Advanced Groundwater-Enabled Geothermal Heating and Cooling

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Darcy Solutions

2021 MN Energy Expo

DARCY

What is an “Aquifer”?

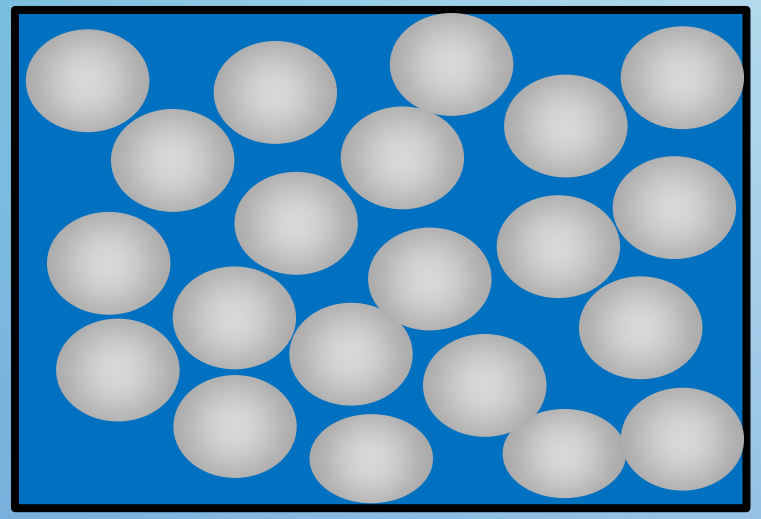
Not found in most dictionaries…

“A subsurface unit that produces a useful amount of water”

What is a useful amount of water?

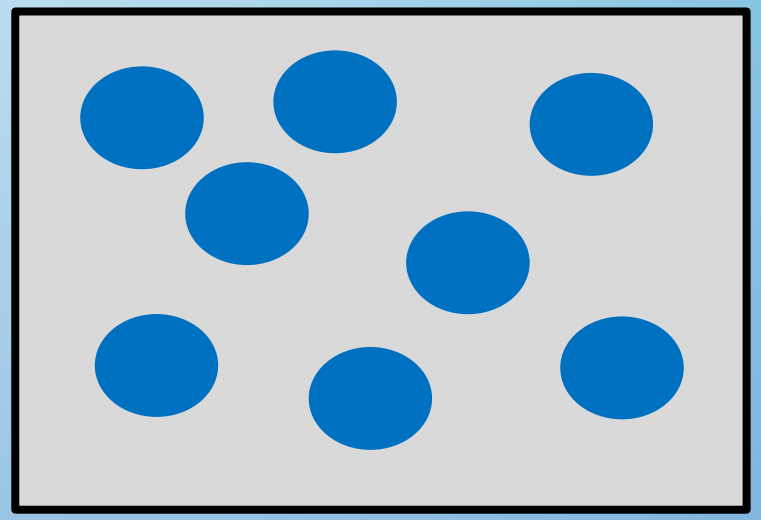
To be useful an aquifer needs porosity and permeability

