Designing Borefields with Angled Drilling

Moderator: Dave Hermantin / *Brightcore Energy*

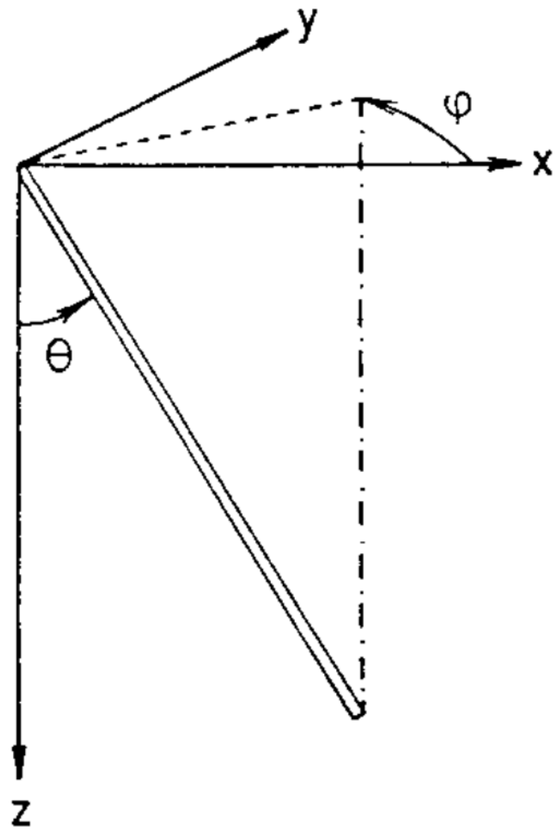
Speakers: Göran Hellström / *Brightcore Energy*
Jefferey Spitler / *Oklahoma State University*
Stan Reitsma / *Geosource Energy*
Dmitry Kuravskiy / *Celsius Energy*

Designing Borefields with Angled Drilling Historical Perspective

Speakers: Göran Hellström/ Brightcore Energy

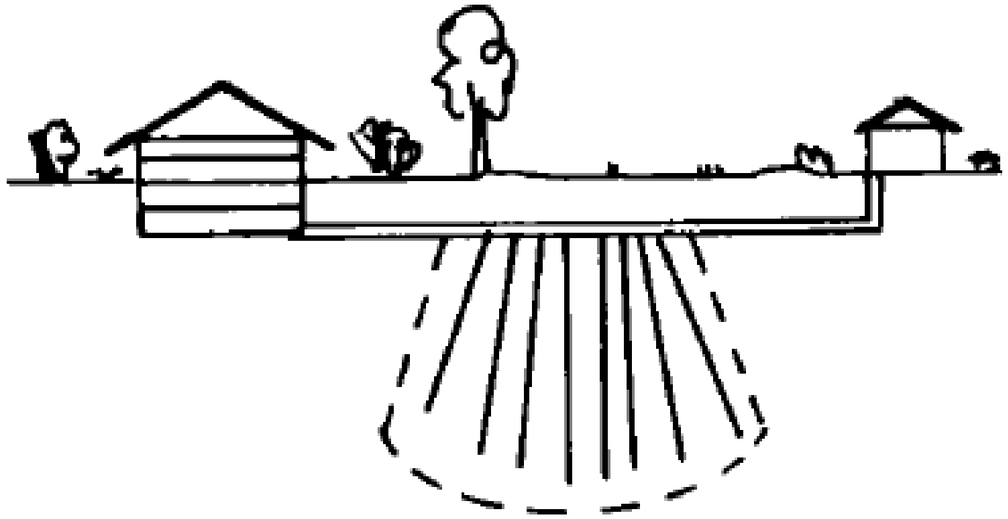
Brightcore
BUILDING ENERGY PERFORMANCE™

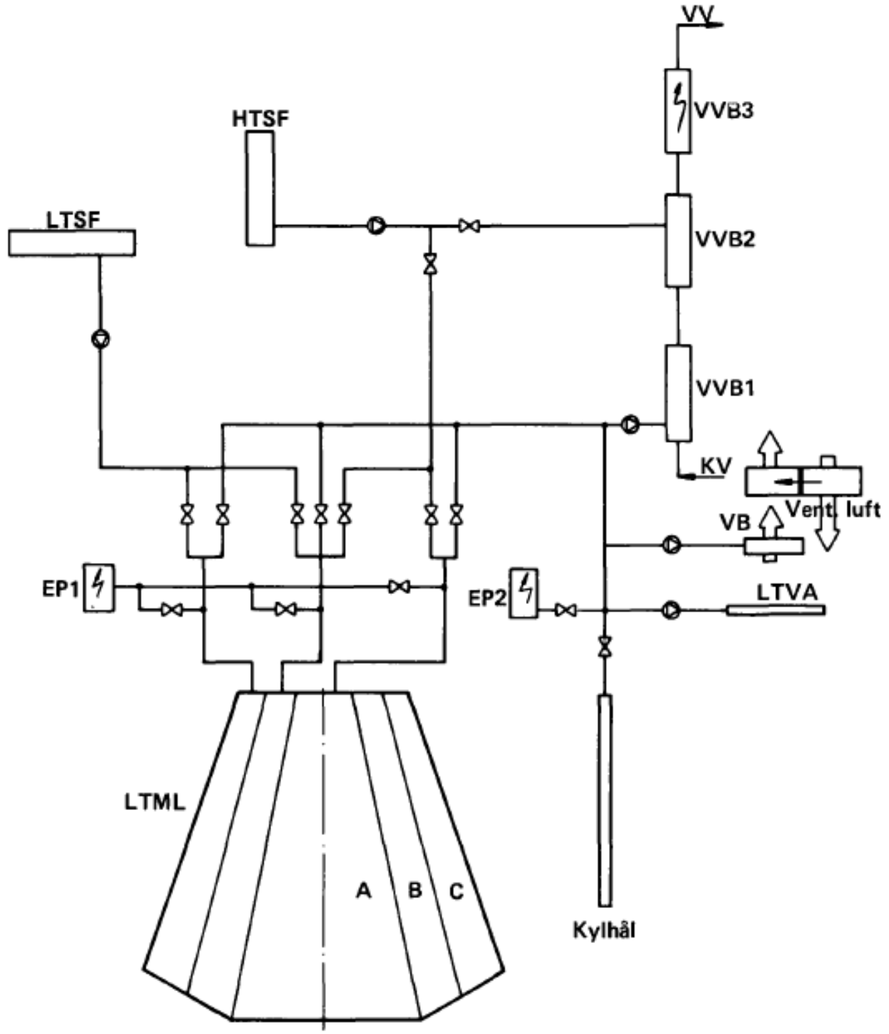
Inclined boreholes – Brief history and examples



Göran Hellström
Brightcoreenergy

1977 Sigtuna, Sweden

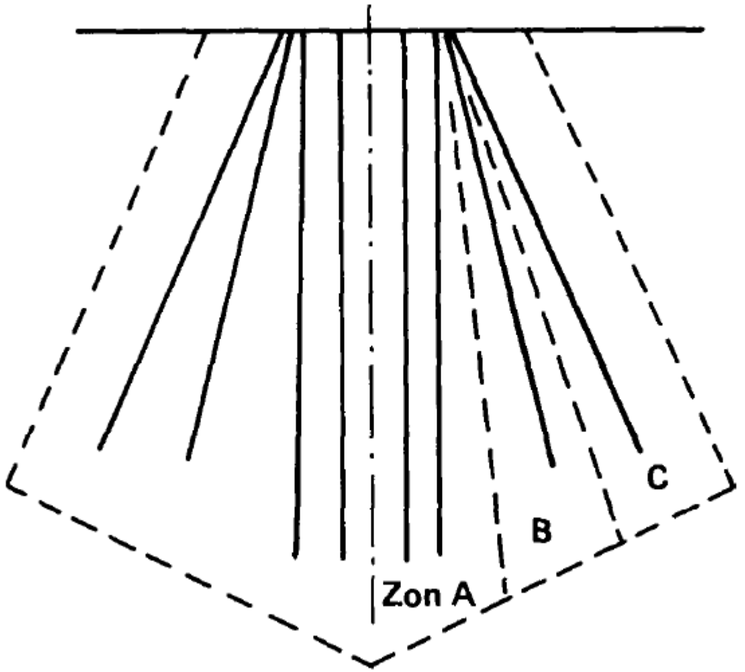


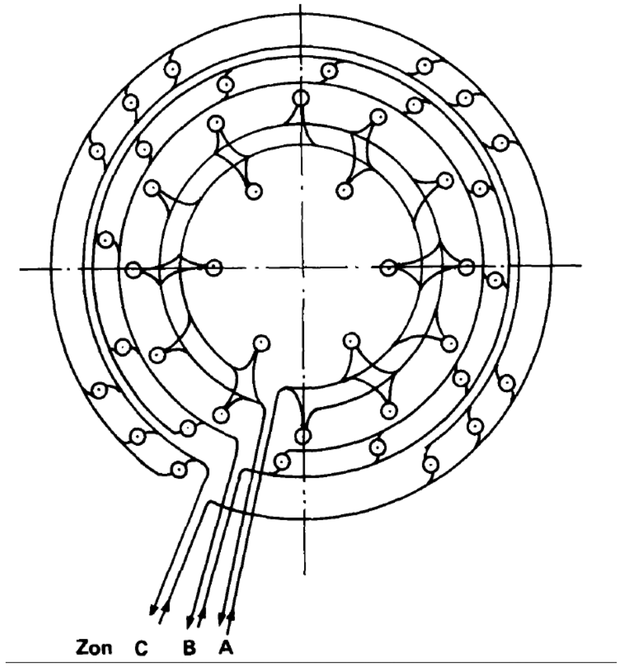


The first multiple borehole (BTES) installation in the world.
Seasonal storage of solar heat.
BTES annual temperature variation 77 °F - 95 °F.

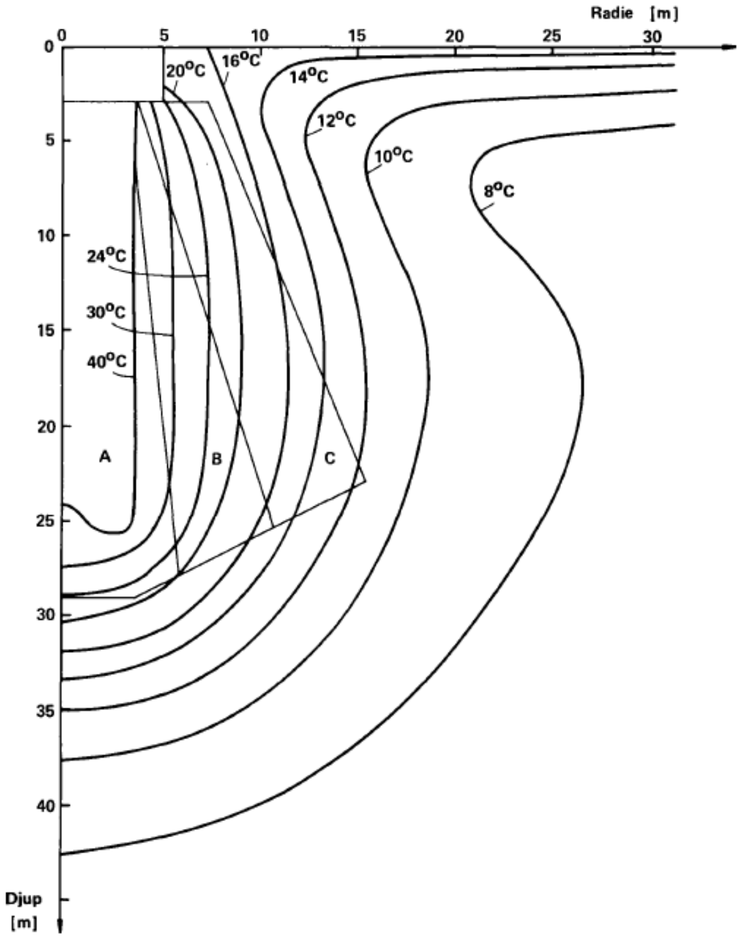
Boreholes drilled November, 1977 – March, 1978

1977 Sigtuna, Sweden



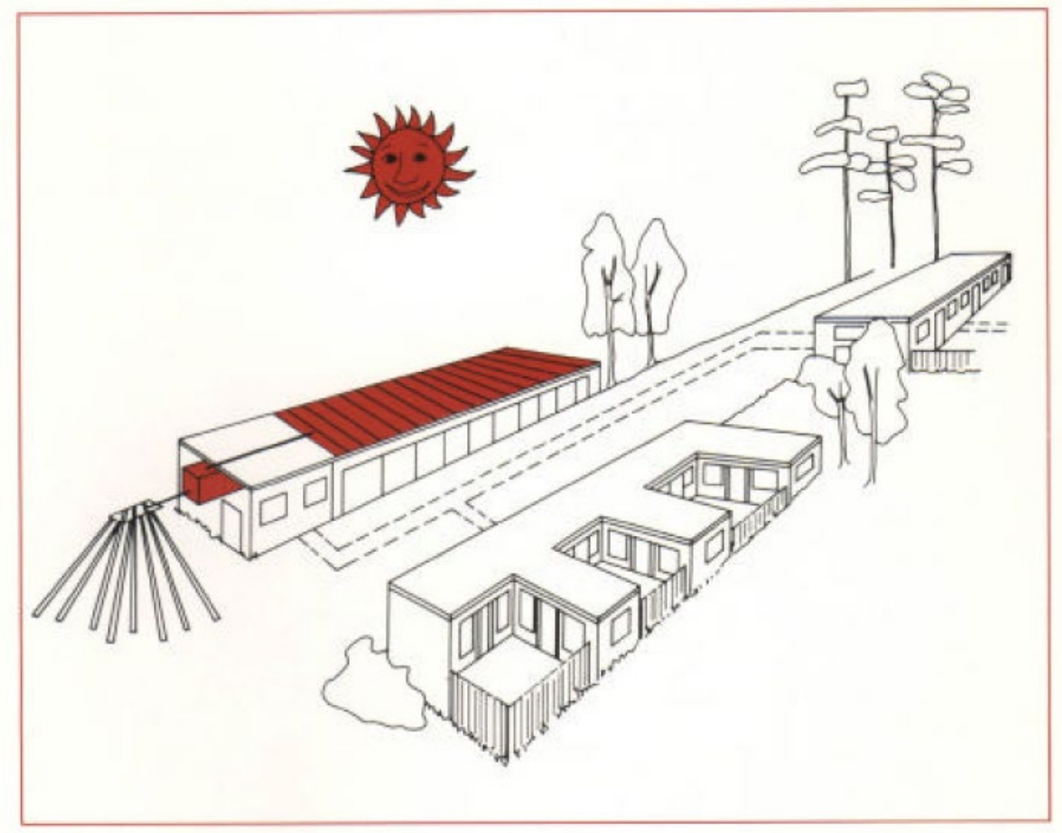


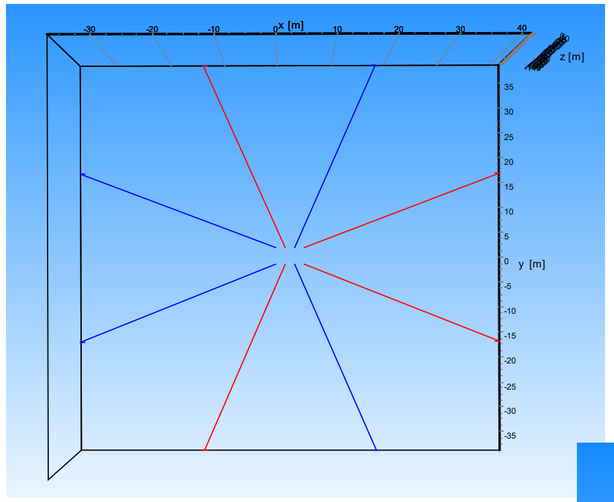
Zone	# boreholes	Depth (ft)	Inclination (°)
A	18	75,5	0
B	12	65,6	13
C	12	65,6	20-21
Total	42		



