ENVIRONMENT AGENCY

PRBs in the UK: New Agency Guidance Monkstown ZVI & New Sequential Reactors

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Thanks to some of those in our research group that have contributed in one way or another to the work presented here.

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Industrial Collaborators: Nortel, Keller, OCSC, ETI, IP, QUESTOR IAB, EcoMesh
Funding Sources: EPSRC, NERC, BBSRC, EU, EA England and Wales, DOENI

Guidance on the Design, Construction, Operation and Monitoring of Permeable Reactive Barriers

National Groundwater & Contaminated Land Centre report NC/01/51

M. A. Carey, B. A. Fretwell, N. G. Mosley & J. W. N. Smith*

Entec (UK) Ltd

*** Environment Agency, NGWCLC**

Technical Advice
Prof. Kalin
Prof. Jefferies
Dr. Boshoff

- ✓Change in UK Legislation
- ✓Change in UK Remediation
- ✓Route to Commercial Use
- ✓Ca. >£100M impact?

Detailed 1-day Guidance Seminars PRB-Net & First Faraday

Workshops

Monday 21 October-Aberdeen

Wednesday 23 October -Belfast

Friday 25 October -Dublin

Monday 28 October - London

Wednesday 30 October - Cardiff

Tuesday 12 November - Sheffield

Thursday 14 November - Newcastle

Training Courses

Environment Agency

7 Regional Offices

Monday 7 October 2002 to

Friday 18 October 2002

Definition

“A *Permeable Reactive Barrier* is an engineered treatment zone of reactive material(s) that is placed in the subsurface in order to remediate contaminated fluids as they flow through it.

A PRB has a negligible overall effect on bulk fluid flow rates in the subsurface strata, which is typically achieved by construction of a permeable reactive zone, or by construction of a permeable reactive ‘cell’ bounded by low permeability barriers that direct the contaminant towards the zone or reactive media”

Why produce this guidance?

- Provide Agency, consultants and remediation contractors with good practice guidance;
- Underpin an Agency Enforcement Position on the regulation of PRBs
- Encourage the effective use of sustainable remediation techniques, including PRBs.

Key principles (1)

- PRB should be selected when it is the 'best practicable technique';
- Guidance applies to a wide range of contaminants and PRB designs;
- Framework for development and justification of PRB design, monitoring regime and decommissioning arrangements.

Key principles (2)

- Design
  - Treatability tests
  - Pilot scale trials
  - Modelling
    - Hydraulic effects
    - Residence time and reactivity
    - Geochemistry and longevity assessment
- Decommissioning

PRB Licensing requirements

- Where treatment of contaminated groundwater takes place it requires a Waste Management Licence (site licence) or PPC Permit, unless:
  - Exclusion (e.g. not controlled waste)
  - Exemption (e.g. subject to a discharge consent - Reg 16, WMLR94)
- Agency may take an Enforcement Position
  - Works Instruction 4/98
  - As amended to include PRBs

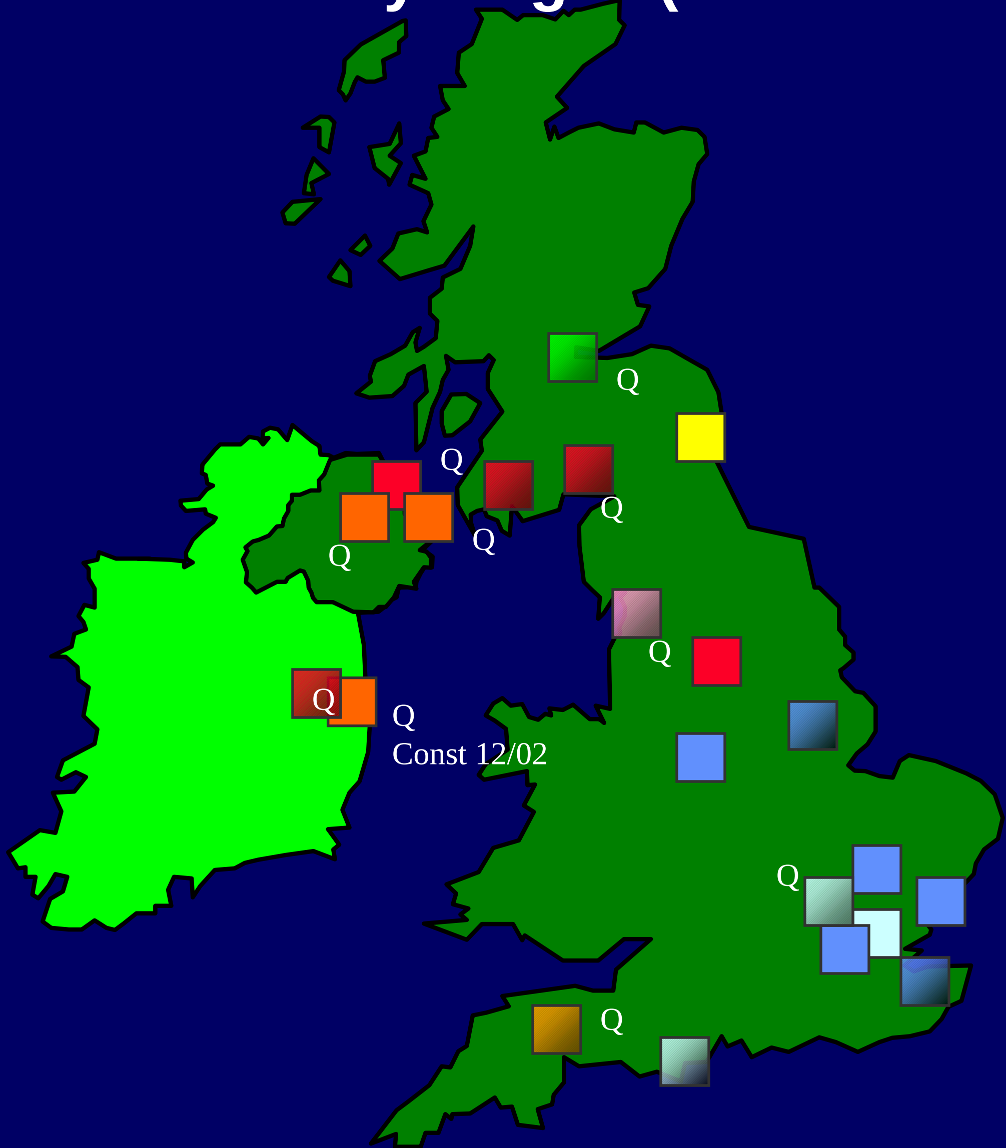
What does the EP not extend to?

- Borehole arrays (e.g. ORC^{TM}, HRC^{TM,} nutrient injection etc) - *in situ* bioremediation;
- Air-sparge / bio-sparge (including sparge curtains);
- Soil solidification / stabilisation;
- treatment of waste soil
  - all MPL
- Low permeability clay / sorption barriers ***
  - Not licensable activity
- ***Technical Guidance***: May be helpful to above treatments.

Framework for guidance

Stage 1: Screening (Sub stage 1 → Sub stage 2 etc)	Preliminary assessment	**Is a PRB a viable option?**
Stage 2: Design	SI, pilot studies and design	**Refine conceptual model and design PRB**
Stage 3: Implementation	Construction	**Installation of PRB**
Stage 4: Operation, maintenance & monitoring	Verification and monitoring	**Does PRB manage risks? Does PRB clog? Decommissioning**

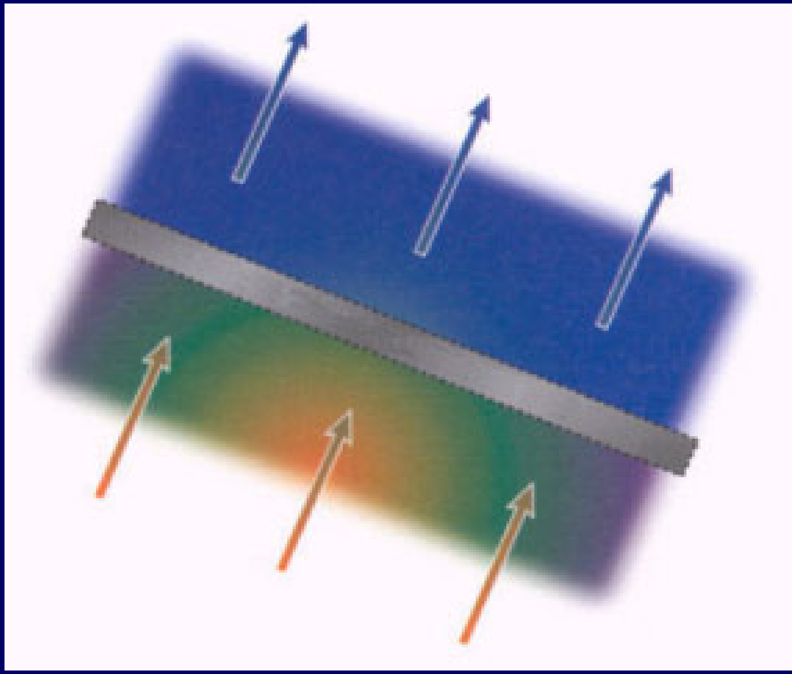
PRB installations in the British Isles
7 PRBs + 12 Soil Mix installed
10 in Feasibility stages (includes new patents for treatments)



- Zero-valent Iron (Fe^0)
- Biological barrier mine water
- Granular Activated Carbon (GAC)
- New patented treatment CS_2
- Sequential Abiotic / Biologic
- Phyto hydraulic-control PRB
- Soil Mix ‘PRB’ (12 known)
- PRB at proposal / trial stage

Sites not identified on map

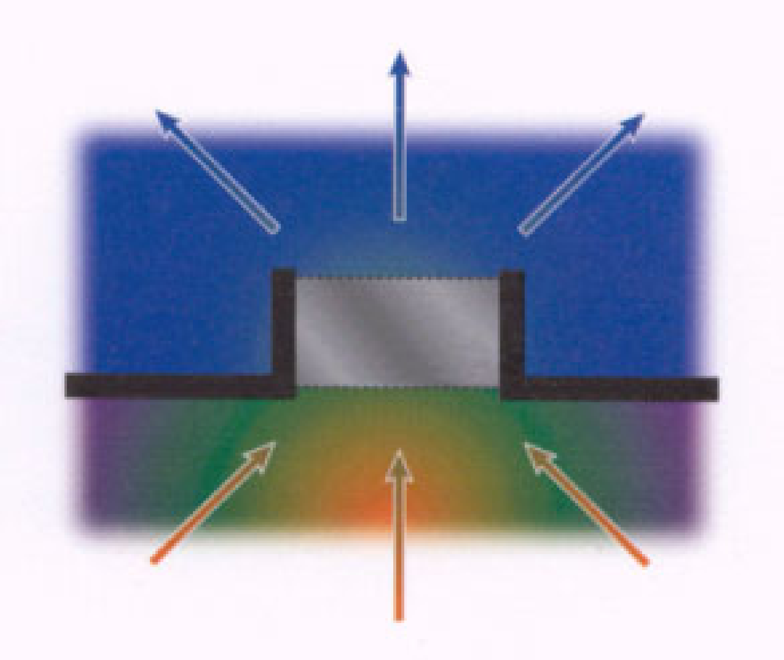
Continuous Wall



USA more popular

Long-term will it be a source term?

Funnel and Gate



UK more popular

Can be cleaned out.

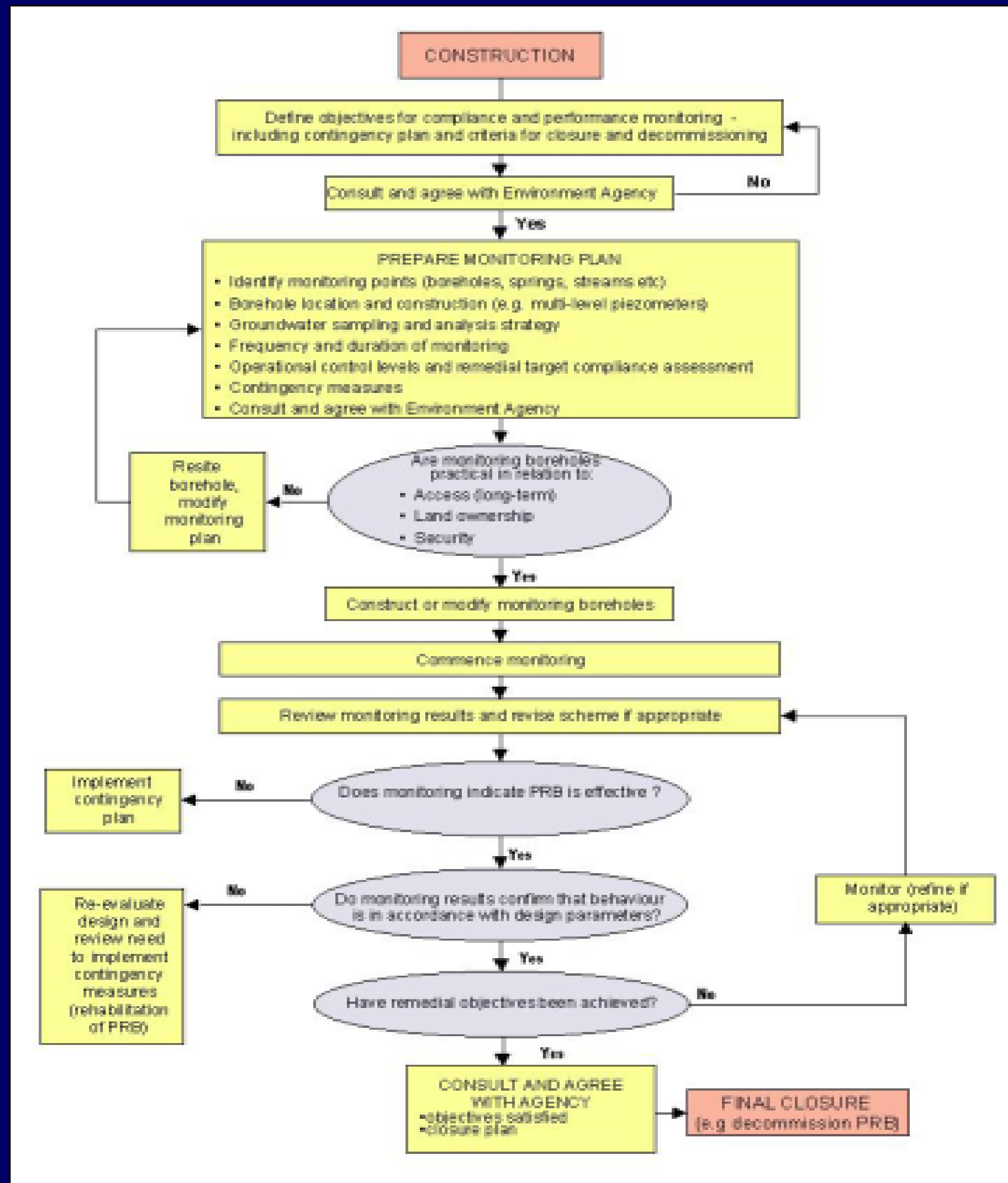
(Reproduced courtesy of EnviroMetal Technologies Inc)

Operation

Maintenance

Monitoring

Decommisioning



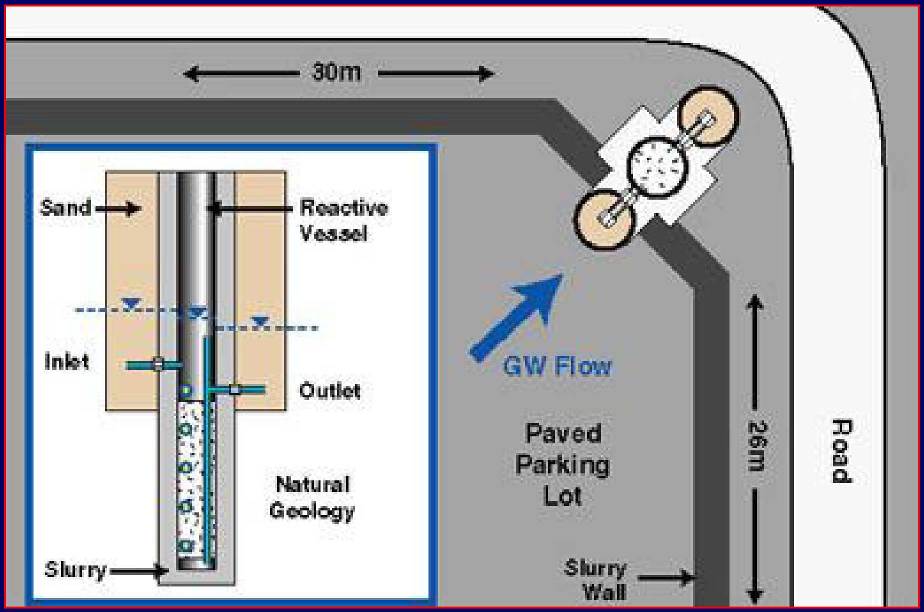
Monitoring objectives:

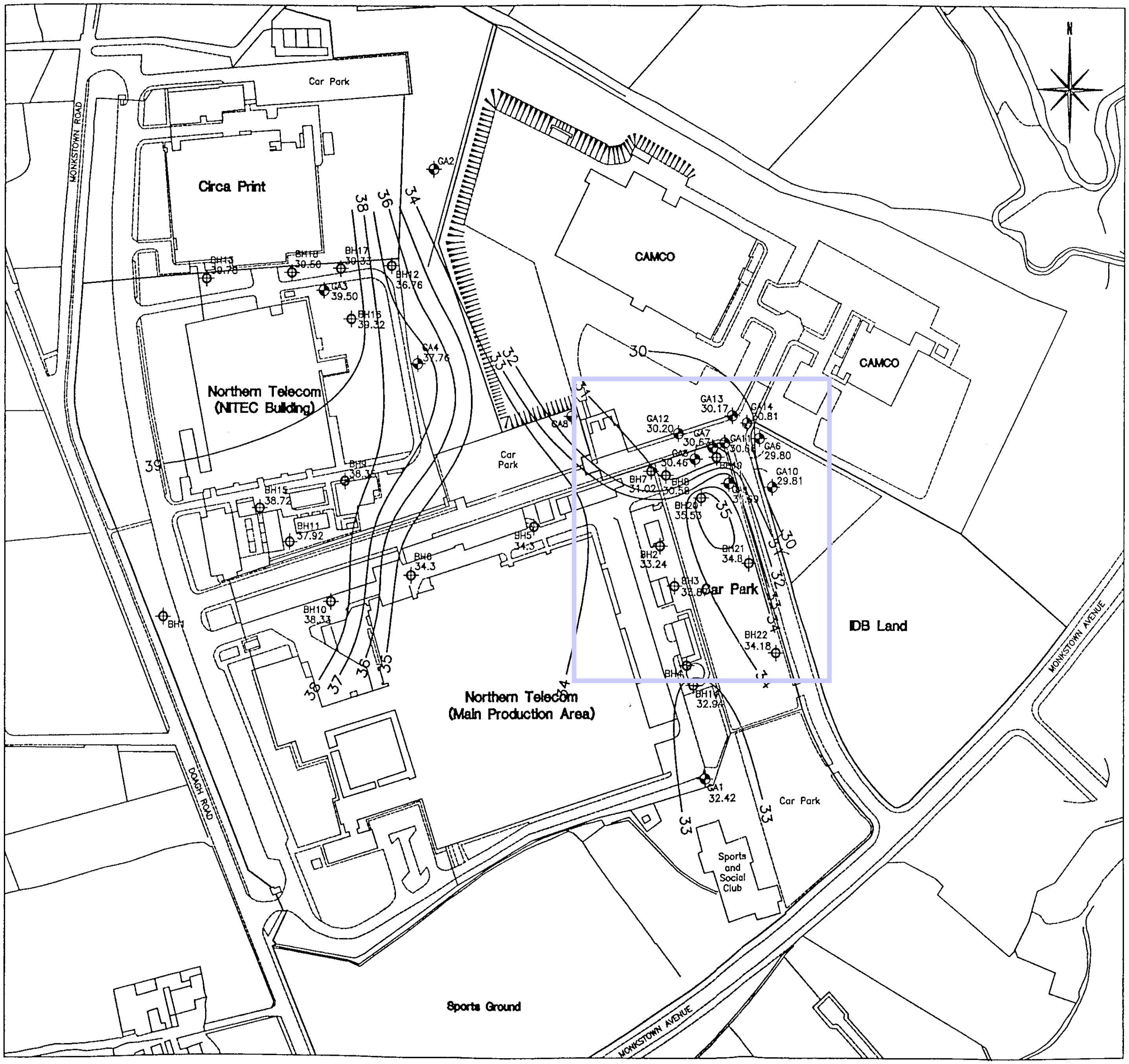
- Performance assessment
  - Outflow concentrations / flux
    - test against remedial objectives
    - validate PRB effectiveness
    - PRB deterioration (fouling)
  - Hydraulic controls
    - By-pass flow
    - impacts on GW flow regime
  - Test conceptual model

