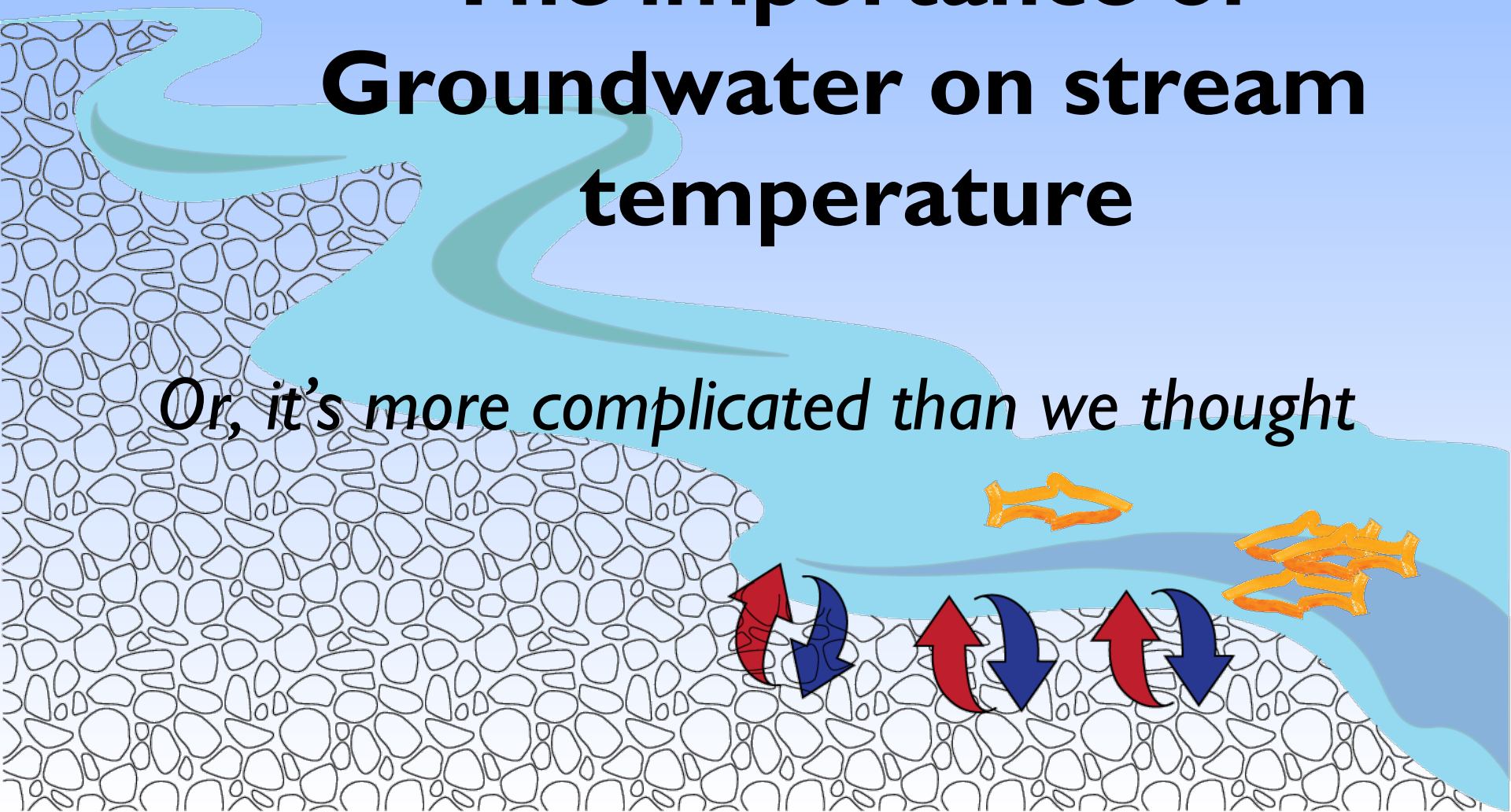
Christine Hatch, Geosciences & Extension
Water Resources & Climate Change
David Boutt, Geosciences

University *of* Massachusetts Amherst

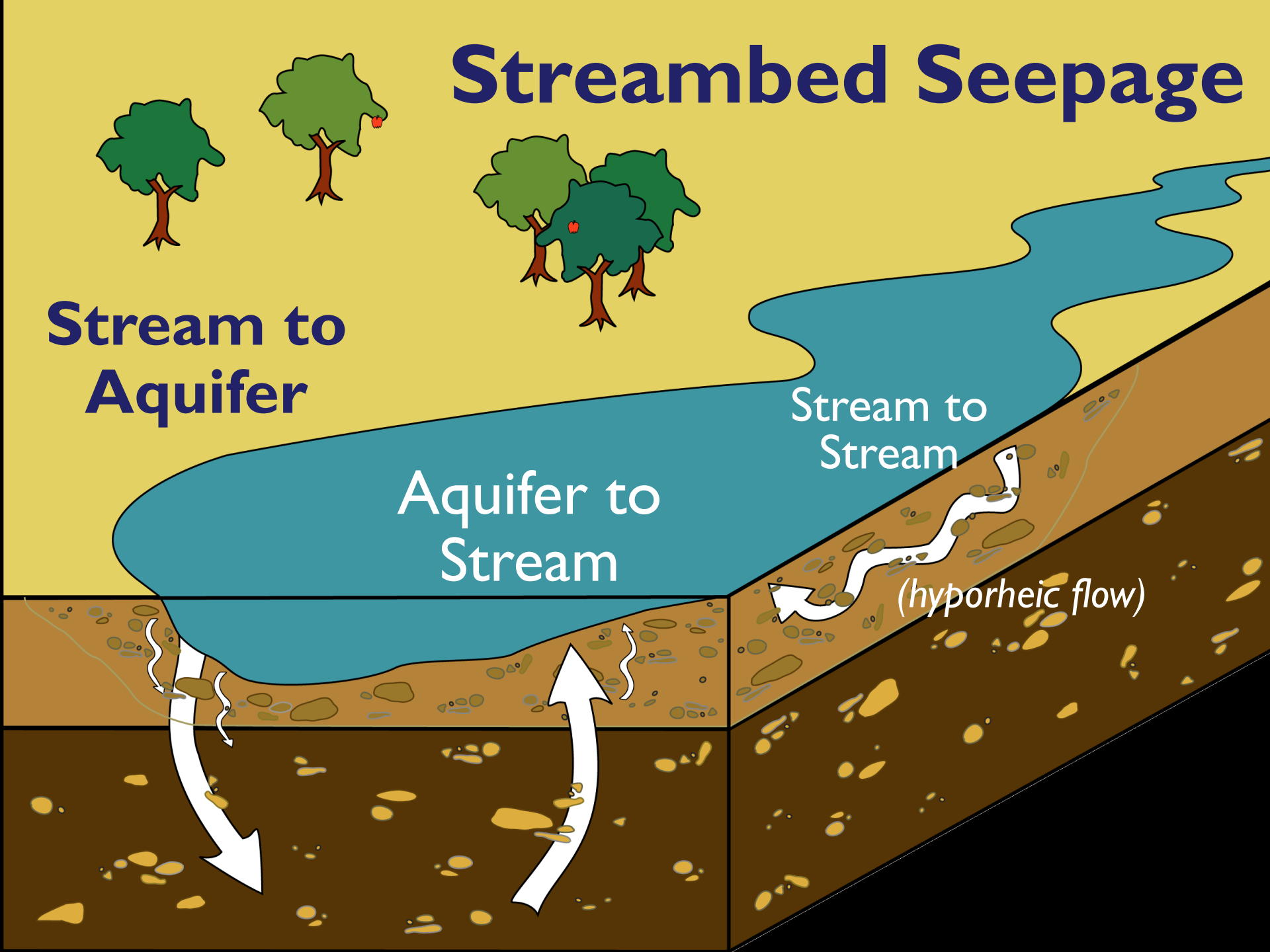
The importance of Groundwater on stream temperature

Or, it's more complicated than we thought



Concepts in SW-GW

- Are streams and groundwaters connected?
- Temperature in the subsurface (a non-conservative tracer)
- Typical assumptions about groundwater temperature
- …are all false!


Streambed Seepage
Stream to Aquifer
Aquifer to Stream
Stream to Stream
(hyporheic flow)

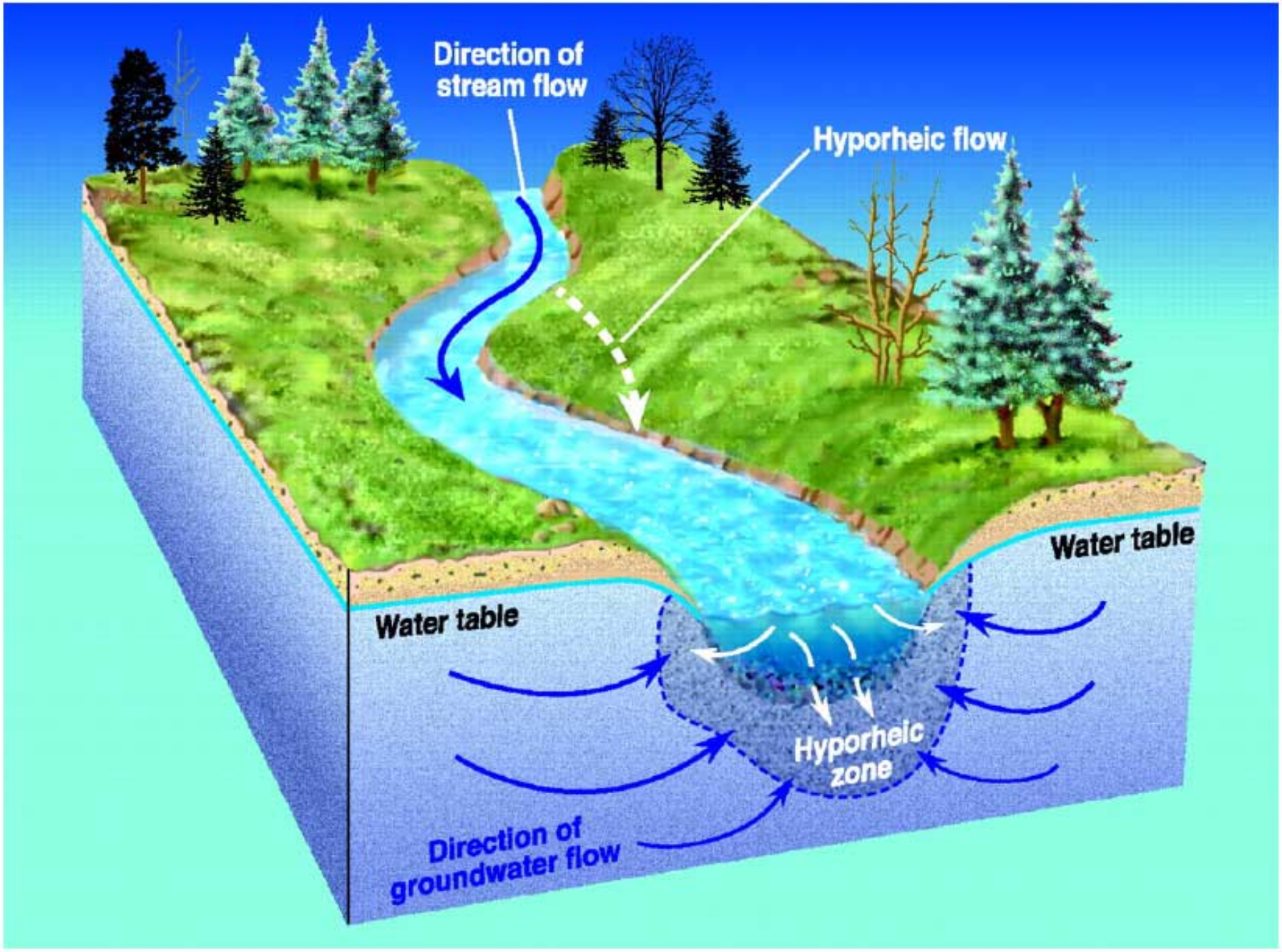
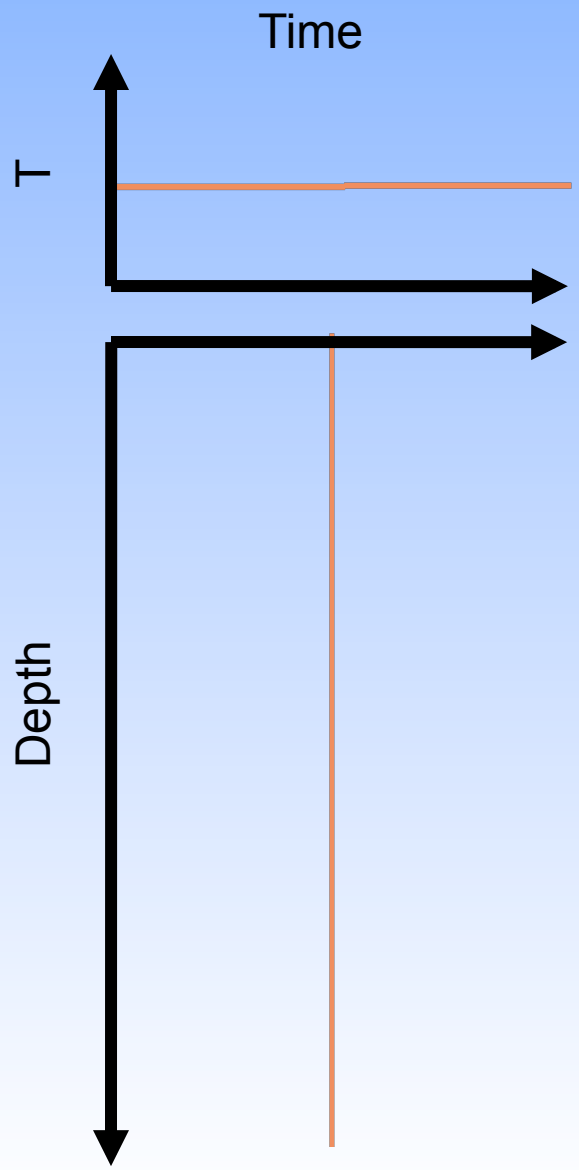
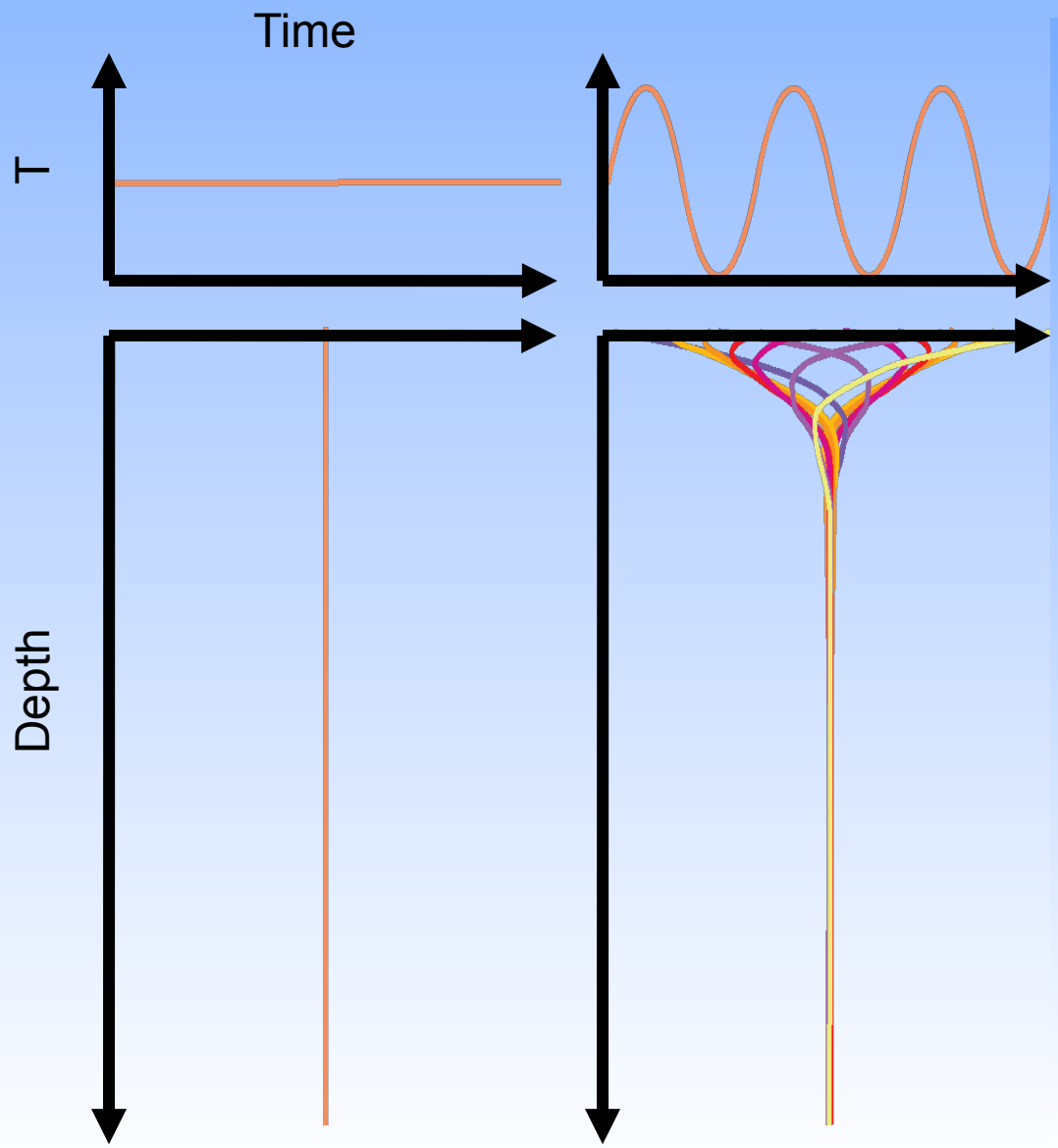


