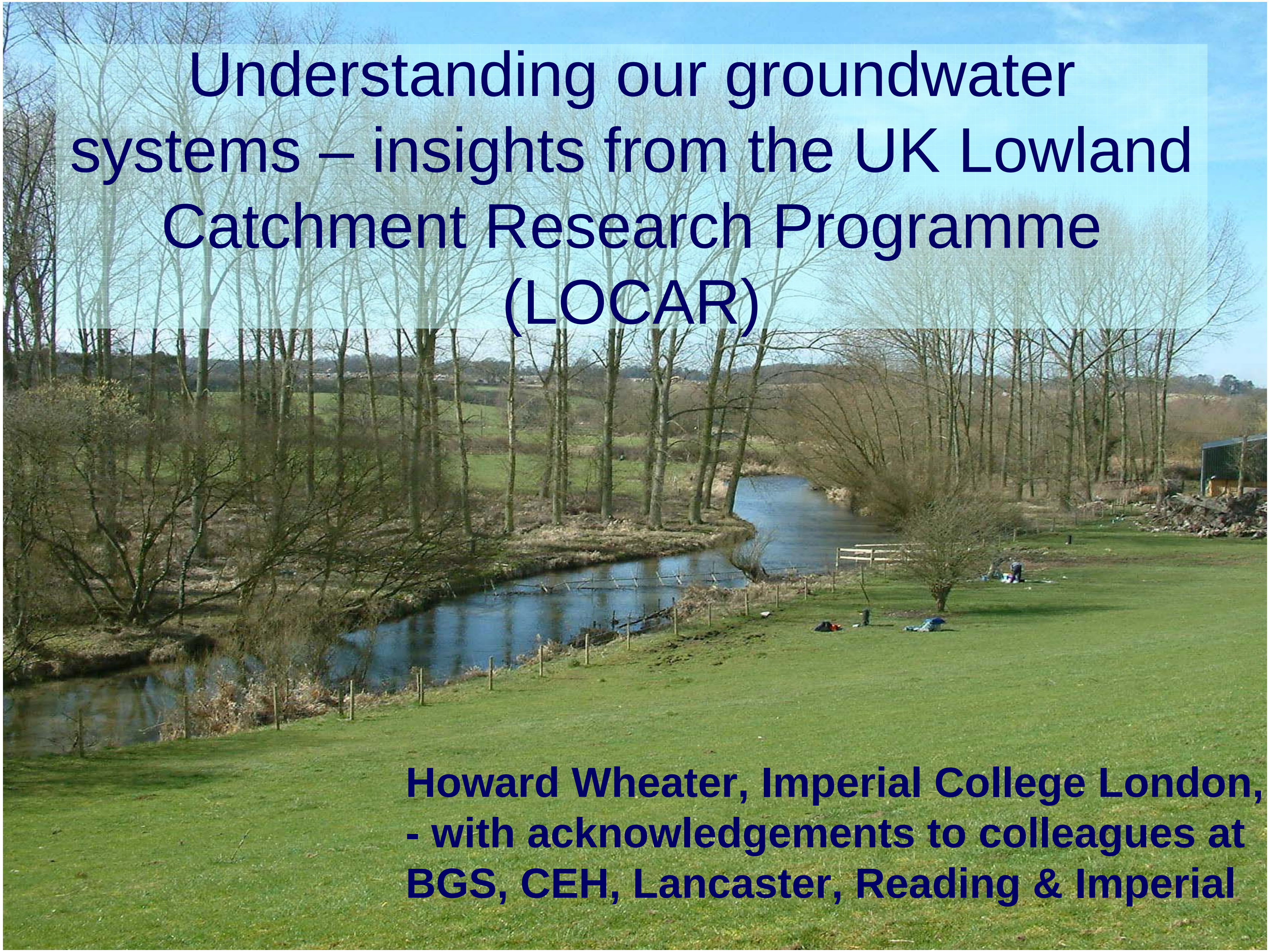
Understanding our groundwater systems – insights from the UK Lowland Catchment Research Programme (LOCAR)

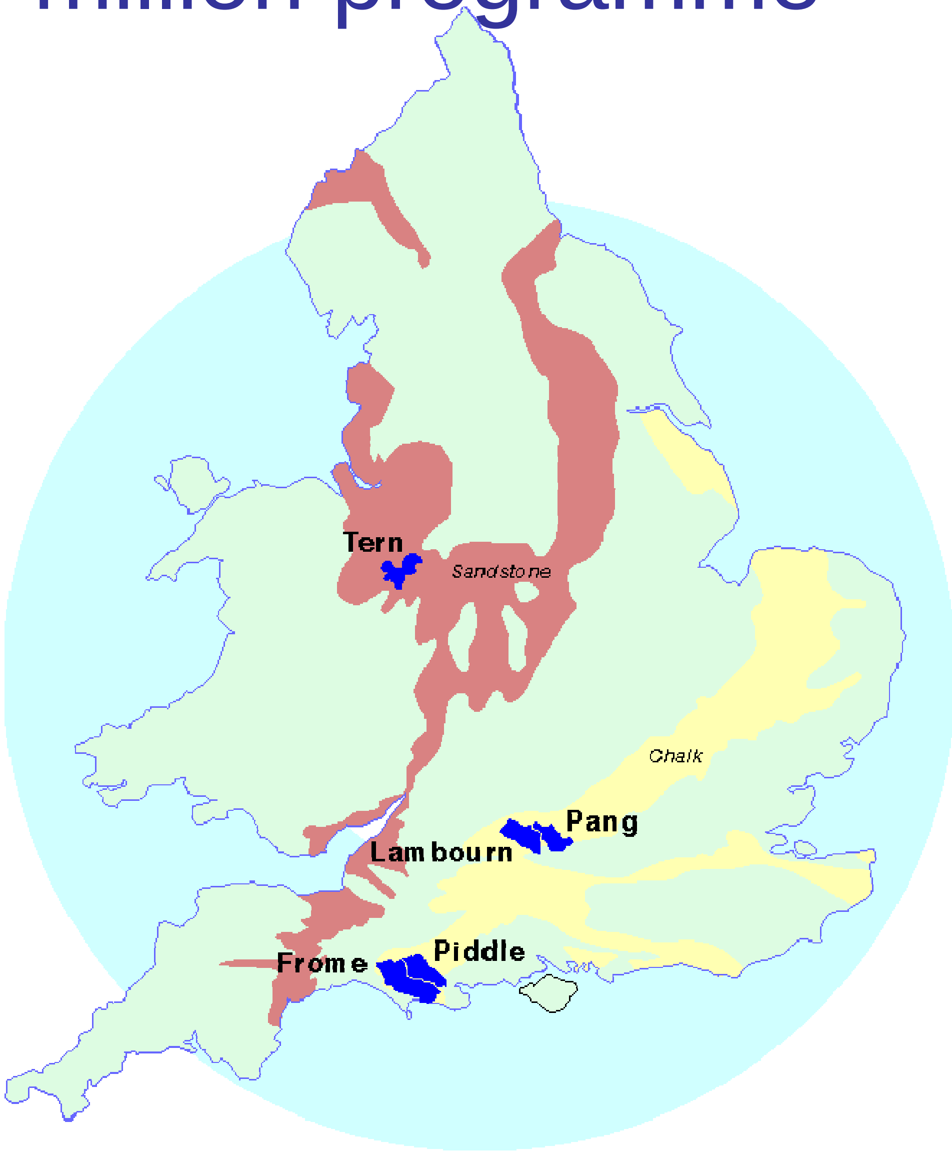


Howard Wheater, Imperial College London,
- with acknowledgements to colleagues at BGS, CEH, Lancaster, Reading & Imperial

LOCAR – a £10 million programme

Science and Policy drivers

Limitations of UK experimental hydrology base
 - uplands/small scale
Management pressures
- lowlands/ larger scale
Lowland permeable catchments
- linking surface water and groundwater
Water Framework Directive
- ecological quality
Need for new interdisciplinary science



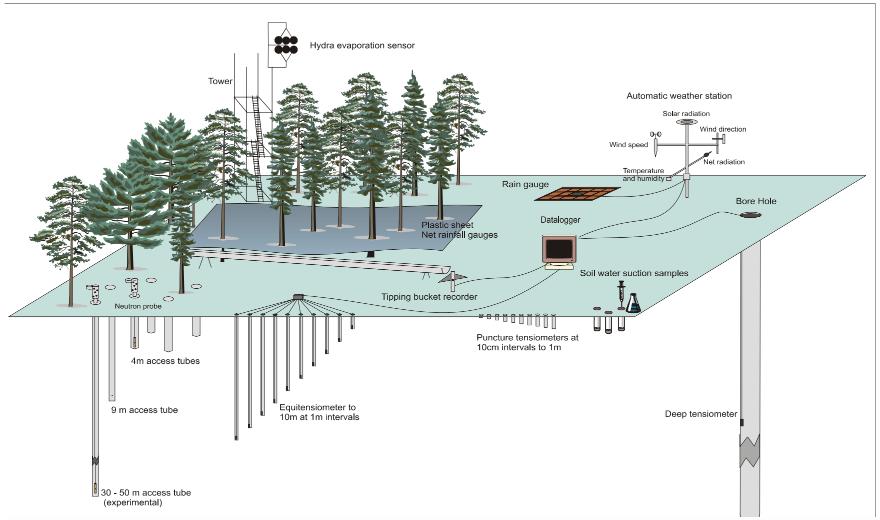
Scientific Aims

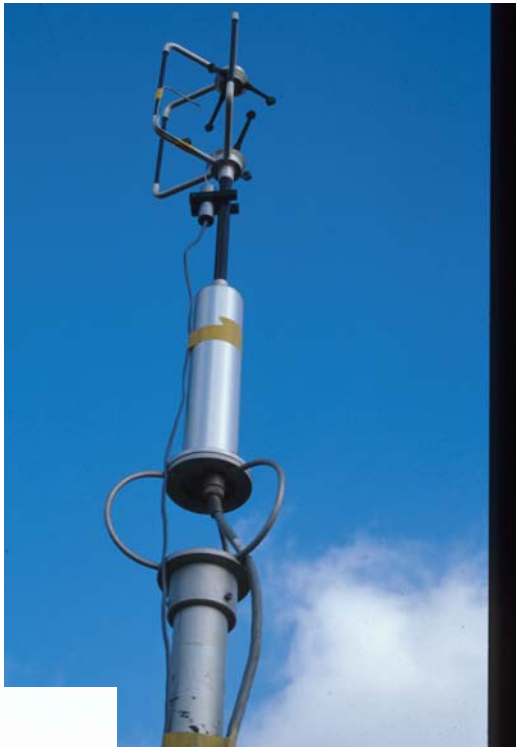
To develop an improved understanding of hydrological, hydrogeological, geomorph-ological and ecological interactions within permeable catchment systems, and their associated aquatic habitats, at different spatial and temporal scales and for different land uses;

To develop improved modelling tools to inform and support the integrated management of lowland catchment systems.

Instruments

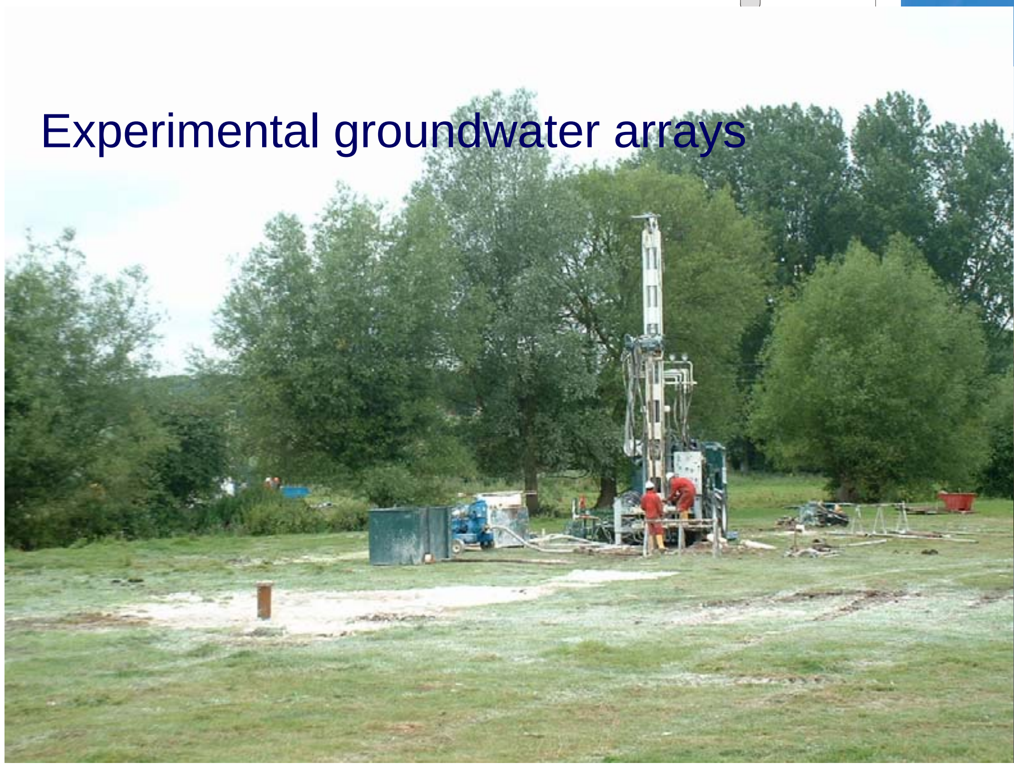
Recharge site





The HYDRA: actual evaporation in the Pang/Lambourn

Experimental groundwater arrays



Water quality

LOCAR SCIENCE PROJECTS I

Evaporation

- Assessment of new methods to estimate grid or catchment evaporation using satellite and ground-based measurements.
- The influence of woodlands on recharge in the Pang catchment

Soils

- Flow and transport of water in the Chalk unsaturated zone

Groundwater

- Characterising permeability and groundwater flow in Chalk catchments using tracer techniques
- Investigation of groundwater flow heterogeneity in the Chalk aquifer using detailed borehole arrays and stochastic modelling techniques
- Assessing stream-groundwater interactions in lowland chalk catchments using hydrogeophysical characterisation of the riparian zone

LOCAR SCIENCE PROJECTS II

- Towards a methodology for determining the pattern and magnitude of recharge through drift deposits

Sediments

- The fine sediment budgets of lowland permeable catchments and their implications for nutrient and contaminant transfer
- Fine sediment and nutrient dynamics in lowland permeable streams: establishing the significance of biotic processes for sediment modification
- Vegetation management influences on fine sediment and propagule dynamics within groundwater-fed rivers: implications for river management, restoration and riparian biodiversity.

LOCAR SCIENCE PROJECTS III

Nutrients

- Hydrogeochemical functioning of lowland permeable catchments: from process understanding to environmental management

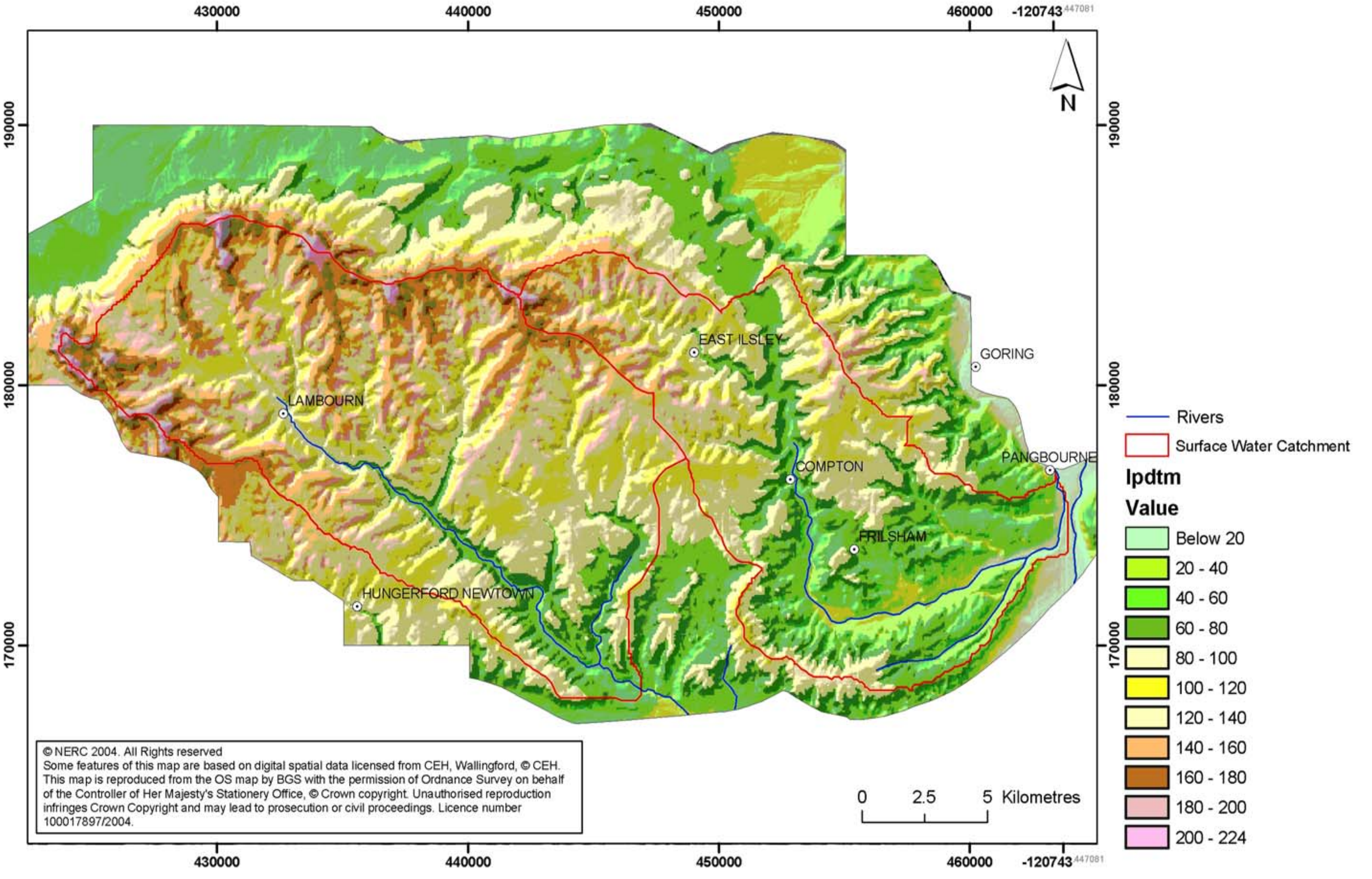
Ecology

- Utilisation of off-river habitats by lowland river fishes: influences of flow regime and land-use change
- Ecological significance of surface and subsurface exchange in lowland channels

