



NY - GEO 2024
October 22 -23 | BROOKLYN, NY



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*



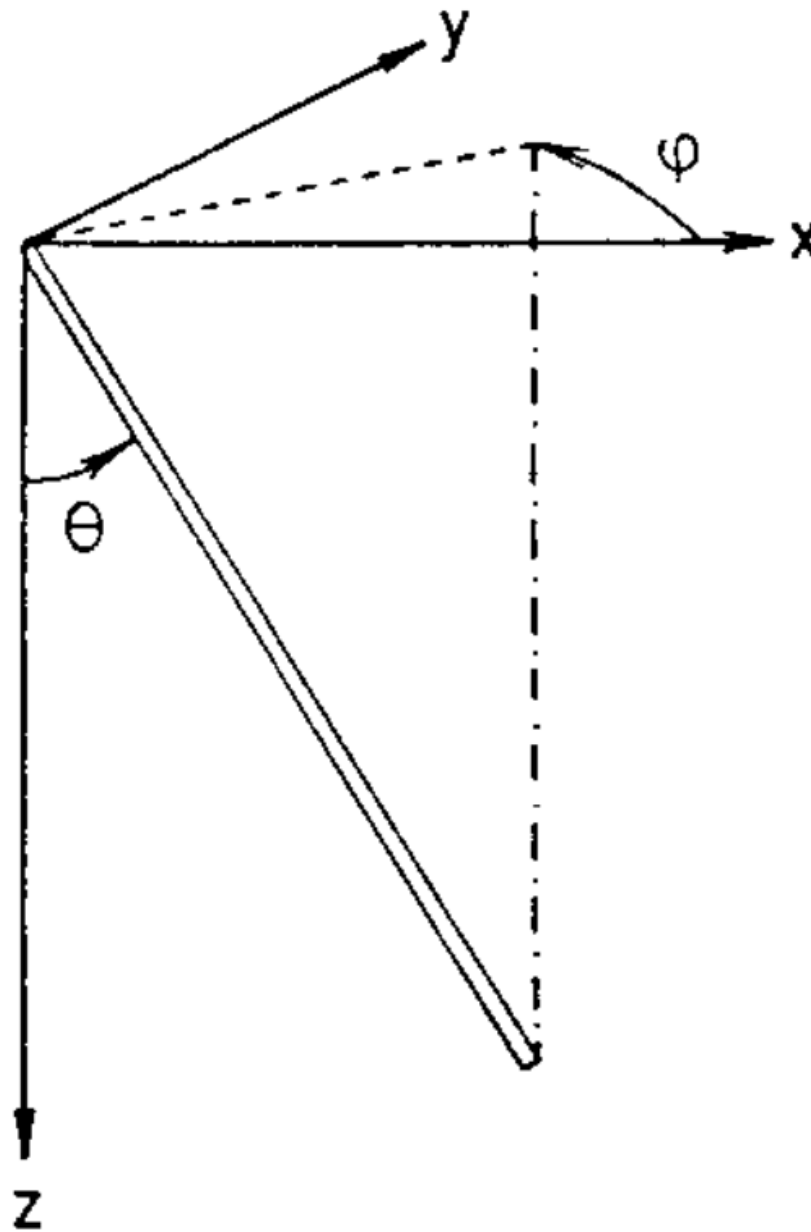
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Designing Borefields with Angled Drilling Historical Perspective

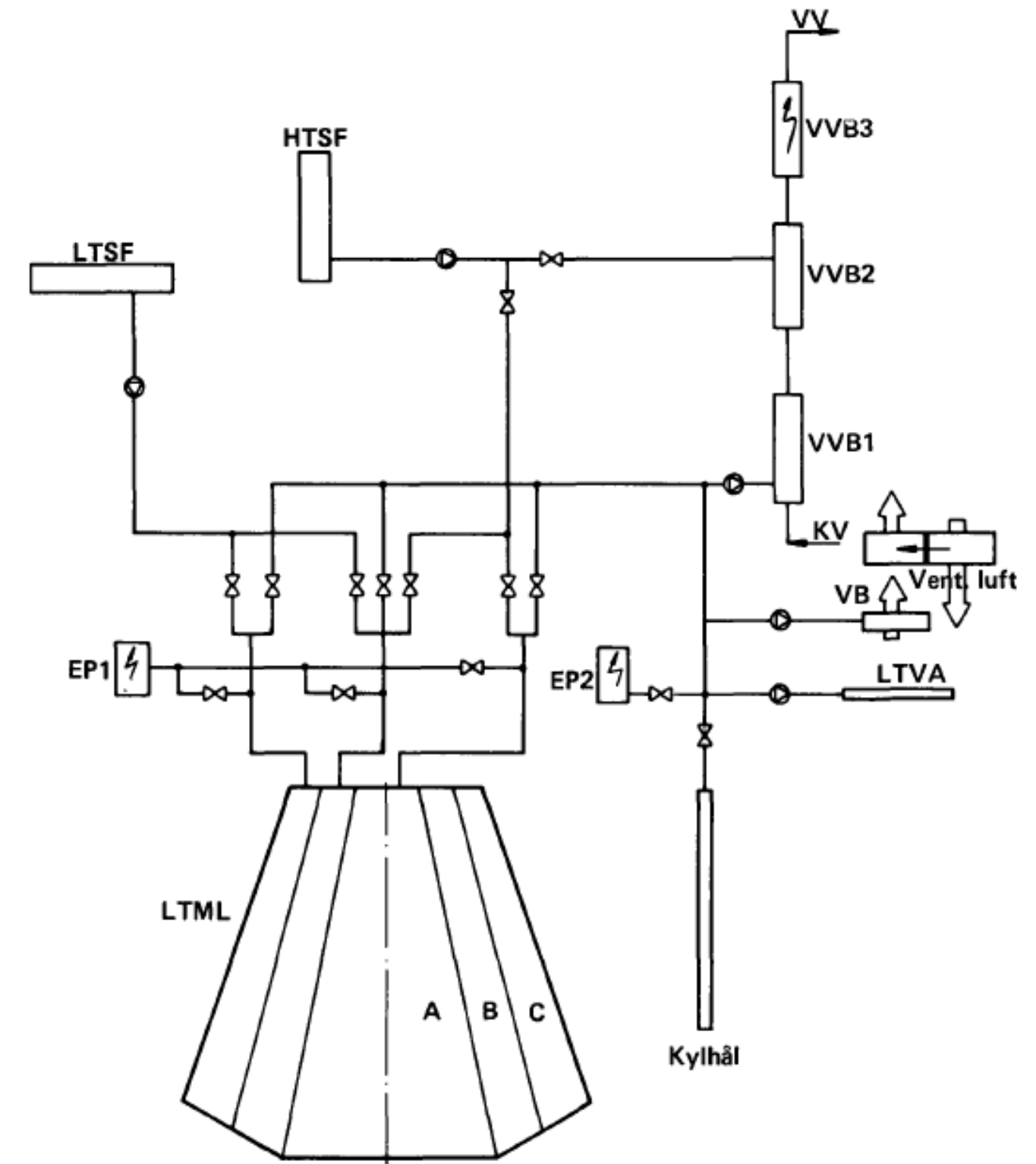
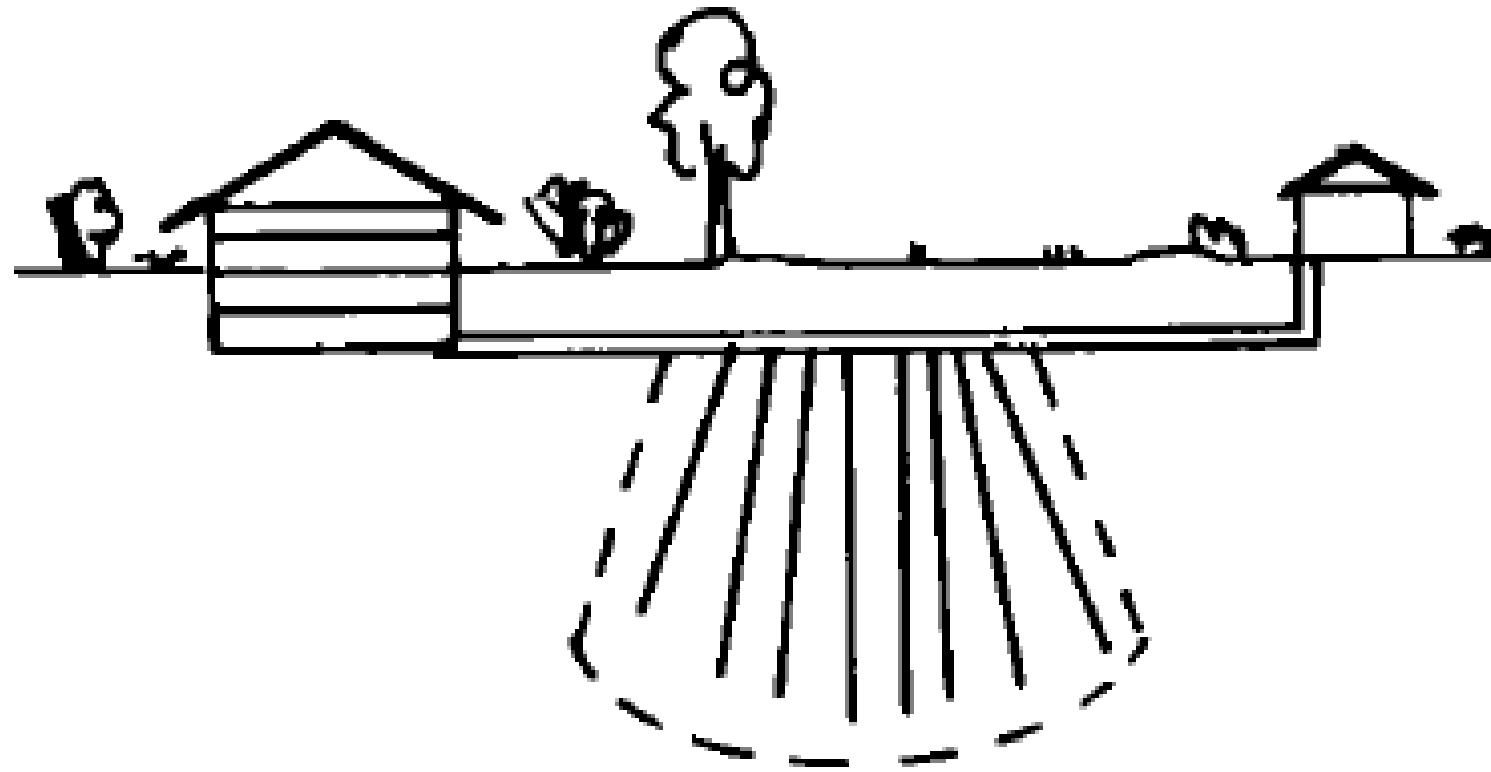
Speakers: Göran Hellström/ Brightcore Energy

Inclined boreholes – Brief history and examples



Göran Hellström
Brightcoreenergy

1977 Sigtuna, Sweden

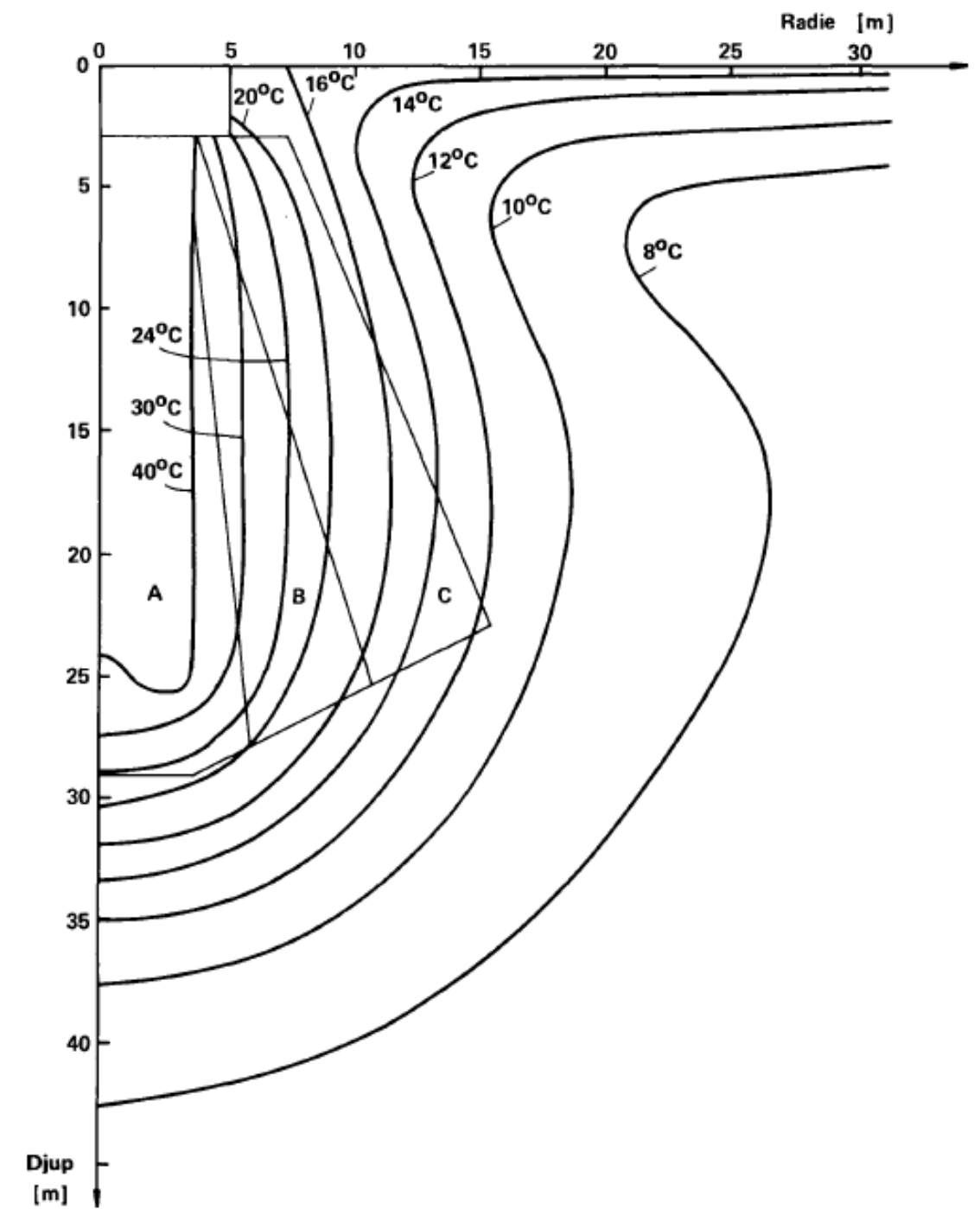
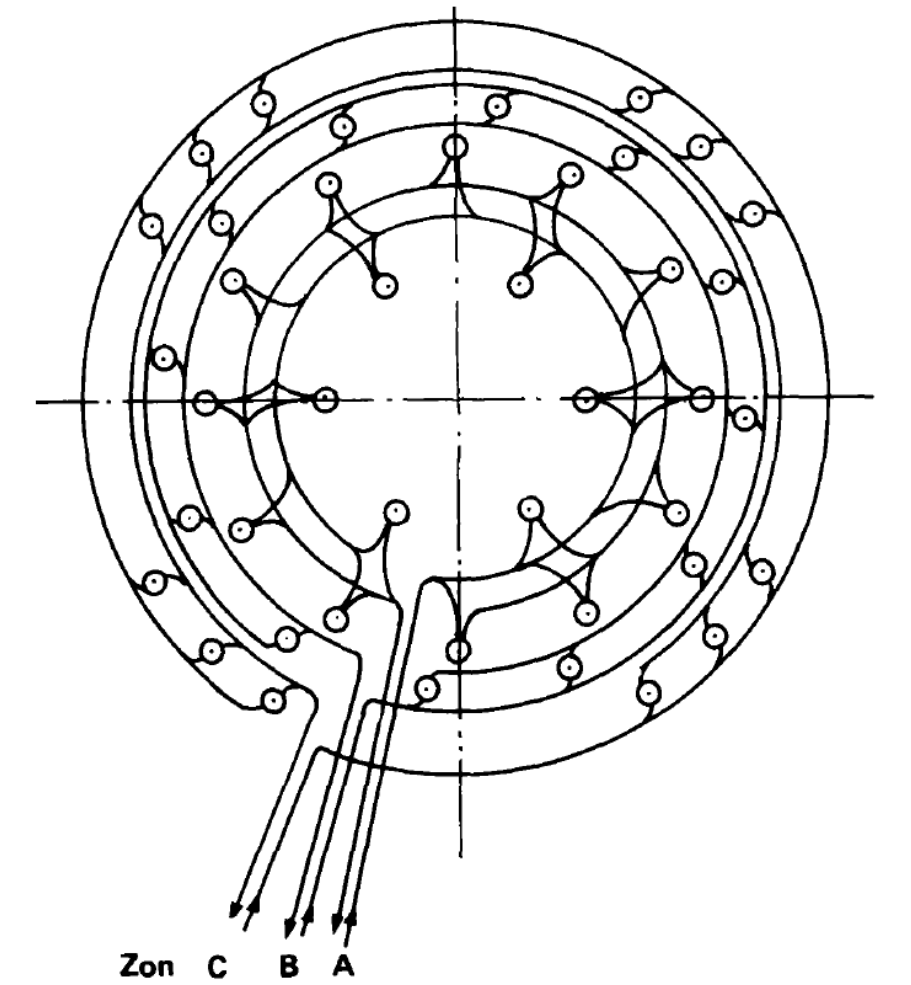
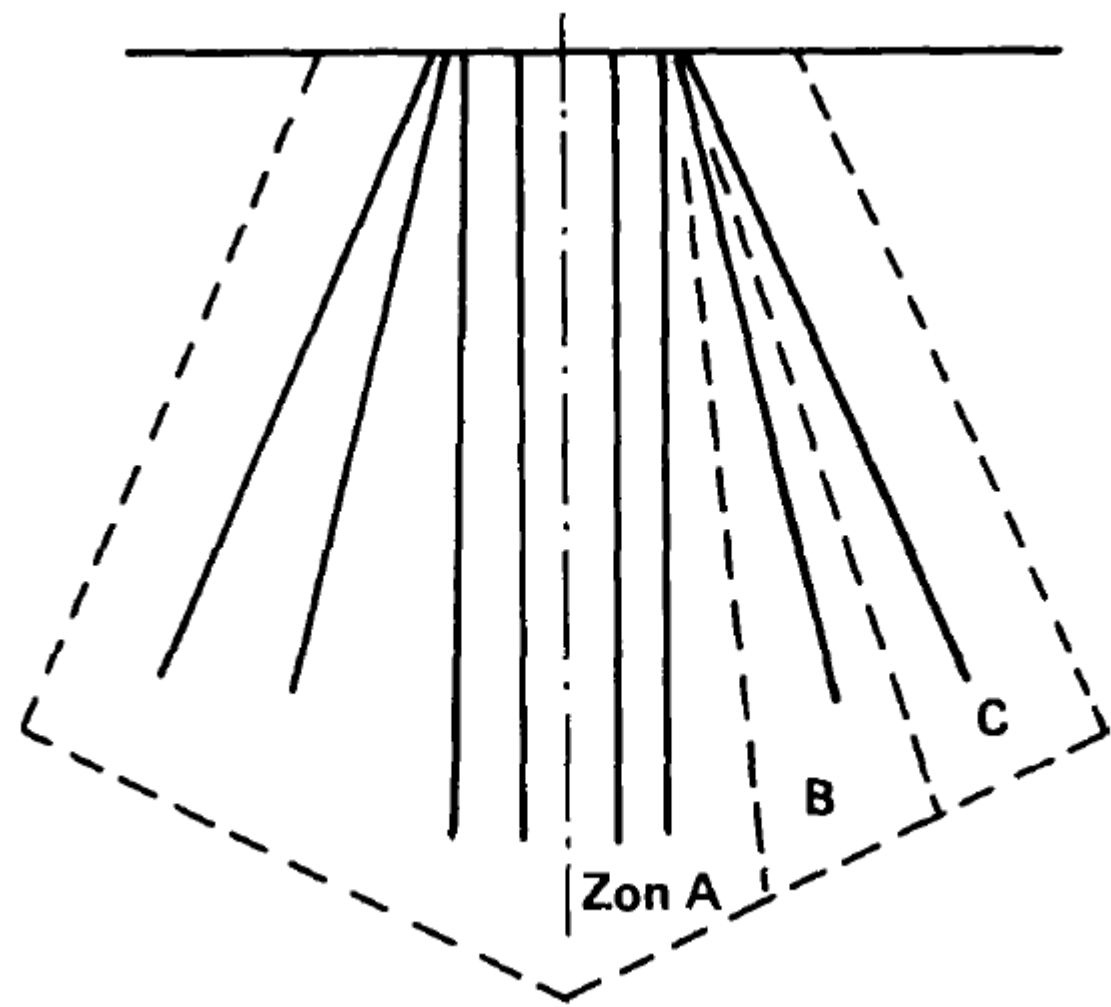


The first multiple borehole (BTES) installation in the world.
Seasonal storage of solar heat.

BTES annual temperature variation 77 °F - 95 °F.

