Geothermal Earth Loop Options

Is there a single “best” approach?

An overview of the different types of geothermal loops and their various cold climate adaptations

PRESENTER:
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Northern GroundSource Inc.
www.NorthernGroundSource.com
1. The Geothermal Heat Pump Concept

INTRODUCTION: The Simple Logic of a “Ground Source” Approach
Recommended References


A common air conditioner is a simple Air-to-Air Heat Pump—exchanges 74°F indoor air with outdoor temperatures that fluctuate broadly and can often swing to over 100°F.
An *air source heat pump* adds Air-to-Air heating capability—it exchanges 70°F indoor air with outdoor temperatures that can swing well below 20°F (common ASHP operating range limit).
Where might we find temperatures close-by that are far more stable and efficient?
Old Faithful Geyser

“Hot Rocks” Power

High Grade Geothermal Energy
“Solar” Geothermal GeoExchange Systems

Low Grade Geothermal Energy
Surface ground temperature swing is much narrower than seasonal air temperature above and gradually becomes stable.
Heat pump technology logically goes...underground!
GSHP requires only 9 kWh\(_T\) from the source to provide 10 kWh\(_T\) to the building since they can provide a COP of 3.7
Environmental Benefits—Great!…

But Tend to Be Geographically Specific

GSHPs create no direct emissions—

BUT…

Like other electric technologies, GSHPs create “upstream” carbon emissions...

Entirely dependent on the method of power generation in the area

[NOTE: Fossil fuels represented on this chart are “point of use” only!]
Economic Benefits—Vary depending on Energy Cost Savings per Net System Cost

50,000 BTUH Heating Load (Typical) Duluth, Minnesota

(Note: Rate Changes Reflected Since 2011)

<table>
<thead>
<tr>
<th></th>
<th>Heating</th>
<th>Cooling</th>
<th>Total</th>
<th>vs. GSHP</th>
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Savings compared to WHAT?...

System Cost compared to WHAT?...

Cost of Ownership = Total System Design & Installation Cost...--PLUS--

System Operating & Mtce. Cost Over Time

...COMPARSED TO SOMETHING ELSE!
Minnesota Power
$200/T Closed Loop ($100/T Open Loop) + $200 ECM
[BONUS: Now Through 08/31/2013 ... $50/T GSHP + $50 ECM]

Great River Energy Affiliates:
Cooperative Light & Power
Lake Country Power
East Central Energy
Arrowhead Electrical Cooperative
$400/T Closed or Open Loop + $100 ECM

2013 Geothermal Rebate Programs
Regional Northeastern Utilities
Consider that GSHP installation costs and benefits are scalable!
Common Misconceptions About Geo’

- Take 50°F from the ground and deliver it to the house, then make up the remaining “difference” with supplemental heat.

- Geothermal heat pumps are not well suited for extremely cold climates—you just don’t get enough benefit from them.

- Simply replaces a conventional furnace or boiler...and everything else remains equal.
2. Understanding the Technology

How Geothermal Heating & Cooling Works (in 3½ minutes or less!)
Ground Source Heat Pumps

Water to Air GHP (Forced Air)  
Water to Water GHP (Hydronic)
Simple Heat Pump

**Mechanical** energy from the human is used to **compress** air inside the tube of a simple tire pump.
Simple Heat Pump

**Mechanical** energy from the human is used to compress air inside the tube of a simple tire pump.

Air inadvertently gets **hot** as it is compressed to higher pressure.
Simple Heat Pump

**Mechanical** energy from the human is used to compress air inside the tube of a simple tire pump.

Air inadvertently gets **hot** as it is compressed to higher pressure.

In process of pumping air... **heat is also being pumped.**
Introducing: The Compressor

The Compressor is the GSHP’s **primary working unit** where gas is compressed, heated, and “pumped” to its heat exchange delivery point.

A **refrigerant** gas (with much better heat concentrating properties than air) is used.
WIKIPEDIA: When two systems...are brought in diathermic contact with each other they exchange heat to establish a thermal equilibrium between each other.

