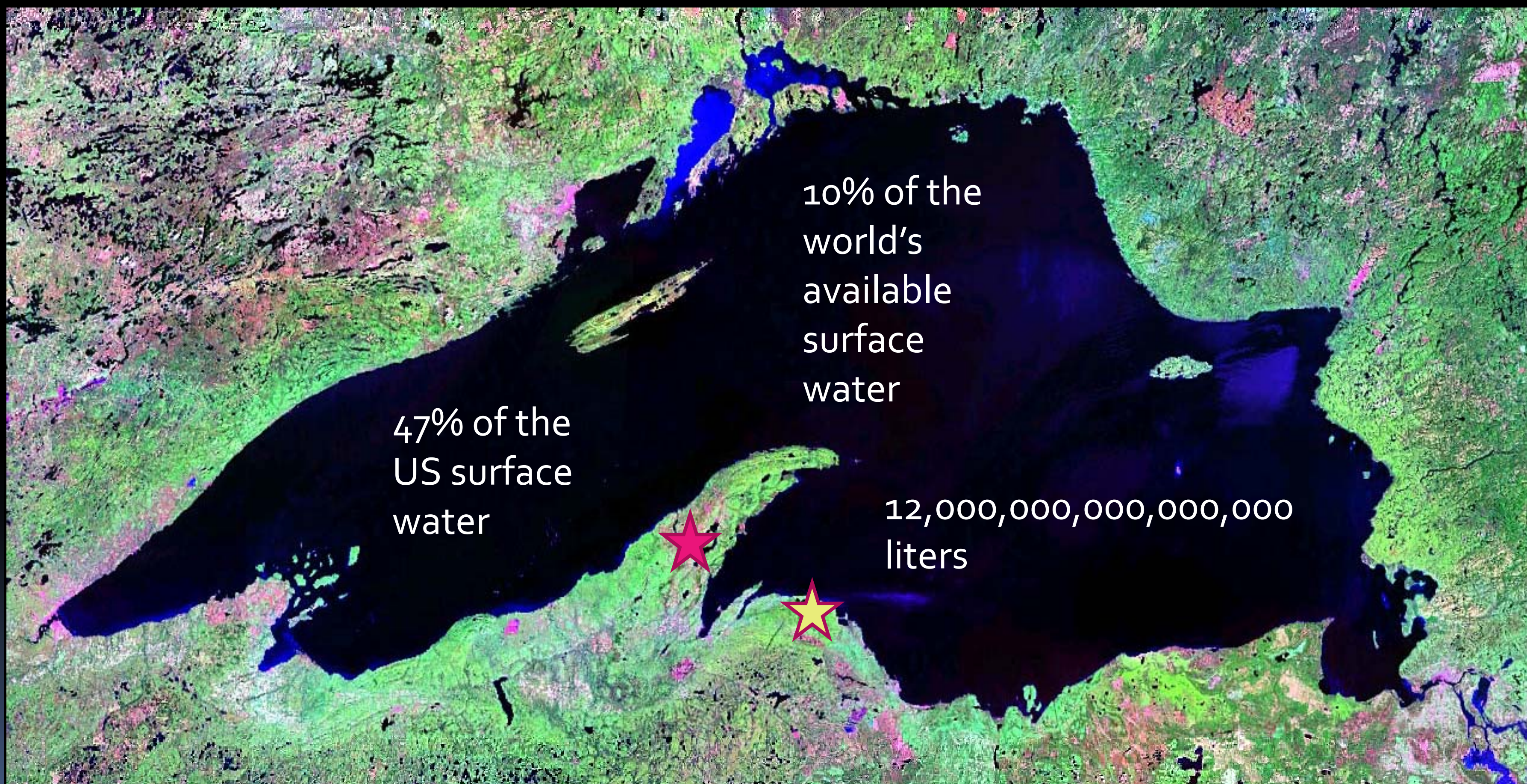
Alex Mayer Department of Geological & Mining Engineering & Sciences
Matt Van Grinsven Department of Geological & Mining Engineering & Sciences
Casey Huckins Department of Biological Sciences

"ECOHYDROLOGY": GROUNDWATER-SURFACE WATER INTERACTIONS AND THE COASTER BROOK TROUT

Lake Superior and Study Area Location



Ecohydrology

- Ecohydrology is a relatively new interdisciplinary area linking hydrology with ecological processes involved in the water cycle.
- Ecohydrology seeks to understand how hydrological processes regulate ecological ones and conversely, how ecological ones may subsequently regulate hydrological ones, on the scale of a watershed.
- Ecohydrology then integrates the knowledge of those two processes and uses it to find innovative solutions to the problems of watershed degradation and restoration.

Outline

- Why study the Coaster Brook Trout?
- Groundwater-surface water interactions
- Study design
- Results
- Conclusions and future work

In the beginning…Lake Superior hosted two native salmonids

- <u>lake trout</u>
  occupied deeper and offshore waters
- <u>brook trout</u>
  occupied the inshore, coastal habitat

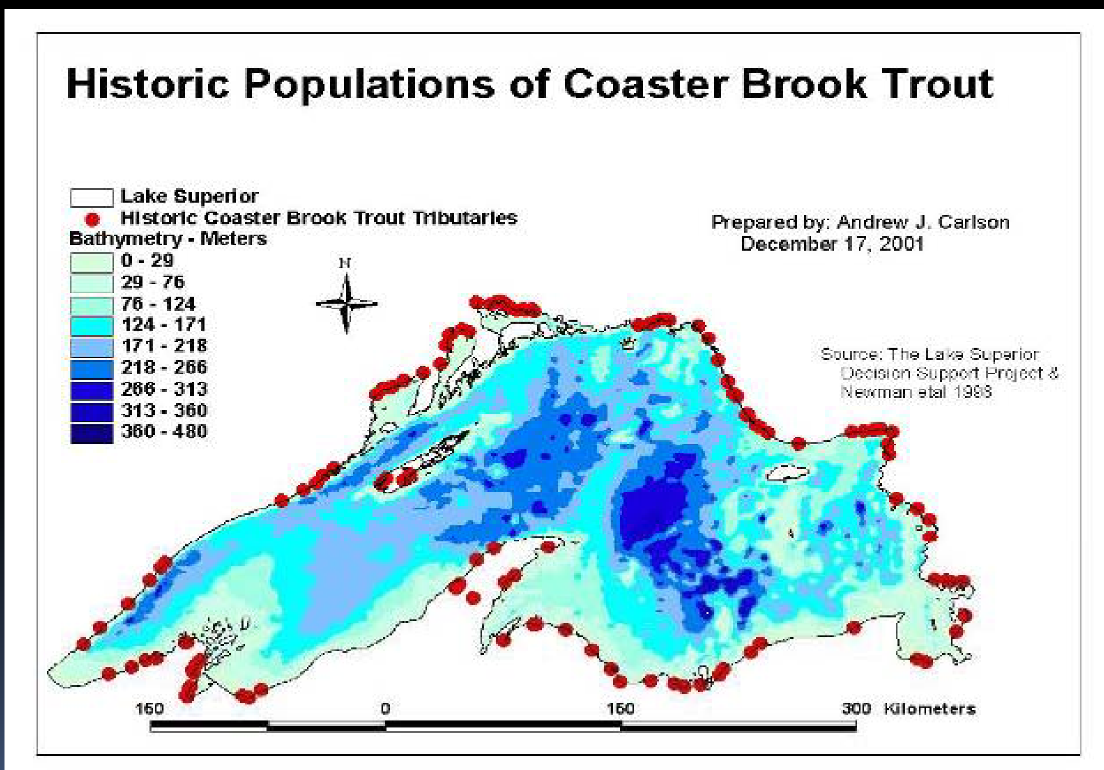
Joseph Tomelleri illustrations in Benke 2002. Trout and Salmon of North America

Coaster brook trout, or "Coasters"

Defined by having a *Great Lake-dwelling component* in their life-history (Becker 1983)

Coasters **were** common through early 1900s

- Over 100 coaster populations (Newman et al. 1999).



