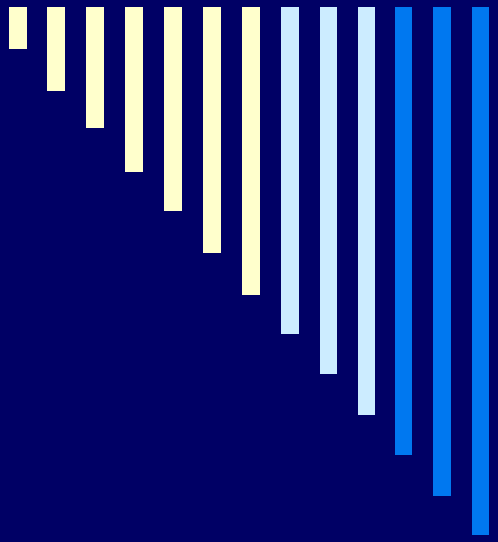
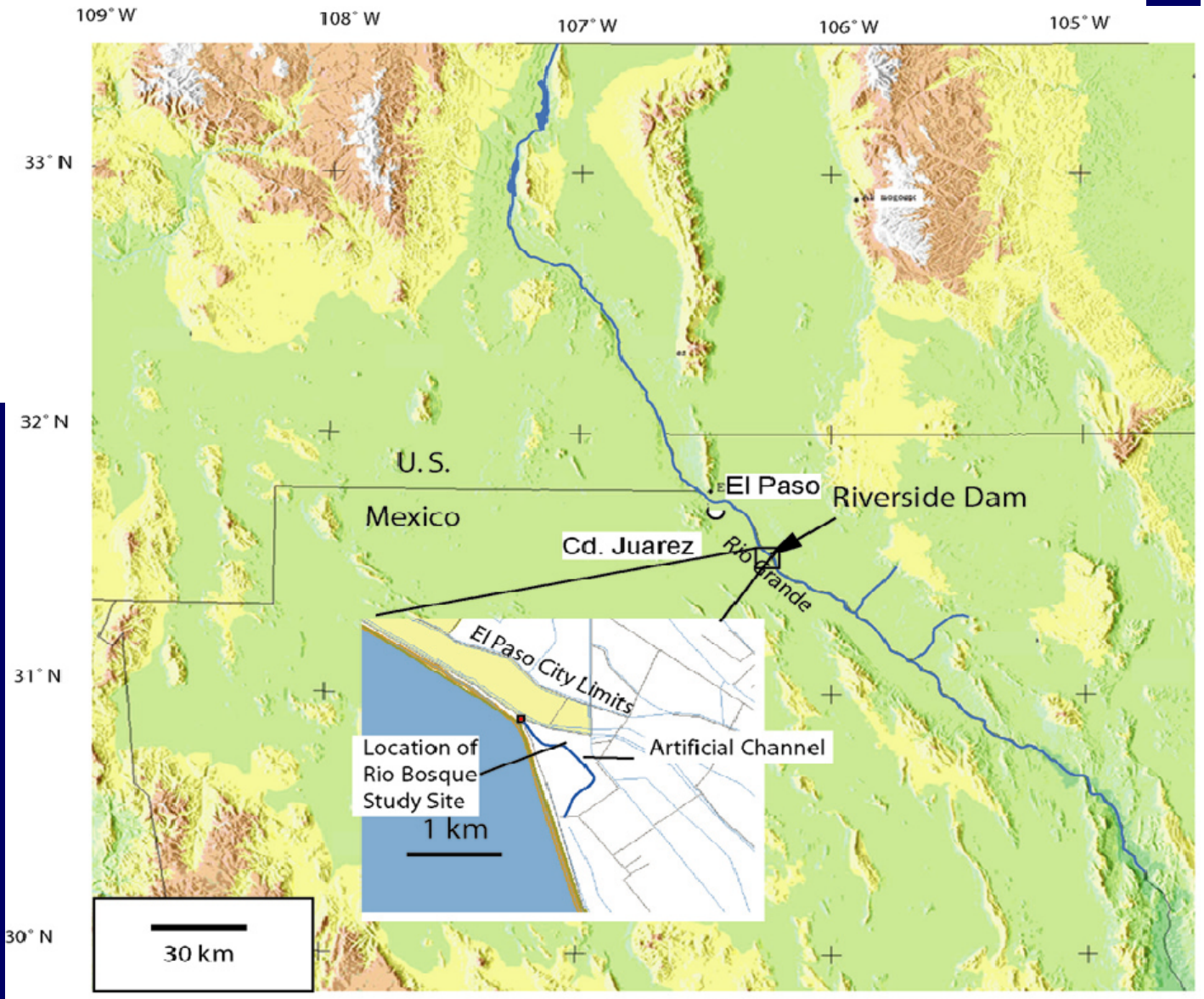


A multi-path microsphere tracer test to understand transport of bacteria and protozoa at a bank filtration site.

Richard Langford
Suresh Pillai
Dirk Schulze Makuch
Ken Widmer
Ahmad Abdel Fattah

Research Objectives

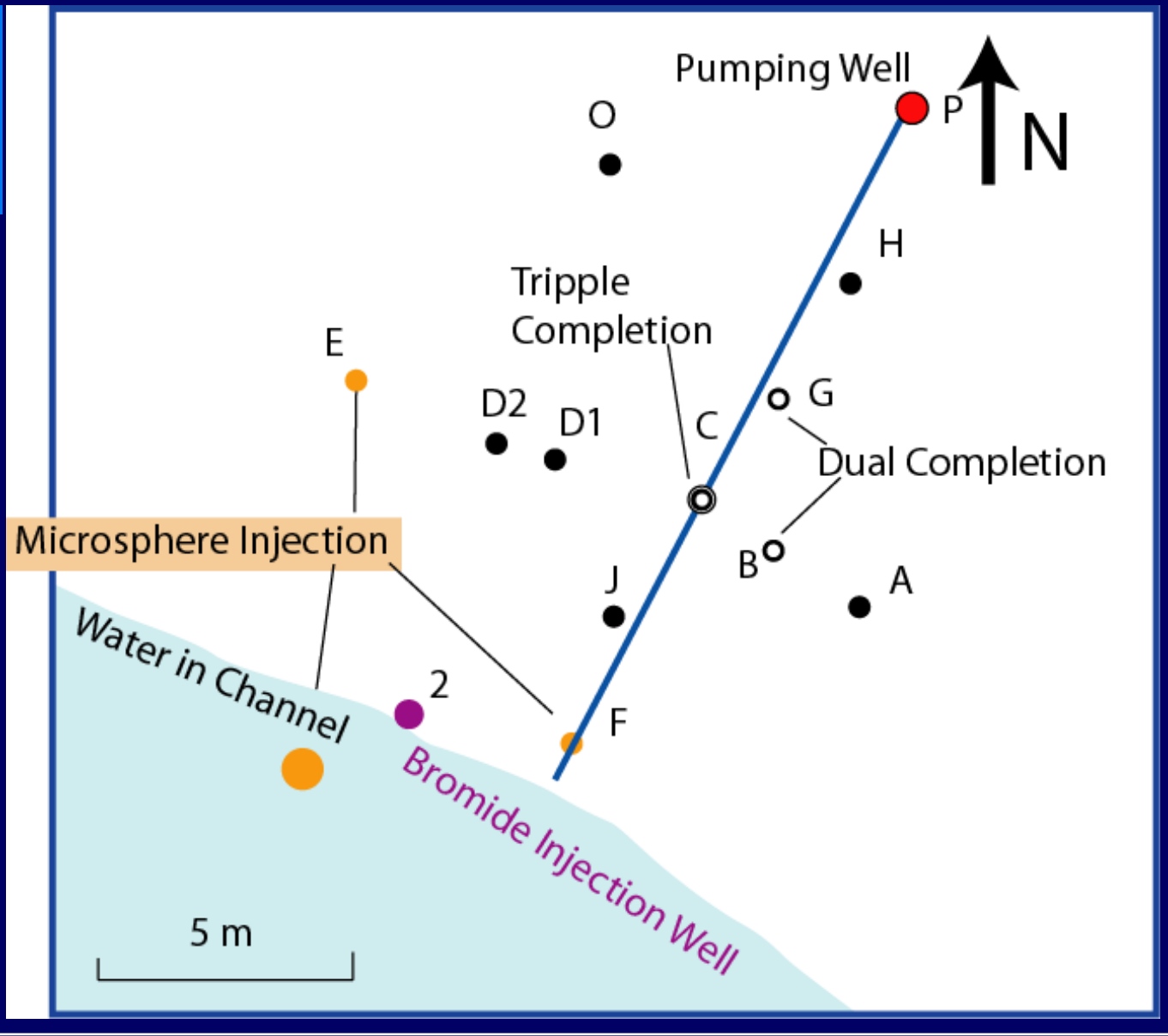
- Little is known about the effectiveness of riverbank filtration in arid environments.
- Pathogenic bacteria, viruses and Cryptosporidium can be reduced or eliminated by bank filtration, but the reasons behind that are not entirely understood at this time.