SIMPLE INTERPRETATION: **Heat moves to Cold...Always!**
Typical Forced Air GSHP System

- Air Loop
- Refrigerant Loop
- Domestic Hot Water Loop
- Ground Loop
Forced Air GSHP Heating Cycle
Forced Air GSHP Cooling Cycle
Hydronic Heating Cycle

DOMESTIC HOT WATER DESUPERHEATER

REFRIGERANT REVERSING VALVE

HYDRONIC HEAT EXCHANGER

IN/OUT FROM BUFFER TANK

THERMOSTATIC EXPANSION VALVE

HEAT EXCHANGER REFRIGERANT/WATER

TO/FROM Earth Loop

Note: Earth Loop and Hydronic loop fluids must be antifreeze protected to 18 degrees F.
Hydronic Cooling Cycle

- DOMESTIC HOT WATER DESUPERHEATER
- REFRIGERANT REVERSING VALVE
- THERMOSTATIC EXPANSION VALVE
- HEAT EXCHANGER REFRIGERANT/WATER
- HYDRONIC HEAT EXCHANGER
- TO/FROM BUFFER TANK
- TO/FROM Earth Loop

Note: Earth Loop and Hydronic loop fluids must be antifreeze protected to 18 degrees F.
QUESTIONS?
3. GSHP System Design

There are many variables to consider in GSHP system design.
The “geothermal system” is generally assigned to the “supply” side of heating/cooling functions.

<table>
<thead>
<tr>
<th>Supply Side (GSHP)</th>
<th>Delivery Side (HVAC)</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Ground Heat Exchanger (GHEX)</td>
<td>• Duct System (incl. Air Exchanger)</td>
</tr>
<tr>
<td>• Ground Source Heat Pump (GSHP or GHP)</td>
<td>• Radiant Floor Tubing, Manifolds, Zone Pumps and Controls</td>
</tr>
<tr>
<td>• Loop Pump or Flow Center</td>
<td>• Radiant Baseboards, Panels, Radiators</td>
</tr>
<tr>
<td>• Some Peripheral and Auxiliary Components (incl. Controls)</td>
<td>• Plumbing/Piping Delivery Systems</td>
</tr>
</tbody>
</table>

The “geothermal system” is generally assigned to the “supply” side of heating/cooling functions.
Many GSHP/HVAC Considerations
(Owner must become “educated” & involved!)
Many GHEX/Earth Loop Options
(Who decides?... Who designs?)
Design Procedure

- Estimate Heating/Cooling loads (BTUH)
- Determine proper heat pump size(s)
- Select indoor air/water distribution system(s)
- Estimate the building’s energy requirement
- Estimate the ground heat exchanger loads
  --Annual load
  --Design month load
DULUTH HOUSE: New Construction

- DULUTH INTL AP (Bin Weather Data)
- 50,000 BTUH Heat Loss (@ -20°F OAT)
- 24,750 BTUH Heat Gain (@ +84°F OAT)

- 5 Ton 3HT/2CL Forced Air Heat Pump
  [NOTE: 1 Ton = 12,000 BTUH]
- Compare to LP or NG Furnace w/AC

SIMPLE FORCED AIR EXAMPLE:
2,500 to 3,000 ft² House (Typical)
Simple Rule #1: As it gets colder, the rate of structural heat loss increases.

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PEAK HEATING LOAD per “DESIGN DAY”

Design to the most “reasonable” lowest outdoor temperature.

FOR EXAMPLE:

Duluth INT ≈ -20°F

THAT MEANS:

If the indoor temperature is kept at 70°F...

That is a difference of 90°F between indoor and outdoor temperatures.

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Figure 3.6 Weather Bin Data for Grand Forks, ND

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+24,750 BTUH

0 BTUH

-50,000 BTUH (Current House @ -20°F)
Auxiliary Electric Resistant Heat... Supplemental/Emergency Heat “Option”

PROPER USE:

- Brief intermittent “heat boost” for extreme cold periods (below balance point)
- Occasionally necessary GSHP/GHEX system sizing scale-back (site limitations)
- Availability of optional “emergency” heat
- Make up for under-sized or inadequate GSHP installation—after the fact!

CURRENT EXAMPLE:
5kW Supplemental
10kW Emergency

1kW = 3,414 Btu
**Simple Rule #2:** Lower loop temp. = less GSHP heat output...but also less loop cost!

