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Fluvial carbon flux within and from peatlands: impacts of management

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Important forms of fluvial carbon in peatlands

- Dissolved organic carbon
- Dissolved inorganic carbon including:
    - Bicarbonates or carbonates
    - Dissolved free CO_2
    - Dissolved free CH_4
- Particulate organic carbon
- Particulate inorganic carbon (rarely measured in peatland studies…)

Also note the continuum from particulate to dissolved forms (despite how we measure them)

Sources of fluvial carbon in peatlands

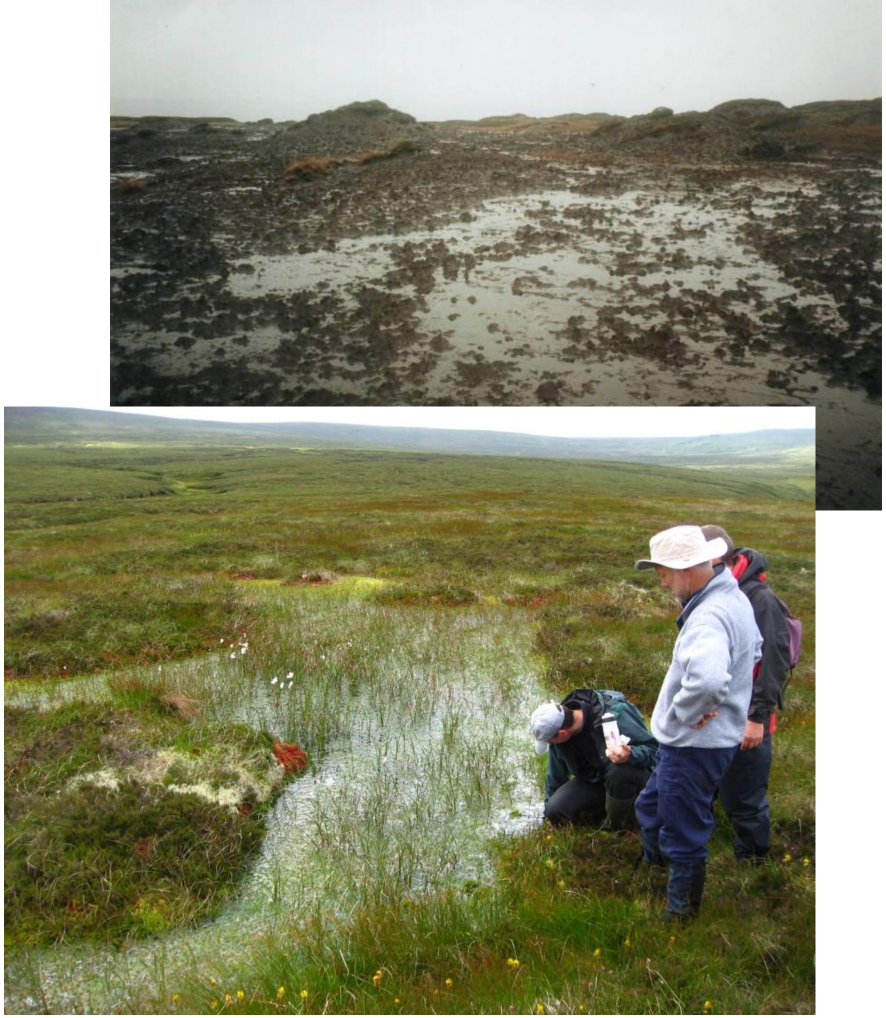
POC and PIC - Physical fluvial erosion

POC - Physical wind erosion (or splash-assisted wind erosion; Foulds and Warburton, 2007; ESP&L)

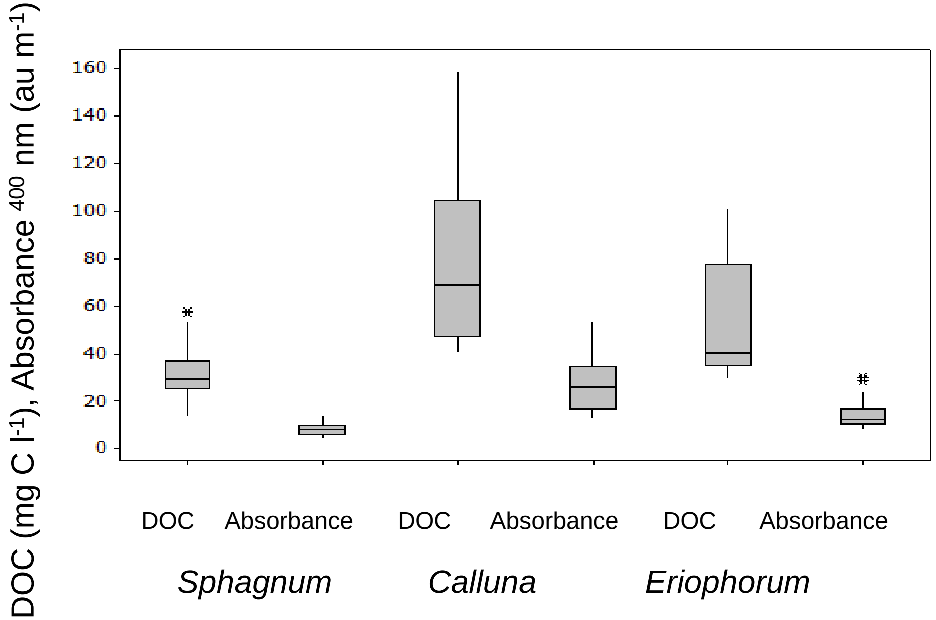
DOC – Biogeochemical processing

Dissolved CH_4 and CO_2 - Soil and root respiration then dissolved in water or in-stream or redeposited sediment processing

Mediated by vegetation cover



Vegetation matters…



The molinia question = an excellent peat forming vegetation

Fred and I are currently doing a study for Yorkshire Water of molinia sites and the C budget c.f. other vegetation covers.

Transport of fluvial carbon in peatlands

Overland flow - typically saturation-excess driven.

Micropore throughflow - typically close to the surface. DOC pore water signal from upper few cm often similar to stream water signal. But DOC and dissolved CO_2 ages/sources appear different - Billett et al 2007)

Macropore/tunnel/pipe ‘bypassing’ flow

Stream network, pools, peat mass, pipes, riparian zones – connectivity of these components and transformations that take place across and between them

Importance of fluvial components

Auchencorth Moss, Scotland: aquatic losses of C = 41 % of NEE, 12-14 % of NEE CO_2-eq. (Dinsmore et al; in press GCB)

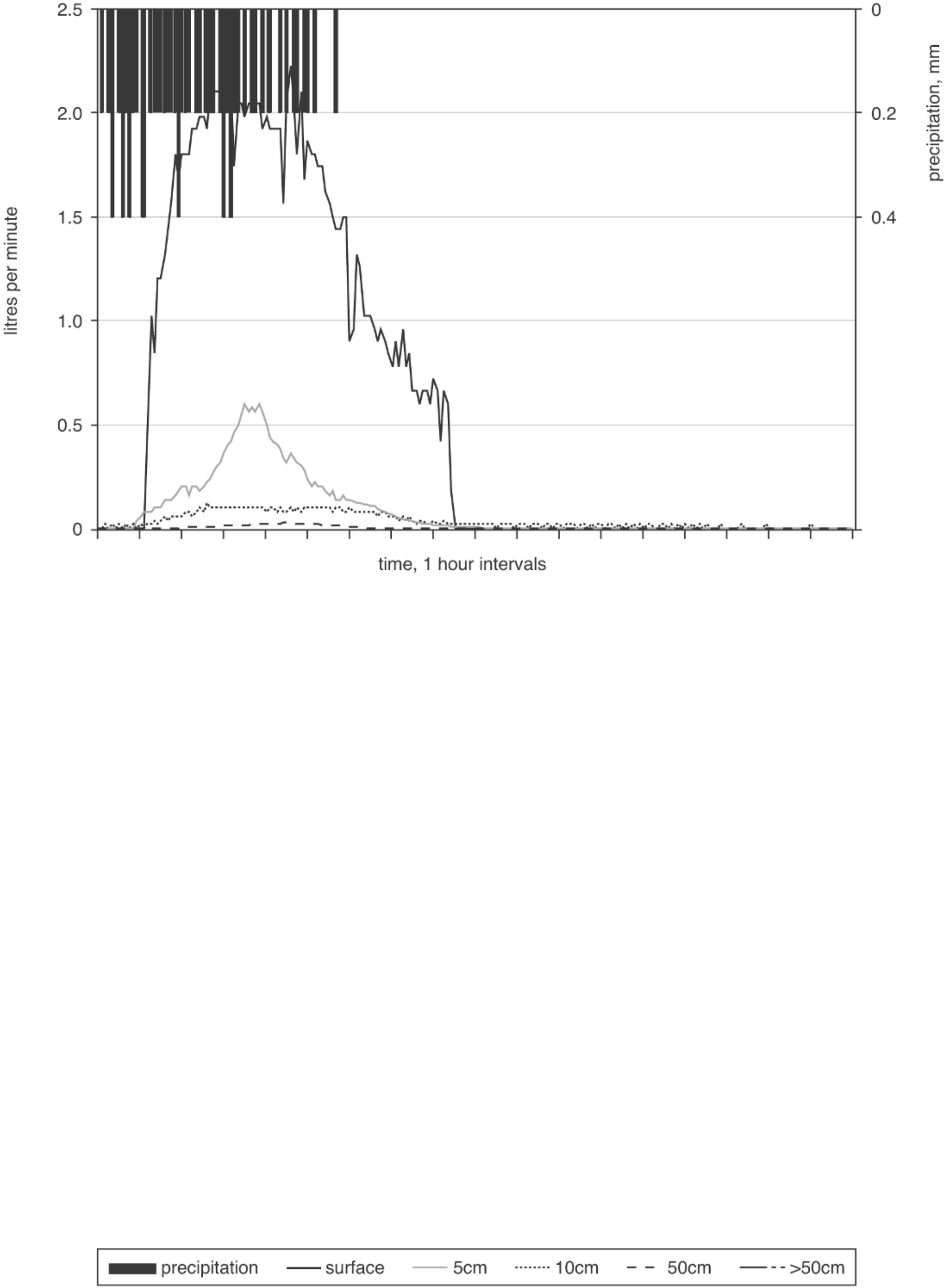
Mer Bleue: aquatic losses of C = 51 % of NEE, 14 % of NEE CO_2-eq. uptake and (Roulet et al., 2007; GCB)

