Spatio-temporal variability in groundwater discharge and contaminant fluxes along Little Bayou Creek

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Introduction

- Discharge of contaminated groundwater plumes could result in the contamination of surface water bodies and vice versa.

- Identification of groundwater discharge type and location would be necessary to calculate total contaminant flux to the stream.

- In the past, groundwater and surface water bodies were considered as separate entities and the links between the two systems were not fully understood.

- Changes in one system could affect the other.

Introduction (continued)

- Natural streams are dynamic systems and the fluvial morphology is likely to change over time and space.

- We are interested in investigating:
  - variability in groundwater discharge patterns along a channelized stream (Little Bayou Creek) at diurnal, seasonal, annual, and decadal timescales
  - the extent to which the discharge sites are spatially persistent.

- Because the stream is located in unlithified sediments, discharge rates of springs appear to fluctuate with soil piping and collapse along joints in fractured clay.

Introduction (continued)

- Understanding patterns of groundwater discharge along a stream can be important for assessing fate and transport of aqueous contaminants.

- Depending upon the chemistry of contaminants and the geologic setting, contaminants in groundwater may be attenuated (e.g., by adsorption and biodegradation) in the discharge zone.

- The proposed study reach of the stream has been contaminated by plumes of groundwater containing trichloroethene (TCE) and technetium-99 (^{99}Tc) released as a result of past activities at PGDP.

- If, as inferred by LaSage et al. (2008b), contaminant fluxes from groundwater to Little Bayou Creek are spatially focused, then targeted remediation approaches (such as installing passive reactive barriers in the discharge zone) may be feasible.

Objectives

- Assess variability in groundwater discharge:
  - spatial (individual springs at meter scale; groups of springs at sub-reach scale [tens of meters]; reach scale)
  - temporal (diurnal at selected points; seasonal; annual).

- Assess spatial-temporal variability in chemical constituents in groundwater and stream water:
  - contaminants: TCE and other volatile organic compounds (VOCs), ^{99}Tc
  - related field parameters (e.g., pH, specific conductance [SC], temperature, dissolved oxygen [DO]).

- Determine contaminant fluxes at spring, sub-reach and reach scales seasonally over one year.

- Compare findings with previous studies conducted along the same reach (1999-2002) and assess the changes over time and space.

Hypothesis

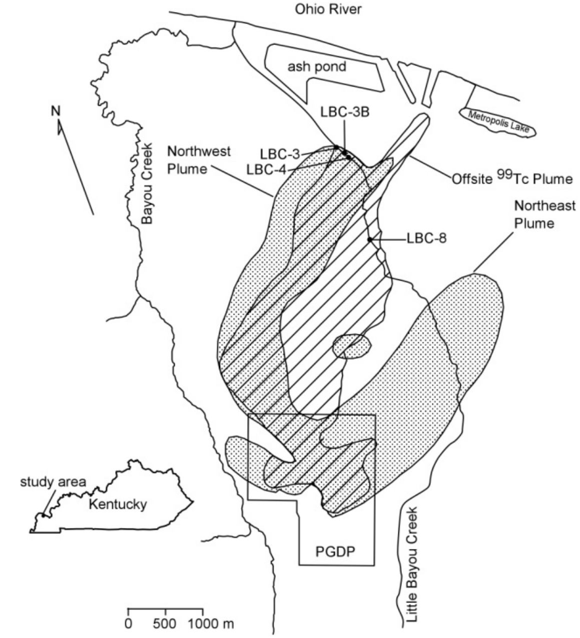
- There is a significant difference in stream and groundwater temperatures during summer and winter, which could be applied to find groundwater discharge locations along the stream channel.