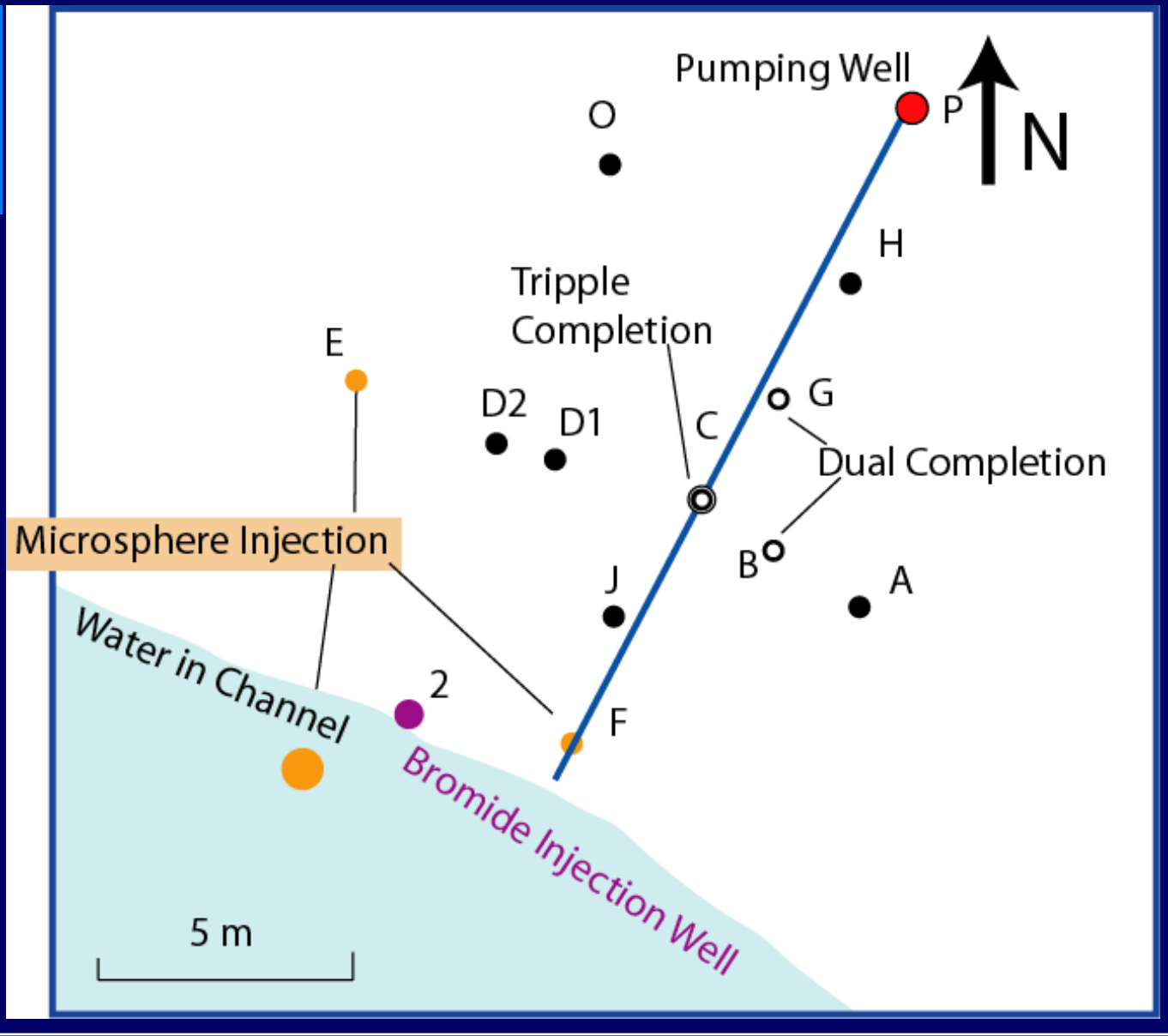
Shaded relief map prepared by PanAmerican Center for earth and Environmntal Sciences from composited 7.5' and 15' and DEMs.

Methods

- **Sediment analysis**
- **Pump test for aquifer properties**
- **Tracer test (Bromide and Microspheres)**
- **Water chemistry**
- **Microbial analysis**
- Simulation of Pathogen Transport via a Computer Model


Pumping Well
P
N
O
H
Tripple
Completion
E
D2
D1
C
G
Dual Completion
Microsphere Injection
B
J
A
Water in Channel
2
F
Bromide Injection Well
5 m

Microbial Sampling


Pumping Well
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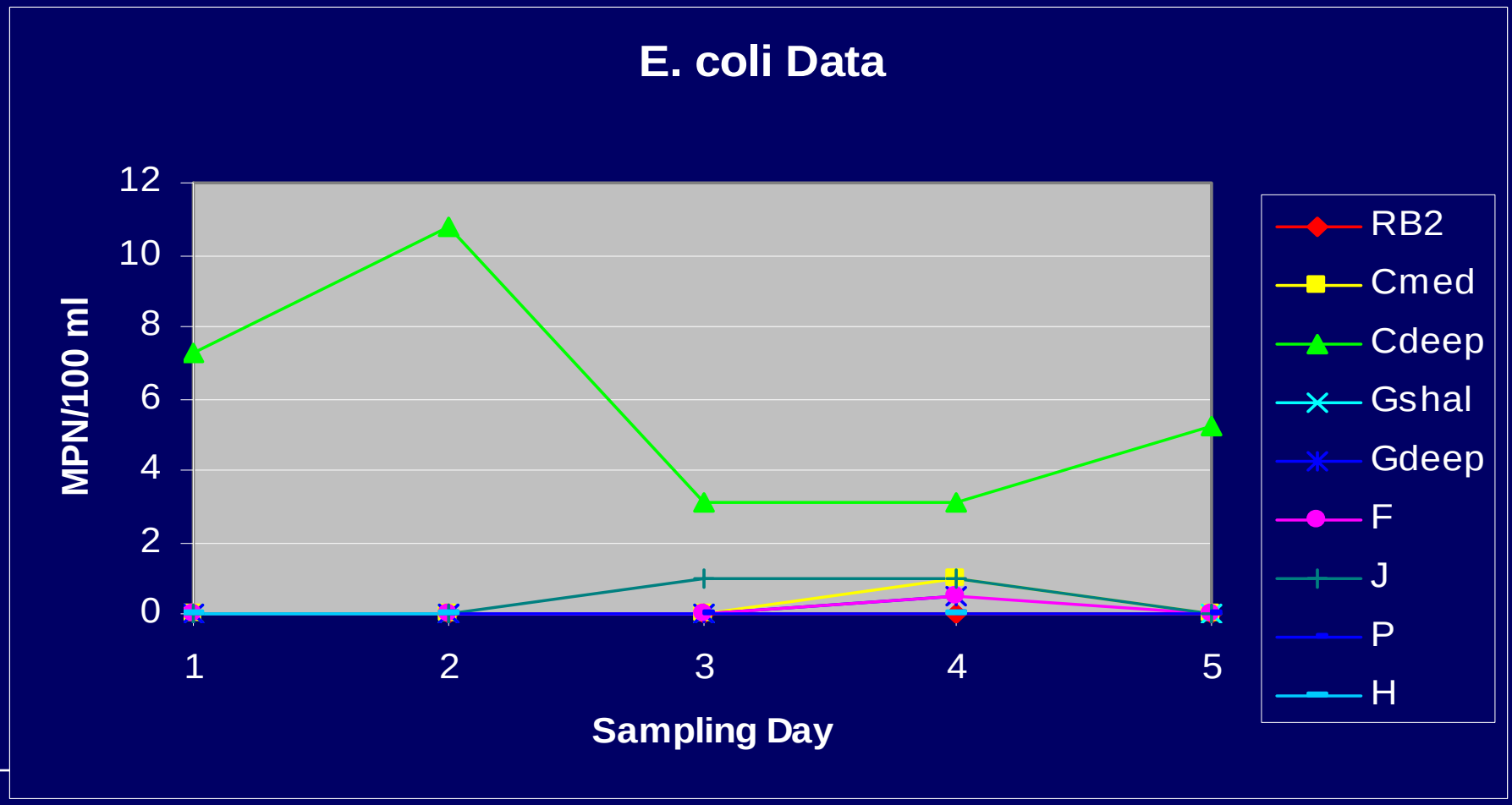
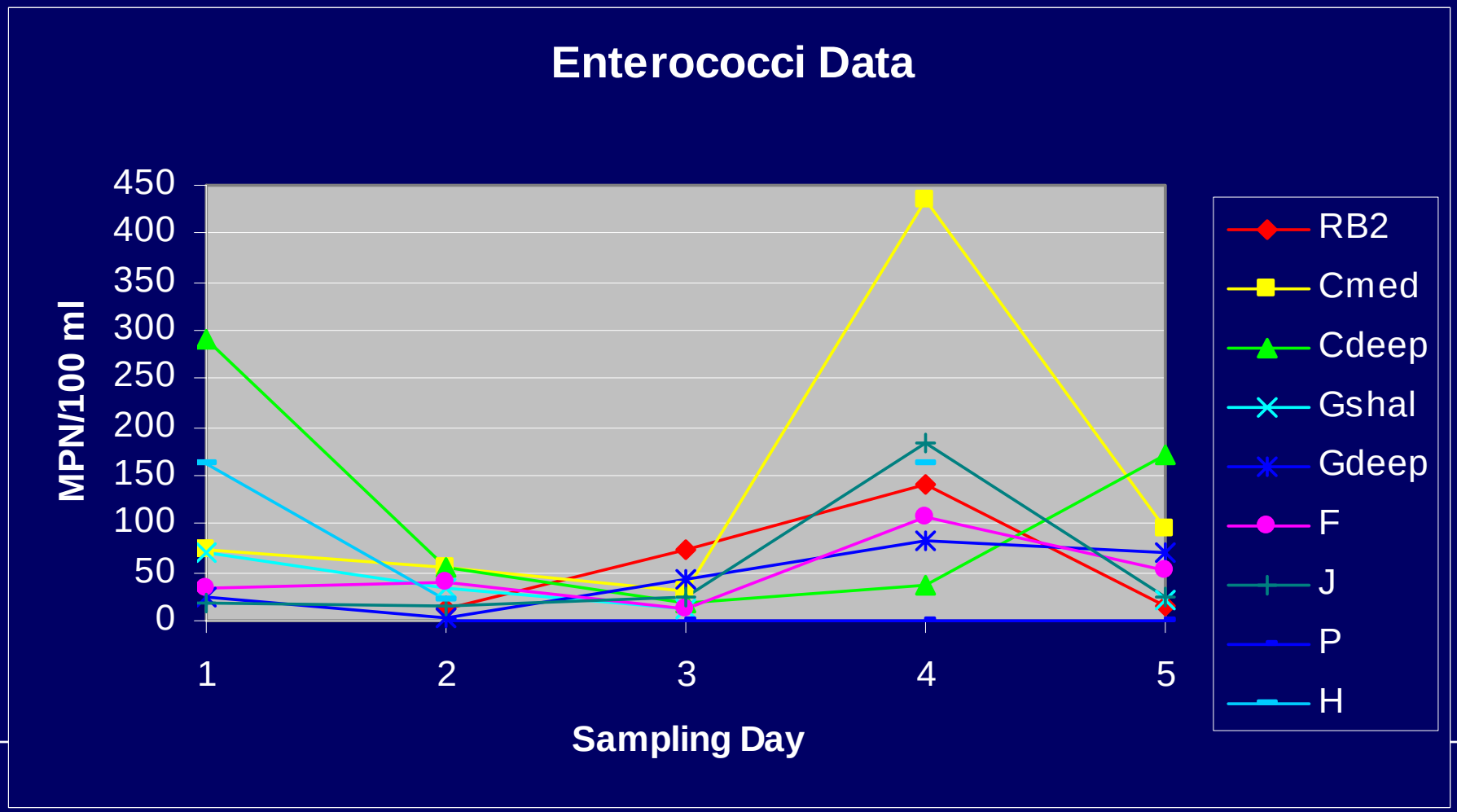
Dual Completion
Microsphere Injection
B
J
A
Water in Channel
2
F
Bromide Injection Well
5 m

