Are Viruses a Hazard in Waste Water Recharge of Urban Sandstone Aquifers?

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Aims

To determine if viruses are a hazard for urban waste-water recharge programmes in urban sandstone aquifers

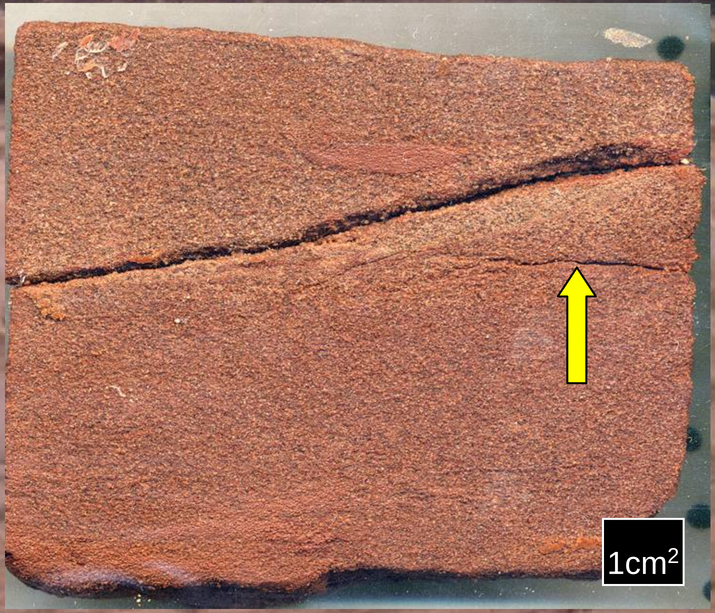
Why viruses?

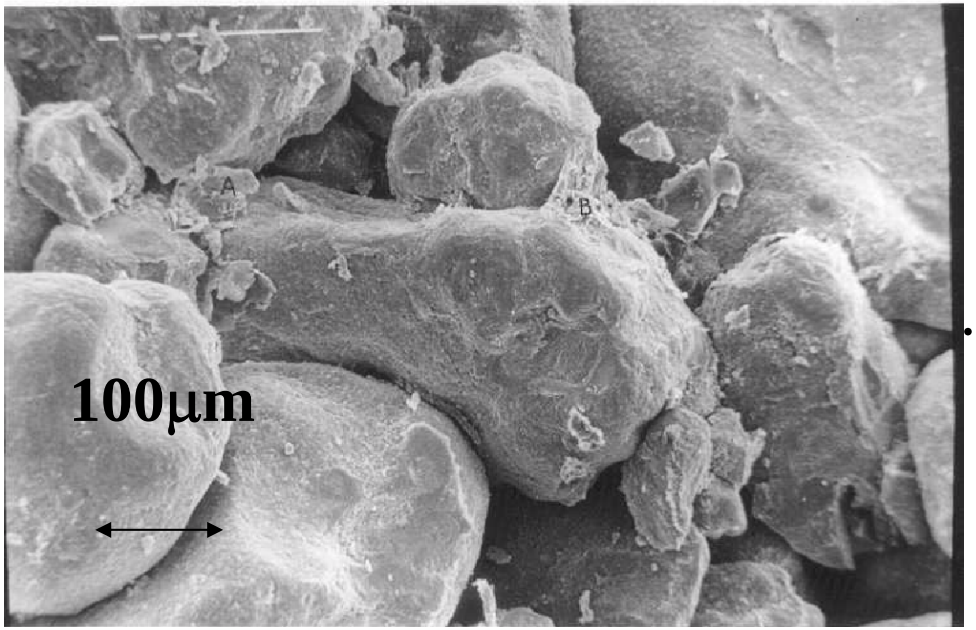
- For most contaminants there is at least a certain amount of experience for predicting mobility
- Viruses
  - comparatively little experience / data (worldwide)
  - recent evidence suggests that may be an issue

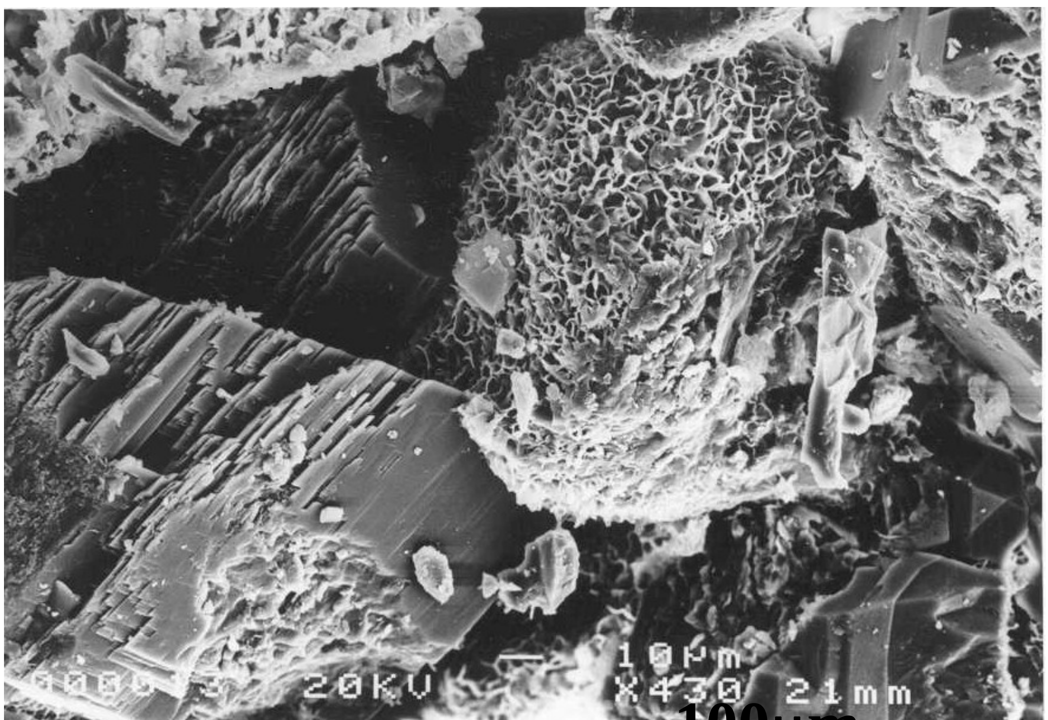
The aquifer

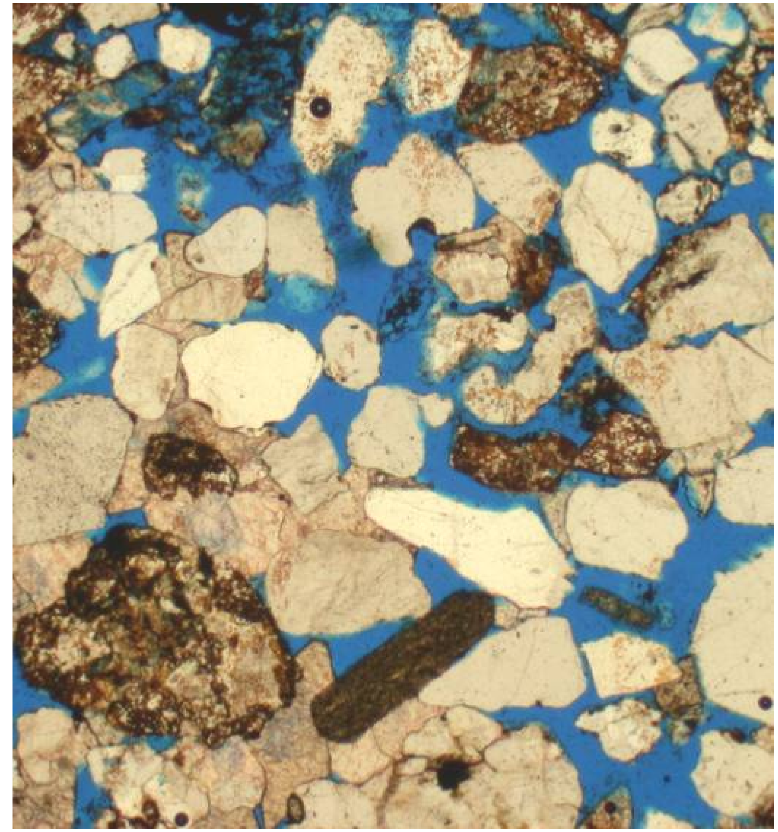
Permo-Triassic Sst sequence.

UK's second most used aquifer, and equivalent red-bed sequences used across EU and beyond.





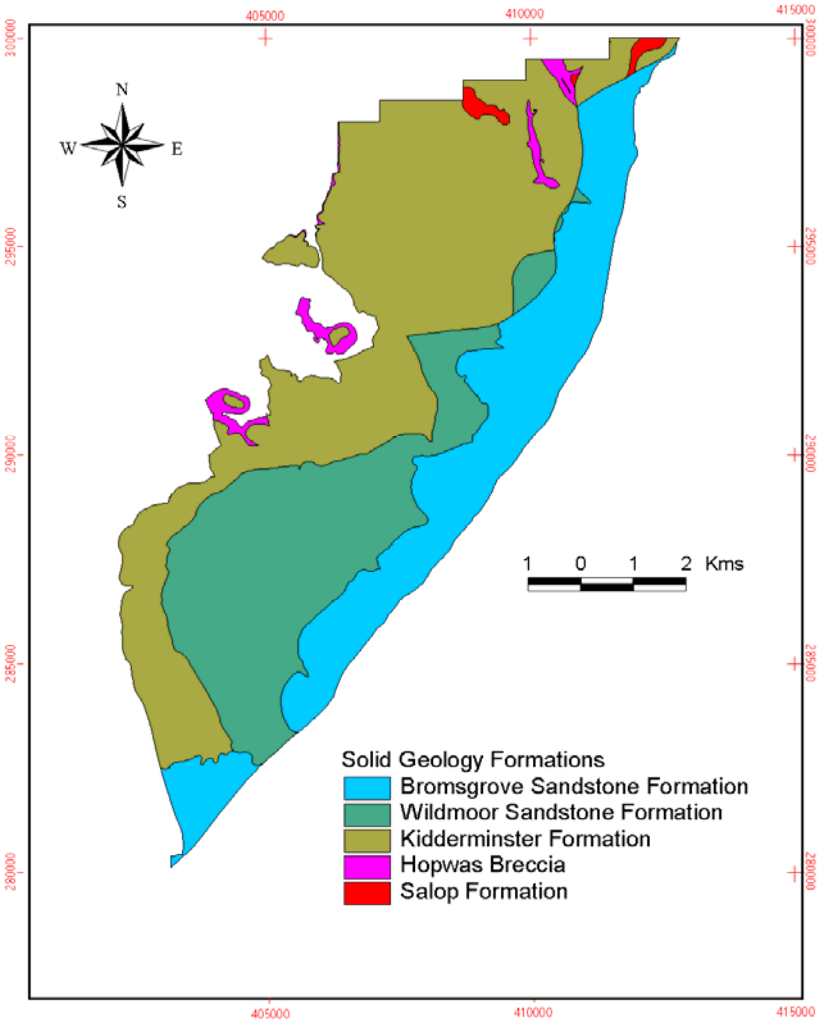




EPSRC

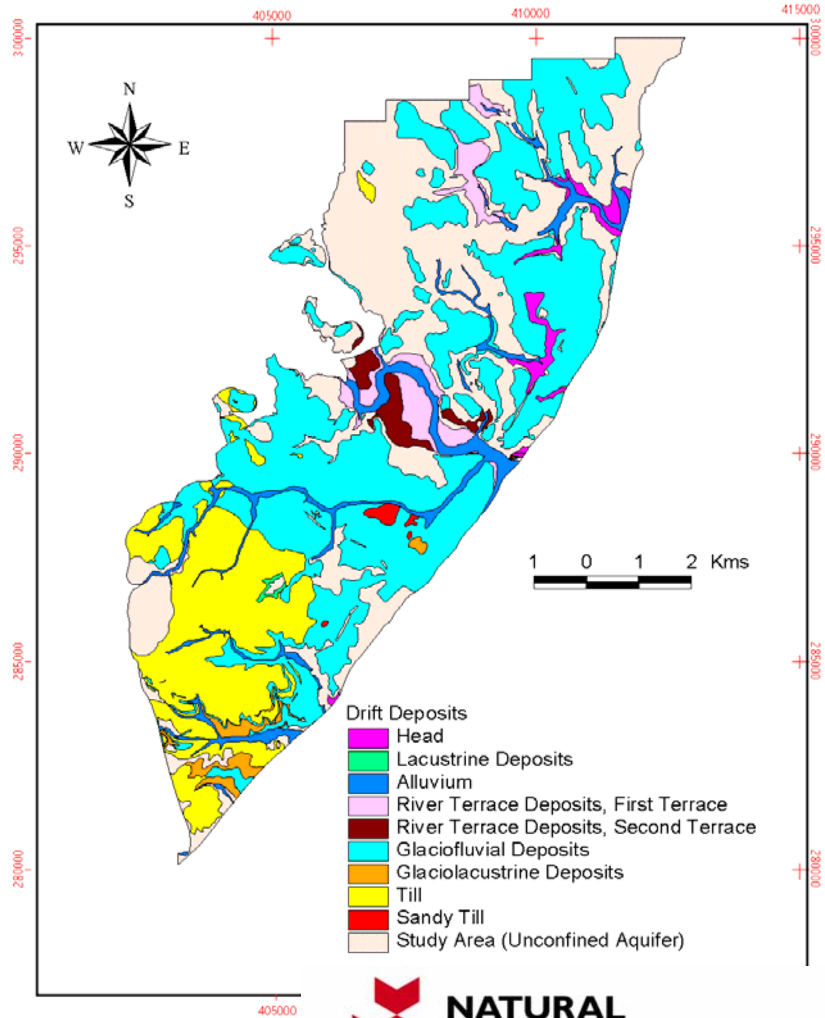
SOLID GEOLOGY OF BIRMINGHAM AREA

(UNCONFINED AQUIFER PART ONLY)