N. Sweden: aquatic losses of C = 31 - 37 % (2yrs) of NEE CO_2-eq. uptake (Nilsson et al 2008; GCB)

DOC is typically the most important aquatic component of the C budget (may often be up to 50 % of NEE C uptake; more typically 10-30 %)

However, in degraded peatlands POC can be more important

UK figures compiled by Evans and Warburton (2008) show: can lose 265 t km^{-1} yr^{-1} of sediment (Evans et al 2006) c.f. intact peatlands where typical rates are 3-12 t km^{-1} yr^{-1}

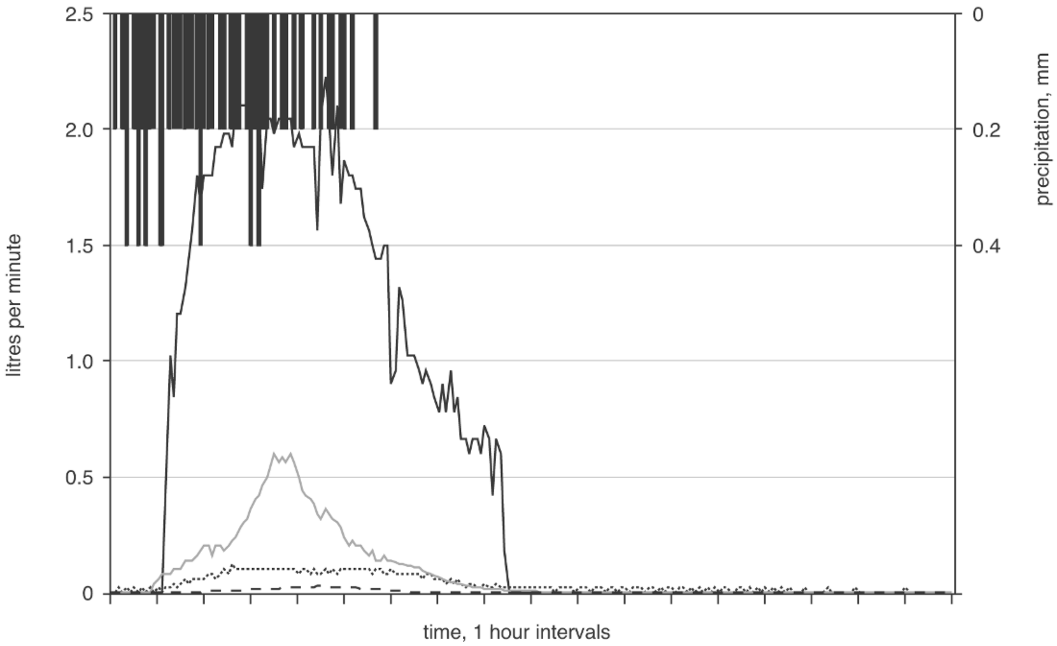


intact

% runoff from Oct 2002-2004 from different peat layers:

0-1cm	76 %
1-5cm	17 %
5-10cm	6%
10-50cm	1 %
50 cm +	0 %

So what effect do peatland drains have on peat hydrology?



intact

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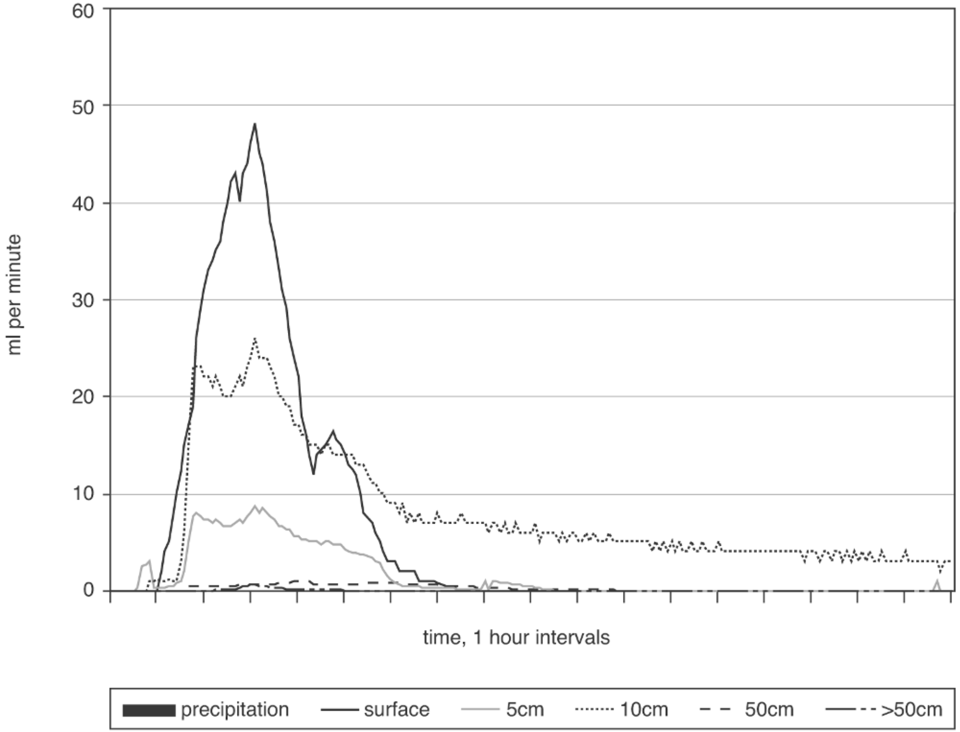


