A hydrological study of Waen y Griafolen blanket bog, North Wales

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Abstract A hydrological study has been carried out for Waen y Griafolen, a blanket bog with an area of approximately 6 km^2. Within the bog, older humified peats are overlain by *Erica* and *Trichophorum* plant communities. The older peats have been incised by a river system, now largely infilled by younger peats with *Sphagnum* and *Juncus* communities. A computer model simulates the removal of channel vegetation in response to climate change. Results indicate a loss of adjacent wetland habitat, combined with increased severity of flash flooding. Conservation measures to protect *Sphagnum* and *Juncus* communities are recommended.
Keywords blanket bog; Wales; hydrological modelling; plant communities

INTRODUCTION

Many mountain rivers in North Wales have their headwaters in peat blanket bogs. An example is Waen y Griafolen, source area for the Afon Mawddach, which formed the focus of a hydrological study by Bangor University over the period 2002-2004. Fieldwork has been supplemented by groundwater and surface water modelling (Awissa, 2003). The blanket bog covers an area of approximately 6 km^2 within a plateau basin in Lower Paleozoic shales.

Waen y Griafolen, designated a Special Area of Conservation, has wetland habitats which may be particularly sensitive to climate change. Modification of natural vegetation zones may in turn lead to a change in hydrological characteristics, affecting flood generation downstream.

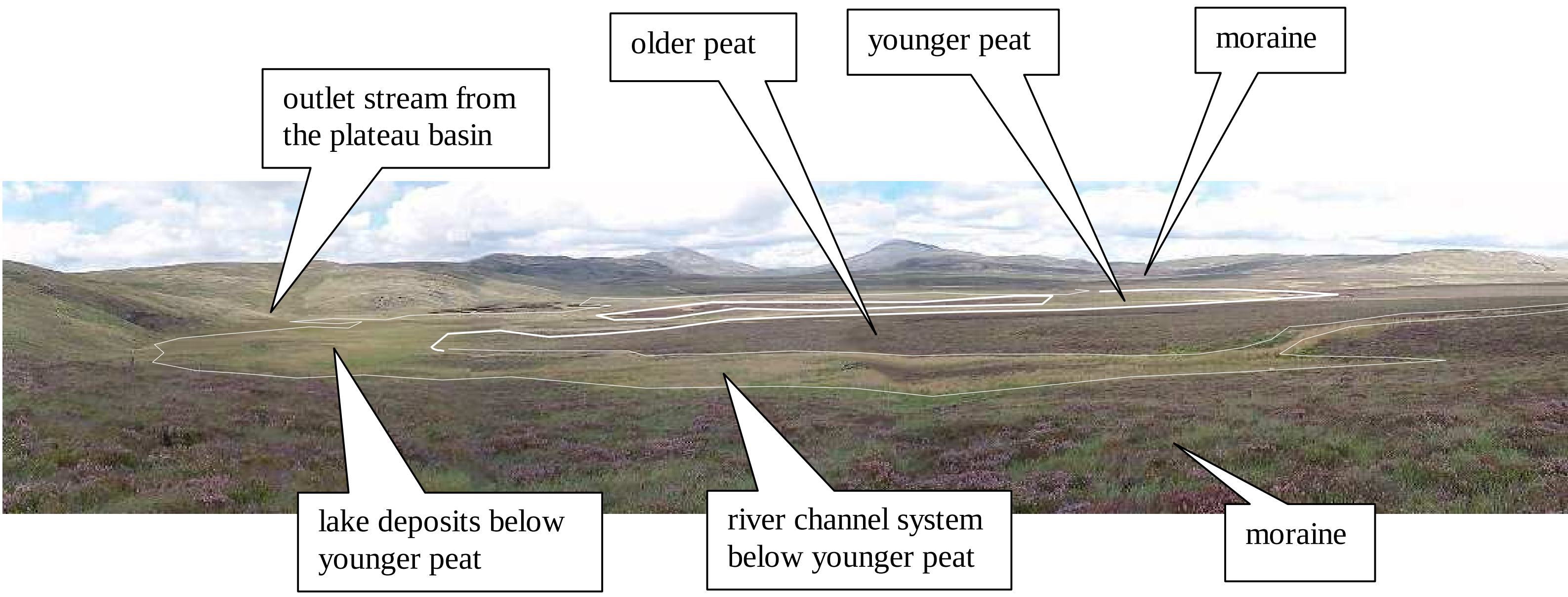


Figure 1 Stratigraphy of Waen y Griafolen blanket bog

STRATIGRAPHY OF THE BLANKET BOG

The structure of superficial deposits, determined by geophysical and auger surveys, reveals a complex sequence of temporal and spatial changes in vegetation and drainage pattern since the last glacial readvance (Fig.1).

