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

LSP Association
assess. advise. restore.

Mark A. Worthington, LSP
Underground Energy, LLC

May 2015

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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

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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

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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

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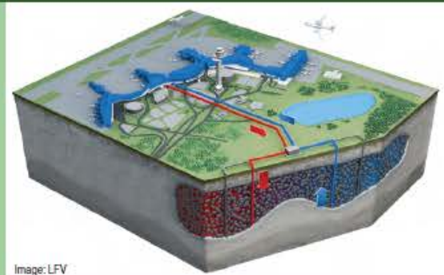
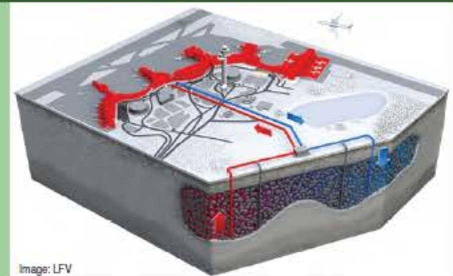
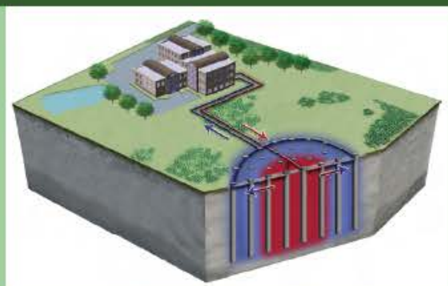
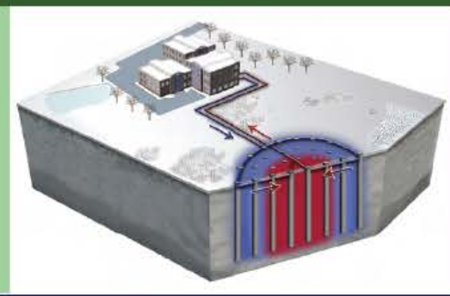
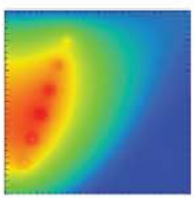
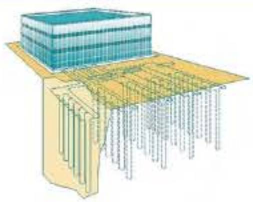
Geothermal Technology Summary

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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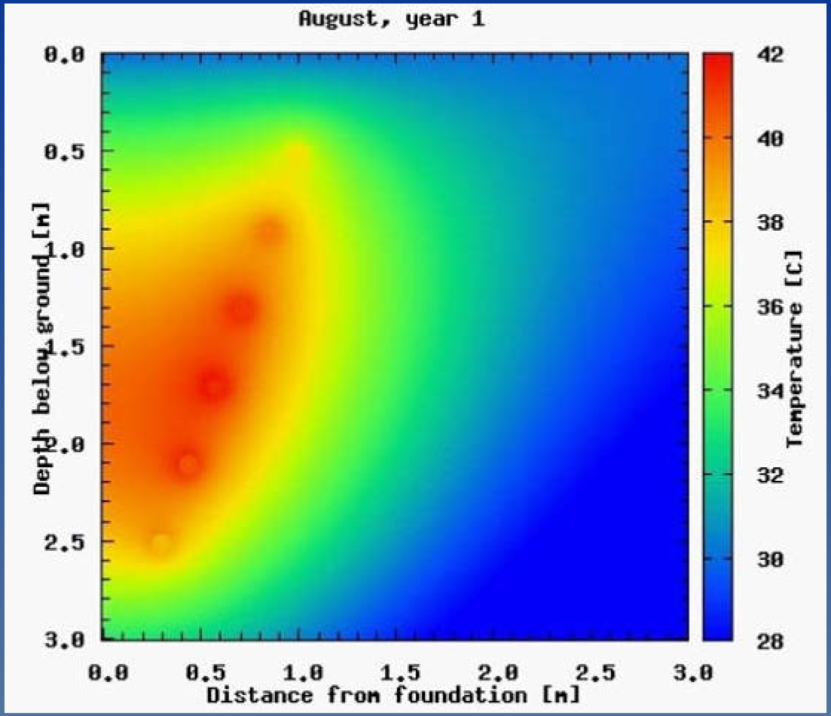
Ground Heat Exchanger Design Practice

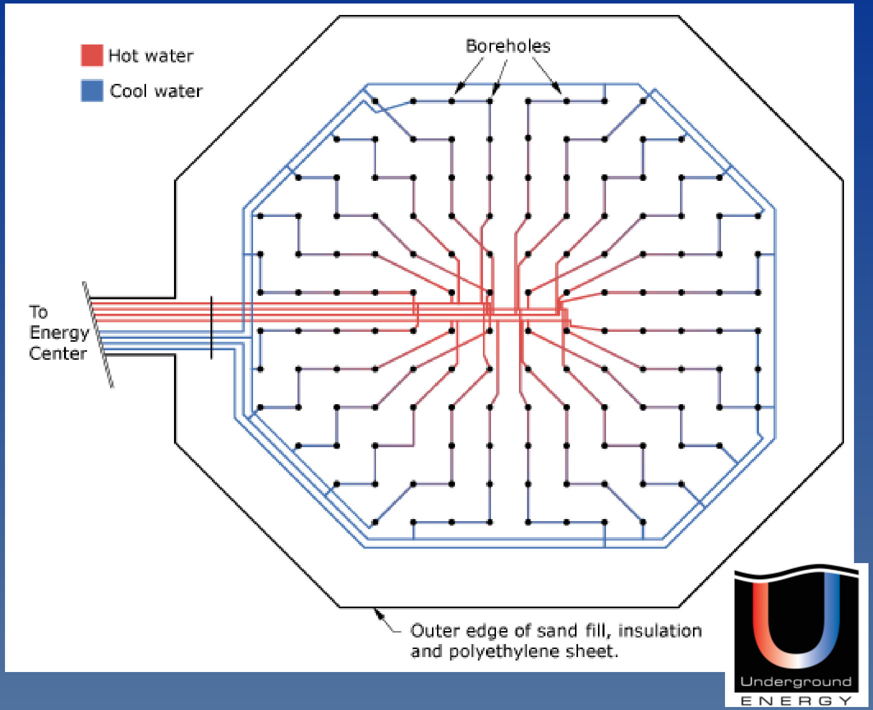
GSHP, GeoExchange

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

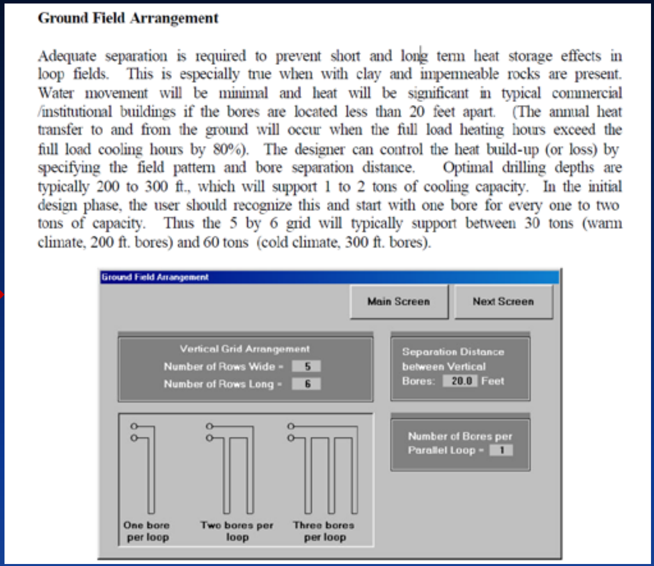
UTES

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).

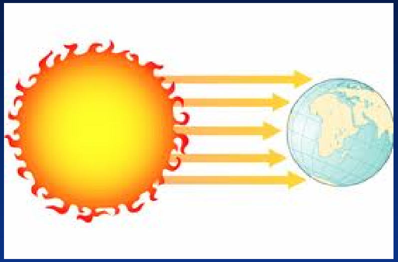
*“Adequate separation is required to **prevent** short and long term heat storage effects in loop fields. This is especially true when with clay and impermeable rocks are present. Water movement will be minimal and heat will be significant in typical commercial /institutional buildings if the bores are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

GchpCalc V 4 Instruction Manual, p. 11

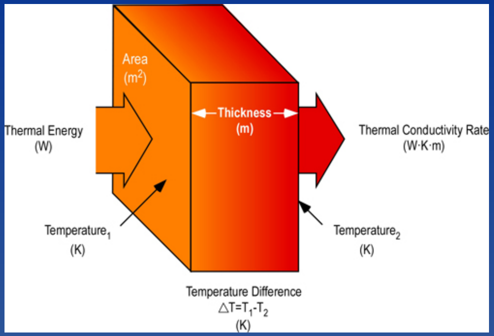
Physics of Heat Transfer

Three Primary Heat Transfer Mechanisms

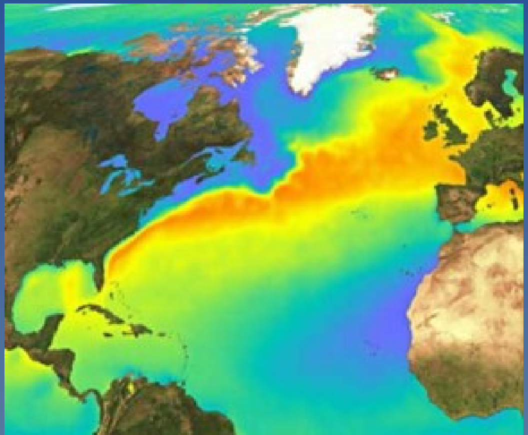
- **Radiation** – Thermal energy transfer via Emission or absorption of electromagnetic waves
  - » Not important in GSHP systems



- **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

Underground Thermal Energy Storage
=
Seasonal Thermal Energy Storage

Ice house in Boxborough, MA

Ice storage in Iran

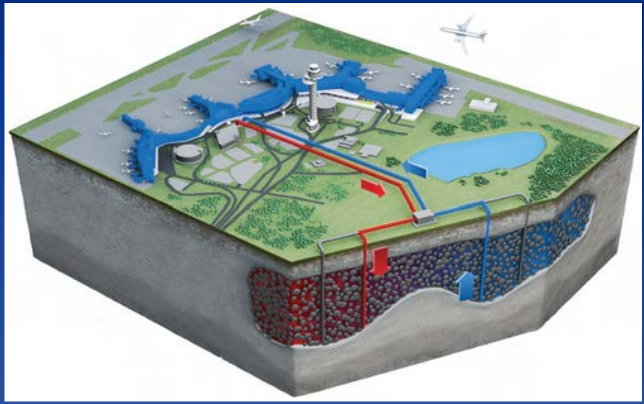
An Enabling Green Technology:

- 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

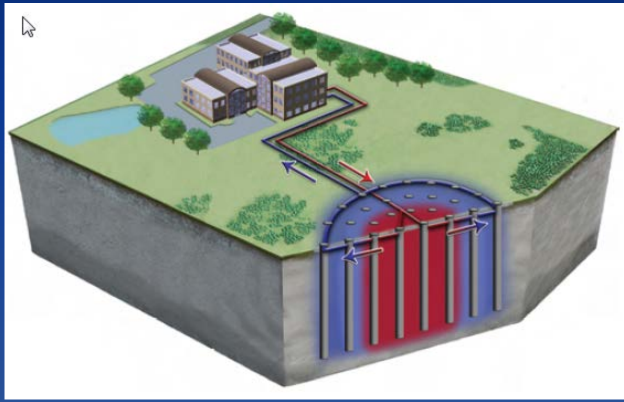
ATES



- 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

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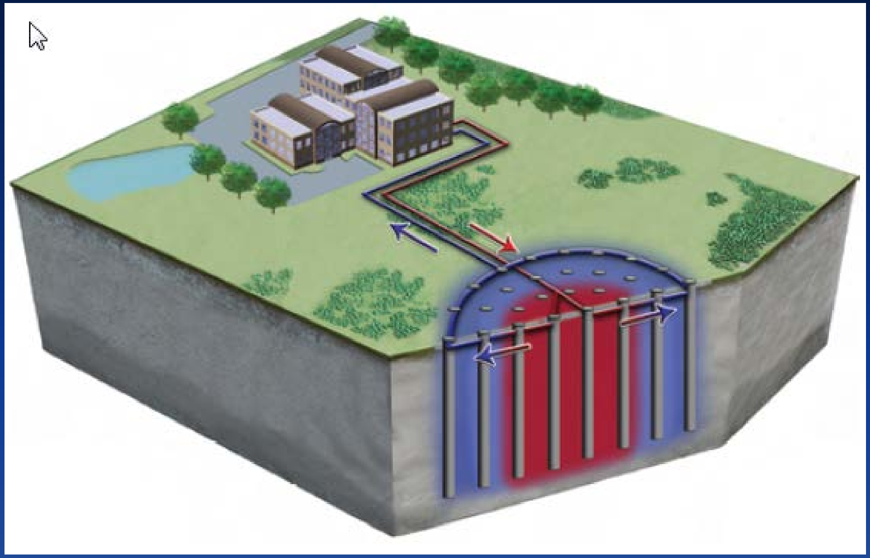
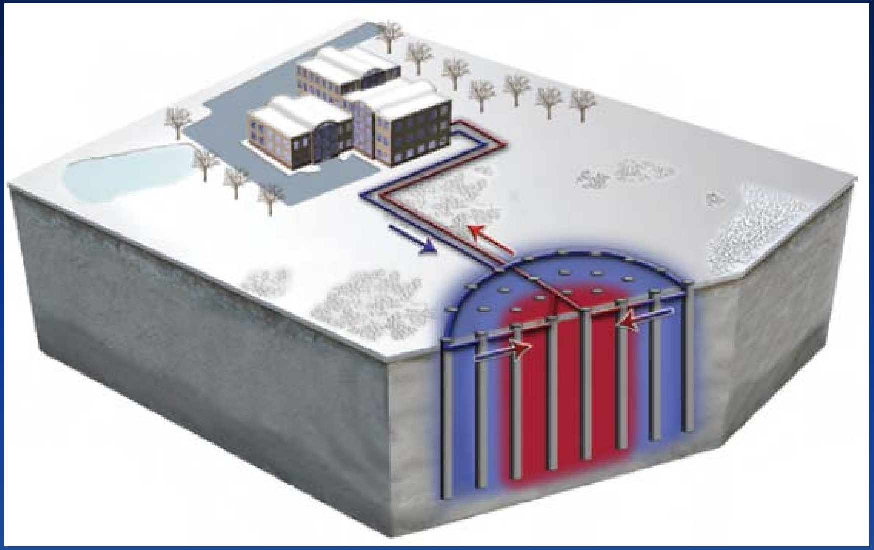
Borehole Thermal Energy Storage (BTES)

Summer

Winter





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

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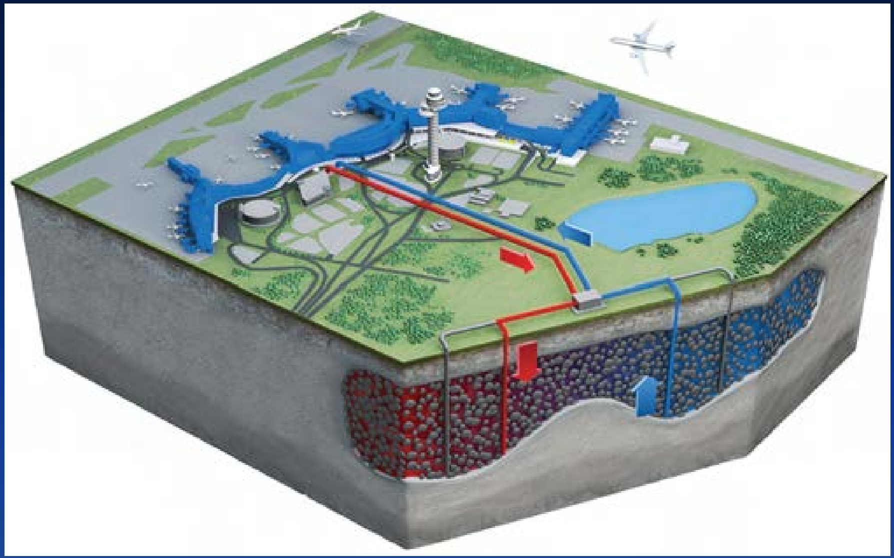
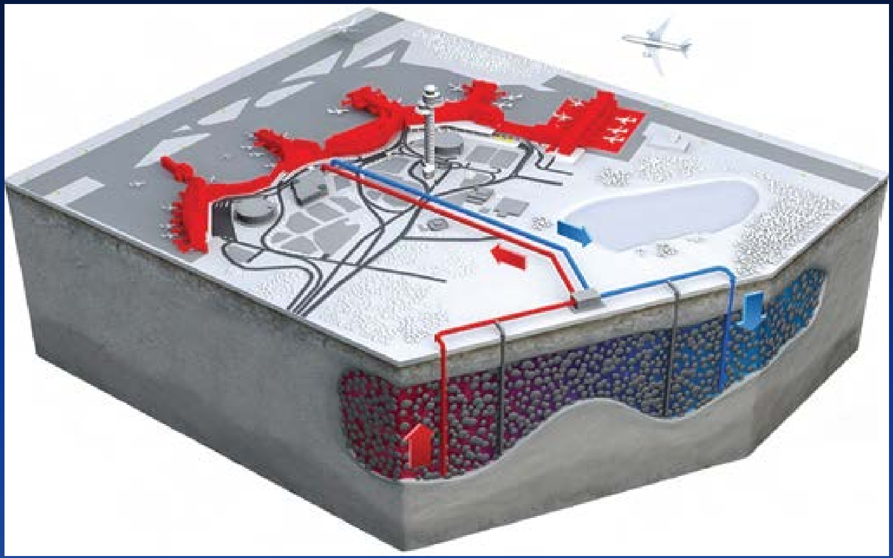
Aquifer Thermal Energy Storage (ATES)

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

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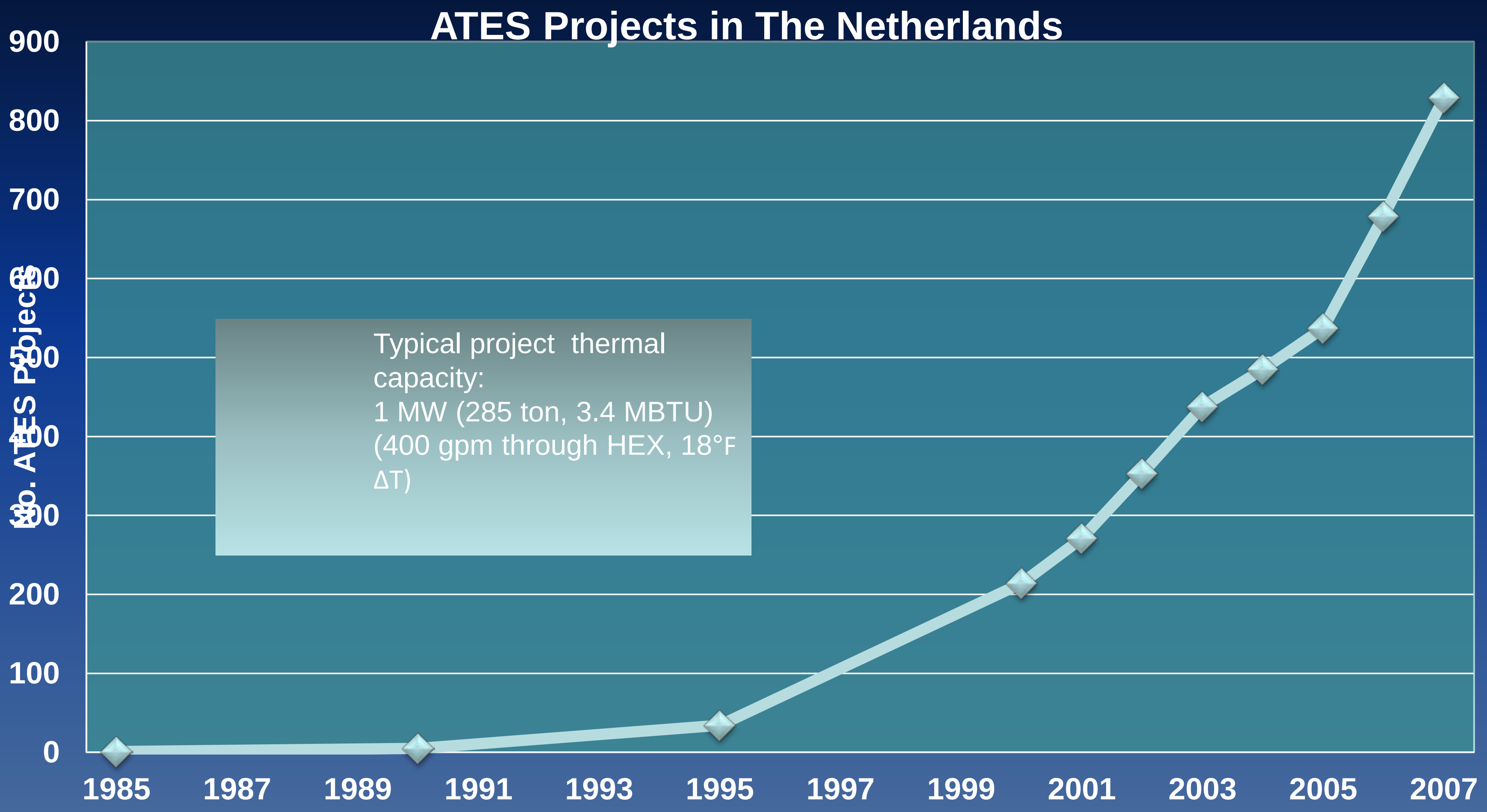
ATES Growth in The Netherlands



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)

