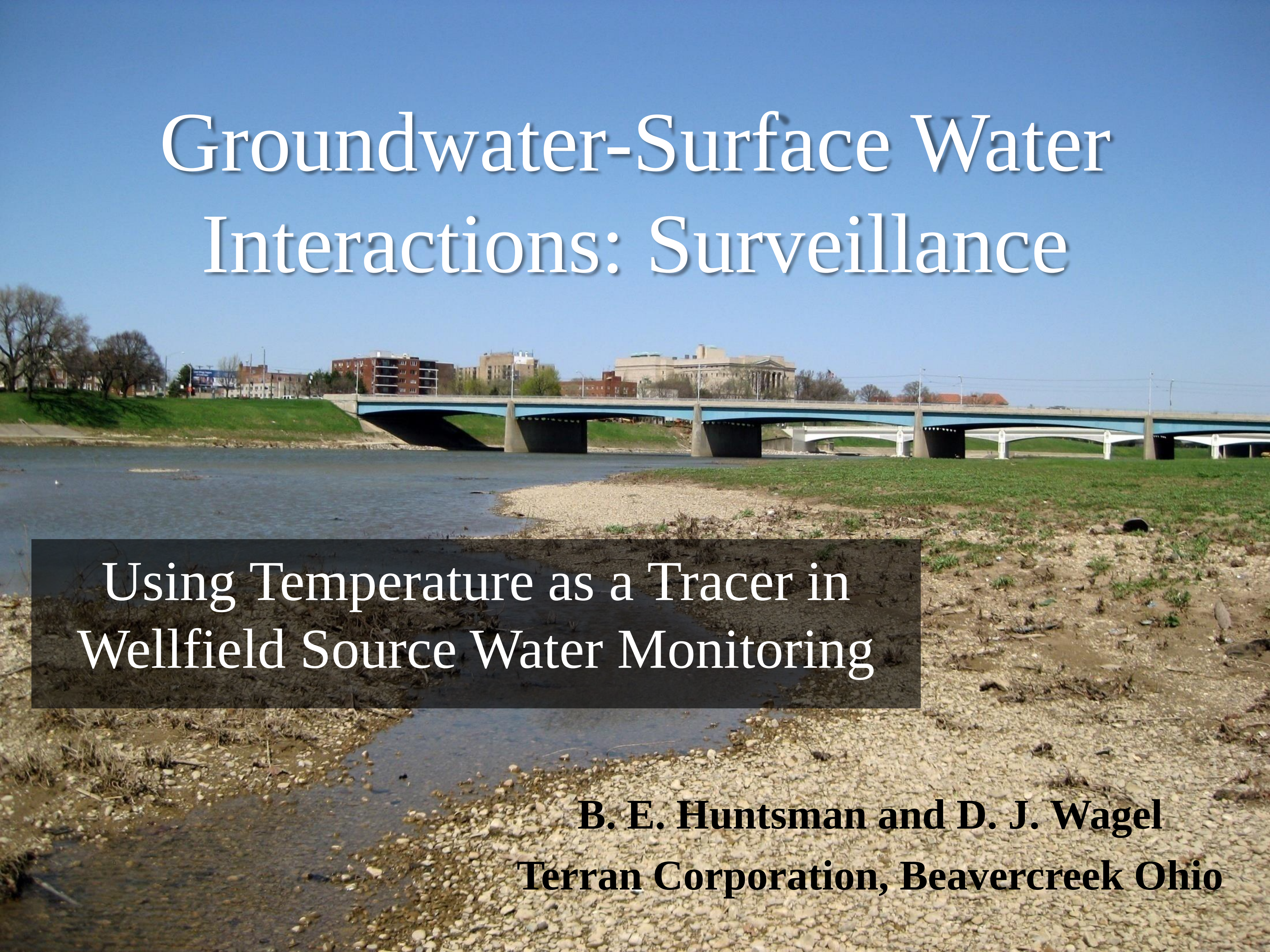


Groundwater-Surface Water Interactions: Surveillance

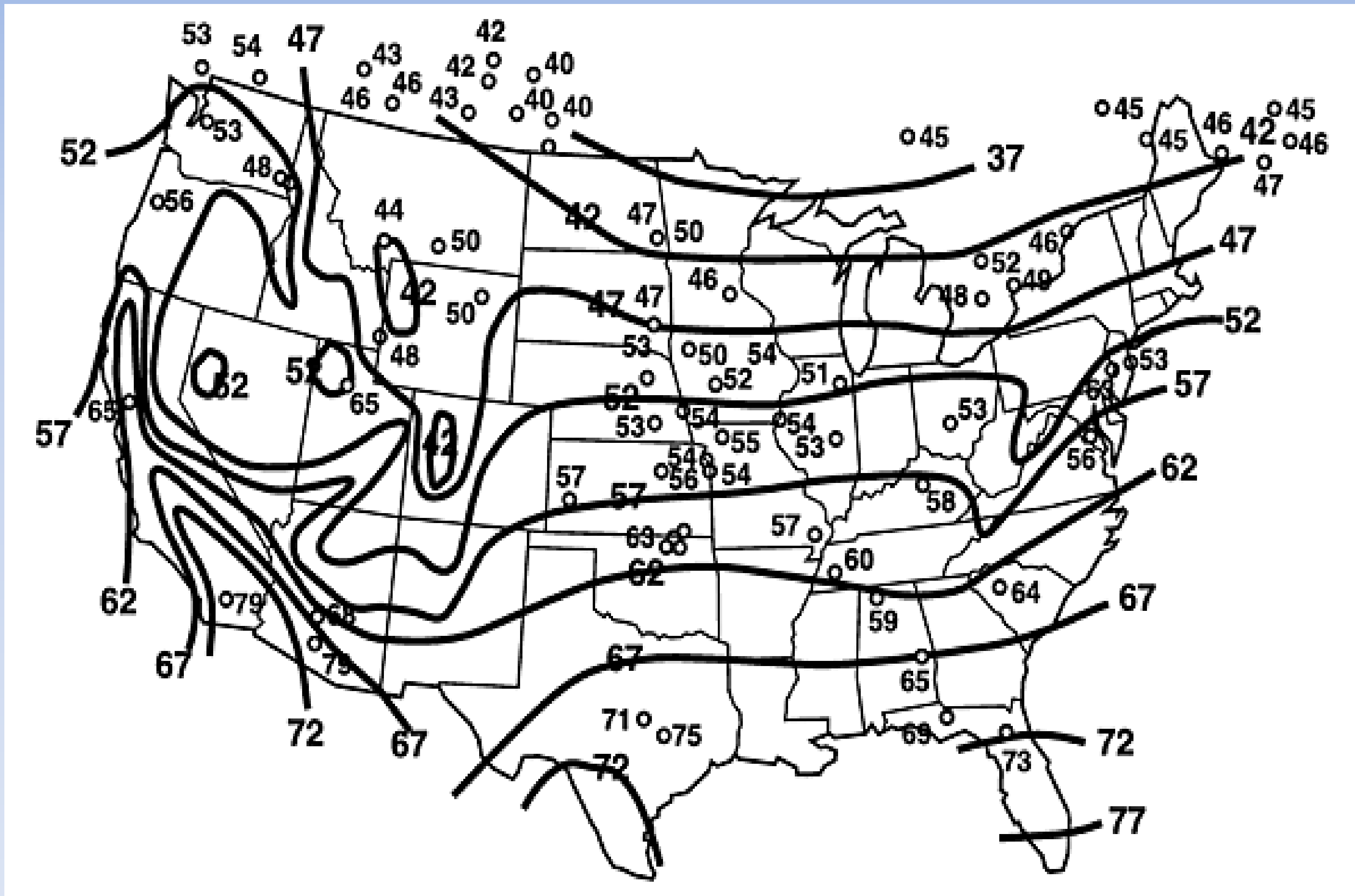
Using Temperature as a Tracer in Wellfield Source Water Monitoring

B. E. Huntsman and D. J. Wagel
Terran Corporation, Beavercreek Ohio

Why Use Groundwater Tracers?

"*As used in hydrology, a tracer is matter or energy carried by water which will give information concerning the direction and/or velocity of the water as well as potential contaminants which could be transported by the water.*"

(Davis et al., 1980)



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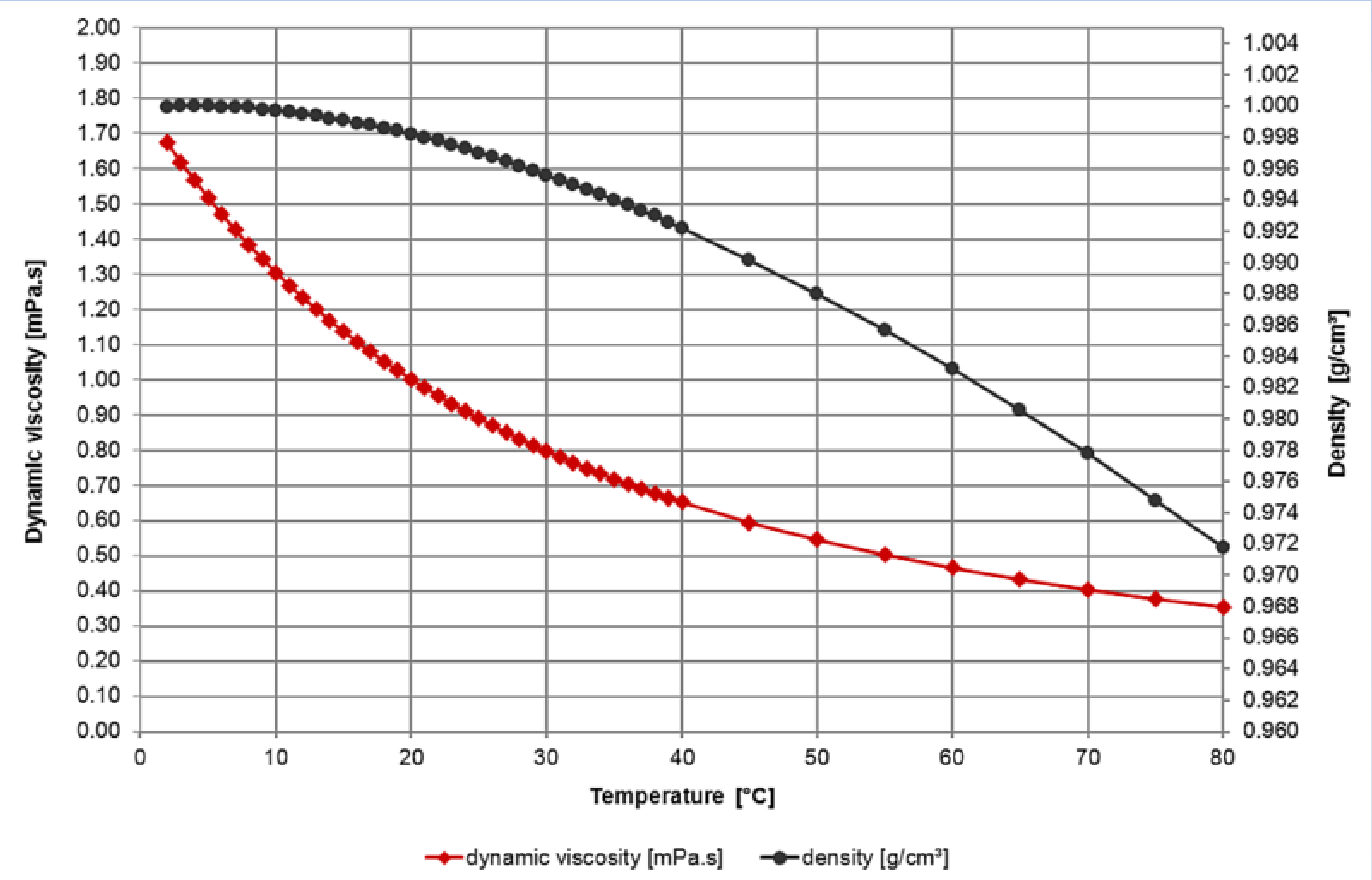
Why Temperature (Heat) as a Groundwater Tracer?