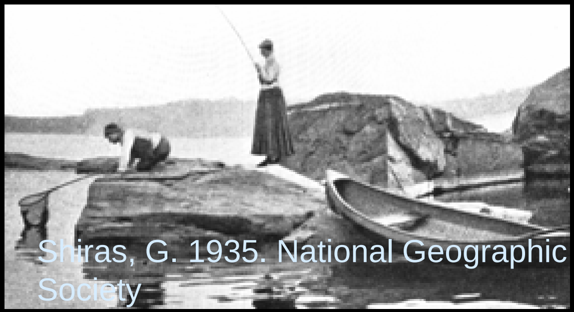
"these superb trout abounded in the nineties [1890s], *when pioneer anglers often reported* ***daily catches of one hundred to three hundred*** *for a small party fishing in the river."*

Decline…

"the trout along the southern shore are approaching extinction, a tragedy assured by the improvident custom of catching the remnant [trout] at the mouths of spawning streams" (Shiras 1921)

Why?

- exploitation (first and foremost)


Shiras, G. 1935. National Geographic Society

- habitat loss and degradation

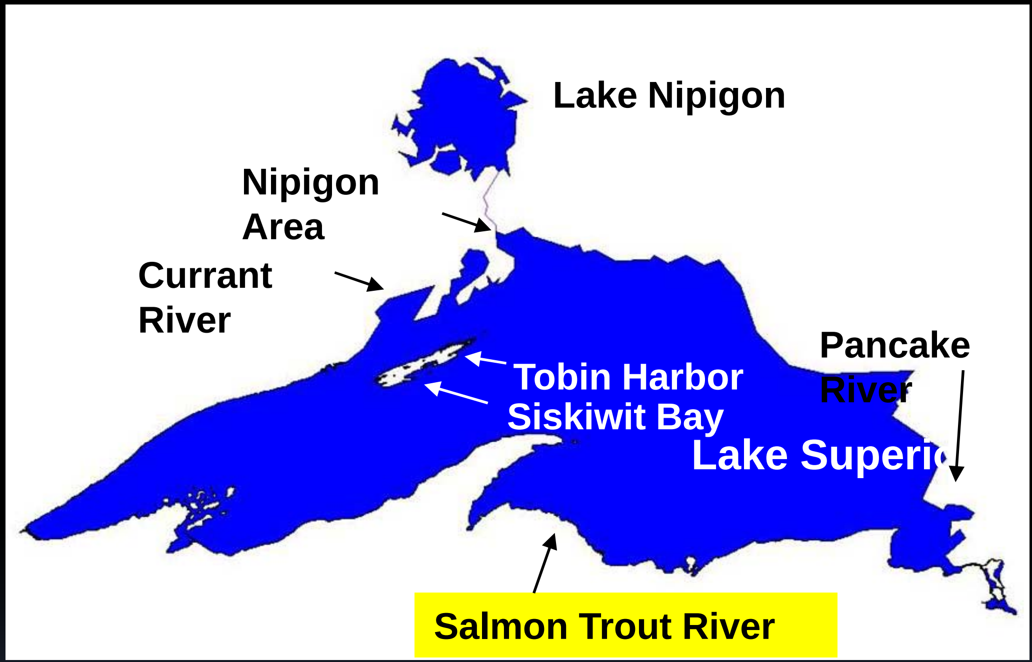

Michigan State University Extension Forest History Webpage (http://forestry.msu.edu/uptreeid/History.htm)

- biotic interactions

  e.g., exotic salmonids

Current situation

- late 1800s and early 1900s - only scattered remnants of populations
- further declines during the 20th century



Attention now turns to restoration

- how can current populations be protected and enhanced?
- where are the best places to re-introduce?

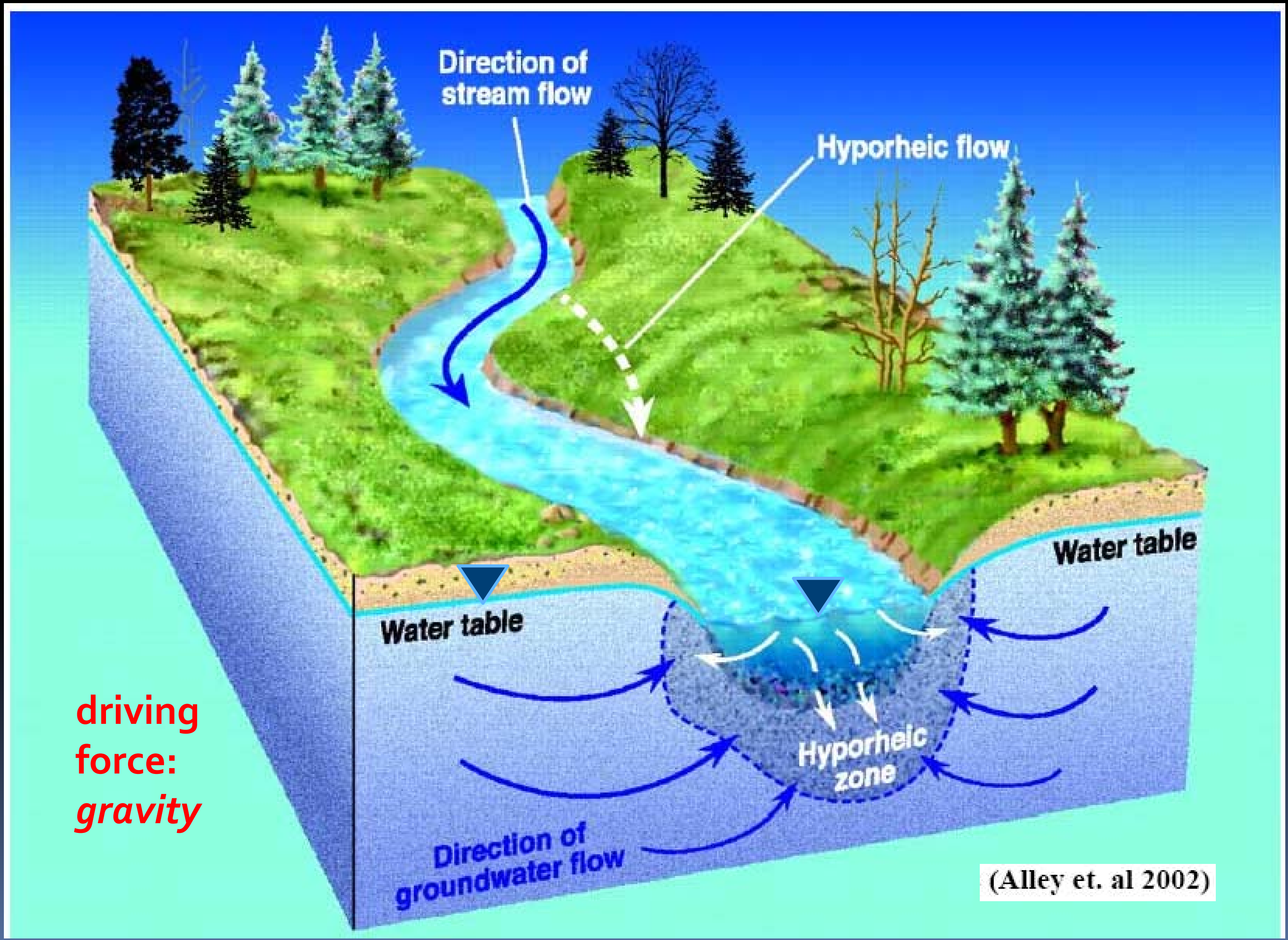
Motivation

- The Salmon Trout River is the only river on the south shore of Lake Superior known to sustain a reproducing coaster brook trout population.
- Related studies demonstrate that brook trout tend to select spawning sites based on the presence of groundwater discharge into the river.
- The results of these studies suggest that groundwater presence is vital to the reproductive success of the coaster brook trout.

