Geological, Engineering and Feasibility Considerations when using GSHP at Contaminated Sites

Mark A. Worthington, LSP
Underground Energy, LLC

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Outline

Part I:

- Environmental vs Geothermal Considerations
- Advective vs Conductive Heat Transfer
- Geothermal Feasibility
  - GeoExchange
  - Underground Thermal Energy Storage (UTES)
    - Aquifer Thermal Energy Storage (ATES)
    - Borehole Thermal Energy Storage (BTES)

Part II: Case Studies

Underground Energy Principals

Mark A. Worthington, President
Principal Hydrogeologist

- MS Hydrology & Water Resources, University of Arizona
- Hydrogeologist with 28 years experience in New England
- Adjunct Instructor, Mass Maritime Academy
- MA Licensed Site Professional (LSP)
- ME Certified Geologist
- LEED AP
- IGSHPA accredited geothermal installer
- Charter / Board Member of NEGPA

Matt Malfa, Principal Engineer

- BS Mechanical Engineering, Worcester Polytechnic Institute
- 14 years systems engineering experience
  - Aerospace design
  - Thermodynamic management
  - Real-time analysis and controls
  - Electromechanical integration

Environmental Hydrogeologist	Geothermal Hydrogeologist
Perform Hydrogeologic Investigations	Perform Hydrogeologic Investigations
Manage Environmental Projects	Manage Geothermal Projects
Delineate contaminant plumes	Design beneficial thermal plumes
Remediate contaminant plumes	Operate beneficial thermal plumes
Render LSP opinions	Render LSP opinions
Create value: regulatory compliance	Create value: energy & cost savings

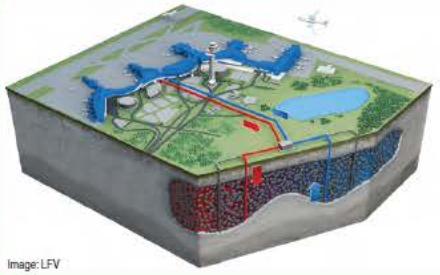
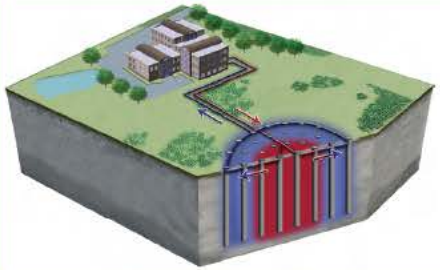
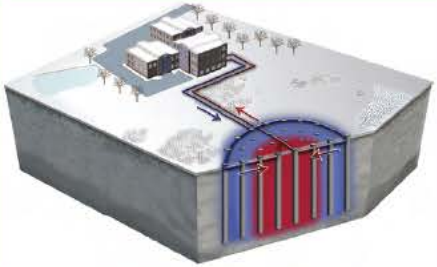
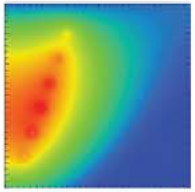
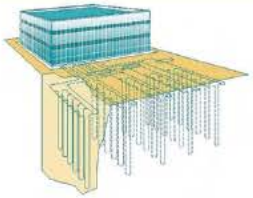
A Hydrogeologist LSP's Perspective

Geothermal Industry Observations:

- Residential market dominated by drillers and HVAC contractors
  - Simple systems, simple Earth couples, low opportunity to add value
- Commercial / Institutional market dominated by mechanical engineers
  - Complex systems, opportunity to add value to Earth couple design
- Primary improvements in geothermal cost/performance will come from optimizing the Earth couple
  - Secondary will be evolutionary improvements in drilling technology
- Depressed natural gas prices are slowing geothermal adoption

Geothermal Technology Summary

Geothermal Energy Storage - The Future of Efficient Buildings

		Summer Cooling	Winter Heating	COP	Capital Cost	Life Cycle Cost
Thermal Energy Storage	ATES (Aquifer Thermal Energy Storage)	 Image: LFV	Image: LFV	8-20	$$$	$$
Thermal Energy Storage	BTES (Borehole Thermal Energy Storage)			4-7	$$$$$	$$$
Existing Applications	Geothermal GSHP Dissipative GHX Design	 		3-4	$$	$$$$
Existing Applications	Fossil Fuel Heating & Conventional Air Conditioning			1-3	$	$$$$$$

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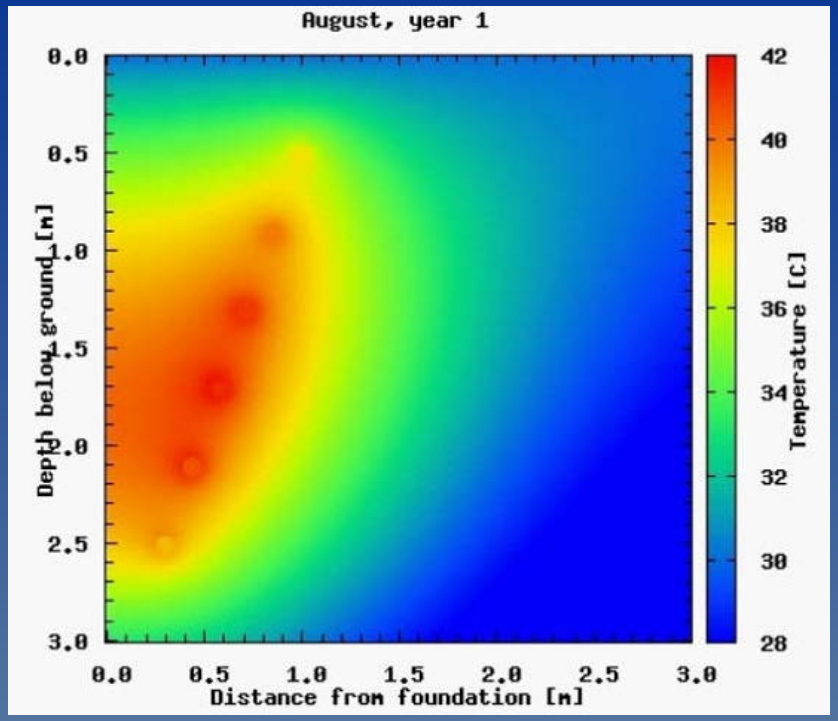
Ground Heat Exchanger Design Practice

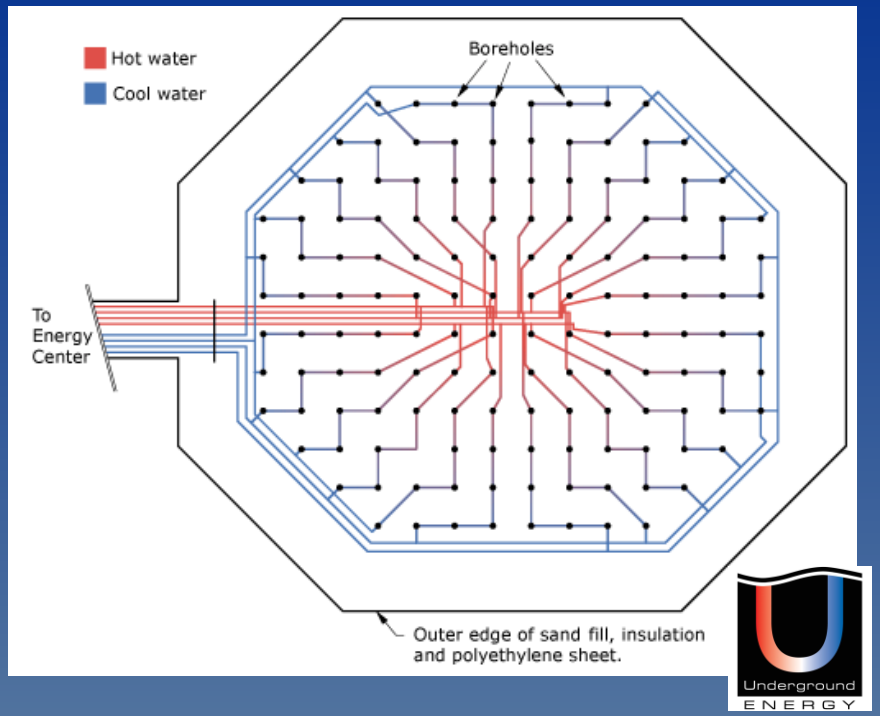
GSHP, GeoExchange

The GHX is used as a radiator
Excess heat or cold is simply radiated away

UTES

GHX is used as a thermal battery
Excess heat or cold stored seasonally (ATES or BTES)

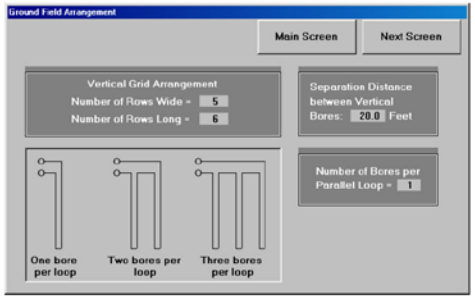




US GSHP Design Practice

Ground Field Arrangement

Adequate separation is required to prevent short and long term heat storage effects in loop fields. This is especially true when with clay and impermeable rocks are present. Water movement will be minimal and heat will be significant in typical commercial /institutional buildings if the bores are located less than 20 feet apart. (The annual heat transfer to and from the ground will occur when the full load heating hours exceed the full load cooling hours by 80%). The designer can control the heat build-up (or loss) by specifying the field pattern and bore separation distance. Optimal drilling depths are typically 200 to 300 ft., which will support 1 to 2 tons of cooling capacity. In the initial design phase, the user should recognize this and start with one bore for every one to two tons of capacity. Thus the 5 by 6 grid will typically support between 30 tons (warm climate, 200 ft. bores) and 60 tons (cold climate, 300 ft. bores).