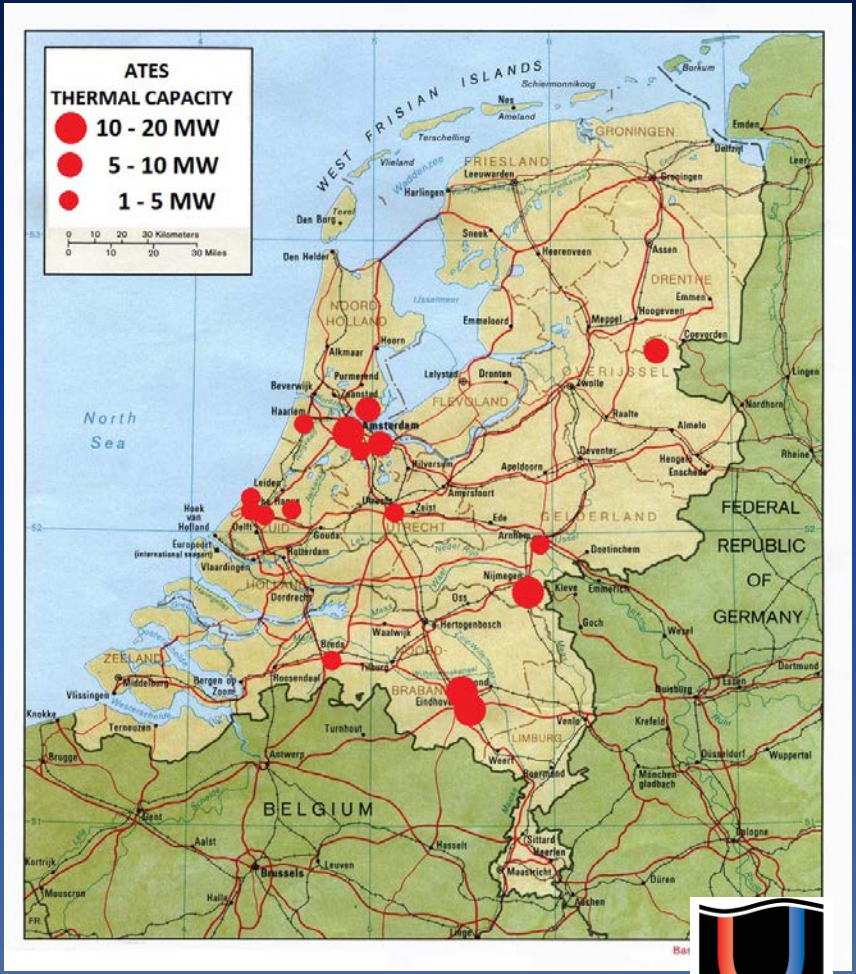
Shell Campus – Amsterdam (construction stage, 15 MW)

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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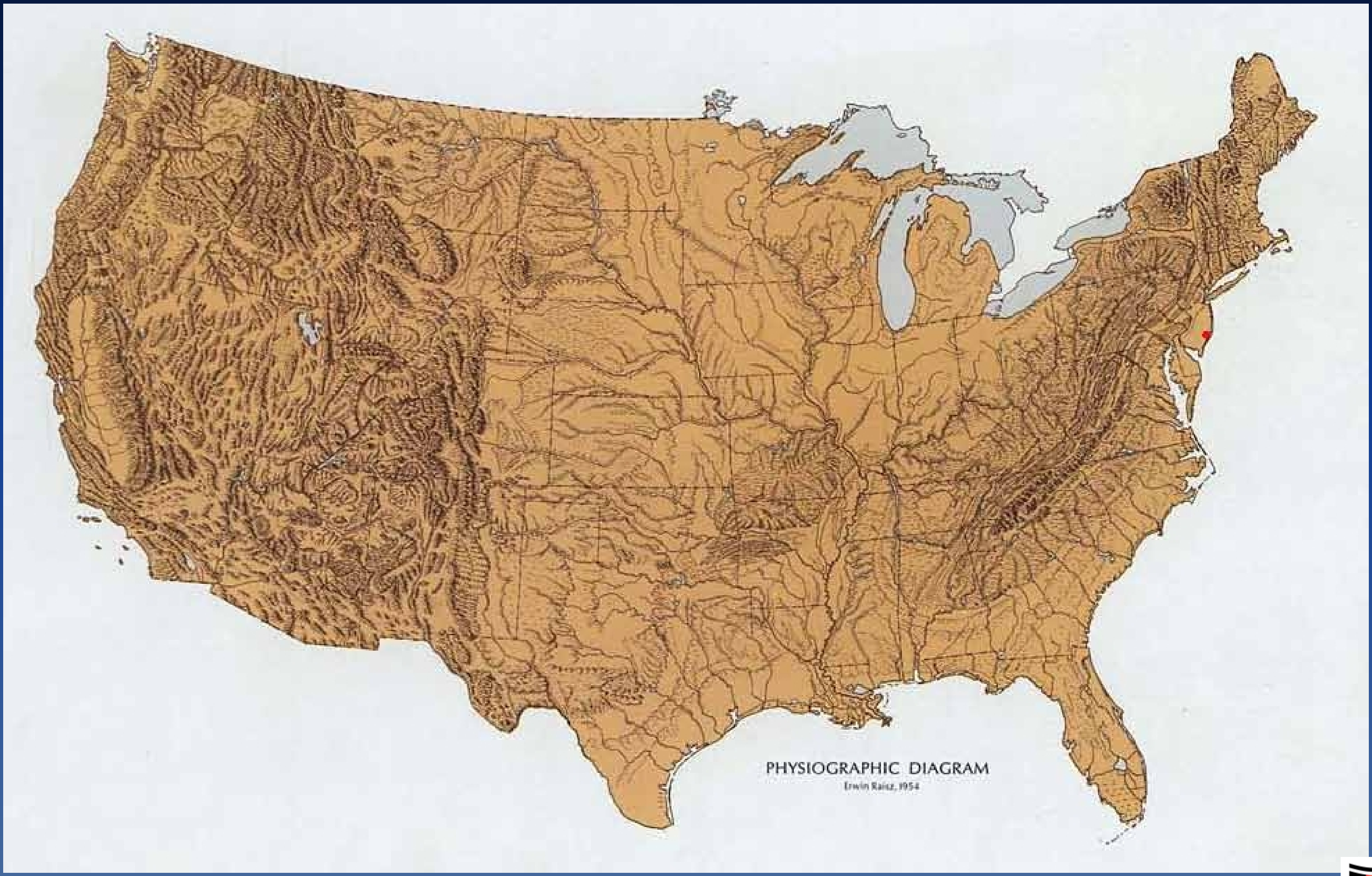
ATES Based District Heating & Cooling Systems in The United States



Richard Stockton College, Pamona, NJ (2 MW)

ATES Siting Considerations

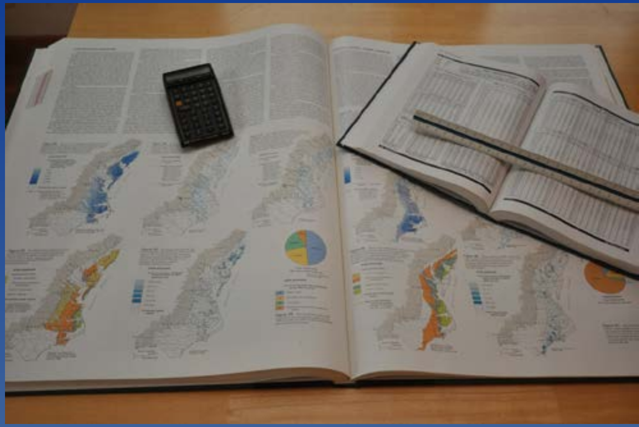
- A suitable temperate climate with seasonally variable thermal loads
- An Aquifer!
  - High transmissivity (T = Kb)
    - K>100 ft/day; b>30-50 ft)
  - Reasonable depth / thickness
  - Reasonable hydraulic gradient ($dh/dx \leq 10^{-3}$)
  - Acceptable water quality
  - Space to separate cold and warm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



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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

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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

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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

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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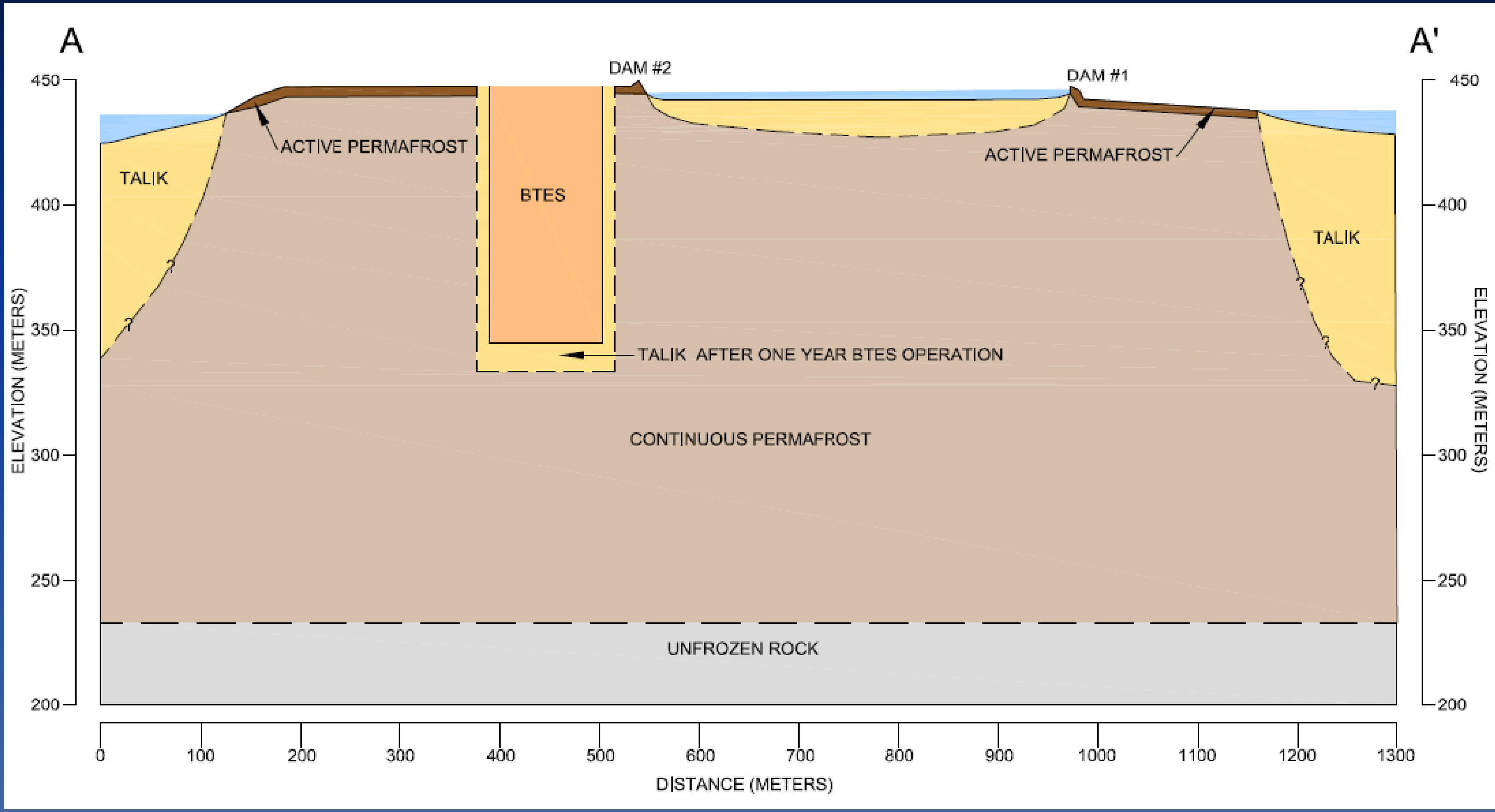
BTES Feasibility Study

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

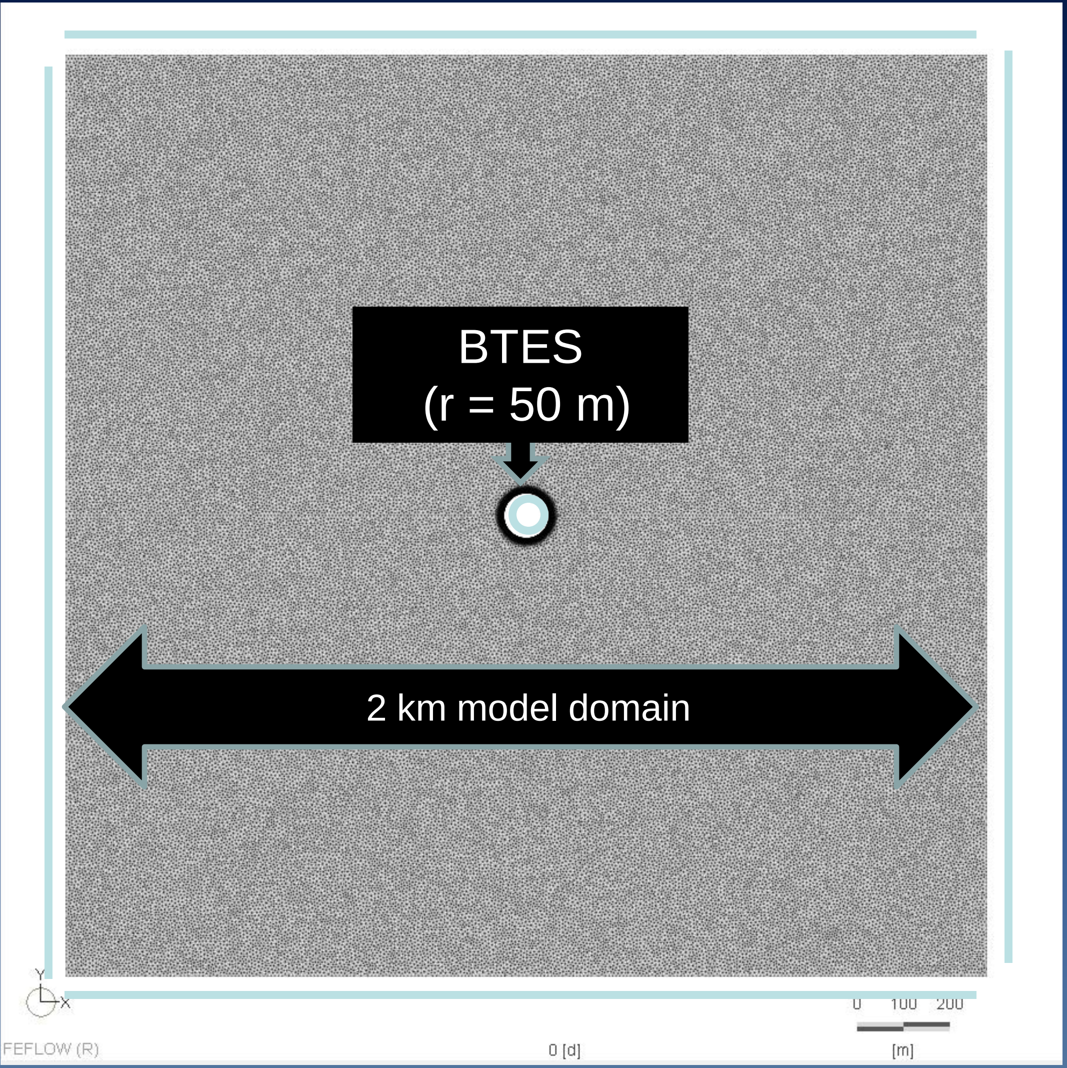
Clay	**Gravel**
K = 10^{-8} m/s	K = 10^{-2} m/s
S_s = 2 x 10^{-3} m^{-1}	S_s = 5 x 10^{-4} m^{-1}
D_h = 5 x 10^{-6} m^2/s	**D_h = 20 m^2/s**

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 x 10^{-7} m^2/s	**D_t = 1 x 10^{-6} m^2/s**

