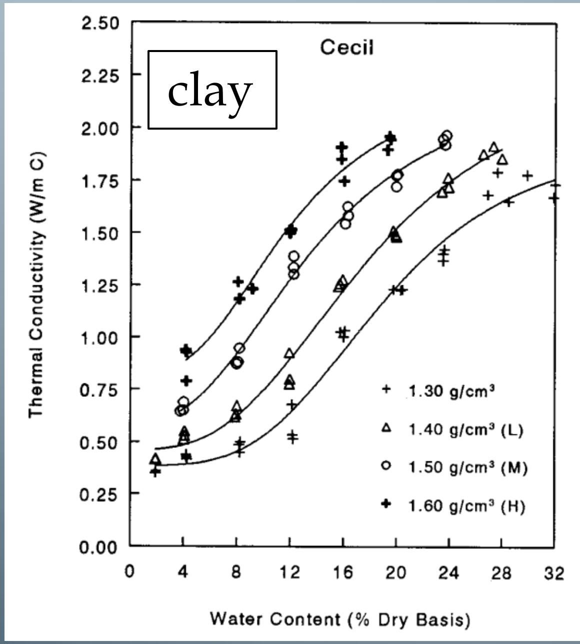


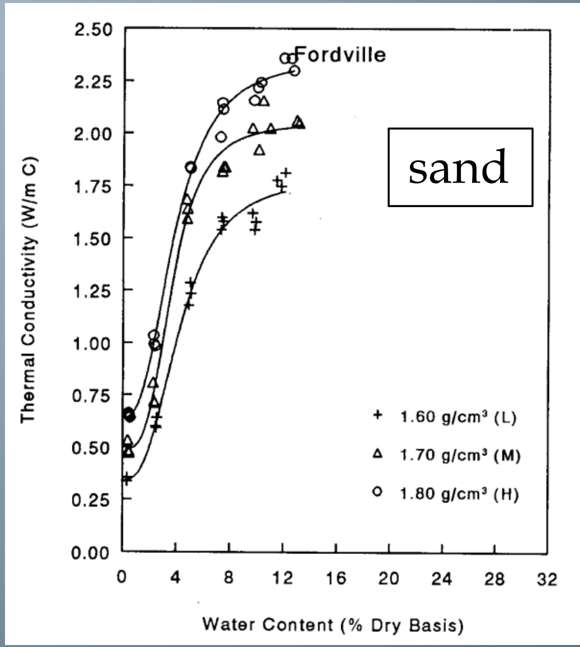
Elevation of the top of the Trenton Limestone

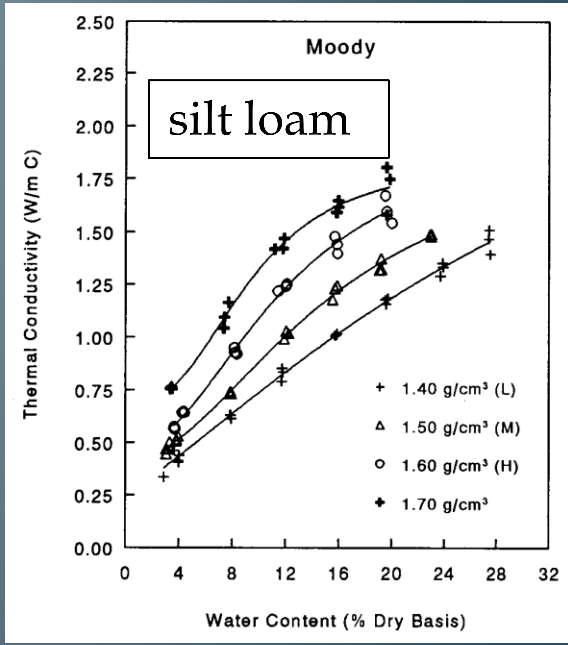


Unconsolidated material thermal conductivity – VCL and HCL applications

Texture, moisture content, and bulk density are primary controls on thermal conductivity of unconsolidated materials