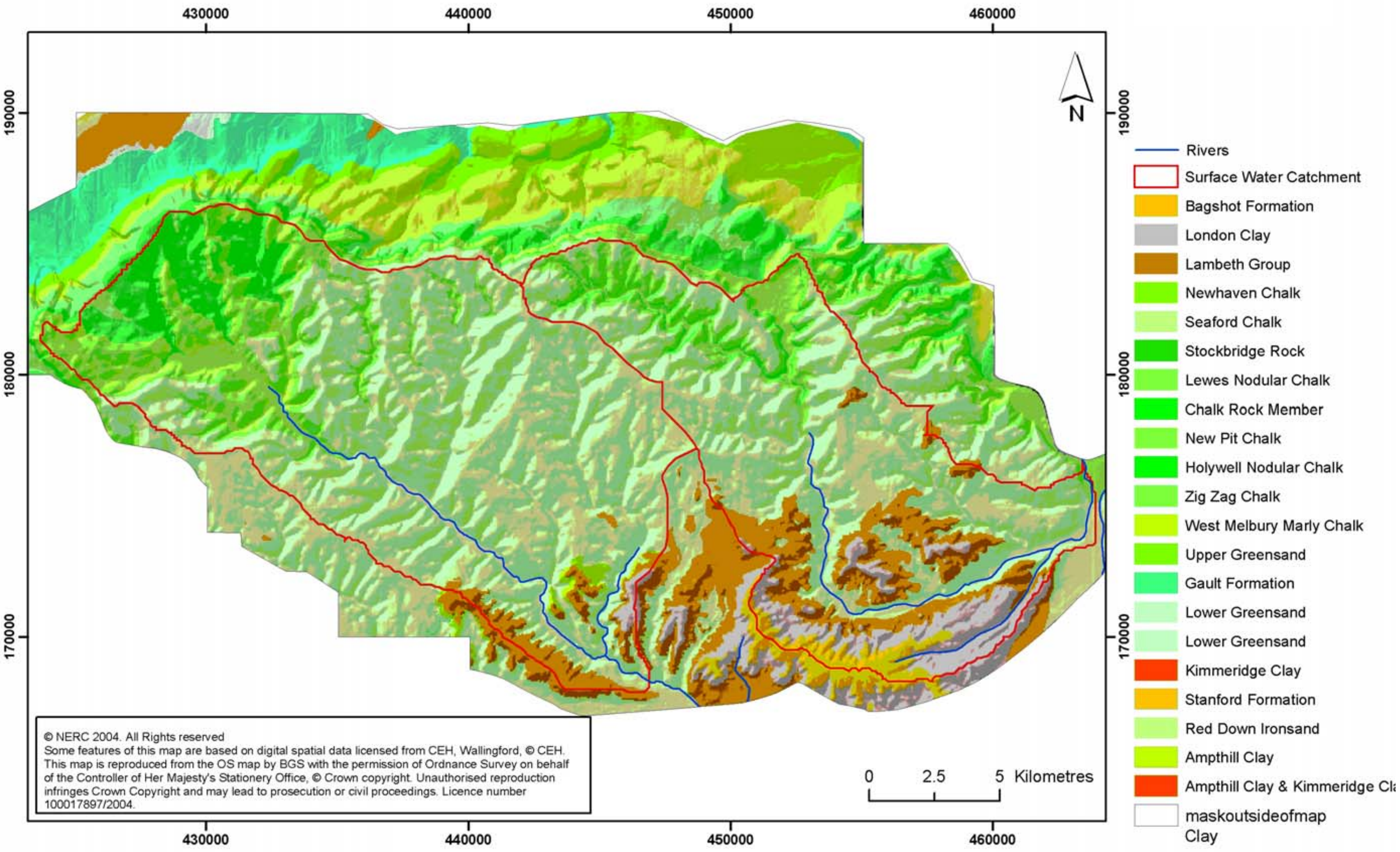
Hydrology of the Pang and Lambourn

The Chalk

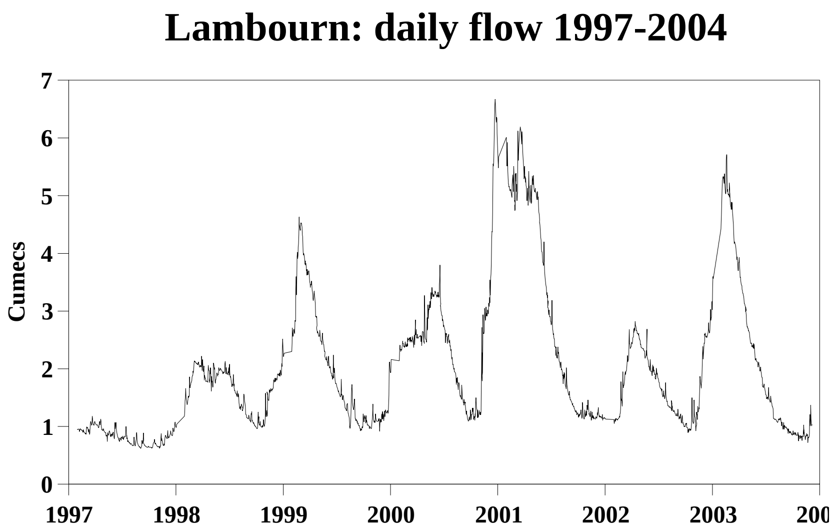
Pang and Lambourn topography and river system