Boreholes drilled November, 1977 – March, 1978

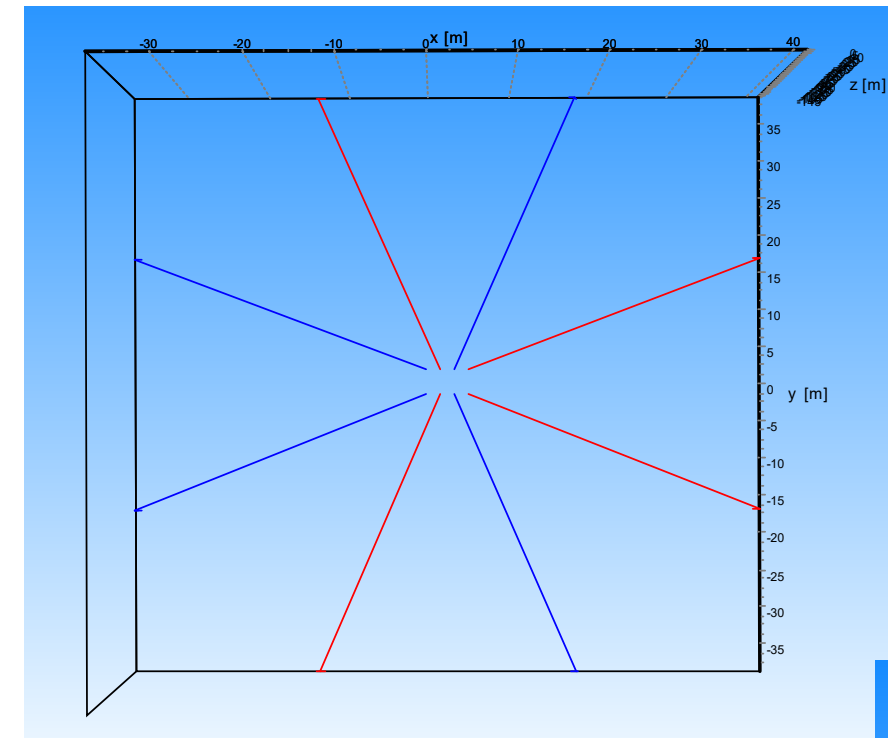
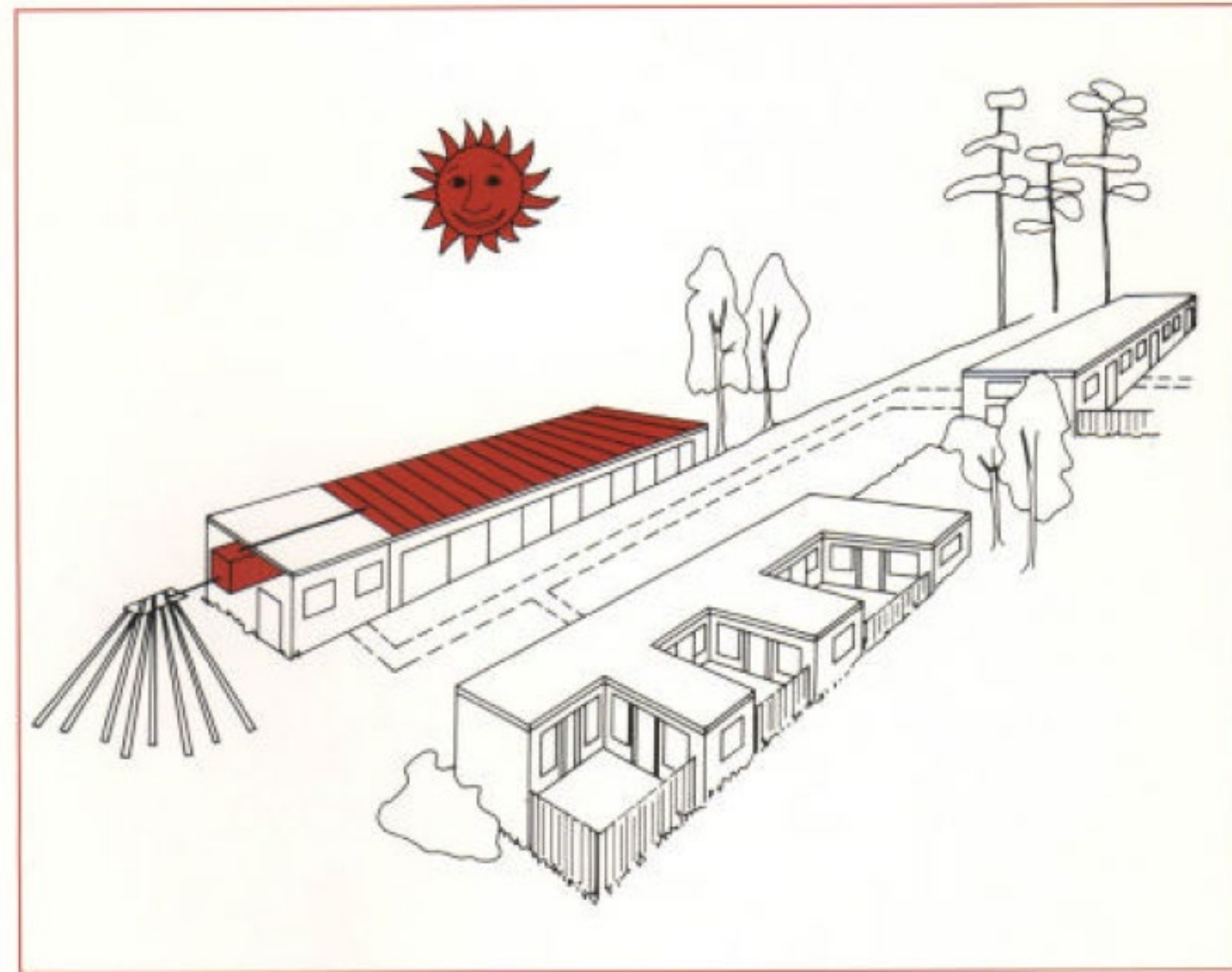
1977 Sigtuna, Sweden



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

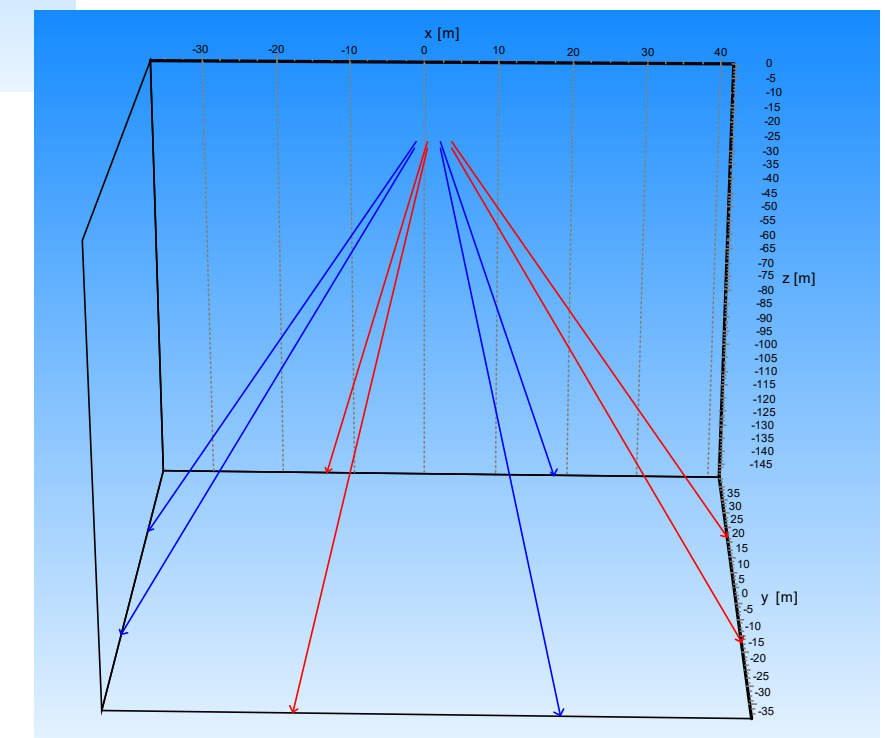
Ground temperatures after 24 months of charging with 15 kW

1983 Vattenfall, Stockholm, Sweden



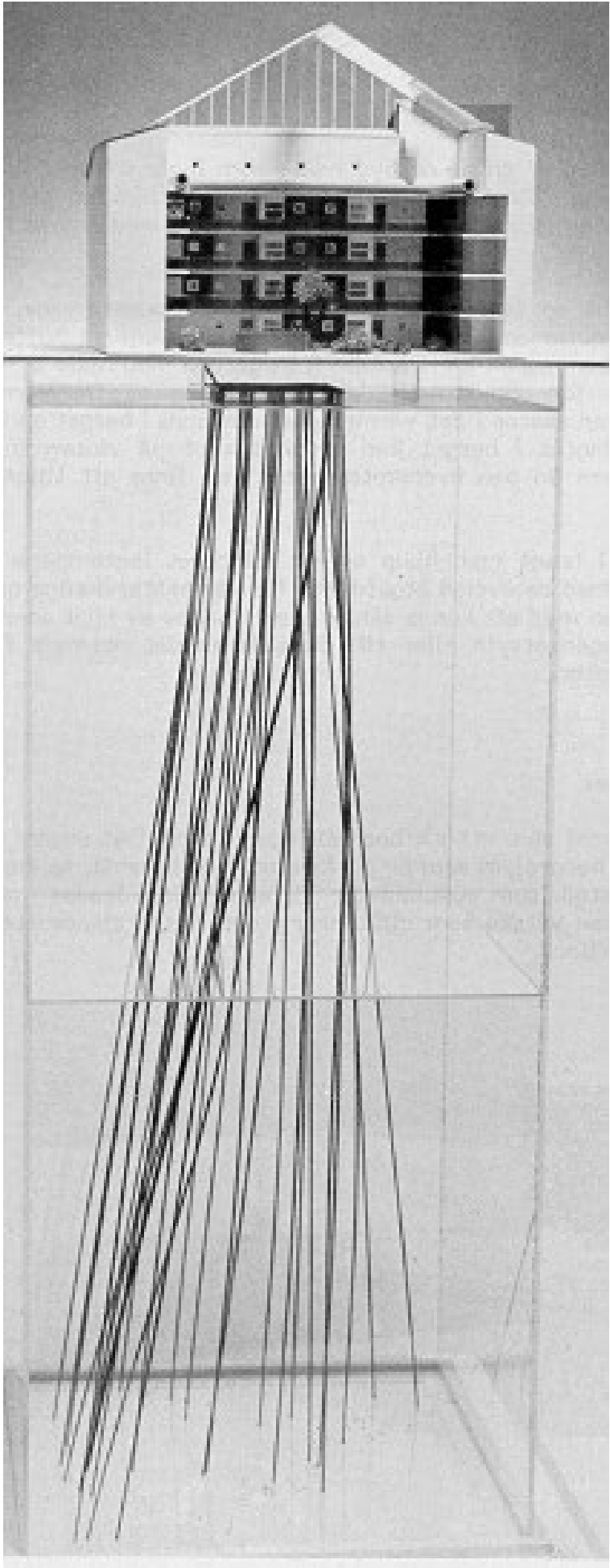
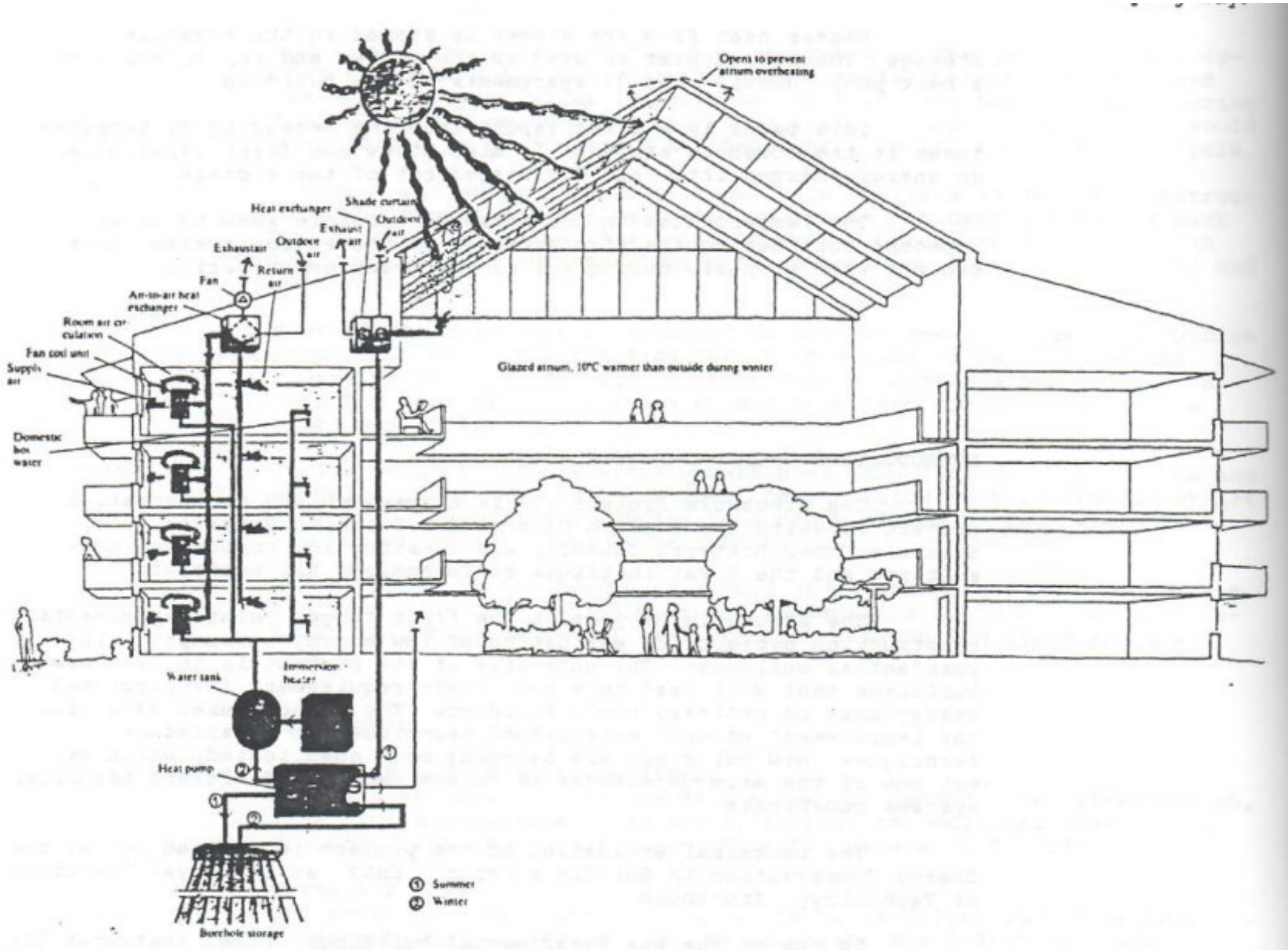
Borehole spacing 5 ft at ground surface

Footprint 15 ft x 5 ft



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

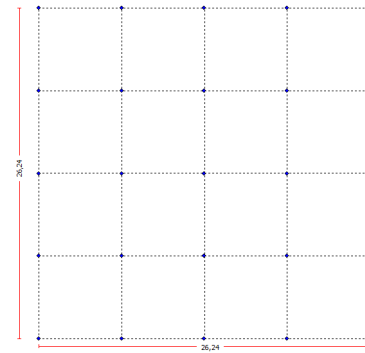
1986 SunCourt, Stockholm



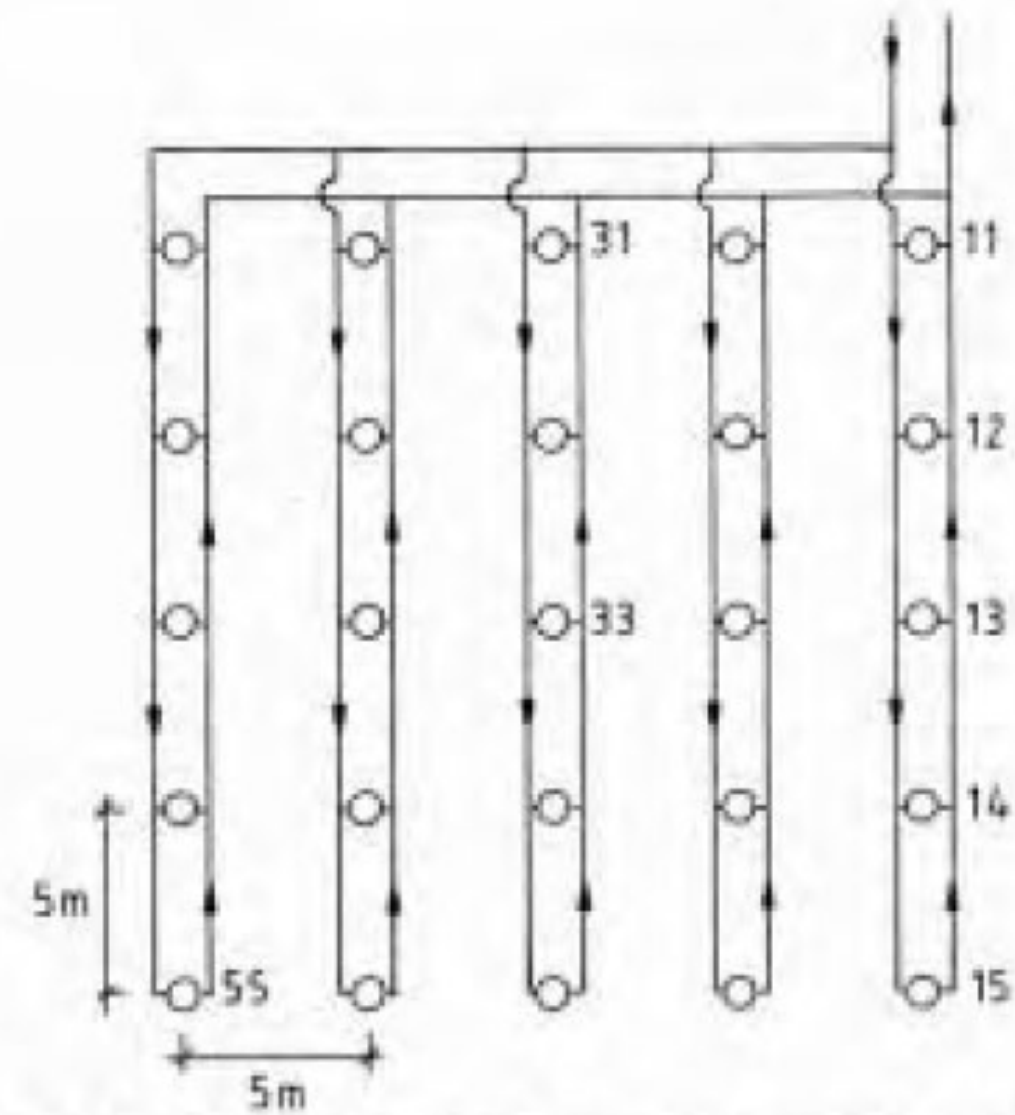
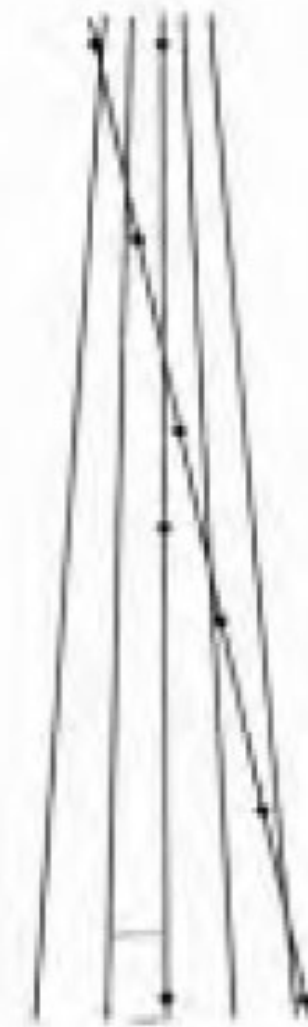
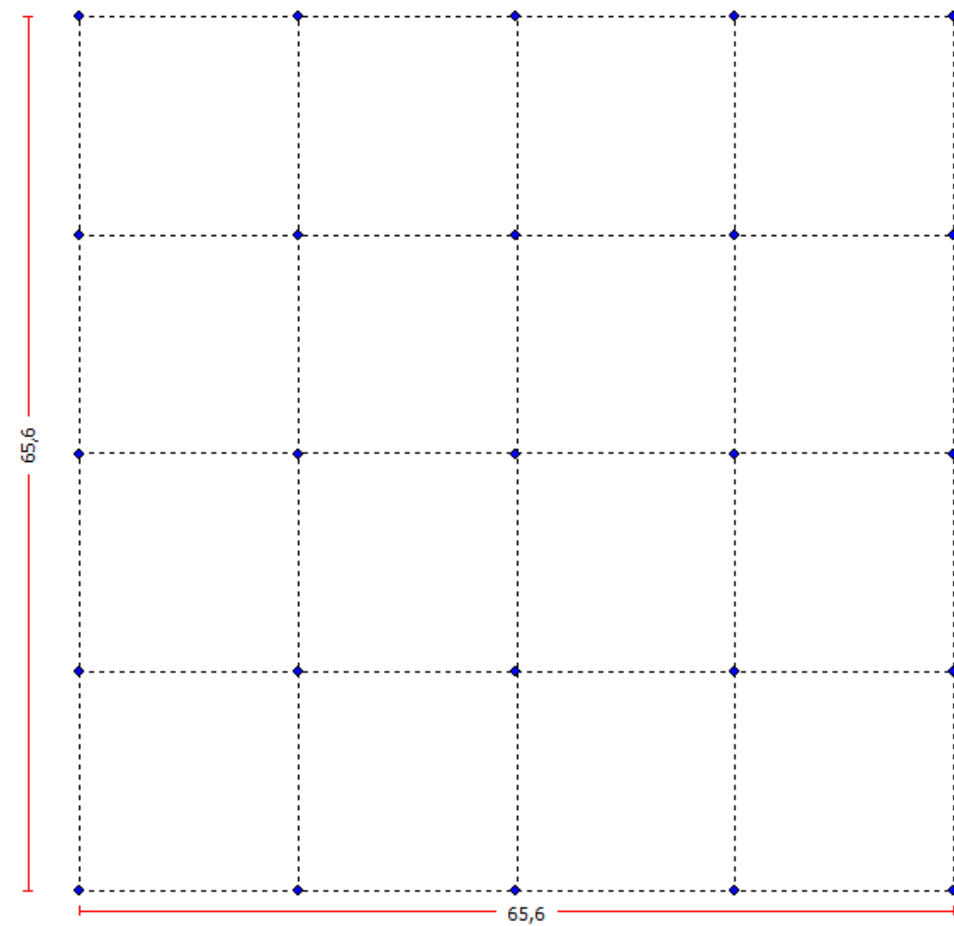
1986 SunCourt, Stockholm