sand

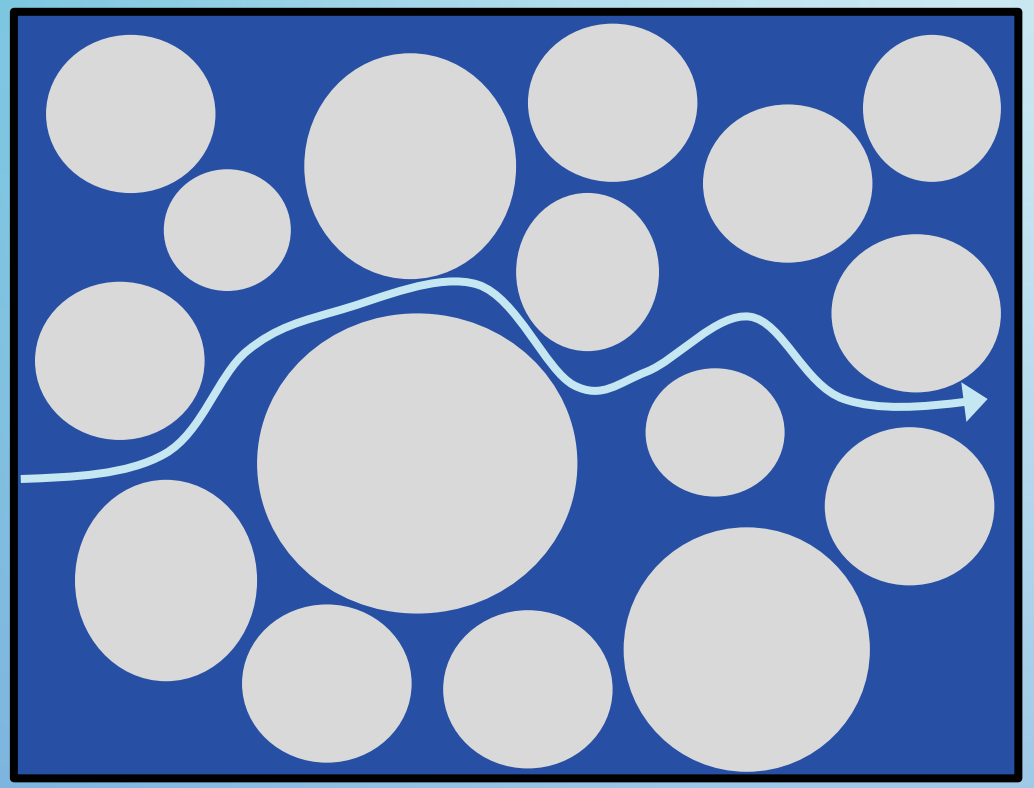


porous and permeable

swiss cheese

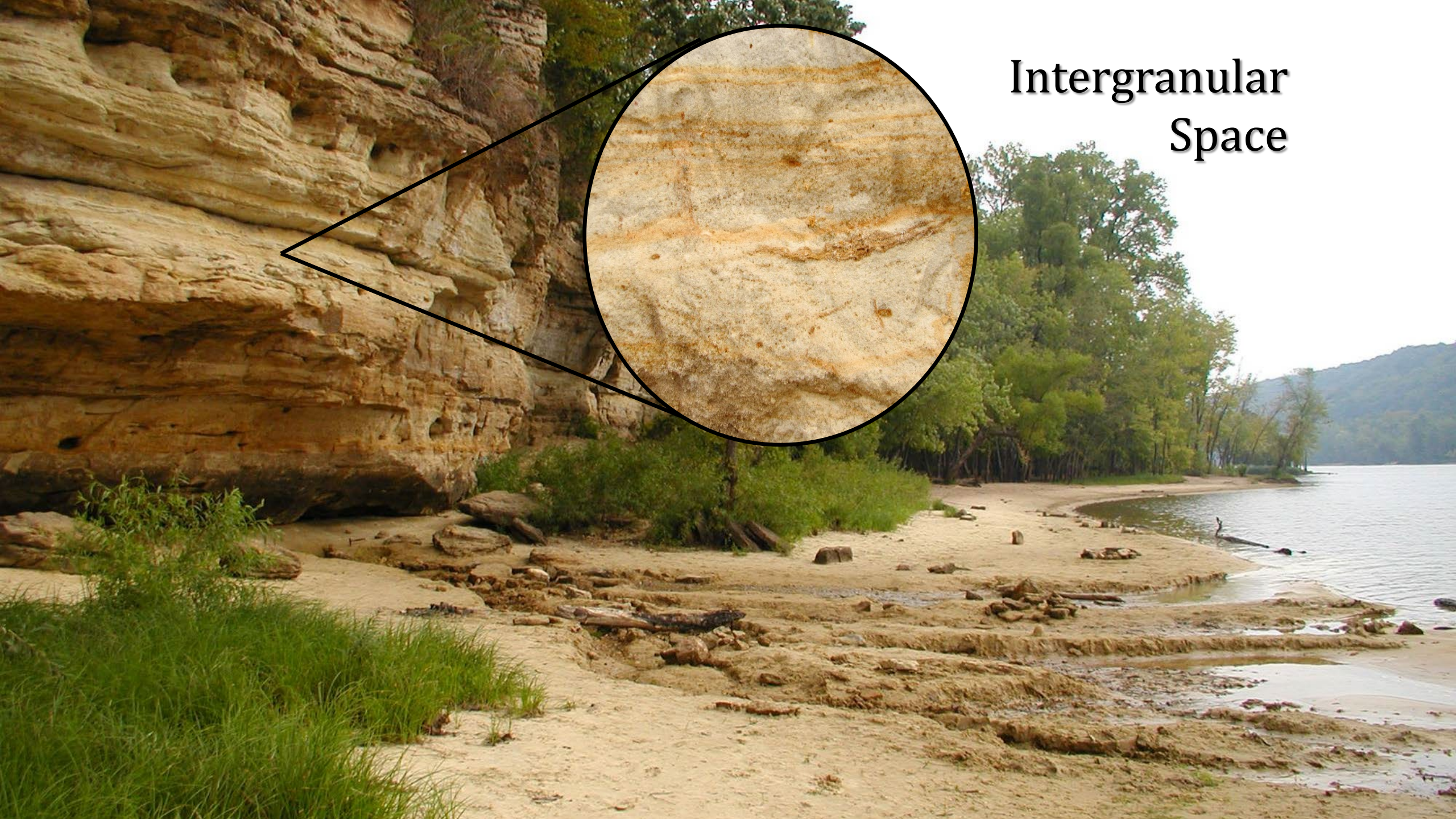


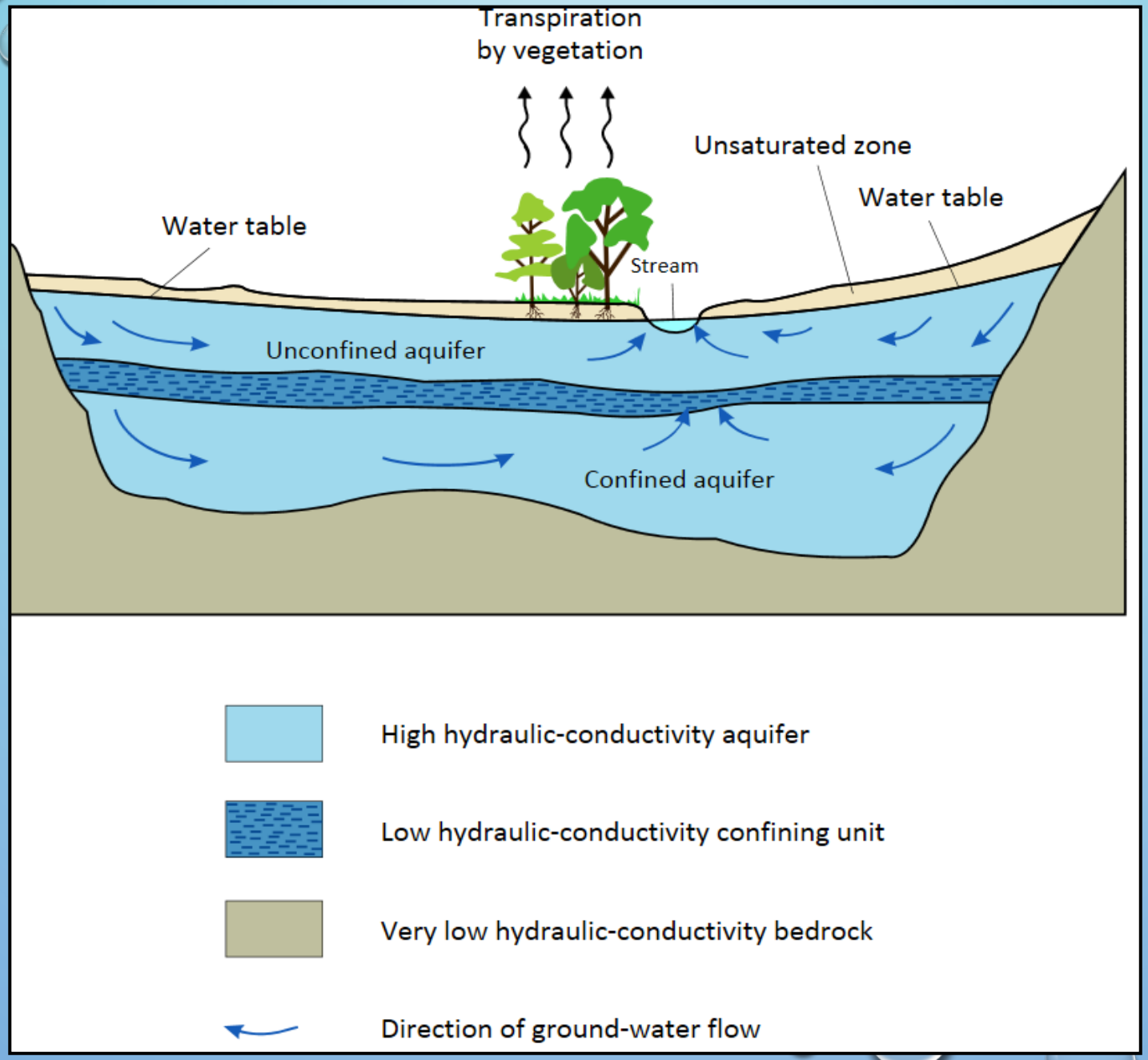
porous not permeable



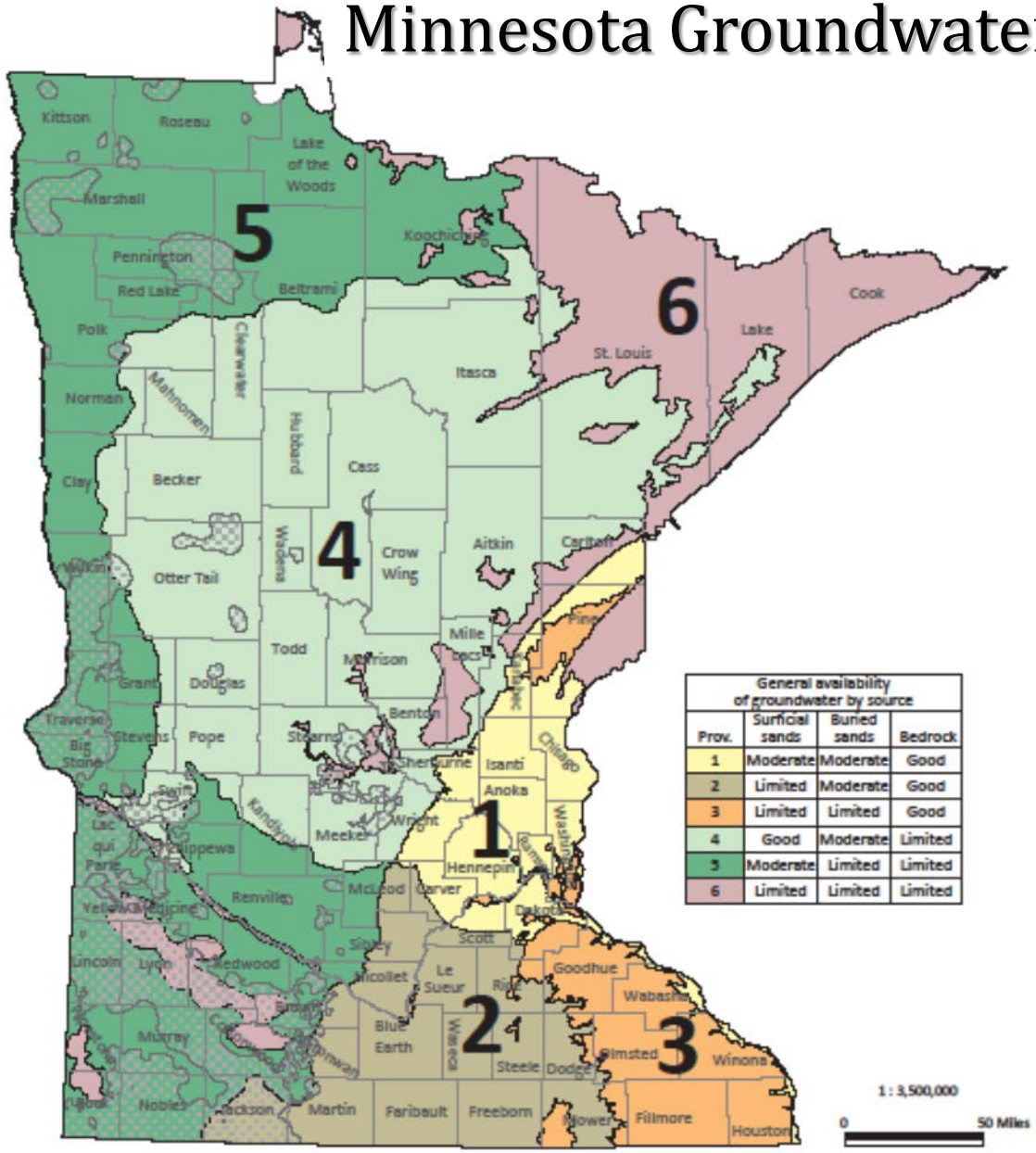
Groundwater flow around and in between grains

Porous Media Flow


Intergranular
Space


Transpiration
by vegetation
Unsaturated zone
Water table
Water table
Stream
Unconfined aquifer
Confined aquifer
High hydraulic-conductivity aquifer
Low hydraulic-conductivity confining unit
Very low hydraulic-conductivity bedrock
Direction of ground-water flow

Minnesota Groundwater Provinces 2021



General availability of groundwater by source			
Prov.	Surficial sands	Buried sands	Bedrock
1	Moderate	Moderate	Good
2	Limited	Moderate	Good
3	Limited	Limited	Good
4	Good	Moderate	Limited
5	Moderate	Limited	Limited
6	Limited	Limited	Limited

1 — **East-Central Province**
Surficial and buried sand and gravel aquifers are common. These unconsolidated aquifers are underlain by thick and extensive Paleozoic (sandstone and carbonate) and Precambrian (sandstone) aquifers.

2 — **South-Central Province**
Thick loam and clay loam glacial sediment, with limited extent surficial and buried sand aquifers, overlying thick and extensive Paleozoic (sandstone and carbonate) aquifers

3 — **Karst Province**
Thin (less than 30 feet) glacial sediment overlying thick and extensive bedrock (carbonate and sandstone) prone to karst features such as solution conduits, sinkholes and caves.

4 — **Central Province**
Surficial and buried sand and gravel aquifers are common. The underlying Cretaceous (shale and sandstone) and Precambrian (igneous and metamorphic) bedrock are typically limited aquifers.

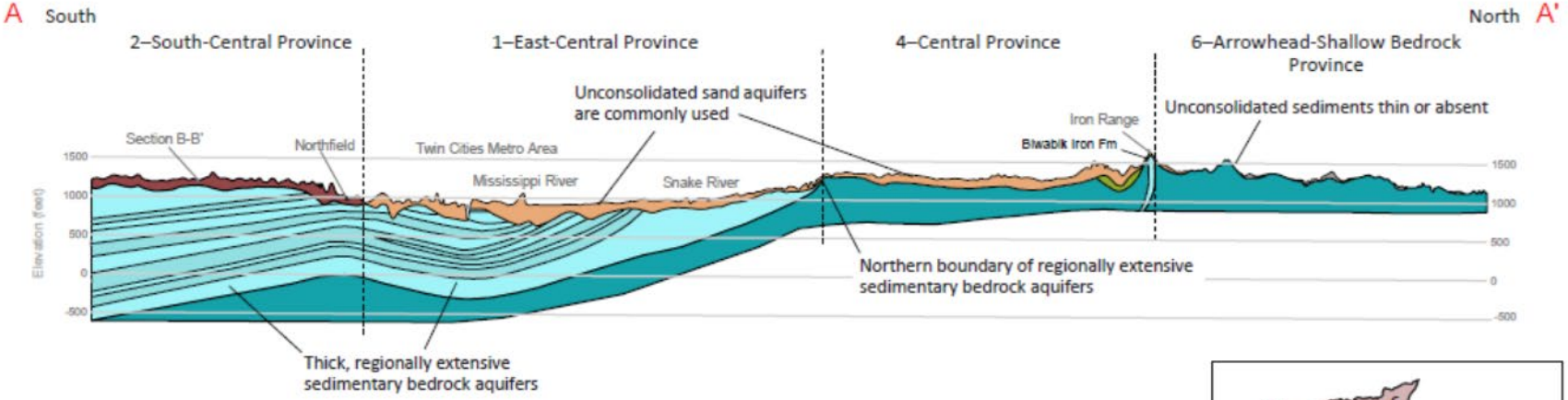
5 — **Western Province**
Loam and clay loam glacial sediment is common with limited surficial and buried sand aquifers. The underlying Cretaceous (shale and sandstone) and Precambrian (igneous and metamorphic) bedrock are typically limited aquifers.