DRIFT GEOLOGY OF BIRMINGHAM AREA

(UNCONFINED AQUIFER PART ONLY)



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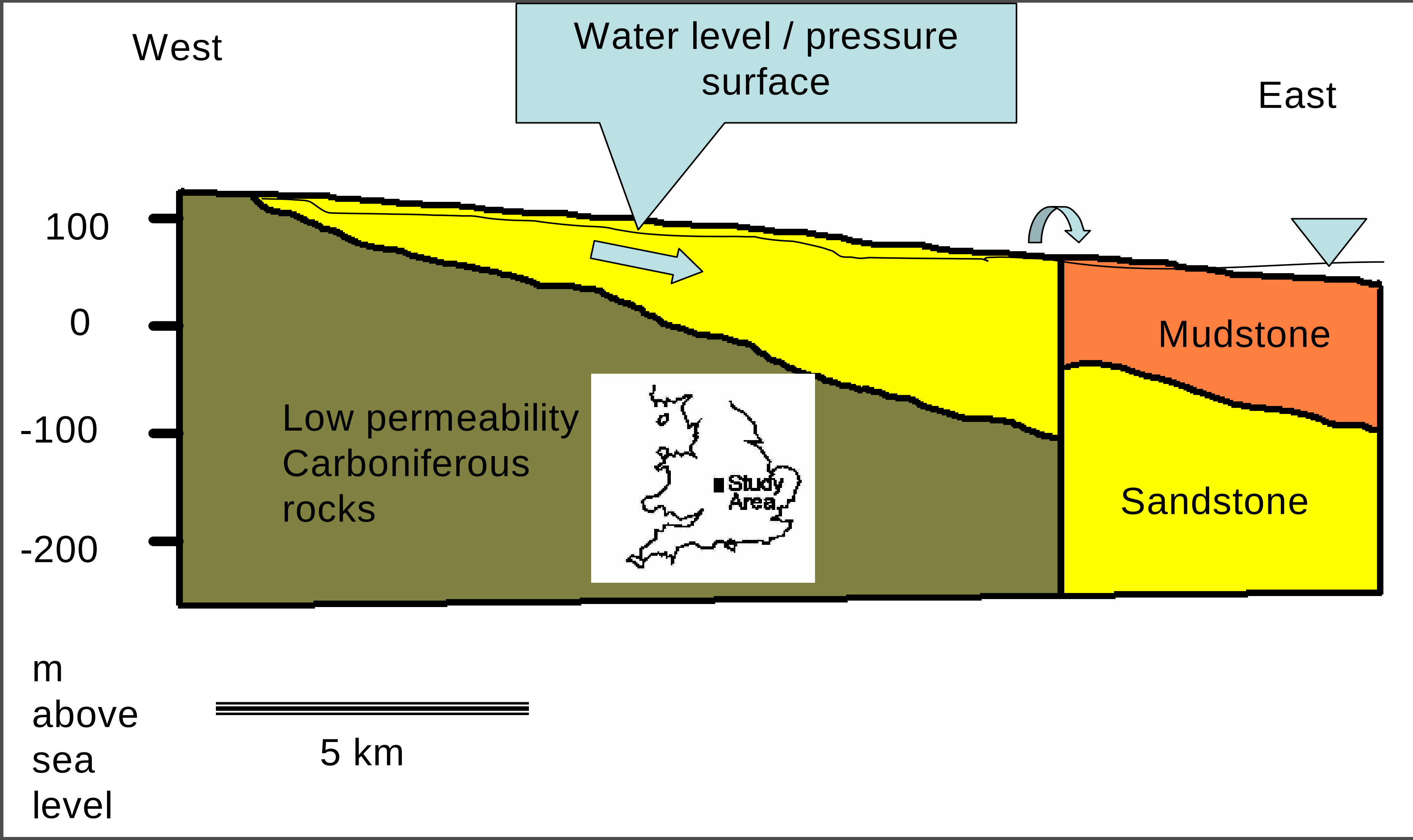
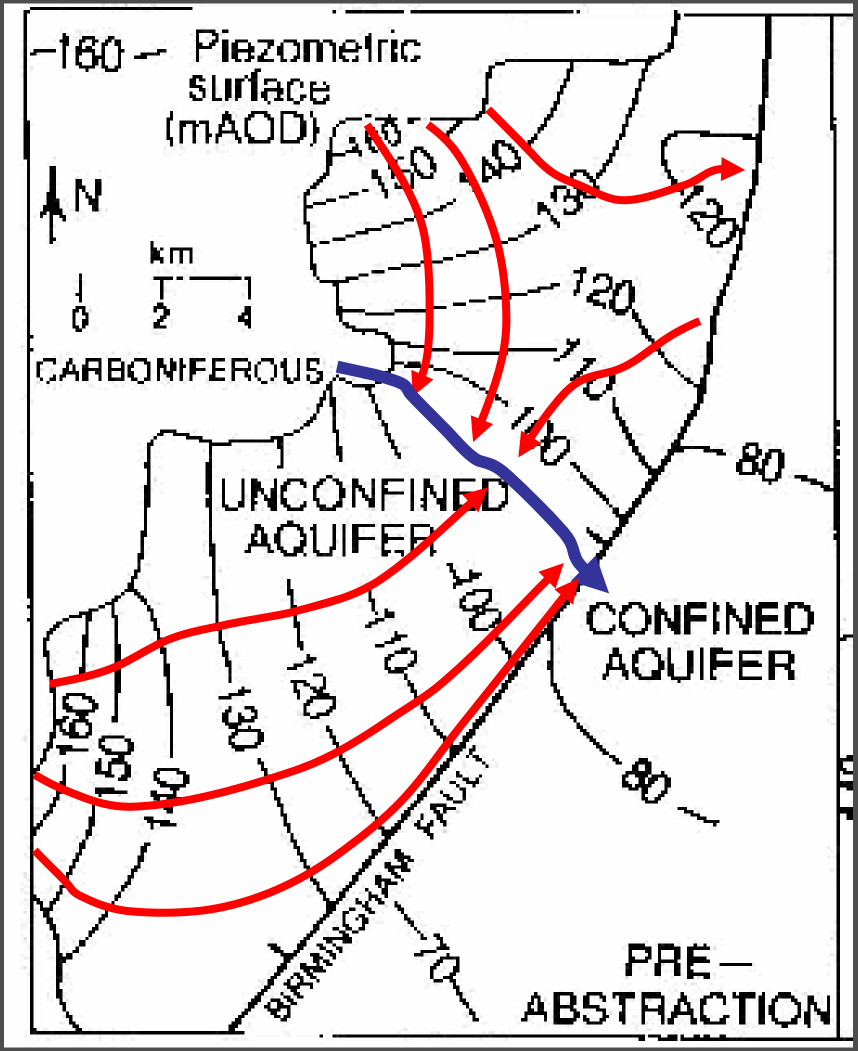
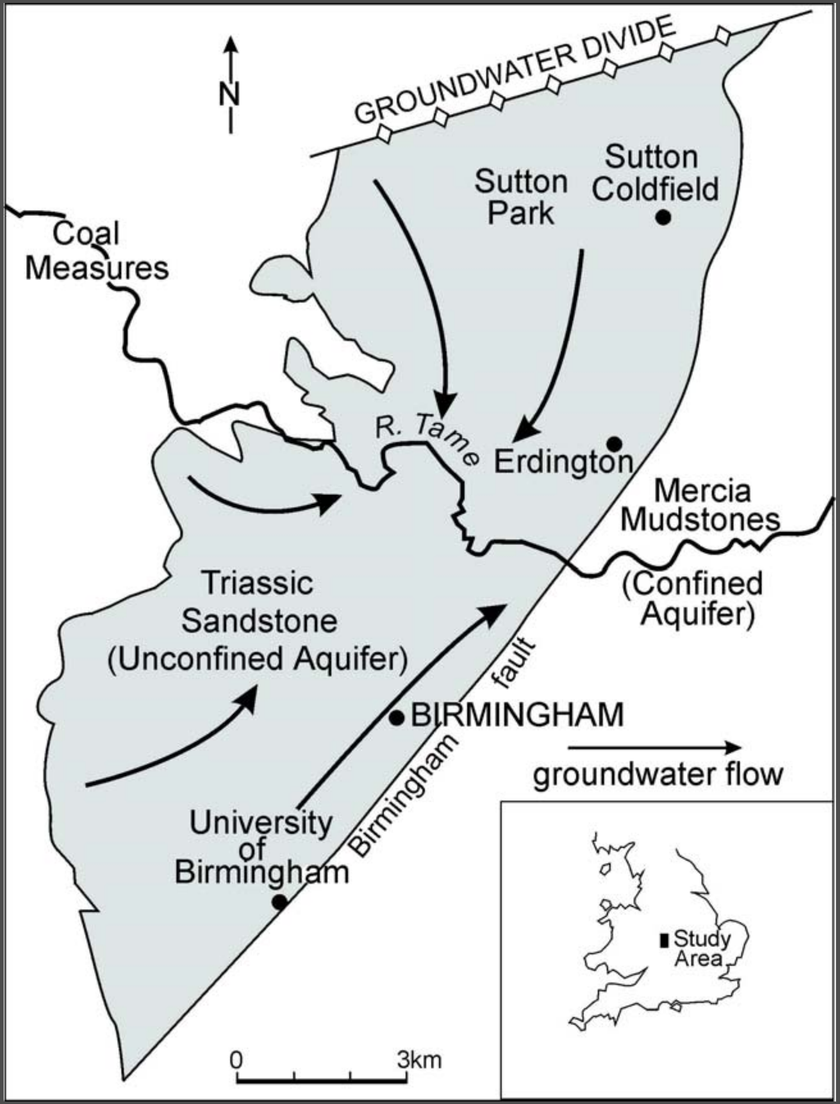
Thomas and Tellam (2006)