- Water's high specific heat capacity allows heated or cooled water to move into and through the aquifer with predictable change
- Can use predominately small, naturally induced temperature changes for calculations
- Simple means and equipment used to measure temperature changes in-situ and real-time
- No need for laboratory analysis (only calibration)
- Environmentally safe/ ecologically informative

Drawbacks of Heat Used in Groundwater Tracing

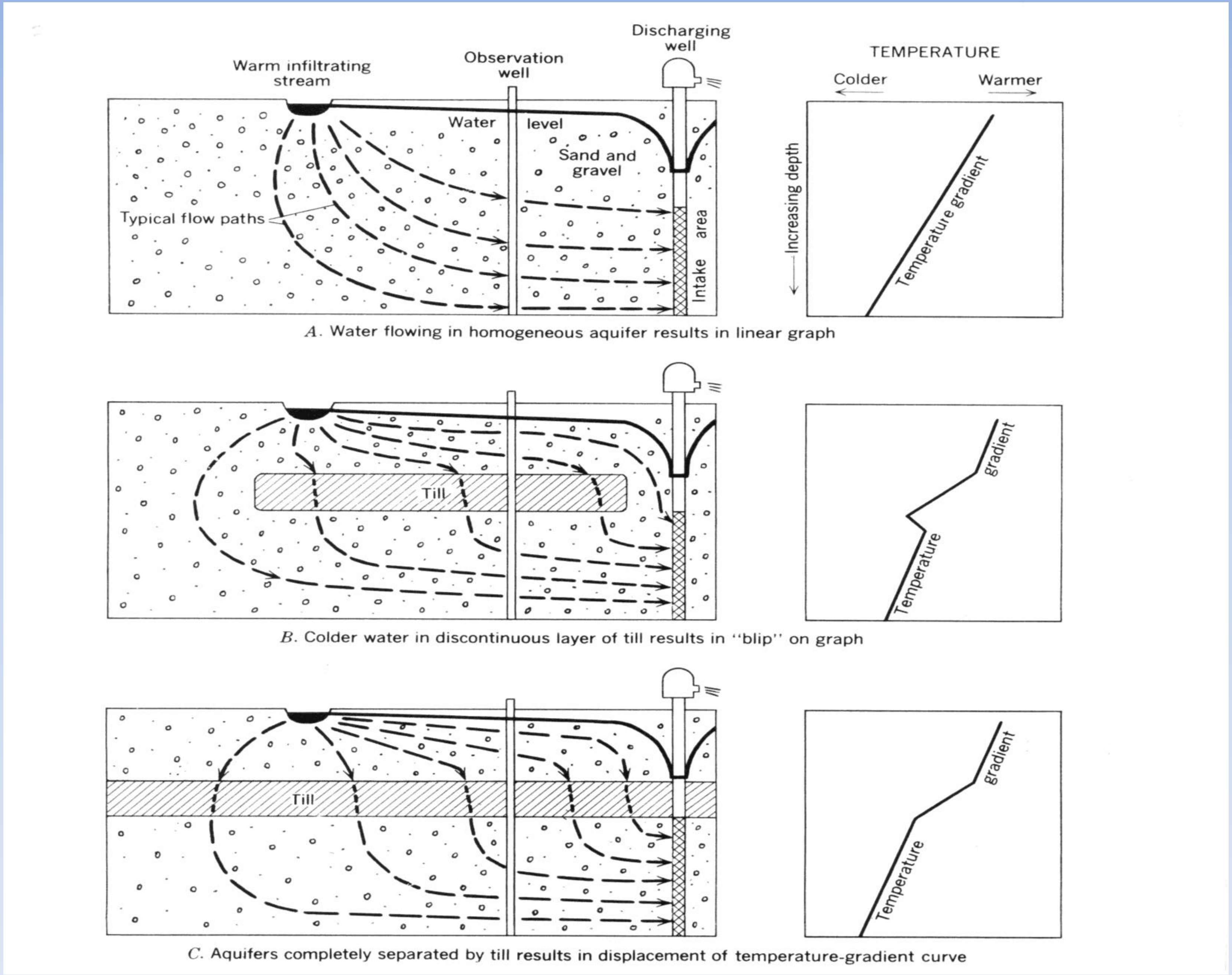
- Density and viscosity differences associated with different water temperatures:
  - Buoyant flow of warm over cold water
  - Changes in apparent hydraulic conductivity; rate of flow varies inversely with viscosity
  - Time needed for measurements to compensate for seasonality

Water Viscosity – a measure of its resistance to deformation by shear and tensile stress – think “thickness” like honey



Some Uses of Temperature (Heat) as a Tracer for Source Water Areas

- Identify surface water infiltration
- Find flow through fractures in rock aquifers or around aquitards in unconsolidated aquifers
- Calculate aquifer recharge and discharge rates
- Quantify streambed sediment hydraulic conductivity for RBF
- Better understanding of wellfield and aquifer interactions



Norris & Spieker, 1962

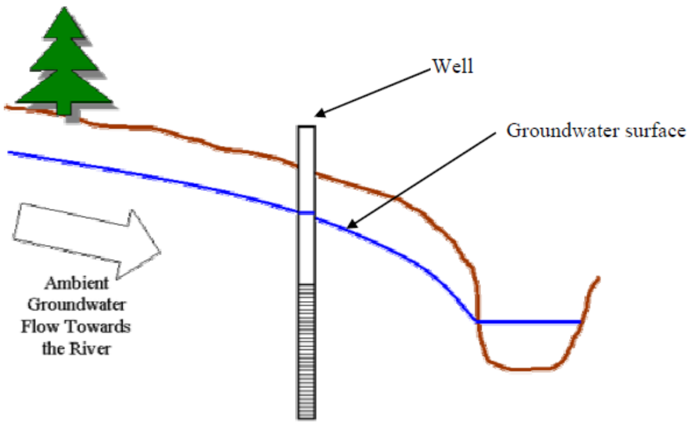


Figure 1. Non-pumping well in the groundwater flow field of a gaining stream.

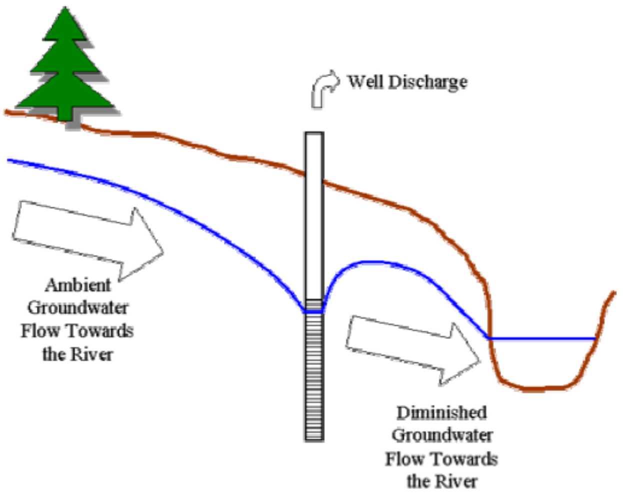


Figure 2. Pumping well in the groundwater flow field of a gaining stream.

