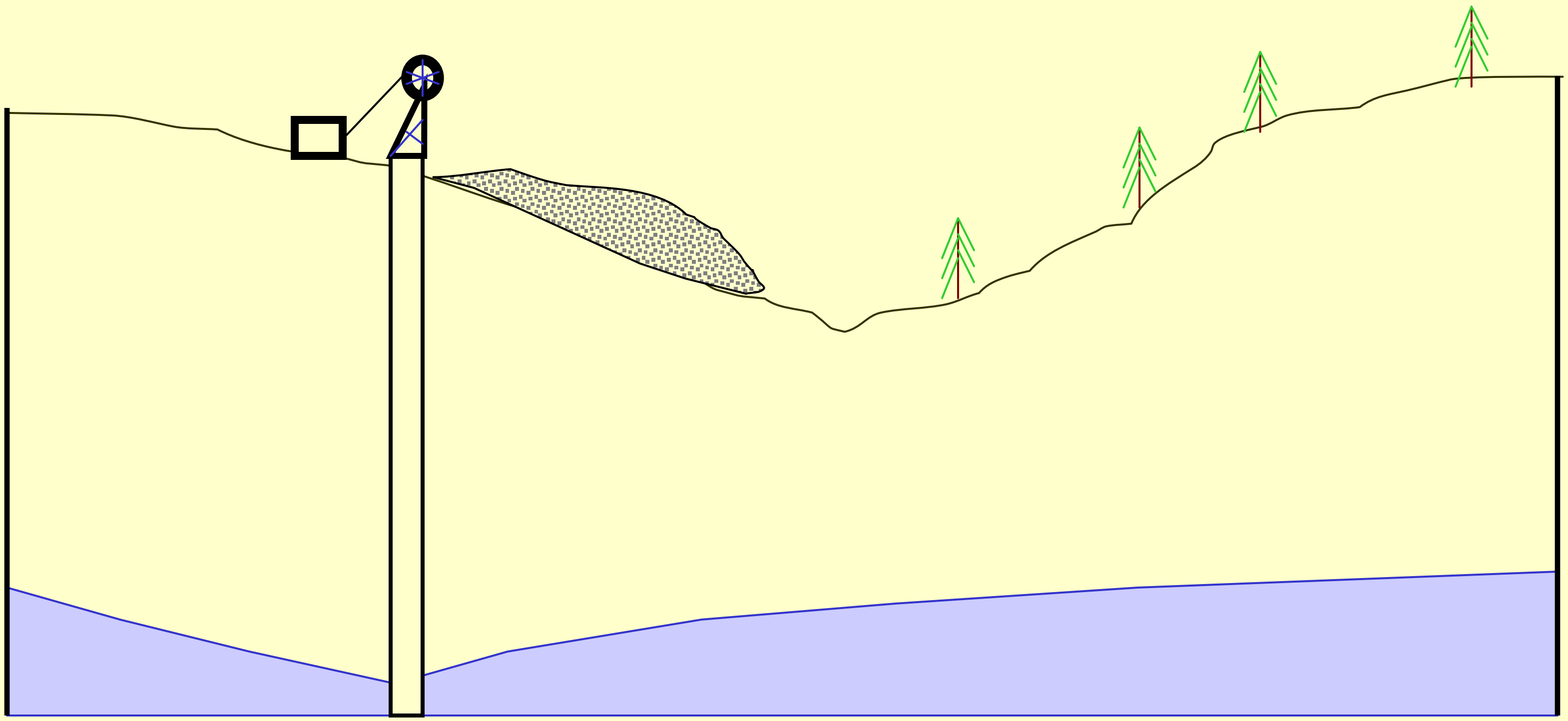
Mine Water Rebound:
PROCESSES AND PRODUCTS
♦ *a UK perspective* ♦

Paul L Younger

HSBC Professor of Environmental Technologies
Hydrogeochemical Engineering Research & Outreach (HERO)
Institute for Research on Environment & Sustainability (IRES)
University of Newcastle upon Tyne, UK
(paul.younger@ncl.ac.uk)

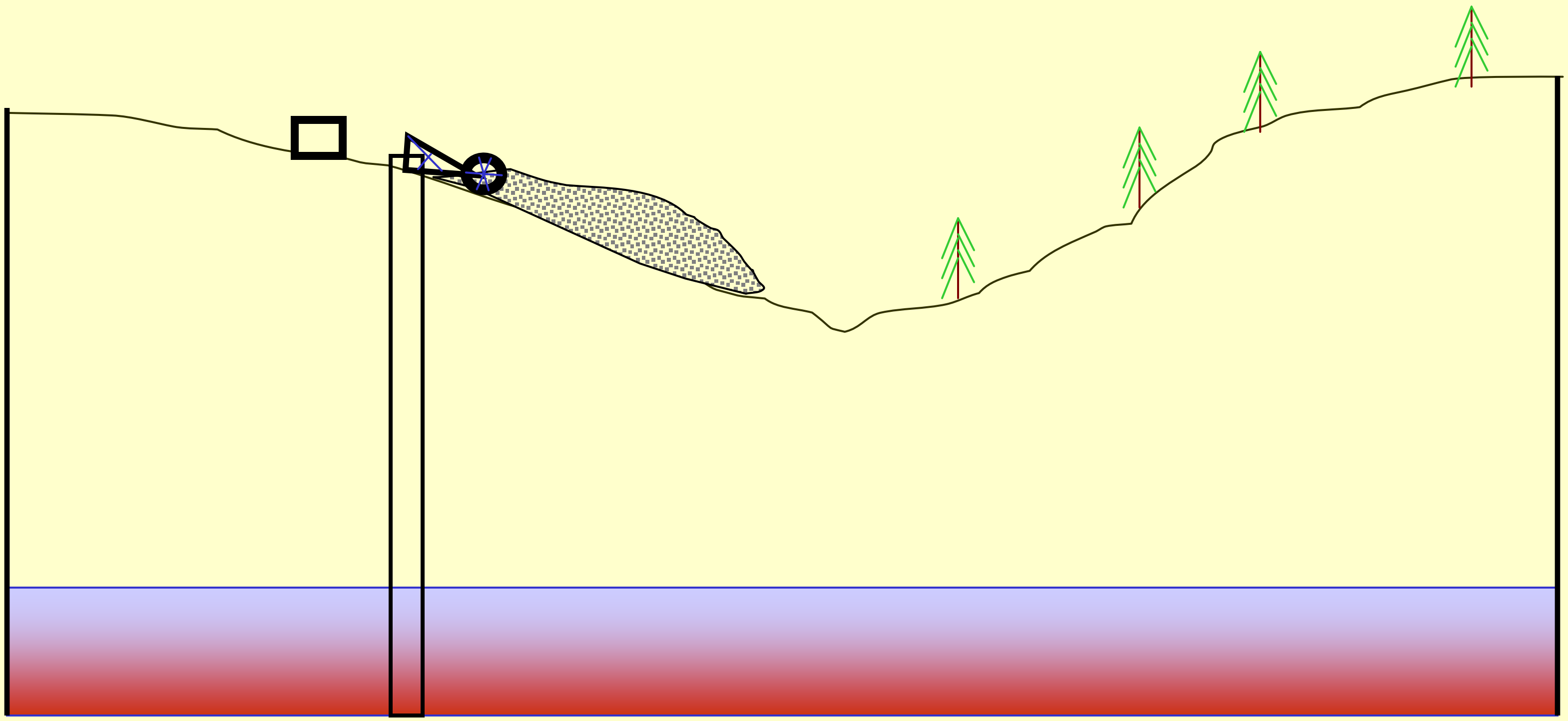
Underground Coal Mine Post-closure Rebound

1. The last shift



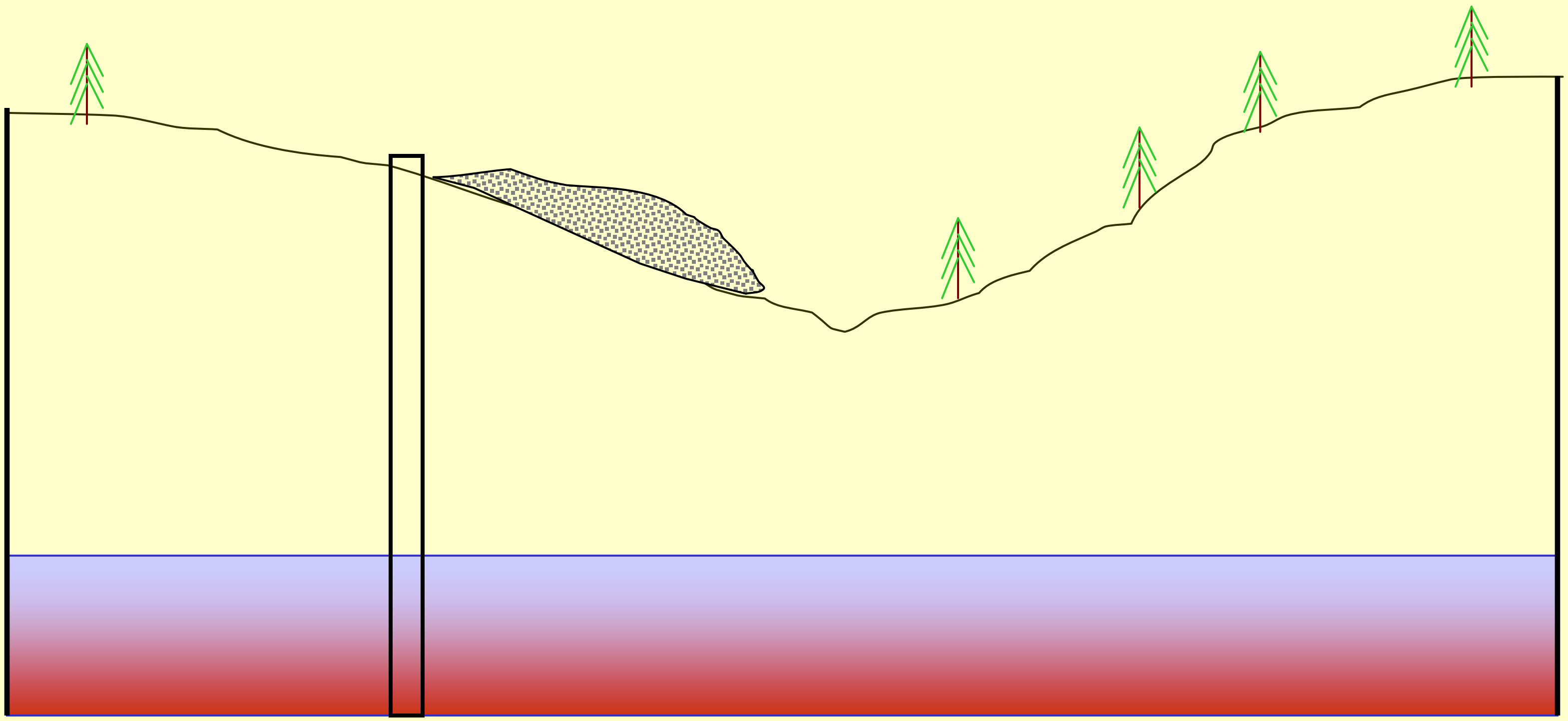
Underground Coal Mine Post-closure Rebound

2. Demolition time …



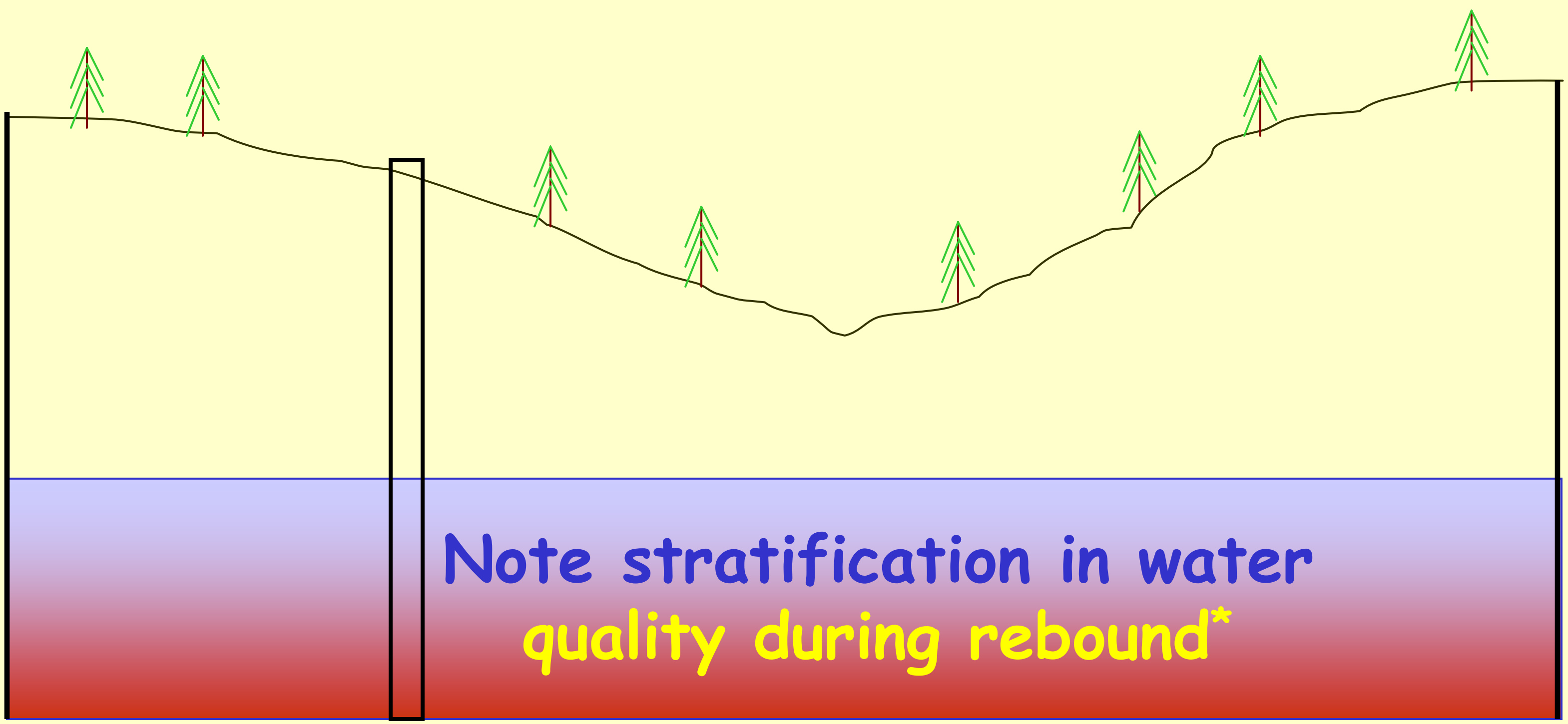
Underground Coal Mine Post-closure Rebound

3. Start surface reclamation …



Underground Coal Mine Post-closure Rebound

4. Reclamation advances



*See: *J. Contam. Hydrol.* 69: 101 - 114 (2004)