BTES Feasibility Study

NWT, Canada

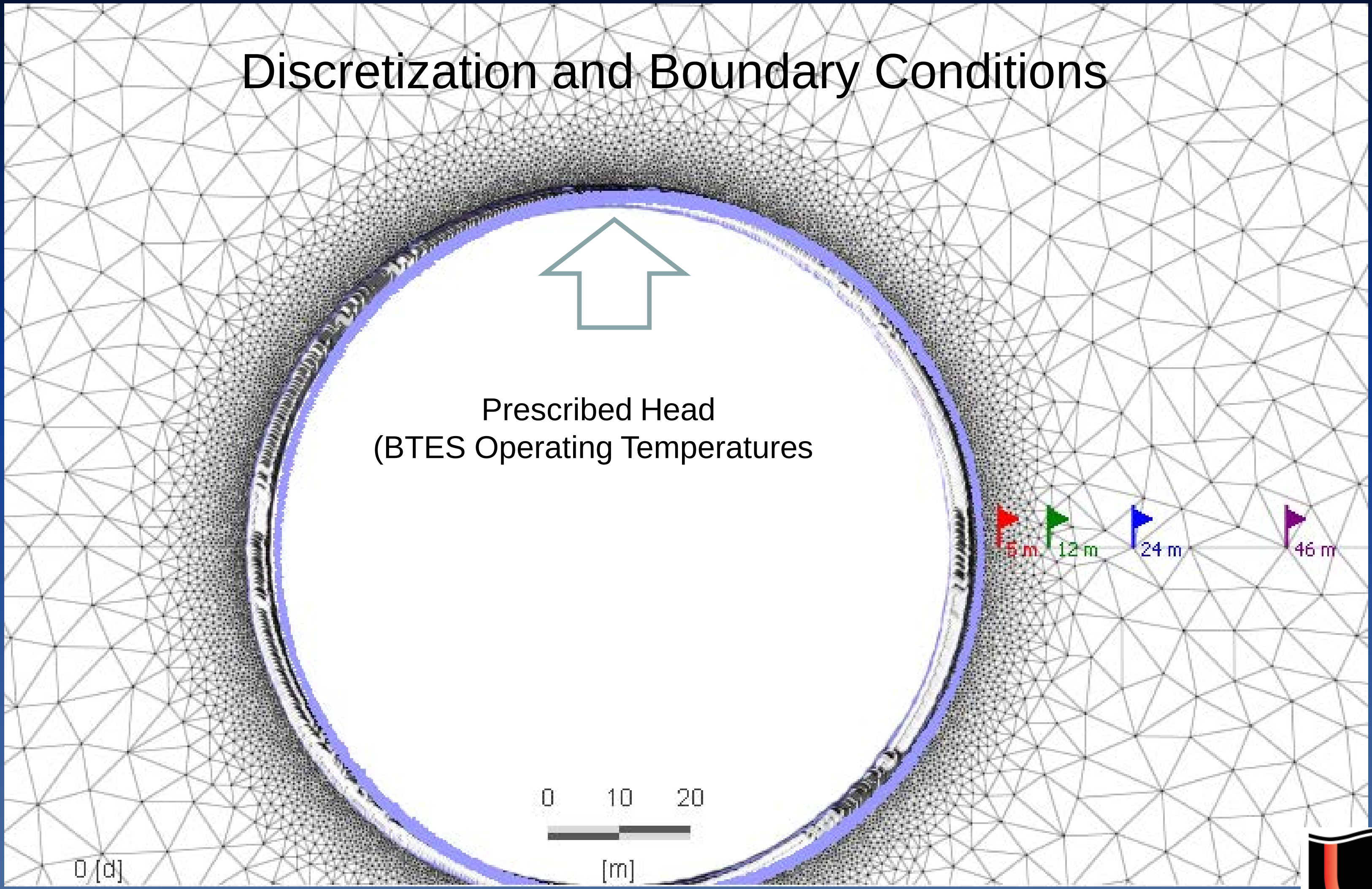


Prescribed Head Boundary Conditions

- 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

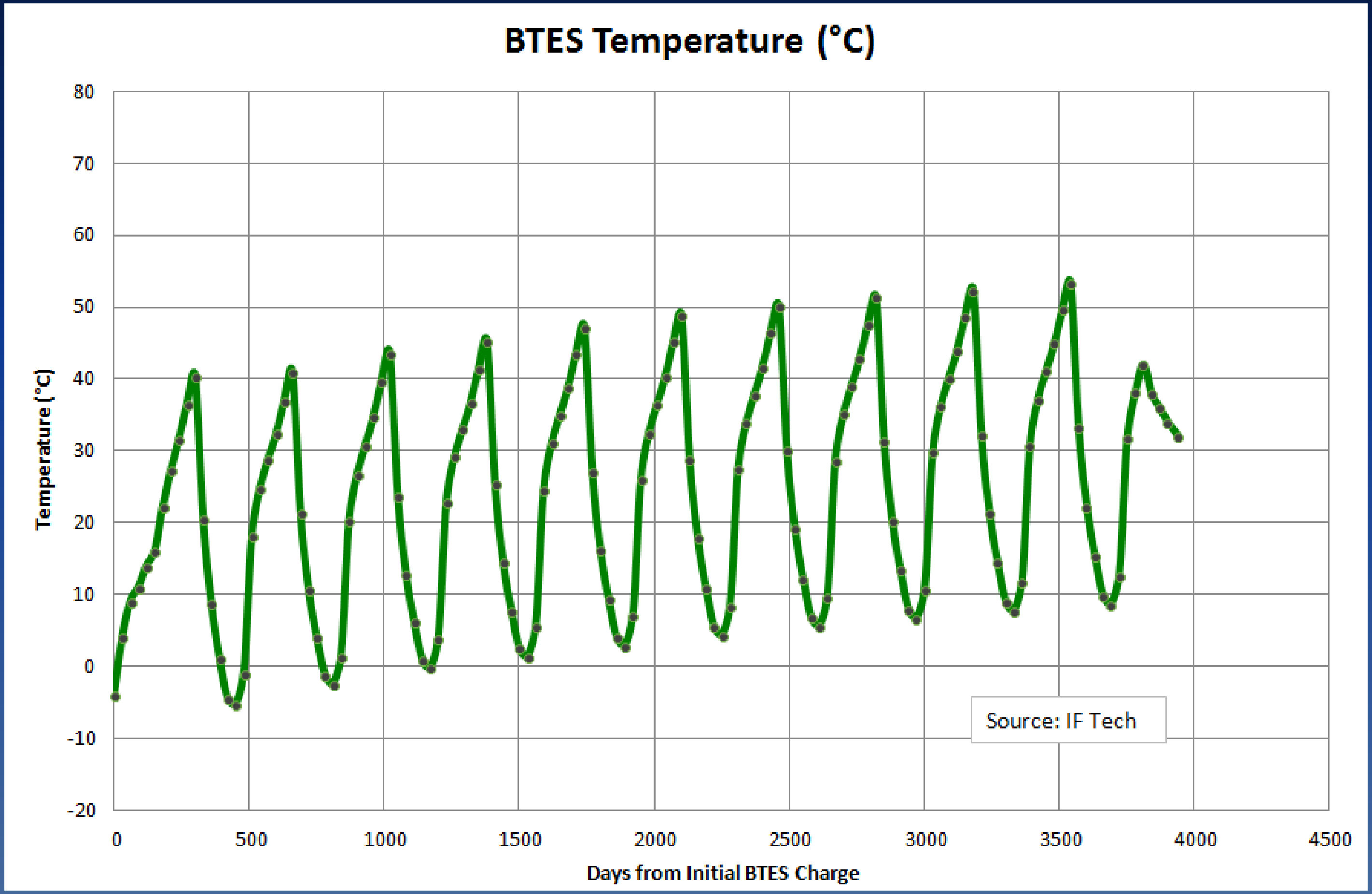
BTES Feasibility Study

NWT, Canada



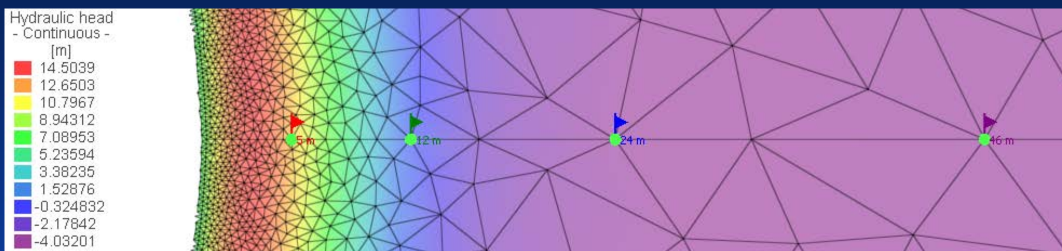
BTES Feasibility Study

NWT, Canada

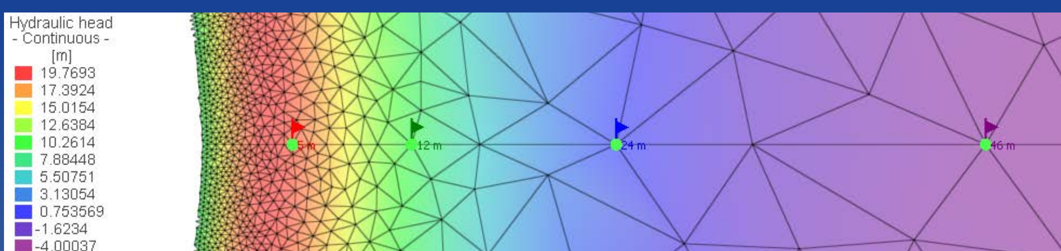


BTES Feasibility Study

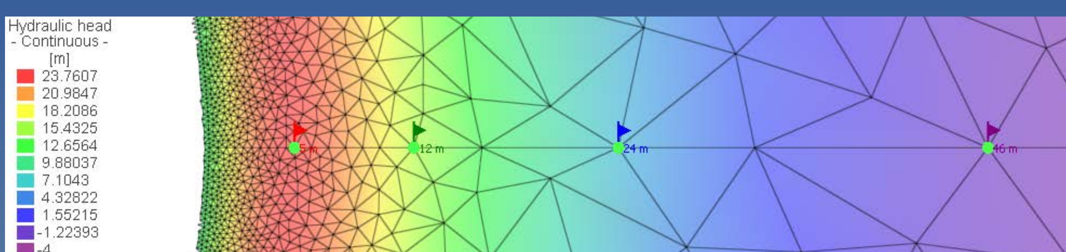
NWT, Canada



1 year



5 years



10 years

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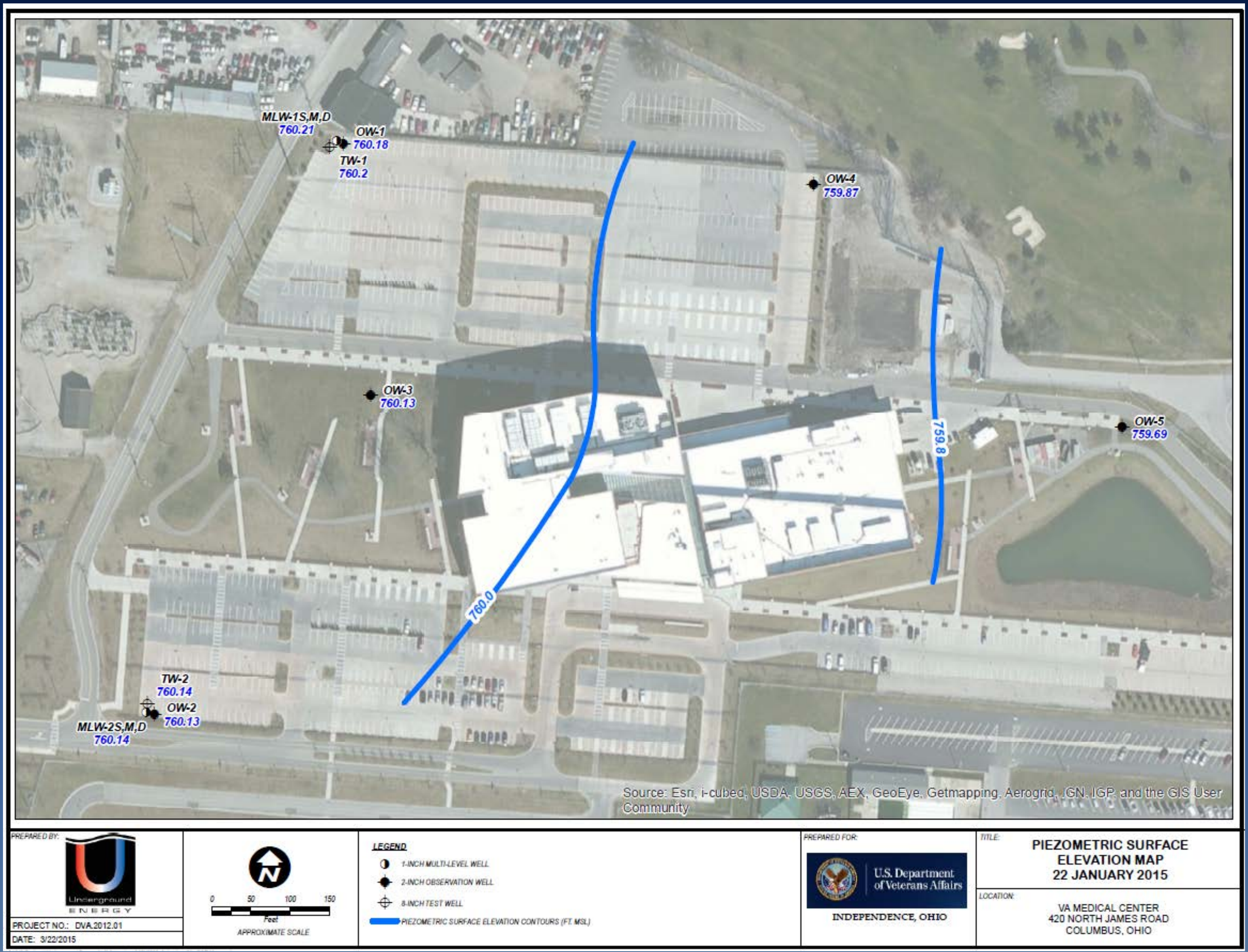
ATES Hydrogeologic Investigation

VA Hospital, Columbus, OH



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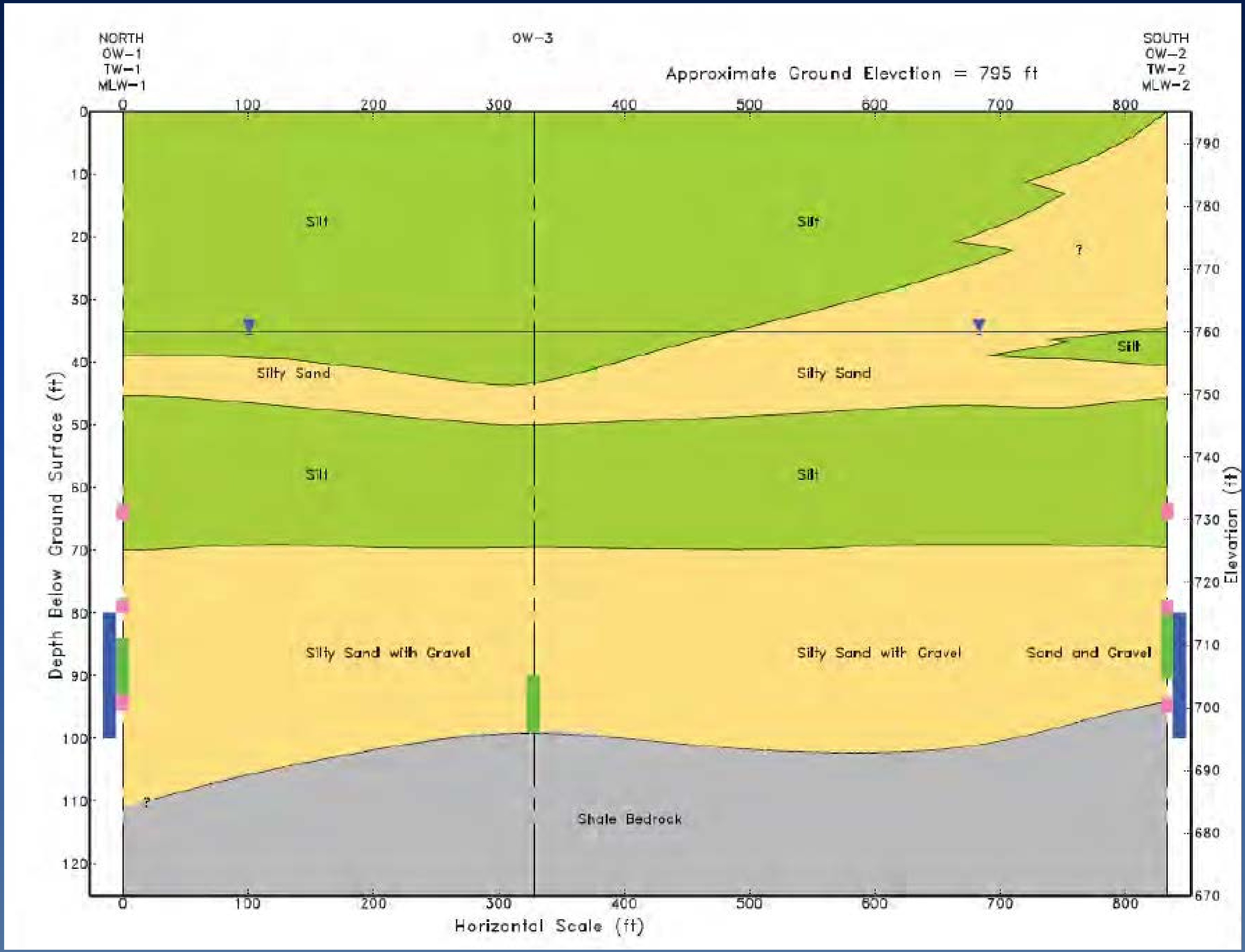
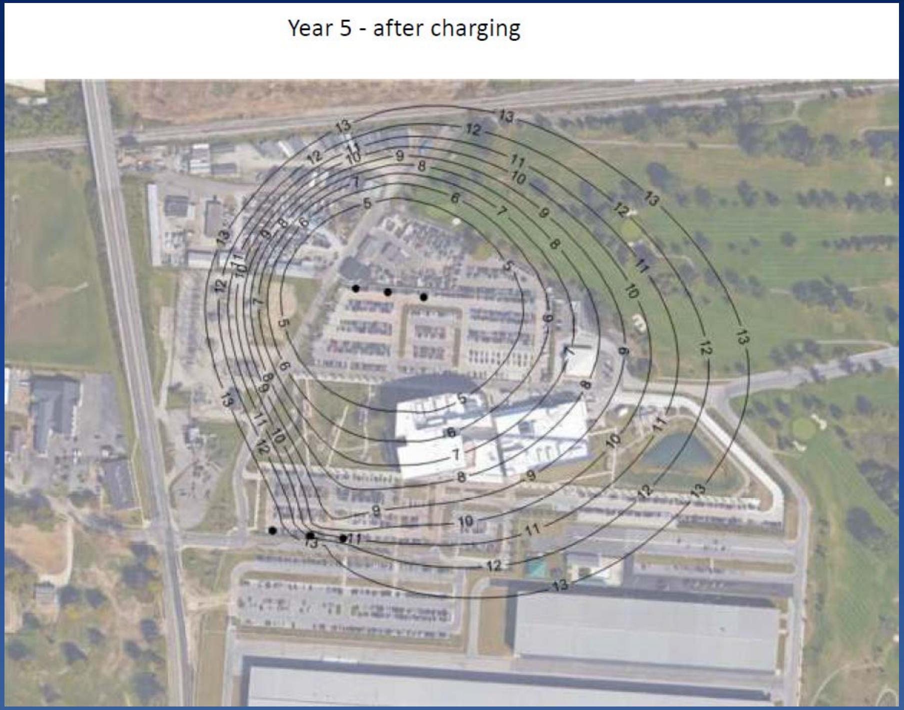
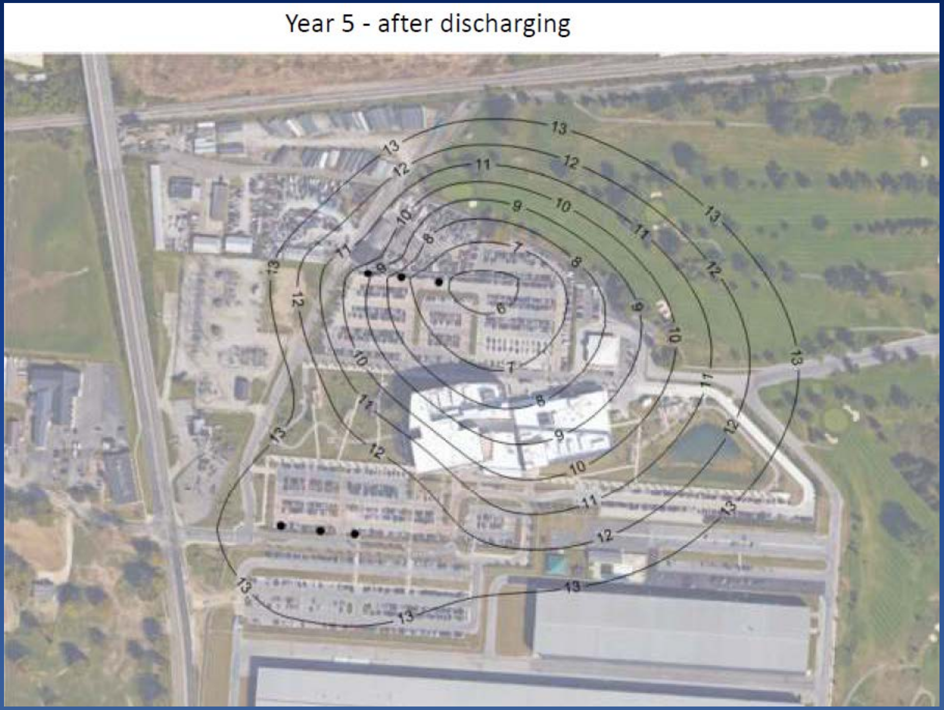


ATES Geothermal Modeling

VA Hospital, Columbus, OH



Year 5 - after charging



Year 5 - after discharging

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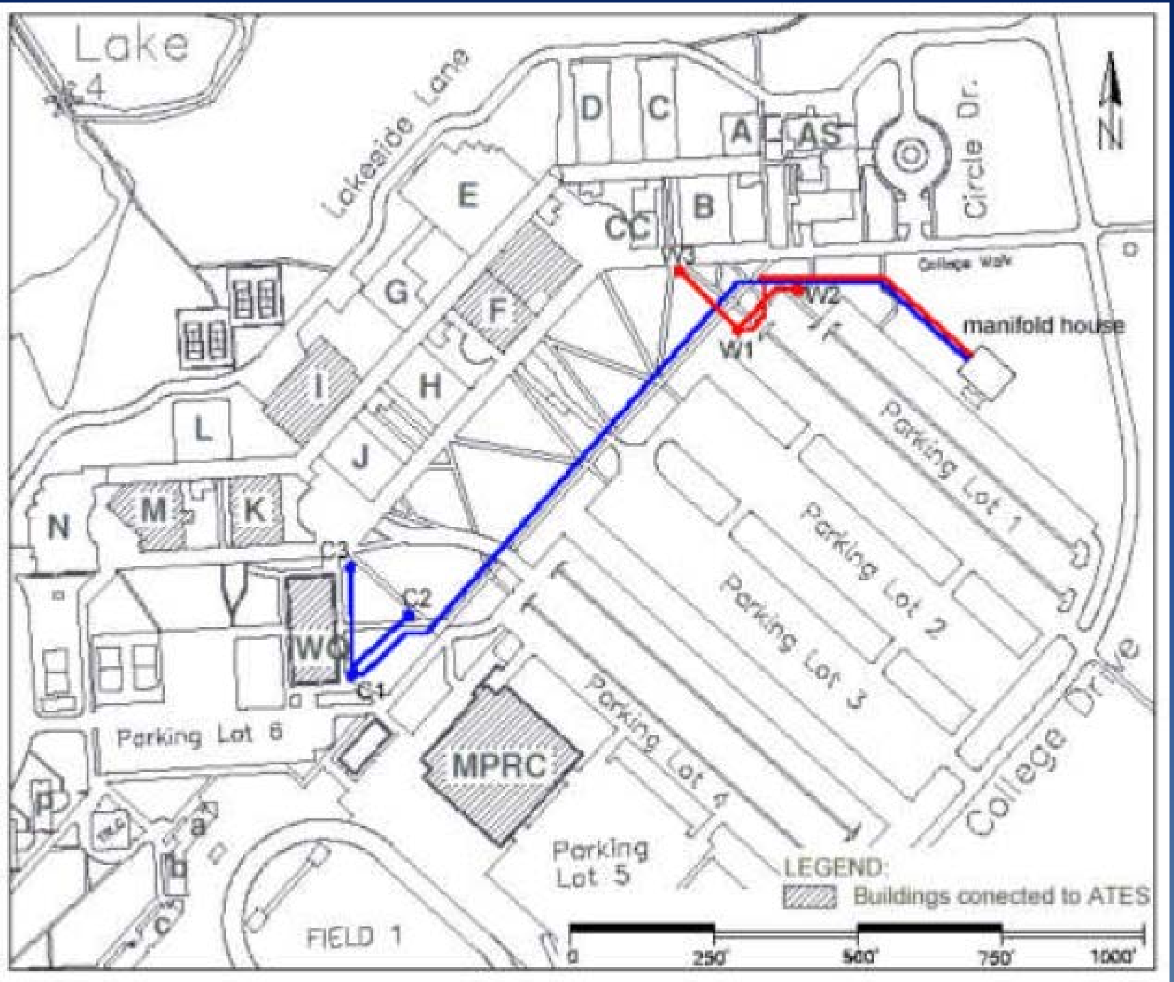
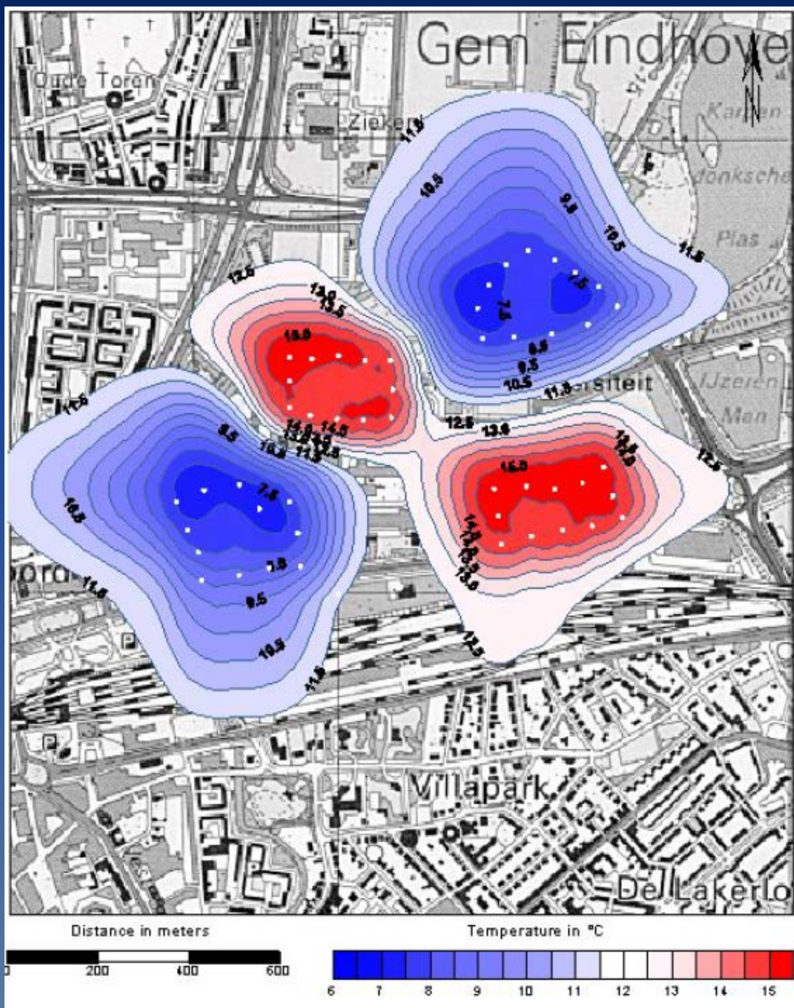
Richard Stockton College ATES Layout



Stockholm Arlanda Airport

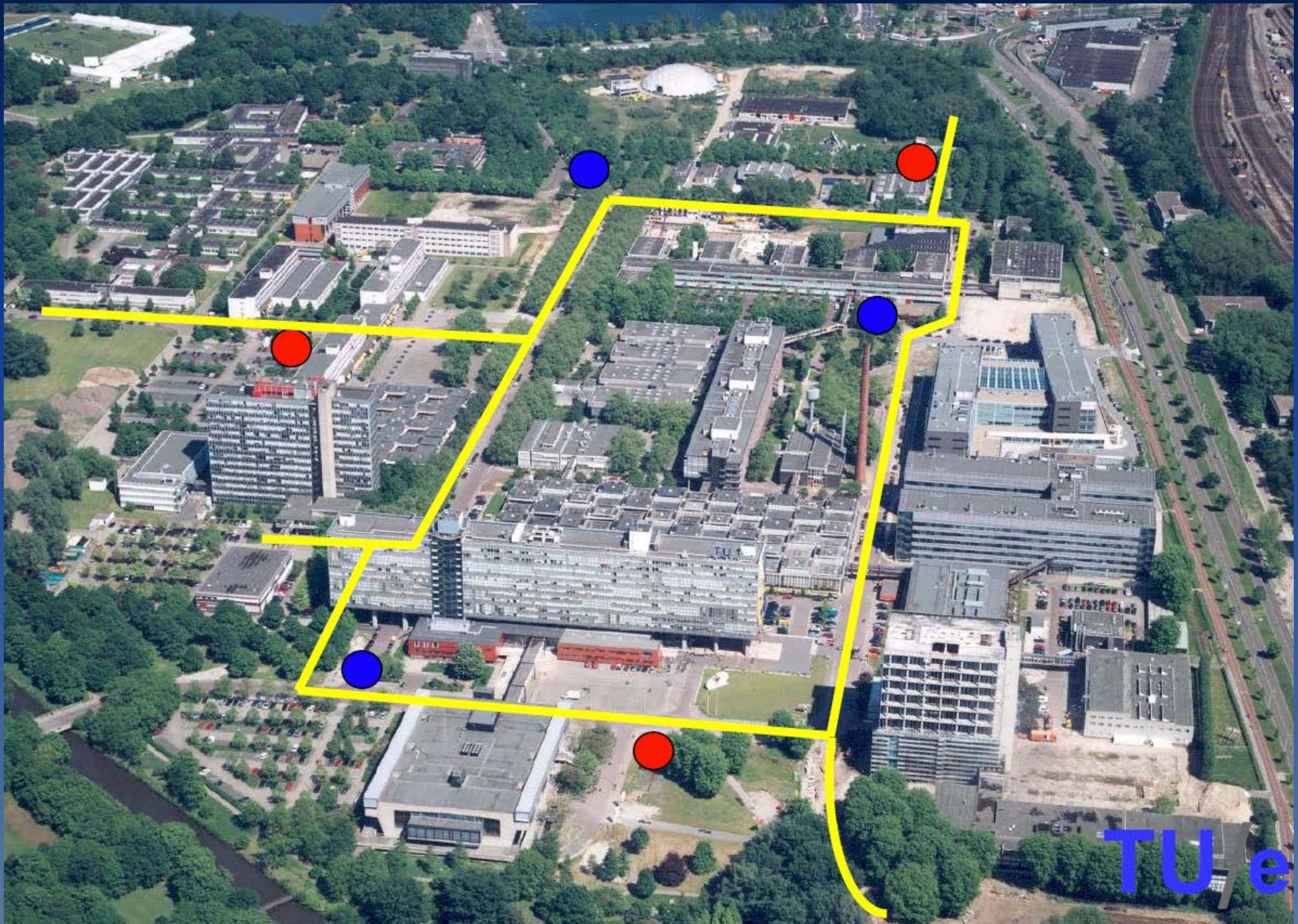
Eindhoven University of Technology
Numerical Modeling of Alternatives

Technical/Economic Optimum



Preferred Option – Minimal Impacts

Eindhoven University of Technology
20 MW ATES Configuration



IF TECH

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	

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

Thank You!