drained

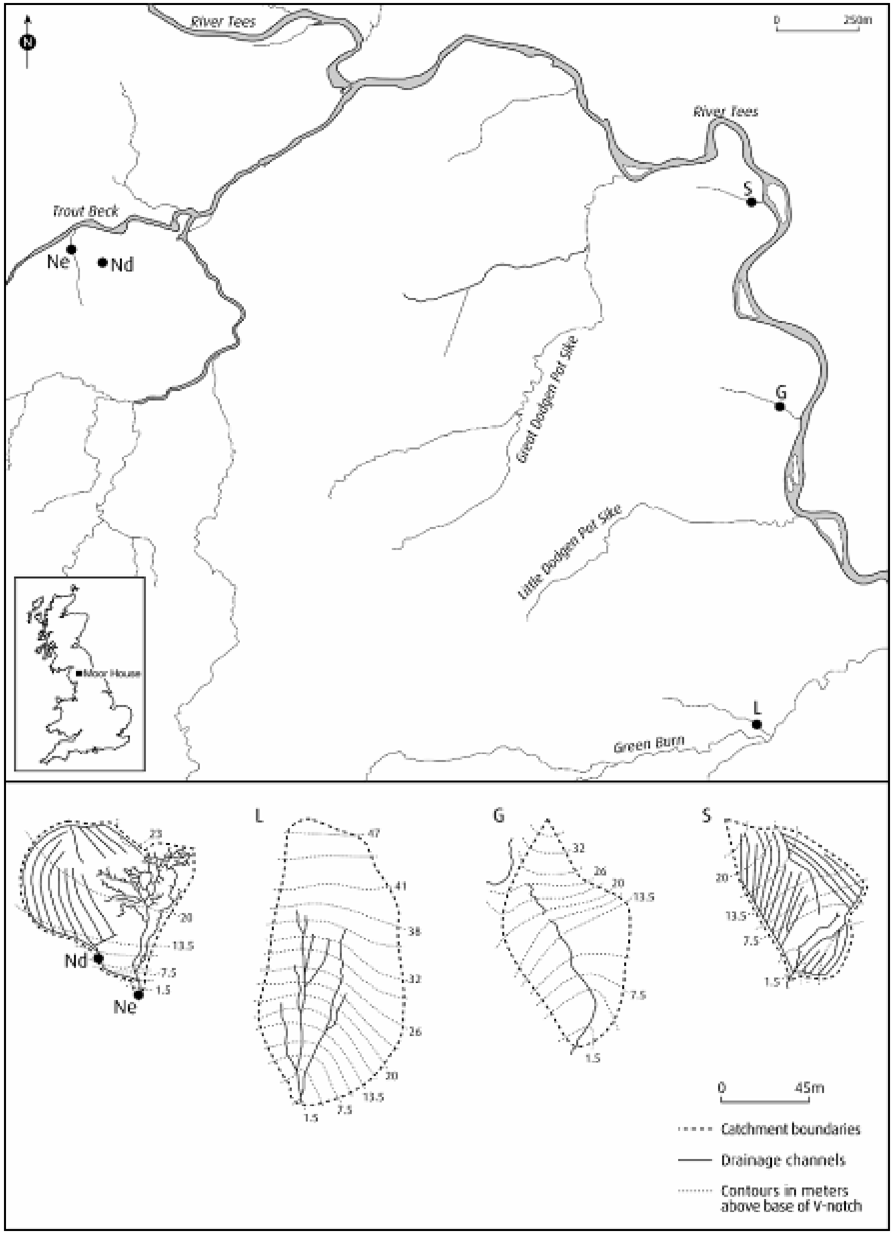
% runoff from Oct 2002-2004
from different peat layers:

0-1cm	37 %
1-5cm	12 %
5-10cm	25%
10-50cm	15 %
50 cm +	11 %

Reported hydrological effects of moorland drainage

	Temp Store	Flood peak	annual runoff	Meas. scale	Proc. Meas.	Process discussion
Lewis 1957	↓	↑	↑	C	X	storage
Oliver 1958		↑		C	X	storage
Howe 1960		↑	↑	X	X	X
Conway & Millar 1960	↓	↑	↑	H	X	Storage, burning
Mustona 1964		↑		H	X	X
Burke 1967	↑	↓	↑	H	WT	storage
Howe et al. 1967		↑	↑	C	X	drainage density
Baden & Egglesmann 1970	↑	↓		H	X	storage, OLF
Inst. of Hydrology 1972		↑	↑	C	X	storage
Moklyak et al. 1975	↑ ↓	↑ ↓	↑ ↓	C	X	YES - lots
Heikurainen 1976	↑	↓		H	X	X
Ahti 1980	↓	↑		H	X	drainage density
Robinson 1986	↓	↑	↑	H	X	YES - lots
Newson & Robinson 1983		↓	↑	C	X	Catch. character.
Guertin et al. 1987		↑		X	X	X
Gunn & Walker 2000	↓	↑	↑	H	X	veg. changes

Holden et al. (2004) Progress in Physical Geography



Conway and Millar (1960) showed drainage:

-increased peak flows

-Increased annual water yield

- decreased low flows

Long-term river flow change?

- Compared data from 1950s with 2002-2004
- No change for undrained catchments in water yield or storm hydrograph characteristics
- Drained catchments had changed:
  - Lower peak flows
  - Significantly increased yield (15 %)
  - Greater low flows
- Short-term studies immediately after drainage do not capture full nature of hydrological response and caution needed if predicting long-term change

Holden, Evans et al (2006) J. Environmental Quality

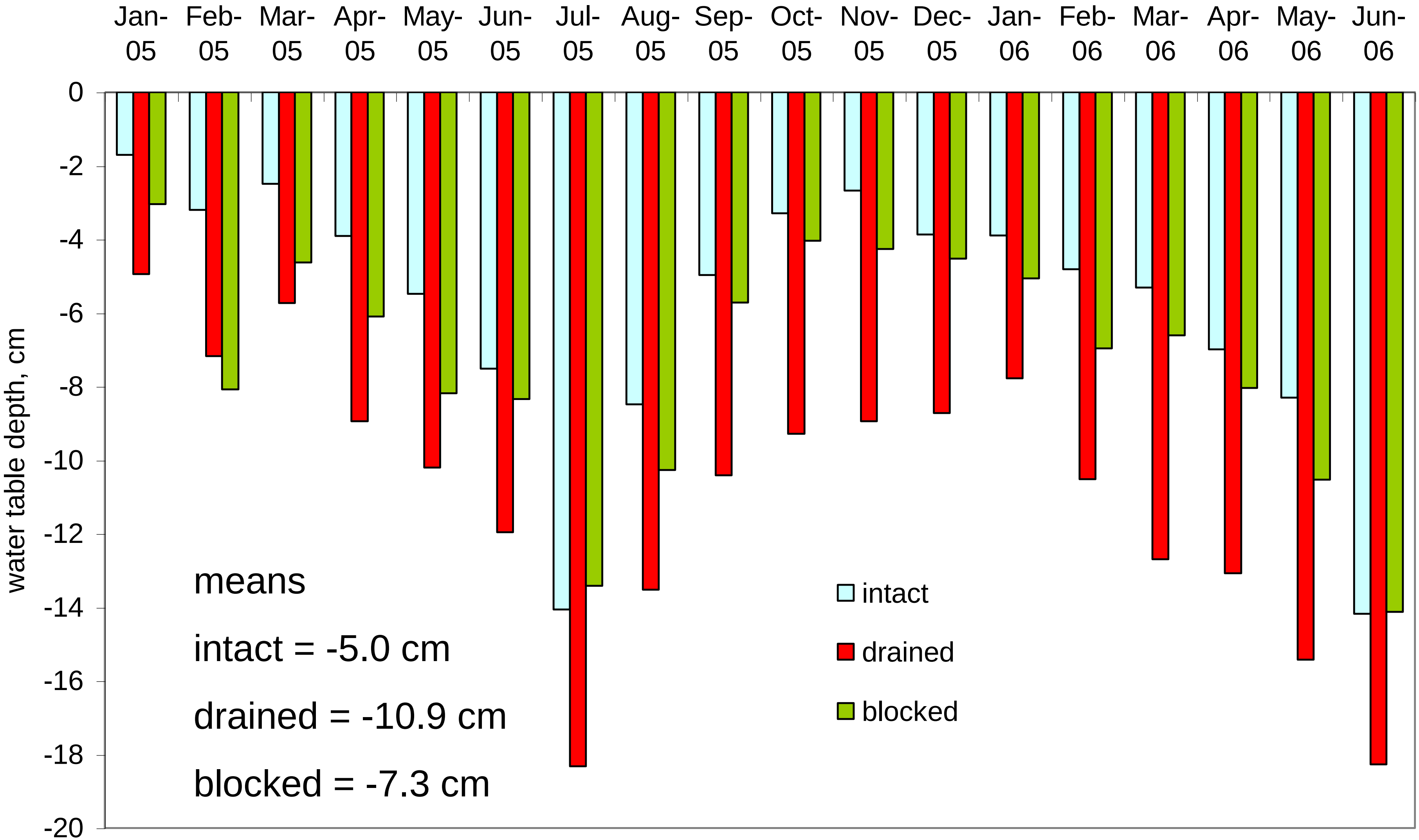
Grip-blocking

3 automated transects across intact, drained and blocked sites; identical slope, aspect, peat depth etc and within 1 km of each other

9 recorders per transect running perpendicular to grips and the slope and sampled with reference to grip location

15, 2 and 1m upslope, 1, 2, 3, 14, 24 and 34m downslope (also 2m upslope of next drain) (36m drain spacing)