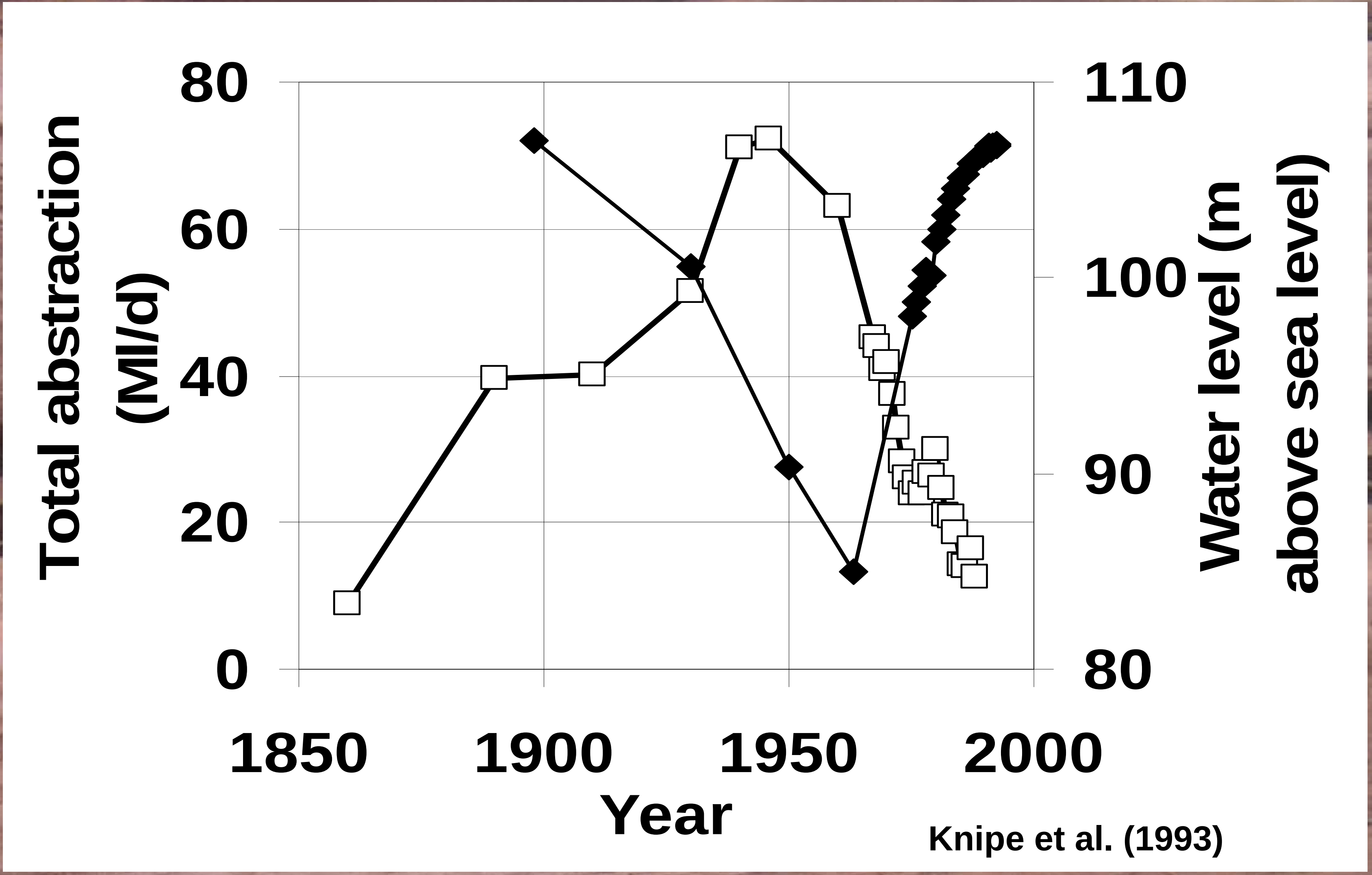


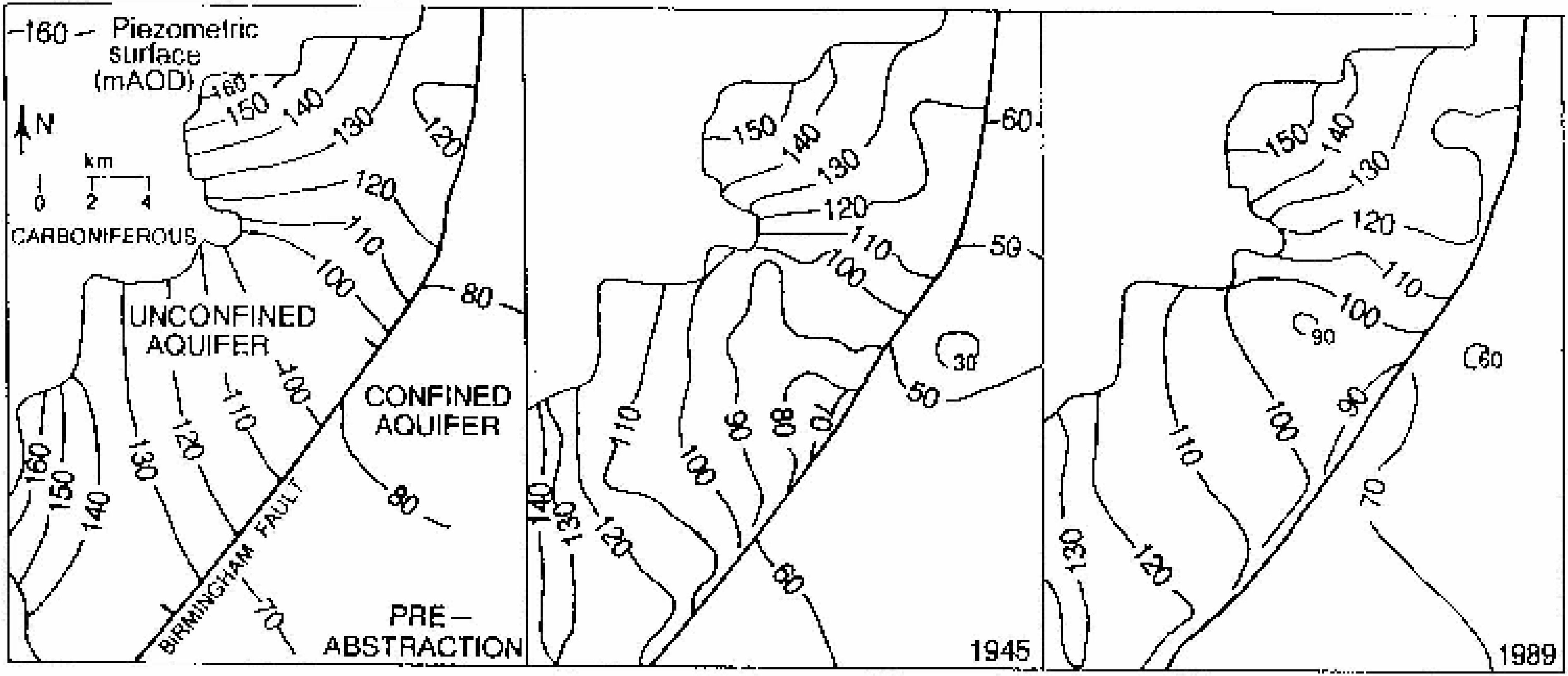
West
Water level / pressure surface
East
100
0
-100
-200
Mudstone
Low permeability Carboniferous rocks
Study Area
Sandstone
m above sea level
5 km