Figure B-3: Groundwater System Involving the Hyporheic Zones (Alley et. al 2002)

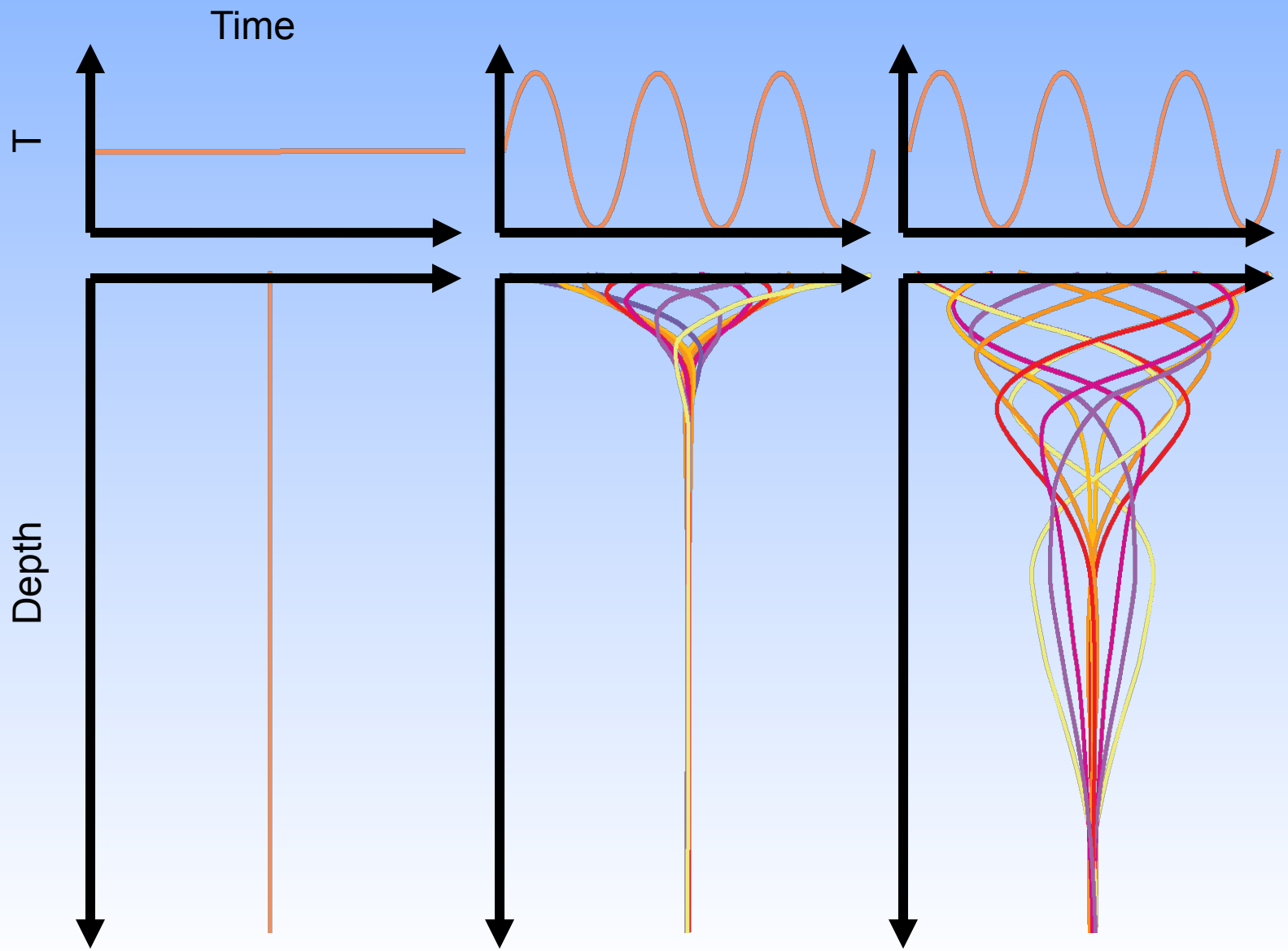
Heat in the Subsurface vs. Time



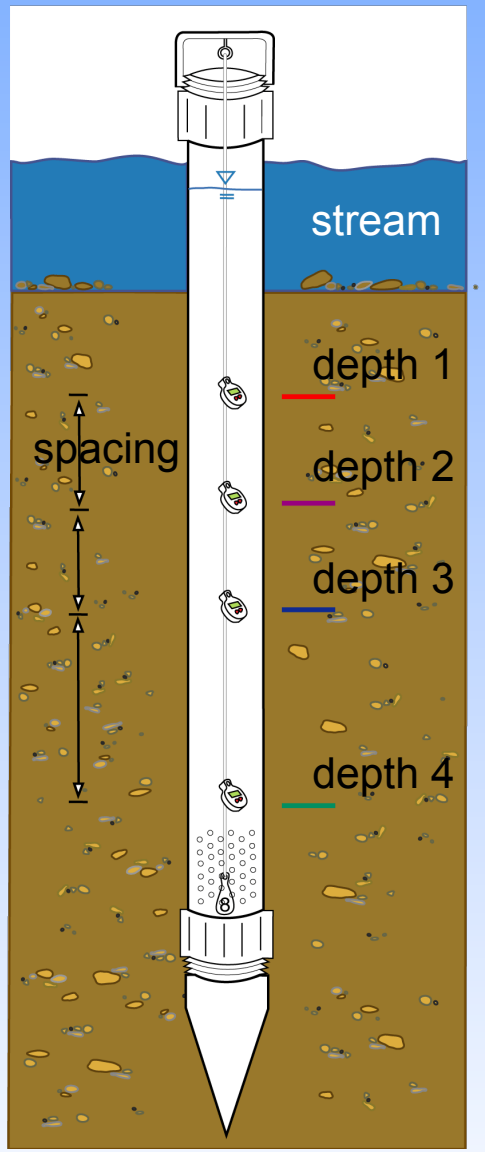
Heat in the Subsurface vs. Time

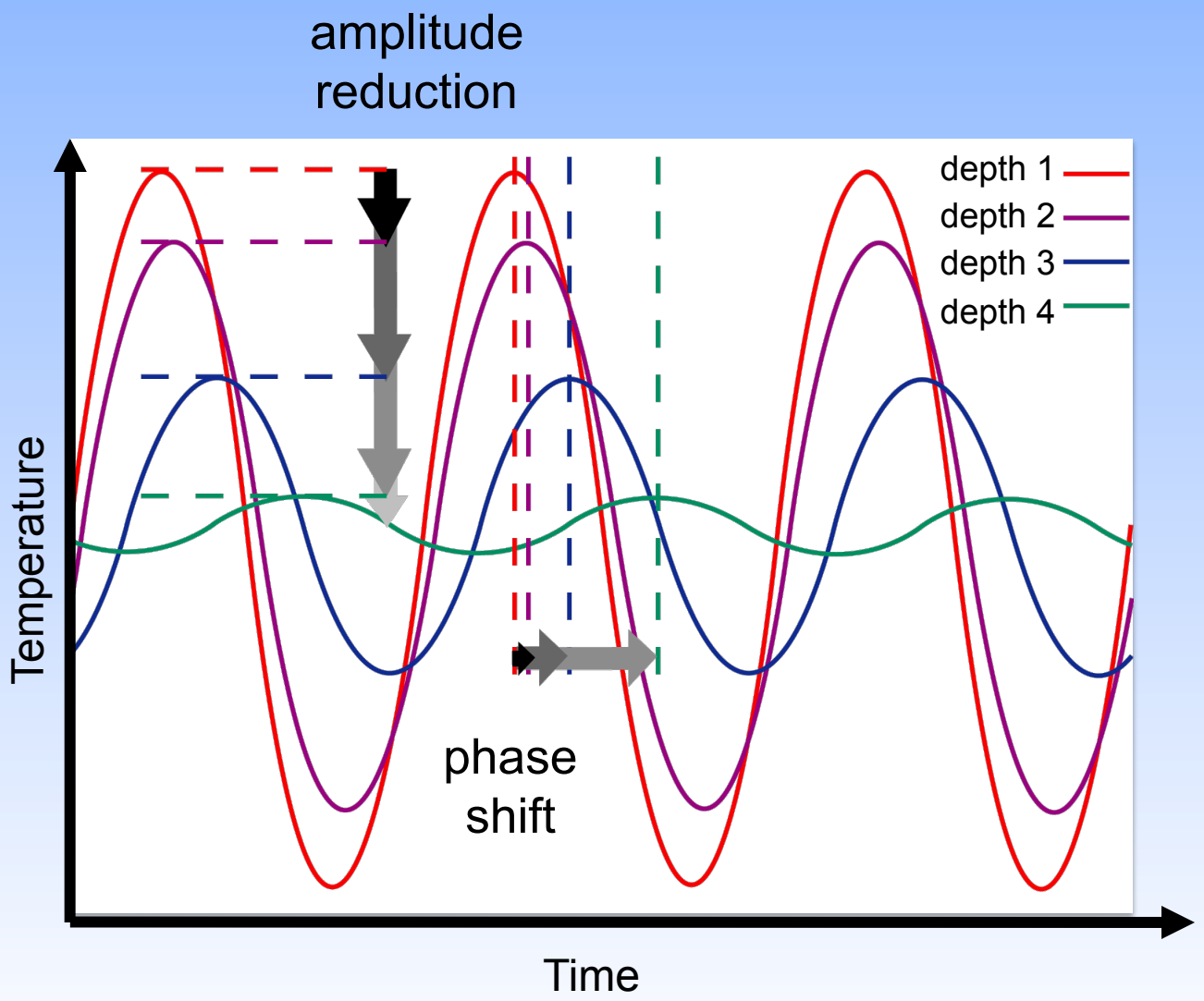


Heat in the Subsurface vs. Time

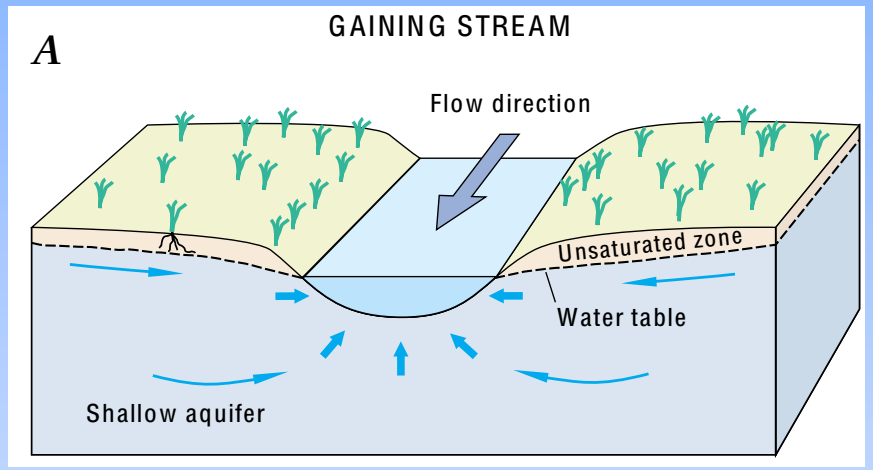


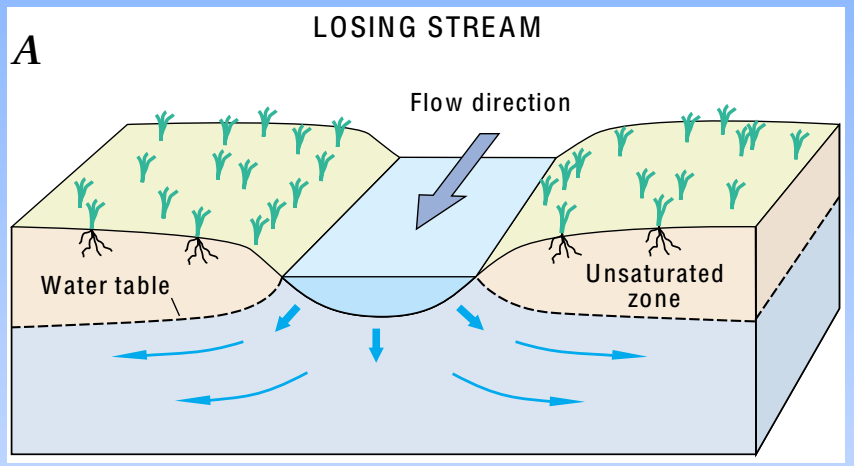
Heat in the Subsurface

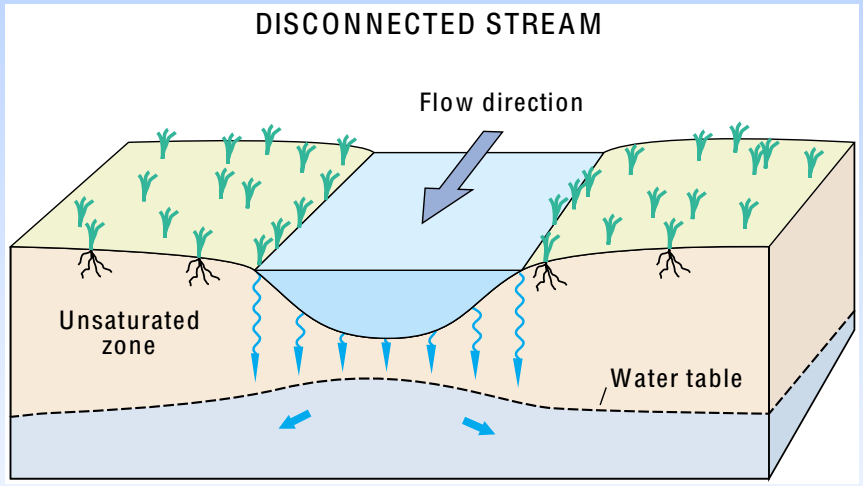




Streams and Groundwater





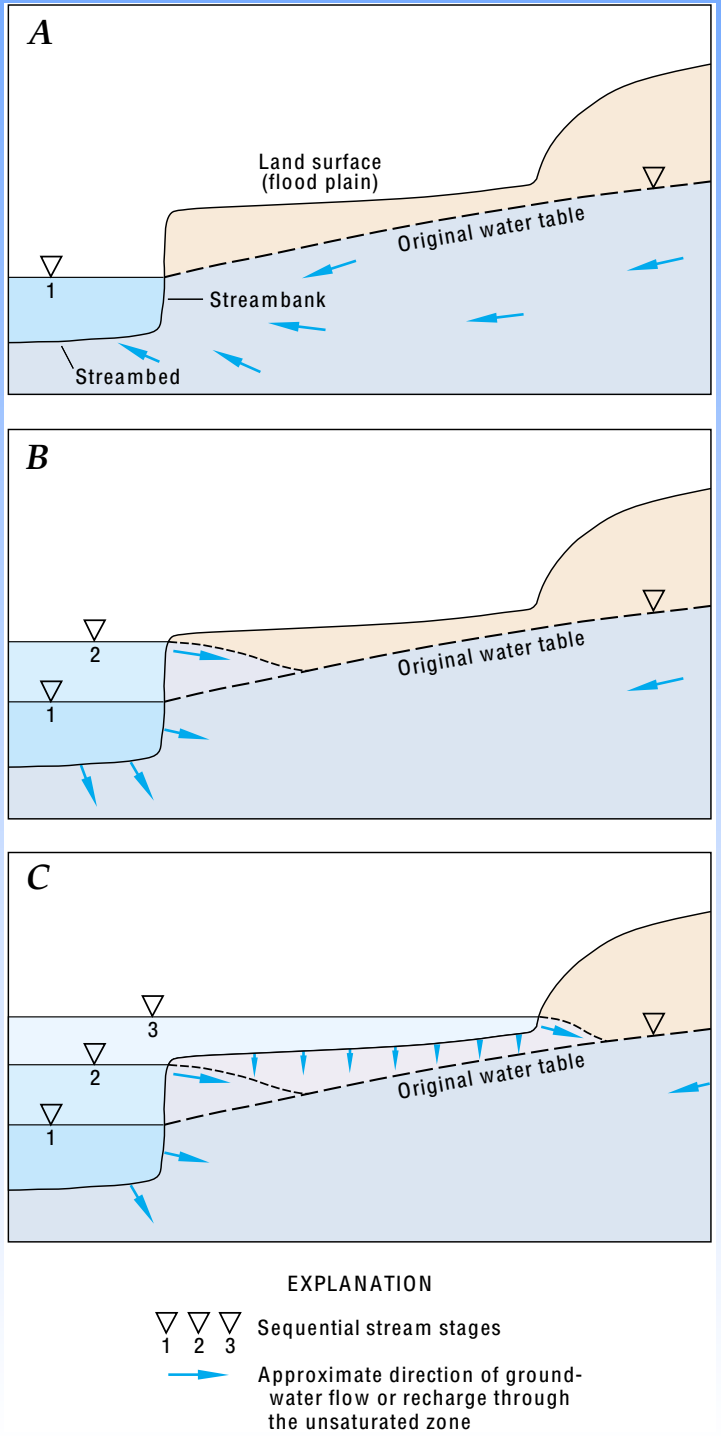