Motivation

- Coaster brook trout spawning locations have been observed to be highly selective and consistent.
- We hypothesize that spatial distributions of groundwater inflows through river-bottom sediments are a critical factor in the selection of spawning sites.
- Why/how?
  - Groundwater inflows prevent freezing during the winter.
  - Areas of high groundwater inflow provide a physically and chemically stable environment.
  - [Biologists are unsure as to how the fish detect areas of high groundwater inflows.]

Groundwater-surface water interactions

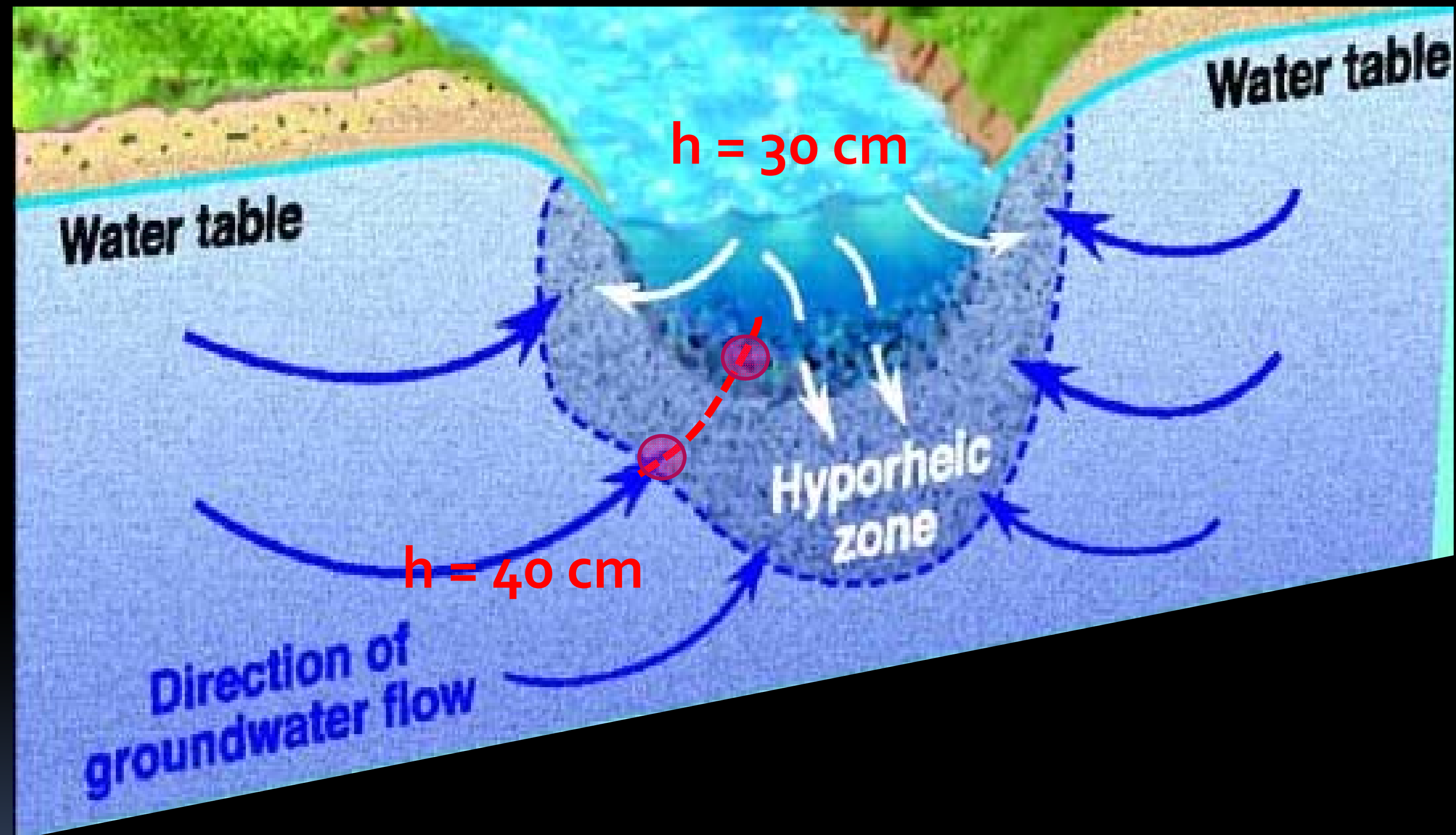


driving force: *gravity*

Objective: Measure groundwater flux as a function of location

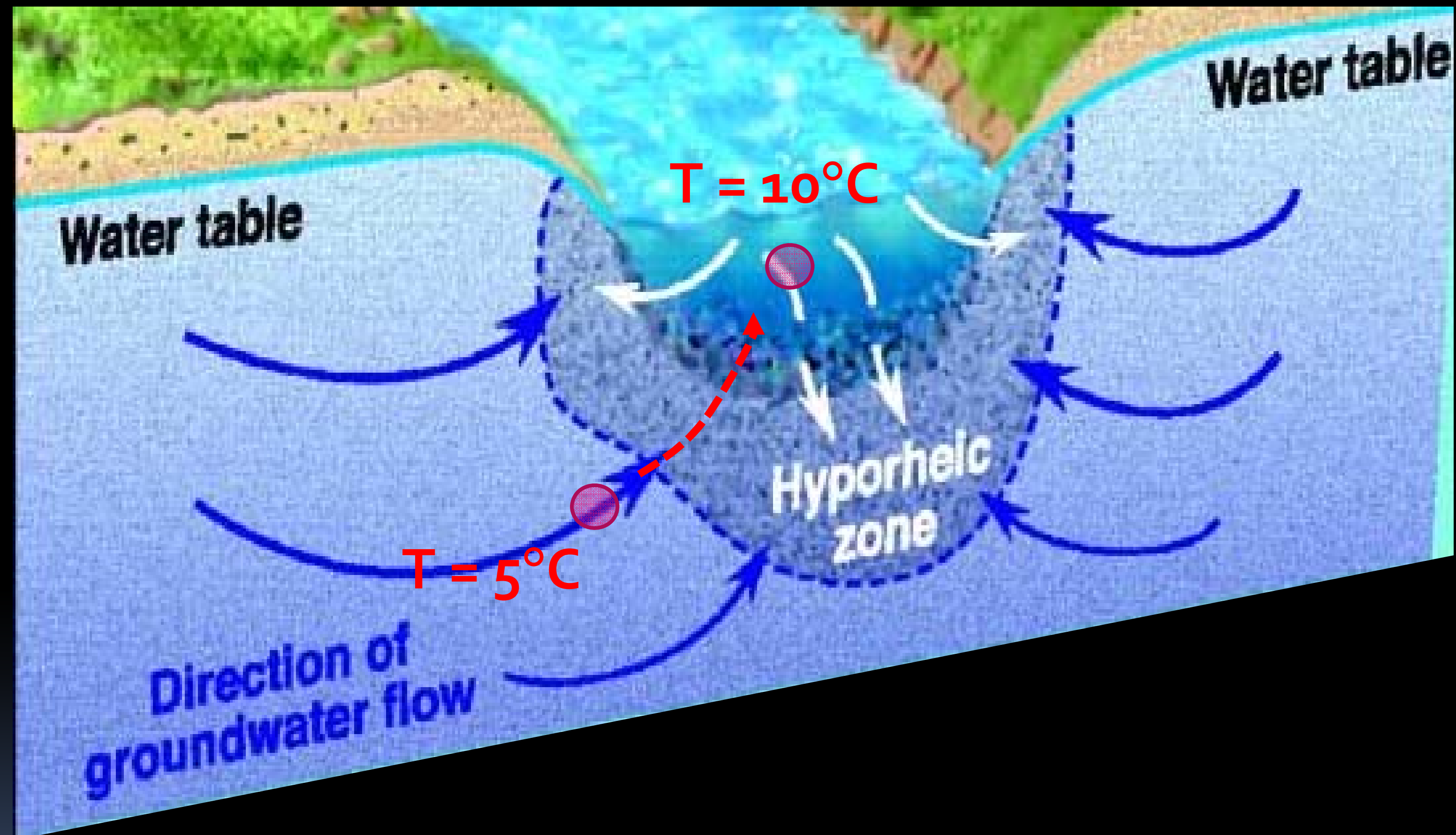
- Groundwater flux: groundwater flow into (or out of) stream per unit area, $q = Q/A$.
- Indirect measurement techniques
  - Head (Pressure)- based
  - Temperature-based