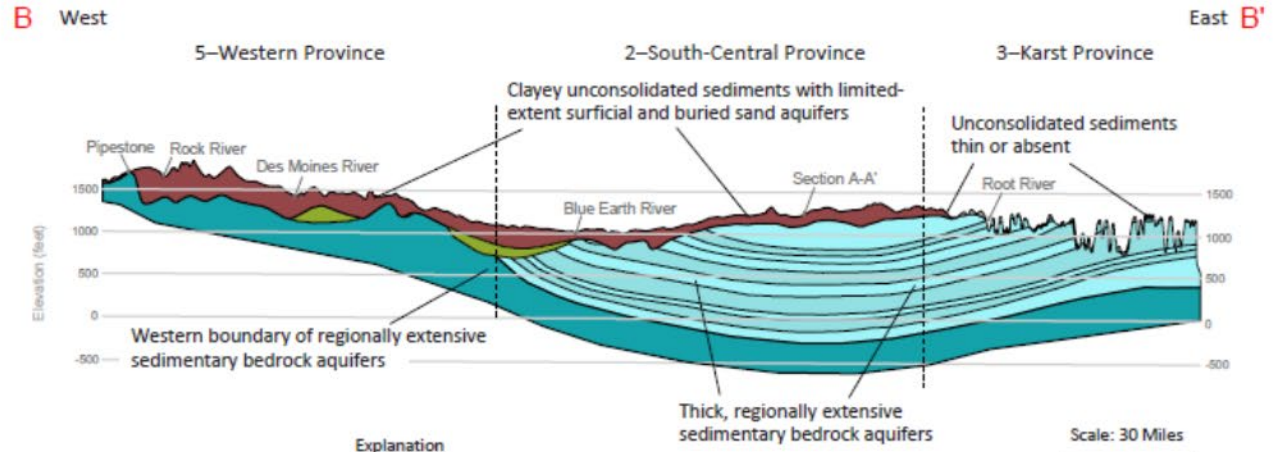
6 — **Arrowhead/Shallow Bedrock Province**
Exposed or shallow (less than 30 feet) Precambrian bedrock, and to a lesser extent Cretaceous bedrock. These types of bedrock have limited aquifers.

Cretaceous Bedrock
Sandstone layers that are interbedded with thick layers of shale or mudstone. Used locally as water sources with limited aquifer characteristics. These units occur beneath the glacial sediment but above the Precambrian bedrock.

DEPARTMENT OF NATURAL RESOURCES

MN Groundwater Provinces 2021 – Generalized Cross Sections





Explanation

- Clayey unconsolidated sediments with limited-extent sand aquifers (Quaternary)
- Sandy unconsolidated sediments; sand aquifers common (Quaternary)
- Thin, unconsolidated sediments with the exception of sand aquifers (Quaternary) in major river valleys that are frequently used
- Cretaceous shale and sandstone; used locally as water source
- Precambrian bedrock; can provide groundwater locally from fractures

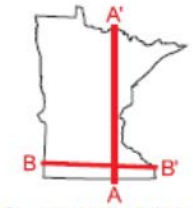
Regional sedimentary bedrock

- Bedrock aquifers*
- Confining units*

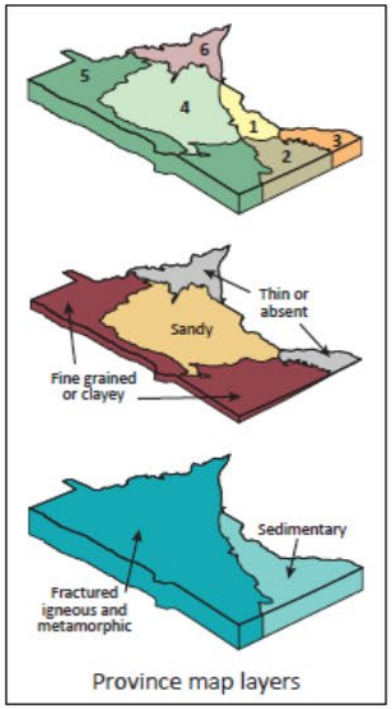
*Aquifer and confining unit characteristics can vary regionally, locally, and according to depth below top of bedrock.

Scale: 30 Miles

Approximate vertical exaggeration X 100



Cross section line locations



Province map layers

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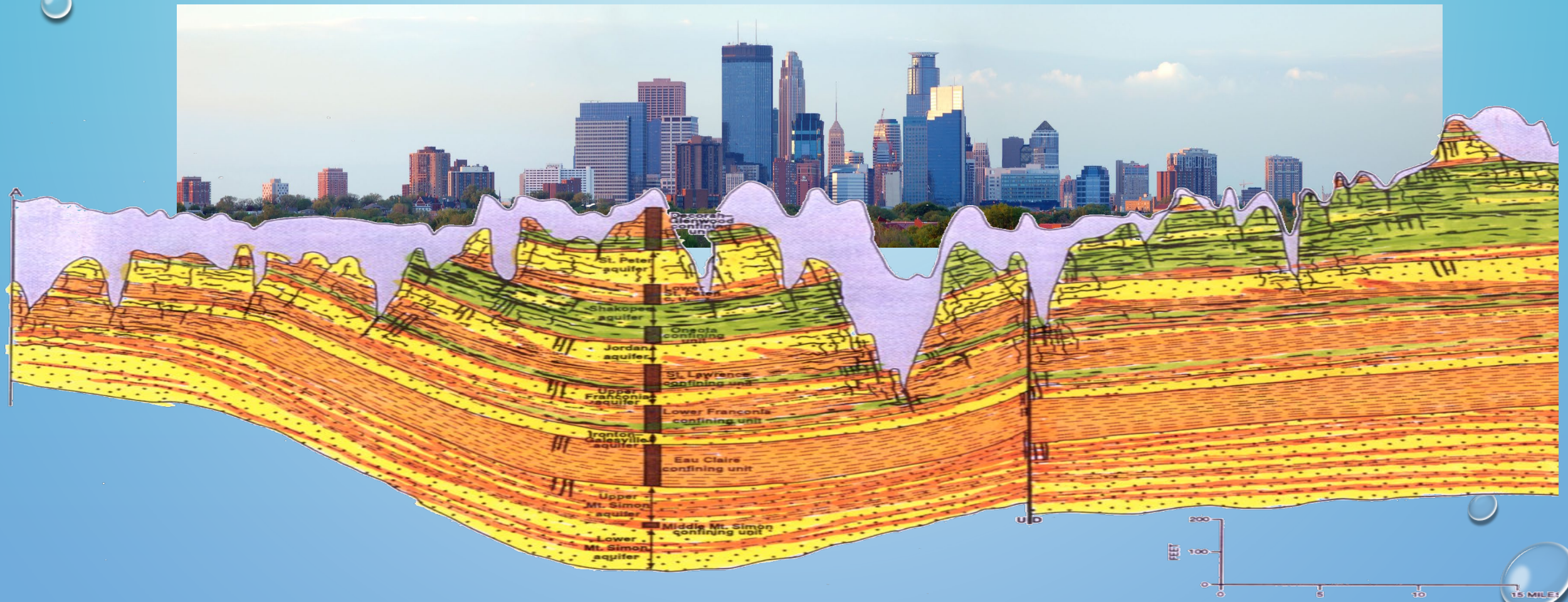
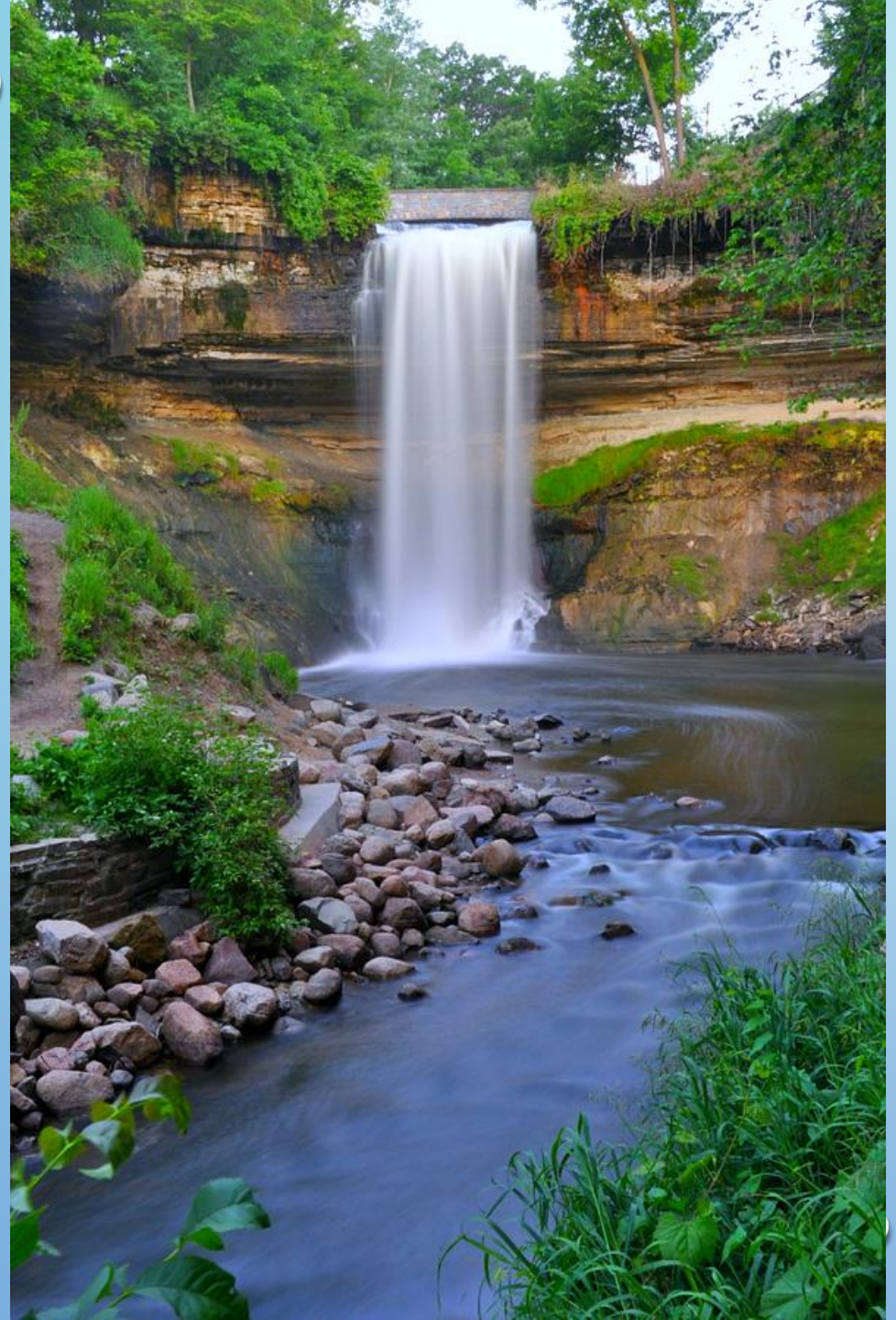

St. Peter aquifer
Shakopee aquifer
Jordan aquifer
Upper Franconia aquifer
Lower Franconia confining unit
Ironton Galesville aquifer
Eau Claire confining unit
Upper Mt. Simon aquifer
Middle Mt. Simon confining unit
Lower Mt. Simon aquifer
UMD
200
100
0
FEET
0
5
10
15 MILES