Monkstown ZVI Site

CL:AIRE TDP Report 4 – Operation

QUB Report in prep on Maintenance and Decommissioning plan





Area of Interest

LEGEND:

GA10 29.81 — Dipped water levels in Golder boreholes on 6.5.94 (m aOD)

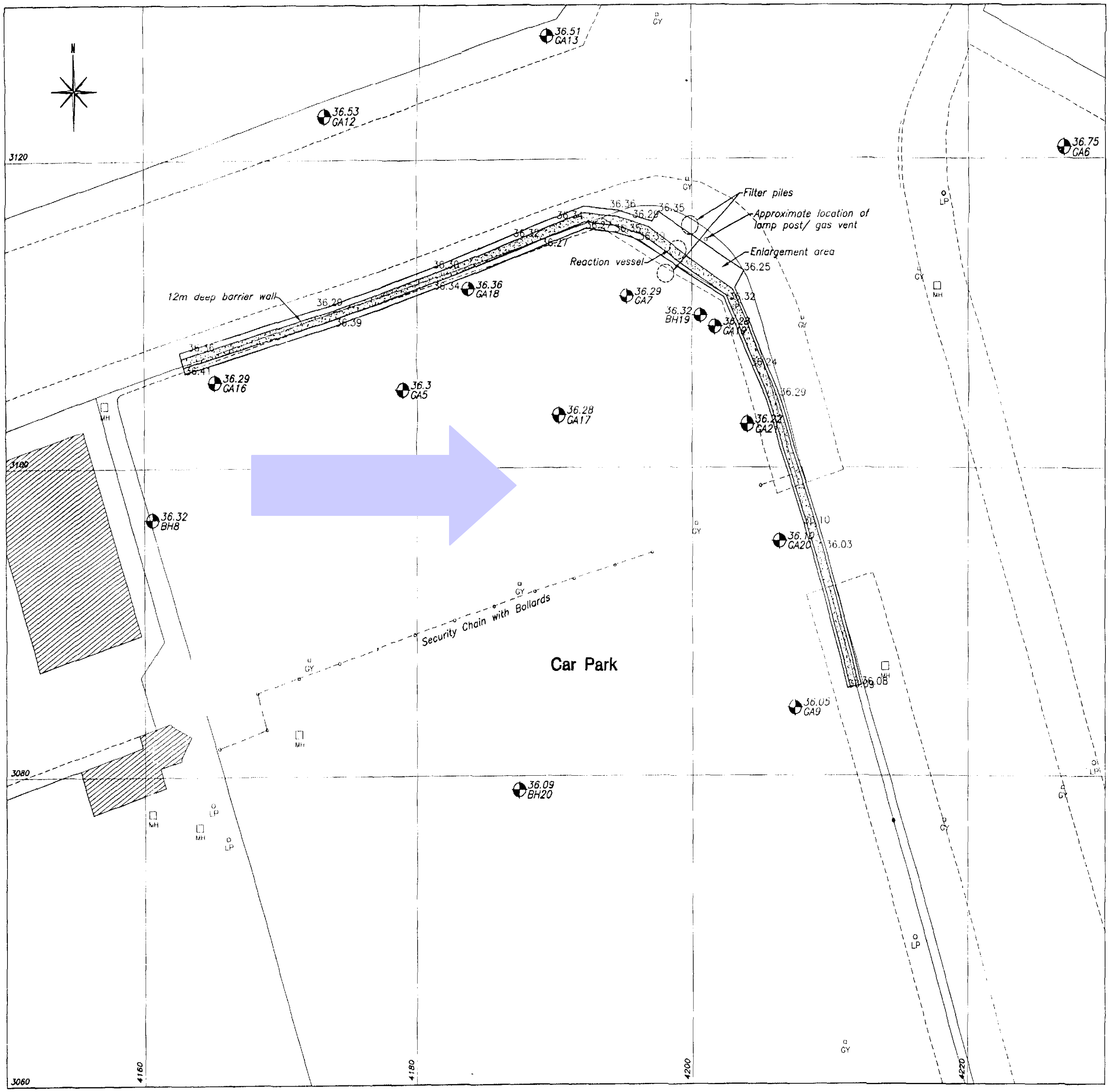
BH8 30.38 — Approximate water levels in WESA boreholes on 6.5.94 (m aOD) (borehole elevations adjusted)

——— Interpreted Groundwater Contours (m aOD)

GA – Golder Borehole
HA – Golder Hand Auger Hole
BH – WESA Borehole

CLIENT	Northern Telecom
PROJECT	Environmental Investigation
SITE	Monkstown
DRAWING	Contour Map of Groundwater Levels Across the Site on 6.5.94
DRAWING №	1
DATE	24.10.94
SCALE	1:2500
DRAWN BY	S.W.
CHECKED BY	
REVISIONS	
PROJECT №	94525110
FILE	ENVIGW

LANDMERE LANE
EDWALTON
NOTTINGHAM
NG12 4DE
TEL: 0602 456544
FAX: 0602 456540
Golder Associates



NOTE

1. Grid shown is local only and should not be referenced to Ordnance Survey grid.
2. Borehole levels refer to Ordnance datum.
3. Survey of barrier wall was carried out by DMC on 12.12.95.

LEGEND

GY	Gully with level
LP	Lamp post
MH	Manhole with level
36.36 GA18	Borehole with reference number and elevation

CLIENT: Nortel

PROJECT: Reactive Barrier Wall Health and Safety File

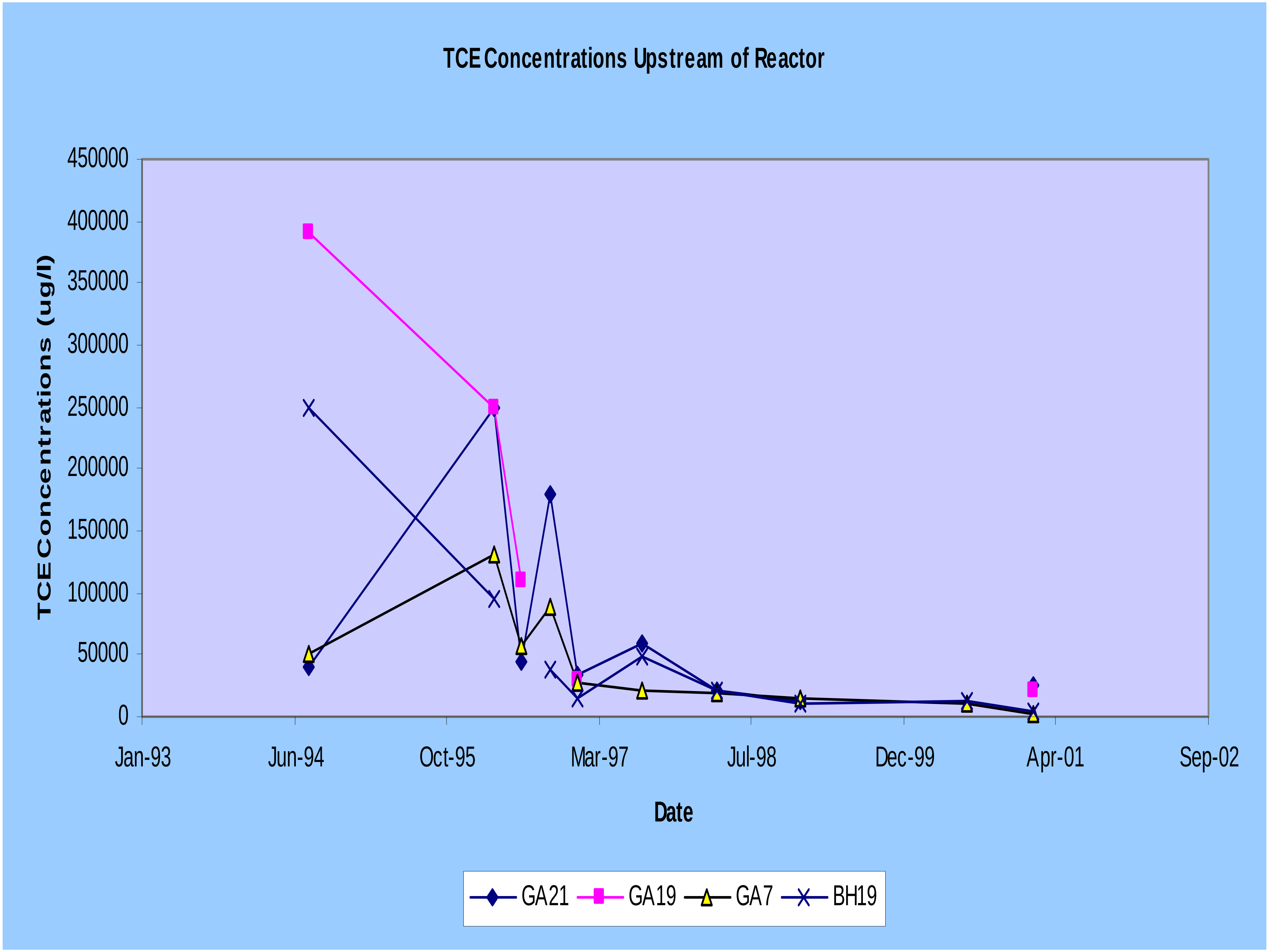
SITE: Monkstown

DRAWING: As Built Drawing of Reactive Barrier Wall

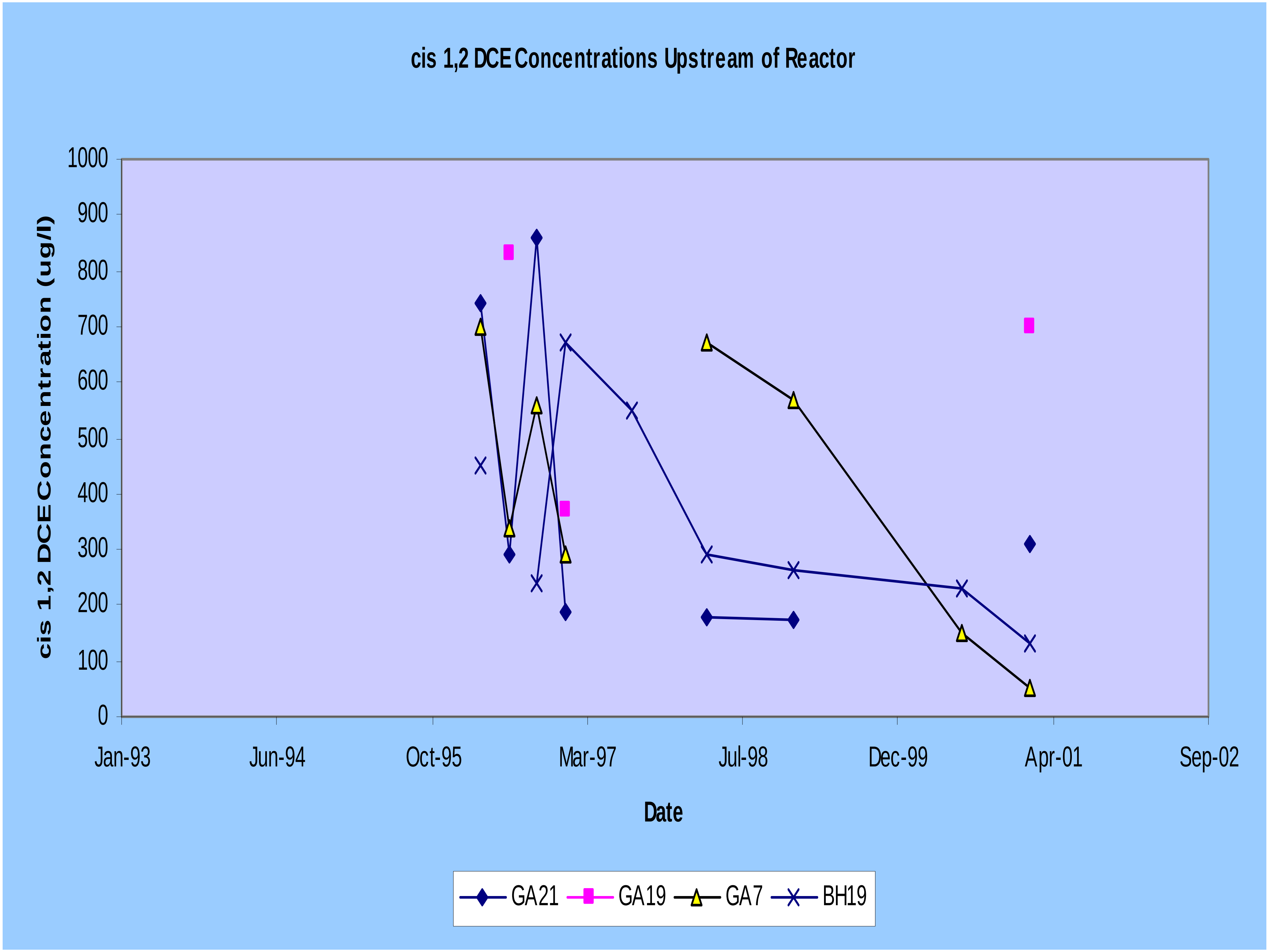
DRAWING №	DATE	03.09.96
3	SCALE	1:200
	PROJECT №	94525110
	FILE	Slbw
REV.	DRAWN BY	R.W.
	ENGINEER	
	REVIEWED BY	

REVISIONS	DATE	ENG	RWD BY

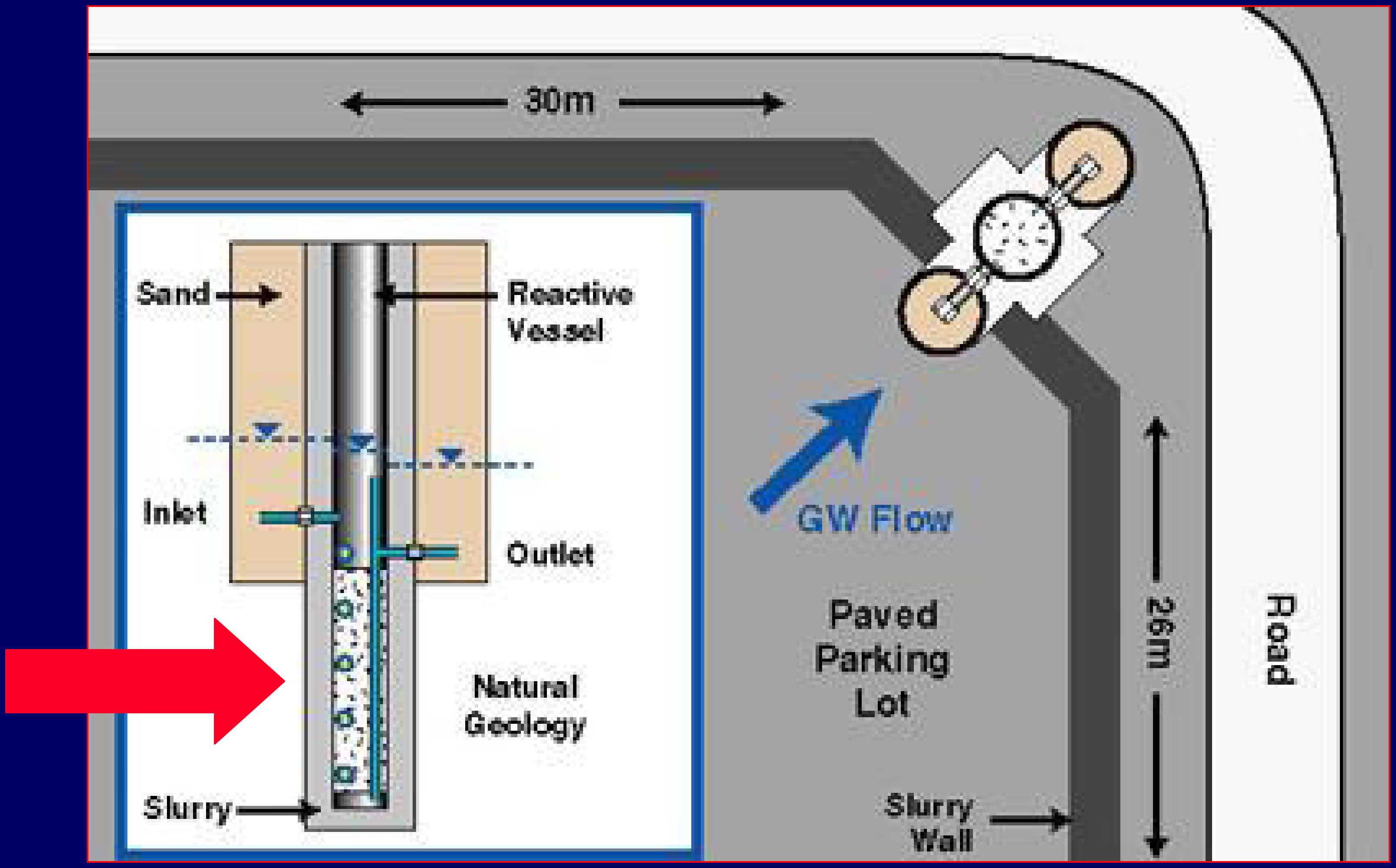
LANDMERE LANE
EDWALTON
NOTTINGHAM
NG12 4DG
TEL: 0115 945 6544
FAX: 0115 945 6540
Golder Associates