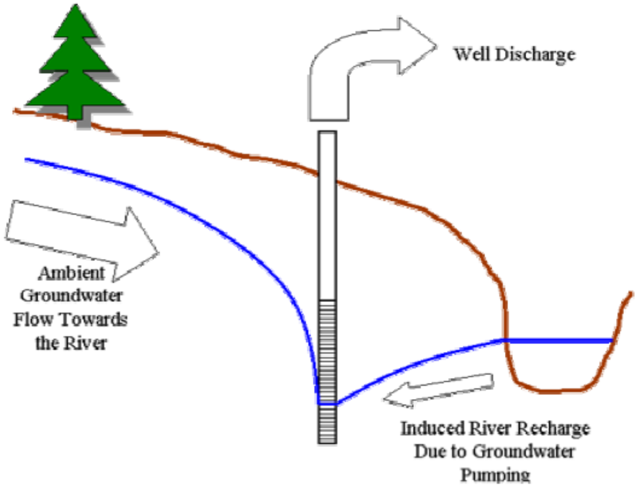
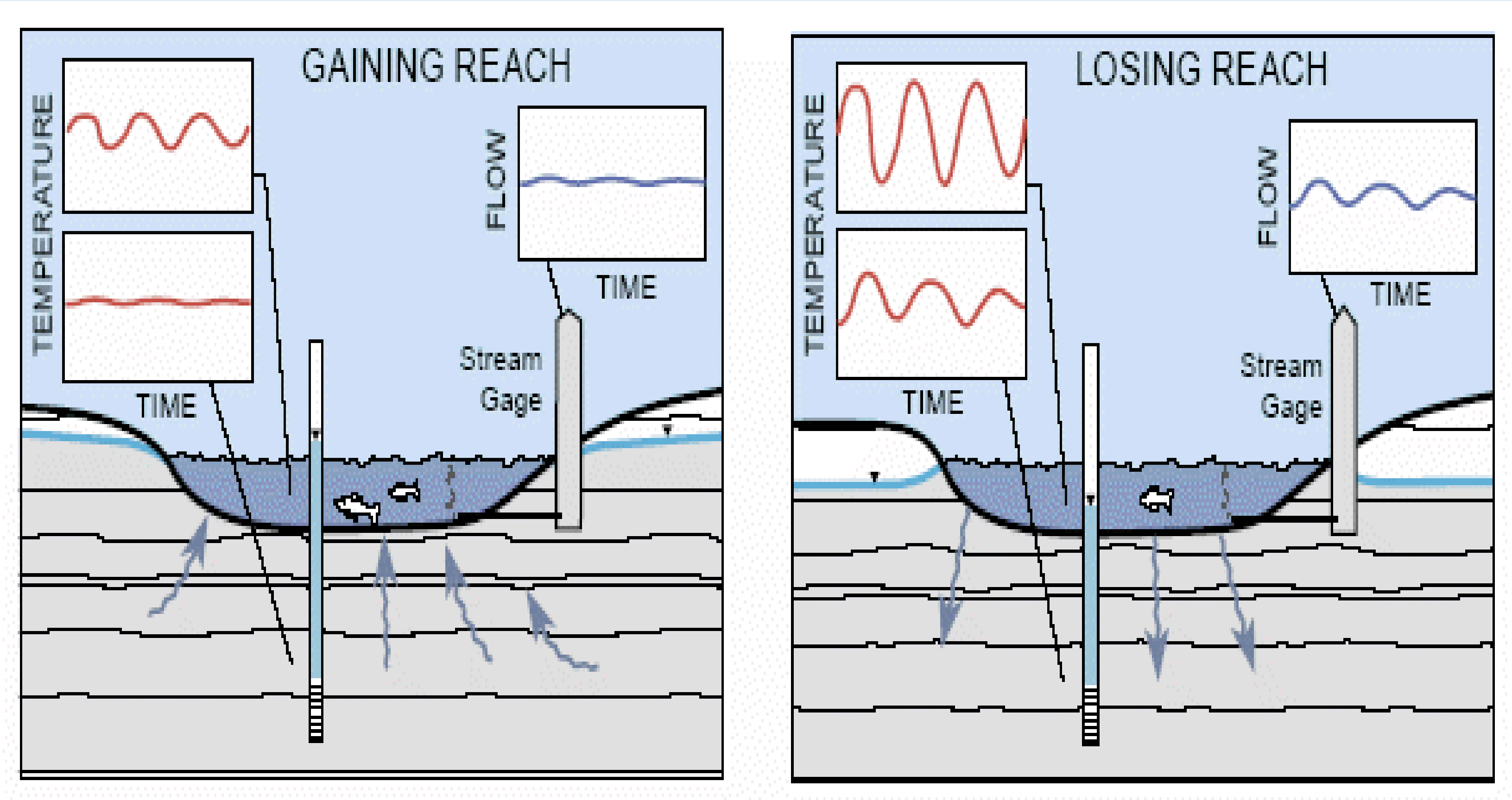


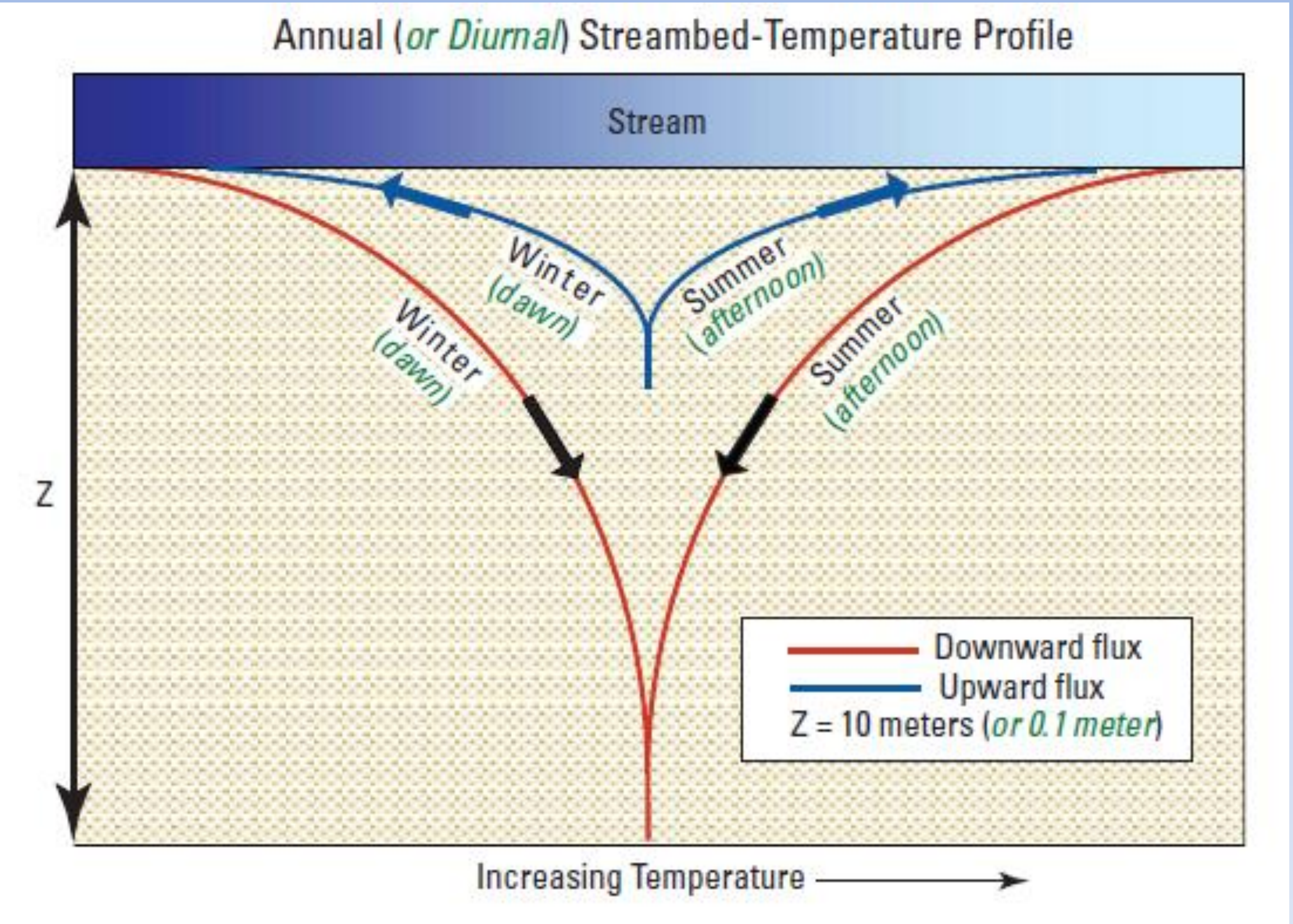
Figure 3. Pumping well in the groundwater flow field of a gaining stream that induces river recharge.