Results of Bacterial Sampling

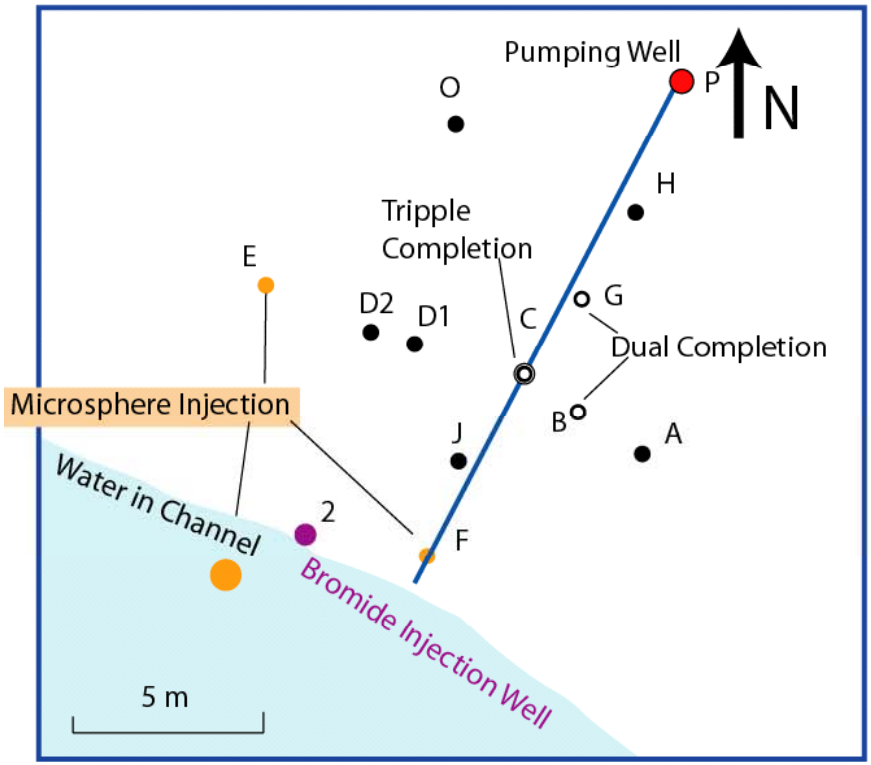
Sample	Somatic Phage	Fecal Coliforms	E. Coli.	Salmonella	Enterococci
RBWC-10-11-02	166	1600	500	0	44
RBWC-10-15-02	88	1600	900	0	
RBWC-10-19-02	8	500	17	0	54
RBWC-10-22-02	456	300	500	0	
RBWC-10-25-02	59	900	280	0	151
RBWC-10-29-02	38	300	30	0	
RBWC-11-02-02	393	50	8	0	182
Average	172.5	750	319.3	0	107.8





- Average Bacteriophage in Canal – 50 PFU/100 ml
- No phage were detected in the well samples
(detection limit of 1 Plaque Forming Unit/100 ml)

No Giardia or Cryptosporidium protozoa were detected in the pumping wells (5 samples collected).


Pumping Well
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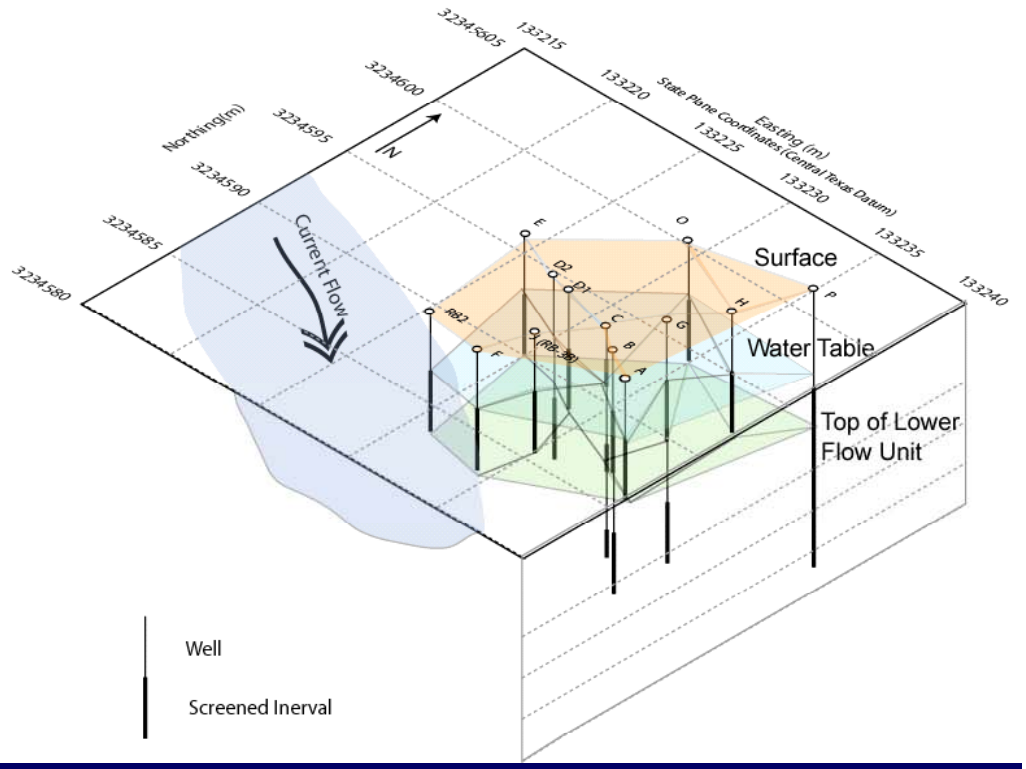
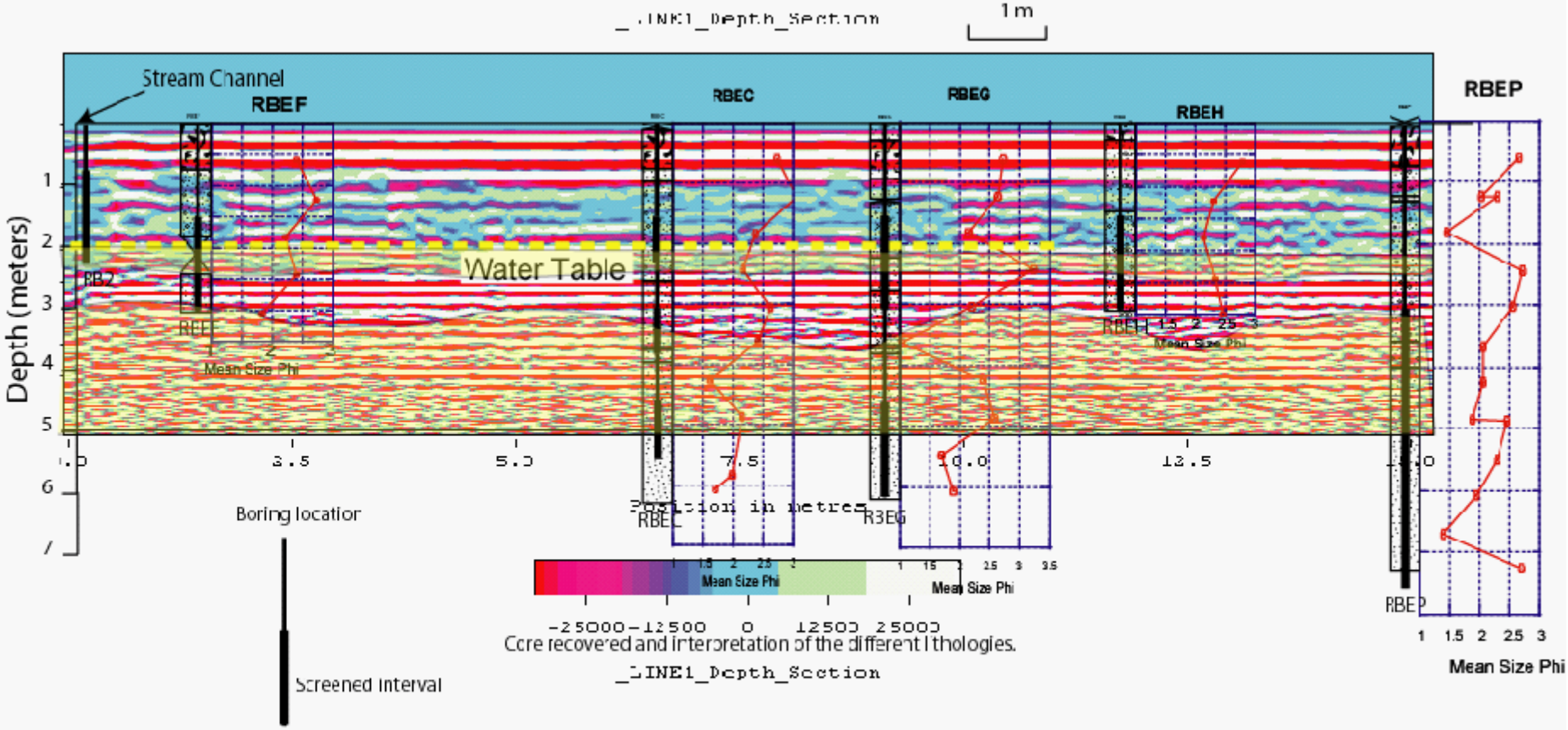
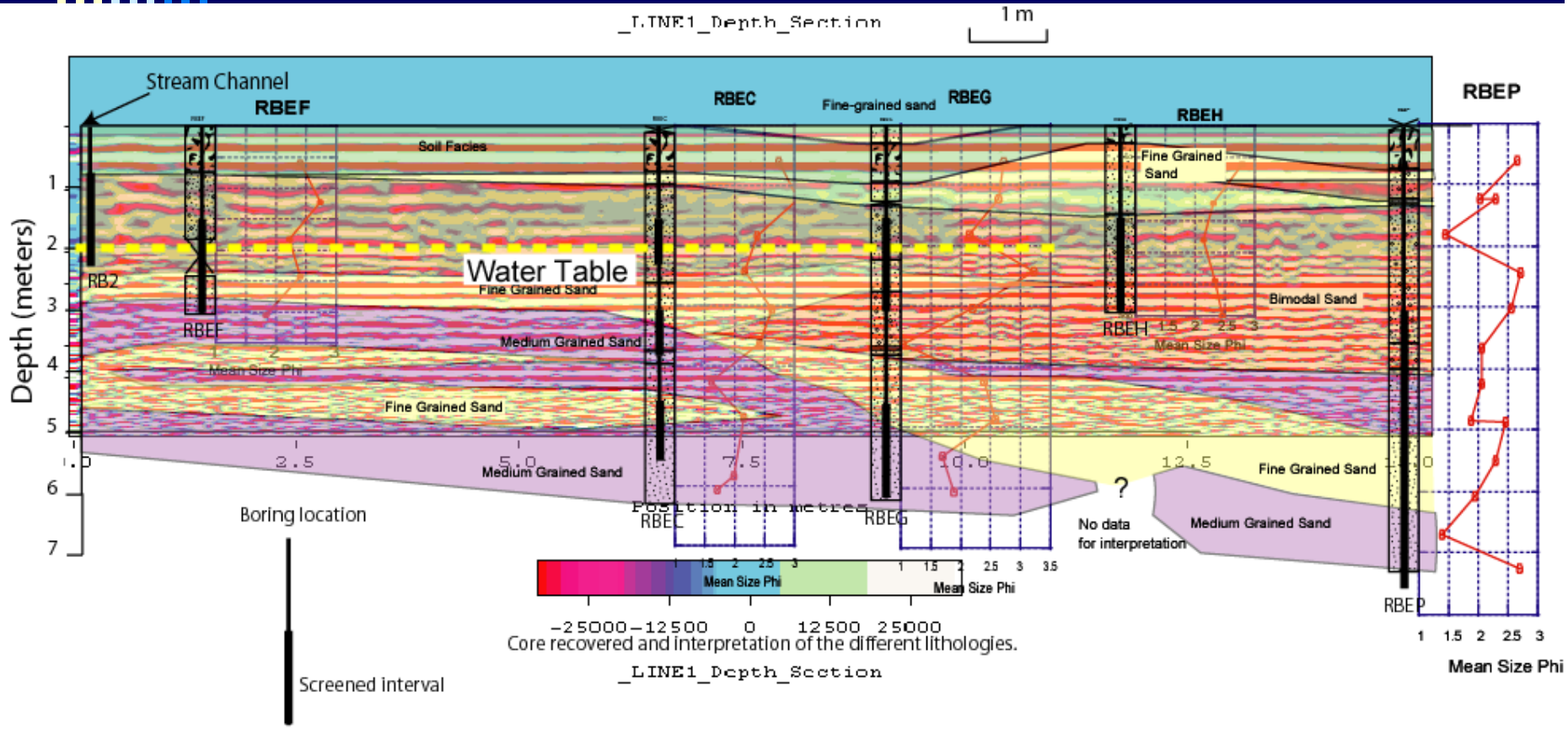
Bromide Injection Well
5 m