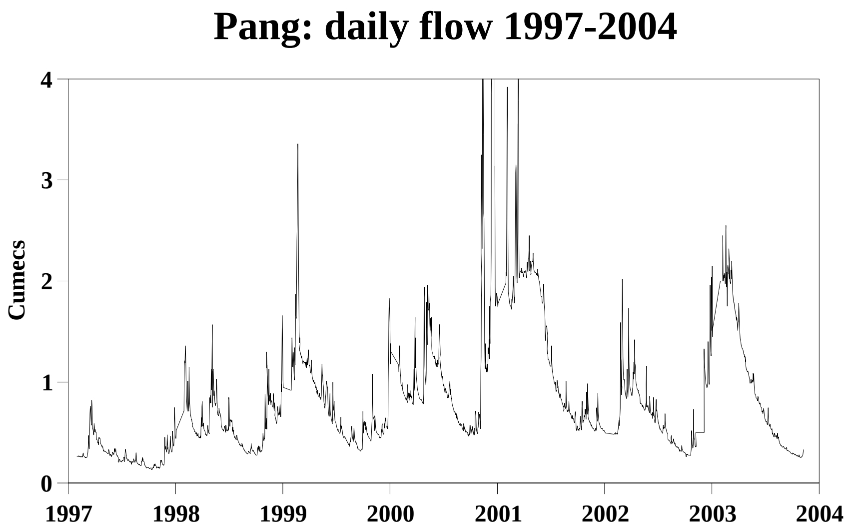


Solid Geology

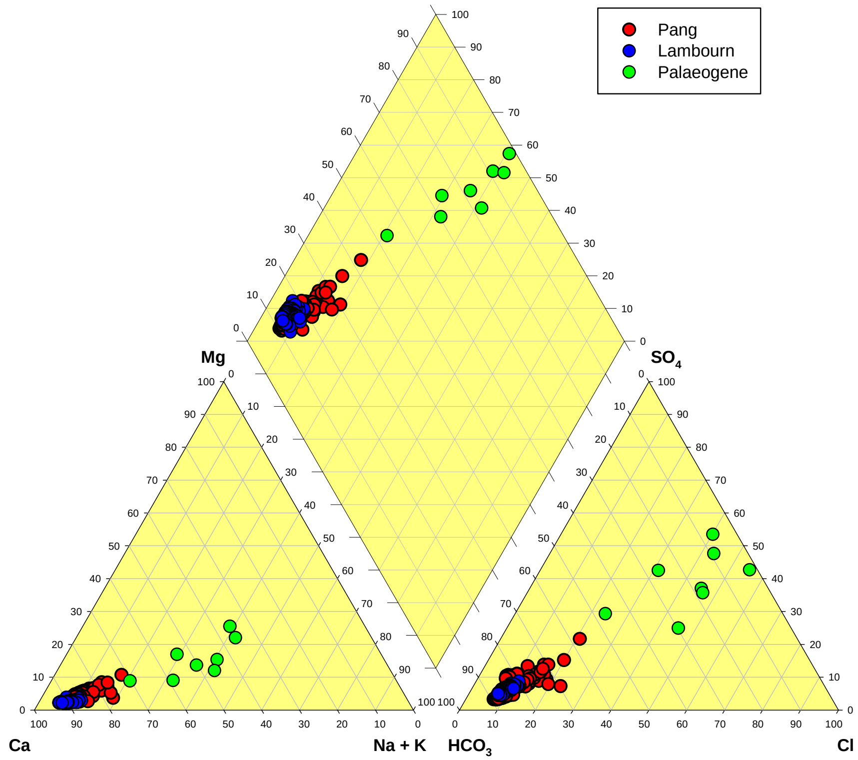


Stream hydrographs

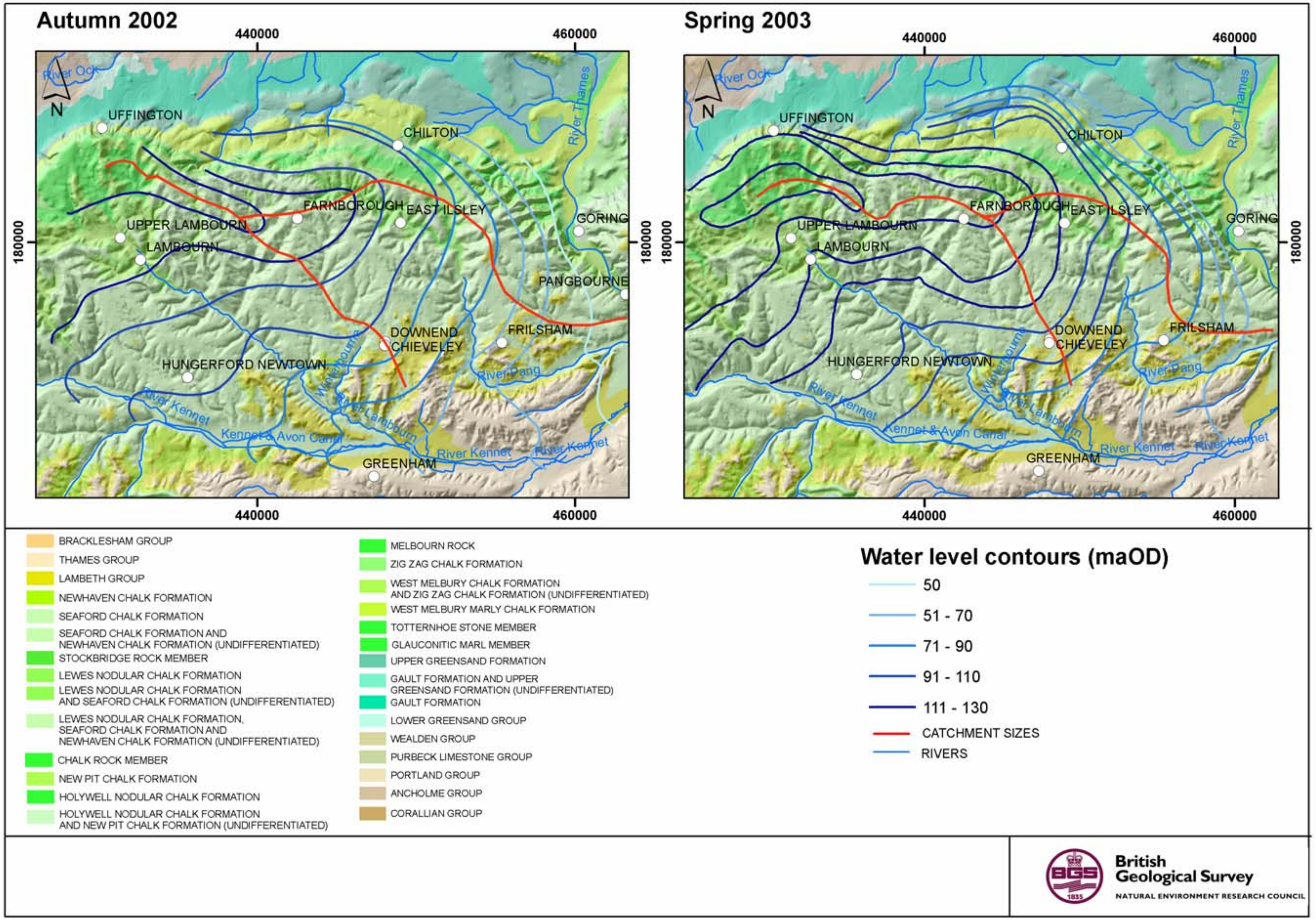




Hydrochemistry of the Pang, Lambourn and Palaeogene

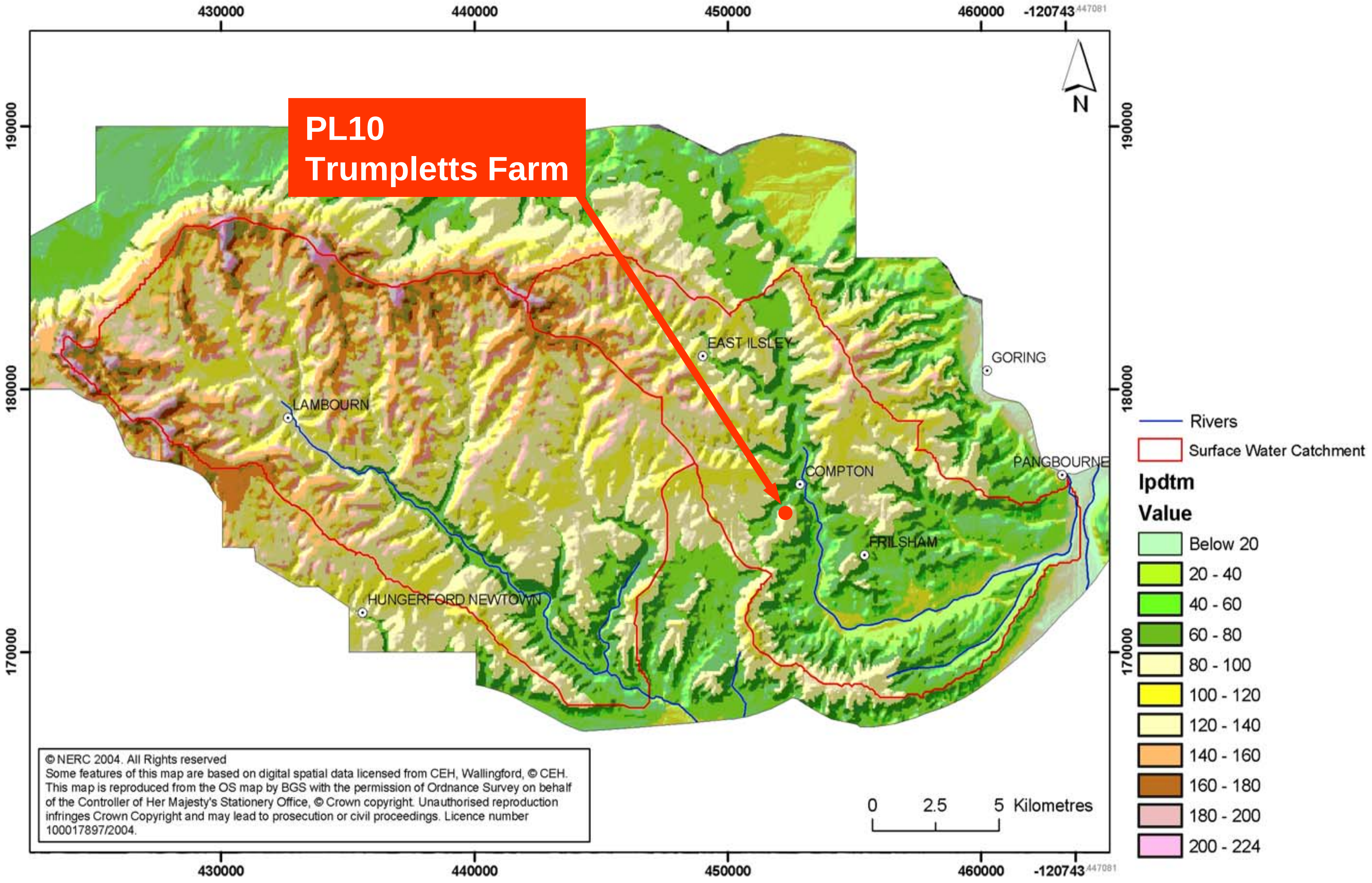


Seasonal variation in catchment area

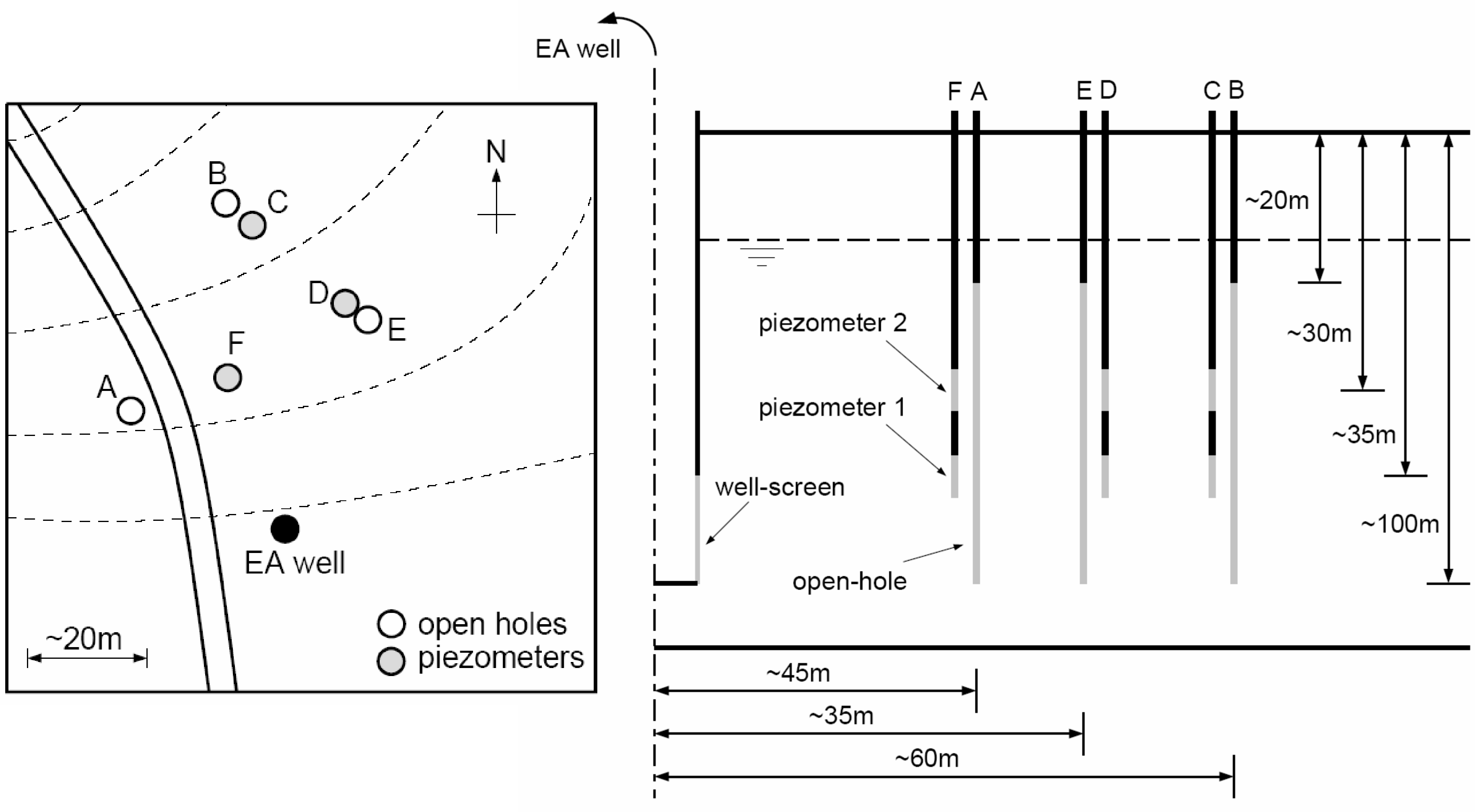


Chalk groundwater

Pang-Lambourn catchment

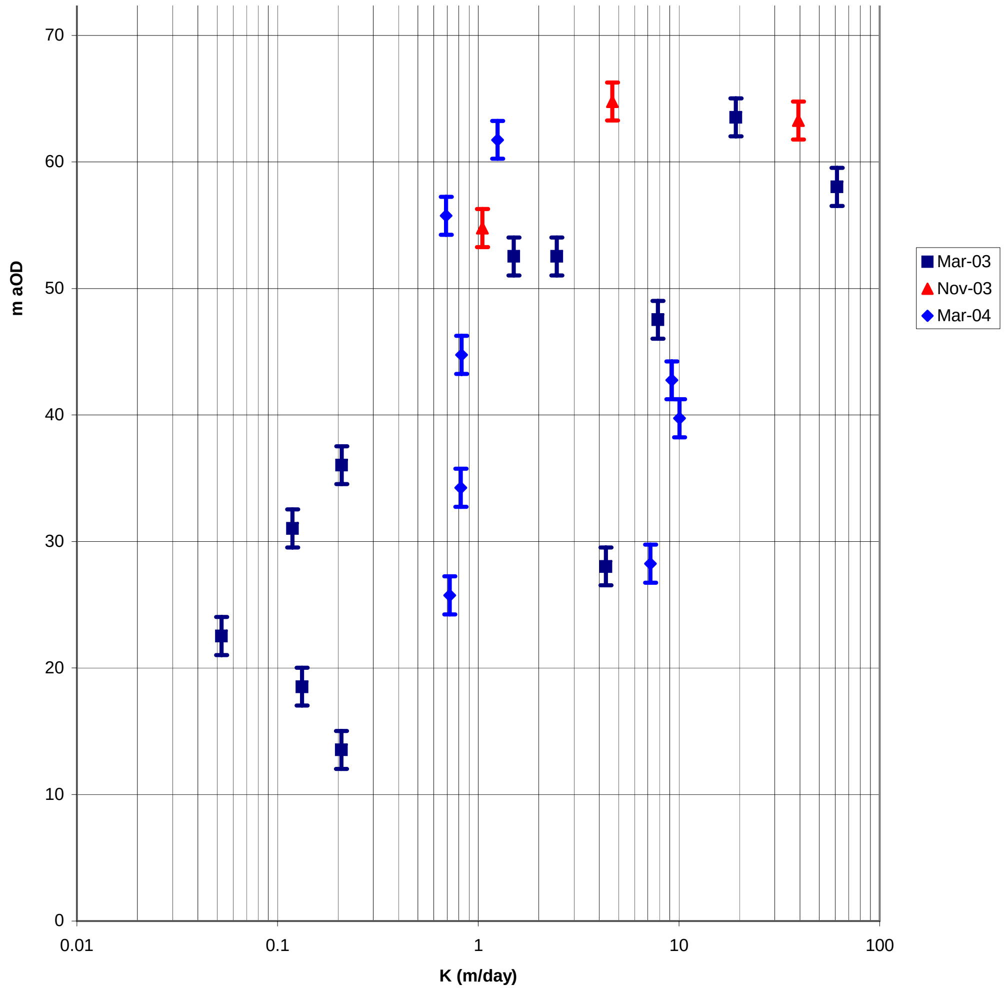


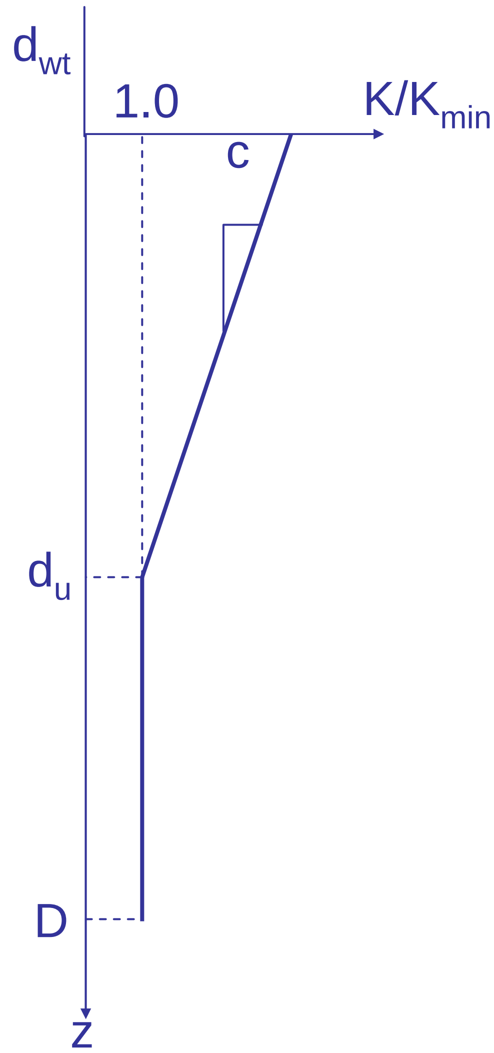
Site layout


B
C
N
D
E
F
A
EA well
~20m
open holes
piezometers
EA well
F A
E D
C B
~20m
~30m
~35m
~100m
piezometer 2
piezometer 1
well-screen
open-hole
~45m
~35m
~60m

Packer Test Results

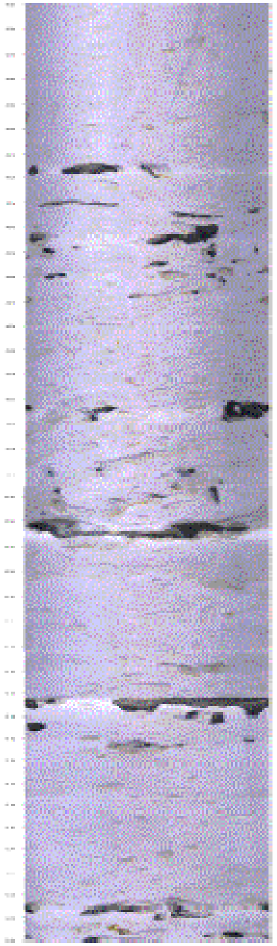
Borehole A





Videoscan logs for Borehole A

Interval: 59.5 – 56.6 mAOD



Discontinuous tabular flint

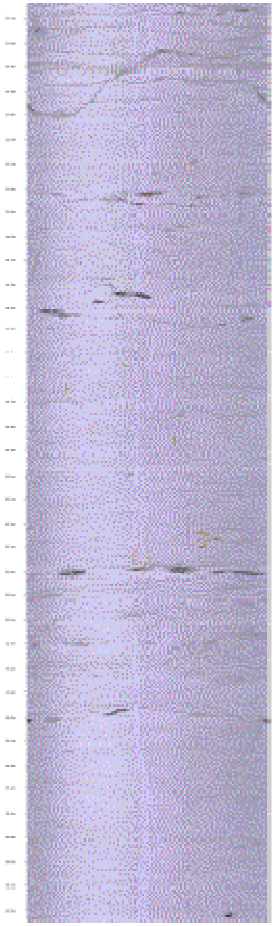
Dispersed small flints

Developed tabular flint

Nodular flint

K = 60 m/d

Interval: 15.0 – 12.1 mAOD



Marl seams

Steep fault with ~ 2cm displacement

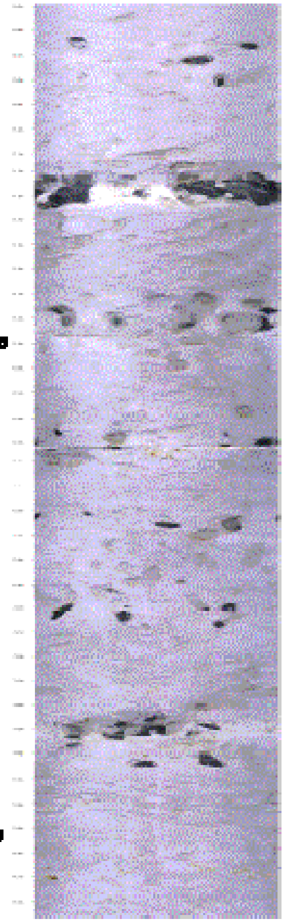
Small cavities developed on bedding parallel fracture