Head (pressure)-based



Darcy's Law: $$q = -K\frac{\Delta h}{\Delta \ell}$$

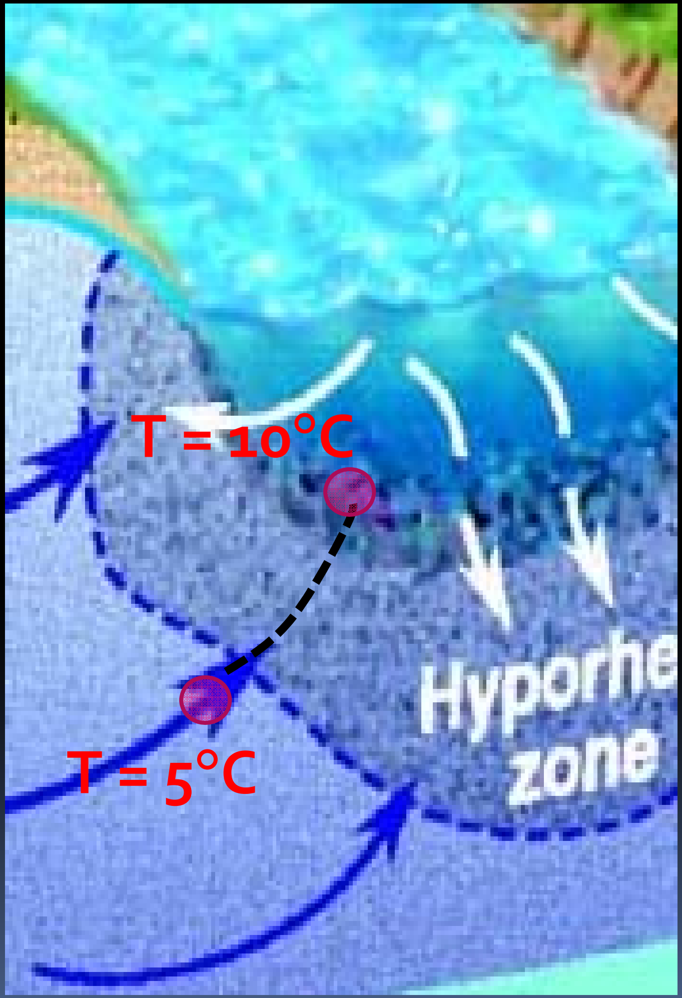
Temperature-based



Heat transfer equation (steady-state)

diffusion   convection

$$nk\frac{\partial^2 T}{\partial z^2} - q_z c_w \rho_w \frac{\partial T}{\partial z} = 0$$