Northing(m)
3234605
3234600
3234595
3234590
3234585
3234580
State Plane Coordinates (Central Texas Datum)
Easting (m)
133215
133220
133225
133230
133235
133240
N
Current Flow
Surface
Water Table
Top of Lower
Flow Unit
Well
Screened Inerval

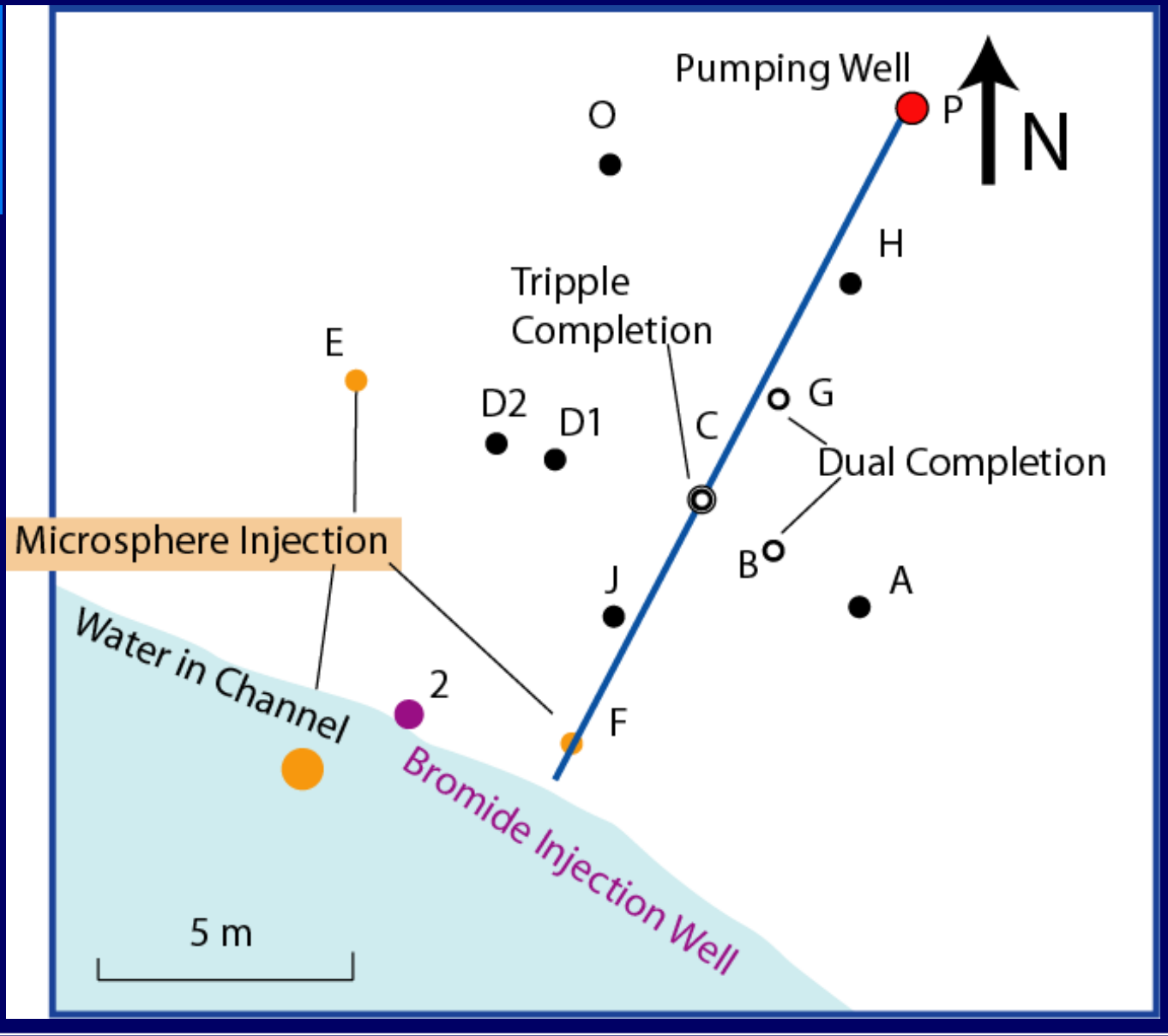
Aquifer Description

- A porous medium unconfined aquifer with a mean grain sizes ranging from 100 to 350 microns.
- The aquifer can be separated into 3 aquifer units with the upper and lower aquifer units representing the high-K units and the middle layer representing a a lower K unit
- The aquifer as a whole behaves as a double-porosity medium based on the pumping test responses from a long-term multiple-well aquifer test


1m
Stream Channel
RBEF
RBEC
RBEG
RBEH
RBEP
Water Table
RB2
Depth (meters)
Mean Size Phi
Boring location
Screened Interval
Position in metres
Mean Size Phi
Core recovered and interpretation of the different lithologies.


_LINE1_Depth_Section
1 m
Stream Channel
RBEF
RBEC
Fine-grained sand
RBEG
RBEH
RBEP
Soil Facies
Fine Grained Sand
Water Table
Fine Grained Sand
Bimodal Sand
RB2
RBEF
Medium Grained Sand
Mean Size Phi
Fine Grained Sand
Depth (meters)
Medium Grained Sand
Fine Grained Sand
?
No data
for interpretation
Medium Grained Sand
Position in metres
RBEC
RBEG
RBEH
RBEP
Boring location
Mean Size Phi
Mean Size Phi
-25000 -12500 0 12500 25000
Core recovered and interpretation of the different lithologies.
_LINE1_Depth_Section
Screened interval
Mean Size Phi