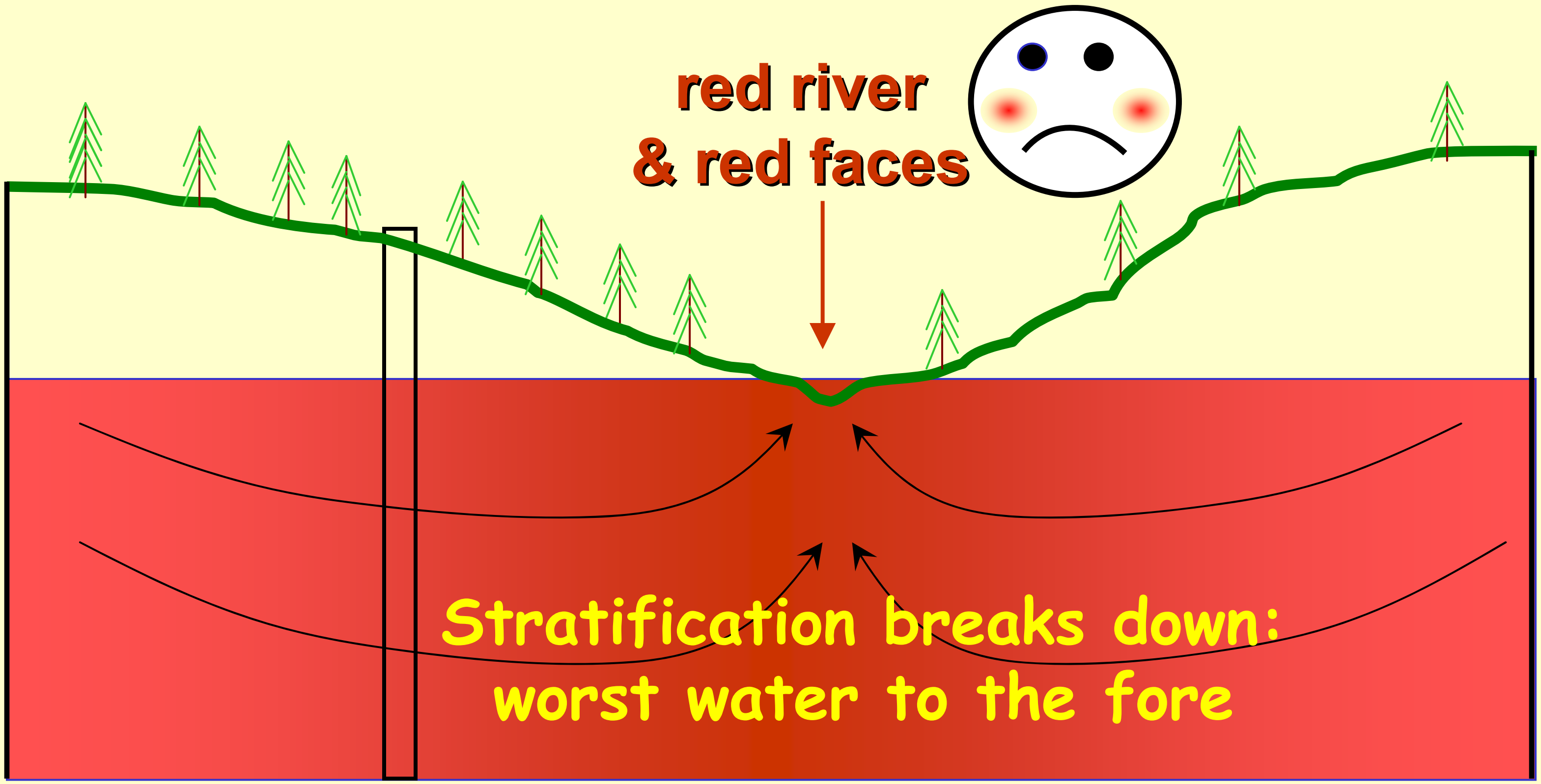
Underground Coal Mine Post-closure Rebound

5. Old site really looking nice now …

*See: *J. Contam. Hydrol.* 69: 101 - 114 (2004)

Underground Coal Mine Post-closure Rebound

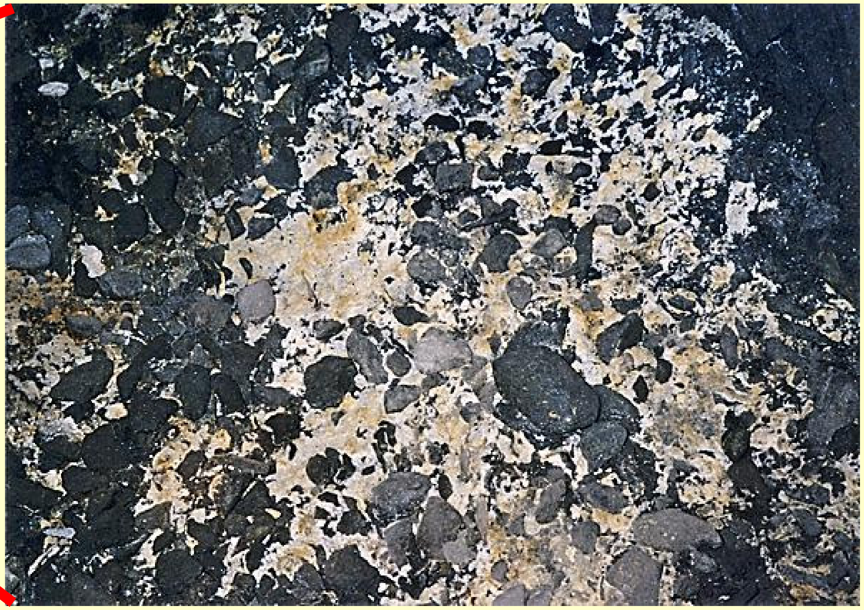
6. Whoops! Mine outflow commences



*See: *J. Contam. Hydrol.* 69: 101 - 114 (2004)

Why mine water quality deteriorates during rebound

Acid-storing salts: efflorescent products of *in situ* pyrite oxidation in water-scarce environment



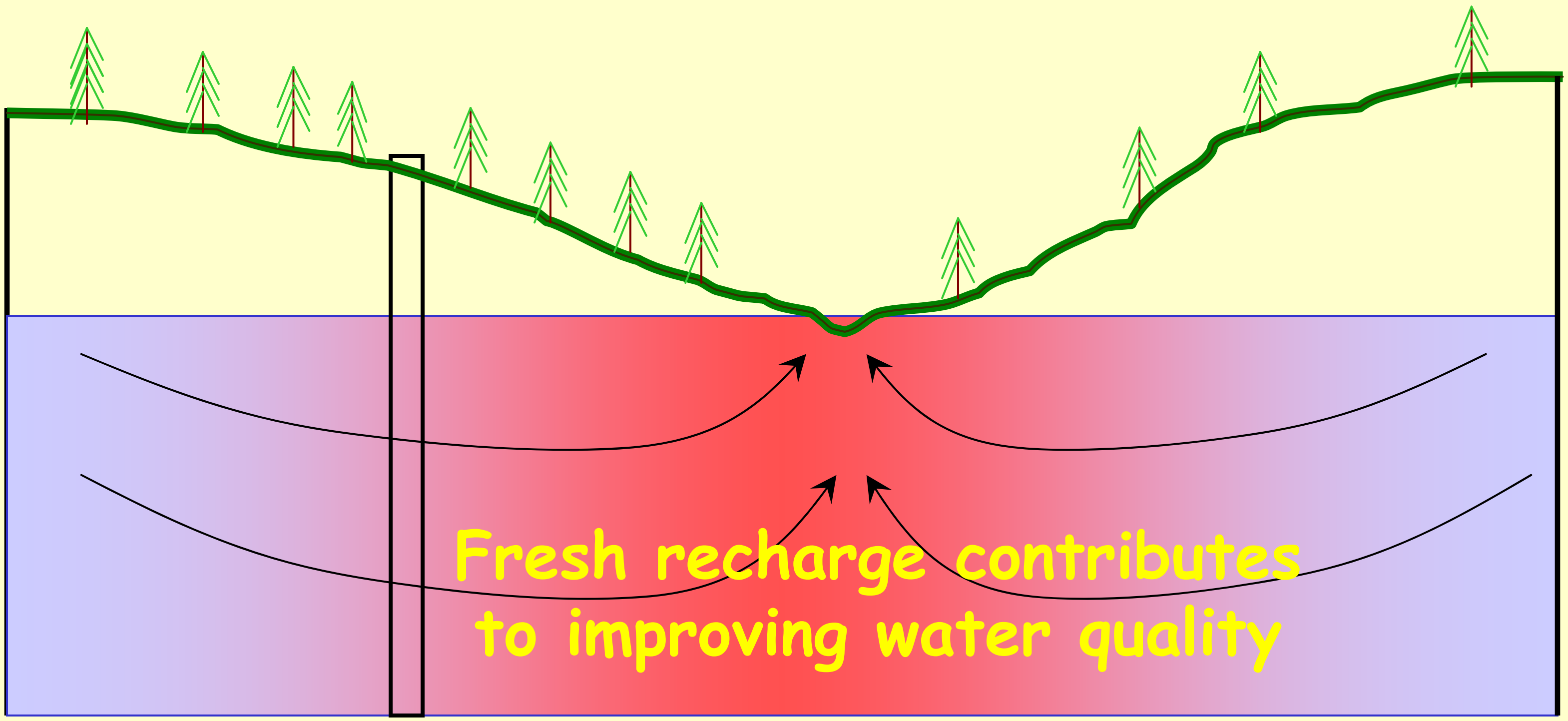
Golden* rules:

- The higher the pyritic S content, the worse will be the pollution
- Pyritic S highest in marine-influenced strata

* Golden: as in 'Fool's Gold'

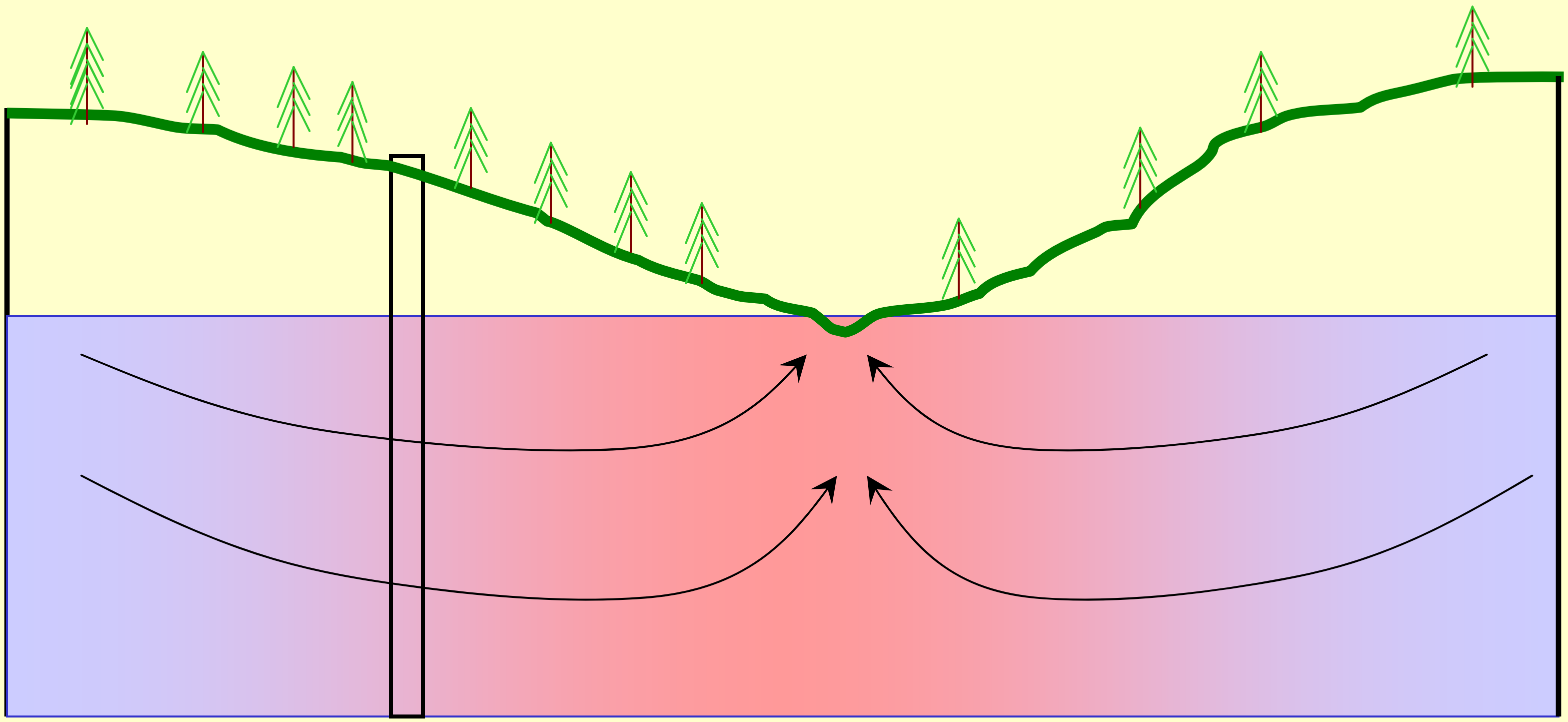
Underground Coal Mine Post-closure Rebound

7. All is not lost: the first flush



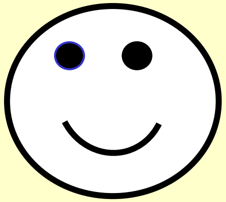
Underground Coal Mine Post-closure Rebound