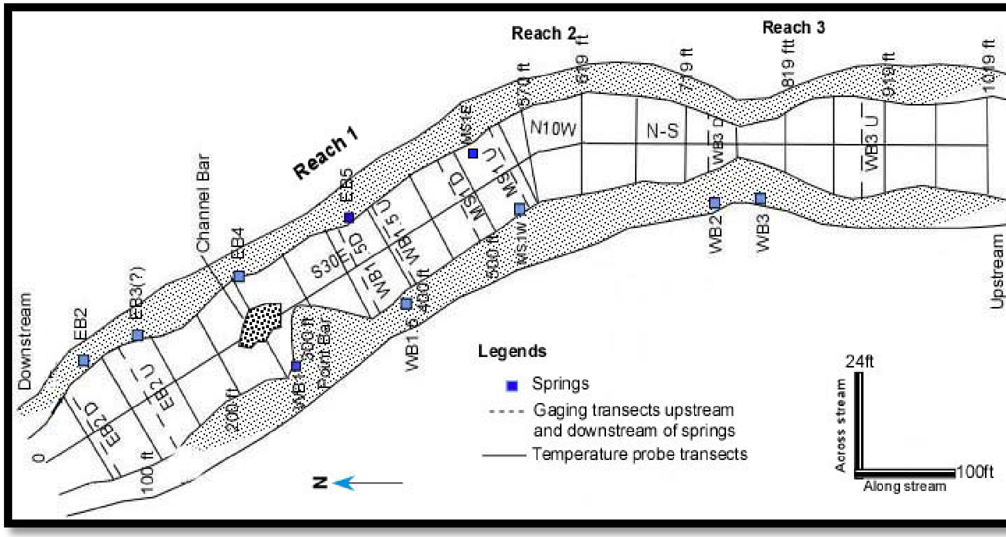
- Groundwater discharge locations can change over time and space.

- Contaminants are introduced into the creek mainly through focused discharge.

Study Area

- The study area lies in McCracken County in western Kentucky.
- Groundwater discharge is focused through springs in the banks and bed along a ~300-m reach of Little Bayou Creek.
- Springs appear to coincide with heterogeneities in the Metropolis Formation.
- Channelization of the creek (i.e., incision into the confining unit) may have promoted groundwater discharge (LaSage et al., 2008a).





Previous Study

- Springs along Little Bayou Creek intercept the NWplume, thus partly “short-circuiting” the flow of contaminated groundwater toward the Ohio River.

- Samples from springs and the stream were collected by LaSage et al. (2008b) from June 1999 - May 2001 for analysis of VOCs and ^{99}Tc.

- TCE and ^{99}Tc were detectable in surface water downstream of the springs and did not appear to be attenuated within the discharge zone

- In the stream samples, the concentrations of contaminants were highest in June (1999 and 2002) and lowest in January (2000, 2001 and 2002), respectively, reflecting seasonal effects.

- LaSage et al. (2008b) did not notice consistent seasonality in TCE and ^{99}Tc concentrations for spring samples.

Previous Study (continued)

- Contaminant concentrations progressively decreased from upstream springs to downstream springs
  - minimal evidence of reductive biodegradation and TCE sorption to stream bed sediments (LaSage et al., 2008).

- Attenuation of TCE was primarily due to volatilization from the stream surface (Mukherjee et al., 2005).

- LaSage et al. (2008b) sampled most of the same springs targeted in this study, but monitored stream flow and chemistry at only two locations along the sample reach.

- LaSage et al. (2008b) did not address:
  - short-term (diurnal) or long term (decadal) variability in discharge
  - decadal variability in groundwater chemistry.