Monthly mean water table depth at each site Jan 2005 to June 2006



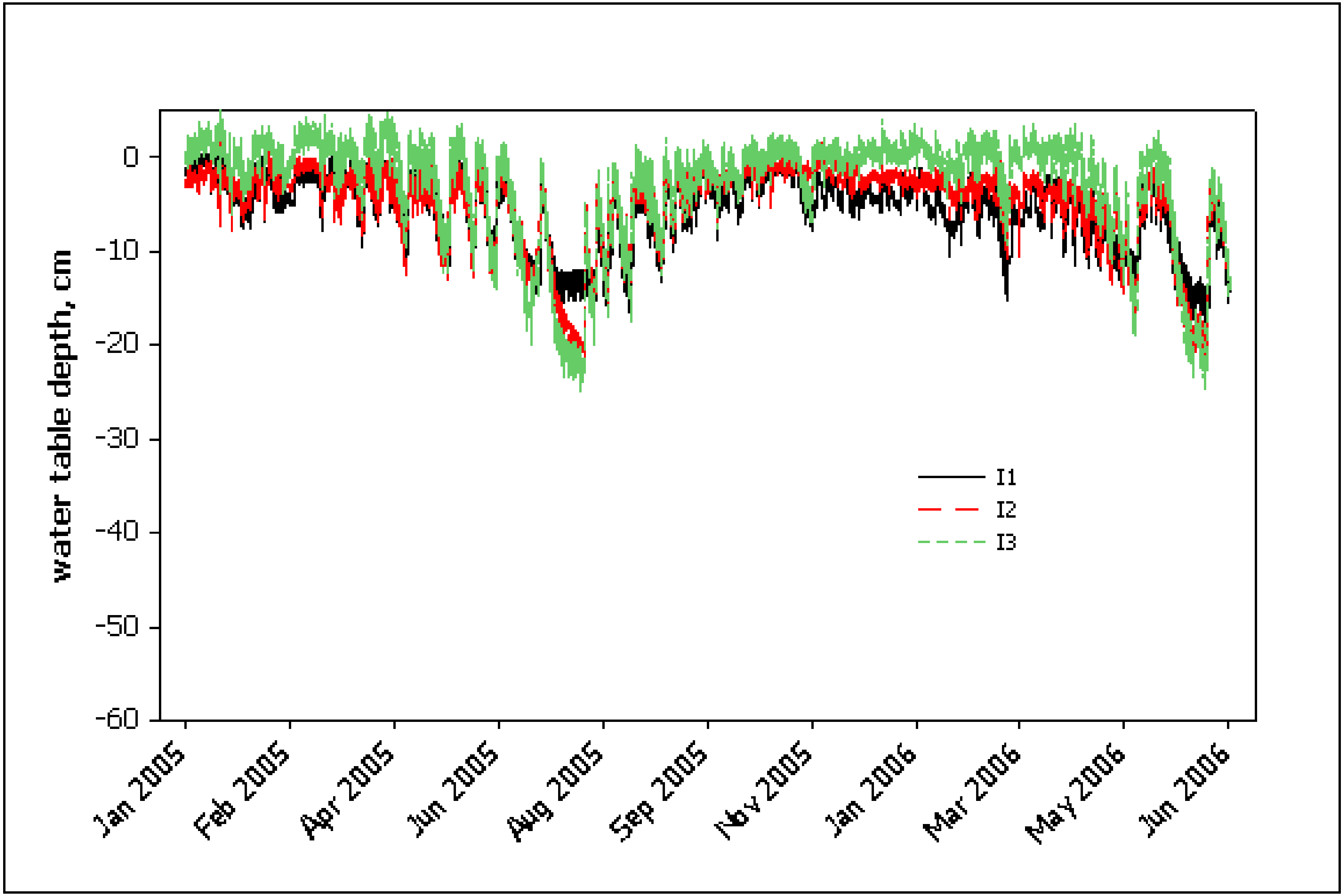
means

intact = -5.0 cm

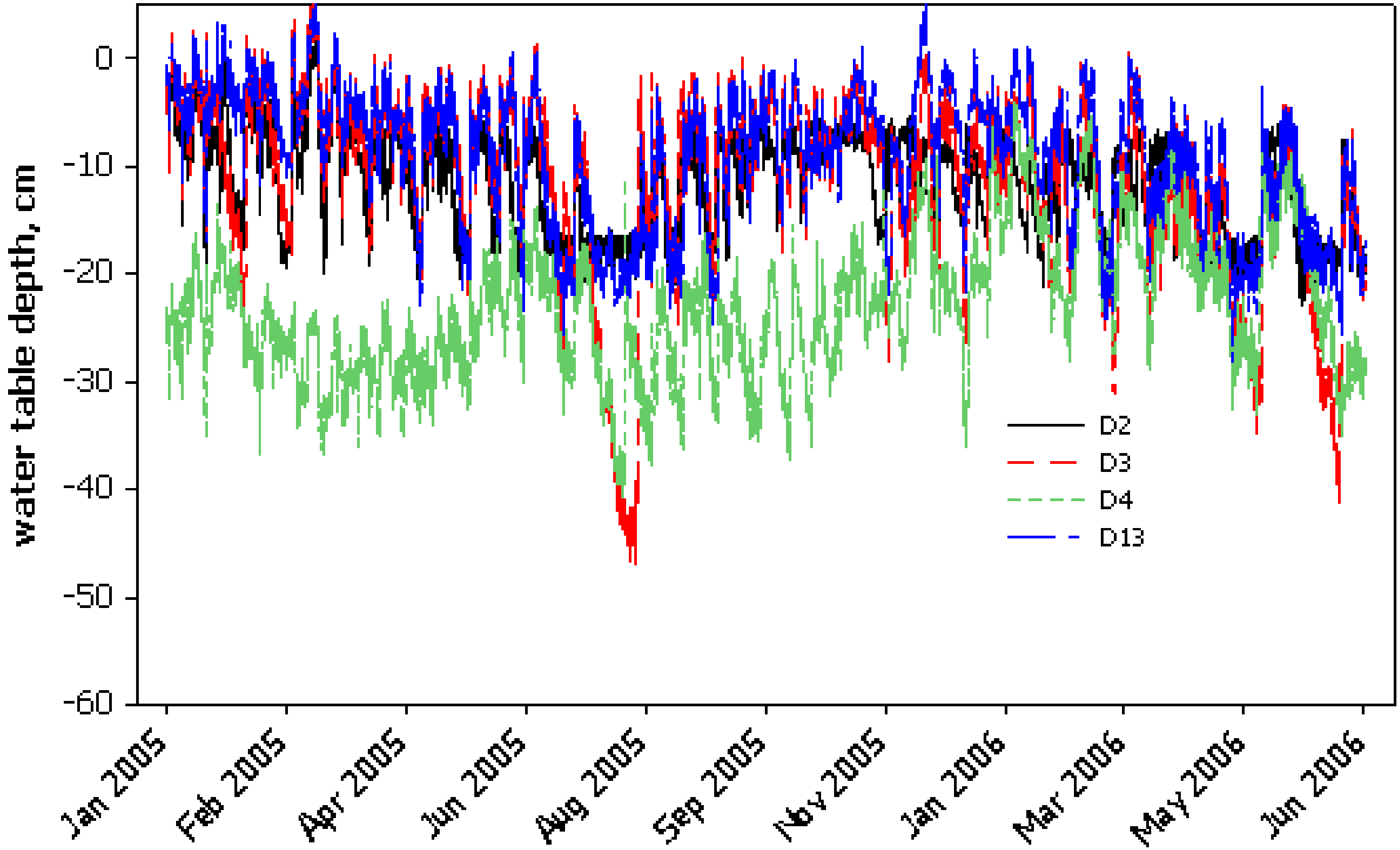
drained = -10.9 cm