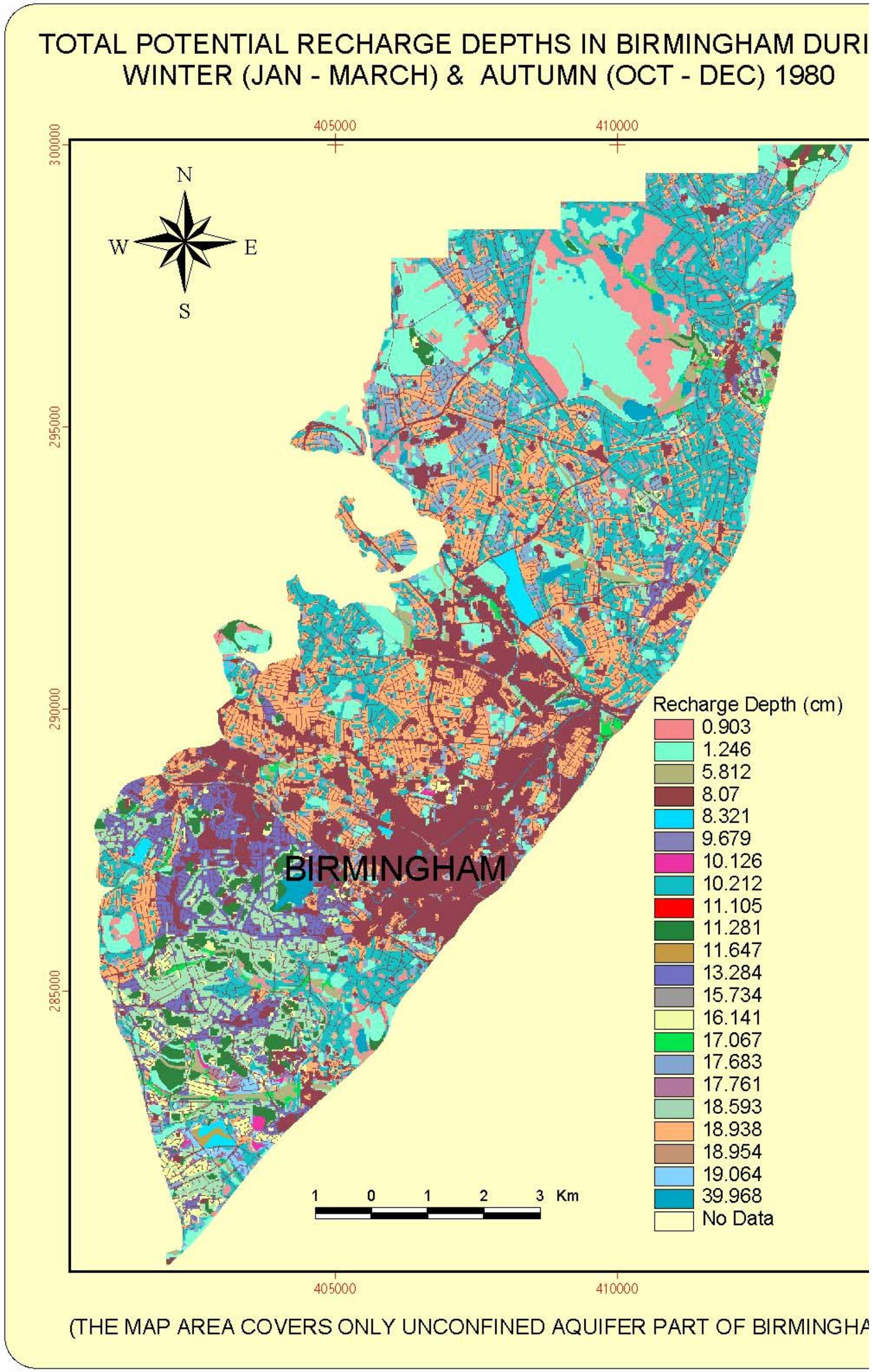


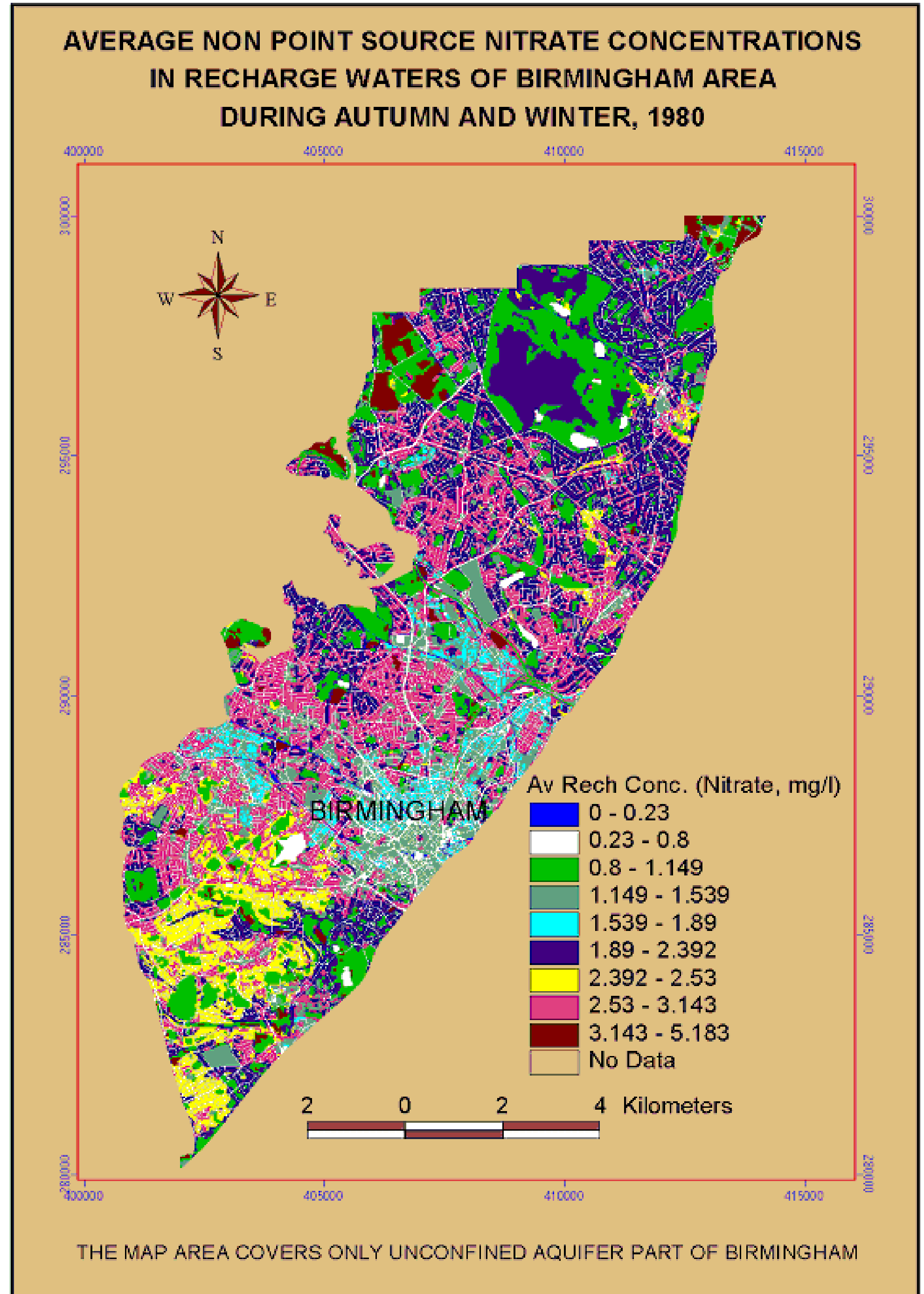
- **Gw velocity ~ 10-100 m/y**

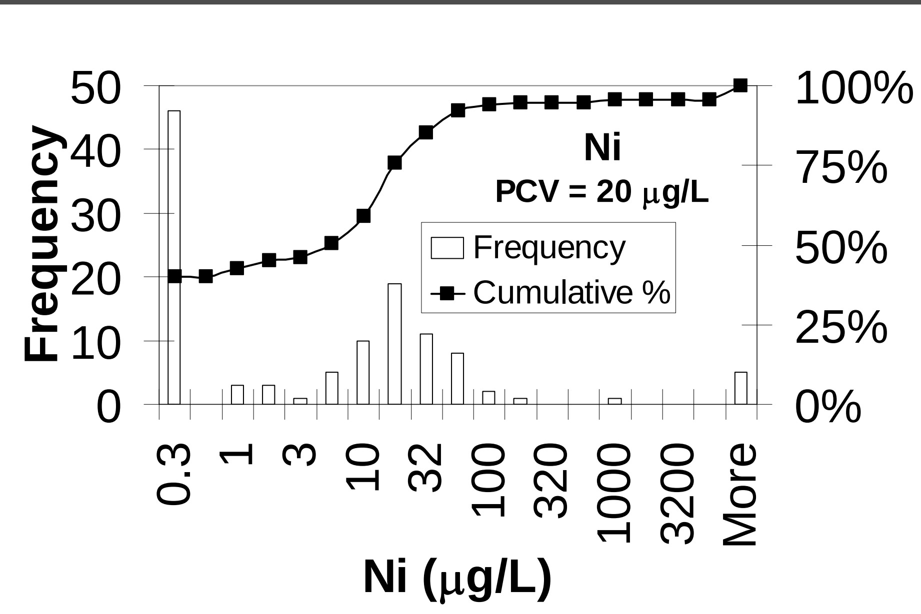

80
60
40
20
0
110
100
90
80
Total abstraction (Ml/d)
Water level (m above sea level)
1850
1900
1950
2000
Year
Knipe et al. (1993)

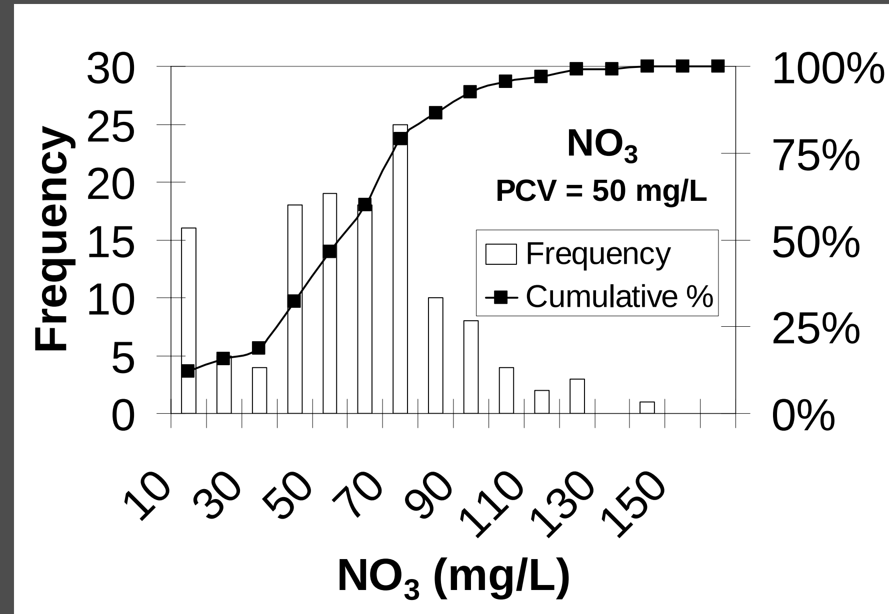


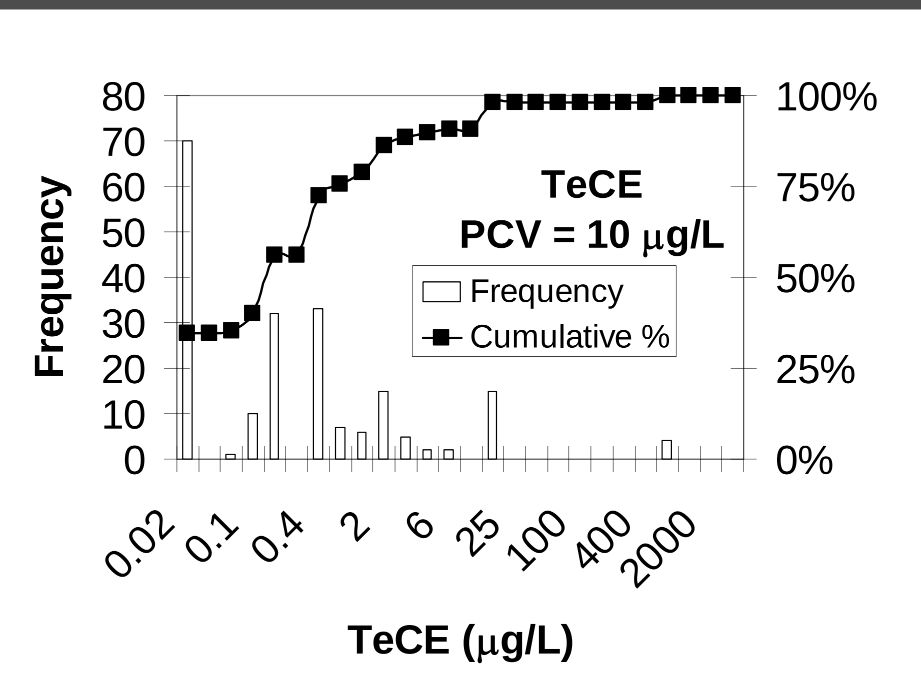
-160 - Piezometric surface (mAOD)
N
km
0 2 4
CARBONIFEROUS
UNCONFINED AQUIFER
CONFINED AQUIFER
BIRMINGHAM FAULT
PRE-ABSTRACTION
160
150
140
130
120
110
100
80
70
60
50
90
30
1945
1989

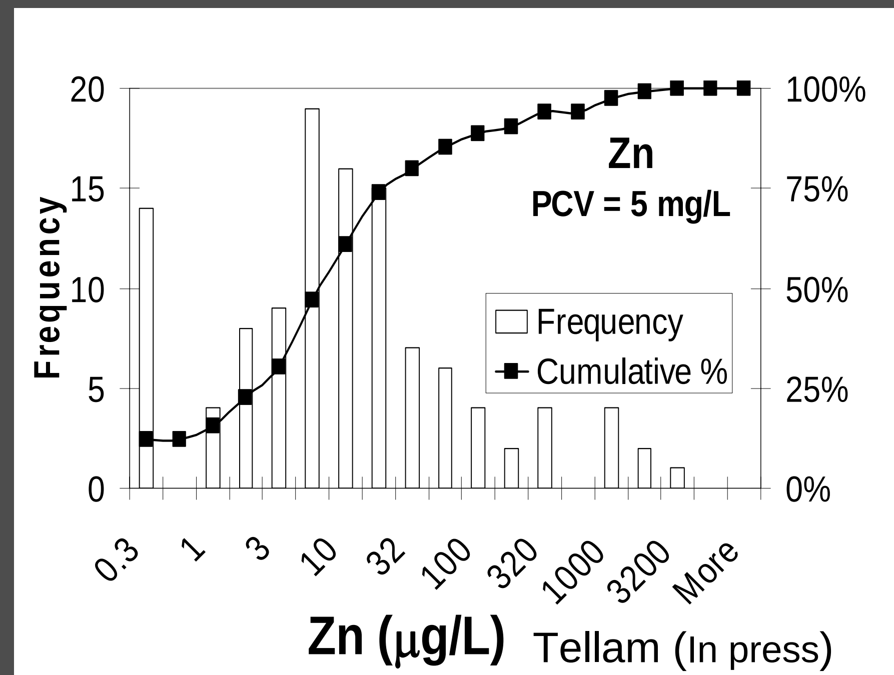

TOTAL POTENTIAL RECHARGE DEPTHS IN BIRMINGHAM DURI
WINTER (JAN - MARCH) & AUTUMN (OCT - DEC) 1980
405000
410000
300000
295000
290000
285000
N
W
E
S
BIRMINGHAM
Recharge Depth (cm)
0.903
1.246
5.812
8.07
8.321
9.679
10.126
10.212
11.105
11.281
11.647
13.284
15.734
16.141
17.067
17.683
17.761
18.593
18.938
18.954
19.064
39.968
No Data
1 0 1 2 3 Km
(THE MAP AREA COVERS ONLY UNCONFINED AQUIFER PART OF BIRMINGHA


AVERAGE NON POINT SOURCE NITRATE CONCENTRATIONS
IN RECHARGE WATERS OF BIRMINGHAM AREA
DURING AUTUMN AND WINTER, 1980
400000
405000
410000
415000
300000
295000
290000
285000
280000
N
W
E
S
BIRMINGHAM
Av Rech Conc. (Nitrate, mg/l)
0 - 0.23
0.23 - 0.8
0.8 - 1.149
1.149 - 1.539
1.539 - 1.89
1.89 - 2.392
2.392 - 2.53
2.53 - 3.143
3.143 - 5.183
No Data
2 0 2 4 Kilometers
THE MAP AREA COVERS ONLY UNCONFINED AQUIFER PART OF BIRMINGHAM









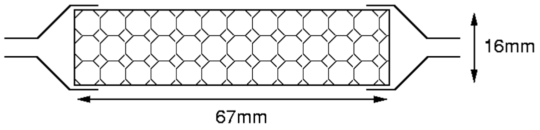
Tellam (In press)

Human virus occurrence in UK urban sst aquifers

Abstraction wells in Birmingham

Date	Site	Enterovirus (PFU/L)	Rotavirus (PFU/L)
Industrial Wells			
19/05/99	8	2	<1
28/05/99	10	1	<1
18/06/99	10	<1	170
19/05/99	17	1	<1
11/06/99	17	<1	<1
18/06/99	B1-55K	<1	8
18/06/99	U2	<1	<1
Piezos			
21/04/99	B	30	450
19/05/99	B	2	<1
31/08/99	B	<1	<1
29/02/00	B	<1	-
21/04/99	D	65	<1
05/05/99	D	1	<1
31/08/99	D	<1	<1
29/02/00	D	4	-
29/02/00	E	<1	-
26/03/99	F	<1	<1
29/02/00	F	4	-

EPSRC Study:
Enteroviruses in Groundwaters



Piezometers in Nottingham

Powell et al. (2000)