Methods

- **Temperature probing**
- Distributed fiber-optic temperature sensing (DTS)
- **Discharge measurements**
  - **Stream gaging**
  - **Spring discharge measurements**
  - **Dye-dilution tracer tests**
- Drive-point piezometer installation
- Installation of thermistors and pore-pressure transducers
- **Springs and stream water sampling**
- Passive vapor-diffusion samplers (PVDSs)

Temperature probing

- Stream bed temperatures are being measured:
  - along transects at intervals of 10 feet along the stream and 3 feet across the stream
  - at the top and at refusal depth by inserting 4-foot stainless steel probe
  - resolution = 0.01^{o}C

Discharge Measurements

Stream gaging

- Gage stream flow up- and downstream of five springs (EB2, WB1, WB1.5, MS1, and WB3) by wading using a current meter with a top-setting rod (Oct. 2010 and Jan. 2011; planned Jun. 2011, Aug. 2011, Oct. 2011, and Jan. 2012).
- Most of the stream sections will be gaged at 6-inch intervals along the transect.
- Gaging spacing may be reduced to 3 inches where the channel is narrow.
- Discharge will be calculated following mid-section method proposed by Rantz et al. (1982).

Spring discharge measurement

- Bank springs: Q is being measured using conventional manual techniques (i.e., a bucket, graduated cylinder, and stopwatch) where spring orifices occur along the bank.
- Streambed springs: will use seepage meters or install drive-point piezometers to calculate upward groundwater flux following Darcy's law.

Dye-dilution tracer tests

- Rhodamine WT
  - Conservative tracer
  - Low detection limit (< 1 μg/L).

• Dye solution of known concentration is injected upstream.

• Sampled at certain distances downstream at specified time intervals starting just before the visible dye cloud appears until the dye cloud no longer visible.

• Dye concentration in the stream samples is determined by spectrophotometer (Cary Eclipse Spectrophotometer, KGS).

• The breakthrough curve obtained after plotting the concentration vs. time of sampling is used to calculate dye discharge and travel time.

Data Analysis

- Results of temperature probing are being mapped on a grid using Surfer.

- Net discharge along sub-reach segments is being calculated using the midsection method of Rantz et al. (1982) for gaging data and mass-balance calculations for dye tracing.

- We will compare values of ΔQ measured by gaging and dye tracing with unmixing calculations based on ^{99}Tc and with Q measurements at individual springs.

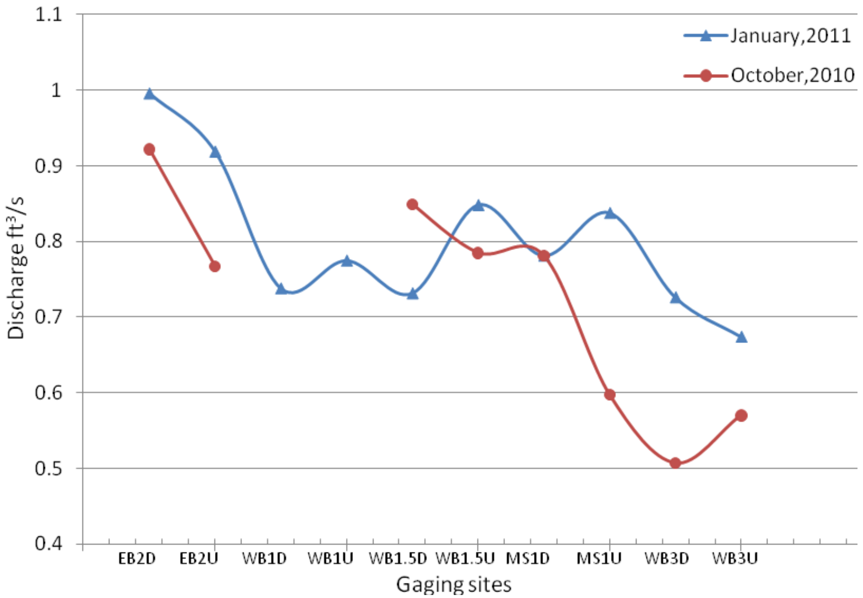
- Concentrations of DO and VOCs other than TCE (e.g., dichloroethenes [possible daughter products]) will enable us to assess whether aerobic conditions associated with focused discharge preclude intrinsic reductive biodegradation of TCE.

Preliminary Results

-The discharge in general increased downstream during both measurement periods.