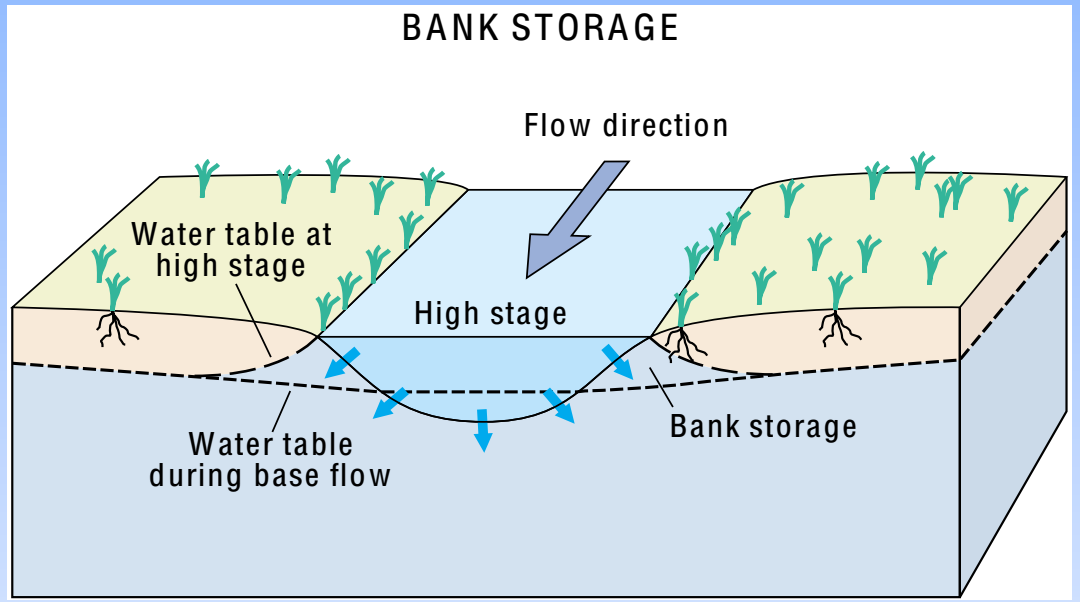
"Streams interact with ground water in three basic ways:

- streams gain water from inflow of ground water through the streambed (**gaining stream**),
- they lose water to ground water by outflow through the streambed (**losing stream**), or
- they do both, gaining in some reaches and losing in other reaches"

(USGS Circ.1139)

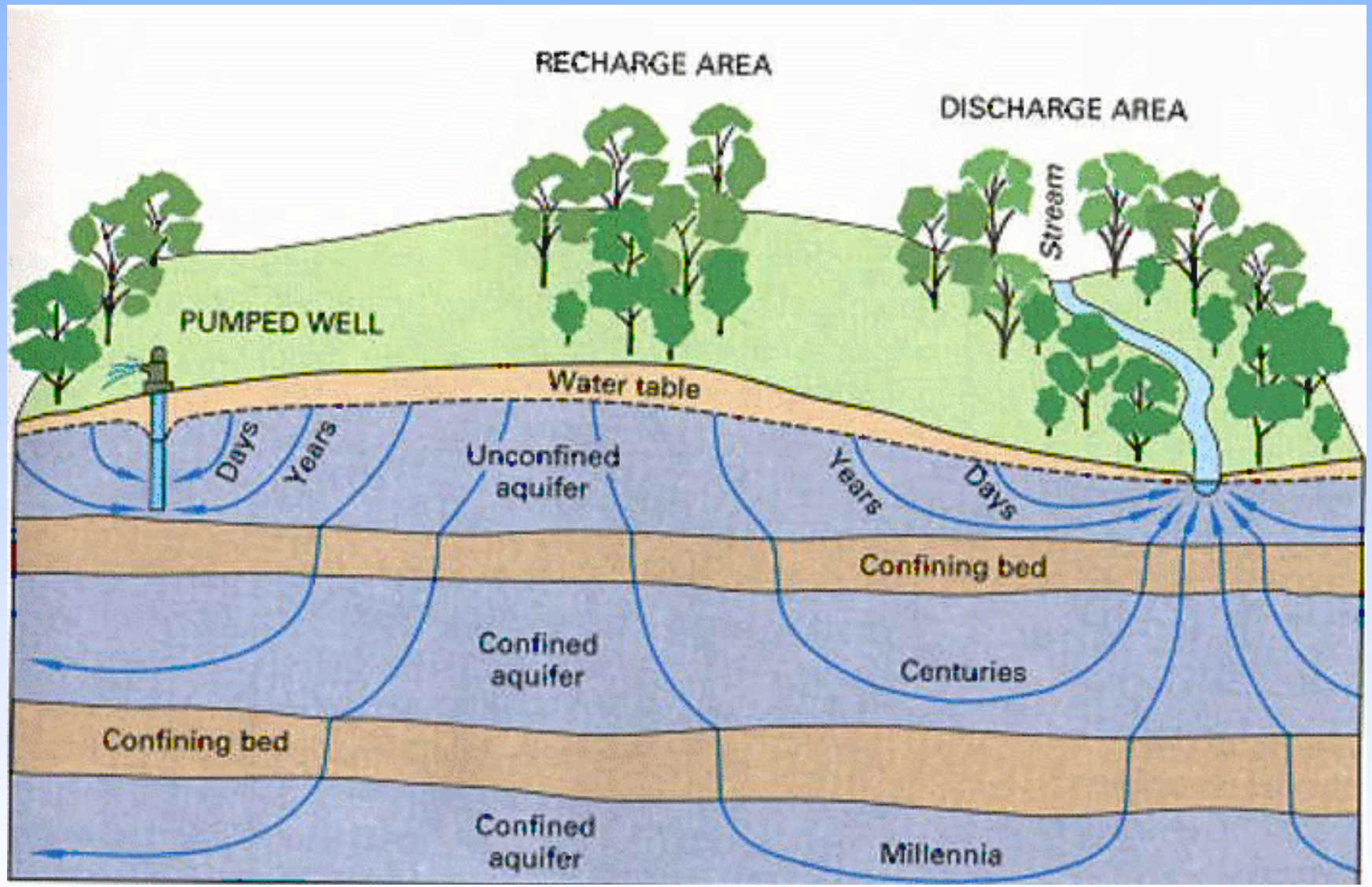
Bank Storage

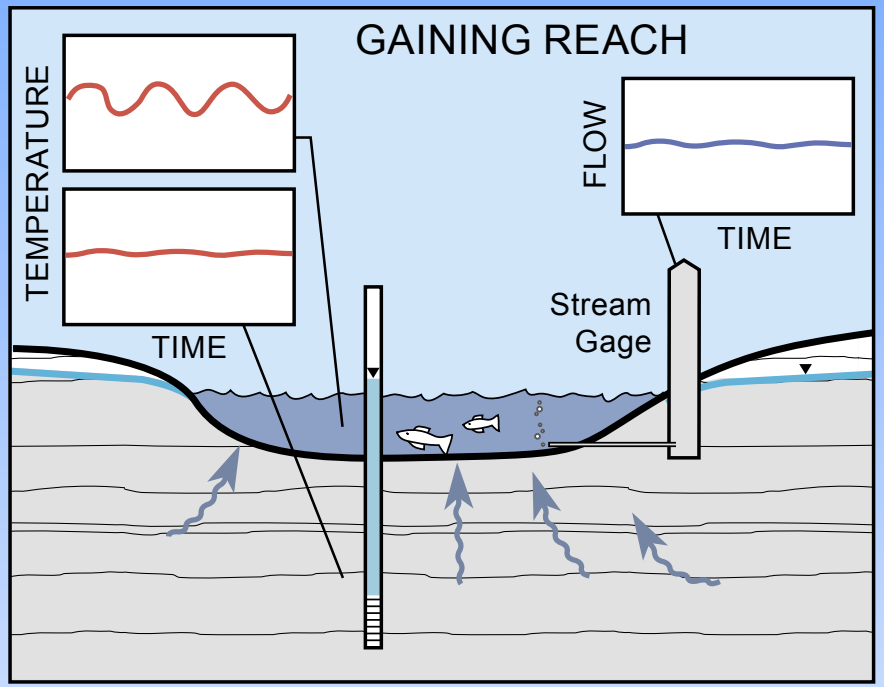


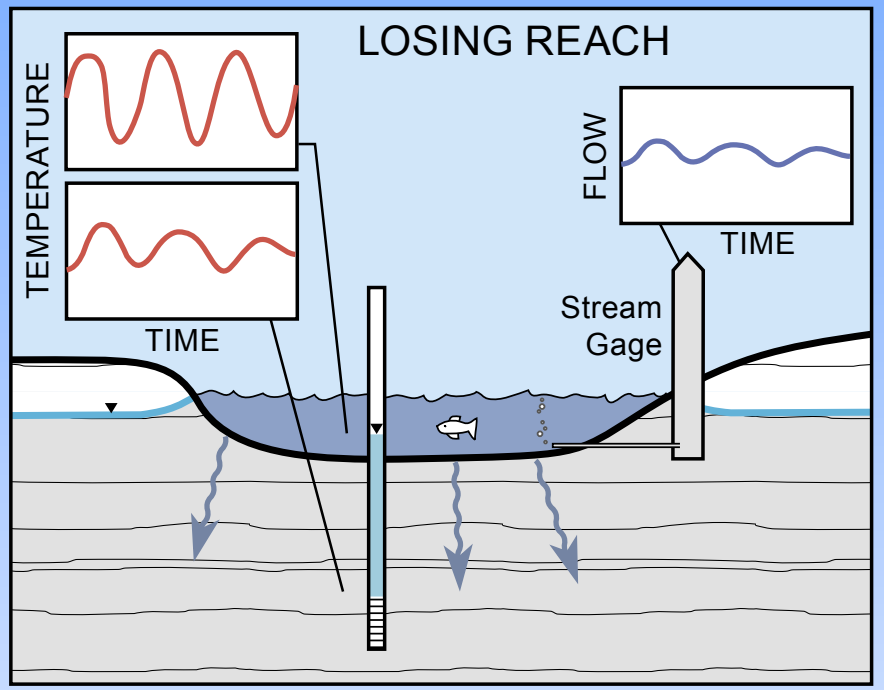


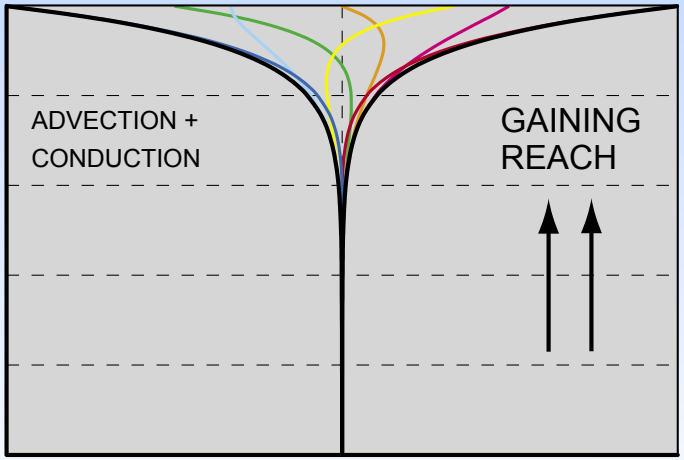
(USGS Circ.1139)

