

Use of heat as a tracer of stream
exchanges
with shallow ground water near bank
filtration facilities

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Why is heat a good tracer for examining ground-water flow near streams?

1. Heat is free of real or perceived issues concerning chemical tracers, in terms of pollution or intangibles.
2. Measurement of temperature gradients form the basis for the use of heat as a tracer; temperature has become an economical and robust parameter to measure in the stream environment
3. Heat and ground-water transport models have become widely accessible, and easily run on systems as small as laptops.

There are three distinct vertical locations within the stream environment, where monitoring temperature patterns permits the application of heat as a tracer of water fluxes

I. Analysis of temperature and streamflow variation (i.e., analysis within the water column).

Constantz, Water Resources Research, 1998.

II. Analysis of streambed surface temperature (i.e., analysis at the water-sediment interface.)

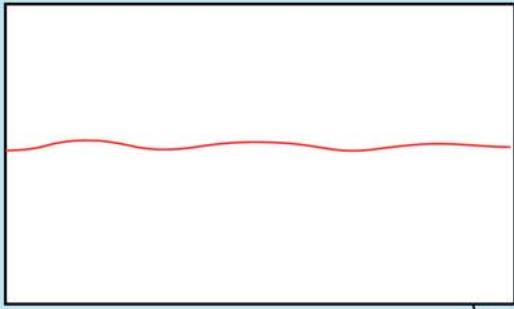
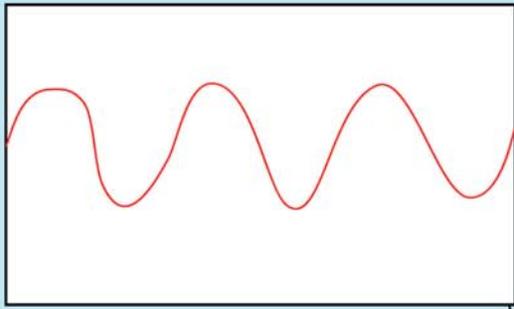
Constantz et al., Water Resources Research, 2001.

III. Analysis of sediment temperature profiles (i.e., analysis beneath the streambed)

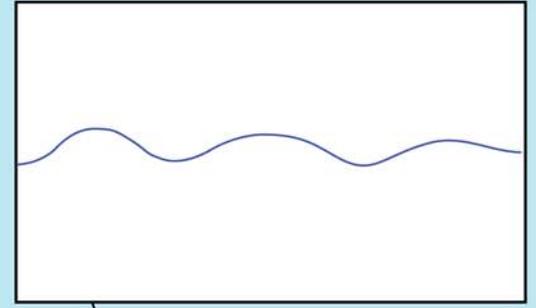
Constantz et al., Water Resources Research, in review; Constantz et al., Vadose Zone Journal, in review; Constantz et al., Ground Water, in review.

GAINING STREAM

Temperature



Streamflow



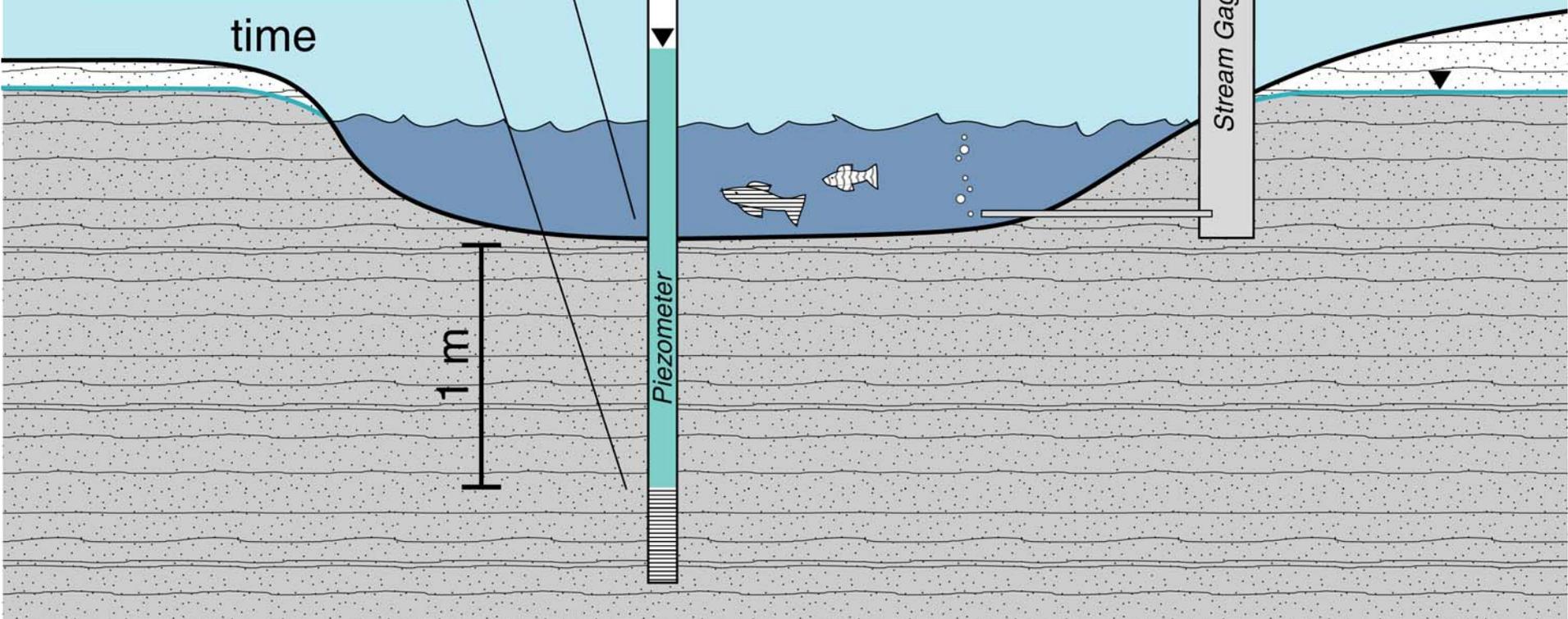
time

time

Piezometer

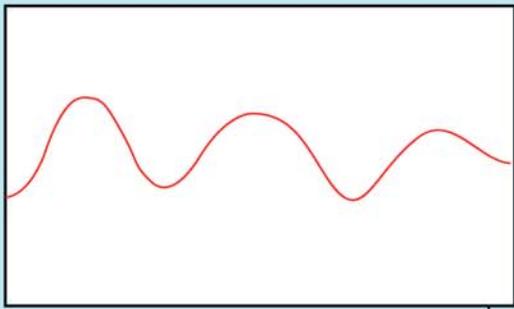
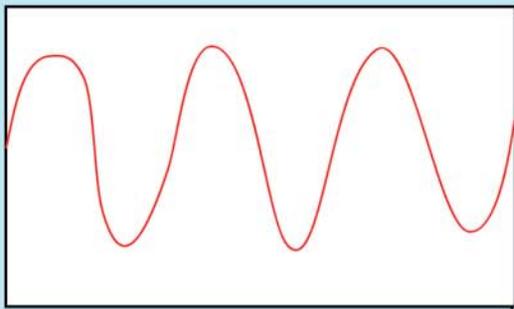
Stream Gage