Engineering Considerations For Using Geothermal Systems at Contaminated Sites

Presented by: Don Maggioli, PE, LSP, CGD (Certified Geothermal Designer)

Alares LLC
248 Copeland Street
Quincy, MA 02169
617-481-6390
dmaggioli@AlaresLLC.com

Course Objectives

1. Provide an understanding of geothermal design principles as they relate to potential environmental issues
2. How environmental conditions impact the design of geothermal systems
3. Discuss feasibility of installing geothermal systems at impacted and MCP sites.

Why Do Geothermal At All

- **Electricity at $.06/kwh---cop at 3.5**

  .16/kwh x kw/3,412btu x 100,000btu/therm x 1/cop =

  $1.33/therm

- **Natural gas at $1.78/therm at 80% AFUE**

  1.78/therm x 1/afue =

  $2.23/therm

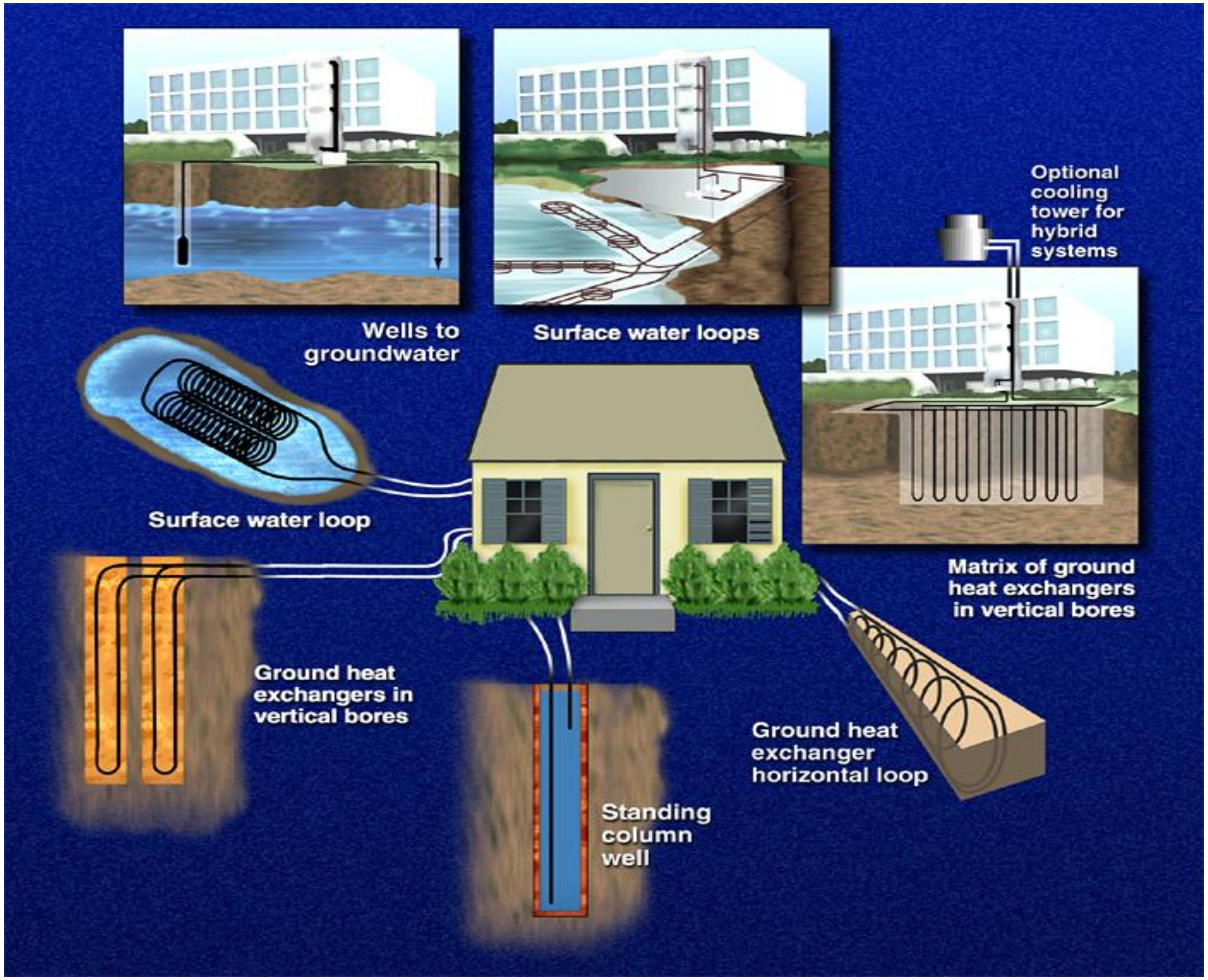
Savings = 40% and also 30% tax credit and accelerated depreciation (can pay for the ground heat exchanger).

Design Procedure

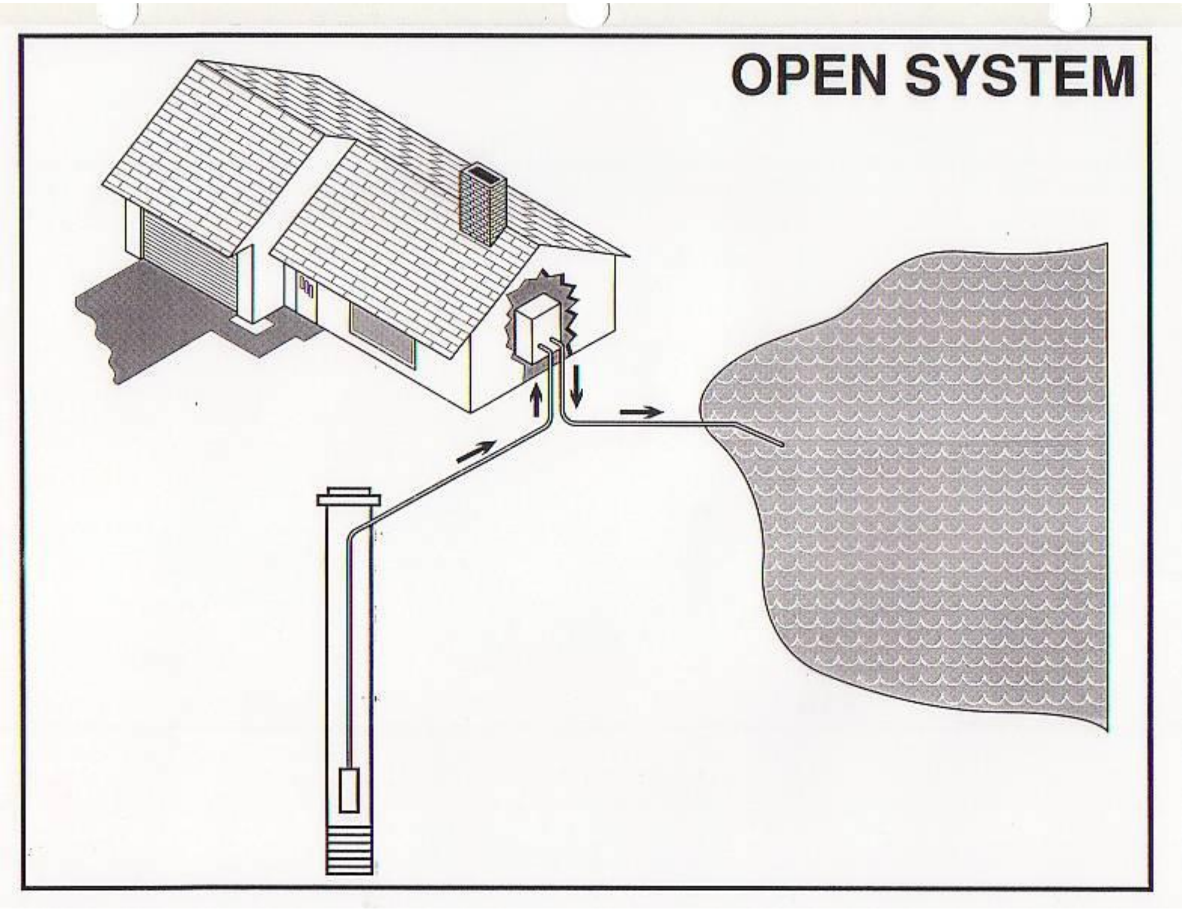
- Determine the heating/cooling loads (Btuh)
- Select heat pump size
- Estimate the building's energy requirement
- Estimate the ground heat exchanger loads
  - Annual load
  - Design month's load

Size drives the type of heat exchanger

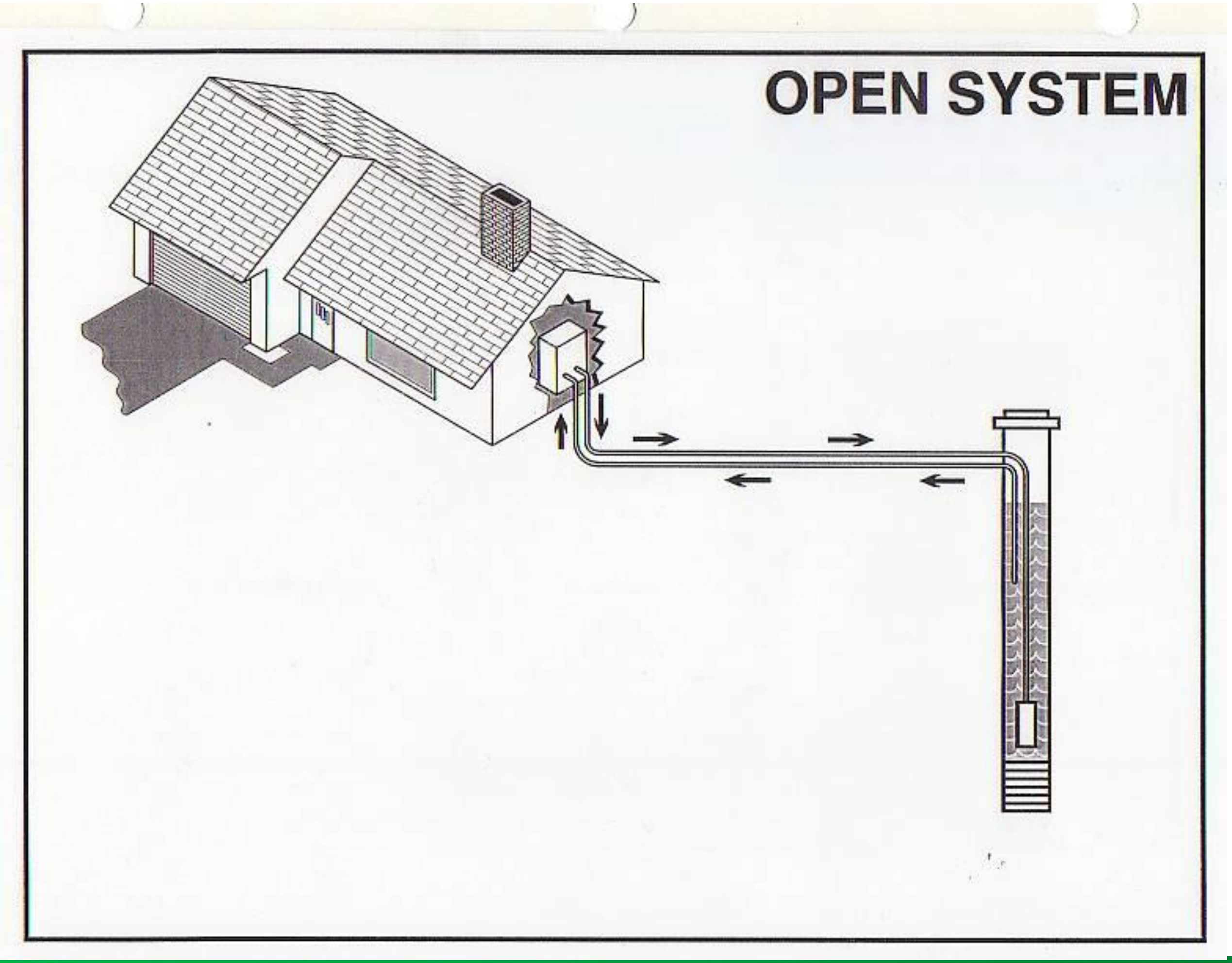
GSHP Types


Wells to
groundwater
Surface water loops
Optional
cooling
tower for
hybrid
systems
Surface water loop
Matrix of ground
heat exchangers
in vertical bores
Ground heat
exchangers in
vertical bores
Ground heat
exchanger
horizontal loop
Standing
column
well