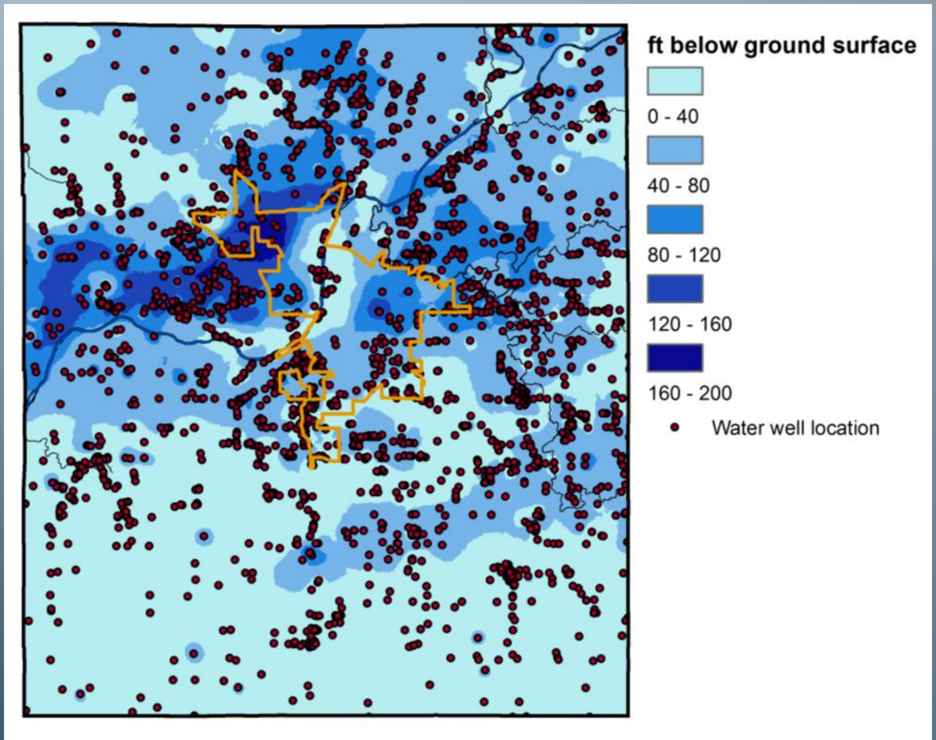


(figures from Remund, 1994)