Example of using recorded temperature to monitor production well capture zone

Temperature Trends
Rivers & Aquifers Interactions

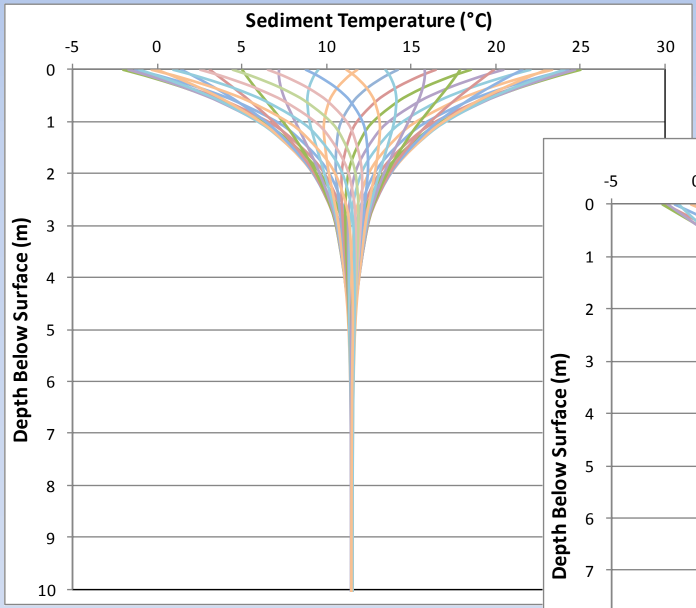


D. A. Stonestrom and J. Constantz, 2004

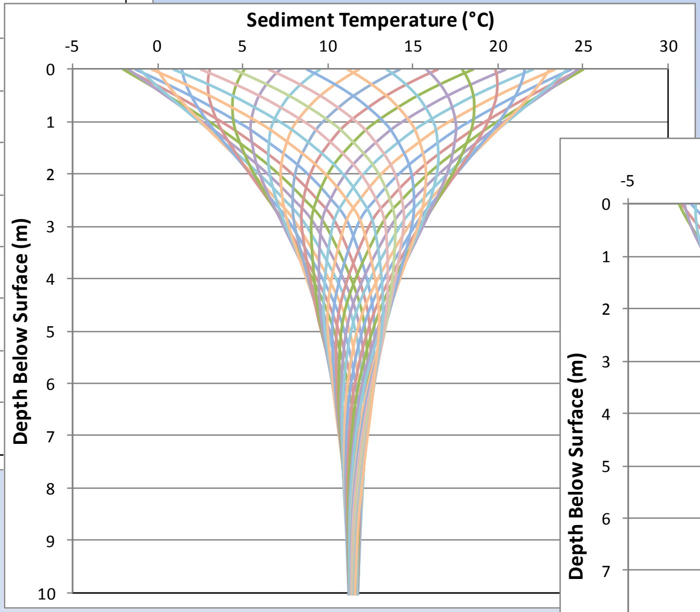


Constantz et al., 2008

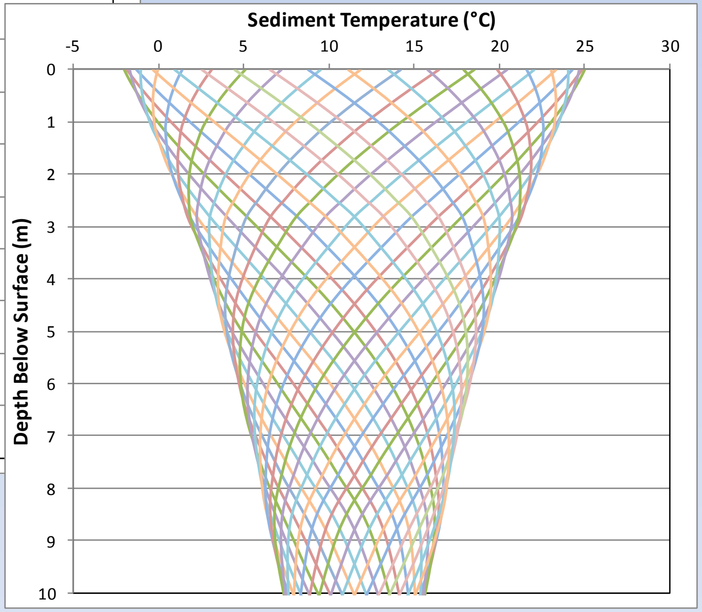
Temperature Envelopes



Water moving 10 cm/day Up



No Vertical Water Movement



Water moving 10 cm/day Down

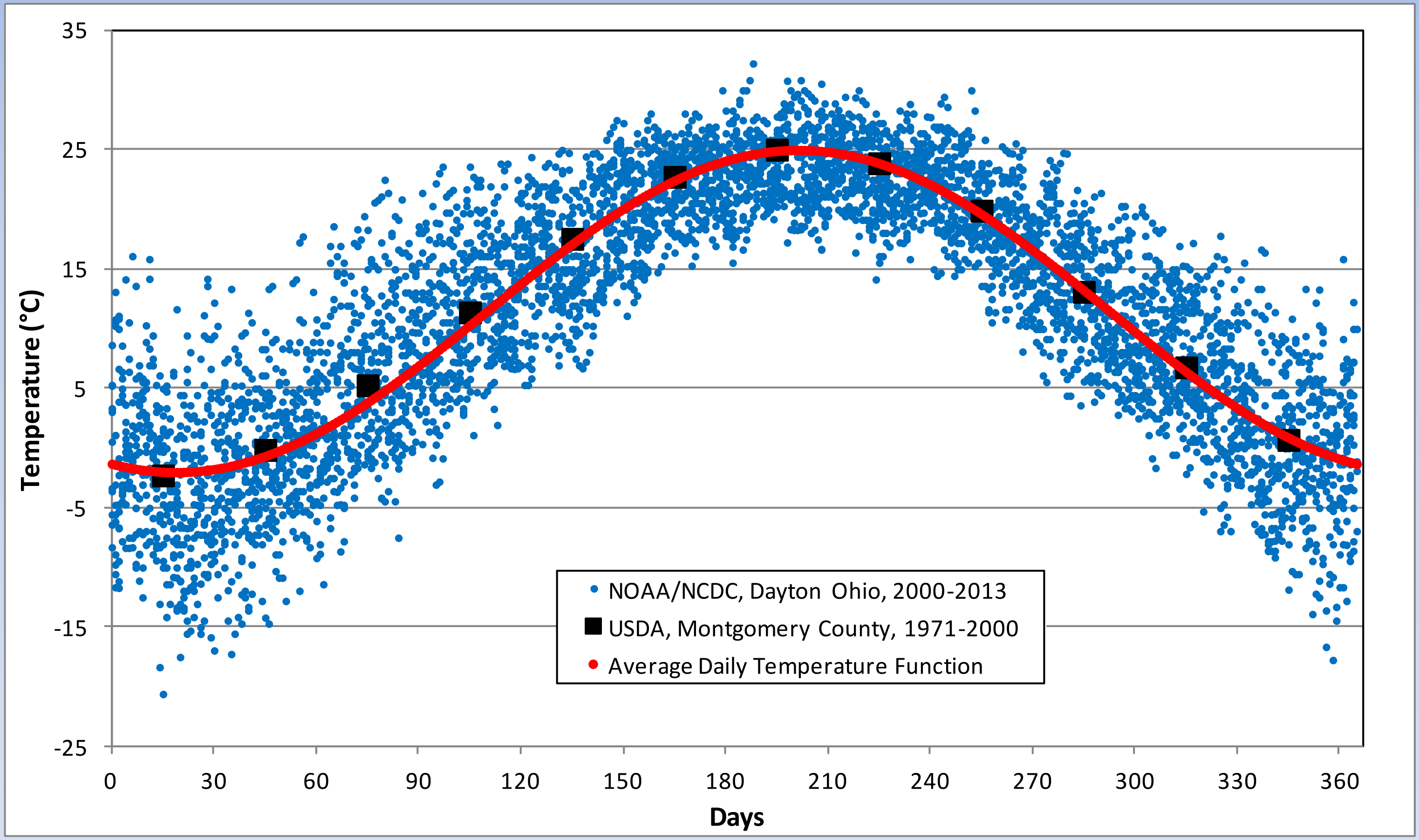
⊕ Location of Proposed Monitoring Well

TERRAN

TERRAN CORPORATION
4080 Executive Drive
Beavercreek, Ohio 45430
Ph: (937) 320-3601
Fx: (937) 320-3620
Web: www.terrancorp.com

Monitoring Instrumentation

Average Daily Temperatures in Dayton, Ohio



$$T_{(t)} = T_m + \Delta T \sin\left[\frac{2\pi(t+\varphi)}{365}\right]$$

$T_{(t)}$ = daily temperature (°C)
T_m = mean annual temperature (°C), 11.5°C
ΔT = temperature amplitude (°C), 13.5°C
t = day of the year (d)
φ = phase difference (d), 255 d

Equations for Sinusoidal Surface Temperature Variations (Stallman, 1965)

$$T = T_{AZ} + \Delta T e^{-az} \sin\left[2\pi t/\tau - bz\right]$$

$$a = \left[\left(K^2 + V^4/4\right)^{1/2} + V^2/2\right]^{1/2} - V$$

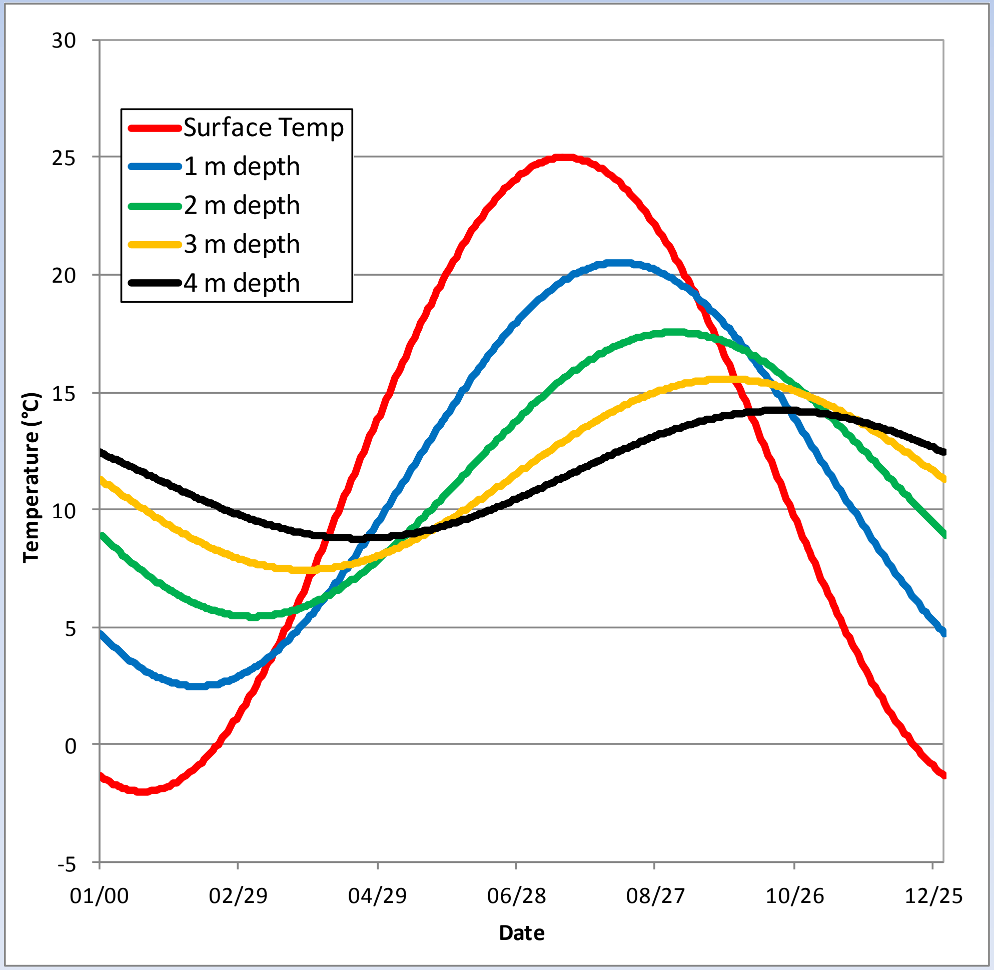
$$b = \left[\left(K^2 + V^4/4\right)^{1/2} - V^2/2\right]^{1/2}$$