Bromide Tracer Results


Pumping Well
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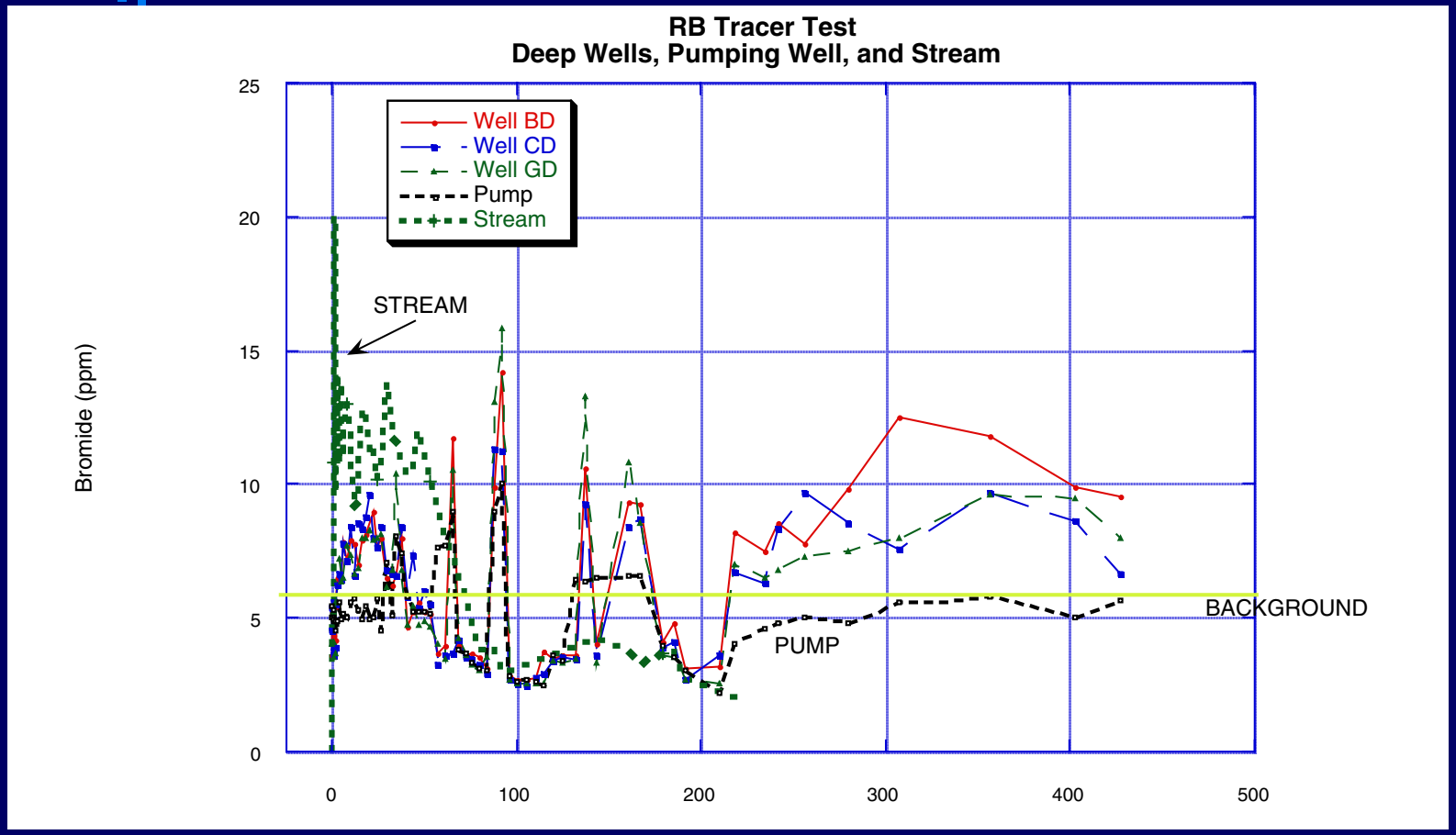
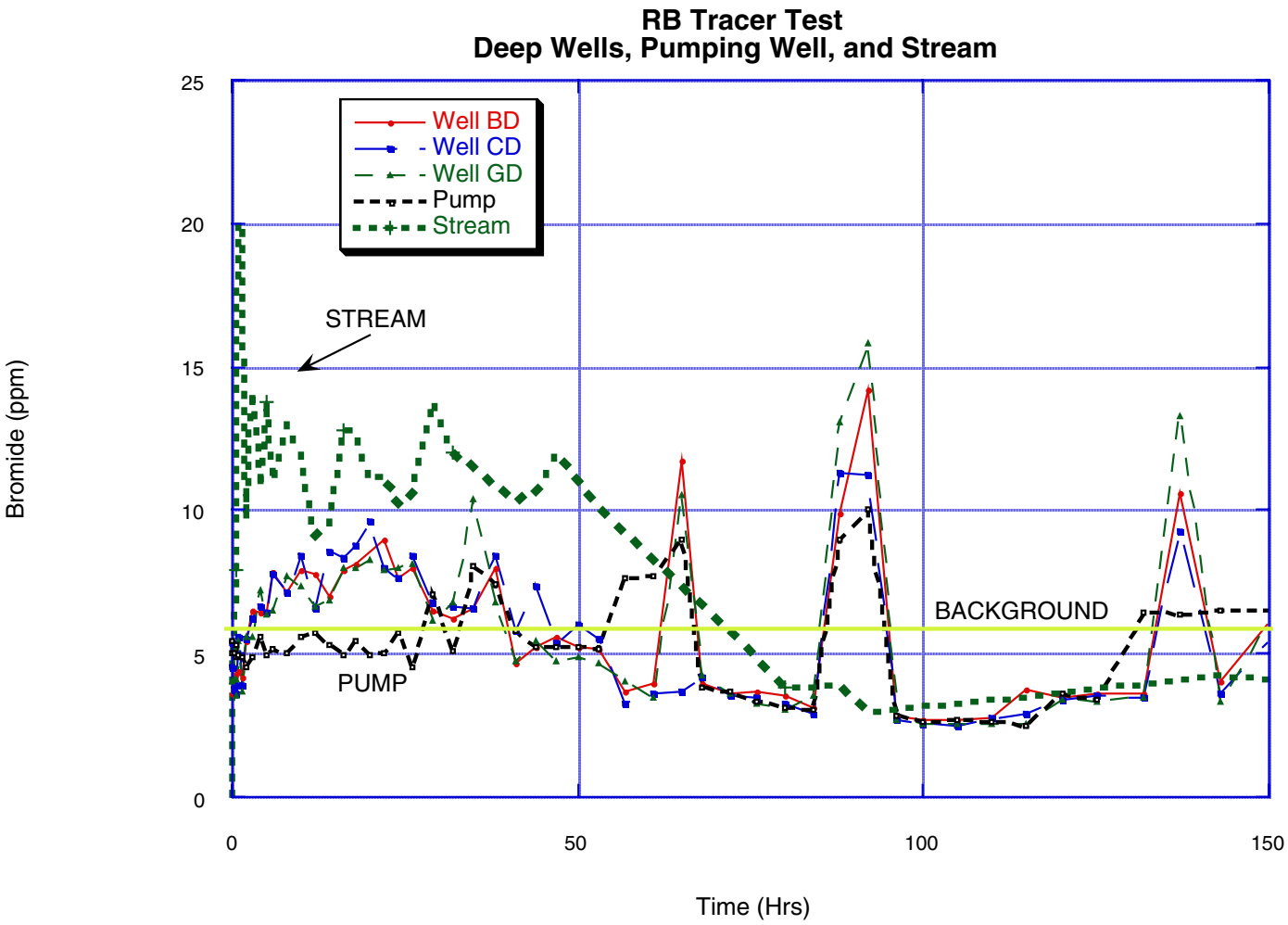
Dual Completion
Microsphere Injection
B
J
A
Water in Channel
2
F
Bromide Injection Well
5 m

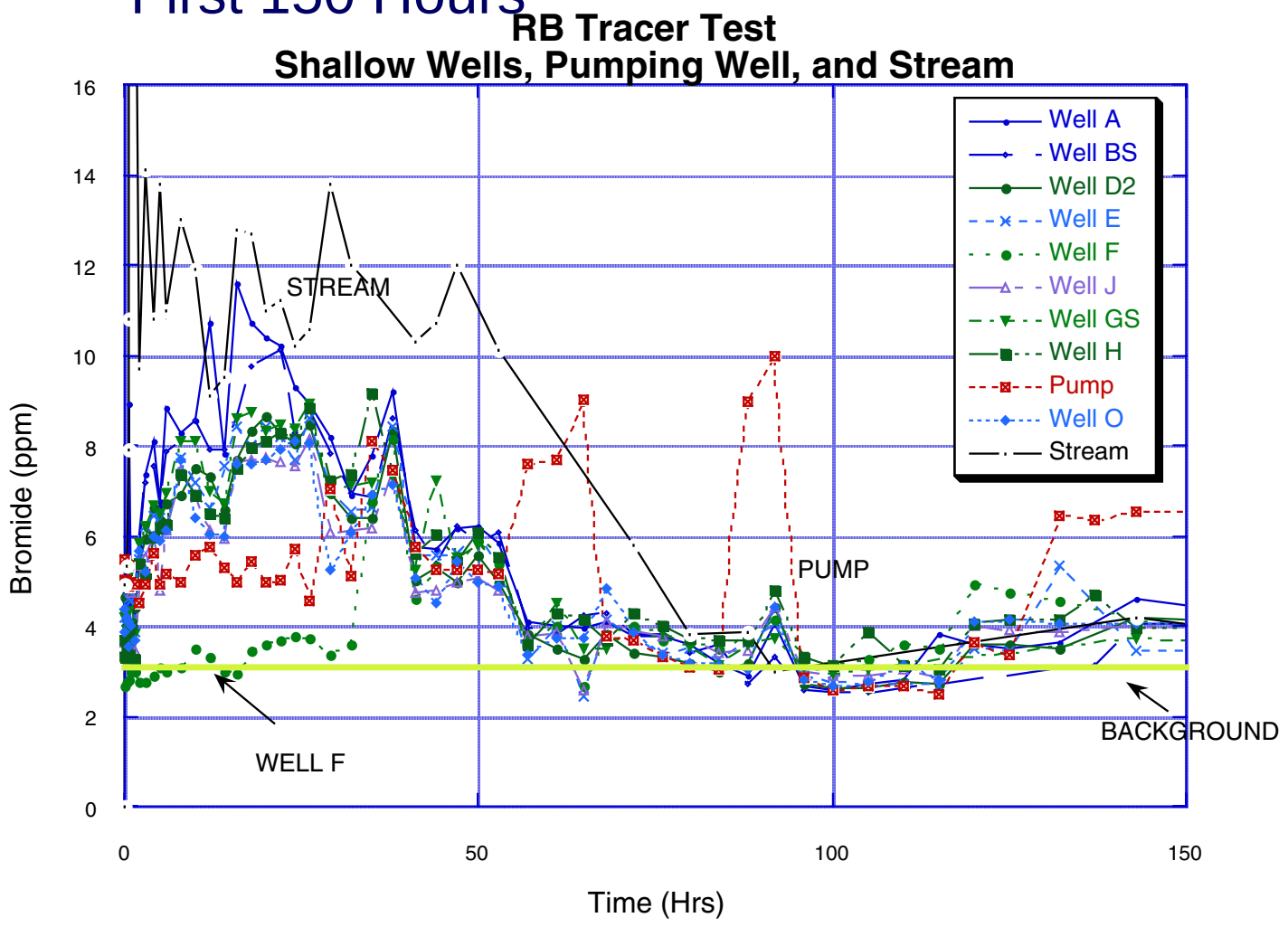
Deep wells show multiple peaks and isolated spikes