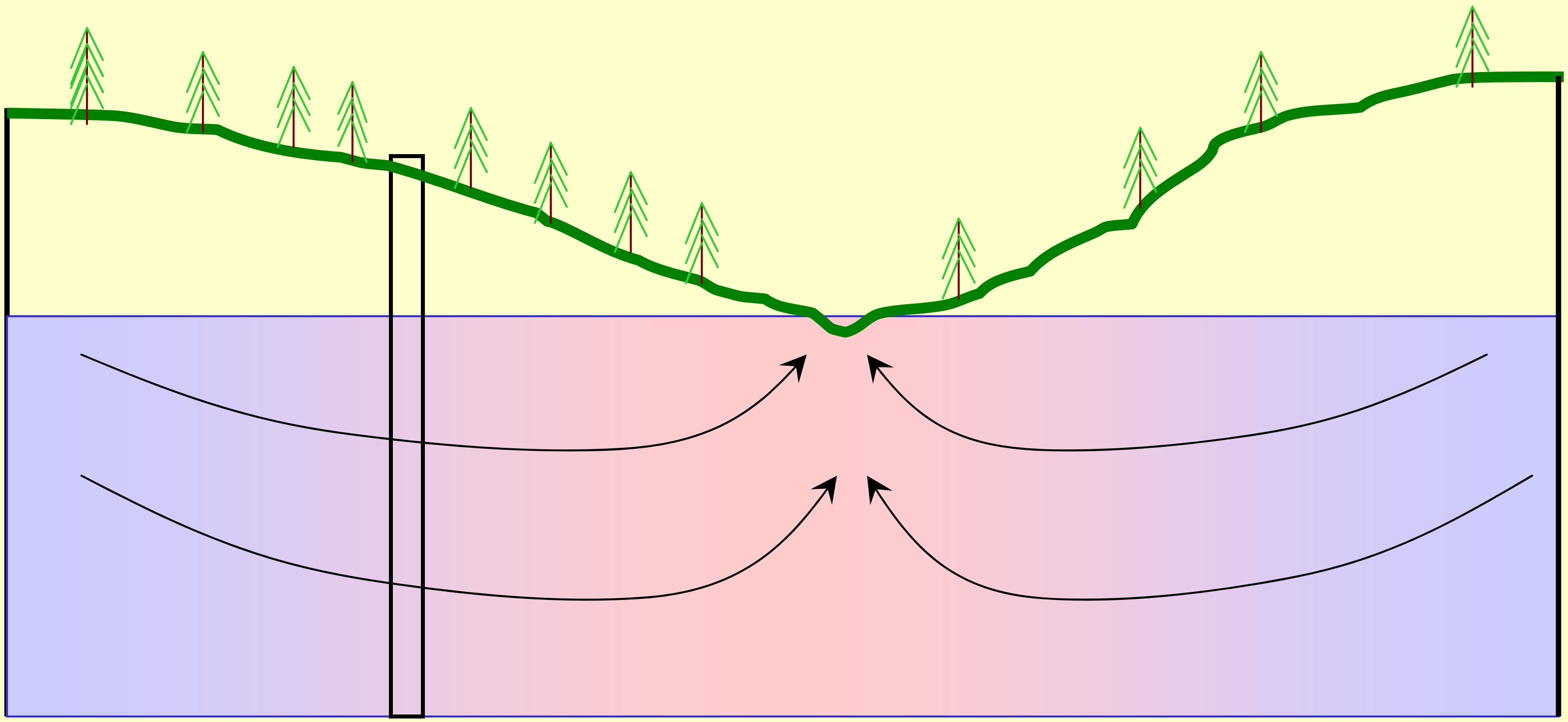
8. Gradual water quality improvement



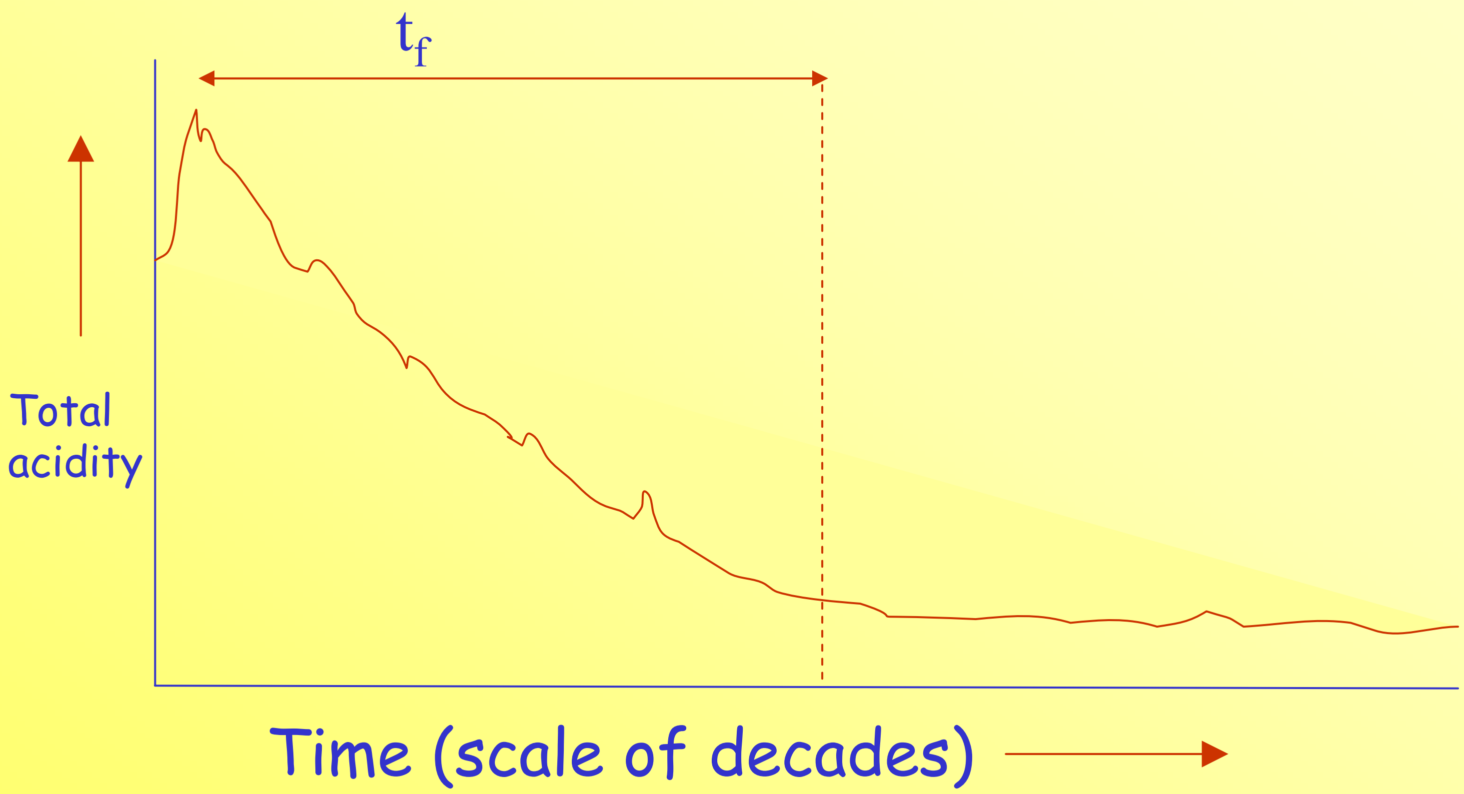
Underground Coal Mine Post-closure Rebound

9. End of first flush





The 'first flush'

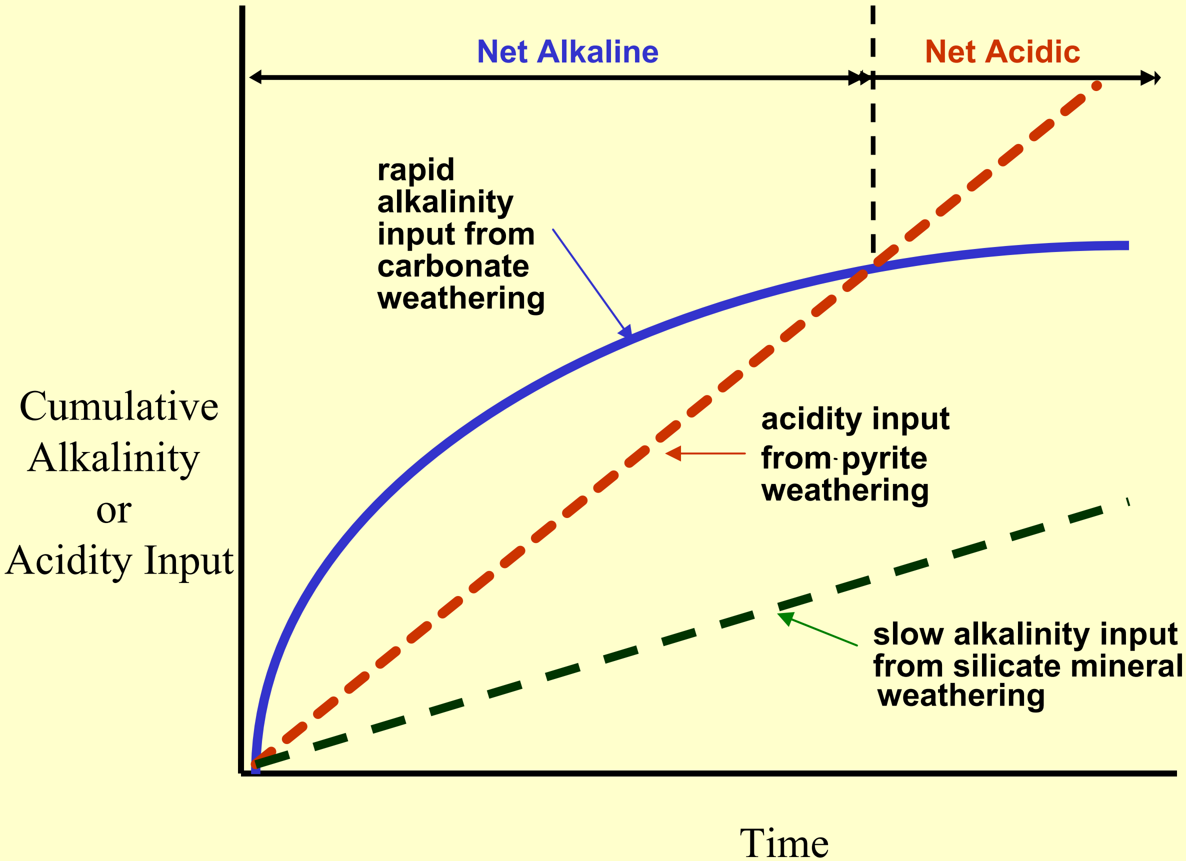


See: ***J. Contam. Hydrol.*** **44: 47 - 69 (2000)**

Beyond the first flush …

- A long-term handicap race:
  - Sulfides only oxidise significantly above water table; silicates and carbonates dissolve above and below water table
  - Kinetics of weathering are also unequal:

    carbonates > sulfides > silicates
  - Relative proportions of sulfides versus carbonates / silicates weathering determines long-term post-flush quality
  - This in turn depends primarily on mineralogy and hydrology of the system in question



- Initially, carbonate (e.g. ankerite) weathering is brisk, providing much alkalinity
- Later, depletion of carbonates leads to pH drop as water becomes acidic
- Eventually, pyrite will be depleted and water becomes alkaline again due to sustained silicate weathering

UNIVERSITY OF NEWCASTLE

ires
Institute for Research on Environment & Sustainability

After the first flush: Bardon Mill Colliery 40 years after closure

HERO Hydrogeochemical Engineering Research & Outreach

THE QUEEN'S ANNIVERSARY PRIZES
FOR HIGHER AND FURTHER EDUCATION
2005

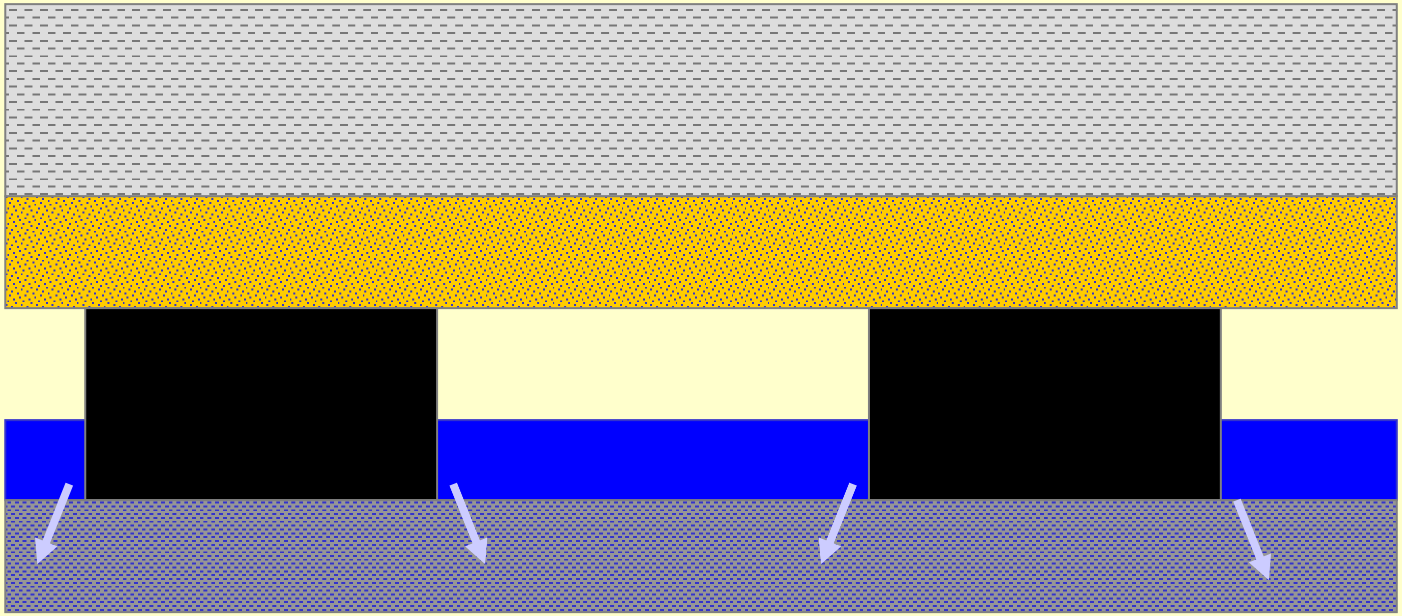
Rising mine waters and reactivation of subsidence

- At least three mechanisms identified:
  - weakening of the floors (and roofs) of mine voids as certain types of strata respond to wetting
  - direct erosion of mine voids etc by rapidly-flowing mine water / pressurised gas
  - reactivation of previously-dormant faults which are intersected by old mine workings subject to recent flooding for the first time

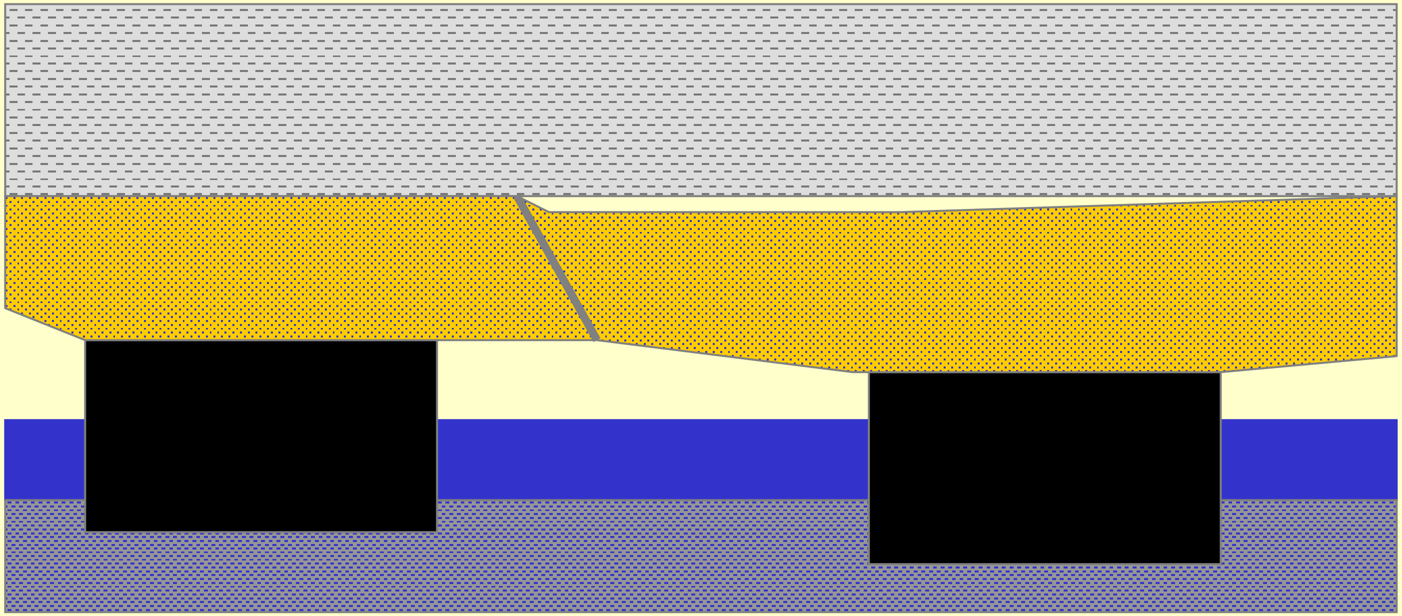
Wetting weakens roof / floor strata and backfill

- Most likely in seat-earths of coal sequences (though also possible in other lithologies)
- Can lead to crown-hole collapses, pseudo-karstification, enhanced groundwater recharge
- More subtle large-scale features (e.g. enhanced settlement of longwall goaf) can form enclosed basins hosting new ponds

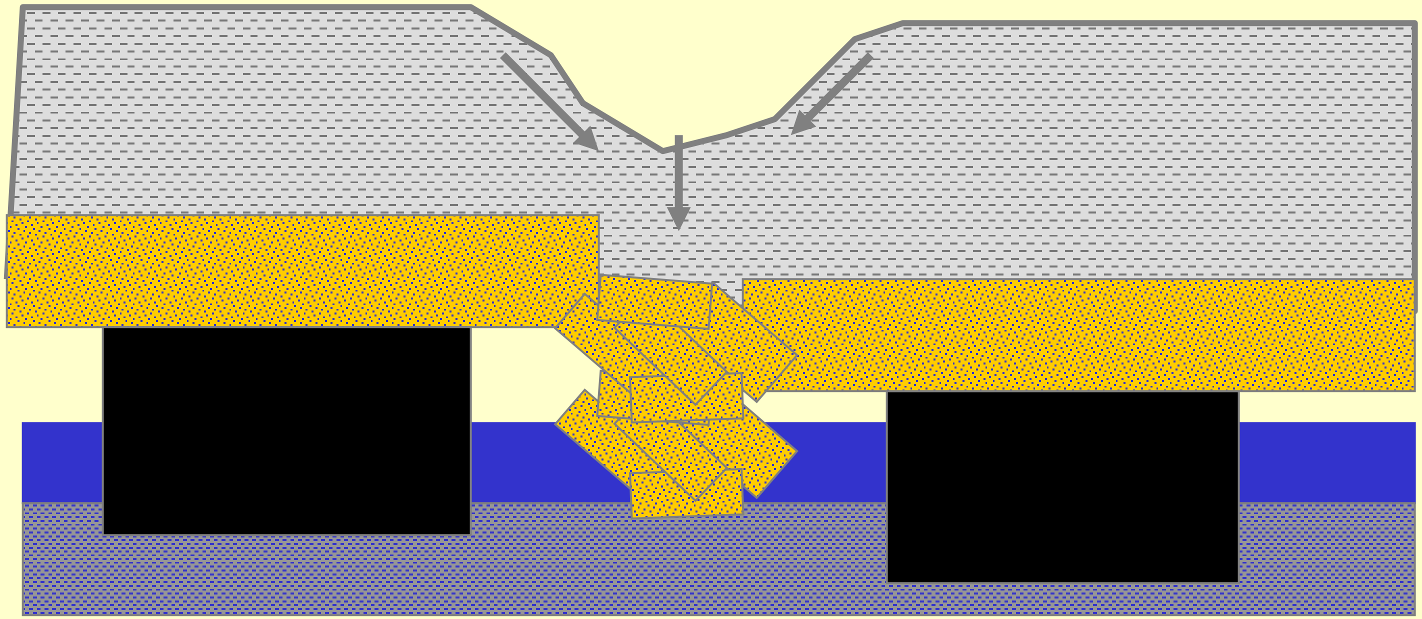
Slaking and pillar failure in old workings