T = temperature

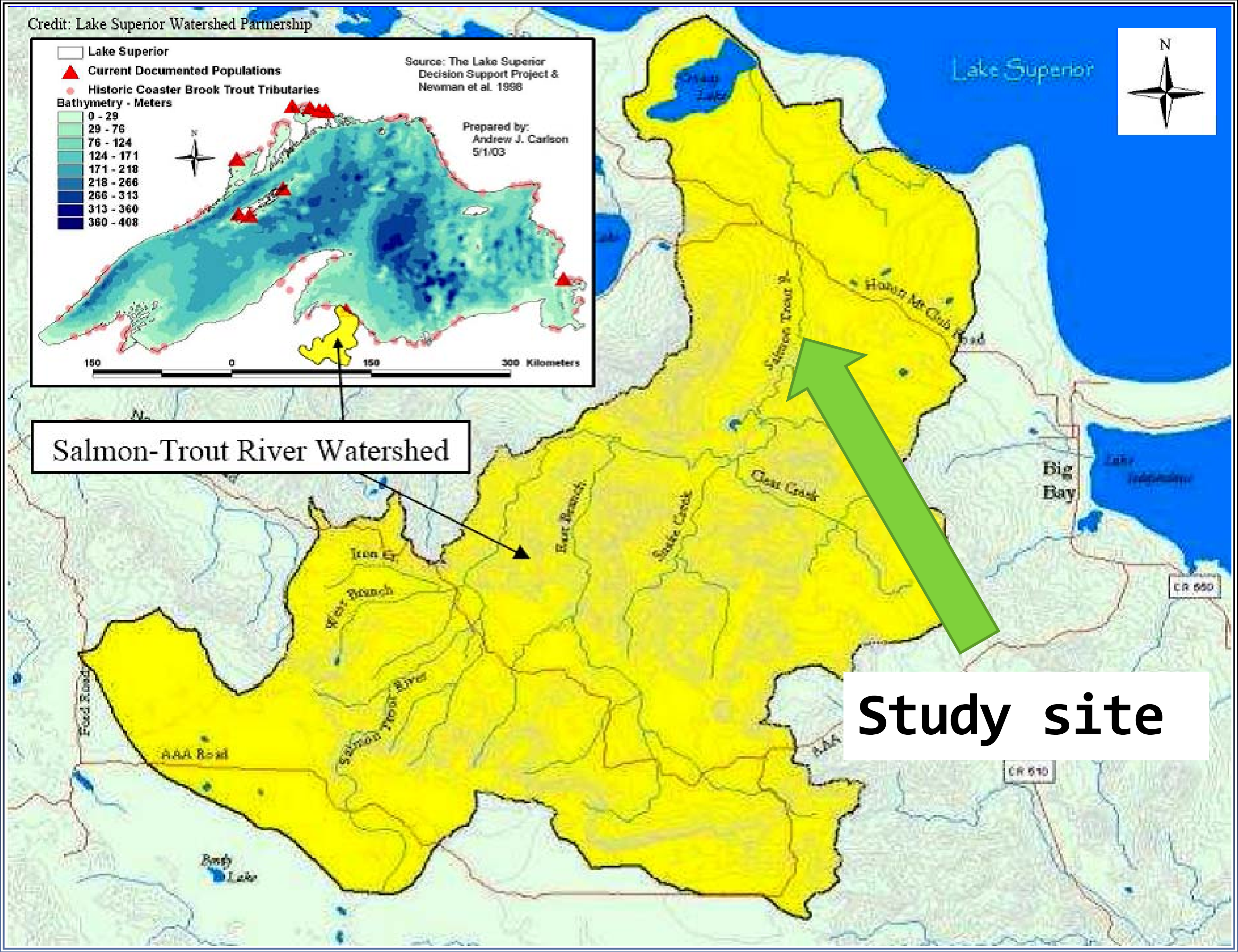
n = porosity

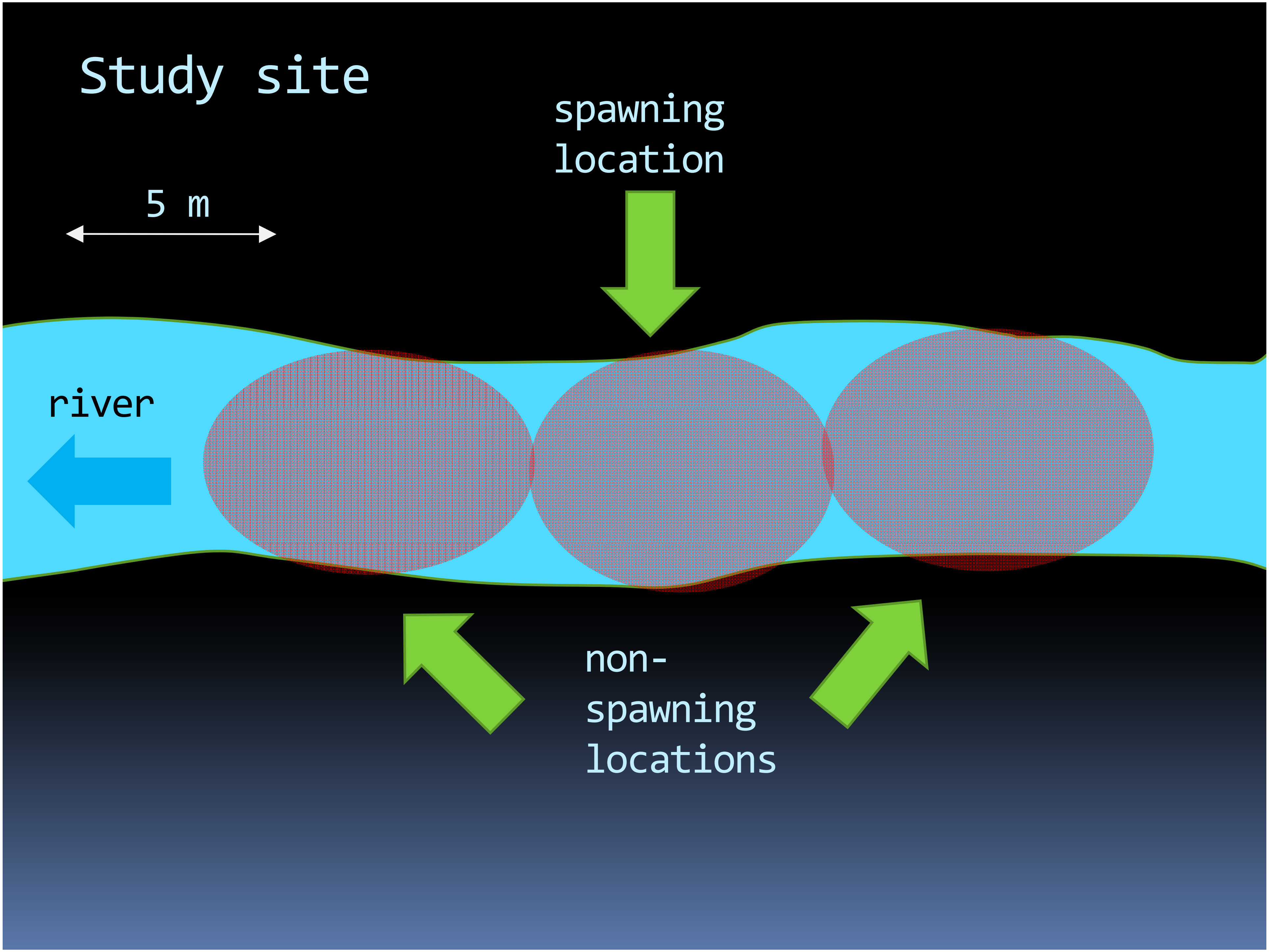
k = water-porous medium matrix thermal conductivity