*"Adequate separation is required to **prevent** short and long term heat storage effects in loop fields. This is especially true when with clay and impermeable rocks are present. Water movement will be minimal and heat will be significant in typical commercial /institutional buildings if the bores are located less than 20 feet apart."*

GchpCalc V 4 Instruction Manual, p. 11

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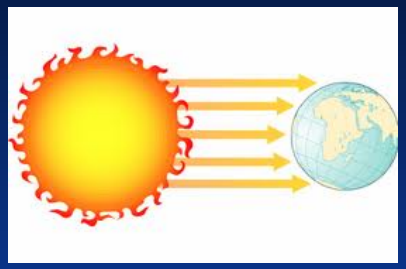
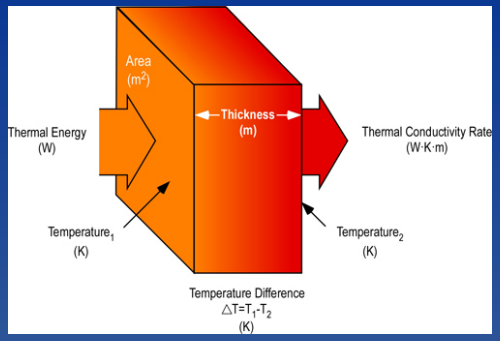
Physics of Heat Transfer

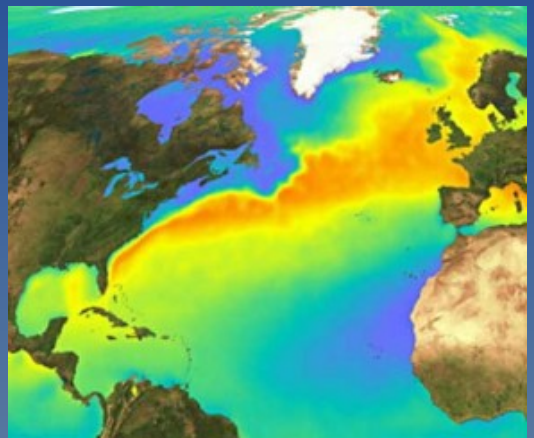
Three Primary Heat Transfer Mechanisms



- **Radiation** – Thermal energy transfer via Emission or absorption of electromagnetic waves
  - » Not important in GSHP systems



- **Conduction** – Thermal energy transfer within or between objects that are in physical contact due to vibration of atoms or molecules



- **Advection** – Thermal energy transfer via physical movement of mass from one area to another

Conductive and Advective Heat Transfer in Earth Coupled Heating and Cooling Systems

Conductive Heat Transfer

- Dominant in absence of groundwater flow
- Good in granites, poor in clays
- Design software based on conduction only

Advective Heat Transfer

- Groundwater flow is the mass transport phenomenon that causes advective heat transfer
- Advection usually dominates heat transfer in the subsurface
- Normally measured with thermal response test

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Optimizing the Earth Couple

- The role of advective heat transport via groundwater flow is of critical importance in designing an efficient Earth couple and is often overlooked by designers.
  - Groundwater flow is usually the dominant heat transfer mechanism.
  - For large (> 150 ton) systems, a simple groundwater study may be the best first step in designing the system.
- The efficiency of the Earth couple can be significantly increased using seasonal thermal energy storage.

Earth Couple Design Matrix			
Earth Couple Design Matrix	Heat Source / Sink	Thermal Battery	
Application	Conventional GeoExchange	UTES	
		ATES	BTES
High Groundwater Flow Rate			
Low Groundwater Flow Rate			
Aquifer Present			
No Aqifer Present			

The Preferred Medium for Seasonal Thermal Energy Storage

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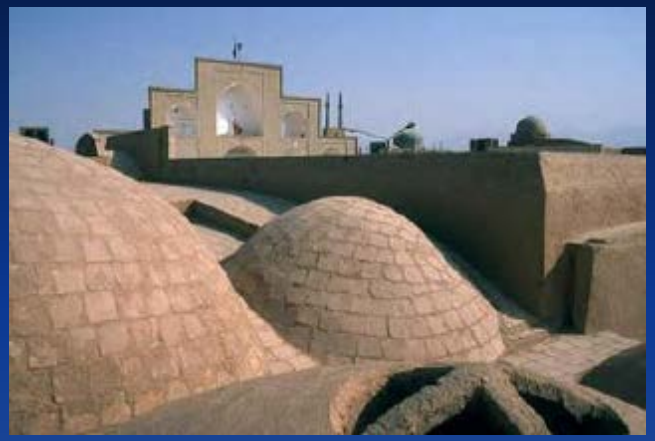
Underground Thermal Energy Storage
=
Seasonal Thermal Energy Storage

Ice house in Boxborough, MA



Ice storage in Iran

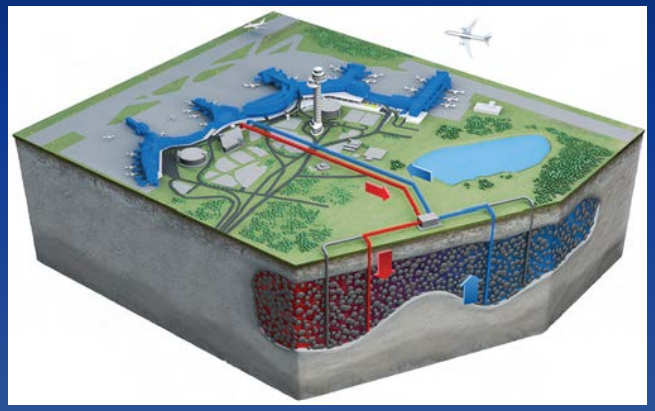
An Enabling Green Technology:

- Winter chilling costs are order-of-magnitude less than summer
- ATES typically recovers ~80% of injected thermal energy
- COP = 8 to 20
- Enables significant energy/emissions reduction with minimal environmental impact

Underground Thermal Energy Storage (UTES)

Aquifer Thermal Energy Storage

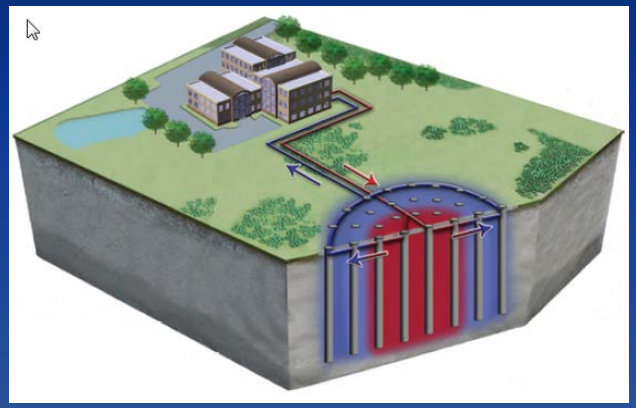
ATES



- Open Loop (hydraulically balanced)
- Seasonal flow reversal (well-to-well)
- Groundwater storage medium
- Economic efficiencies of scale

Borehole Thermal Energy Storage

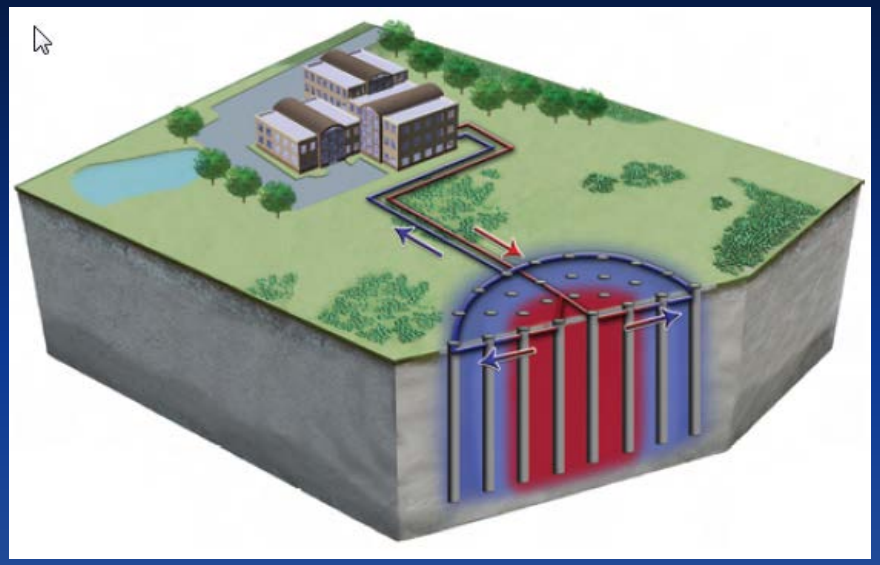
BTES



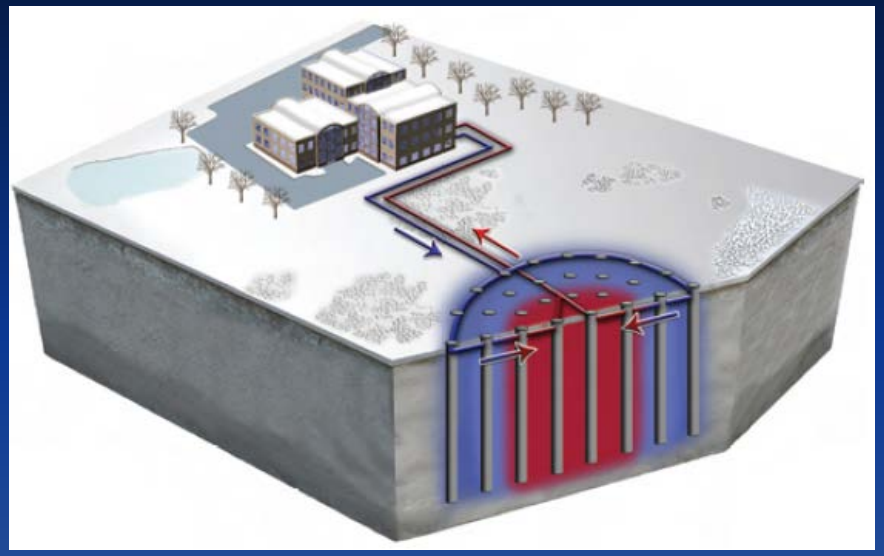
- Closed loop
- Seasonal flow reversal (GHX)
- Soil/rock storage medium
- Cost varies with thermal capacity

Borehole Thermal Energy Storage (BTES)

Summer



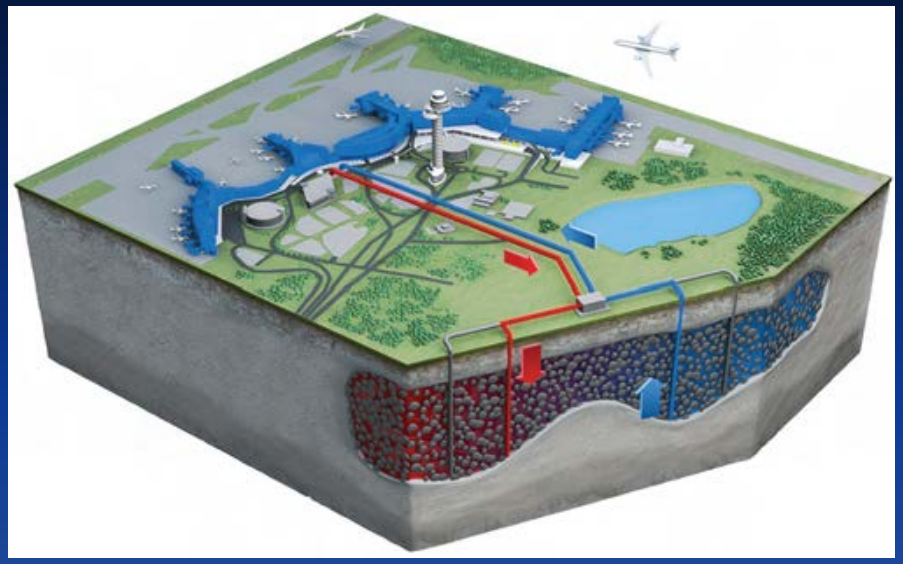
Winter



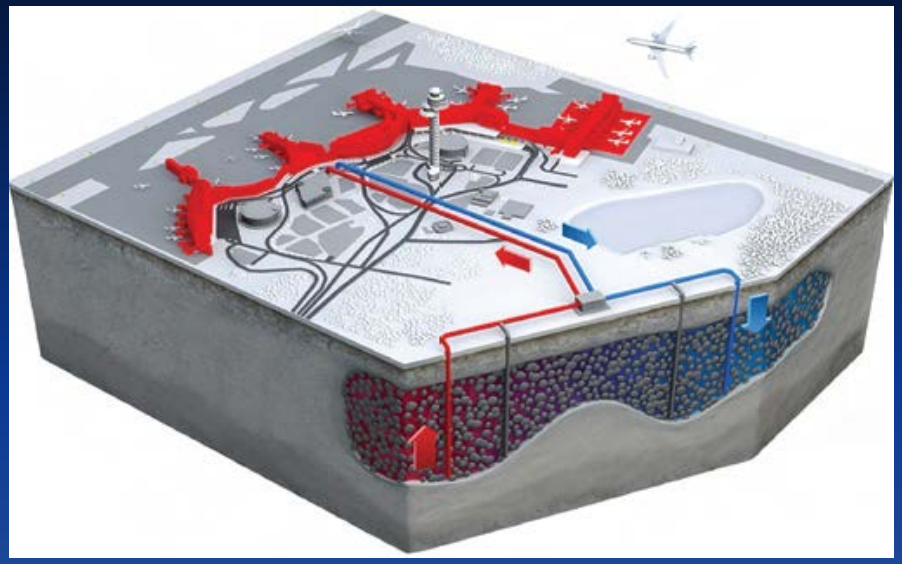
- Closed loop
- Radial array configuration – may use multiple arrays
- Seasonal reversal of flow within the loop
- Small footprint on storage site