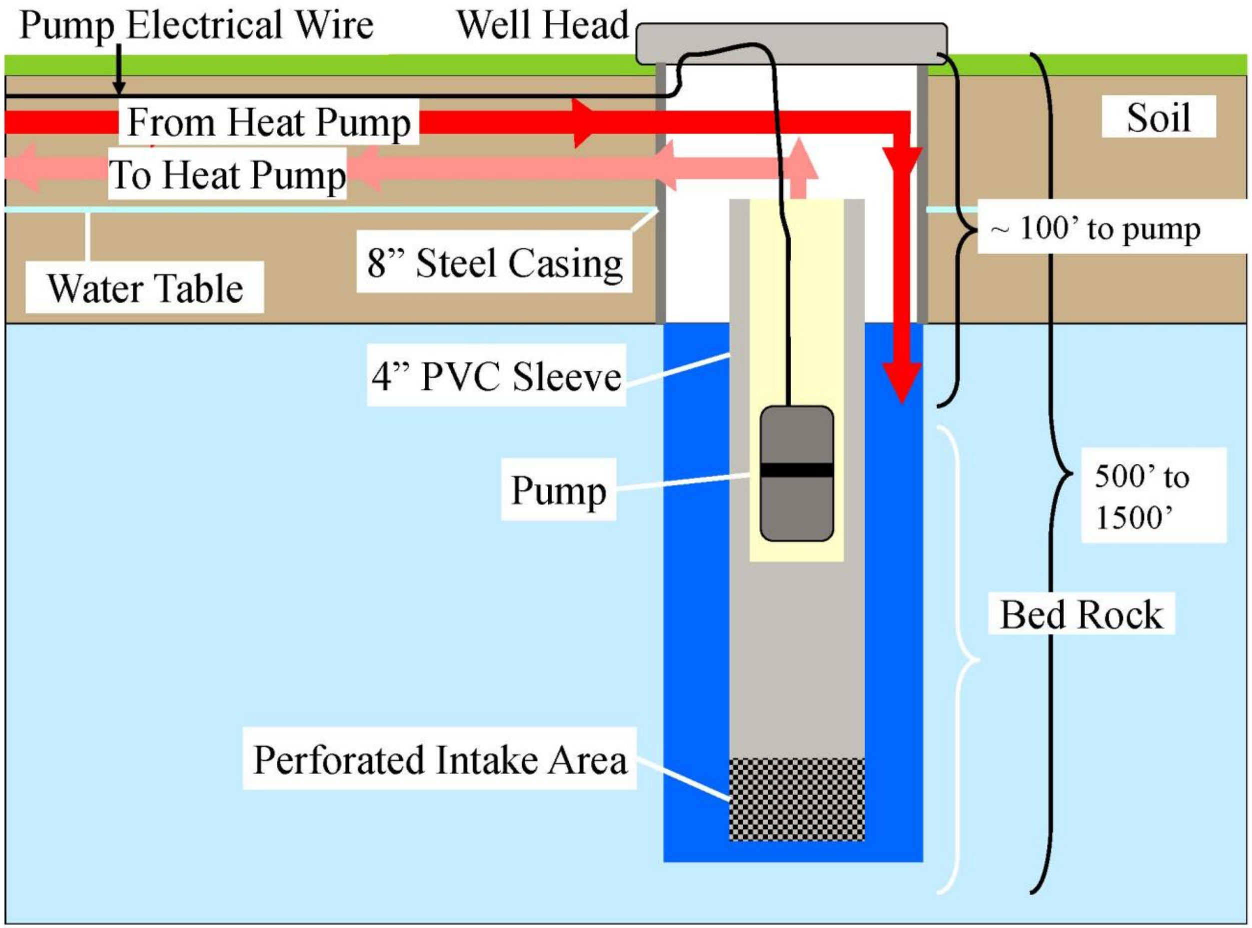
Open Loop Example



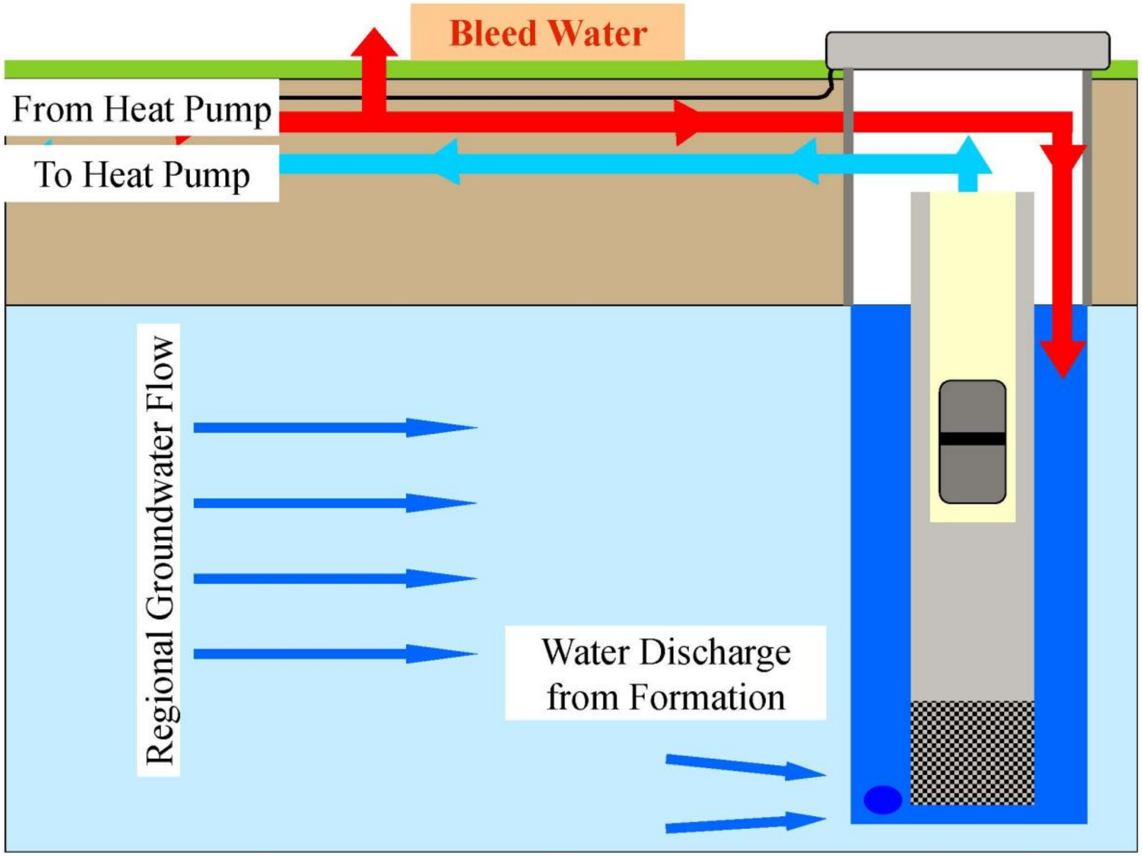
Standing Column Example



Standing Column Example



Standing Column Bleed



Using Pond as the Heat Exchanger

Closed Loop System Configurations

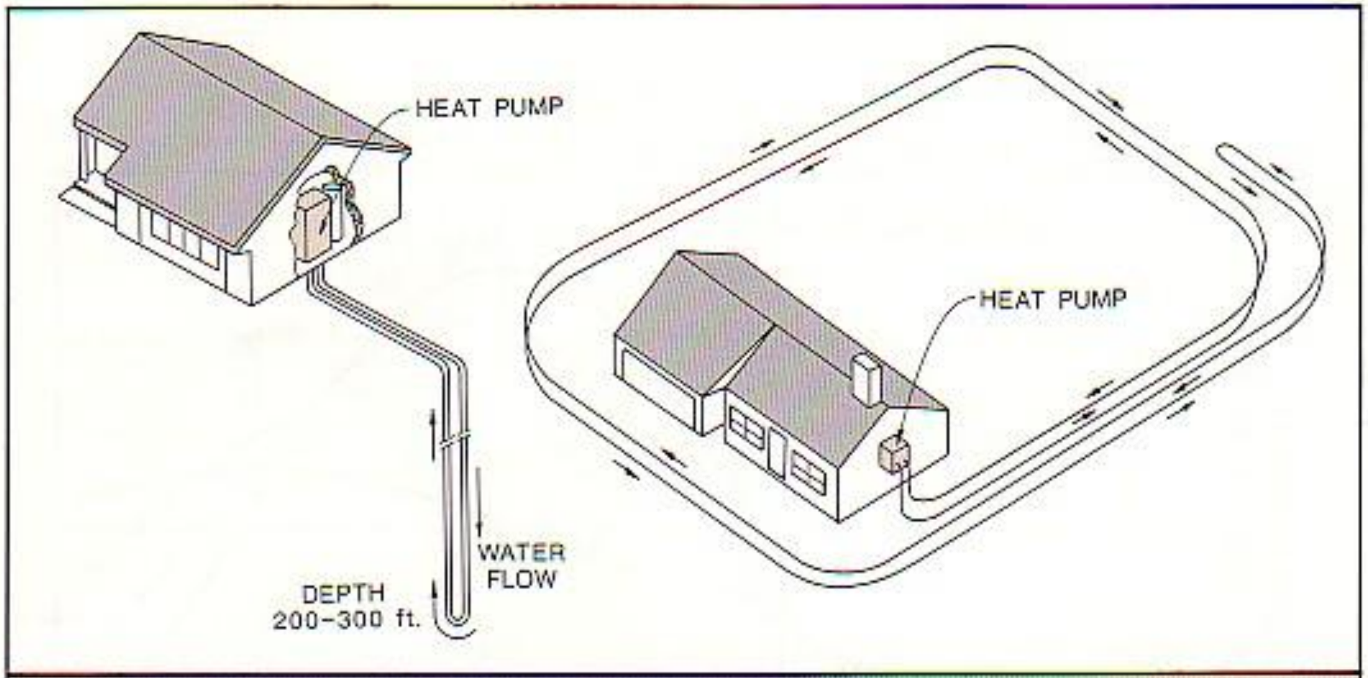
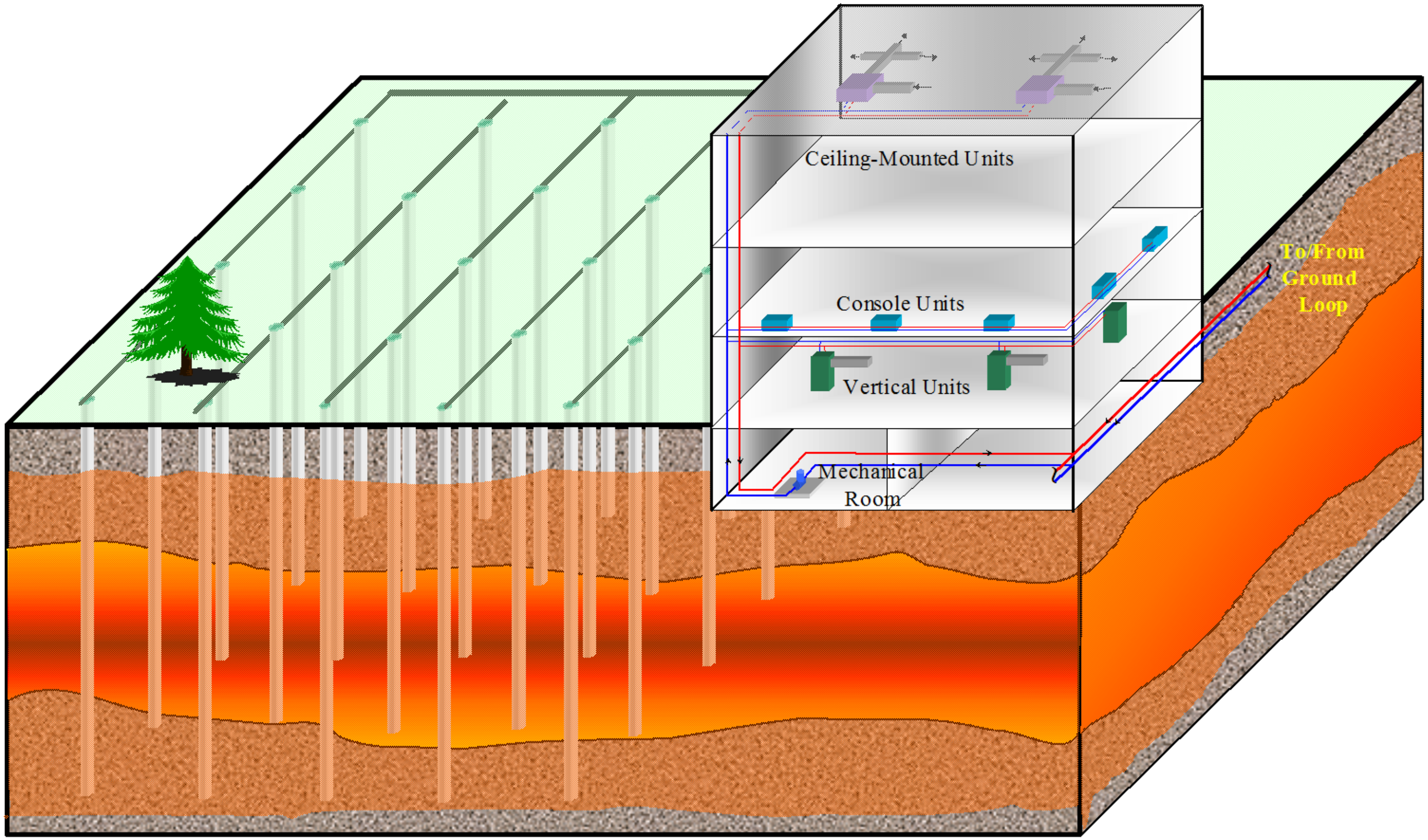


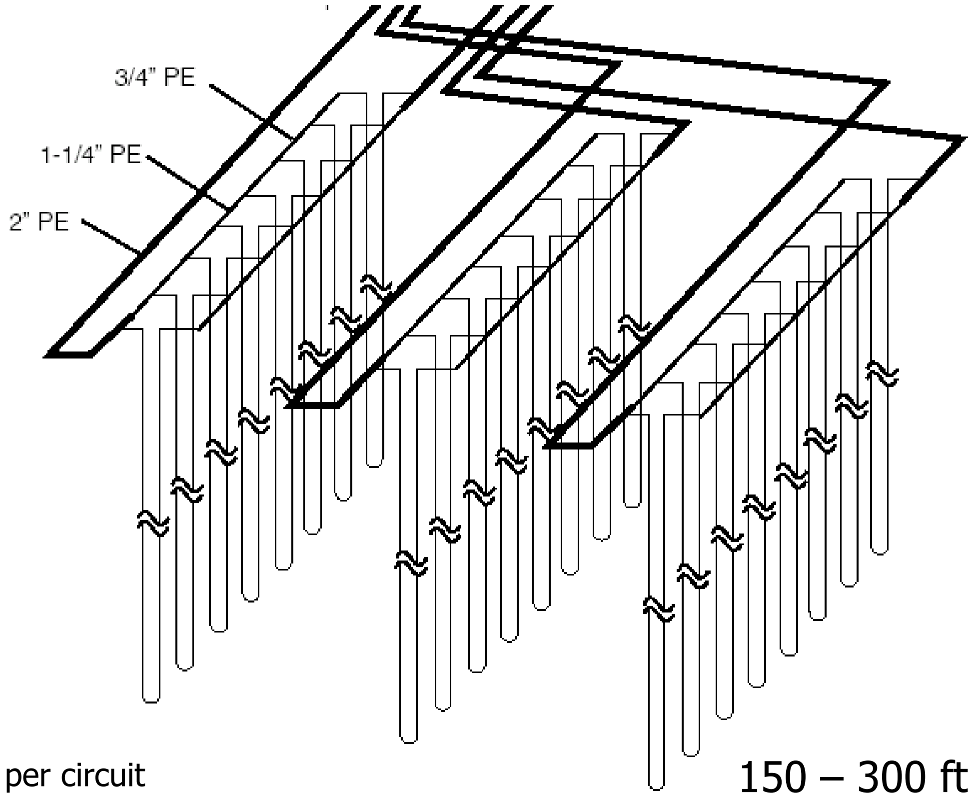
FIGURE 1.3: System Configurations

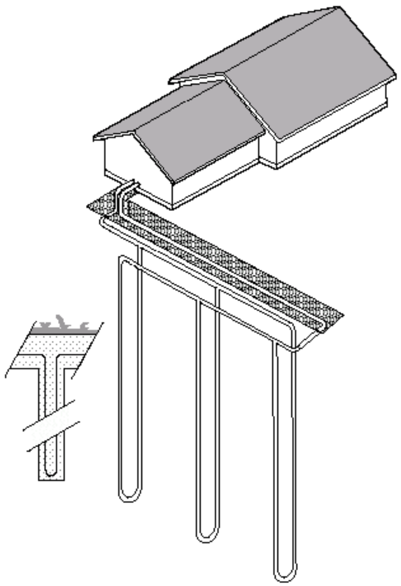
Slinky Installation for Shallow Excavation Limitations

Bore Field Example



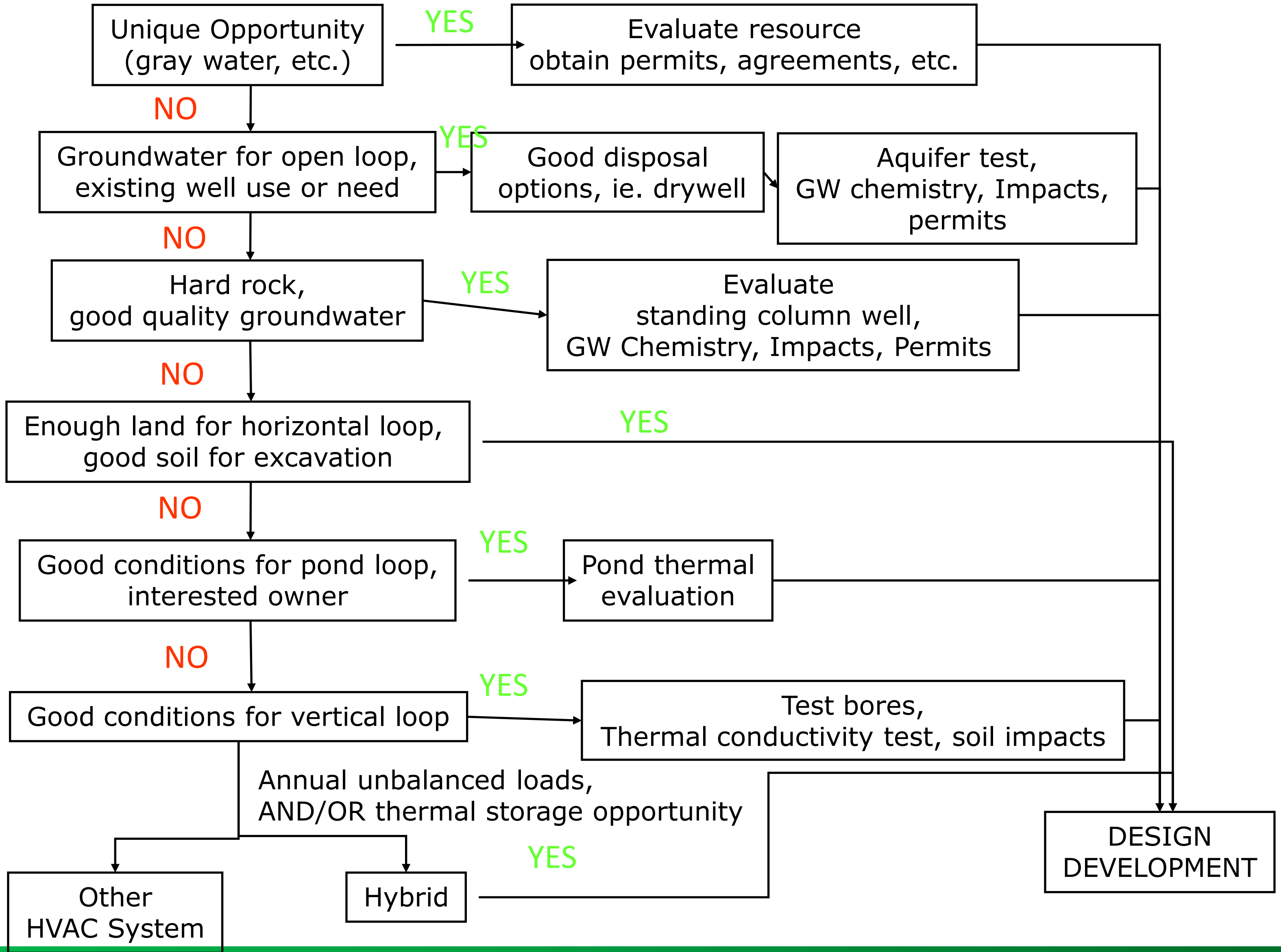
System Construction – Vertical Loops





1 bore per circuit
u-tubes can range in diameter from ¾ to 1 ¼ inch (1-inch is most common)

150 – 300 ft typical depth
Reverse-return piping arrangement



Unique Opportunity (gray water, etc.)
YES
Evaluate resource obtain permits, agreements, etc.
NO
Groundwater for open loop, existing well use or need
YES
Good disposal options, ie. drywell
Aquifer test, GW chemistry, Impacts, permits
NO
Hard rock, good quality groundwater
YES
Evaluate standing column well, GW Chemistry, Impacts, Permits
NO
Enough land for horizontal loop, good soil for excavation
YES
NO
Good conditions for pond loop, interested owner
YES
Pond thermal evaluation
NO
Good conditions for vertical loop
YES
Test bores, Thermal conductivity test, soil impacts
Annual unbalanced loads, AND/OR thermal storage opportunity
YES
Other HVAC System
Hybrid
DESIGN DEVELOPMENT

Rules of Thumb for each Geothermal System Type

- Open Loop (Pump and Dump) – 3 gpm/ton
- Vertical Closed Loop- 150 ft to 200 ft per ton
- Horizontal Closed Loop - 200 ft to 500 ft
- Standing Column Well – 30 tons per well

Perspective - Examples of Heating/Cooling a 2,500 s.f. House for each Geothermal System Type

- Open Loop (Pump/injection) – a 21 gpm well
- Vertical Closed Loop – 3 wells (400 ft)
- Horizontal Closed Loop – (Slinky 200 ft to 300 ft)
- Standing Column Well – 1 well (400 ft with bleed)

Examples of Heating/Cooling a 40,000 s.f. Building for each Geothermal System Type

- Open Loop (Pump and Dump) – a 300 gpm well
- Vertical Closed Loop – 36 wells (500 ft)
- Horizontal Closed Loop - 2,000 ft (slinky)
- Standing Column Well – 3 wells (1,600 ft)

Evaluate Existing Environmental Conditions

1. Avoid Costly Mistakes
2. Protection of Sensitive Receptors
3. May render some type of geothermal systems not feasible

Environmental Issues Evaluation Process

1. The type of ground exchanger (open, closed, standing column well) drives the study
2. Existing environmental conditions
3. Review Existing Reports, if available
4. Review On-line Databases (MassDEP Searchable List)
5. Are there Environmental Issues at other sites in the area
6. Install Test Well to determine site geology
7. Examine Permitting Requirements-NPDES, UIC, Groundwater Discharge
8. May require water pre-testing and/or treatment
9. If soil or groundwater contamination, what is the extent.

Installation Standards Help Minimize Environmental Impacts

1. International Ground Source Heat Pump Association (IGSHPA)
2. National Groundwater Association (NGWA)

Regulatory Requirements May Render GSHP Infeasible

- Check with the local Board of Health to determine whether a local well permit is also required for your type of geothermal well. (Hingham example)
- Check with the local plumbing inspector to determine whether town allows the dual use.
- Dual use is not typically approved for commercial geothermal applications.

Open Loop and Related Environmental Issues

Open Loop

1. Must have understanding of hydrogeology.
2. Effects on aquifer both extraction and injection.
3. Must have understanding of water chemistry.
4. Must understand permit requirements.

Key Environmental Concerns

- Improperly constructed boreholes that could possibly serve as channels for contamination from surface to subsurface or from one aquifer to another
- Rate of water withdrawal may affect groundwater supply (Boise Example)
- Reinjection of water into different aquifer

ALARES

Water Testing Requirements

- Tables located in Guidelines for Ground Source Heat Pump Wells-Underground Injection Control Program December 2013
- Examples include arsenic, lead, vinyl chloride, Xylenes, etc.
- May trigger treatment requirements or notification
- Design may include additives or treatment of contaminants prior to discharge which adds cost to the GSHP system.

Other Design Requirements

- Requires 90 to 120 day post system startup sampling
- Level sensors required in discharge wells to prevent overflow

Open Loop

Advantages

- Low cost, especially for large loads and residential applications that need a drinking water well
- Water well drilling technology is well-established
- Stable source temperature
- Standing column well option in certain circumstances

Disadvantages

- Water quality dependent
  - Scaling
  - Corrosion
  - Iron bacteria, well fouling
- Water disposal
- Laws and regulations
- Permits, water rights

Equipment and Design Problems

Open-Loop System

The two most often encountered problems are inadequate flow in the production well and plugging that causes pressure build-up in the injection well. Other maintenance issues include the need to clean or rework production and injection wells and the need for chemical treatment of injected water to control scaling or bacterial growth that plugs the injection wells

The principal cause appears to be iron bacteria and, where a mature colony is established, extremely difficult to eliminate. The next most common problem associated with open loop systems is pump failure.

Potential Iron Fouling Issues

Iron sludge from a blocked strainer

Pump Test Required for Open Loop Systems

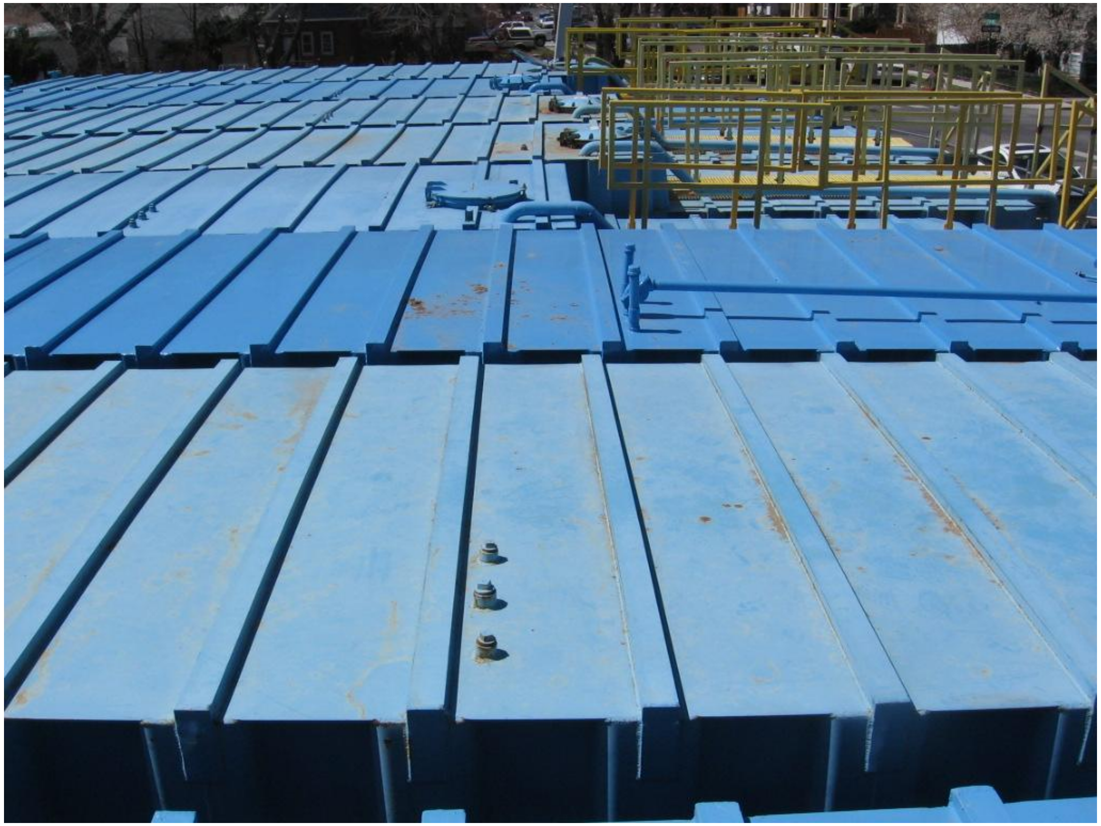
- Obtain design flow rates
- Obtain water chemistry data (needed for permit and possible treatment design)
- Test requires permits (allow time to obtain permit)

Investigate reuse options

- Reuse of bleed water in facility applications
- Discharge drywell system (UIC)
- Discharge to surface water (NPDES permitting)

Pump Test Water Disposal Issues

Pump Test Equipment



Pump Test Equipment

Borehole Excavate Disposal Issues

- If cannot be reused on site, must properly dispose off-site
- Soil sampling required.
- Could trigger notification requirement

Closed Loop Systems

Key Environmental Concerns

- Antifreeze leaks that could migrate to groundwater
- Improperly constructed boreholes that could possibly serve as channels for contamination from surface to subsurface or from one aquifer to another

Regulatory Requirements

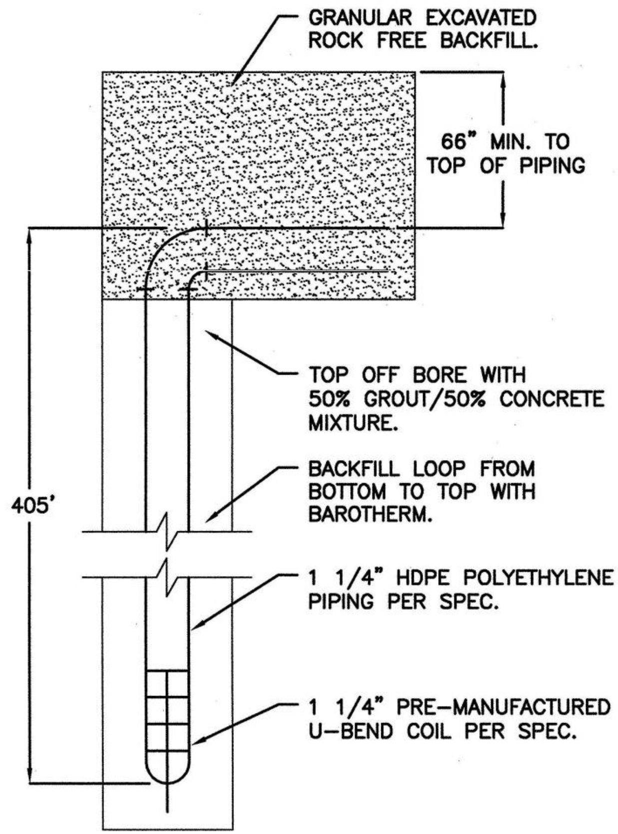
- UIC permit
- Certified Well Driller
- Shall be located at least 10 feet from potable water and sewer lines.
- The GSHP system shall have an automatic shutdown device(s) to minimize antifreeze leaks in the event of a pressure/fluid loss (usually operates 30 psi).
- Signage-type of antifreeze used

Other Requirements

- Closed-loop shall be located at least 25 feet from potential sources of contamination.
- Closed-loop shall be located at least 50 feet from private potable water supply wells
- Closed loop shall not be permitted within the Zone I of public water supply wells.
- Closed-loop shall be located at least 10 feet from surface water bodies.