### [Current 5 Ton 3HT/2CL Forced Air GSHP] GV/GH 580/581

<table>
<thead>
<tr>
<th>LOOP TEMP.</th>
<th>DESIGN LOOP TEMPERATURE</th>
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</thead>
<tbody>
<tr>
<td>30°F EWT suggested for 5T Horz. Earth Loop Designed to 8’ Depth</td>
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</table>

### Proper GSHP Sizing per “Peak Load”

*Design to the most reasonable minimum loop temperature.*

**FOR EXAMPLE:**
- NE Minnesota ≈ 30°F
- NW Wisconsin ≈ 30°F

**RESULT:**
- Reduces GHEX Installation Cost!
- Remember Goal—maximize benefits...while minimizing cost!
Antifreeze protection is required for lower loop temperatures (i.e., Leaving Water Temperature).
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<tr>
<th>Heating (High Capacity)</th>
<th>Cooling (High Capacity)</th>
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<tbody>
<tr>
<td>Heating Capacity 51,700 Btu/hr</td>
<td>Total Cooling Capacity 57,500 Btu/h</td>
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<tr>
<td>% Sizing 103.4%</td>
<td>Sensible Cooling Capacity 43,125 Btu/h</td>
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<td>Installed COP 3.70</td>
<td>% Oversizing 74.2%</td>
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<tr>
<td>Balance Point Temp. -22.1 °F</td>
<td>Installed EER 12.50</td>
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<td>Heating (Low Capacity)</td>
<td>Cooling (Low Capacity)</td>
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<td>Heating Capacity 37,700 Btu/hr</td>
<td>Total Cooling Capacity 46,100 Btu/h</td>
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<td>% Sizing 75.4%</td>
<td>Sensible Cooling Capacity 34,575 Btu/h</td>
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<td>Installed COP 3.95</td>
<td>% Oversizing 39.7%</td>
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<td>Installed EER 14.41</td>
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**51,700 BTUH GSHP CAP @ 30F EWT**

**50,000 BTUH Heating Load @ -20°F**
### 5T GSHP Runtime & Operating Cost

#### Heating
- High Capacity Runtime: 250 hours
- Low Capacity Runtime: 2,532 hours
- Resistance Heat Runtime: 31 hours

- Heat Pump Energy Use: 8,445 kWh
- Resistance Heat Energy Use: 20 kWh
- Pumping Energy Use: 776 kWh

**Total Cost:** $831.82

#### Cooling
- High Capacity Runtime: 0 hours
- Low Capacity Runtime: 275 hours

- Heat Pump Energy Use: 799 kWh
- Pumping Energy Use: 76 kWh

**Total Cost:** $78.90

**HP Operating Cost:** $760.14
**Resistance Heat Operating Cost:** $1.83
**Pumping Cost:** $69.85

**Total Cost:** $831.82
<table>
<thead>
<tr>
<th>Heating (High Capacity)</th>
<th>Cooling (High Capacity)</th>
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<tr>
<td>Heating Capacity 41,100 Btu/hr</td>
<td>Total Cooling Capacity 47,500 Btu/h</td>
</tr>
<tr>
<td>% Sizing 82.2%</td>
<td>% Oversizing 43.9%</td>
</tr>
<tr>
<td>Installed COP 3.54</td>
<td>Installed EER 12.50</td>
</tr>
<tr>
<td>Balance Point Temp. -9.5 °F</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Heating (Low Capacity)</th>
<th>Cooling (Low Capacity)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heating Capacity 29,000 Btu/hr</td>
<td>Total Cooling Capacity 37,000 Btu/h</td>
</tr>
<tr>
<td>% Sizing 50.0%</td>
<td>% Oversizing 12.1%</td>
</tr>
<tr>
<td>Installed COP 3.70</td>
<td>Installed EER 14.23</td>
</tr>
</tbody>
</table>

41,100 BTUH GSHP CAP @ 30F EWT
50,000 BTUH Heating Load @ -20°F
### Heating
- High Capacity Runtime: 607 hrs
- Low Capacity Runtime: 2,535 hrs
- Resistance Heat Runtime: 160 hrs
- Heat Pump Energy Use: 8,281 kWh
- Resistance Heat Energy Use: 291 kWh
- Pumping Energy Use: 724 kWh

### Cooling
- High Capacity Runtime: 0 hrs
- Low Capacity Runtime: 330 hrs
- Heat Pump Energy Use: 787 kWh
- Pumping Energy Use: 76 kWh

### 4.0<5T GSHP Runtime & Operating Cost

<table>
<thead>
<tr>
<th>Heating</th>
<th>Cooling</th>
</tr>
</thead>
<tbody>
<tr>
<td>HP Operating Cost: $745.30</td>
<td>HP Operating Cost: $70.83</td>
</tr>
<tr>
<td>Pumping Cost: $65.16</td>
<td>Total Cost: $77.69</td>
</tr>
</tbody>
</table>