blocked = -7.3 cm

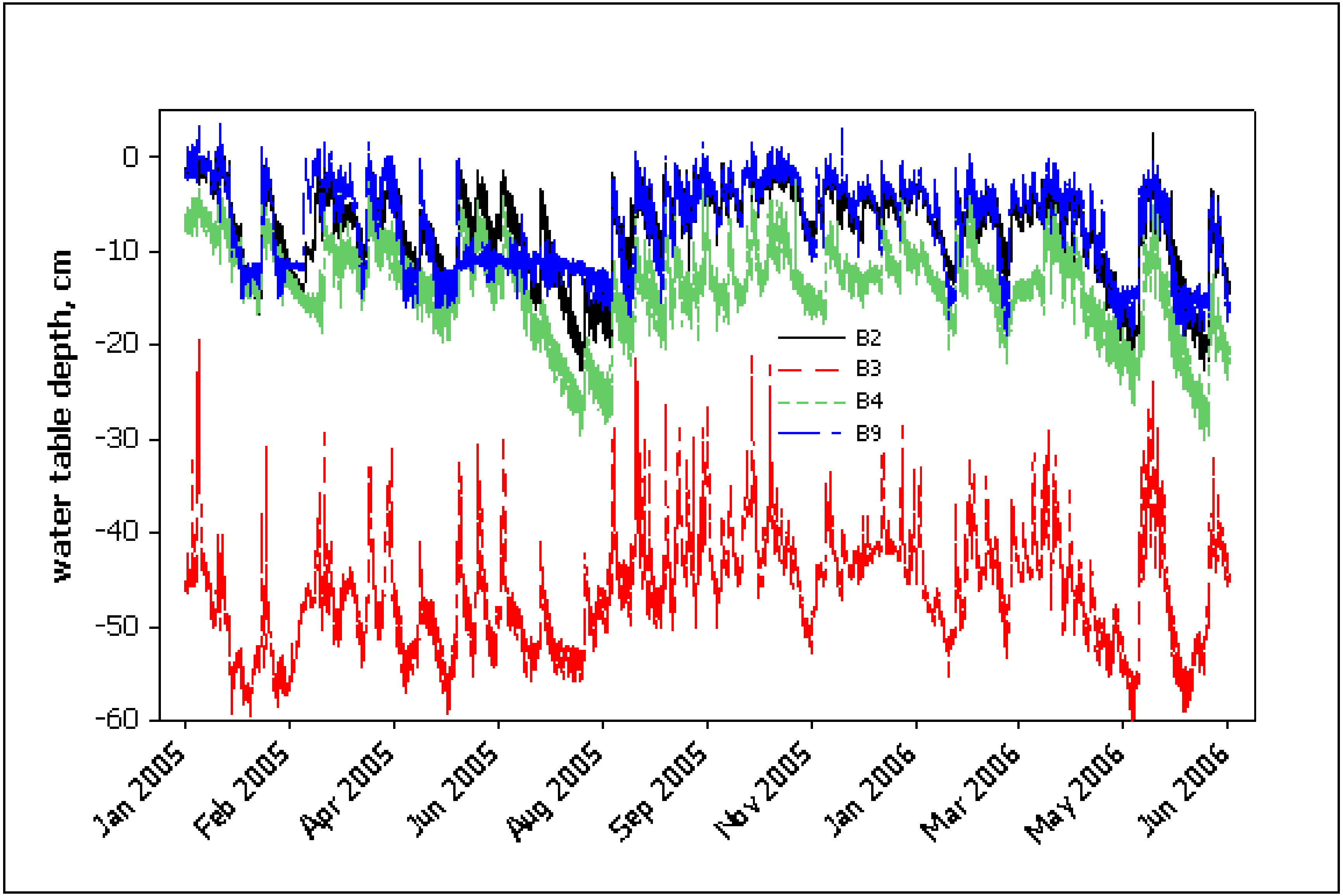
Example intact water table record (20 min intervals)

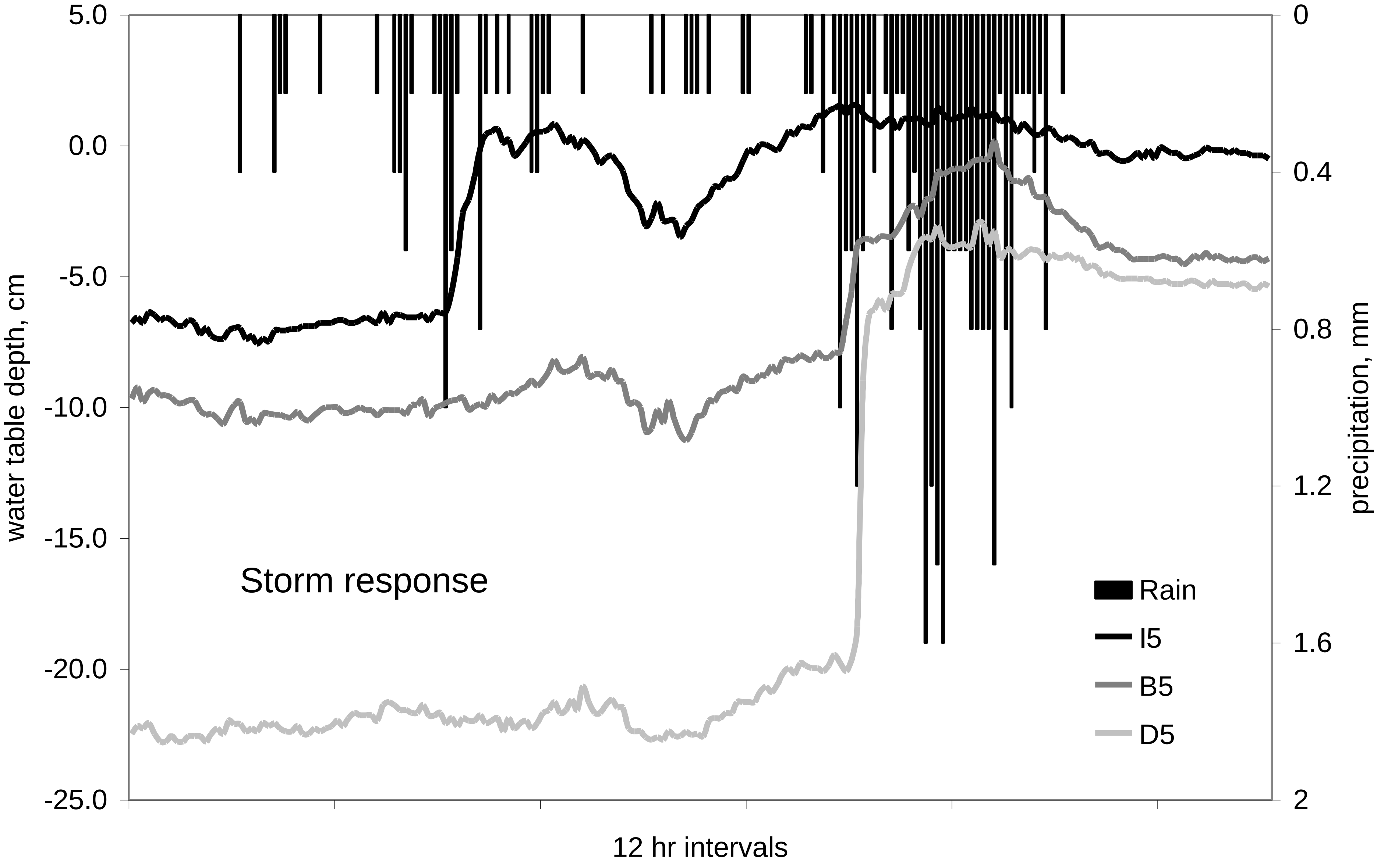


Example drained water table record (20 min interval)