-The stream segment between WB1D and MS1U appears to be more or less consistent, with SD = 0.05 ft^3/s in January.

- Stream discharge was greater in January than in October for six of eight gaging locations.



Preliminary Results

- Relative to gaged discharge, discharge calculated by dye dilution was
  - less at the farthest upstream location (WB3U)
  - greater at two intermediate locations
  - approximately equal at the farthest downstream location (EB2D)

- Differences in dye-dilution and gaged values at MS1U (0.122 ft^3/s) and WB1.5D (0.344 ft^3/s) suggest considerable flow in the hyporheic zone.

- However, sampling of dye at a single point in the channel probably led to errors in calculating discharge where transverse mixing was incomplete.
  - We will attempt to avoid these errors in future dye-dilution tests.

- Travel time for tracer from farthest upstream to farthest downstream was ~ 2.5 hours.

Site ID	Dye dilution Q (ft3/s)	Gaged Q (ft3/s)	Difference
WB3 U	0.5541	0.674	-0.1199
MS1U	0.96	0.838	0.122
WB1.5 D	1.074	0.73	0.344
EB2 D	1.0007	0.996	0.0047

Dye sampling location	Travel time (minutes)
WB3 U	30.8
MS1 U	60.1
WB1.5 D	104.6
EB2 D	149.6

Preliminary Results

- T probe data from Jan. 2011 were plotted in Surfer 9 using the kriging interpolation method to obtain quasi 3-D surface maps of T distribution along the study reach.

- Maps of T at the top of the stream bed and at total probe depth were generated for each of three sub-reaches.

- Most T anomalies were found to be associated with the springs.

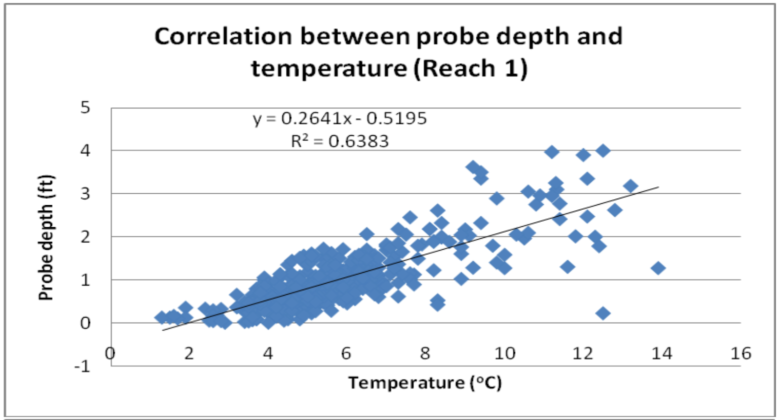
- We need to synchronize our T probing transect with that of LaSage et al. (2008a) to evaluate changes in T distribution along the stream bed from 2002 to 2011.

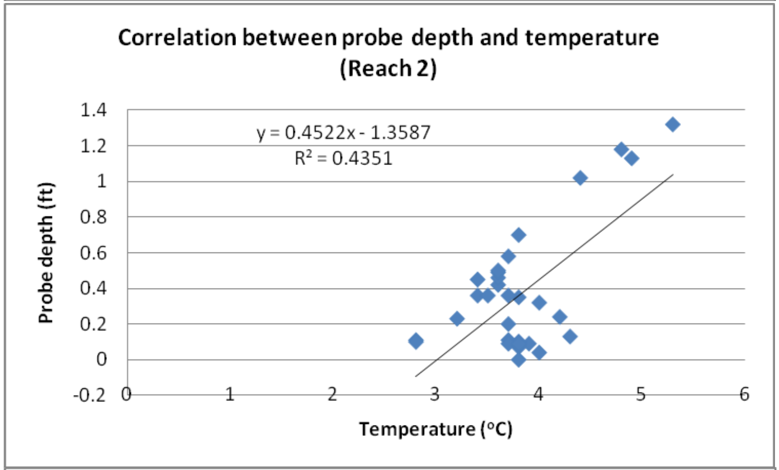
• Probe depth is positively correlated with T: r^2 = 0.64, 0.43, and 0.73 for the subreaches.