Ground temperatures after 24 months of charging with 15 kW

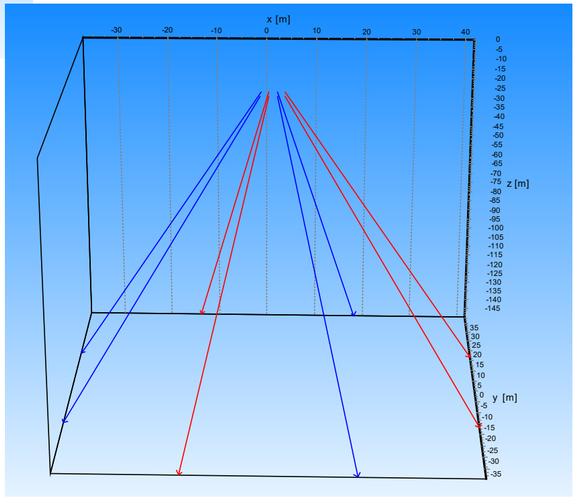
1983 Vattenfall, Stockholm, Sweden





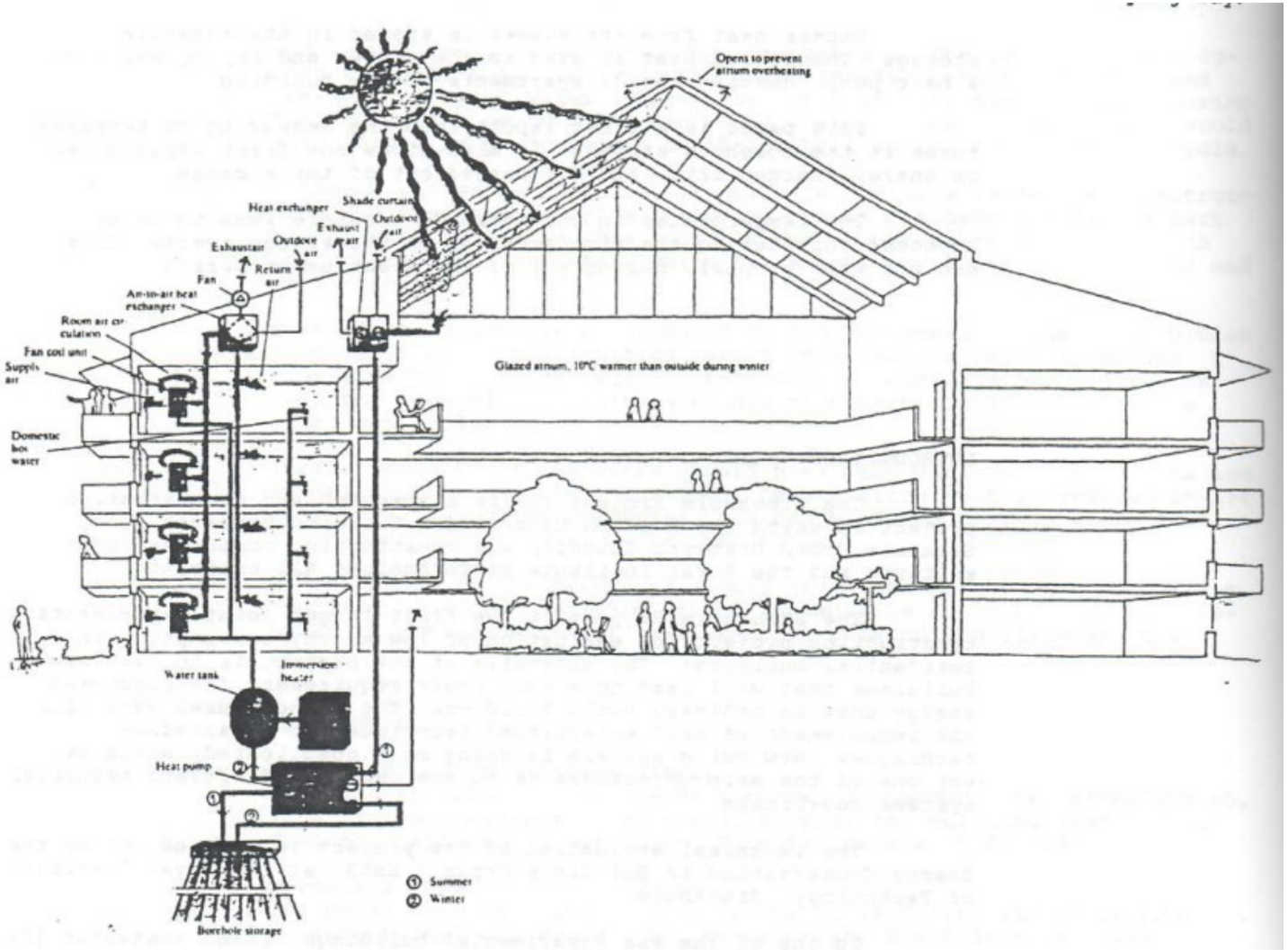
Borehole spacing 5 ft at ground surface

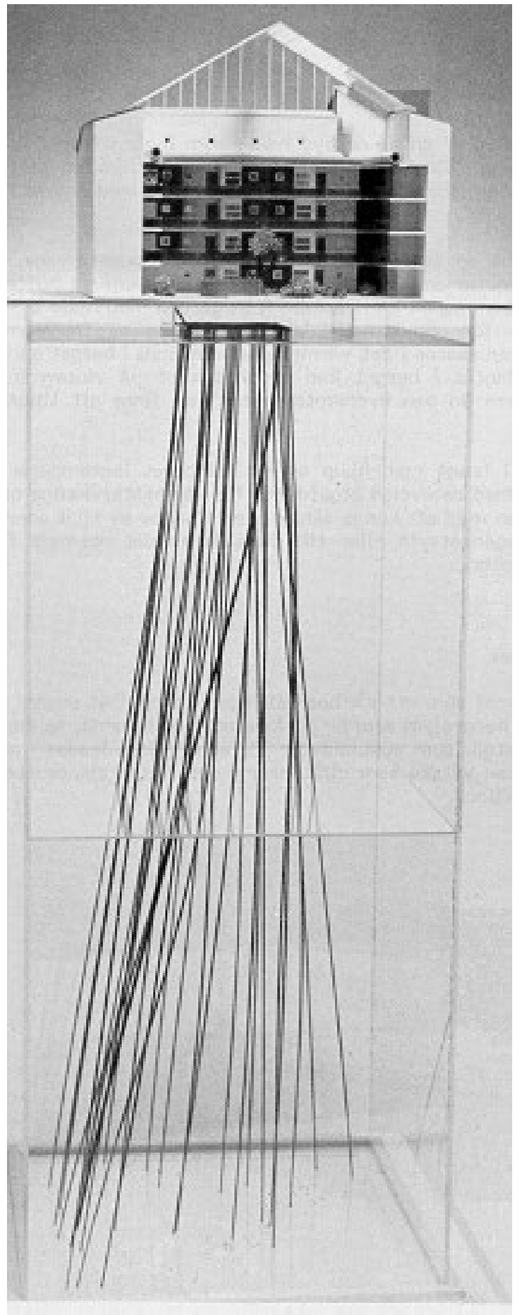
Footprint 15 ft x 5 ft



Standardized market offering with eight boreholes, ”star” (2x4) configuration, borehole depth 500 ft or 600 ft, inclination 15°

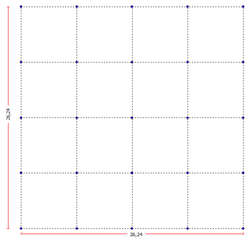
1986 SunCourt, Stockholm





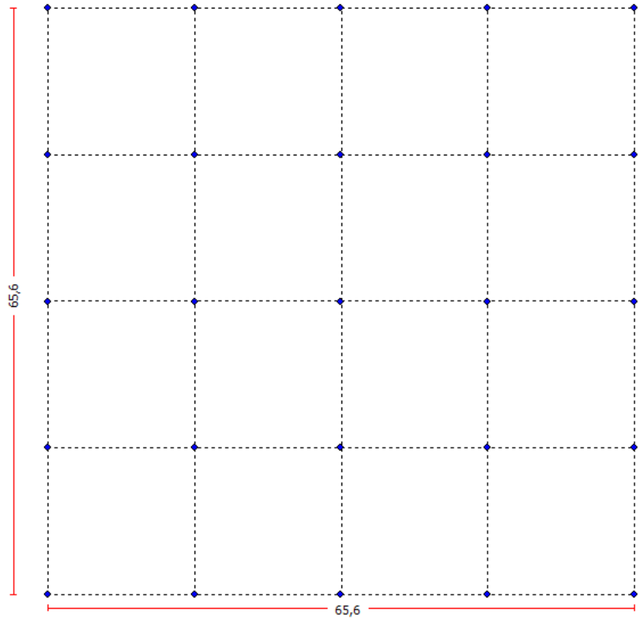
1986 SunCourt, Stockholm

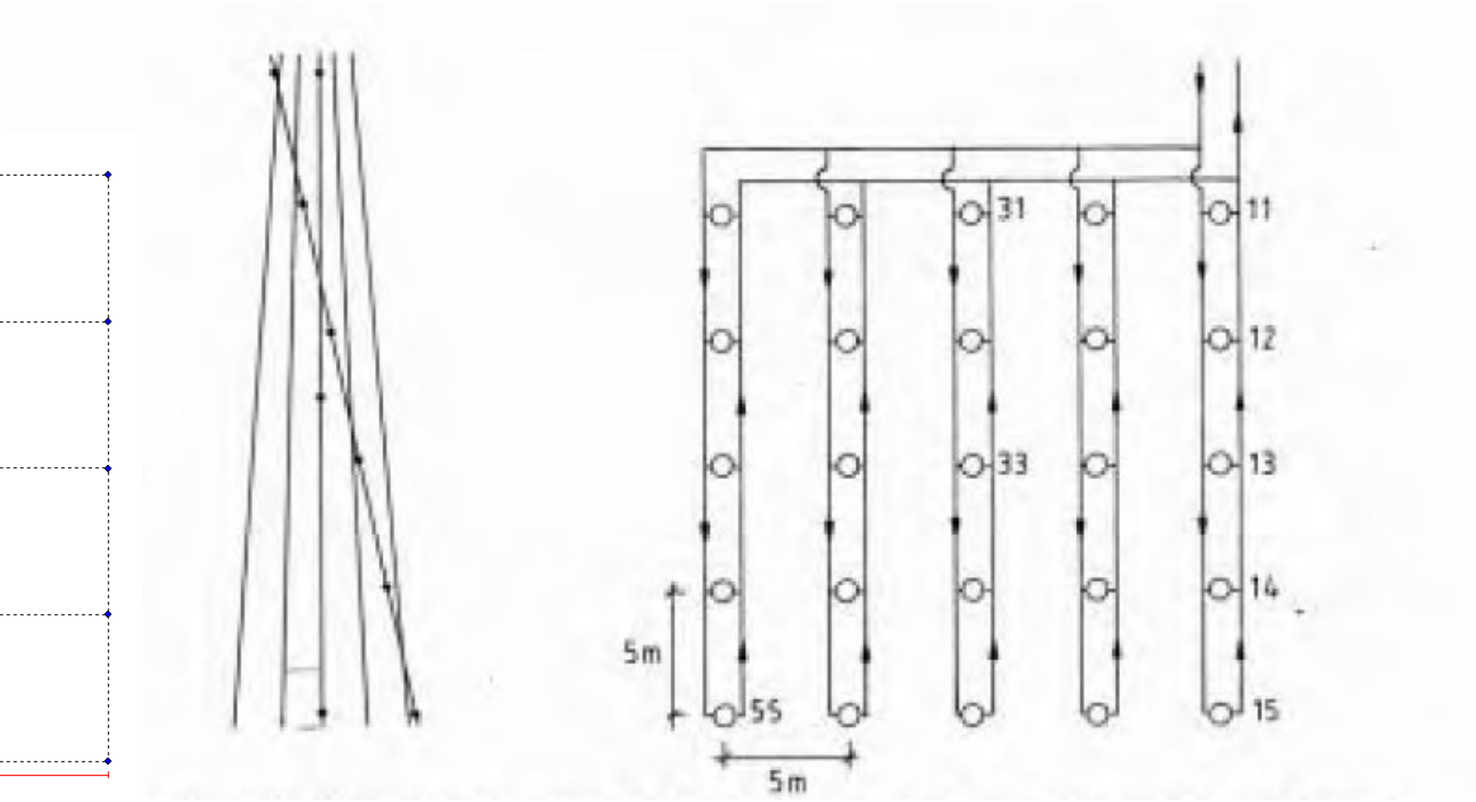
Ground surface
6.5 ft spacing



Footprint 26 ft x 26 ft

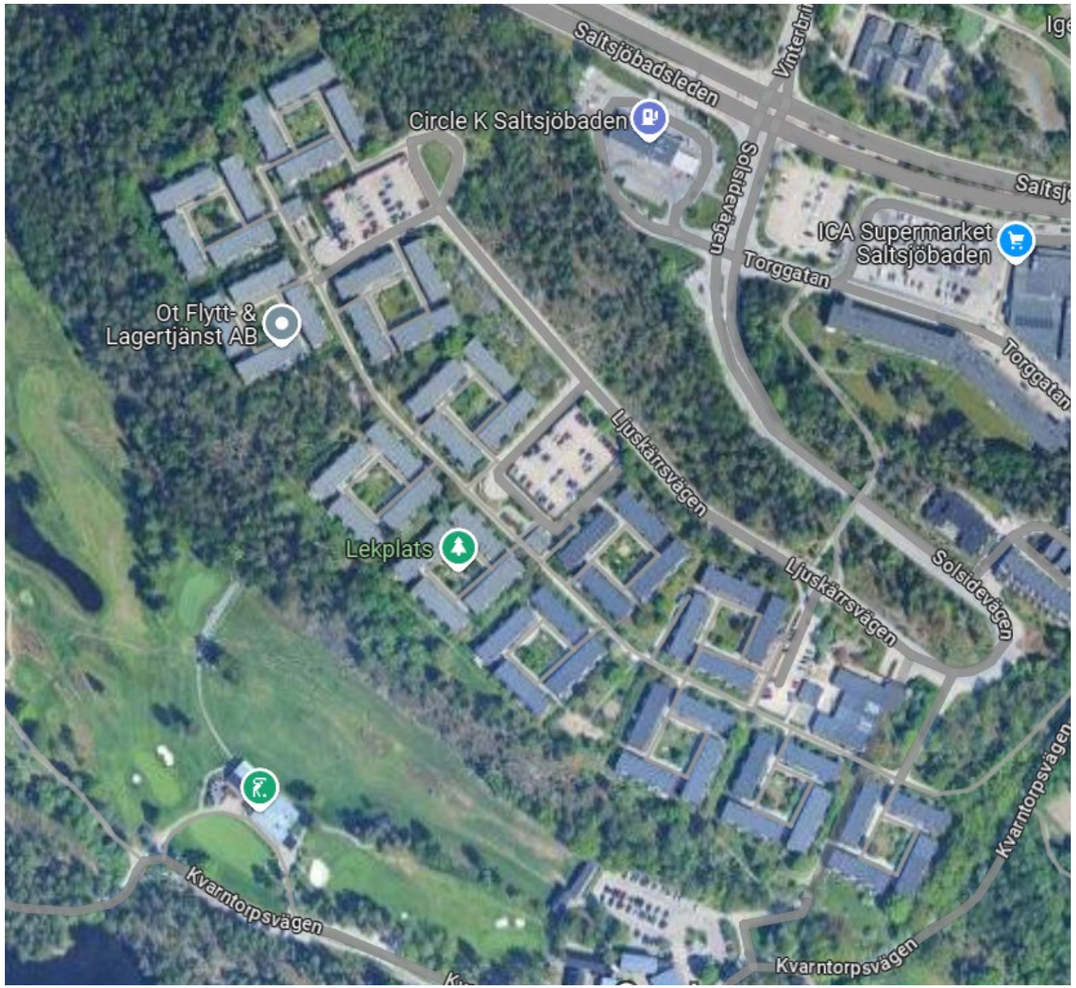
Bottom
16.4 ft spacing

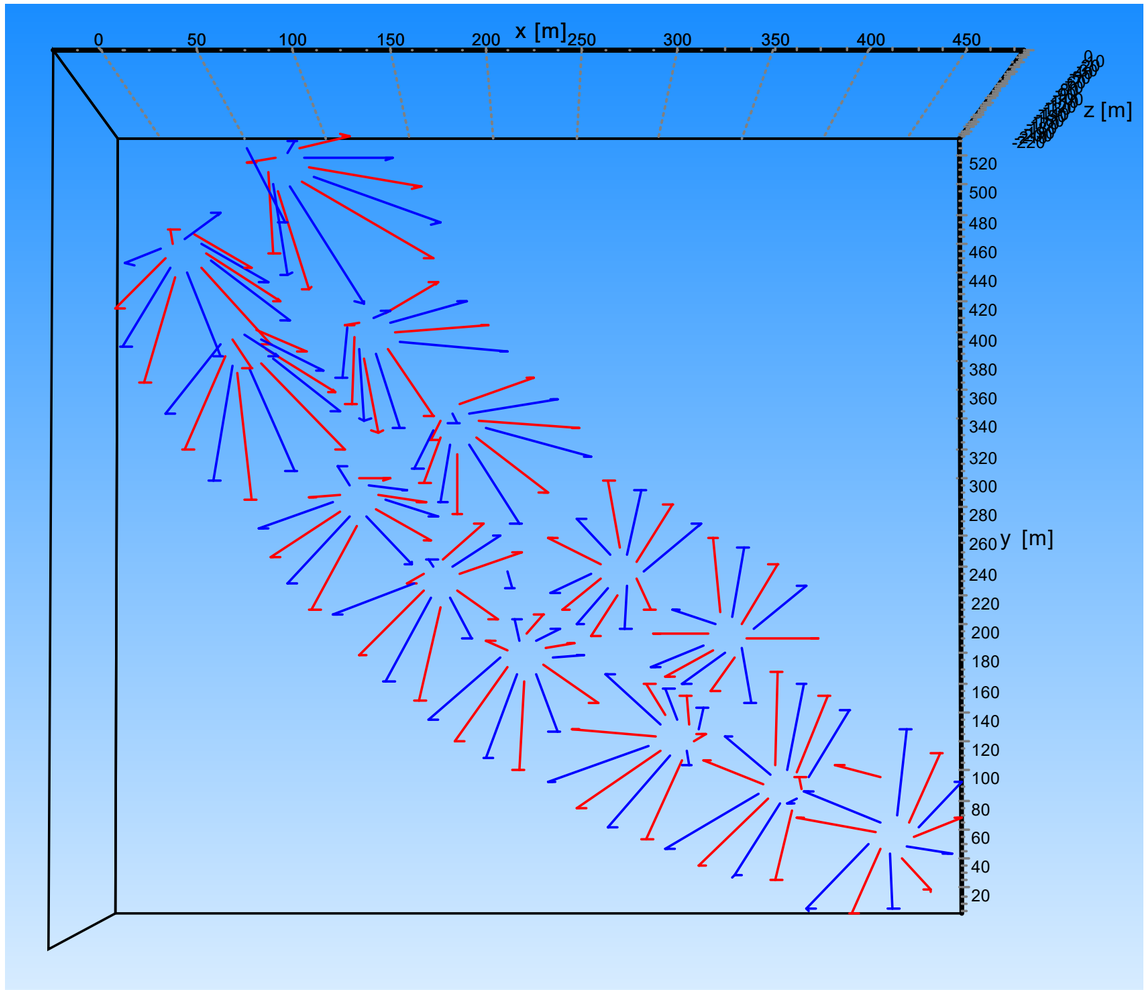




25 boreholes, 260 ft deep. Maximum inclination 8.6°.