Small cavities developed in thin marl

Zone of drilling induced enlargement marked by pitting on borehole wall

K = 0.2 m/d

Interval: 37.5 – 34.6 mAOD



Local borehole enlargement associated with nodular flint

Partially developed bedding plane with flints above

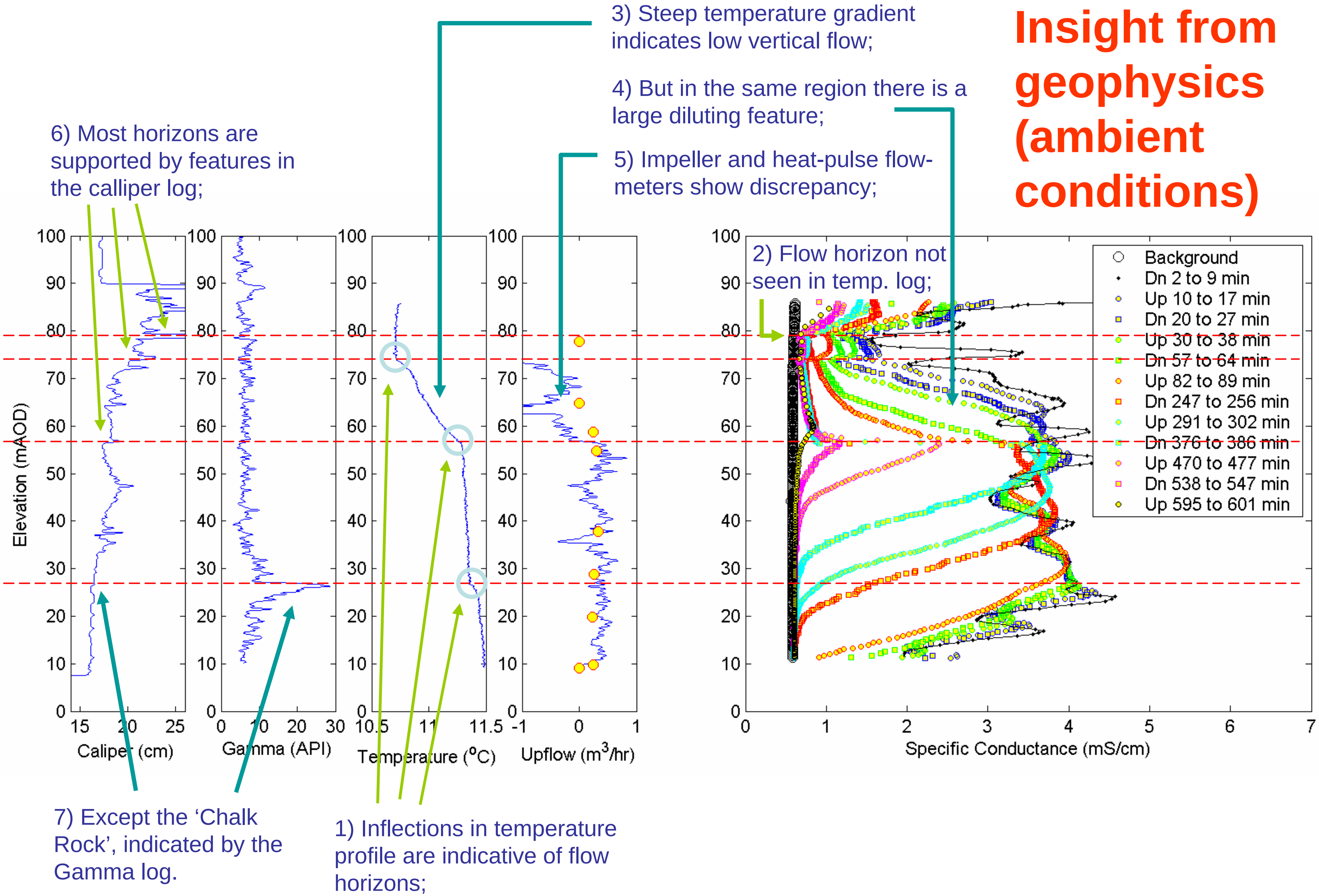
Low angle fracture

Flint with local borehole enlargement

Interval of marls and nodular chalk

K = 0.2 m/d

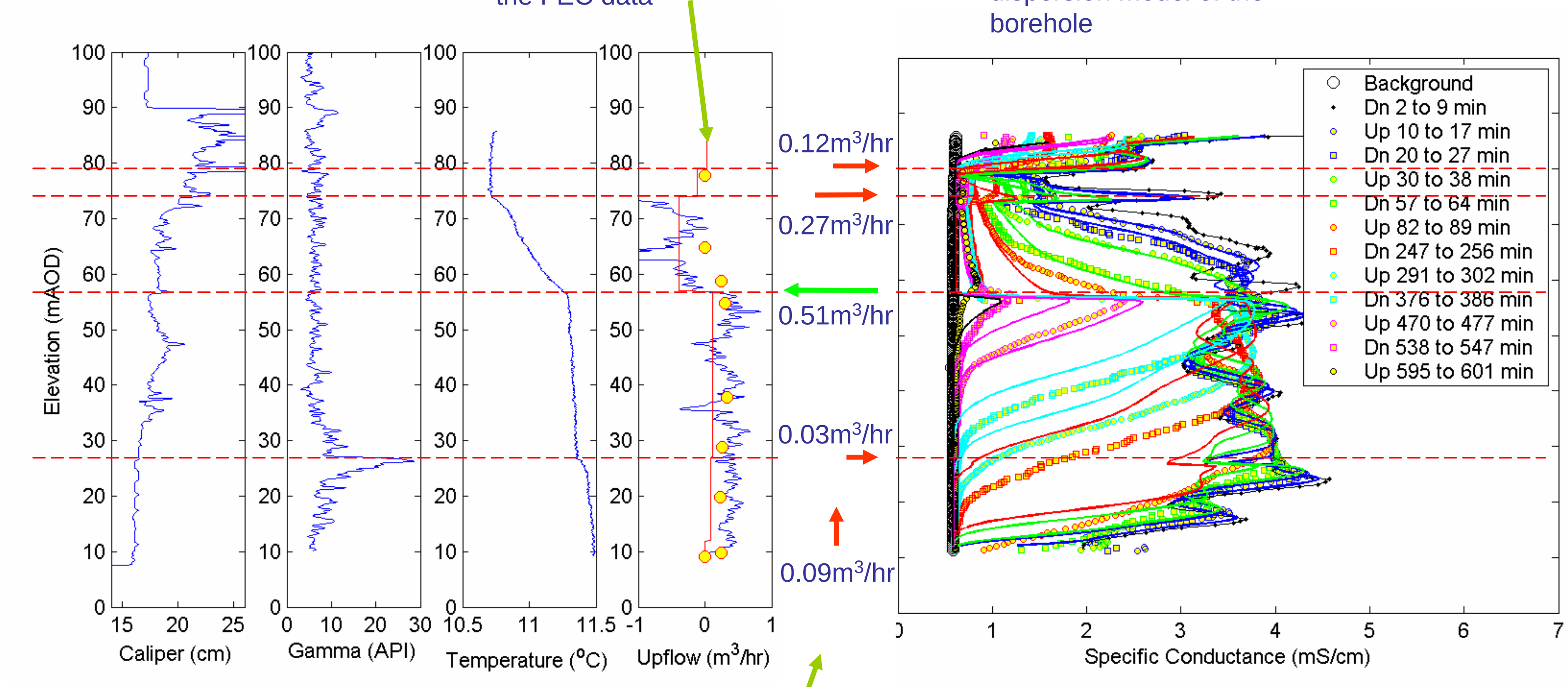
Insight from geophysics (ambient conditions)



Inversion of in/outflows from FEC logs

Red line indicates the Upflow obtained by inverse modelling of the FEC data

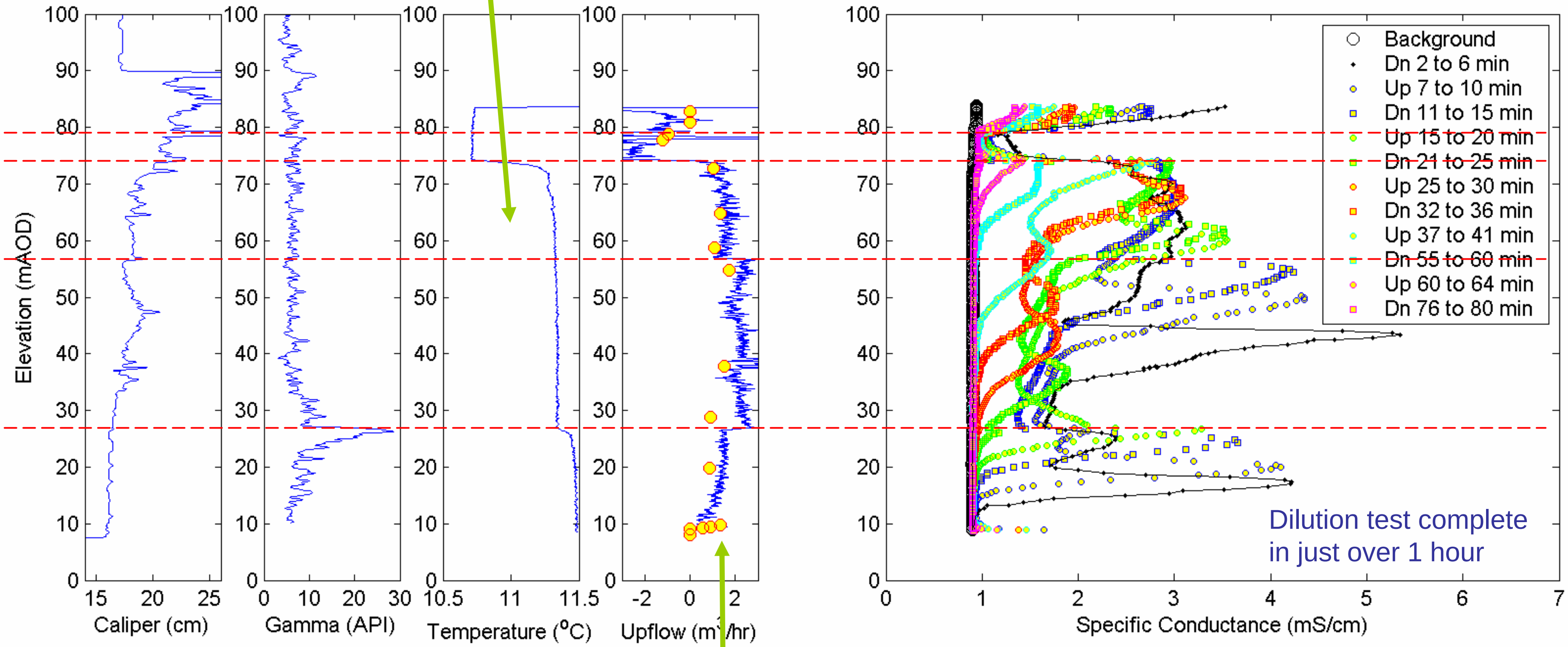
Solid lines show fits to the FEC data using an advection dispersion model of the borehole



Note that these flows are very high!!

Insight from geophysics (pumped condition)

Note that the temperature gradient has now been lost



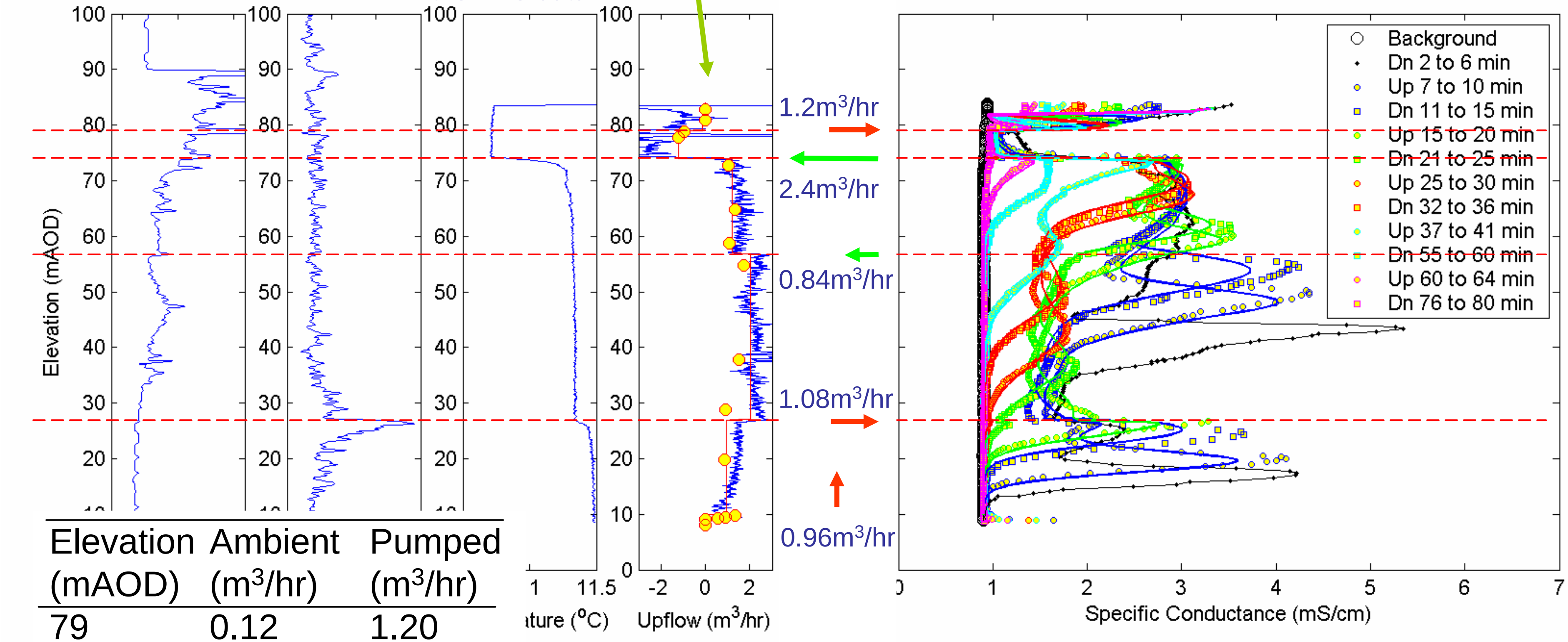
Dilution test complete in just over 1 hour

Vertical flow rates have markedly increased

Inversion of in/outflows from FEC logs (pumped conditions)

Red line indicates the Upflow obtained by inverse modelling of the FEC data

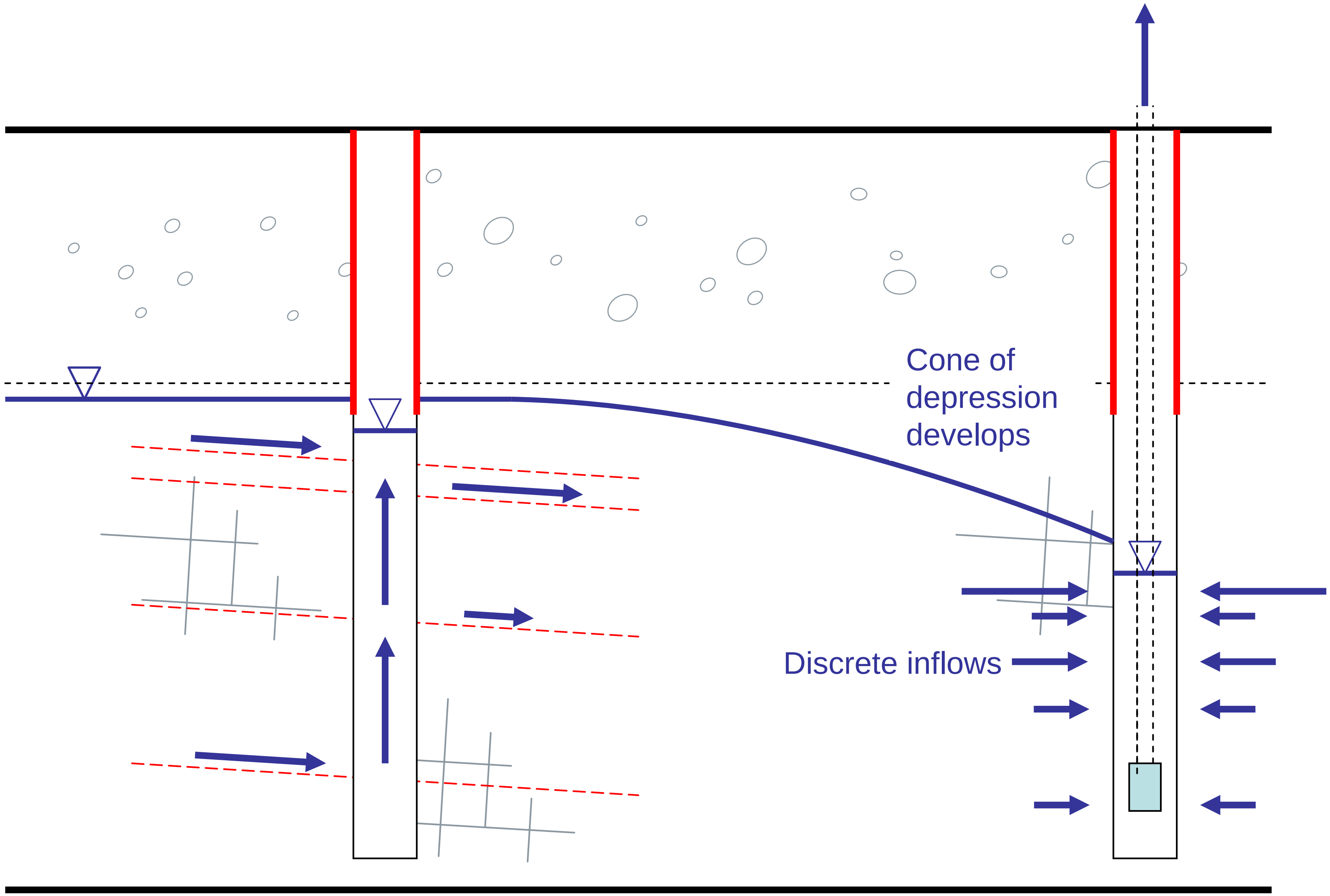
Solid lines show fits to the FEC data using an advection dispersion model of the borehole



Elevation (mAOD)	Ambient (m^3/hr)	Pumped (m^3/hr)
79	0.12	1.20
74	0.27	-2.40
57	-0.51	-0.84
27	0.03	1.08
10	0.09	0.96

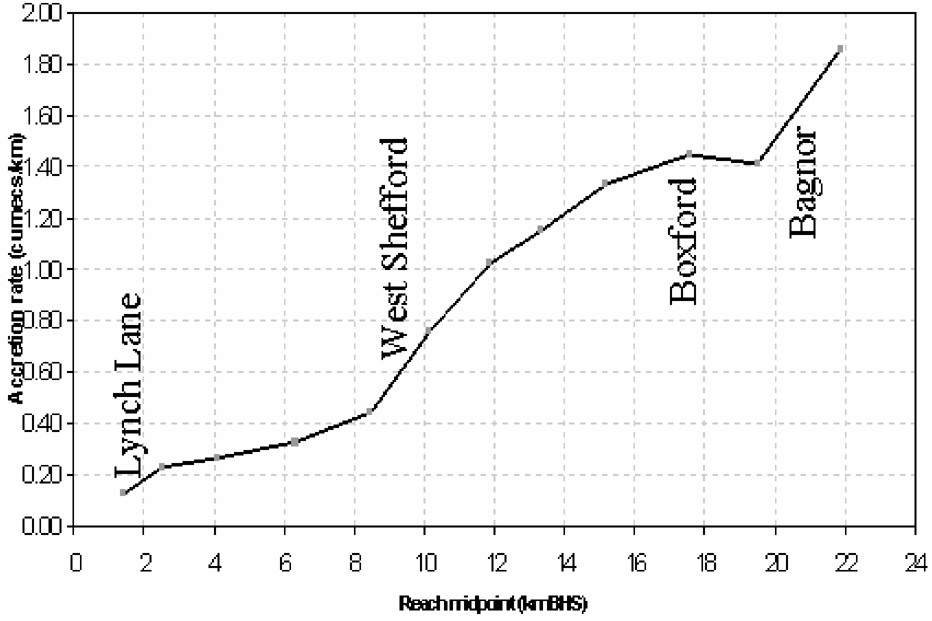
1) Pumping has increased flows by an order of magnitude.
2) Flow has actually reversed at 74mAOD.