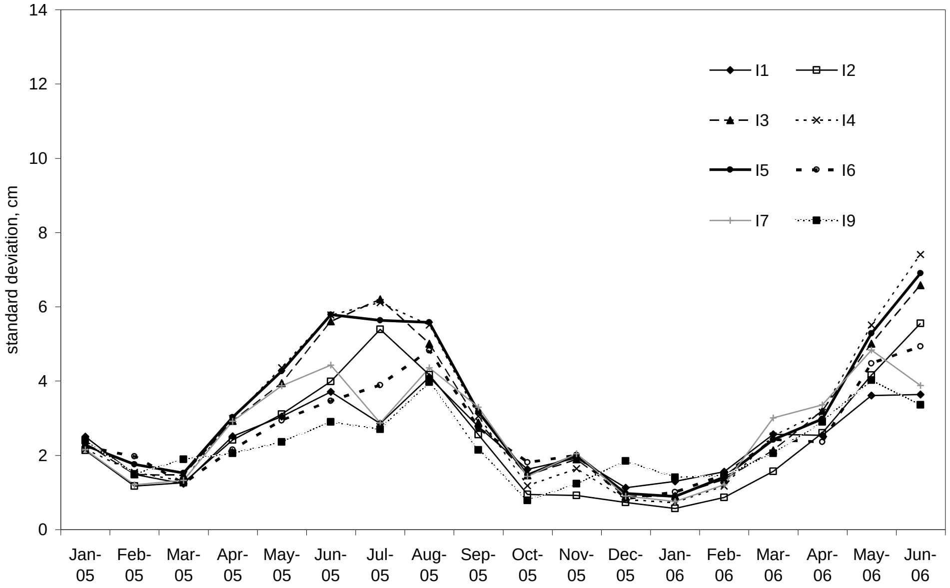


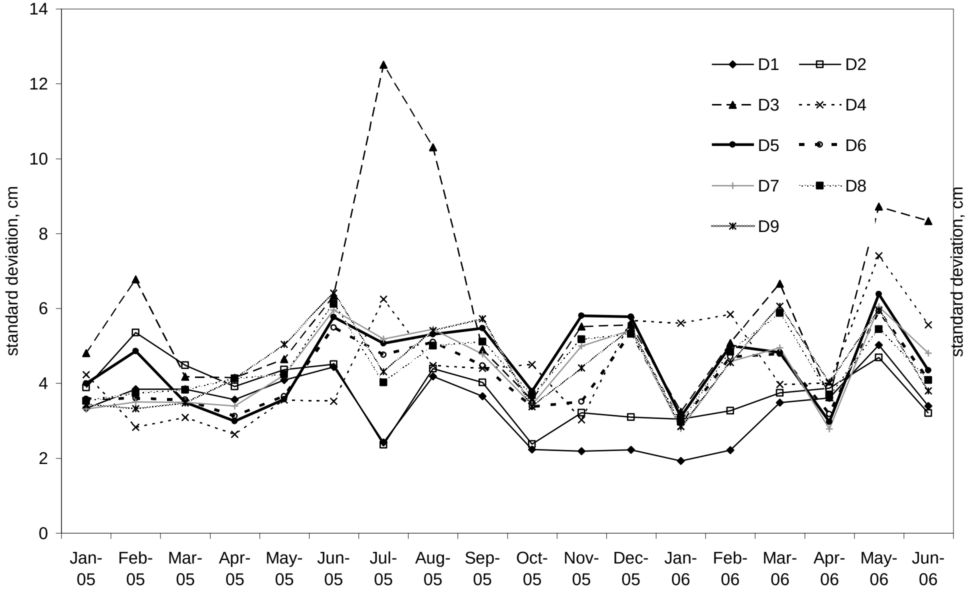
Example blocked water table record (20 min interval)

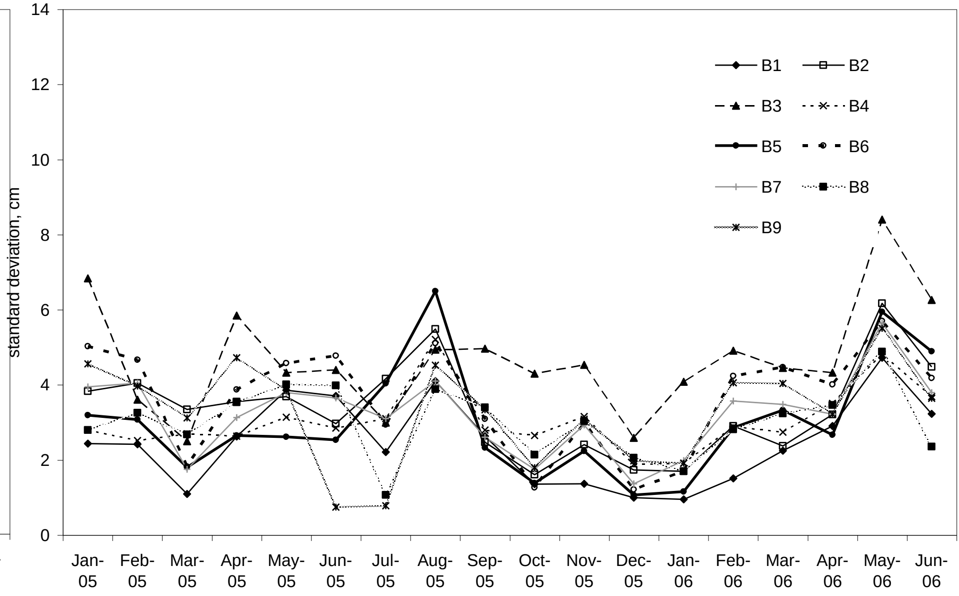



5.0
0.0
-5.0
-10.0
-15.0
-20.0
-25.0
water table depth, cm
0
0.4
0.8
1.2
1.6
2
precipitation, mm
Storm response
Rain
I5
B5
D5
12 hr intervals

Standard deviation patterns in water table for each month







National survey of drain blocking

- DOC less overall from blocked drains

- Not true everywhere so you have to accept at some sites that DOC won’t decrease (at least in short-term)

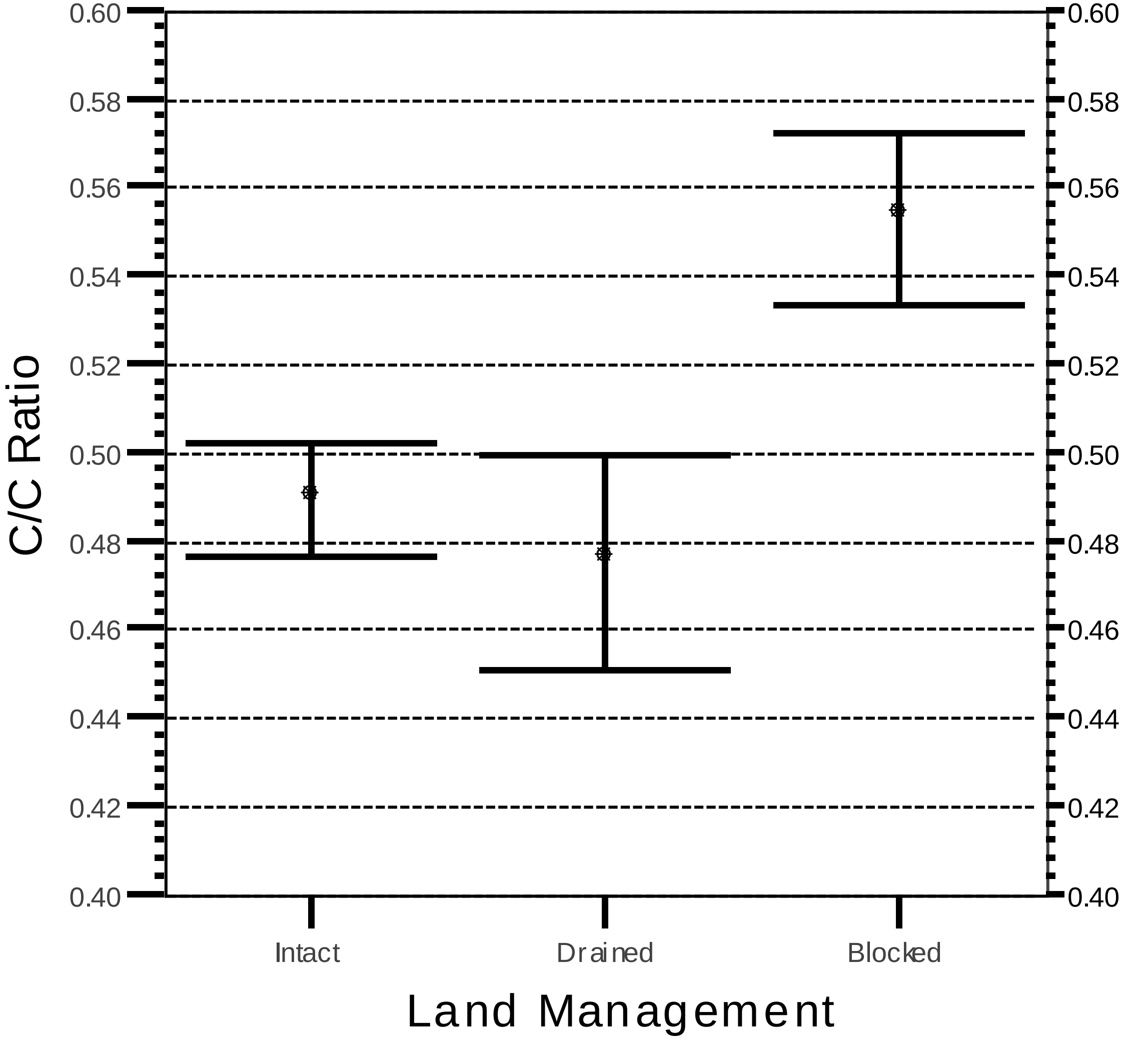
Armstrong, Holden et al (2009) Journal of Environmental Management

Armstrong, Holden et al. (in review) Journal of Hydrology

DOC constituents changed

- Colour decreased in blocked drains
- Ratio of carbon to colour significantly increased
- For each unit of colour the DOC content was greater

- Treatability issues



Wallage, Holden and McDonald (2006) Science of the Total Environment

POC loss is significantly reduced by drain blocking

- Upper Wharfedale - drains were found to be major sources of suspended sediment with 18·3% of the sediment originating from the unblocked drains which drained 7·3% of the area.

- The winter quarter of the year was more important than other seasons for producing suspended sediment, even though precipitation totals were not greatest during this period.