Aquifer Thermal Energy Storage (ATES)

Summer

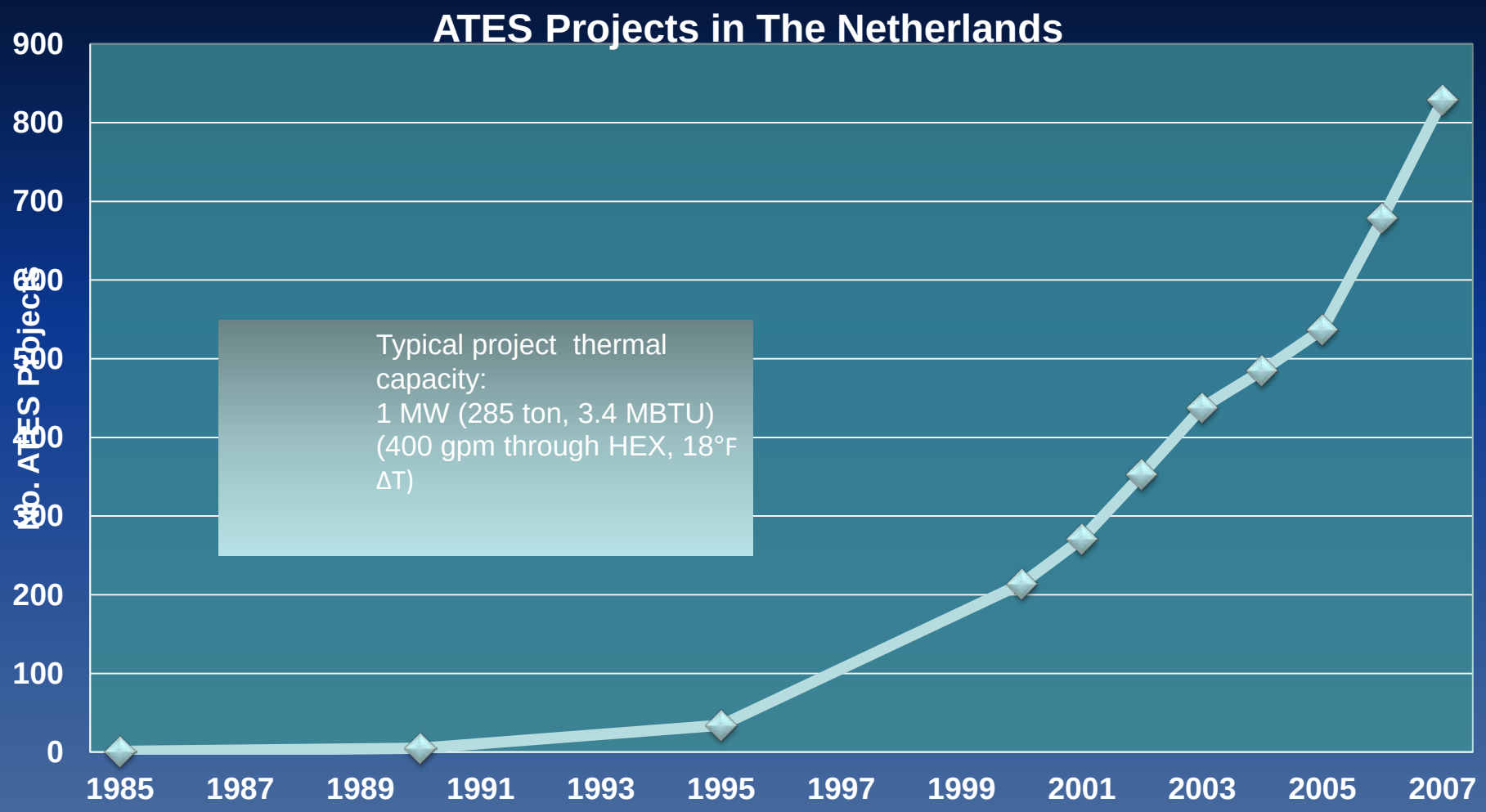


Winter



- Seasonal thermal energy storage enabled by:
  - High heat capacity of (ground)water
  - Dynamics of fluid flow in porous media
  - Low ΔT, low advection
  - Hydraulic modeling and management of aquifer
- Open loop with separate warm and cold stores
- Seasonal reversal of warm and cold withdrawal / injection
- Hydraulically balanced
- Well suited to thermally imbalanced loads

ATES Growth in The Netherlands



Source: National Bureau of Statistics

ATES Growth in The Netherlands

1990

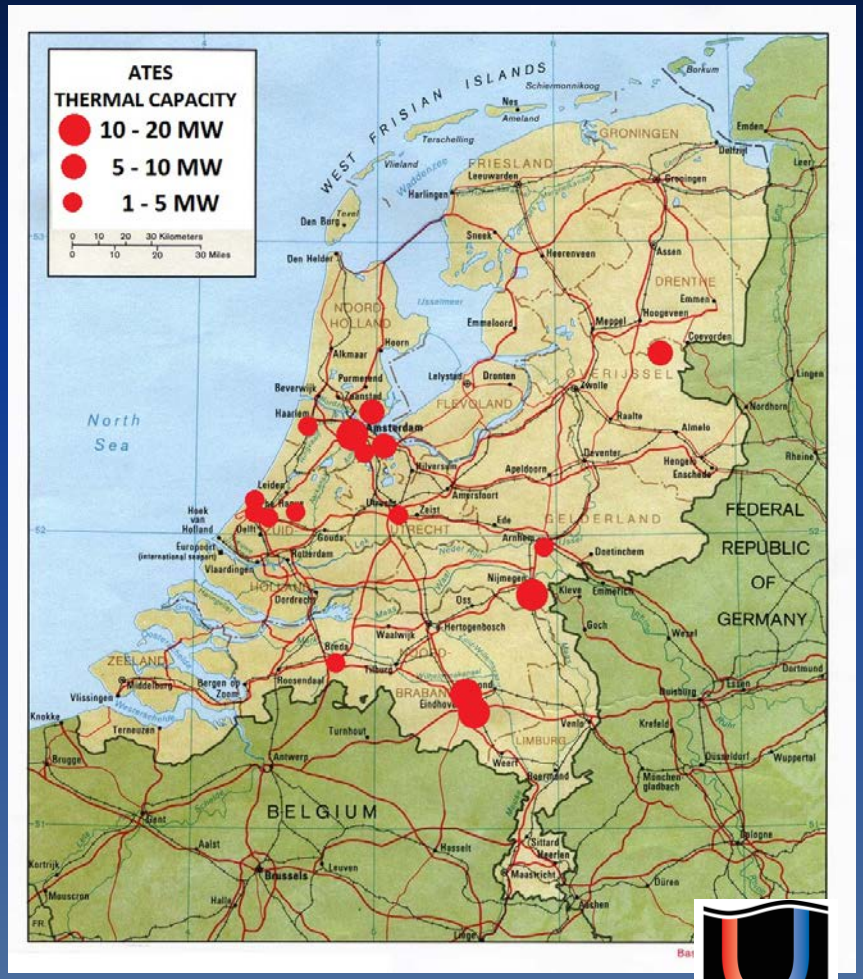
2000

2010

Source: www.iftechnology.nl/

ATES Based District Heating & Cooling Systems in The Netherlands

- Wavin industrial park – Hardenberg (5.0 MW)
- The Resident office park - The Hague (3.0 MW)
- Schalkwijk housing project – Haarlem (1.5 MW)
- Chassee mixed development – Breda (4.0 MW)
- Eastern Trade Wharf mixed development – Amsterdam (4.0 MW)
- University Campus – Eindhoven (20 MW)
- Spoorwijk housing project I – The Hague (1.2 MW)
- University Campus – Utrecht (3.5 MW)
- Mahler 4 mixed development – Amsterdam (6.5 MW)
- Philips High-Tech Campus – Eindhoven (10 MW)
- City centre mixed development – Arnhem (construction stage, 3.8 MW)
- Shell Campus – Amsterdam (construction stage, 15 MW)
- University hospital – Nijmegen (construction stage, 15 MW)
- Spoorwijk housing project II – The Hague (0.9 MW)
- Overheem housing project – Zoetermeer (1.3 MW)
- Eastern Dock Island mixed dev. – Amsterdam (constr. stage, 7.0 MW)