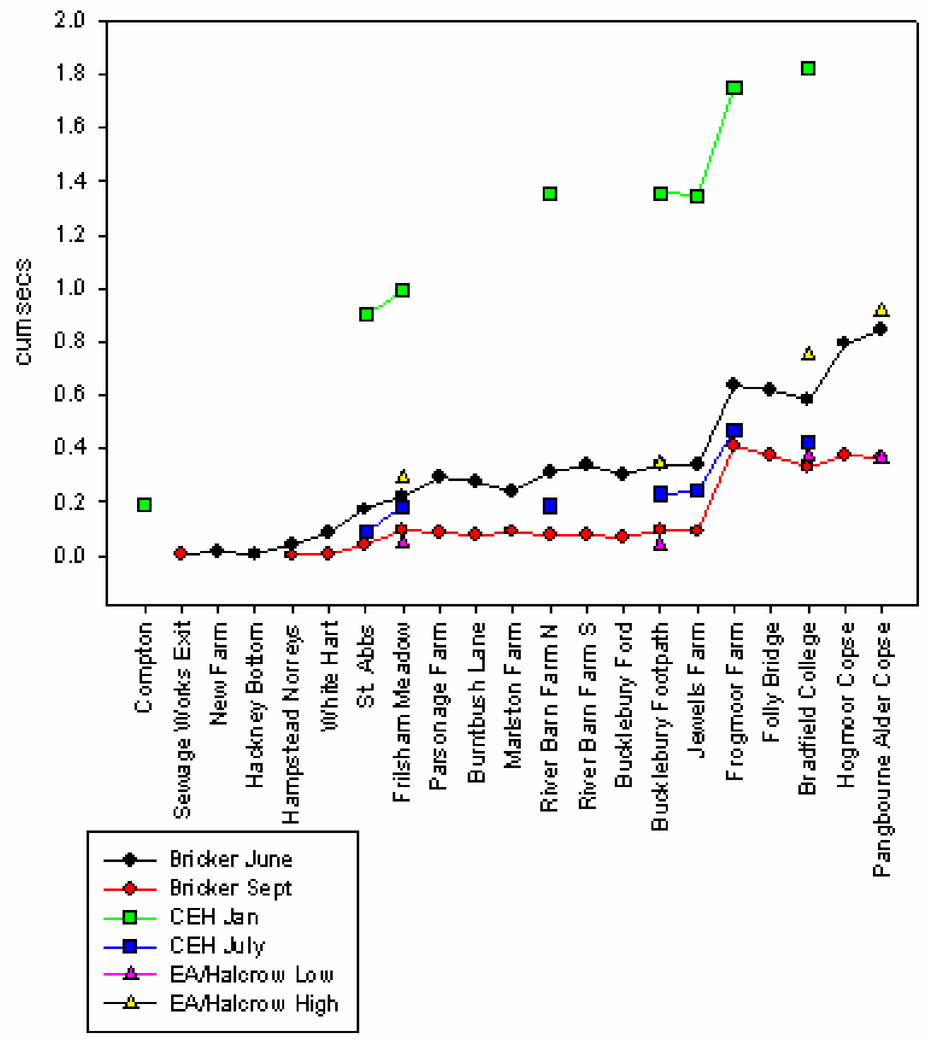
Implication of drilling a borehole and pumping an abstraction well



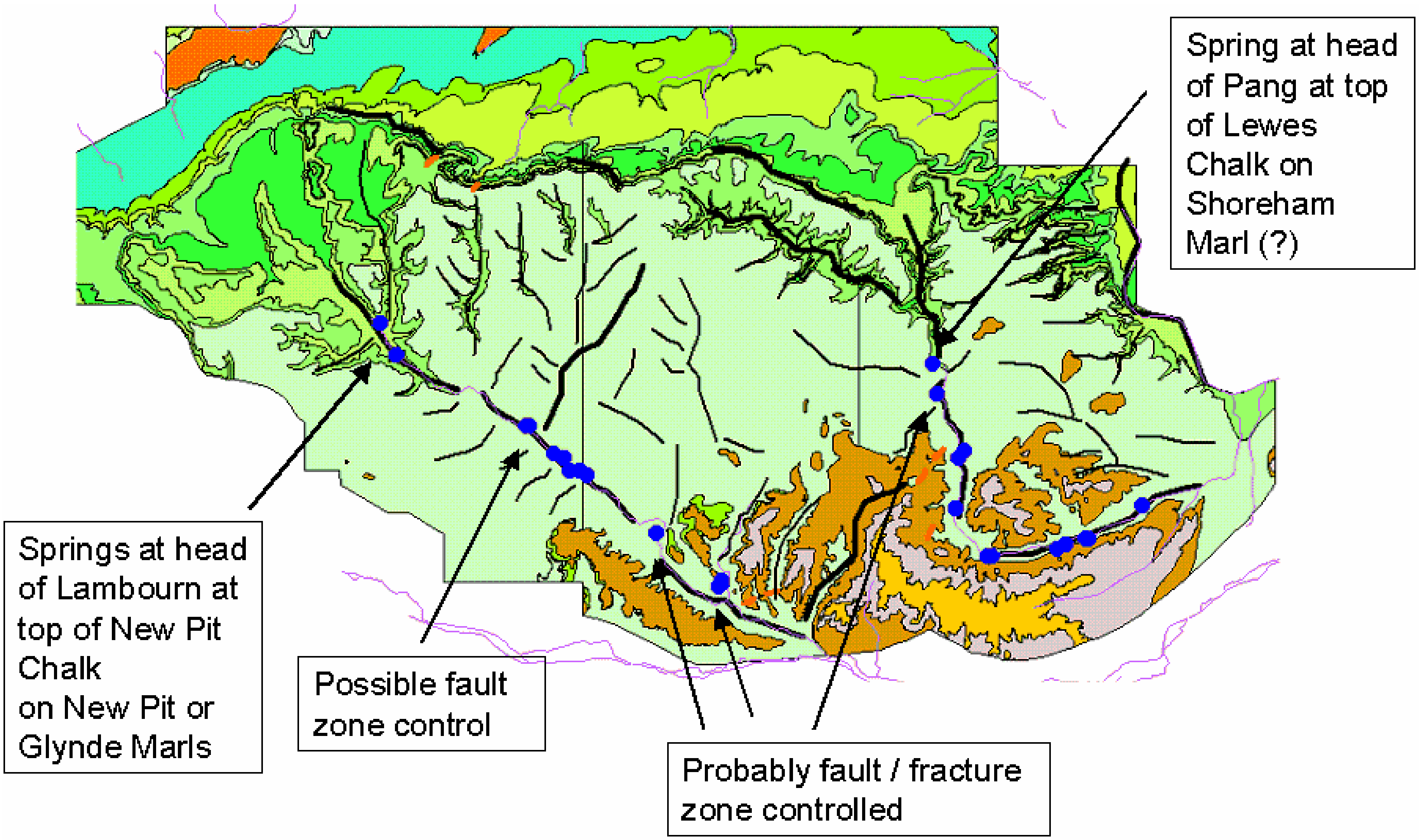
Stream-aquifer interactions

Flow accretion in the Pang and Lambourn

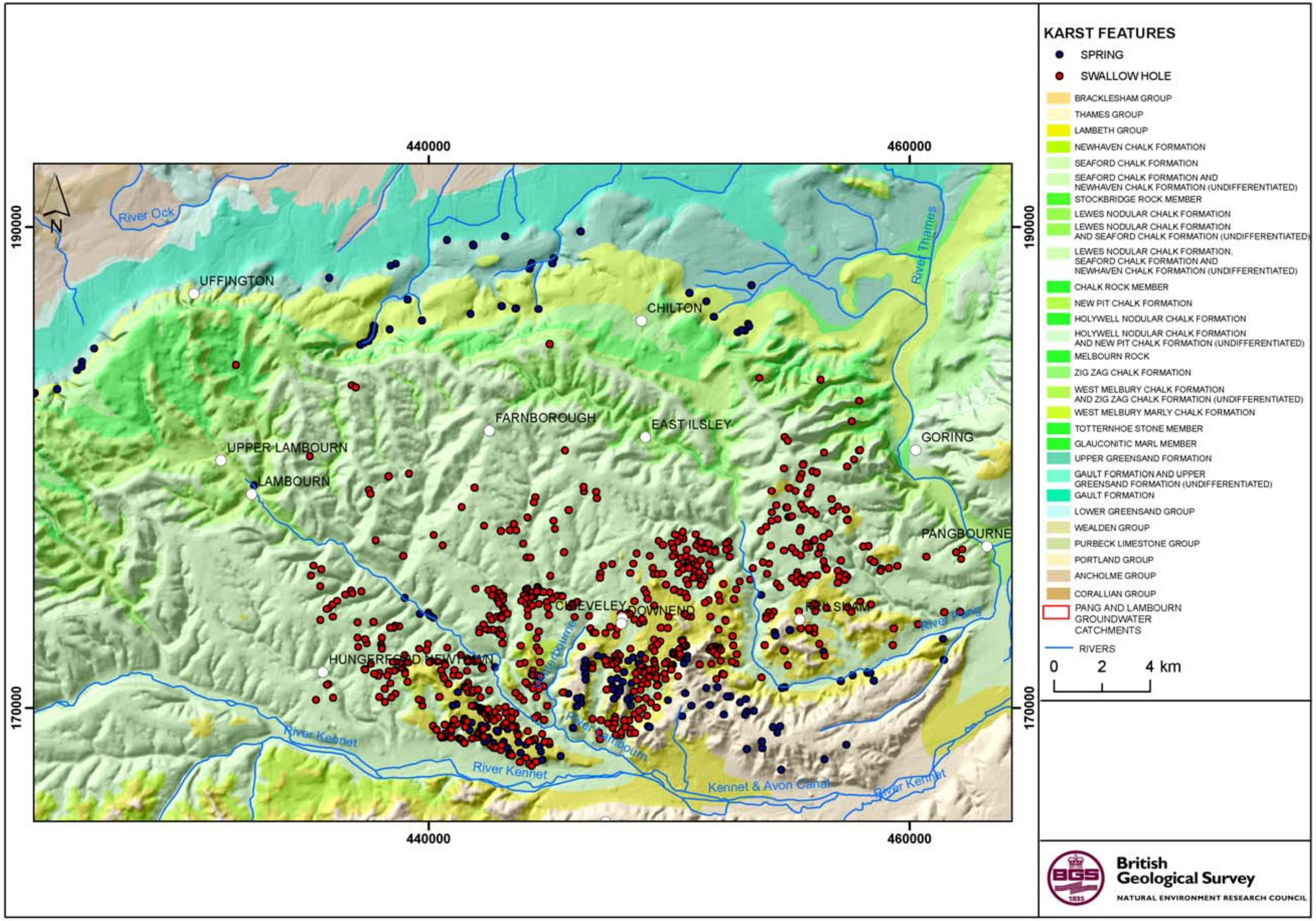




Structure and control on springs

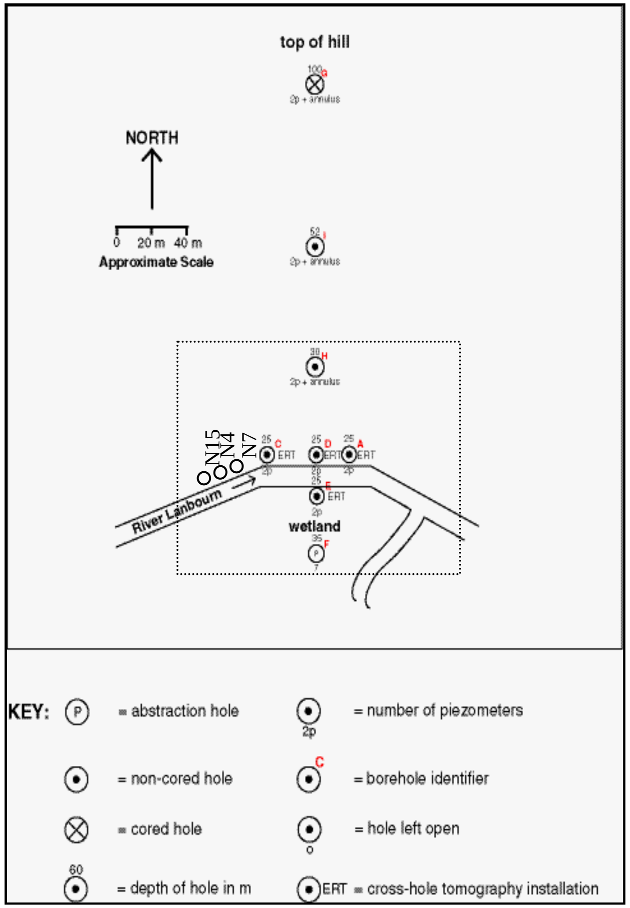


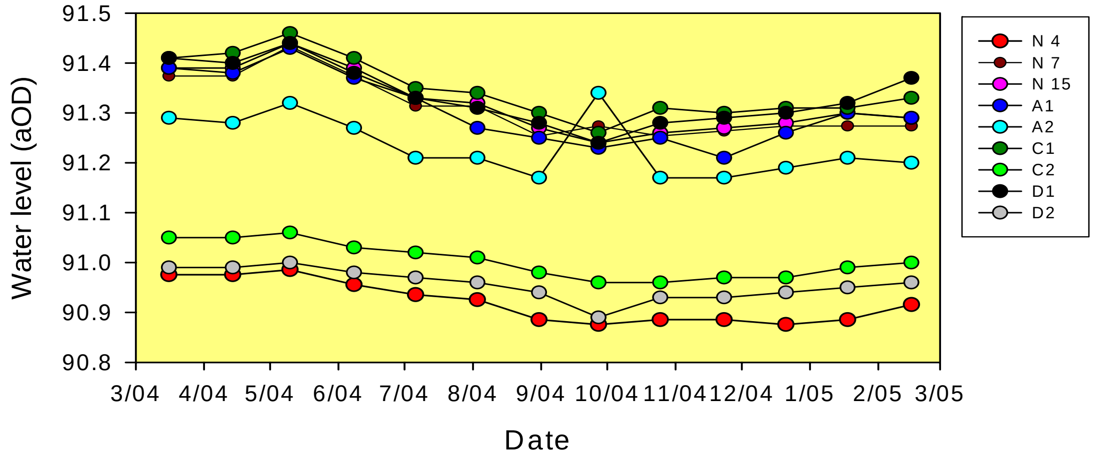
Springs and sinks on Pang/Lambourn

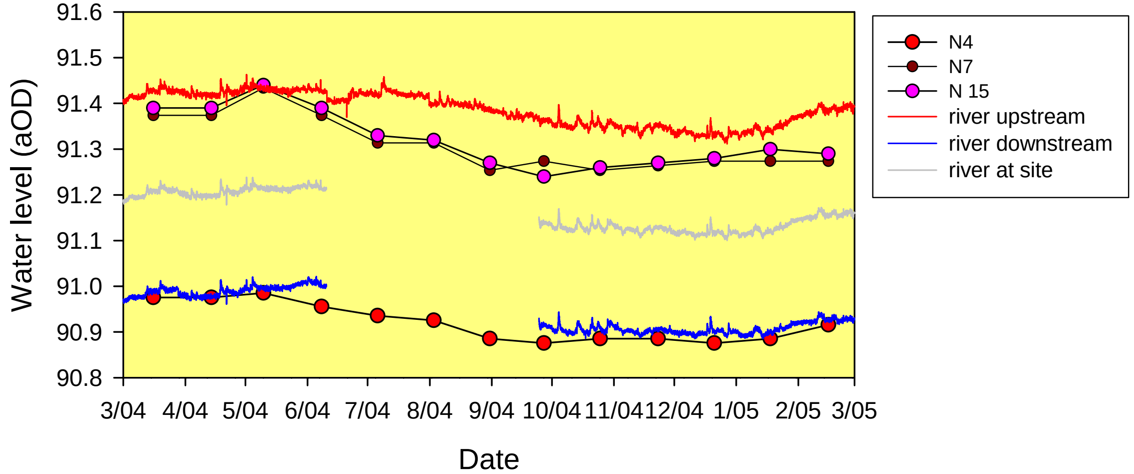


Boxford Site borehole transects

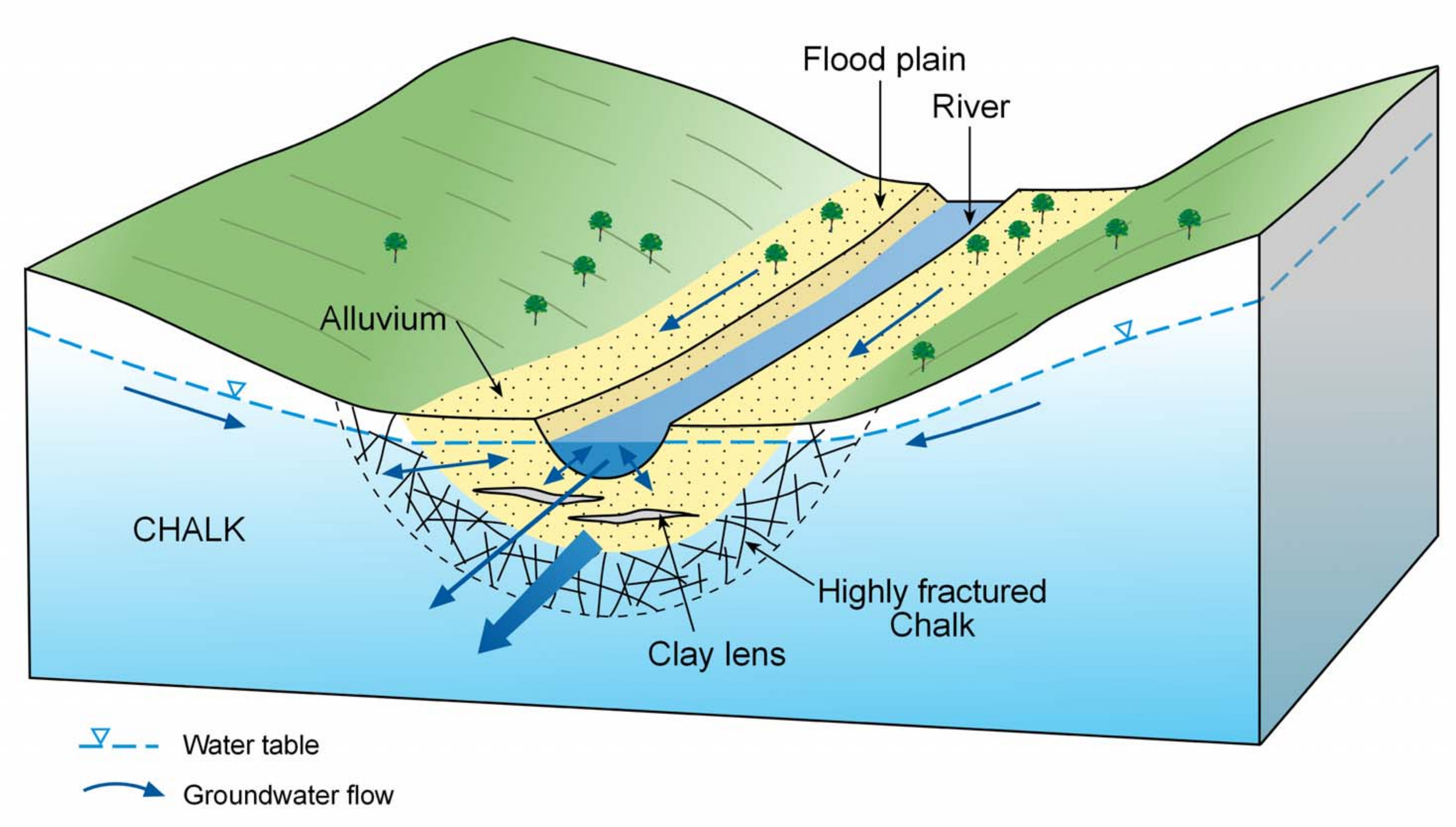
Water levels at Westbrook, River Lambourn