Total Cost: $836.67
51,700 BTUH GSHP CAP $831.82 Annual Heating Cost

41,100 BTUH GSHP CAP $836.67 Annual Heating Cost

Similar Result?...What's the Hitch?
Saves Only 272 ft. of Total Pipe

GHEX Sizing (i.e., cost)...about the same!
Saves 26 ft. Off Each Bore Hole

(Slightly More Savings on Drilling)
• Cooling-Dominant Derived Rule: Do not size GSHP heating capacity more than 25% above the cooling load (impractical?)

• Manufacturer-Derived Rule: Do not size GSHP to less than 85% of the peak heating load (roughly 1 Ton undersizing)

• Cold Climate Sizing Trend: Size to perform 96-100% of all the heating (but consider sizing scale-back for honest “hardships”)
QUESTIONS?
4. Earth Loop Considerations are Site Specific

Is there a single “best way” to do it?...There are many options!
Common GHEX/Loop Options
GHEX Options by General Descending Cost:

- Vertically Bored in Rock
- Vertically Bored “Standing Column” (Rock)
- Vertically Bored in Deep Soil/Overburden
- Horizontally Drilled
- Horizontally Trenched or Excavated
- Lake Loop (Permit?)
- Pond Loop (Existing Pond)
- Open Loop / Pump & Dump

Common GHEX/Loop Options
Wetlands

Wetland concerns must be evaluated on every site... prior to breaking ground. It may not be completely evident that an area is actually classified as type of wetland until inspected by the proper authority.

**Required Sequencing:**
- AVOID
- MINIMIZE
- MITIGATE
Well Logs

Well logs can provide excellent information about local geological formations and soil types.

MN County Well Index:
http://www.health.state.mn.us/divs/eh/cwi/

Site test boring data can also be very useful!
Soil Properties & Composition

Site soil samples can be cross referenced with a soil thermal properties table for more exacting ranges of conductivity.

Bore hole cutting samples can also be collected and analyzed for composition and thermal properties.
Conductivity Testing

An *in situ* (on site) thermal conductivity test is the most effective way to determine the thermal properties of soil and rock across a specific formation. It can be well worth the expense on larger boring projects where margins in cost are critical. It must be done at the design stage!
High Density Polyethylene (HDPE) has become widely established as the pipe of choice across the GSHP industry. It possesses the best characteristics of durability and conductivity...*combined.*
HDPE Pipe Joining Requires Heat Fusion
HDPE Pipe Joining Requires Heat Fusion
The Mother of All Fusion Rigs!
Header Configuration for 8T Vertical GHEX

Loop flow is balanced using a “Step-down” Reducing Reverse Return design—system air purging and flushing is achieved by “choking” flow progressively along header as fluid is channeled through loops and available flow decreases.
IGSHPA STANDARD 3A.11 (1996)
All pipes passing through walls will be **sleeved** and **sealed** with non-hardening caulking material [emphasis added].

SCH40 PVC Pipe Sleeves (Typical)...
High thermal resistance (insulating value), rigidity, and excellent adherence to sealing caulks, foams, and hydraulic cements.

**Wall and Slab Penetrations**
Should be completed **before** pouring!
IGSHPA STANDARD 3A.11 (1996)
All pipes passing through walls will be **sleeved** and **sealed** with non-hardening caulking material [emphasis added].

**Long Sweep Elbows for Pipe Bends!...**
Proper pipe sleeve sizing and configuration will make it a lot easier to place geothermal HDPE supply/return header pipes later.

**Wall and Slab Penetrations**
Should be completed **before** pouring!
Closed-Loop Vertically Bored GHEX
<table>
<thead>
<tr>
<th>Nominal (Fixed) Length</th>
<th>Design Loop Length</th>
</tr>
</thead>
<tbody>
<tr>
<td>Generally acceptable for smaller (1 to 16 Ton) GSHP systems where designer is very familiar with local site geology and climate.</td>
<td>Generally required for larger GSHP systems, where loads must be more precisely met in order to eliminate unnecessary redundancy or oversizing expense.</td>
</tr>
<tr>
<td>Design/performance enhancements can be made by increasing spacing, pitch, depth, moisture, loops, etc.</td>
<td>Soil sampling and analysis or in situ conductivity testing is usually specified.</td>
</tr>
</tbody>
</table>

**Nominal versus Design Pipe Length**

**REMEMBER:** Maximum Performance Benefit...at Minimum Installation Cost
With 4,100 vertical bore holes at 400 ft. deep each, Ball State University will soon have the largest ground source heat pump system in the country.