Site A Multilevel	Depth of sample (mbgl)	Coliphage PFU/L	Enterovirus (cell culture)	Enterovirus RT-PCR	Rotavirus RT-PCR	Norwalk like viurs RT-PCR	Adenovirus PCR	Astrovirus RT-PCR
1	8.24	<1	nd	nd	nd	nd	nd	nd
2	11.22	<1	nd	nd	nd	detected	nd	nd
3	15.00	<1	nd	nd	nd	detected	nd	nd
4	18.00	<1	nd	nd	nd	nd	nd	nd
5	22.38	<1	nd	nd	nd	detected	nd	nd
6	26.45	<1	nd	nd	nd	nd	nd	nd
7	30.35	<1	nd	nd	nd	detected	nd	nd
8	35.33	30	nd	nd	nd	nd	nd	nd
9	39.30	<1	nd	nd	nd	detected	nd	nd
10	42.50	<1	nd	nd	nd	no sample	nd	nd
11	49.22	<1	nd	nd	nd	nd	nd	nd

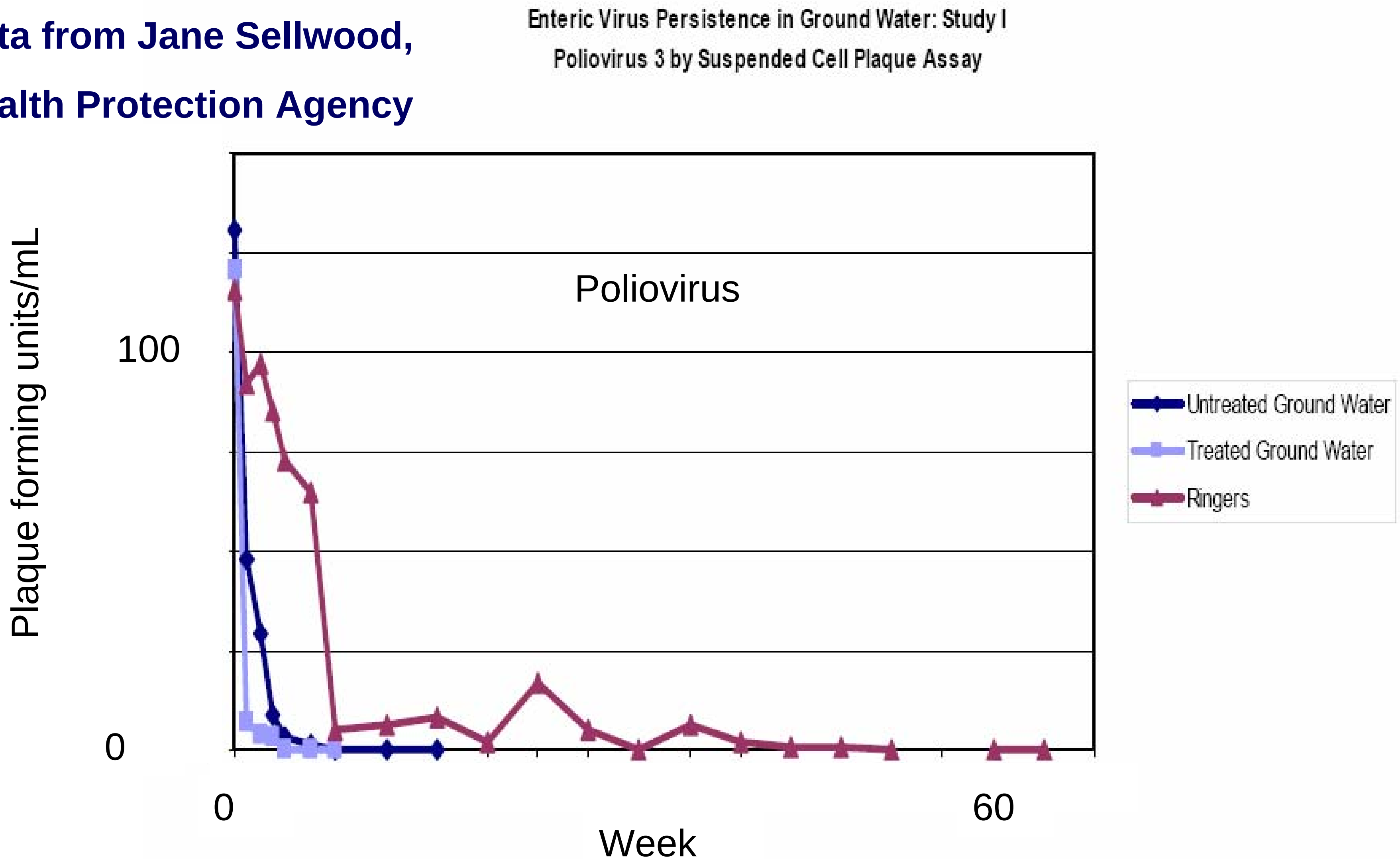
nd - not detected

Powell et al. (2003)

Experimental studies of virus survival

Data from Jane Sellwood,

Health Protection Agency



Last detection by PCR (weeks):

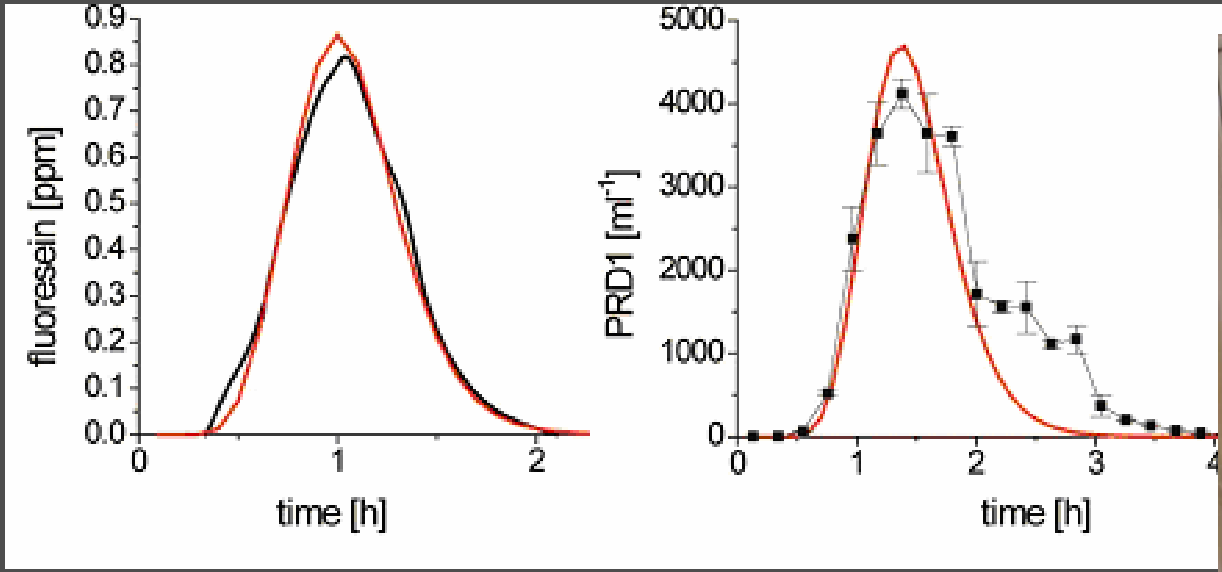
	Untreated Groundwater	Treated Groundwater	Ringers Solution
Enterovirus	32	16	>104
Adenovirus	96	>104	>104
Norovirus Genogroup I	84	100	>104
Norovirus Genogroup II	96	>104	>104