System Construction Vertical Loops

- Installed by standard drilling methods
  - Auger: soils, relatively shallow holes
  - Mud-rotary: soft sediments and sedimentary rocks
  - Air-rotary: soft to hard relatively dry rocks
  - Air-hammer: hard rock
  - Cable-tool: hard rock, deep holes (slow drilling)
  - Sonic drilling: high drilling rates in most materials
- Loop (or borehole heat exchanger) is rolled off a reel into borehole
- Borehole is grouted from the bottom to the top with a "tremie pipe" to insure a good seal
  - Standard bentonite grout
  - Thermally-enhanced grouts (bentonite/sand mixture)



BORE-HOLE DETAIL

SCALE: N.T.S.

Bore Field Example

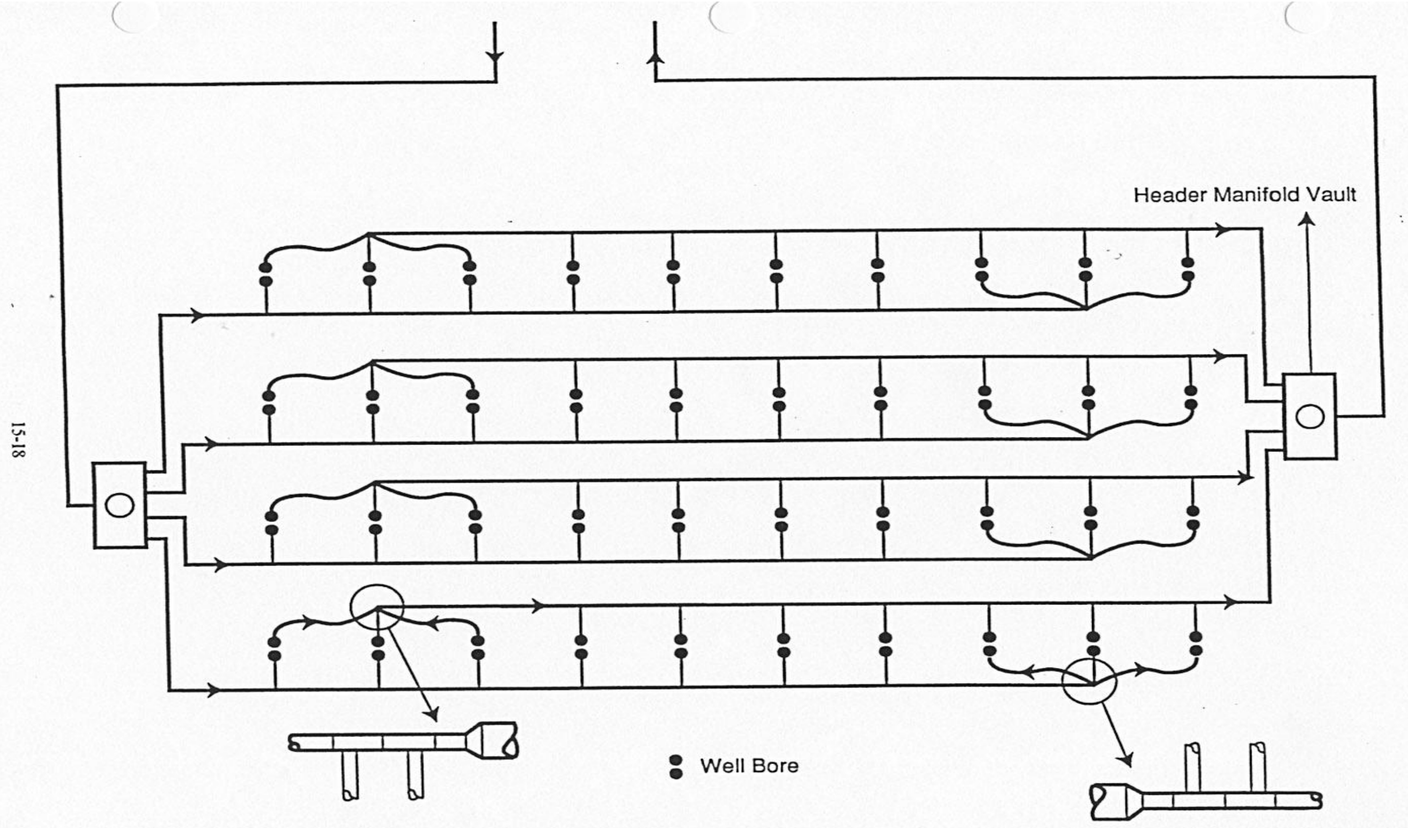


Figure 15.11 Diagram of Borefield with Manifold Vault.

Sediment and Stormwater Run-off From the Site

Header Loop Example

Approved Antifreeze

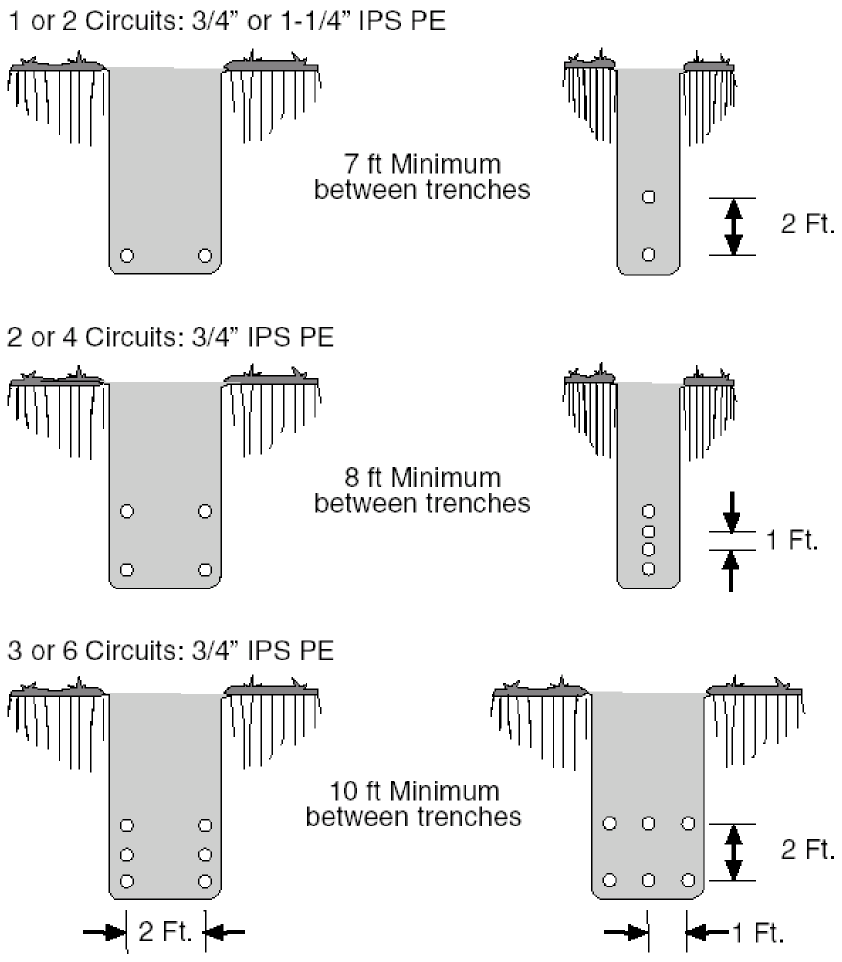
- Propylene glycol (CAS No. 57-55-6) and ethanol (CAS No. 64-17-5) are the only acceptable antifreeze additives for closed-loop GSHP wells
- All other antifreeze chemicals and denaturants must be approved by MassDEP prior to use.
- Release of 10 pounds of ethanol to the ground surface or groundwater is considered a reportable release of a hazardous material per the Massachusetts Contingency Plan (310 CMR 40.0000). ie. 7.6 gallons of water/ethanol solution would meet the reportable release threshold

Surface Containment along Borehole

1. Grouting with Tremie under pressure from bottom to top.
2. Provides seal from ground surface to aquifer to prevent entry of potentially contaminated surface water into the formation
3. Provides separation between aquifers

Trailer mounted grout unit

System Construction
Horizontal Loops



- **4 – 6 ft burial depth**
- **Consider for large open areas such as athletic fields**
- **AUL Sites (need soil management plan)**
- **Sites with GW impacts only**

Borehole Thermal Testing for Closed Loops

- Reducing the costs due to uncertainty
- Procedure

  Test bore hole drilled

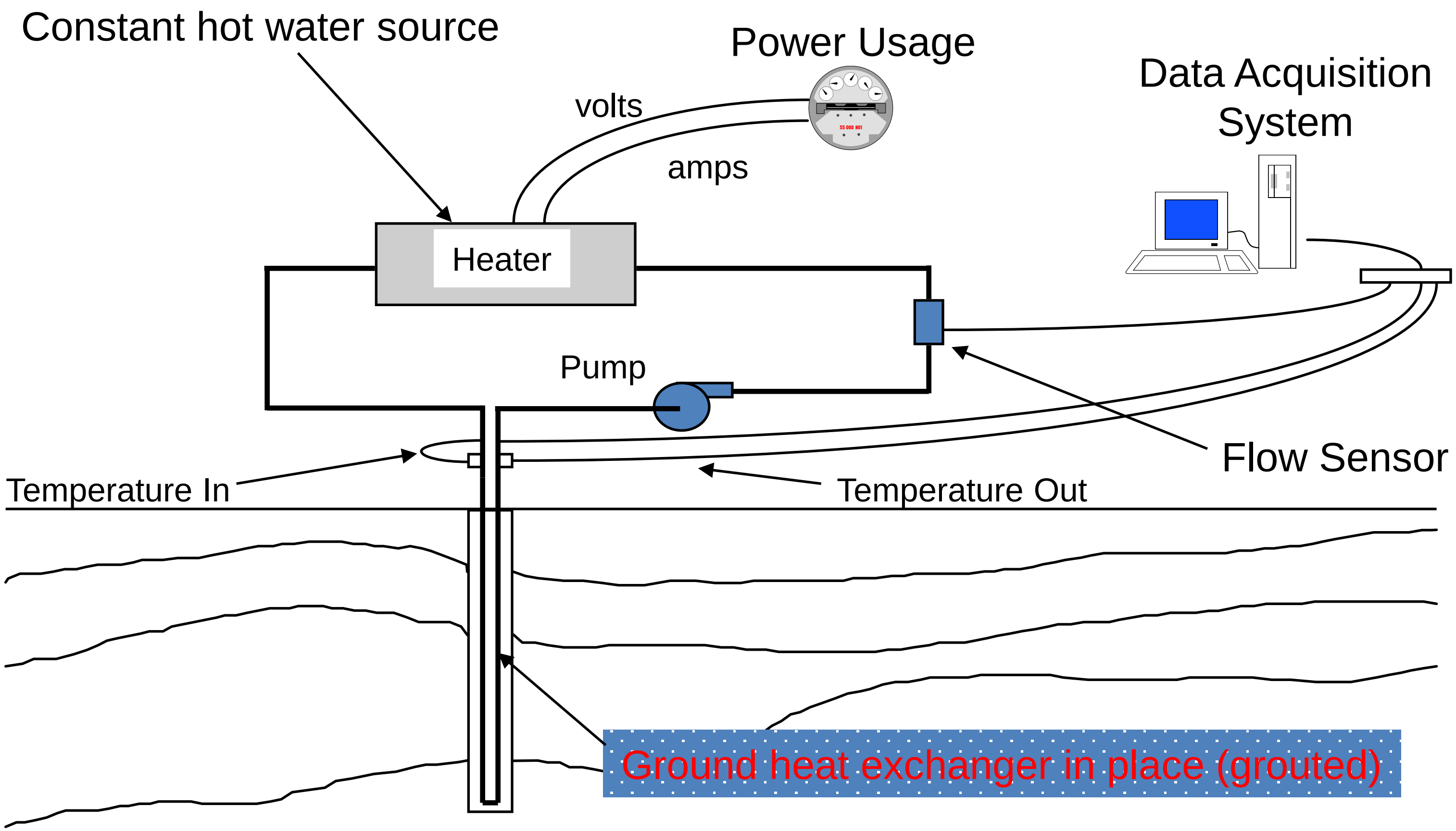
  Heat exchanger installed (includes grout, spacer, etc.)

  Thermal load placed on loop

  Time - Temperature curve developed

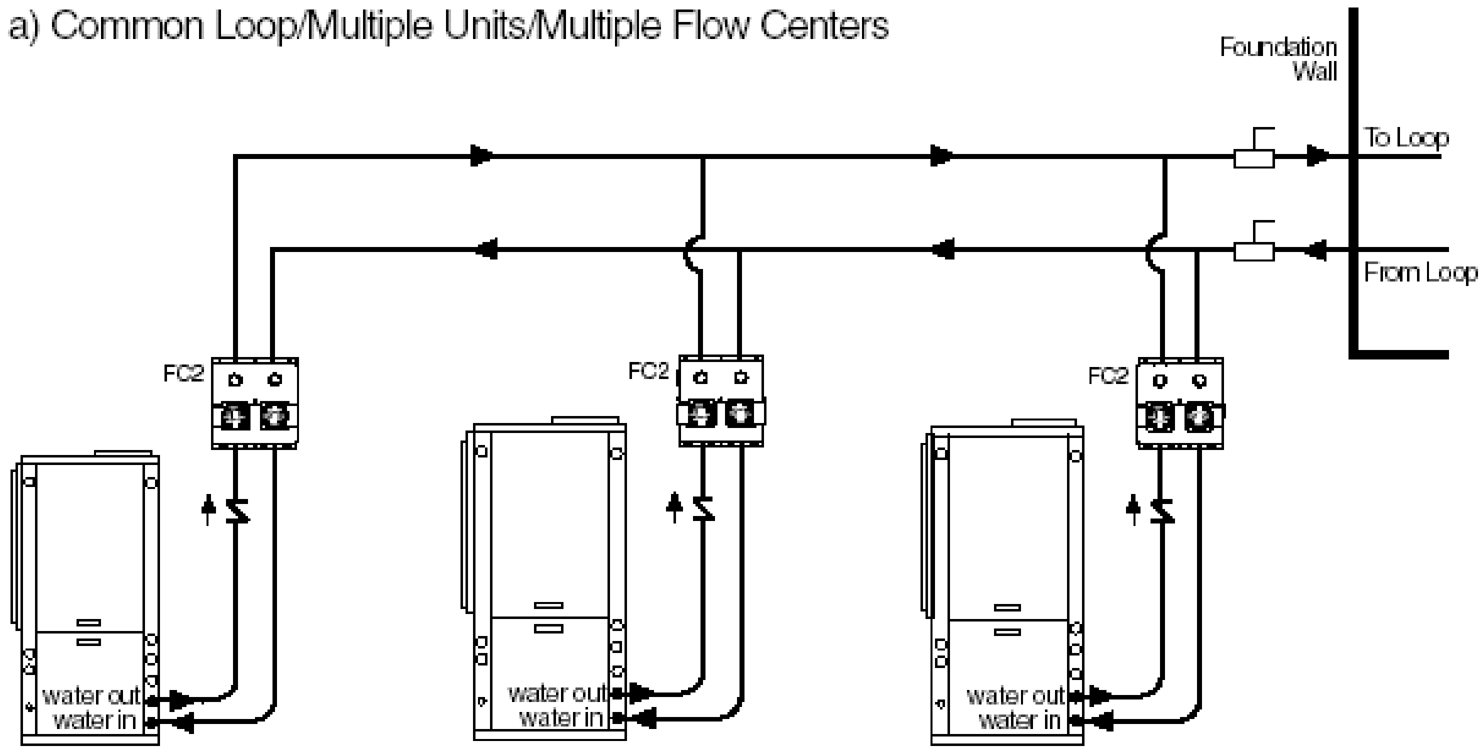
  Thermal conductivity derived

In-situ Test System Schematic



Thermal Testing

Pump Room Example



Heat Pumps

Pump Room

Considerations for using GSHP at MCP Sites – Open Loop

1. Open Loop systems very risky – may worsen environmental impact.
2. Most likely will not be issued a permit from the UIC program.
3. Standing Column Wells may work if "no bleed" but must be installed in areas of the site with minimal impact.
4. May require RAM Plan (soil and groundwater management plan) depending on MCP phase.
5. Recommend employing LSP to evaluate potential impacts if owner/developer considering installing open loop system.

Considerations for using GSHP at MCP Sites – Closed Loop

1. Closed Loop systems less risky – have less environmental impact.
2. May be installed at sites with AUL-depending on location and concentration levels of contaminates.
3. Will soil and groundwater management plan
4. Recommend employing LSP to evaluate potential impacts if owner/developer considering installing closed loop system.

Course Objectives

1. Provide an understanding of geothermal design principles as they relate to potential environmental issues
2. How environmental conditions impact the design of geothermal systems
3. Determine feasibility of installing geothermal systems at impacted and MCP sites.

Conclusions

1. Get environmental professional with geothermal experience involved early in the design.
2. Person conducting feasibility evaluation must have understanding the method of geothermal earth couples and how subsurface conditions could be affected.
3. Evaluate Permit requirements.
4. Environmental conditions can be managed.
5. Not all sites are appropriate for geothermal.

GSHPs at Disposal Sites

Lawrence Lessard, LSP
Achieve Renewable Energy, LLC.

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GSHPs at Remedial Sites
Concepts to Consider

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Today’s Topics

- Direct Use of GSHPs for HVAC
- General Care and Feeding of GSHPs
- Concept I: Convenient Co-location of GSHPs at Remedial Sites
- Concept II: GSHPs for Remedial Enhancement *or Deciding to Go Down the Rabbit Hole*

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You do not need a volcano for Geothermal HVAC

Direct Use of GSHPs at Remedial Sites

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‘Traditional’ Use of GSHPs for HVAC

- GSHPs use the Earth as a source of heating, cooling and process water
- ***Moves*** free energy instead of creating heat through burning expensive fuel
- Releases or absorbs heat from the ground

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Use of Groundwater Recovery as the Ground-Source

- GSHPs use the remedial process water for heat extraction or rejection
- Still ***Moves*** thermal energy and may be more efficient because of higher source temperature
- Has been done at sewage treatment plants
- Has been evaluated at Baird-McGuire

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Care and Feeding of GSHPs

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GSHP Design Preferences

- Intermittent operation when there is an HVAC Demand
- Available source water flow, typically 2.5 - 3 GPM/Ton
- Source and load water quality requirements
- Maximum flow velocities are typically less than 6 ft/sec. to avoid erosion of heat exchanger.
- Have a ground-source that meets or exceeds the HVAC demand for *long-term* (decades) stable source temperature

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Minimum Water Quality Requirements

- Can’t pump trash - not designed for high TSS
- Sensitive to corrosive conditions
- Protect against mineral precipitate and bio buildup
- Warranty keyed to water quality

Example Water Quality Requirements

Material		Copper	90/10 Cupronickel	316 Stainless Steel
pH	**Acidity/Alkalinity**	7 - 9	7 - 9	7 - 9
Scaling	Calcium and Magnesium Carbonate	(Total Hardness) less than 350 ppm	(Total Hardness) less than 350 ppm	(Total Hardness) less than 350 ppm
Corrosion	Hydrogen Sulfide	Less than 0.5 ppm (rotten egg smell appears at 0.5 ppm)	10 - 50 ppm	Less than 1 ppm
	Sulfates	Less than 125 ppm	Less than 125 ppm	Less than 200 ppm
	Chlorine	Less than 0.5 ppm	Less than 0.5 ppm	Less than 0.5 ppm
	Chlorides	Less than 20 ppm	Less than 125 ppm	Less than 300 ppm
	Carbon Dioxide	Less than 50 ppm	10 - 50 ppm	10 - 50 ppm
	Ammonia	Less than 2 ppm	Less than 2 ppm	Less than 20 ppm
	Ammonia Chloride	Less than 0.5 ppm	Less than 0.5 ppm	Less than 0.5 ppm
	Ammonia Nitrate	Less than 0.5 ppm	Less than 0.5 ppm	Less than 0.5 ppm
	Ammonia Hydroxide	Less than 0.5 ppm	Less than 0.5 ppm	Less than 0.5 ppm
	Ammonia Sulfate	Less than 0.5 ppm	Less than 0.5 ppm	Less than 0.5 ppm
	Total Dissolved Solids (TDS)	Less than 1000 ppm	1000 - 1500 ppm	1000 - 1500 ppm
	LSI Index	+0.5 to -0.5	+0.5 to -0.5	+0.5 to -0.5
Iron Fouling (Biological Growth)	Iron, FE^{2}+ (Ferrous) Bacterial Iron Potential	< 0.2 ppm	< 0.2 ppm	< 0.2 ppm
	Iron Oxide	Less than 1 ppm, above this level deposition will occur	Less than 1 ppm, above this level deposition will occur	Less than 1 ppm, above this level deposition will occur
Erosion	Suspended Solids	Less than 10 ppm and filtered for max. of 600 micron size	Less than 10 ppm and filtered for max. of 600 micron size	Less than 10 ppm and filtered for max. of 600 micron size
	Threshold Velocity (Fresh Water)	< 6 ft/sec	< 6 ft/sec	< 6 ft/sec