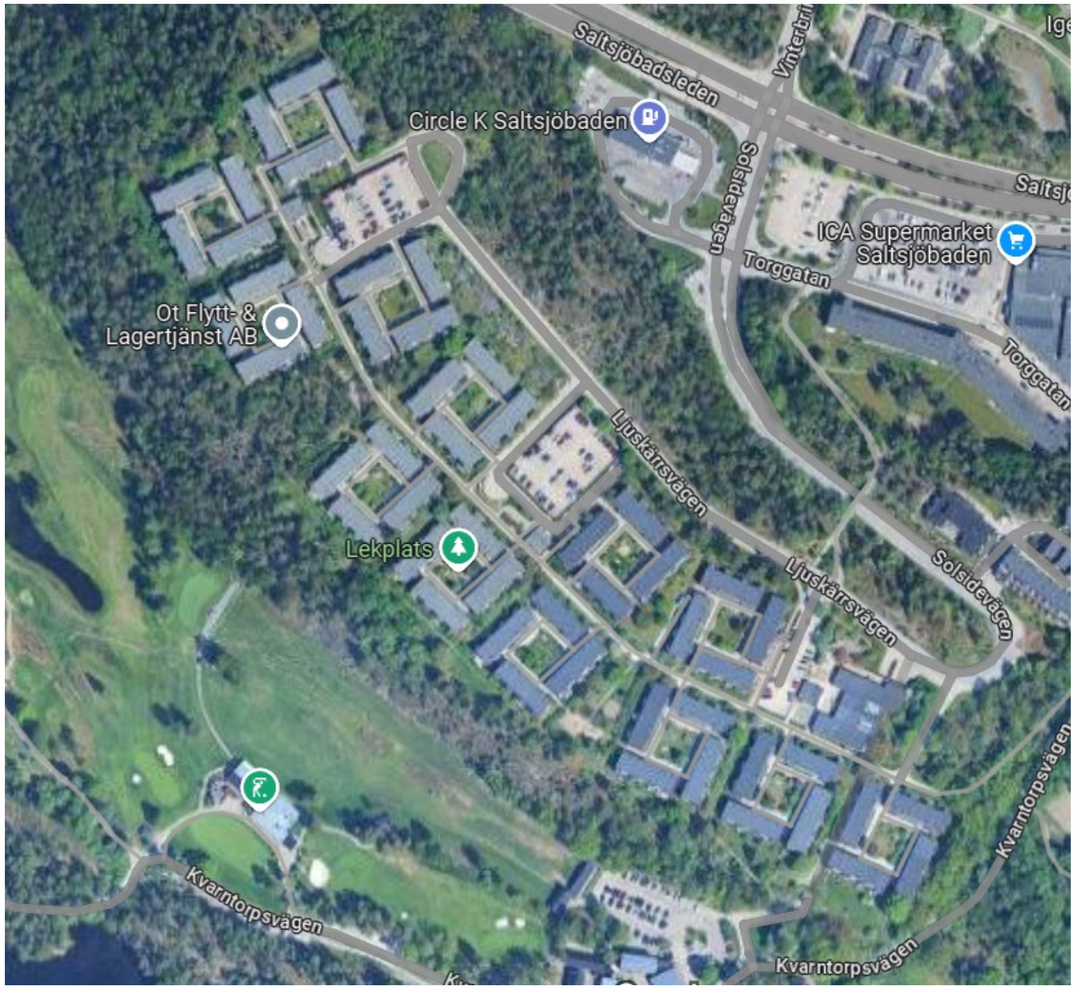
2008 Ljuskärrsberget, Stockholm, Sweden

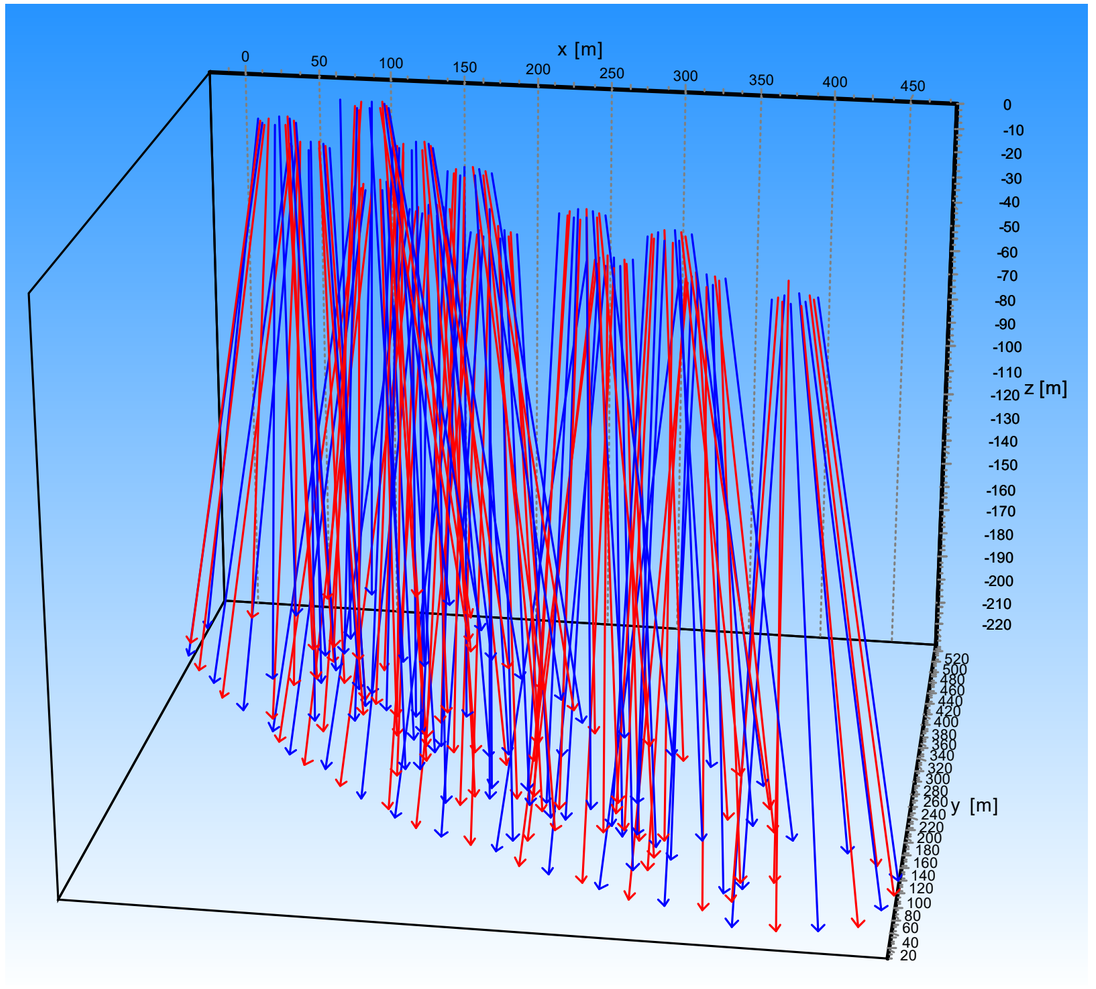




13 groups of houses, 13-14 boreholes each, total of 156 boreholes, 750 ft deep, inclination 15°

2008 Ljuskärrsberget, Stockholm, Sweden





13 groups of houses, 13-14 boreholes each, total of 156 boreholes, 750 ft deep, inclination 15°

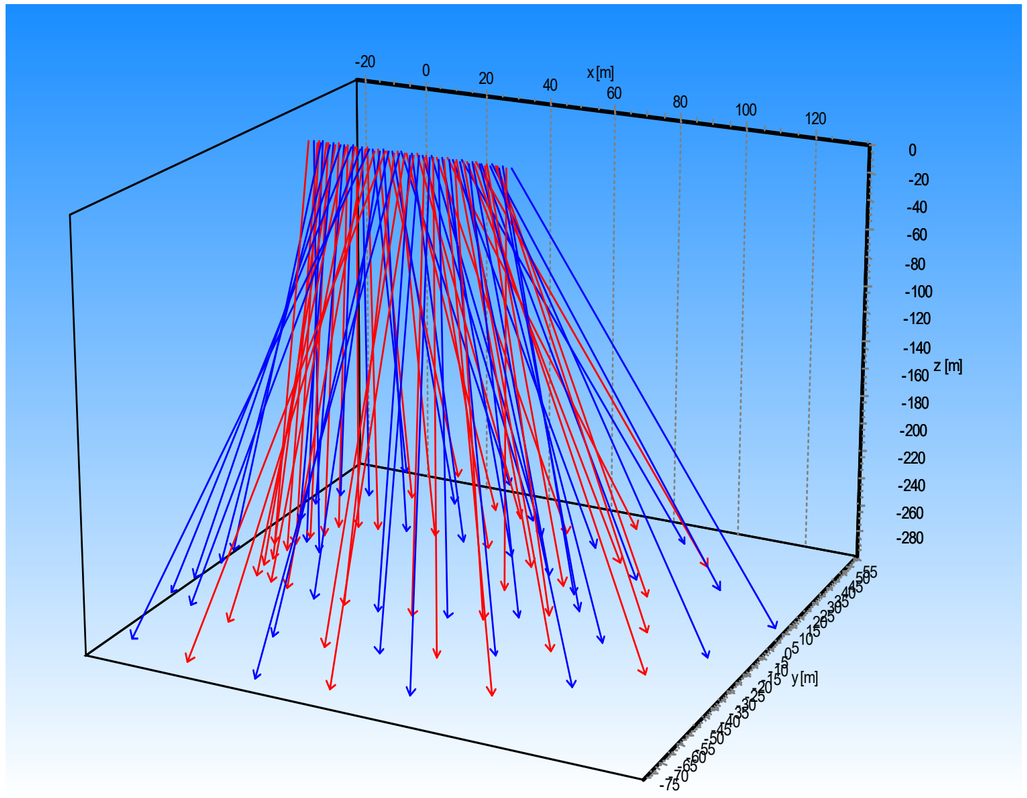
2014 Fredhäll dataserver/Campus Konradsberg

FREDHÄLL TELESTATION
- Free cooling of dataserver 1,2 MW (continuous)

CAMPUS KONRADSBERG
- Heating with heat pump 5000 MWh/year

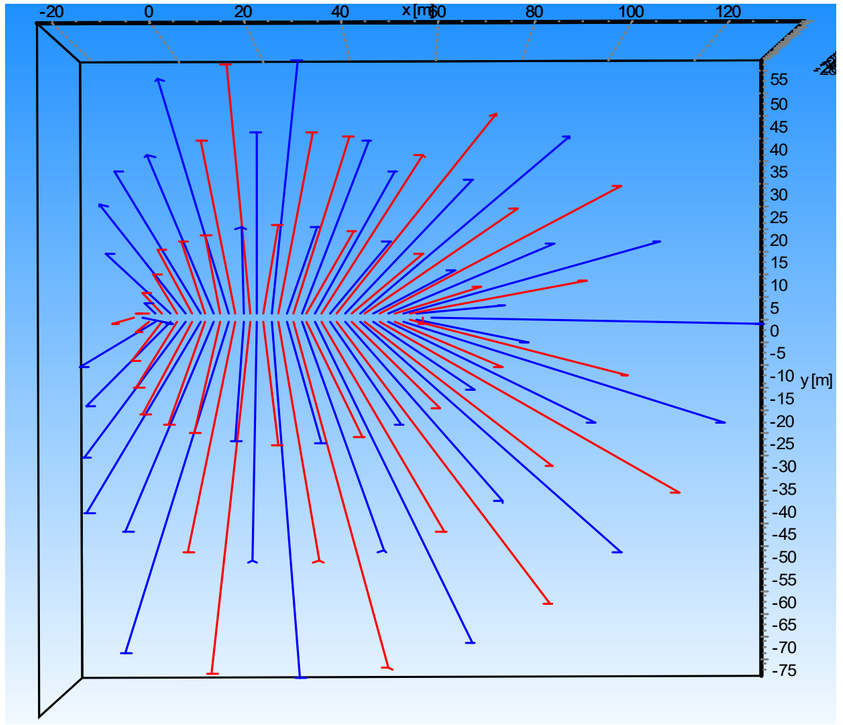
Common BTES
- 82 boreholes x 1000 ft

2014 Fredhäll dataserver/Campus Konradsberg

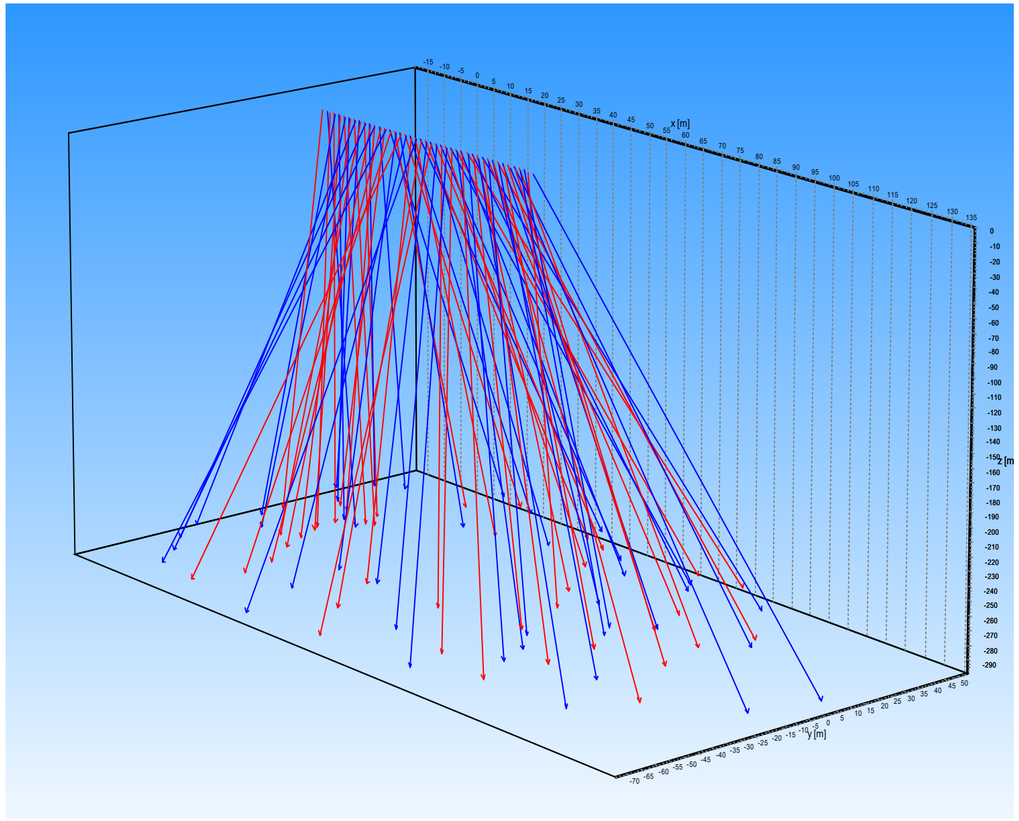


82 boreholes
1000 ft

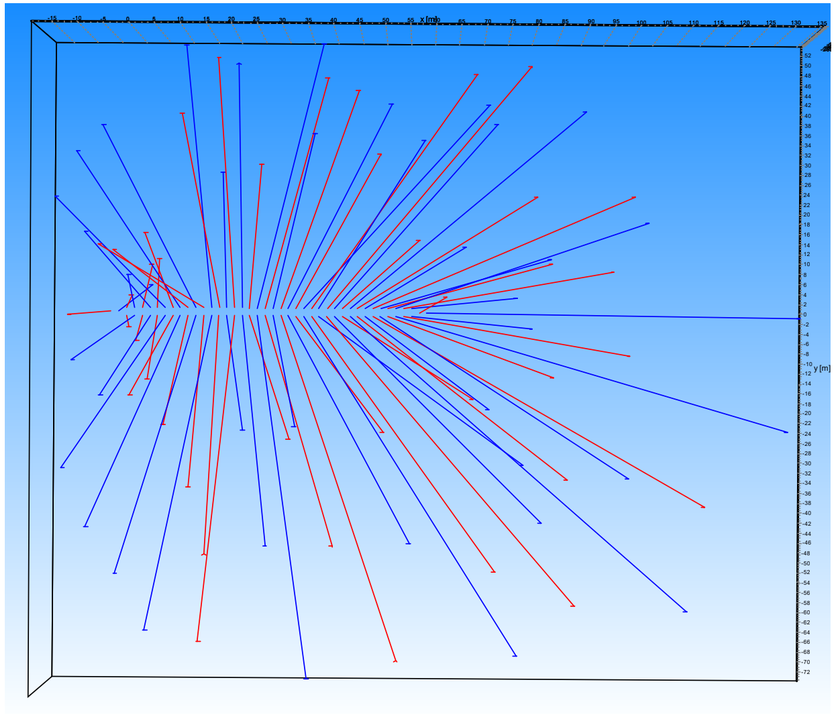
Borehole configuration layout as planned



2014 Fredhäll dataserver/Campus Konradsberg



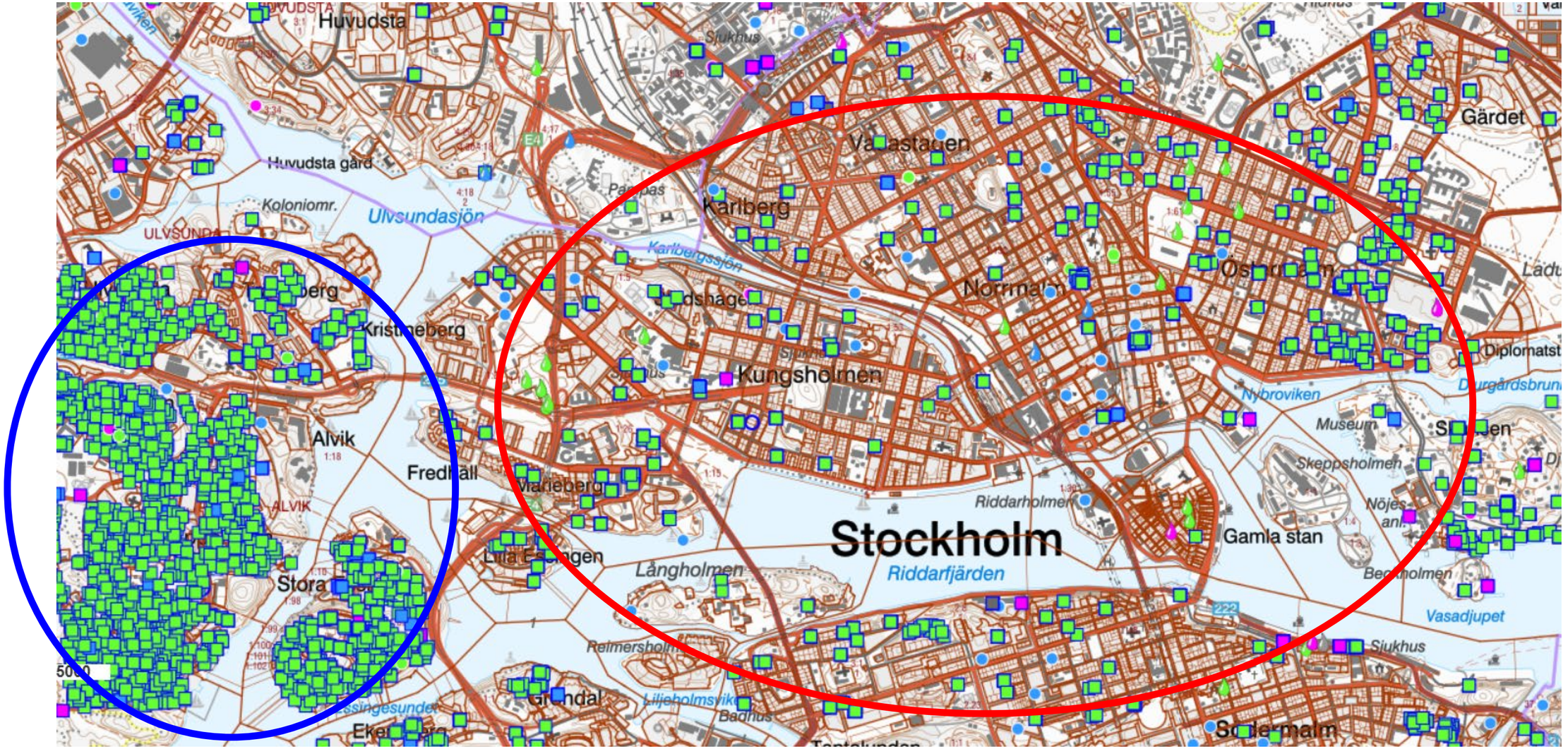
Borehole configuration as measured



82 boreholes
1000 ft depth
Average deviation at target depth 28 ft (2,8 %)