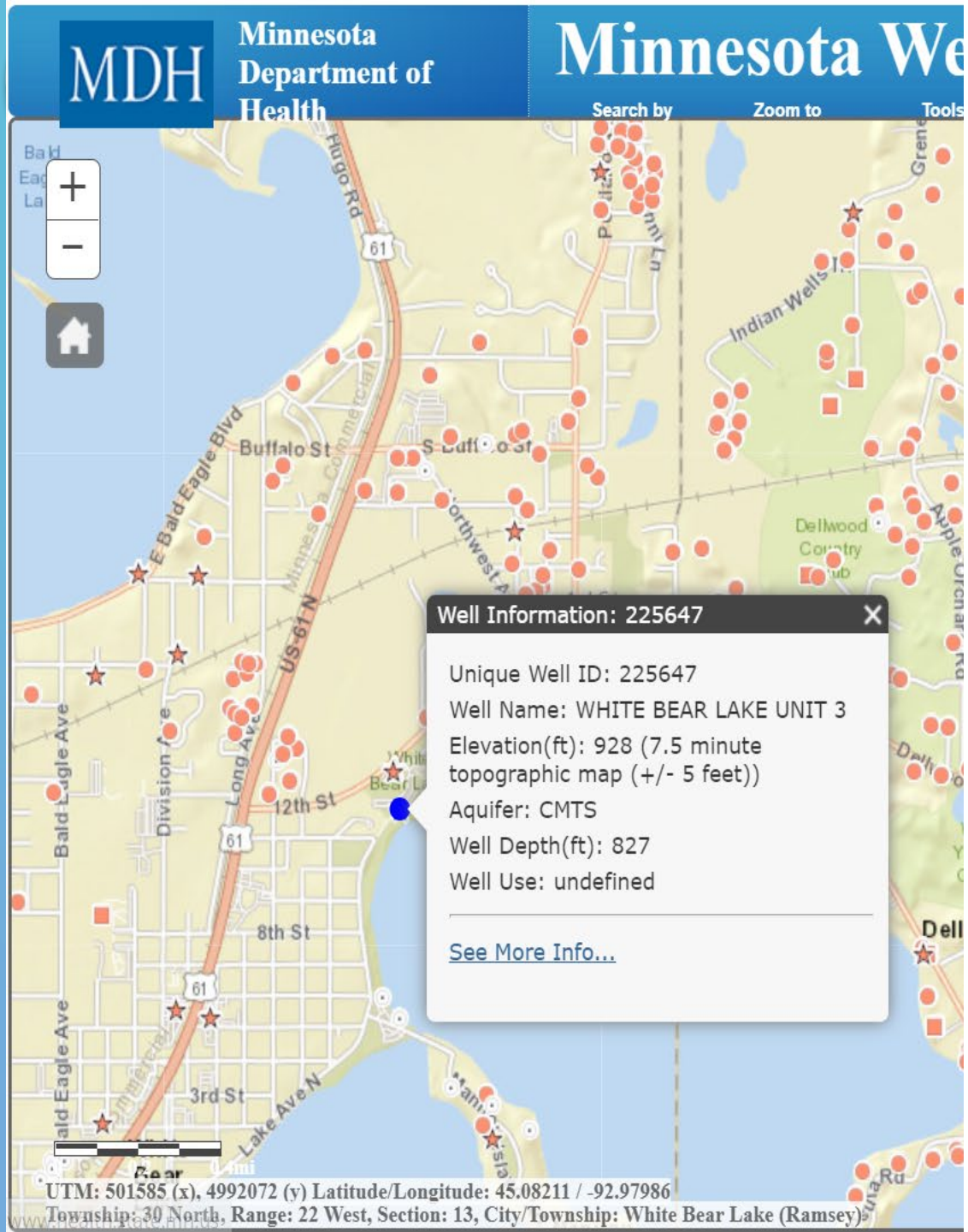
Platteville Limestone

Glenwood Shale

St. Peter Sandstone

Minnehaha Falls

Photograph by Kim Windingland



Minnesota Unique Well Number

225647

County Ramsey
Quad White Bear
Quad ID 118C

MINNESOTA DEPARTMENT OF HEALTH

WELL AND BORING REPORT

Minnesota Statutes Chapter 1031

Entry
Upda
Recei

Well Name	Township	Range	Dir	Section	Subsection
WHITE BEAR	30	22	W	13	BABACB

Elevation 928 ft. **Elev. Method** 7.5 minute topographic map (+/- 5 feet)

Address

C/W WHITE BEAR LAKE MN

Stratigraphy Information

Geological Material	From	To (ft.)	Color	Hardness
CLAY & SAND &	0	15		
SAND	15	55		
BLUE CLAY	55	87		
SAND & GRAVEL	87	152		
SAND & GRAVEL	152	173		
SOAP & LIMESTONE	173	187		
LIMESTONE	187	250		
LIMESTONE	250	290		
SANDSTONE	290	333		
SANDSTONE	333	364		
SANDSTONE	364	384		
GREEN SHALE	384	400		
GREEN SHALE	400	415		
BLUE & GREEN SHALE	415	558		
BLUE & GREEN SHALE	558	570		
SANDSTONE	570	614		
SANDSTONE	614	620		
SANDY LIMESTONE	620	632		
LIMESTONE	632	713		
LIMESTONE	713	733		
SANDSTONE	733	827		

Well Depth 827 ft. **Depth Completed** 827 ft.

Drill Method Cable Tool **Drill Fl**

Use lake level augmentation

Well Hydrofractured? Yes ☐ No ☐ I

Casing Type Step down J
Drive Shoe? Yes ☐ No ☐ Above

Casing Diameter		Weight	
20 in. To	173 ft.	78.6	lbs./ft.
4 in. To	741 ft.	10.7	lbs./ft.
12 in. To	237 ft.	49.5	lbs./ft.

Open Hole From 741 ft. To

Screen? ☐ **Type**

Static Water Level
31 ft. land surface Mea

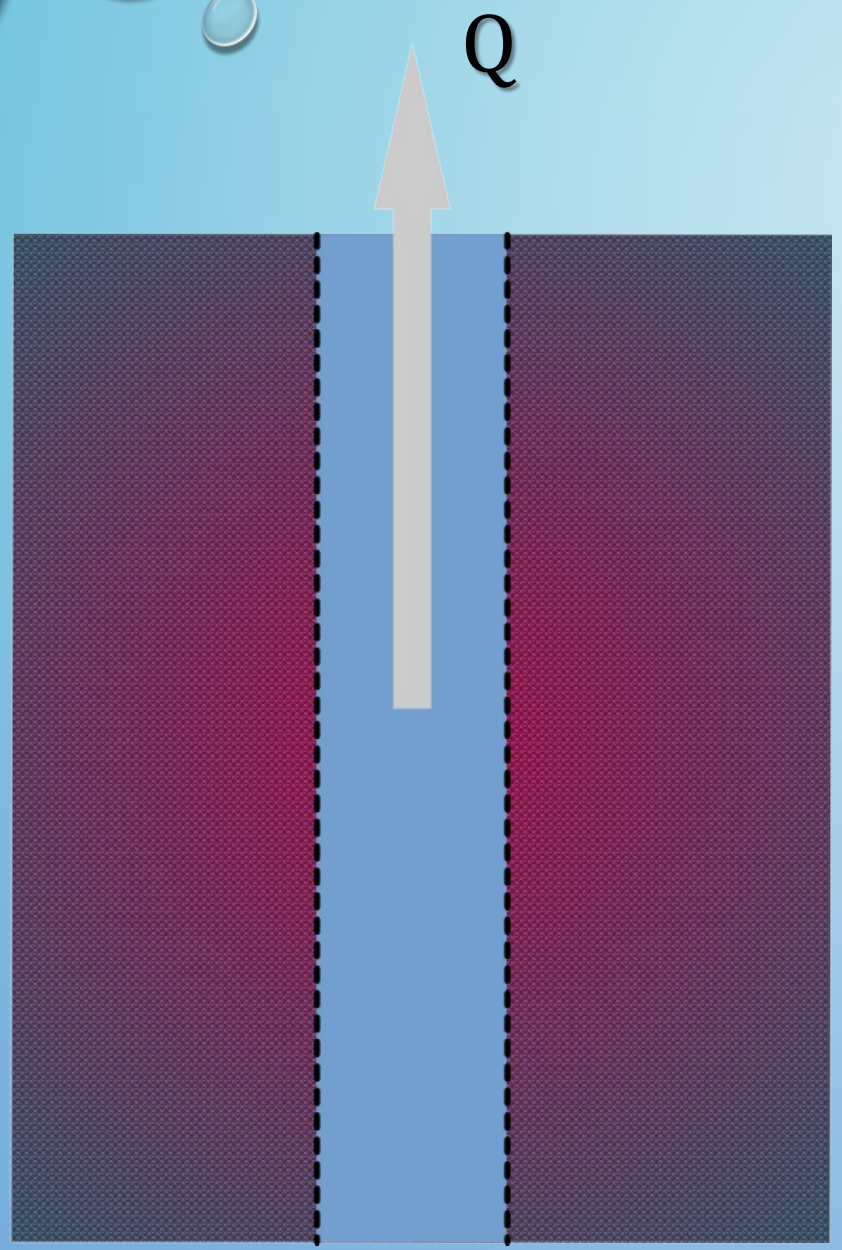
Pumping Level (below land surface)
57 ft. hrs. Pumping at 12

Wellhead Completion
Pitless adapter manufacturer
☐ Casing Protection ☐ 12 in. above
☐ At-grade (Environmental Wells and Borings ON