Slaking and pillar failure in old workings



Slaking and pillar failure in old workings



Failures ascribed to wetting-induced settlement - I

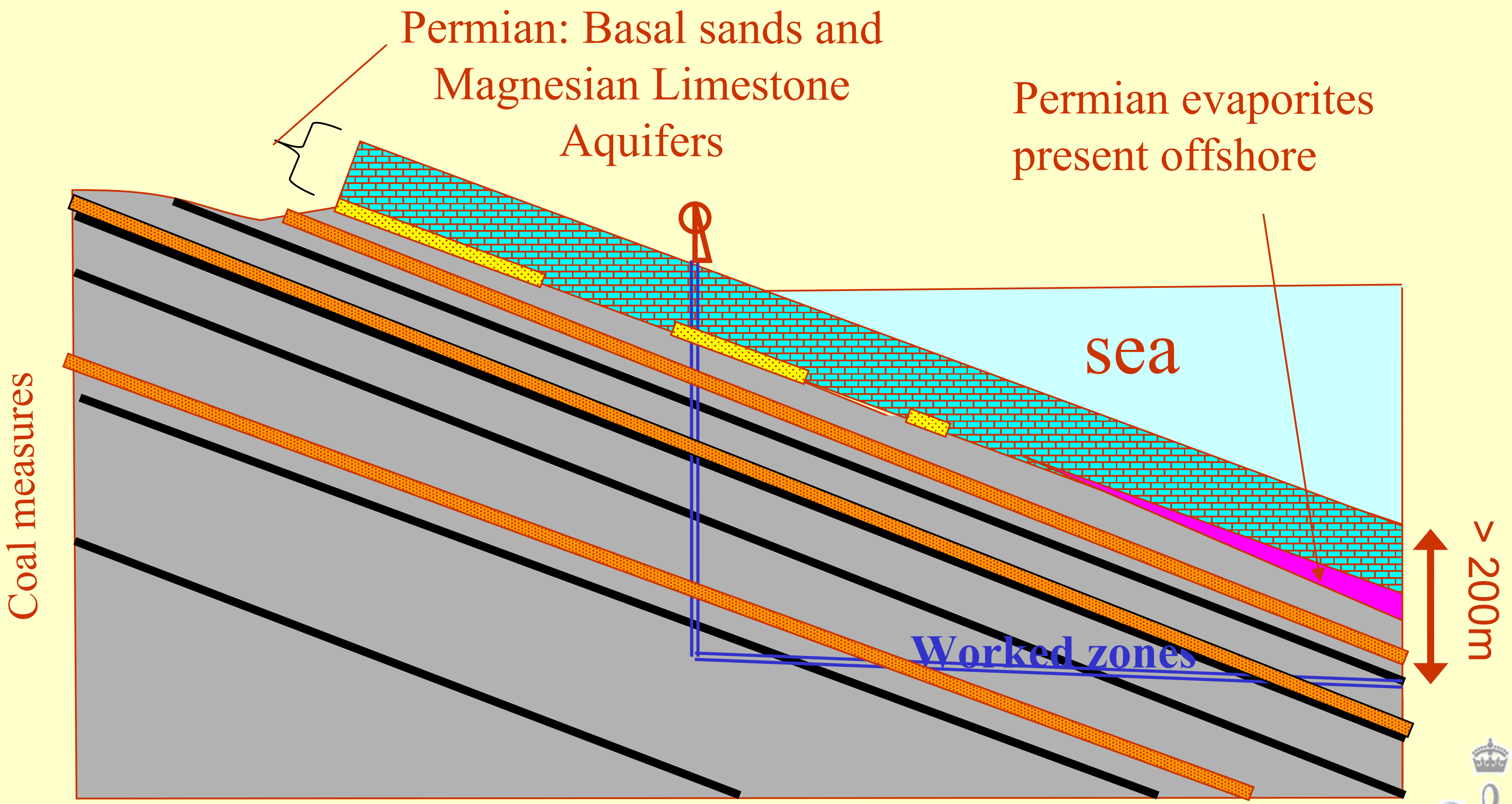
Failures ascribed to wetting-induced settlement - II

Near UK's main N-S trunk road and Europe's largest indoor mall (Metro Centre), May 2002

UNIVERSITY OF NEWCASTLE

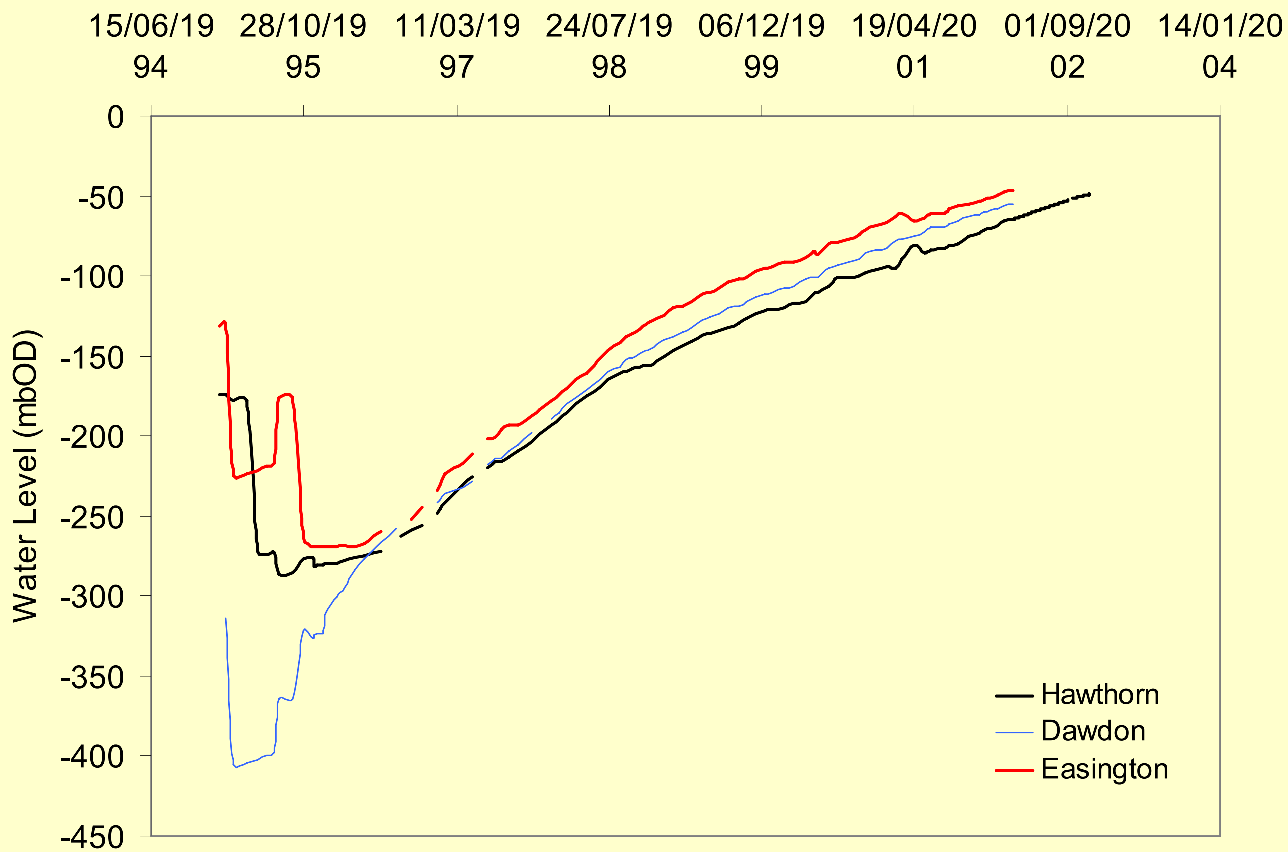
ires Institute for Research on Environment & Sustainability

Simplified geological cross-section: Durham Coalfield



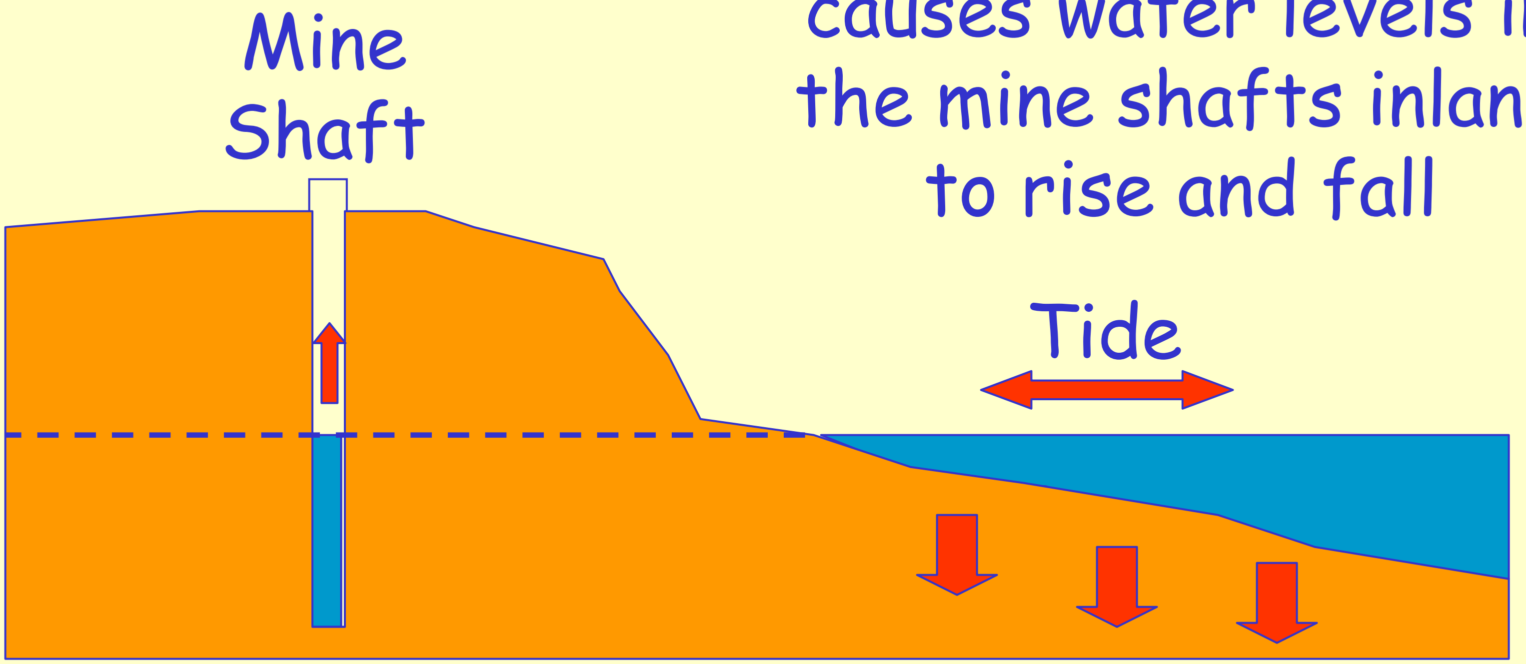
The Queen's Anniversary Prizes For Higher and Further Education 2005

Mine water recovery in E. Durham

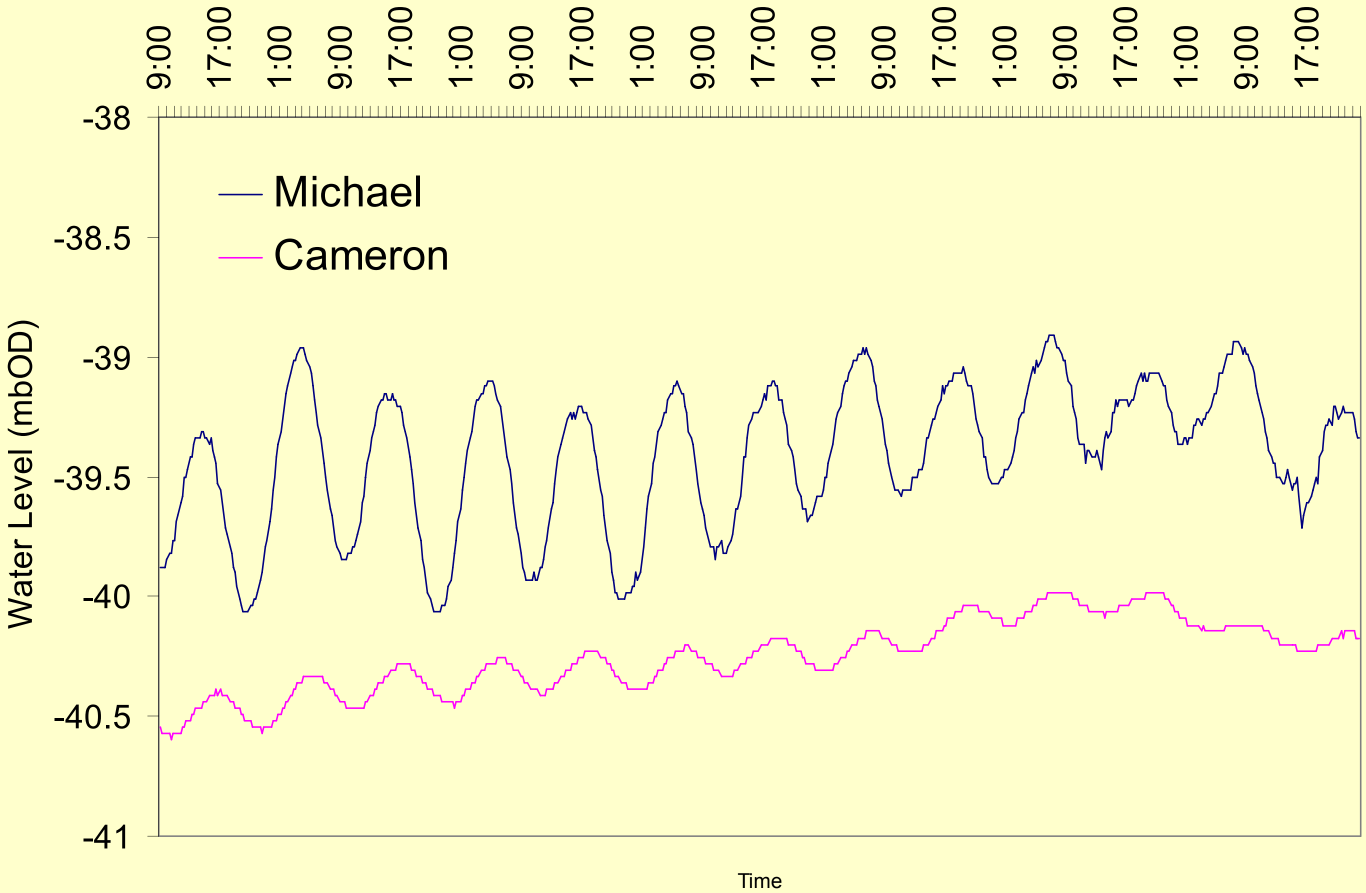


Tidal loading and piezometry

Compression of strata due to tidal loading causes water levels in the mine shafts inland to rise and fall