Ground surface
6.5 ft spacing

Footprint 26 ft x 26 ft

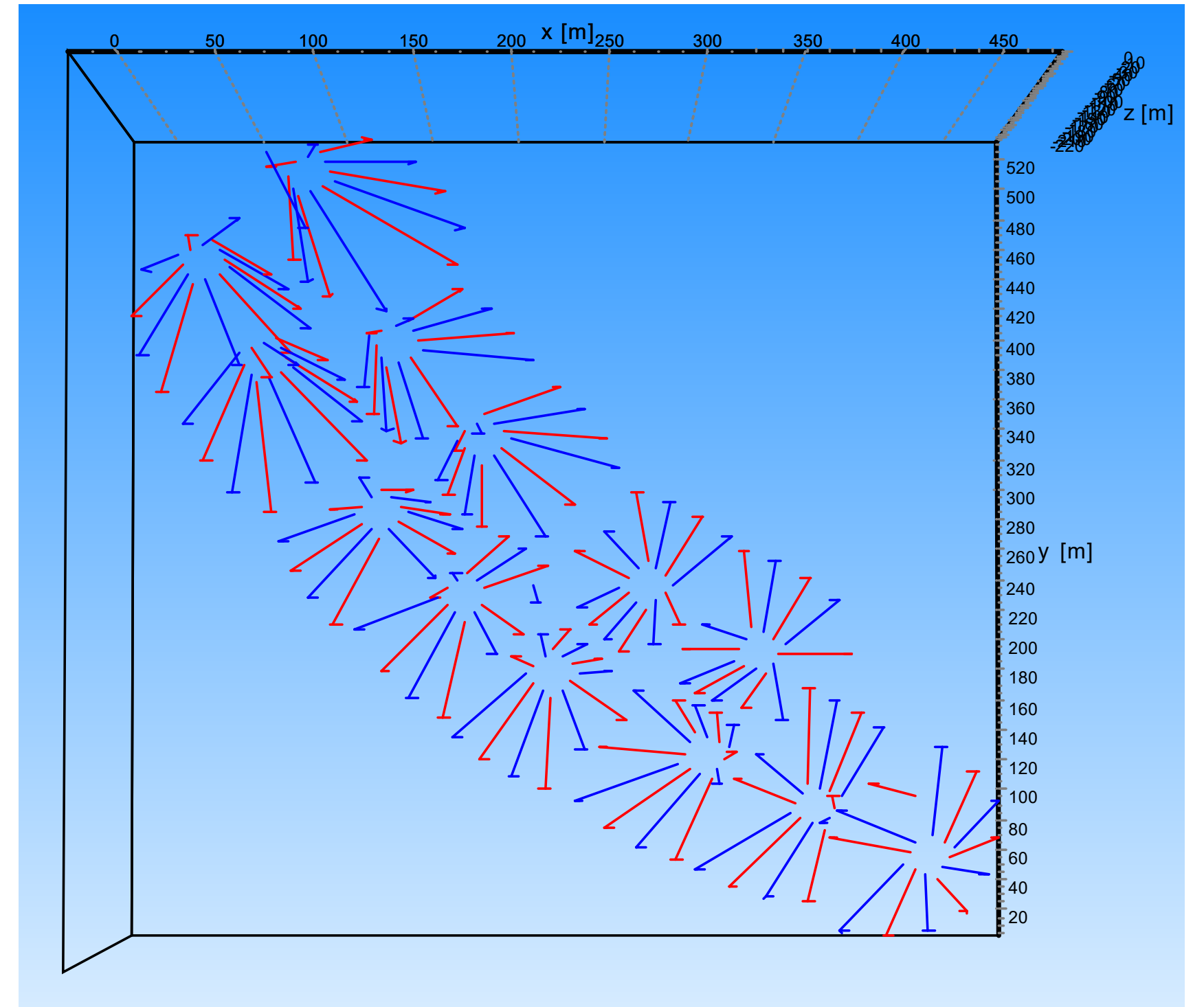
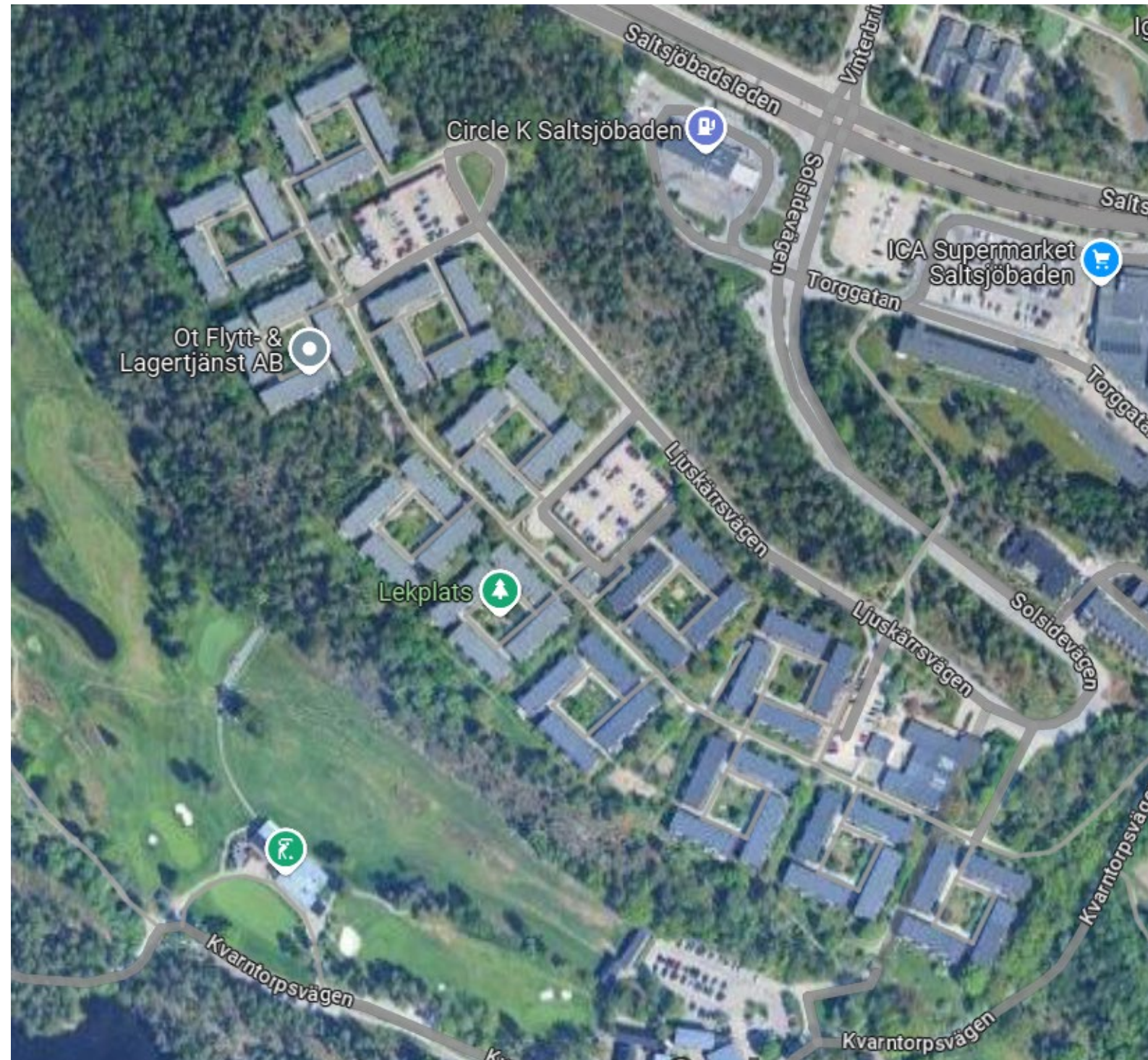


Bottom
16.4 ft spacing



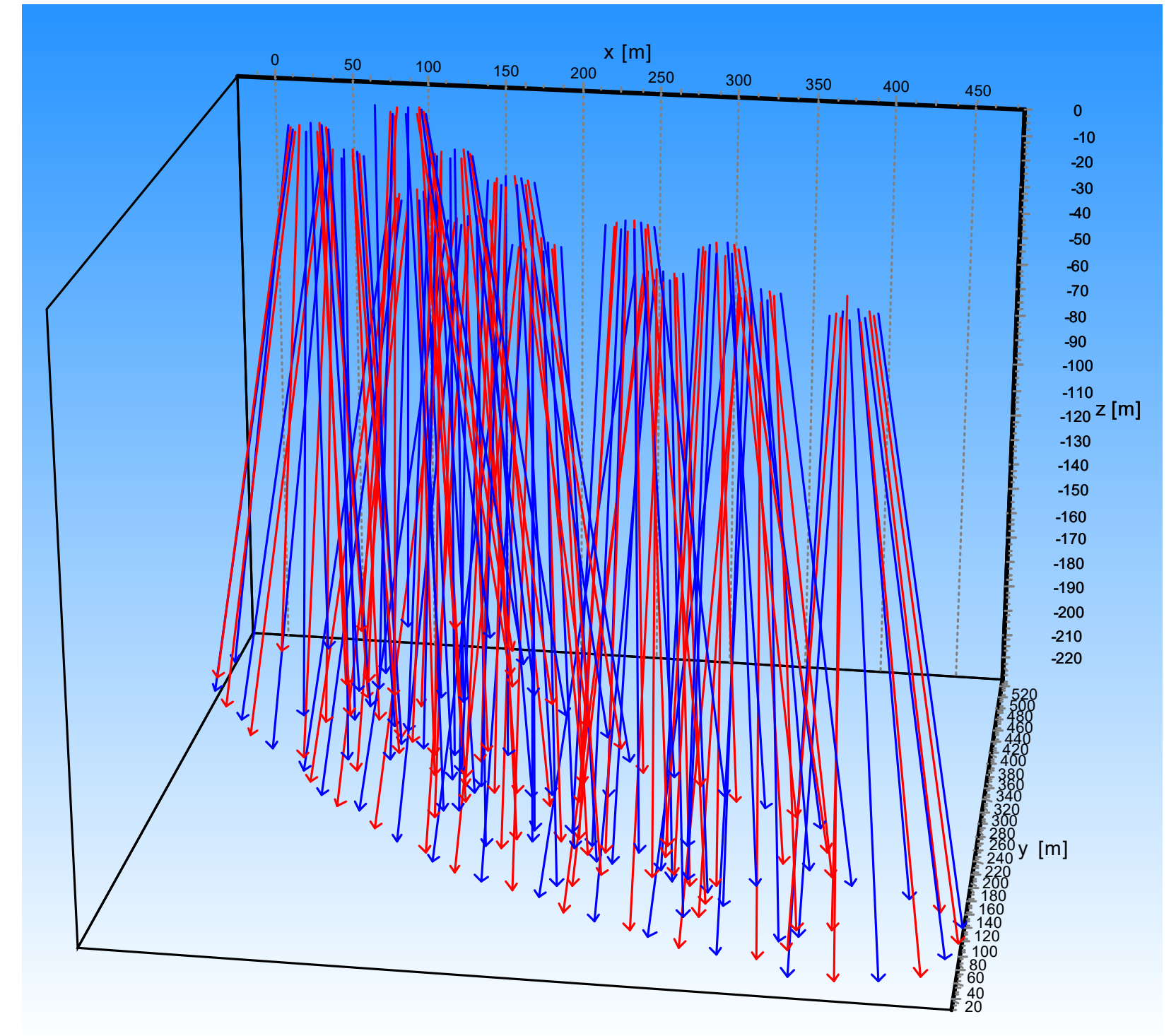
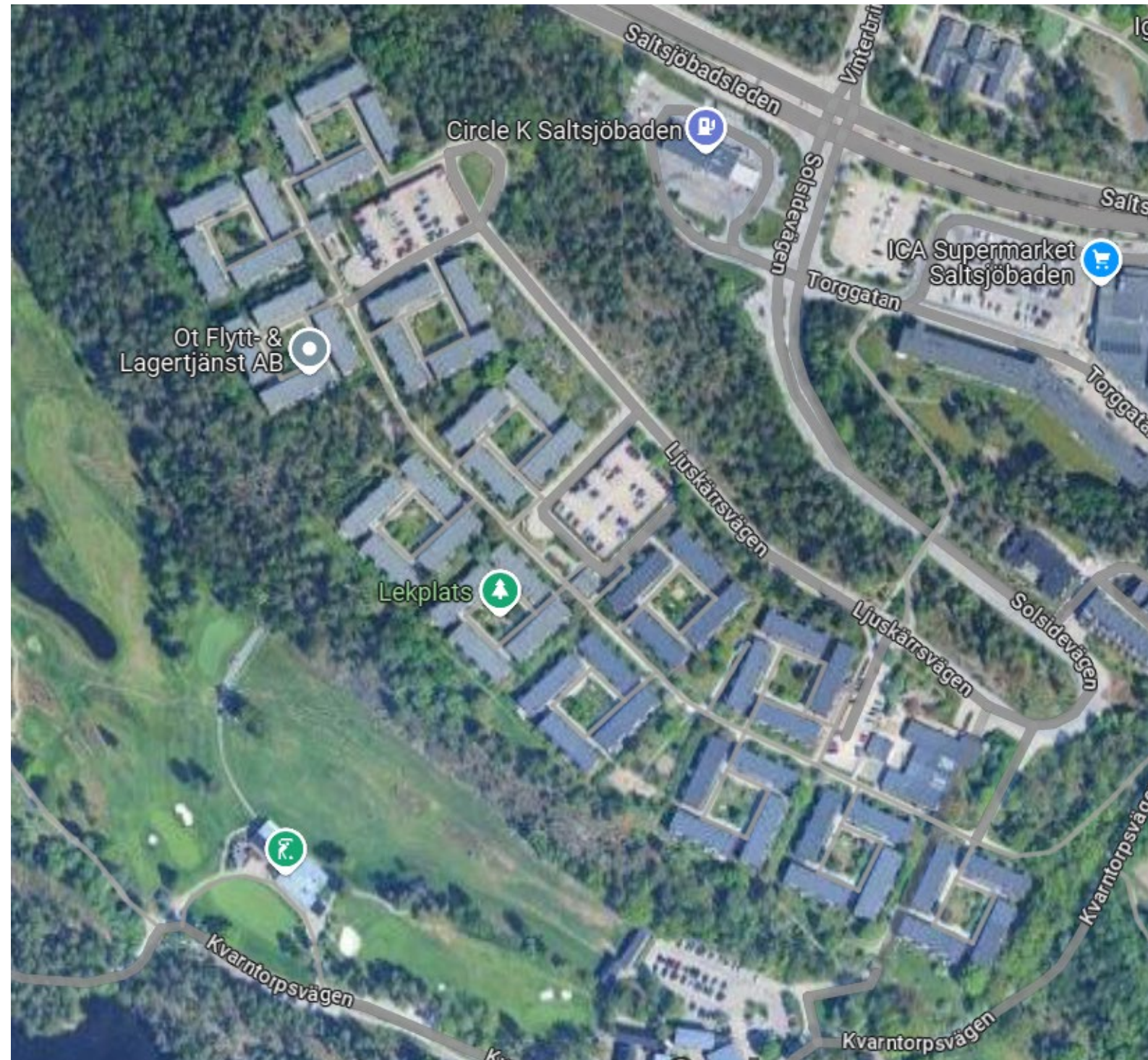
25 boreholes, 260 ft deep. Maximum inclination 8.6°.