q_z = vertical groundwater flux

c_w = water volumetric heat capacity

ρ_w = water density

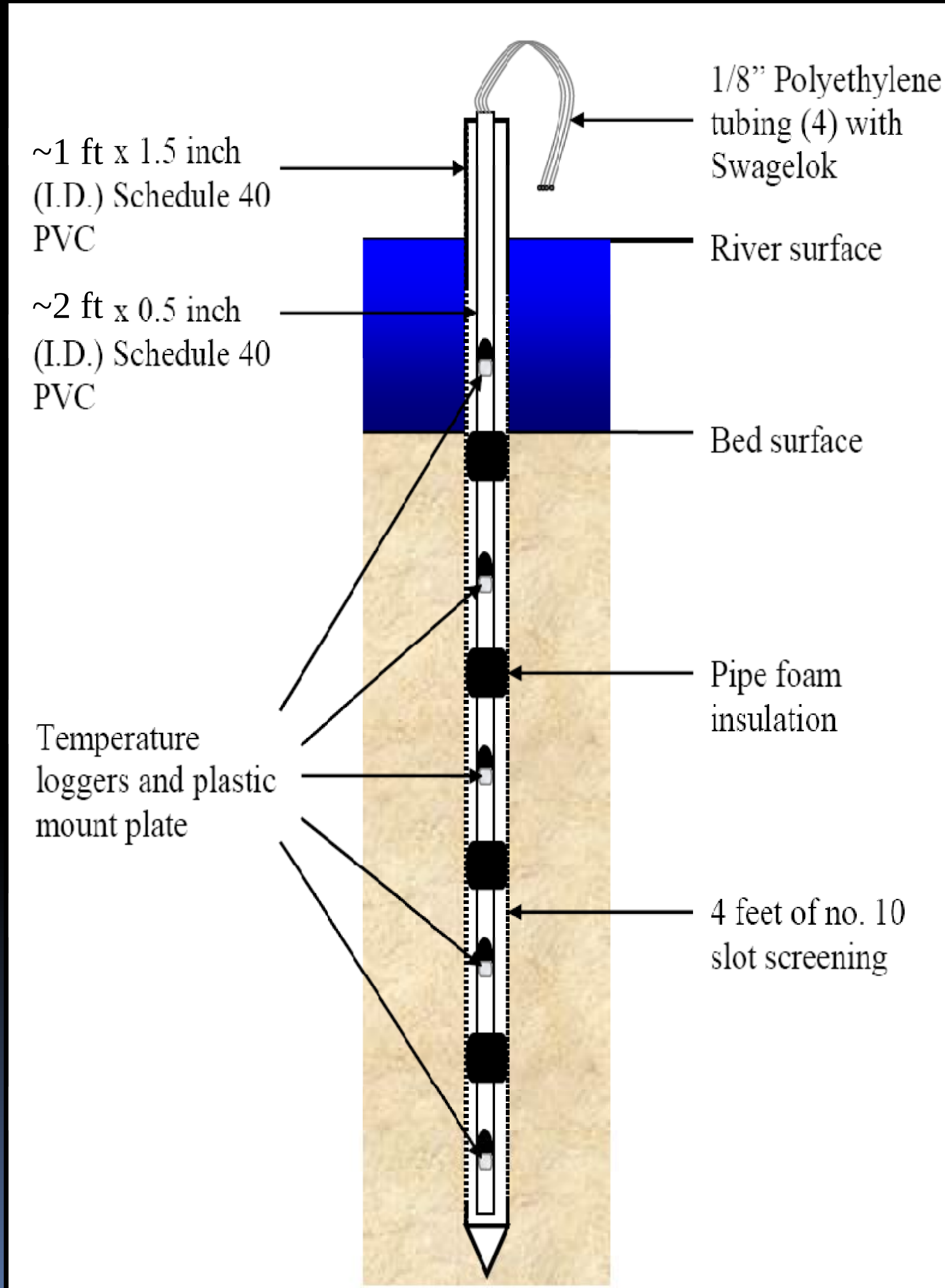

Credit: Lake Superior Watershed Partnership
Lake Superior
Current Documented Populations
Historic Coaster Brook Trout Tributaries
Bathymetry - Meters
0 - 29
29 - 76
76 - 124
124 - 171
171 - 218
218 - 266
266 - 313
313 - 360
360 - 408
Source: The Lake Superior Decision Support Project & Newman et al. 1998
Prepared by: Andrew J. Carlson 5/1/03
150 0 150 300 Kilometers
Salmon-Trout River Watershed
Lake Superior
N
Salmon Trout R.
Huron Mt Club Road
Clear Creek
Big Bay
East Branch
Snake Creek
Iron Cr.
West Branch
Salmon Trout River
AAA Road
Ford Road
CR 550
CR 510
Study site


Study site
spawning location
5 m
river
non-spawning locations

Monitoring well design

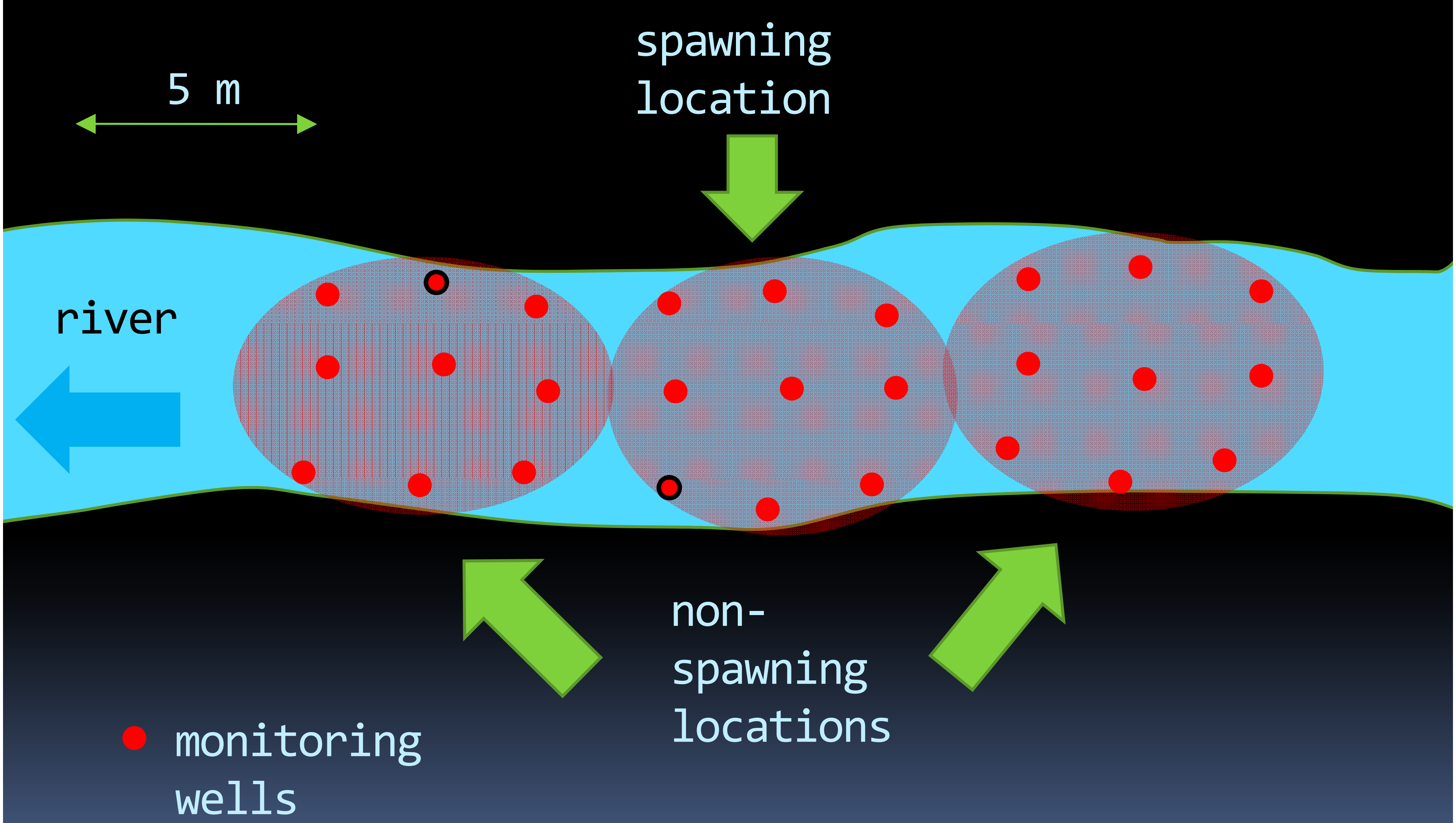
- Allows for discrete measurement of temperature and pressures with depth.

“i-button” temperature logger



Monitoring well installation

Monitoring well network



Modeling & parameter inversion

$$nk\frac{\partial^2 T}{\partial z^2} - q_z c_w \rho_w \frac{\partial T}{\partial z} = nc\rho\frac{\partial T}{\partial t}$$