1 m

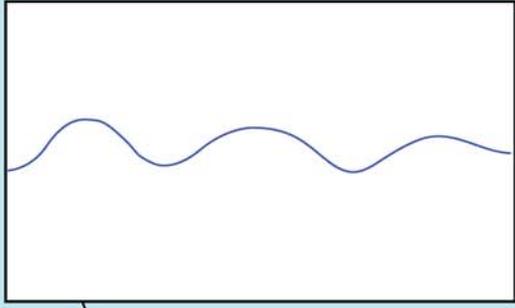


LOSING STREAM

Temperature

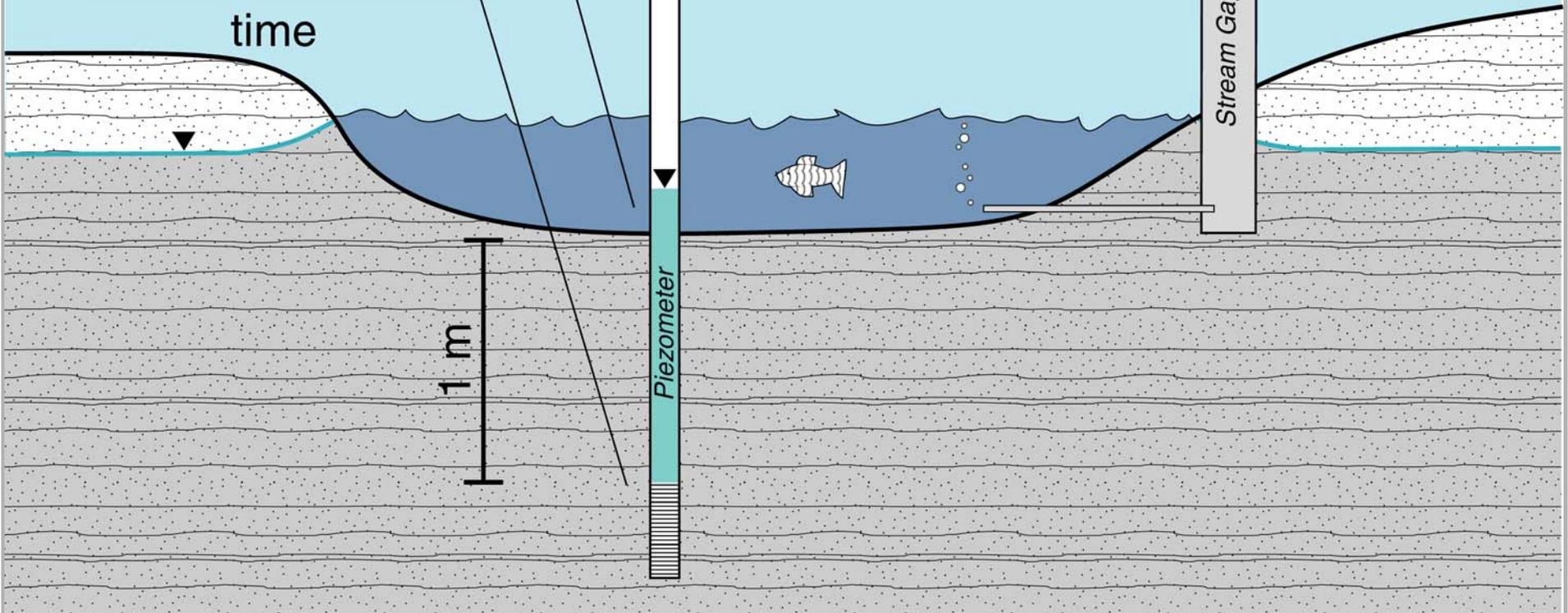


Streamflow



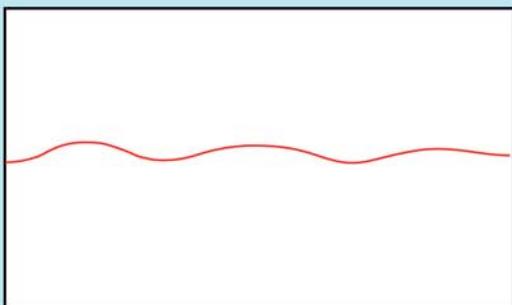
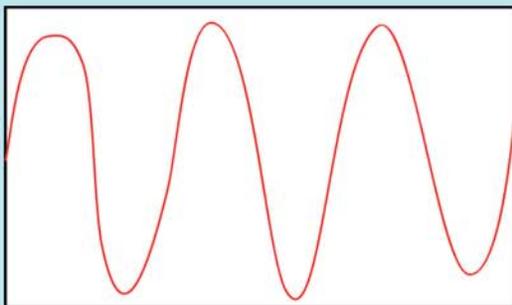
time