Geophysical investigations of glacial and post-glacial stratigraphy were carried out at 8 sites across the bog, using a combination of Electromagnetic and Vertical Electrical Sounding techniques. Three distinct layers were detected above the Ordovician mudstone bedrock, and have been identified as: peat, sandy boulder clay drift, and a lower layer of high clay content - either a lake clay or older glacial drift (Table 1).

Layer	Average resistivity (Ωm)	Average thickness (m)
Peat	204.88	2.3
Sandy boulder clay	366.25	2.0
Clay	20.76	3.2
Mudstone	188.00	

Table 1 Summary of geophysical observations at Waen y Griafolen

Horizons of river gravel and lake clay were found beneath the active peat, indicative of an earlier and more extensive surface drainage system eroded into the bog surface.

At the western edge of the Waen y Griafolen basin, erosion has exposed the base of the old humified peat (Fig.2). At this horizon, a palaeosoil occurs with tree roots identified as *Salix* (personal communication, P. Denne) in growth position. A wood sample has been dated by Oxford University Radiocarbon Accelerator Unit as 8905 ± 45 years before the reference year AD 1950. Thus, Waen y Griafolen has developed over the past 9000 years and the period of erosion represented by the buried river channels and lake bed might be linked to a period of increased rainfall identified across Europe at around 2600 years before the present (Bellamy, 1986).

Figure 2. Older humified peat experiencing erosion near the plateau basin outlet stream, as a result of drying out in response to a fall in stream base level.

Figure 3. *Salix* root layer at the base of the older peat illustrated in Fig.2. This material has been radiocarbon dated as 8905 ± 45 years before the reference year AD 1950.

VEGETATION COMMUNITIES

Vegetation mapping has been carried out by quadrat survey in conjunction with air photographs. Four vegetation communities are prominent within the blanket bog (Table 1). *Juncus* and *Sphagnum* communities infill former river channels and lake basins (Fig.2), and overlie younger peat. The *Erica* community occupies the central area of the blanket bog above older peat, whilst the *Trichophorum* community occurs towards the margins of the older peat area.

Community	Dominant species	Subsidiary species
Juncus channel	Juncus effusus, Polytrichum commune, Eriophorum vaginatum	Rhytidiadelphus loreus, Sphagnum subnitens, Nardus stricta
Sphagnum channel	Sphagnum auriculatum, Carex nigra, Eriophorum vaginatum	Juncus effusus, Vaccinium oxycoccus
Erica moor	Erica tetralix, Cladonia portentosa, Trichophorum cespitosum	Vaccinium myrtilis, Sphagnum capillifolium, Empetrum nigrum
Trichophorum moor	Trichophorum cespitosum, Juncus effusus	Eriophorum vaginatum, Nardus stricta

Table 2. Vegetation communities within Waen y Griafolen

Figure 4. *Juncus* community infilling a former river channel, incised into older peat covered by *Erica* community. This area exhibits peat hag erosion which is now actively regenerating following a water table rise.

Figure 5 (above). Small surface stream within a broad drainage channel infilled by younger peat Juncus community.

Figure 6 (right). *Sphagnum* community in an infilled river channel.

HYDROLOGY

Groundwater levels have been continuously monitored over a period of 12 months at a borehole in the centre of the bog, supplemented by measurements at a surrounding array of dip wells. It is found that the older humified peats have a surprisingly low water storage capacity and may become saturated during a single storm event (Fig.7). Storm flow occurs predominantly through fast surface runoff into the *Juncus* and *Sphagnum* infilled channels, where slow lateral movement takes place towards open stream courses at the basin outlet. There appears to be little vertical water movement into the underlying impermeable Ordovician shales, which is consistent with observations by Reeve et al. (2000) at similar sites.

Some modification of drainage pattern on the *Erica* moor areas of the bog occurs as a result of a series of ploughed ditches approximately 0.5m wide and 1m in depth (Fig. 8). These were cut around the middle of the 20th century in an attempt to improve the pasture for sheep. Much of the drainage network is now overgrown, and there is no visible effect of modifying the natural vegetation in comparison to similar unploughed areas of the bog. The drains are generally dry, and probably only carry water at the peak of storms.

A hydrograph recorder was in operation on the outlet stream from the plateau basin. Over a series of storms, peak flows were recorded approximately two hours after commencement of rainfall.