2008 Ljuskärretsberget, 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)

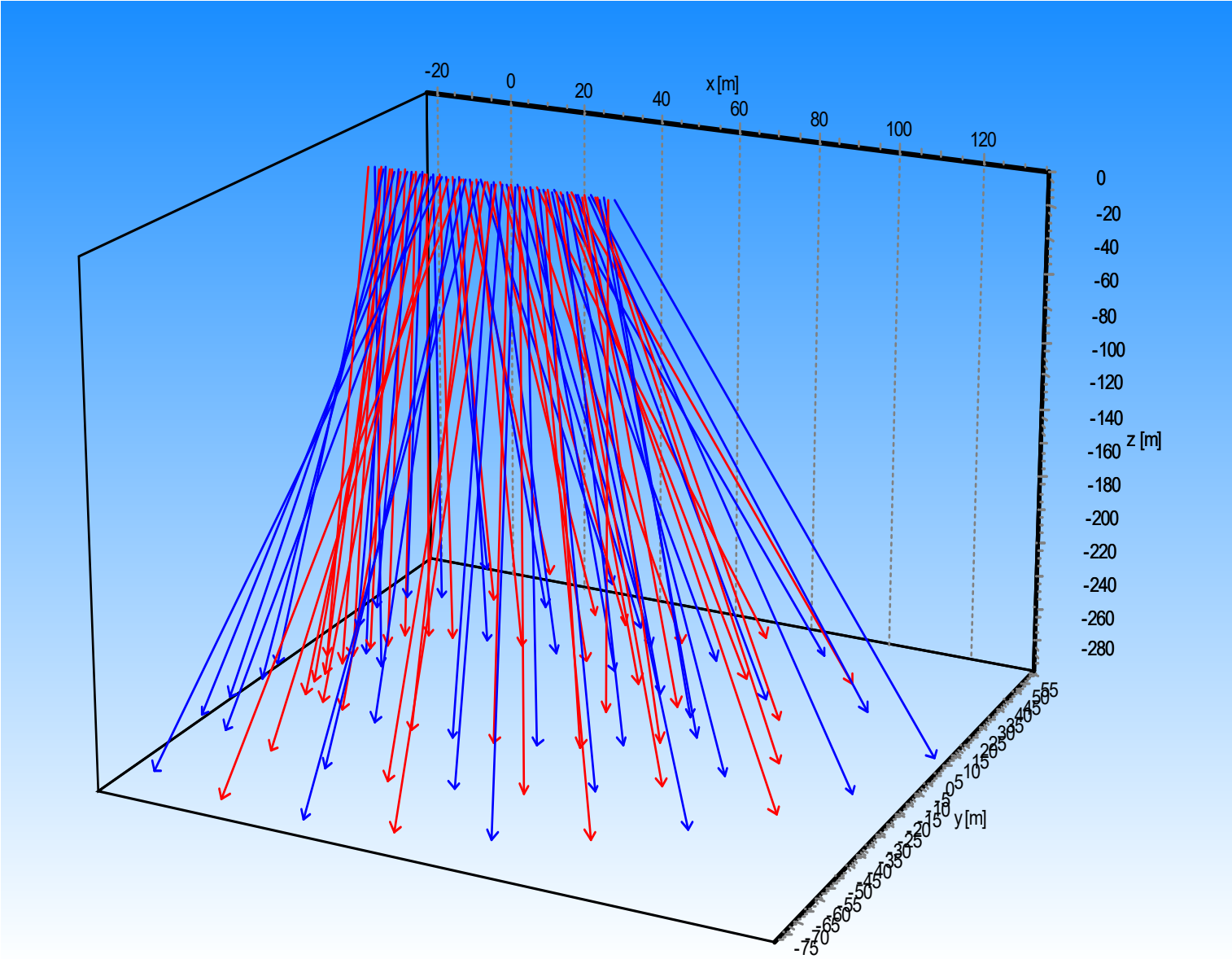
CAMPUS KONRADSBERG

- Heating with heat pump 5000 MWh/year

Common BTES

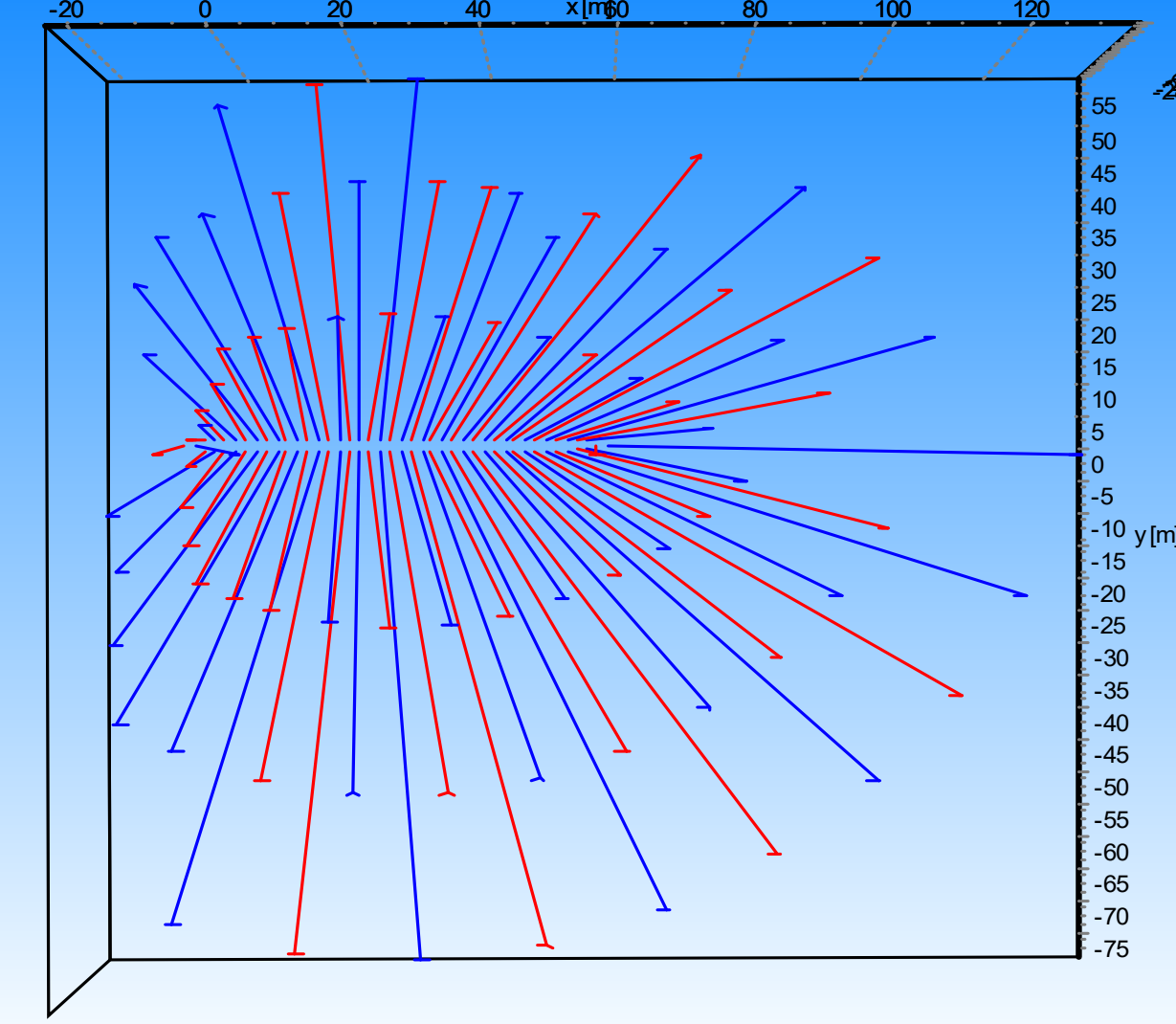
- 82 boreholes x 1000 ft

2014 Fredhäll dataservert/Campus Konradsberg

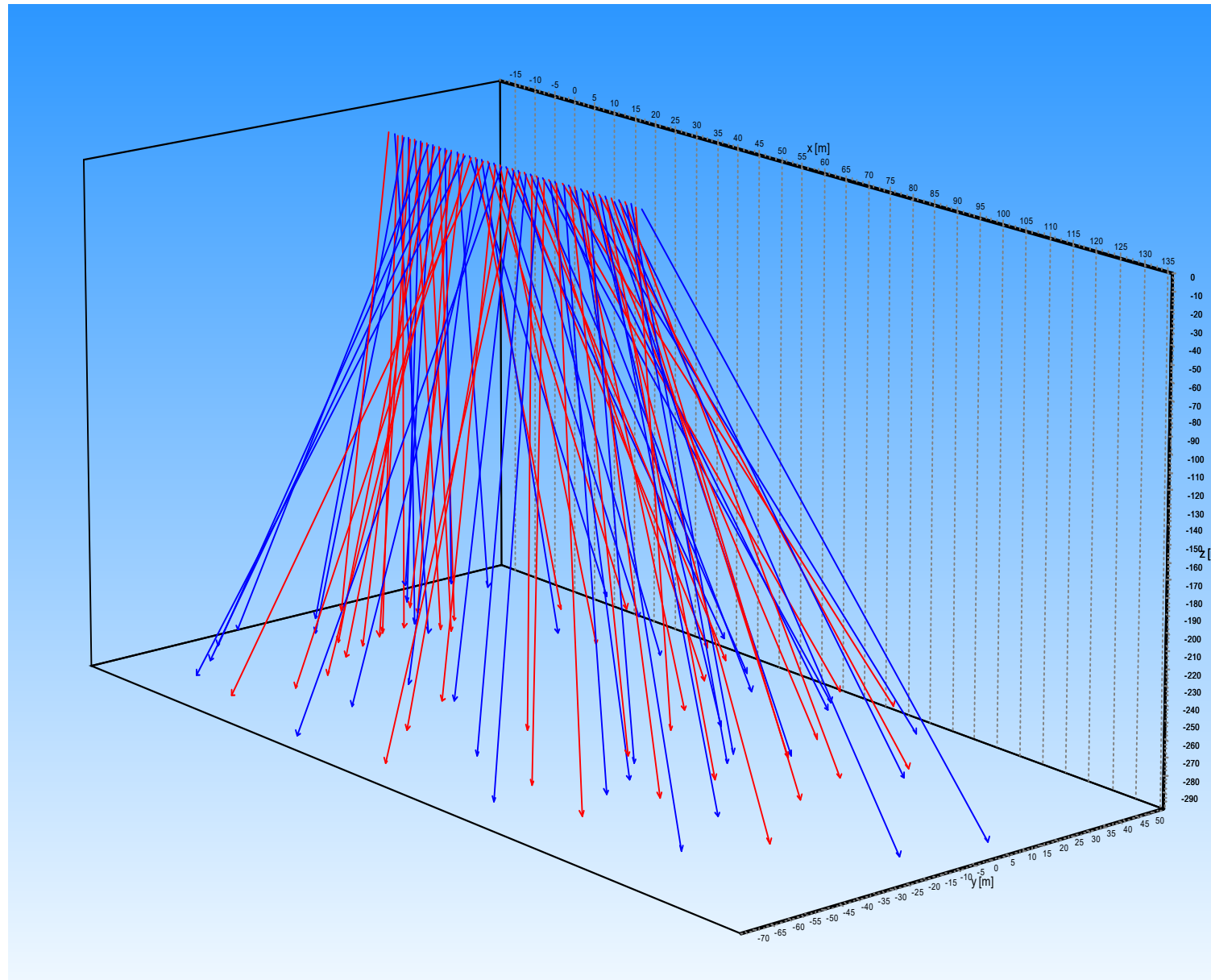


82 boreholes
1000 ft

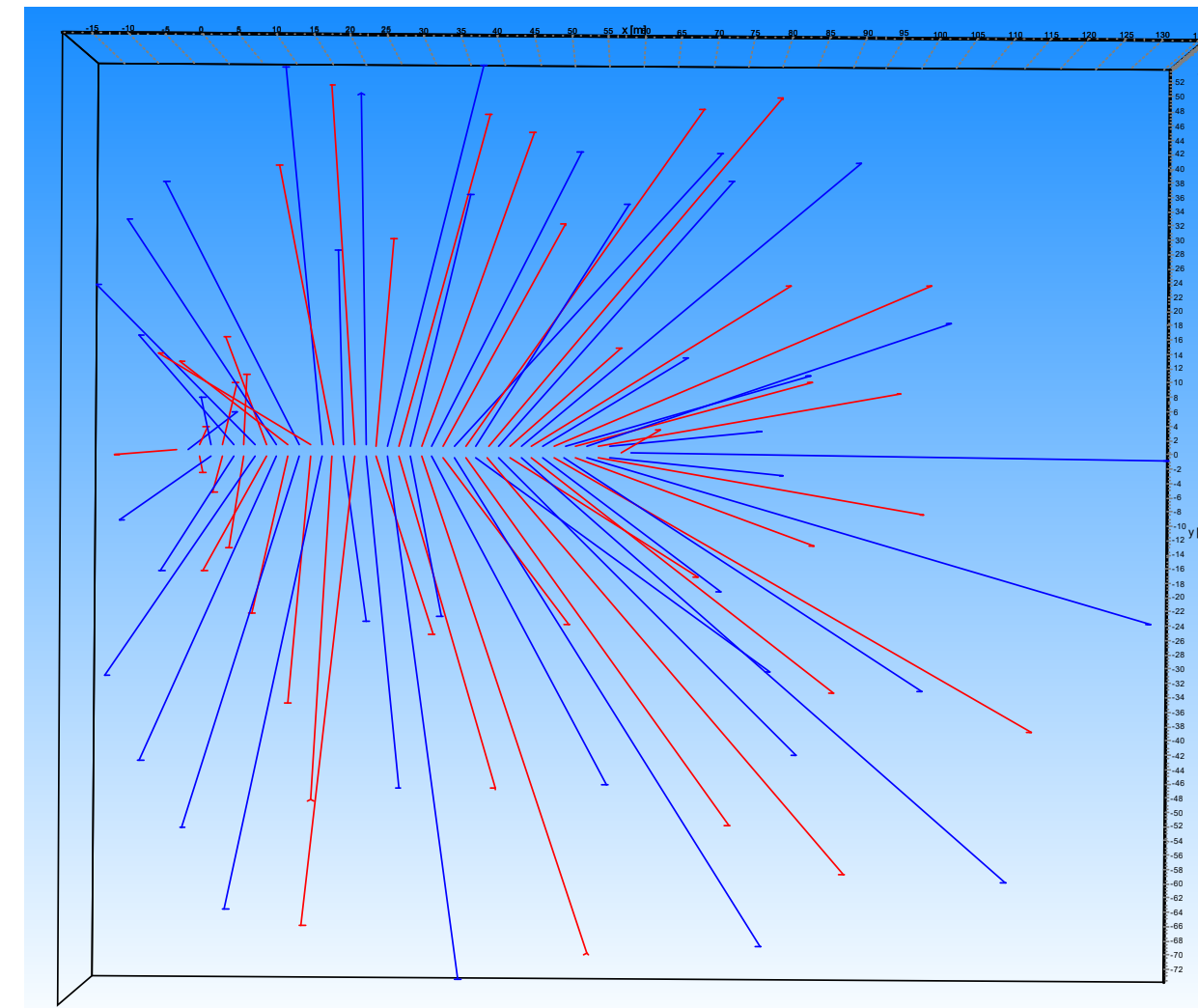
Borehole configuration layout as planned



2014 Fredhäll dataservert/Campus Konradsberg



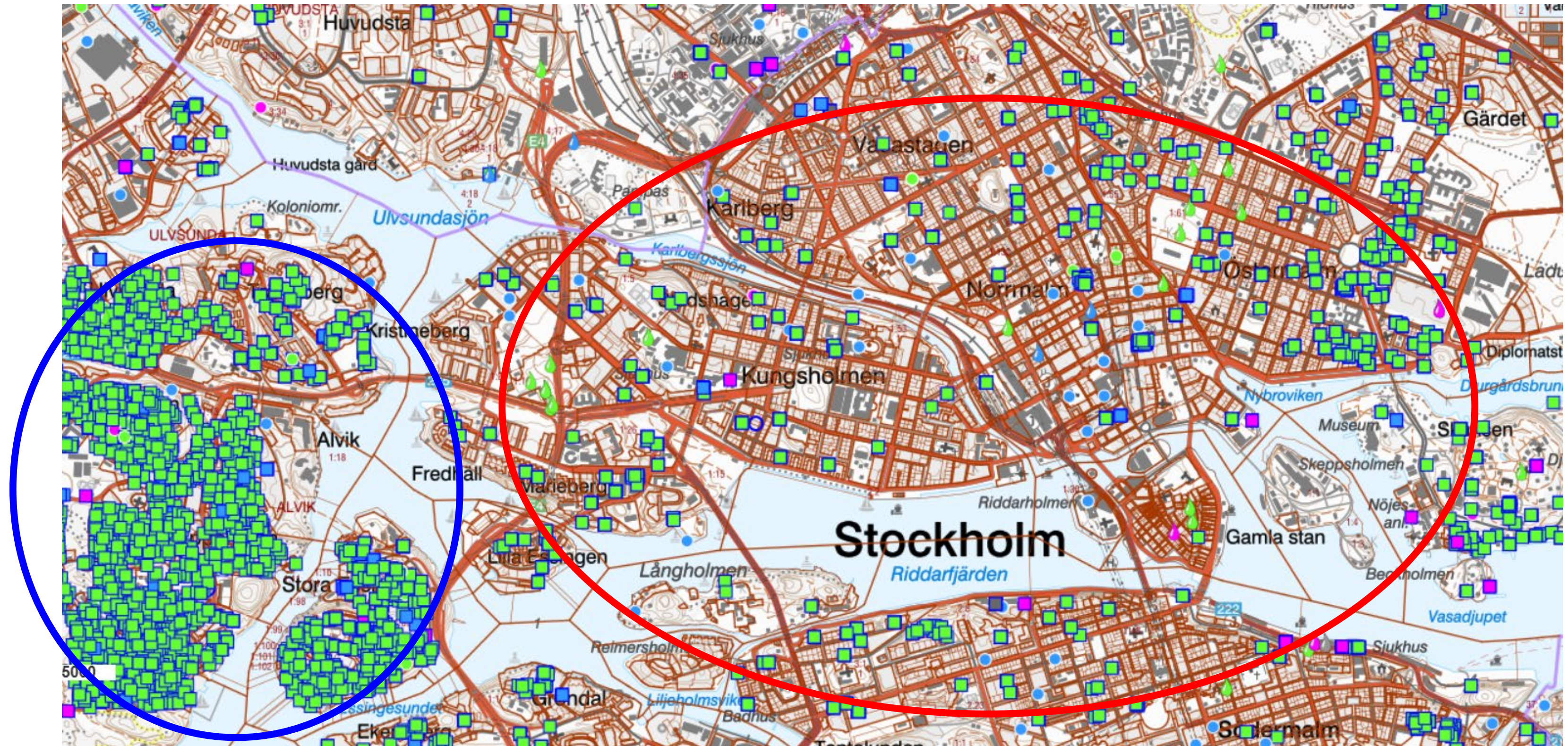
Borehole configuration as measured



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

Geoenery in city centre

Stockholm City Council – Inclined boreholes fully approved concept

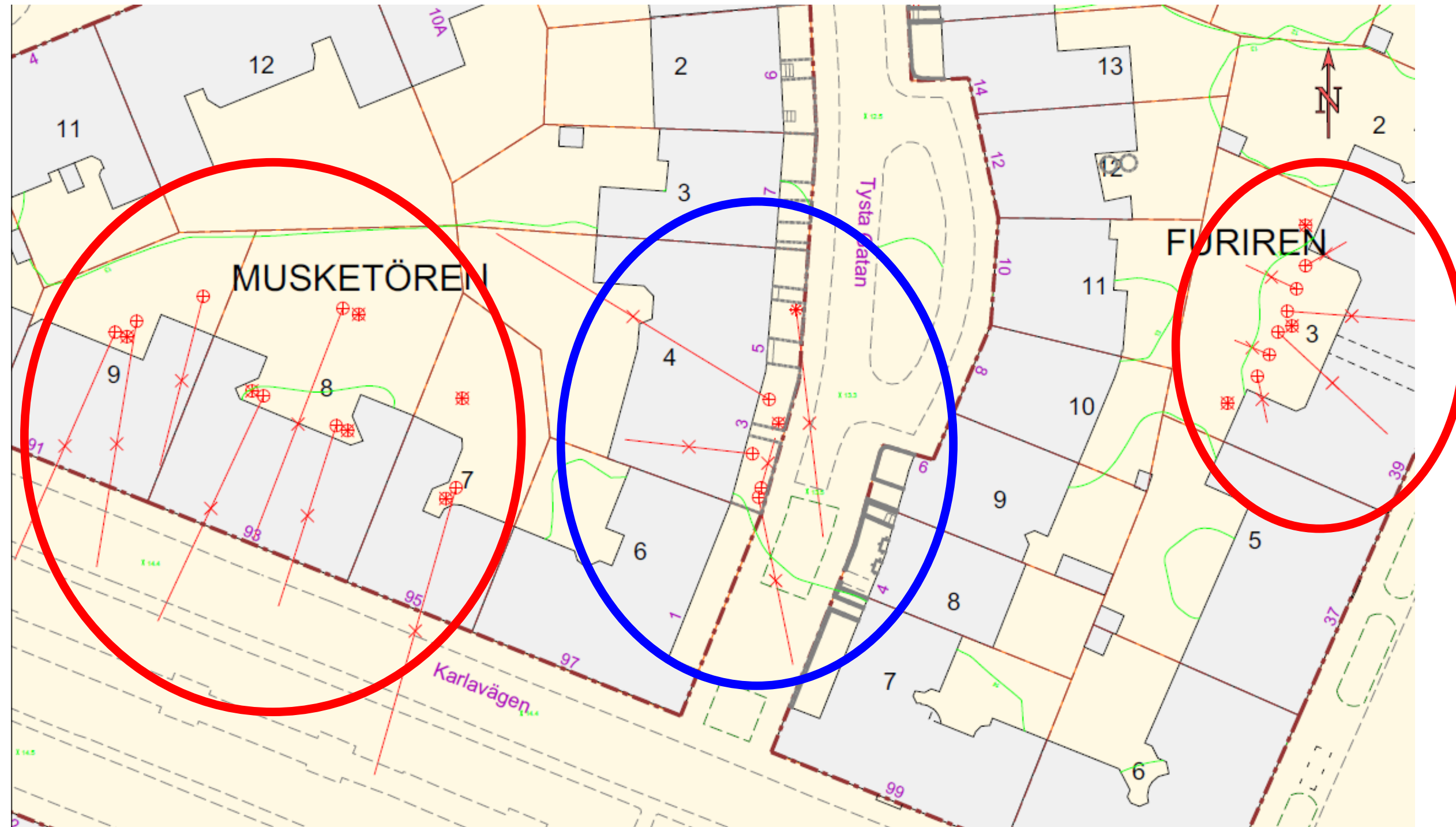


Single-family houses

Apartment and office buildings

Geoenery in city centre

Stockholm City Council – Inclined boreholes fully approved concept



Drilling on inner court

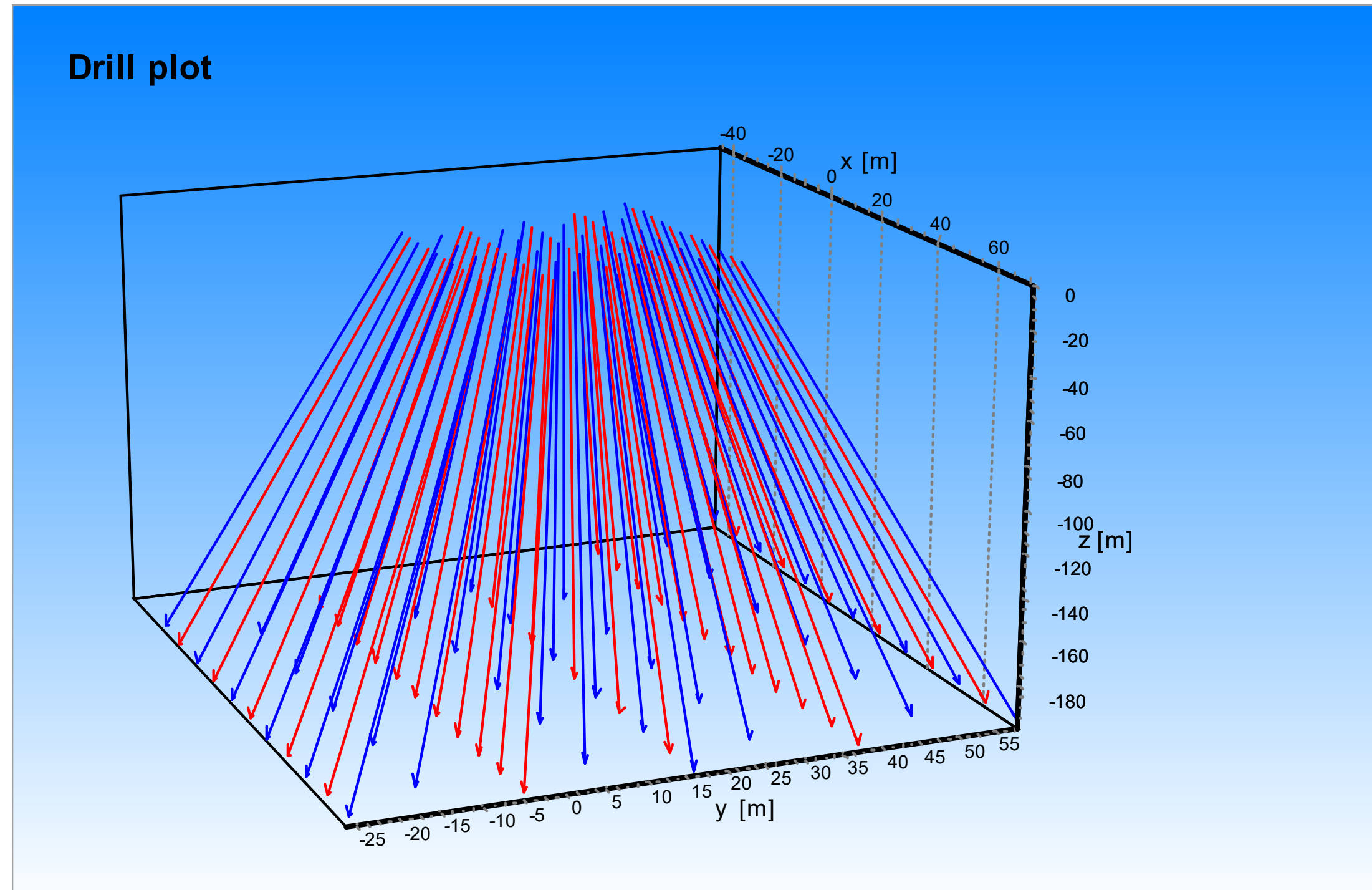
Drilling from the street

Also possible to drill from garages

About 2/3 of all boreholes are inclined

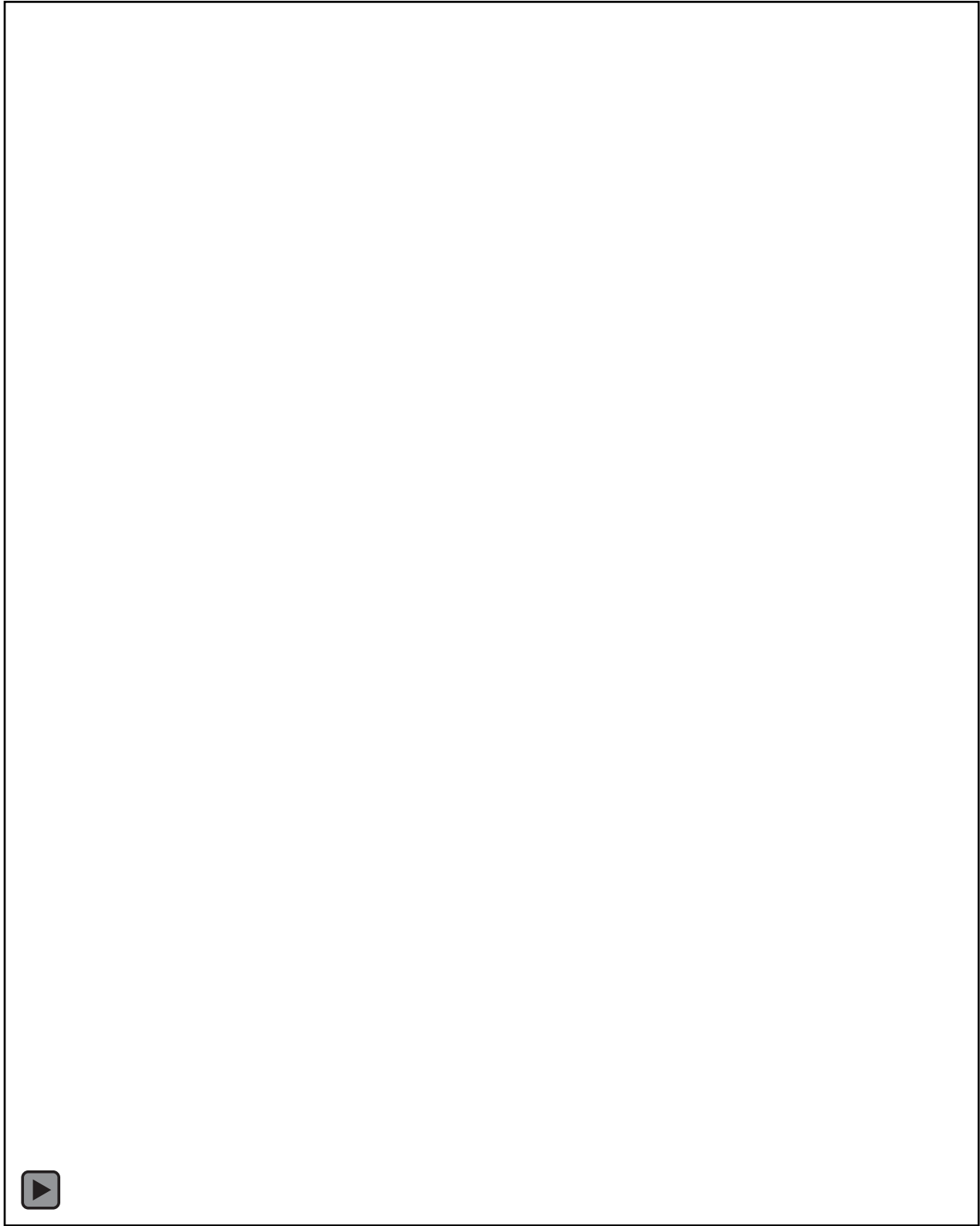
Inclined boreholes in order to reach larger ground volume