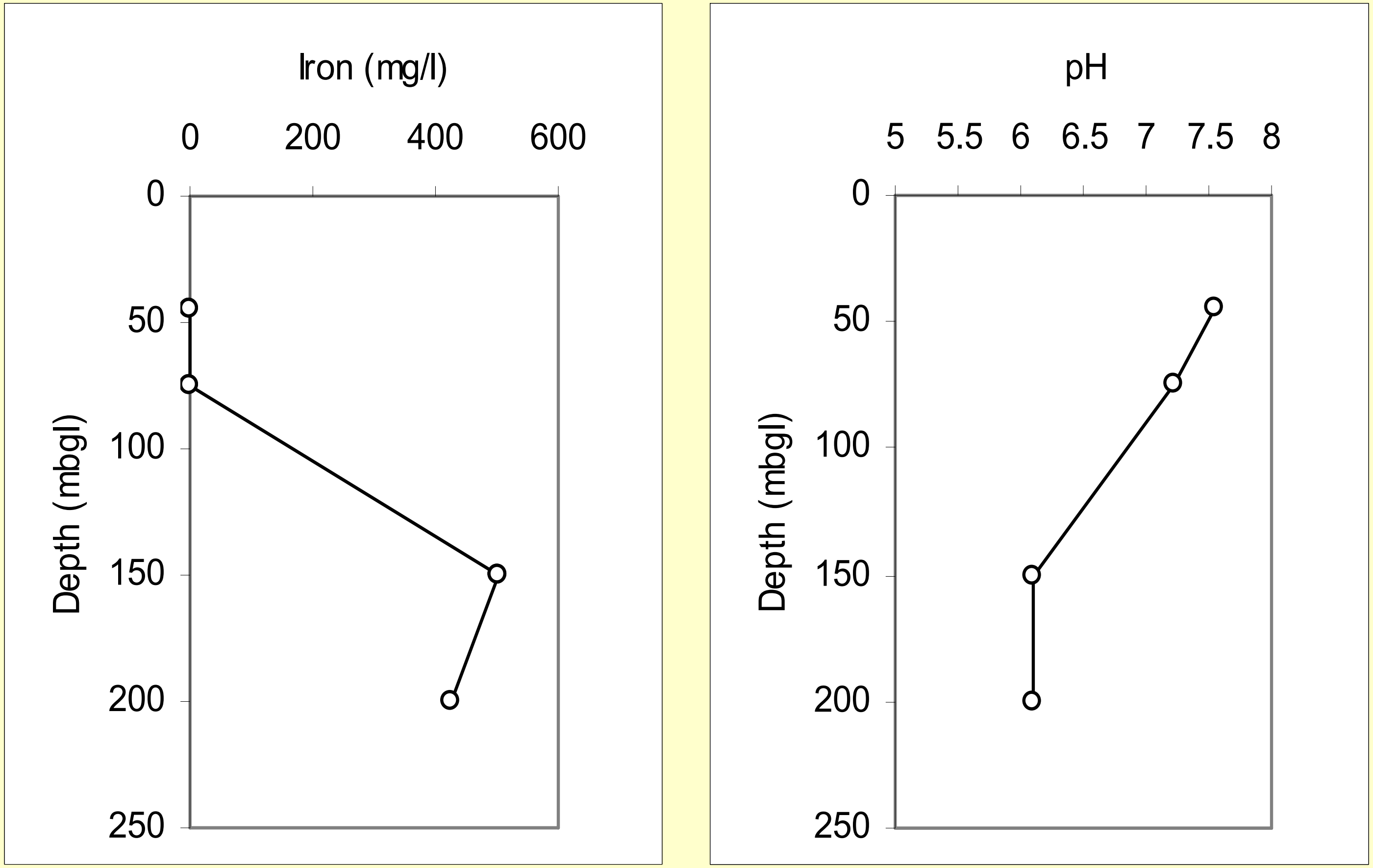
Example data - tidal loading



HERO

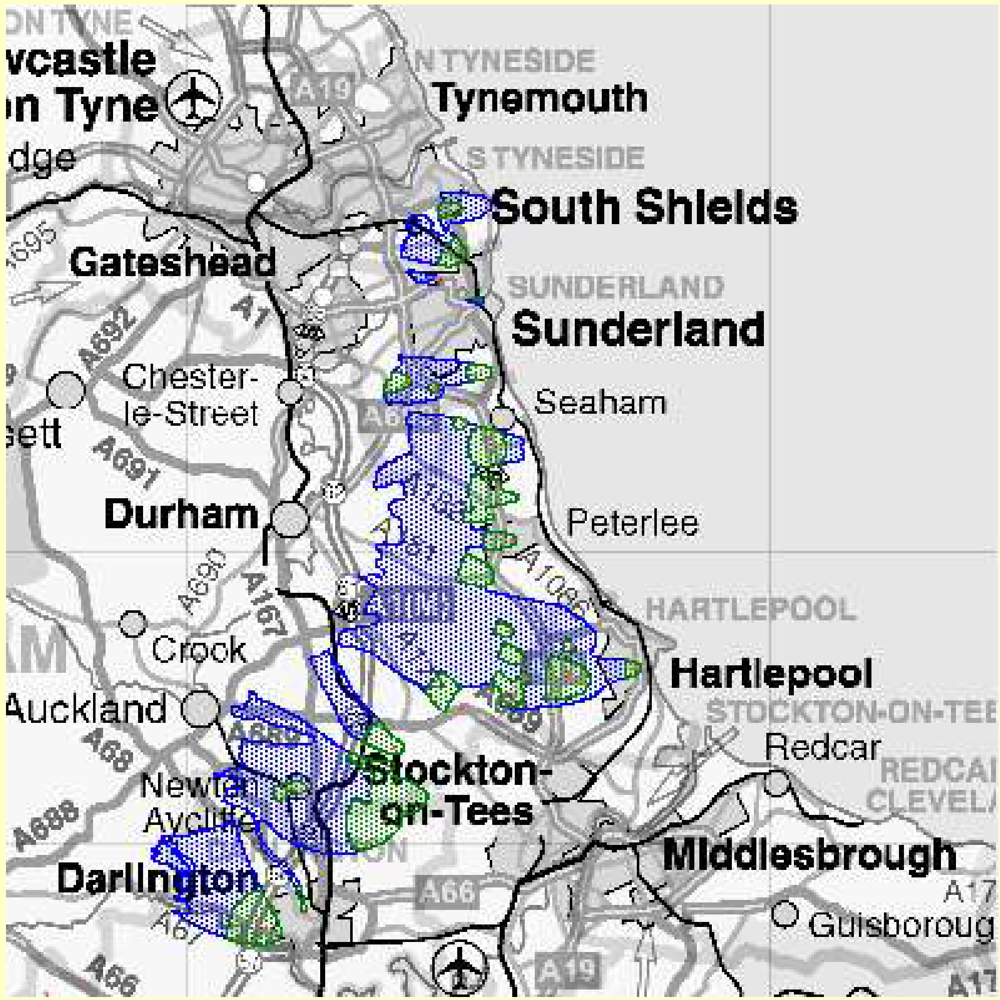
Amplitude of oscillation damped with increasing distance inland

Hydrochemical stratification

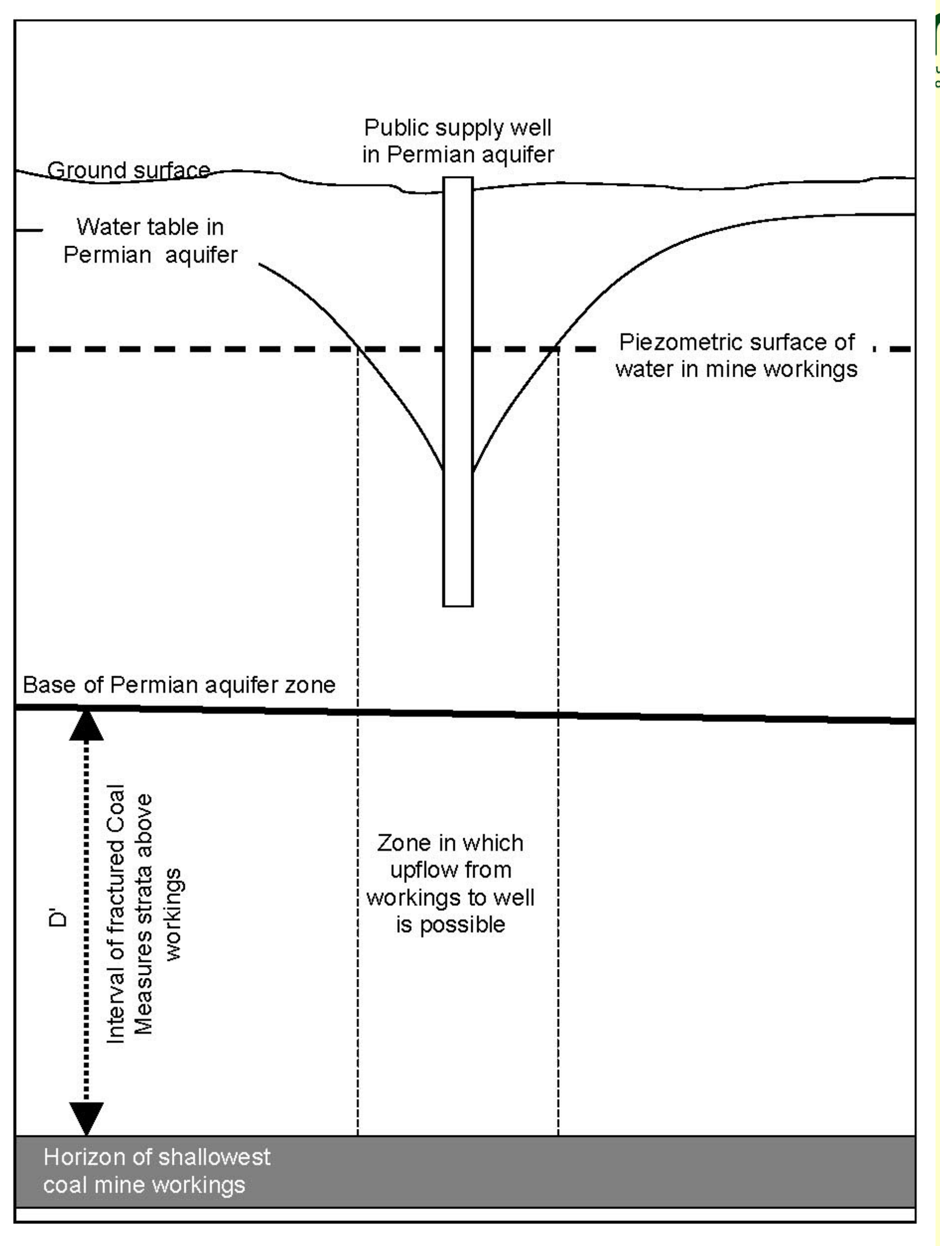


It is important to know what lies at depth before planning for post-rebound period …

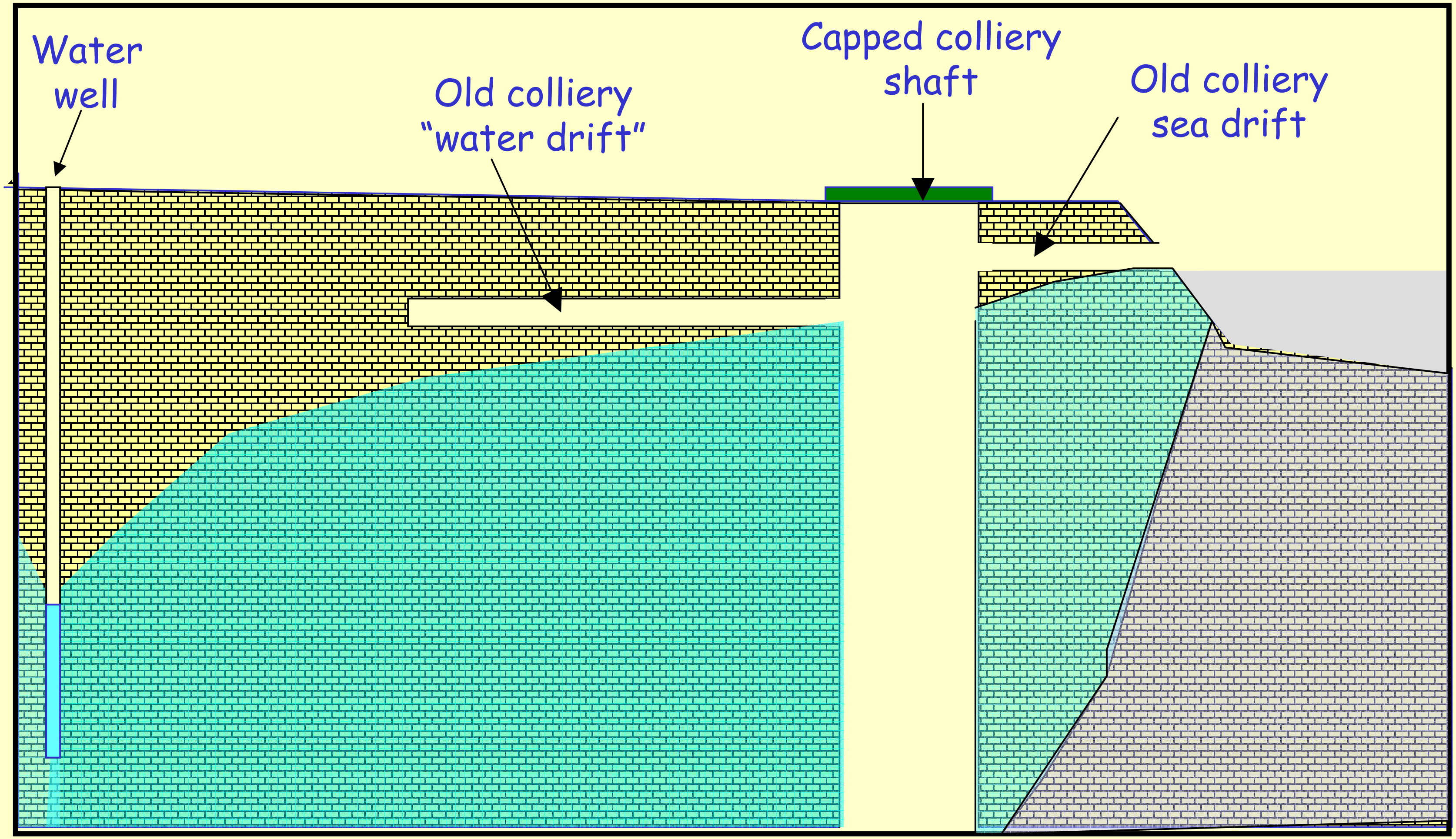
Groundwater source protection zones in East Durham area