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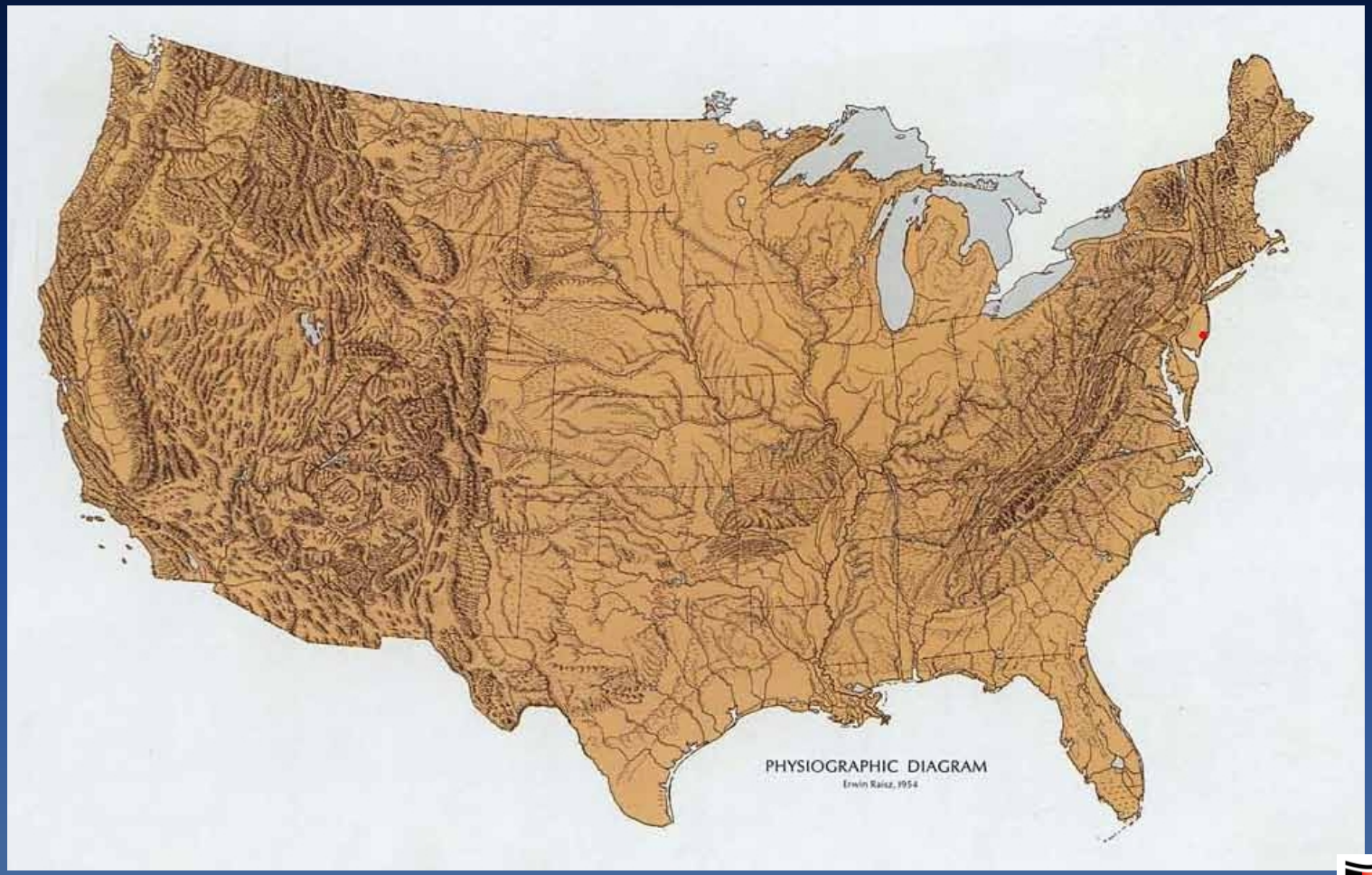
ATES Based District Heating & Cooling Systems in The United States



Richard Stockton College, Pamona, NJ (2 MW)

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ATES Siting Considerations

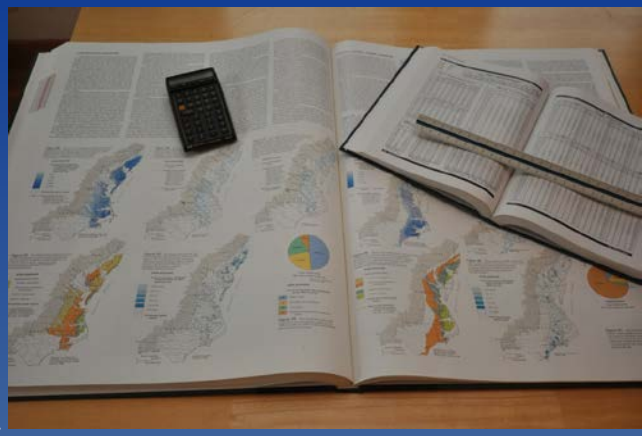
- A suitable temperate climate with seasonally variable thermal loads
- An Aquifer!
  - High transmissivity (T = Kb)
    - –K>100 ft/day; b>30-50 ft)
  - Reasonable depth / thickness
  - Reasonable hydraulic gradient ($dh/dx \leq 10^{-3}$)
  - Acceptable water quality
  - Space to separate cold and warm store areas (>100m)
- Favorable regulatory climate (open loop OK)

ATES Project Phasing

- Phase I – Desktop Feasibility Study
  - Non-intrusive, look for fatal flaws
  - Preliminary cost estimate
- Phase II – Pre-Design Work
  - Hydrogeologic characterization
  - Thermal and hydraulic modeling of well field
- Detail Design
  - Well and equipment specifications
  - Integration with MEP systems
  - Detailed cost estimate
- Construction
- Commissioning
- Operation, Maintenance & Monitoring

ATES Feasibility Study Components

- Engineering Evaluation
  - Heating & cooling loads
  - Conceptual design
  - Calculate electricity and emissions reductions
- Hydrogeologic Evaluation
  - Aquifer physical and hydraulic properties
  - Aquifer geochemical properties
- Financial Evaluation
  - Estimate construction cost
  - Estimate financial benefit
  - Identify incentives and financing mechanisms
- Regulatory Evaluation
  - Identify permits required



ATES Engineering Evaluation

- Obtain thermal load information from client/owner
- Evaluate different ATES configurations
  - Peaking vs base load
  - Cooling vs heating
  - Chilled loop tie-in vs stand-alone building
- Prepare conceptual design
  - Size wells to meet system thermal capacity
  - Define operating parameters and temperatures
  - Calculate energy and emission savings
  - Typical values:
    - Cooling: 60-80% saving on electricity
      80-90% reduction of electrical peak
    - Heating: 20-30% saving on primary energy

ATES Hydrogeologic Evaluation

- Research area and regional hydrogeology
  - State GIS aquifer maps
  - USGS reports
  - Facility records
  - Local well drillers
- Identify physical and hydraulic aquifer properties
  - Depth, thickness, transmissivity, well yields
  - Confined vs unconfined aquifers
  - Local hydraulic gradient
- Identify aquifer geochemical properties
  - Areas/sources of contamination
  - Major cations and anions
  - Redox conditions

ATES Permitting

- Regulations
  - Underground Injection Control (310 CMR 27.00)
    - »MMADEP has primacy in MA
    - »Temperature is only regulated parameter
    - »Registration, not a permit
  - Water Management Act
    - »Potentially applicable if Q > 100,000 gal/day (~70 gpm)
    - »Waiver likely for nonconsumptive use
  - Local Wetlands (?)
  - MCP Oil/Hazardous Waste Disposal Sites (?)

- Impacts and Recommended Mitigation:
  - Thermal – use modest ΔT
  - Hydrologic (wetlands) – site warm store closest to wetlands
  - Displacement of Existing Groundwater Contaminant Plumes – site cold and warm wells on same streamline

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Conclusions

- Seasonal thermal energy storage technology represents the next generation of efficiency for geothermal heating and cooling systems.
- UTES is an innovative “green” technology that can significantly reduce operating and life-cycle costs, save energy, reduce CO_2 emissions, and reduce dependency on fossil fuels, all with minimal environmental impact.
- ATES is the seasonal thermal energy storage application best suited to district energy systems and because it is more cost efficient than other Earth coupling techniques at large scales.
- ATES should work well in Massachusetts where acceptable aquifers exist.
- District energy systems or large buildings that overlie a transmissive aquifer should consider performing a feasibility study for ATES when planning expansion of a chilled water loop or new facilities.
- MCP disposal sites may be able to derive a thermal energy benefit from UTES.
- MA Renewable Thermal legislation will increase economic viability of UTES projects.
- We anticipate that UTES projects in the US will be economically attractive and that adaptation of the technology will follow a similar trend as has been observed in Northern Europe.

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Thank You!

PART II:
CASE STUDIES

UTES Feasibility Study and Project Examples

- Canada
  - BTES at NWT underground mine
- USA
  - ATES at VA Medical Centers in Ohio
  - ATES at Richard Stockton College, Pamona, NJ
  - ATES for Confidential Client, Massachusetts
  - ATES for Wyandanch Rising Project, Babylon, NY
- Europe
  - ATES at Eindoven University, The Netherlands
  - ATES at Stockholm Arlanda Airport, Sweden

Thanks to the following firms who provided ATES FS and operational data:
IF Technology, USA (Stockton College, Eindoven University)
P.W. Grosser Consulting (Babylon, NY)
LFV (Stockholm International Airport)

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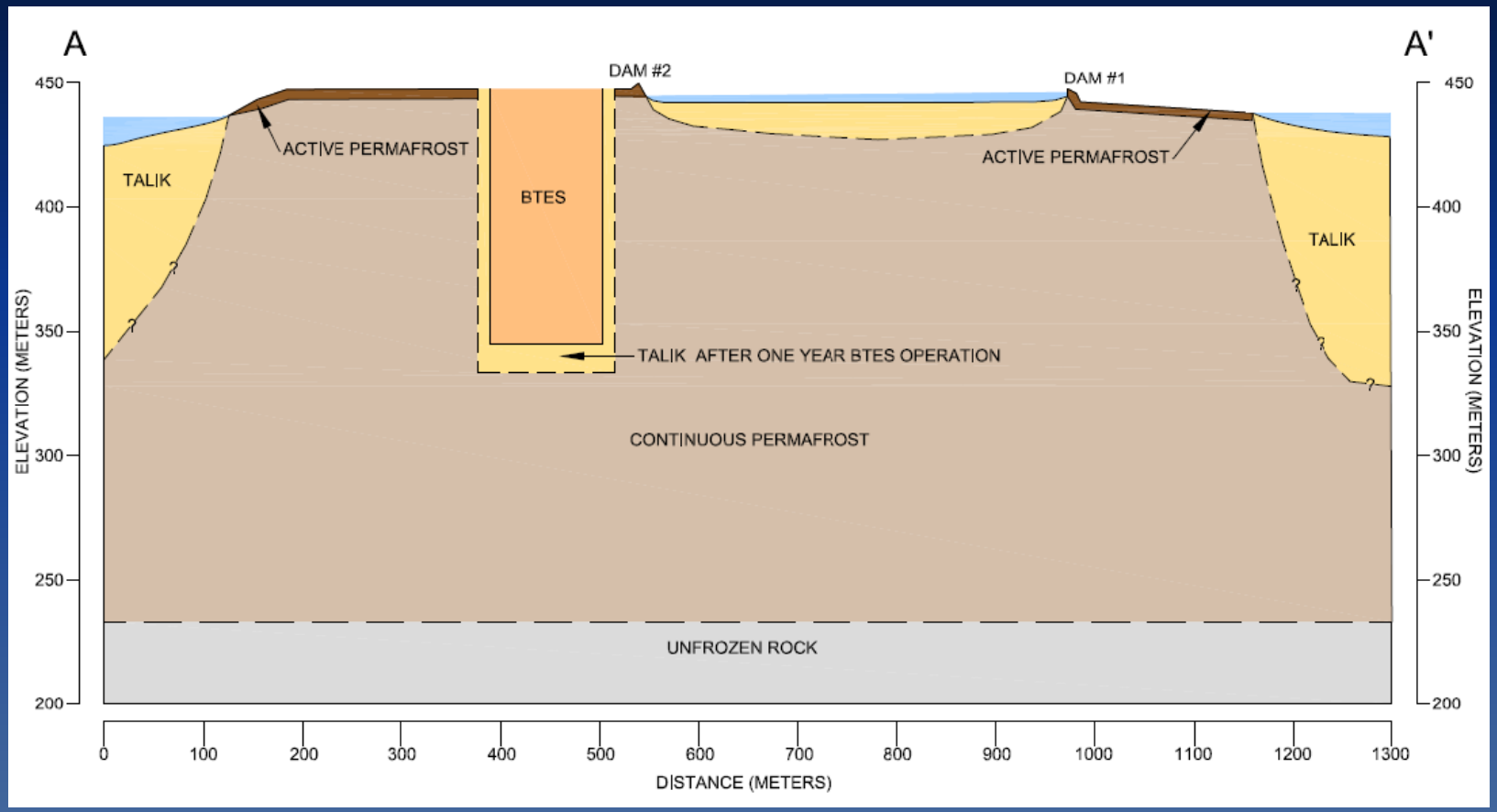
BTES Feasibility Study