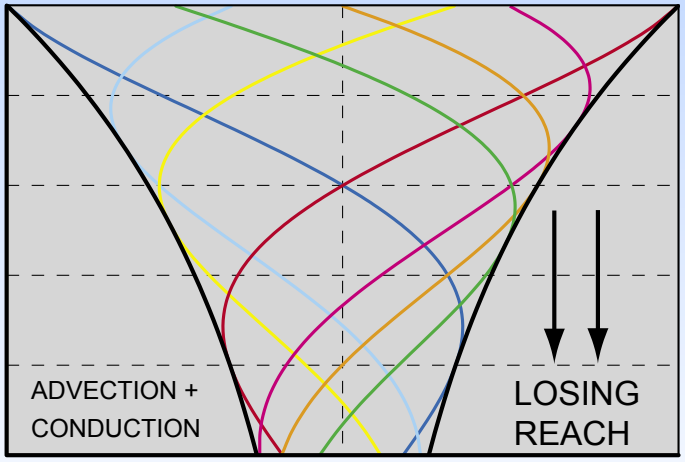
Groundwater systems often operate on much longer timescales than surface water systems (**residence time**)







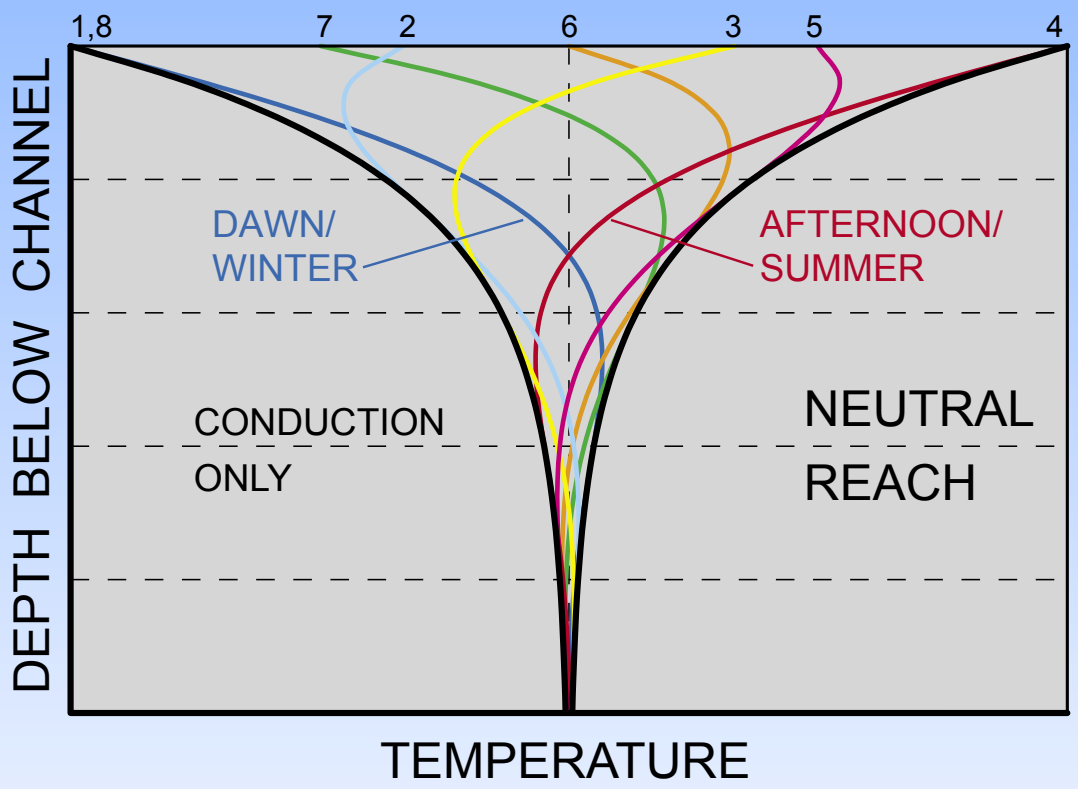


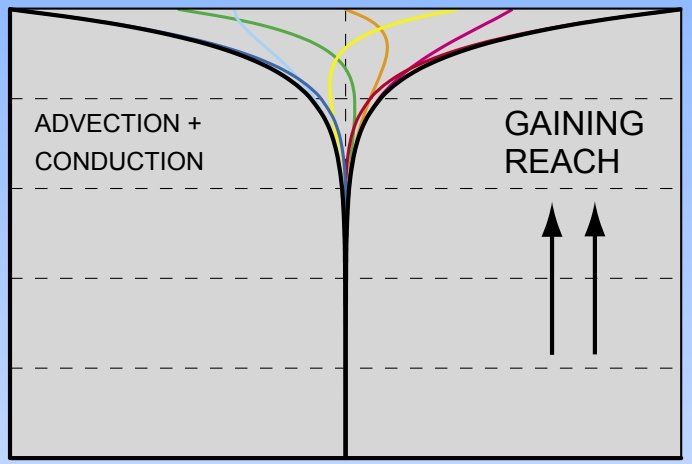


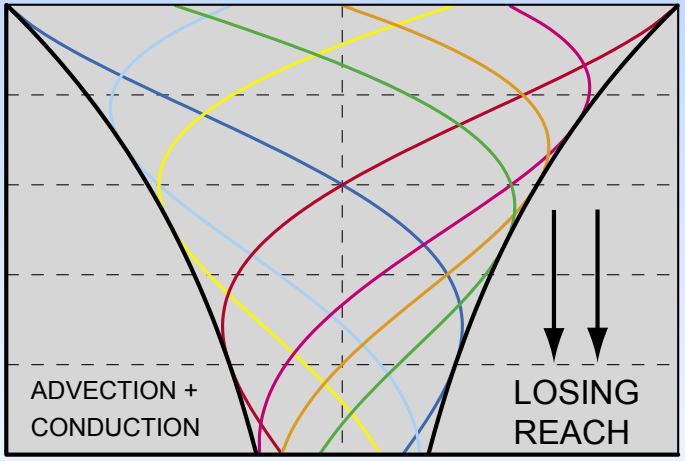
USGS Fact Sheet 2004-3010

USGS
science for a changing world

Using Temperature to Study Stream-Ground Water Exchanges

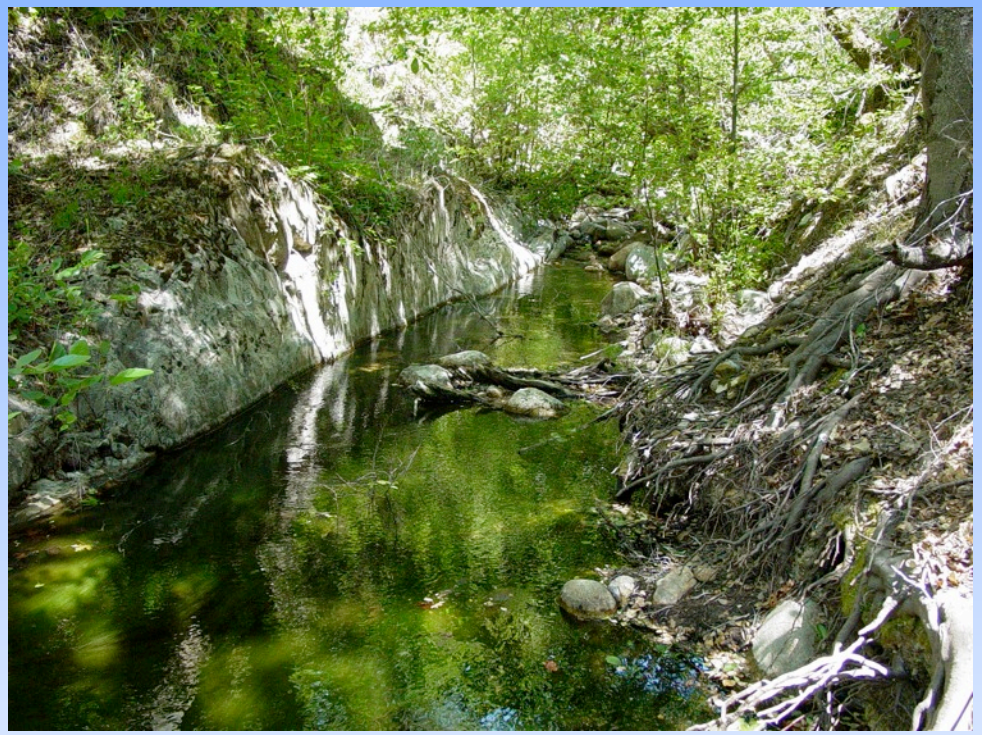






USGS Fact Sheet 2004-3010
Stonestrom & Constantz, 2004

Ecohydrology: Thermal Refugia (Cool GW)



Bedrock pools

Steelhead Salmon eggs and newt

Warm, sunny reach

Figure 1. (a) Salinas Valley Watershed, arrow indicates Horse Creek. **(b)** CA locator map. **(c)** Arroyo Seco precipitation model. Arrows mark DTS reach on Horse Cr.