NOTES: Grains = ppm divided by 17
mg/L is equivalent to ppm

2/22/12

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Alternatives for Poor Water Quality

- Frequent Maintenance
- Scheduled Equipment Replacement
- Intermediate Heat Exchanger
  (still need maintenance)
- Closed Loop Configuration

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Other Considerations

- Load-side Design is as Important as Source-side
  - Refrigerant system operation requires load to accept the heating/cooling at the designed output.
- GHPSs are not Intrinsically Safe/XP
  - Need to consider operational location and may need hydronic method to move heated/chilled fluid to remedial zone

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Concept I: Convenient Co-location

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Remedial Soil Excavation

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Excavation Considerations - Repeated

- Deeper is Better
  - GSHP piping should be at least 5 feet BGS
  - Deeper placement improves heat transfer
  - Placement in groundwater improves heat transfer

- GHPSs are not Intrinsically Safe/XP
  - Need to consider operational location and may need hydronic method to move heated/chilled fluid to remedial zone

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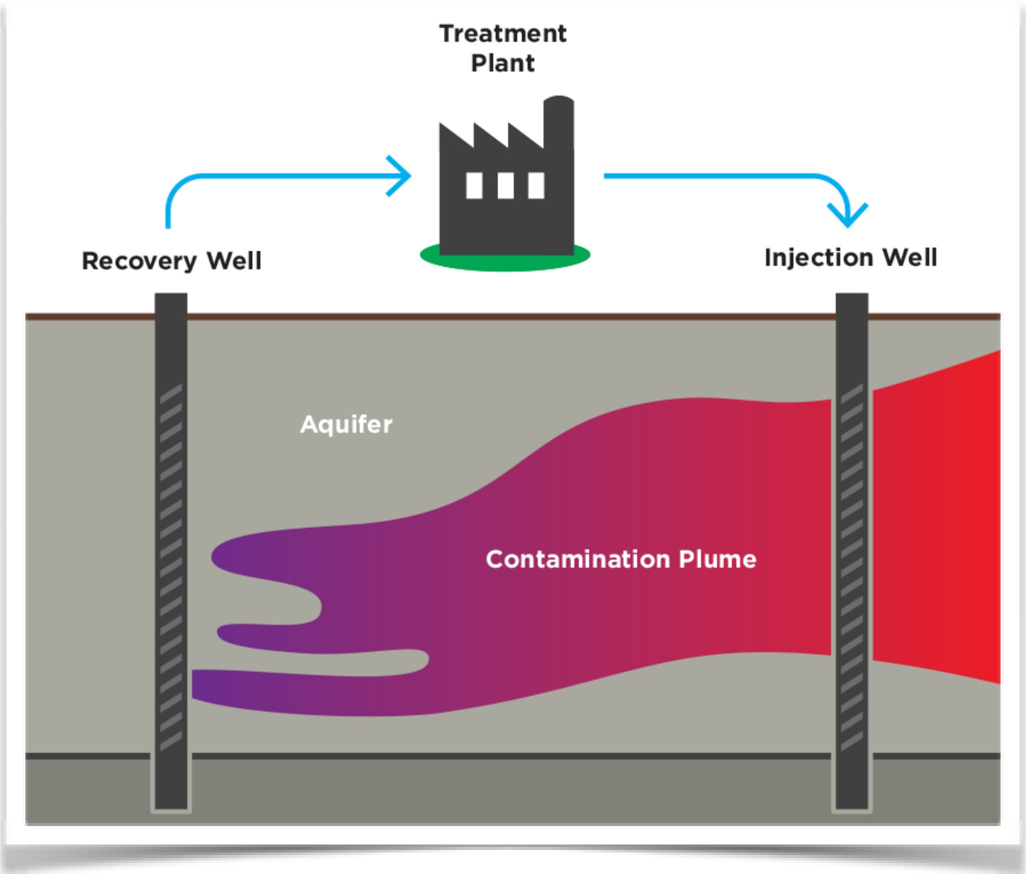
Direct Use: Groundwater Pump and Treat



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Groundwater Pump and Treat

- Use the existing flow of remedial system as source for GSHP
- Heating and/or cooling can be provided to loads such as remedial enclosure, proximal building other process water system.
- Alternatively, use a separate ground-source.

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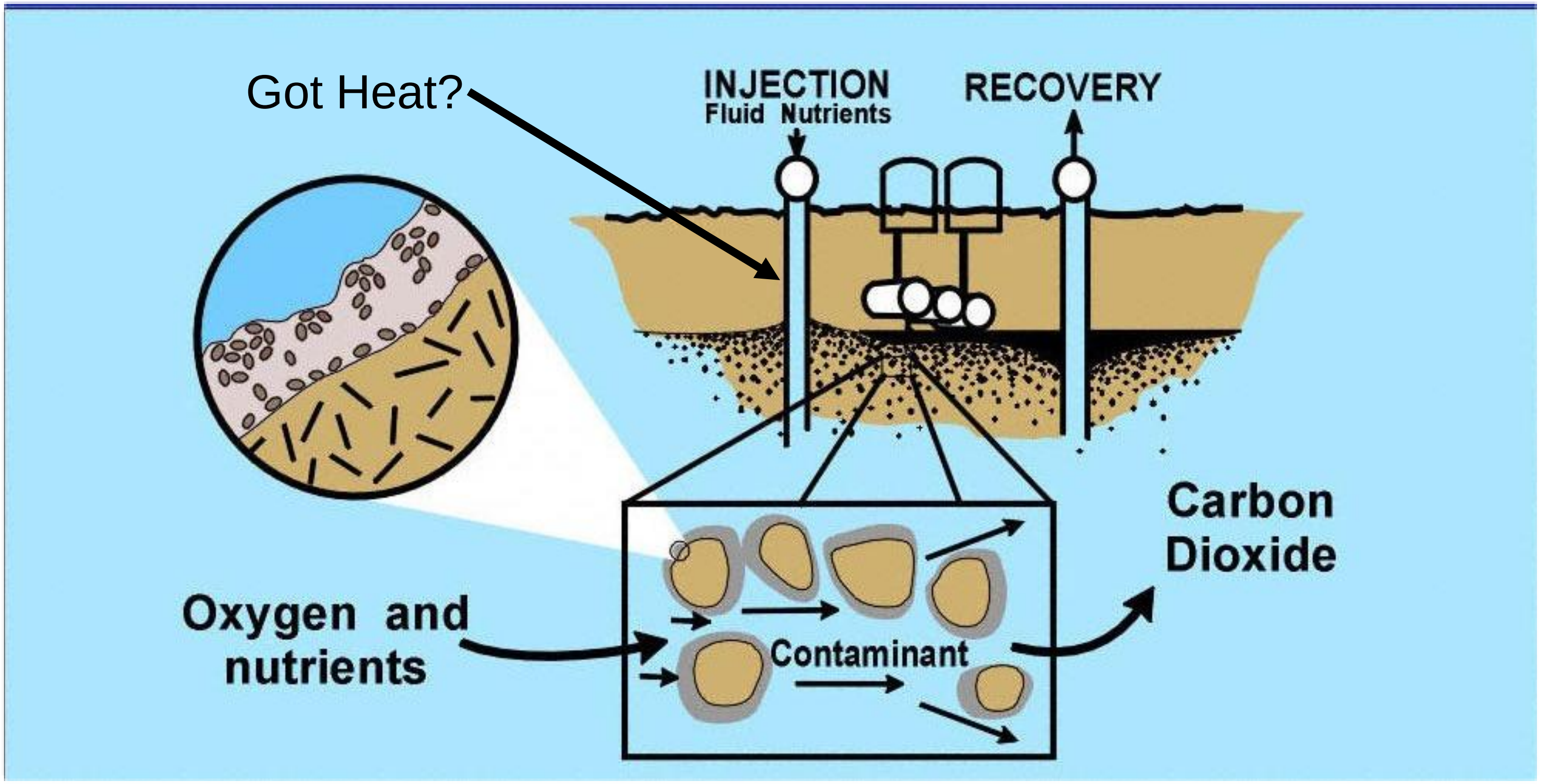
Bioremediation



GSHPs and Bio

- Rule of Thumb: Microbial activity doubles with a 10 Deg. C. increase in temperature
- Cooling can be provided to loads such as remedial enclosure, proximal building, or other process water system.
- Alternatively, use a separate ground-source.

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Patent Pending

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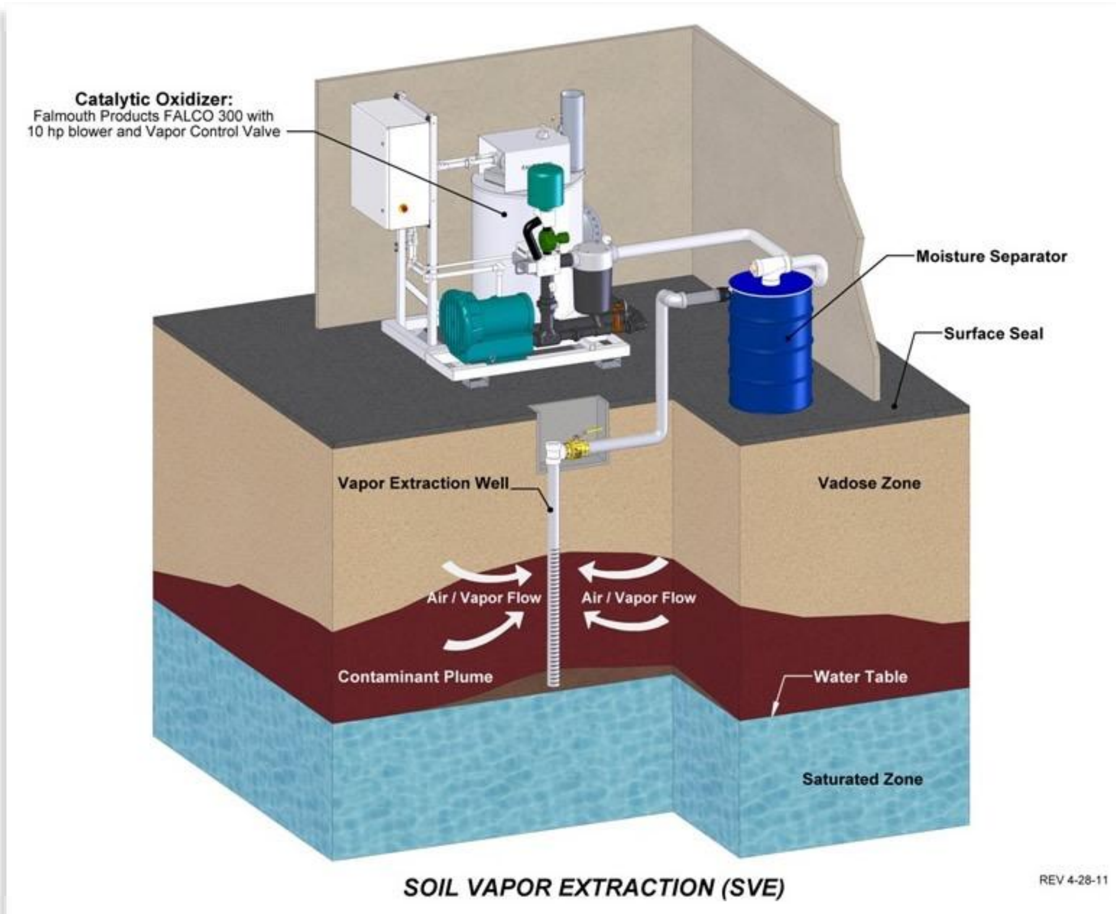
Soil Vapor Extraction



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SVE or Bio Co-location

- Consider horizontal closed loop where trenching is planned
- For current or future use
- Deeper is better than shallower
- Installation in or close to saturated zone is better than dryer soil

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Concept II: Remedial Enhancement with GSHPs

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Remedial Enhancement
Want to go Down the Rabbit Hole?

- Consider how moving heat from one part of the disposal site to another might enhance remedial effect.
- Would it be efficacious to increase or decrease microbial activity, volatilization, contaminant desorption at a Disposal Site?
- If so, do we use GSHPs under normal design conditions or do we go down the rabbit hole and push operating limits for heating/cooling outside of recommended ranges?
- If short-term temperature excursions are helpful for remedial enhancement, do we need to design for decades of stability?
- The ultimate limiting factor may be the operational range of the refrigerant used in the GSHP (usually R-410A).

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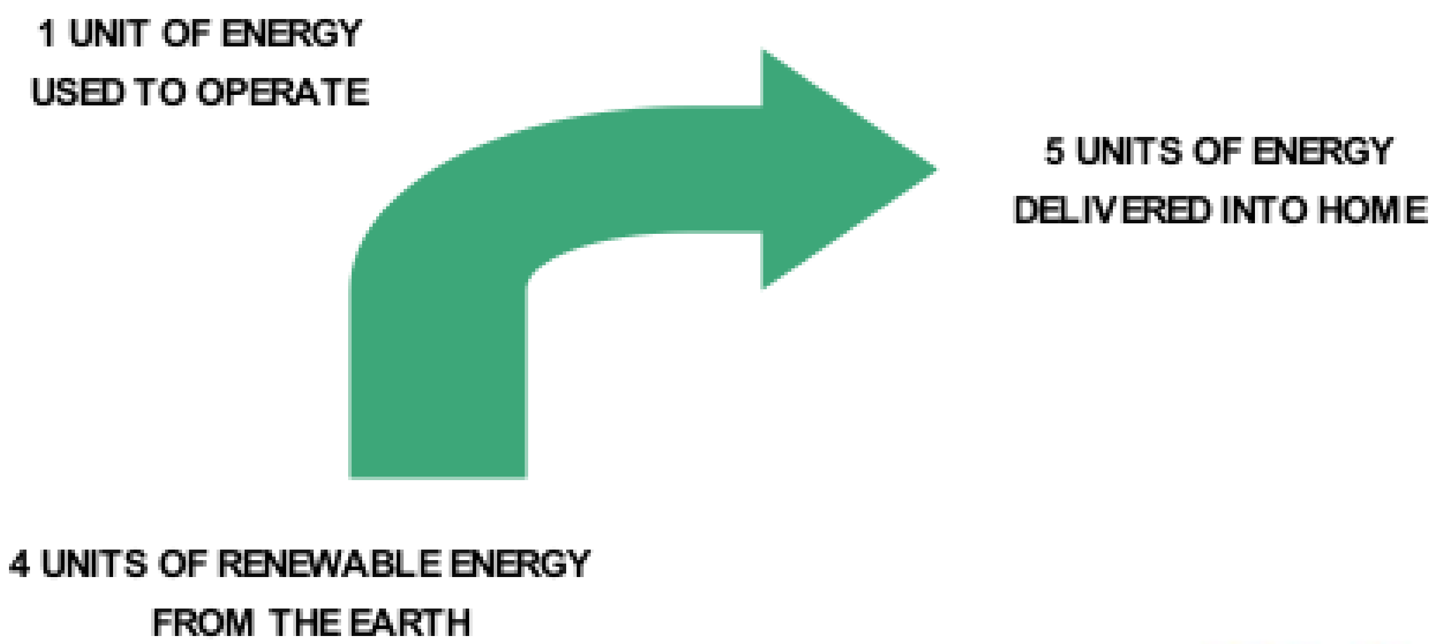
Geothermal Heating Cycle Efficiency



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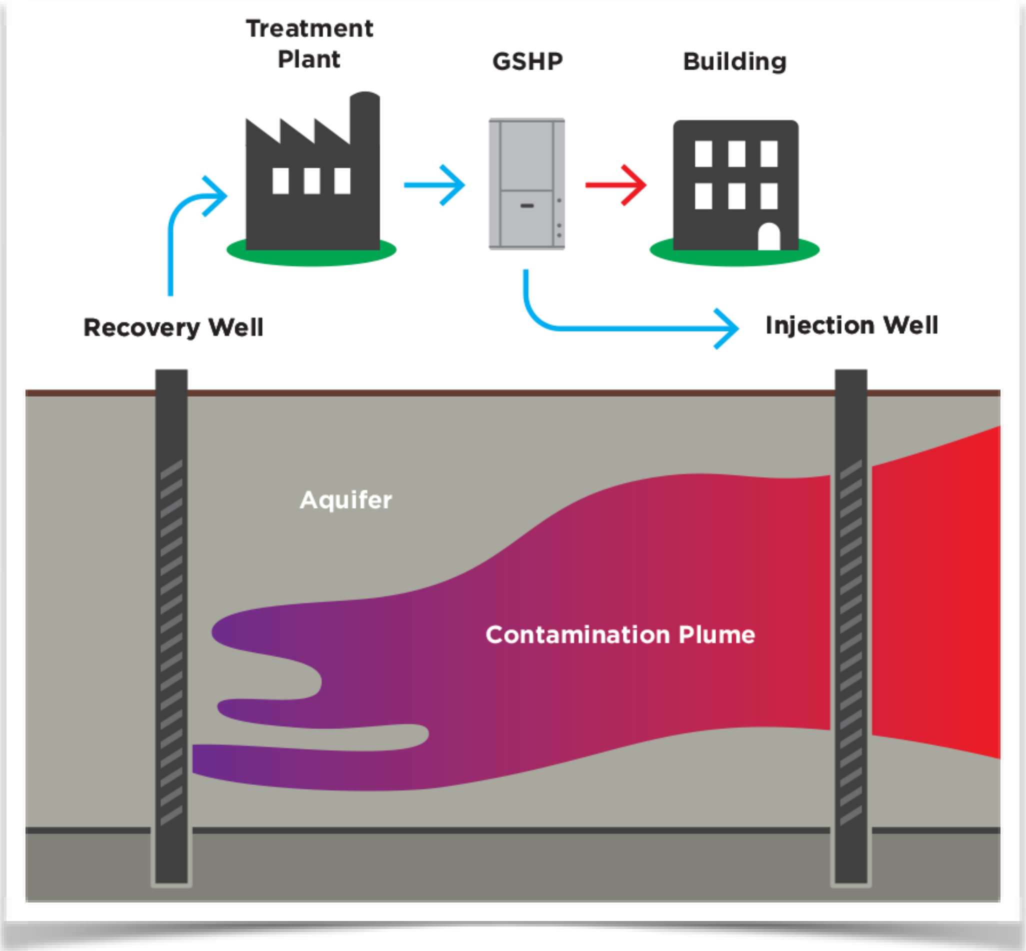
Comparison of Heating System Efficiencies

P&T or Bio



Treatment Plant
GSHP
Building
Recovery Well
Injection Well
Aquifer
Contamination Plume

Pump and Treat or Bioremediation

- Rule of thumb: Microbial respiration rate doubles with a 10 degree C increase in temperature
- Could use a separate ground-source to heat recovered groundwater before discharge
- Could use a closed-loop installation that is intentionally ‘too short’ and ‘too dense’ to heat soil in the treatment zone
- Could heat GW prior to air stripping to enhance volatilization

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Patent Pending

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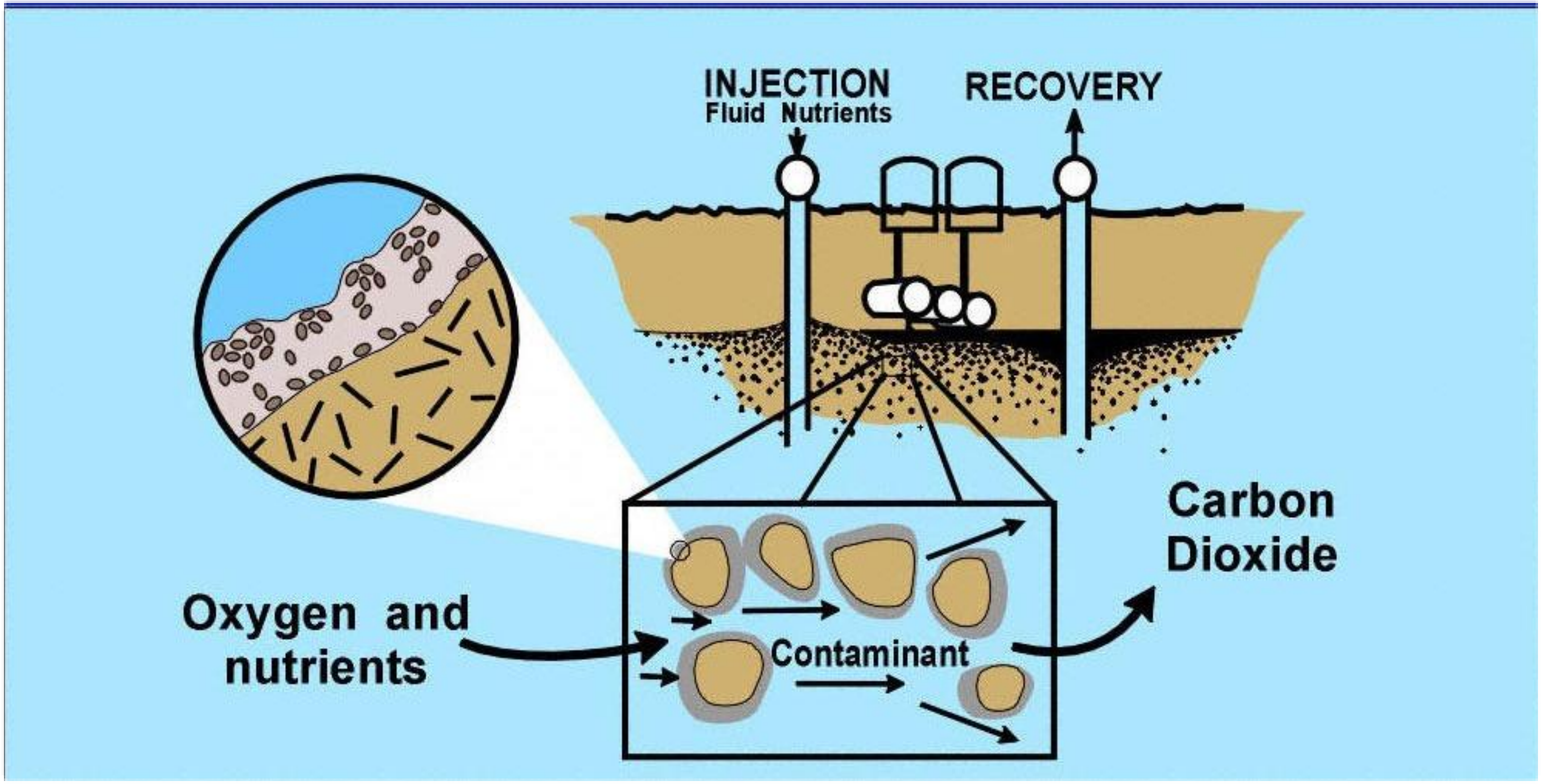
Bioremediation