Grouting Information Well Grouted? ☒ Yes

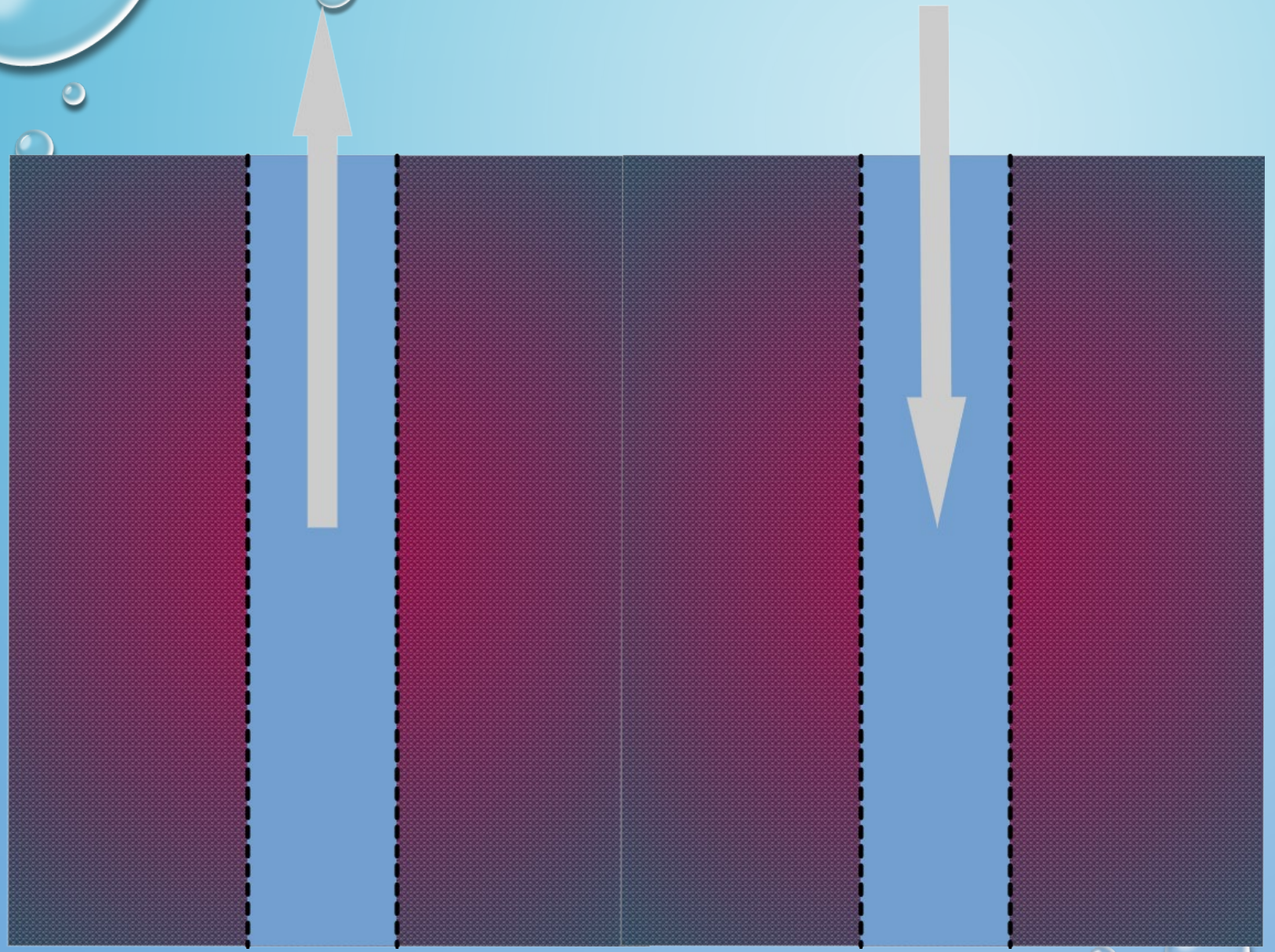
Material	Amount	
neat cement	54	Cubic

Nearest Known Source of Contamination
feet Direction
Well disinfected upon completion? ☐ Ye



Old style
“Pump and Dump”

Consumes valuable groundwater resources



Pump and Reinject

Potential to introduce contamination and change chemistry

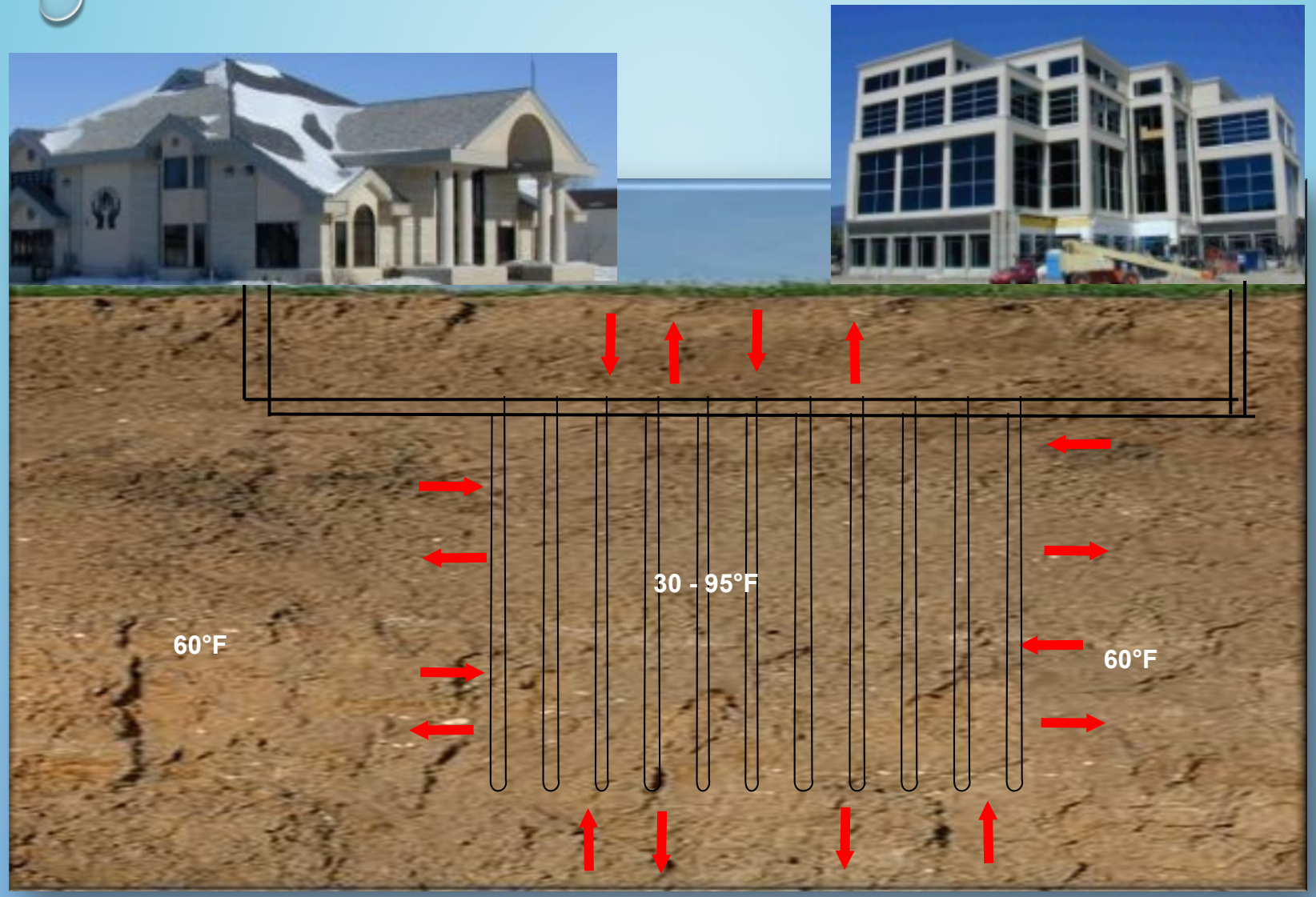
Requires significant energy to pump to surface and to re-inject

Traditional Vertical Ground Loops

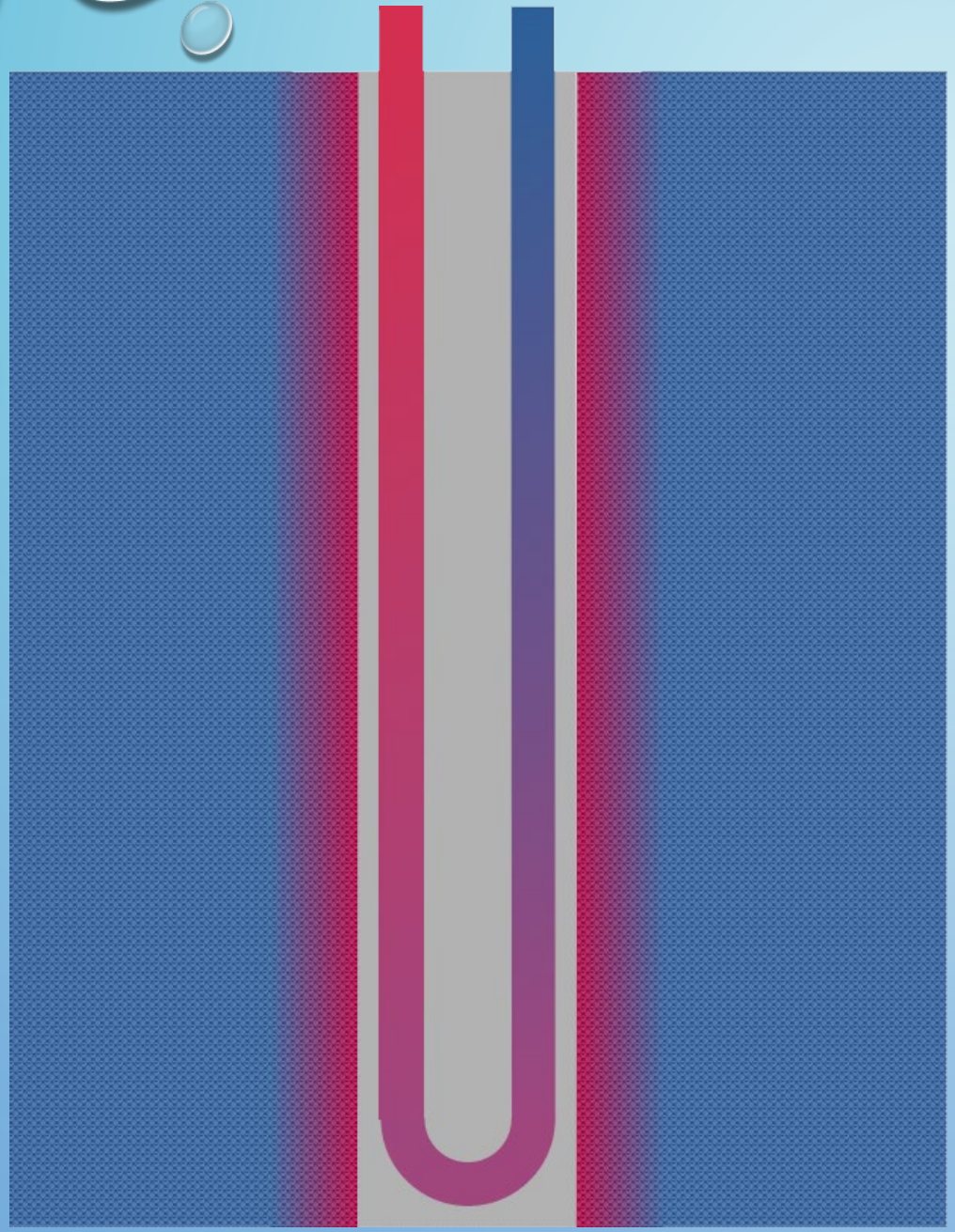
Purposely ignore groundwater
- Although saturated conditions are preferred

Boreholes are grouted
- Carefully defined to not be water wells

Unaccounted groundwater flow
- Can create interference between ground loops



Traditional Vertical Ground Loop Installation



Ground Loop (grouted)