- Drains which had been dammed at intervals along their length using peat blocks had very low sediment yields. Even poorly dammed drains, where water could still flow along the full course of the drain, had 54 times less suspended sediment production than unblocked drains.

- Could be >100 fold decrease from well blocked drains in sediment yields

Holden et al., (2007) Earth Surface Processes and Landforms

Fluvial degassing

Research has suggested peatland headwaters are hotspots for degassing with waters that are supersaturated in CH_4 and CO_2 (e.g. Jones and Mullholand, 1998; Hope et al 2001; Billett and Moore 2008; McNamara et al., 2008).

More rapid degassing when the stream system is turbulent

This aquatic loss to the atmosphere of CO_2 and CH_4 needs to be included in carbon and GHG budgets for peatlands – may represent c. 15 % of the NEE CO_2 - eq. So we should not just be measuring GHG emissions from the peatland surface, but also from the waterbodies too !

Pools may well be hotspots for degassing (Waddington and Roulet, 1997) and pipe outlets are too…

The methane problem

Pools are hotspots of degassing – yet we are creating thousands of them by the way we are blocking drains or creating bunds

Most damaged peatlands release large quantities of greenhouse gases, particularly CO_2, thereby contributing to the enhanced greenhouse effect or ‘global warming’.

Restoration of these damaged peatlands is promoted as a means of restarting their carbon sink function so that they take up or sequester more carbon from the atmosphere in the form of CO_2 than they release to it; that is, so that they act as a 'brake' on global warming.

But methane is potent greenhouse gas – hence a Defra review

Defra methane review I

A questionnaire survey of international scientists + workshop of UK experts were complemented the literature review.

General conclusions

Across all peatland types, very little work on restoration impacts on CH_4 emissions and how such emissions affect the carbon sink function. Work has started but more work is needed especially in blanket bogs and fens. Despite the lack of work, it is possible to make the following tentative general conclusions:

Restoration does not necessarily lead to a peatland becoming a carbon sink (either in terms of a simple carbon balance or in terms of its effect on global warming potential): it should not be assumed that all restored peatlands are carbon sinks.

Methane is often an important component of the carbon balance of restored peatlands when considered in terms of global warming potential even when, in terms of mass, CH_4 losses are only a few percent (3-5%) of the net exchange of CO_2 between the peatland and the atmosphere.

Defra methane review II

Restored peatlands have less of an impact on global warming than unrestored peatlands.

Thus, although they may not be carbon sinks, they have a smaller global warming potential than damaged peatlands.

Restoration is therefore generally beneficial from a global warming point of view. However, we did find examples of restored peatlands that had higher GWPs than unrestored peatlands; much seems to depend on the nature of damage and the type of restoration.

Methane is only part of the picture. An important pathway of carbon loss from peatlands is flowing water. Losses of fluvial dissolved CO_2 and DOC are important.

Off-site transformations

A priority area for research

DOC and POC make it ‘off site’ (Jonsson et al., 2007; JoH).

You could say that a worst-case scenario is to assume and that all DOC and POC is eventually transformed downstream to CO_2 which is then lost to the atmosphere. In the UK many water companies want this to happen and may actively promote it.

However, some DOC and POC almost certainly will end in long-term sedimentary storage where it may reside for decades or centuries.

But – DOC and POC stored in sediments may decompose anaerobically in lakes, rivers and estuaries and produce CH_4

Defra methane review III

<u>Blanket peatlands:</u>

•Much blanket bog restoration involves blocking of drainage ditches. Those methods of ditch or drain blocking that do not create additional areas of open water are preferred over those that do (CH4 emissions tend to be higher from areas of standing water).

•Research is needed on how drain blocking affects CH4 and DOC losses from blanket peat, including previously-afforested blanket peat. Studies should be conducted over several years (to reduce uncertainty in the findings caused by inter-annual variability in weather conditions). Care should be taken to ensure a sufficient number of damaged and restored areas are compared to reduce the chance of site-specific factors confounding the 'bigger picture'.

Defra methane review IV

Raised bog:

Blocked ditches = hotspots of CH4 emissions. Bunded areas with open water and sedges may also be important hotspots. Where possible areas of open water on restored raised bogs should be minimised.

Research is needed on how carbon-balance processes are affected when afforested bogs are restored & the carbon balance of wet sedge communities (are high emissions of CH_4 from these communities offset by high rates of net CO_2 uptake?).

Fens:

There is apparently no published work on how restoration of cultivated fen peat affects the carbon balance. Work on abandoned cultivated peatlands in Finland suggests that even simple cessation of arable agriculture leads to a lowering of the global warming potential of fens.

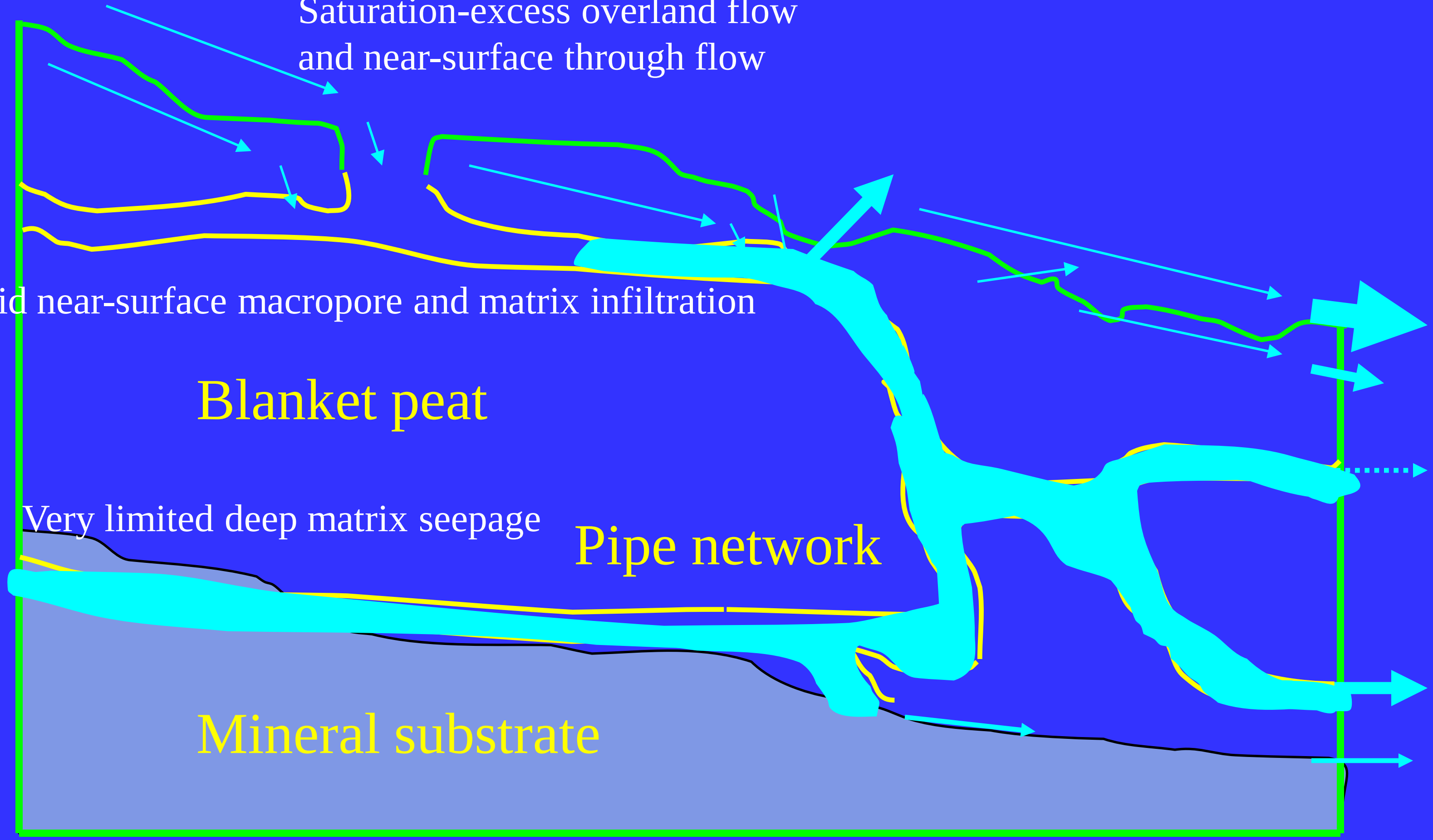
Work is needed on carbon-balance processes on UK fen sites undergoing restoration from arable farming, especially given the large scale restoration planned for Wicken Fen and the restoration that will take place as part of the Great Fen Project.