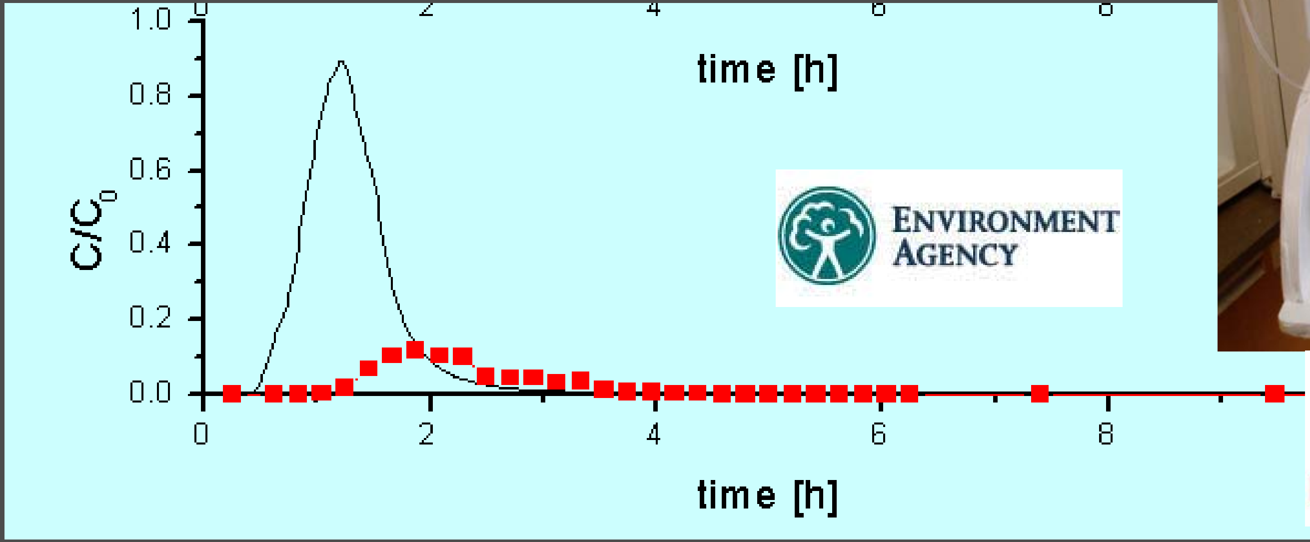
Data from Jane Sellwood,

Health Protection Agency

Experimental studies of virus mobility

laboratory column expts





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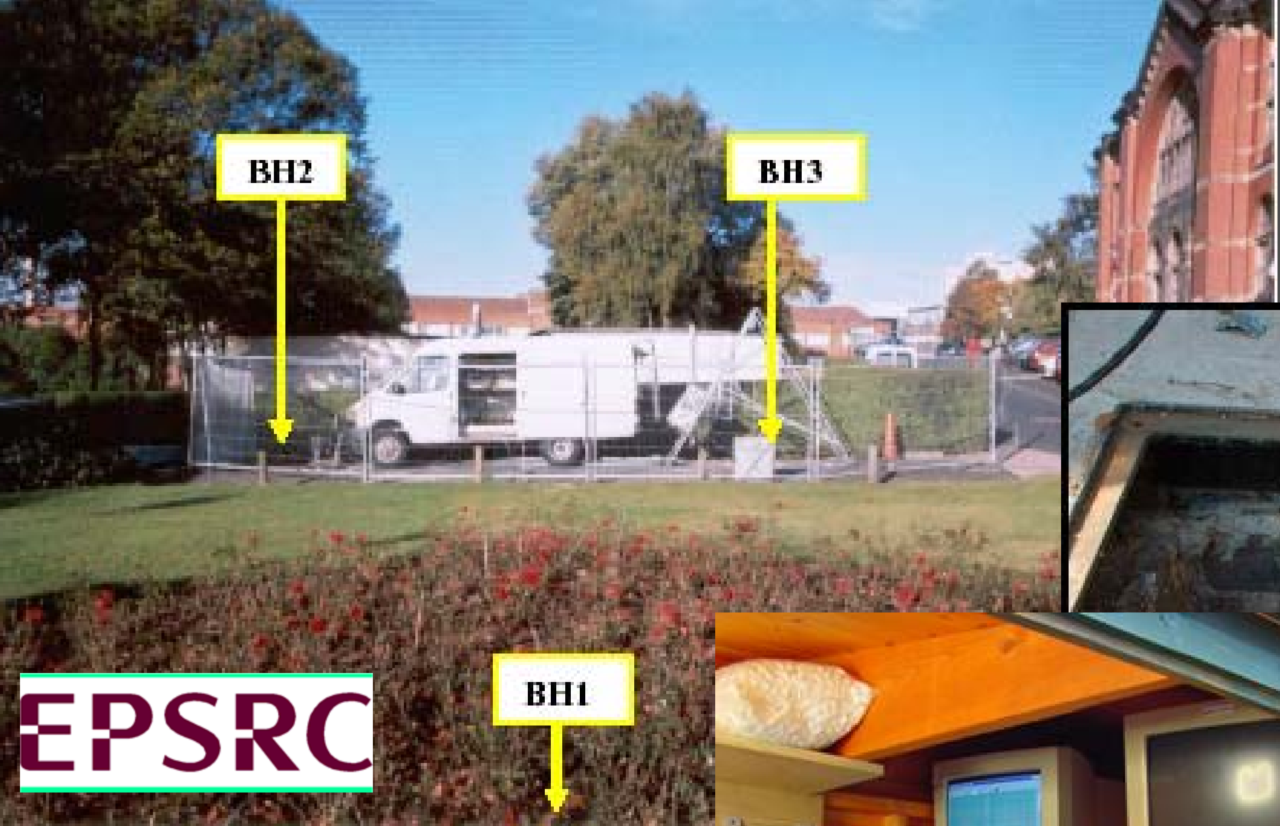
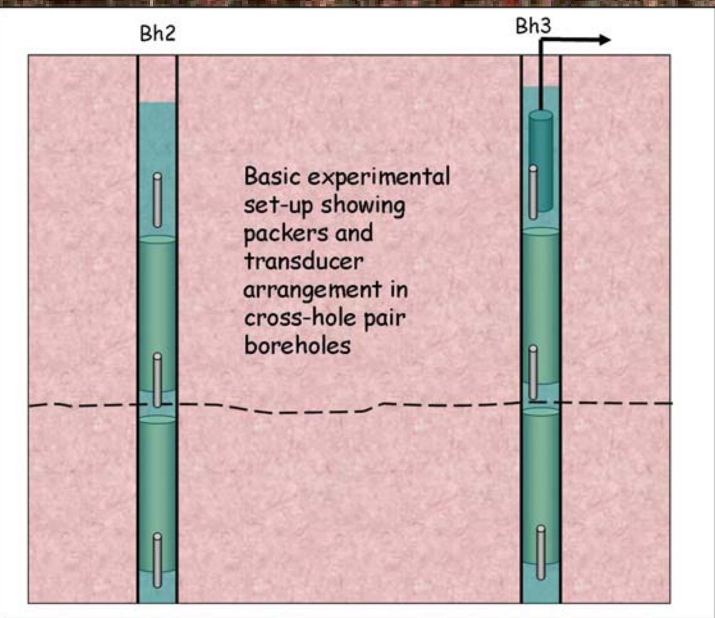
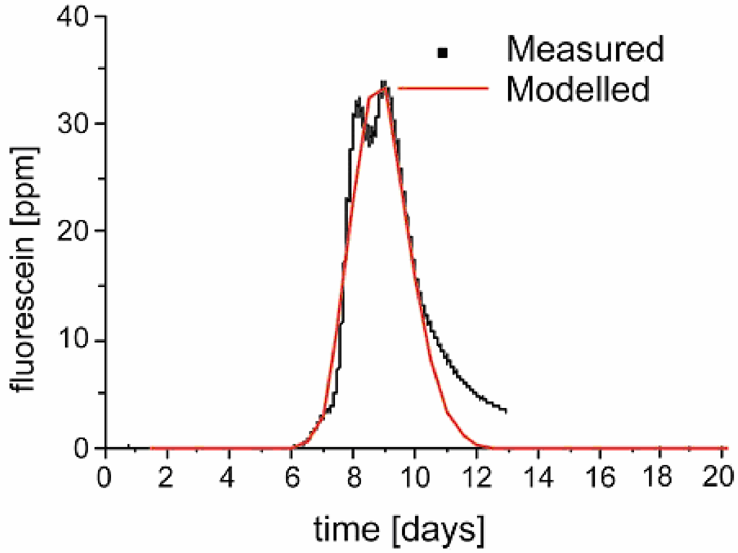
field


BH2
BH3
BH1


Bh2
Bh3
Basic experimental set-up showing packers and transducer arrangement in cross-hole pair boreholes

Recovery Well

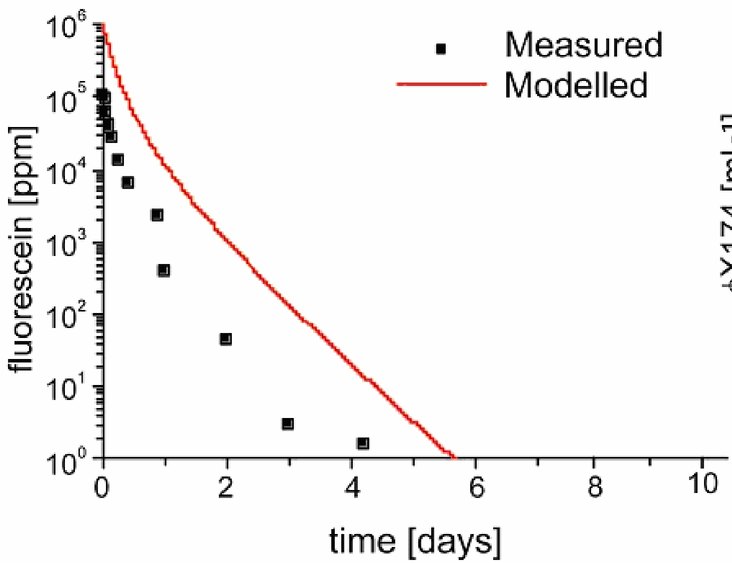


Recovery Well

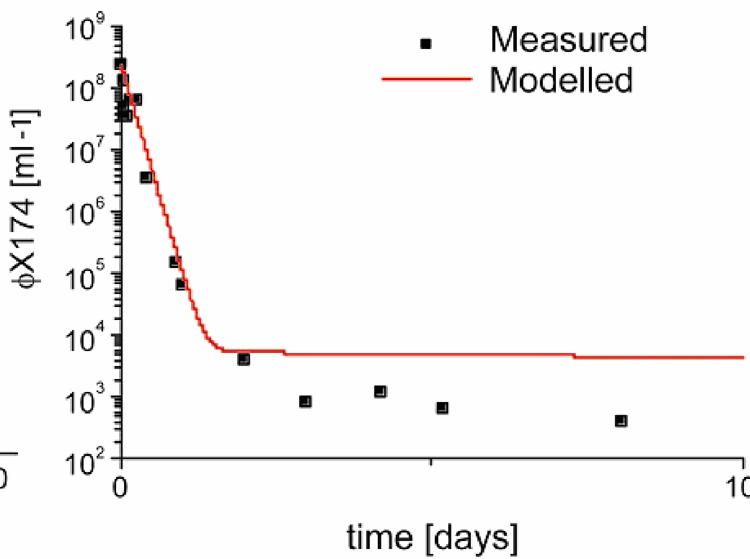
No virus recovered

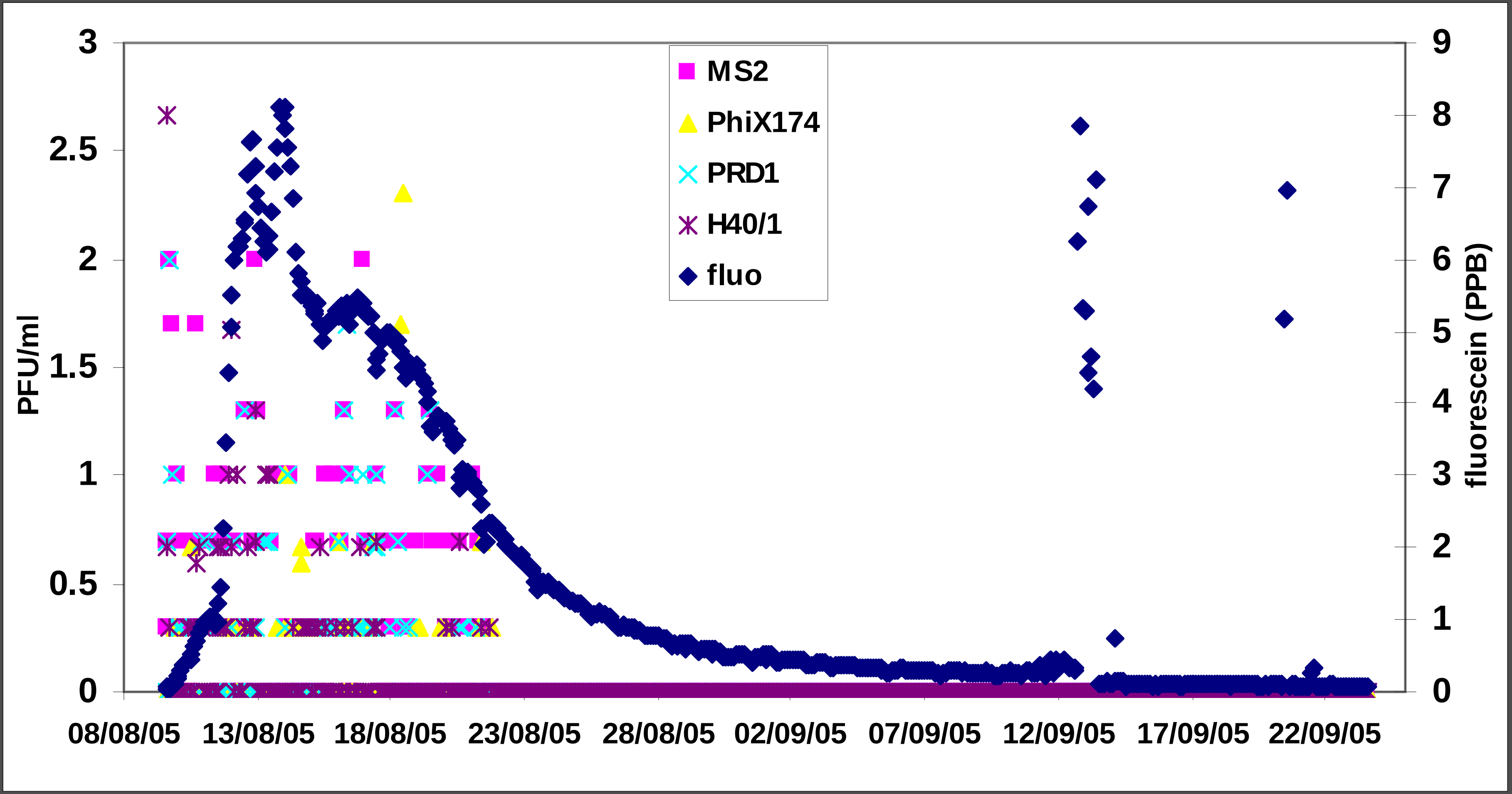
Joyce et al. (In press)

Injection Well



Injection Well





Joyce et al. (In press)

The SWITCH project WP3.2: approach, issues, design, and progress

Approach

can we use the aquifer’s attenuation capacity to make sure that viruses are not present in recovered waste water?

Empirical investigation ….

The main issues to be addressed are:

1. **velocities and distances of travel of viable viruses under aquifer conditions**