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

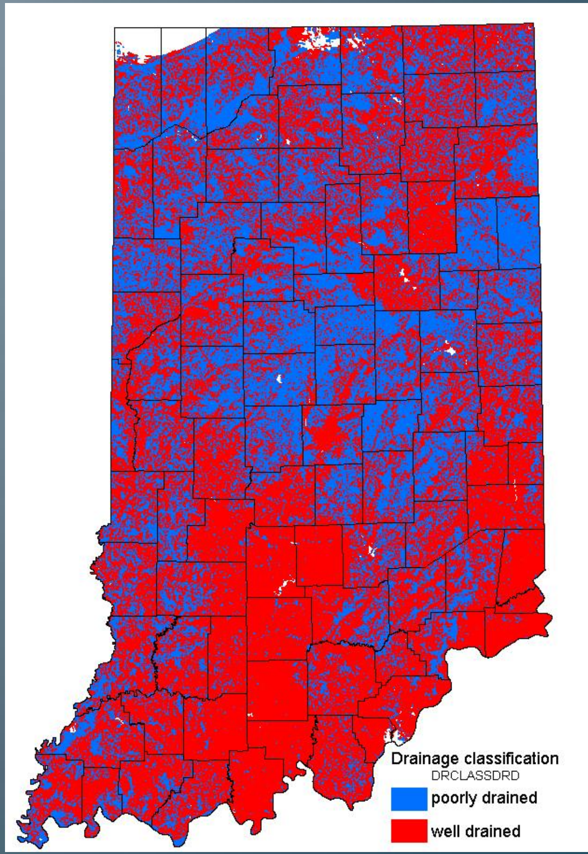
Datasets related to moisture content

Generalized static water levels for Tippecanoe County



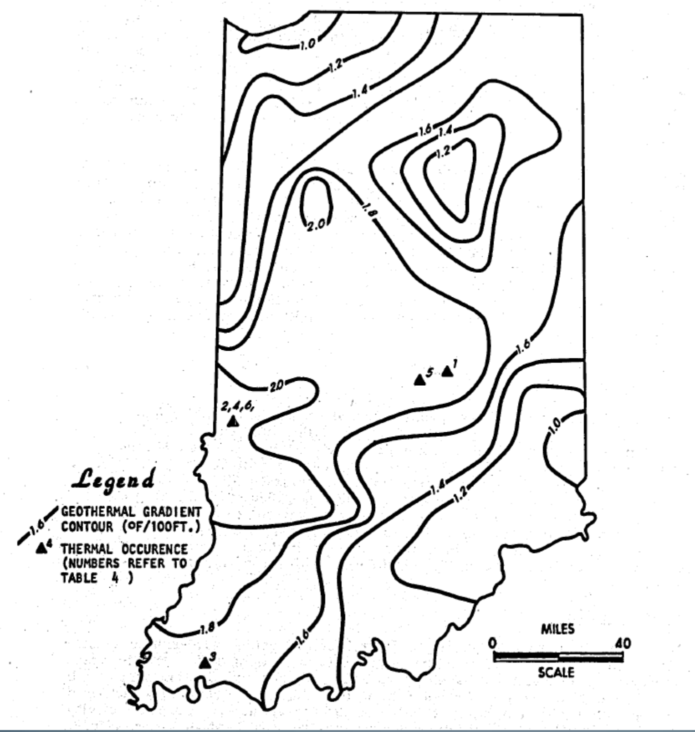
VCL and VOL applications

Soil Survey Geographic Database (SSURGO) drainage classification



HCL applications

Geothermal gradient in Indiana



Geothermal gradient in Indiana (from AAPG and USGS, 1976)

Vaught (1980) noted issues with AAPG/USGS gradient map due to inclusion of bottom hole temps. from shallow wells in the analysis

Data have been pulled from petroleum well logs relating to thermal gradients in IN:

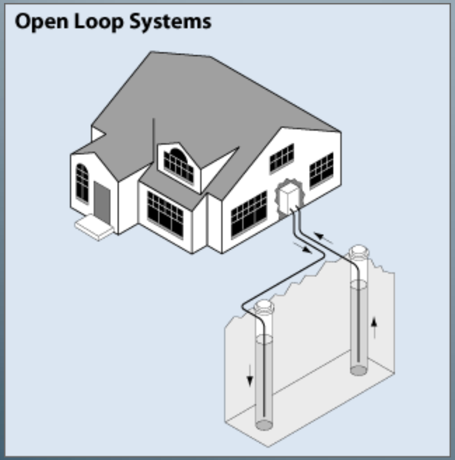
~10,000 bottom hole temperature records

~50 borehole temperature logs

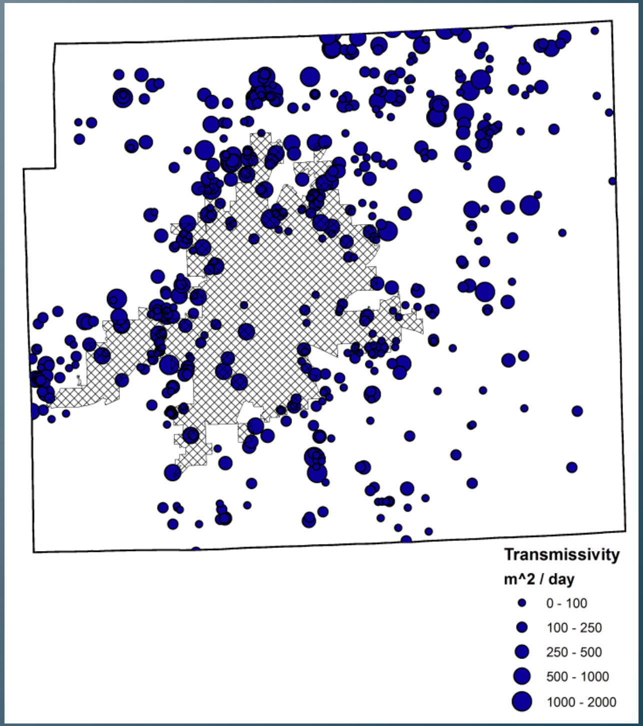
Other datasets related to GSHP design and preparation for site investigations

Open loop systems are typically double well configurations with a supply well and an injection well

Well entrance velocities for injection wells are ½ that of pumping wells so formations must be conducive to doubling well screen lengths



T values for Allen County



Transmissivity (T=Kb)