Leakage pathway threat to wells in Permian (Magnesian Limestone) aquifer



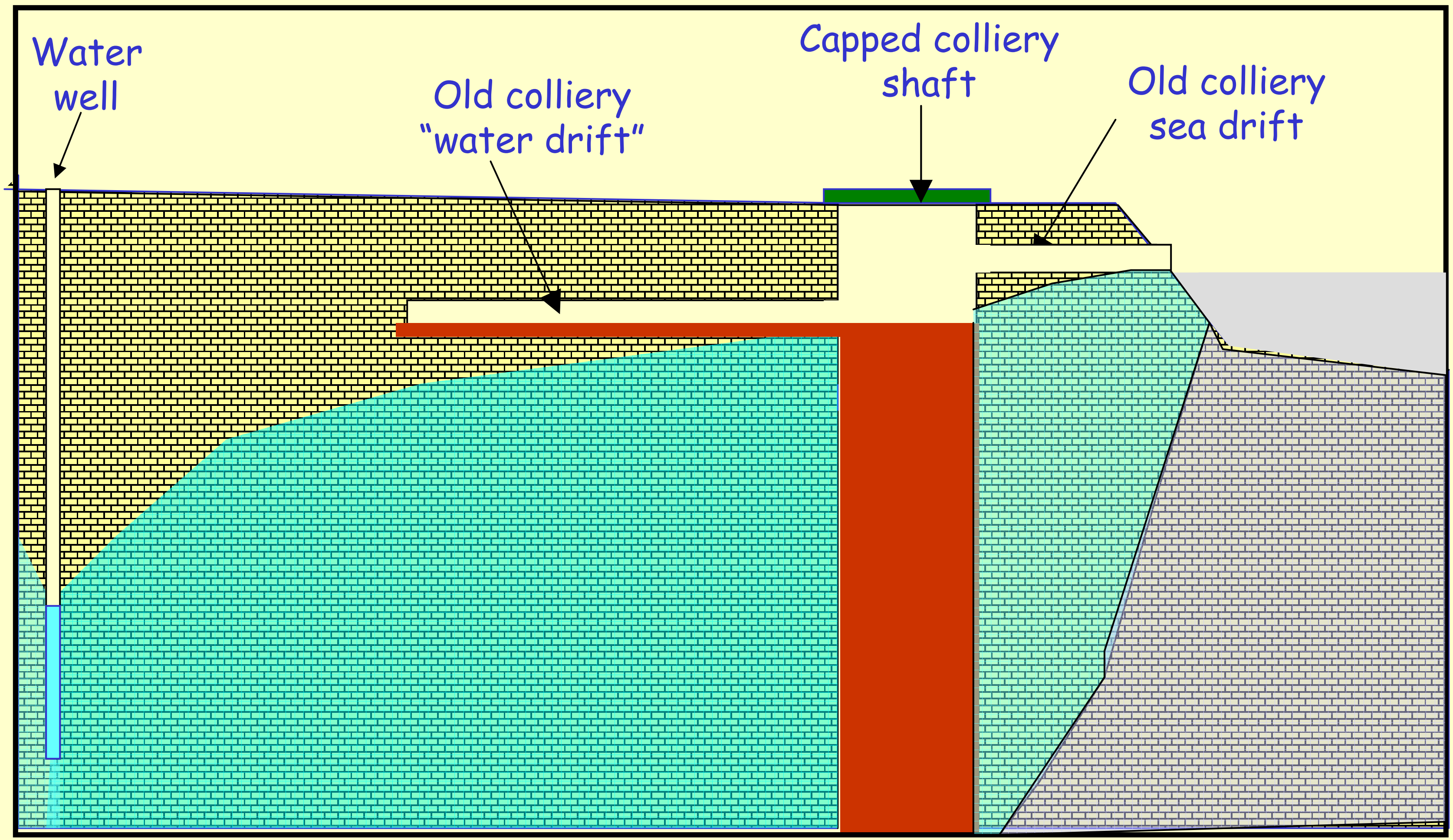
Water drifts pollution pathway - I



UNIVERSITY OF NEWCASTLE

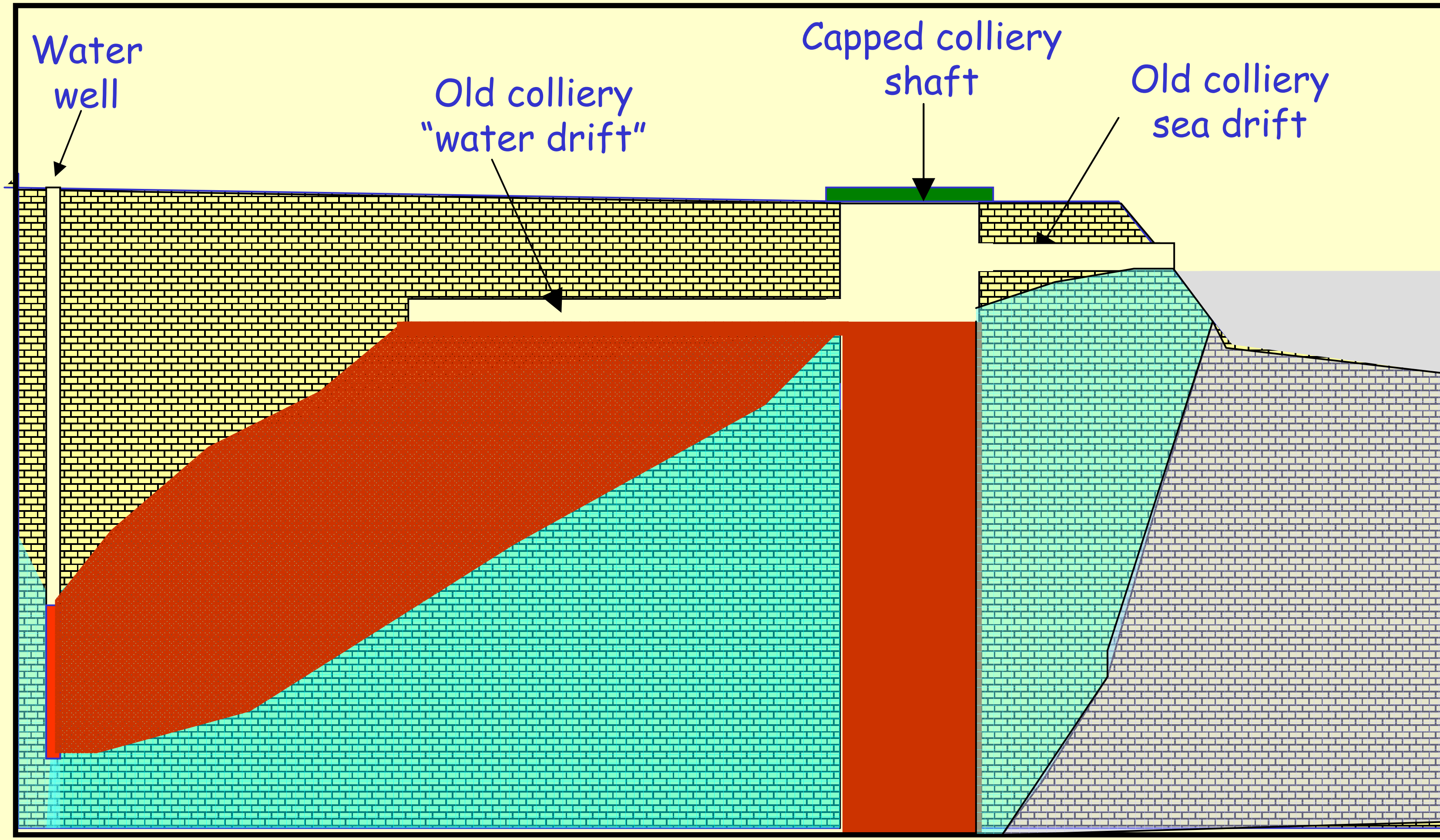
ires
Institute for Research on Environment & Sustainability

Water drifts pollution pathway - II

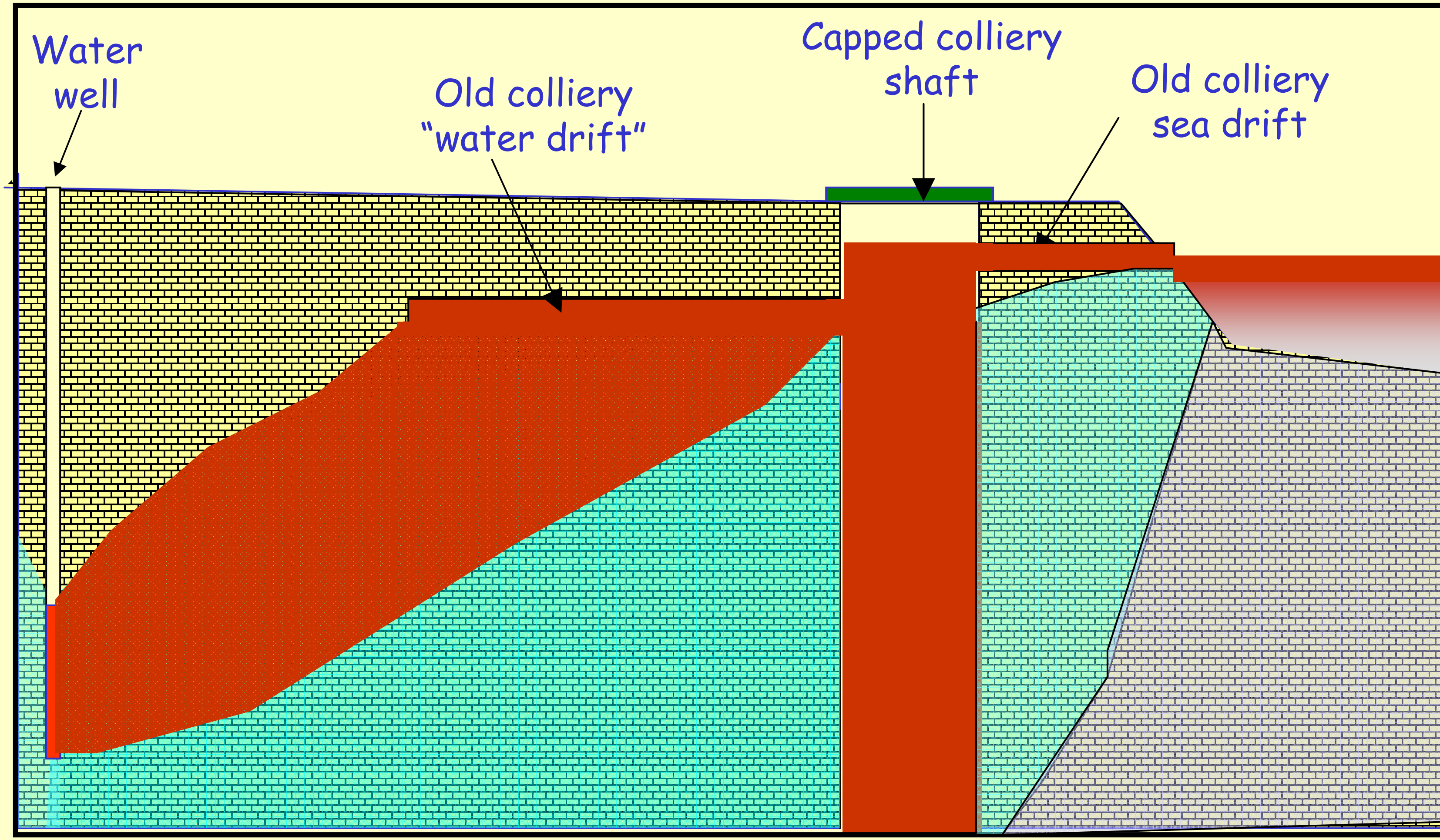


THE QUEEN'S ANNIVERSARY PRIZES
FOR HIGHER AND FURTHER EDUCATION
2005

Water drifts pollution pathway - III



Water drifts pollution pathway - IV



Predicting post-closure changes: rationale and specification

- Rationale: *to clarify whether a pollution prevention scheme will be needed post-rebound, and if so to provide site-specific design criteria*

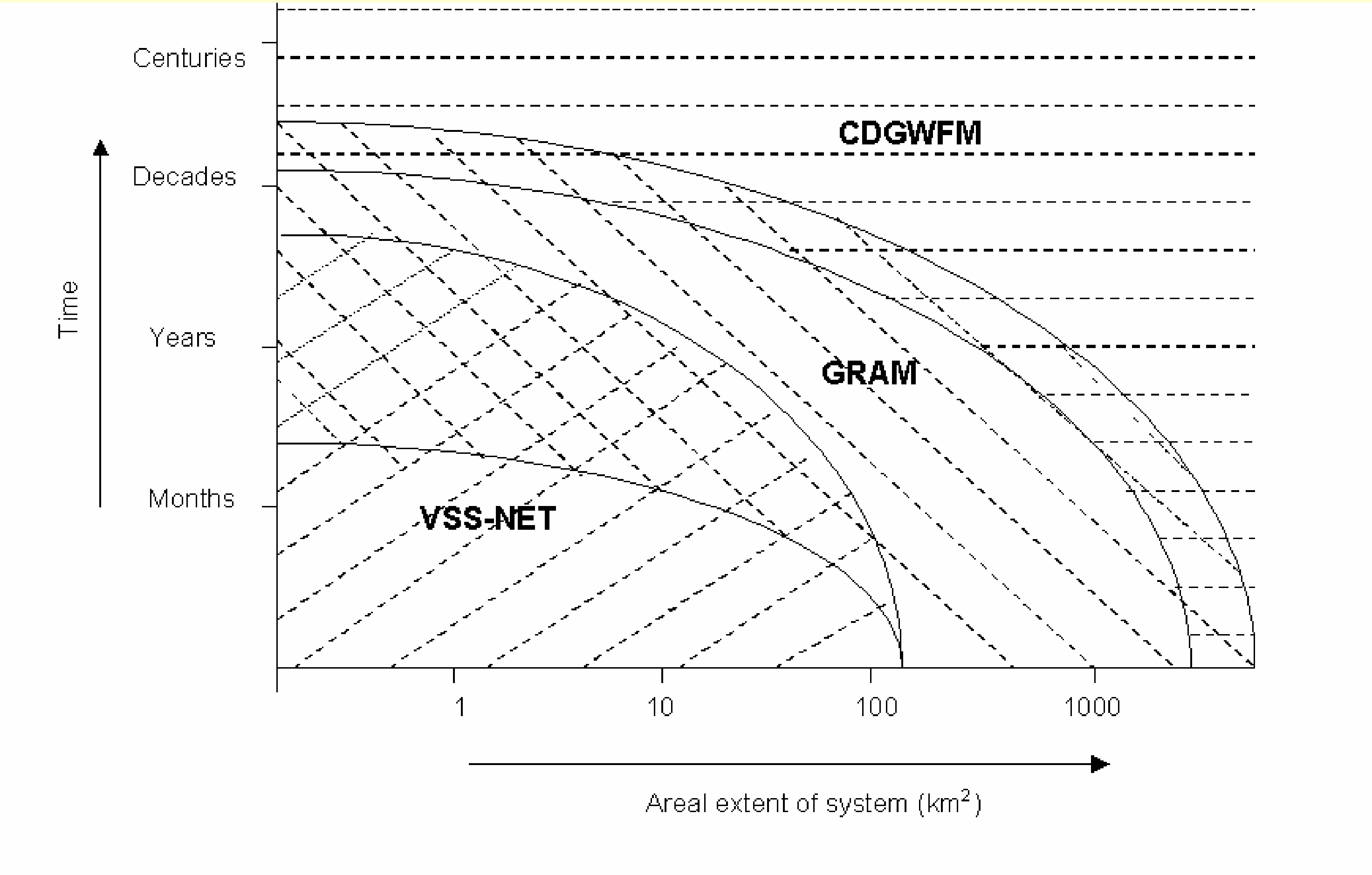
- Necessary predictions:
  1. Hydrological predictions:
     - Timing of rebound to surface
     - Likely outflow rates after rebound
  2. Geochemical predictions:
     - Likely quality of water post-rebound

Hydrological prediction tools*

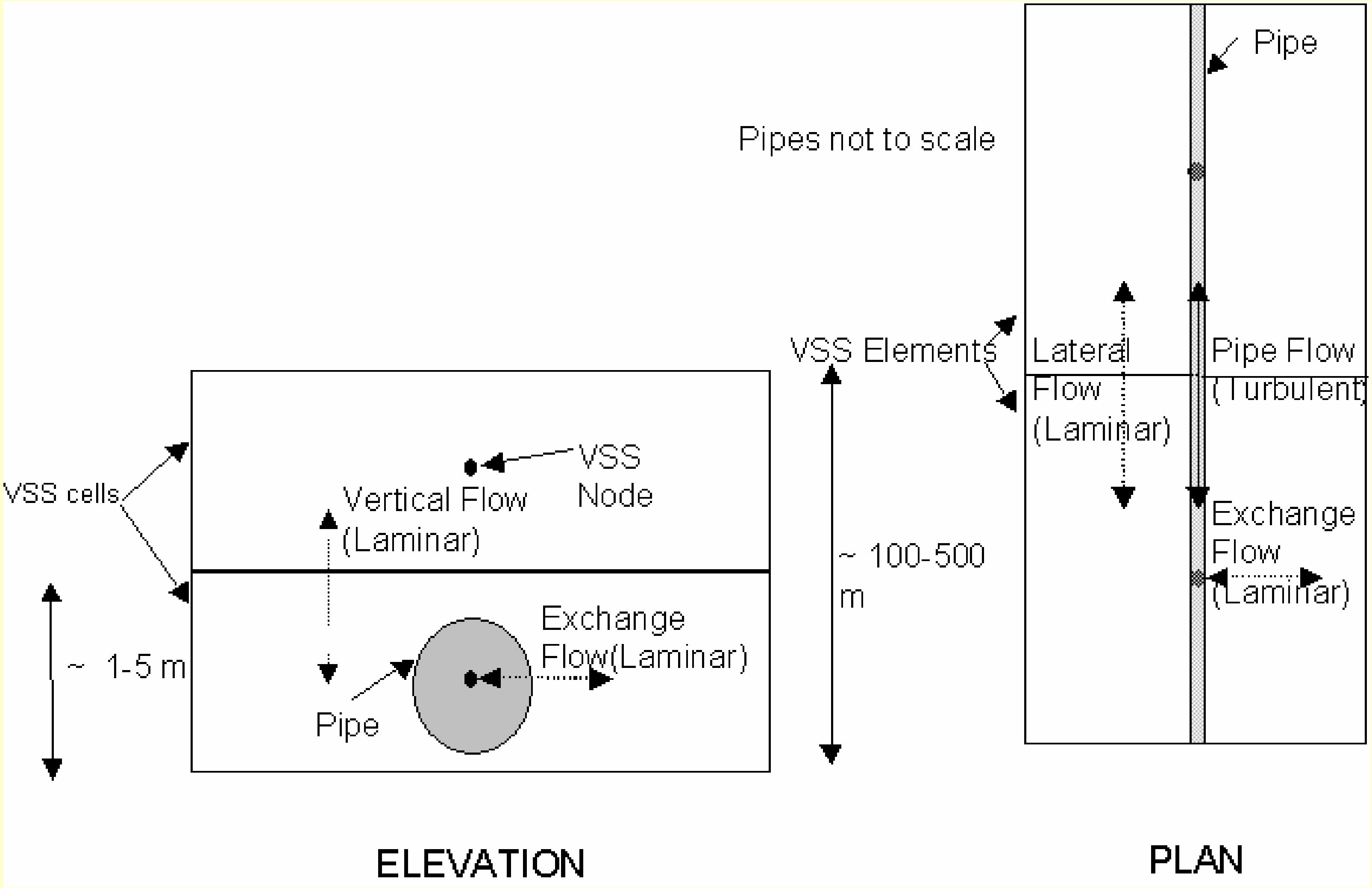
- Range of modelling tools for a range of scales:
  - GRAM (Groundwater Rebound in Abandoned Mineworkings):
    - semi-distributed modelling approach
    - based on concept of mine pools and decants
  - VSS-NET:
    - Physically-based, fully 3-D, variably saturated porous medium coupled to pipe network model representing major mine roadways / shafts etc
  - Conventional distributed groundwater flow models:
    - Usable at scales at which effects of major mined flow-path features cannot (need not) be resolved