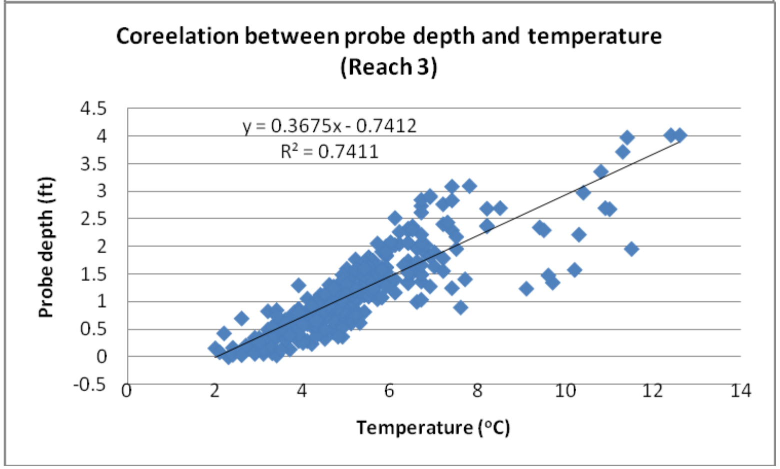
• The computed correlation coefficients are statistically significant, but they do not show strong correlations.

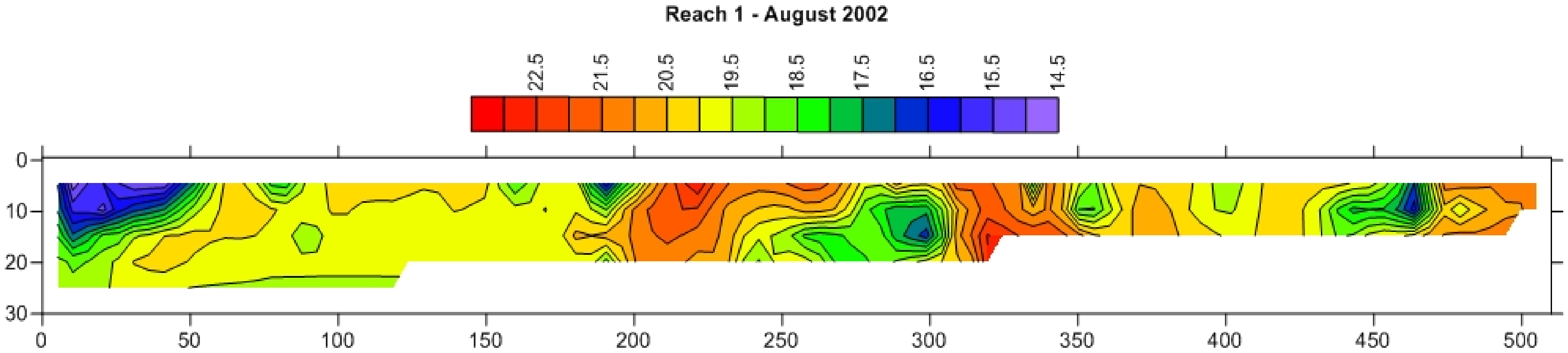
• Locations of springs were inferred and, in most cases, observed where temperatures were markedly (5-8 ^oC) above background.

• The standard deviation in temperature anomaly along the streambed and the direct probe temperature at the springs was 1.9 ^oC.