time



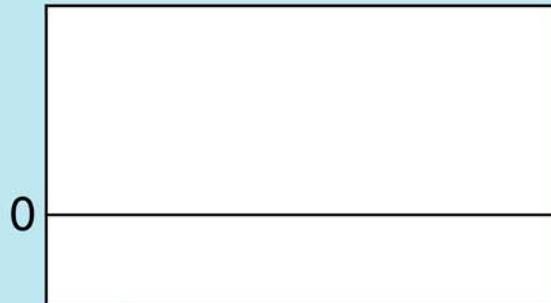
DRY STREAMBED

Temperature

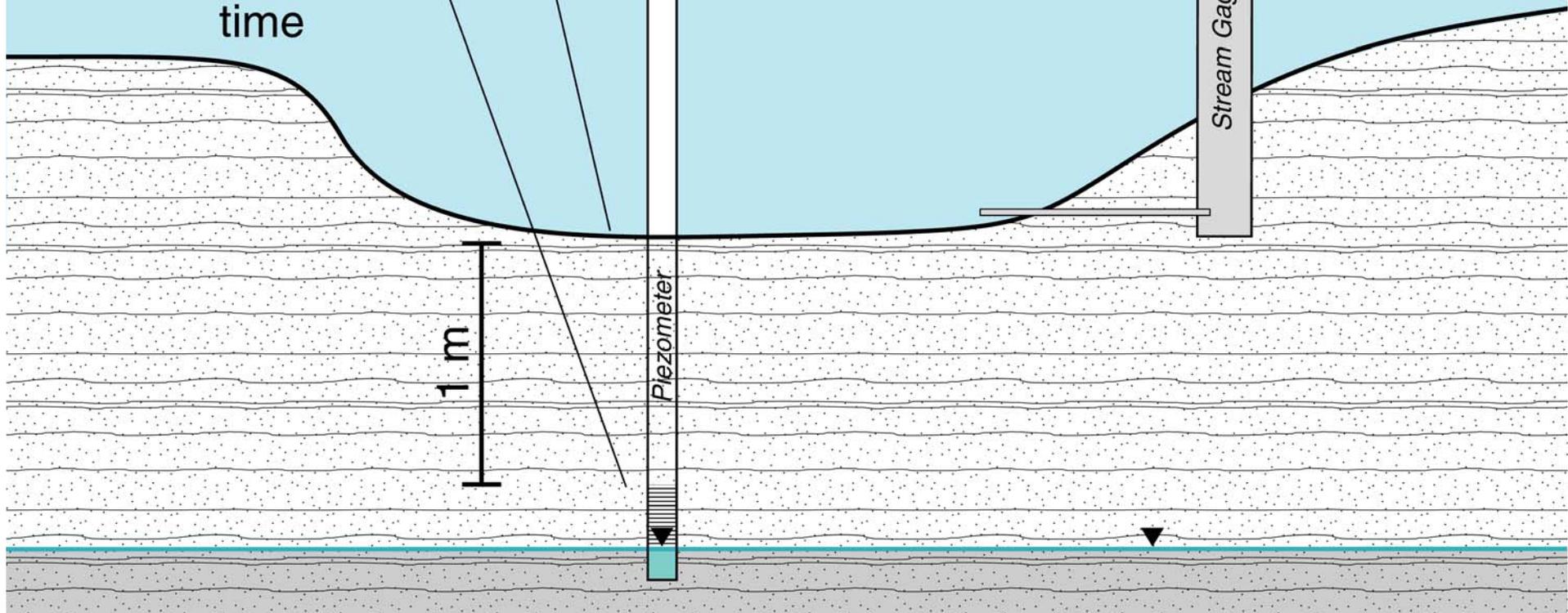


time

Streamflow

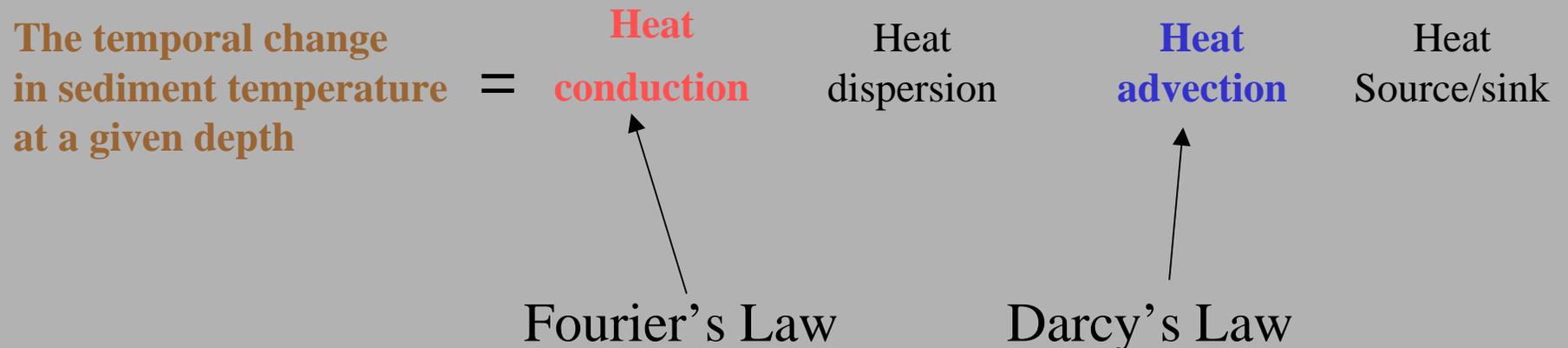


time

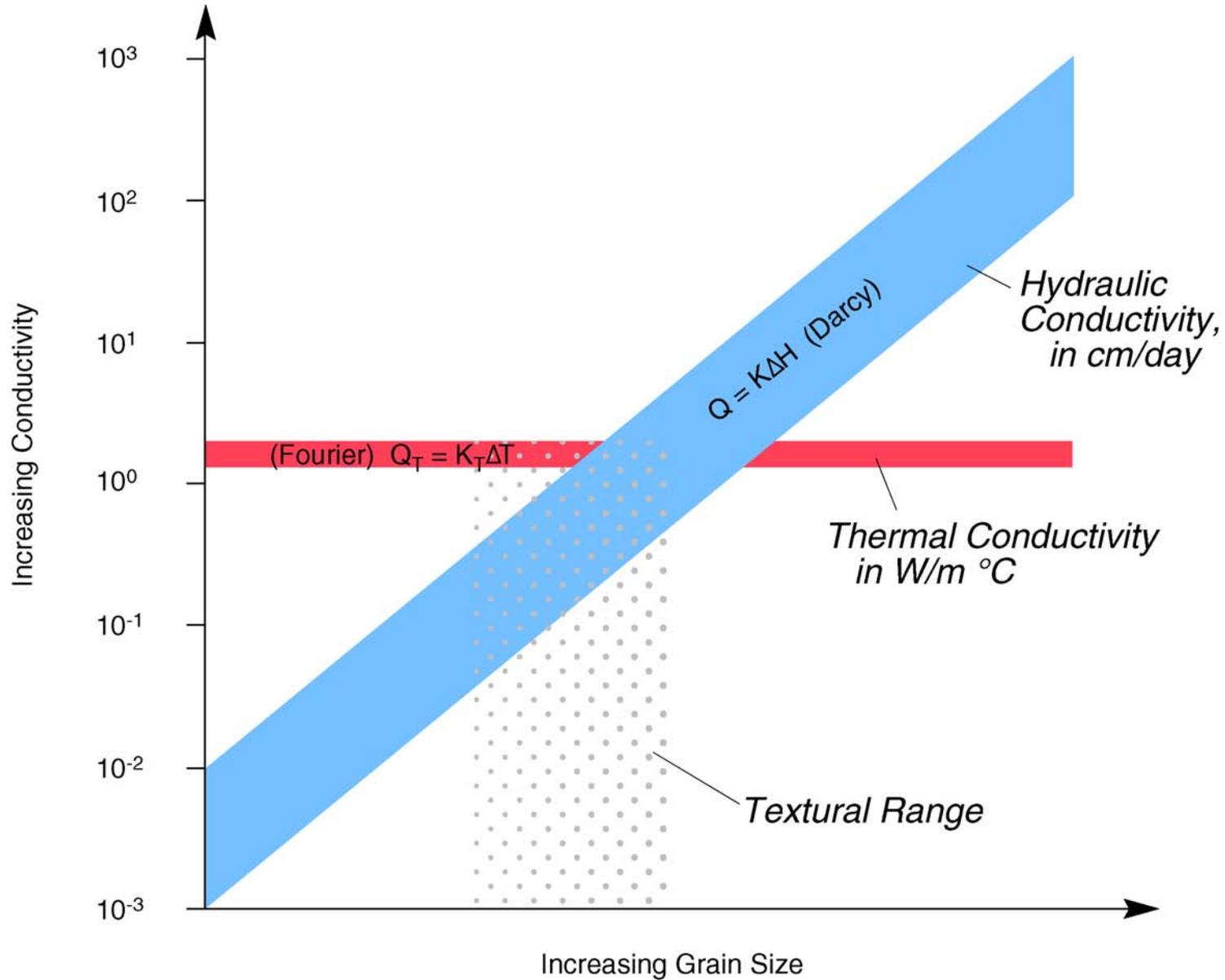


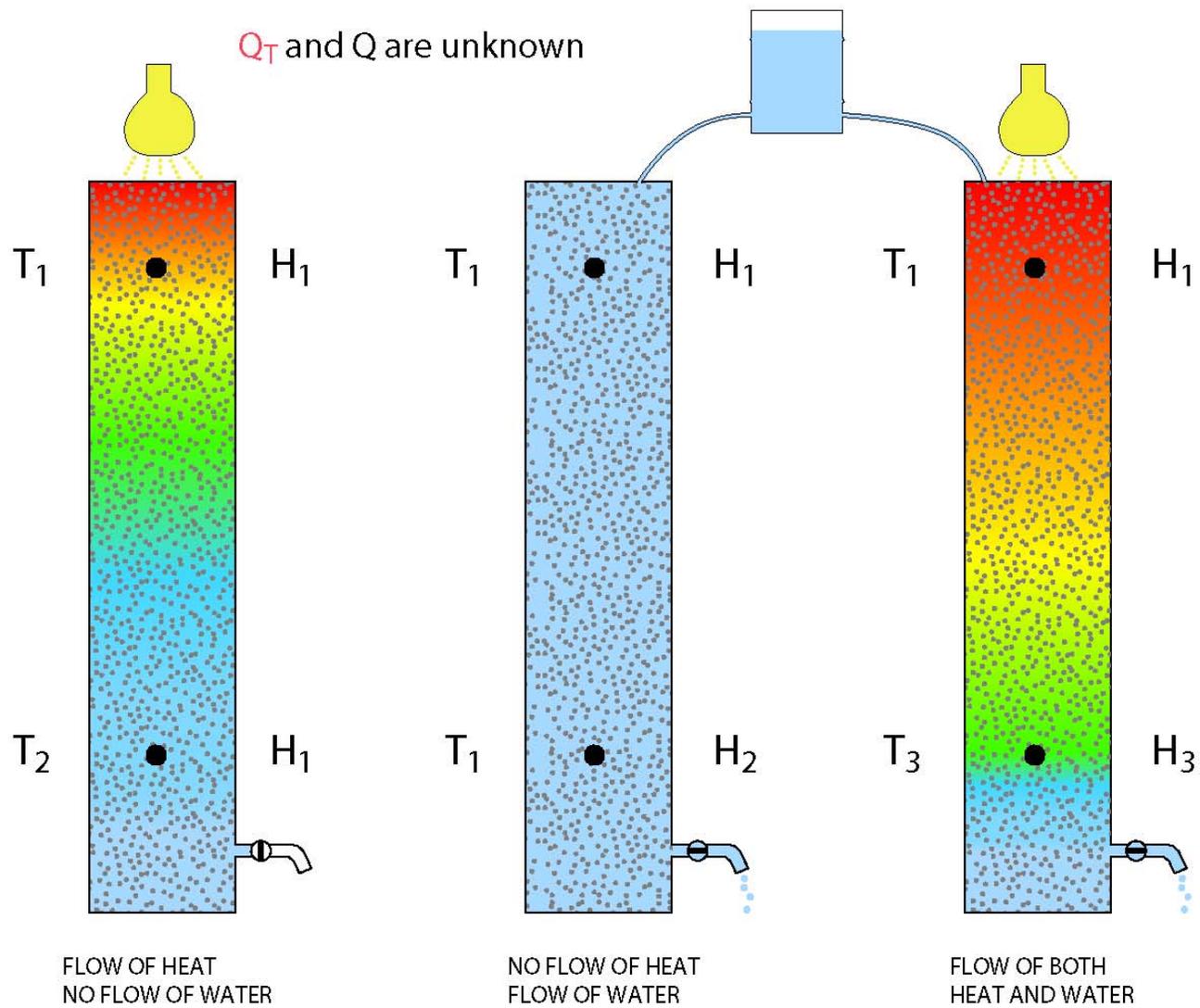
The USGS heat and ground-water transport simulation model, VS2DH, was modified from VS2DT by Rick Healy and Anne Ronan, VS2DH is designed for ponding conditions, such that heat and water transport in the vapor phase is negligible relative to their transport in the liquid phase. A form of the advection-dispersion equation is used within VS2DH to describe heat and ground-water transport for this case.

$$\frac{\partial[\theta C_w + (1-\phi)C_s]T}{\partial t} = \nabla \cdot K_t(\theta)\nabla T + \nabla \cdot \theta C_w D_h \nabla T - \nabla \cdot \theta C_w T q + Q C_w T$$