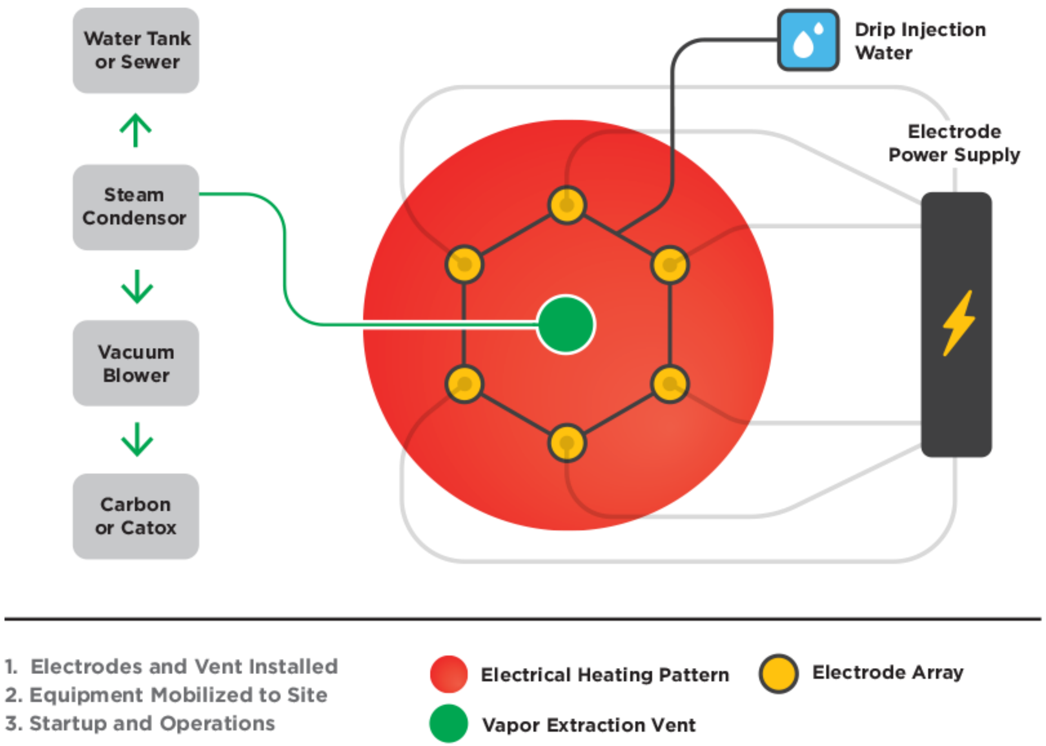


Patent Pending

SVE and DPE

6 Ph. Heating used by firms like Terra Therm to enhance remedial effect.

Groundwater is often boiled generating steam



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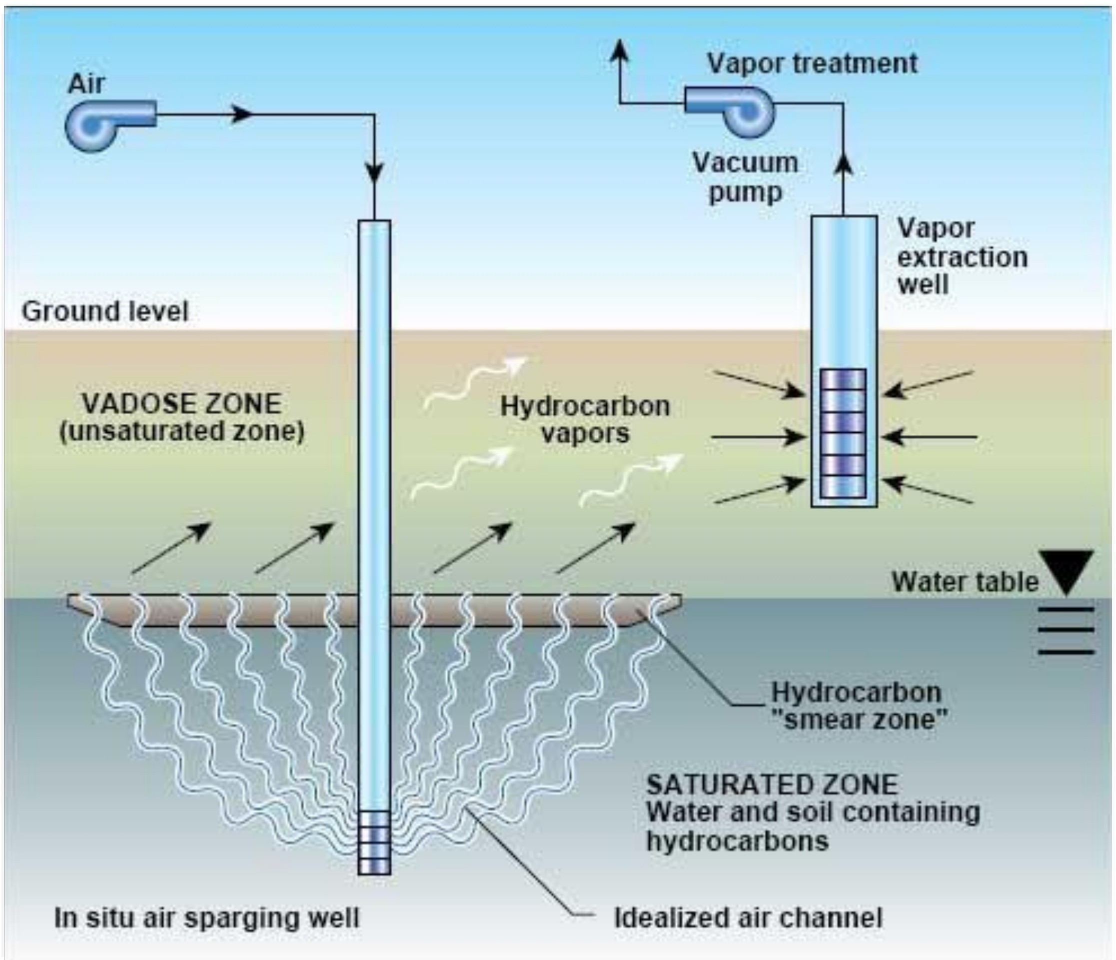
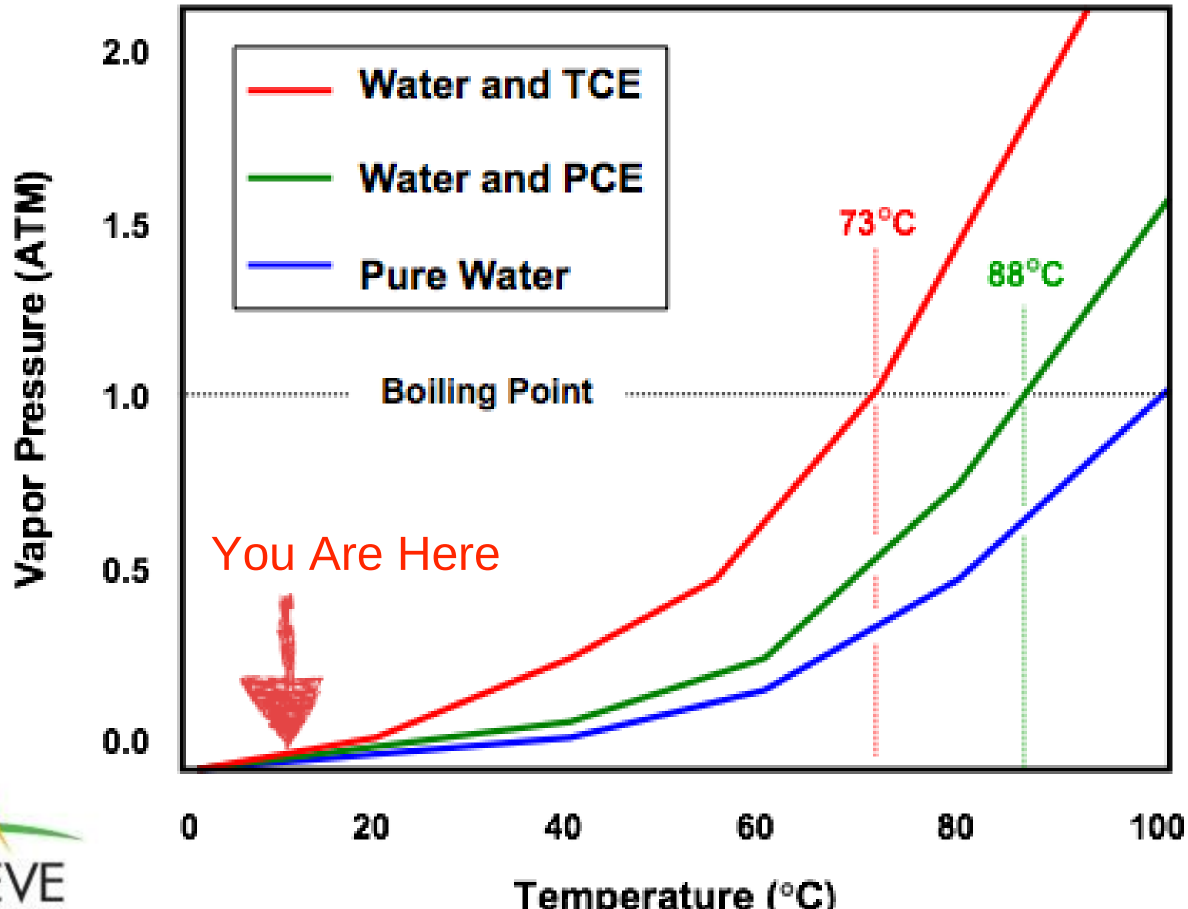
Traditional SVE/AS



SVE is Limited by Volatilization Rate



Pure TCE
B.P. = 87°C

Pure PCE
B.P. = 121°C

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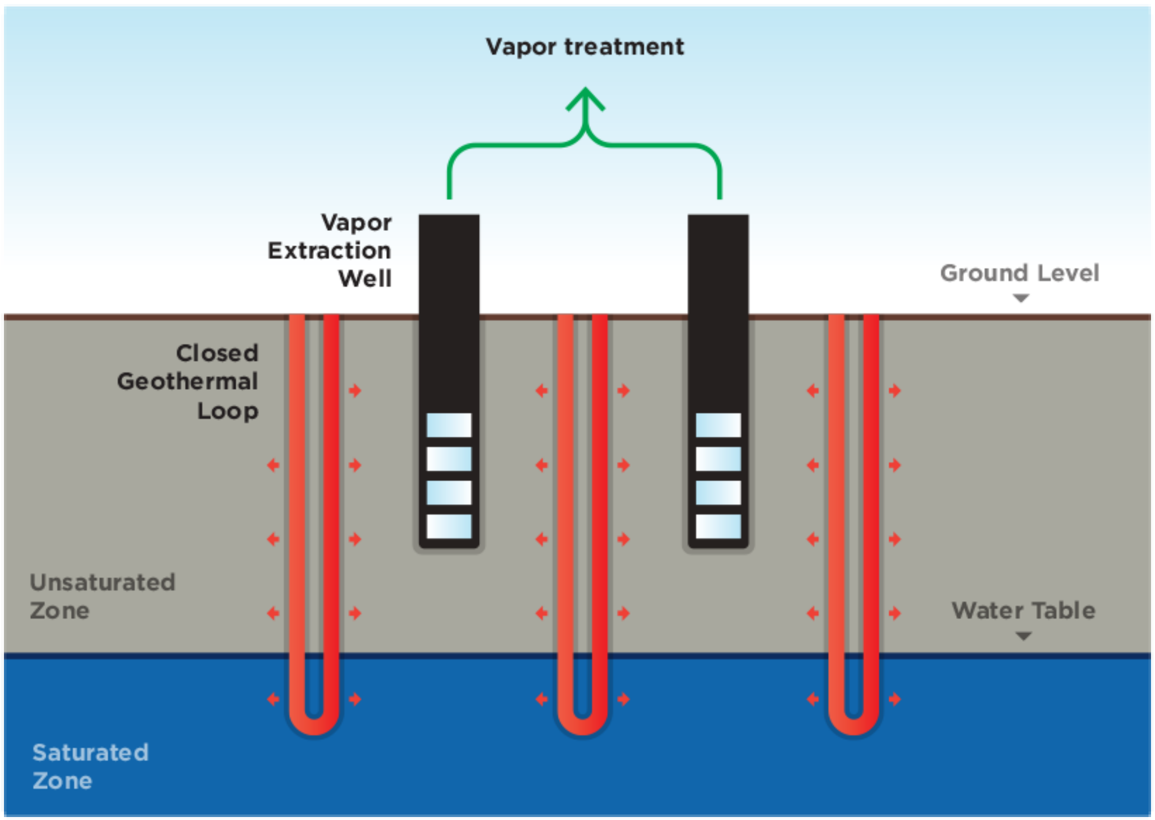
GSHP Heating



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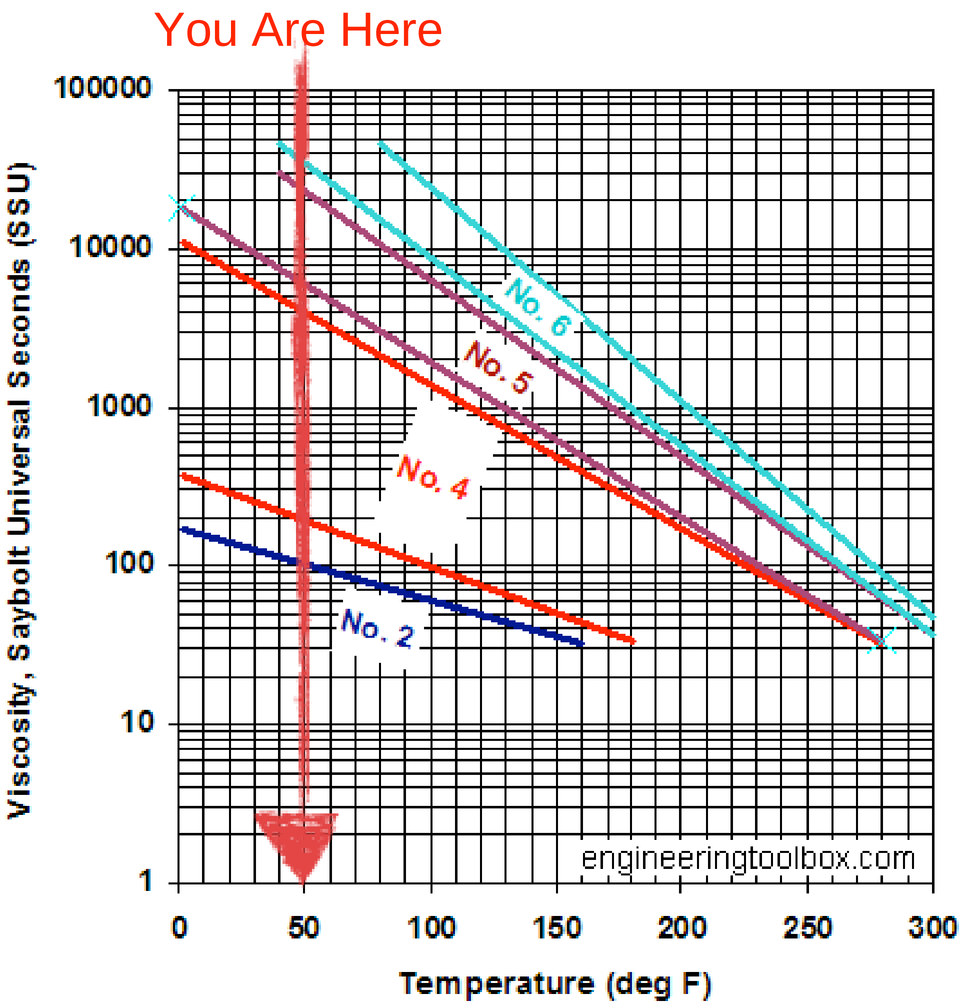
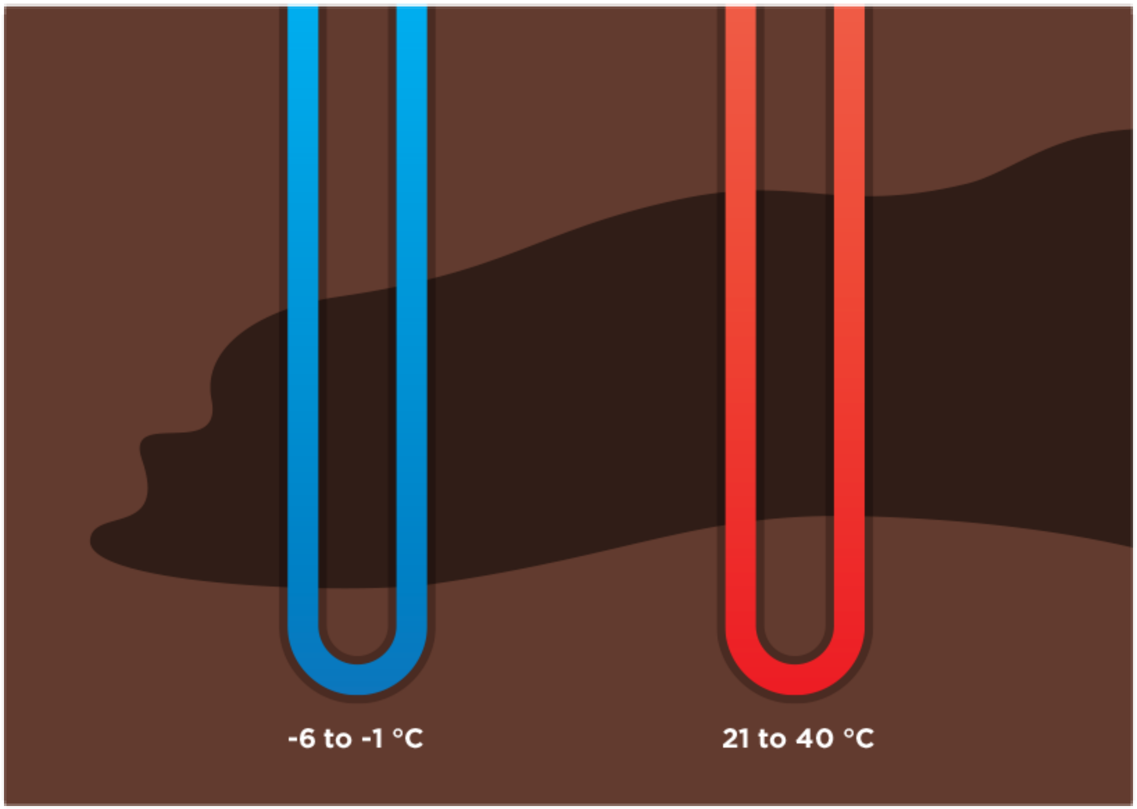
Oil Viscosity



Change Migration Rates
Use Heat/Cold to Change Viscosity



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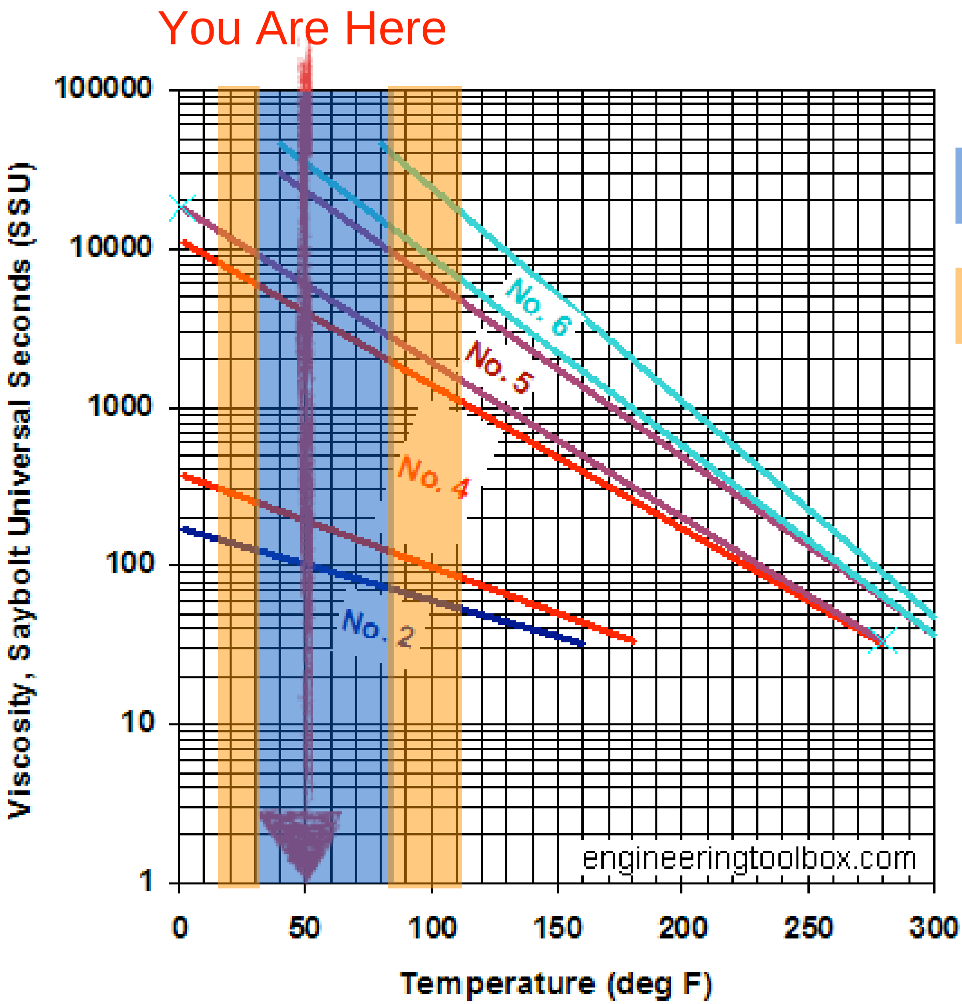
Oil Viscosity



Normal GSHP Operation

Down the Rabbit Hole

The 'Normal' range is for reliable, unattended operation. Remedial actions can potentially tolerate, and often include, maintenance and monitoring.

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