2018 Frölunda torg, Gothenburg, Sweden

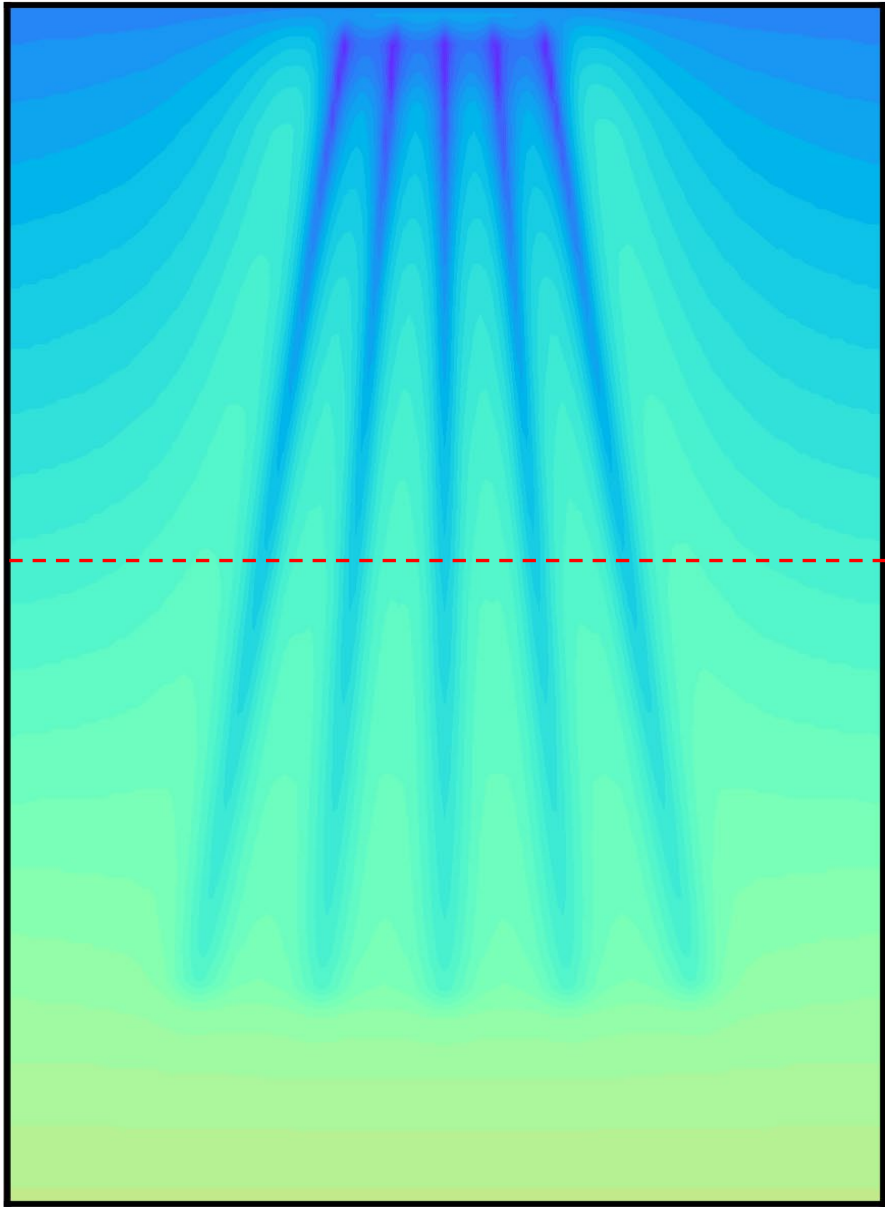


80 boreholes drilled from an old bowling alley under a shopping mall
Borehole depth 655 ft, maximum inclination 14°

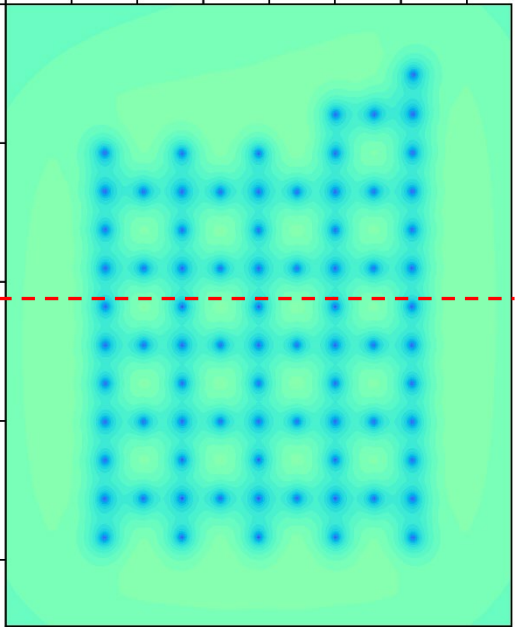
2018 Frölunda torg, Gothenburg, Sweden



Five year animation of balanced system



Vertical



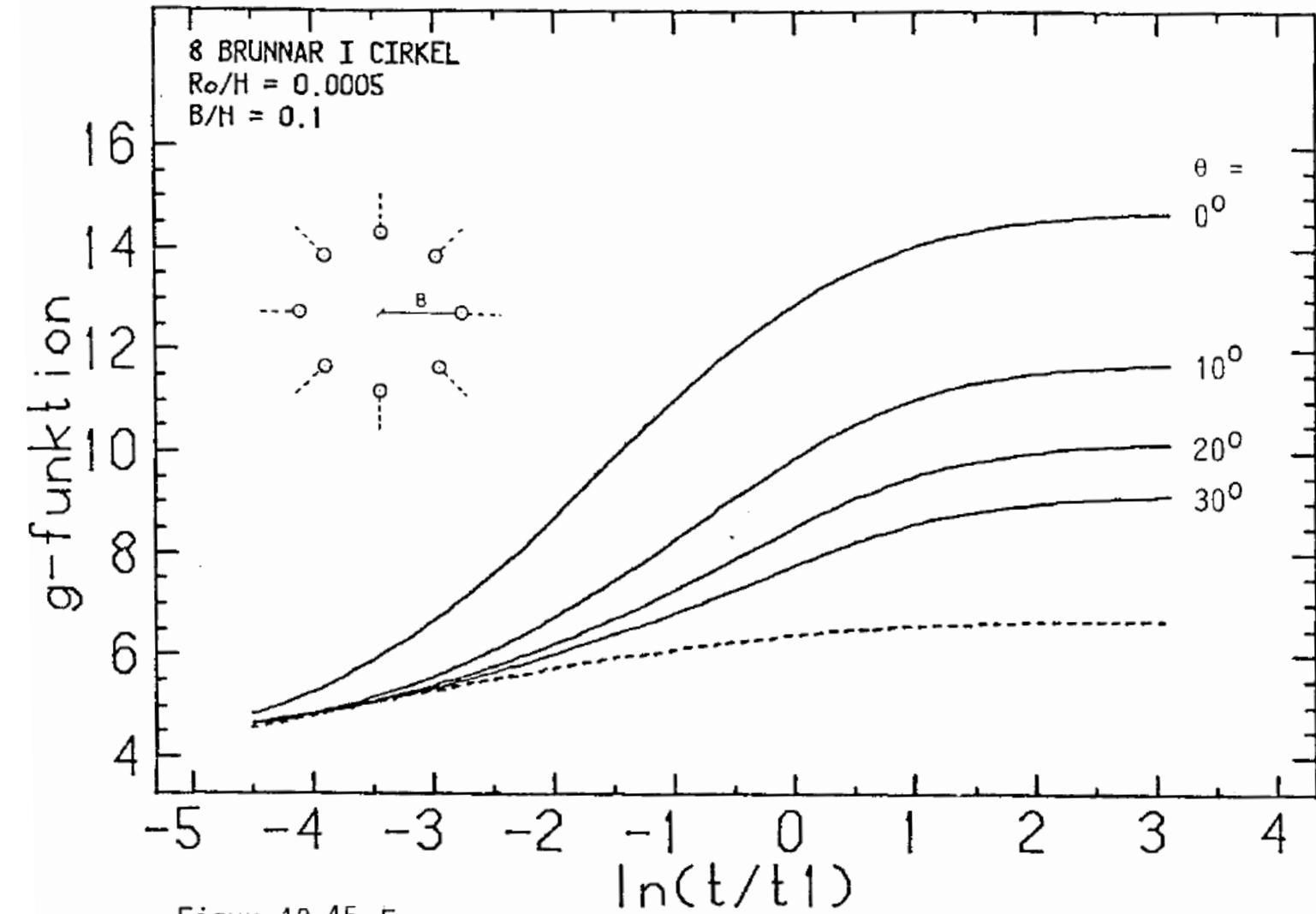
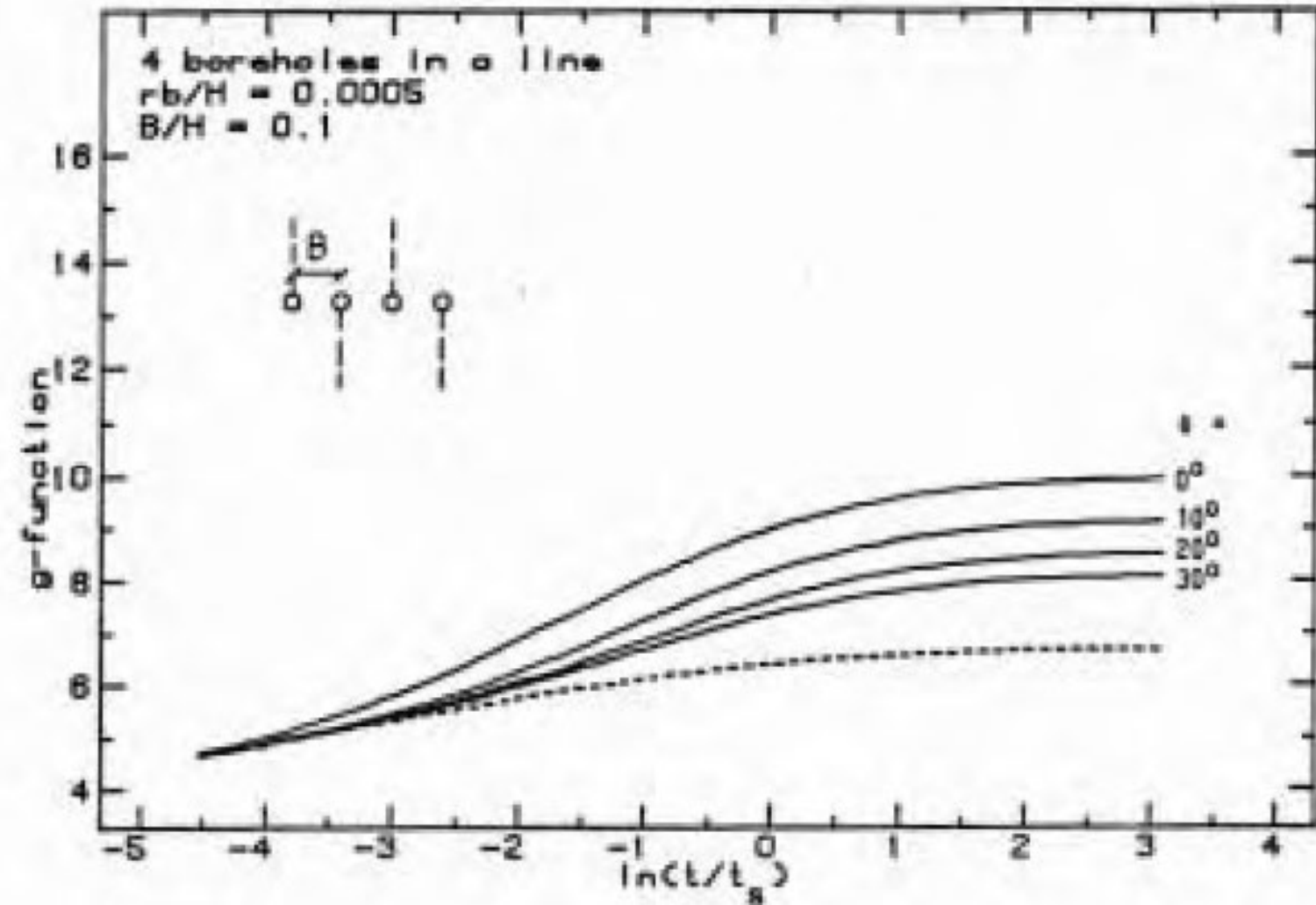
Horizontal mid-depth

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

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



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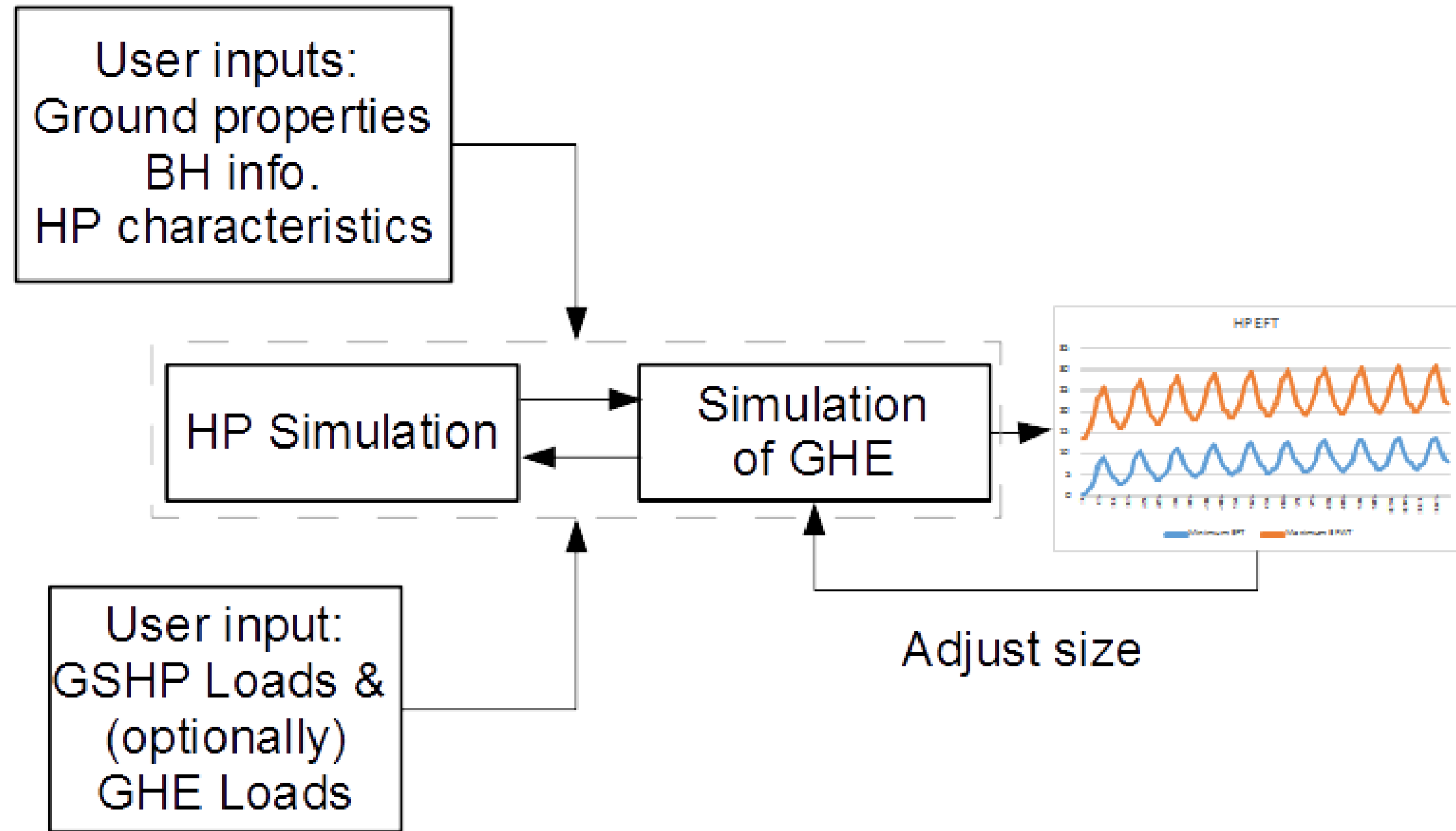
Designing angled borehole ground heat exchangers with GLHEPRO

Speaker: Jeffrey D. Spitler

**School of Mechanical and Aerospace Engineering
Oklahoma State University**

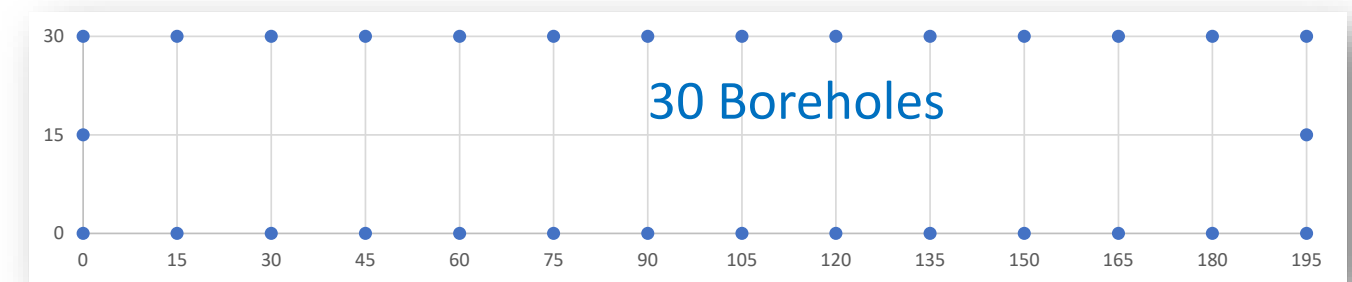
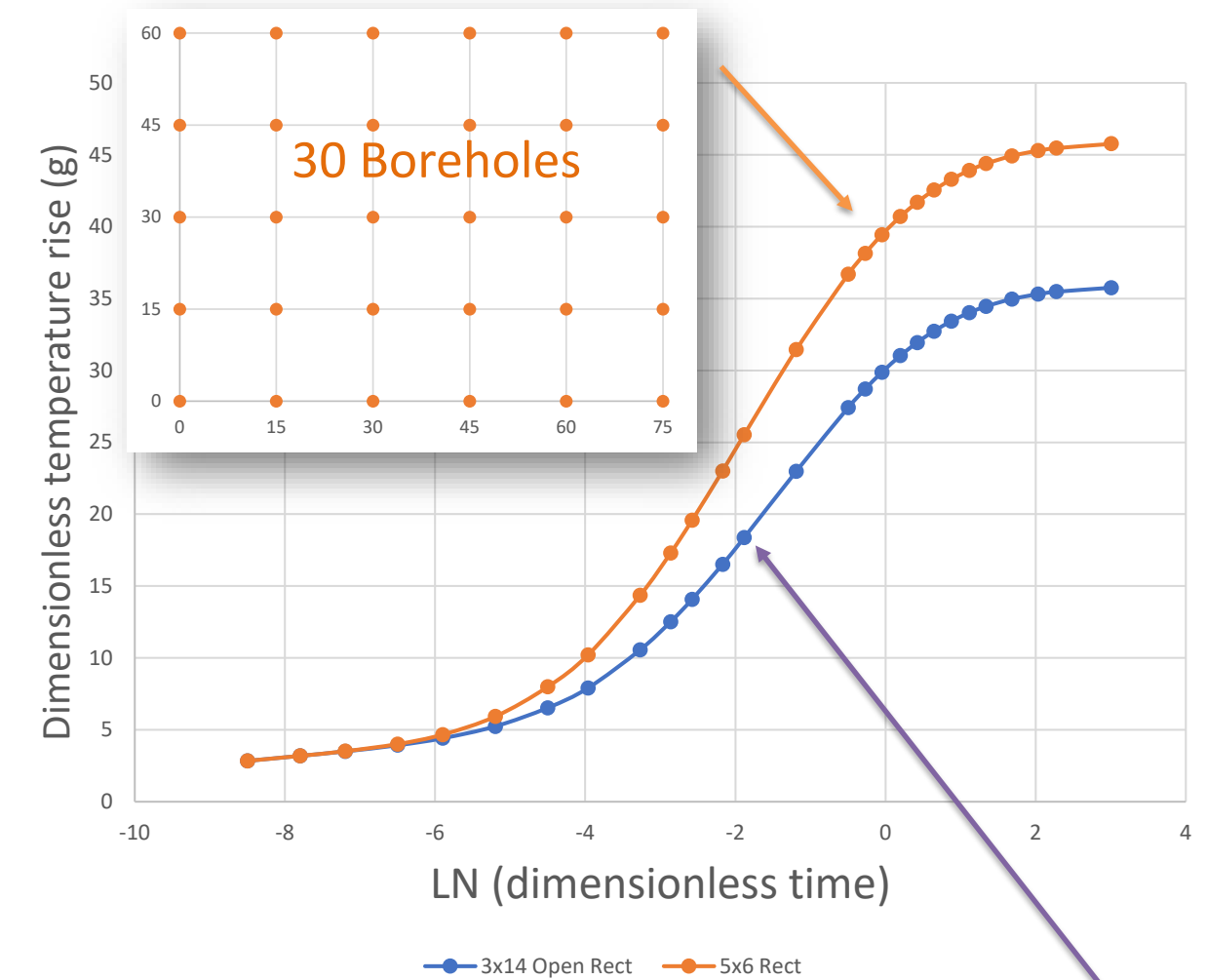
GLHEPRO background

- 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.