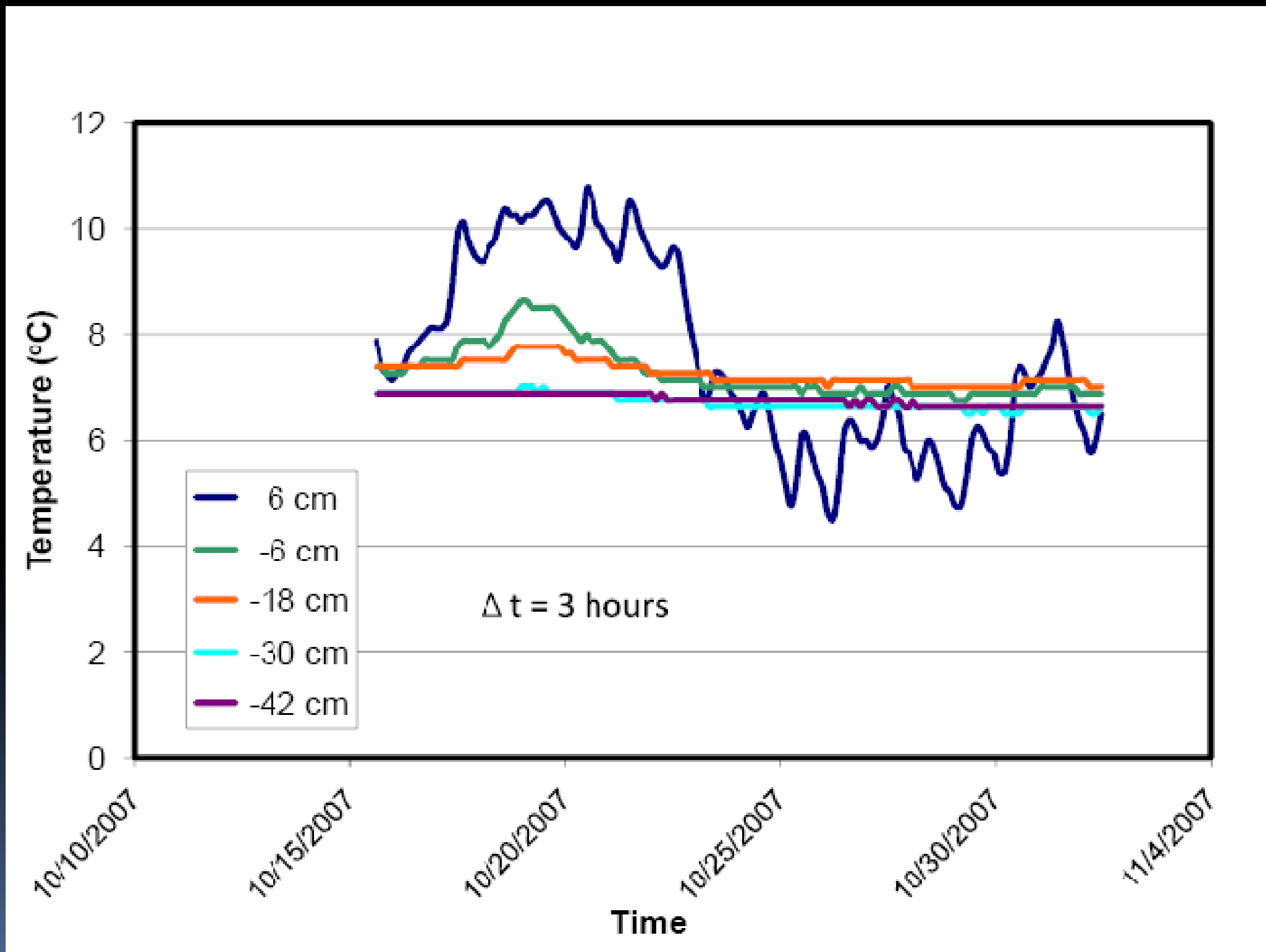
- Solve heat transfer equation using implicit finite-difference approximation.
- Find "best-fit" value of q_z using steepest descent method, where best-fit is defined as

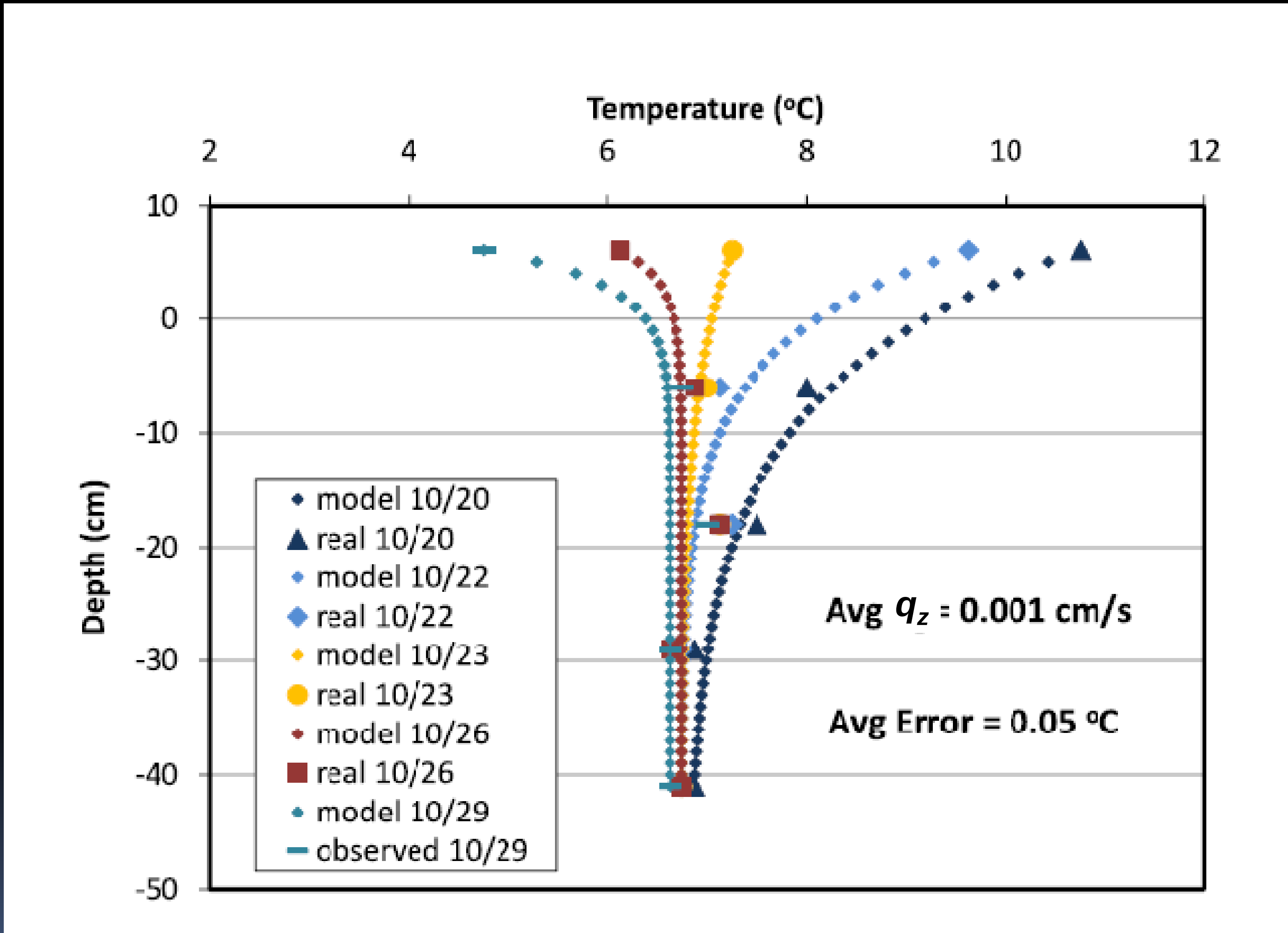
$$\min \sum_{i=1}^{N} \left(T_{i,\text{model}} - T_{i,\text{observed}} \right)^2$$

- All other parameters estimated independently using empirical relationships.