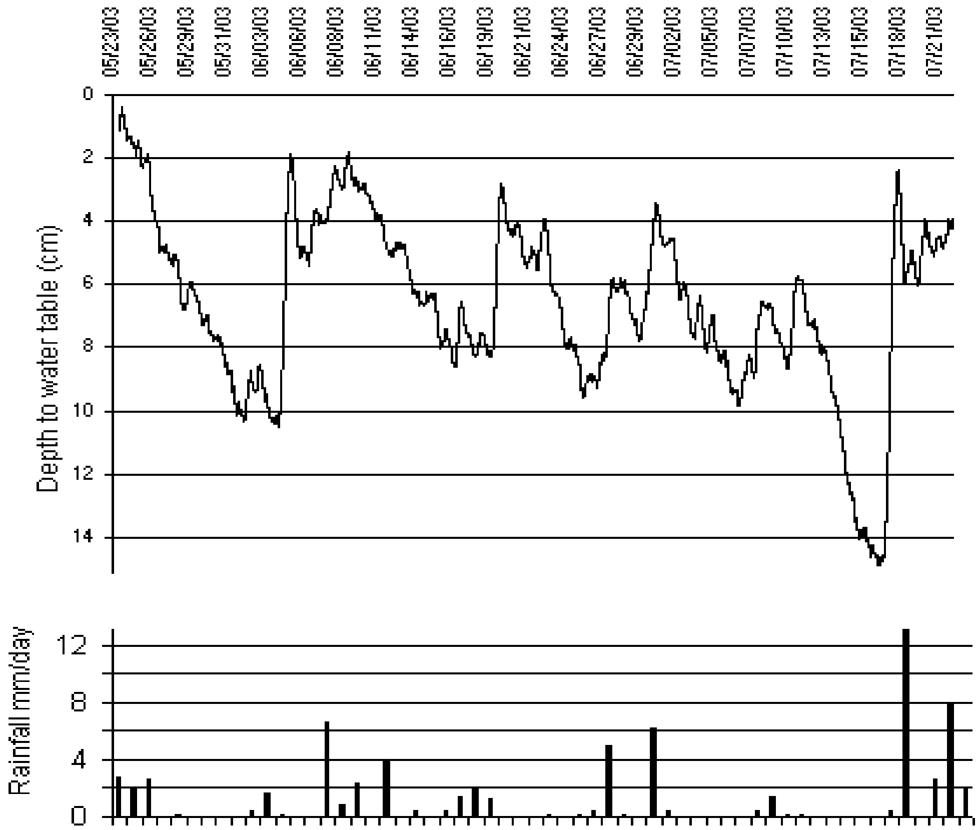
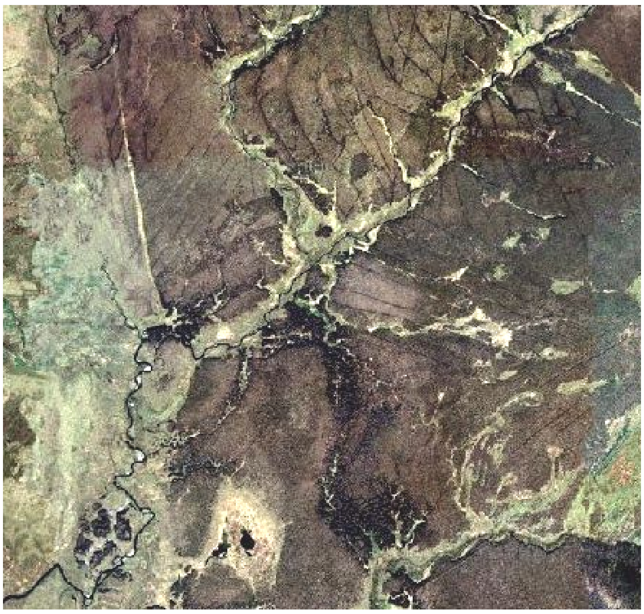


Figure 7. Example watertable and rainfall records for the borehole site. These records include the rainfall event of 18 July 2003 which forms the basis of the MODFLOW case study.



1 km

Figure 8. Vertical air photograph of the central area of Waen y Griafolen, showing the pattern of ploughed drainage ditches cutting across *Erica* moor on older peat.

MODFLOW MODELLING

A majority of climate change models for western Britain predict an increase in winter rainfall coupled with drier and hotter summers, and a higher rainfall intensity for individual storm events (Arnell, 2002. Skaugen et al., 2003. Jones et al. 2005). These trends may combine to promote a reversion to fluvial erosion of the blanket bog.