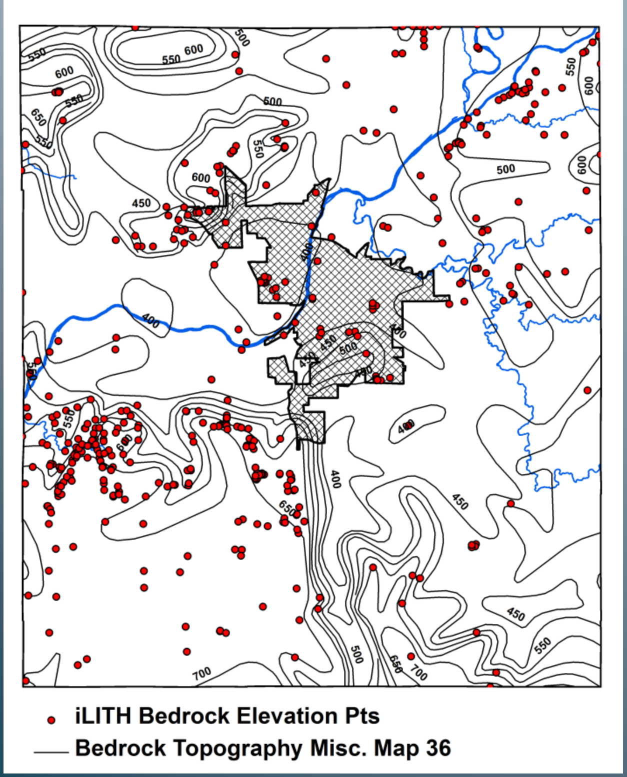
T units are L^2 / t
K= hydraulic cond. (L/t)
b= aquifer thickness (L)

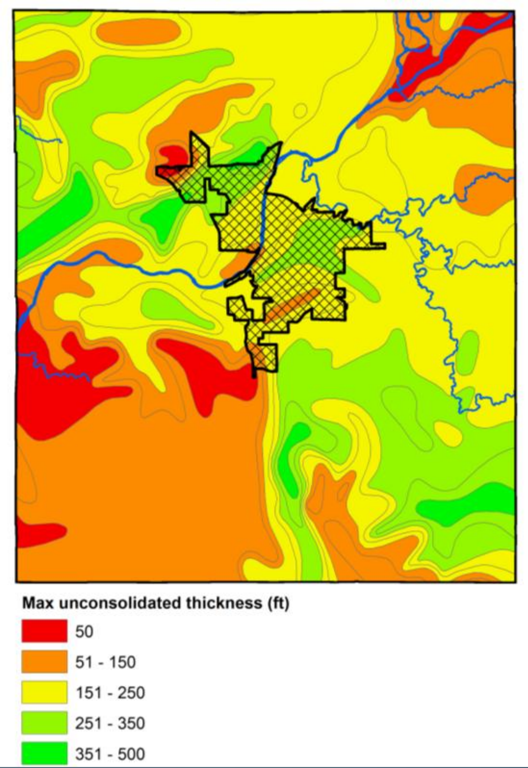
Other datasets related to GSHP design and preparation for site investigations

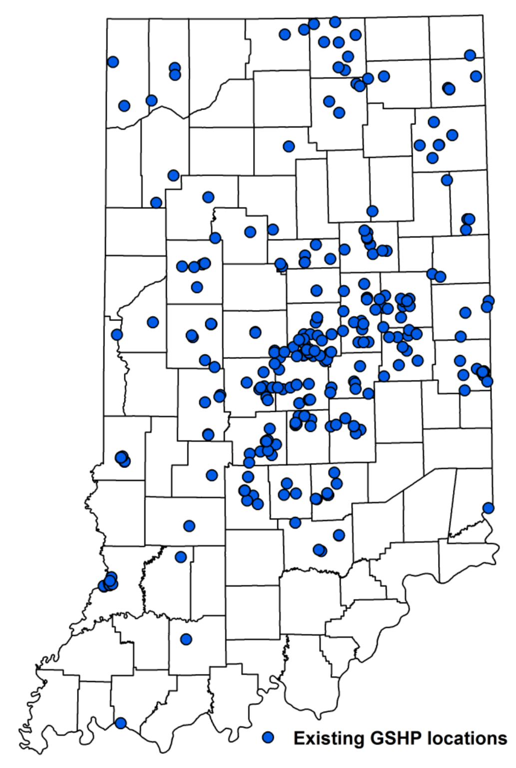
Bedrock elev. data for Tippecanoe County

Unconsolidated material thickness for Tippecanoe County

Existing vertical GSHP locations based on water well database







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Vaught , T.L., 1980. “An Assessment of the Geothermal Resources of Indiana Based on Existing Geologic Data”. Report DOE/NV/10072-3, U.S. Department of Energy, 38 p.

Project timeline

September 2010 – State contributions to NGDS begin

August 2011 – End of year 1

August 2013 – State contributions to NGDS completed

Questions? / Feedback?