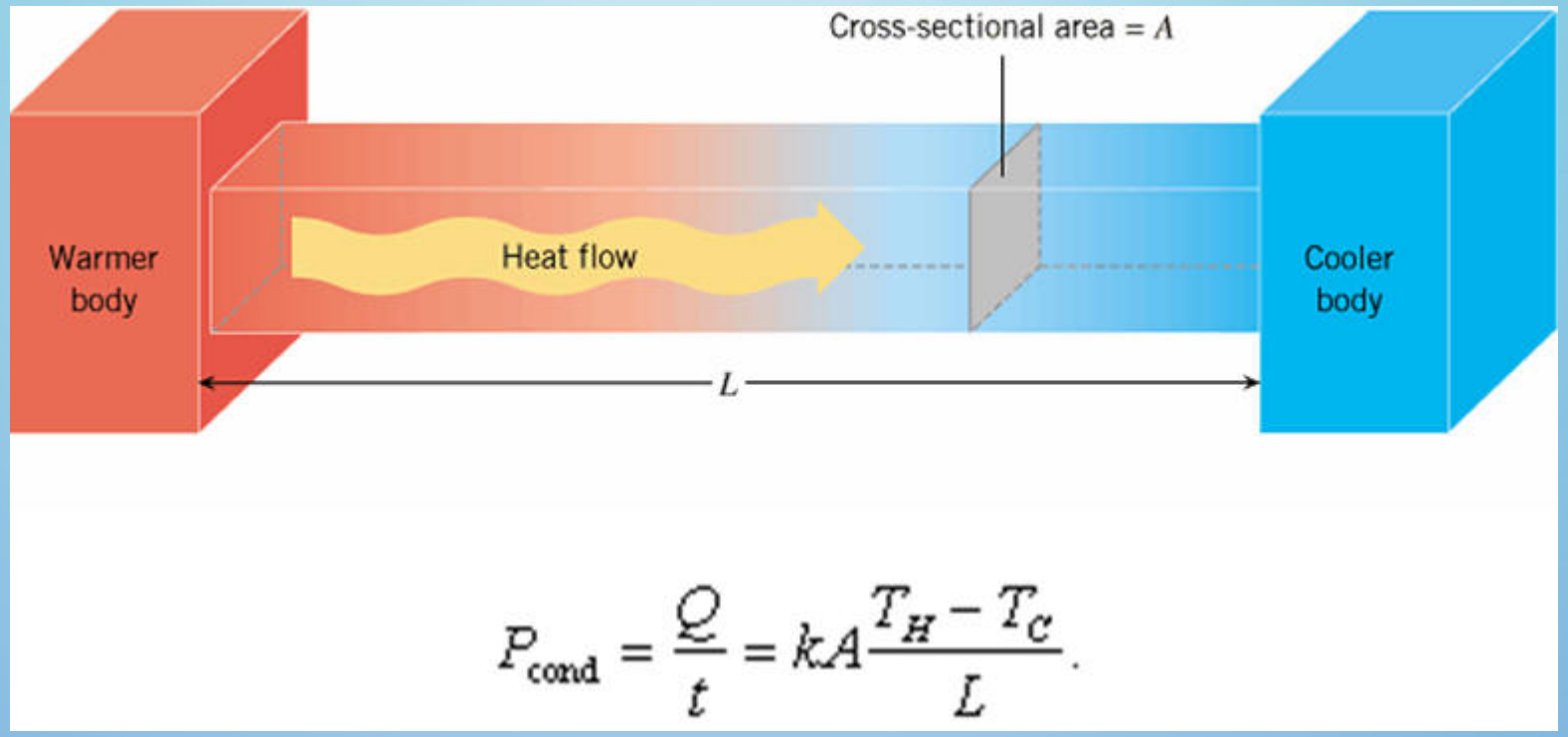
Geologic Sediments have a large thermal mass

But are relatively good insulators

Thermal Conduction is grain by grain

Water filled spaces help

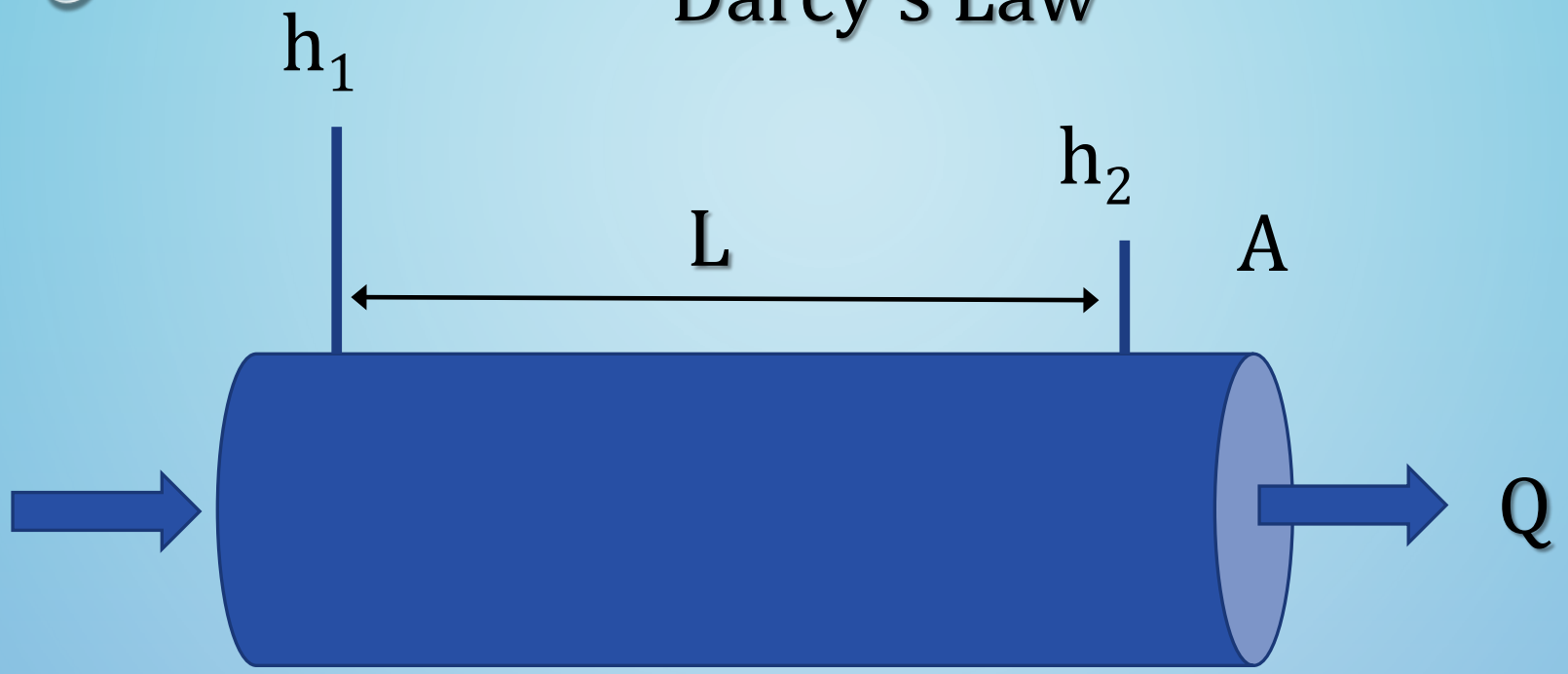
Thermal Conductivity



$$P_{cond} = \frac{Q}{t} = kA\frac{T_H - T_C}{L}.$$

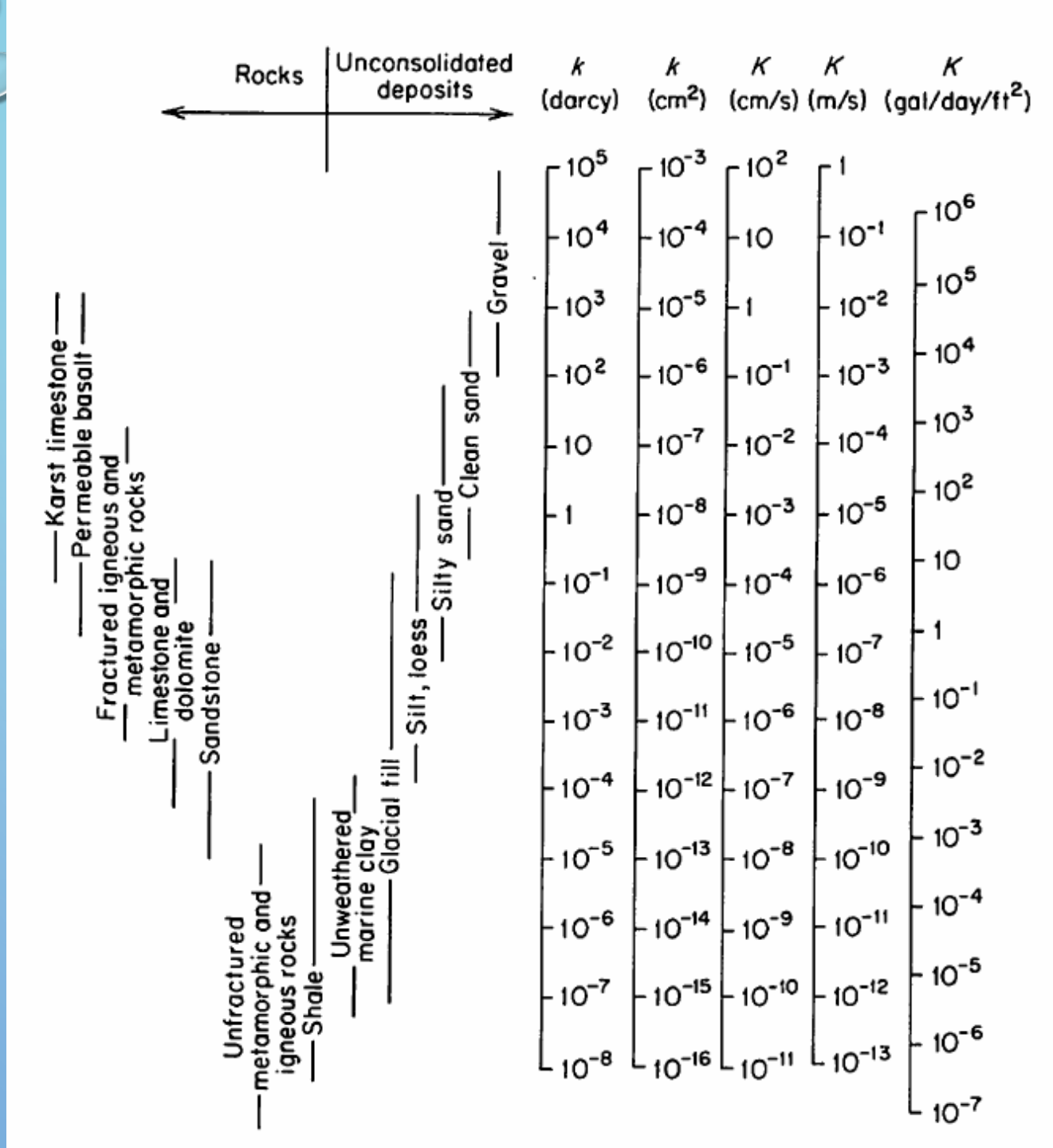
Typical geologic materials: 0.1 - 5 W/(mK)