Borehole Locations

Define a system of boreholes. You may include any combination of up to 30 vertical and inclined boreholes.

Borehole #	Head (x,y,z) [ft]	Length [ft]	Inclination Angle [°from Vertical]	Direction Angle [°from N(+y)]
1	0.00,2.00,5.00	700.00	10	0
2	1.29,1.53,5.00	700.00	20	40
3	1.97,0.35,5.00	700.00	10	80
4	1.73,-1.00,5.00	700.00	20	120
5	0.68,-1.88,5.00	700.00	10	160
6	-0.68,-1.88,5.00	700.00	20	200
7	-1.73,-1.00,5.00	700.00	10	240
8	-1.97,0.35,5.00	700.00	20	280
9	-1.29,1.53,5.00	700.00	10	320

Edit

Add

Modify

Delete

Files

Import File

Export File

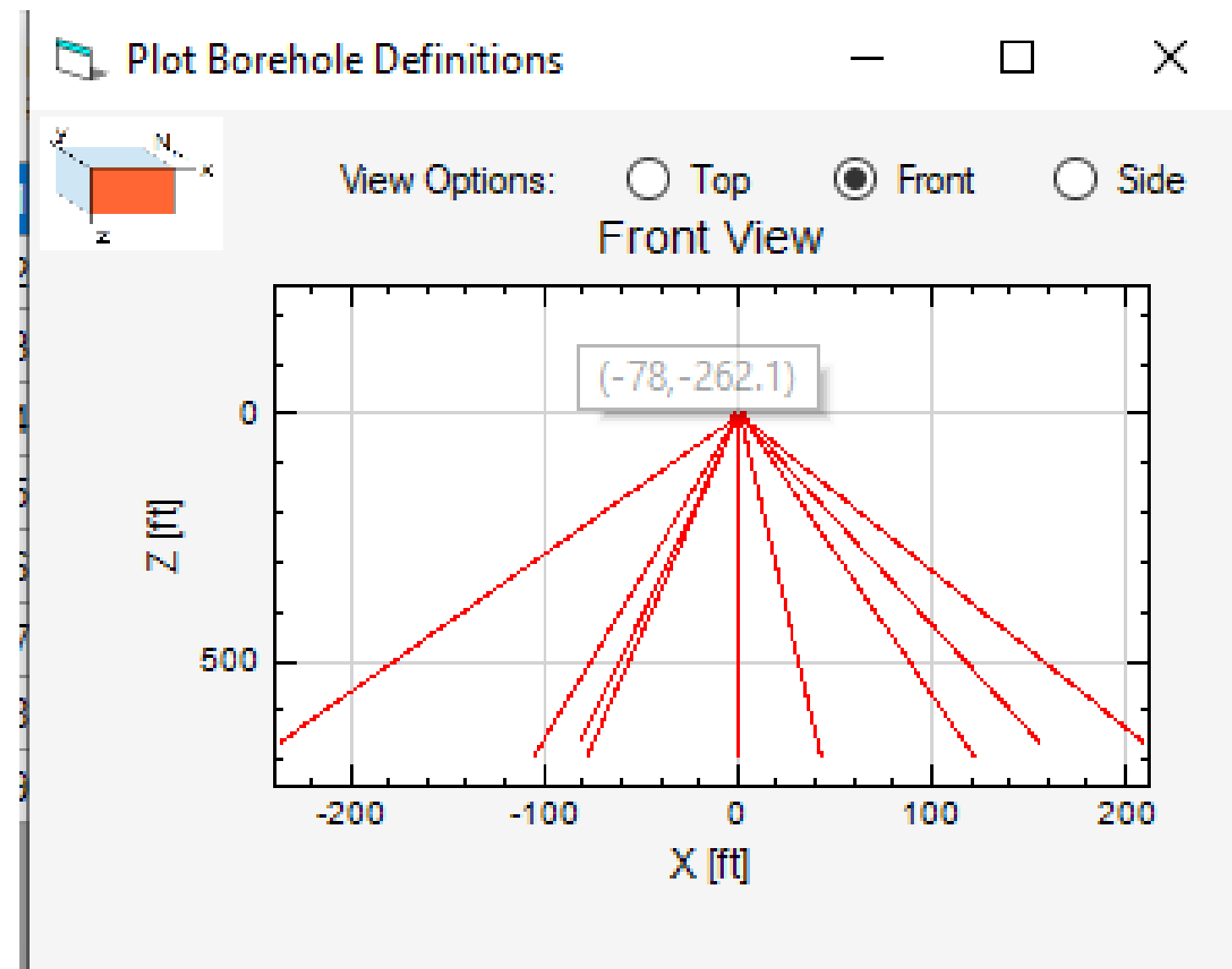
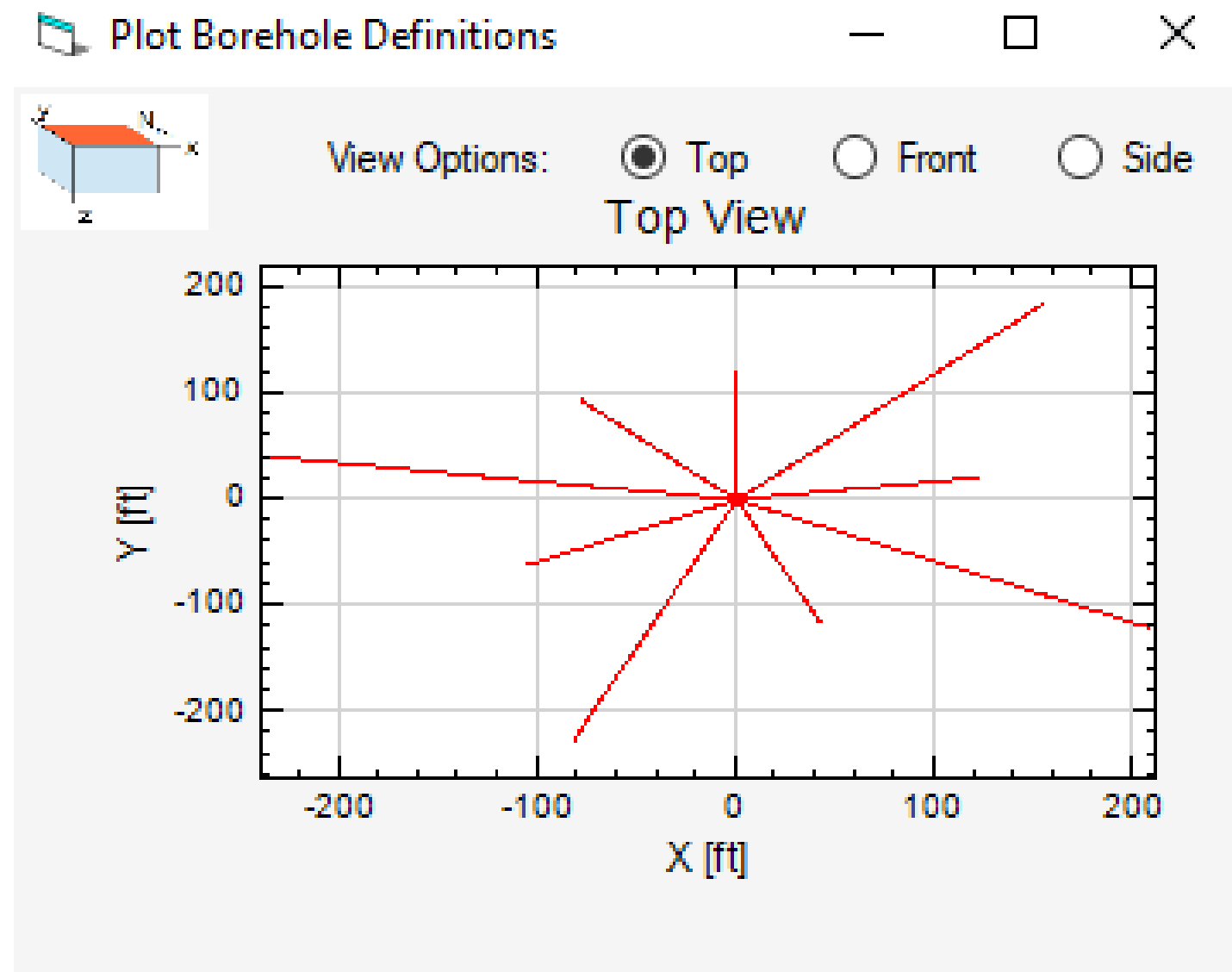
View

View System

Ok

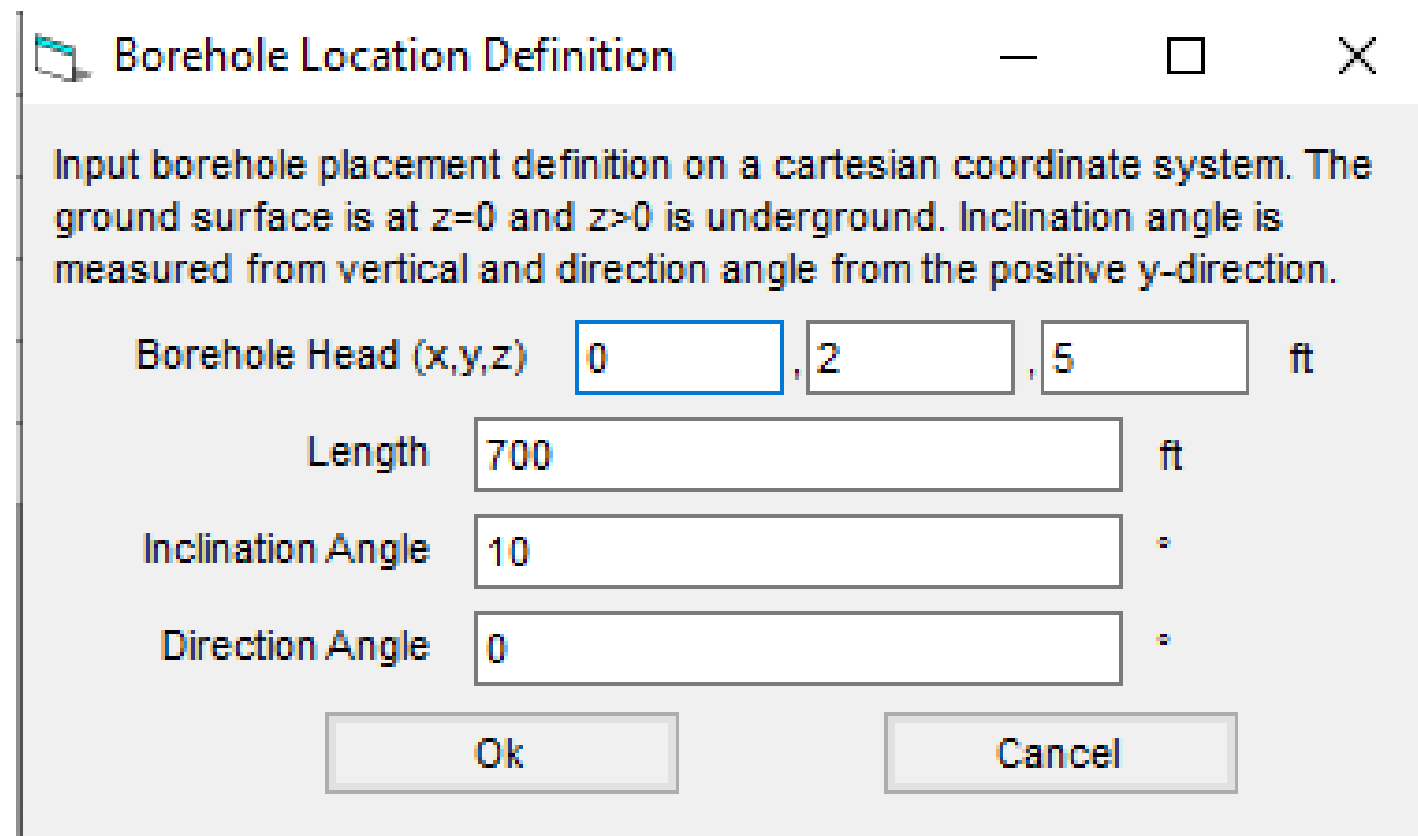
Cancel

Boreholes



GLHEPRO FPFLS

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



Borehole Location Definition

Input borehole placement definition on a cartesian coordinate system. The ground surface is at $z=0$ and $z>0$ is underground. Inclination angle is measured from vertical and direction angle from the positive y-direction.

Borehole Head (x,y,z) , , ft

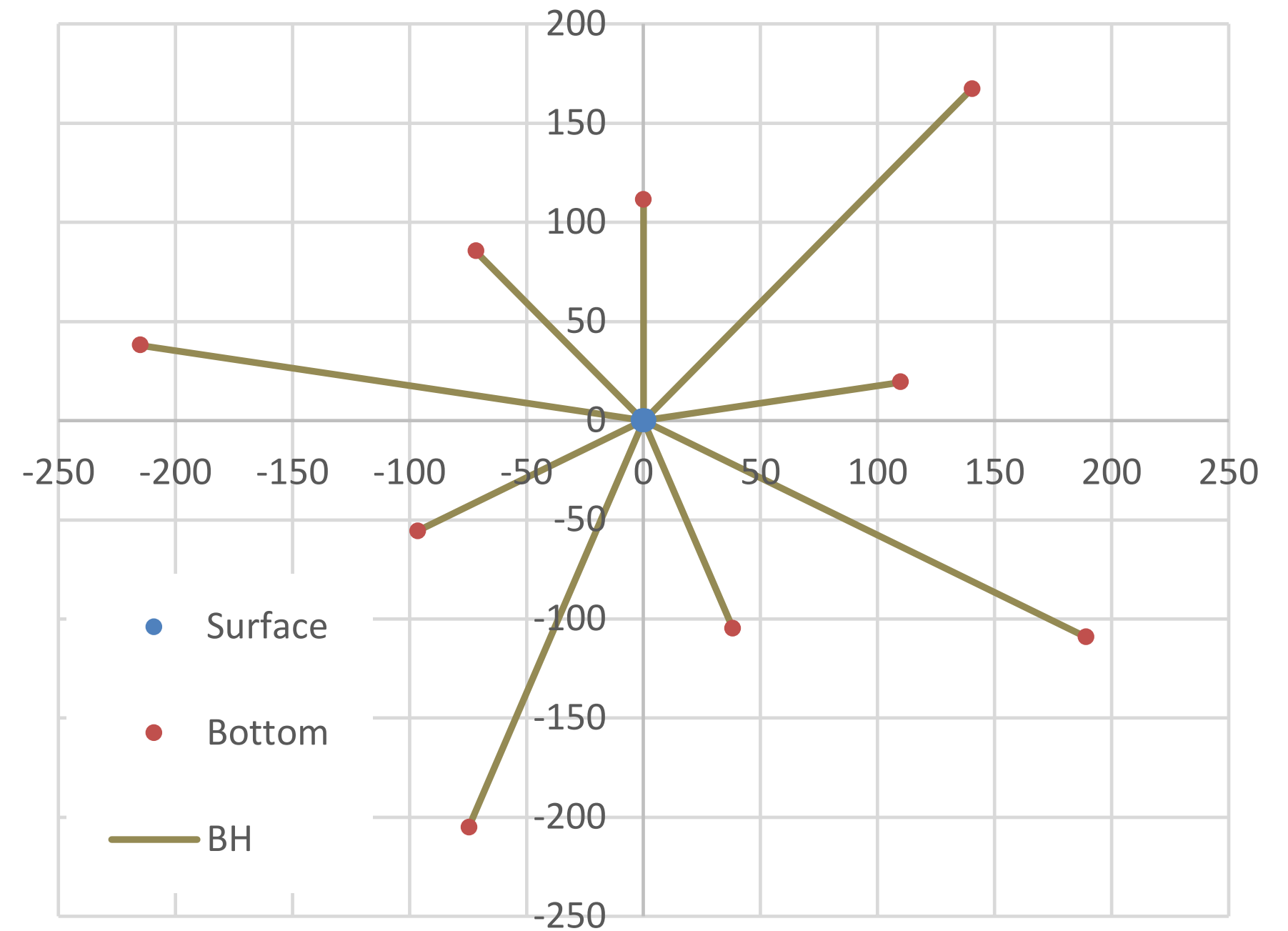
Length ft

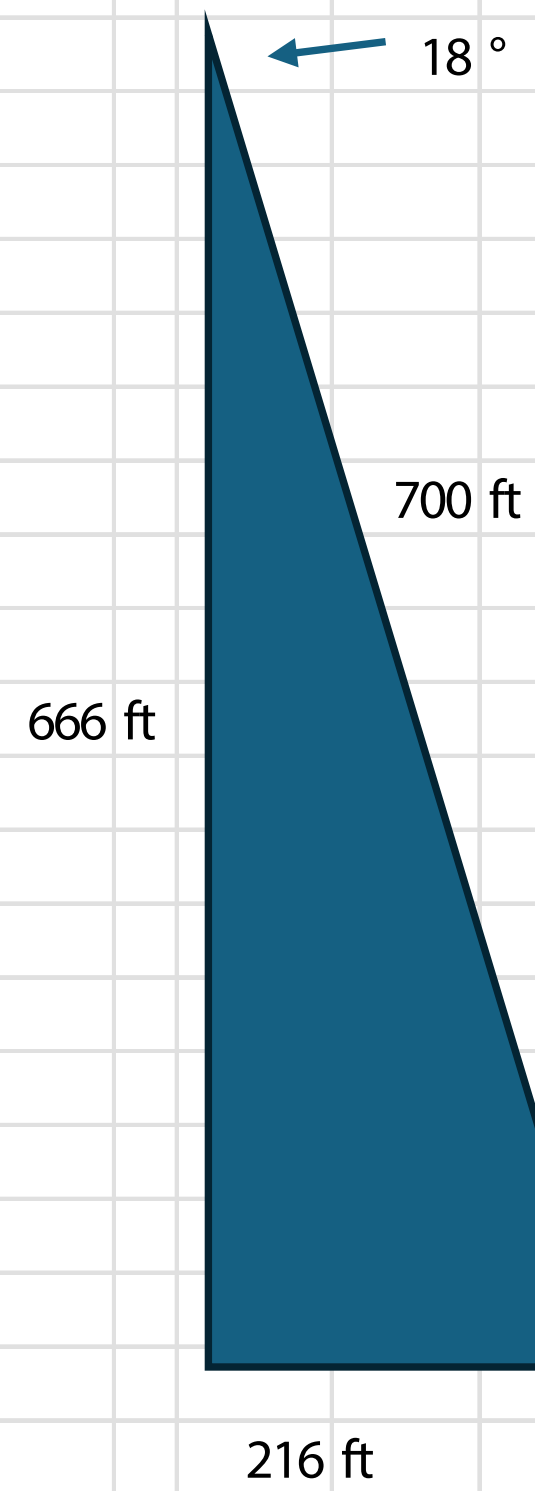
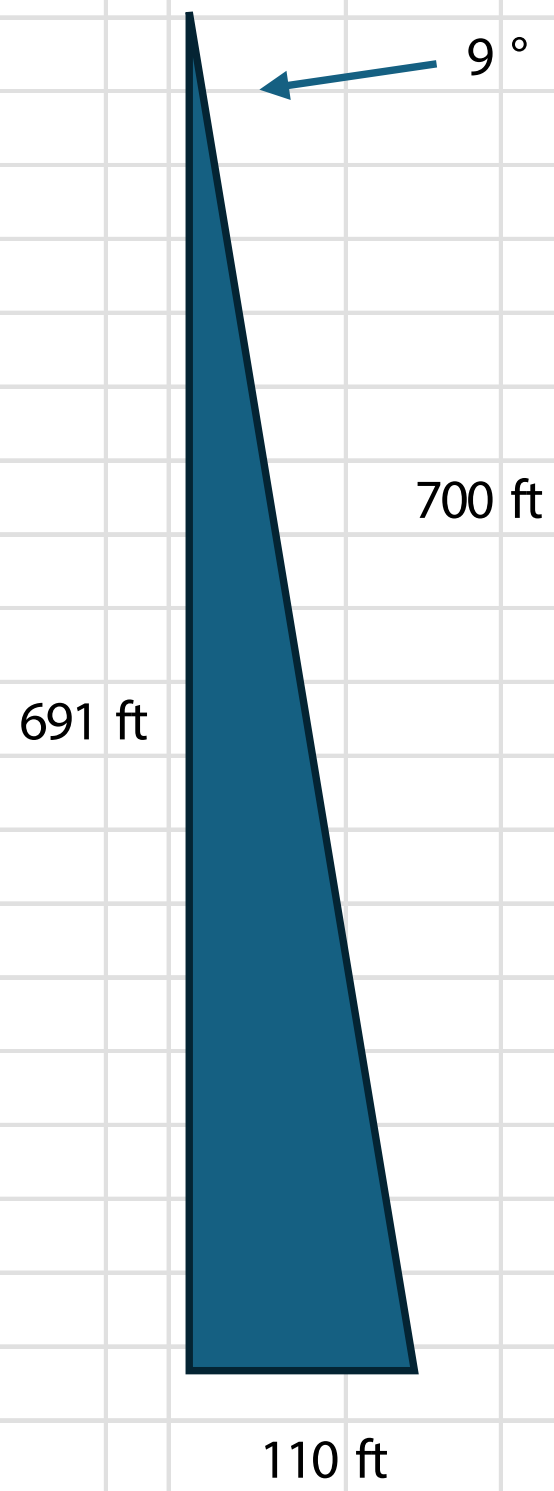
Inclination Angle °

Direction Angle °

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





AutoSave Off 9BH_circle_alt_9_18.xl... Saved to this PC

File Home Insert Page Layout Formulas Data Review View Automate Developer

Clipboard Font Alignment Number Conditional Formatting Format as Table Cell Styles Cells Editing

J25

	A	B	C	D	E	F	G	H	I
1	BH#	x(ft)	y(ft)	z(ft)	length(ft)	inclination	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		

Borehole Locations

Define a system of boreholes. You may include any combination of up to 30 vertical and inclined boreholes.