$$K = \pi c\rho / k\tau$$

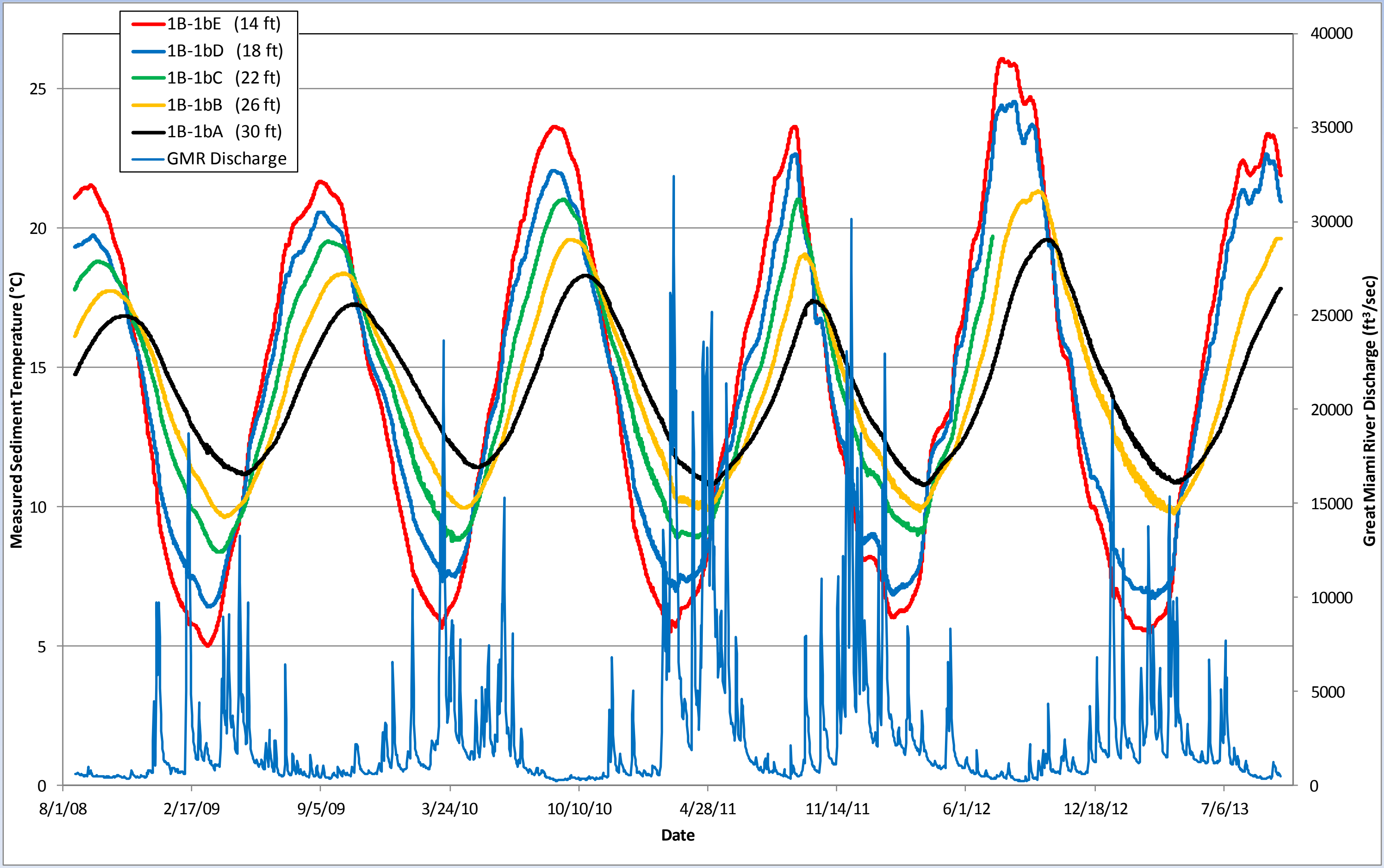
$$V = \upsilon c_0 \rho_0 / 2k$$

Sediment Temperature is function of:

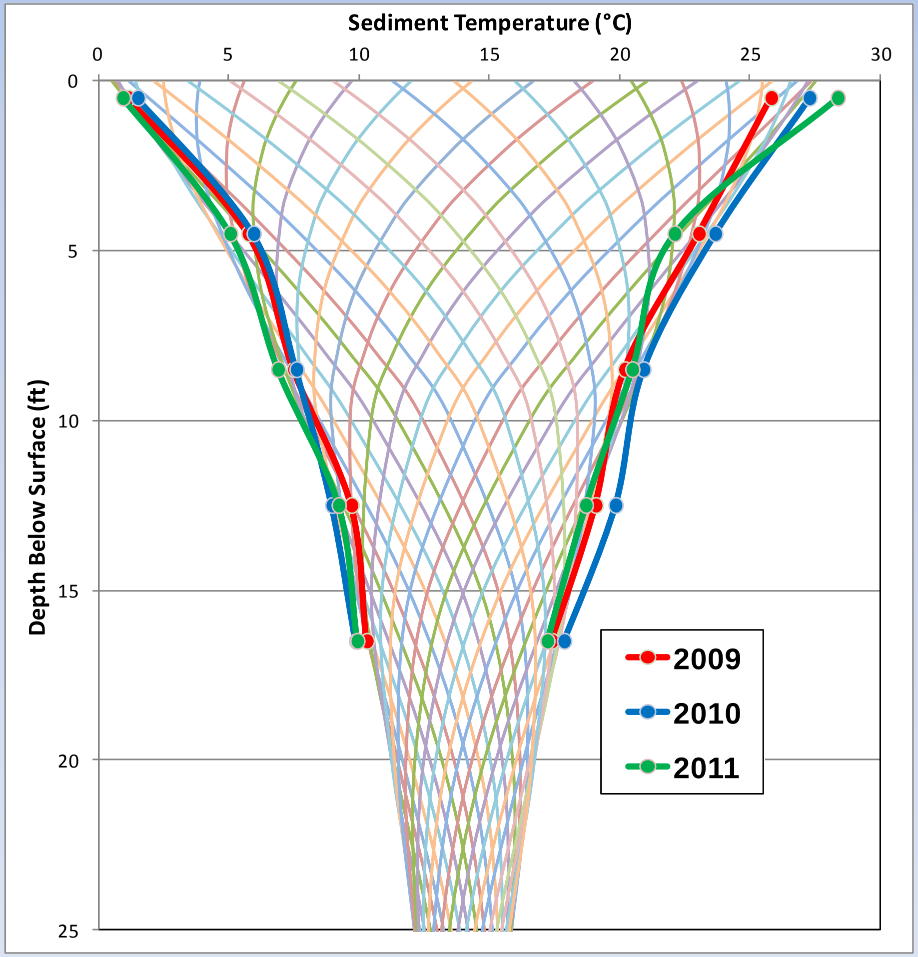
- Vertical water velocity
- Heat conductivity of sediment
- Time and depth below the surface
- Specific heat of water and sediment
- Density of water and sediment
- Porosity
- Period of oscillation
- Average temperature
- Amplitude of surface temperature