Darcy's Law

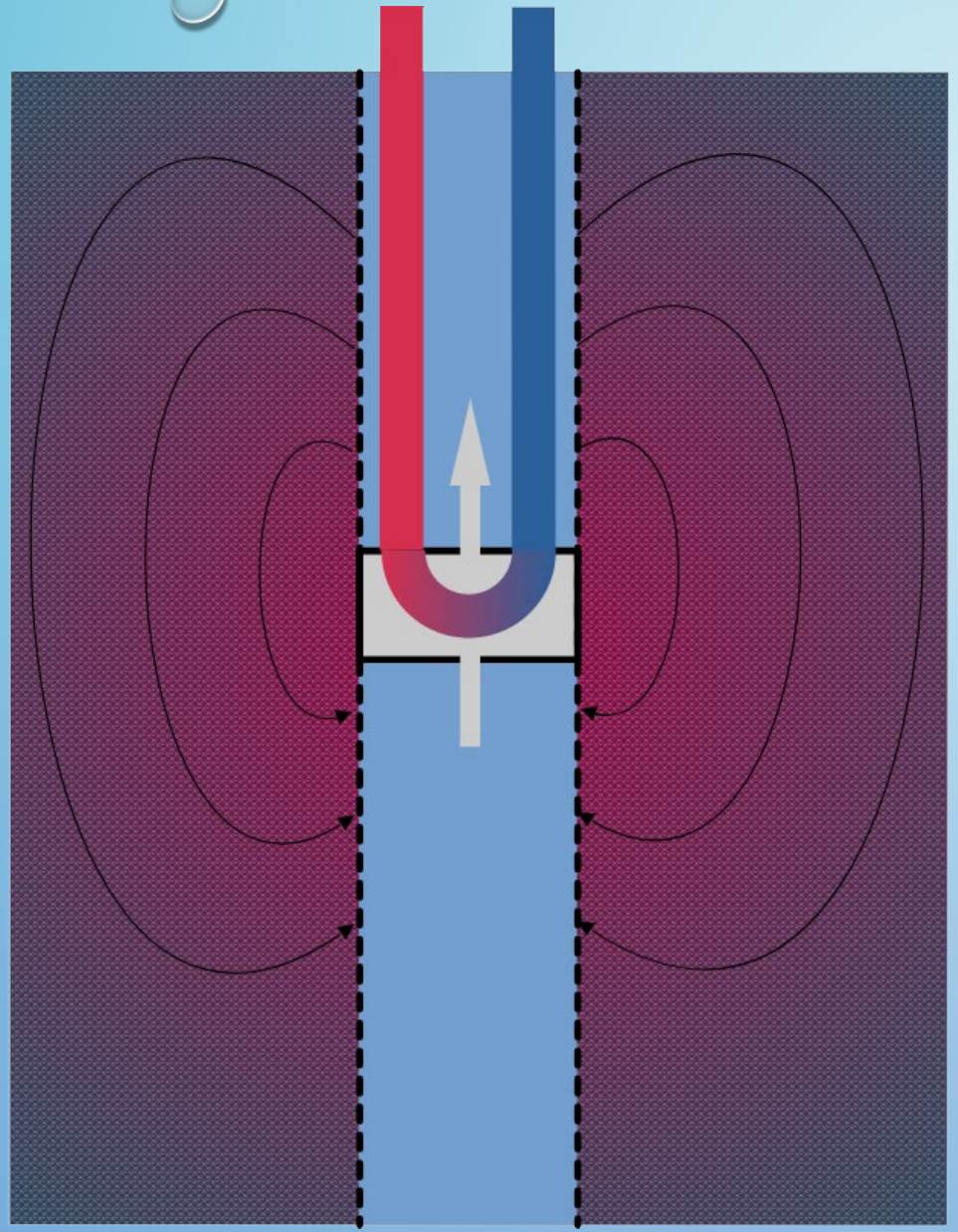


$$\frac{Q = K A (h1 - h2)}{L}$$

K = Hydraulic Conductivity



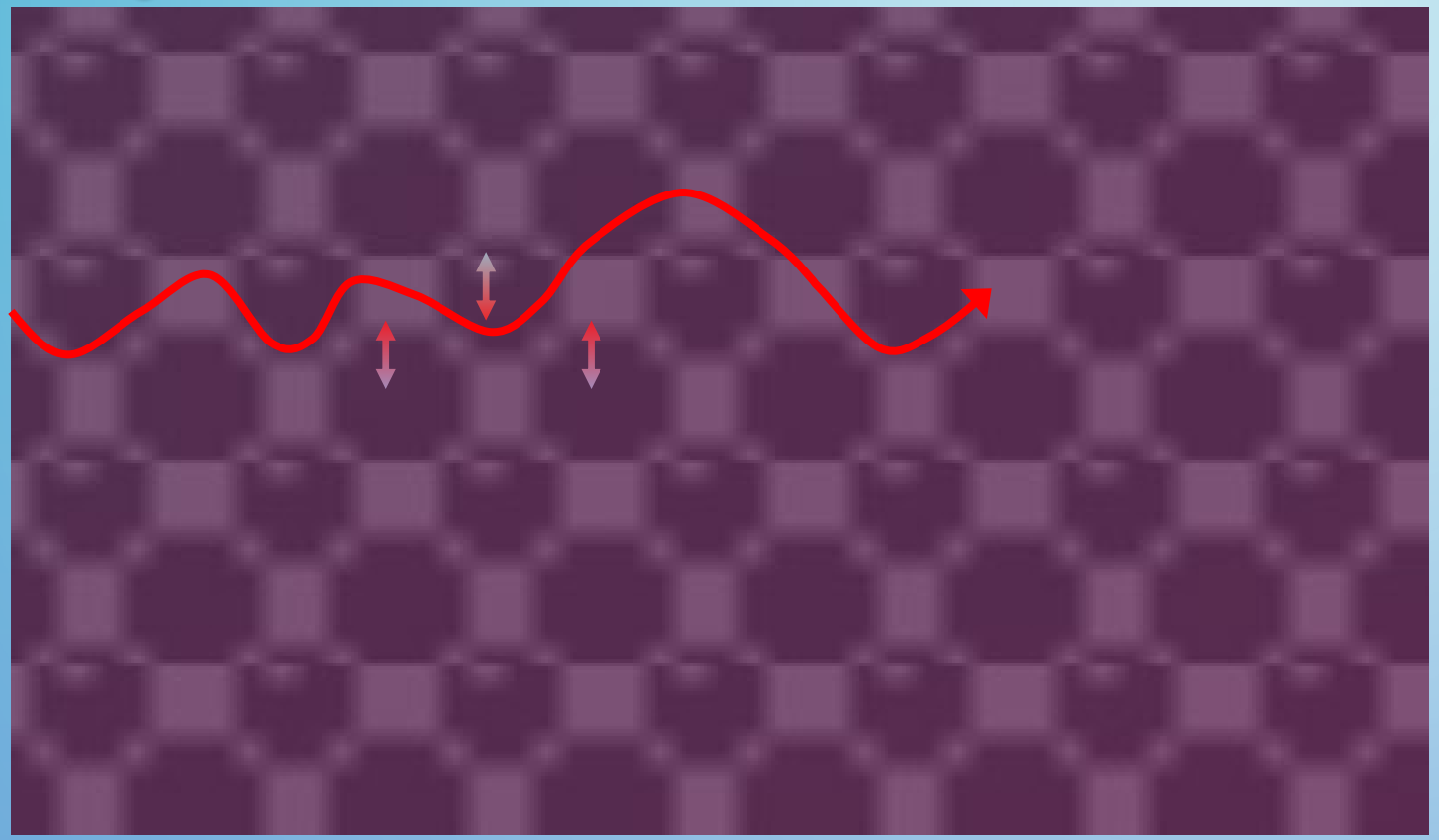
10 orders of magnitude



Closed building loop transfers heat via in-well heat exchanger

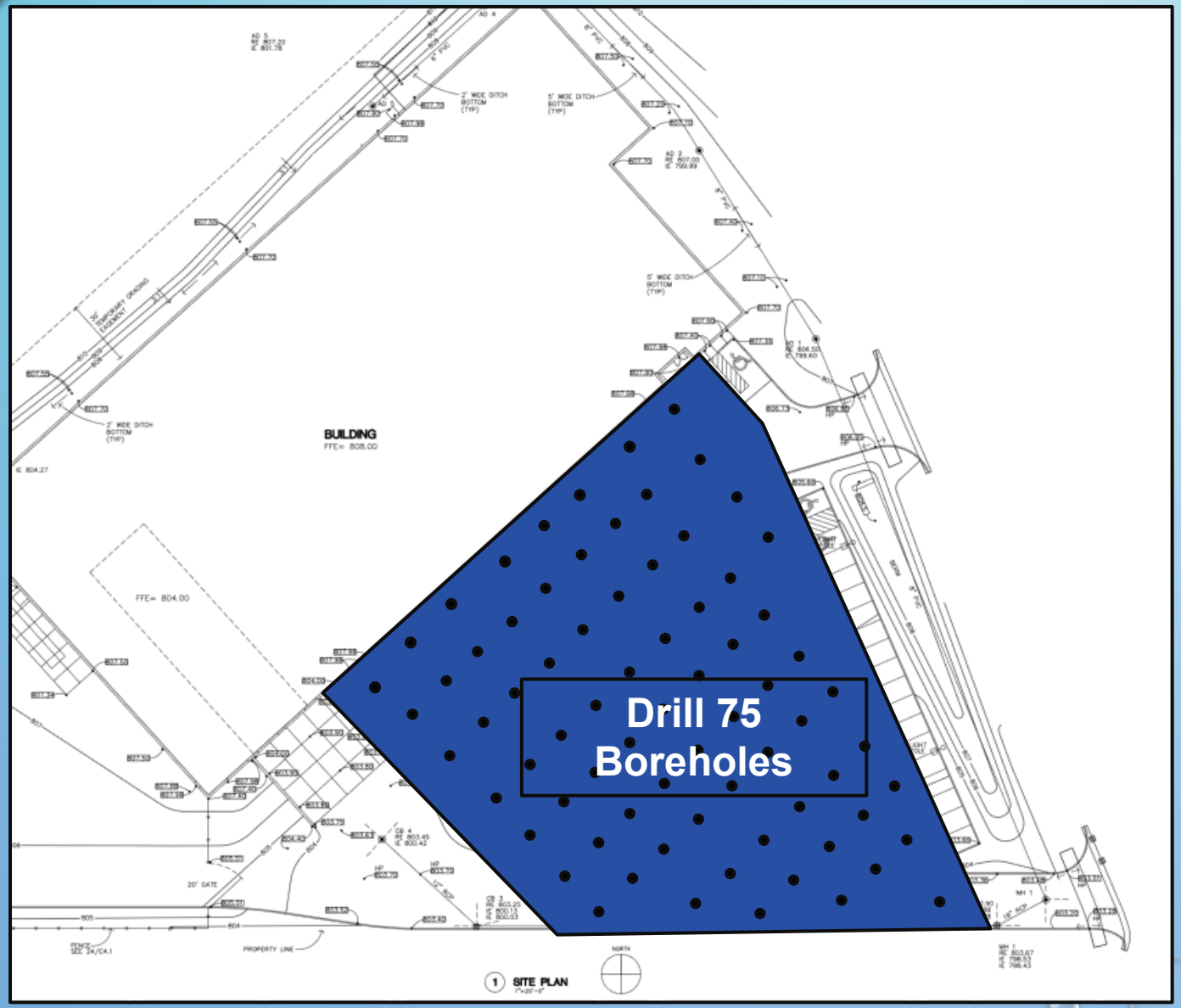
Pumped Groundwater stays below ground

Heat is transported advectively by groundwater

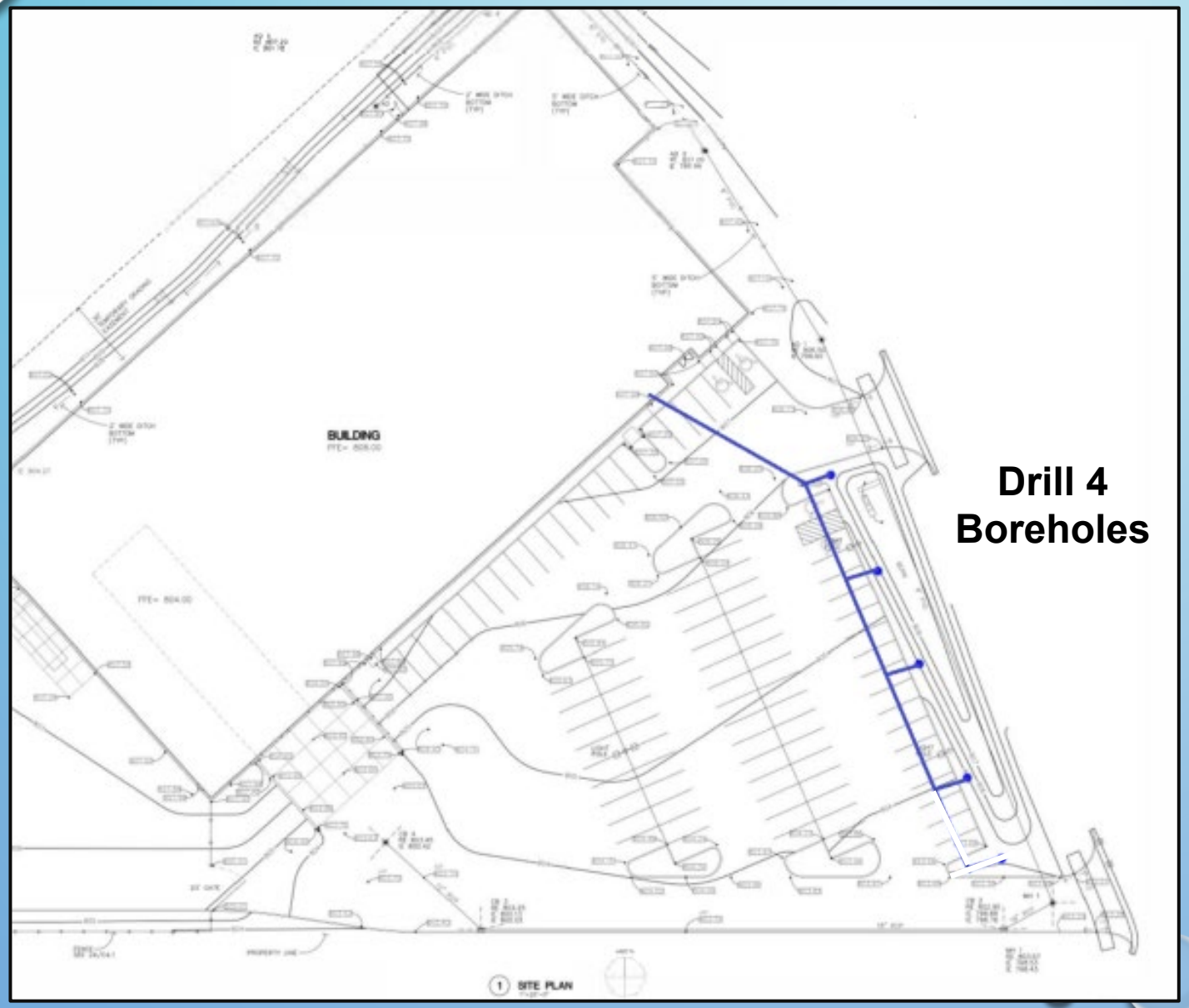


Thermal energy is transported by fluid flow

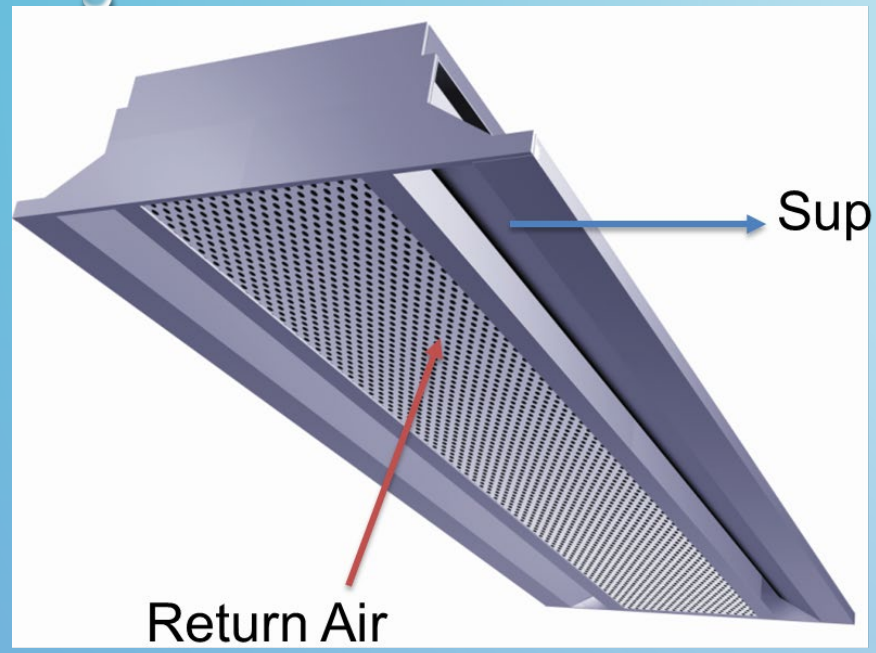
Heat is transferred to grains some distance from borehole

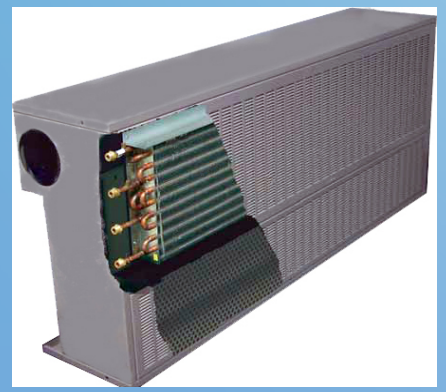


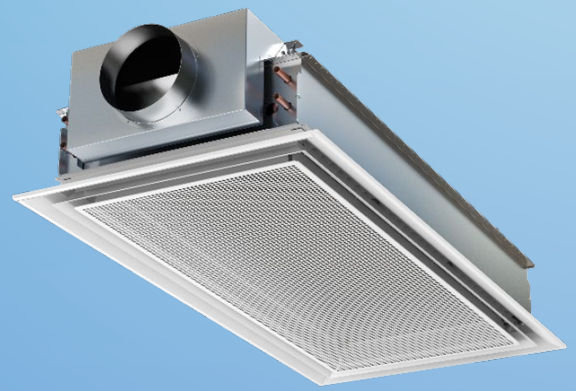
Traditional Ground Loop Systems can require numerous boreholes and site disruption



Groundwater Pumping Systems can use a much smaller number of boreholes and reduce footprint requirements 95%







Induction Displacement Chilled Beams

- Cooling-only system
- Sends 60-65°F dehumidified air to space with 58°F ground water
- Up to 80% reduction in cooling-related energy use and emissions vs. code-standard system

GROUNDWATER SYNERGIES WITH COMMON HVAC EQUIPMENT

BENEFITS TO REFRIGERATION COOLING EQUIPMENT

- SUBSTANTIALLY LOWERS CONDENSING TEMPERATURES
- HIGHER EFFICIENCY – 0.25KW/TON, IEER UP TO 50
- LOWERS ELECTRICAL DEMAND BY ~ 50%+
- NO PROPYLENE GLYCOL, REQUIRED PER MN DOH

INDUSTRY EXAMPLES: COOLING & HEATING

WATER-COOLED VSD CENTRIFUGAL CHILLER

- ASHRAE 90.1 85°F TOWER WATER .55 KW/TON, .38 NPLV