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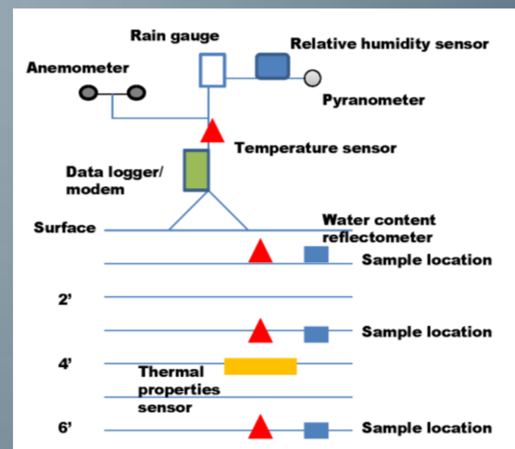
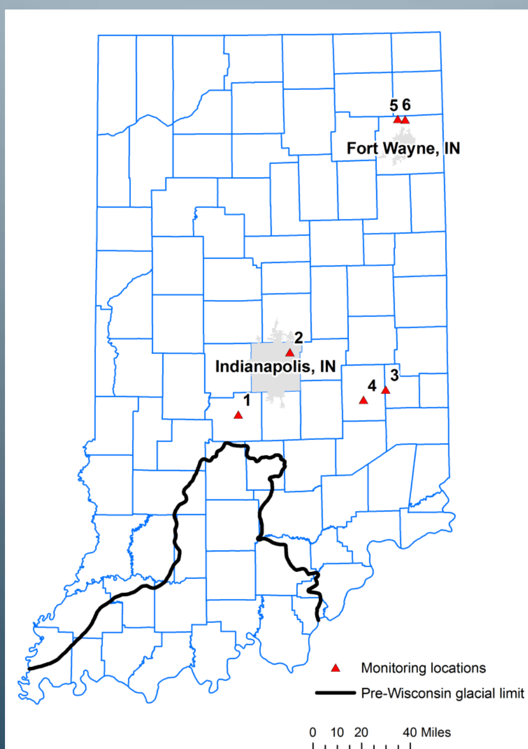
Project recently funded through DOE geothermal technologies program