NWT, Canada



Hydraulic vs. Thermal Diffusivity

Hydraulic Diffusivity (D_h)

$$D_h = \frac{K}{S_s} \quad \left(\frac{m^2}{s}\right)$$

K = hydraulic conductivity $\left(\frac{m}{s}\right)$

S_s = specific storage $\left(\frac{1}{m}\right)$

Thermal Diffusivity (D_t)

$$D_t = \frac{k}{\rho c_p} \quad \left(\frac{m^2}{s}\right)$$

k = thermal conductivity $\left(\frac{W}{m°K}\right)$,

ρ = density $\left(\frac{kg}{m^3}\right)$

c_p = specific heat capacity $\left(\frac{J}{kg°K}\right)$

Hydraulic Diffusivity Examples

Clay	Gravel
$K = 10^{-8}$ m/s	$K = 10^{-2}$ m/s
$S_s = 2 \times 10^{-3}$ m^{-1}	$S_s = 5 \times 10^{-4}$ m^{-1}
$D_h = 5 \times 10^{-6}$ m^2/s	**$D_h = 20$ m^2/s**

Thermal Diffusivity Examples

Clay	Granite
k = 0.5 W/m°K	k = 2.7 W/m°K
ρC_p = 1.6 MJ/m^3°K	ρC_p = 2.5 MJ/m^3°K
$D_t = 3 \times 10^{-7}$ m^2/s	**$D_t = 1 \times 10^{-6}$ m^2/s**

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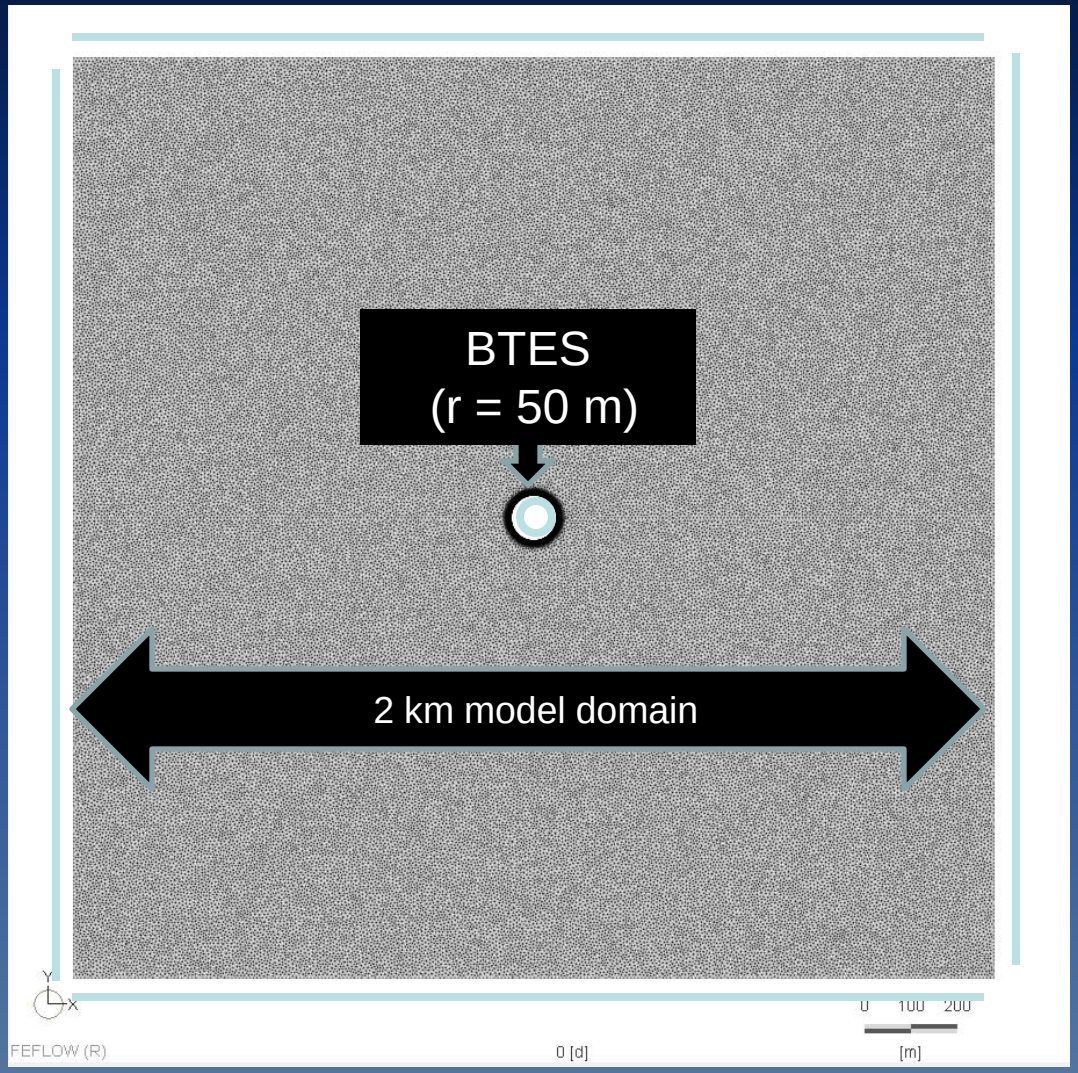
BTES Feasibility Study

NWT, Canada

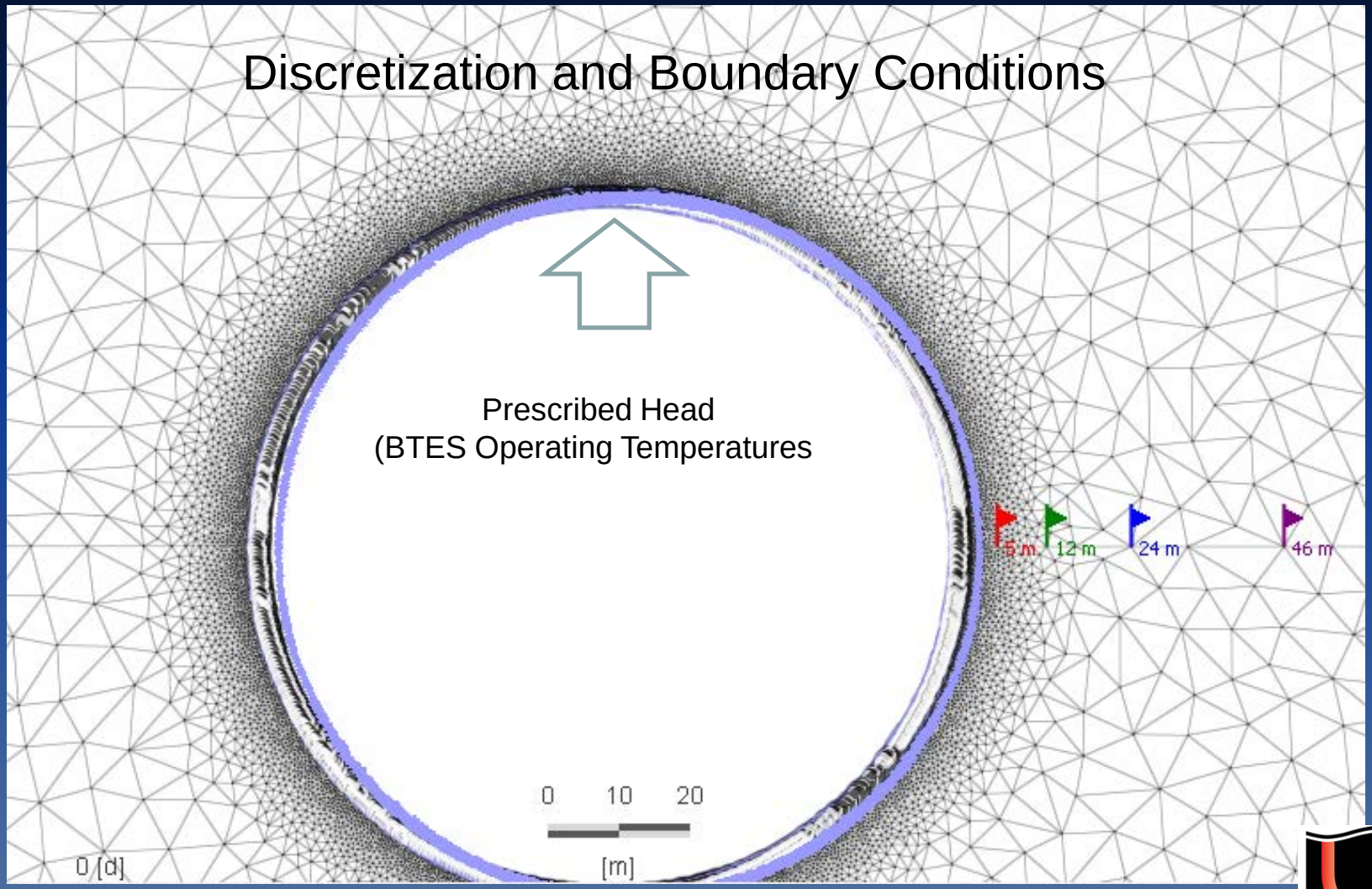


Prescribed Head Boundary Conditions

- All mesh boundaries
- Static head/temp exterior BCs
  - h = -4 m (-4 °C)
  - ambient rock temperature
- Transient (BTES cycling) interior BC
  - used IF Tech average EWTs
  - Simulated 10 BTES charge/discharge cycles