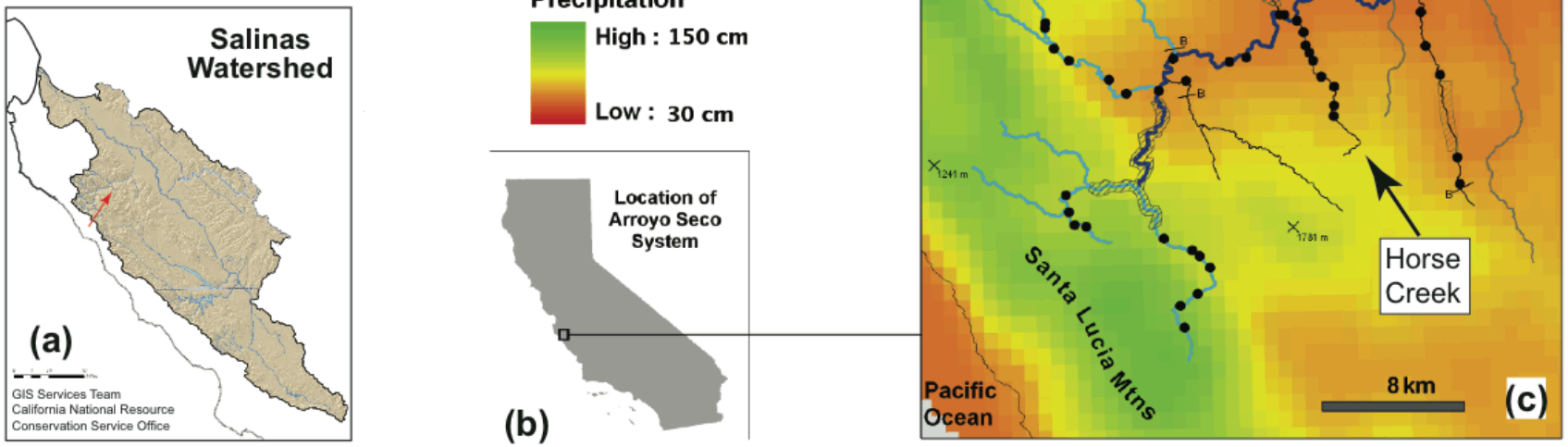
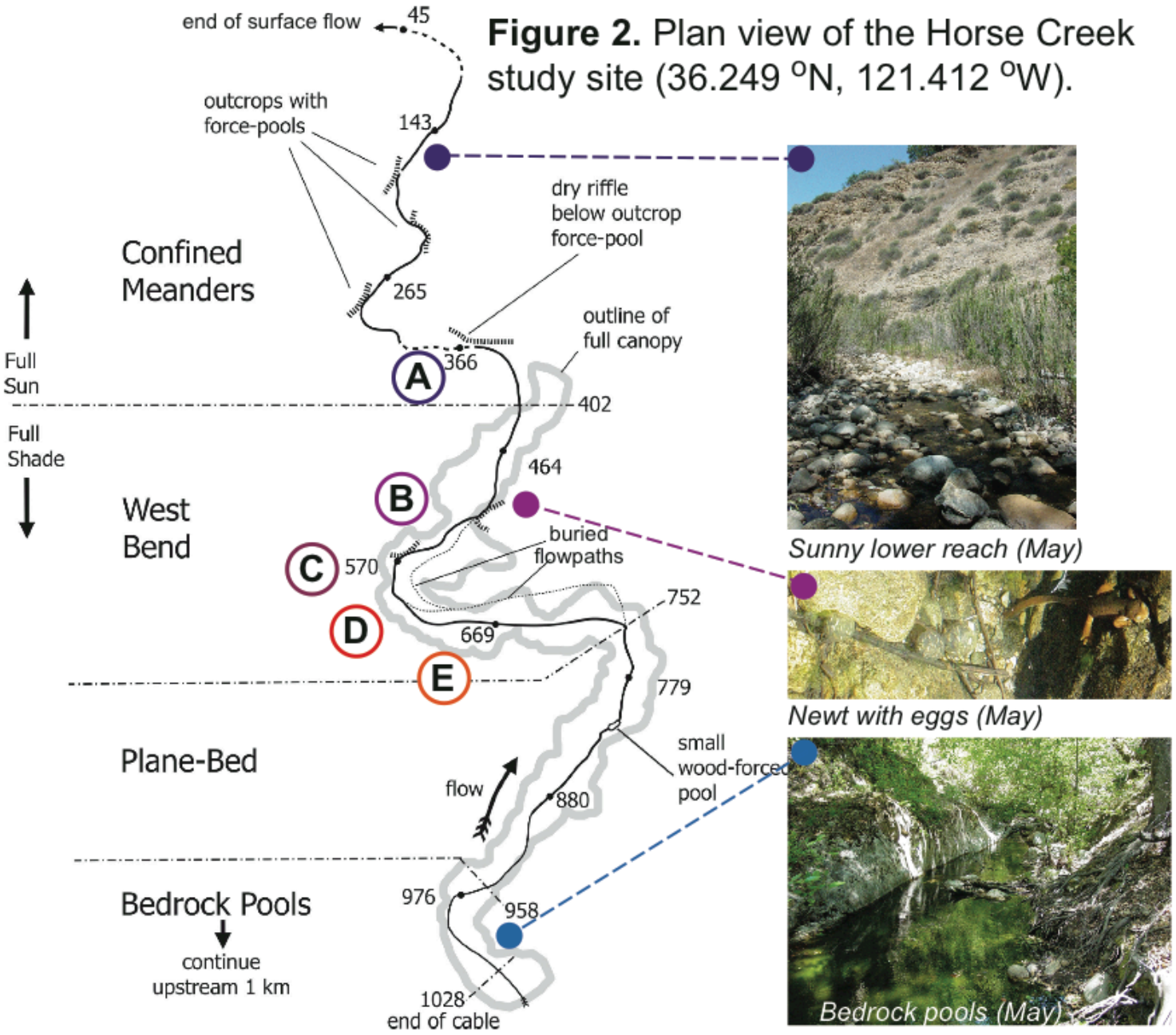
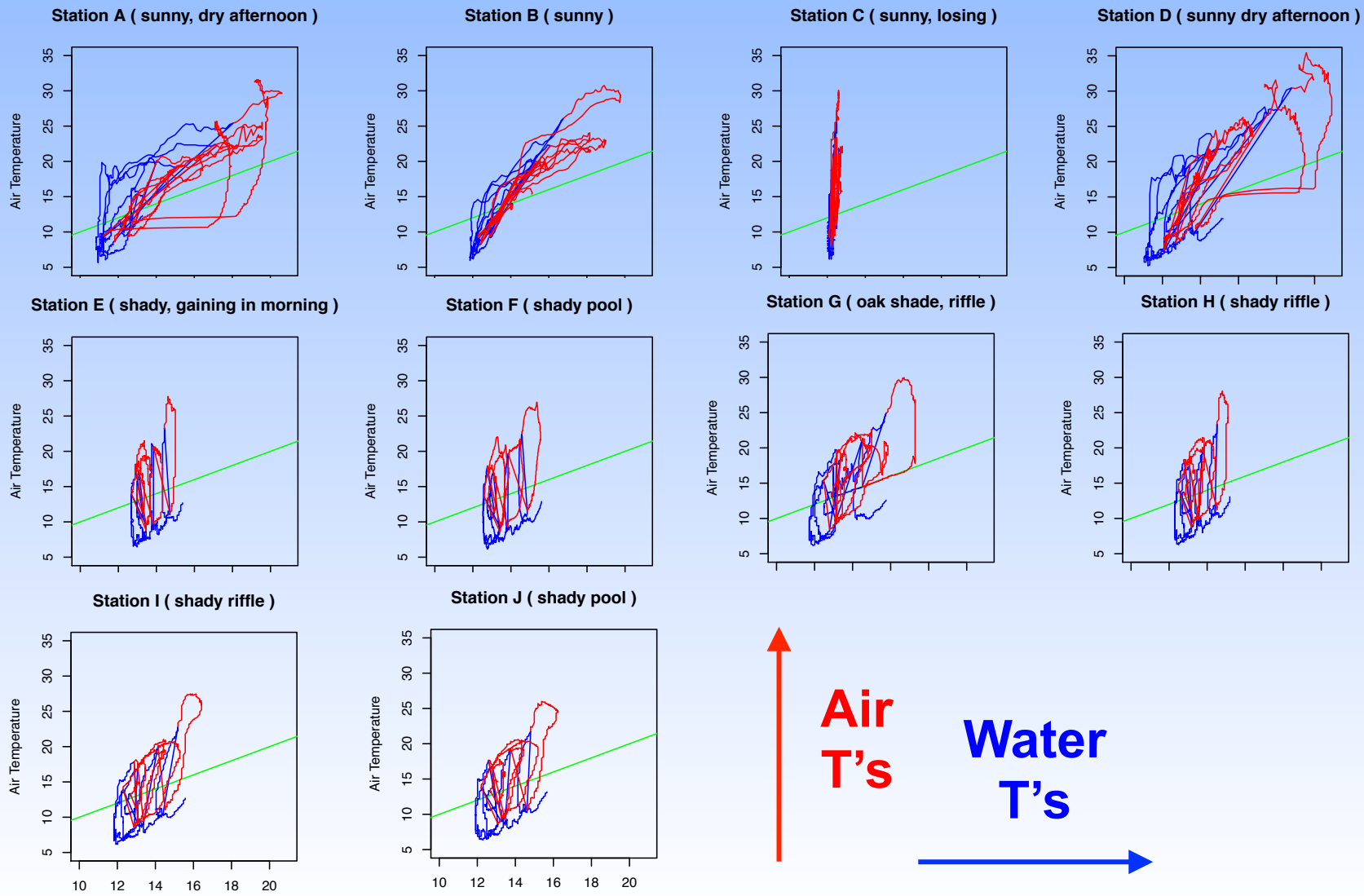
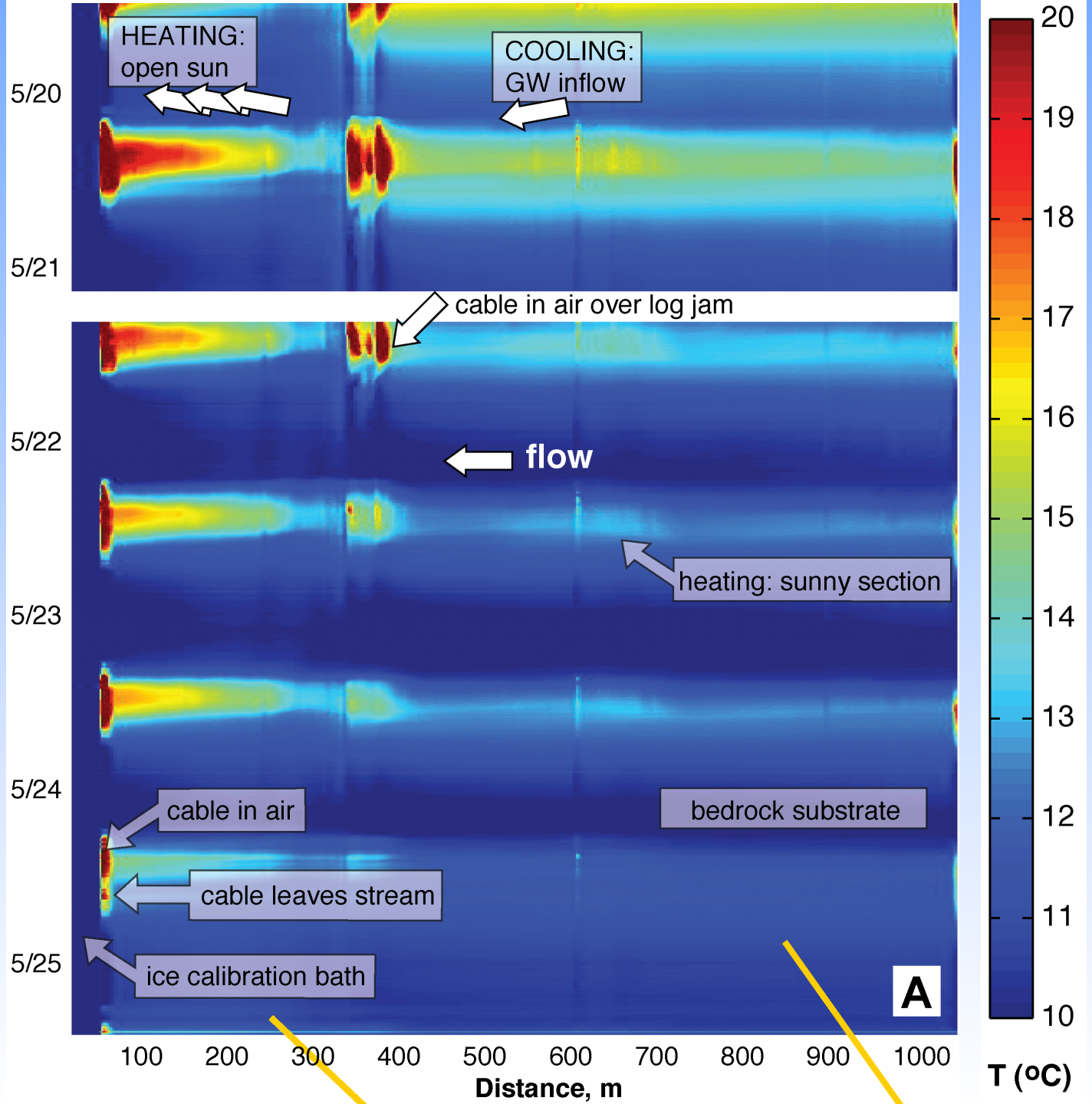


Figure 2. Plan view of the Horse Creek study site (36.249 °N, 121.412 °W).

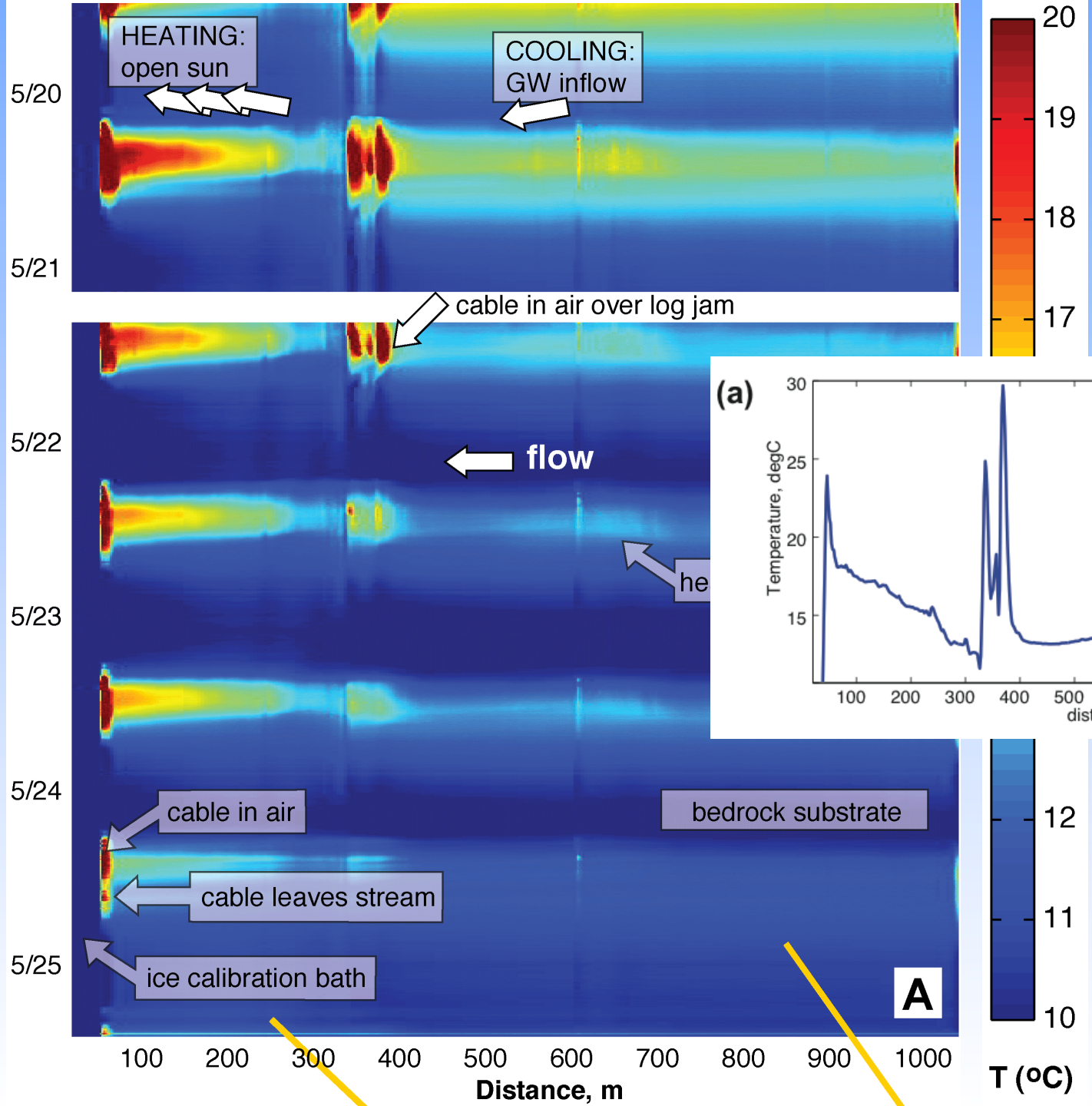


Relationship between air and water temperatures along Horse Creek




HEATING:
open sun
COOLING:
GW inflow
5/20
5/21
cable in air over log jam
5/22
flow
heating: sunny section
5/23
5/24
cable in air
bedrock substrate
cable leaves stream
5/25
ice calibration bath
A
100
200
300
400
500
600
700
800
900
1000
Distance, m
20
19
18
17
16
15
14
13
12
11
10
T (oC)

May


HEATING:
open sun
COOLING:
GW inflow
5/20
5/21
cable in air over log jam
5/22
flow
5/23
5/24
cable in air
bedrock substrate
cable leaves stream
5/25
ice calibration bath
A
100
200
300
400
500
600
700
800
900
1000
Distance, m
20
19
18
17
12
11
10
T (ºC)

May

(a)
Temperature, degC
30
25
20
15
100
200
300
400
500
600
700
800
900
1000
distance, m

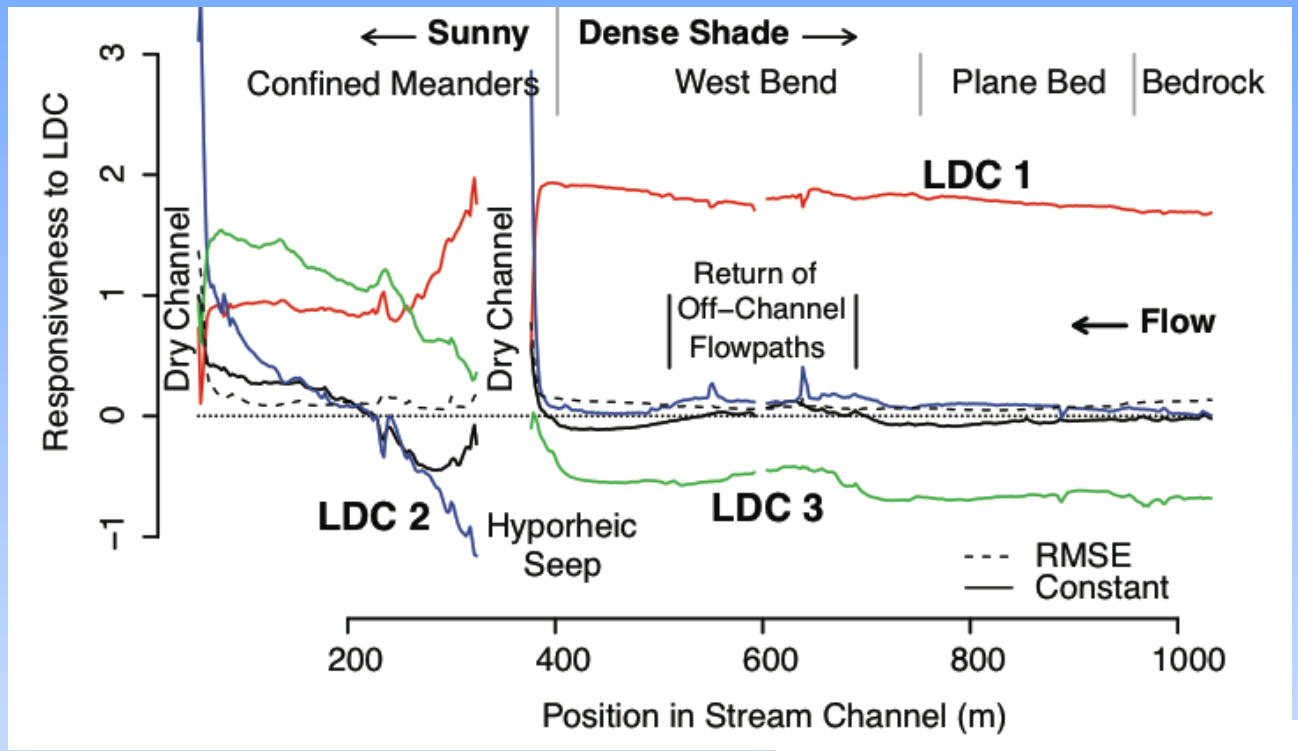


Figure 6. [STEP 10] Heating rates (q_m matrix) associated with the second thermal component (LDC 2) downstream of the dry riffle, showing anti-phase fluctuations. Direction of flow is from top to bottom.