Borehole #	Head (x,y,z) [ft]	Length [ft]	Inclination Angle [°from Vertical]	Direction Angle [°from N(+y)]
1	7.10,0.00,5.00	700.00	9	0
2	5.90,5.00,5.00	700.00	18	40
3	1.20,7.00,5.00	700.00	9	80
4	-3.90,6.70,5.00	700.00	18	120
5	-6.70,2.40,5.00	700.00	9	160
6	-7.30,-2.60,5.00	700.00	18	200
7	-3.60,-6.20,5.00	700.00	9	240
8	1.30,-7.60,5.00	700.00	18	280
9	5.50,-4.60,5.00	700.00	9	320

Edit

Add

Modify

Delete

Files

Import File

Export File

View

View System

Ok

Cancel

Circle configuration

GLHEPRO Results

Borehole Information

Borehole Configuration : FPFLS Borehole Array

Each Borehole Length : -45.76 ft/borehole

Total Borehole Depth : 5888.12 ft

Number of Boreholes : 9 boreholes

Average Temperature

Maximum Average Temperature : 80.50 °F at Month 356

Minimum Average Temperature : 63.30 °F at Month 1

Peak Temperature

Maximum Peak Temperature : 90.00 °F at Month 355

Minimum Peak Temperature : 54.65 °F at Month 1

OK

GLHEPro - Atlanta_med_ofc_one_half_circle

File Loads Units Action Help Register

Vertical BH Horizontal GHE **FPFLS BH**

Borehole Parameters

Average Active Borehole Length (L): 654.24 ft

Borehole Diameter: 4.33 in

Borehole Thermal Resistance: 0.1625 °F/(Btu/(hr·ft))

Number of Boreholes: 9

Ground Parameters

Soil type currently entered: Average Rock

Thermal Conductivity of the ground: 1.4 Btu/(hr·ft·°F)

Volumetric heat capacity of the ground: 34.943 Btu/(°F·ft³)

Temperature Profile Location: United States, Atlanta-Hartsfield-Jackson Intl AP

Average Annual Ground Temperature: 64 °F

Fluid Parameters

Total flow rate for entire system: 109.998 gal/min

Fluid Type: Propylene Glycol / Water

Fluid Concentration: 15% Average Temperature at Peak Conditions: 68 °F

	Freezing Point	Density	Volumetric Heat Capacity	Conductivity	Viscosity
▶	°F	lb/ft³	Btu/(°F·ft³)	Btu/(hr·ft·°F)	lbm/(ft·h)
	20.99	63.44	60.63	0.296	4.33422

Heat Pump

Heat Pump Selected: ClimateMaster : TS024_ECM_MOTOR@6GPM_610CFM

4x8 rectangle

GLHEPRO Results

Borehole Information

Borehole Configuration : RECTANGULAR CONFIGURATION
32 : 4 x 8, rectangle

Each Borehole Depth : 581.94 ft
Total Borehole Depth : 18622.17 ft
Distance between borehole centers : 20.00 ft

Average Temperature

Maximum Average Temperature : 84.76 °F at Month 356
Minimum Average Temperature : 63.59 °F at Month 1

Peak Temperature

Maximum Peak Temperature : 89.99 °F at Month 356
Minimum Peak Temperature : 59.33 °F at Month 1

OK

glhepro - Atlanta_med_ofc_full_load_4x8

File Loads Units Action Help Register

Vertical BH Horizontal GHE FPFLS BH

Borehole Parameters

Active Borehole Depth : 581.94 ft

Borehole Diameter : 4.33 in

Borehole Thermal Resistance : 0.1644 °F/(Btu/(hr-ft))

Borehole Spacing : 20 ft

Borehole Geometry : RECTANGULAR CONFIGURATION 32 : 4 x 8, rectangle

Ground Parameters

Soil type currently entered : Average Rock

Thermal Conductivity of the ground : 1.4 Btu/(hr-ft-°F)

Volumetric heat capacity of the ground : 34.943 Btu/(°F-ft³)

Average Annual Ground Temperature : 64 °F
Temperature Profile Location : United States, Atlanta-Hartsfield-Jackson Intl AP

Fluid Parameters

Total flow rate for entire system : 220.000 gal/min

Fluid Type: Propylene Glycol / Water
Fluid Concentration: 15% Average Temperature at Peak Conditions: 68°F

	Freezing Point	Density	Volumetric Heat Capacity	Conductivity	Viscosity
▶	°F	lb/ft³	Btu/(°F-ft³)	Btu/(hr-ft-°F)	lbm/(ft-h)
	20.99	63.44	60.63	0.296	4.33422

Heat Pump

Heat Pump Selected : ClimateMaster : TS024_ECM_MOTOR@6GPM_610CFM

Summary

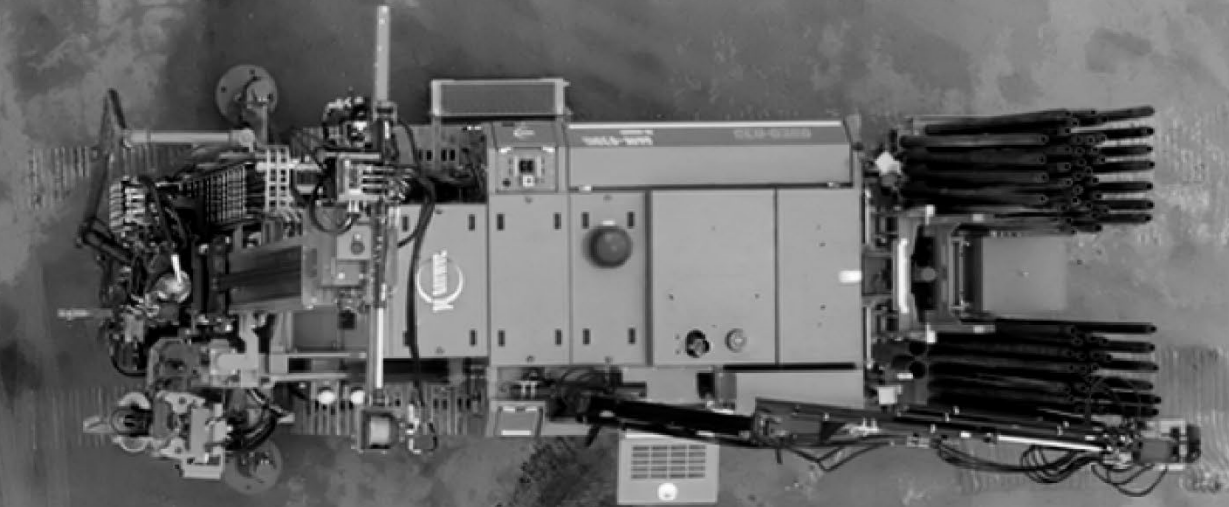
- Two circular drill pads with alternating 9°, 18° tilt:
11,776 feet of drilling
- One rectangular 4x8 field with 32 boreholes on
20 ft spacing: 18,622 feet (37% savings)
- One rectangular 4x8 field with 32 boreholes on
30 ft spacing: 15,283 feet (30% savings)



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

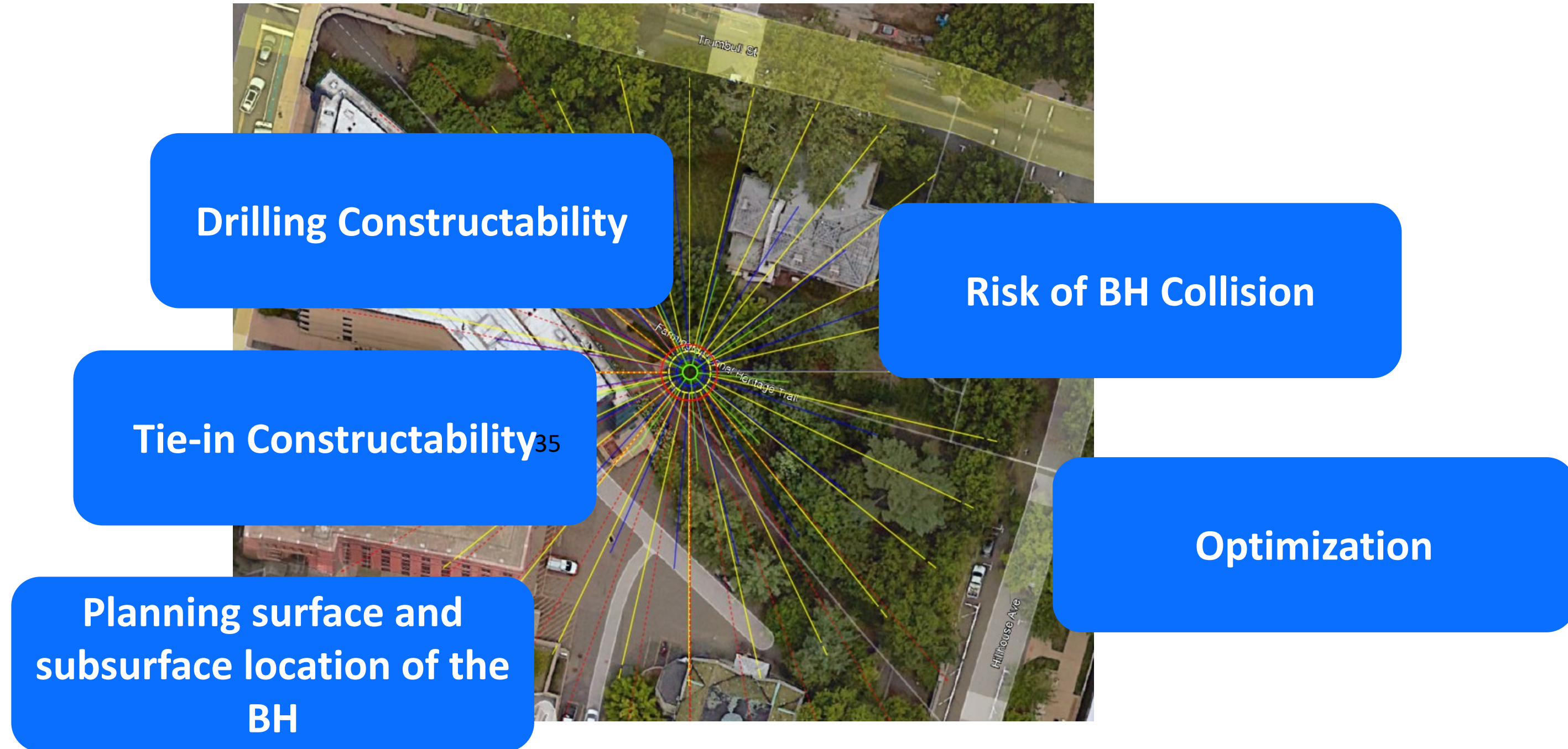
Make-up holes, crane-bases and other physical obstacles

Future borehole access

Strategic placement of extra boreholes for next-phase development

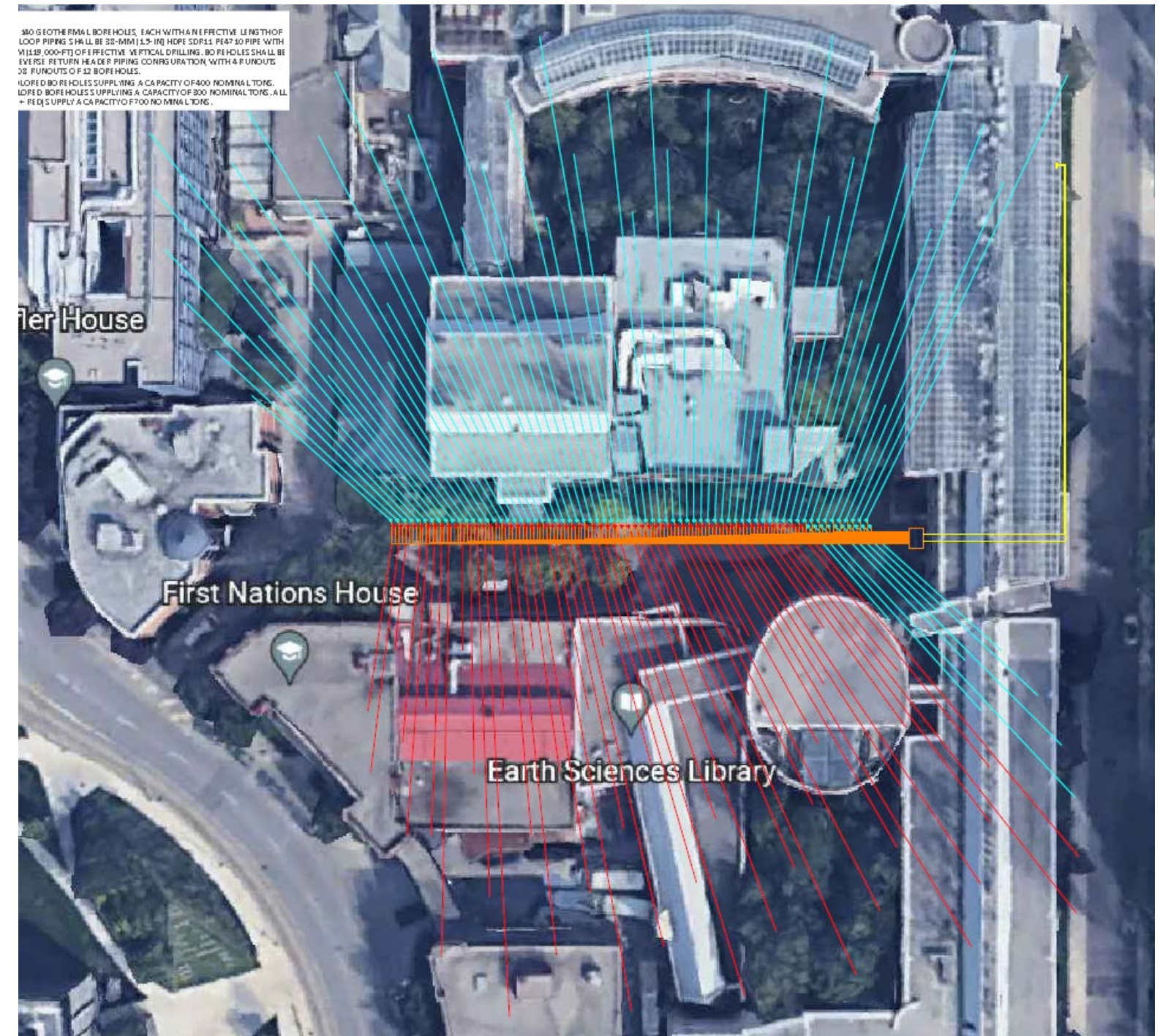


Angled Boreholes: Considerations in Borefield Design



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

Lengths

	COOLING	HEATING	Temperatures	
Total Bore Length (ft):	144500.0	144500.0	COOLING	HEATING
Borehole Length (ft):	850.0	850.0	Unit Inlet (°F): 90.0	40.0
			Unit Outlet (°F): 84.3	32.3

Calculations

Calculate

Design Day

Prediction Time: 30.0 years

Design Method

Fixed Temperature

Fixed Length

Inlet Temperatures: 90.0 °F, 40.0 °F

Borehole Length: 850 ft

Grid Layout

Use External File

Borehole Number: 170

Rows Across: 17

Rows Down: 10

Separation: 17.5 ft

Piping Design

Piping Builder

Vertical Grid Arrangement

Borehole Number: 170

Rows Across: 17

Rows Down: 10

Borehole Separation: 17.5 ft

Non-Rectangular and Angled Boreholes

Use External File

Filename: No File

Boreholes per Parallel Circuit

Bores Per Circuit: 1

Fixed Length Mode

On/Off

Borehole Length: 850 ft

Lengths

	COOLING	HEATING	Temperatures	
Total Bore Length (ft):	144500.0	144500.0	COOLING	HEATING
Borehole Length (ft):	850.0	850.0	Unit Inlet (°F): 90.0	40.0
			Unit Outlet (°F): 84.3	32.3