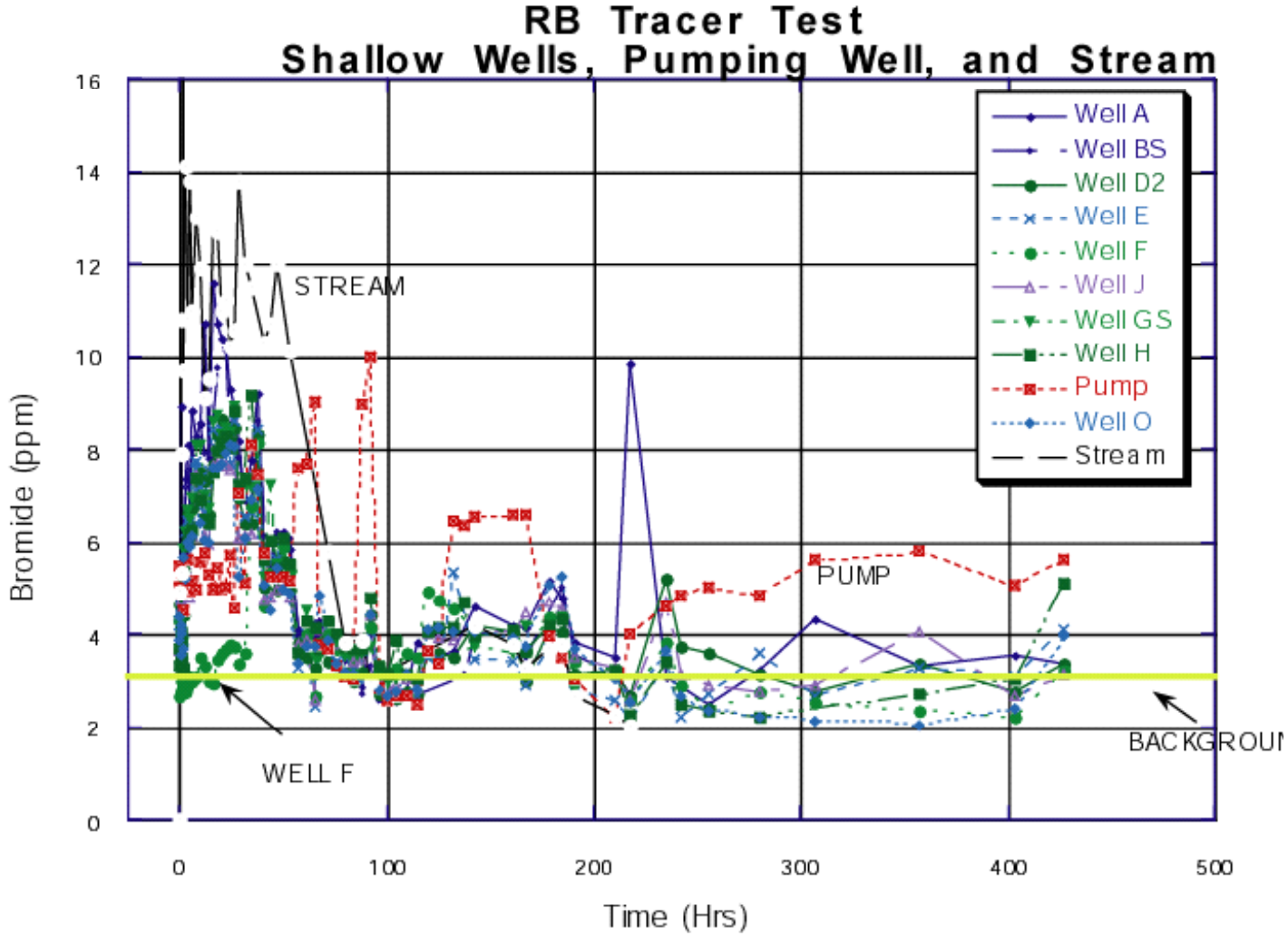


Deep Wells – First 150 Hours



First 150 Hours





Wells in the shallow aquifer unit do not show the second and third peaks. These are in the deep aquifer (See above). The second peak is between120 and 190 hours and the Third Peak is between 220 and 500 hours.

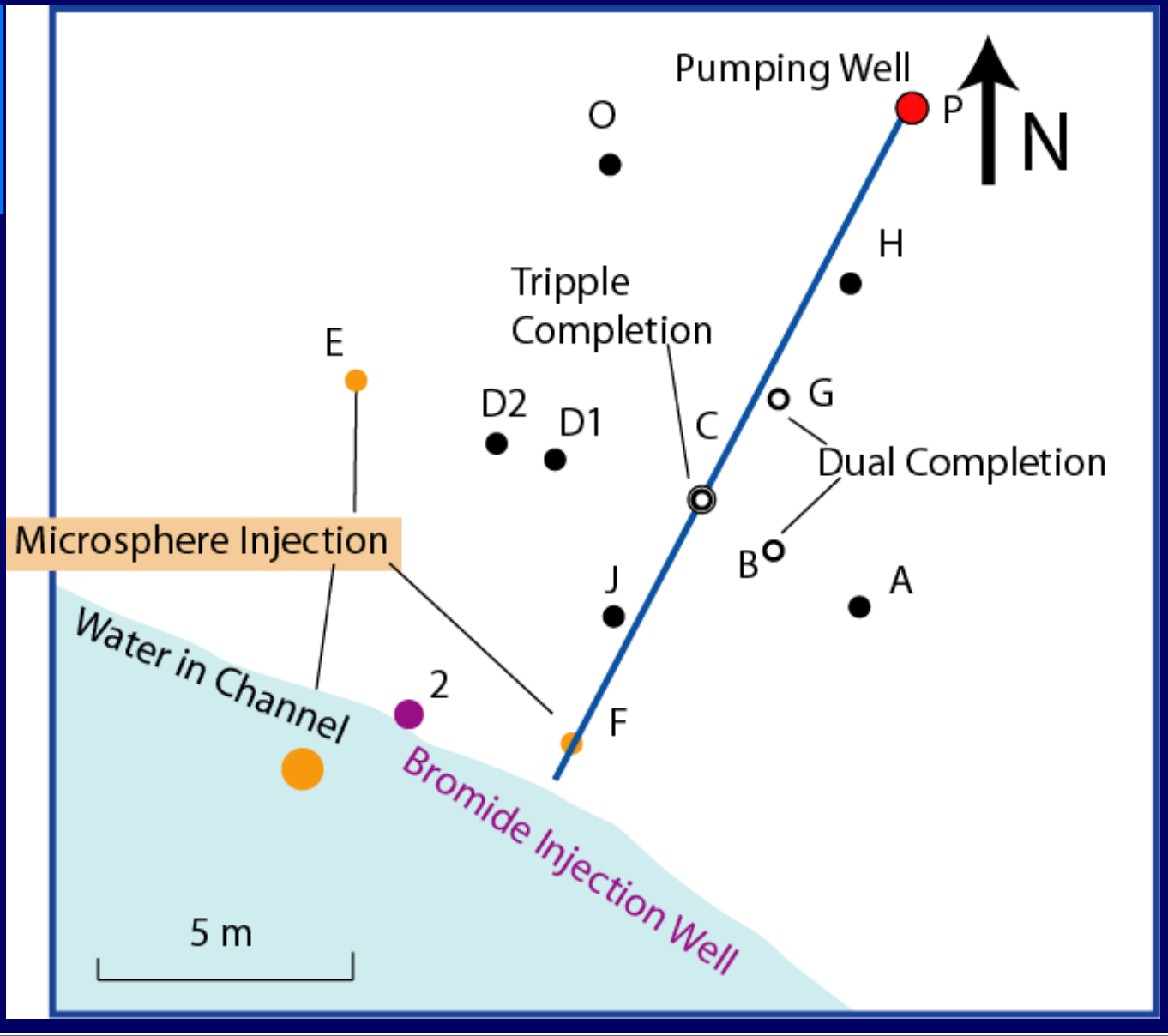
Conclusions from Bromide tests

- The first appearance of bromide is in the stream, where it appears 30 minutes after injection. The bromide is traveling *against* a 2 m hydraulic gradient.
- Three distinct peaks in Bromide concentration are visible in the observation wells.
- Each peak is found in all of the wells nearly at the same time. This indicates that the bromide travels very quickly in preferential paths.

Conclusions (cont'd)

- The first peak in the well is found in the shallow flow unit and reaches a maximum in all wells at 25-30 hours.
- The second and third peaks were also confined to the deep flow unit and was very long-lived, lasting from 220-450 hours. This peak had some of the highest concentrations of bromide. (15 ppm or 3 times background).