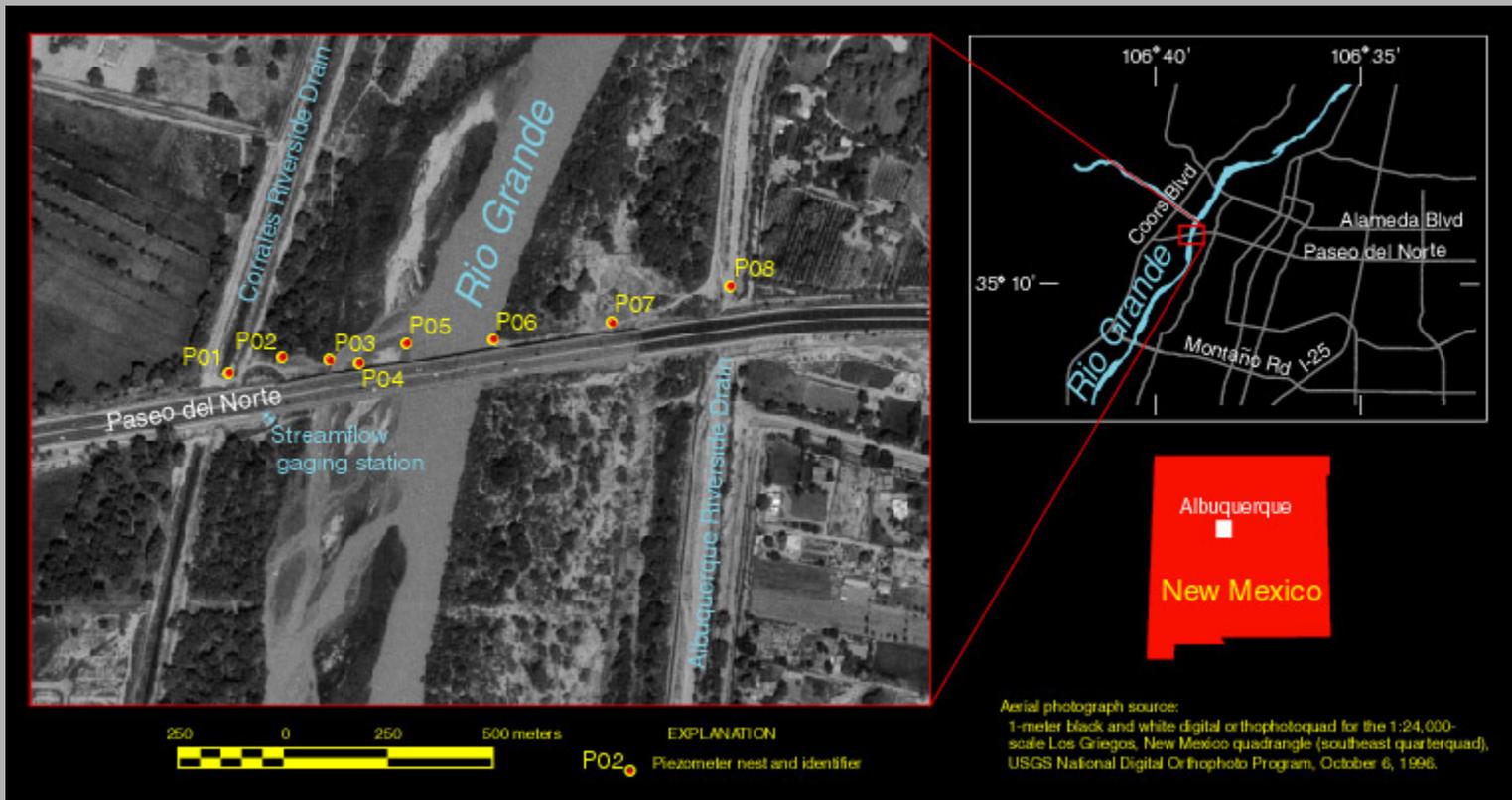
UNCERTAINTY IN THE SATURATED CONDUCTIVITY



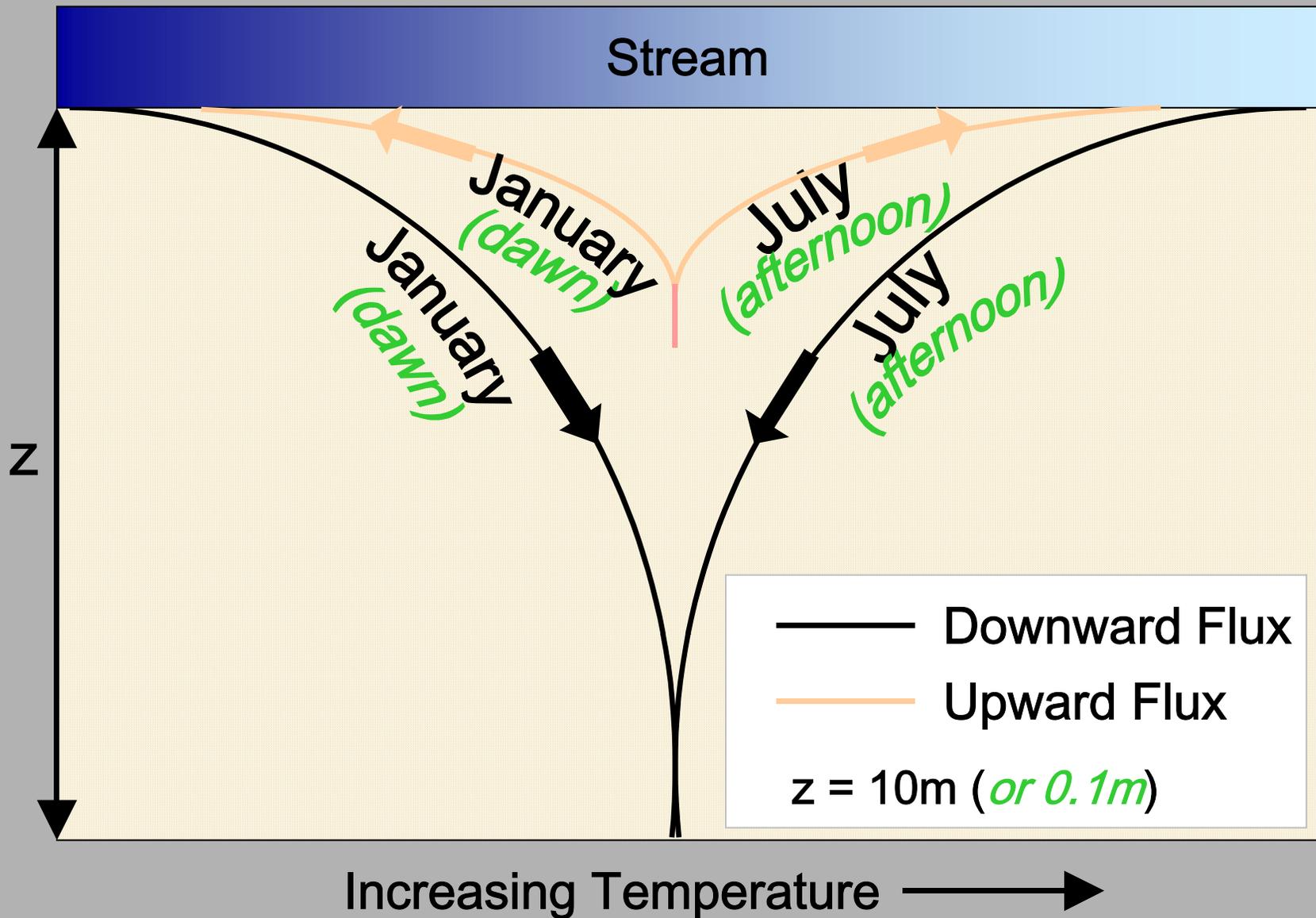


T_3 is observation. K_T is estimated and K is adjusted until $T_{sim} = T_3$.