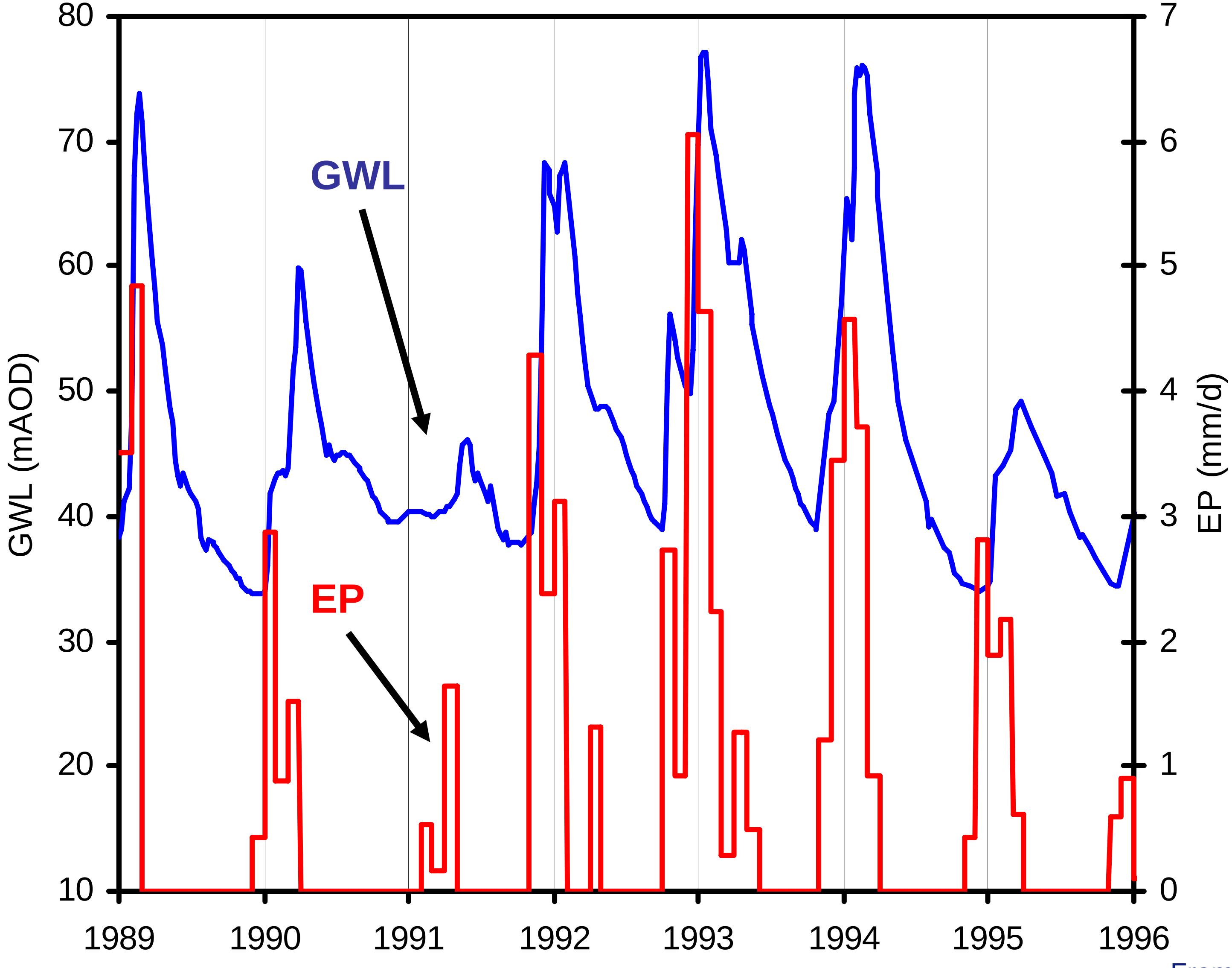


Flow mechanisms in the river corridor



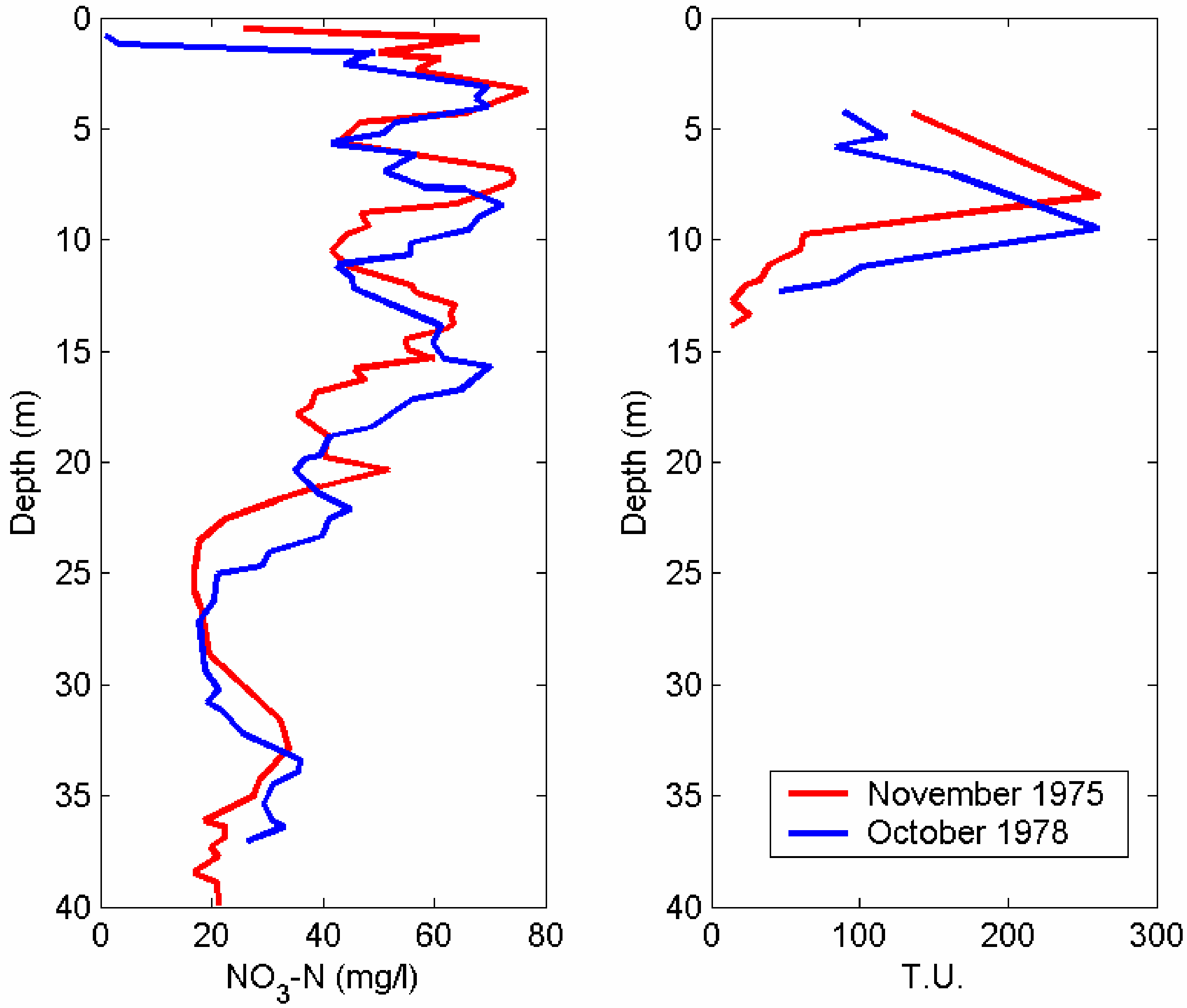
The Chalk unsaturated zone

Fast water table response



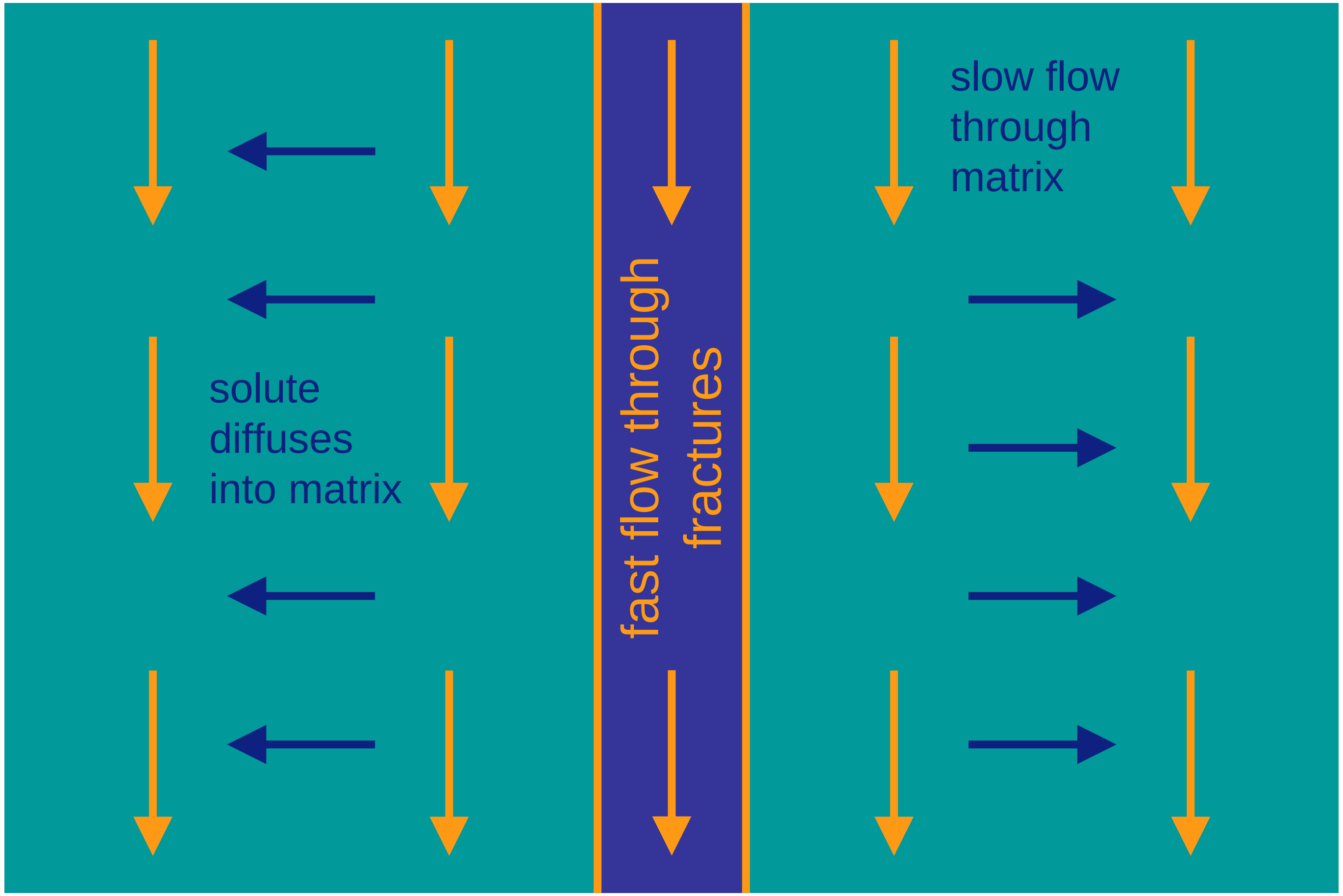
From Chilgrove

Slow solute migration

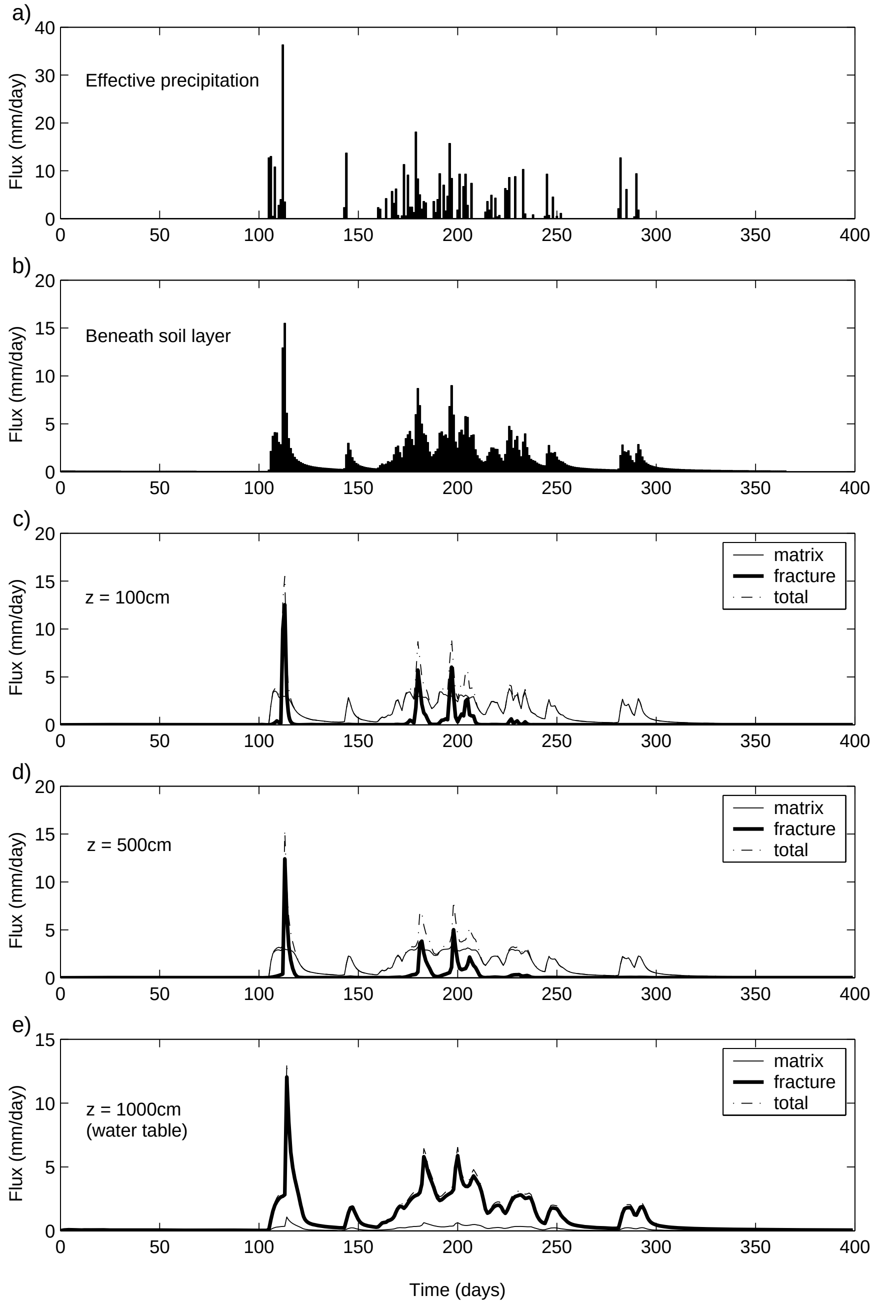


acquired from Oakes et al. (1981)