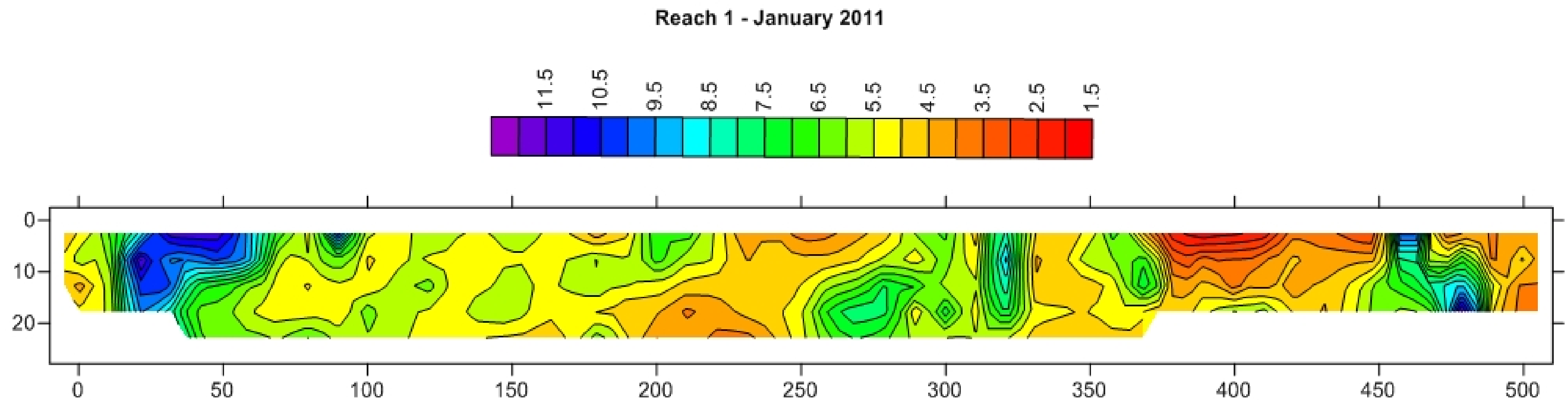






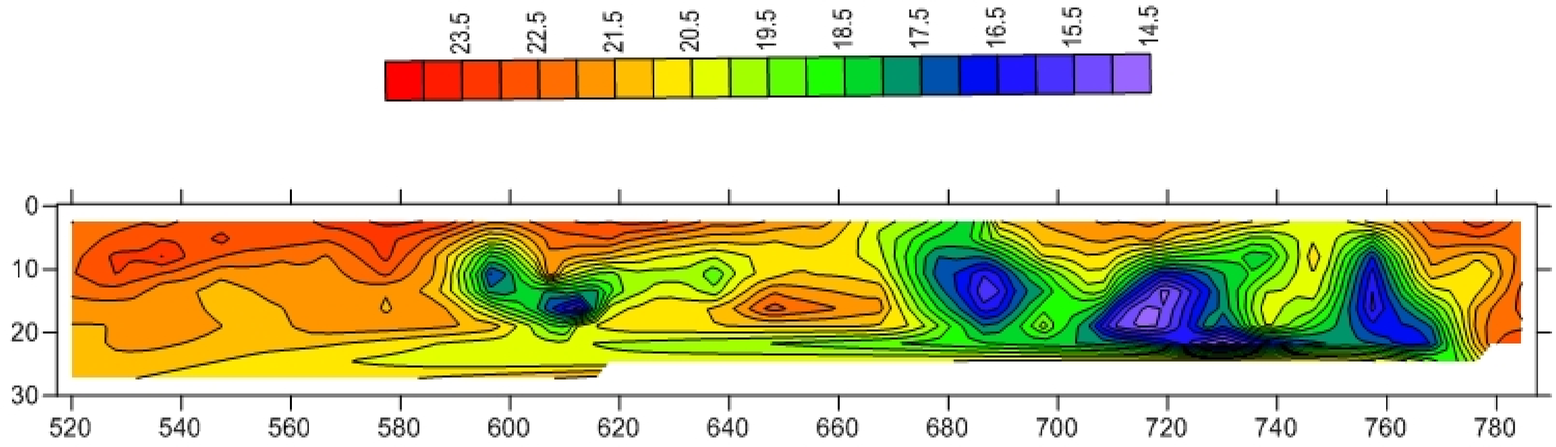


Reach 1 - August 2002
22.5
21.5
20.5
19.5
18.5
17.5
16.5
15.5
14.5
0
10
20
30
0
50
100
150
200
250
300
350
400
450
500