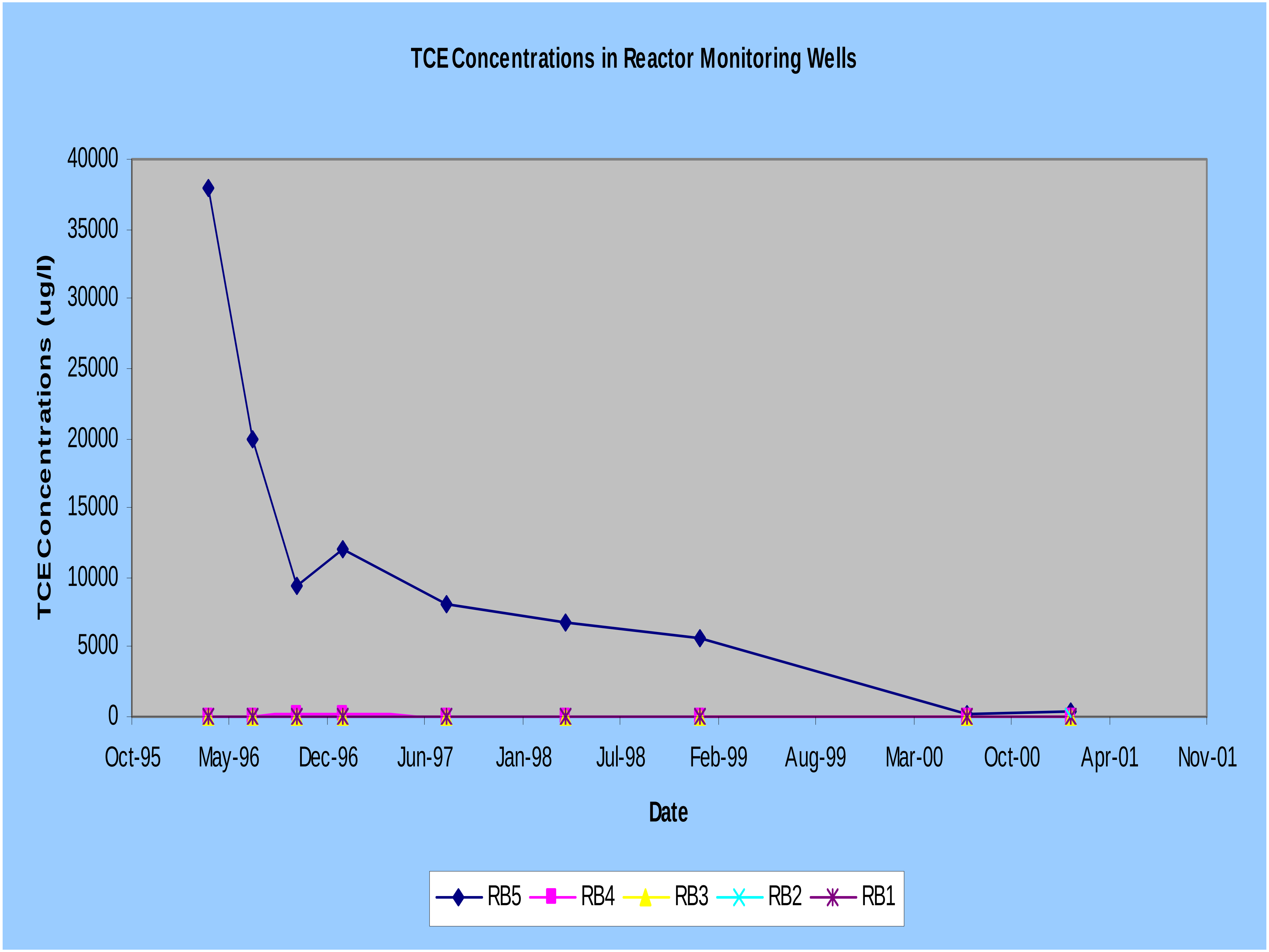


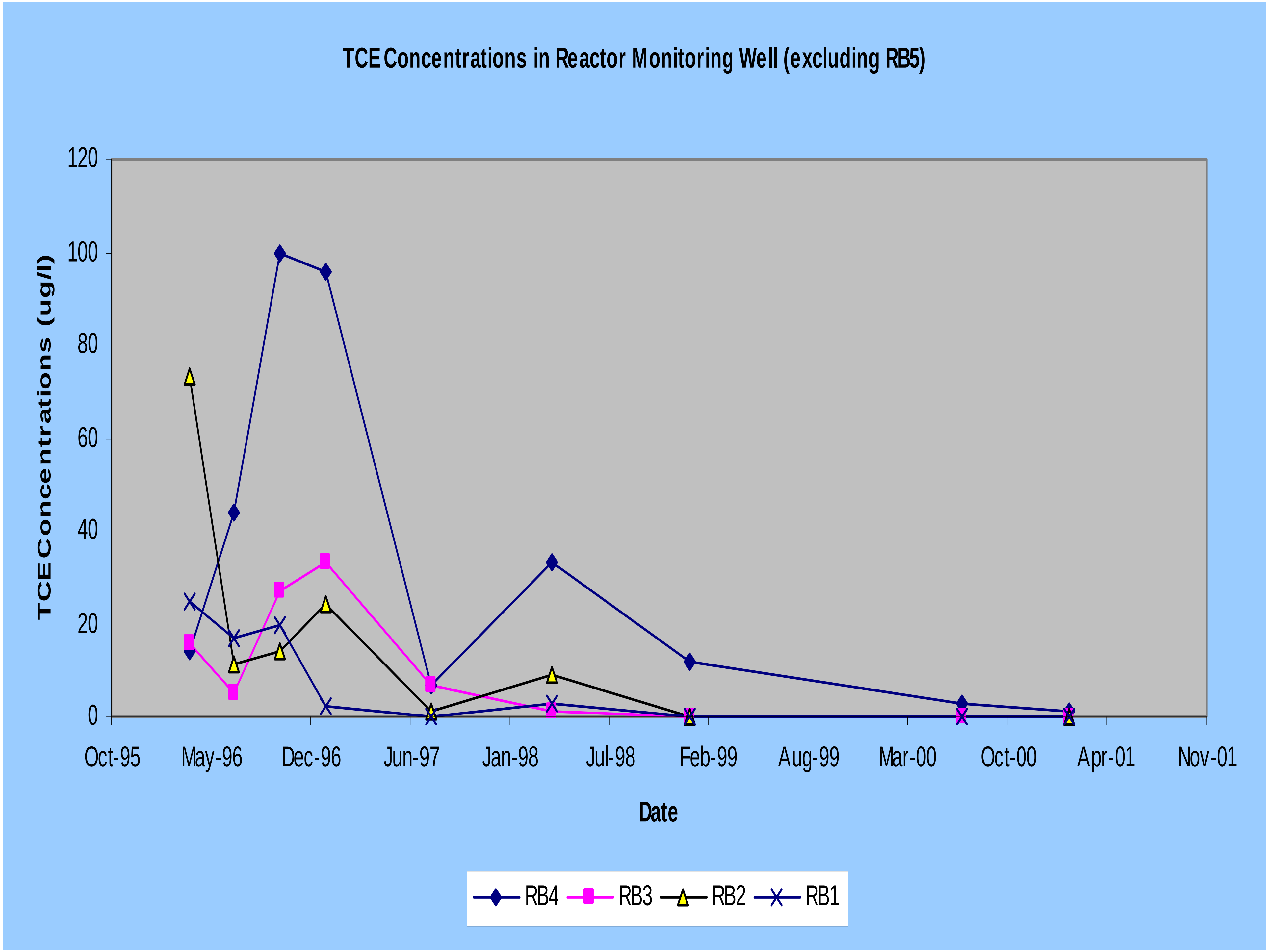
TCE Concentrations Upstream of Reactor
TCE Concentrations (ug/l)
450000
400000
350000
300000
250000
200000
150000
100000
50000
0
Jan-93
Jun-94
Oct-95
Mar-97
Jul-98
Dec-99
Apr-01
Sep-02
Date
GA21
GA19
GA7
BH19

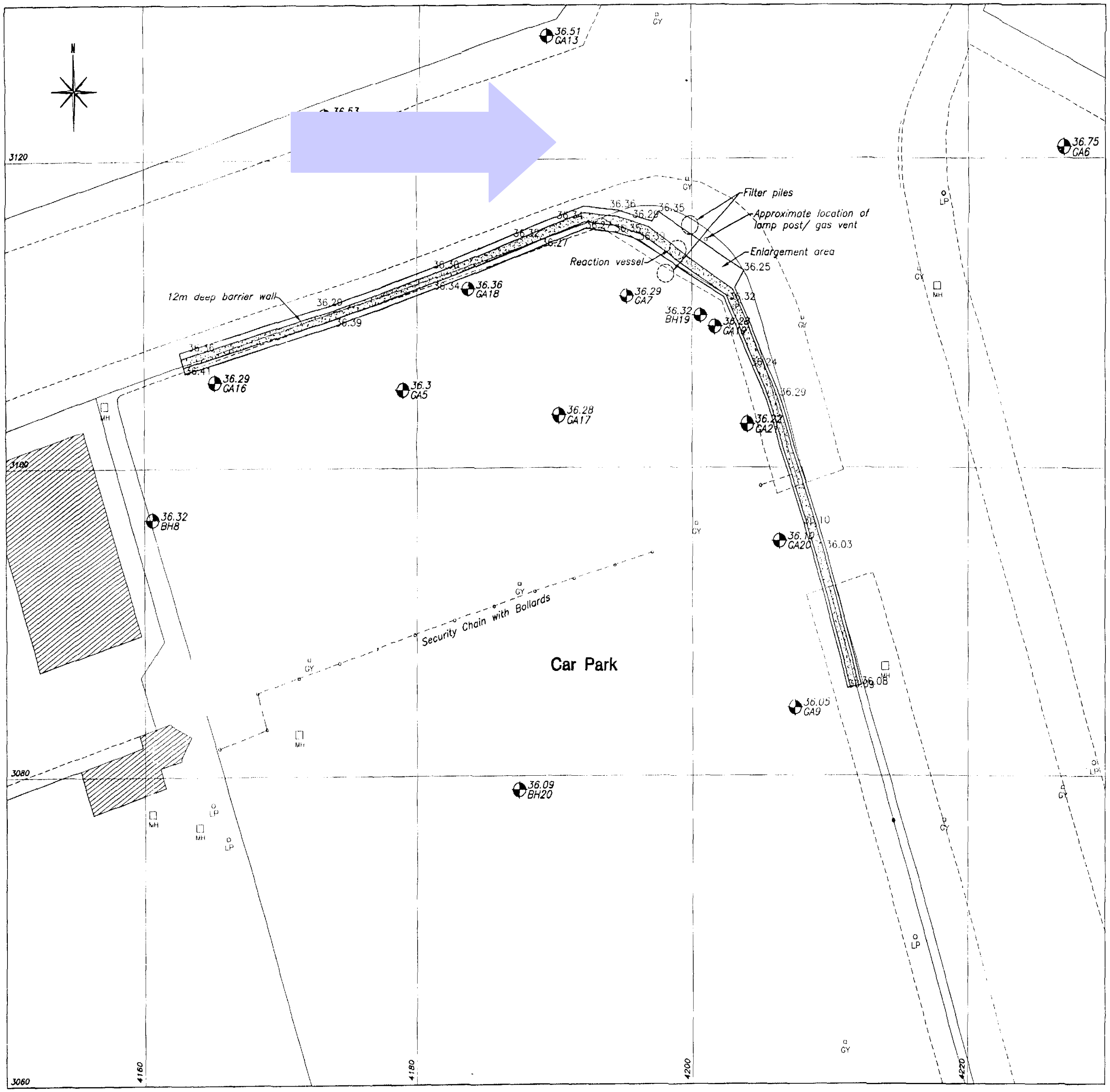

cis 1,2 DCE Concentrations Upstream of Reactor
cis 1,2 DCE Concentration (ug/l)
0
100
200
300
400
500
600
700
800
900
1000
Jan-93
Jun-94
Oct-95
Mar-97
Jul-98
Dec-99
Apr-01
Sep-02
Date
GA21
GA19
GA7
BH19

PRB implementation in Belfast/N.Ireland




TCE Concentrations in Reactor Monitoring Wells
TCE Concentrations (ug/l)
40000
35000
30000
25000
20000
15000
10000
5000
0
Oct-95
May-96
Dec-96
Jun-97
Jan-98
Jul-98
Feb-99
Aug-99
Mar-00
Oct-00
Apr-01
Nov-01
Date
RB5
RB4
RB3
RB2
RB1


TCE Concentrations in Reactor Monitoring Well (excluding RB5)
TCE Concentrations (ug/l)
120
100
80
60
40
20
0
Oct-95
May-96
Dec-96
Jun-97
Jan-98
Jul-98
Feb-99
Aug-99
Mar-00
Oct-00
Apr-01
Nov-01
Date
RB4
RB3
RB2
RB1



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DATE	03.09.96
SCALE	1:200
PROJECT No	94525110
FILE	Slbw
DRAWN BY	R.W.
ENGINEER	
REVIEWED BY	
REV.	
REVISIONS	DATE / ENG / RWD BY

Golder Associates
LANDMERE LANE
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NOTTINGHAM
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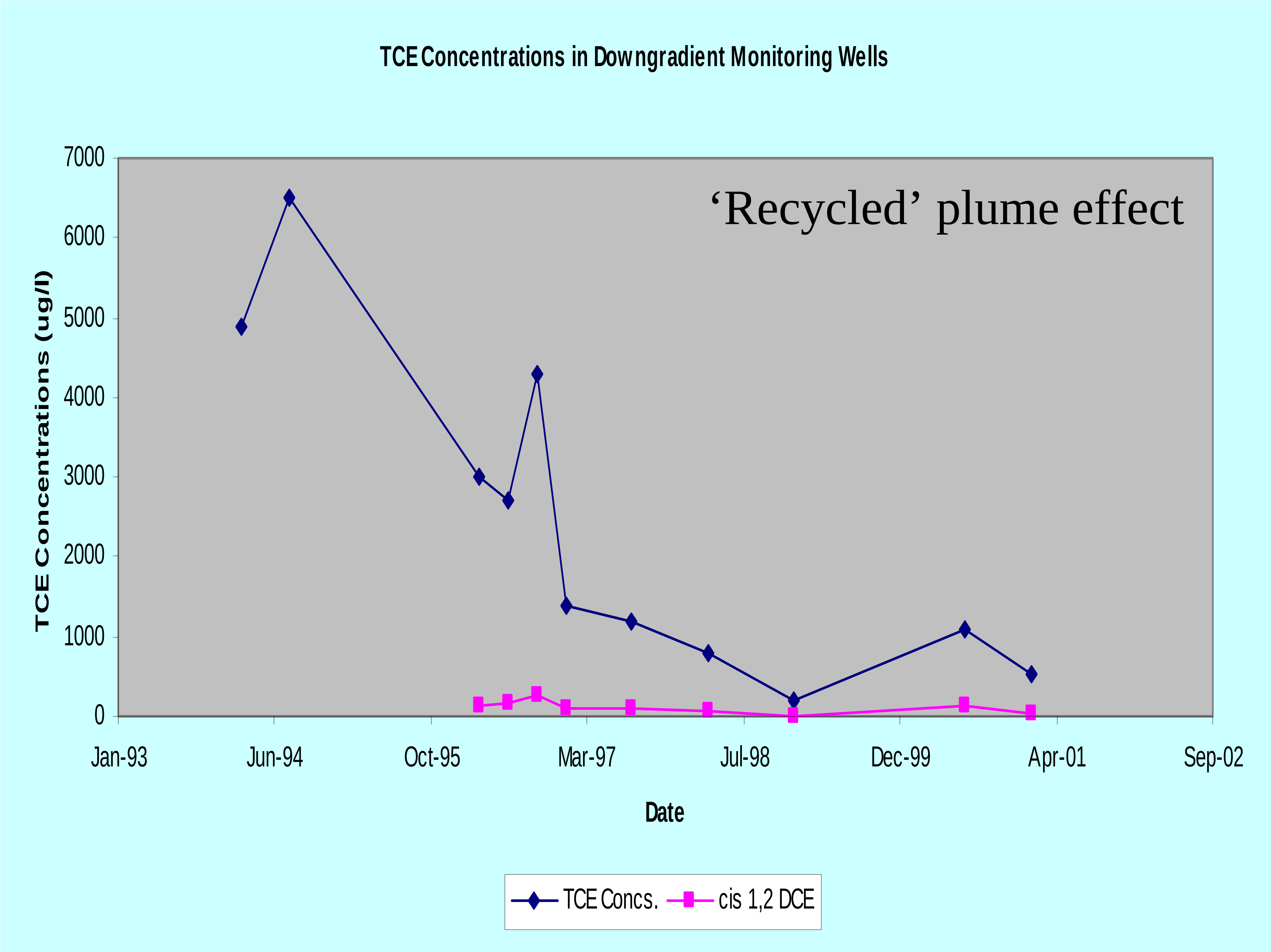
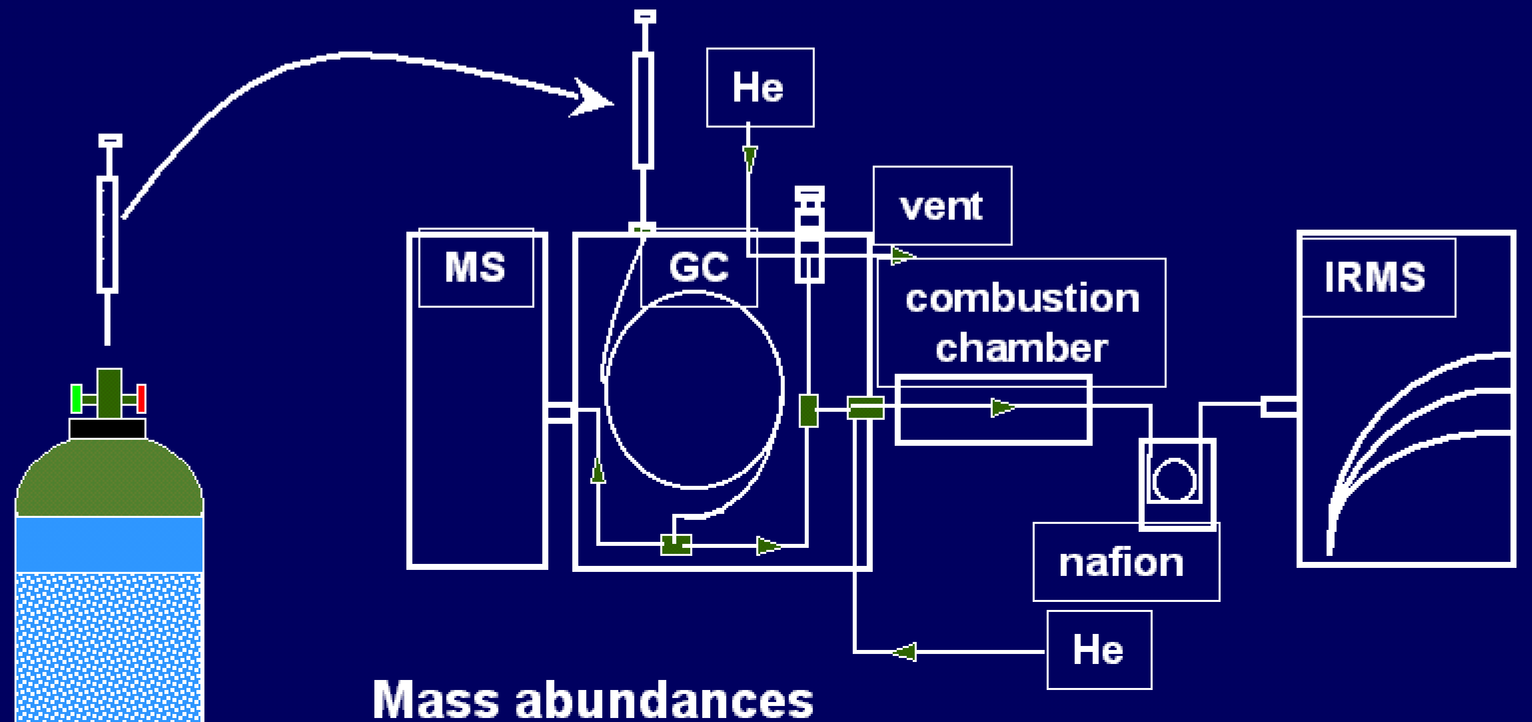
TEL: 0115 945 6544
FAX: 0115 945 6540


TCE Concentrations in Downgradient Monitoring Wells
'Recycled' plume effect
TCE Concentrations (ug/l)
7000
6000
5000
4000
3000
2000
1000
0
Jan-93
Jun-94
Oct-95
Mar-97
Jul-98
Dec-99
Apr-01
Sep-02
Date
TCE Concs.
cis 1,2 DCE

PRB implementation in Belfast/N.Ireland - 5 Years Later…..