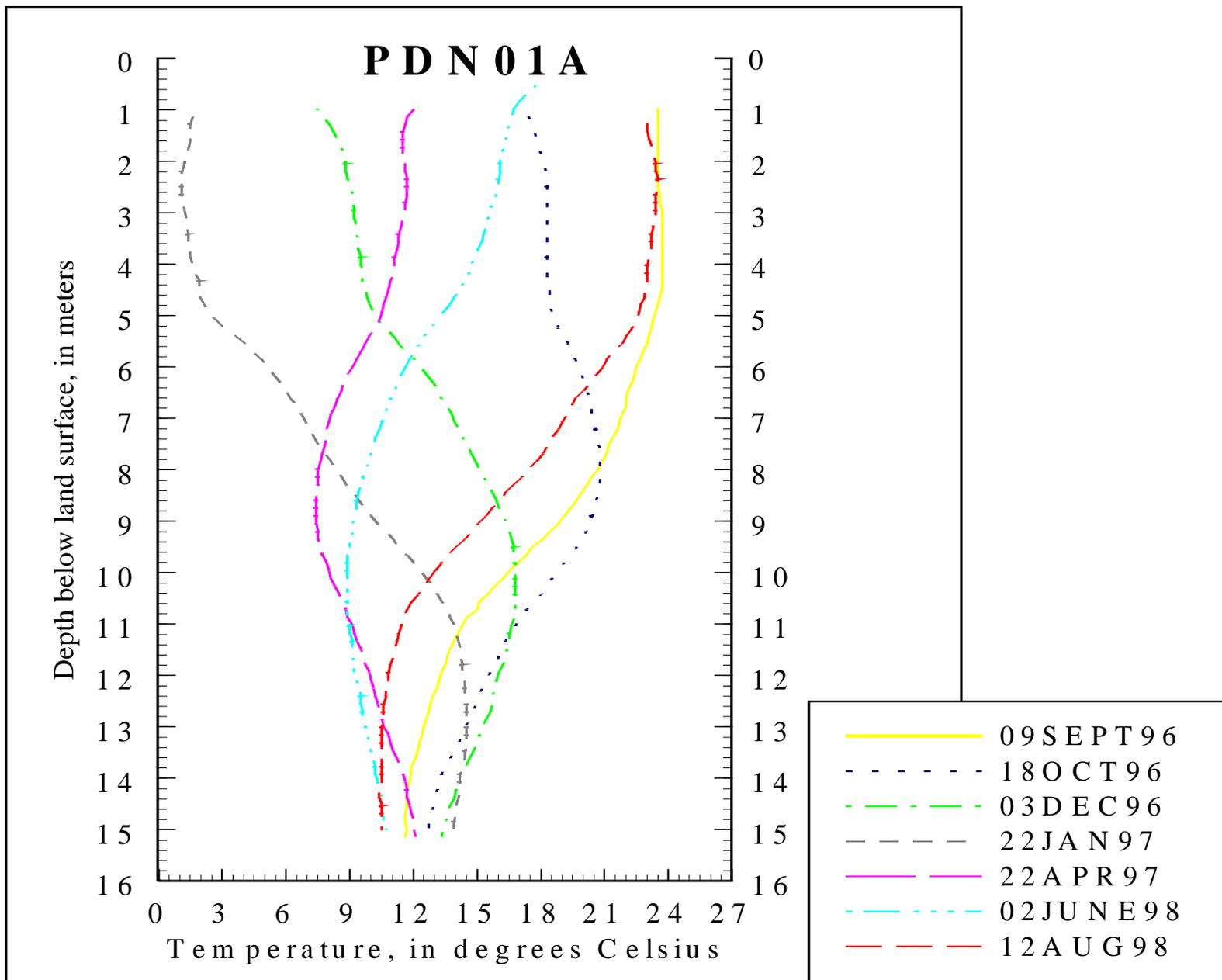
Paseo bridge site map

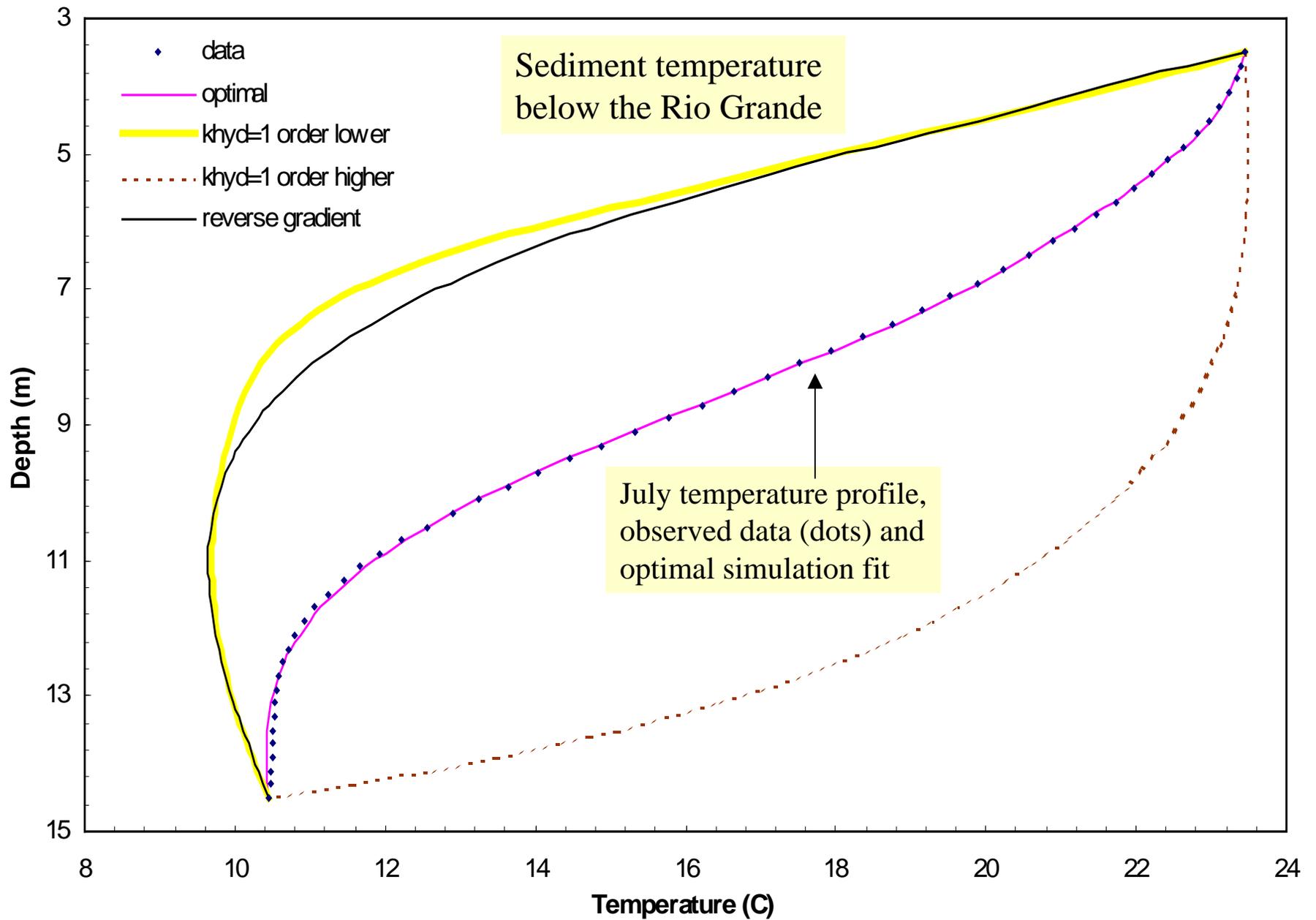


Annual (*or Diurnal*) Streambed Temperature Profile

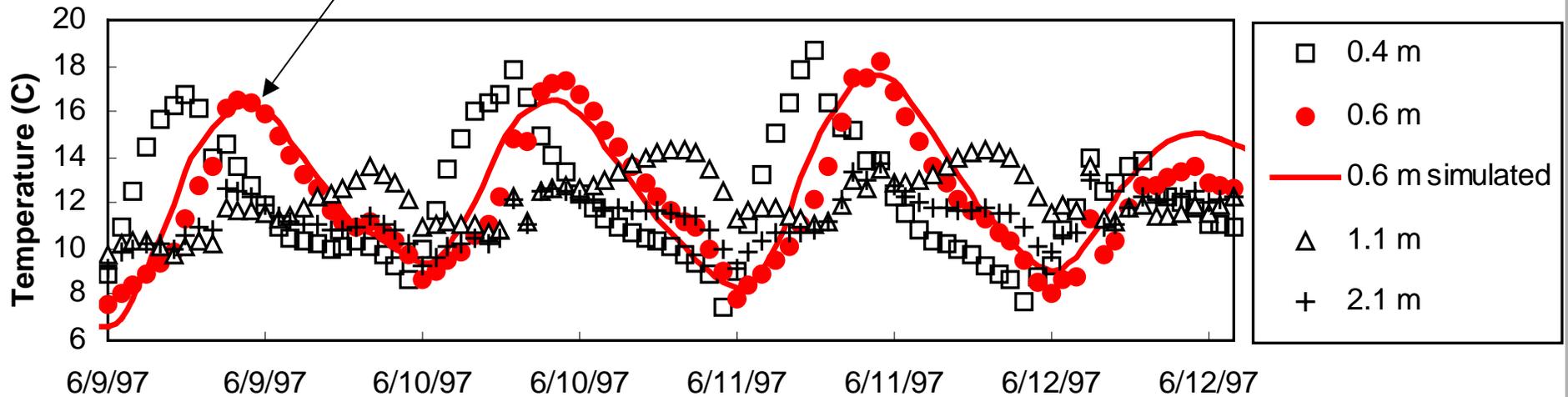


Yearly temperature envelopes

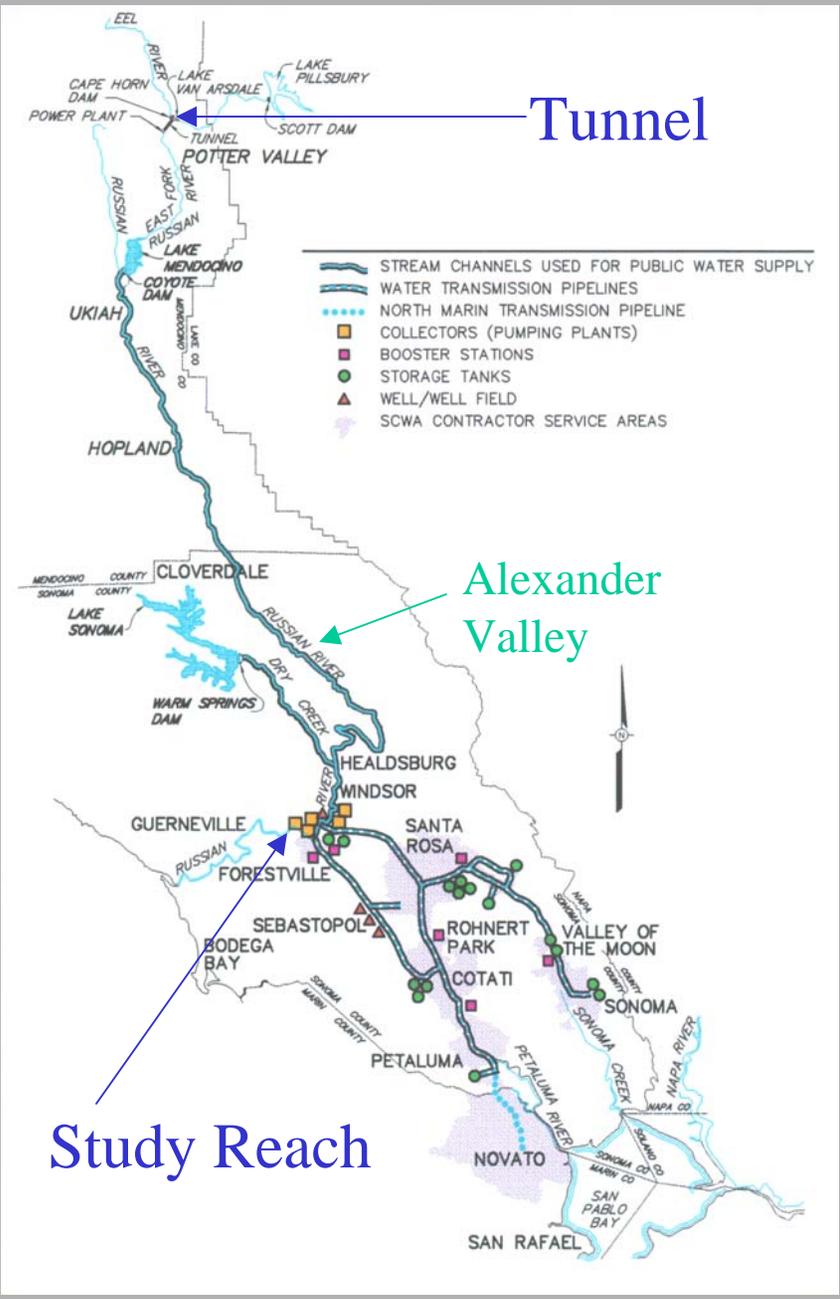




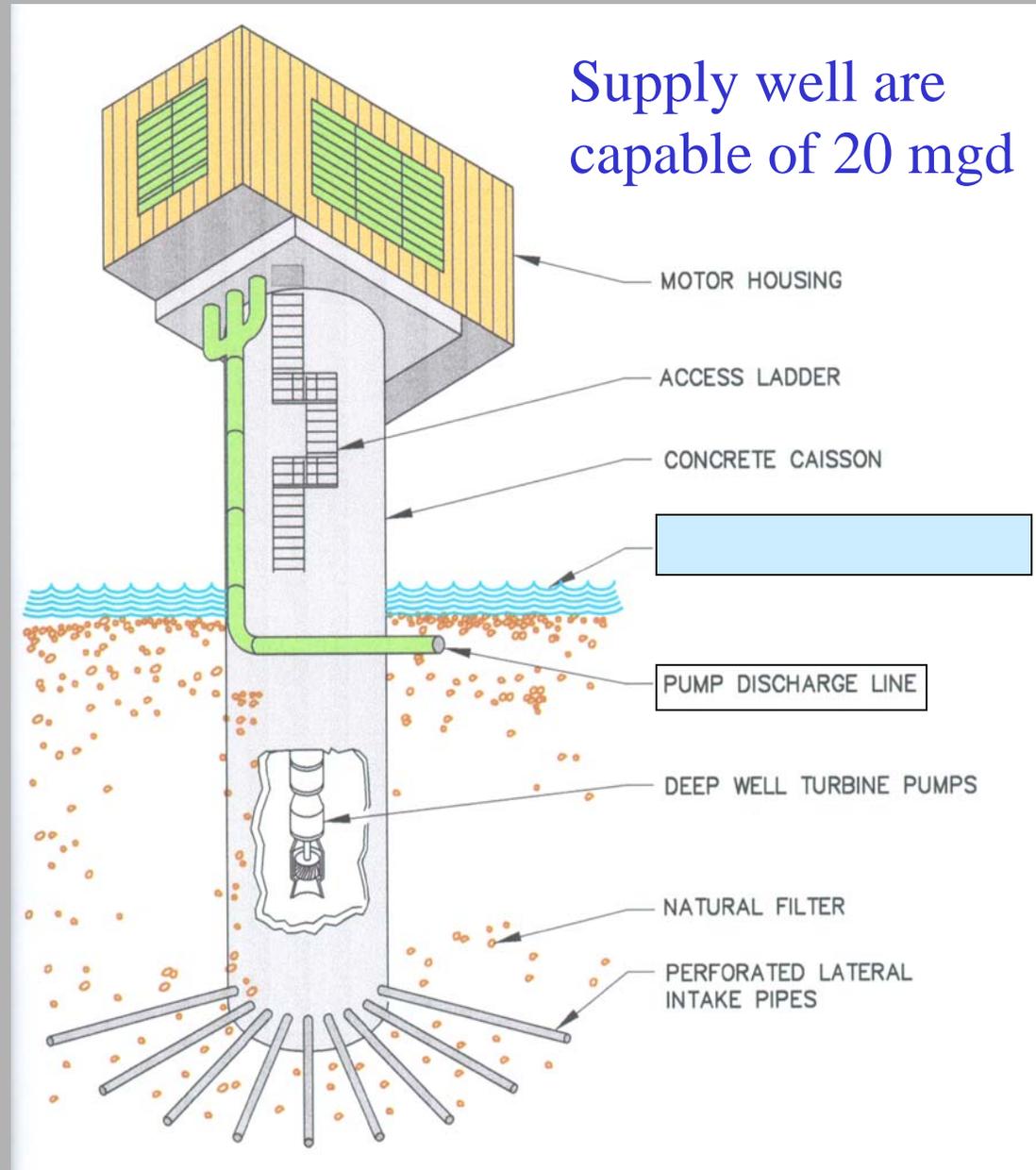
Inverse fit of simulated sediment temperature to observed temperature at a depth of 0.6 m.