More than 40 buildings on the 660-acre Ball State University campus will be converted to geothermal heating and cooling. It is slated for completion in 2013.

Closed-Loop Vertically Bored GHEX
Even a rock bored system can pay off…
After grouting, U-bend pipes are pressure tested and header trench is excavated...

Casings are cut & removed from trench (orphan spreader clip visible in exploded view).

Closed-Loop Vertically Bored GHEX
...but metal casings required down to rock!
Proper grouting provides sanitary protection of water supply, preserves hydraulic characteristics of artesian formations...and improves heat transfer!

Pressure tremie grouting is required for each bore hole using appropriate grout mixing and pump equipment.

Cross section of cement grouted U-Bend bore without spreader clips.
In rock formations neat cement is mixed with fine sand or other additive to enhance grout.
In soil formations use a high-solids “Western” Bentonite mixture—NOT Mud Drilling Grout.

**Bentonite Grout-1**
- A high solids bentonite grout usually consists of sodium bentonite that is premixed with selected additives.
  - Not calcium but sodium so it can swell (potential to swell to more than 15 times its dry volume)
  - “Premixed material” is mixed with water and pumped into the borehole through a tremie pipe
  - Pump grout immediately after mixing since the viscosity increases with hydration time

**Enhanced Grout-1 Bentonite-Additive Mixtures**
- Most success in increasing thermal conductivity was found when utilizing fine sands:
  - Common limestone
  - Masonry
  - Quartzite (silica sands and quartzite produce approximately the same effect)

**Bentonite Grout-2**
- A falling head permeameter is used to determine if the mixture has permeability at or below $1 \times 10^{-7}$ cm/s
- Saturated or relatively moist borehole produces a seal over an indefinite period
- In a dry borehole, grout shrinking takes place and loses its seal and contact

**Enhanced Grout-2 Bentonite-Additive Mixtures**
- Addition of granular material greatly reduced
  - the linear shrinkage potential of the mixture
  - making the grouting material more stable in situations where drying could occur
- Definite limitation to amount of additive that could be mixed with bentonite, as a workable mixture, and maintain a permeability of less than $1 \times 10^{-7}$ cm/s
Optional Configurations for 3 Ton Vertically Bored Closed-Loop GHEX

- One loop circuit per Ton of nominal GSHP capacity (this will vary by design!)
- 200’ X ¾” U-Bend HDPE pipe/bore hole
- Thermally enhanced high-solids Western Bentonite or Portland Cement Grout
- You must use Propylene Glycol in MN
- In MN...bore holes must be fully cased in any unconsolidated overburden over drilled rock!

Figure 5.1. Vertically-bored “3-ton” Closed-Loop GHEX.
### Long Term Thermal Effects of GHEX on Deep Soil & Rock Formations

- **B** = bore hole spacing
- **H** = bore hole depth
- **g** = temp resistance
- **t**<sub>1</sub> = time constant
  - \(= \frac{H^2}{9a}\)
- **a** = diffusivity
  - \(= \frac{k}{(r \cdot c)}\)
- **a** = 0.6 ft\(^2\)/day
- **H** = 200 ft
Adjusted Bore Length for Current 5T System
(Also applies to Horizontally Drilled GHEX Designs!)
ADVANTAGES:

• Requires least amount of site surface area
• Minimal excavation required (header only)
• Versatility in pipe configuration & placement (may utilize small yards, parking lots, etc.)
• Higher, more stable deep earth temperatures (Duluth Complex 46°F to 48°F)
**DISADVANTAGES:**

- Cost is generally higher compared to other GHEX loop options
- Might require adding expensive steel casings in unconsolidated overburden when boring into rock formations (must use in Minnesota!)
- Propylene Glycol is usually specified instead of better performing Methanol (Minnesota!)
- Drilling equipment access can be limited
- Drilling fluid & cuttings can make a huge mess
- There is often more science involved in grouting than drilling—local contractors may be limited
Horizontal Directional Drilling

HDD Machine Drilling
150 Ton GHEX for a Minnesota School
Horizontal Directional Drilling