Calculations

Calculate

Design Day

Prediction Time: 30.0 years

Design Method

Fixed Temperature

Fixed Length

Inlet Temperatures: 90.0 °F, 40.0 °F

Borehole Length: 850 ft

Grid Layout

Use External File

Borehole Number: 170

Rows Across: 17

Rows Down: 10

Separation: 17.5 ft

Piping Design

Piping Builder

Non-Rectangular and Angled Boreholes

Use External File

Filename: No File

Boreholes per Parallel Circuit

Bores Per Circuit: 1

Fixed Length Mode

On/Off

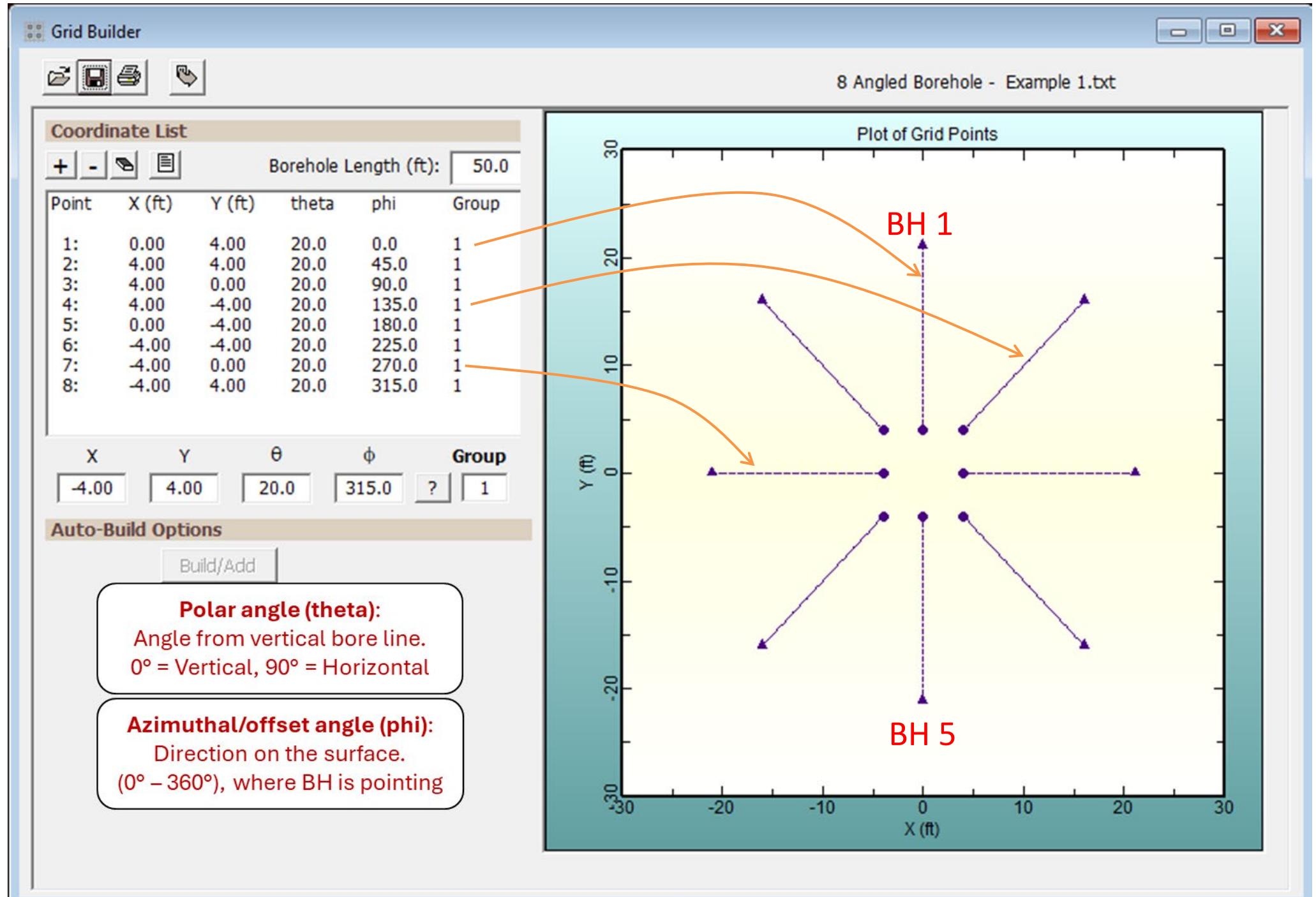
Borehole Length: 850 ft

Design Steps in GLD

Feature Available in the Latest Version of GLD

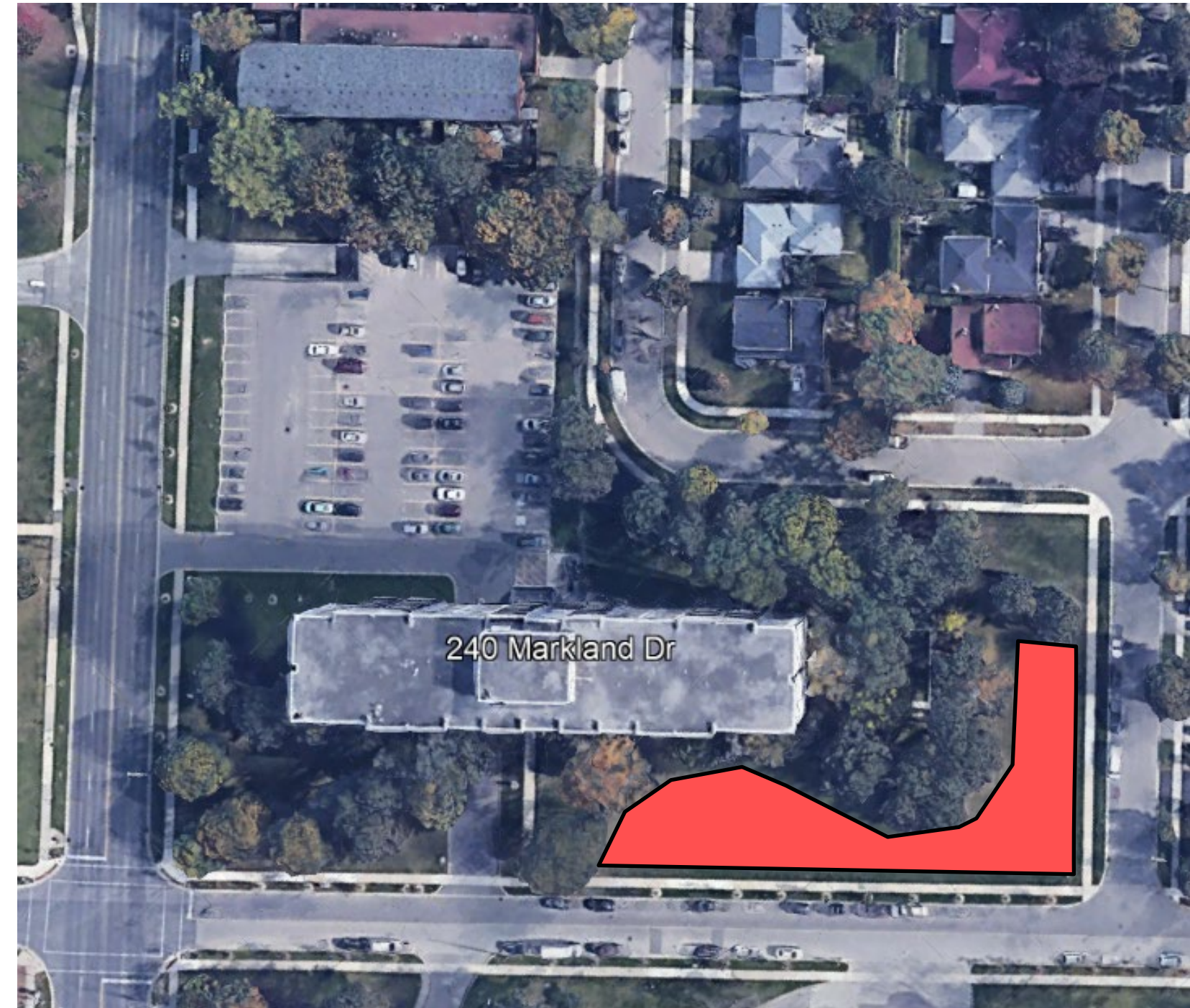
How to develop Grid file for Angled Boreholes in GLD ?

Simplified Example →



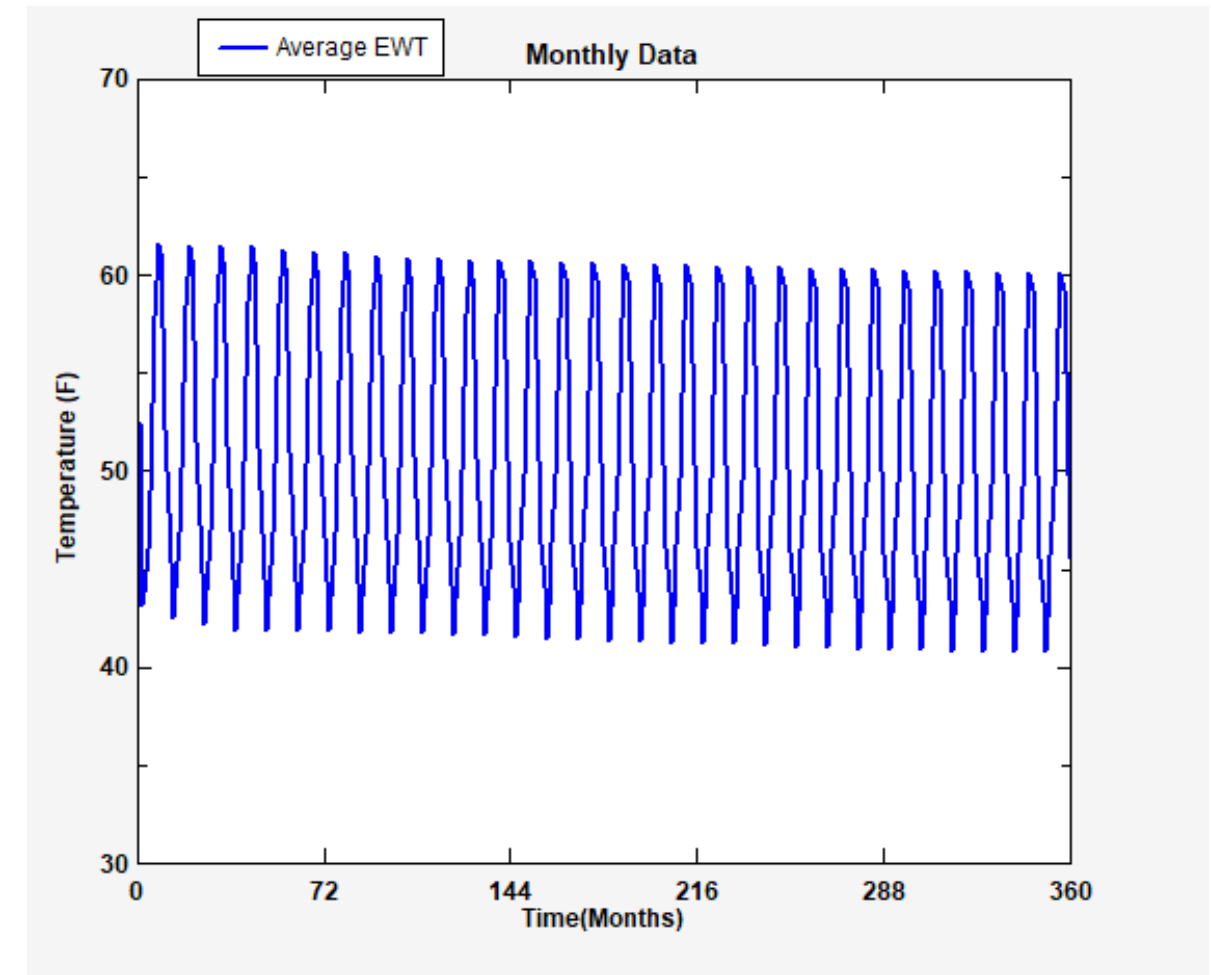
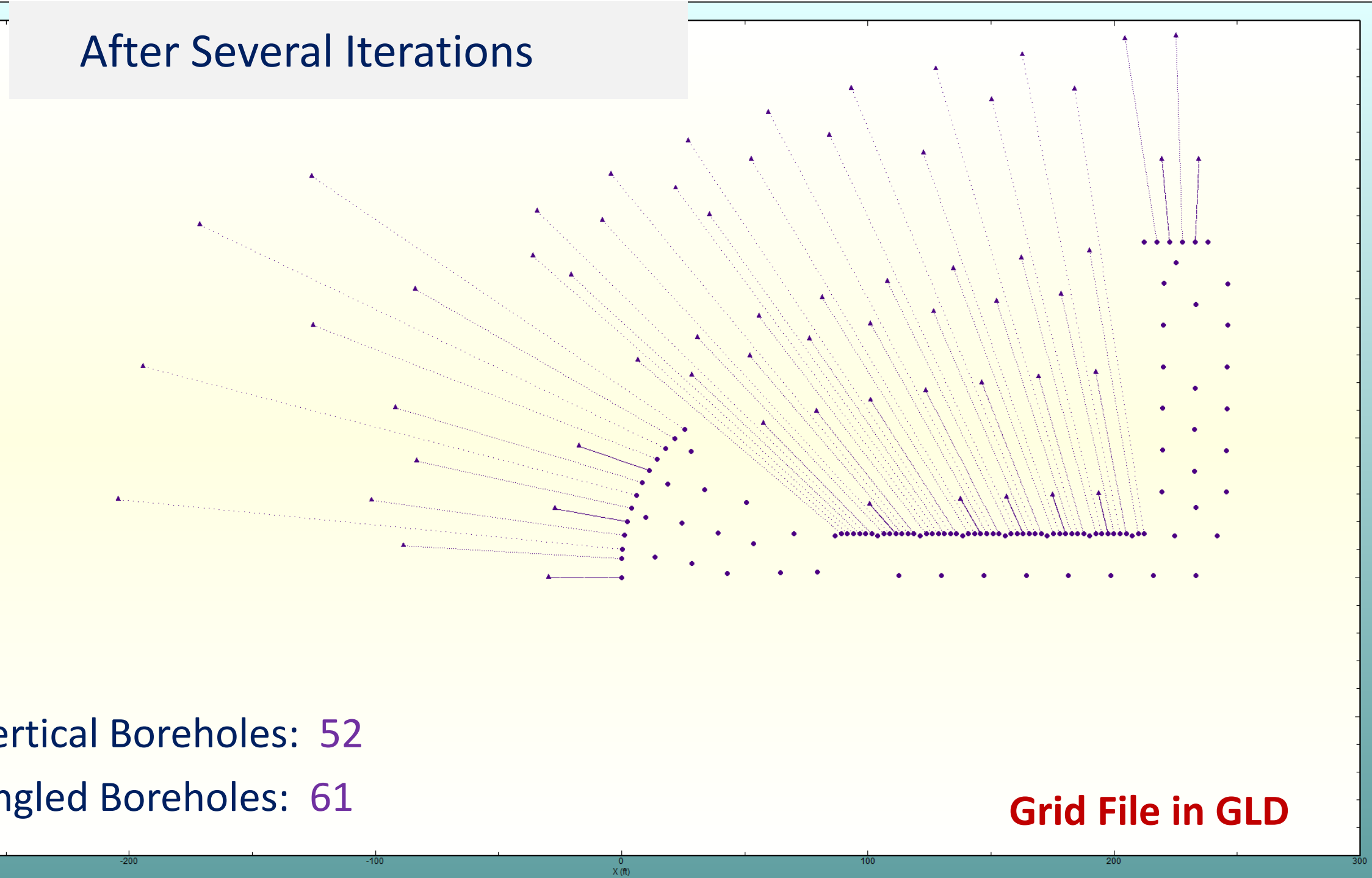
Sample Case Study – 240 Markland

- Total surface area available: 1250 m² (13,500 sq ft)
- Required Boreholes: 113 to 850'
- Site capacity for vertical only BH: 59
- Designed: 52 vertical, 61 angled



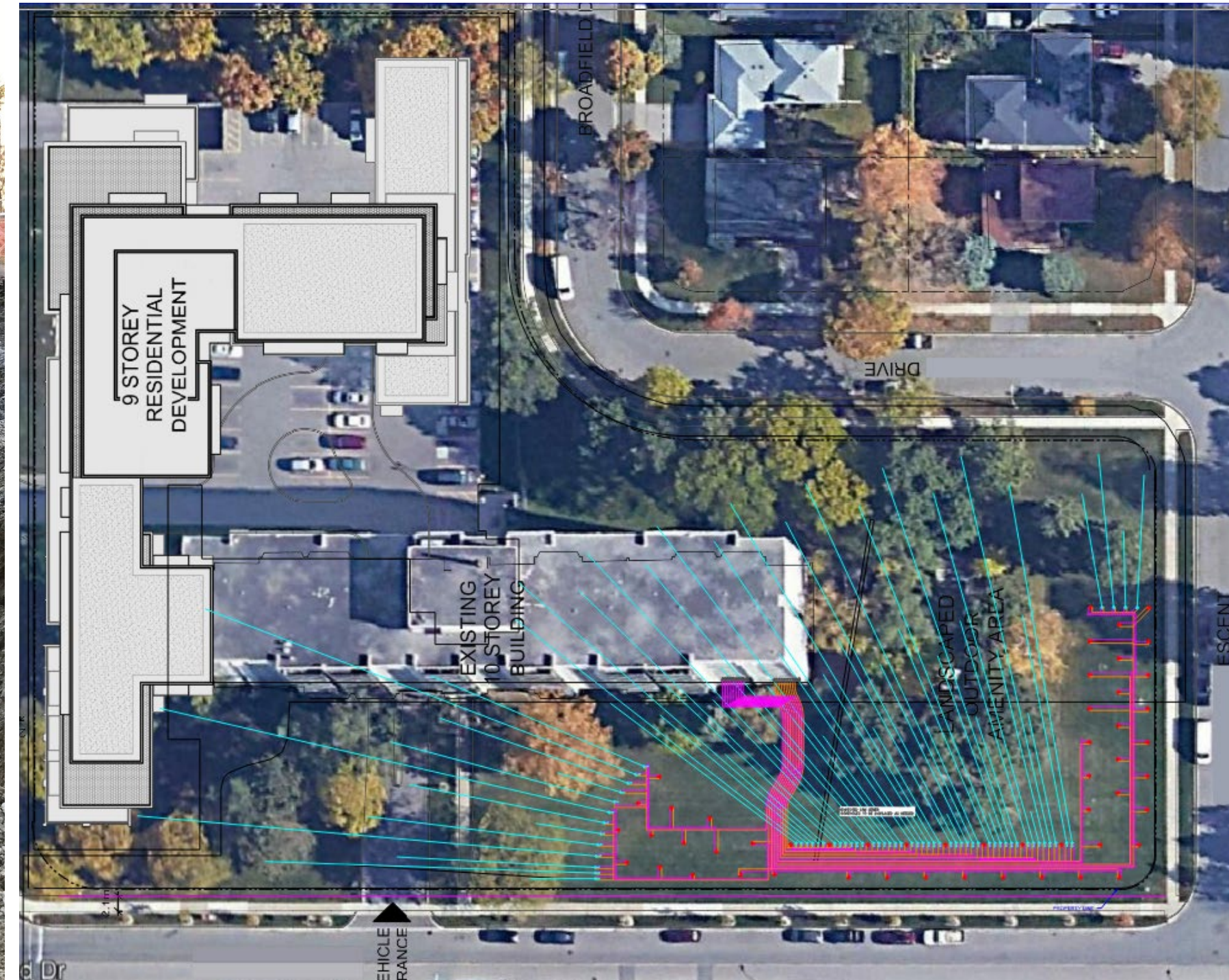
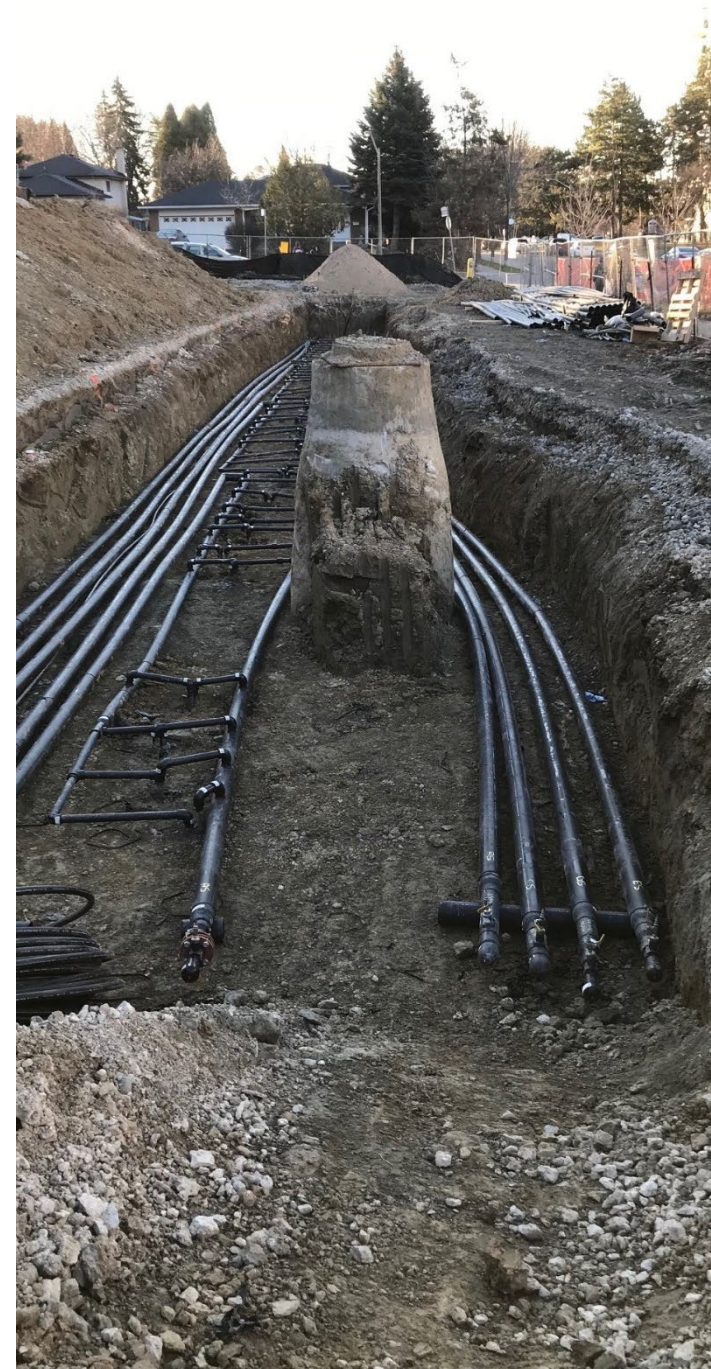
Sample Case Study – 240 Markland

GLD Output



Sample Case Study – 240 Markland

Top view of Angled Borehole on Site



Sample Case Study – 240 Markland



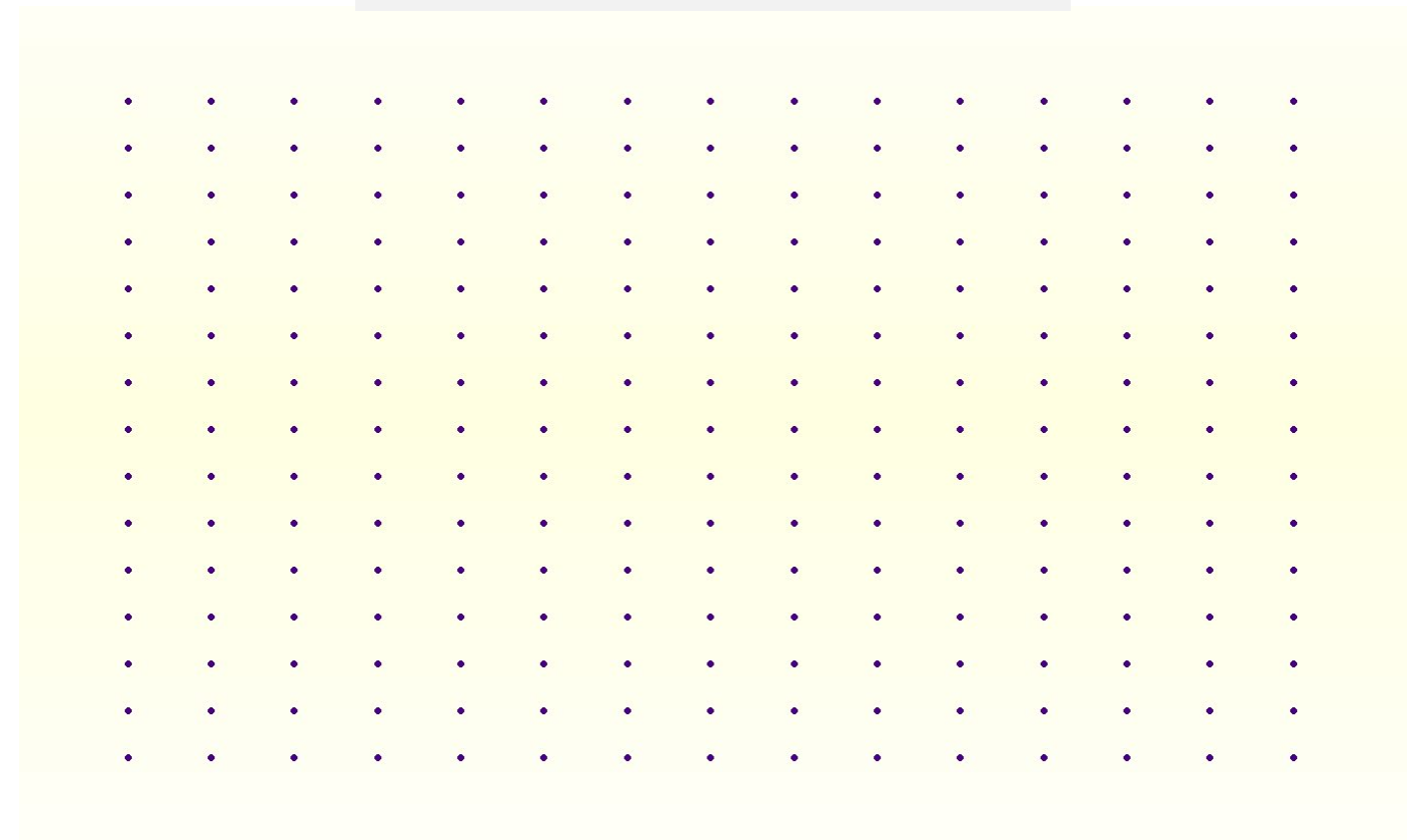
Insights from Design Experience

- 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.





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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*