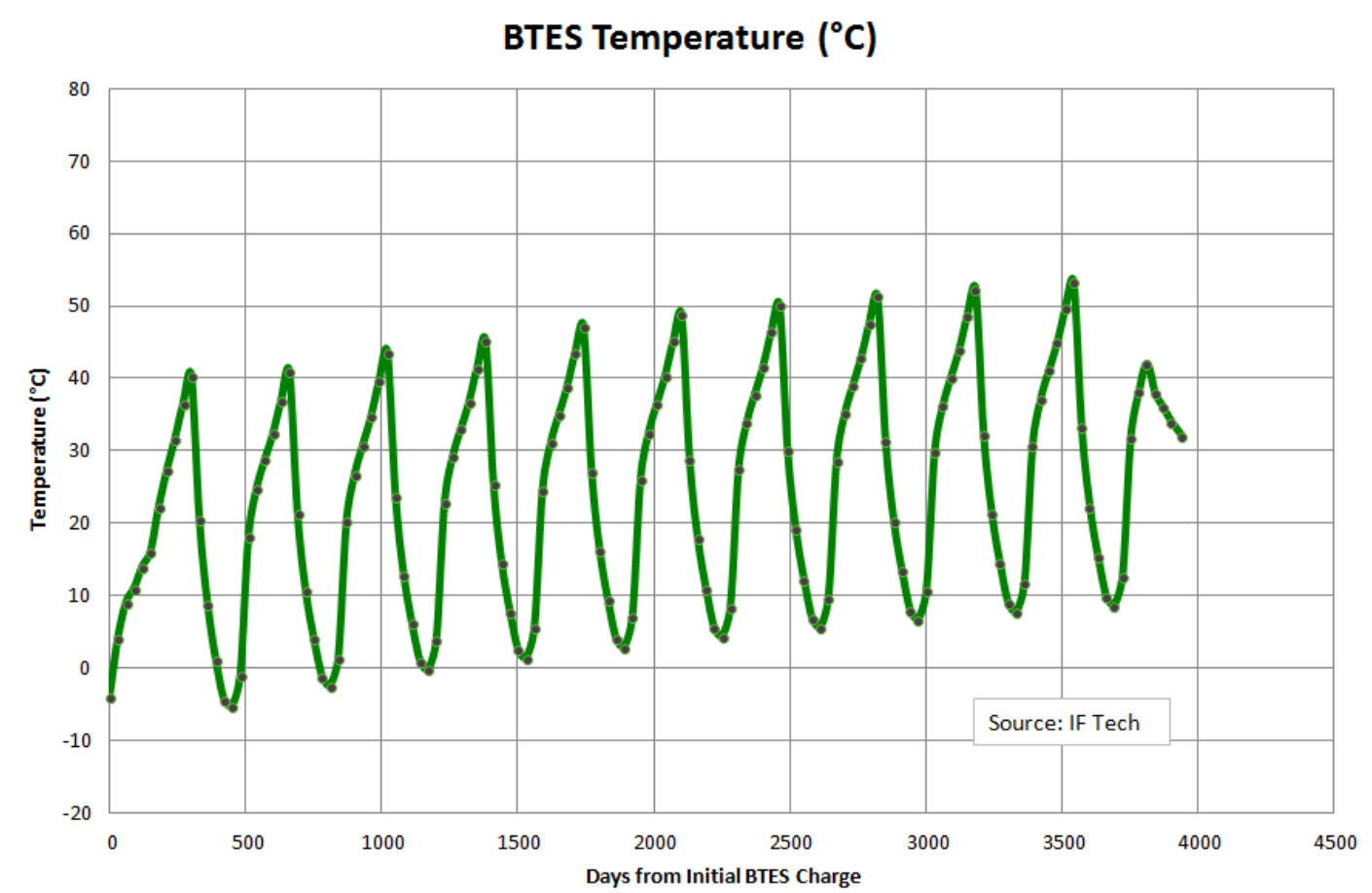
BTES Feasibility Study

NWT, Canada



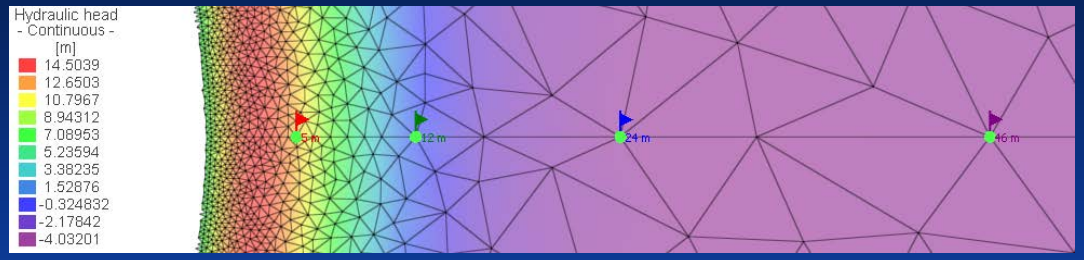
BTES Feasibility Study

NWT, Canada

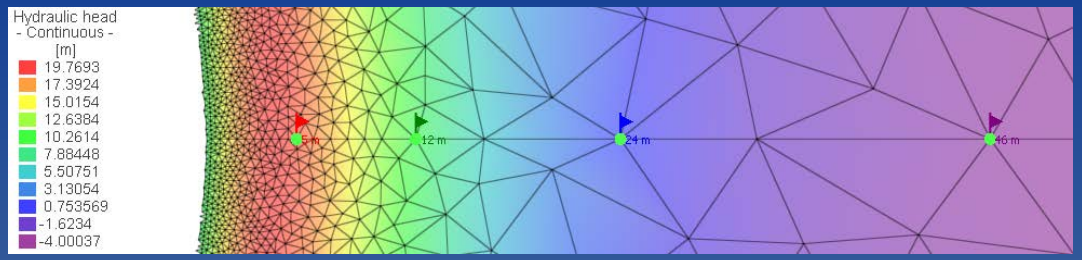


BTES Feasibility Study

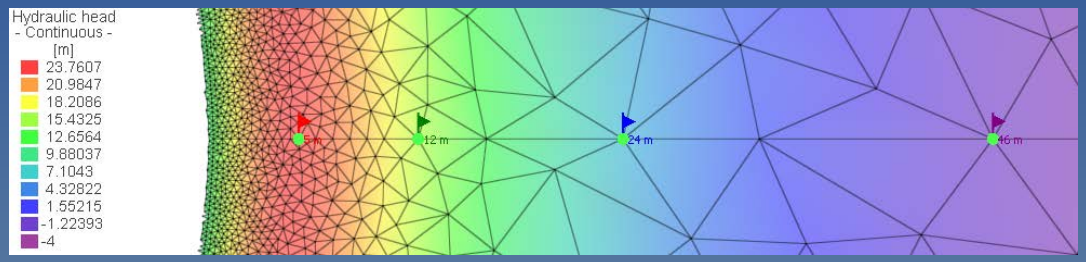
NWT, Canada



1 year



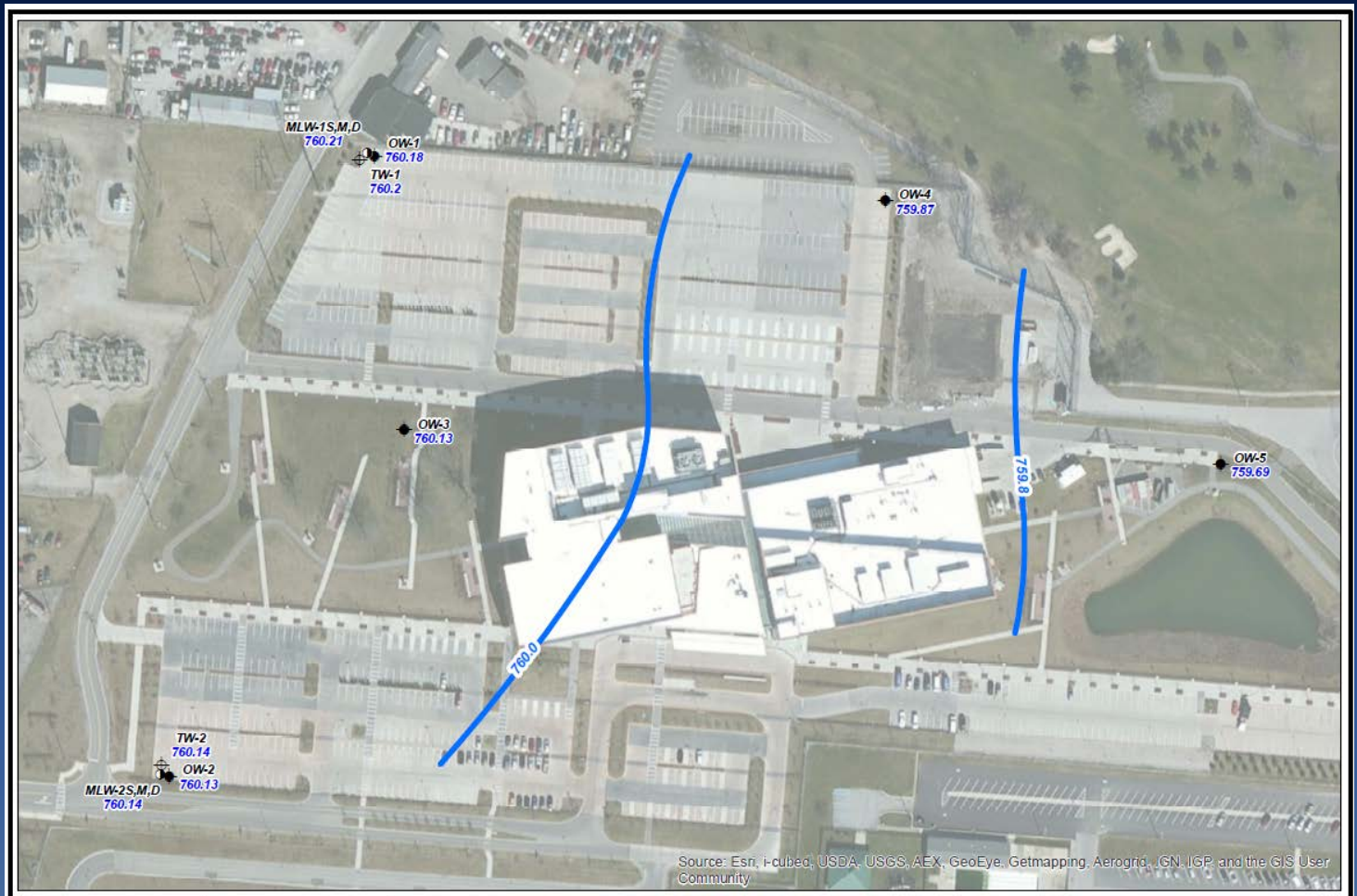
5 years



10 years

ATES Hydrogeologic Investigation

VA Hospital, Columbus, OH



PREPARED BY:
Underground ENERGY
PROJECT NO.: DVA.2012.01
DATE: 3/22/2015

0 50 100 150
Feet
APPROXIMATE SCALE

LEGEND
1-INCH MULTI-LEVEL WELL
2-INCH OBSERVATION WELL
8-INCH TEST WELL
PIEZOMETRIC SURFACE ELEVATION CONTOURS (FT. MSL)