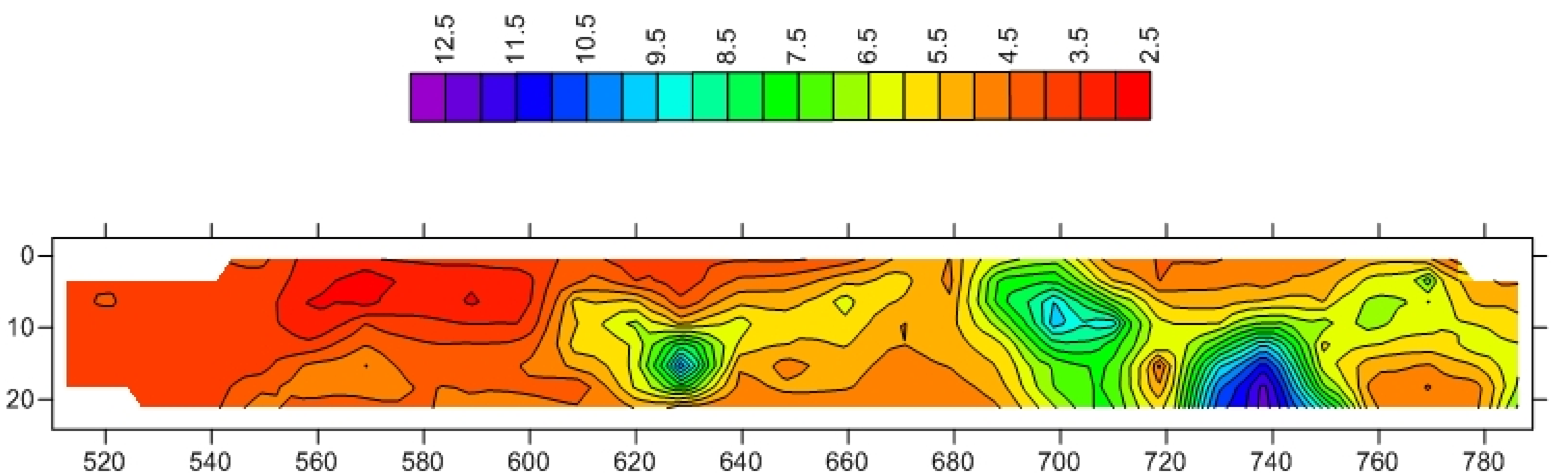


Reach 1 - January 2011
11.5
10.5
9.5
8.5
7.5
6.5
5.5
4.5
3.5
2.5
1.5
0
10
20
0
50
100
150
200
250
300
350
400
450
500