This fit predicted a streambed flux rate of **0.75 m/day**. Temperature-based estimates of the surface area of streamflow permits estimates of total seepage loss for this remote, ungaged seasonal stream.

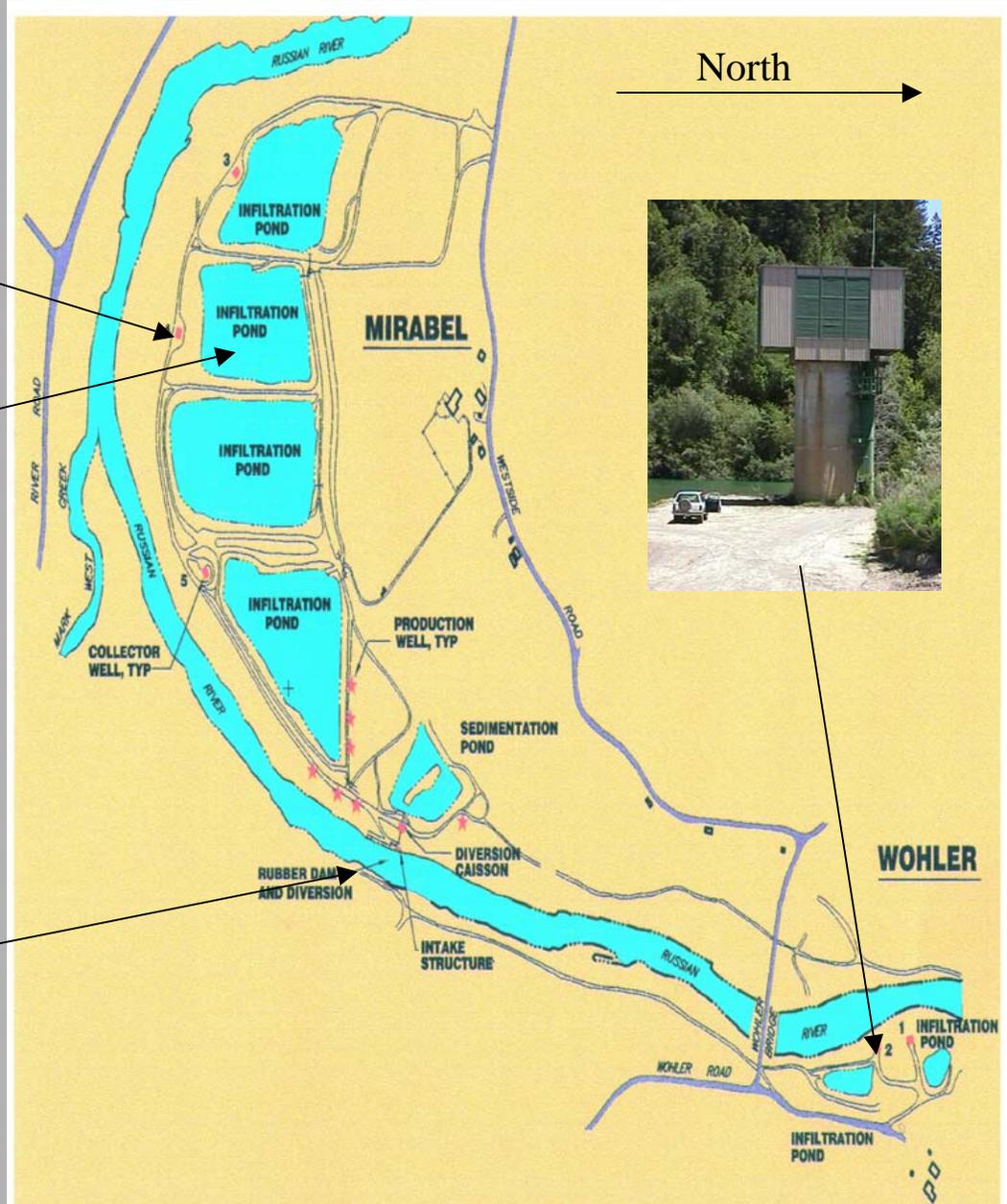


Sonoma County Water Agency operates the largest natural filtration system in the world. The streambed of the Russian River reduces the cost of water treatment by filtering out suspended sediment and colloidal materials.





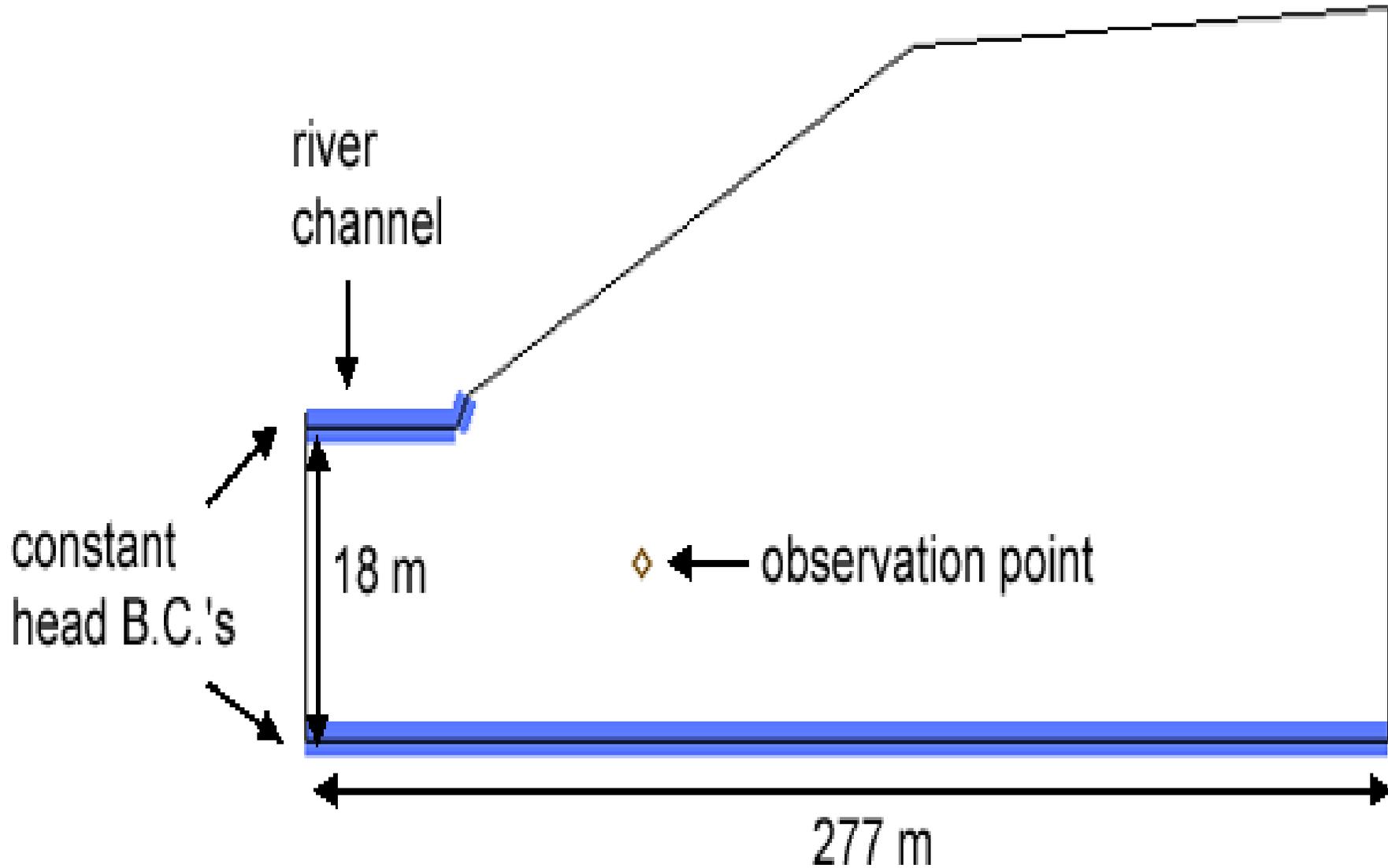
The inflatable dam is erected, May – Nov.