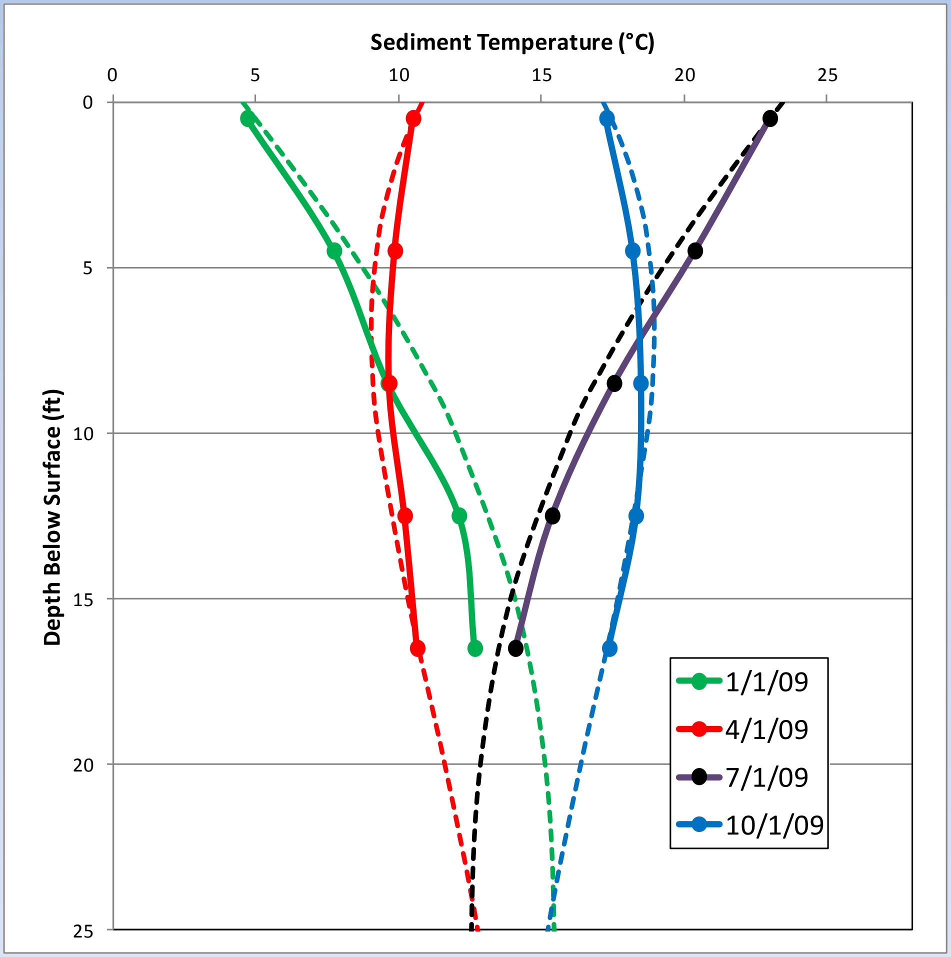


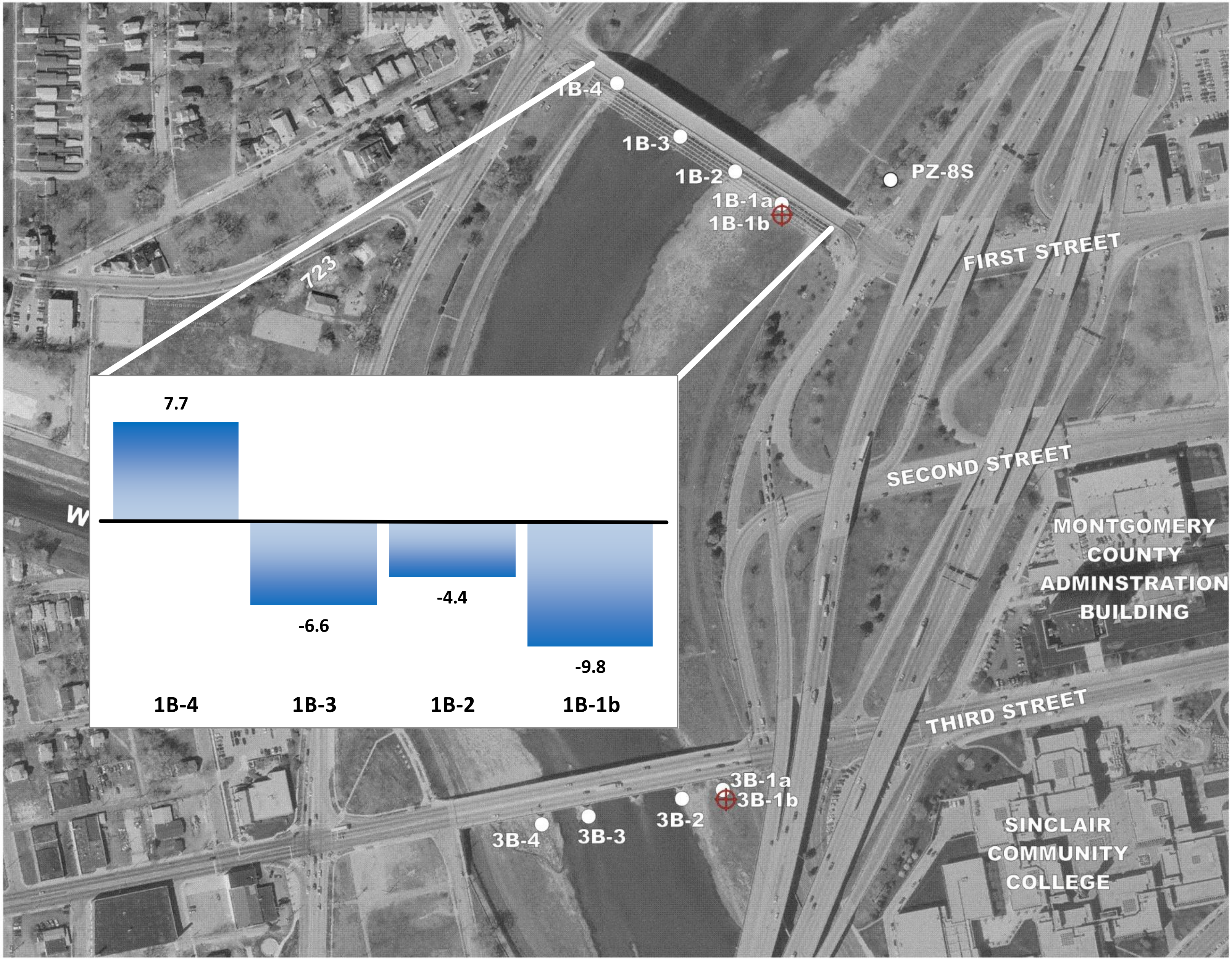
GMR Discharge and Temperatures Measured at 1B-1b



Temperature Envelopes Measured for 1B-3 Water Moving 4 cm/day Down