Geoenergy in city centre

Stockholm City Council – Inclined boreholes fully approved concept

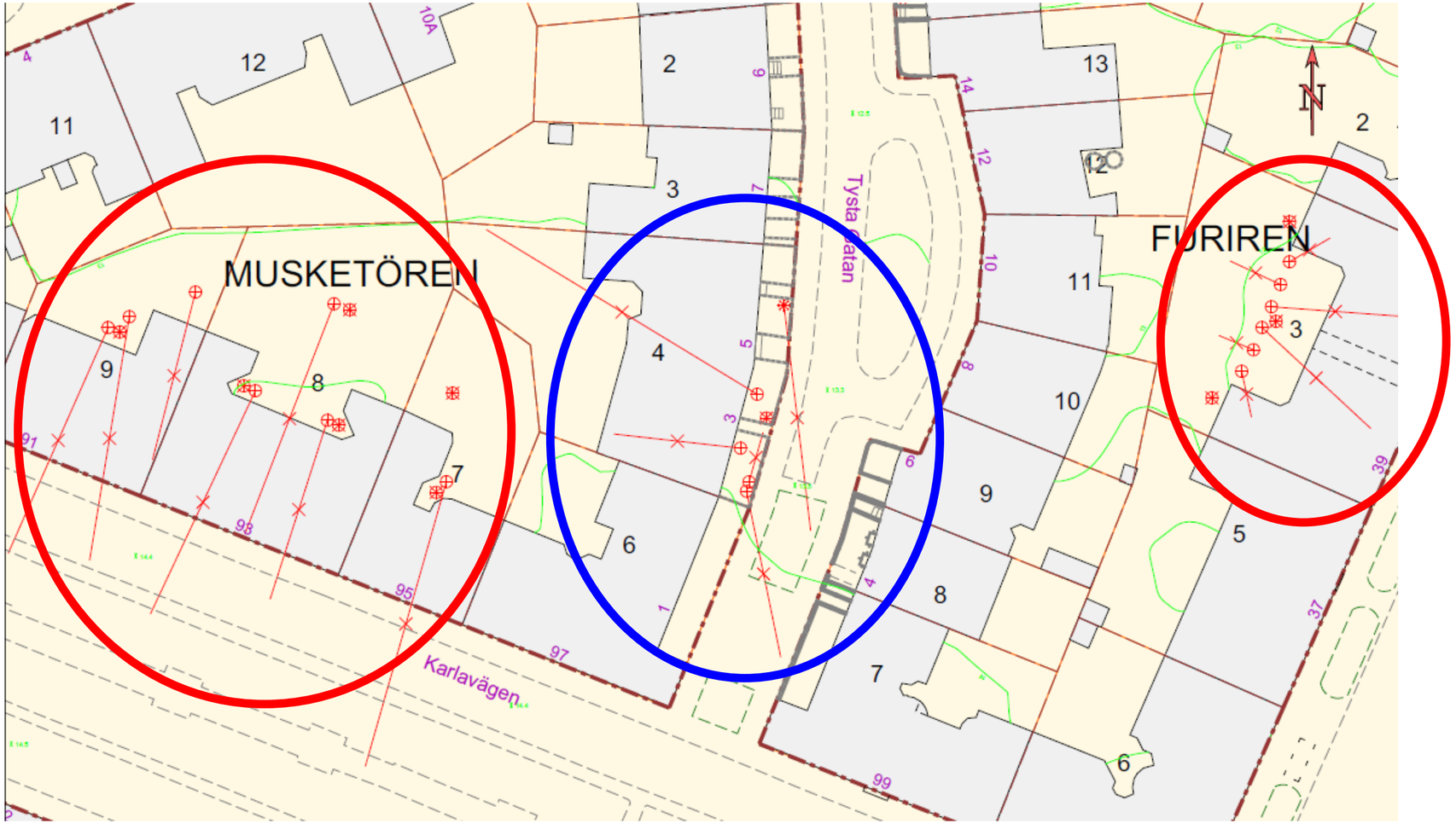


Single-family houses

Apartment and office buildings

Geoenergy in city centre

Stockholm City Council – Inclined boreholes fully approved concept



Drilling on inner court

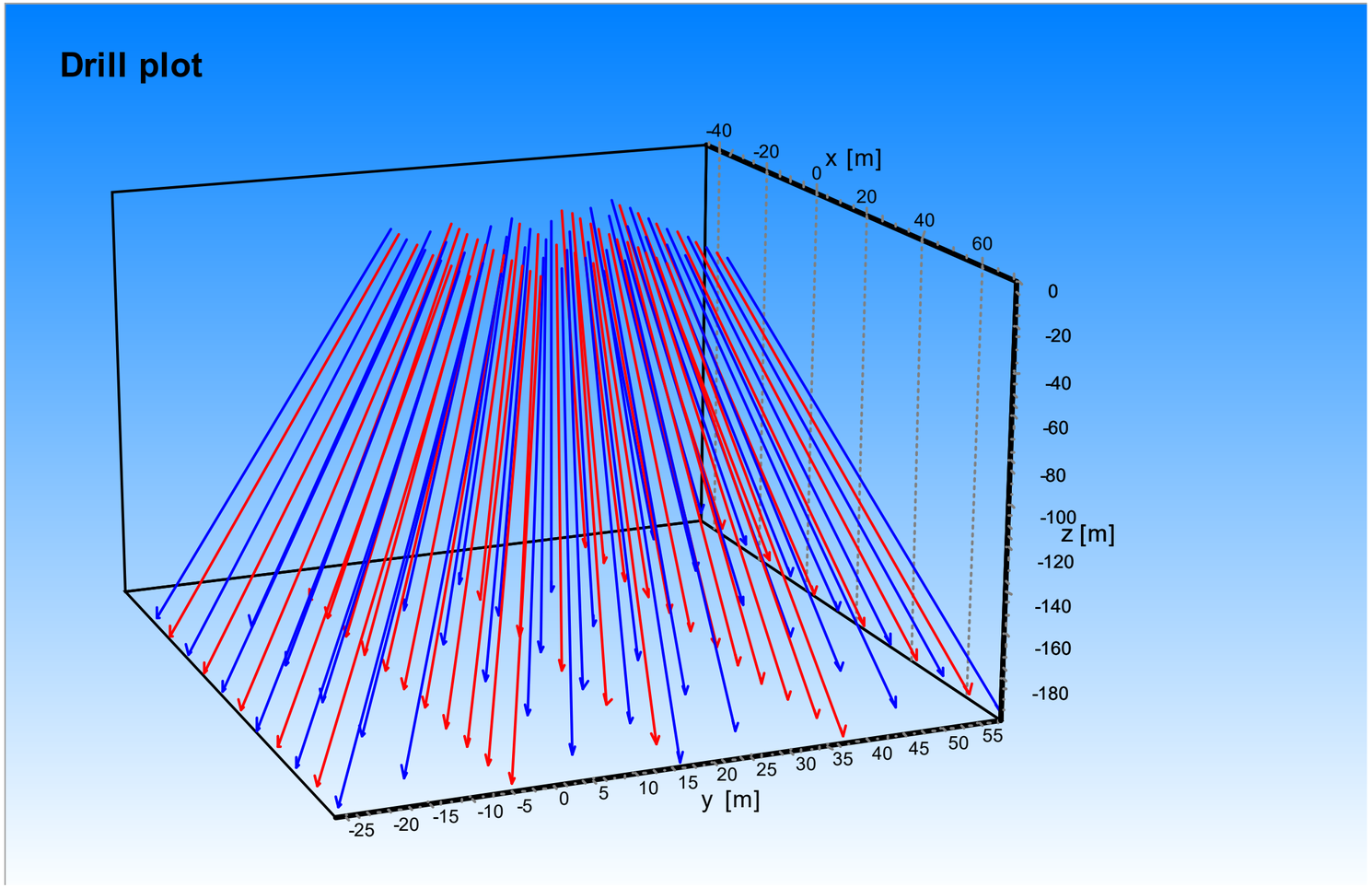
Drilling from the street

Also possible to drill from garages

About 2/3 of all boreholes are inclined

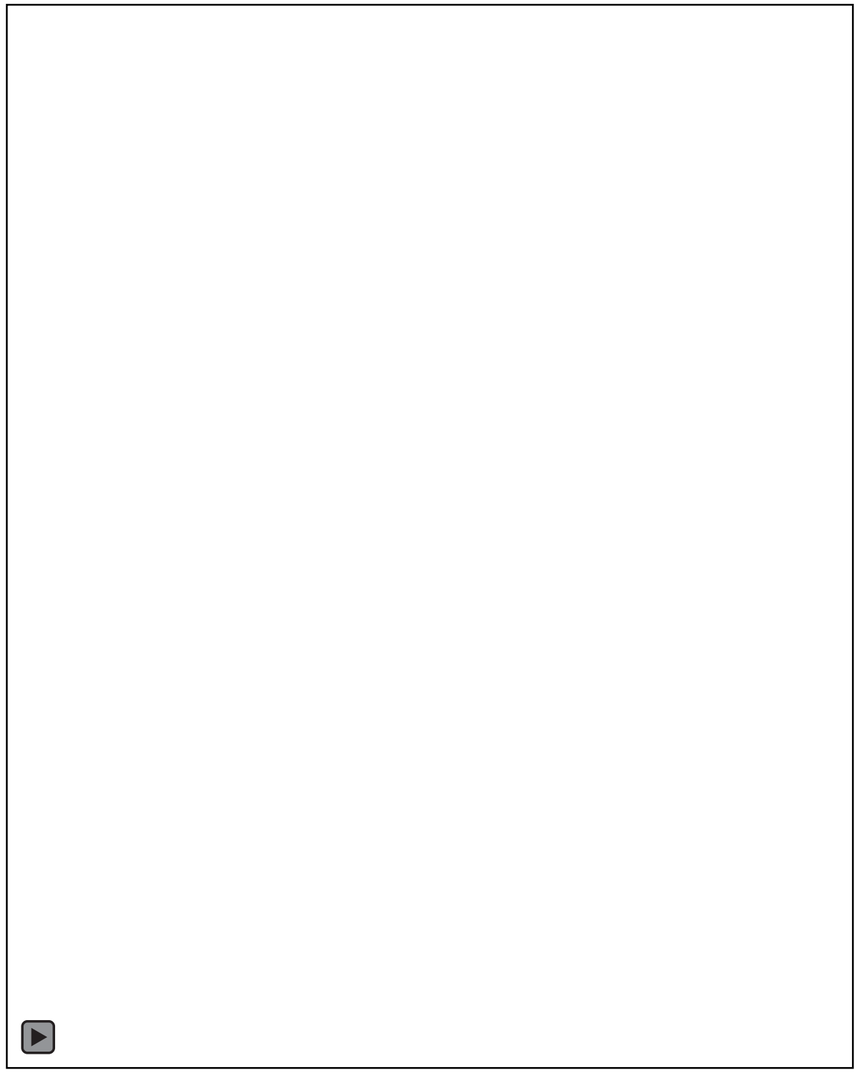
Inclined boreholes in order to reach larger ground volume

2018 Frölunda torg, Gothenburg, Sweden

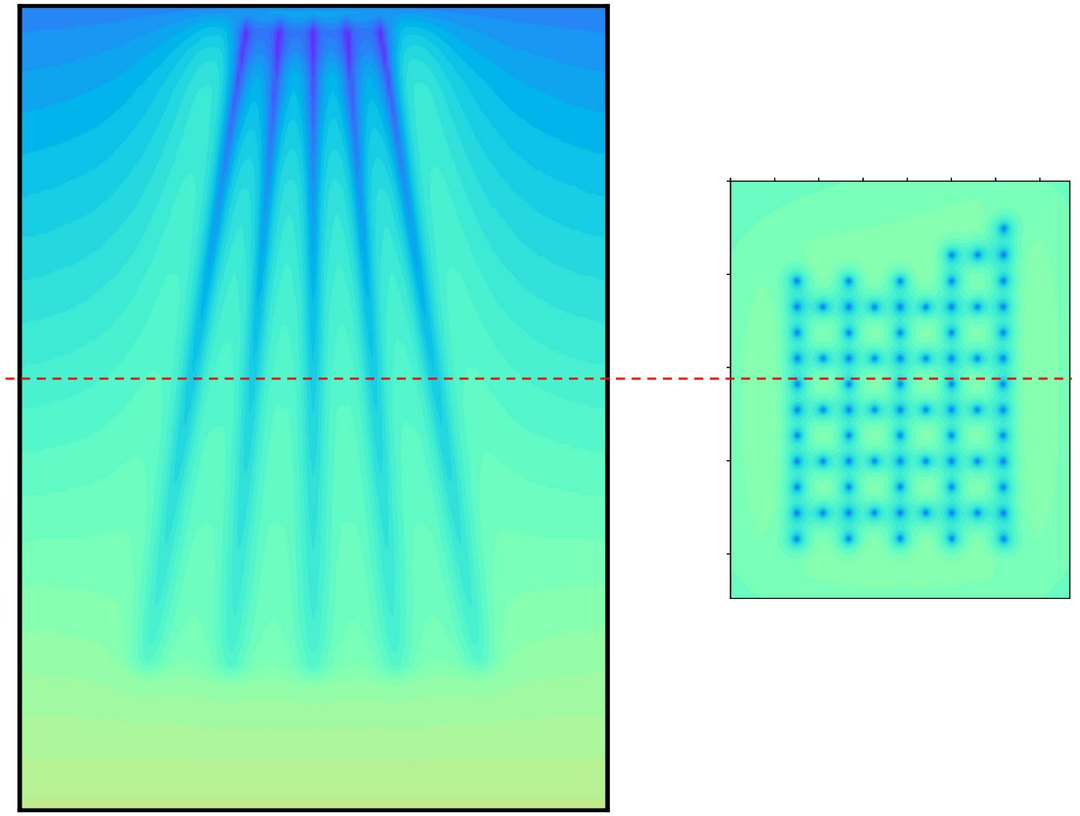


80 boreholes drilled from an old bowling alley under a shopping mall
Borehole depth 655 ft, maximum inclination 14°

2018 Frölunda torg, Gothenburg, Sweden



Five year animation of balanced system



Vertical

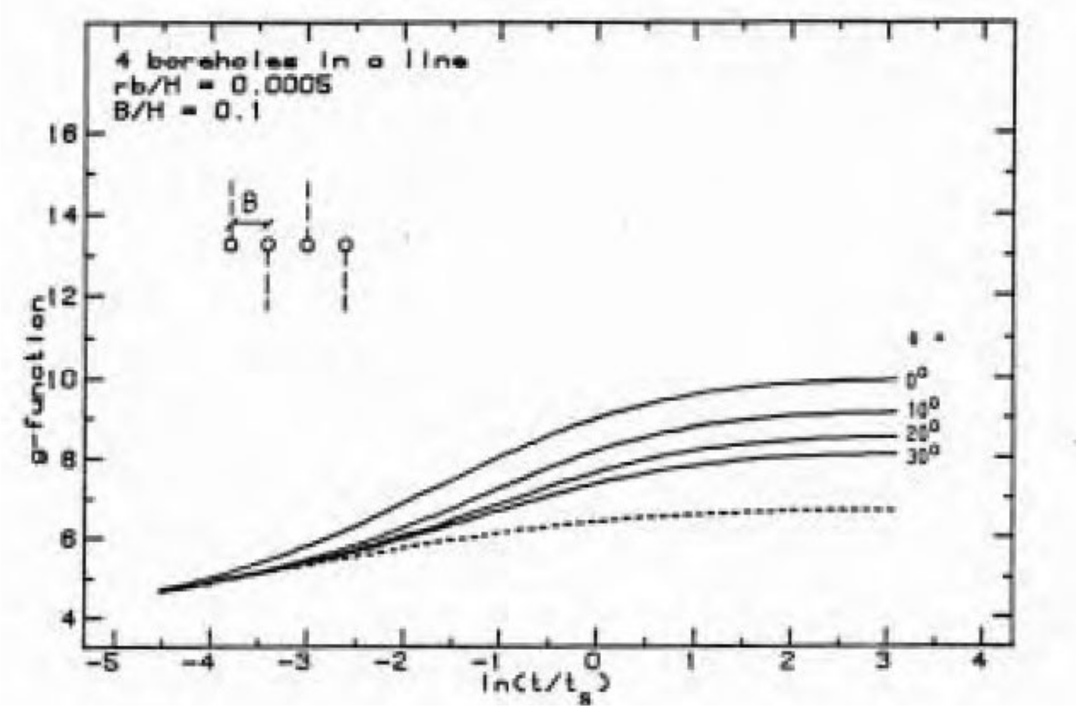
Horizontal mid-depth

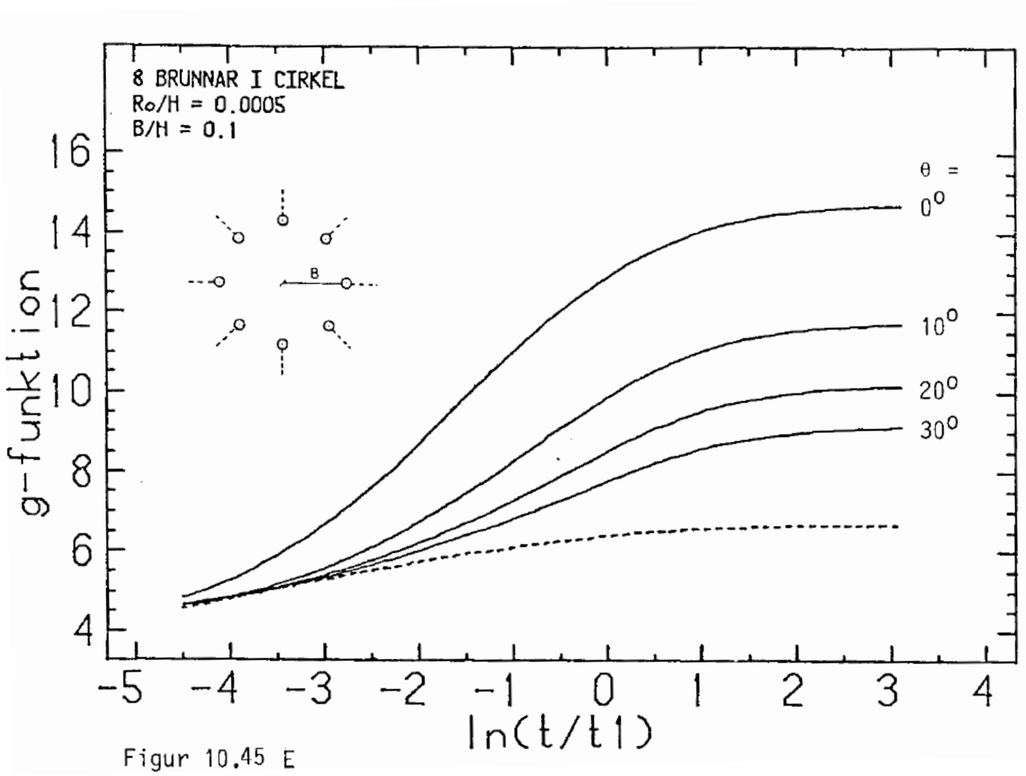
Winter peak ground temperatures

Theoretical studies

- 1985 Eskilson Claesson
- 1987 Eskilson
- 2006 Cui et al
- 2009 Marcotte Pasquier
- 2011 Lamarche
- 2012 Johansson et al
- 2013 Gupta Suni
- 2015 Zhao et al
- 2017 Lazzarotto Björck
- 2024 Dean Lightstone

Early design tools





Figur 10.45 E

1987 Eskilson presented design tools for 2 to 9 boreholes based on g-functions

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Summary

Advantages of inclined boreholes

- Reduce footprint of borehole configuration
- Increase flexibility of borehole locations

- Increase borehole spacing to reduce thermal influence
- Increase thermally active ground volume