Holey peat

- Inside the peat there are often small holes (macropores) which have formed through plant roots or when the peat cracks during dry period
- Water flowing through these can enlarge them and form natural ‘pipes’

Pipeflow runoff pathway coupling

Holden and Burt (2002) *Catena;* Holden et al (2002) *ESP&L*, Holden (2004) *ESP&L*



Saturation-excess overland flow
and near-surface through flow

Rapid near-surface macropore and matrix infiltration

Blanket peat

Very limited deep matrix seepage

Pipe network

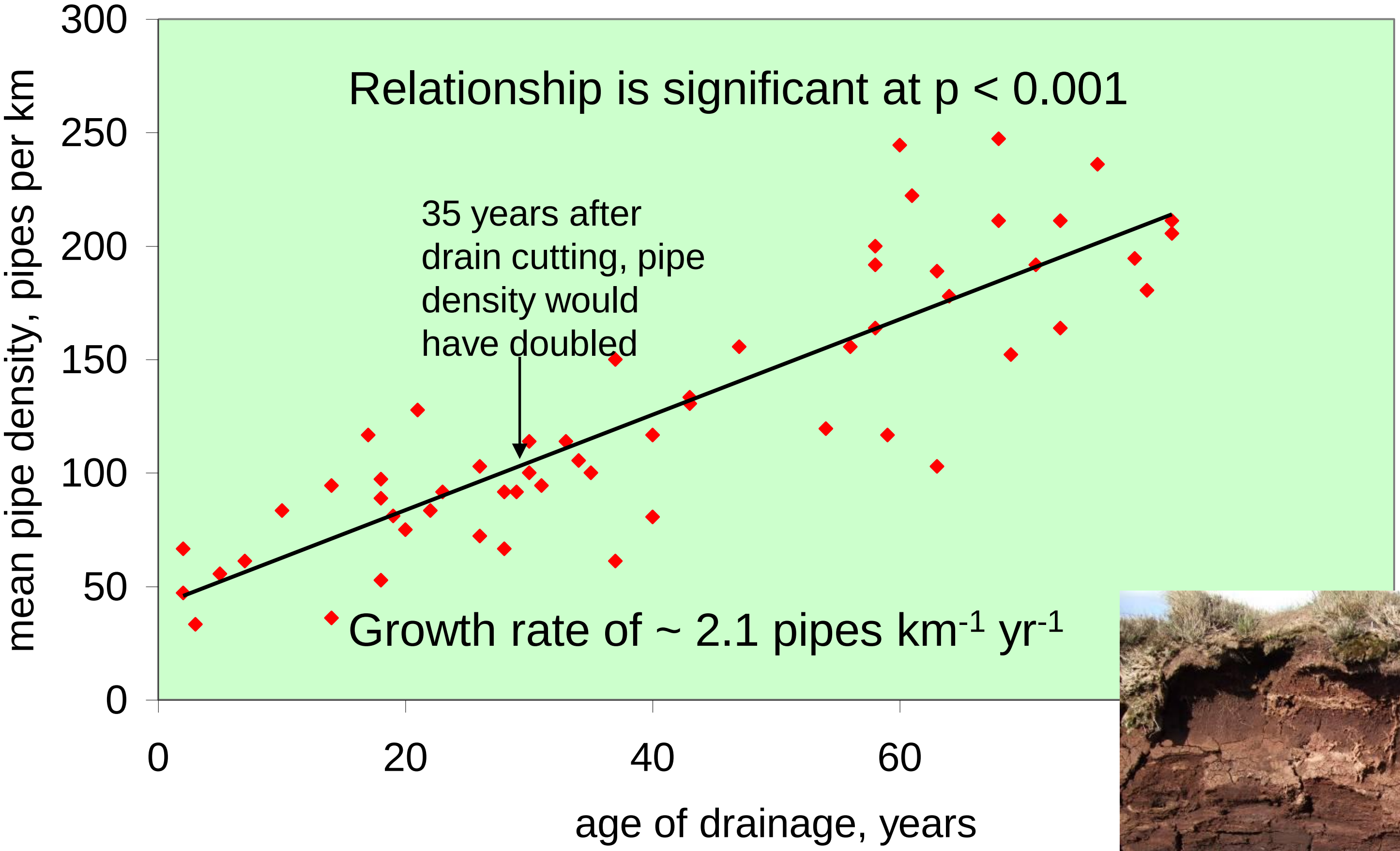
Mineral substrate

Localised ephemeral interface flow

GPR work has shown that:

- Pipes are found in all UK peatlands: a survey of 320 catchments found pipes > 10 cm in diameter in all cases.
- Mean 69.2 pipes km^{-1}
- Piping greater where drains present (127.4 per km)
- What rate do networks develop and how important is this to the carbon/sediment budget?
- Test through use of “ergodic” method

Scatter plot of mean pipe density against age of drainage



Holden (2006) Journal of Geophysical Research

Calluna associated with enhanced piping

GPR work showed:

- *Calluna* median = 108 km^{-1}
- Non-*Calluna* median = 25 km^{-1}

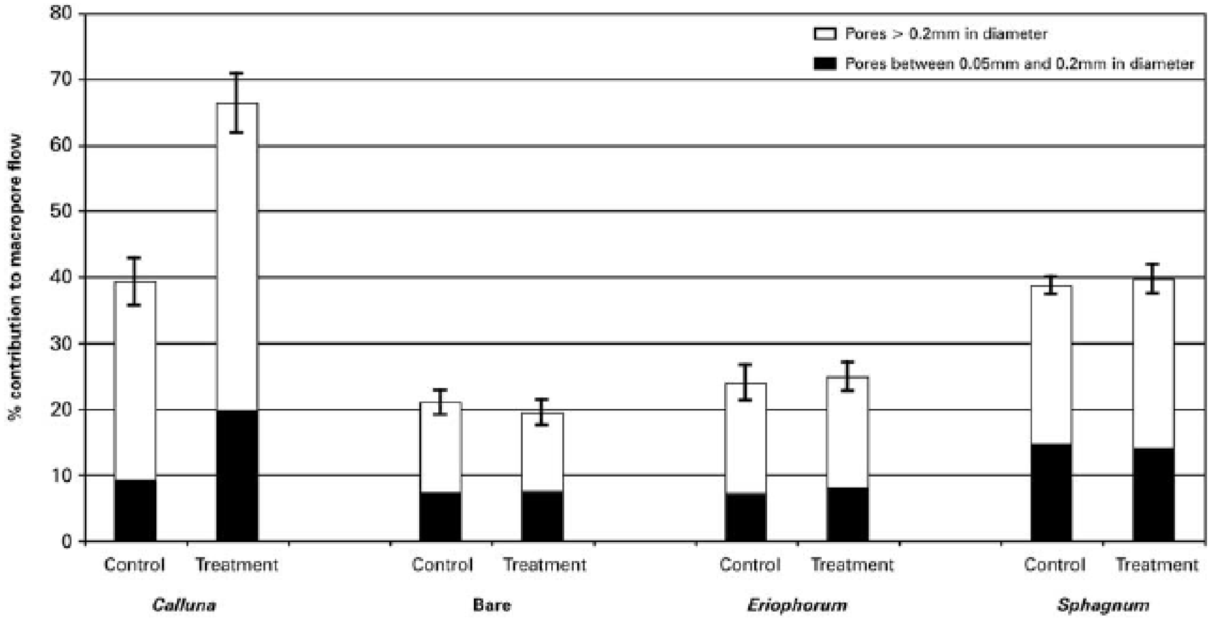


Figure 2. The mean proportion of macropore flow at the peat surface for control blocks and blocks subject to rainfall treatment, with standard error bars.

Holden 2005. Water Resources Research

Pipes and carbon

NERC funded 2007-2010 £410K – water@leeds and CEH Edinburgh

Tests have shown so far:

- 20-30 % of the flow from the pipes

- 53 % of dissolved carbon from the pipes

- 200 % of particulate carbon from the pipes (i.e. not all sediment released by pipes makes its way to the stream and some is held in storage)

- Hotspots for degassing of CO_2 and CH_4
- Pipeflow could explain long-term changes at the Conway and Millar sites (10 % flow intact, 30 % flow drained). Blocking?

EMBER - Effects of Moorland Burning on the Ecohydrology of River systems

- Lee Brown, Joseph Holden and Sheila Palmer, water@leeds
- NERC funded (£650K) 2009-2012
- Hydrology, hydrochemistry of patch burning (different ages of patches etc)
- Catchment runoff and water quality (burnt vs unburnt)
- Stream ecosystem response in monitored catchments
- Mesocosm studies

Dissolved and particulate carbon release from natural pipes