2002: Nortel approached QUB for long-term R&D

Experimental Setup - *GC-MS/IRMS*



Mass abundances

44: $^{12}C^{16}O_2$ 98,42

45: $^{13}C^{16}O_2$ 1,095

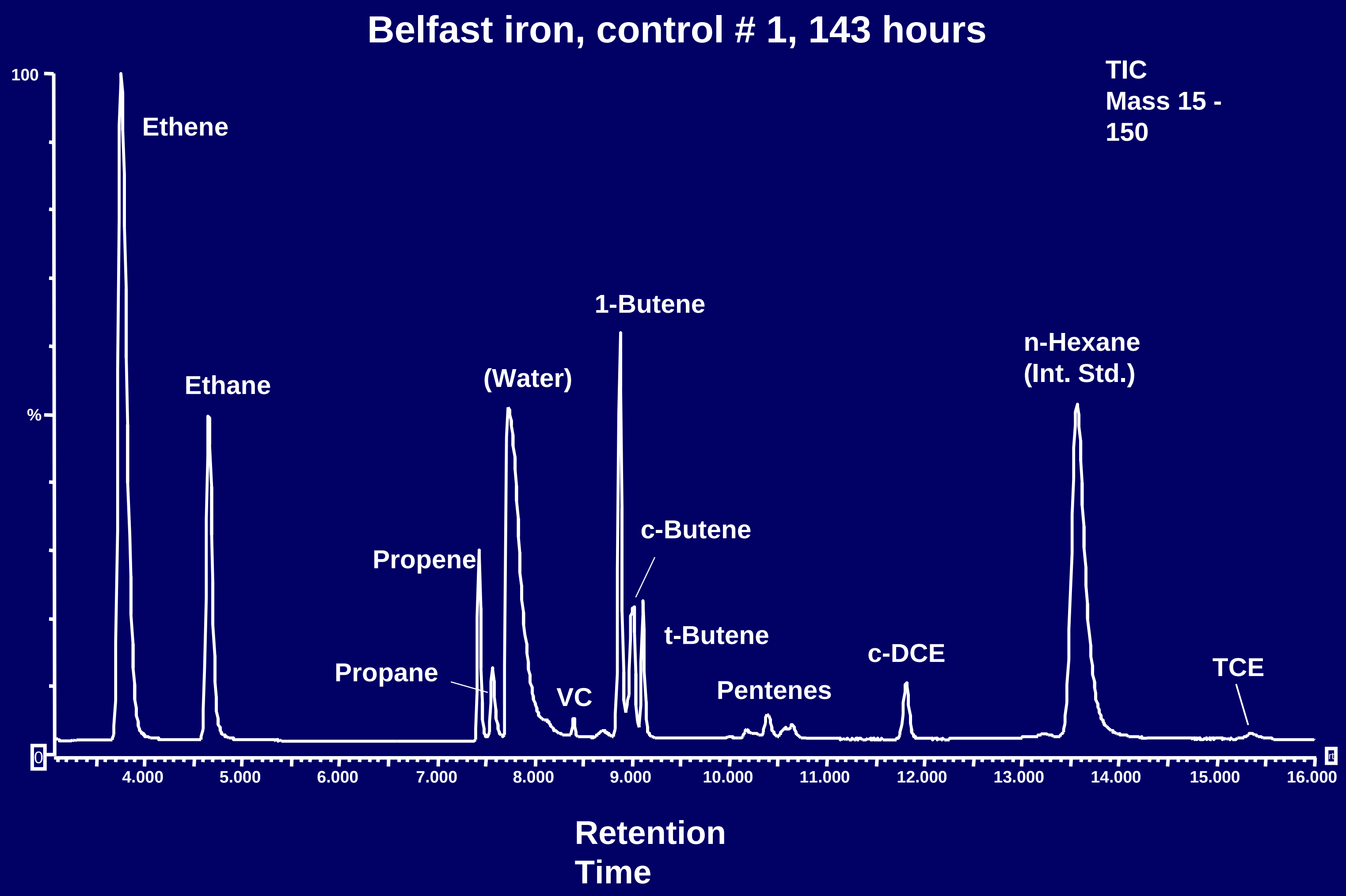
45: $^{13}C^{16}O^{17}O$ $7{,}7*10^{-2}$

46: $^{12}C^{16}O^{18}O$ 0,402

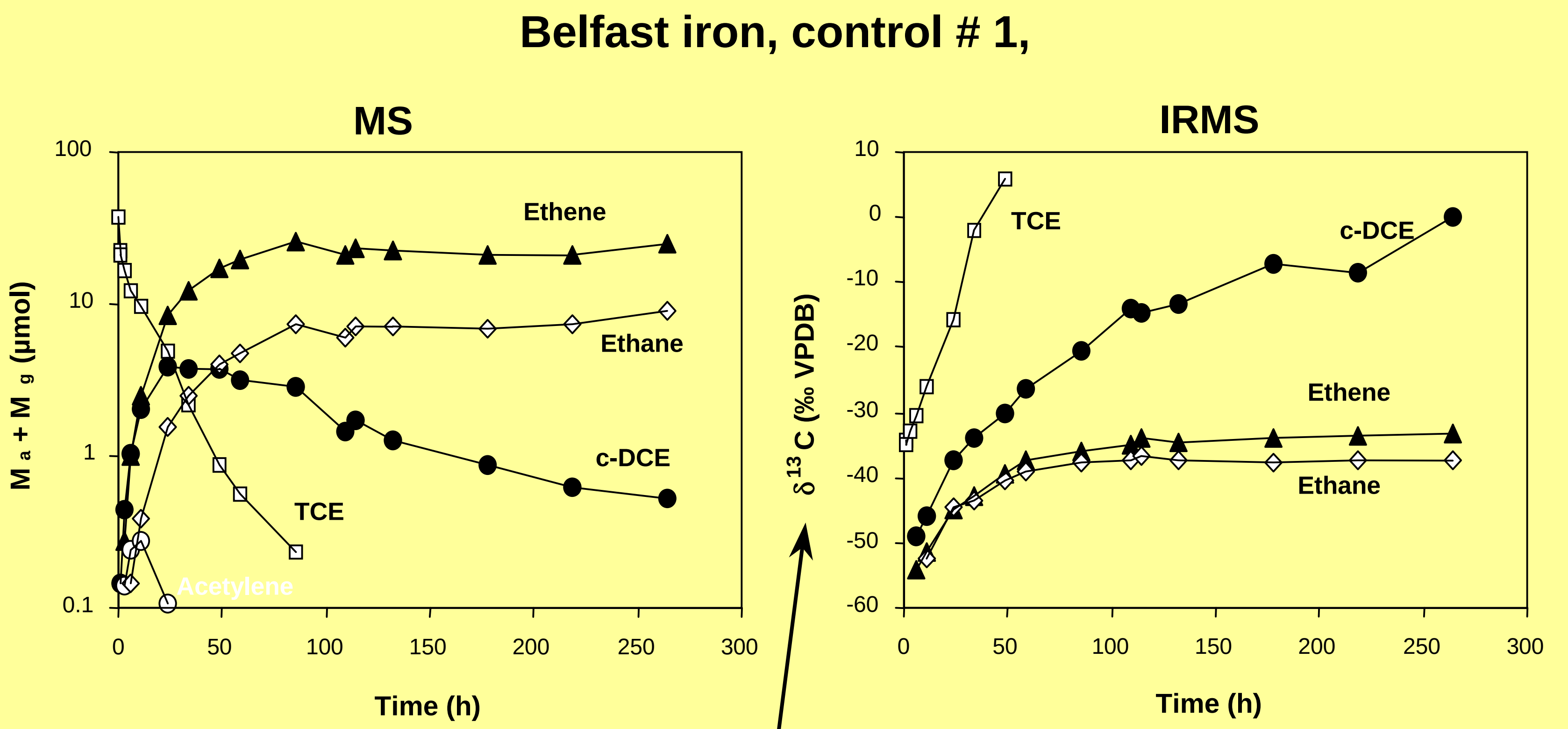
46: $^{13}C^{16}O^{17}O$ $8{,}6*10^{-4}$

46: $^{12}C^{17}O_2$ $1{,}5*10^{-5}$

TCE Degradation with Fe^0 - Products

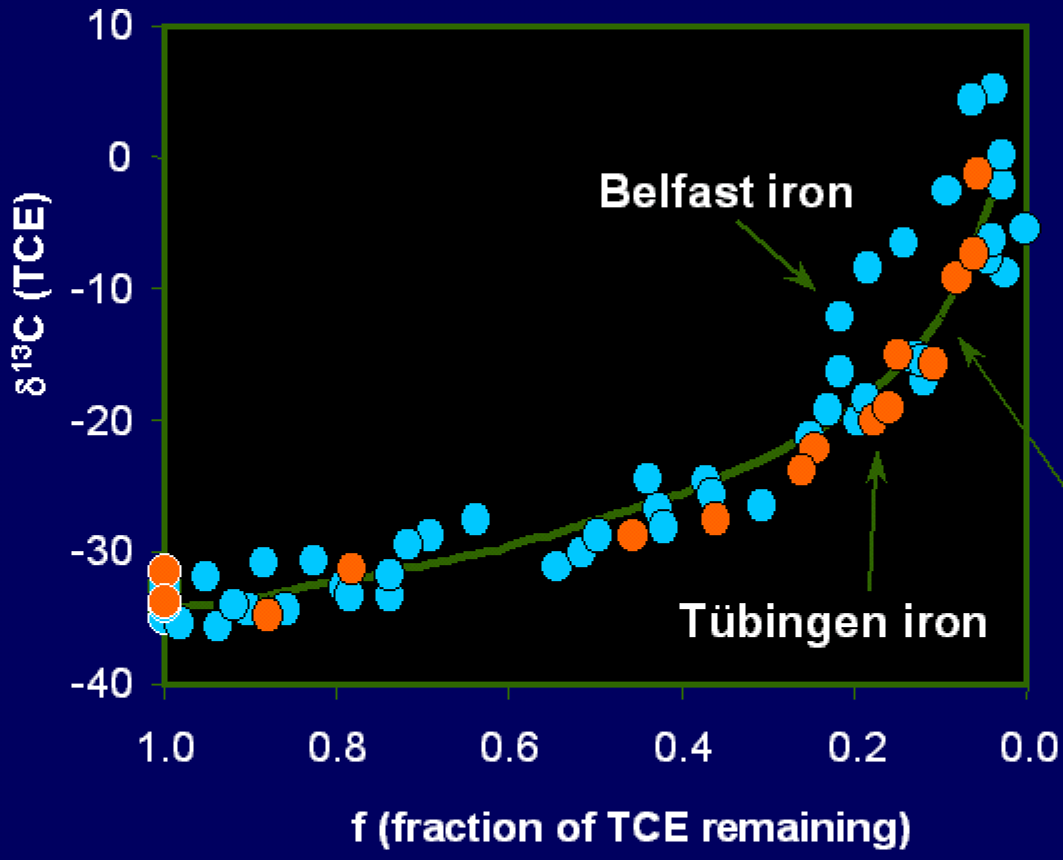


TCE Degradation Fe^0 – GC-MS/IRMS



$$\delta\ ^{13}C_{VPDB} = \frac{^{13}C/^{12}C_{(sample)} - ^{13}C/^{12}C_{(std)}}{^{13}C/^{12}C_{(std)}} \cdot 1000\ [‰]$$

TCE Degradation with Fe^0 – Isotopes



9 independently performed experiments with different reaction rates and different types of iron

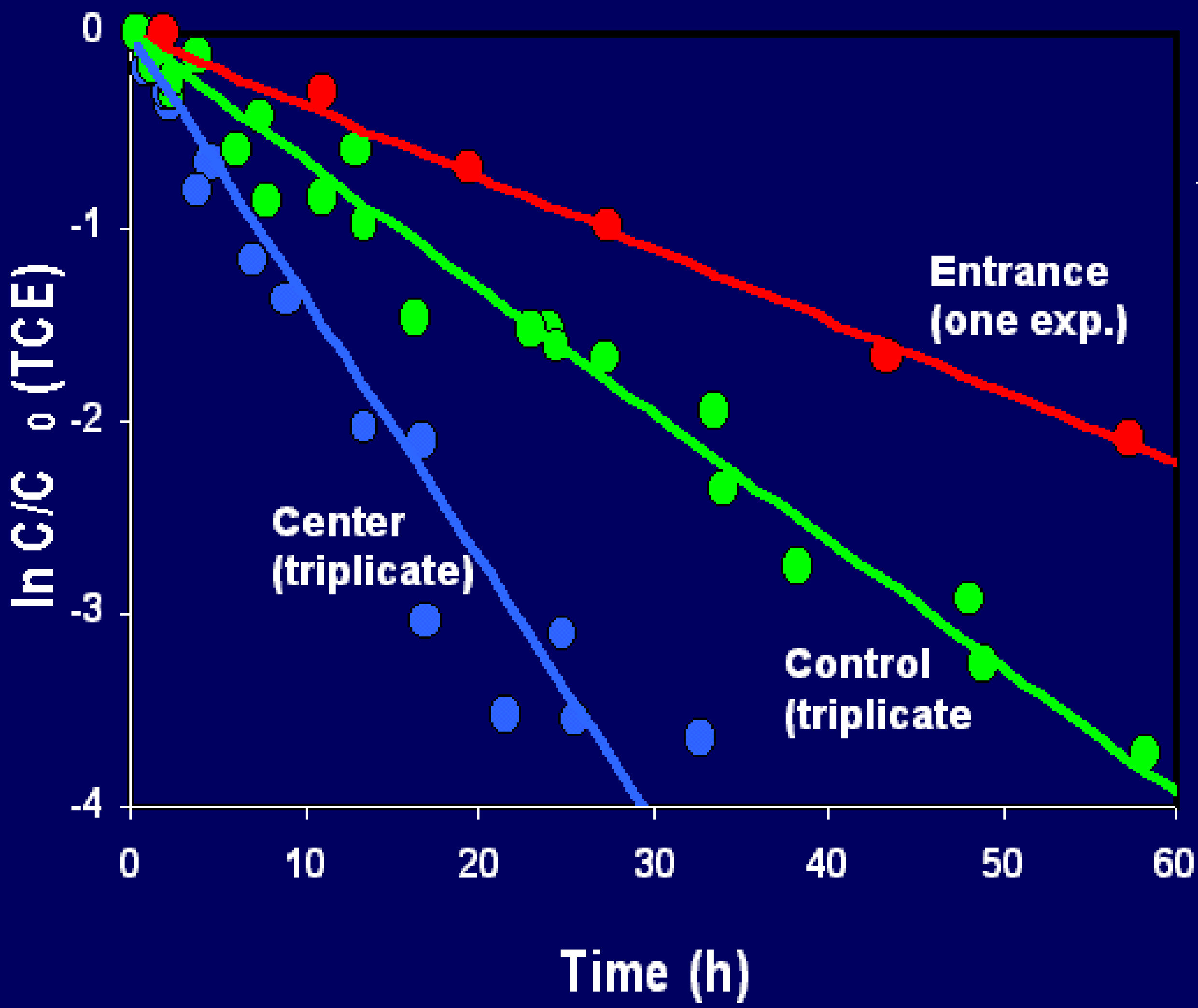
Enrichment factor ε

(similar to a Rayleigh-type fractionation)

$$\varepsilon = \frac{1000 \cdot \ln \dfrac{10^{-3} \cdot \delta^{13}C_{TCE} + 1}{10^{-3} \cdot \delta^{13}C_{TCE\,(0)} + 1}}{\ln f}$$

ε = -10

Belfast Iron - Rates



$$-\frac{d[TCE]}{dt} = k_{obs}[TCE]$$

$K_{obs} = 0.037\ h^{-1}$

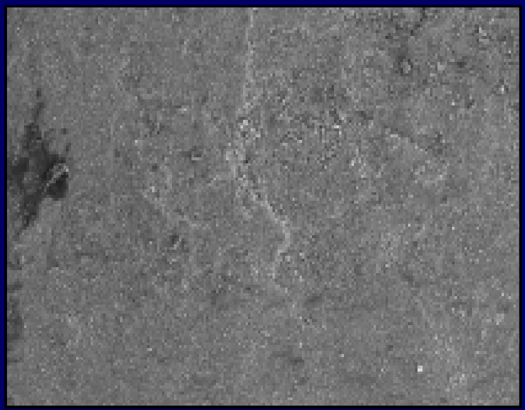
$K_{obs} = 0.065\ h^{-1}$

$K_{obs} = 0.136\ h^{-1}$

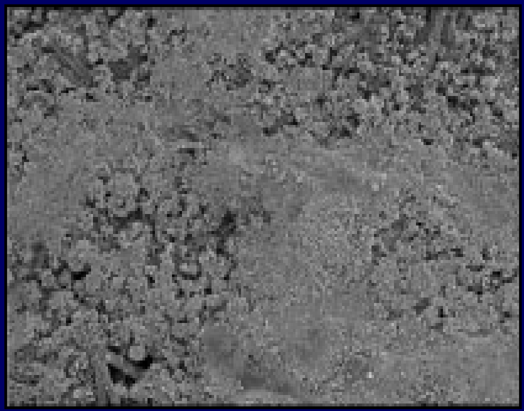
Fastest rate = old iron in the reactor

Belfast Iron – QUB EM Images

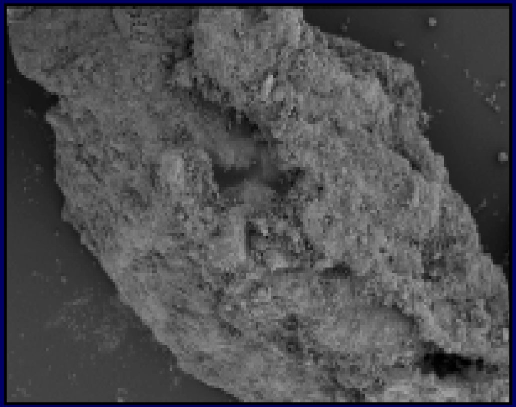
Control | Center | Entrance



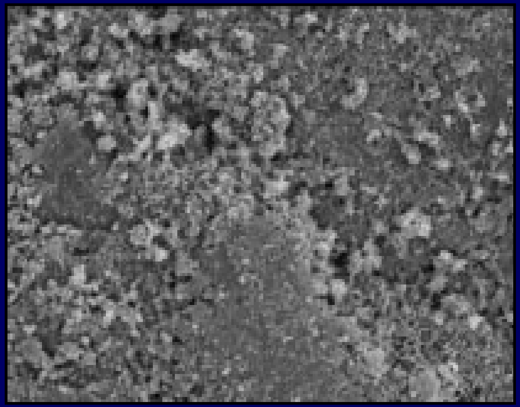
x 300



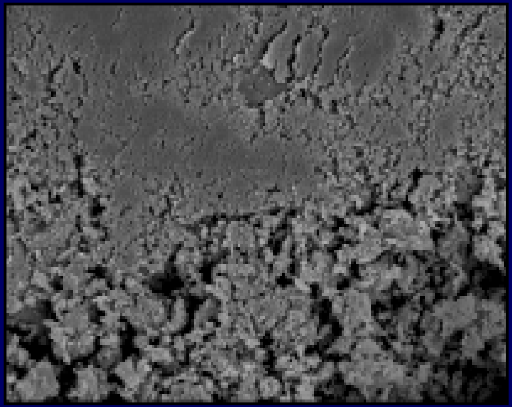
x 300



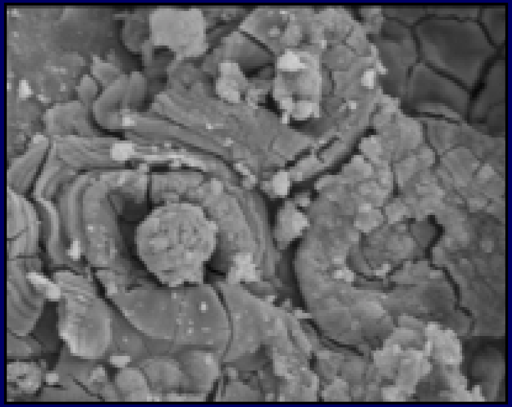
x 50



x 3000



x 3000

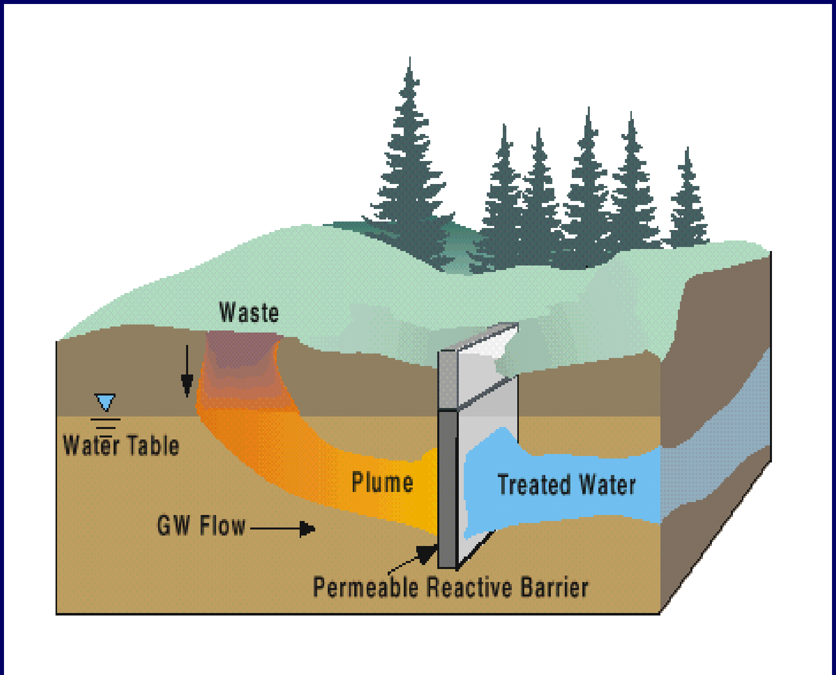


x 4500

Monitoring objectives:

- Performance assessment
  - ✓Outflow concentrations / flux (Gate)
    - ✓tested against remedial objectives
    - ✓validated PRB effectiveness
    - ✓PRB deterioration (fouling) not threat
  - ✓Hydraulic control (Funnel)
    - ✓By-pass flow – none noted
    - ✓impacts on GW flow regime - negligible
  - ✓Test conceptual model

BROWNFIELD REDEVELOPMENT
QUB Project for Biologic PRB at Portadown



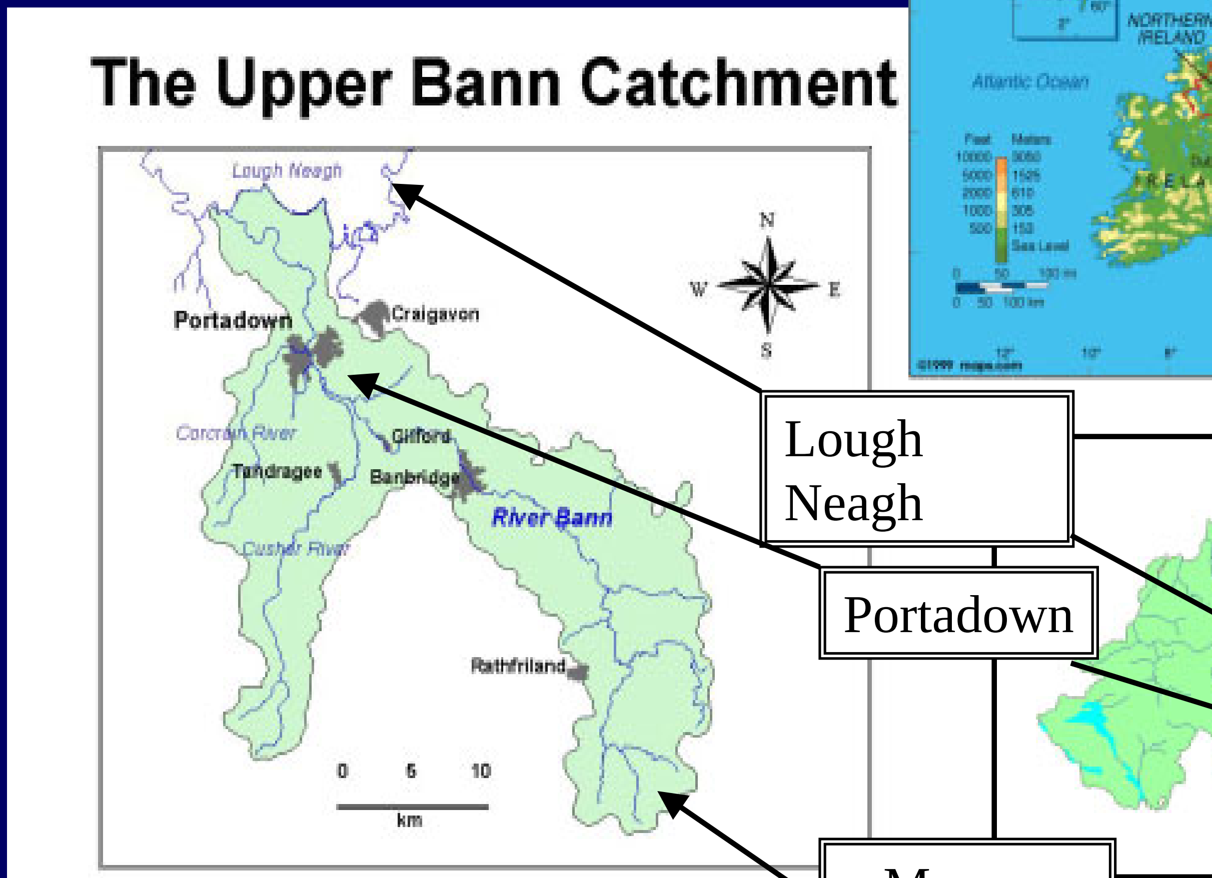
Portadown Gas Works

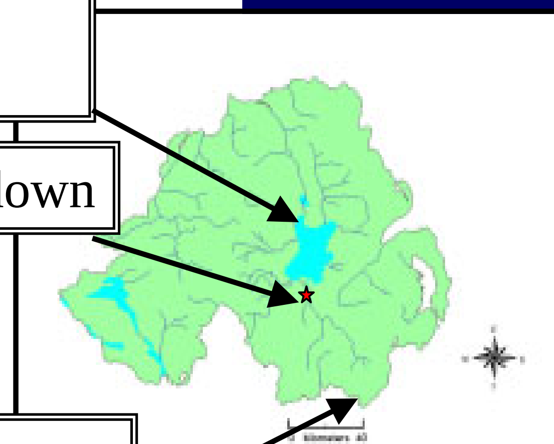
- Hydrogeology & Modelling
- BioGeochemistry
- Microbial Ecology
- Microbial Genetics
- Full-scale implementation
- Evaluation

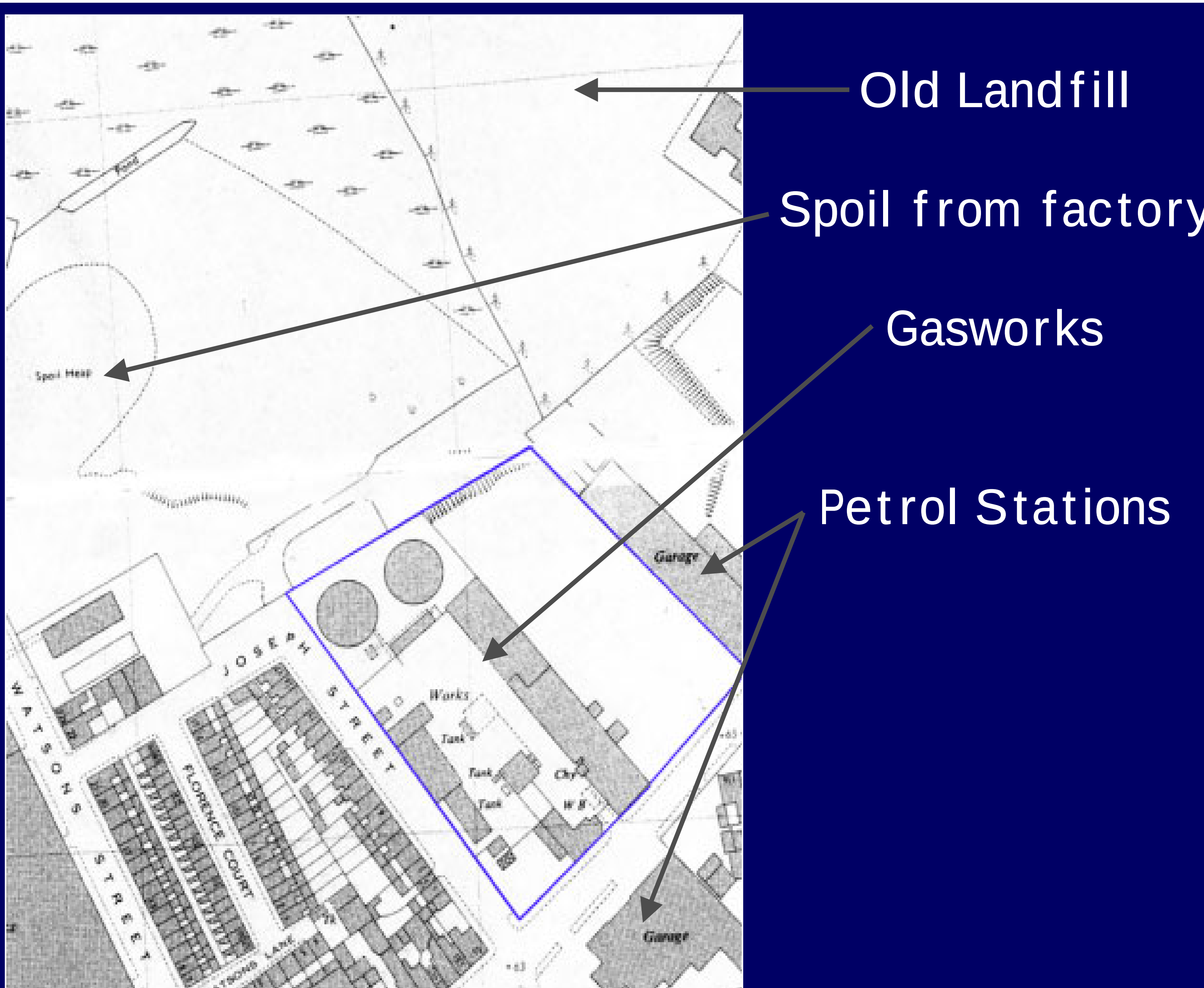
Up to 1500 existing gasworks sites in the UK still requiring remediation

Desk Study

- Location in Northern Ireland

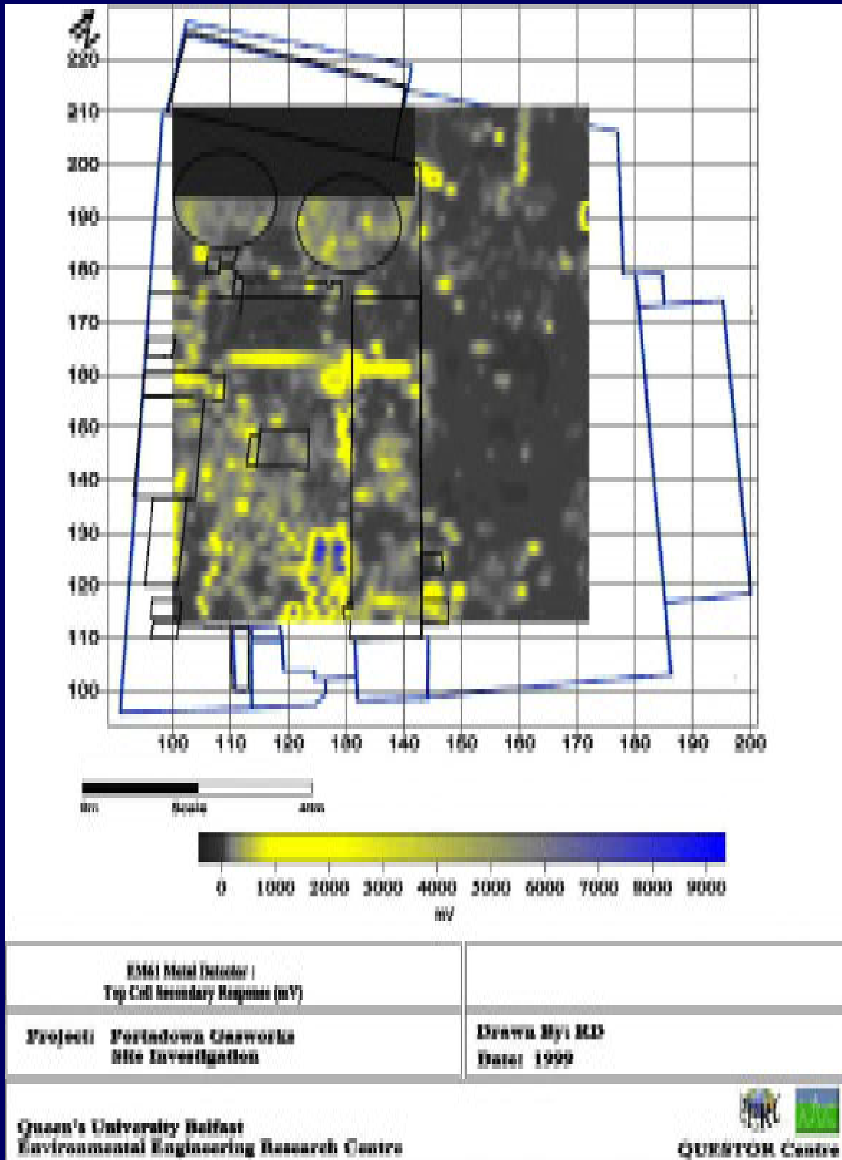


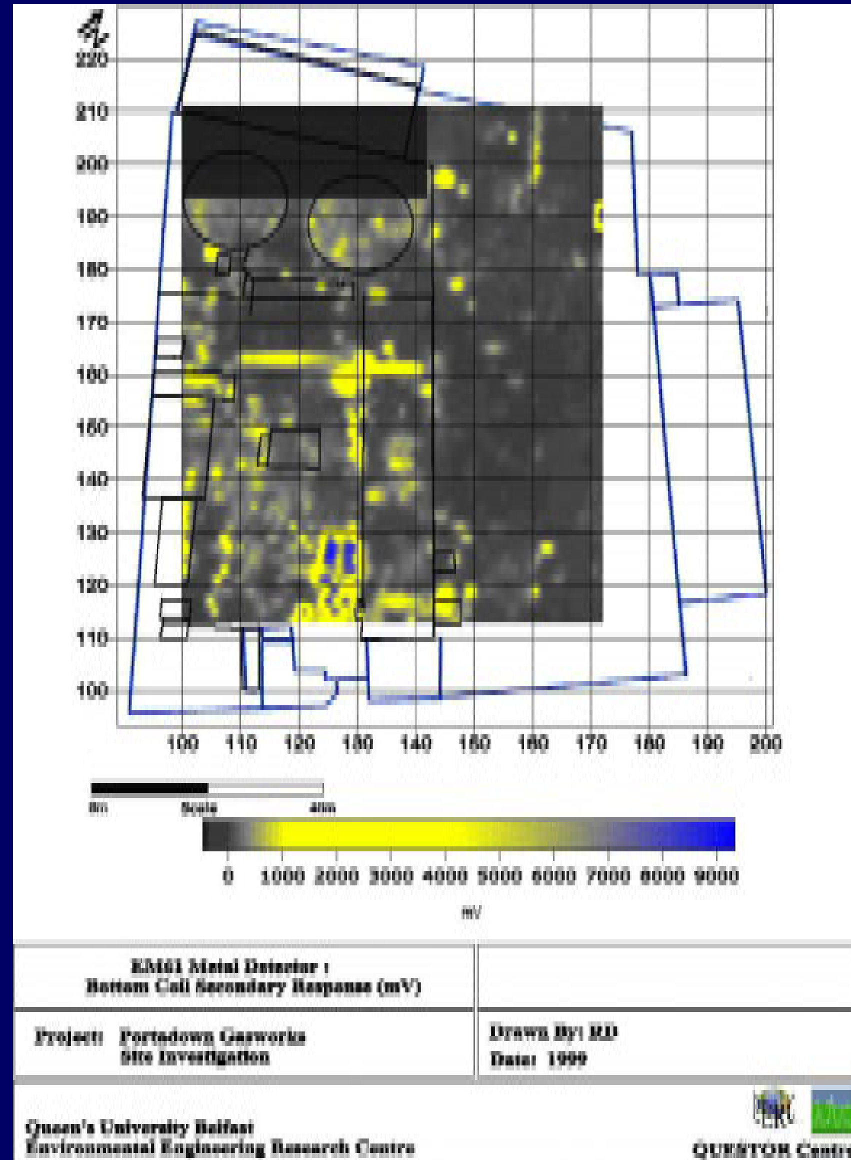



Old Landfill
Spoil from factory
Gasworks
Petrol Stations
Spoil Heap
JOSEPH STREET
WATSONS STREET
FLORENCE COURT
Works
Tank
Tank
Tank
Garage
Garage

Site Investigation

Portadown Gasworks Site Investigaton


Scale
mV
EM61 Metal Detector :
Top Coil Secondary Response (mV)
Project: Portadown Gasworks
Site Investigation
Drawn By: RD
Date: 1999
Queen's University Belfast
Environmental Engineering Research Centre
QUESTOR Centre