Designing angled borehole ground heat exchangers with GLHEPRO

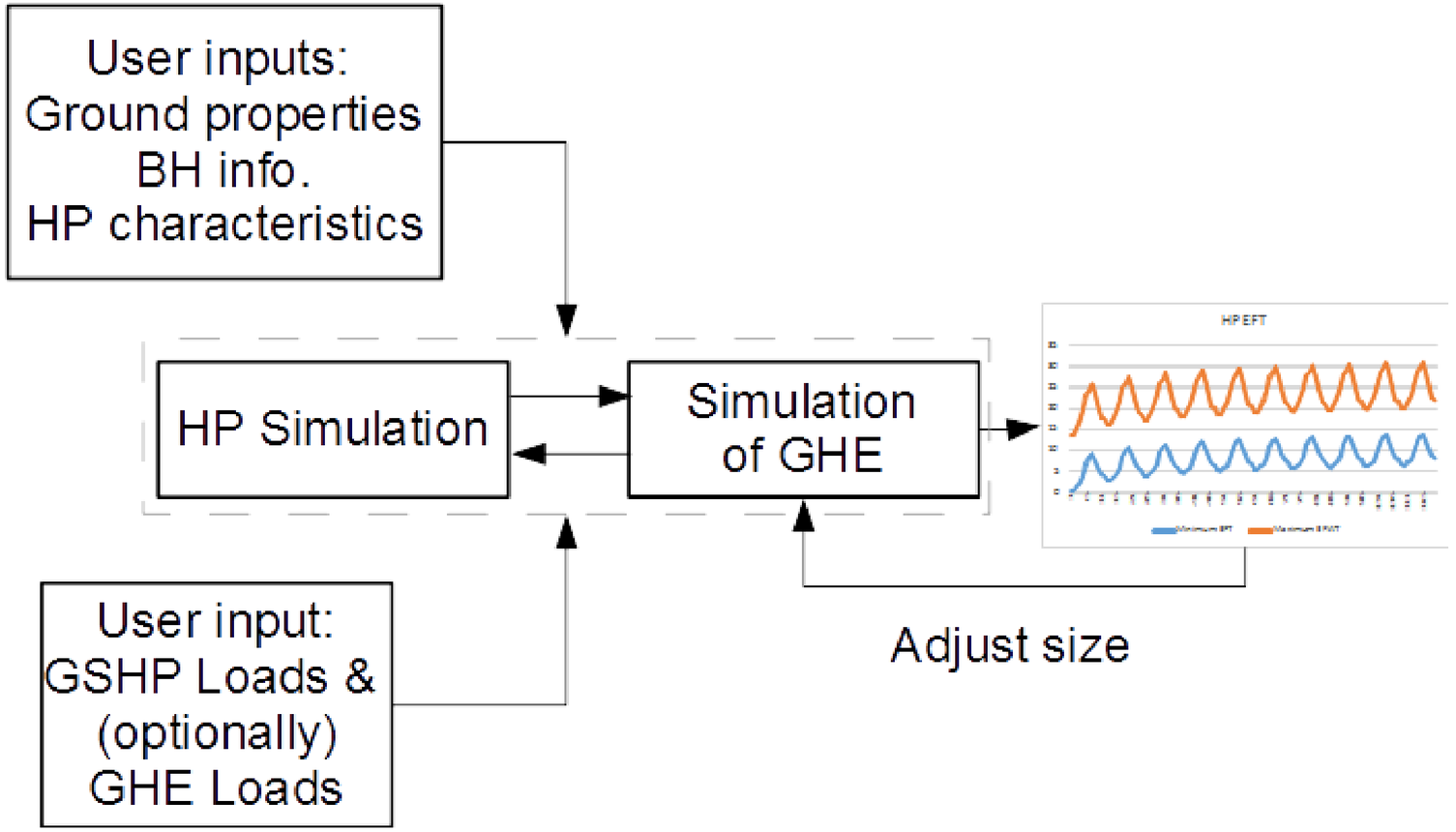
Speaker: **Jeffrey D. Spitler**

School of Mechanical and Aerospace Engineering

Oklahoma State University

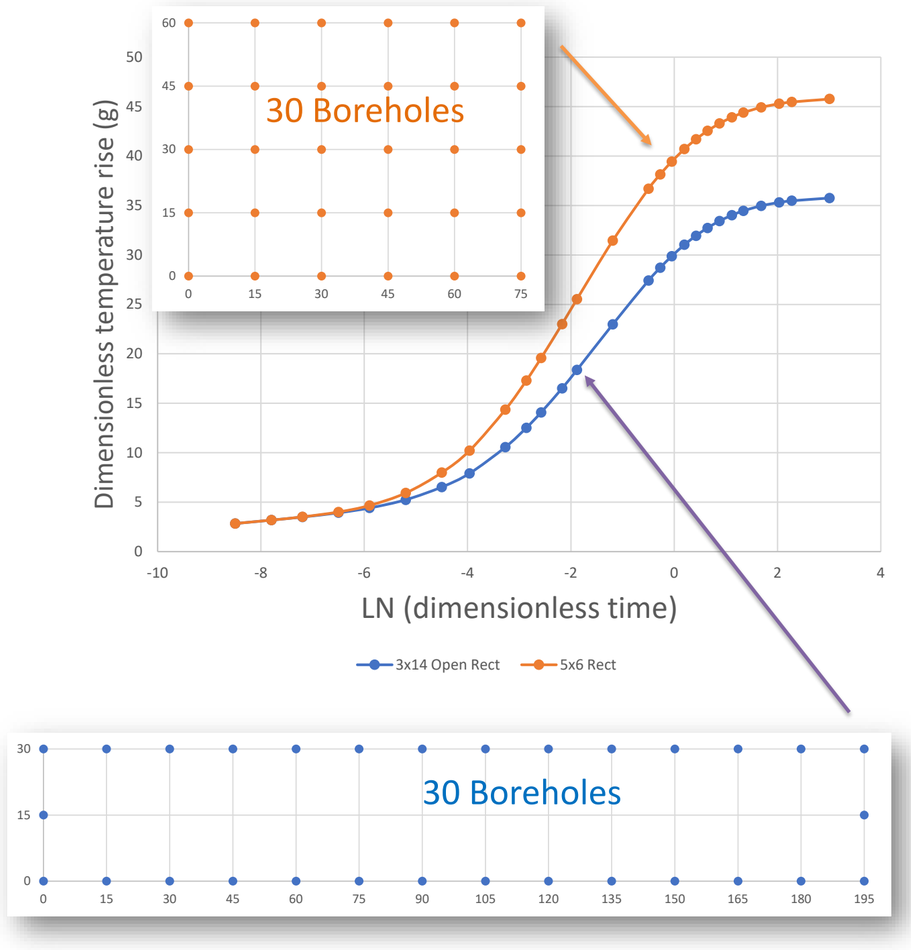
GLHEPRO background

- Simulation-based ground heat exchanger (GHE) design tool.
  - Vertical boreholes
  - Horizontal (GHE)
  - Angled boreholes
  - Even curved boreholes (as line segments)
  - Models heat pumps
  - First version released in 1994.



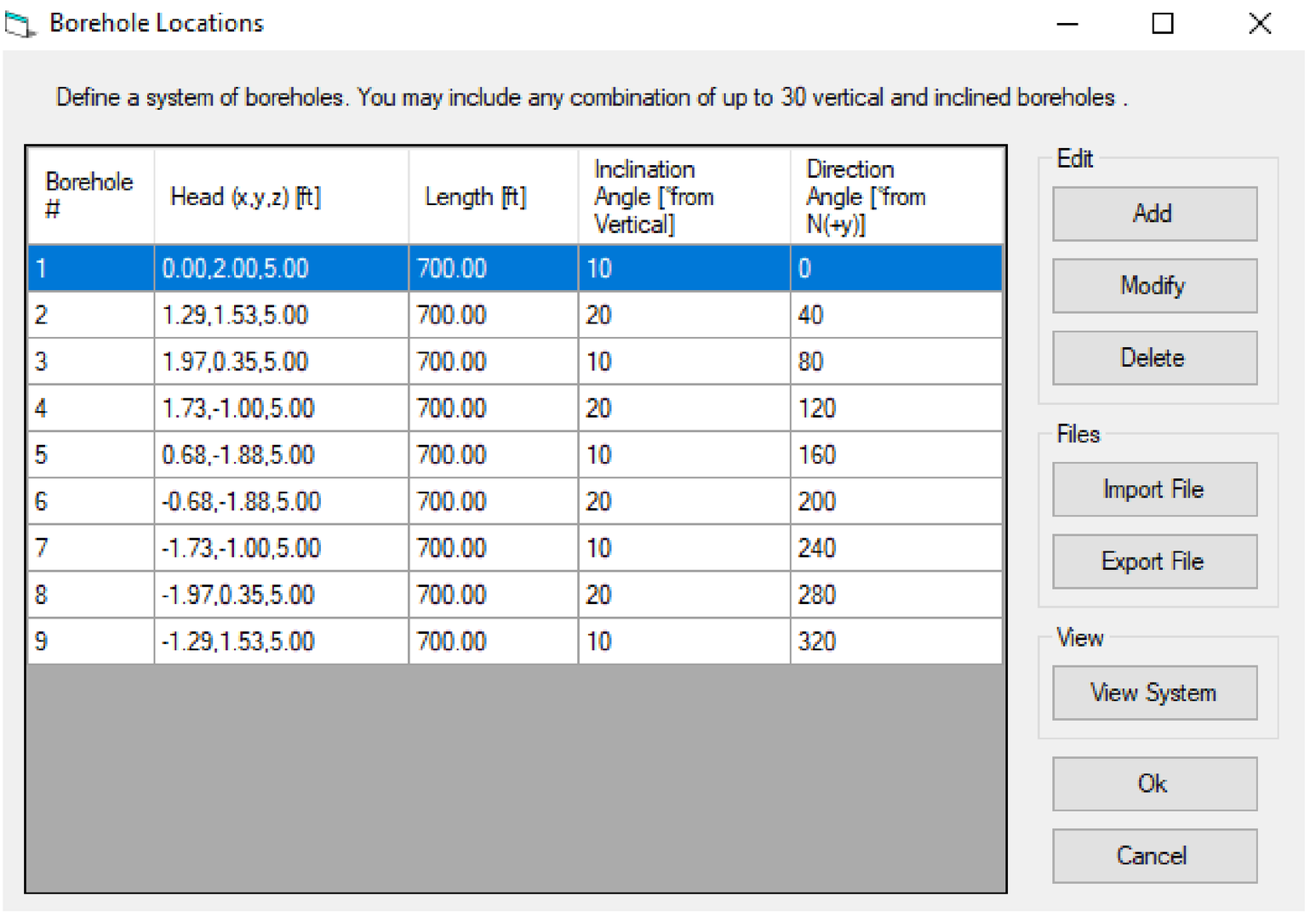
g-functions

- Basis of the simulation used in GLHEPRO.
- g-functions are dimensionless thermal response function that give, for a fixed pulse, dimensionless temperature rise vs. dimensionless time.
- Since 2016, GLHEPRO can calculate g-functions for angled borehole systems using the “Free placement, finite line source” algorithm.

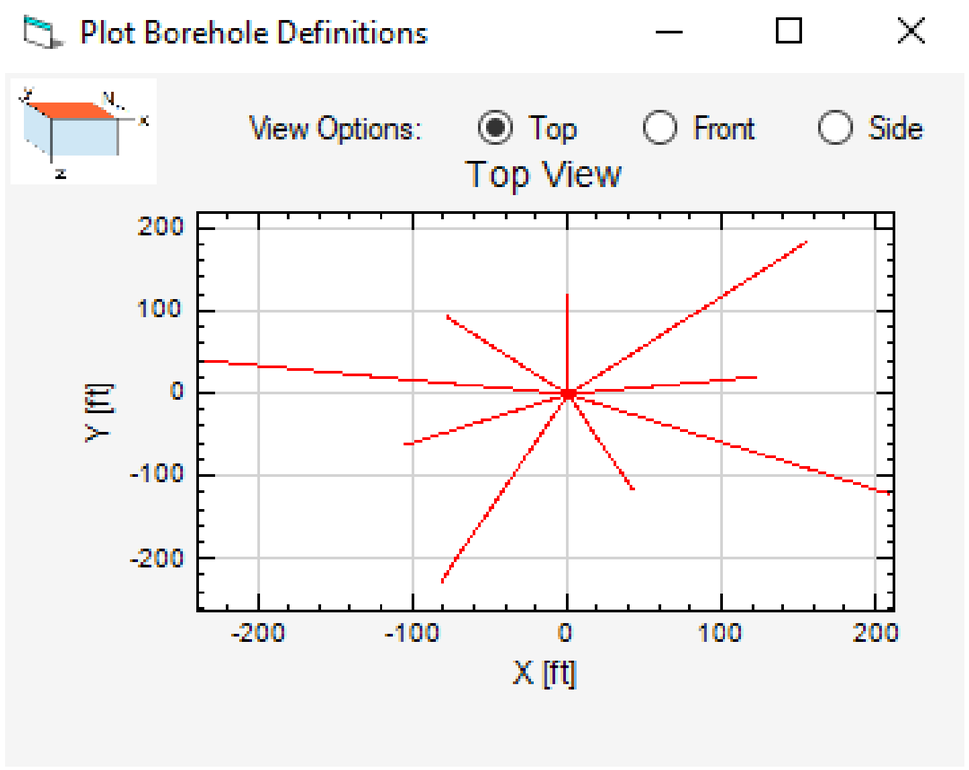


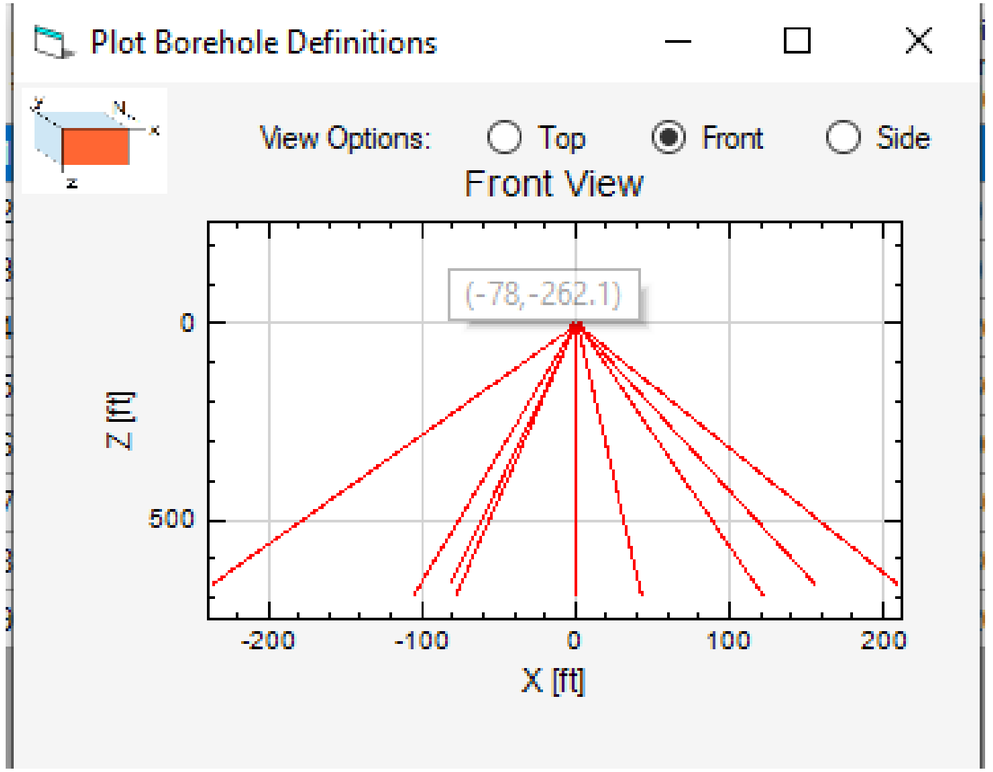
GLHEPRO FPFLS

- Free placement finite line source.
- Calculates g-functions for user-specified borehole fields.
- Allows sizing of angled borehole fields.



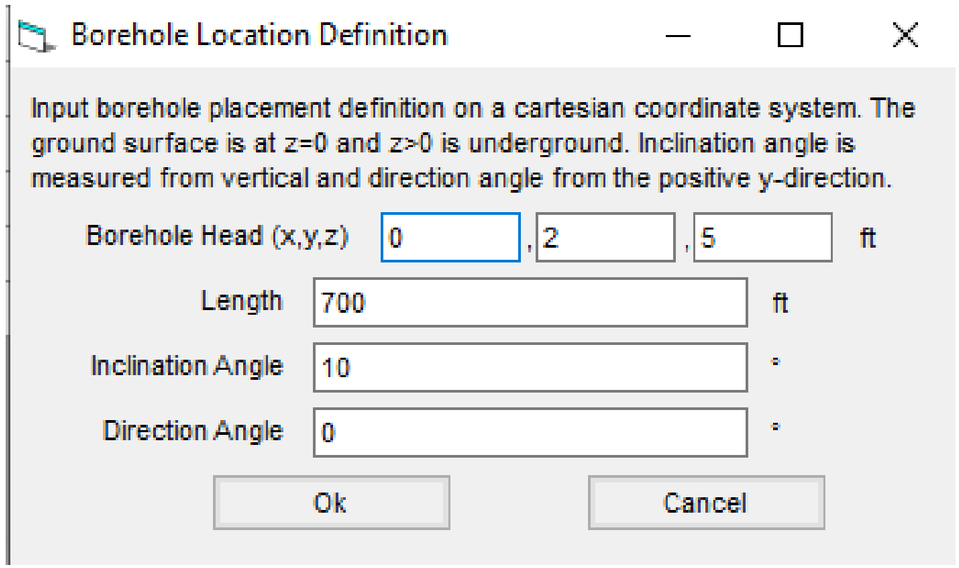
Boreholes


Plot Borehole Definitions
View Options:
Top
Front
Side
Top View
200
100
0
-100
-200
Y [ft]
-200
-100
0
100
200
X [ft]


Plot Borehole Definitions
View Options:
Top
Front
Side
Front View
(-78,-262.1)
0
500
Z [ft]
-200
-100
0
100
200
X [ft]