- HDD Machine Pulls Drill Stem As Pipe Reels Off Far End
- U-Bend & Tremie Attached to Reamer
- Drill Bit Emerging from Borehole
- Pipe Tails In Header Trench
- U-bend Pipe End
- Tremie Pulled Back to Grout Borehole
Horizontal Directional Drilling
Horizontal Directional Drilling

Pulled Pipe Tails
Ready for Header
Excavation
Horizontal Directional Drilling
Good Grout Conductivity = 1.2
5 X 263 ft. Horz. Bore Length

Poor Grout Conductivity = 0.4
5 X 330 ft. Horz. Bore Length

The Importance of Responsible Grouting
(Big Cost Difference—about 70’ per Bore Length!)
Optimum Grout Conductivity?

- By increasing “design” grout conductivity, required pipe and bore lengths will decrease.
- Grout conductivity need not exceed that of the formation (but it is still better to come close).
- Grout (and grout application) costs increase as conductivity and enhancements are increased.
- Cheapest grouts start at about 0.40 Btu/hr/ft °F.
- It has been effectively demonstrated that Grout Conductivity Benefit per Reduced Bore Length Cost drops off at about an “88” (0.88) grout.
HDD loops may be loosely described as “a vertical loop set on its side” (bottom tier limited to 45’ depth)

- One loop circuit per Ton of nominal GSHP capacity (will vary by design!)
- 225’ X 3/4” U-Bend HDPE pipe/bore hole
- Minimum “average” recommended pipe depth & spacing is 15’
- Thermally enhanced high-solids Western Bentonite Grout is highly advised
- Methanol is presently acceptable; Propylene Glycol may soon be required
**ADVANTAGES:**

- Versatility in pipe configuration & placement: possible beneath buildings, parking lots, play fields, trees & landscaped areas, other obstacles
- Tier-level “layering” is possible (from 45’ depth)
- Minimal disturbance to site—excavation can even be limited to small consolidated area using “fan” configuration and “close header”
- Cost generally lower than vertically bored GHEX (may also be competitive with some horizontally trenched applications—but also consider grout!)

**Horizontally Bored GHEX**
**DISADVANTAGES:**

- Limited to unconsolidated (soil) formations
- Required HDD bore lengths and spacing may exceed property dimensions and/or setbacks
- Boulders or other obstructions may hinder boring, damage equipment, or even alter design.
- HDD grouting is currently unregulated and often ignored—or even *purposely* eliminated just to lower cost!
- Coming under closer scrutiny by state health regulators (particularly “slant and plant” drilling)

**Horizontally Bored GHEX**
QUESTIONS?
Horizontally Trenched (or Excavated) GHEX
What is wrong with this picture?
What is wrong with this picture?
Nothing is wrong with this picture!

Selected pipe and trench spacing should not change GSHP design efficiency—just pipe length, excavation footprint...and cost!

Correction Table for Different Trench Spacing

Table 5.24. Soil Resistance ($R_o$) and Trench Spacing Multiplier ($S_m$) – 5-Pipe 1 Laying.

Table 5.25. Soil Resistance ($R_o$) and Trench Spacing Multiplier ($S_m$) – 8-Pipe 1 Laying.
The world’s “first” geothermal heat pump system—probably a single pipe in one long trench...

Eventually modified to conserve space and installation expense...

**Current 5T System**
Single 1 ¼” Pipe Laying  
= 4,721 ft.

Trench = 4,721 ft.

**Current 5T System**
Two 1 ¼” Pipe Standing  
= 6,063 ft.

Trench = 3,032 ft.

Earth Coil Type: Horizontal - Single Layer  
Water Flow: Series  
Typical Pipe Size: 1 1/2 to 2 inches  
Nominal Length: 350 to 500 feet/ton  
Burial Depth: 4 to 6 feet

**FIGURE 4.2: Single-Pipe Horizontal Ground Heat Exchanger**

Earth Coil Type: Horizontal - Two-Layer  
Water Flow: Series  
Typical Pipe Size: 1 1/2 to 2 inches  
Practical Length: 210 to 300 feet of trench/ton  
420 to 600 feet of pipe/ton  
Burial Depth: 4 feet and 6 feet

**FIGURE 4.3: Two-Pipe Horizontal Ground Heat Exchanger**

**How did we ever get the “slinky”?**
Then advanced to multiple parallel circuits using a single common header...

How did we ever get the “slinky”?
How did we ever get the “slinky”?