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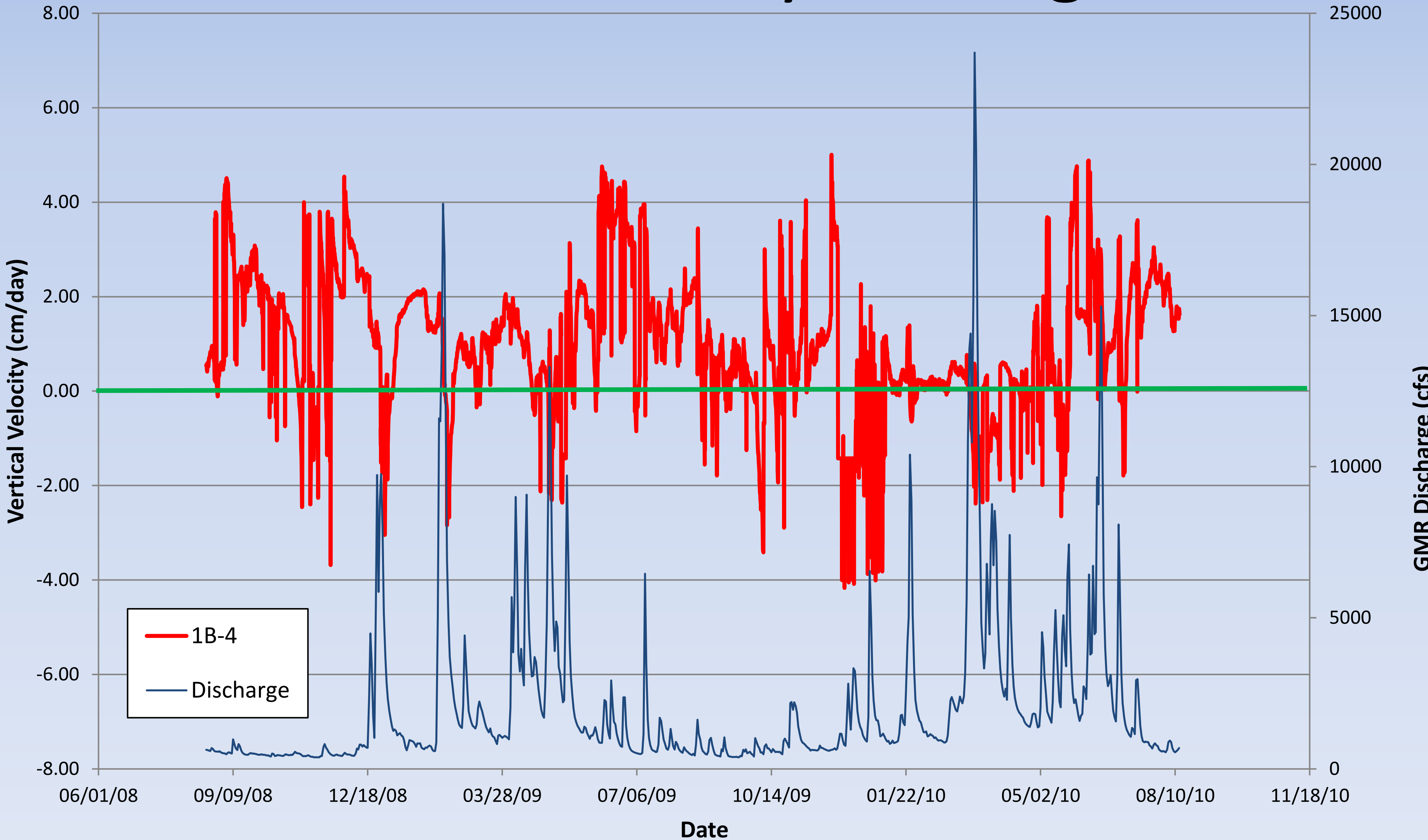
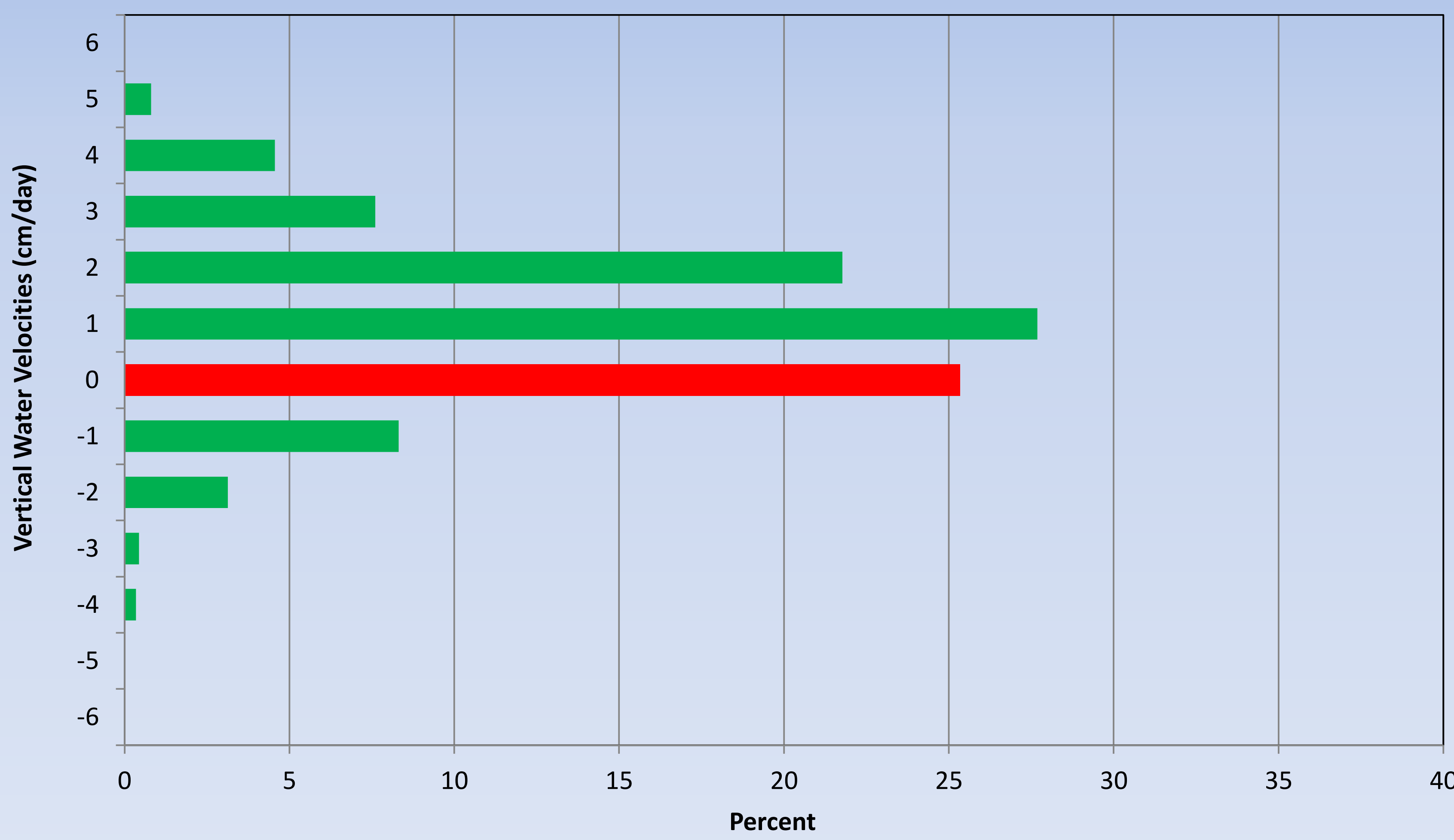
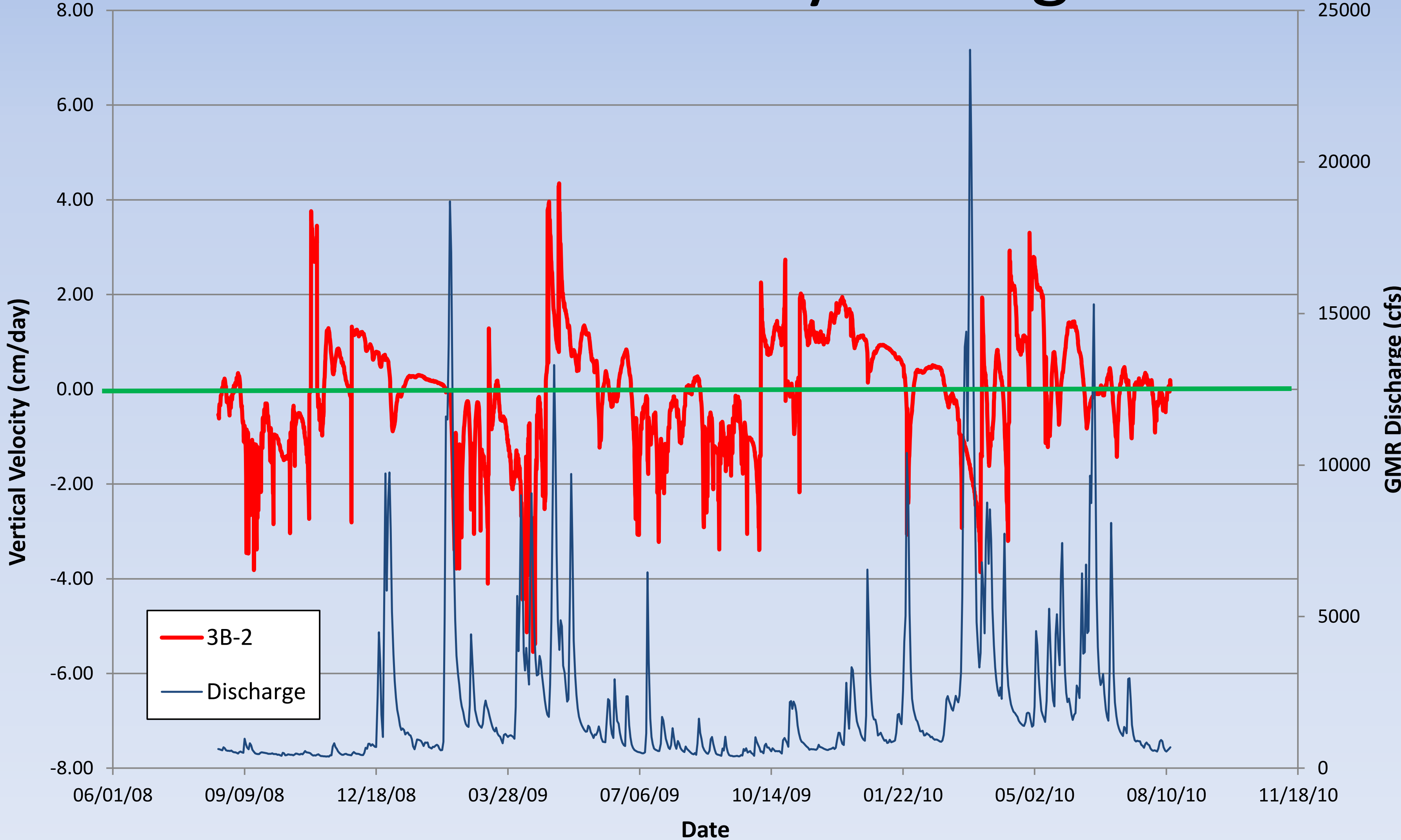
Temperature Profile at 1B-4 Predominately Gaining