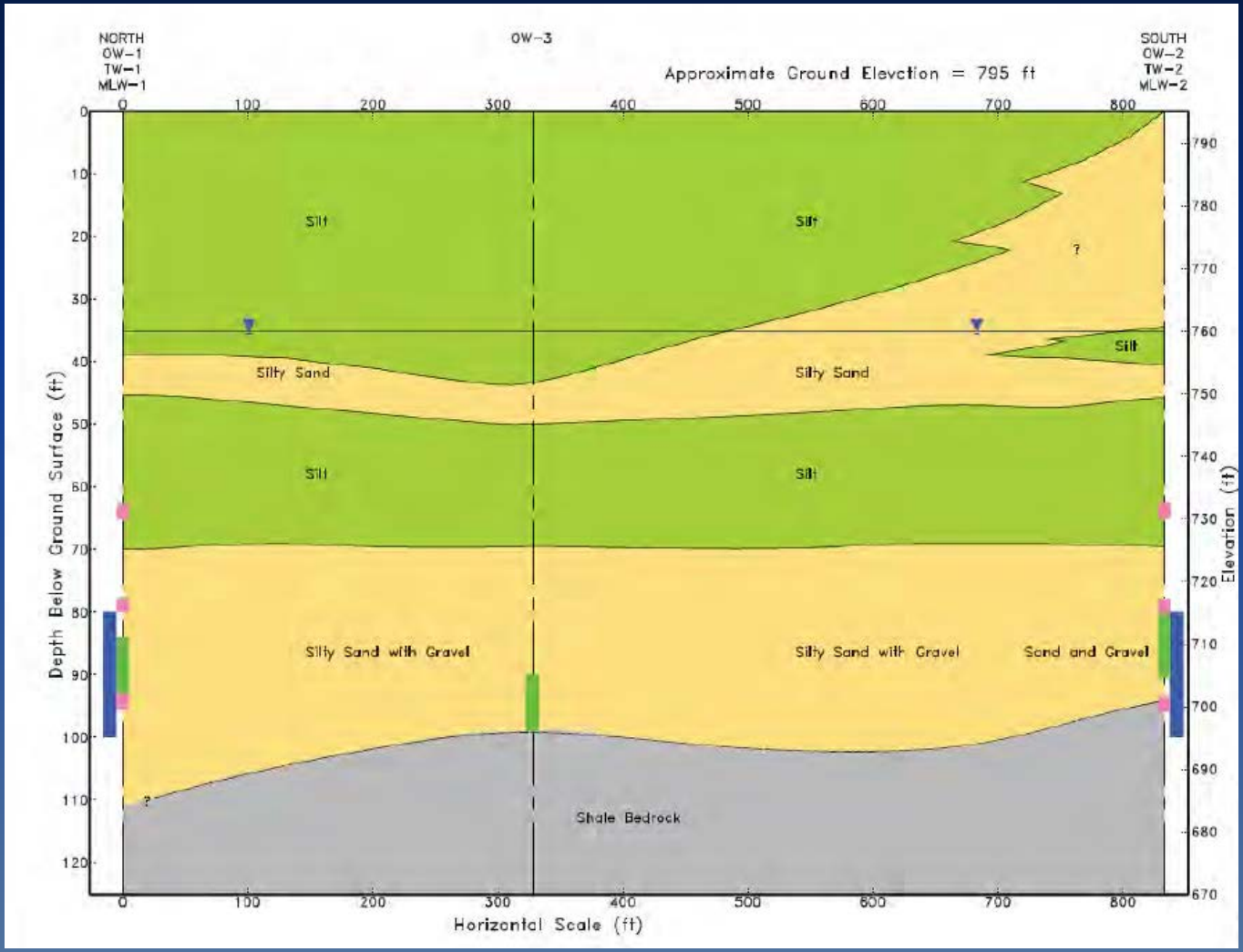
PREPARED FOR:
U.S. Department of Veterans Affairs
INDEPENDENCE, OHIO