- WITH 58°F GROUND WATER .28 KW/TON, .23 NPLV

GROUND-WATER COOLED MODULAR HEAT PUMPS

COOLING

- ASHRAE 90.1 .72 KW/TON, .56 NPLV
- WITH 58 DEG F .35 KW/TON, .30 NPLV

HEATING

- ASHRAE 90.1 4.3 COP
- 48 DEG F GROUND WATER 5.0 COP

GROUND-WATER SOURCE HEAT PUMPS

COOLING

- 86 DEG F FROM TOWER 15.3 EER
- 58 DEG F FROM GEO 23.0 EER

HEATING

- 35 DEG F FROM BOILER 4.0 COP
- 48 DEG F FROM GEO 4.6 COP

GROUND SOURCE VARIABLE REFRIGERANT FLOW (VRF) WITH HEAT RECOVERY

COOLING

- 86 deg F from Tower — 12 EER, 15 IEER
- 58 deg F from Geo — 20 EER, 25 IEER

HEATING

- 35 deg F from Boiler — 3.5 COP
- 55 deg F from Geo — 4.9 COP

SIMULTANEOUS HEATING & COOLING (HEAT RECOVERY)

- 55 deg F Ground Water — 7-8 COP

100% DEDICATED OUTSIDE AIR SYSTEM (DOAS)

ASHRAE 90.1-2016 REQUIRES ENERGY RECOVERY ABOVE 2500 CFM WITH 100% OA

MANDATORY TOTAL ENERGY RECOVERY WHEEL: 88 / 72 TO 78 / 65

- OPTIONAL 4 ROW OUTSIDE AIR PRE-COOLER: 78 / 65 TO 63 / 62
- OPTIONAL DX OR CHILLED WATER COIL: 63 / 62 TO 55 / 54
- OPTIONAL WHEEL OR RETURN WATER FOR SENSIBLE REHEAT: 60 TO 65

- IN COOLING MODE WATER EXCHANGED WITH THE AQUIFER CAN PRE-COOL THE LEAVING AIR TEMPERATURE TO 63°/62°F
- IN HEATING MODE, WATER EXCHANGED WITH THE AQUIFER CAN PREHEAT THE LEAVING AIR TEMPERATURES TO 40°F

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With support from:

U.S. DEPARTMENT OF ENERGY
NSF
USDA

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