Then advanced to multiple parallel circuits using a single common header...

Until someone figured out yet another way to conserve time, space, and resources!

Current 5T System
Four 1” Pipe Standing
= 9,491 ft.

Two Trenches @ 1,186 ft.

Earth Coil Type: Horizontal – Four-Layer
Water Flow: Parallel
Typical Pipe Size: Parallel loops 3/4 to 1 inch; headers 1 1/2 to 2 inches
Burial Depth: 6 feet, 12-inch spacing

FIGURE 4.4: Four-Pipe Horizontal Ground Heat Exchanger

(But not without new challenges—clay slurry shown being applied to fill voids inside trench)

How did we ever get the “slinky”?
"Laying Slinky" Configurations for Colder Climates

Closer Spacing = longer pipe requirement, smaller consolidated excavation footprint (500 ft²/T)

Wider Spacing = shorter pipe requirement, expanded excavation footprint (1,000 ft²/T)
Pipe coils are rolled out individually down entire length of trench...and back.

Example of excavated 8 Ton “Laying Racetrack” configuration (850 ft²/T)

“Laying Racetrack” Configuration is still an option.
Standard or “Racetrack” Configuration for Cold Climate GHEX Applications

- One loop circuit per Ton of nominal GSHP capacity (as sized to peak heating load!)
- 800’ X ¾” HDPE pipe per coil
- Return loops are spaced 12” apart (minimum)
- Excavation Footprint ≈ 2’ X 400’ per coil @ approx. 8’ depth
• One loop circuit per Ton of nominal GSHP capacity (as sized to peak heating load!)

• 800’ X ¾” HDPE pipe per slinky coil

• Each coil is 36” diameter and overlapped every 18” (equivalent to 8 pipes laying)

• Slinky coil = 95’

• Excavation Footprint ≈ 5’ X 100’ per coil @ approx. 8’ depth

Typical Slinky GHEX Configuration for Cold Climate Geothermal Applications
How Moisture Improves Thermal Conductivity of Soil

At complete dryness the heat flow passes mainly through the grains, but has to bridge the air-filled gaps between the grains around their contact points.

At very low water contents the soil particles are covered by thin absorbed water layers.

The thickness of these layers increases with increasing water content. At a certain Xw liquid rings start to form around the contact points between the grains; they show a curved air-water interface.

From this point on the thermal conductivity increases rapidly with increasing Xw, until the rings almost completely fill the original gap. When Xw increases still further the complete pores are filled with water, up to saturation. This is reflected by the slower increase of k with Xw.
Soaker Systems

A storm water or gray water drain tile piping system can be laid-in on top of a horizontal GHEX to enhance moisture in dry soils.

(This approach may also be considered where driveways or paved parking lots are planned. Generally such systems are also buried much deeper.)
ADVANTAGES:

- Generally costs less than either vertical or horizontal drilling options
- Excavation process remains fairly straightforward—local (even on-site) operators can usually be used
- Seasonal loop recovery tends to be more forgiving close to the surface where sun and rain have influence (esp. “heat only” GSHP systems)
- Often the most practical, as well as economical, option in challenging or unpredictable geology

Horizontally Trenched GHEX
**DISADVANTAGES:**

- Requires the largest area of available space: Total excavation area = entire GHEX footprint (and then some!)
- Arguably the largest impact with *least* amount of flexibility in loop configuration and placement
- Cannot be placed beneath structures, driveways, septics, parking lots, etc.—with a *few* exceptions
- Other buried services can be affected if crossed
- More vulnerable to damage during installation

Horizontally Trenched GHEX
Pond & Lake Loops
Pond Heat Exchangers combine exceptional GSHP system performance...

With an aesthetic component you just can’t get from a conventional earth loop.

Pond Heat Exchangers
Offer an attractive alternative to buried loops
Pond Heat Exchangers combine exceptional GSHP system performance...

With an aesthetic component you just can’t get from a conventional earth loop.

Pond Heat Exchangers
Offer an attractive alternative to buried loops
Conventional 18” pitch slinkies are zip-tied together and covered with chain link mesh... 
This 8 Ton GSHP application operates consistently at 36°F EWT throughout winter.

Floated Geo-mat Application
PHEX is constructed on shore, floated & sunk.
Hybrid Pond Heat Exchangers

Hybrid Pond/GHEX for potentially low water

Conventional slinky GHEX can often be laid directly in pond basin (at standard 8’ depth)... Cover it with 2’ of clean gravel before flooding and it may be more forgiving during drought.
Many Other PHEX Design Options

More condensed arrays...require loose spacing

Mountain melt water basin in Steamboat Springs, CO, used for Geo’...and trophy trout!