2. **effects of (pumping-induced) gw velocity changes**

3. **effect of attachment on viability**

Design and Progress

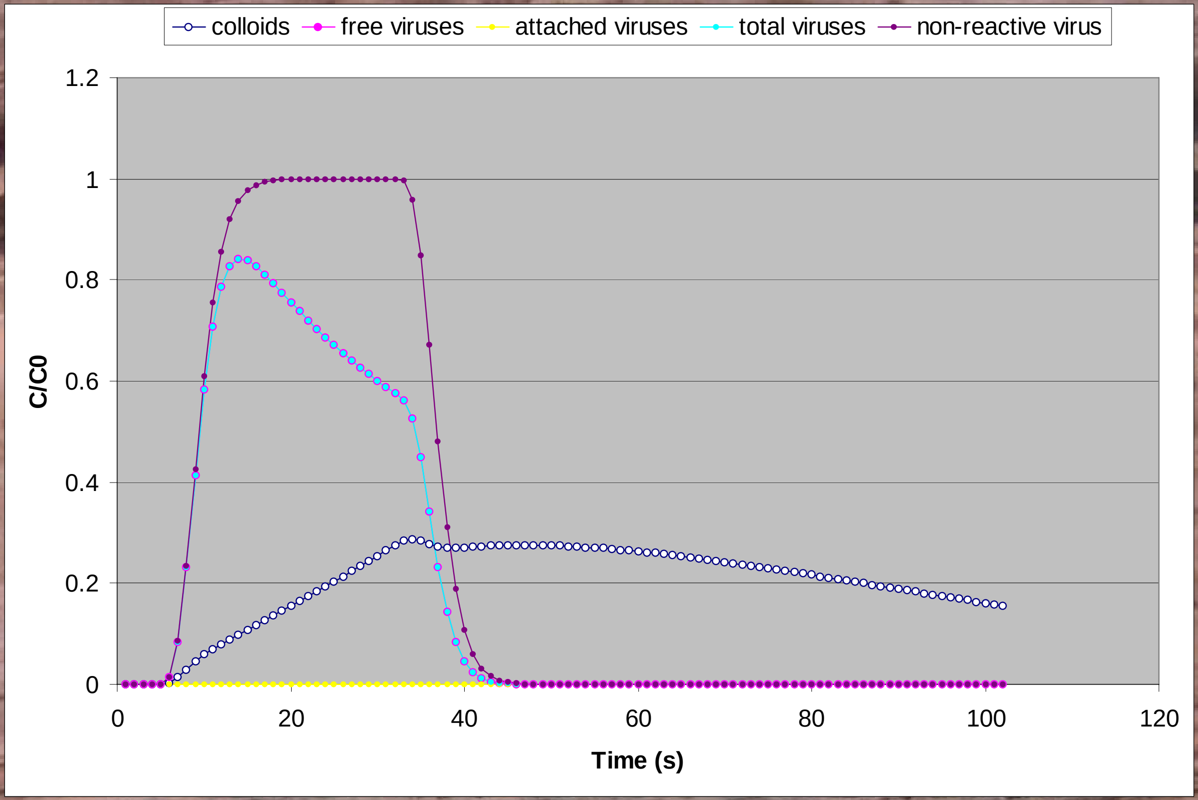
- ***field monitoring***
  - velocities and distances of travel under aquifer conditions
- ***field experimentation***
  - velocities and distances of travel under aquifer conditions
  - effects of pumping-induced gw velocity changes
- ***laboratory experimentation***
  - effects of pumping-induced velocity changes
  - effects of attachment on viability
- ***modelling***

modelling

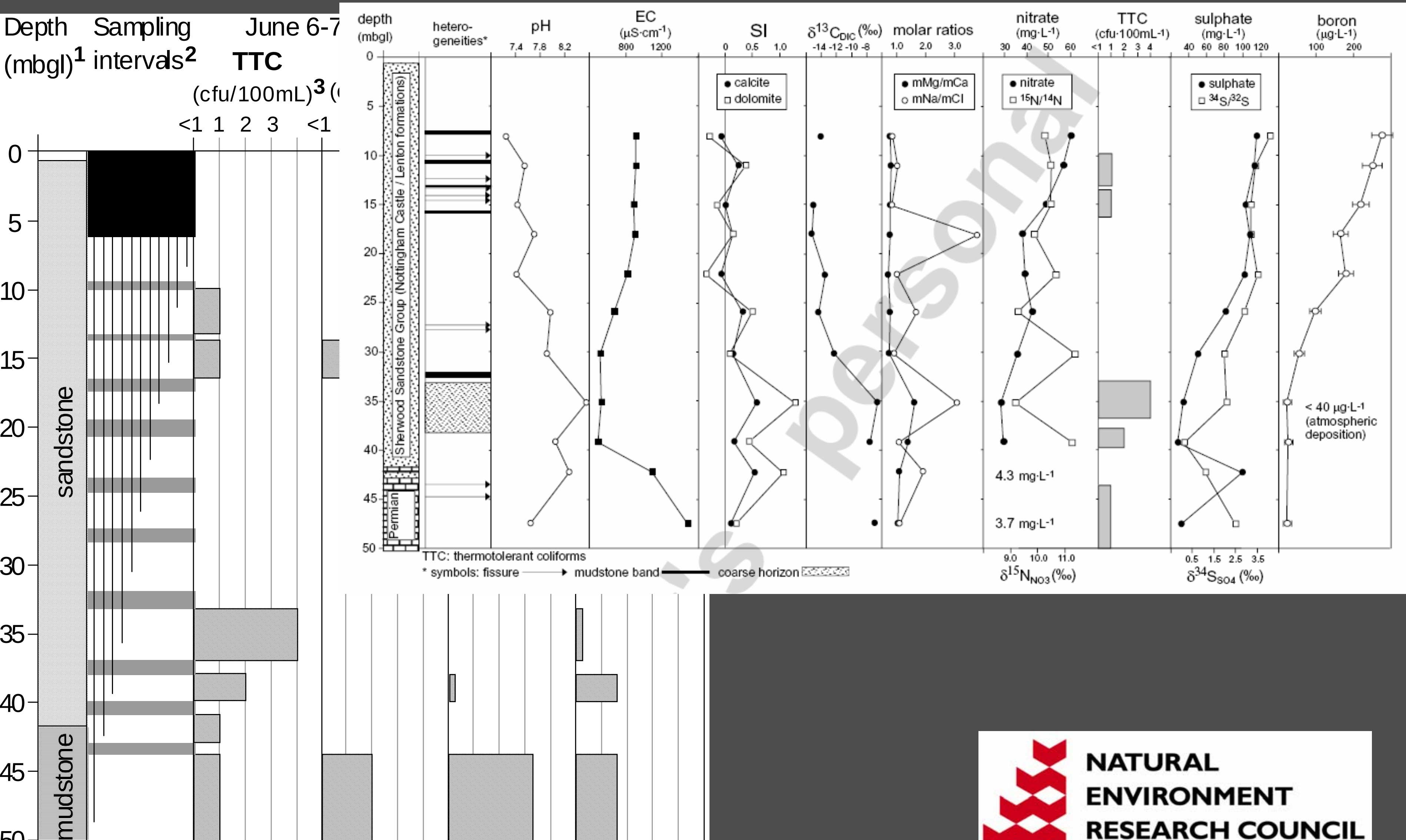
Used in all other aspects of project:

- planning expts
- hydrogeological assessment of field systems
- interpretation of field and lab data
- extrapolation of results

Will use flow models and possibly a colloid transport model developed in a project just ending



field monitoring



(1) mbgl: metres below ground level
(2) sampling intervals separated by bentonite seals (gray shade)
(3) cfu/100mL: colony-forming units / 100mL

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Site A Multilevel	Depth of sample (mbgl)	Coliphage PFU/L	Enterovirus (cell culture)	Enterovirus RT-PCR	Rotavirus RT-PCR	Norwalk like viurs RT-PCR	Adenovirus PCR	Astrovirus RT-PCR
1	8.24	<1	nd	nd	nd	nd	nd	nd
2	11.22	<1	nd	nd	nd	detected	nd	nd
3	15.00	<1	nd	nd	nd	detected	nd	nd
4	18.00	<1	nd	nd	nd	nd	nd	nd
5	22.38	<1	nd	nd	nd	detected	nd	nd
6	26.45	<1	nd	nd	nd	nd	nd	nd
7	30.35	<1	nd	nd	nd	detected	nd	nd
8	35.33	30	nd	nd	nd	nd	nd	nd
9	39.30	<1	nd	nd	nd	detected	nd	nd
10	42.50	<1	nd	nd	nd	no sample	nd	nd
11	49.22	<1	nd	nd	nd	nd	nd	nd

nd - not detected

March sampling ~ same time as clinical max NLVs: June sampling ~ Coxsackie clinical max

Site A Multilevel	Depth of sample (mbgl)	Coliphage PFU/L	Enterovirus (cell culture) (PFU/2mL)	Enterovirus RT-PCR	Rotavirus RT-PCR	Norwalk like viurs RT-PCR	Adenovirus PCR	Astrovirus RT-PCR
1	8.26	<1	nd	nd	nd	nd	nd	nd
2	11.00	<1	1 (Coxsackie B4)	nd	nd	nd	nd	nd
3	15.22	<1	nd	nd	nd	nd	nd	nd
4	18.00	<1	1 (to be confirmed)	nd	nd	nd	nd	nd
5	22.12	<1	nd	nd	nd	nd	nd	nd
6	26.29	<1	nd	nd	nd	nd	nd	nd
7	30.30	<1	nd	nd	nd	nd	nd	nd
8	35.40	<1	nd	nd	nd	nd	nd	nd
9	39.23	<1	1 (Coxsackie B4)	nd	nd	nd	nd	nd
10	41.47	<1	nd	nd	nd	nd	nd	nd
11	49.12	<1	nd	nd	nd	nd	nd	nd

nd - not detected

field monitoring: aims

- to confirm previous finding that viable human viruses exist to at least 40 m depth
  - sample example piezometer system

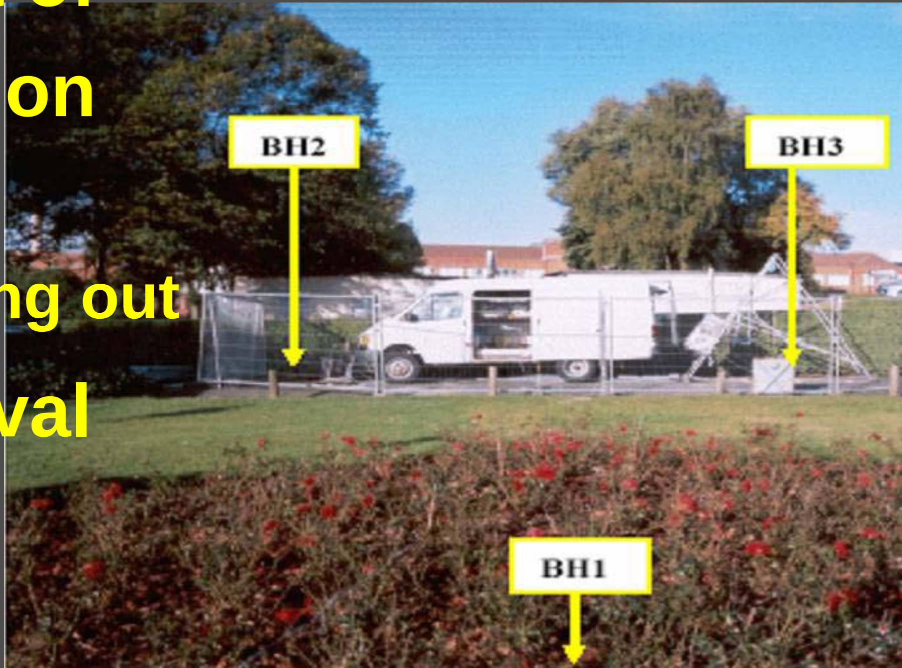
- to determine if there is seasonality, and therefore constrain velocity
  - sample piezometer monthly for 1.5 years

- to determine the frequency of occurrence
  - sample wells

field experimentation (phage):

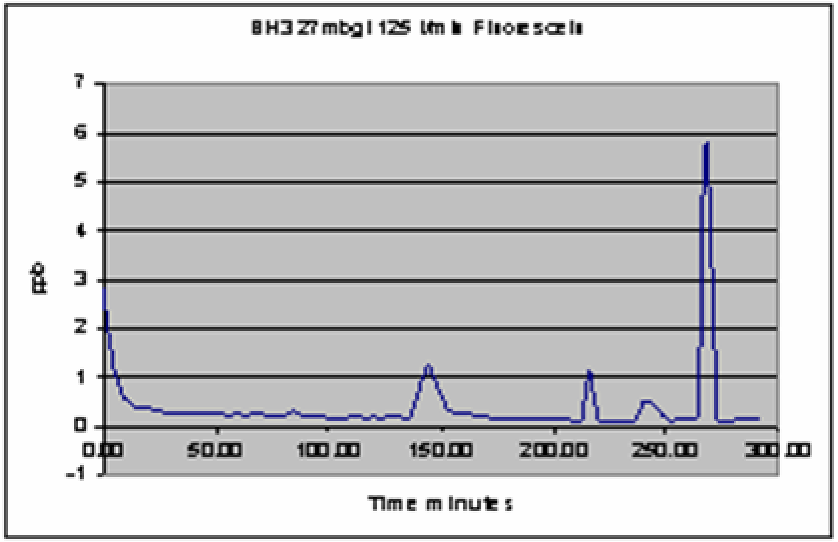
aims

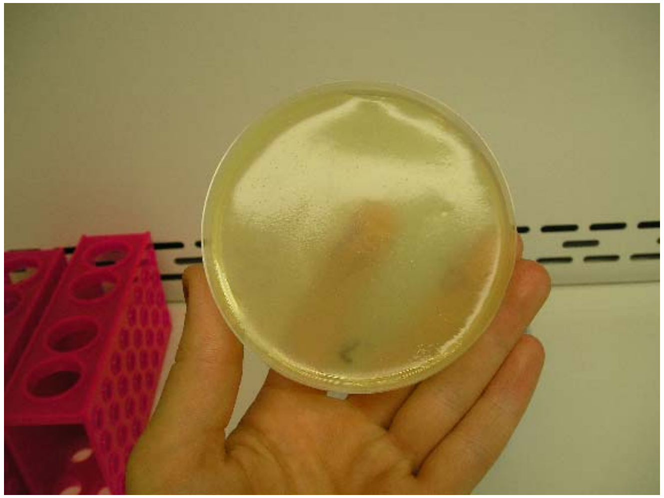
- to determine the effect of residence time on virus attenuation
    - stopped flow push-pull testing
- to determine the effect of velocity / velocity change on virus release
    - vary Q when pumping out
- to determine the removal of virus with distance
    - undertake 20 m test