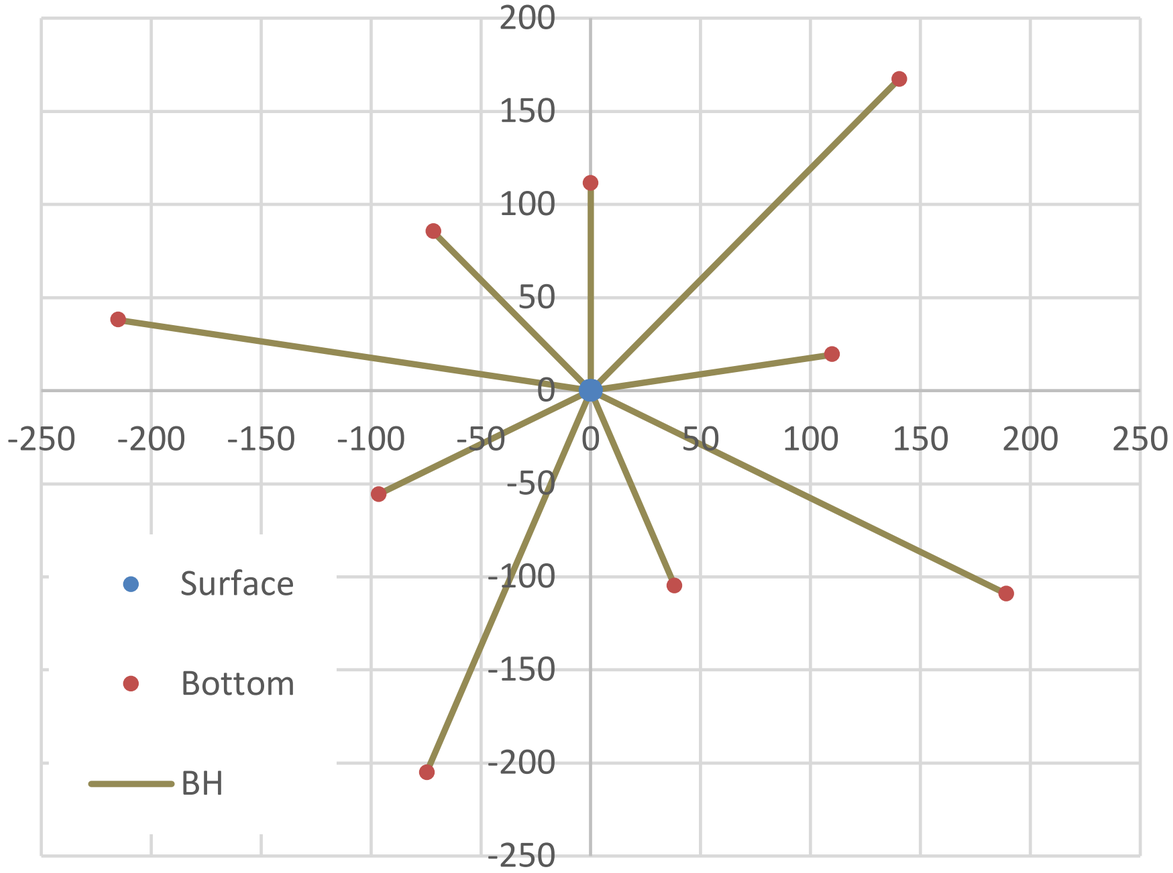
GLHEPRO FPFLS

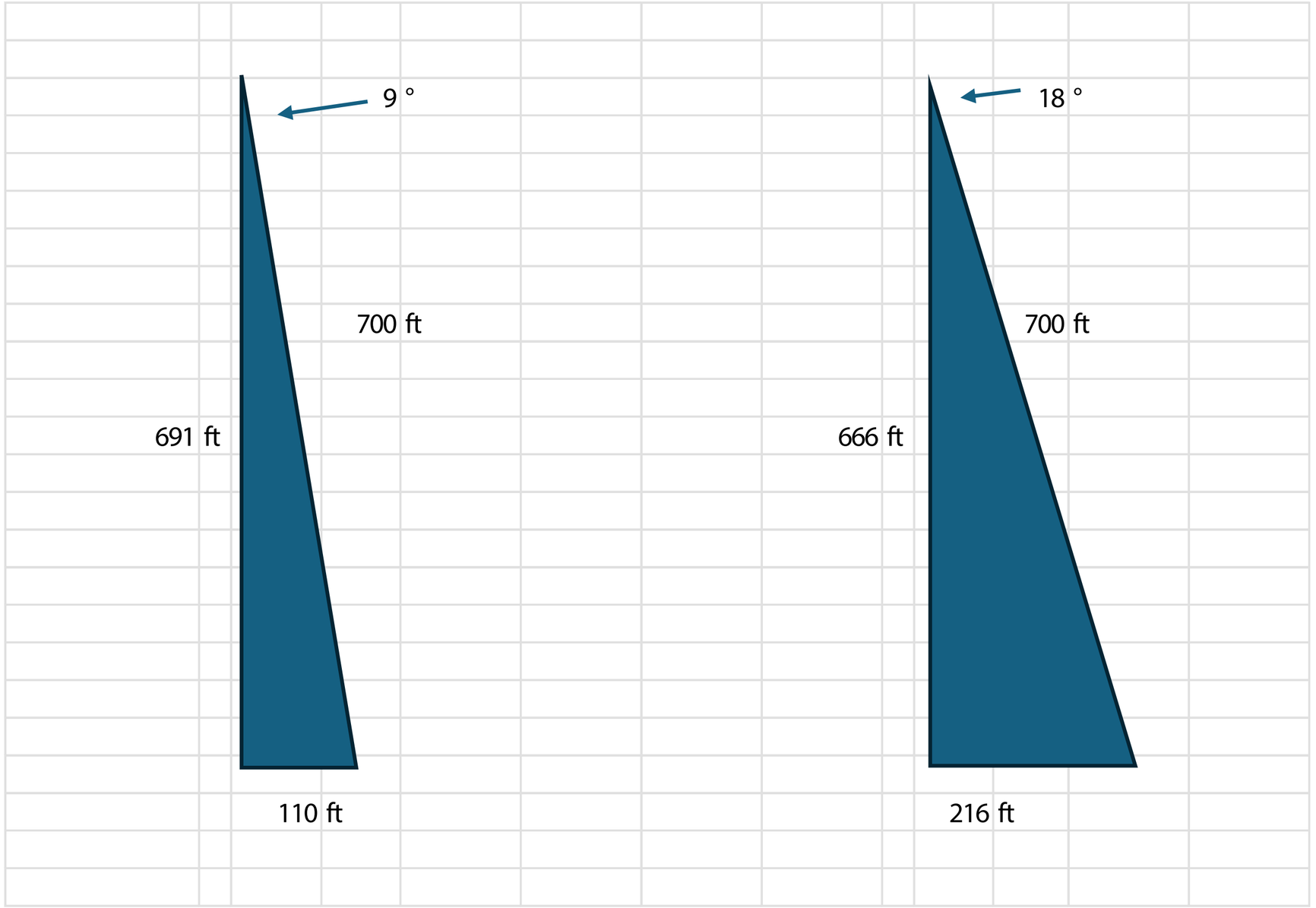
- Import field description from an Excel file, or
- Enter borehole geometry in a form.

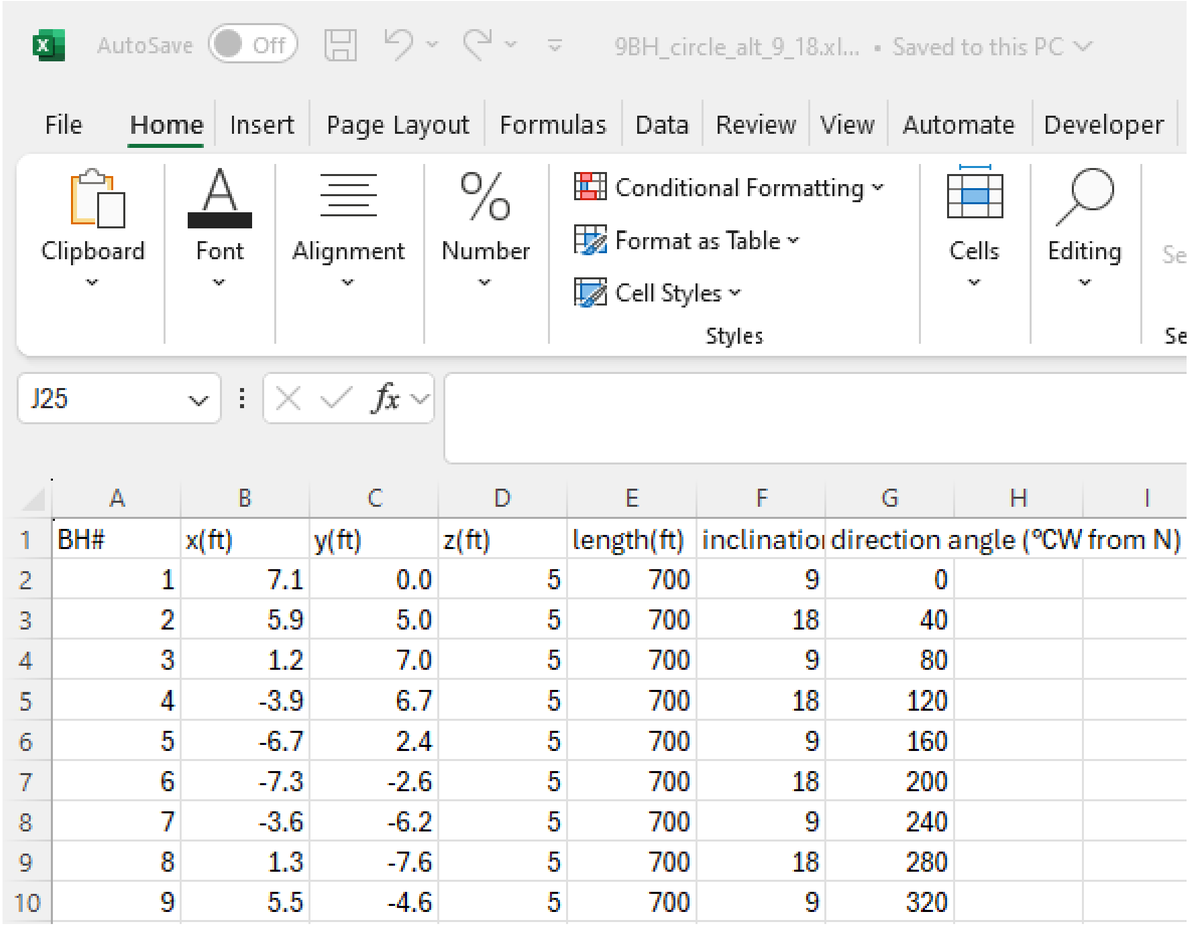


Example

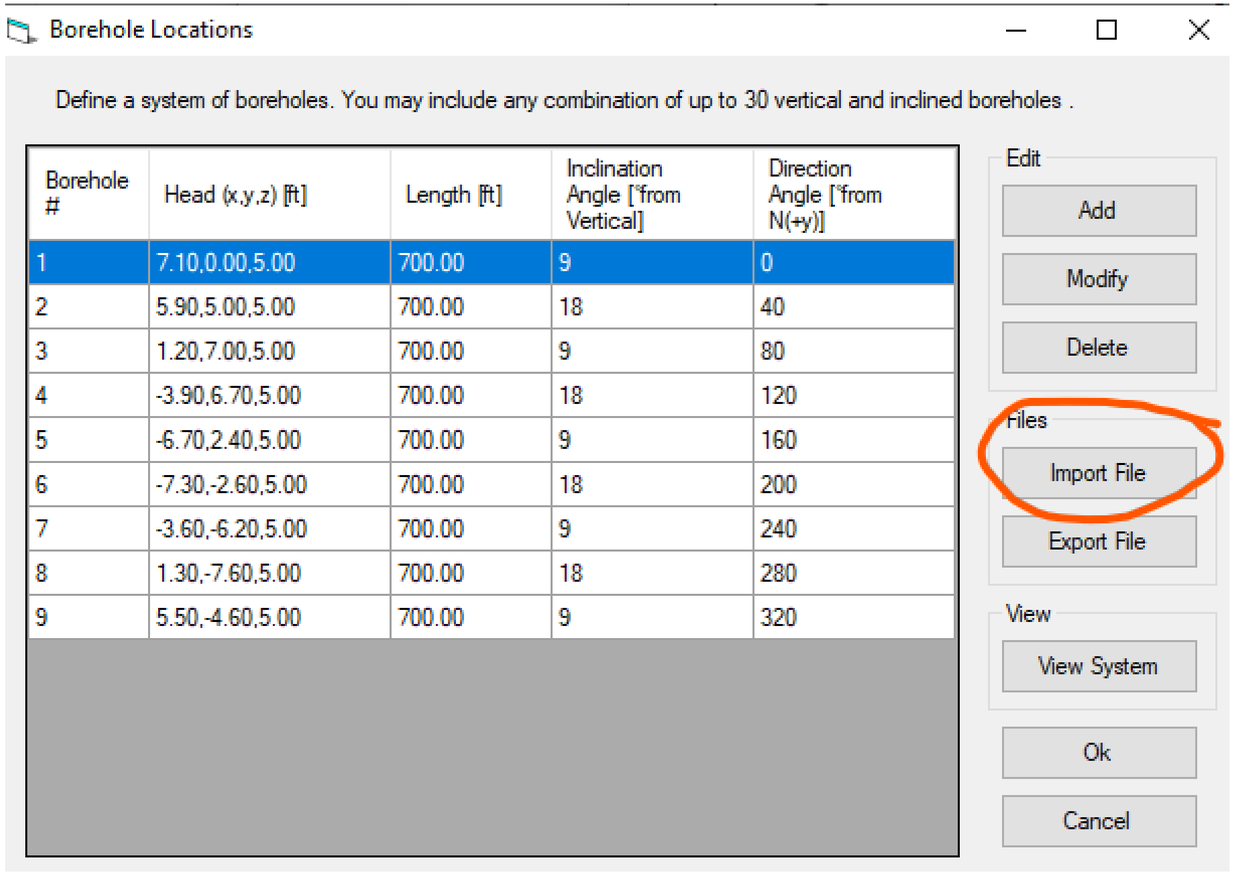
- Medium office building in Atlanta; cooling dominated.
  - Conventional design:
    - 4x8 rectangle, 20’ spacing
  - 2 circle installations:
    - 9 boreholes each, alternating 9°, 18° tilt.
    - Each installed in 13’ circle at surface.
    - Initial guess: 700’ length



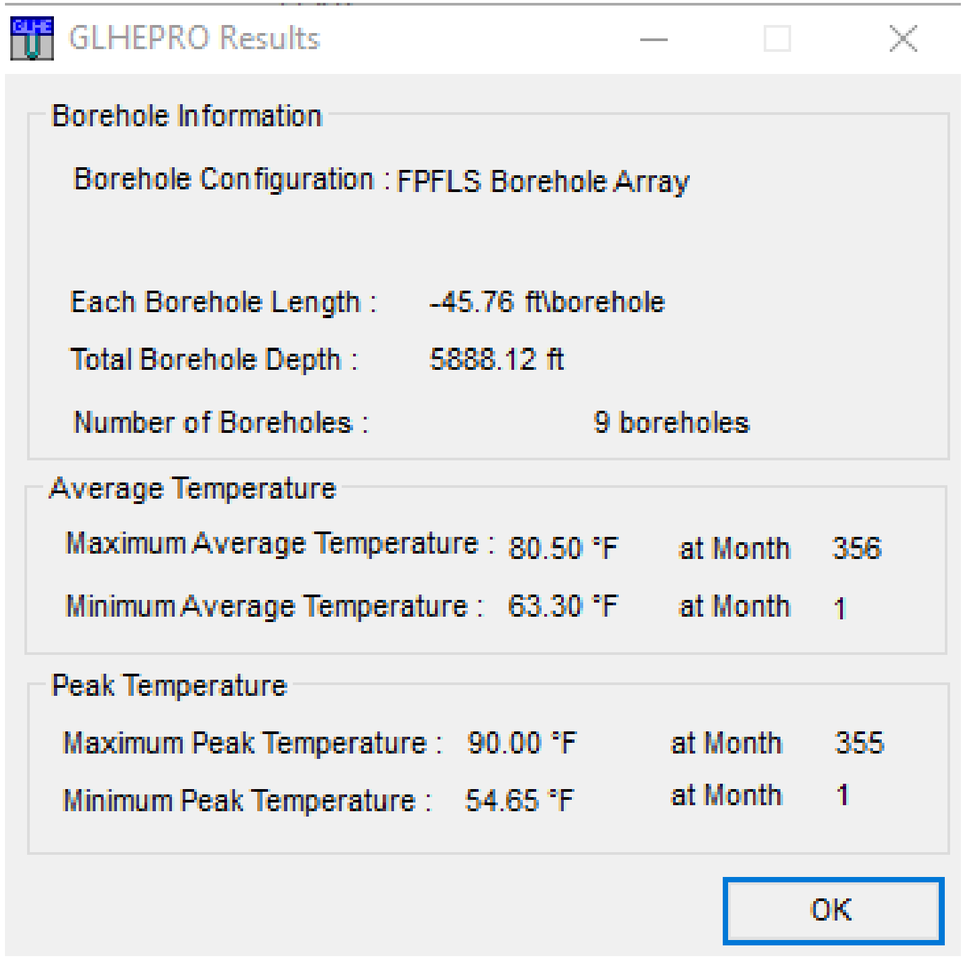

9 °
700 ft
691 ft
110 ft
18 °
700 ft
666 ft
216 ft

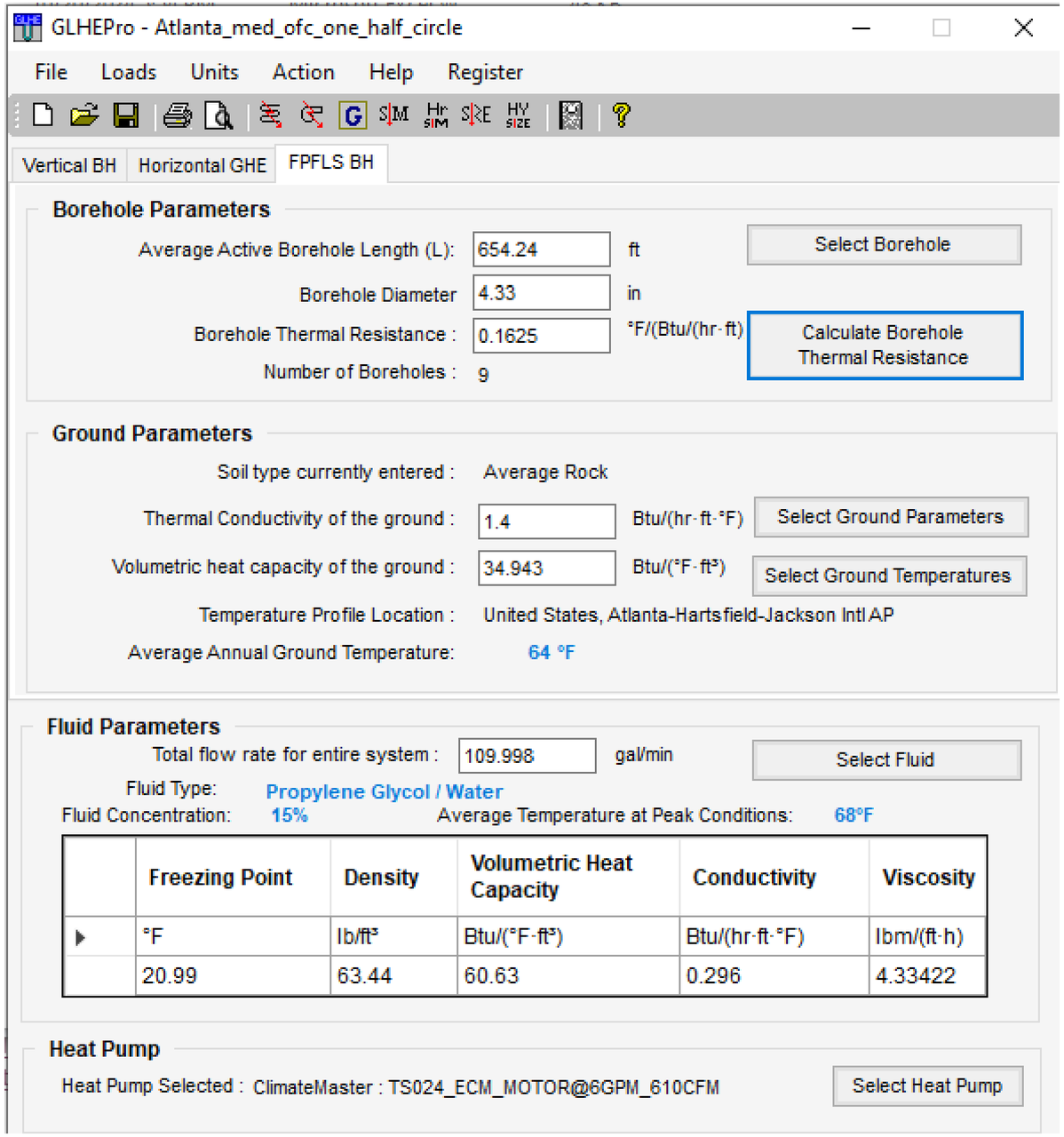


	A	B	C	D	E	F	G	H	I
1	BH#	x(ft)	y(ft)	z(ft)	length(ft)	inclinatio	direction angle (°CW from N)		
2	1	7.1	0.0	5	700	9	0		
3	2	5.9	5.0	5	700	18	40		
4	3	1.2	7.0	5	700	9	80		
5	4	-3.9	6.7	5	700	18	120		
6	5	-6.7	2.4	5	700	9	160		
7	6	-7.3	-2.6	5	700	18	200		
8	7	-3.6	-6.2	5	700	9	240		
9	8	1.3	-7.6	5	700	18	280		
10	9	5.5	-4.6	5	700	9	320		