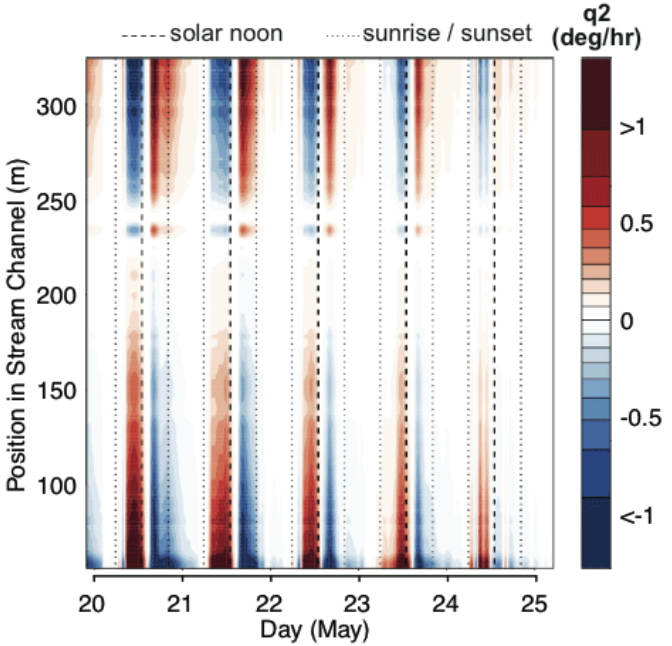
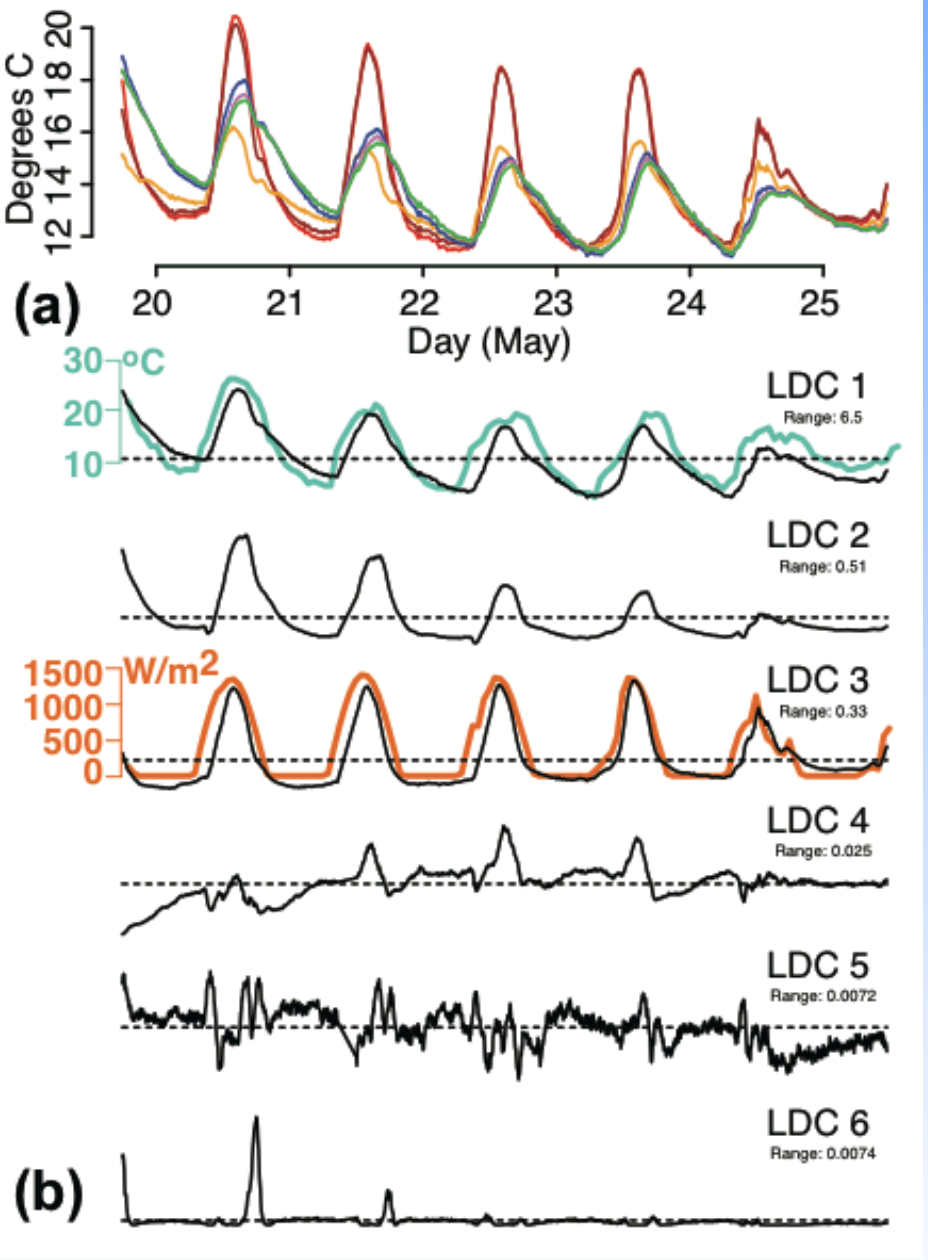
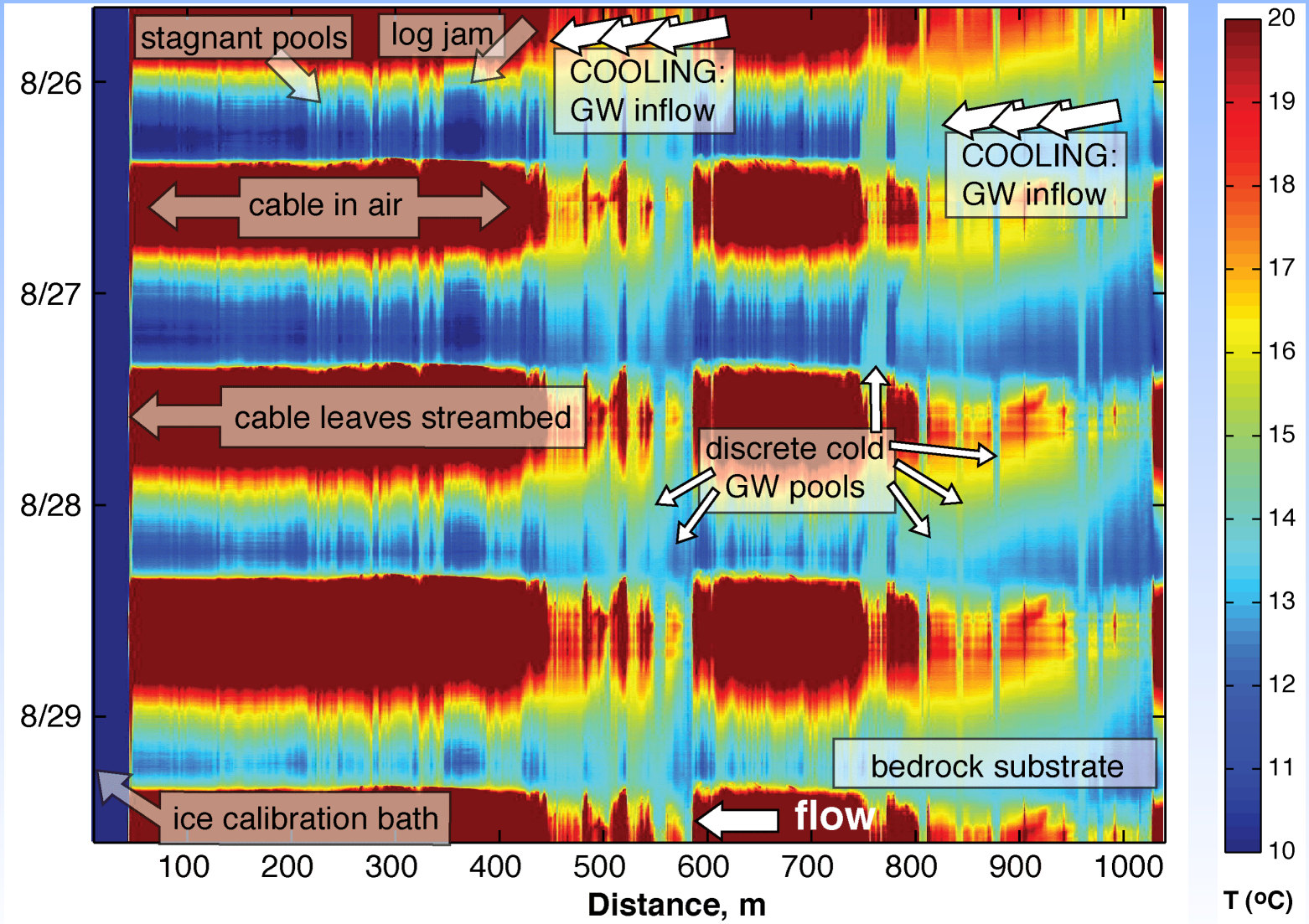


Figure 7. (a) [STEP 3-6] (a) Mean temperatures of segment groups and (b) least-dependent components (LDCs) for DTS time series data divided into six groups. Colors are the same as in Figure 4. **(b)** Least-dependent components from the MILCA algorithm [*Stogbauer et al.,* 2004] are scaled to sum to the mean temperature series and sorted by amplitude. Broad colored lines are air T (^{o}C, @LDC 1) and insolation (W/m^2, @LDC 3), respectively, at Arroyo Seco.

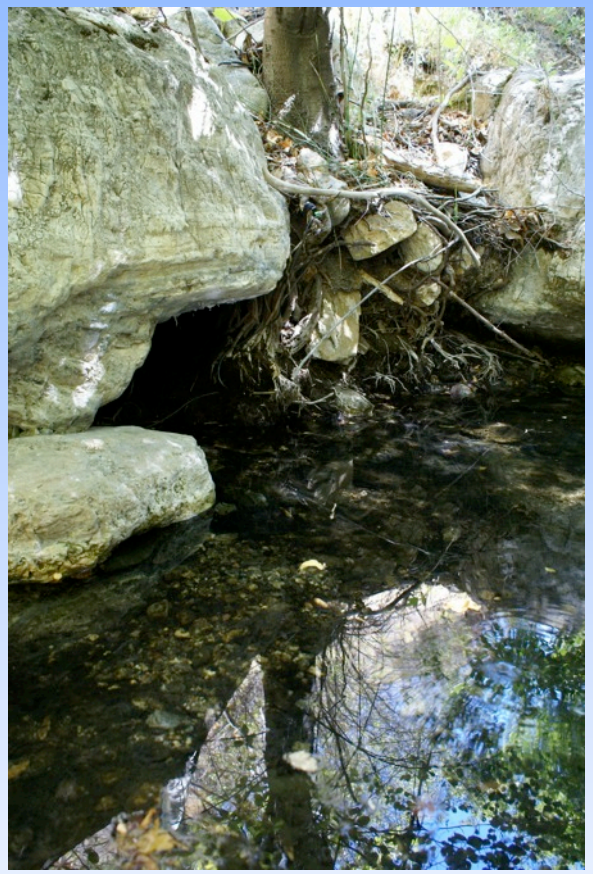


Fire in Big Sur Wilderness

August

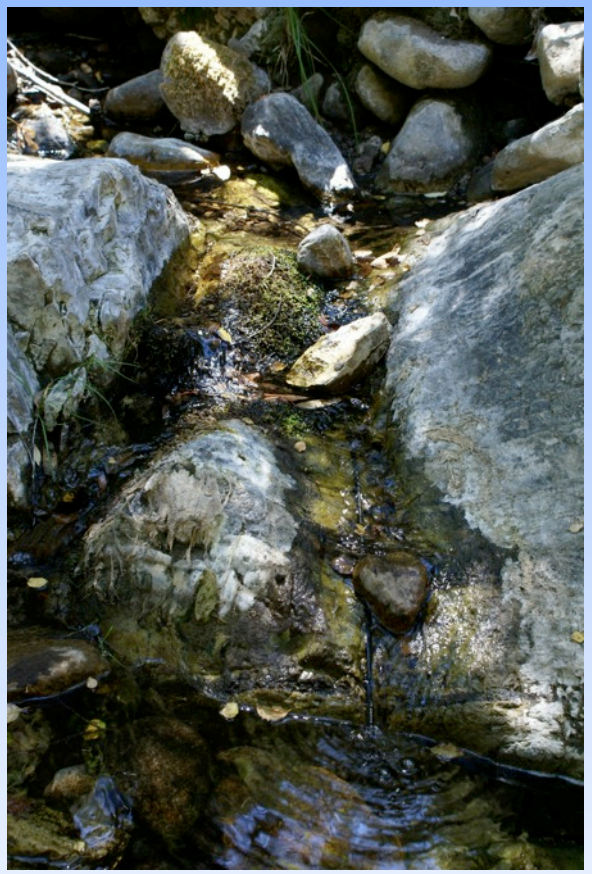

stagnant pools
log jam
COOLING:
GW inflow
COOLING:
GW inflow
cable in air
cable leaves streambed
discrete cold
GW pools
bedrock substrate
ice calibration bath
flow
8/26
8/27
8/28
8/29
100
200
300
400
500
600
700
800
900
1000
Distance, m
20
19
18
17
16
15
14
13
12
11
10
T (ºC)