Scale
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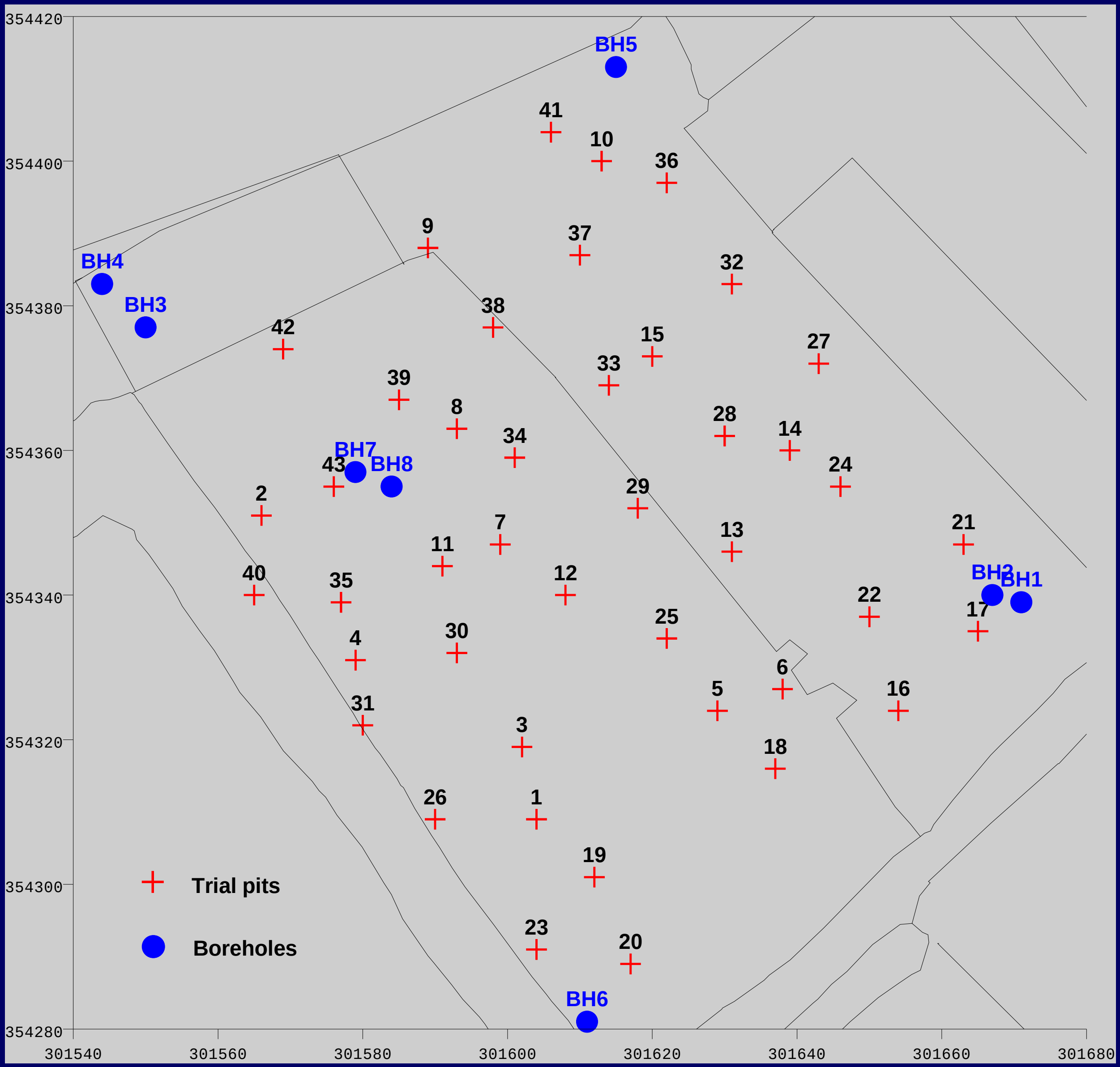
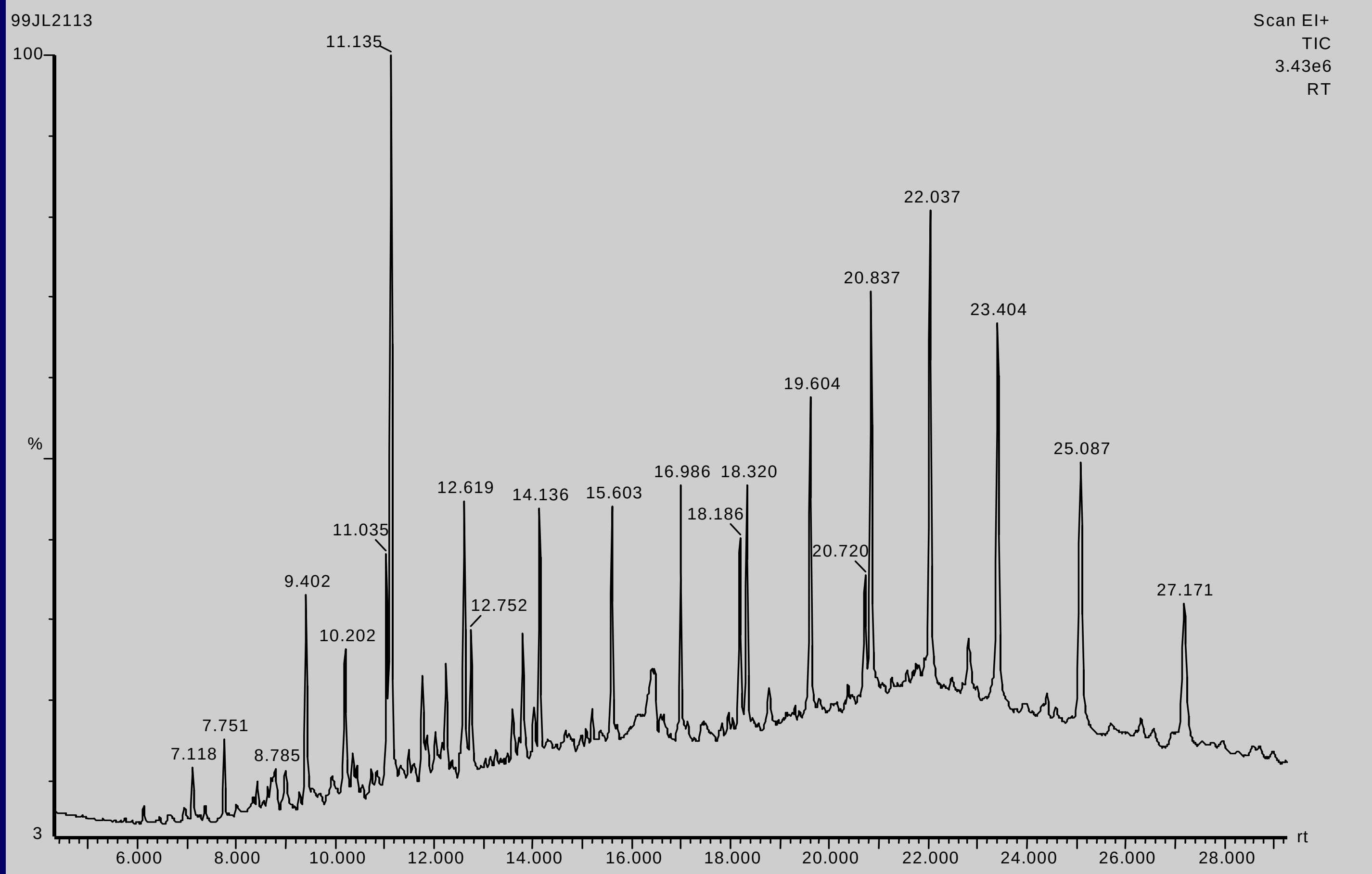
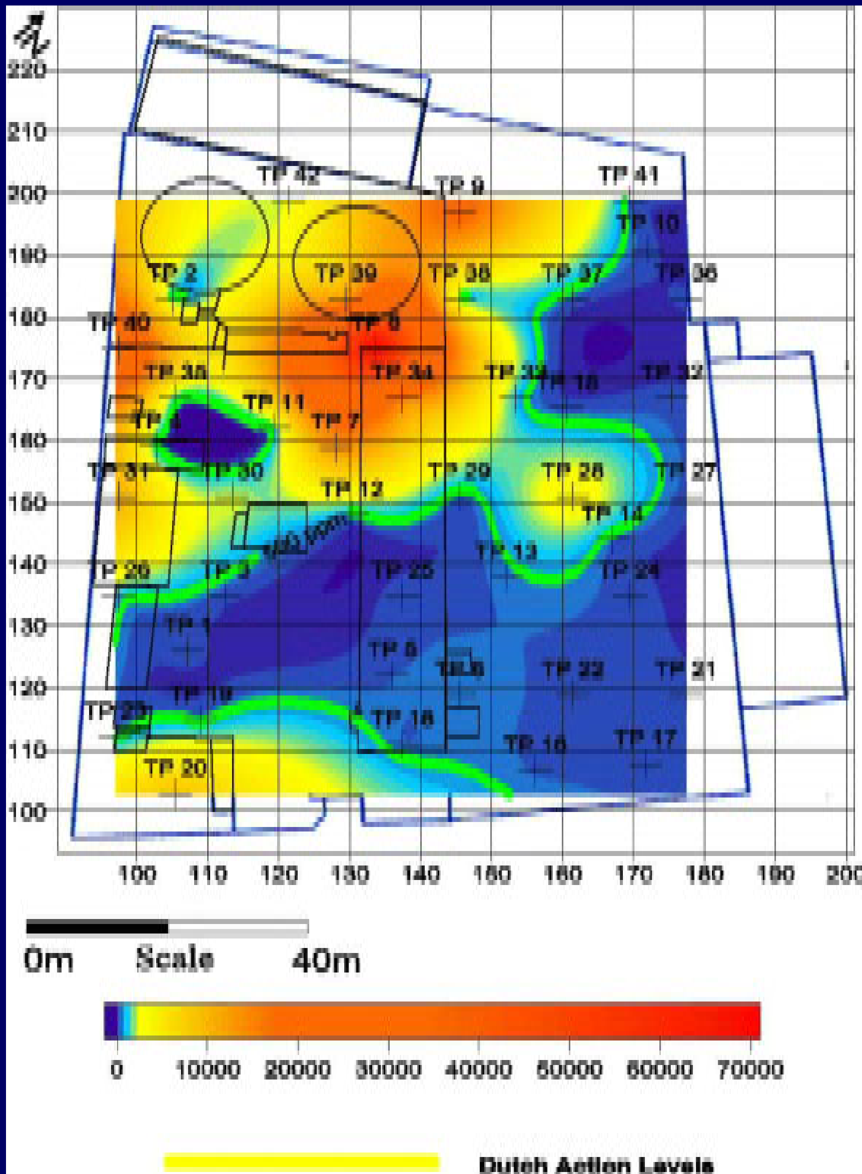


Intrusive SI

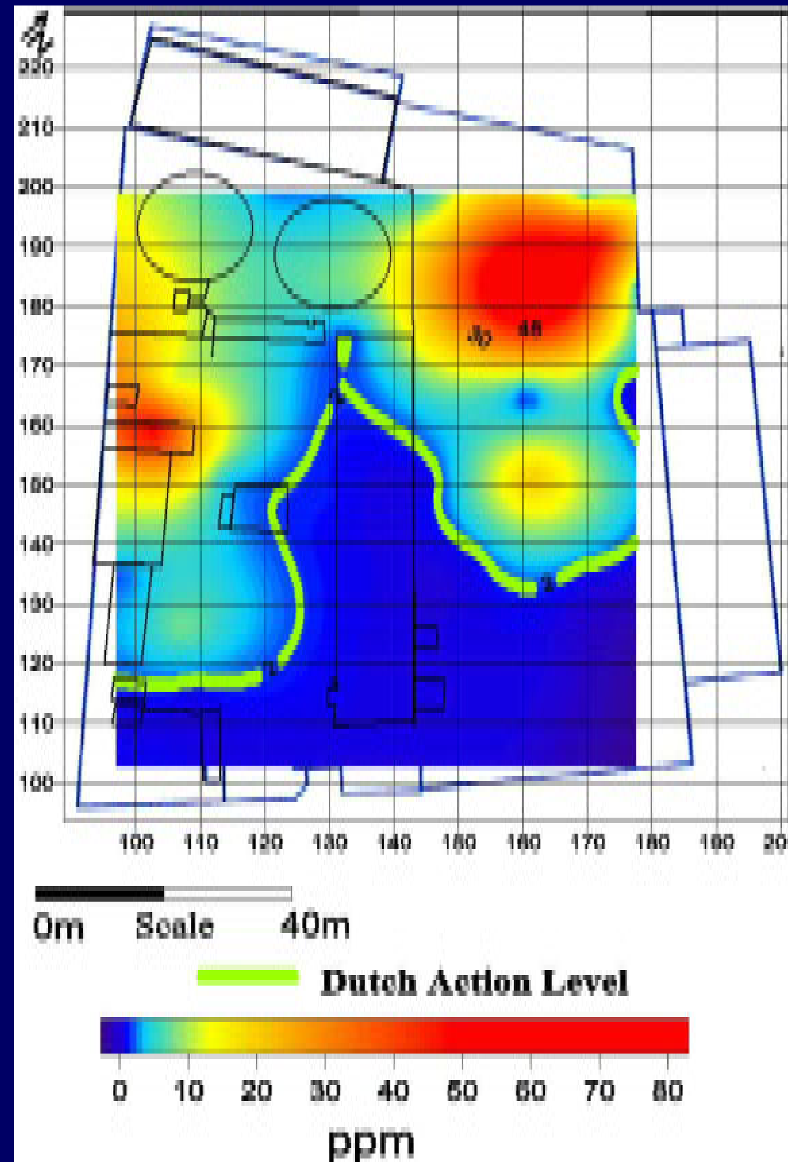


Example GC-MS of a soil extract from made ground contaminated with aliphatic compounds.