*** See: Adams & Younger, *Ground Water* : 39: 249 – 261 (2001)**

Hydrological prediction tools: choose to suit scale

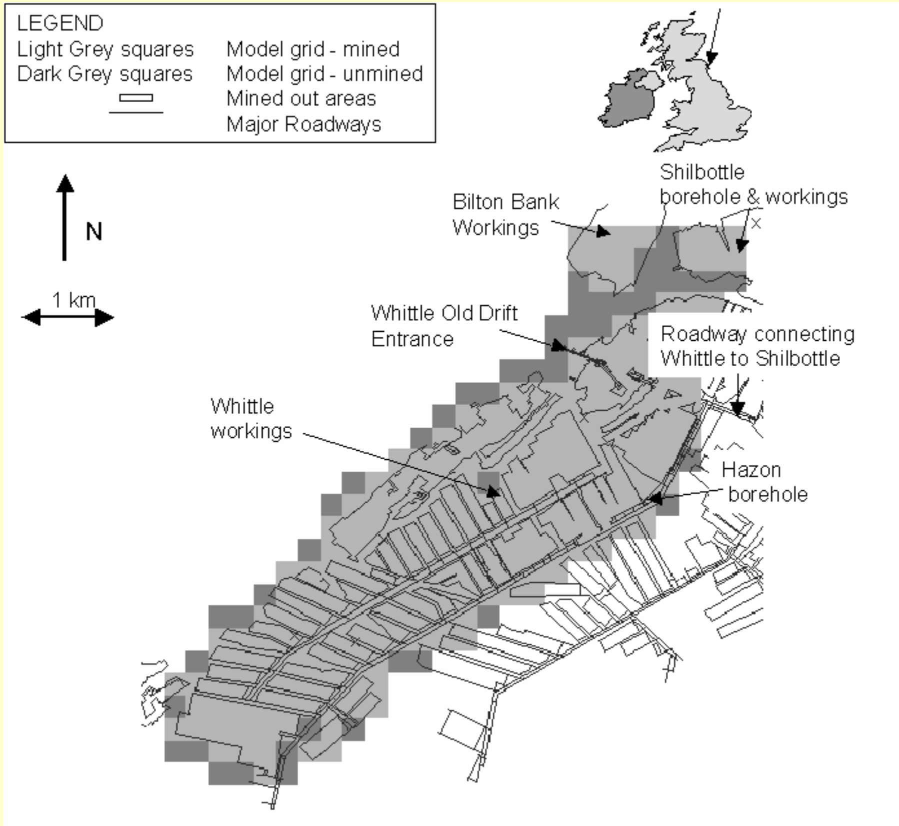


VSS-NET


Pipes not to scale
Pipe
VSS Elements
Lateral Flow (Laminar)
Pipe Flow (Turbulent)
Exchange Flow (Laminar)
~ 100-500 m
VSS cells
VSS Node
Vertical Flow (Laminar)
Exchange Flow(Laminar)
Pipe
~ 1-5 m
ELEVATION
PLAN

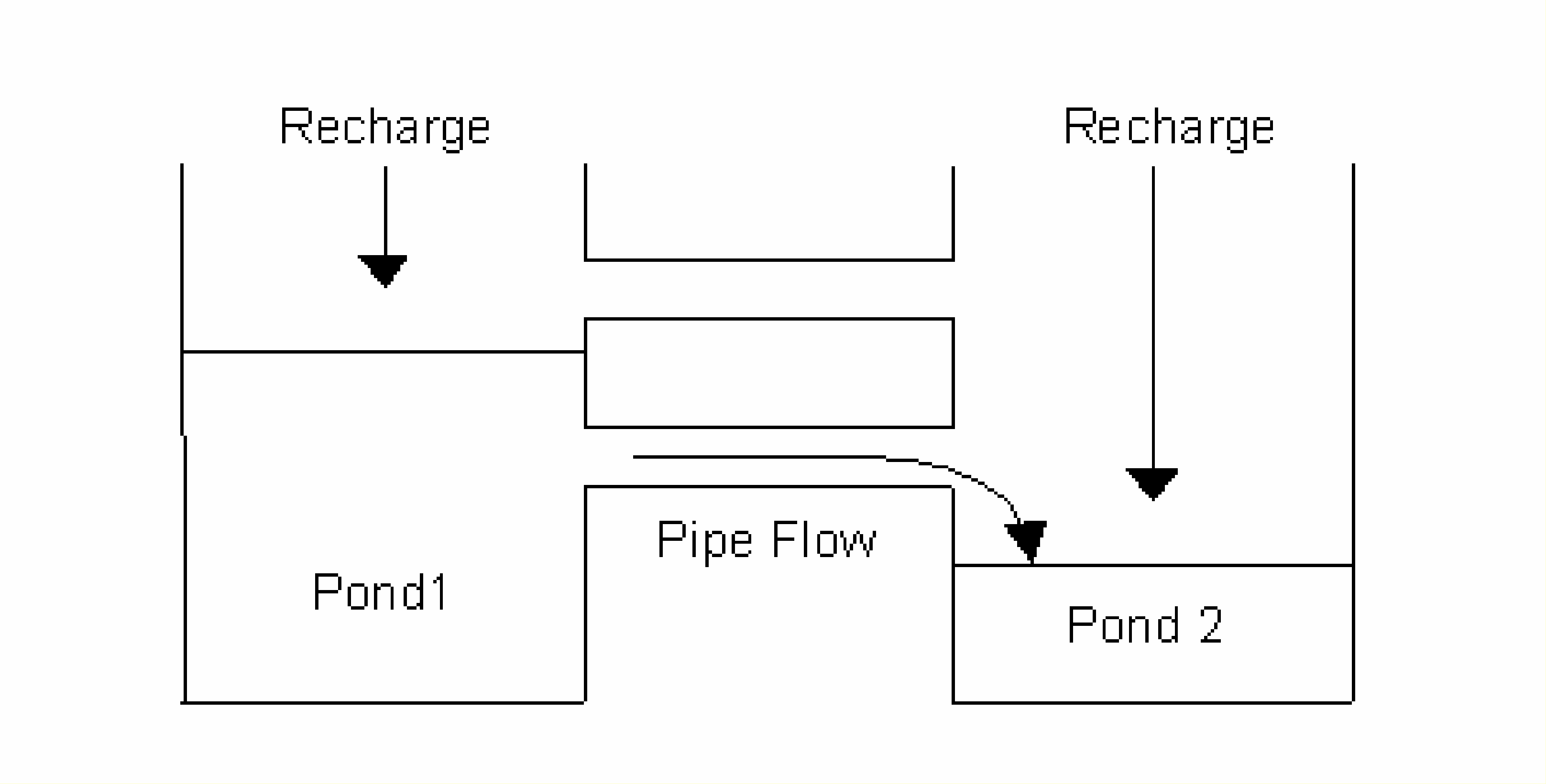
VSS-NET:

example application – Whittle Colliery, Northumberland

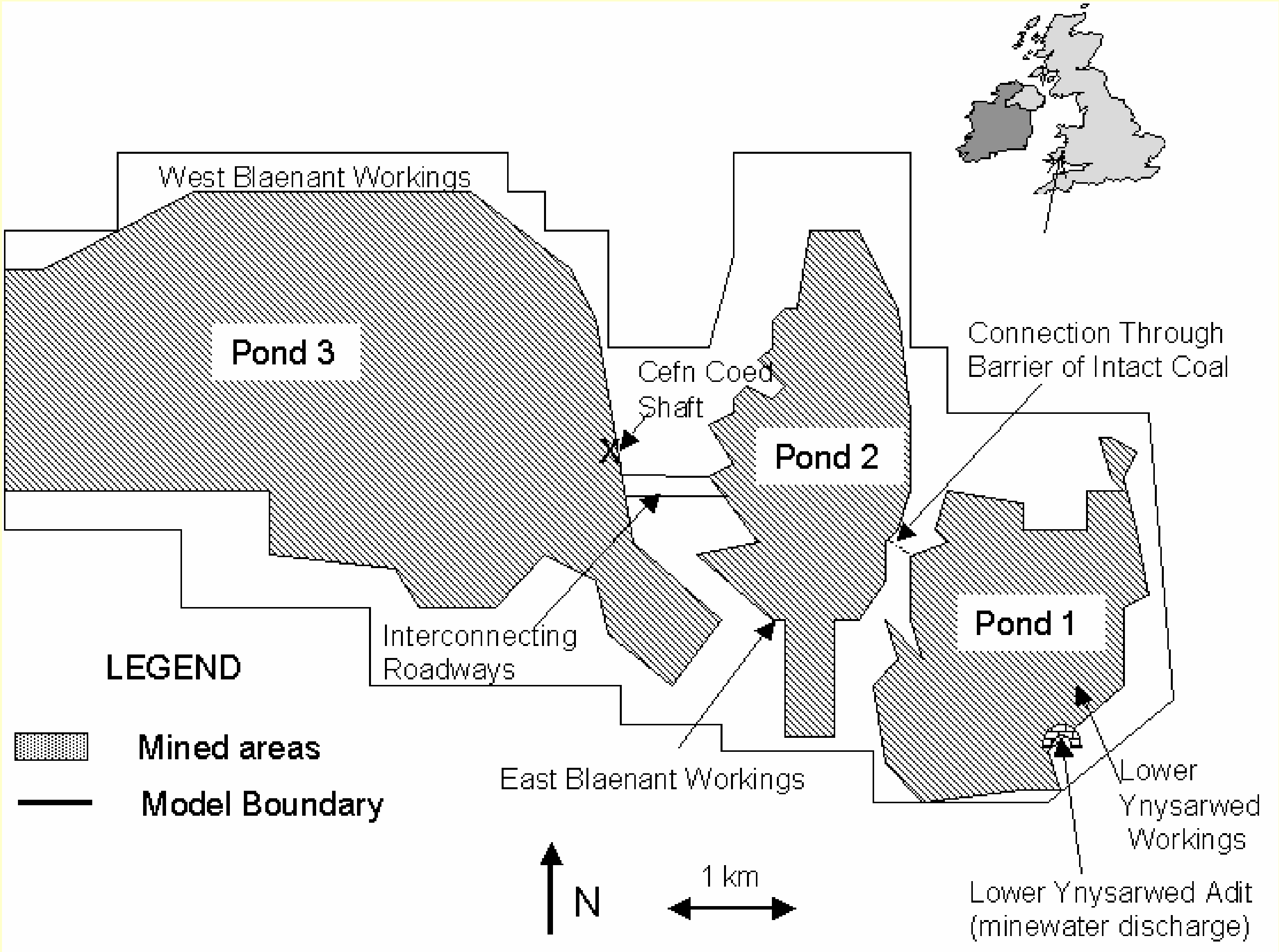


- Post-audit (in 2004) of 1998 VSS-NET predictions
  - Completion of rebound to 50mAOD:
    - Predicted: May 2002
    - Observed: May 2002
  - Median post-rebound flow rate:
    - Predicted: 1.7 Ml/d
    - Observed (2002 – 2006): 1.7 Ml/d

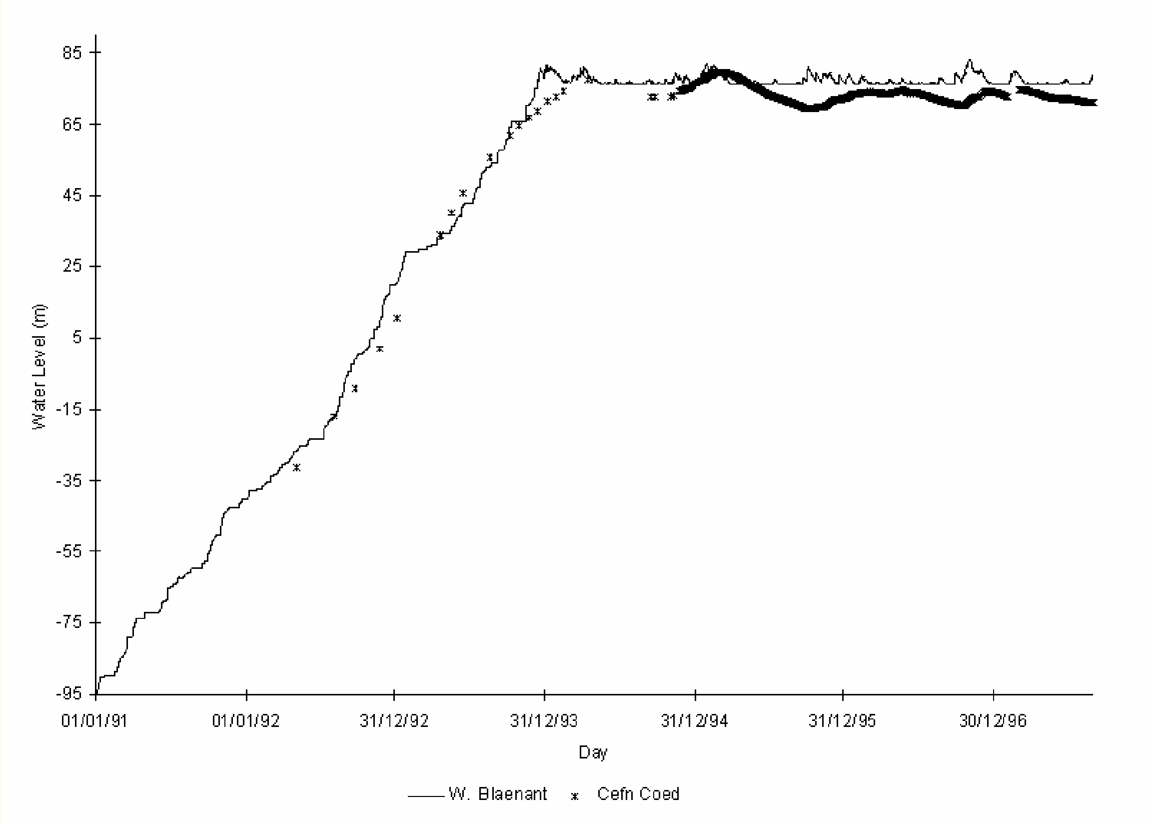
GRAM



GRAM: example application – Blaenant Colliery, S Wales. I. Pond definition



GRAM: example application – Blaenant Colliery, S Wales. II. Predicted vs observed rebound



Models of first flush

- Classic analytical approach – feasible but limited real-world applicability
- Full numerical modelling – notionally feasible, but given complex hydraulics would require enormous cpu time
- Empirical models – based on hydrological principles; easy to use

Analytical Model of First Flush – Modified Sauty Solution to ADE

- $C(t) = 0.5\, C_o\, [\mathrm{erfc}(\{L - v_a\, t_w\}/\{2(Dt_w)^{0.5}\}] + C_a$
- Where:

  $C(t)$ = concentration at outflow from mine at time t (i.e. the elapsed time since the mine began to overflow)

  $C_o = C_p - C_a$

  C_p = peak concentration at start of first flush

  C_a = steady concentration at end of first flush

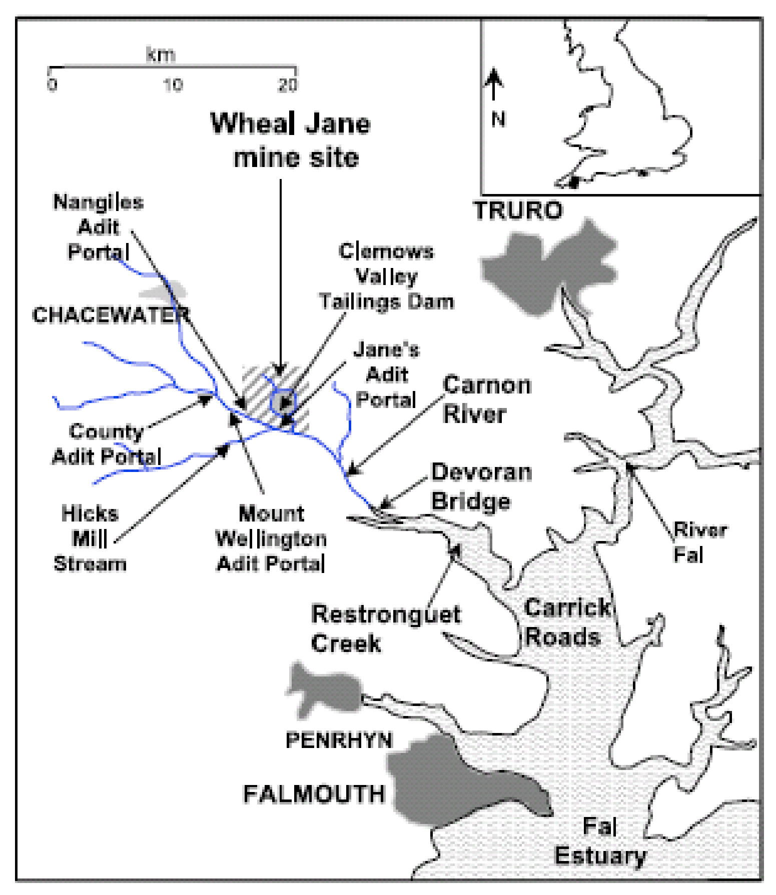
  v_a = average groundwater flow velocity within the mine system (L/T)

  t_w = "working time", the difference between the total length of the main flushing period (found on a trial-and-error basis) and time since overflow commenced