…dry pools, diminishing O_2…



Algae turned black

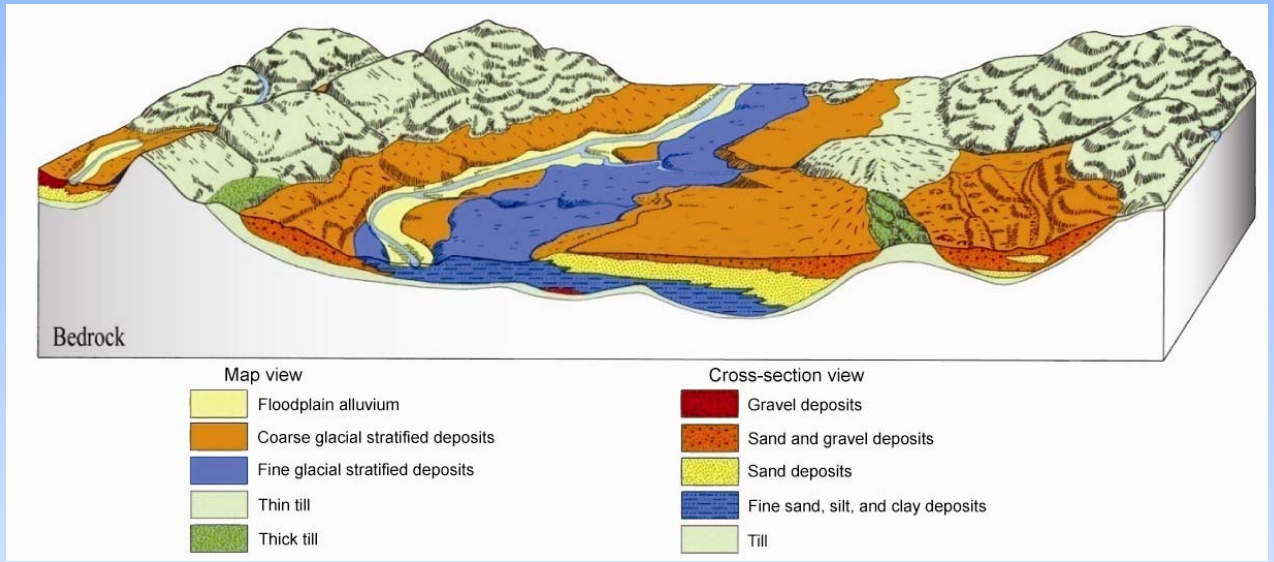
Young of the year perished



Bedrock pools barely flow

Assumptions about groundwater

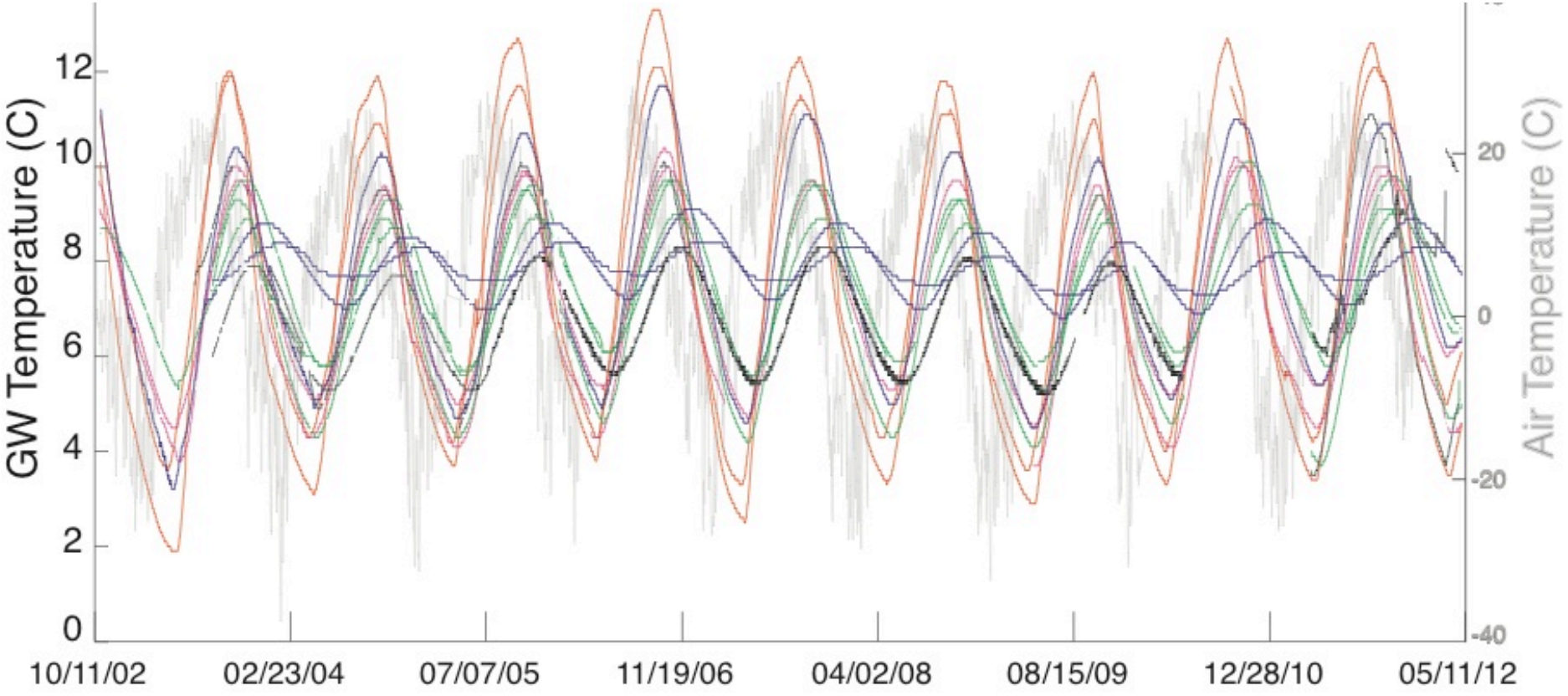
- Surface and groundwaters are connected everywhere



Stone et al., 1992

- Groundwater temperatures track air temperatures
- Groundwater temperature is approximately equal to mean annual temperature

Ground water temperatures are variable in time (or space)

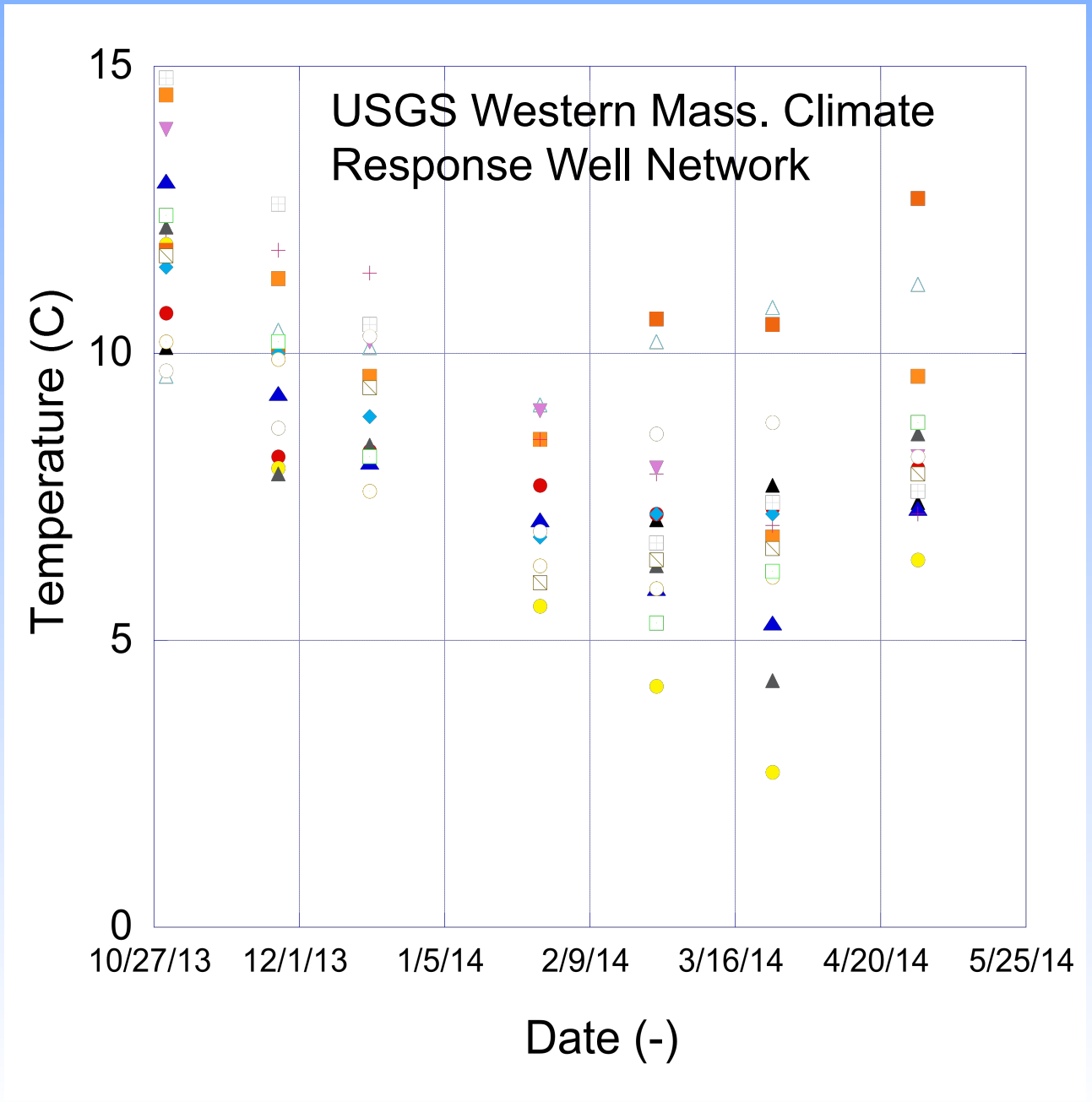


Ground Water Observations in glacial sediments, N. Minnesota

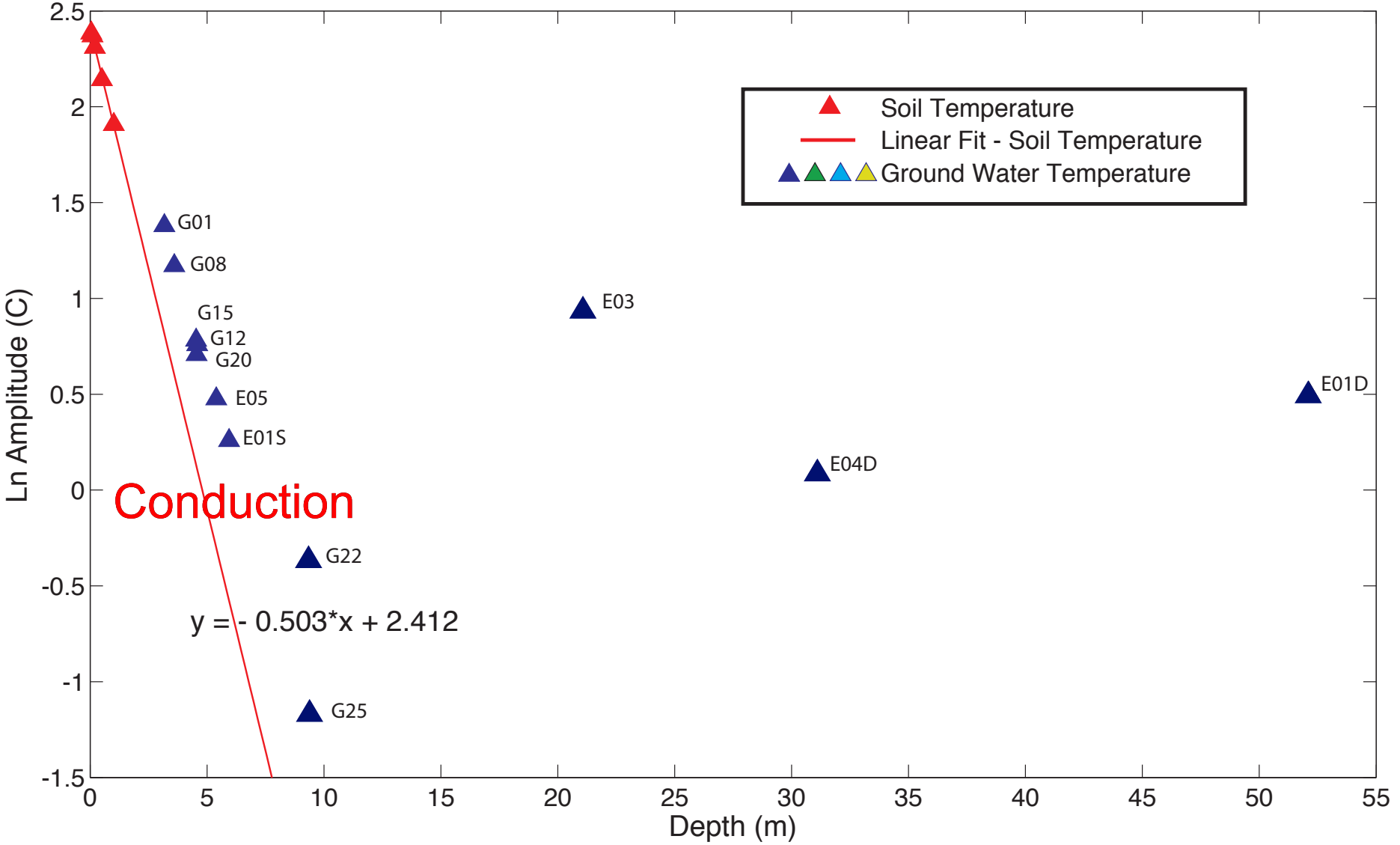
Orange Lines are Shallow Wells (5-10 m)

Blue and **Black** Lines are Deep Wells (> 20 m)