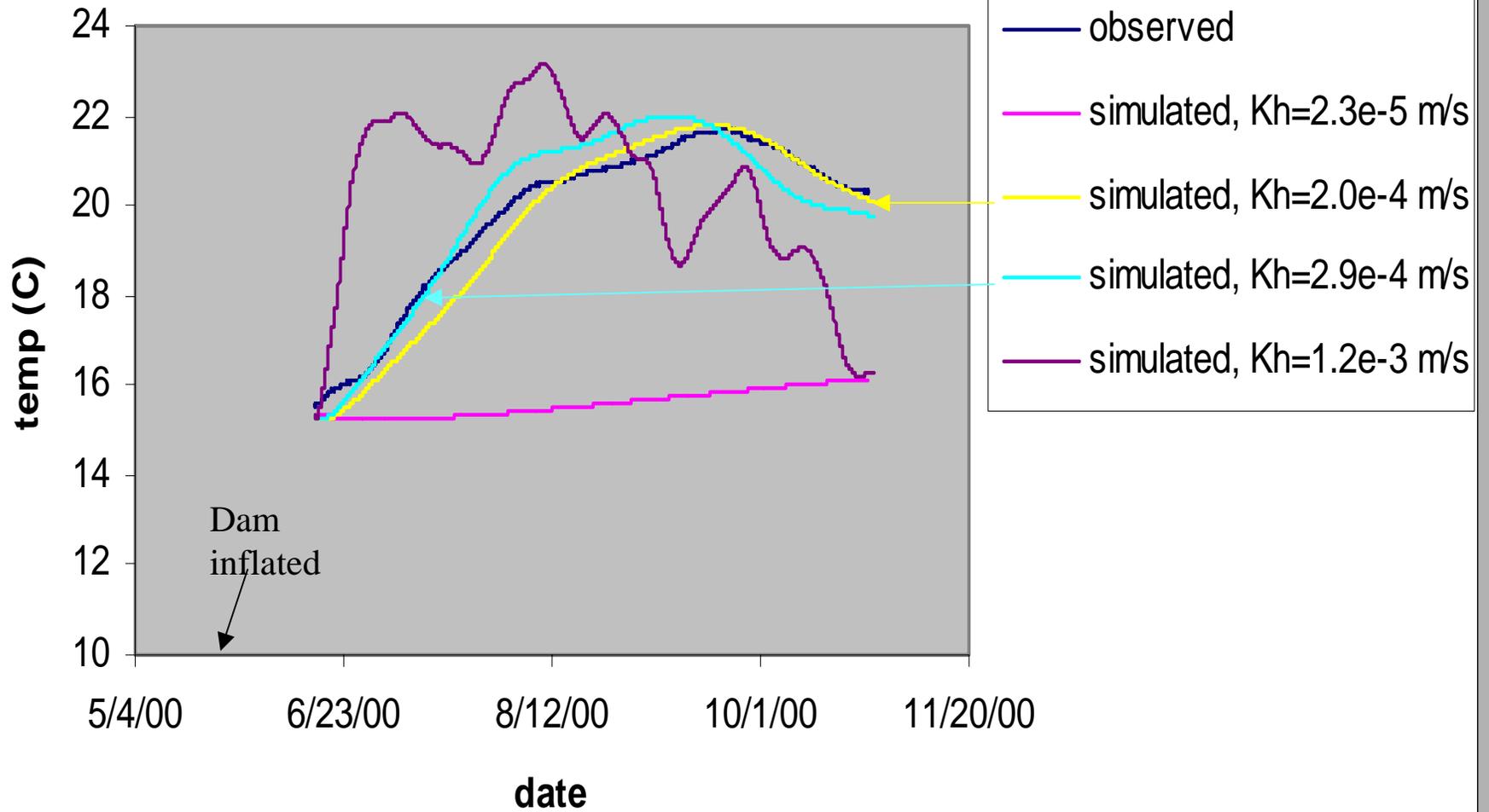
**In-stream sediment monitoring
for determining seepage rates**



Deeper ground-water monitoring



Wholer TW-01: Kh/Kv=1



Wholer Well TW-01

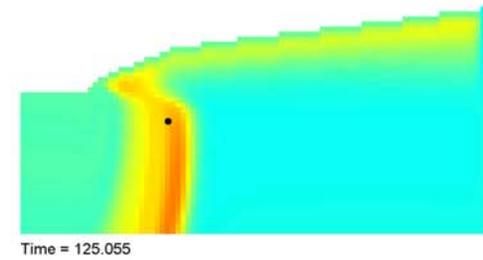
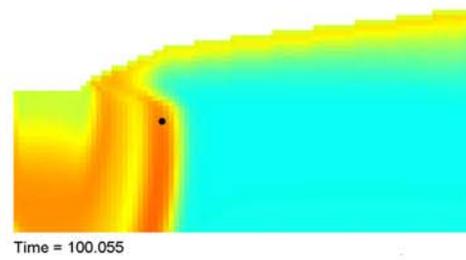
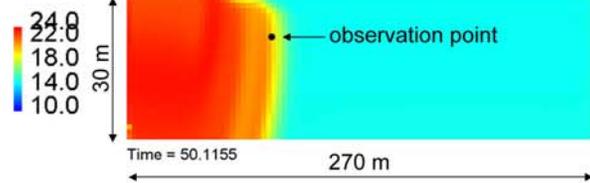
$Kh=2.0E-4$ m/s

50 days

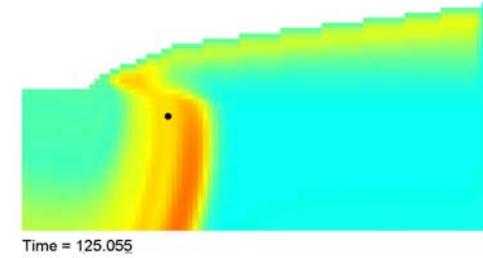
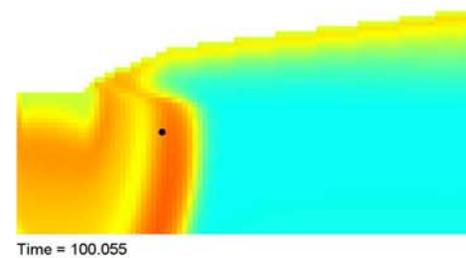
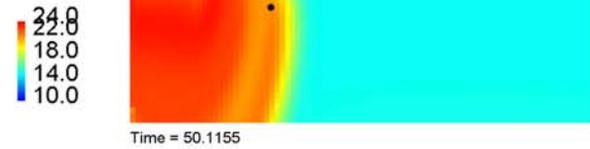
100 days

125 days

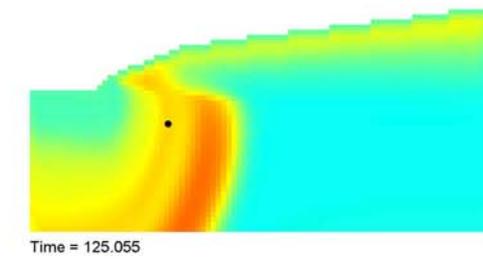
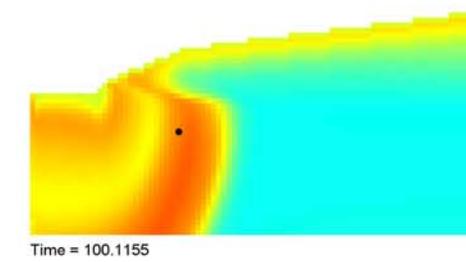
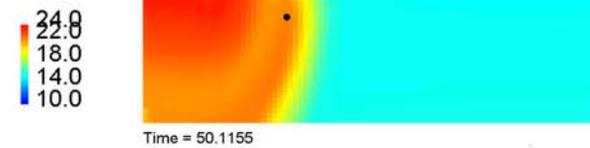
$Kh/Kv=1$