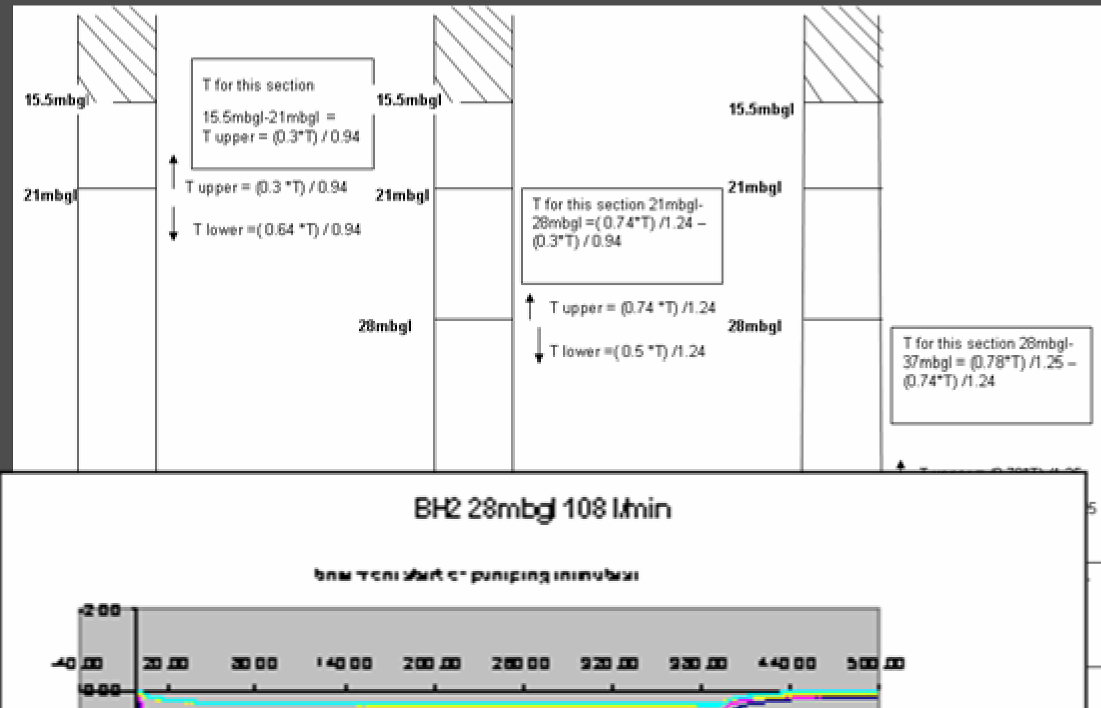
progress

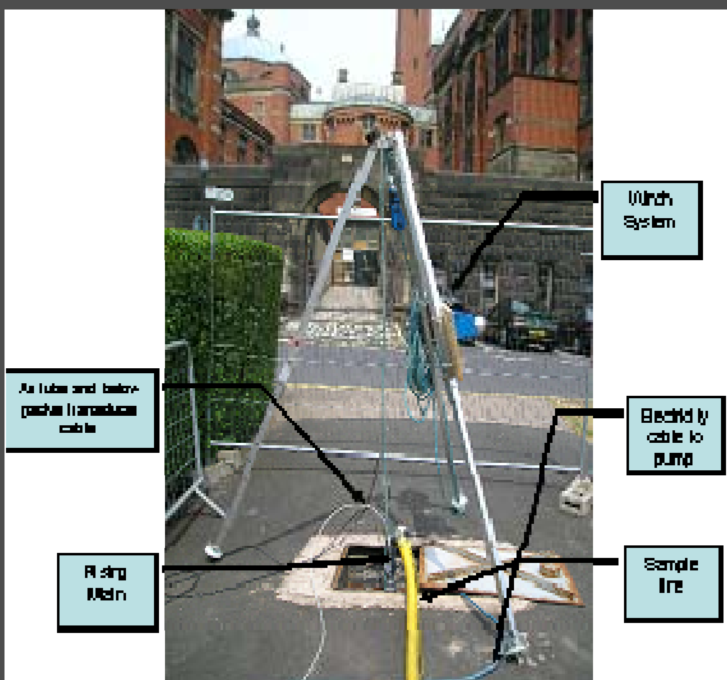
- pumped intervals previously used for injection ~ 1 year earlier
  - no phage detected
  - inactivated, or transported away??

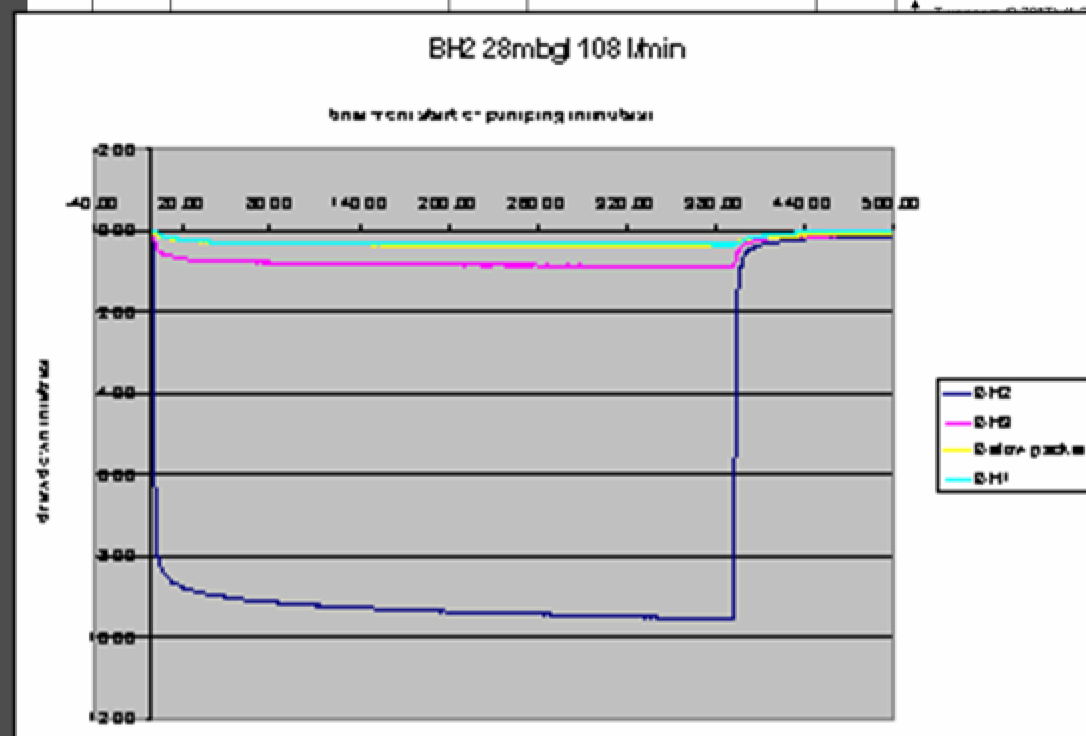




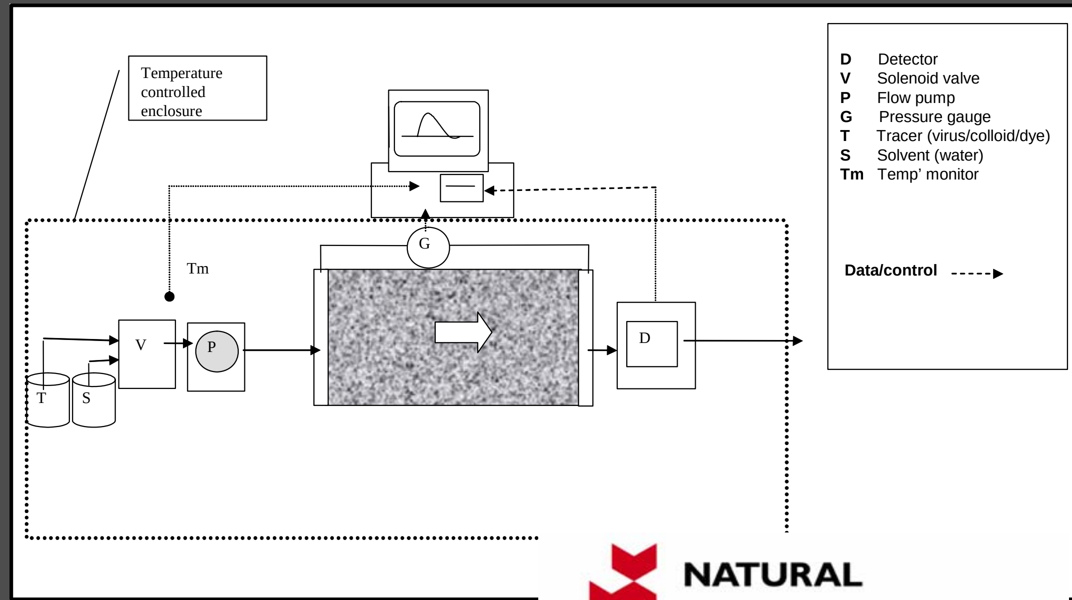
- developed a preliminary flow model of the site







laboratory experimentation



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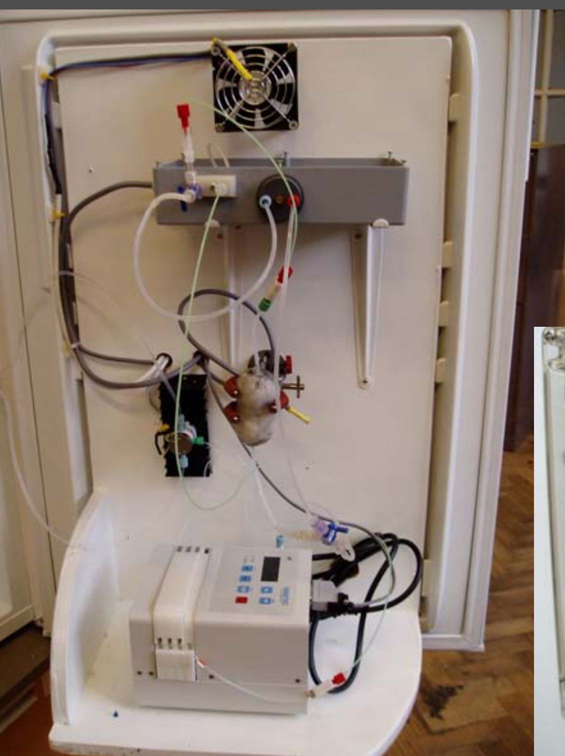


laboratory experimentation: aims

- to determine the effect of attachment on the viability of subsequently detached viruses
  - stopped-flow expts

- to determine effect of flow velocity on mobility
  - use several flow rates

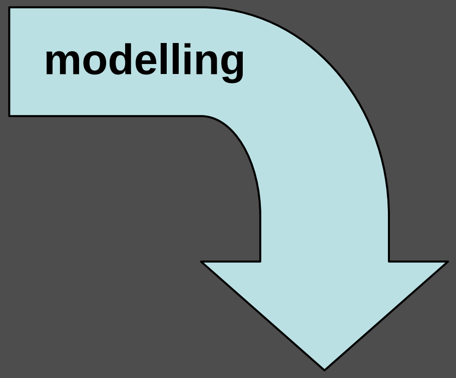
……. if time permits

Integration

can we use the aquifer's attenuation capacity to make sure that viruses are not present in recovered waste water?

Empirical investigation ….

1. **velocities and distances of travel of viable viruses under aquifer conditions**
2. **effects of (pumping-induced) gw velocity changes**
3. **effect of attachment on viability**



- **Hazard?**
- **Rules to reduce risk**

Integration

Monitoring

- distance travelled
- velocity in aquifer system
- min pathway frequency

Field Expts

- f(time)

f(velocity)

f(distance)

Lab Expts

- f(time)
- f(velocity)

dependence on source characteristics

modelling

Hazard?

Rules to reduce risk