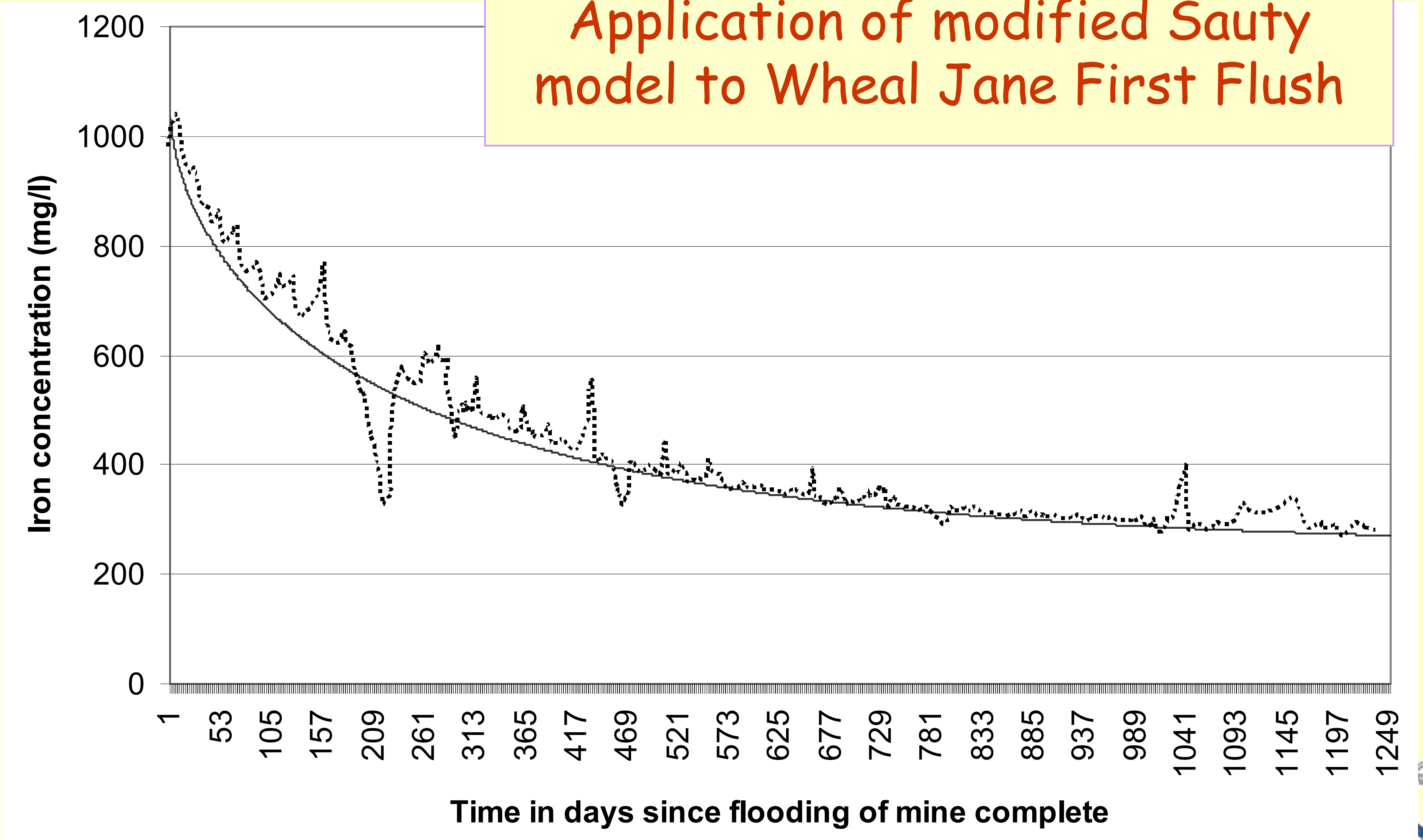
  D = longitudinal dispersion coefficient ($L^2.T^{-1}$)

  (erfc is the complementary error function)

Example application – Wheal Jane



Application of modified Sauty model to Wheal Jane First Flush



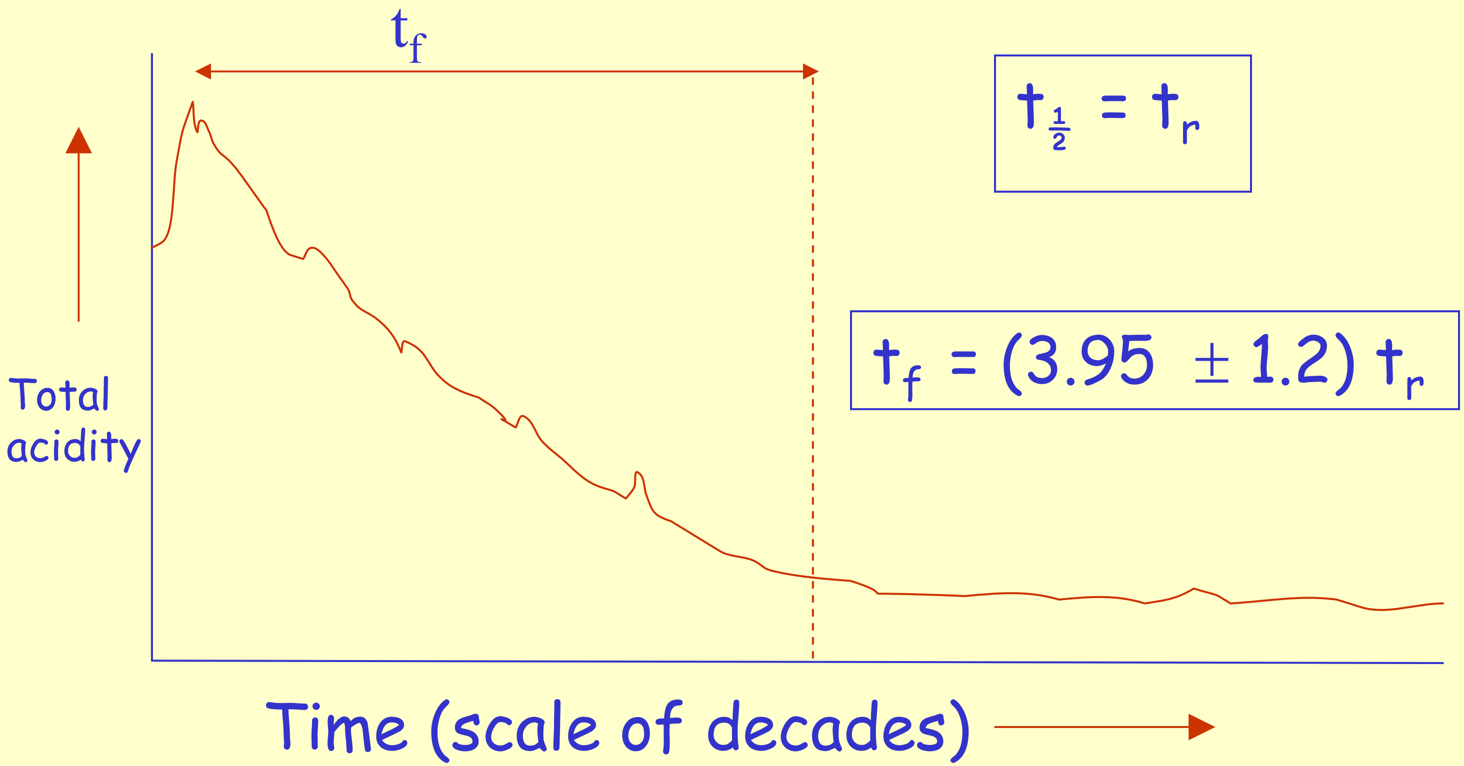
Empirical model for first flush

- Controls on first flush:

  Hydraulic turnover rate

  = F (total pore volume / rate of recharge)
- Closely resembles controls on rebound rate (notwithstanding loss of head-dependent mine water sources as water table rises)
- Observations since 1960s suggest exponential first-flush with half-life = duration of preceding rebound period

Empirical model for first flush



$$t_{\frac{1}{2}} = t_r$$

$$t_f = (3.95 \pm 1.2)\, t_r$$

(Jl. Contam. Hydrol., 44, pp 47 - 69 (2000))

Partial first flush model

- Found to be especially applicable to very large systems in which a large proportion of the workings lie down-gradient from the final surface decant / pumping point
- Where original model states:

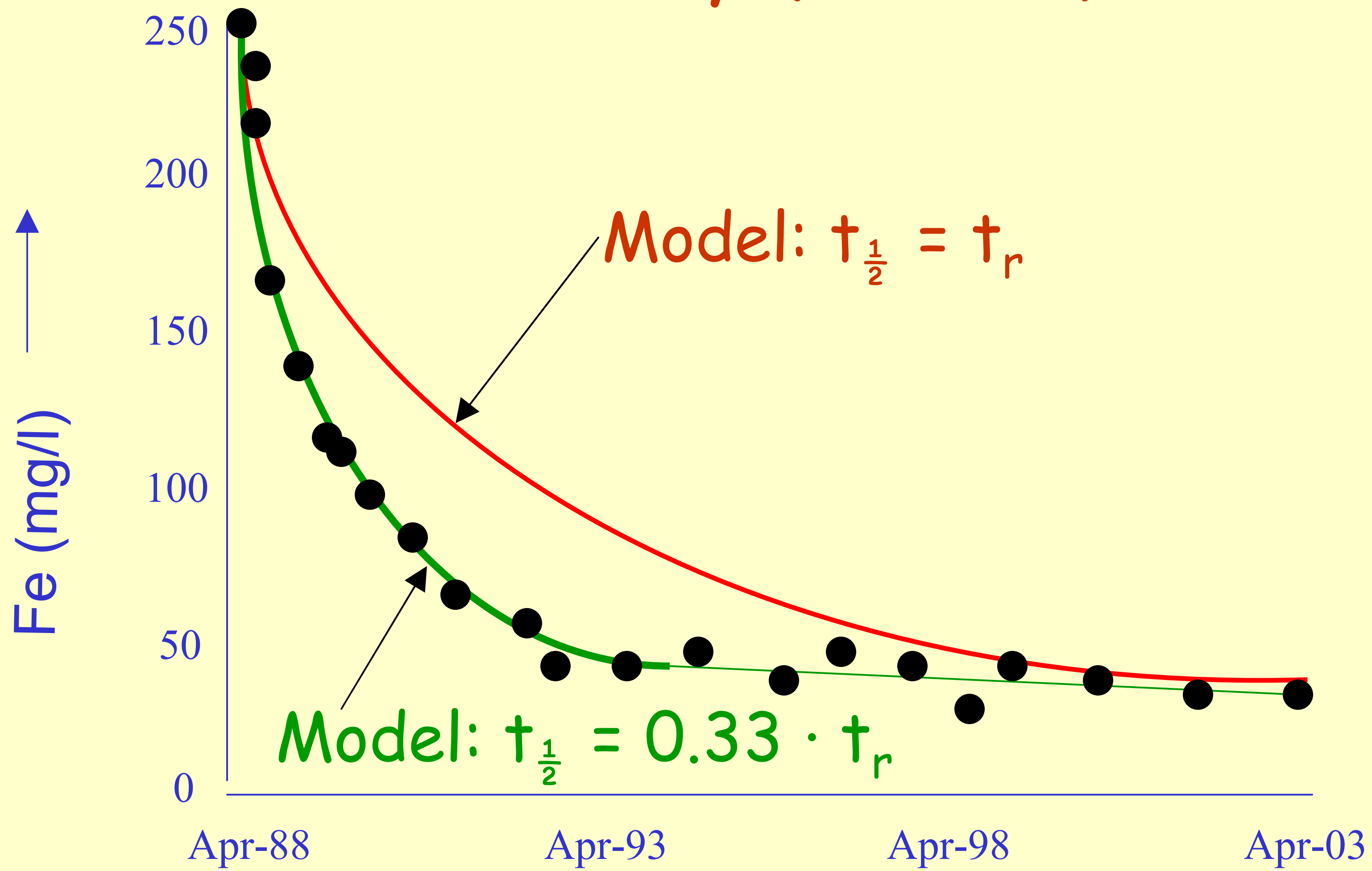
$$t_{\frac{1}{2}} = t_r$$

- Modified model is:

$$t_{\frac{1}{2}} = \nu \cdot t_r$$

where ν can range from 0.1 for very large 'dead-end' systems to 1 (i.e. original model)

Example: Fendue Lyon Colliery (France)



Conclusions

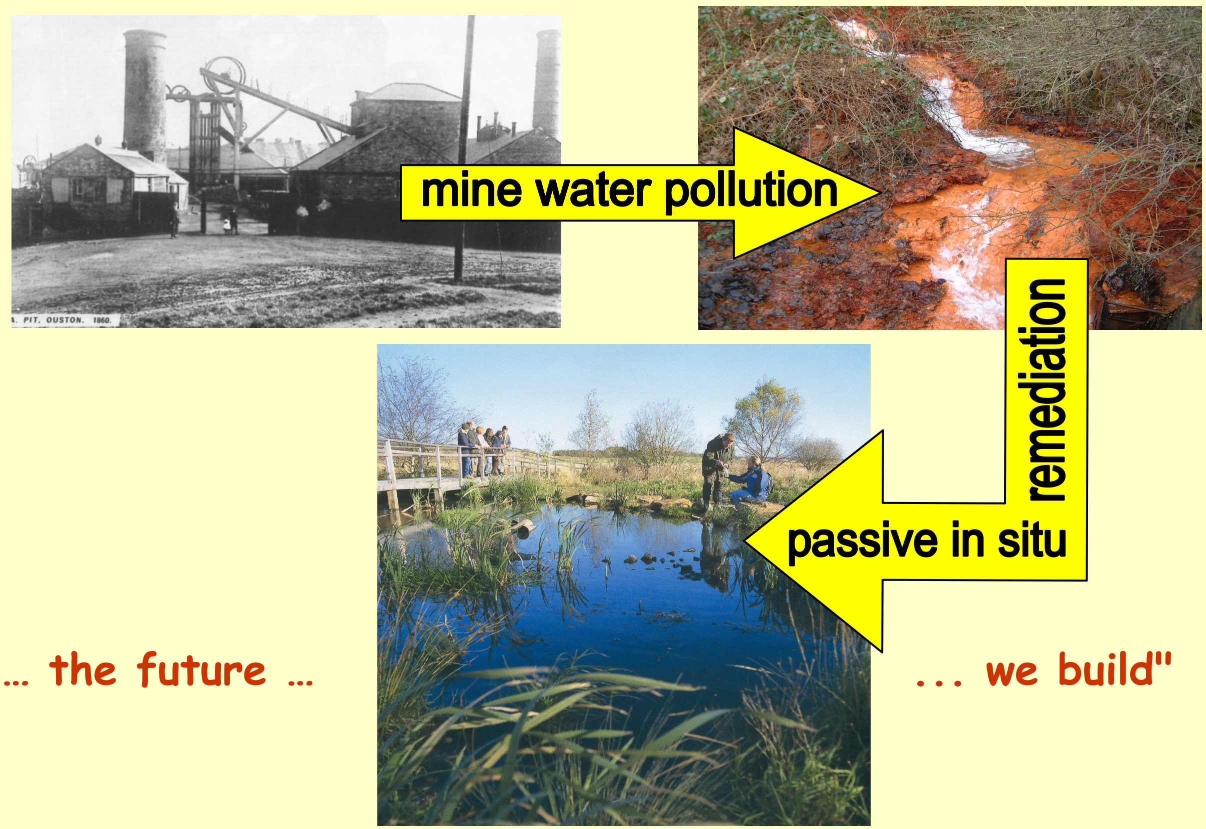
- Proven methodologies exist for predicting:
  - Rebound rates
  - Post-rebound flows
  - Post-rebound water quality evolution (established for Fe; POSSUM model under development for all other major contaminants)
- Challenges lie in parameterisation, especially *a priori* recognition of 'dead-end' pore space in extensive deep mine systems

UNIVERSITY OF NEWCASTLE

ires
Institute for Research on Environment & Sustainability

Thank you – *Merci – Tapadh leibh*

"The past … … we inherit …



… the future … … we build"

HERO Hydrogeochemical Engineering Research & Outreach

The Queen's Anniversary Prizes
For Higher and Further Education
2005