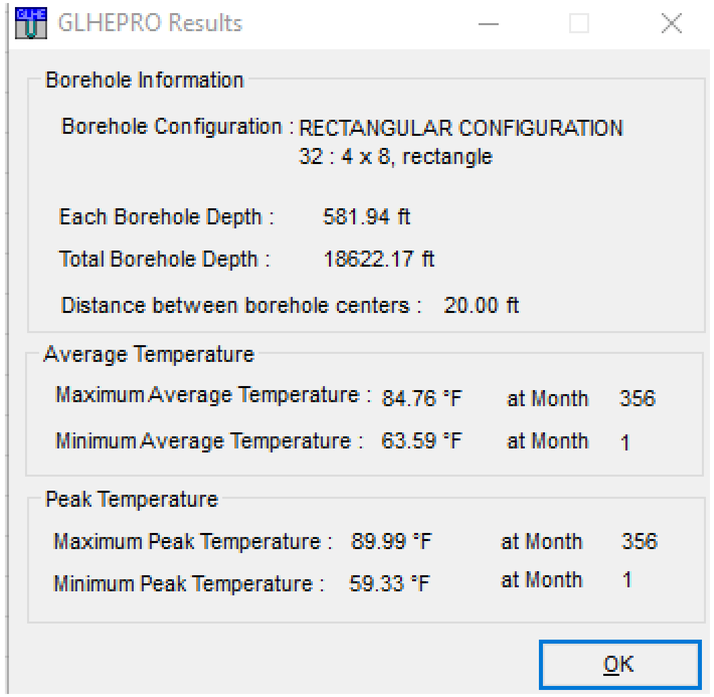


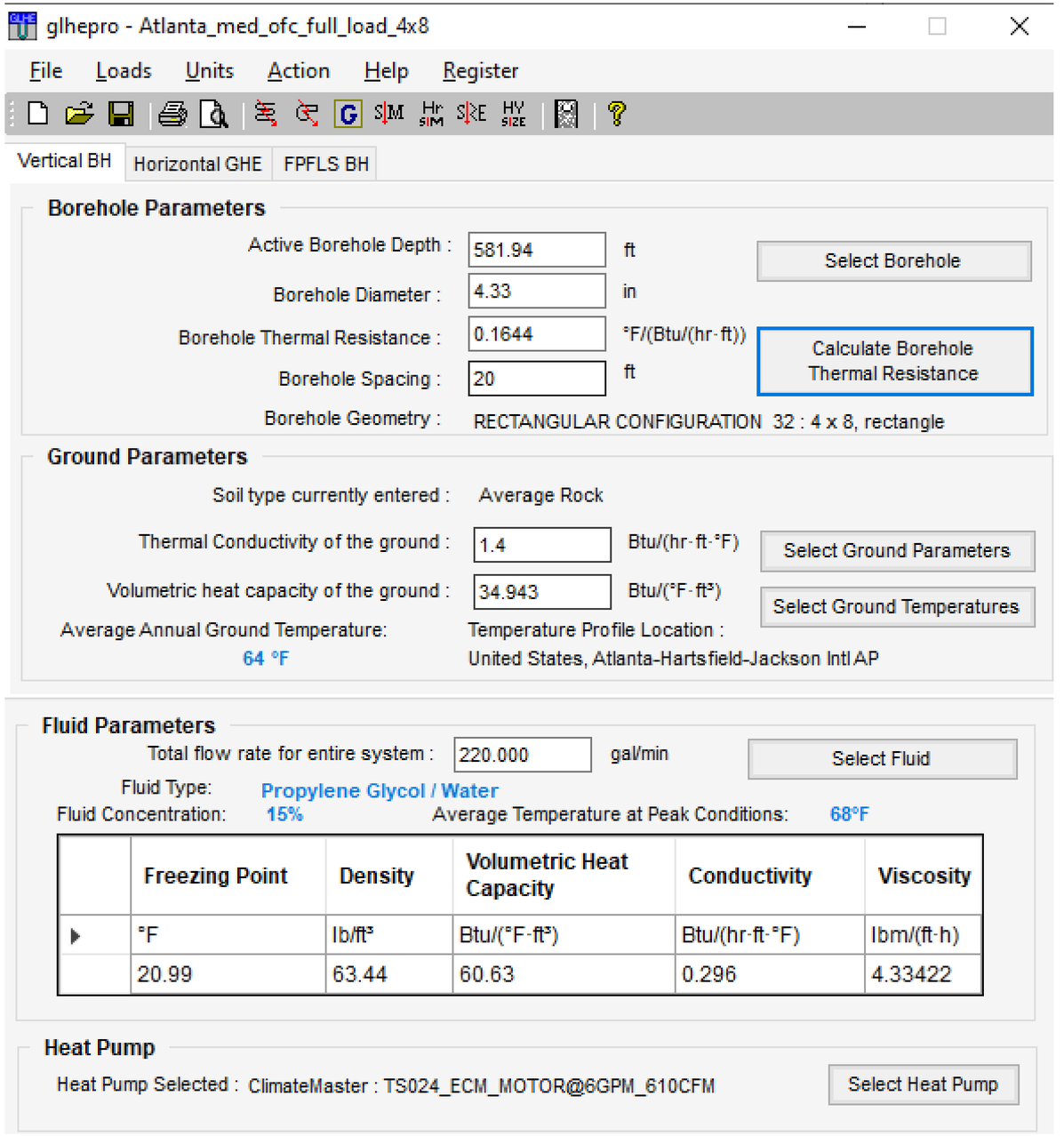
Circle configuration





4x8 rectangle





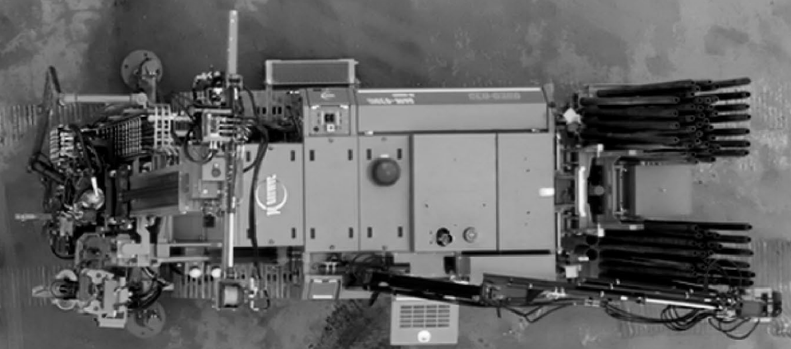
Summary

- Two circular drill pads with alternating 9°, 18° tilt: 11,776 feet of drilling
- One rectangular 4x8 field with 32 boreholes on 20 ft spacing: 18,622 feet (37% savings)
- One rectangular 4x8 field with 32 boreholes on 30 ft spacing: 15,283 feet (30% savings)

Geosource
Geoexchange
Solutions

Designing Borefields with Angled Drilling
Example of using GLD for design

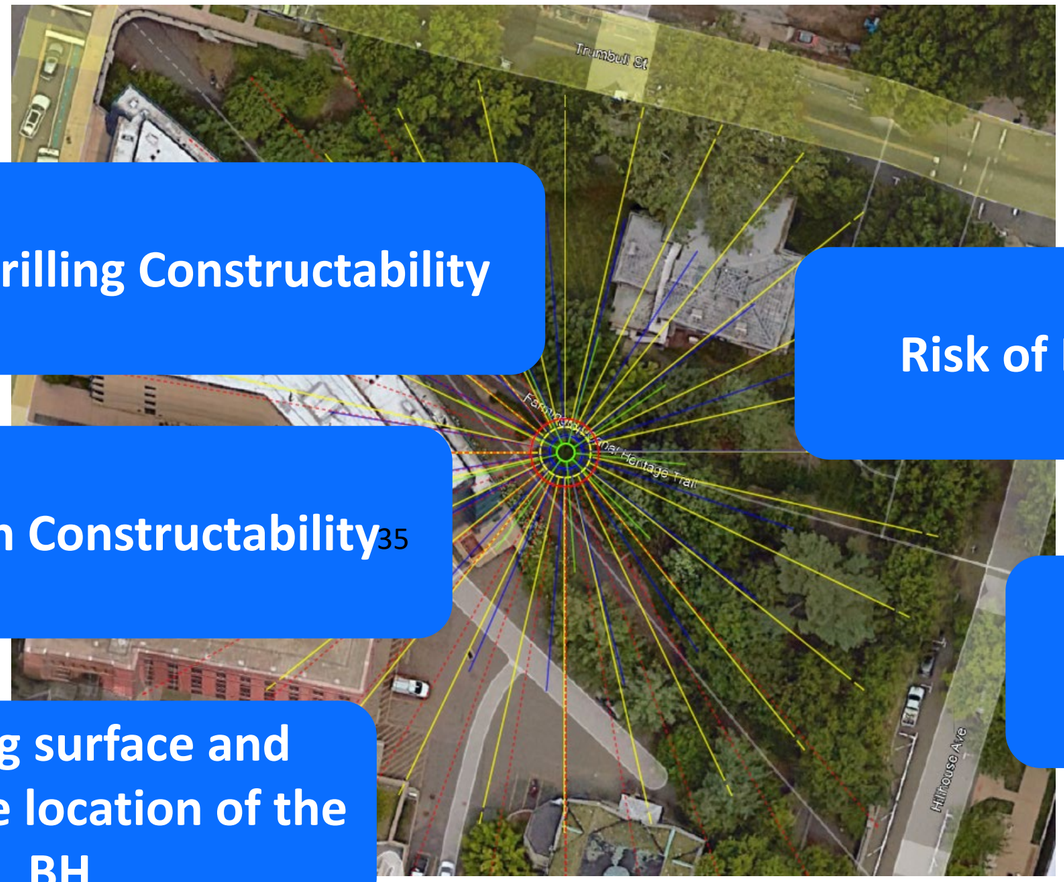
Stanley Reitsma, P.Eng PhD CEO



Application of Angled Boreholes

Space Constraints	Required borehole count exceeds site capacity, retrofits
Construction Simplicity & Schedule	Minimize tie-in interferences, laydown areas, ongoing use
Obstacles	Make-up holes, crane-bases and other physical obstacles
Future borehole access	Strategic placement of extra boreholes for next-phase development

Angled Boreholes: Considerations in Borefield Design



Drilling Constructability

Risk of BH Collision

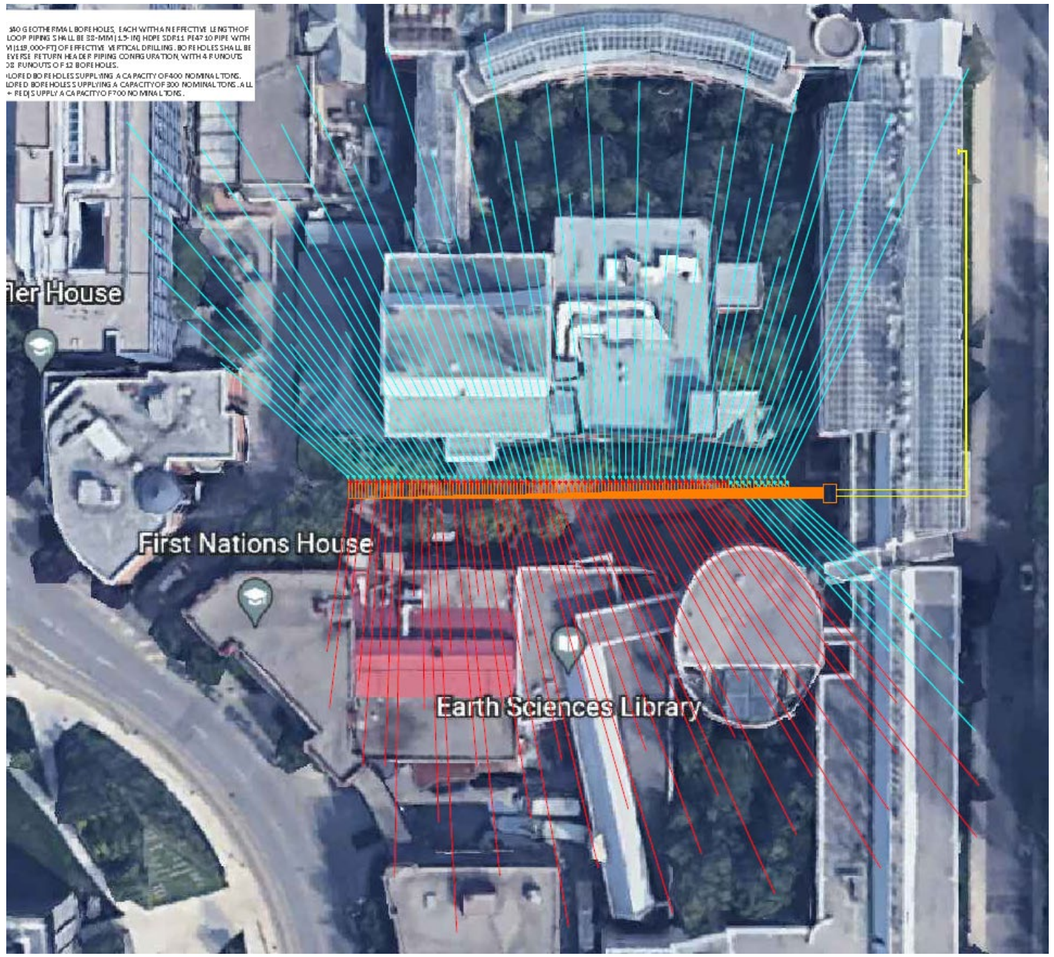
Tie-in Constructability

Optimization

Planning surface and subsurface location of the BH

Angled Boreholes: Considerations in Borefield Design

- Effective BH spacing
  - Estimated based on rock/soil volume accessed by boreholes.
- Behavior will not necessarily be the same as verticals – interference at top
- Borehole trajectory
  - Straight holes?
  - Steer to give different borehole configurations?



Design Steps in GLD

Conventional Vertical Borehole Design

- Input Building Energy Hourly Load
- Select Heat Pump model of choice
- Input Heat carrier fluid properties
- Input subsurface thermal properties
- Input Borehole dimension and U-Tube configuration
- Input Vertical Grid arrangement details
- Run Short-term and Long-term analysis
- Run Iterations

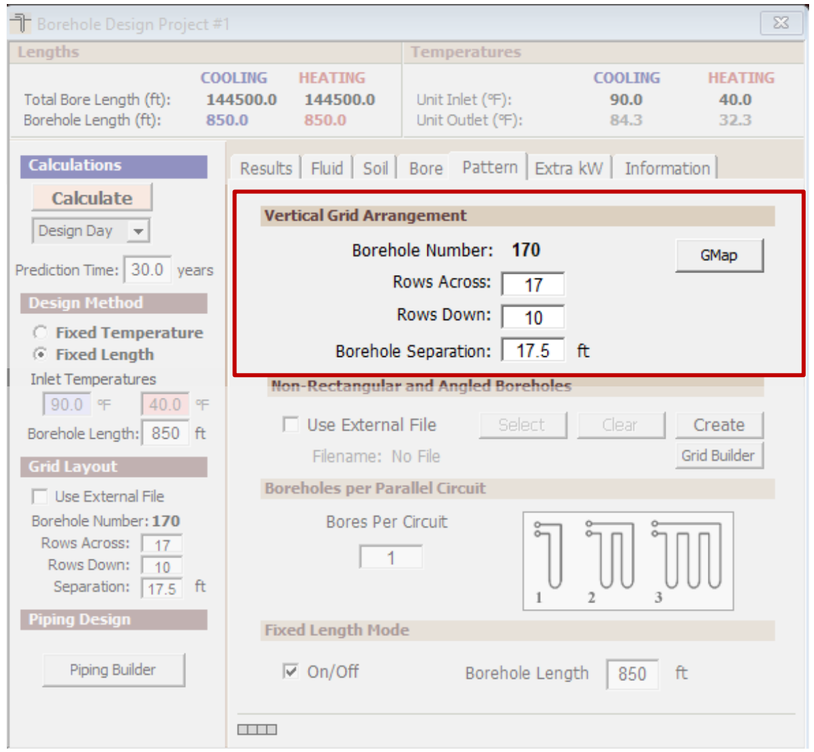
Specialized Angled Borehole Design

- Input Building Energy Hourly Load
- Select Heat Pump model of choice
- Input Heat carrier fluid properties
- Input subsurface thermal properties
- Input Borehole dimension and U-Tube configuration
- Input Angled BH arrangement details
- Run Short-term and Long-term analysis
- Run Iterations