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

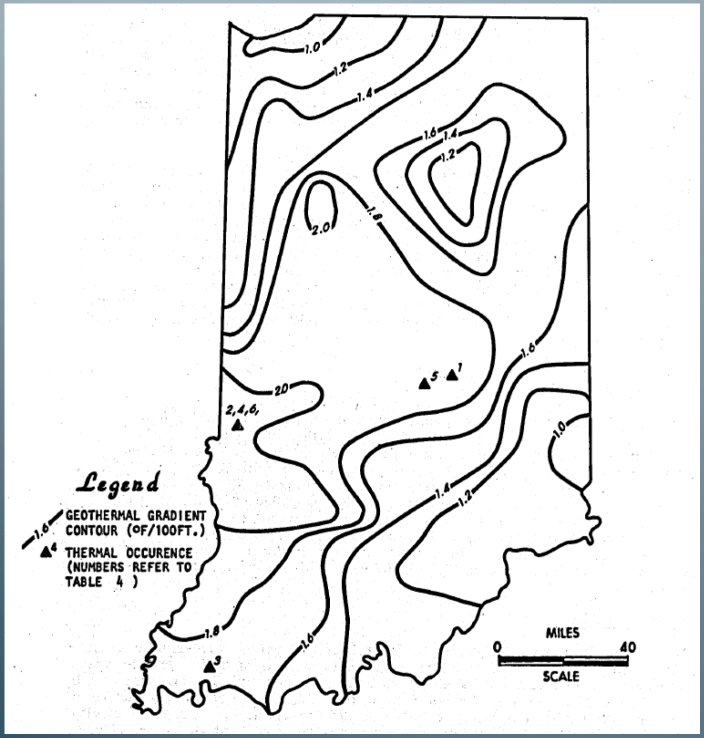




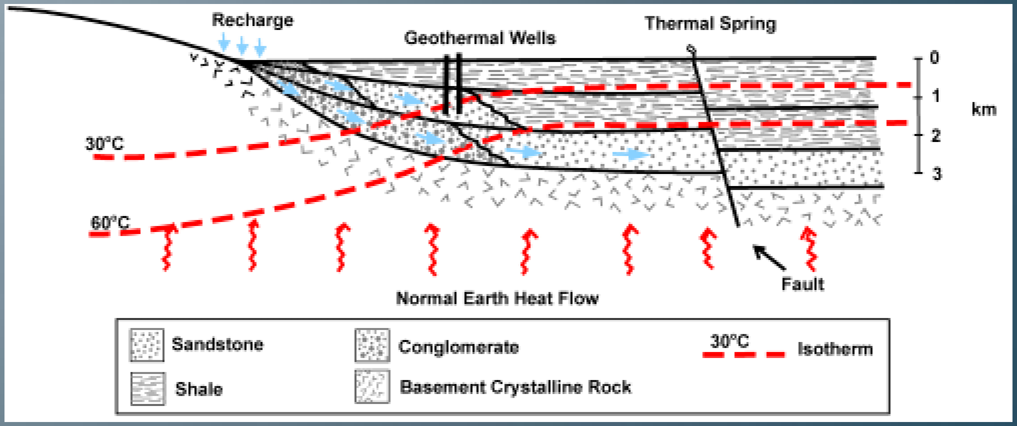
Site Number	Hydrogeologic setting	Sediment texture / parent material (5 feet bgs)	Comments
1	W. Fork White R. outwash plain	Sandy loam / alluvium	Extensive suburban development occurring adjacent to proposed Int.69 corridor
2	W. Fork White R. fringing washed till plain	Loam / glacial till	
3	E. Fork White R. Greensburg morainal system	Clay loam / glacial till	Existing horizontal GSHP at this site
4	E. Fork White R. tributary meltwater channel	Stratified coarse sand to gravelly sand / outwash	
5	Cedar Ck. – Eel R. outwash	Fine sand / outwash	Existing groundwater monitoring site, extensive development
6	Erie Lobe Wabash moraine	Silty clay / glacial till	Existing groundwater monitoring site, extensive development

Regional-scale influences of groundwater flow on geothermal gradients

Vought (1980) noted issues with AAPG/USGS gradient map due to inclusion of bottom hole temps. from shallow wells in the analysis



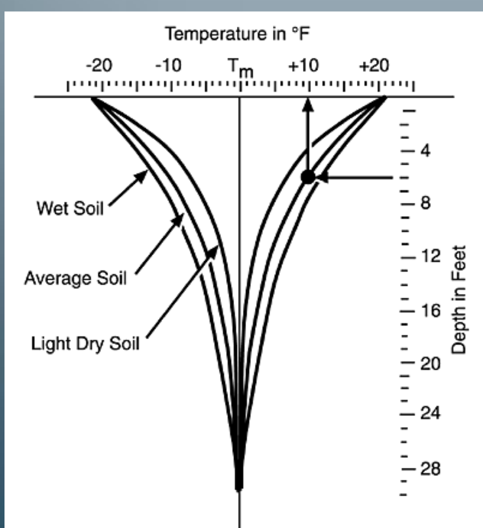
Geothermal gradient in Indiana (from AAPG and USGS, 1976)



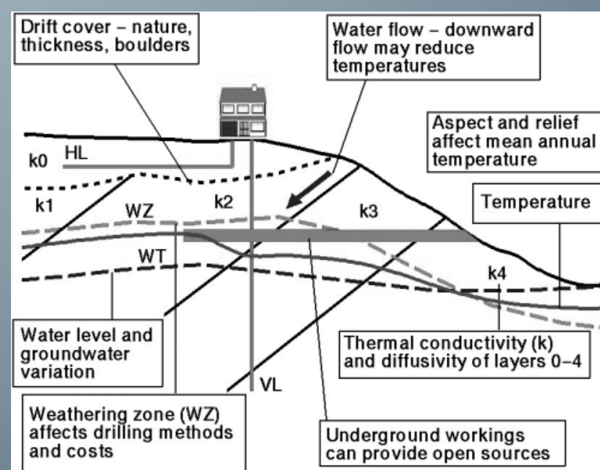
Recharge along the perimeter of a sedimentary basin (Anderson and Lund, 1979)

Local-scale influences of groundwater flow on near-surface temperature gradients

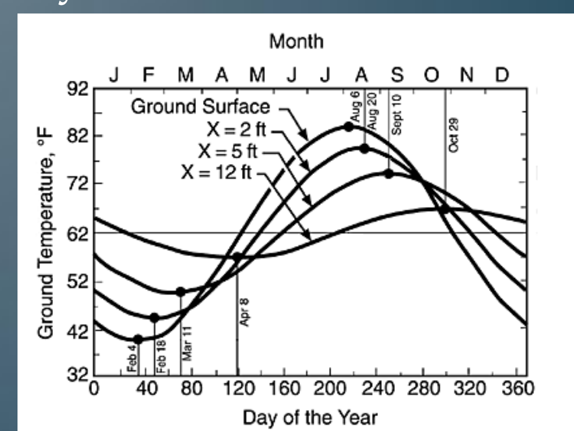
We assume that near-surface temps. will be constant at depths greater than ~30′