TITLE:
PIEZOMETRIC SURFACE ELEVATION MAP
22 JANUARY 2015

LOCATION:
VA MEDICAL CENTER
420 NORTH JAMES ROAD
COLUMBUS, OHIO

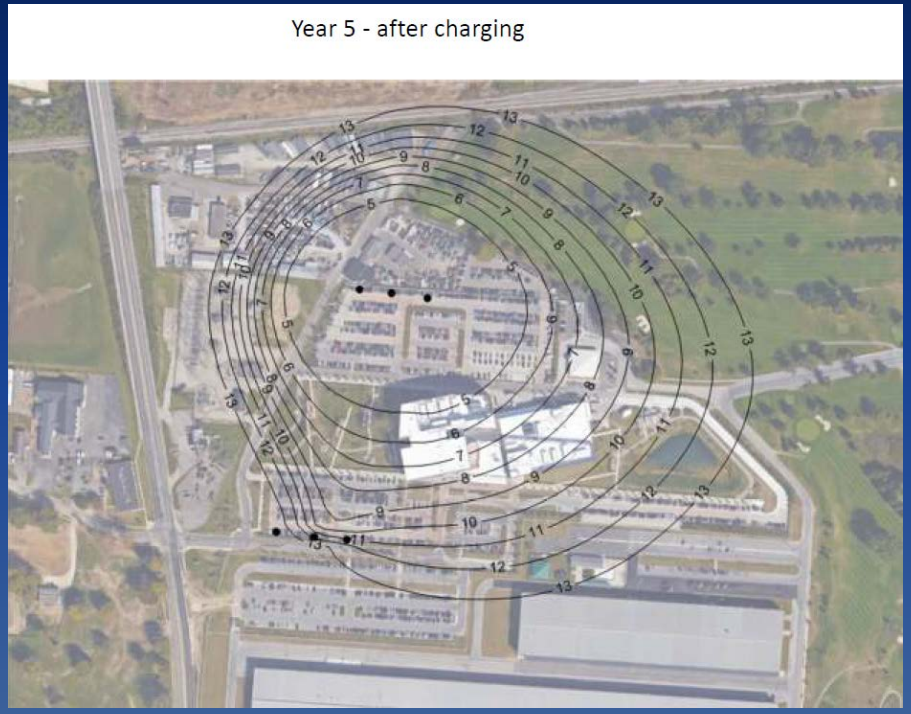
ATES Hydrogeologic Investigation

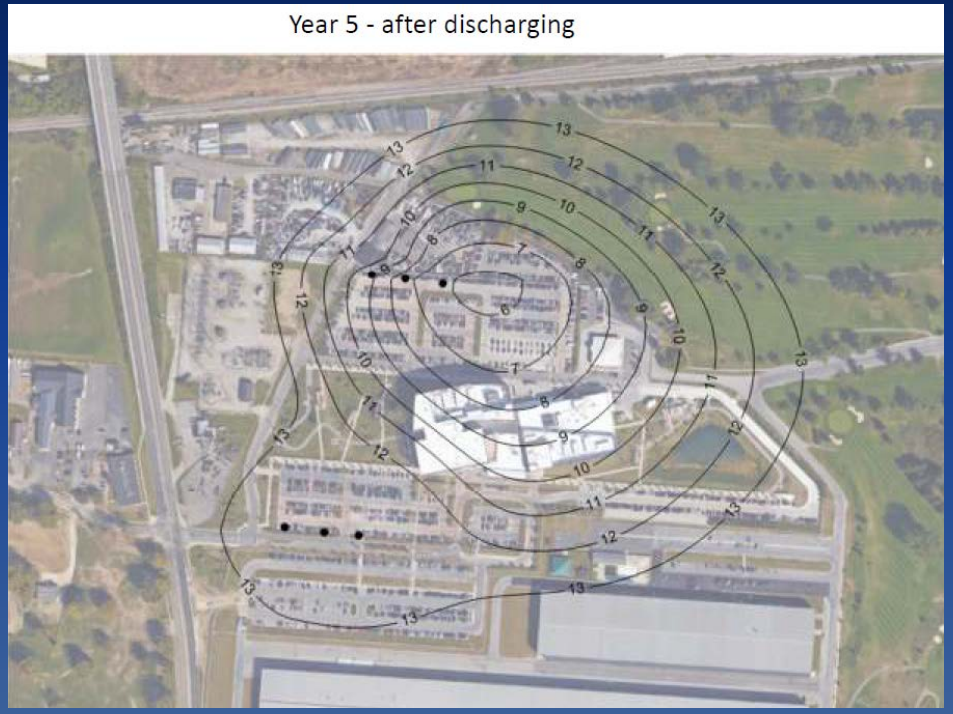
VA Hospital, Columbus, OH



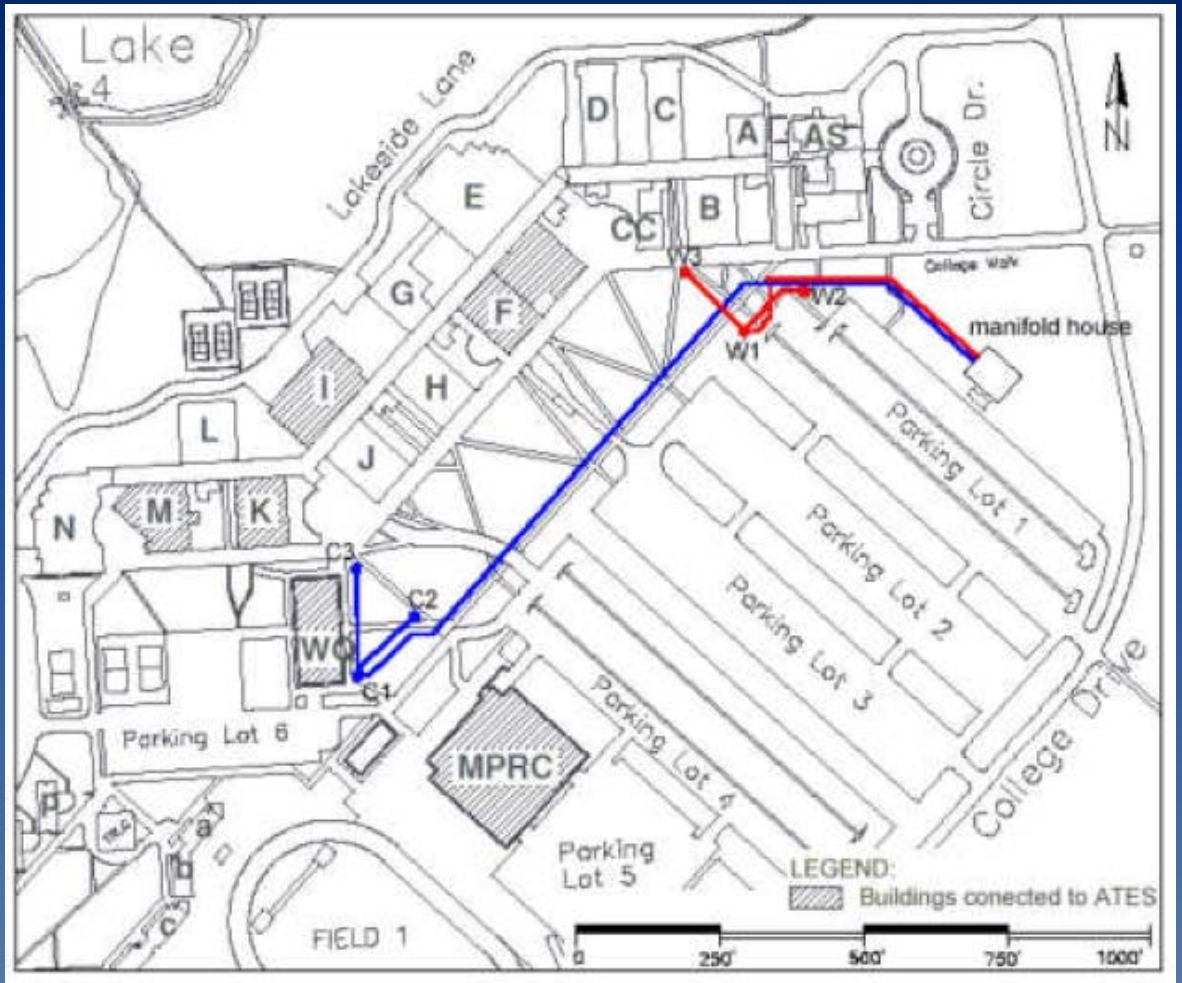
ATES Geothermal Modeling

VA Hospital, Columbus, OH





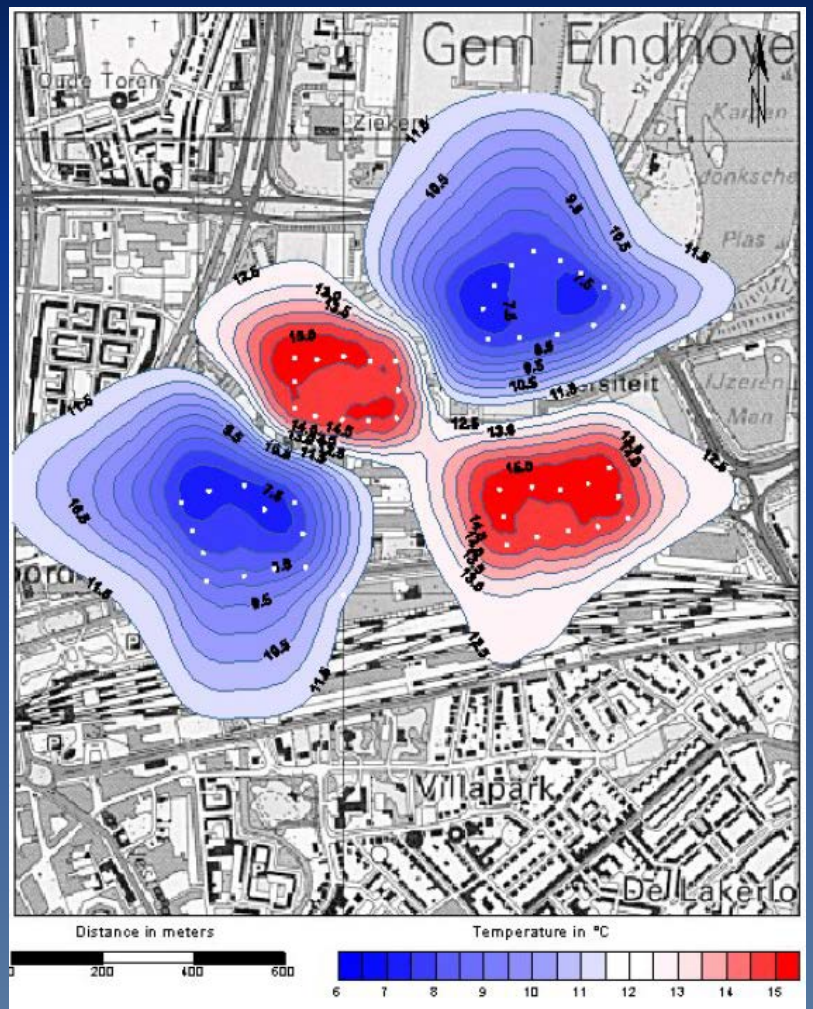
Richard Stockton College ATES Layout



Stockholm Arlanda Airport

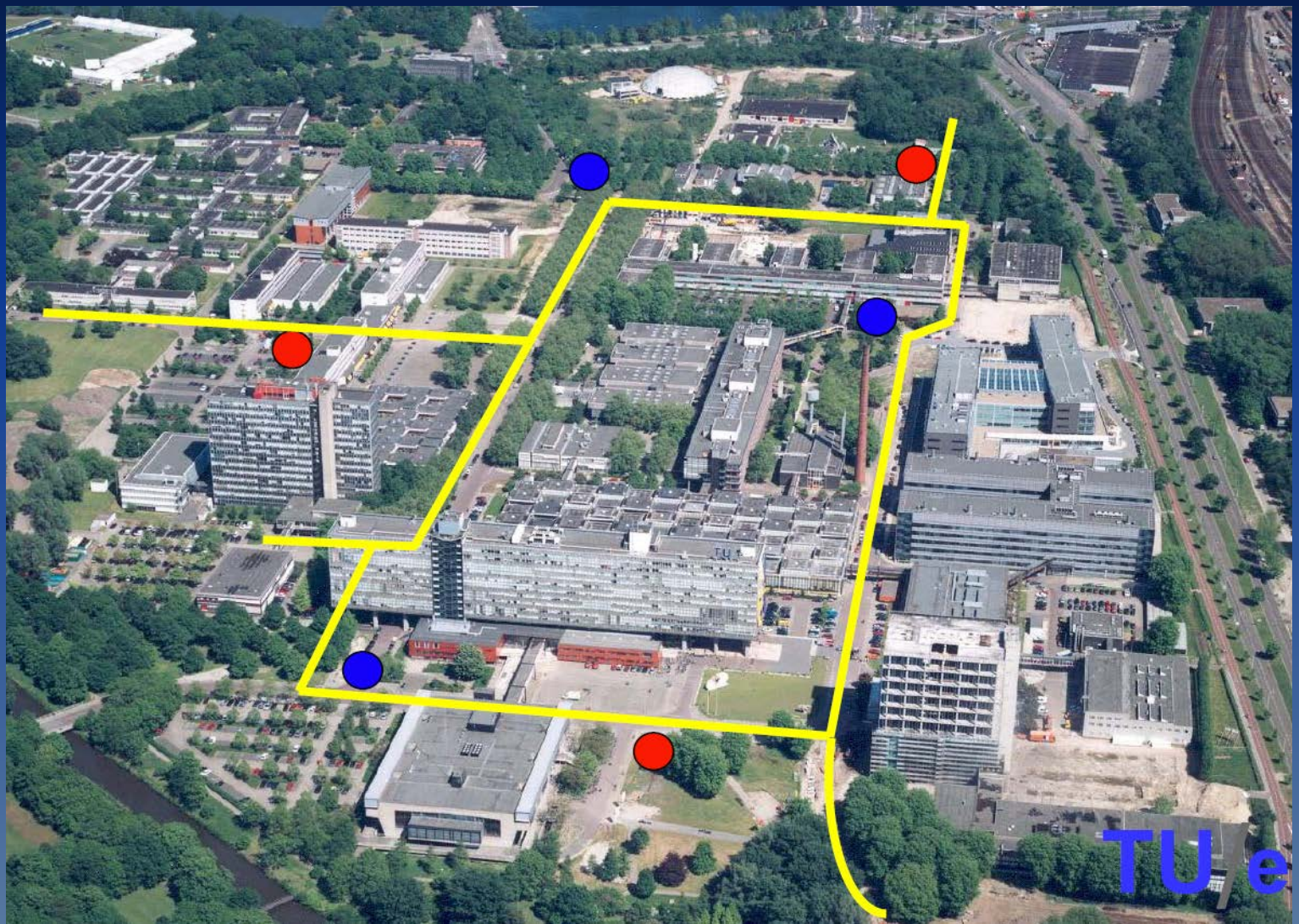
Eindhoven University of Technology
Numerical Modeling of Alternatives

Technical/Economic Optimum



Preferred Option – Minimal Impacts

Eindhoven University of Technology
20 MW ATES Configuration



ATES Case Studies: Physical Data

ATES Project	Year Installed	Max Aggregate Pumping Rate	No. of Wells	Aquifer Depth (ft)	Aquifer Type
New Jersey Stockton College	2008	1200 gpm	6 (2 x 3)	100-200 ft	Confined Coastal Plan
Massachusetts Confidential Client		600 gpm	6 (2 x 3)	35-55 ft	Unconfined Glaciofluvial
Long Island, NY Wyandanch Rising			6 (2 x 3)	~ 500 ft	Confined Coastal Plain
The Netherlands Eindoven University	2002	9,900 gpm	36 (2 x 18)	90-260 ft	Confined Coastal Plain
Stockholm, Sweden Arlanda Airport	2009	3,170 gpm	11 (5c, 6w)	50-100 ft	Unconfined Glacial Es

Underground ENERGY

ATES Case Studies: Thermal Data

ATES Project	Thermal Capacity	Ambient Groundwater Temperature	System Delta T	Cooling Supply Temperature	Cooling Return Temperature	Heating / Cooling Configuration
New Jersey Stockton College	800 tons	53° F	16° F	43-48° F	59-64° F	Cooling
Massachusetts Confidential Client	400 tons	50° F	16° F	43-50° F	59-64° F	Cooling
Long Island, NY Wyandanch Rising	1,050 tons	52° F				Cooling / Heating
The Netherlands Eindoven University	5,700 tons (20 MW_t)	53° F	13° F			Cooling / Heating
Stockholm , Sweden Arlanda Airport	2,900 tons	46° F			59-68° F	Cooling / Heating

ATES Case Studies: System Performance Data

ATES Project	COP	Annual Energy Savings (MWh/yr)	Annual Energy Savings (%)	Annual CO2 Reduction (tons/yr)	Annual CO2 Reduction (%)
New Jersey Stockton College	9	500 MWh/yr	60%		60%
Massachusetts Confidential Client	15	5,610 GJ	61.4%	263 tons/yr	61.4%
Long Island, NY Wyandanch Rising	5.2 (cool) 3.5 (heat)				
The Netherlands Eindhoven University		2,600 MWh/yr (elec) 37,000 MWh/yr (gas)		13,300 tons/yr	
Stockholm , Sweden Arlanda Airport	17	4,000 MWh/yr (h) 10,000 MWh/yr (c)		7,700 tons/yr	

Underground ENERGY

ATES Case Studies: Financial Data

ATES Project	Capital Cost ($)	Annual Energy Savings ($)	Financial Incentives	Funding Sources	Simple Payback (years)
New Jersey Stockton College	$1.2 M	$100,000	Utility rebate	Bond	12 yr
Massachusetts Confidential Client	$1.2 M	$96,000	10% federal tax credit to 3rd party, utility rebate	Internal	8-9 yr
Long Island, NY Wyandanch Rising	$4.2M		10% federal tax credit EPAct 179(D)	PPA	
The Netherlands Eindhoven University	$14.7 M		$1.8 M grant		6-10 yr
Stockholm , Sweden Arlanda Airport	$6.8M	$1,400,000			5 yr

Underground ENERGY

Thank You!