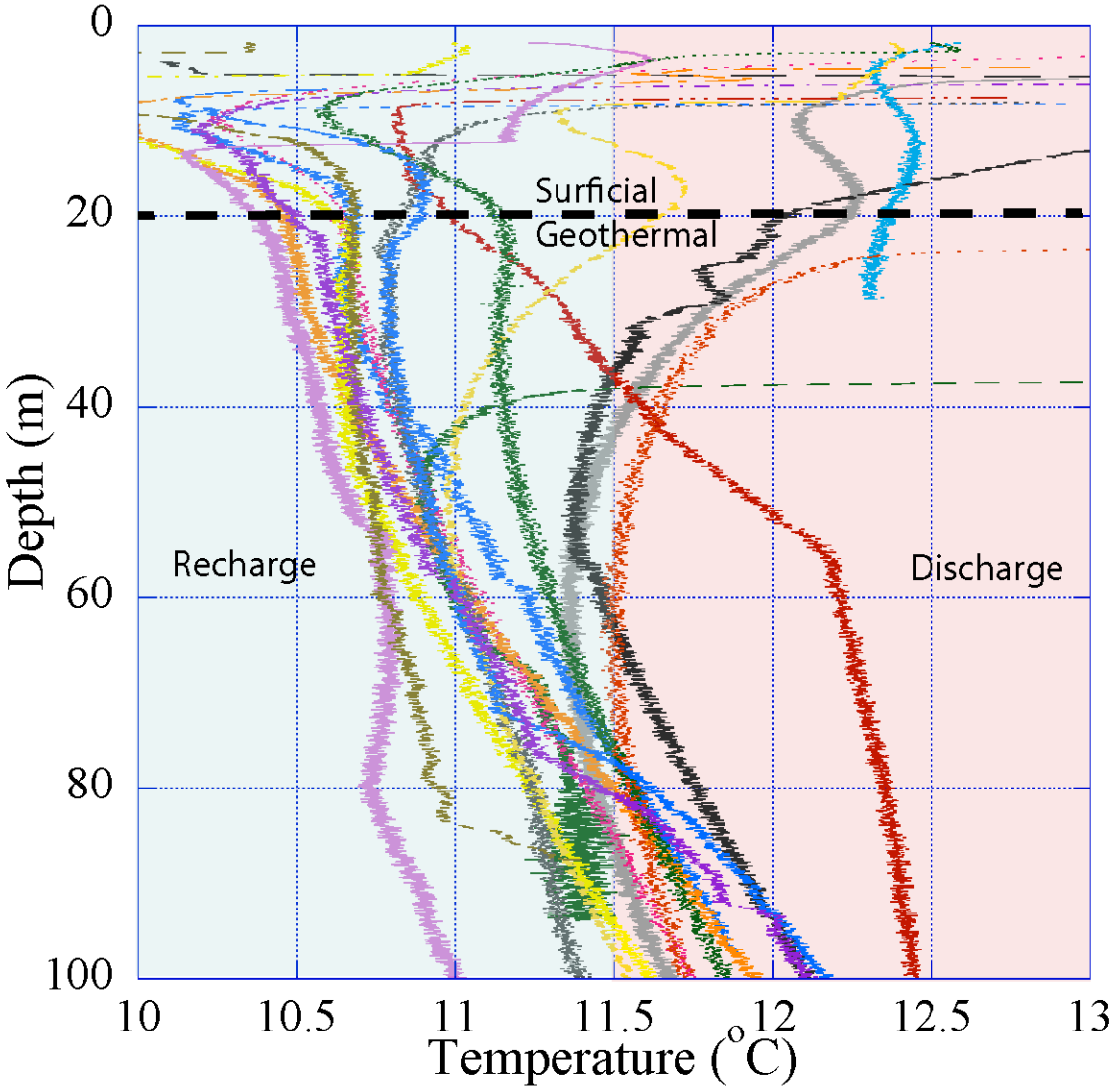
Ground water temperatures are variable in time (or space)



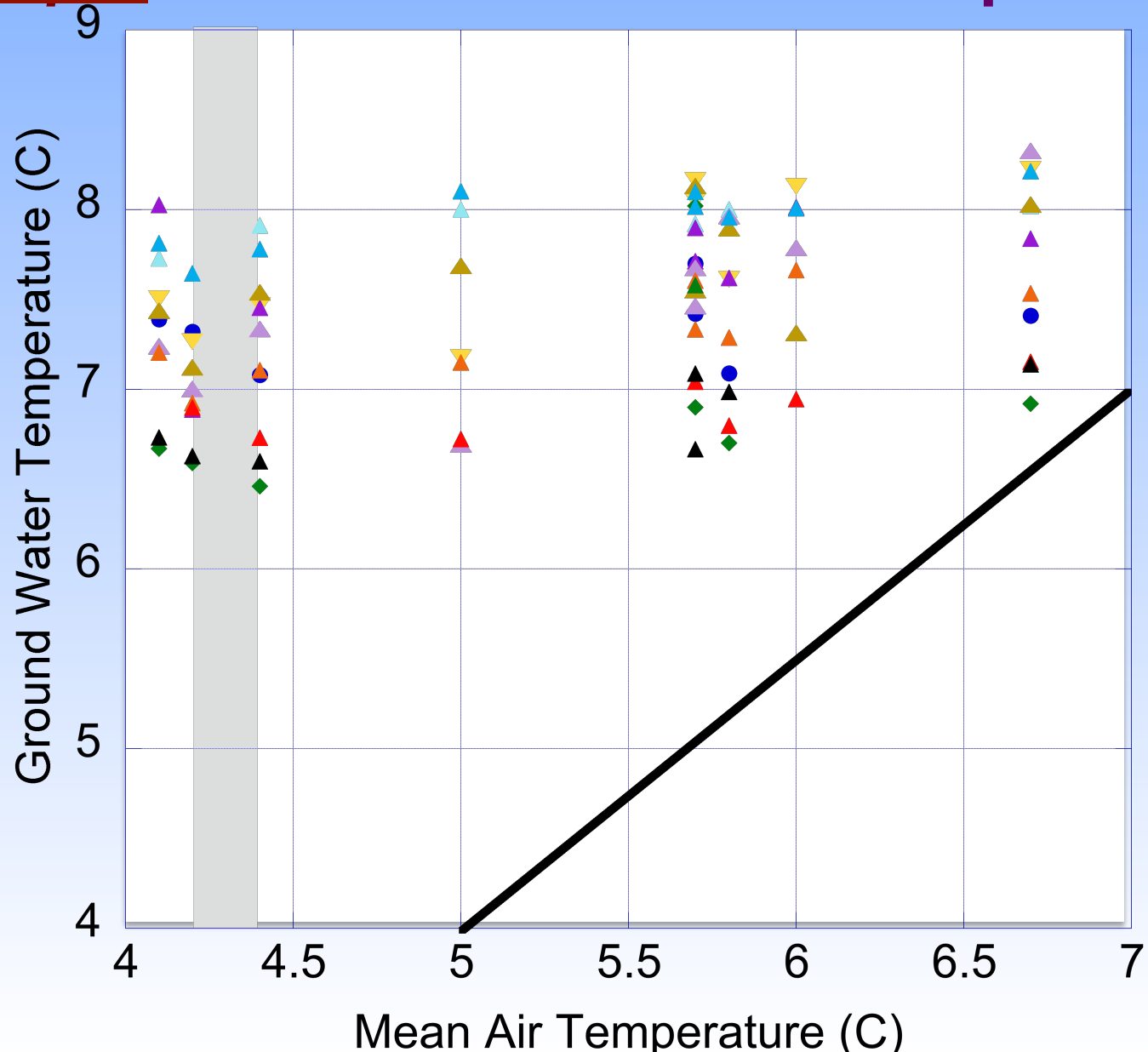
Ground water temperature can deviate significantly from a purely conductive state (*via advection*)



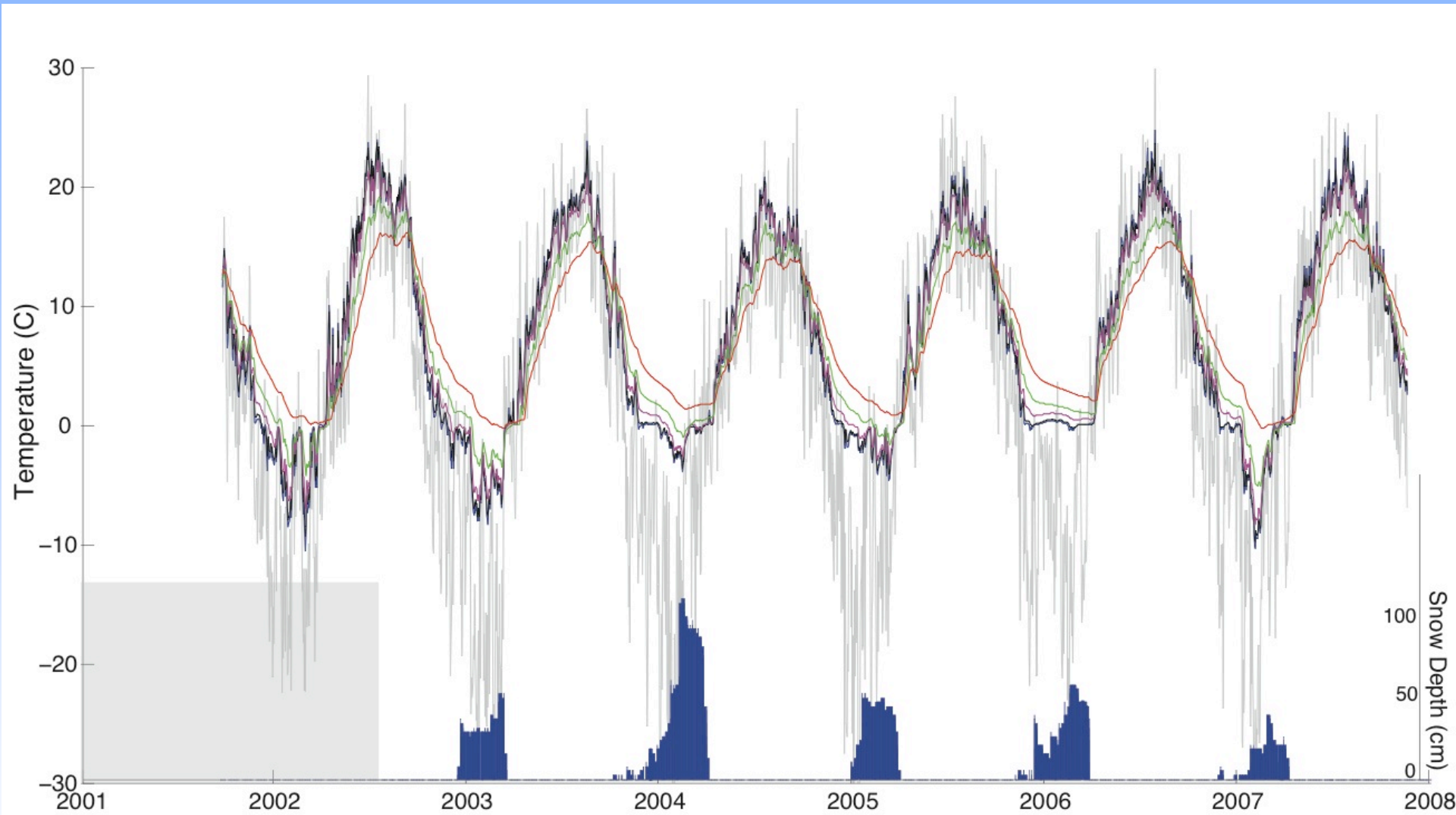
Ground water temperature can deviate significantly from a purely conductive state (*via advection*)



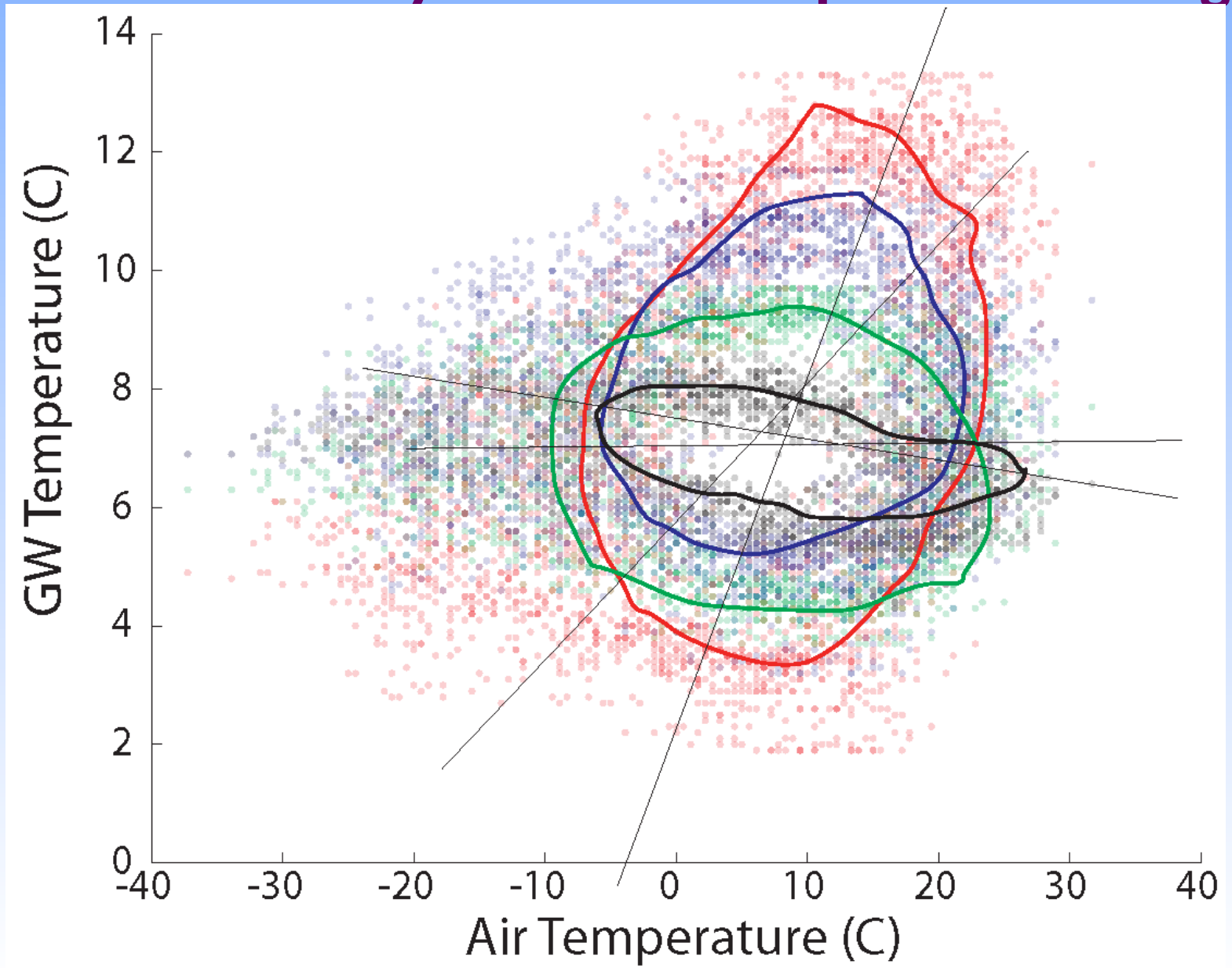
Mean annual ground water temperatures are ***not equal*** to the mean annual air temperature



Ground water temperatures do not necessarily track air temperature changes



Ground water temperatures do not necessarily track air temperature changes



What we know about groundwater

- Groundwater temperatures are variable in time (or space)
- Groundwater temperature can deviate significantly from a purely conductive state (*via advection*)
- Groundwater temperatures **<u>are not</u>** equal to mean annual temperature
- Groundwater temperatures **<u>do not</u>** necessarily track air temperatures

The paradox of cooling streams in a warming world: Regional climate trends do not parallel variable local trends in stream temperature in the Pacific continental United States

Ivan Arismendi,[1] Sherri L. Johnson,[2] Jason B. Dunham,[3] Roy Haggerty,[1] and David Hockman-Wert[3]

Received 20 February 2012; revised 6 April 2012; accepted 12 April 2012; published 16 May 2012.