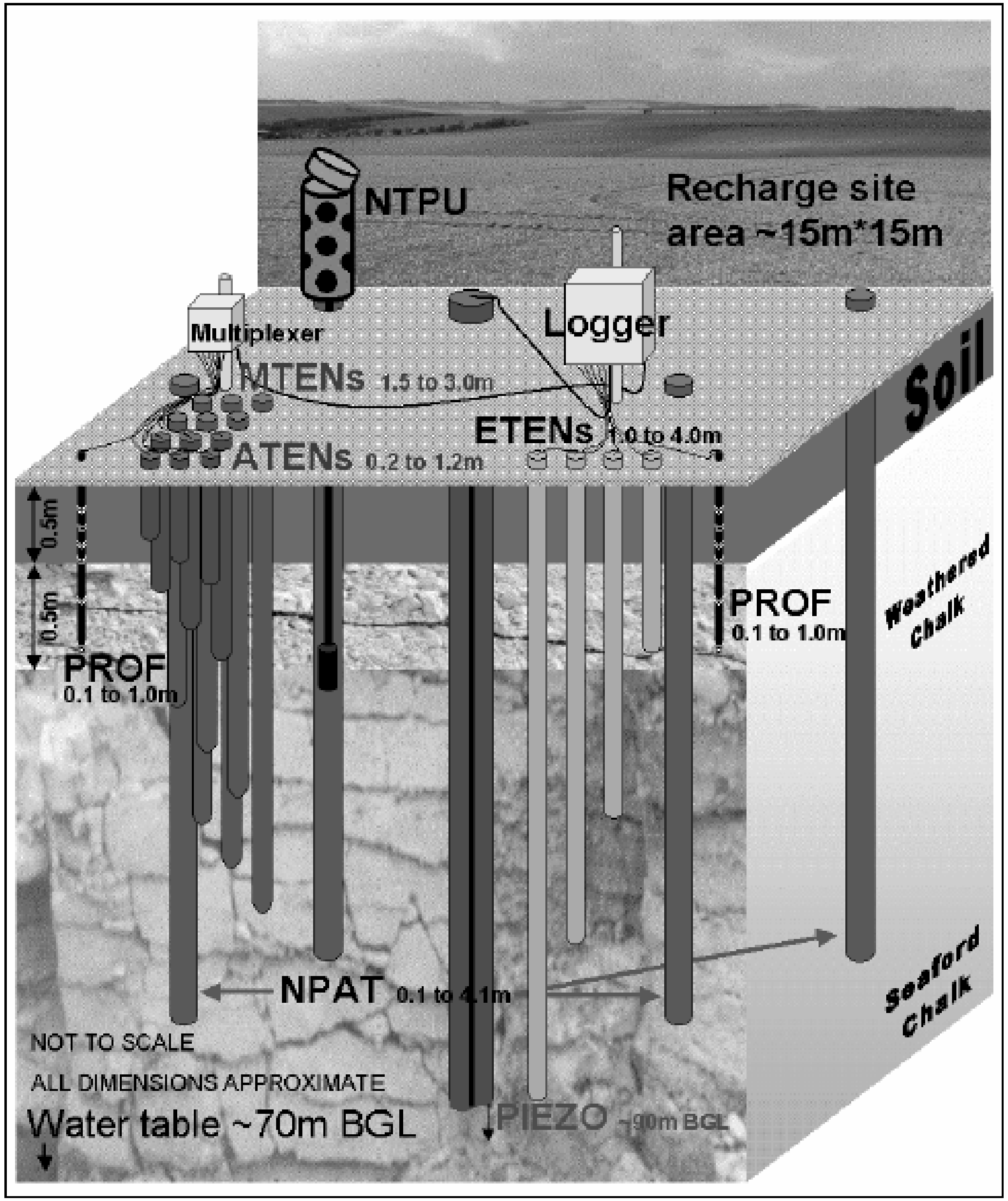
Conceptual dual permeability model



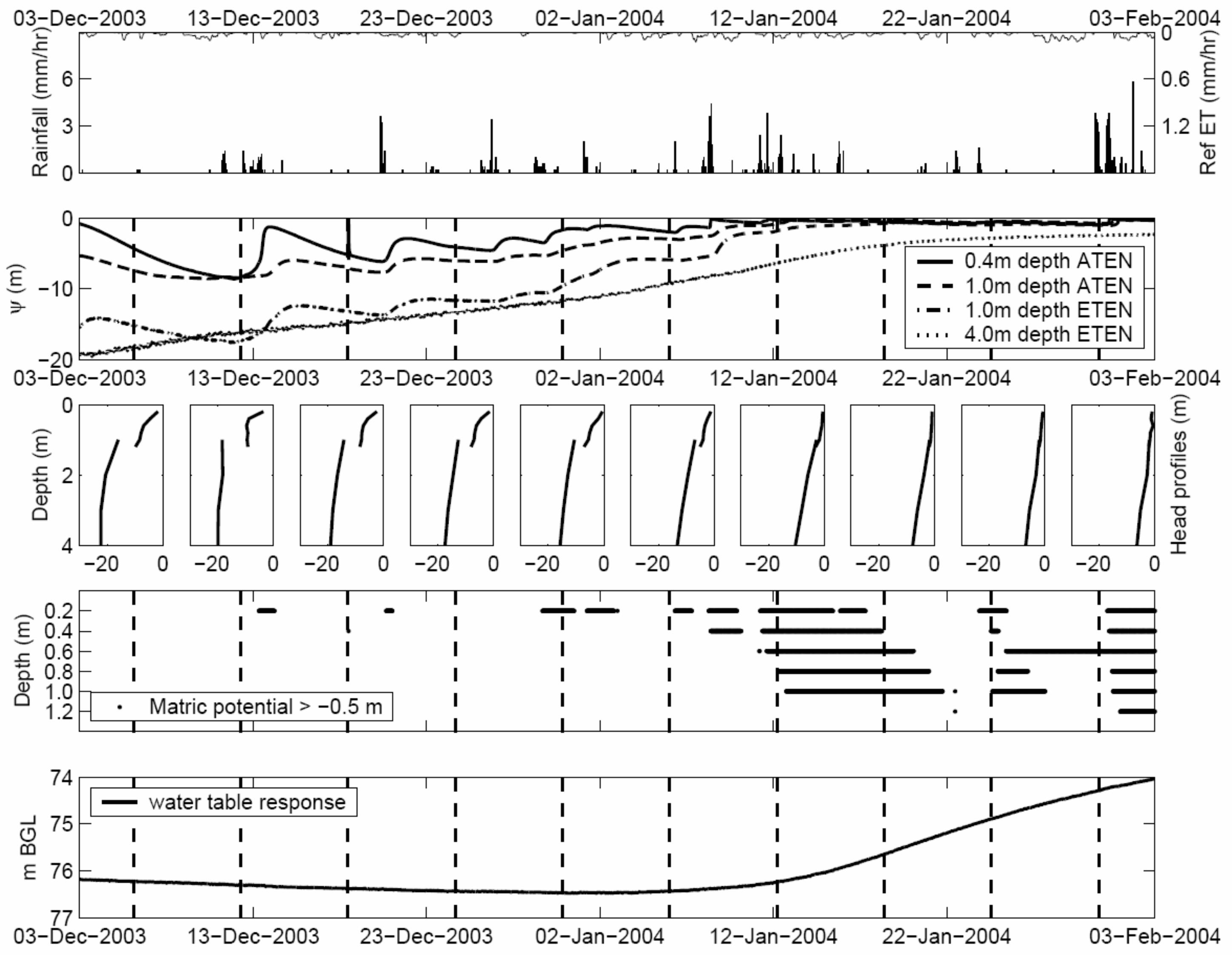
Simulation of unsaturated zone matrix-fracture interactions