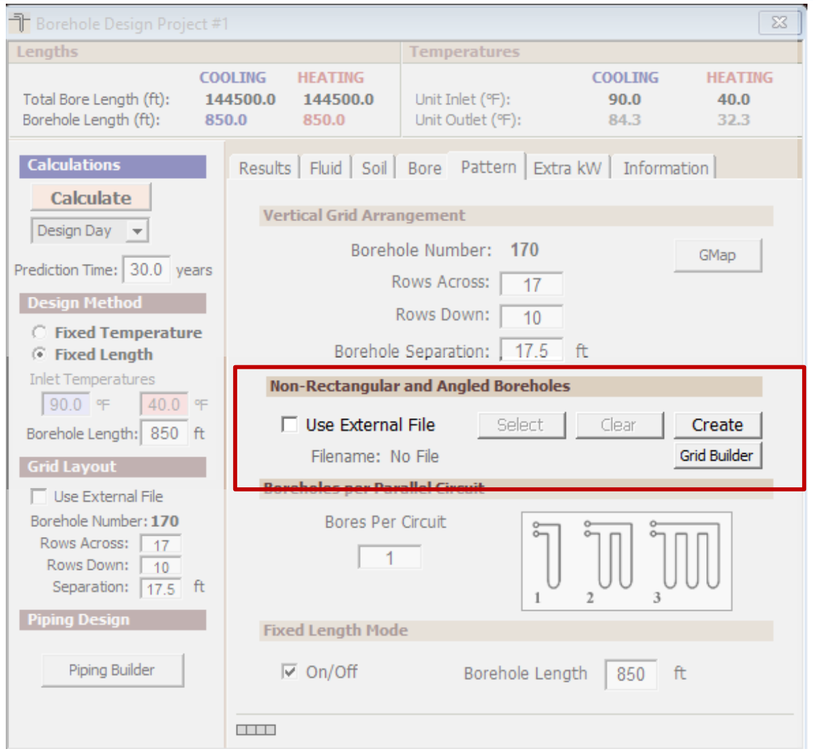
Design Steps in GLD

Feature Available in the Latest Version of GLD

Conventional Vertical Borehole Design



Specialized Angled Borehole Design

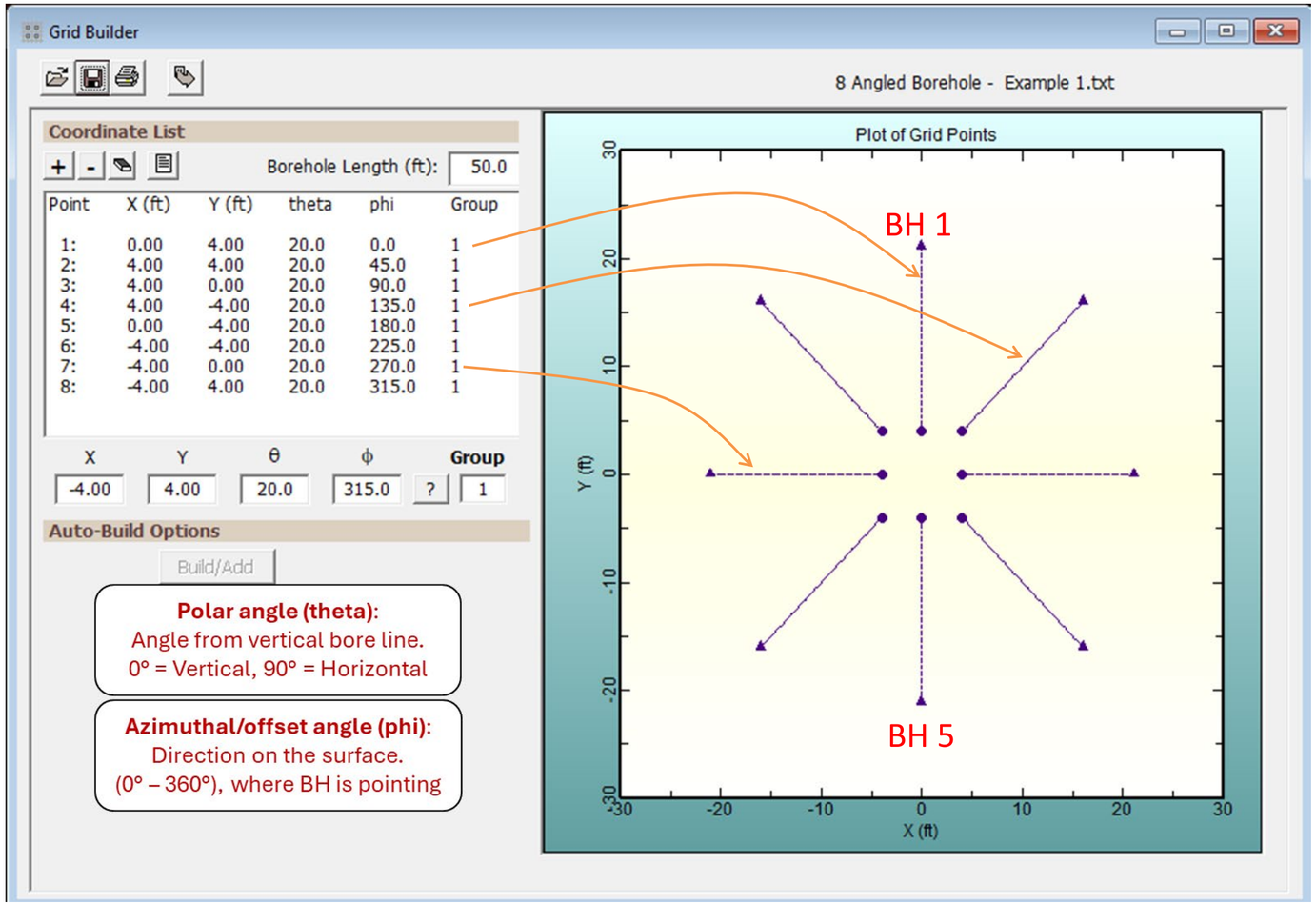


Design Steps in GLD

Feature Available in the Latest Version of GLD

How to develop Grid file for Angled Boreholes in GLD ?

Simplified Example →

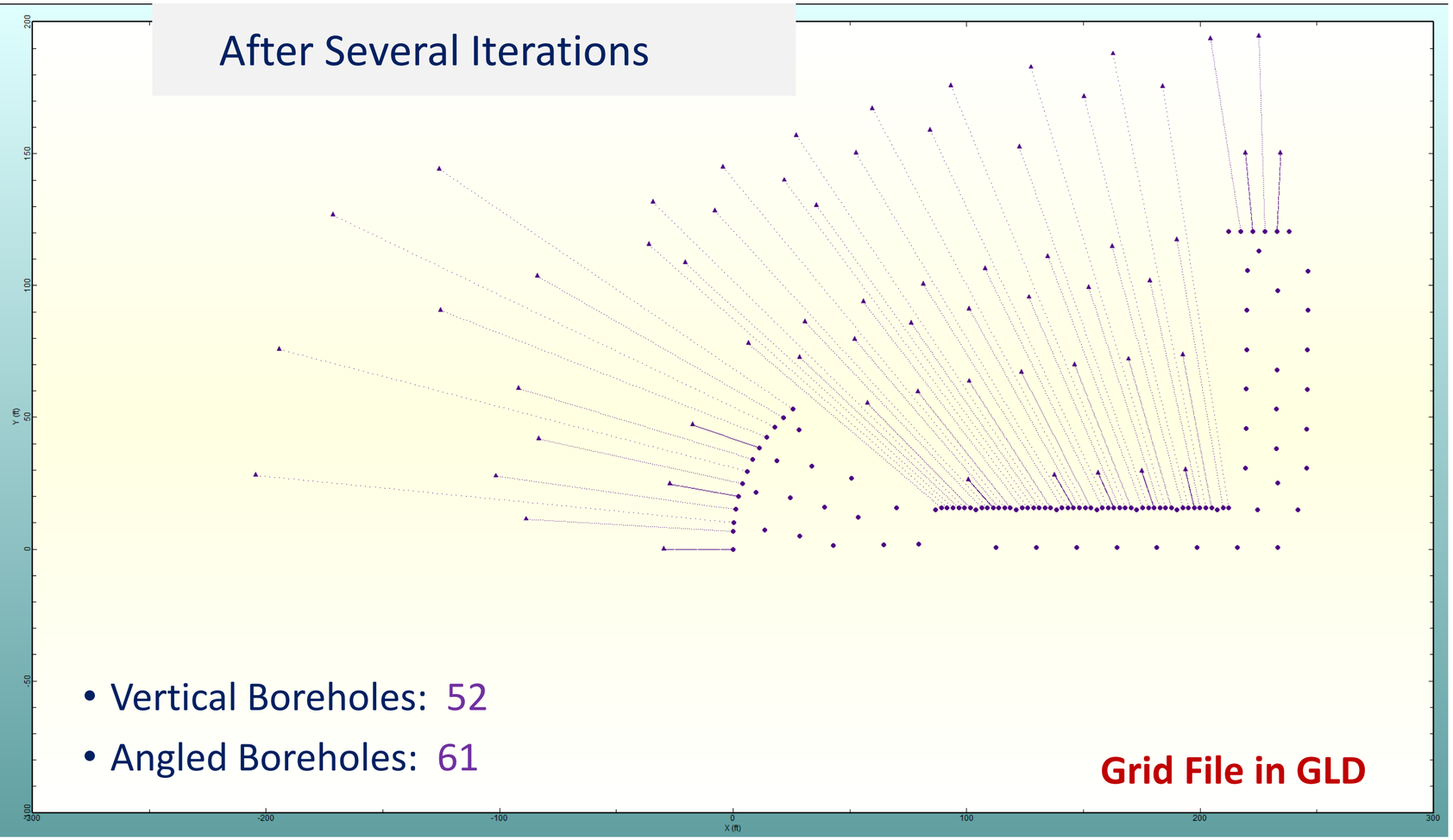


Sample Case Study – 240 Markland

- Total surface area available: 1250 m^2 (13,500 sq ft)
- Required Boreholes: 113 to 850’
- Site capacity for vertical only BH: 59
- Designed: 52 vertical, 61 angled

Sample Case Study – 240 Markland

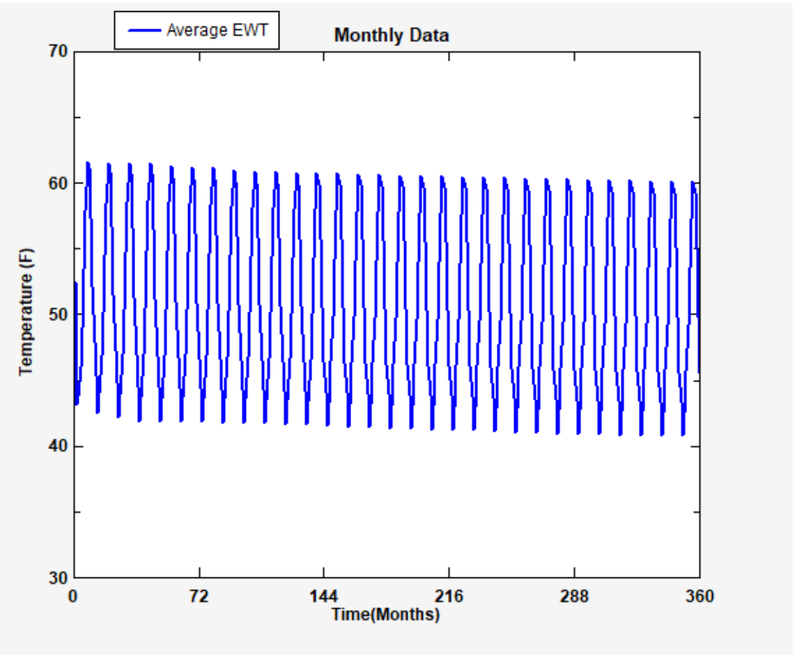
After Several Iterations



- Vertical Boreholes: 52
- Angled Boreholes: 61

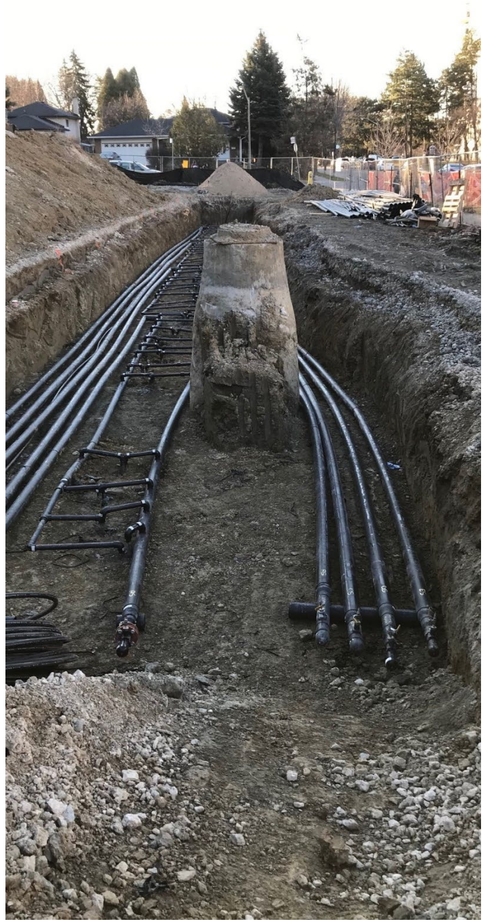
Grid File in GLD

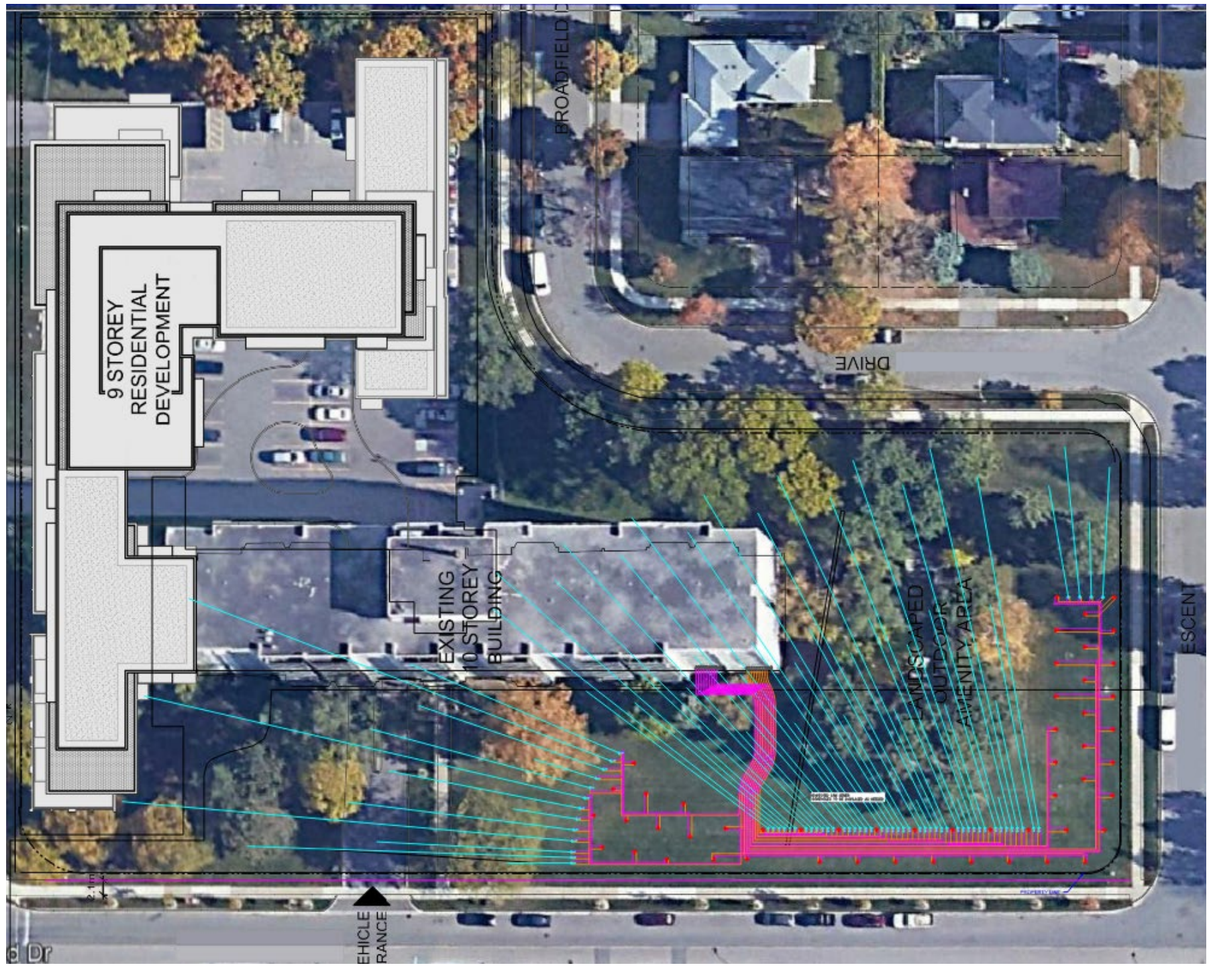
GLD Output



Sample Case Study – 240 Markland

Top view of Angled Borehole on Site



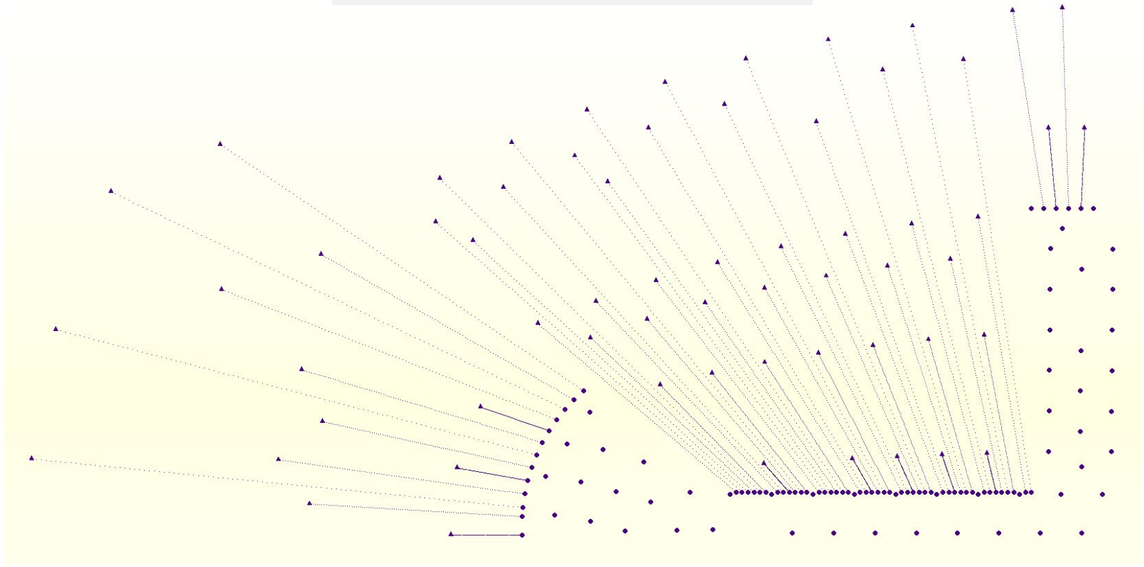


Sample Case Study – 240 Markland

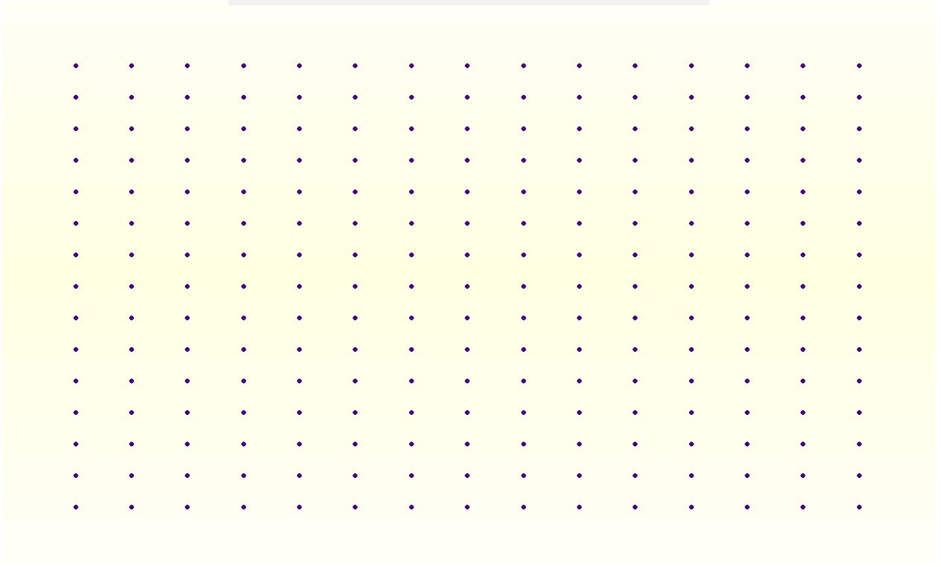
Insights from Design Experience

- Creating grid files will require more time.
- The process is now significantly easier than in the past.

Vertical + Angled



Vertical



Combining Drilling Expertise And Design Innovation Through Angled Boreholes.

Designing Borefields with Angled Drilling

Moderator: **Dave Hermantin / *Brightcore Energy***

Speakers: **Göran Hellström / *Brightcore Energy***

Jefferey Spitler / *Oklahoma State University*

Stan Reitsma / *Geosource Energy*

Dmitry Kuravskiy / *Celsius Energy*

Geothermal Drilling 1:45 – 2:45