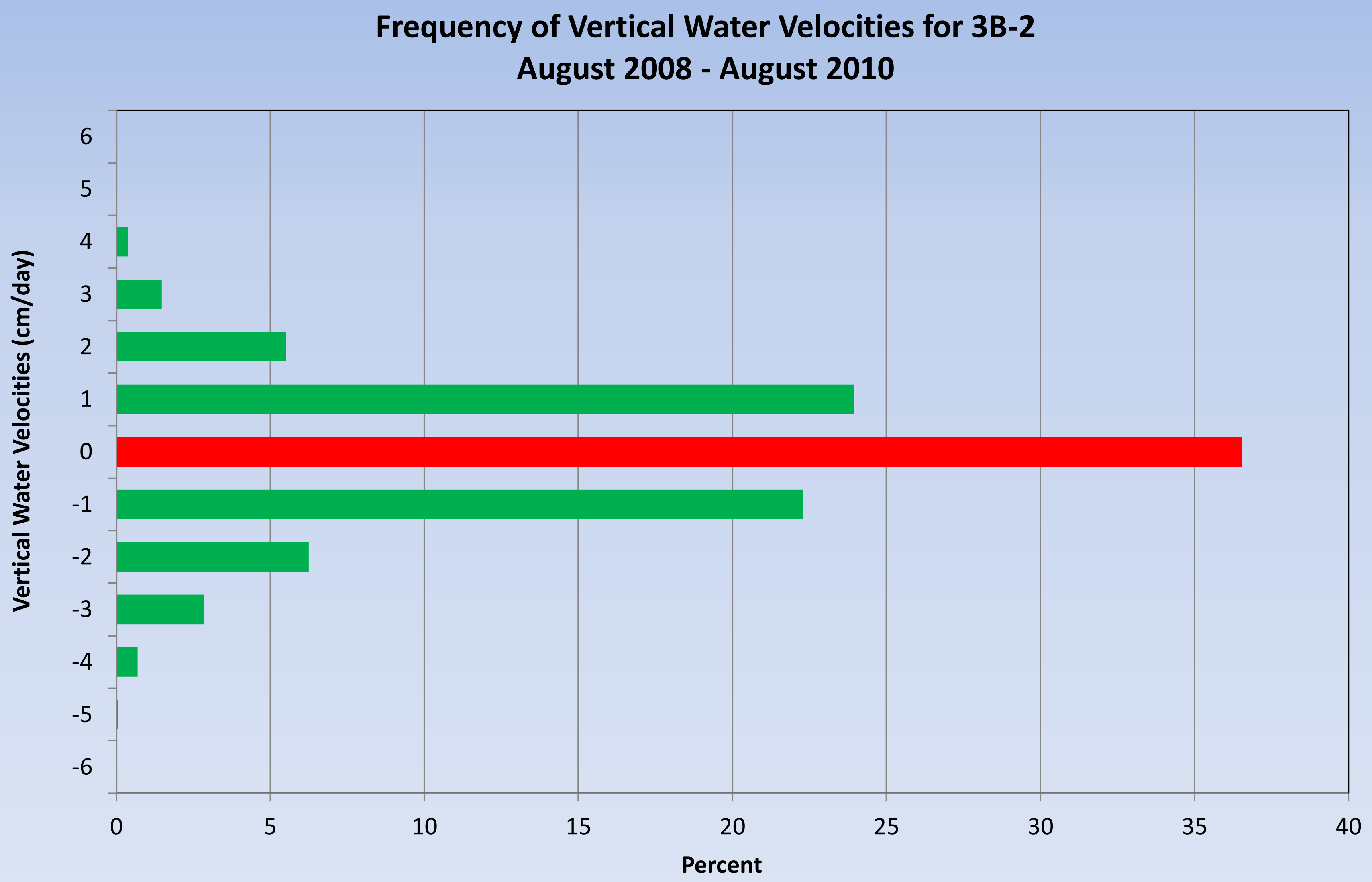


Frequency of Vertical Water Velocities for 1B-4
August 2008 - August 2010

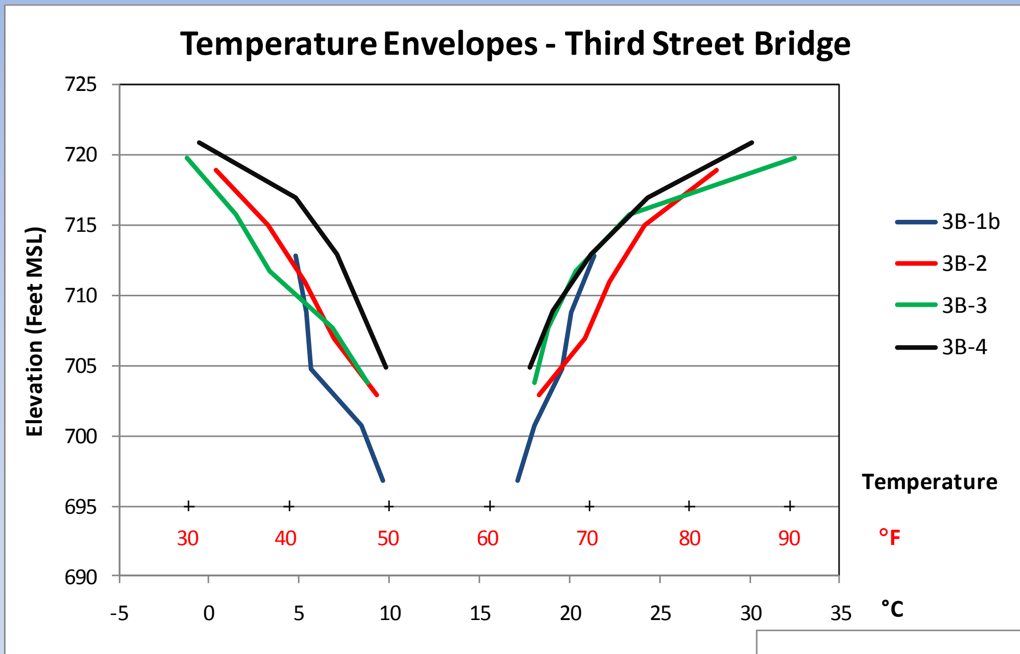


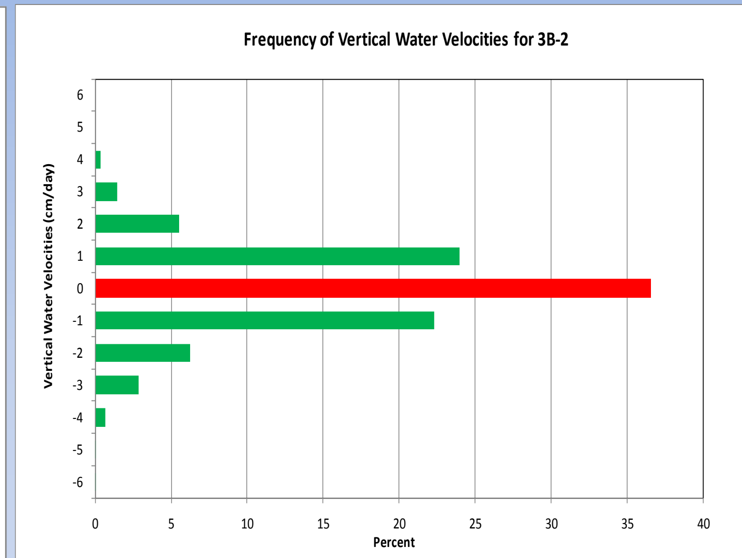
Temperature Profile at 3B-2 Predominately Losing

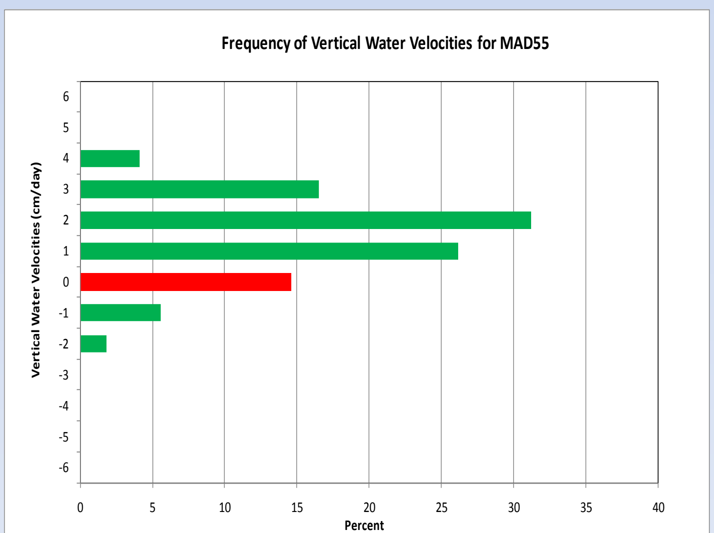


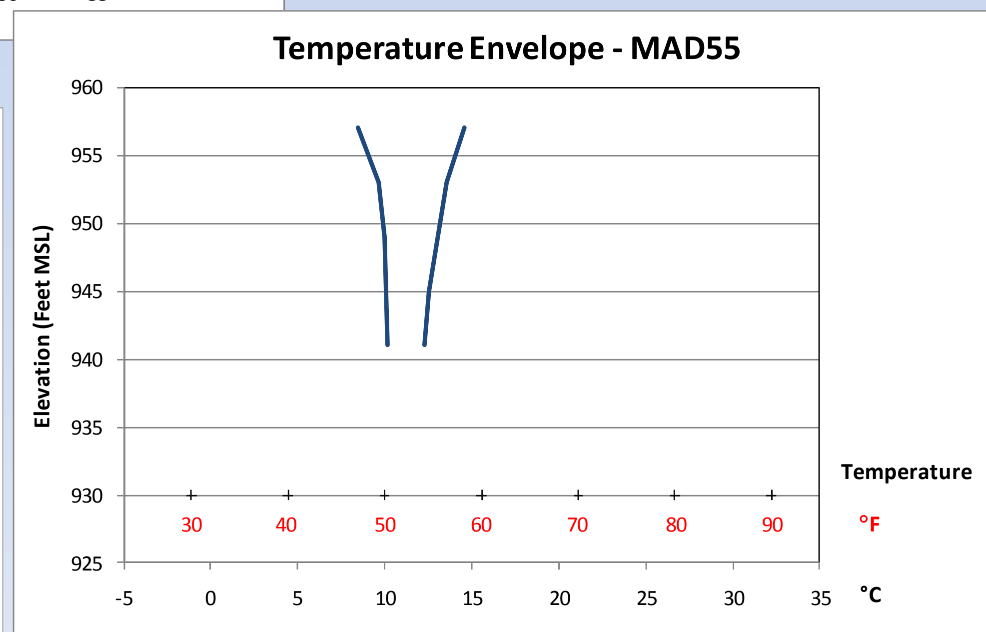


Frequency of Vertical Water Velocities for 3B-2
August 2008 - August 2010
Vertical Water Velocities (cm/day)
6
5
4
3
2
1
0
-1
-2
-3
-4
-5
-6
0
5
10
15
20
25
30
35
40
Percent

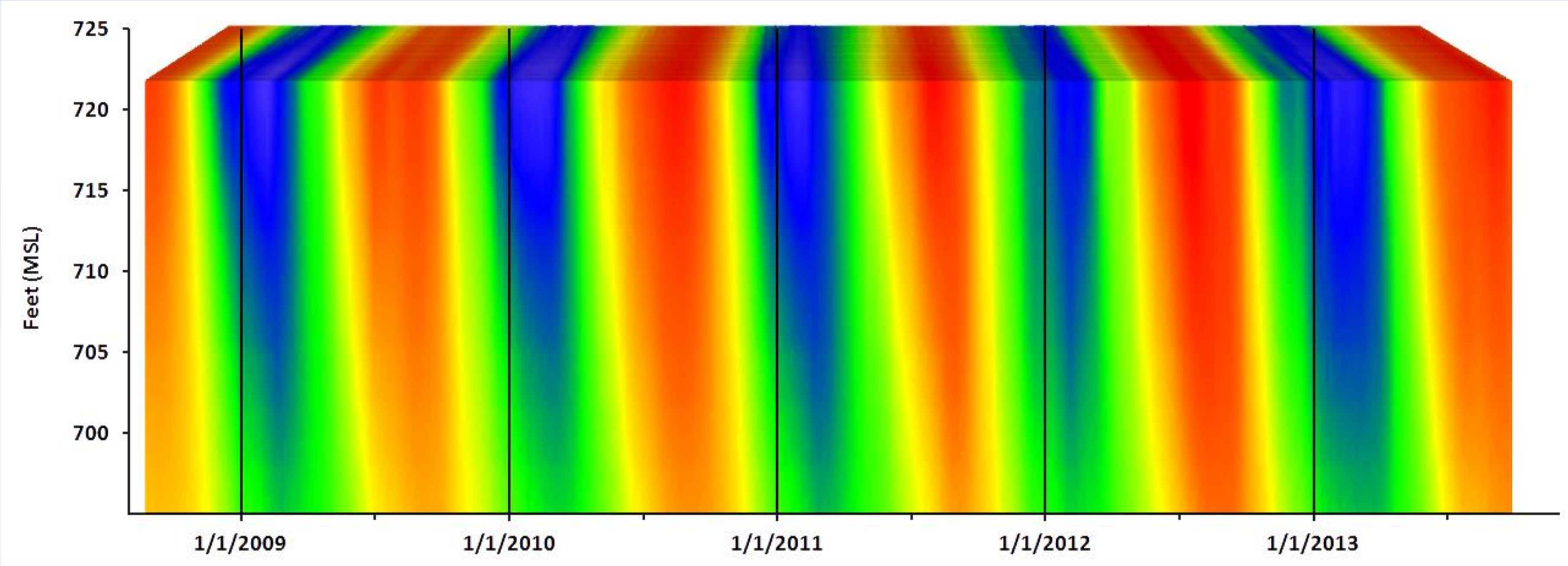

Temperature Envelopes - Third Street Bridge
Elevation (Feet MSL)
725
720
715
710
705
700
695
690
3B-1b
3B-2
3B-3
3B-4
Temperature
30
40
50
60
70
80
90
°F
-5
0
5
10
15
20
25
30
35
°C

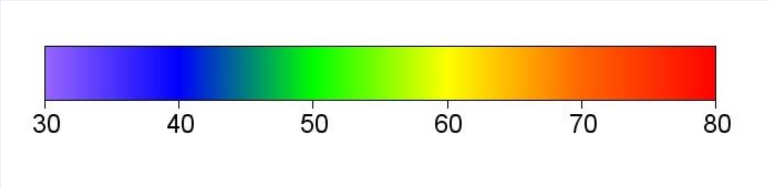

Frequency of Vertical Water Velocities for 3B-2
Vertical Water Velocities (cm/day)
6
5
4
3
2
1
0
-1
-2
-3
-4
-5
-6
0
5
10
15
20
25
30
35
40
Percent


Frequency of Vertical Water Velocities for MAD55
Vertical Water Velocities (cm/day)
6
5
4
3
2
1
0
-1
-2
-3
-4
-5
-6
0
5
10
15
20
25
30
35
40
Percent


Temperature Envelope - MAD55
Elevation (Feet MSL)
960
955
950
945
940
935
930
925
Temperature
30
40
50
60
70
80
90
°F
-5
0
5
10
15
20
25
30
35
°C

Aquifer Temperatures Measured at the First Street Bridge 2008-2013





CONCLUSIONS

- Temperature measurements can be used to determine flow into and through aquifers to production wells
- Identification of areas of recharge as well as estimates of water flux to a well field may be made using temperature measurements
- Representative hydraulic conductivities of recharge areas can be calculated using temperature measurements
- Groundwater travel times through a source water area to a pumping well can be estimated using temperature