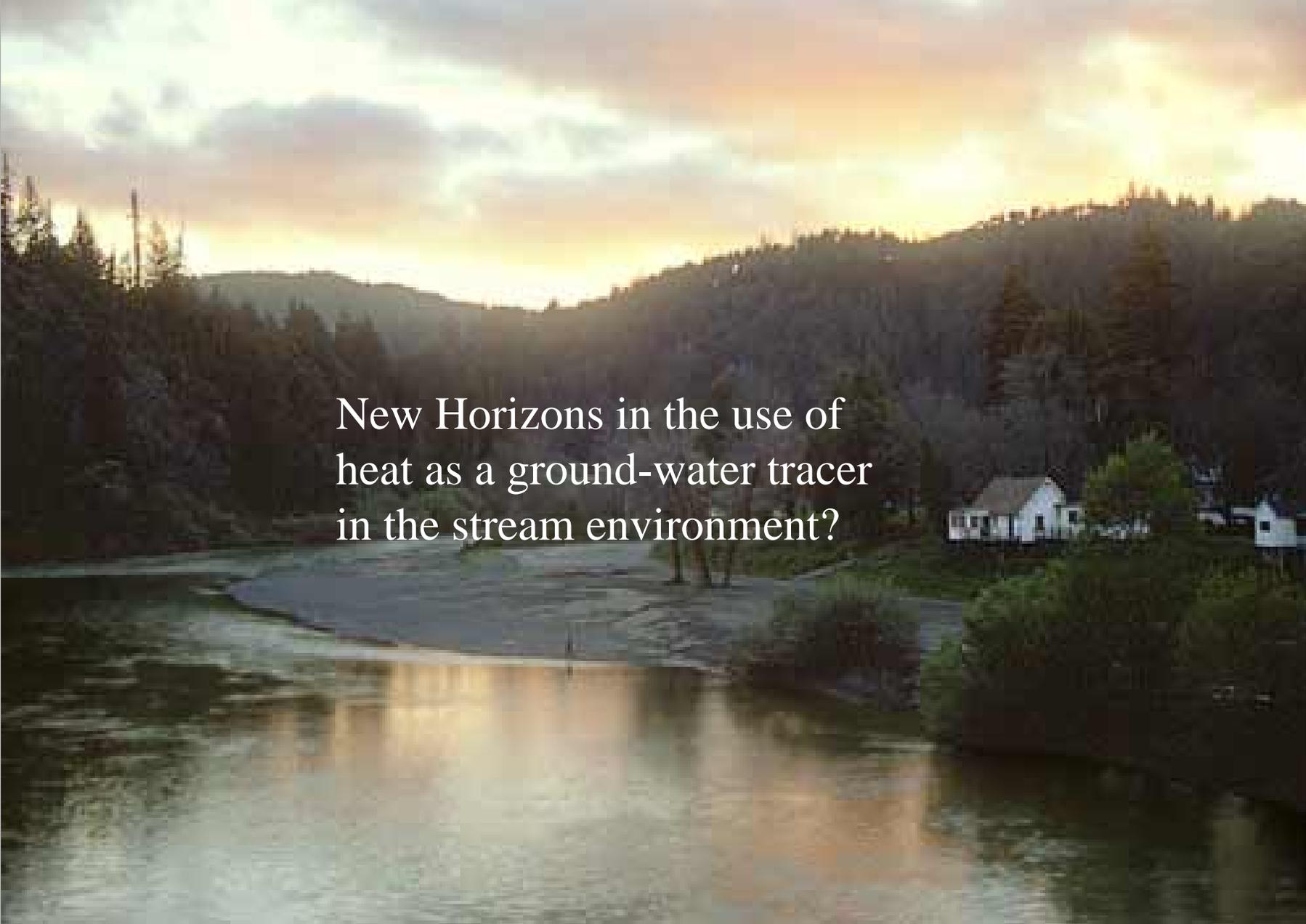


$Kh/Kv=2$



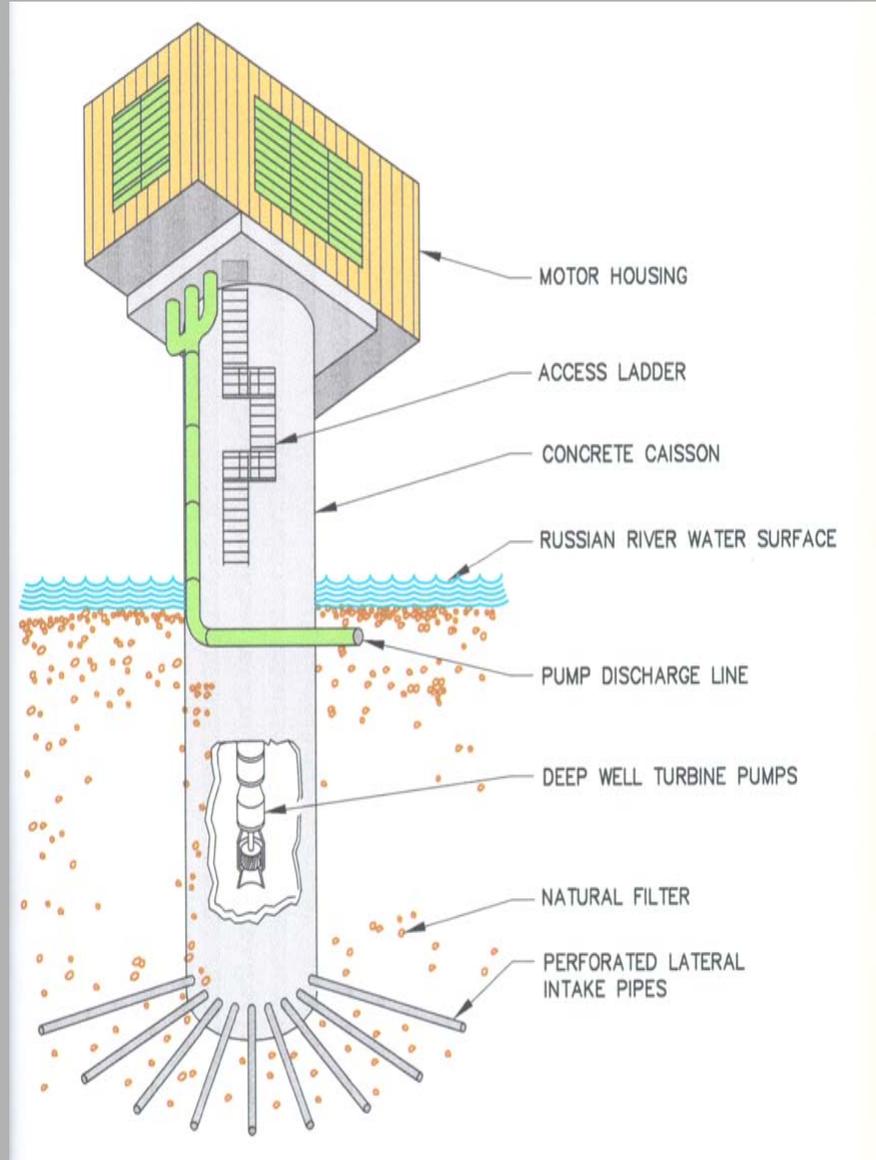
$Kh/Kv=5$





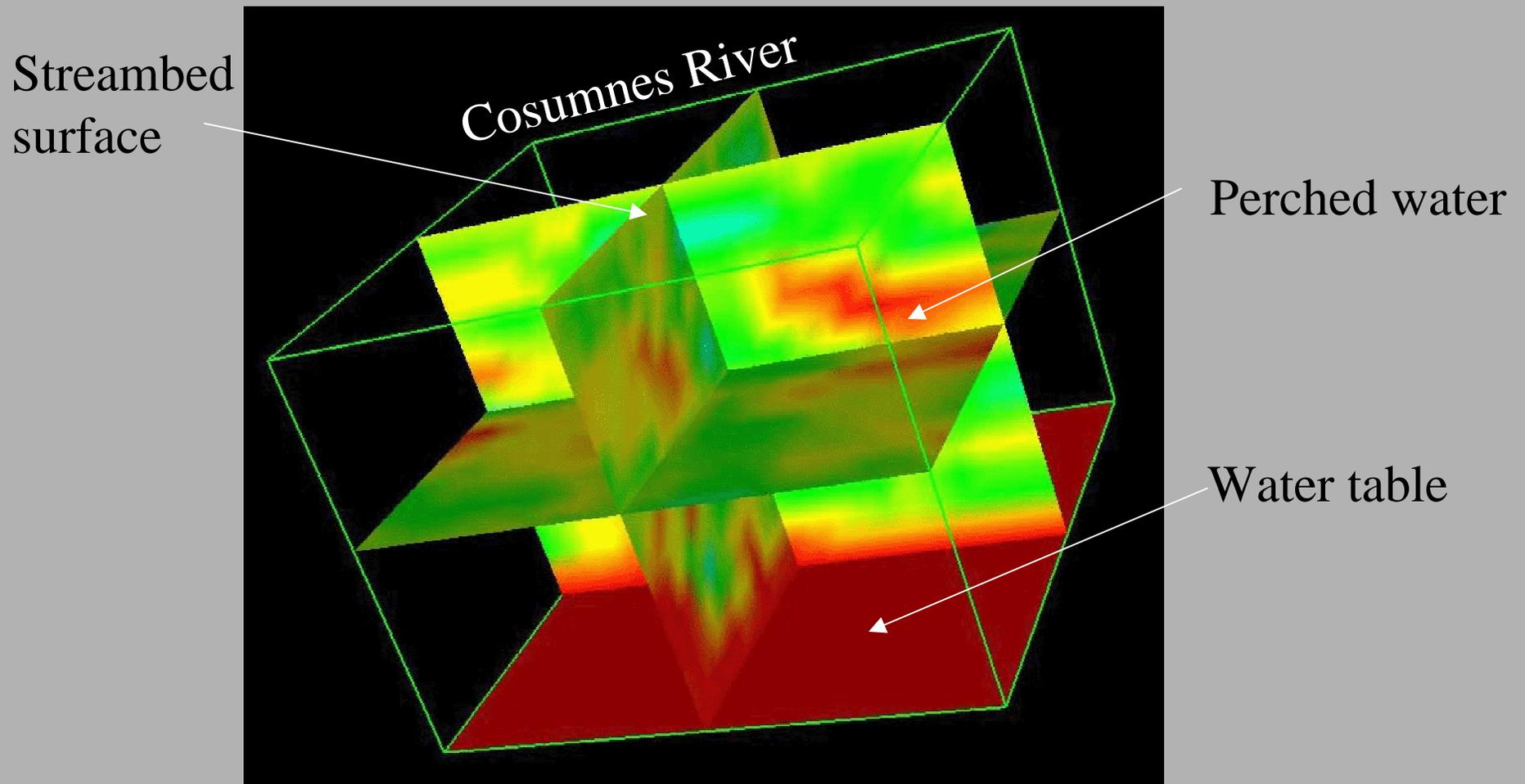
New Horizons in the use of
heat as a ground-water tracer
in the stream environment?

Supply wells cause the streambed to desaturate in the summer



3-D GW modeling using TOUGH2 and SUTRA

Observed sediment temperature used to calibrate the model



TOUGH2 contour plot of sediment water content below the river three months after flow ceased. Red color represents saturated sediments and blue is driest sediments. Horizontal plane spans 100 m in both directions.