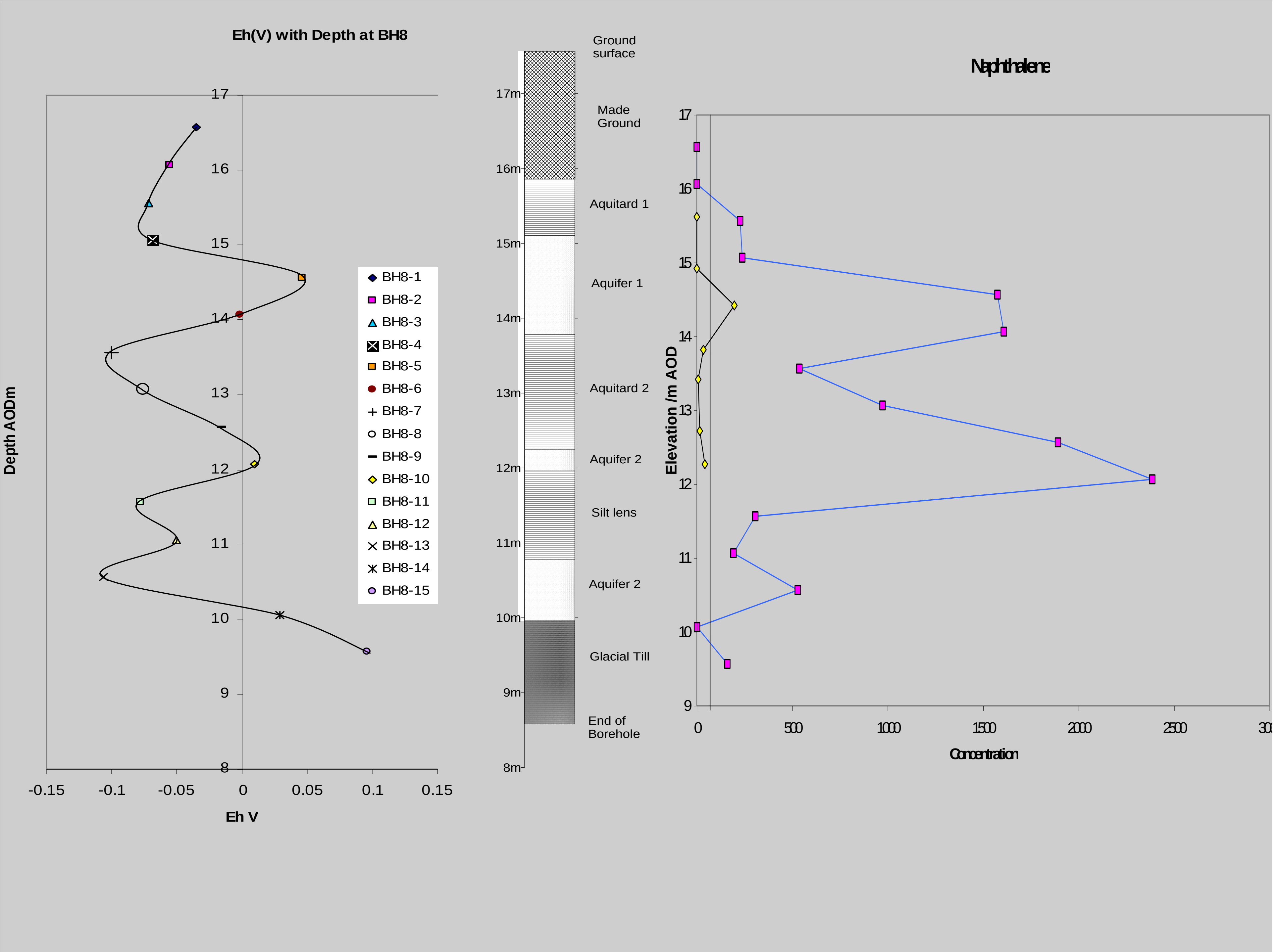
Mineral Oil



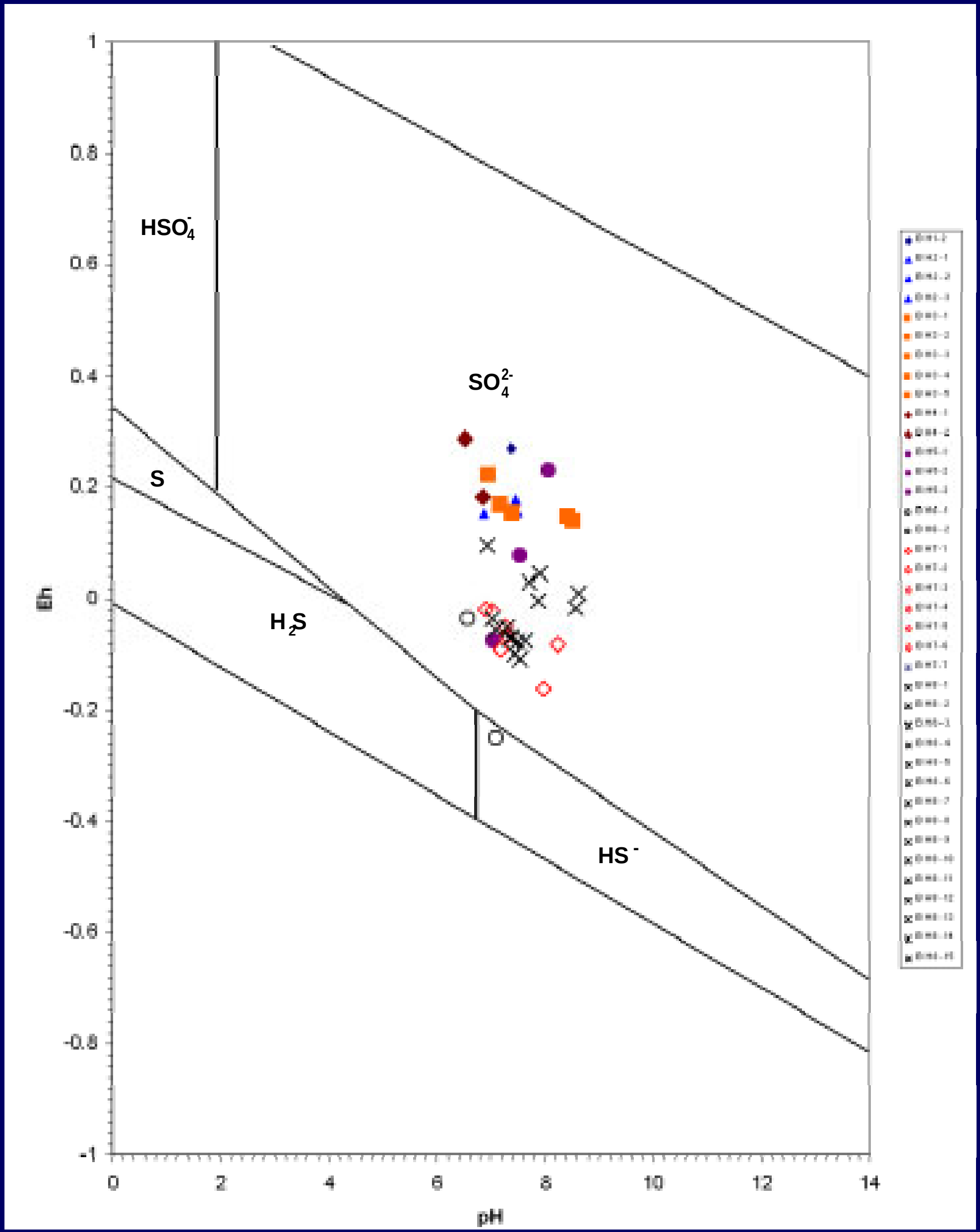
Complexed Cyanide



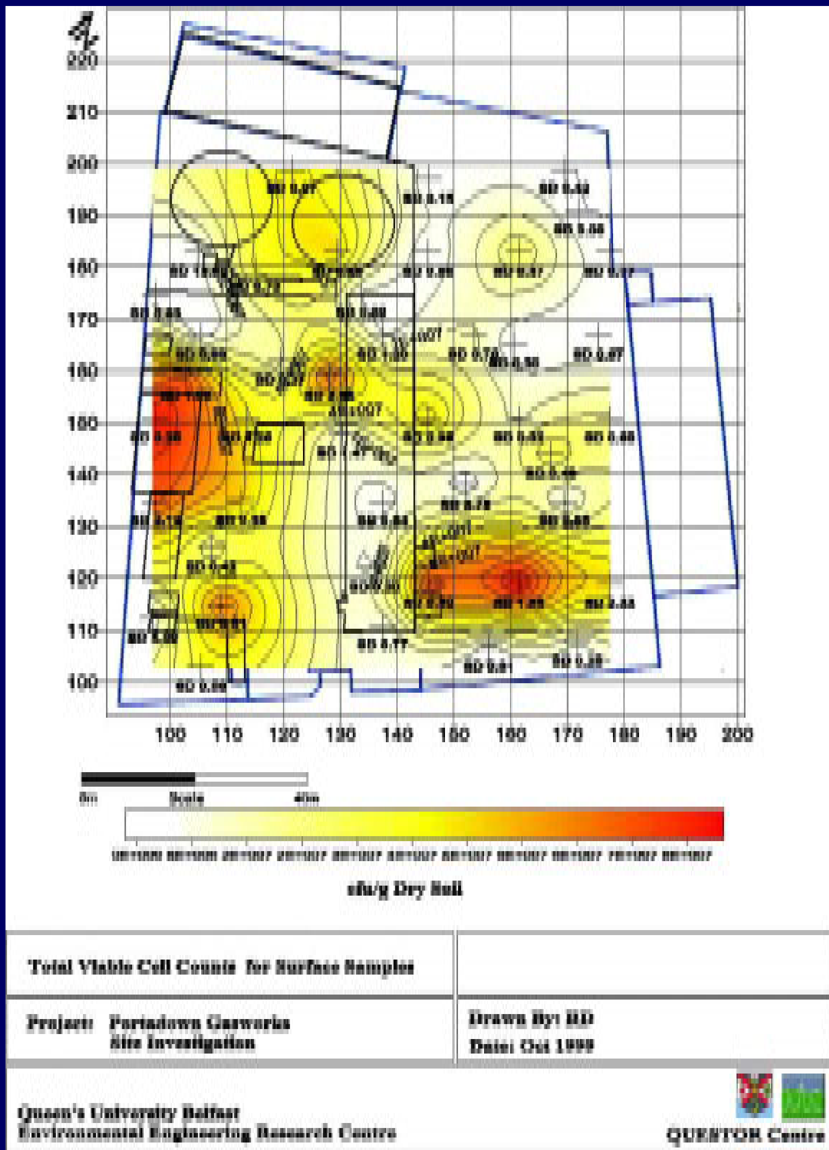
3-D Multi-level information

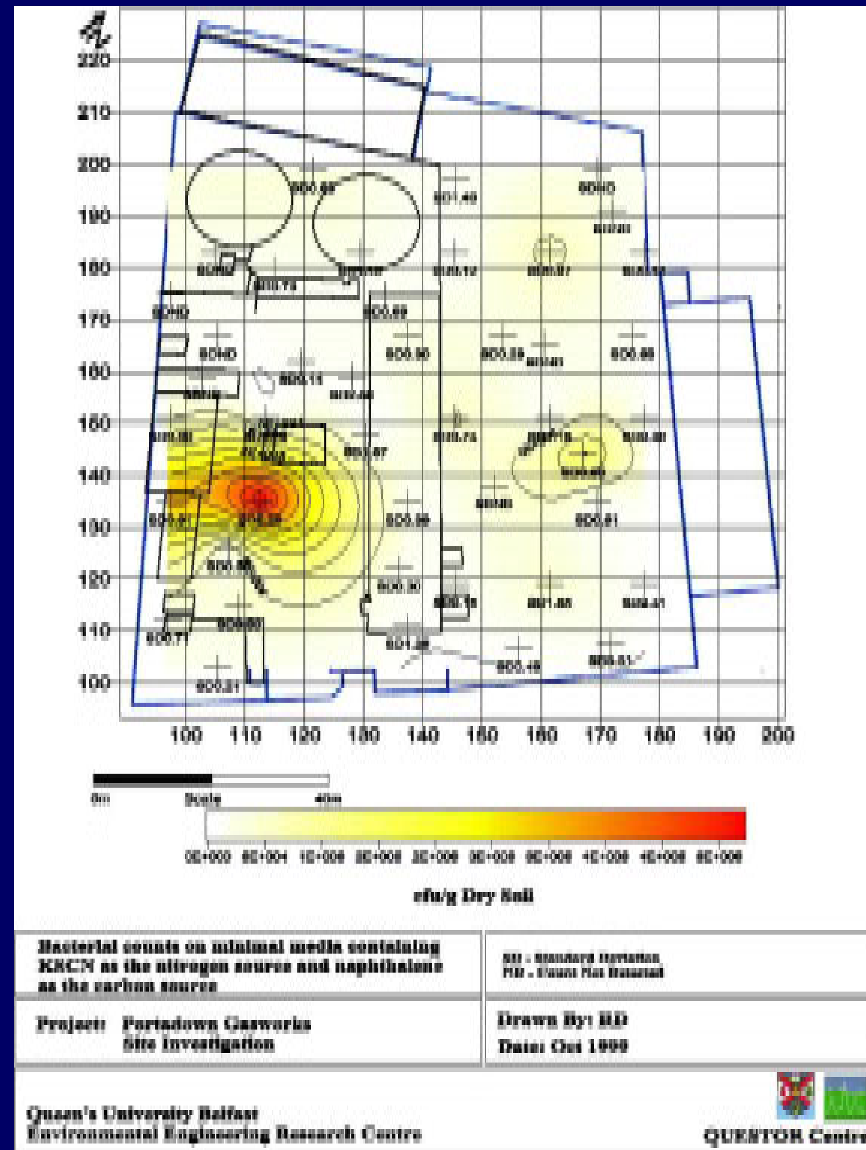


Eh(V) with Depth at BHB8
Depth AODm
Eh V
-0.15
-0.1
-0.05
0
0.05
0.1
0.15
17
16
15
14
13
12
11
10
9
8
BH8-1
BH8-2
BH8-3
BH8-4
BH8-5
BH8-6
BH8-7
BH8-8
BH8-9
BH8-10
BH8-11
BH8-12
BH8-13
BH8-14
BH8-15
Ground surface
Made Ground
Aquitard 1
Aquifer 1
Aquitard 2
Aquifer 2
Silt lens
Aquifer 2
Glacial Till
End of Borehole
17m
16m
15m
14m
13m
12m
11m
10m
9m
8m
Naphthalene
Elevation /m AOD
Concentration
0
500
1000
1500
2000
2500



Geochemistry of groundwater on site is controlled by nitrate – ammonia microbial processes and therefore very little H_2S is formed

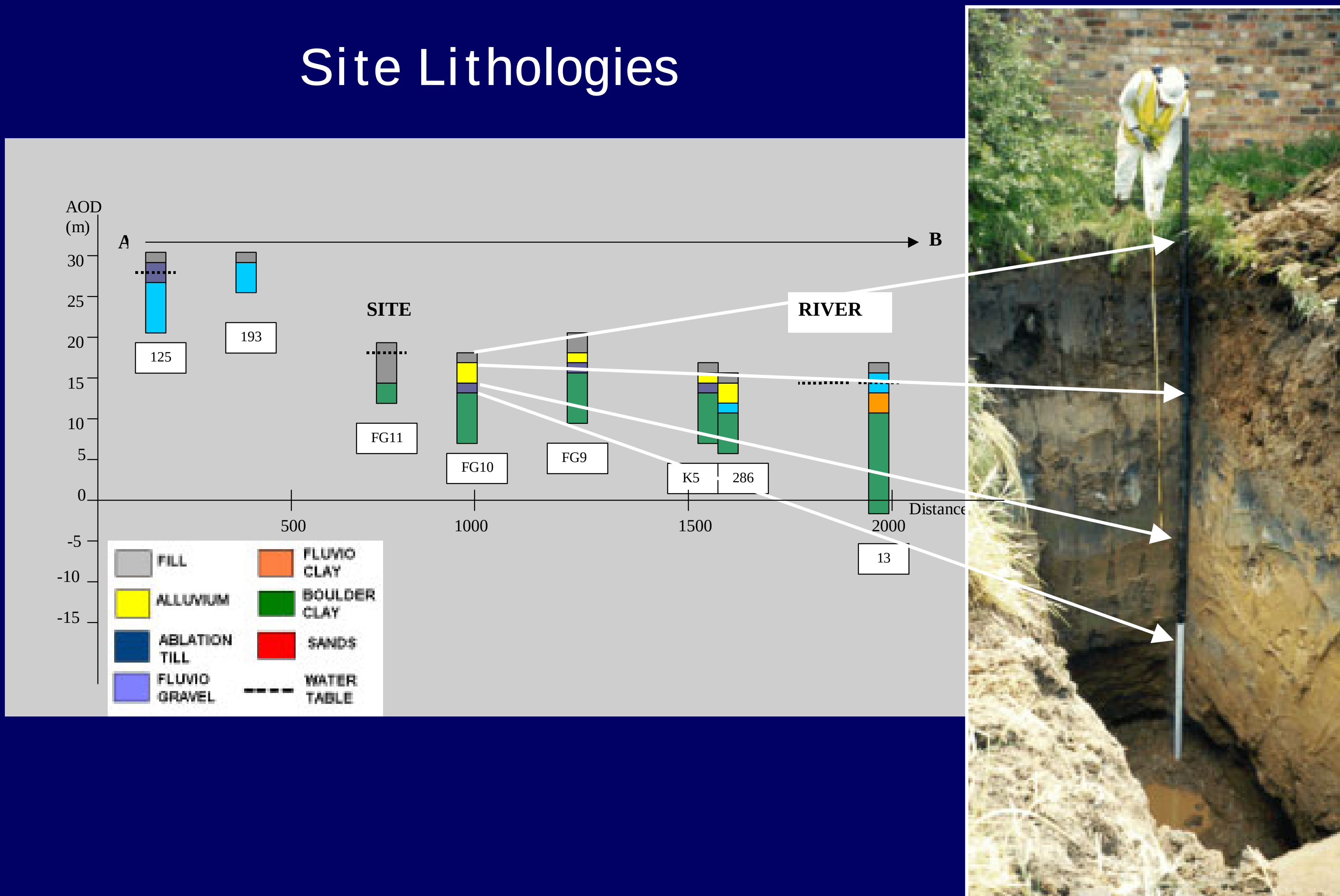


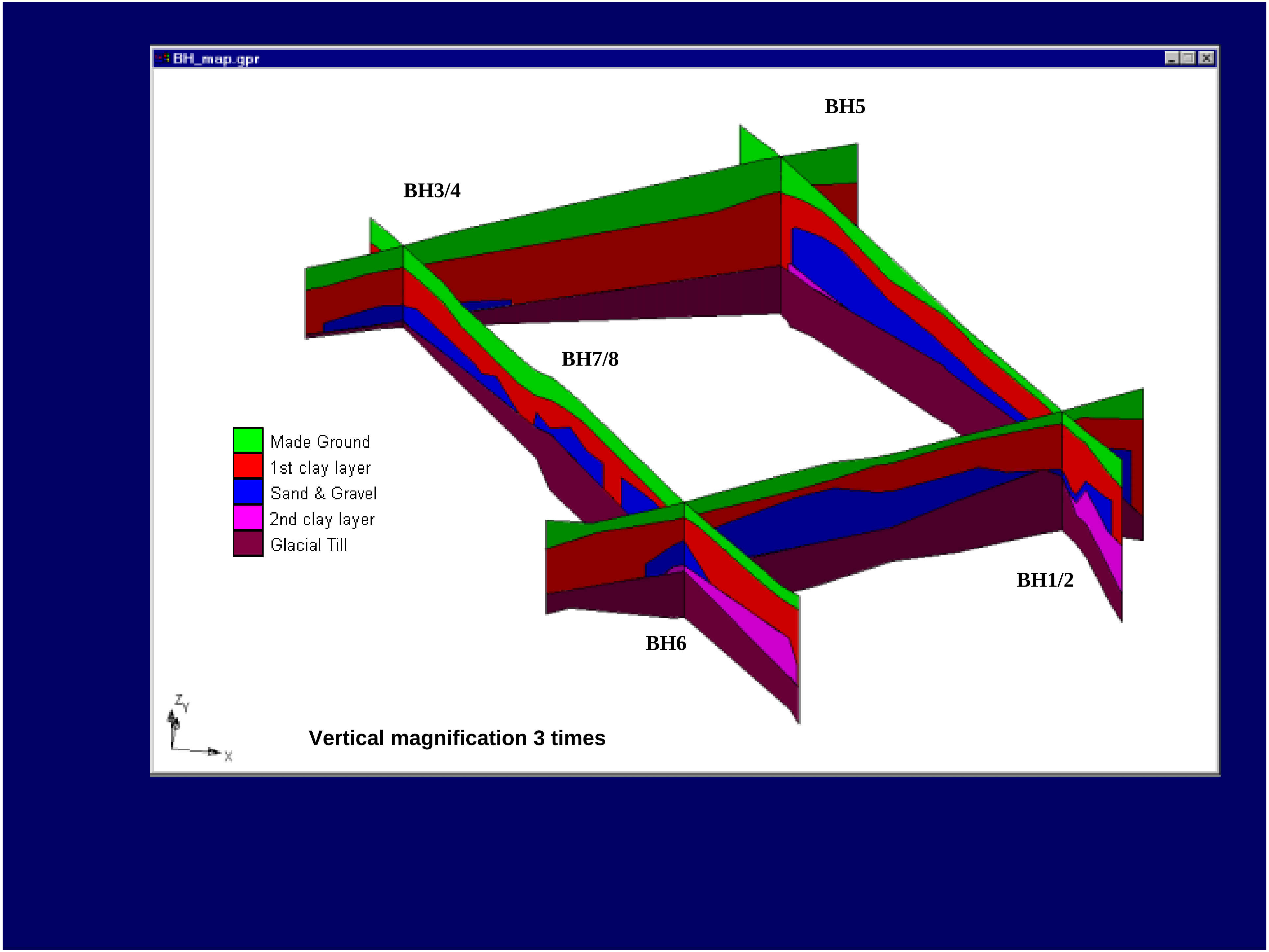


Microbiological Investigation

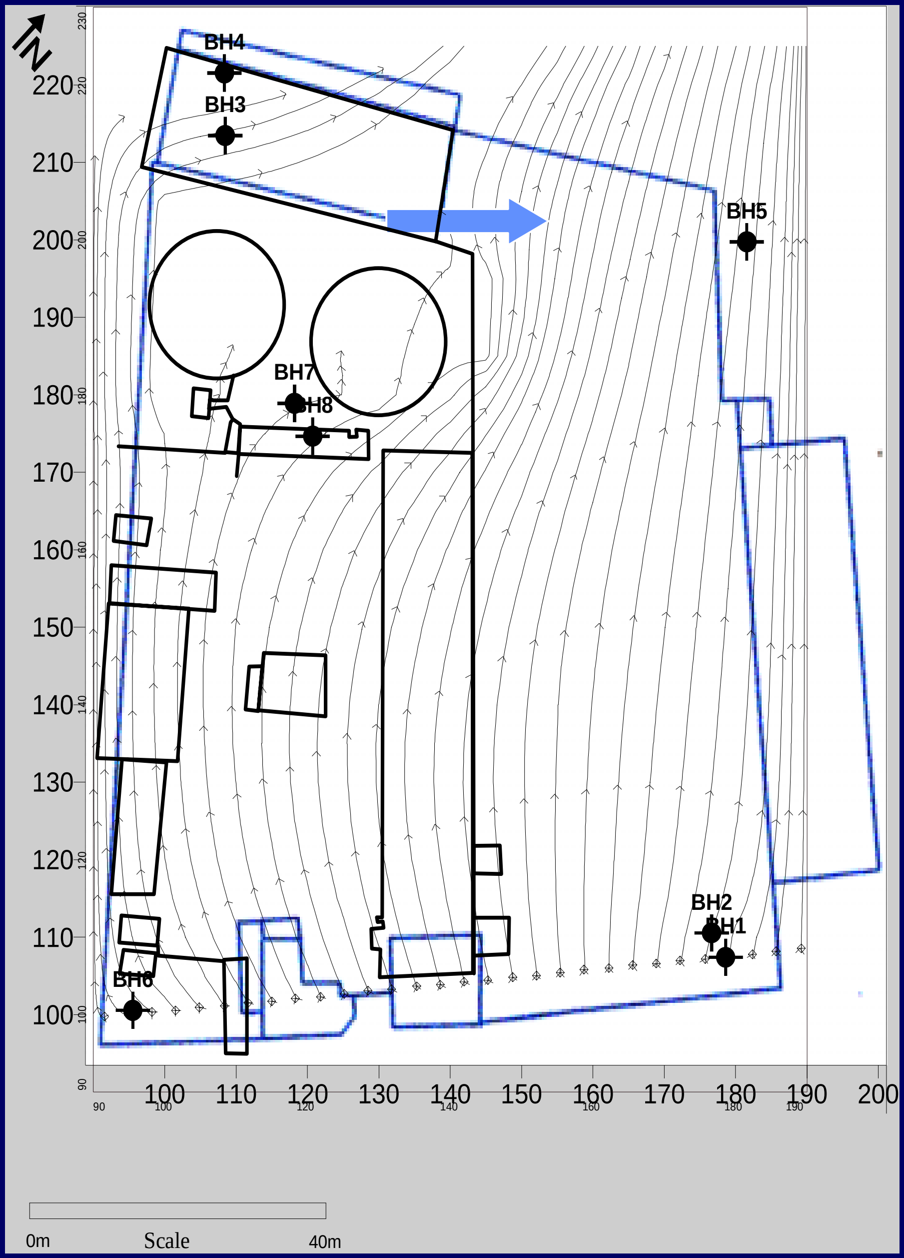
Conceptual Geologic Framework

Site Lithologies




BH_map.gpr
BH5
BH3/4
BH7/8
BH1/2
BH6
Made Ground
1st clay layer
Sand & Gravel
2nd clay layer
Glacial Till
Vertical magnification 3 times

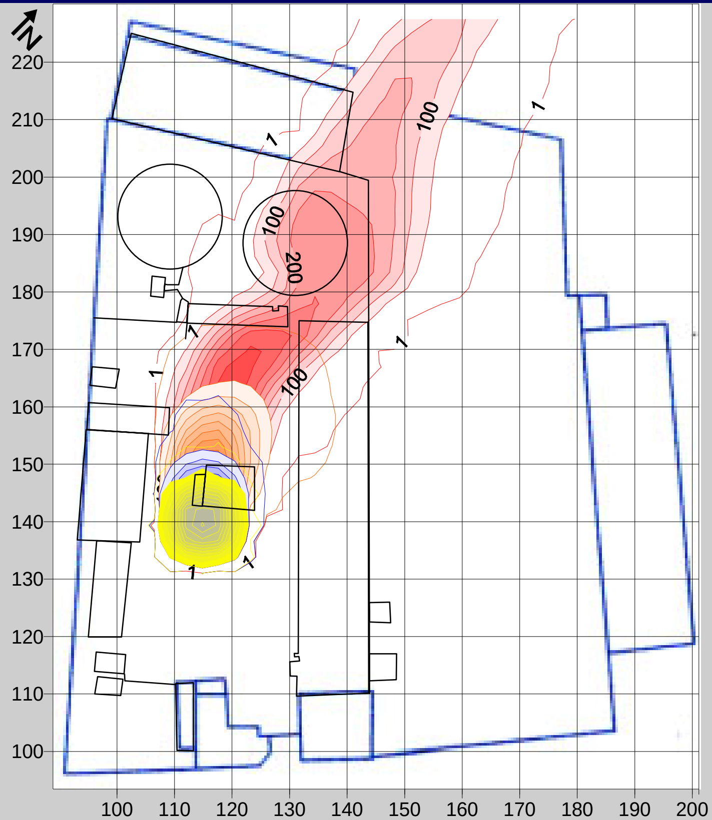
Hydrogeologic Framework



Final Flow Field Pre-Works

Note the effect of underground structures on pathlines.