GW recharge settings may have reduced temps. relative to adjacent discharge settings

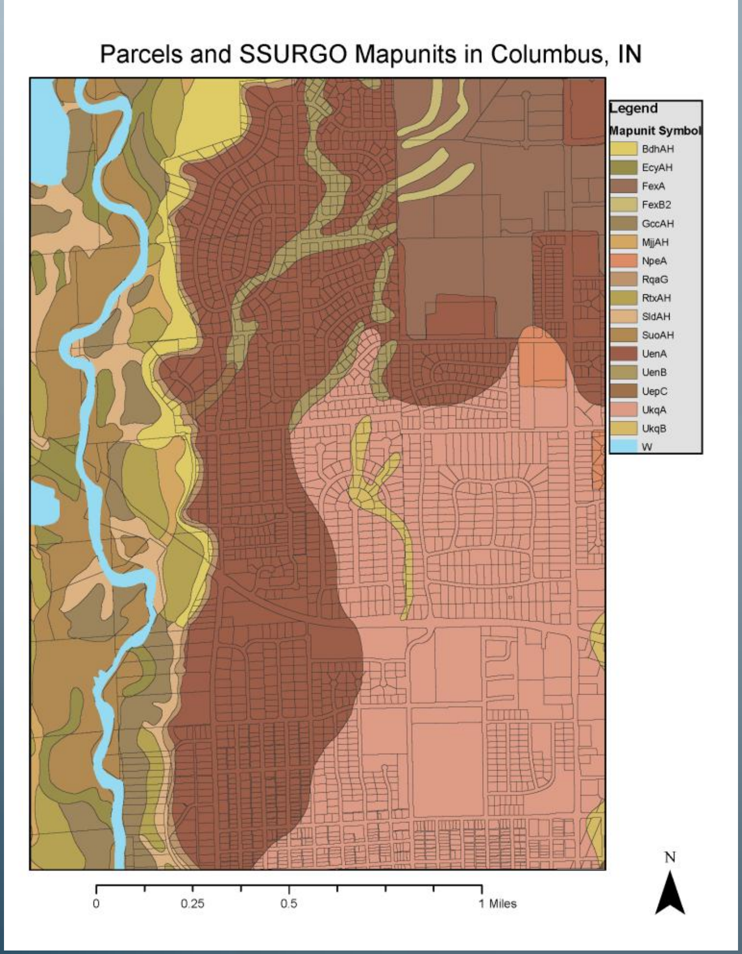


Near-surface temperatures fluctuate seasonally and this must be considered when designing HCL systems