Microsphere Tracer Test


Pumping Well
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Completion
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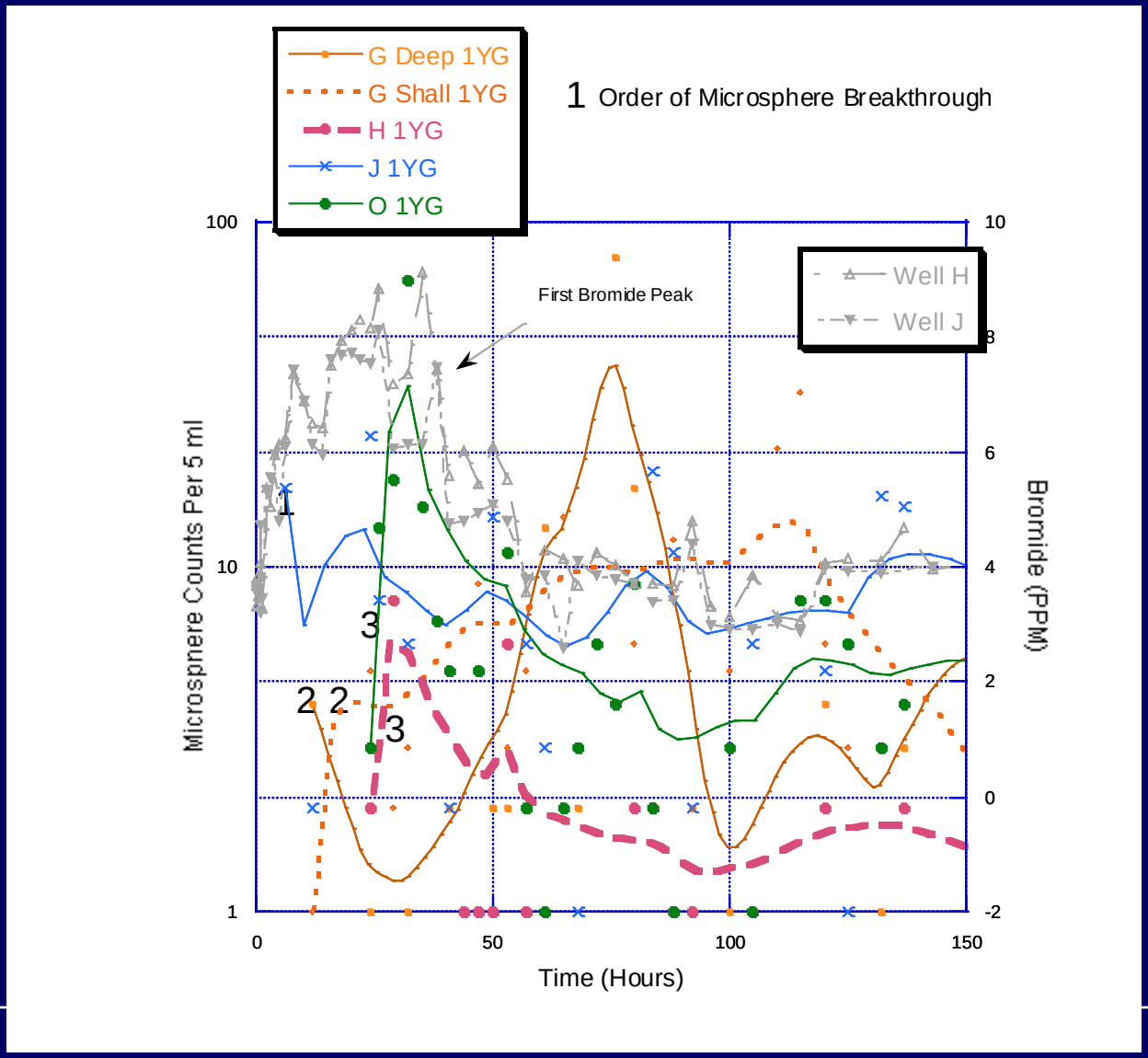
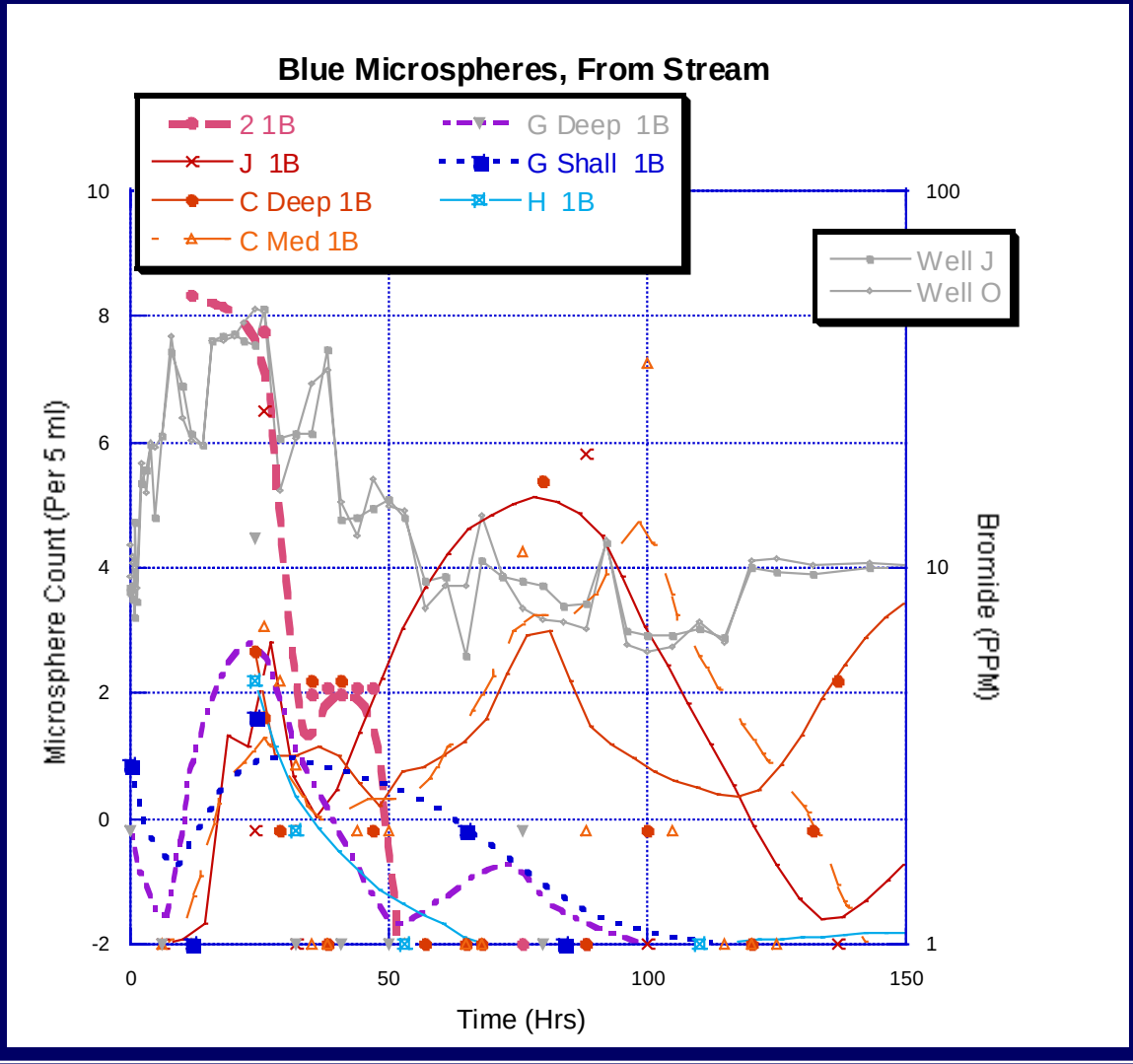
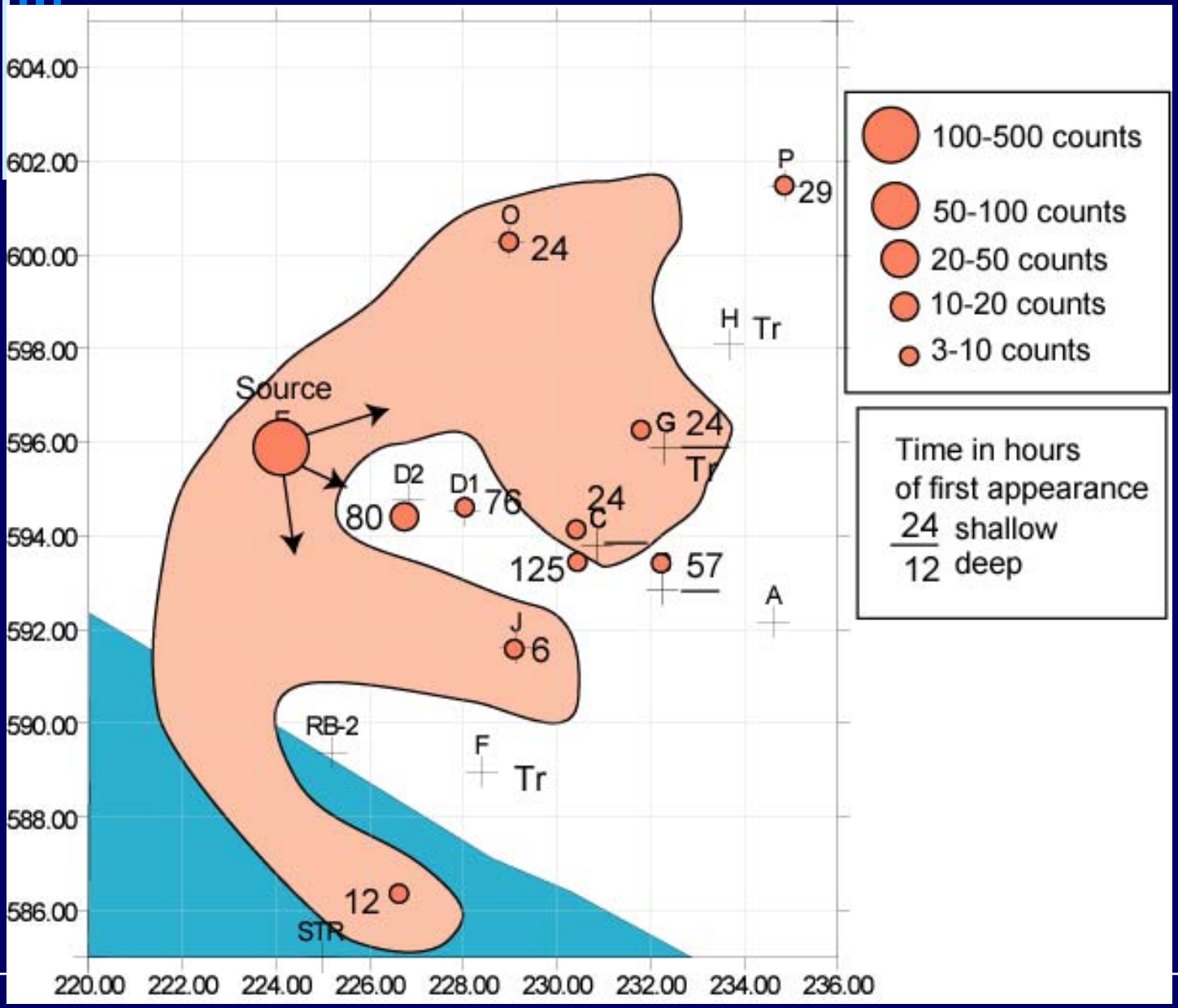
Dual Completion
Microsphere Injection
B
J
A
Water in Channel
2
F
Bromide Injection Well
5 m