(off-site migration of plume encountered where modelled predicted)



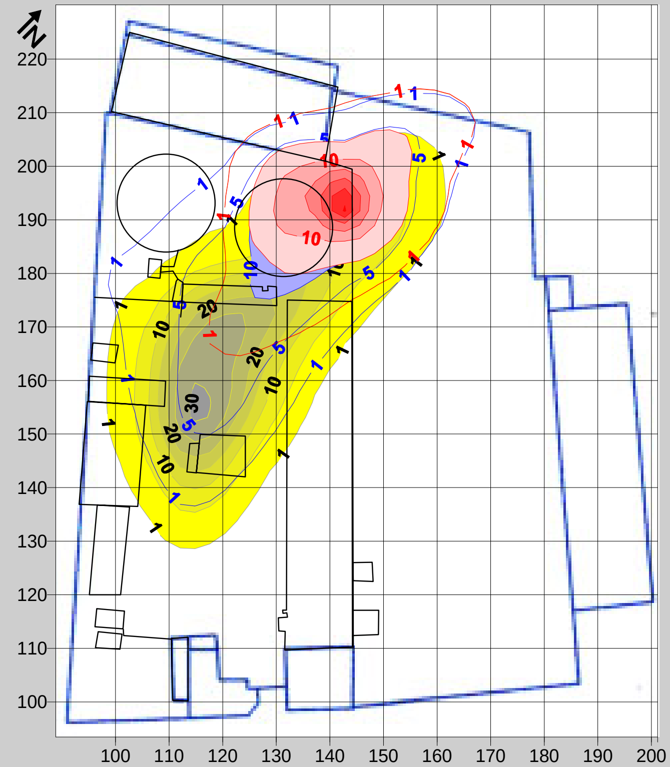
0m Scale 40m

Extent of modelled individual contamimant plumes moving from tar well within aquifer 2 over 1.7 years	Phenanthrene mg/L 2 methylnaphthalene mg/L
Project: Portadown Gasworks Site Investigation	Naphthalene mg/L Mineral oil (benzene) mg/L

Queen's University Belfast
Environmental Engineering Research Centre

Drawn By: RD

QUESTOR Centre



0m Scale 40m

Source: Tar Well in Aquifer 2,
500mg/l constant contamination

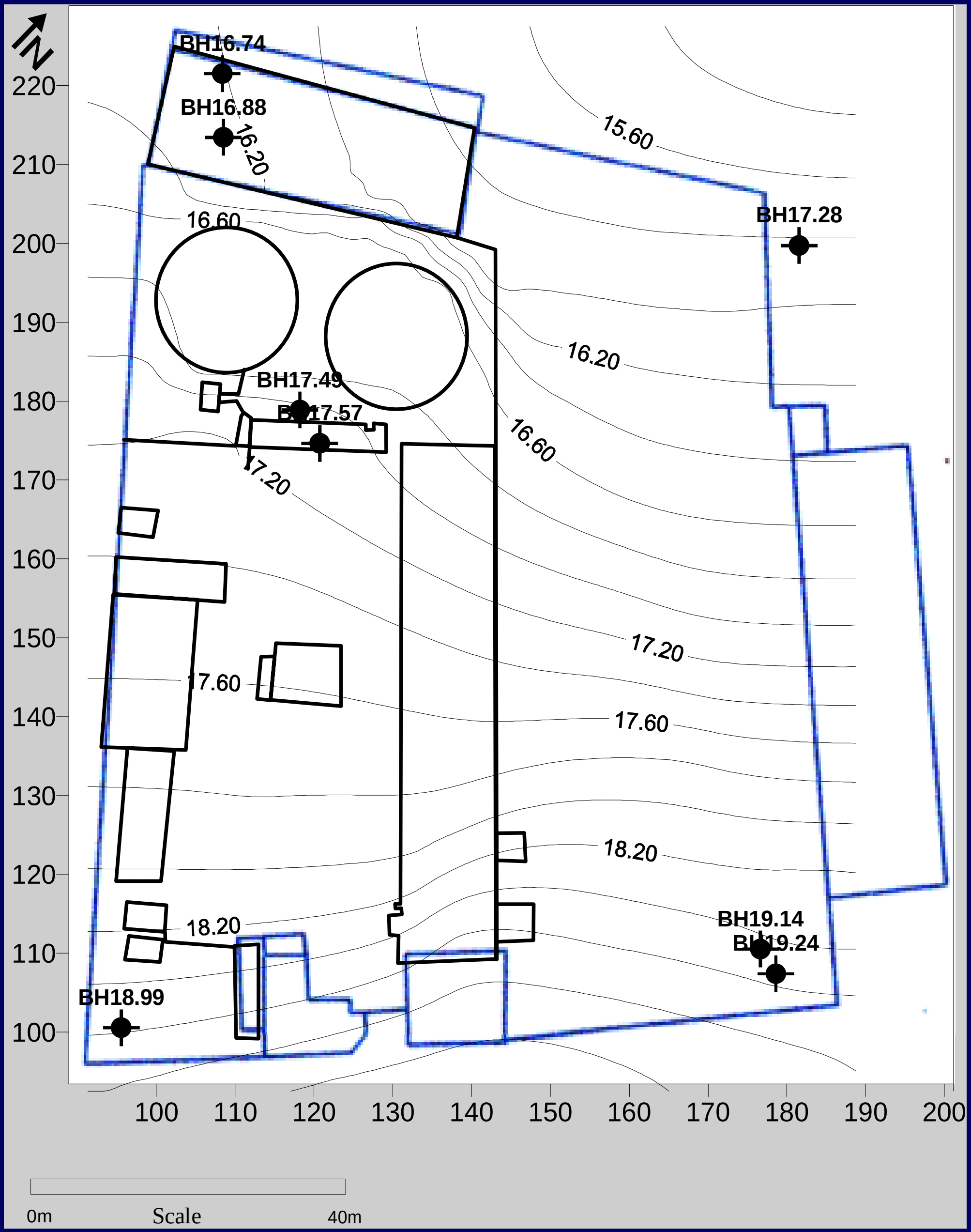
Modelled contaminant plumes distribution within made ground after 100 years, source - Tar well	Mineral oil /naphthalene Phenanthrene mg/l
Project: Portadown Gasworks Site Investigation	2 Methylnaphthalene mg/l

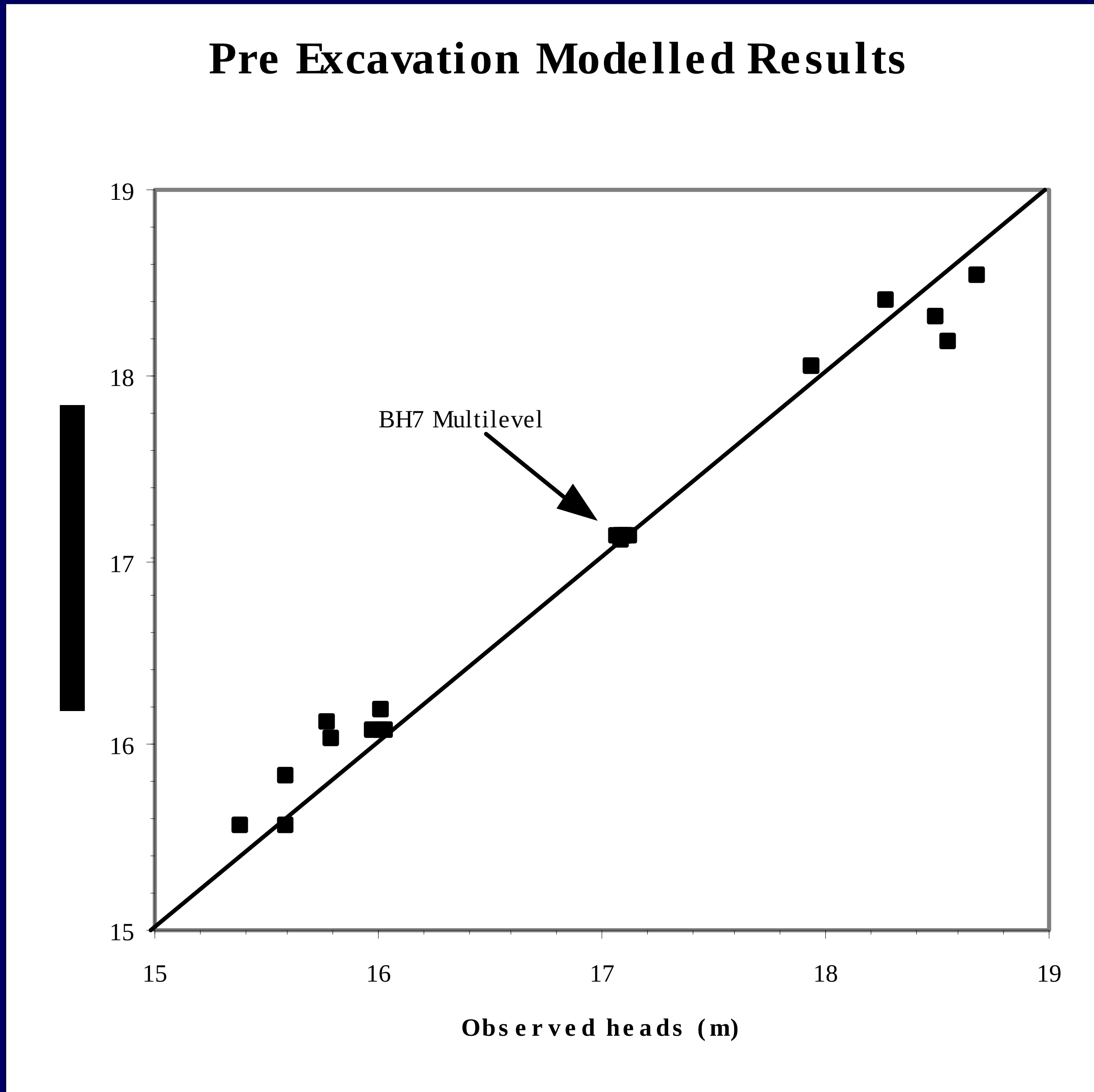
Queen's University Belfast
Environmental Engineering Research Centre

Drawn By: RD

QUESTOR Centre

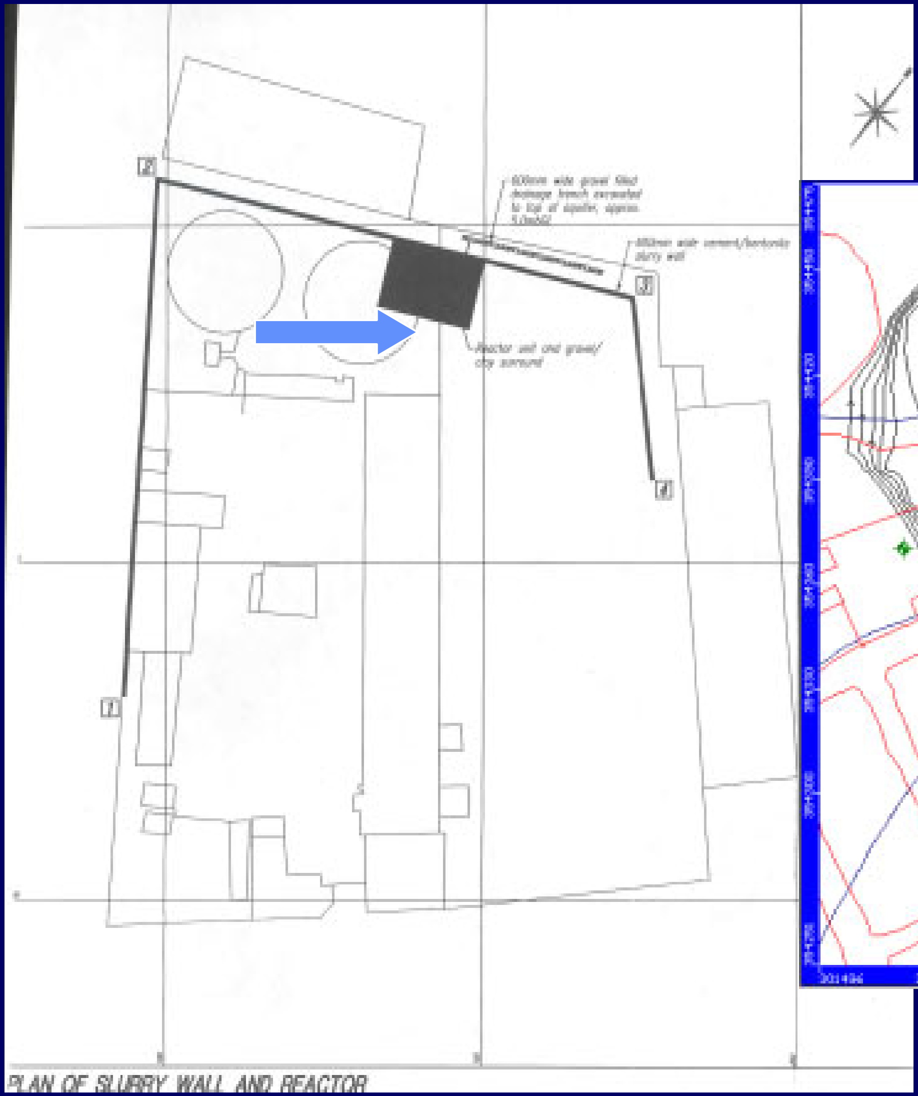
Modelled Water Table for Site

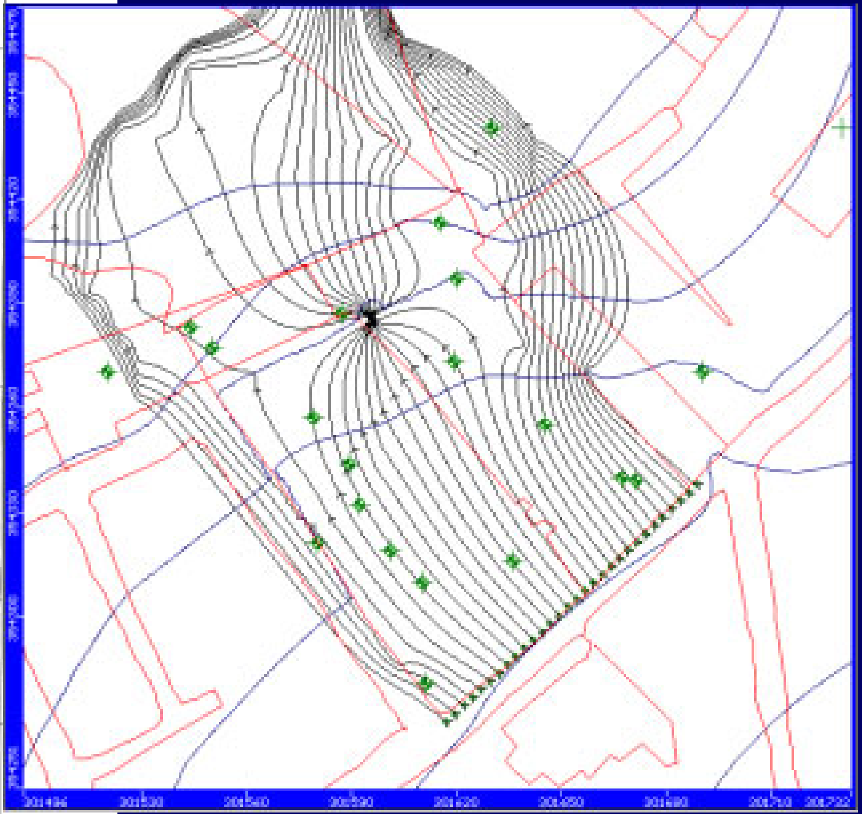




Fit of Observed and Modelled Water Table at Site

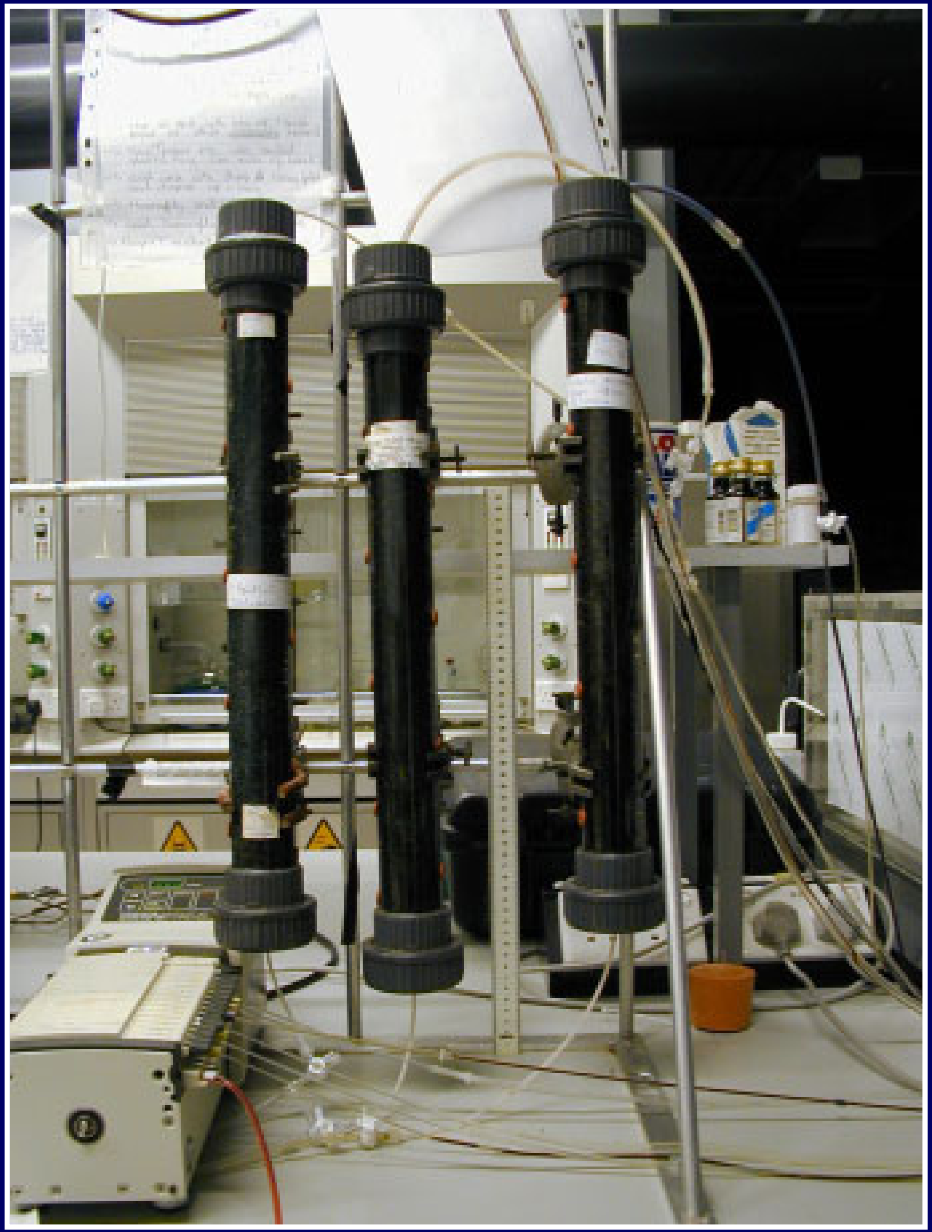
Reactor Placement to Intercept Plume





Laboratory Feasibility Study

Treatability study using actual site water

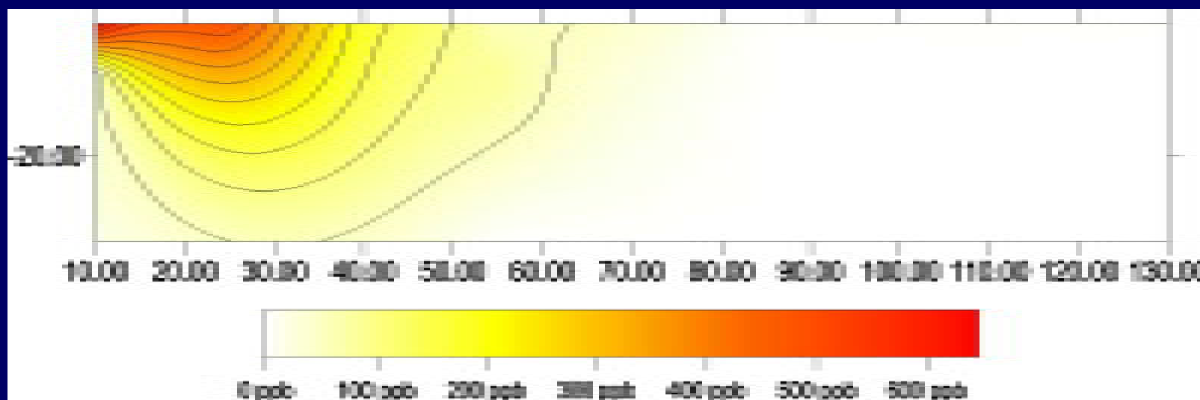


Columns at QUB

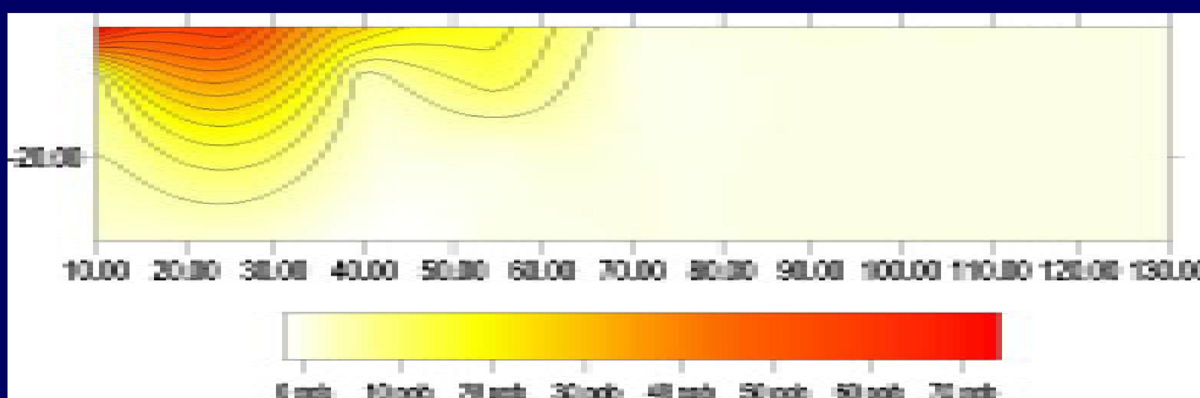
1-D Flux and Rate Experiments

2-D Biologic Treatment Feasibility Study

Rates of BTEX removal for the lab-scale reactor were use in full-scale designed to ensure adequate residence time and hence removal of contaminated substances. (note: Microtox indicates toxicity is removed after only 1 week of pilot scale operation)



Benzene Degradation in the Biobarrier



Toluene Degradation in the Biobarrier