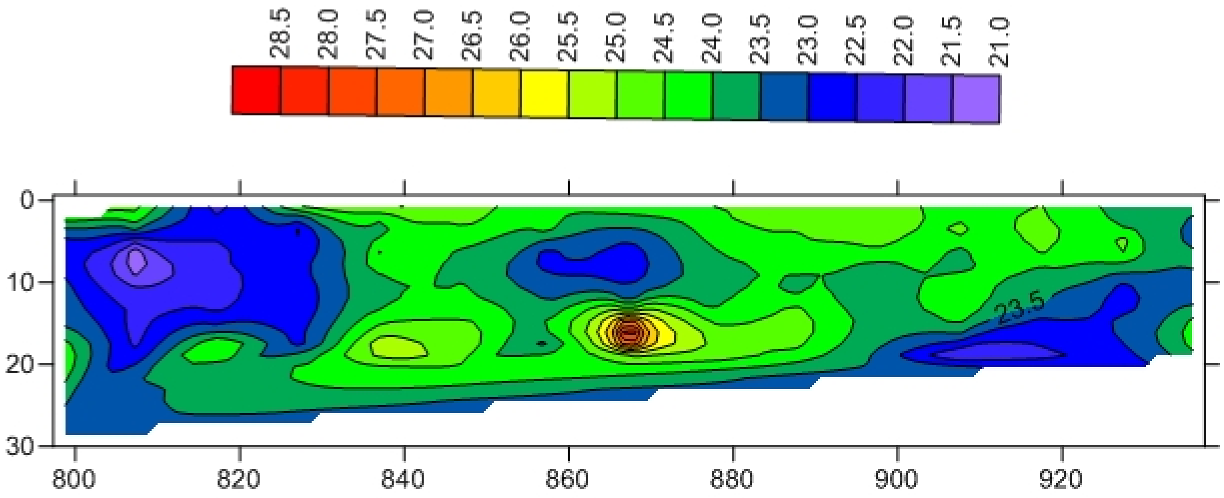
Reach 2 - August 2002



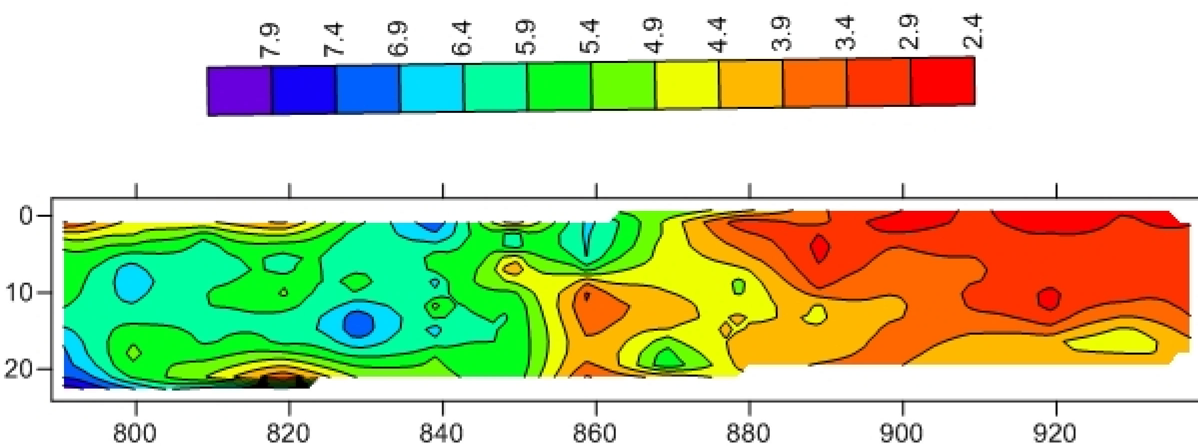
Reach 2 - January 2011



Reach 3 - August 2002



Reach 3 - January 2011



Preliminary Results

- Water samples collected in Jan. 2011 were analyzed for VOCs at McCoy and McCoy Laboratories, Inc. (Madisonville, KY) by GC-MS according to U.S. Environmental Protection Agency Method 8260.

- Only TCE was detected, and concentrations in springs were markedly lower than those reported by LaSage et al. (2008b).

- This suggests that the pump-and-treat system installed in the RGA downgradient of PGDP may have begun to remove a significant amount of contaminant mass from groundwater. Analyses of ^{99}Tc are pending.

Sampling location		TCE (µg/L)
Stream water samples	WB3 U	Below detection limit
	WB3 D	8.4
	MS1 U	6
	MS1 D	5.4
	WB1.5 U	5.8
	WB1.5 D	6.2
	WB1 U	6.2
	WB1 D	6.1
	EB2 U	5.6
	EB2 D	5.4
Groundwater samples	WB3	160
	WB2	59
	MS1 W	17
	WB1	6.5
	EB5	Below detection limit
	EB2	Below detection limit

References

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