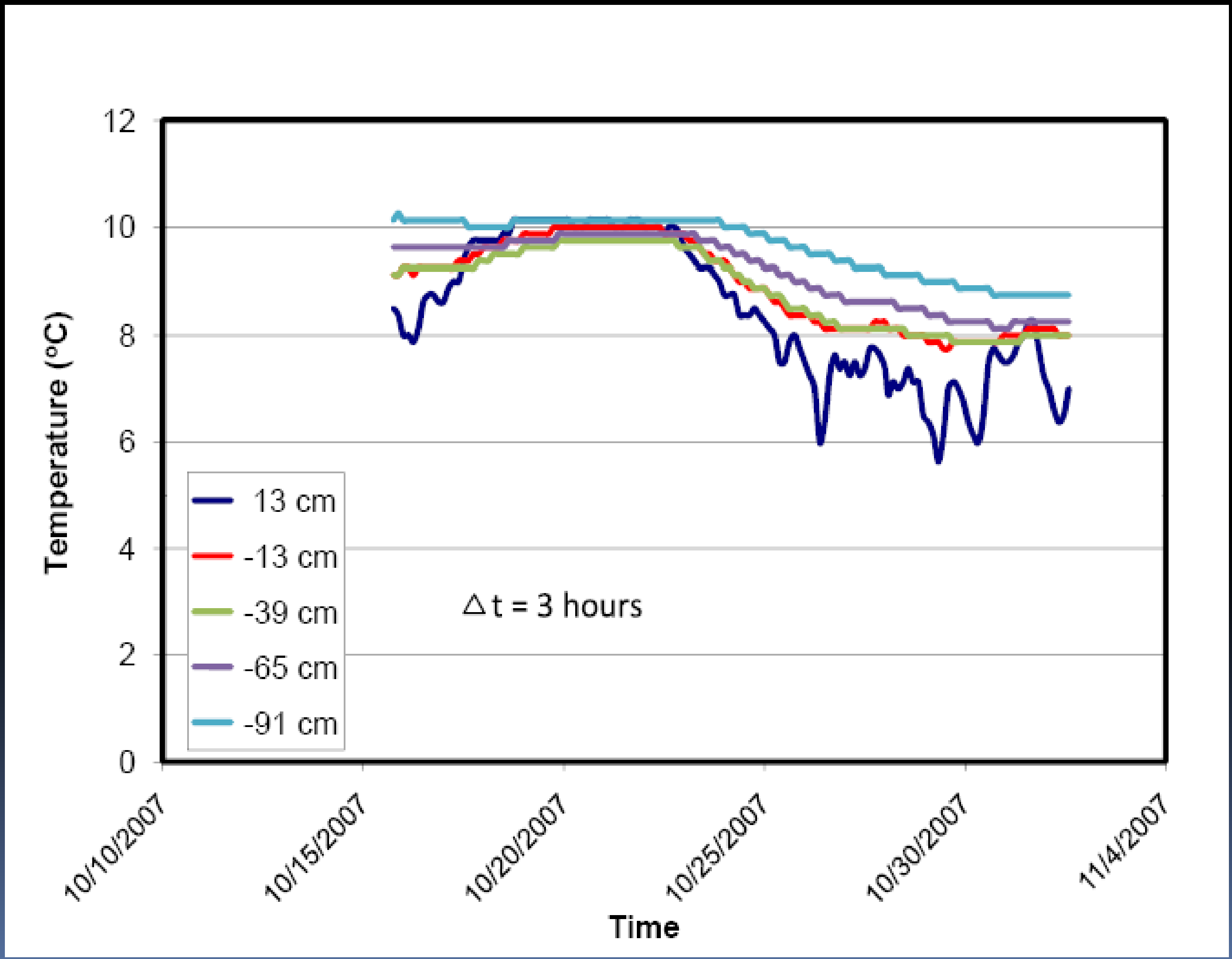
Results

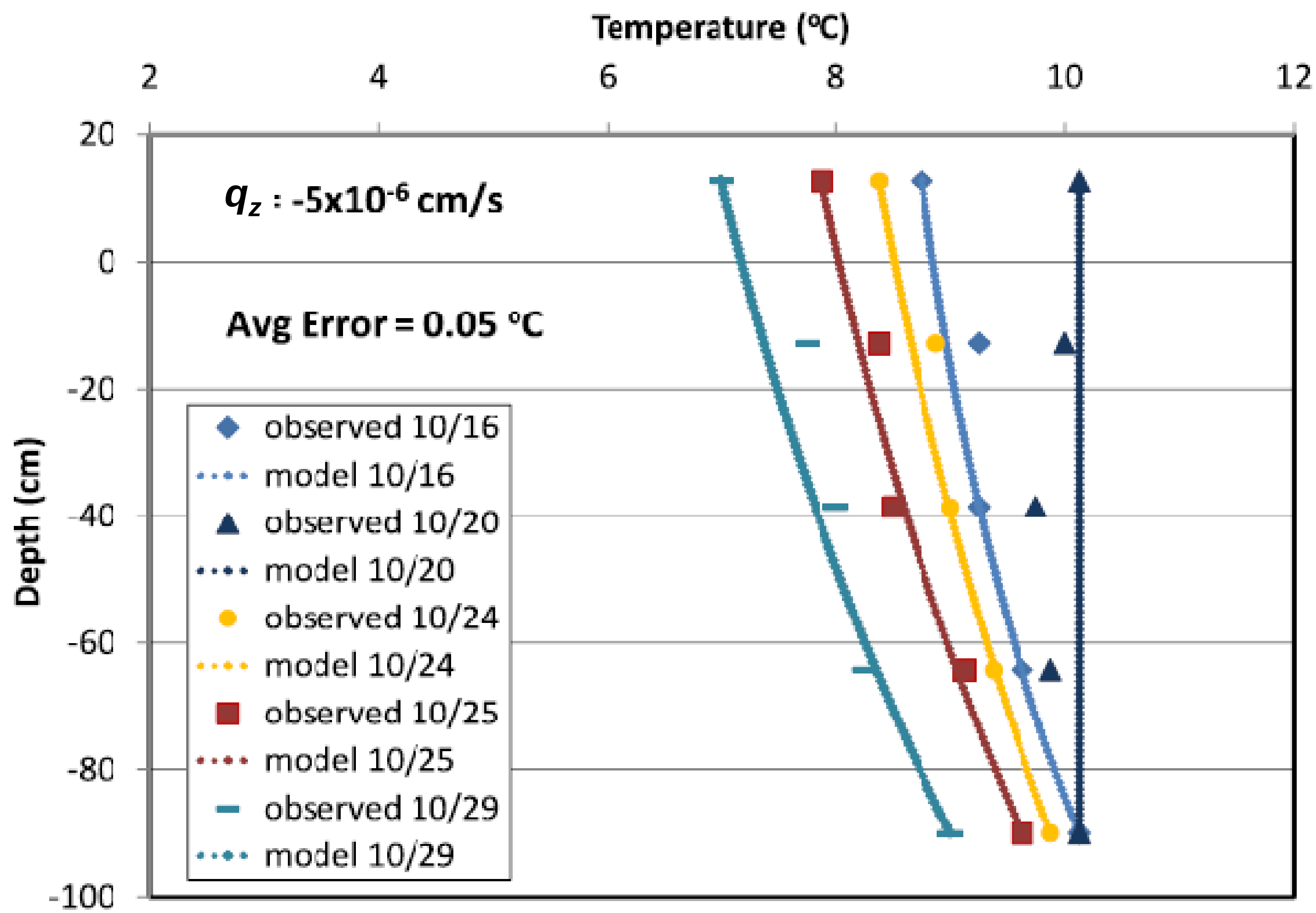
Well 6.3 (spawning section)




Temperature (°C)
2
4
6
8
10
12
10
0
-10
-20
-30
-40
-50
Depth (cm)
model 10/20
real 10/20
model 10/22
real 10/22
model 10/23
real 10/23
model 10/26
real 10/26
model 10/29
observed 10/29
Avg q_z = 0.001 cm/s
Avg Error = 0.05 °C

Well 8.1 (non-spawning section)





Temperature (ºC)
2
4
6
8
10
12
20
0
-20
-40
-60
-80
-100
Depth (cm)
qz : -5x10-6 cm/s
Avg Error = 0.05 °C
observed 10/16
model 10/16
observed 10/20
model 10/20
observed 10/24
model 10/24
observed 10/25
model 10/25
observed 10/29
model 10/29

Conclusions and future work

- A monitoring system capable of providing estimates of groundwater fluxes has been implemented.
- Significant variations were observed in groundwater fluxes between locations in the spawning- and non-spawning areas.
- The pressure monitoring system will be improved so that pressure measurements can be used to estimate groundwater fluxes.

Conclusions and future work

- Simultaneous inversion of temperature and pressure data will provided more confidence in groundwater flux estimates.
- A second site will be instrumented this spring.
- Groundwater discharge surveys of streams will be conducted to assess suitability for introduction of coaster brook trout.