Yellow Green Microspheres, from well near stream bank



Blue Microspheres, injected into stream bed




604.00
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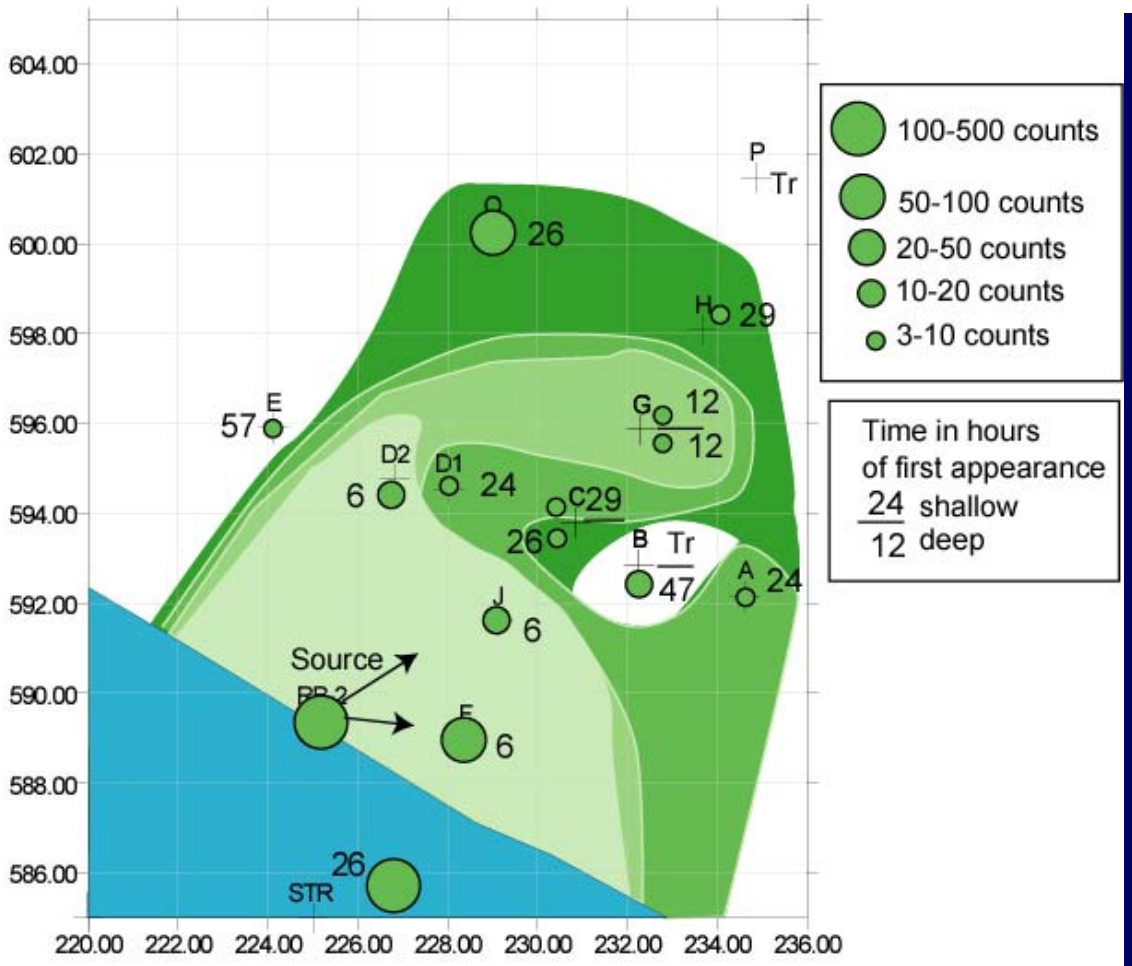
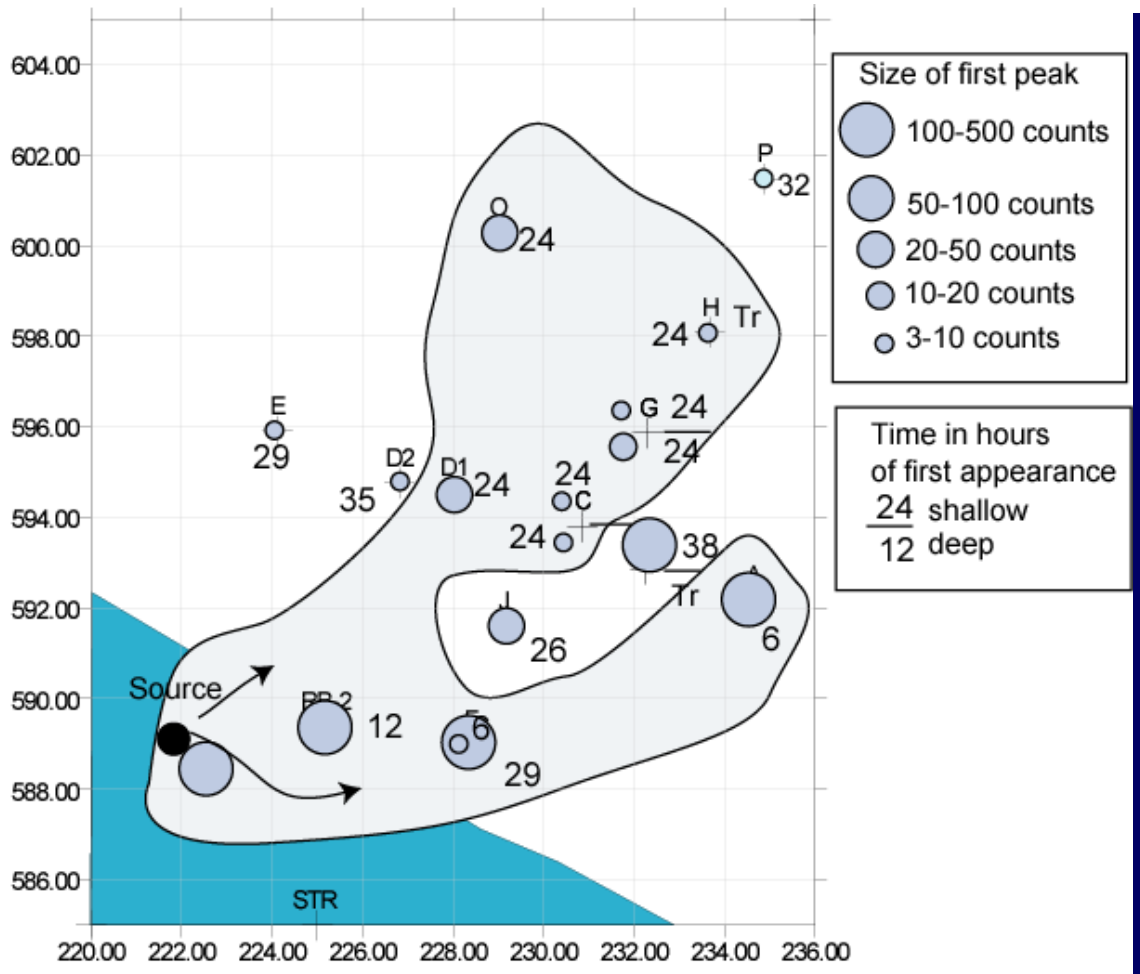
226.00
228.00
230.00
232.00
234.00
236.00
Source
E
O
24
P
29
H
Tr
G
24
Tr
D2
80
D1
76
C
24
125
57
A
J
6
RB-2
F
Tr
12
STR
100-500 counts
50-100 counts
20-50 counts
10-20 counts
3-10 counts
Time in hours
of first appearance
24
shallow
12
deep



Note, The first appearance was determined by the first count of five or above, or the first three successive counts below five.



Note, The first appearance was determined by the first count of five or above, or the first three successive counts below five.

Microsphere test - Results

- The 1μm micospheres were abundant in the observation wells and allowed tracing of flow-paths. These showed multiple peaks similar to the bromide results. This indicates highly preferential transport paths in the sediment.
- Microspheres from the three injection sites had distinctly different transport paths and rates.
- Both bromide and microspheres appeared in the stream soon after injection, moving apparently against an 2-m head difference.
- The 6 μm and 10 μm microspheres were observed in low concentrations and were episodically detected in the stream and in two widely spaced observation wells.
- The detection of larger sized microspheres indicates the potential migration of cysts and oocysts under riverbank filtration conditions.

Significance of Results

- Inorganic microspheres may mimic the episodic occurrence of microorganisms in wells.
- Even in this relatively homogeneous aquifer, preferential transport within the aquifer results in highly divergent transport paths and rates. Microspheres from one of the injection sites traveled *essentially perpendicular* to the expected transport direction.
- Even small variations in the sand grain size can effectively compartmentalize the aquifer.

Proposed Next Steps….

- The next steps of this project will include field studies to observe the migration and persistence of selected organisms (E.coli, enterococci, coliphages, cysts, oocysts and enteroviruses) in the pumping well and observation wells under two different pumping rates.
- Continued combined chemical analysis along with the microbial analysis will document whether changes in water chemistry alter the transport and persistence behavior of the organisms during riverbank filtration

Sample	Somatic Phage	Fecal Coliforms	MPN	E. Coli.	MPN	Salmonella	Enterococci
RBWC 10-11-02	166	1600	5.5.4	500	5.5.2	0	44
RBWC 10-15-02	88	1600	5.5.4	900	5.5.3	0	
RBWC 10-19-02	8	500	5.5.2	17	3.3.0	0	54
RBWC 10-22-02	456	300	5.5.1	500	5.5.2	0	
RBWC 10-25-02	59	900	5.5.3	280	5.4.3	0	151
RBWC 10-29-02	38	300	5.5.1	30	5.1.0	0	
RBWC 11-2-02	393	50	5.2.0	8	3.0.0	0	182
Average	172.5	750.0		319.3		0.0	107.8

Background microbial counts in the channel.

Note: All data is number of organisms per 100 ml.
All samples had proper results for negative and positive controls.
MPN refers to the number of positive tubes for 10 ml, 1 ml, and 0.1 ml sample volumes.