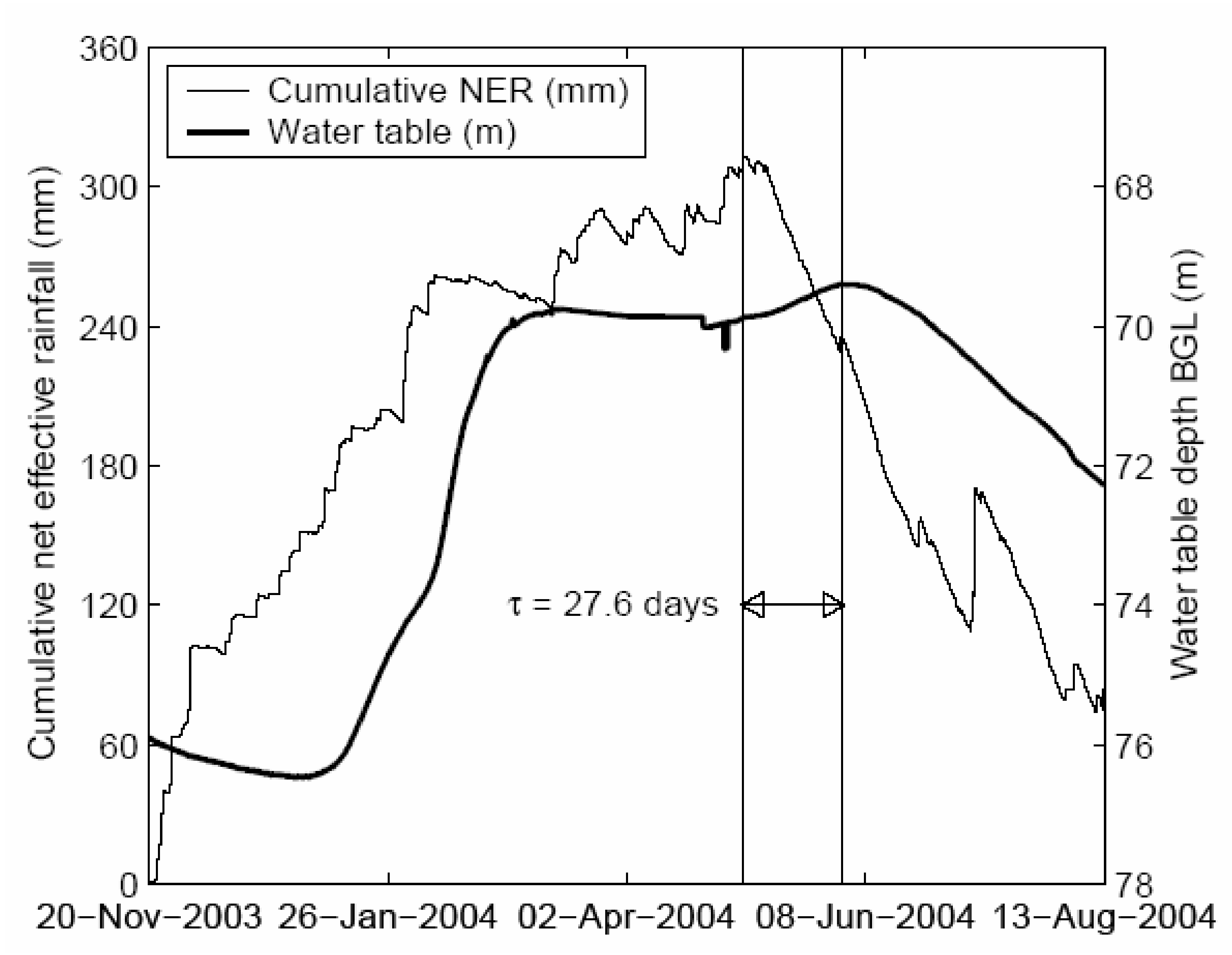
Recharge site instrumentation



Chalk unsaturated zone and groundwater - recharge period

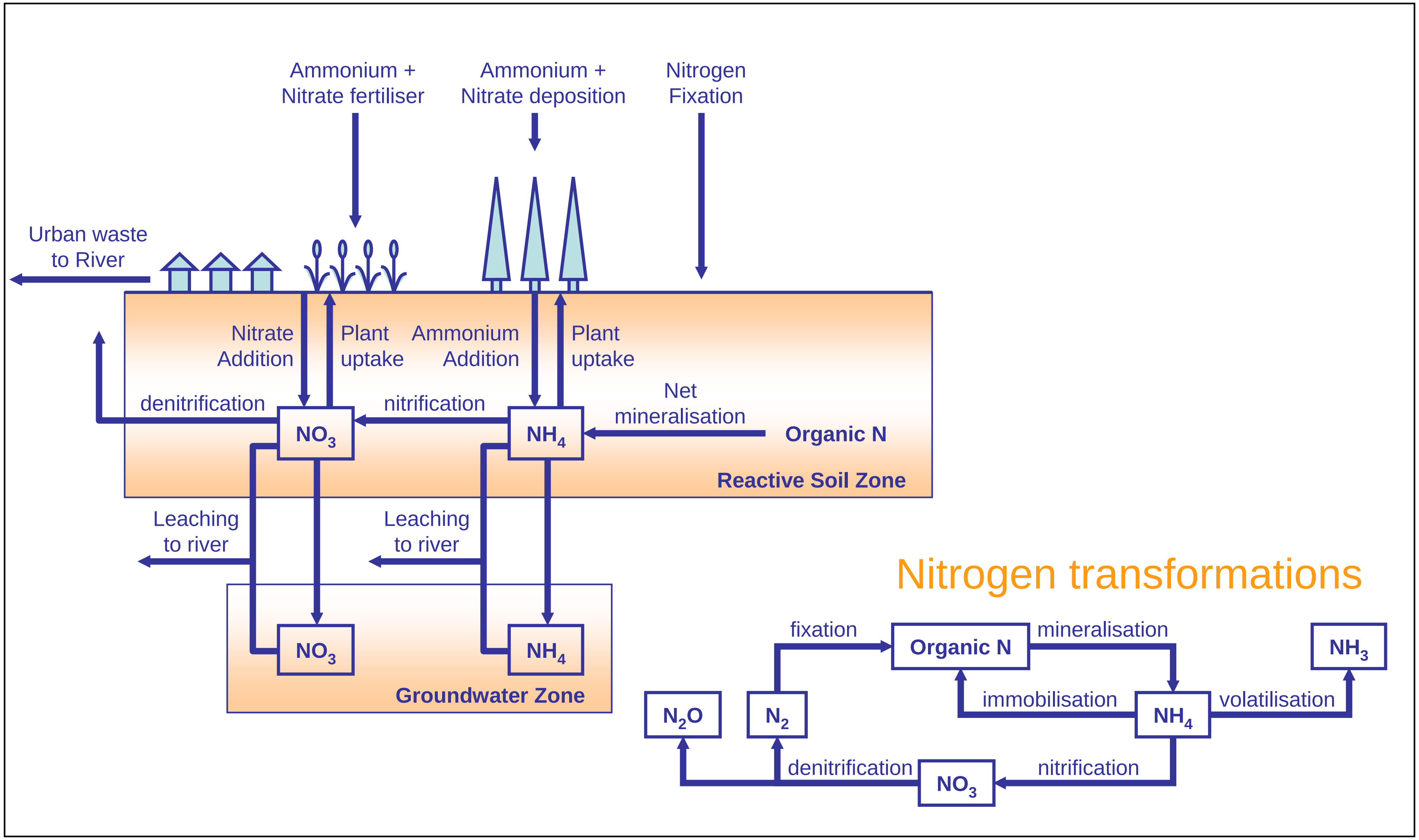


Effective rainfall and groundwater rise

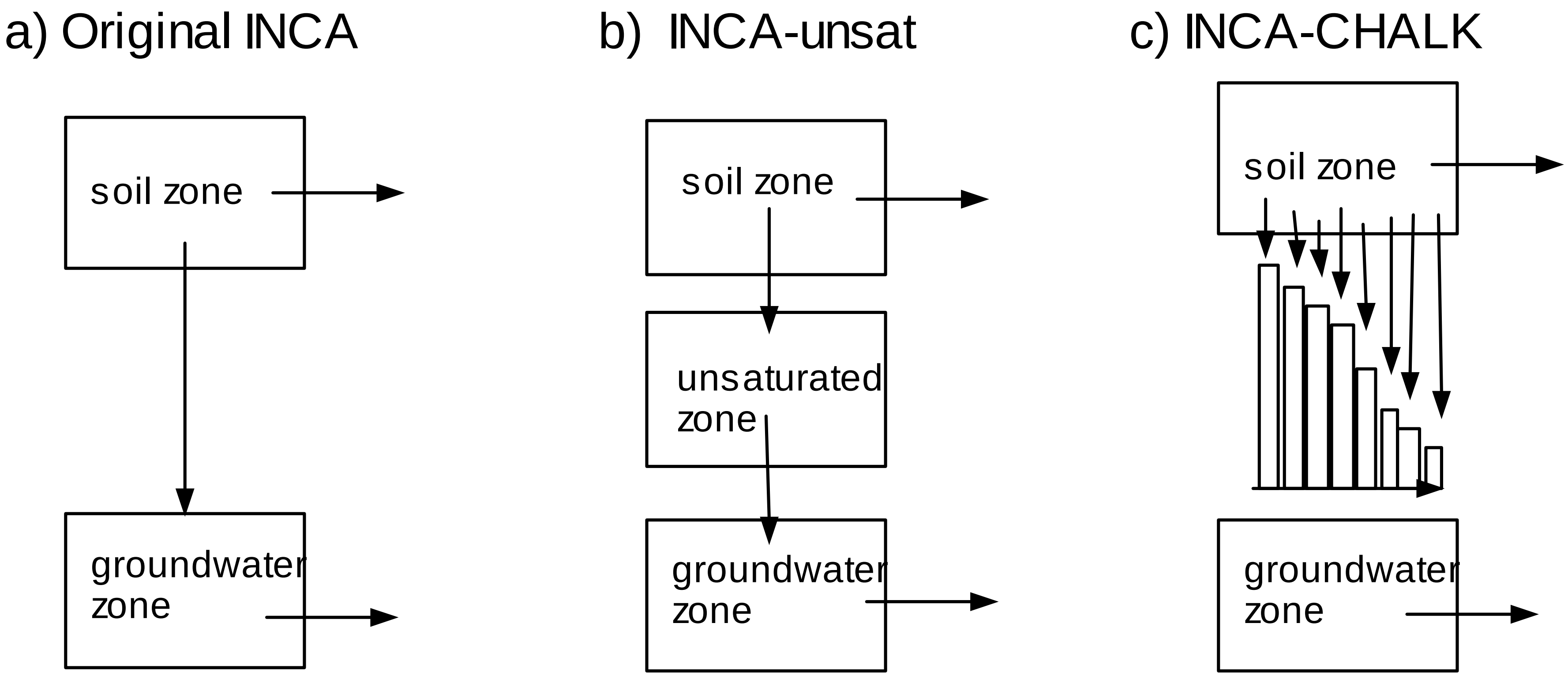


Modelling nutrients at catchment-scale

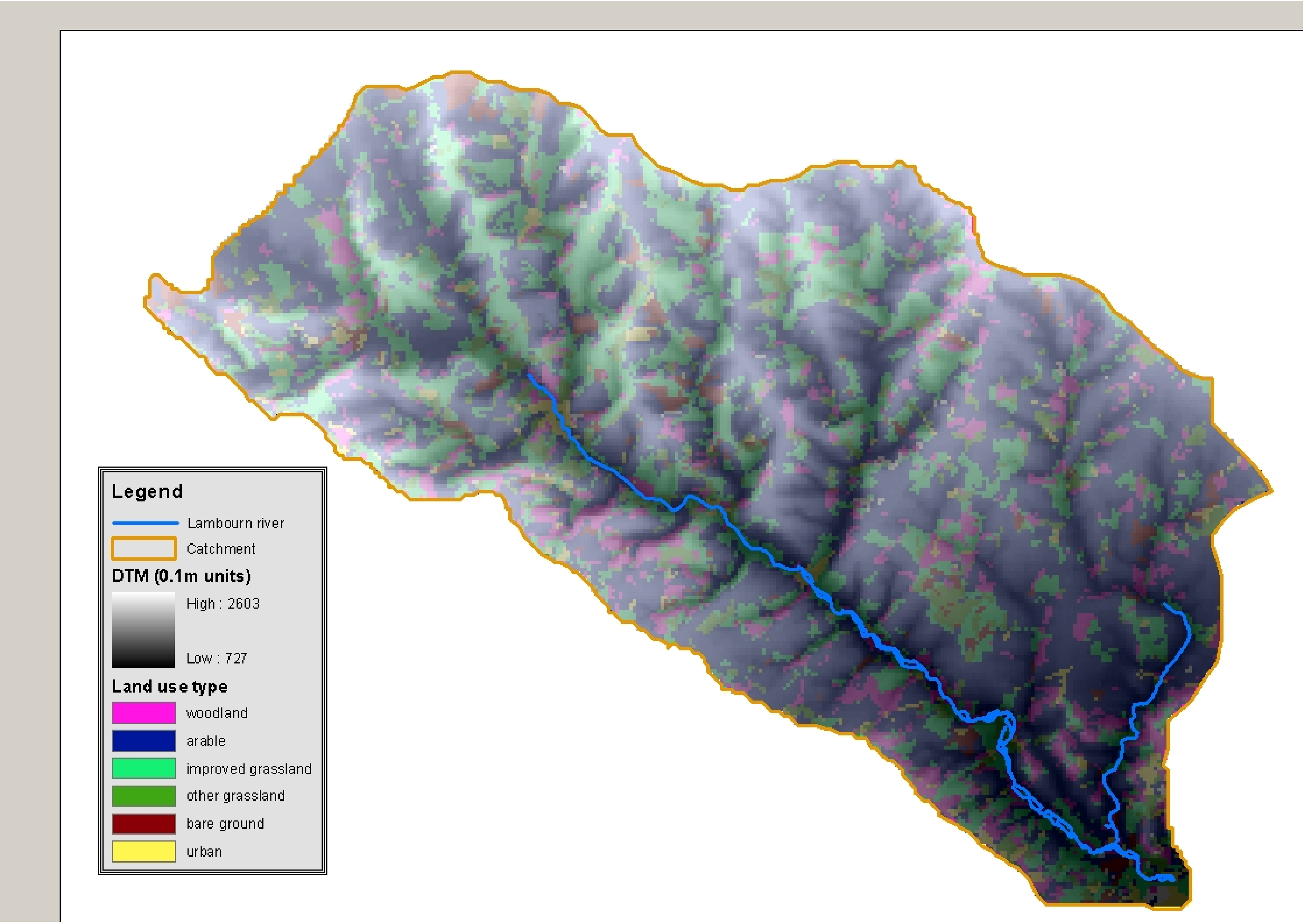
INCA nitrogen pathways and transformations



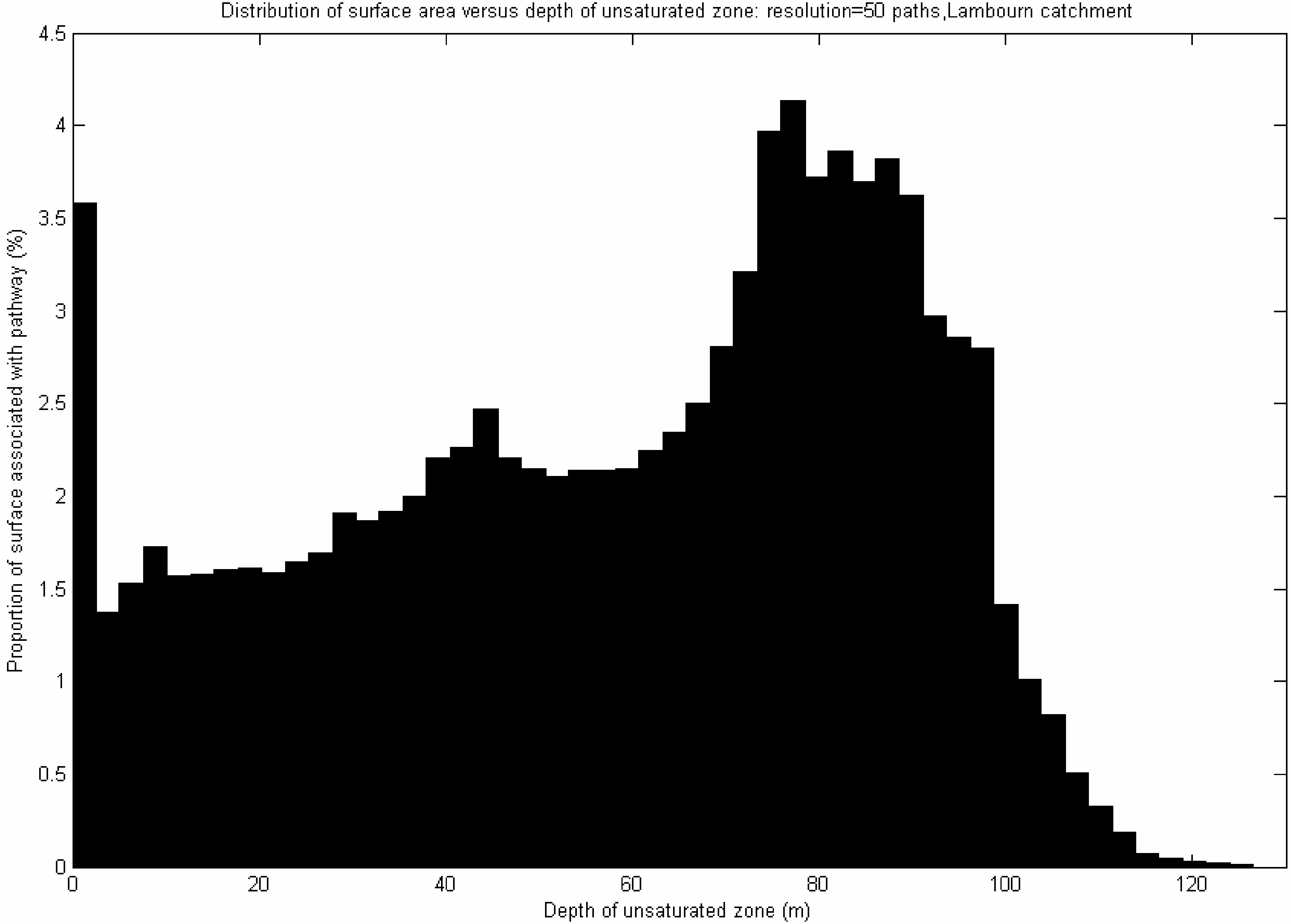
INCA-Chalk


a) Original INCA
b) INCA-unsat
c) INCA-CHALK
soil zone
groundwater zone
soil zone
unsaturated zone
groundwater zone
soil zone
groundwater zone

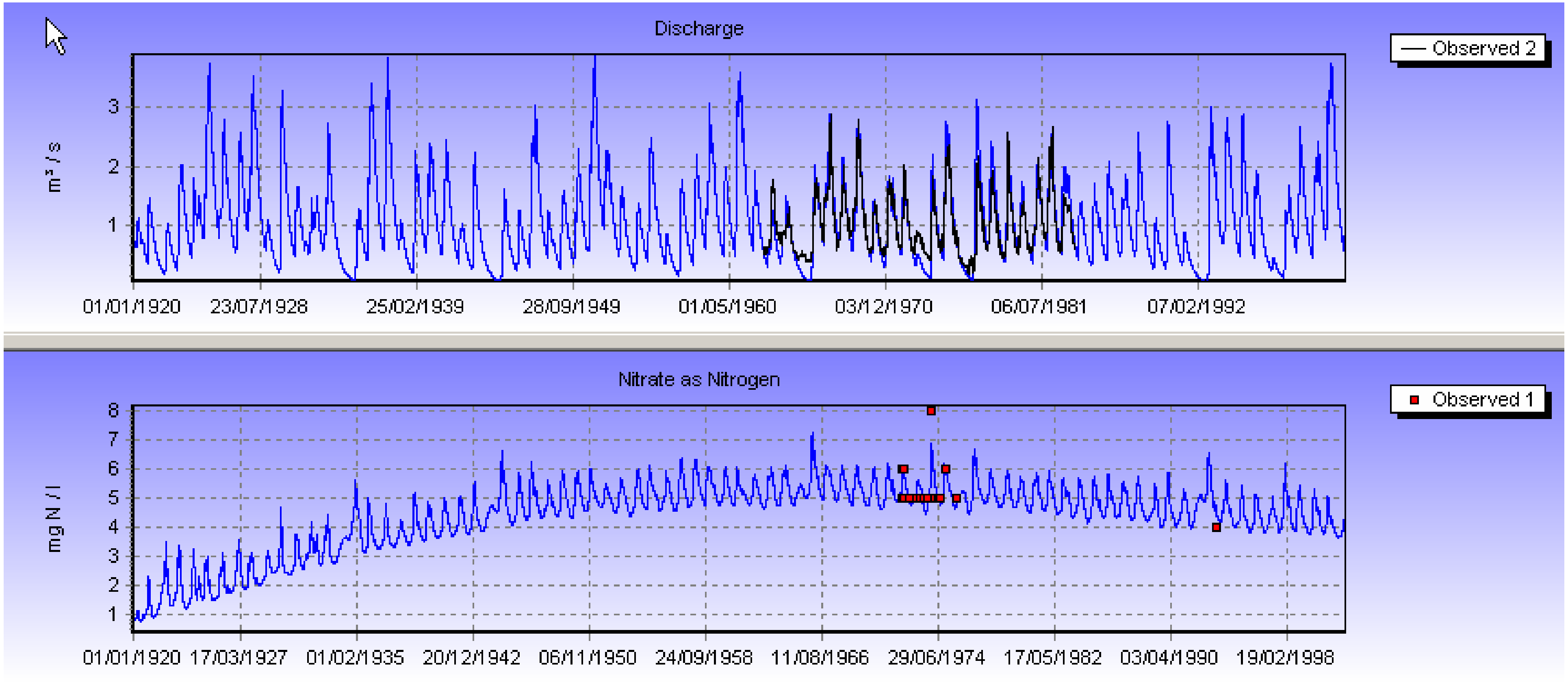
Initial trial: Lambourn catchment



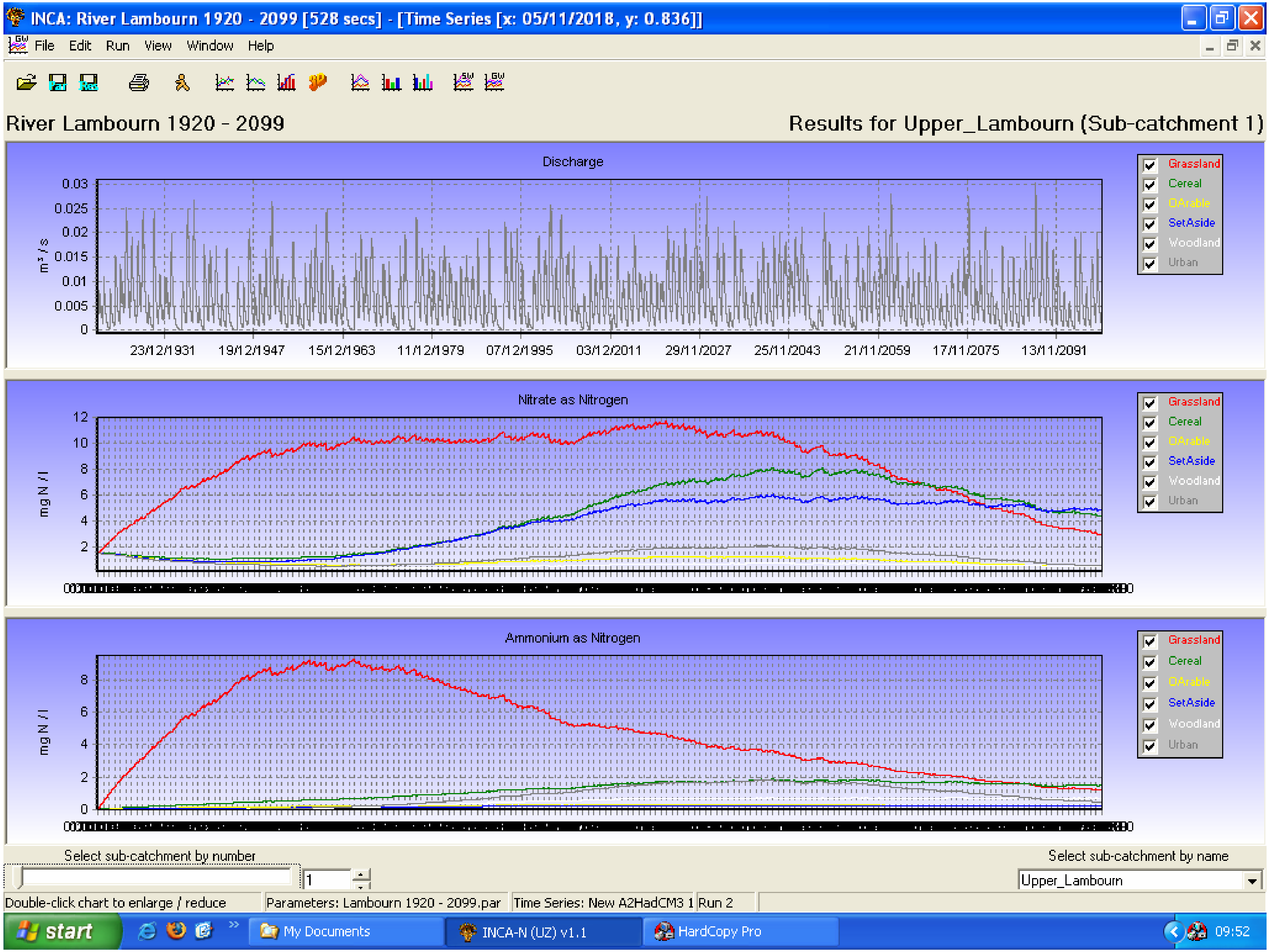
Travel time distributions through unsaturated zone



Hindcast simulation, INCA-Chalk, Lambourn: simulated versus observed flow and nitrate at Welford (EA data)



Groundwater with A2HADCM3 scenario, nitrate loading cut to zero from 2003



Some conclusions (1)

- Hydrological science has some way to go before understanding these Chalk systems can be thought of as sufficient to adequately manage water quality, wetlands, and individual abstractions without significant risk of error
- The management of riverine and riparian ecology requires a more detailed understanding of flow regimes than we currently have
- Interpretation of pumped borehole data can be misleading – the construction of a borehole and perturbation by pumping can change flow paths
- Unsaturated processes are important in solute transmission, in maintaining evaporation and potentially in maintaining drought flows

Some conclusions (2)

- At present regional numerical models simulate very few of the mechanisms discussed. The development of appropriate models to represent this sort of complexity is needed to help understand, predict behaviour of and design monitoring for catchments under changing land use and climate
- However, numerical models are the only way forward to integrate diverse data sets and provide a unified interpretation of hydrological and hydrogeological response – the EA plans for progressive development of regional models are an important step in this direction
- Simplified models can represent important characteristics of catchment-scale flow and solute transport, and provide useful support for policy and catchment scale management
- Integrated multidisciplinary research is essential to improve our understanding of groundwater systems; current momentum should be maintained