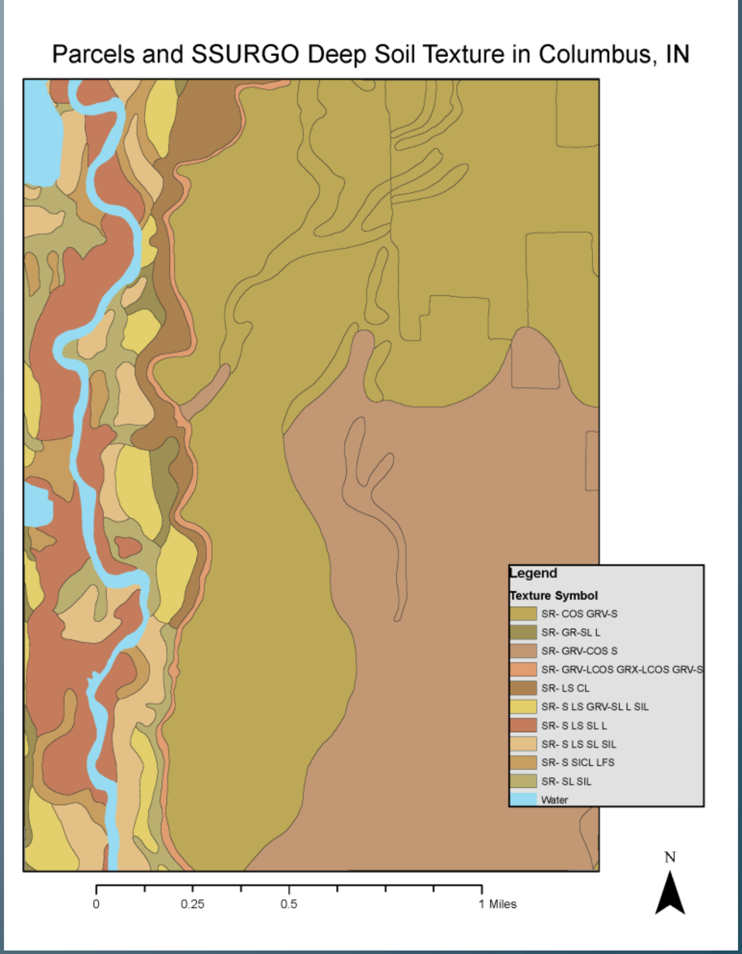


SSURGO data related to horizontal GSHP design

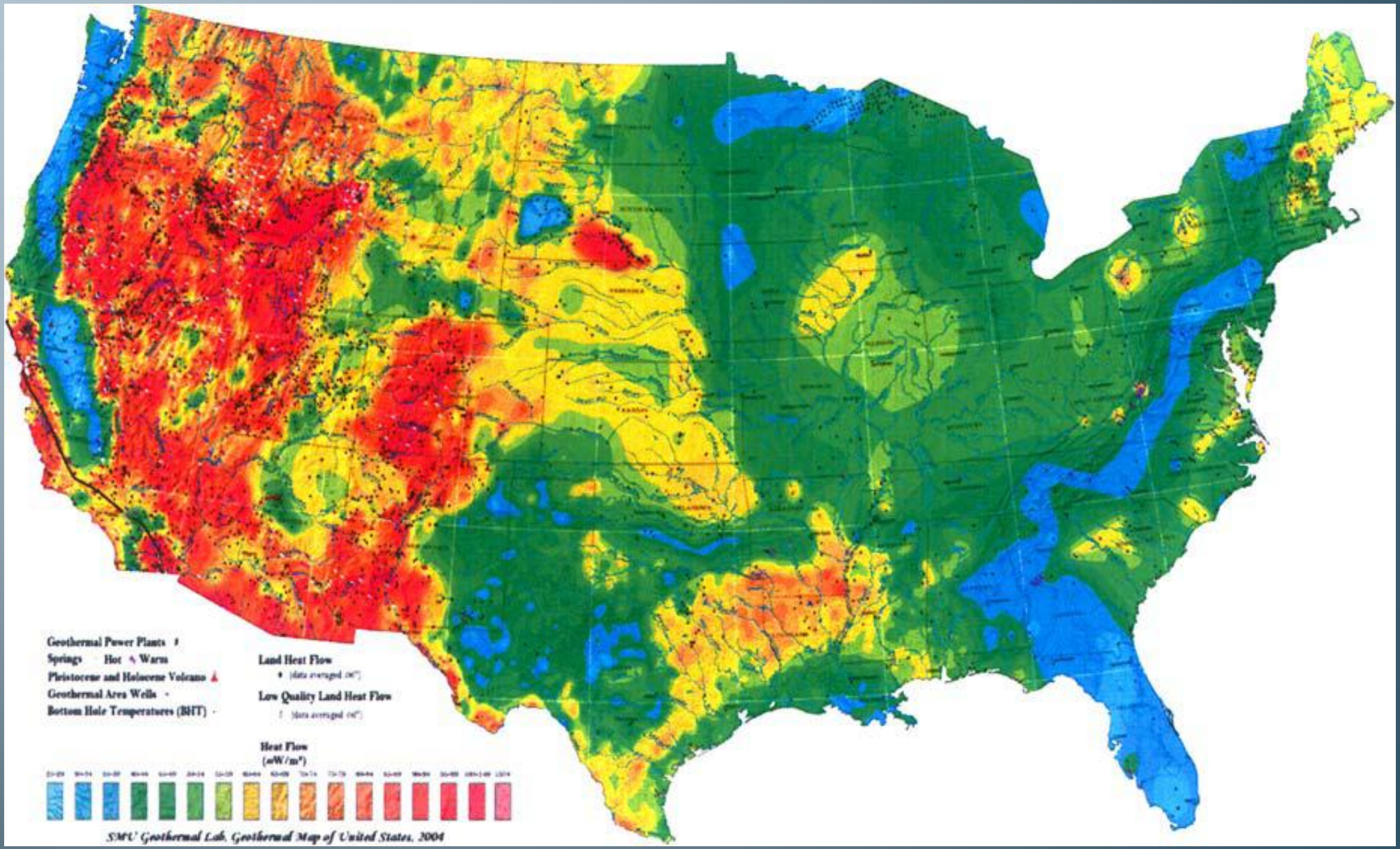
Parcels and mapped units



Deepest soil horizon textures (parent material)



Heat flow in the U.S



Heat flow in the U.S. (from Blackwell and Richards, 2004)