This 55 Ton application utilizes 4 X 10 loops using 500’ coils of 1" HDPE—33 Tons added later.
Pond Heat Exchangers
Cages combine durability with on-site mobility
The 700,000 sq. ft. building complex of Great River Medical Center in Burlington, IA, is served by 800 heat pumps and a 1,500 Ton loop system with 82 miles of pipe in a 15 acre lake!

ADVANTAGES:

- Can cost more than a conventional buried loop if pond must be excavated—but less if it is already existing!
- Better expected GSHP performance & efficiency: loop temperatures between 33°F and 40°F
- Minimal disturbance to site—excavation generally limited to a single S/R header trench to house
- Aesthetic value

Pond & Lake Loops
DISADVANTAGES:

- Potential for loop freeze-up and failure due to drop in pond level/volume (ways to minimize)
- Exposures—pipe needs protection from boat anchors, fish hooks...and beavers!
- Permits—wetland permit may be required for excavated pond; state water use permit is always required for “lake energy exchanger” placement and/or removal within any MN/WI public water
- No dependable, well established design criteria for pond loops—nominal PHEX configurations are most typical
Open Loop (Pump-and-Dump) Systems

Instead of a buried closed loop GHEX, domestic water from house is simply pumped through the GSHP coil then discharged somewhere outside. (Pictured is a simple shallow drain tile in sand.)
Open Loop (Pump-and-Dump) Systems
Leaving water temperature is tuned to 37°F.

An open loop flow control assembly typically includes, filter strainer, P/T ports, back-flush bibs, solenoid valve, and flow meter. (Pictured is an assembly that is “presuperheater” capable.)
Open Loop systems allow for the same amount of flexibility in GSHP design.

- Lowest safe entering water temperature (EWT) limit = 43°F
- Flow requirements scale upward from 4 to 14 GPM (approx. 3 to 8 Ton GSHP) for residential sizing
- LWT is tuned to 37°F regardless of EWT (determines ultimate system flow rate)
- Up to 10K GPD & 1M GPY allowed without permit in MN
How much is a “lot” of water?

Calculate number of gallons in 1” rainfall on 1 Acre of land:

43,560 sq.ft./Acre

144 sq.in./sq.ft **BUT** 1,728 cu.in./sq.ft.

43,560 X 1,728 = 75,271,680 cu.in./Acre

0.00432900433 gals./cu.in.

75,271,680 X 0.0043290 = 325,851.1 gals.

325,851 gallons fall on 1 Acre of land for every 1” of rainfall.

On a controlled open loop, a 5 Ton cold climate GSHP discharges approximately twice that amount (650,000) gallons in one year.
Open Loop Reinjection Well Options

Where surface discharge opportunities are limited.
Coaxial “Standing Column” Reinjection Wells
Limited to rock formations—Must be precisely engineered
ADVANTAGES:

- Pump-and-Dump design, using existing domestic well, is least expensive loop option available
- Requires minimal disturbance to site—excavation generally limited to single discharge pipe trench
- Higher expected GSHP performance & efficiency: loop temperatures generally fall between 43°F and 48°F in Duluth Complex
- Heat pump sizing can often be scaled back by a nominal Ton—making many forced-air retrofits much easier
- Installation is frequently “plug and play”

Open Loops
DISADVANTAGES:

- Higher domestic water usage can potentially affect aquifer
- At the mercy of the well—water temperature and recovery rate must remain sufficient and stable
- Water quality can also be a factor—routine back-flushing of the GSHP water coil is generally recommended
- Metered city water can be cost prohibitive
- Site discharge opportunities may be limited (no septic or sanitary sewers)
- Reinjection wells are inherently risky in lower temperature formations like Duluth Complex—they are also starting to present other concerns, particularly relating to well water contamination.

Open Loops
QUESTIONS?
RESOURCES:

- Minnesota Geothermal Heat Pump Association
  www.MNGHPA.org
- Wisconsin Geothermal Association
  www.wisgeo.org
- International Ground Source Heat Pump Association
  www.igshpa.okstate.edu
- GeoExchange
  www.GeoExchange.org
- Association of Energy Engineers
  www.aeecenter.org