Modelling has been carried out using MODFLOW software to investigate the effects of replacing the linear *Juncus* and *Sphagnum* zones by open stream channels, using the rainfall event of 18 July 2003 as a case study. Continuous watertable depth measurements during and after this event were recorded at the central borehole on Waen y Griafolen. The watertable depth at this central borehole had previously been shown to be a good predictor of watertable depths at a ring of 6 dip wells around the margins of the bog. A sequence of water table depths across the bog could therefore be synthesised for the storm event. This in turn provided data for calibration of bulk hydraulic conductivities and drain conductances within a MODFLOW model (see Figures 9a and 9b).

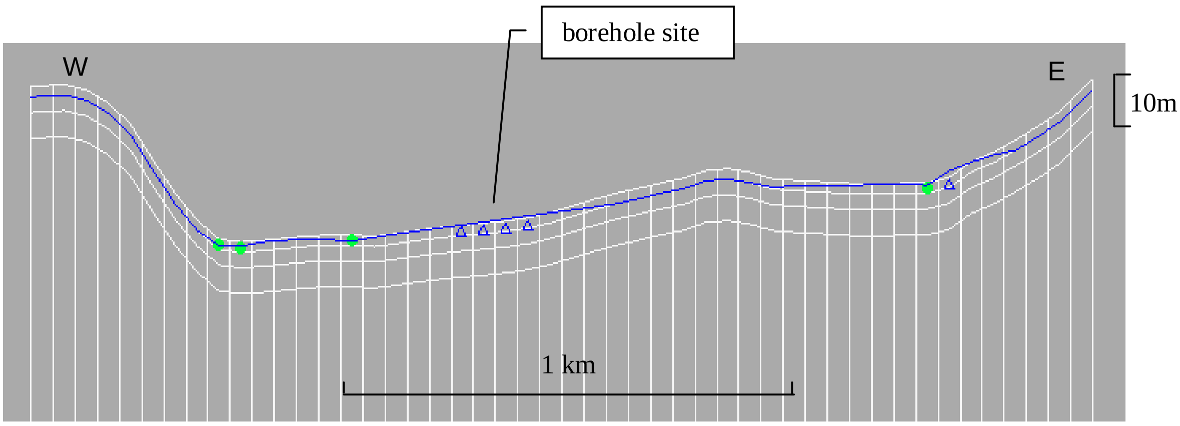


Figure 9a. West-east cross section of Waen y Griafolen 2 hours after commencement of the 18 July 2003 storm event. Water table is marked by blue line. Zones of surface saturation marked by blue triangles. Surface waterflows marked in green.

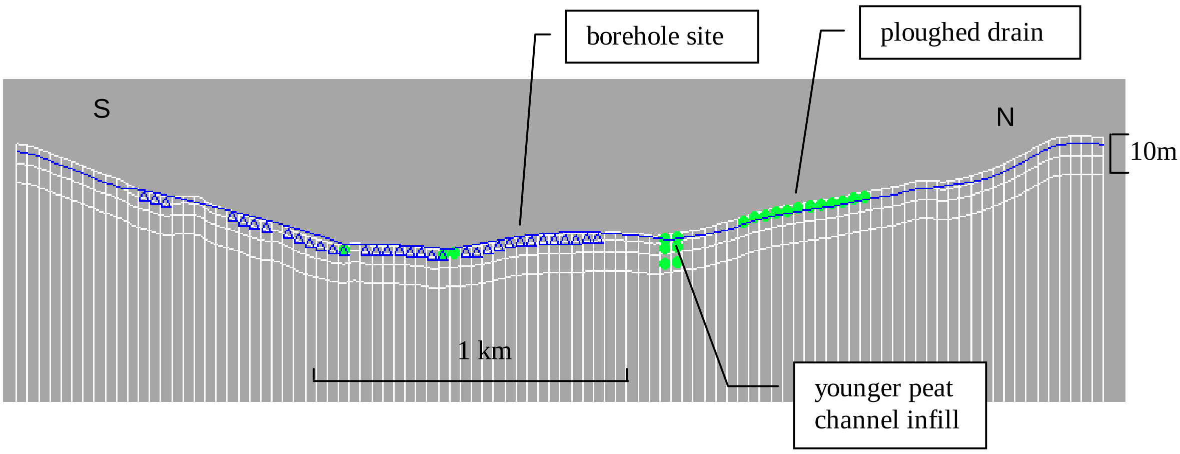


Figure 9b. South-north cross section of Waen y Griafolen 2 hours after commencement of the 18 July 2003 storm event.

In a first model, A1, the 18 July 2003 storm event was simulated assuming current hydrological characteristics for the older blanket peat and the younger peat filled channels. Zones of surface saturation 2 hours after commencement of the storm event are illustrated in Figure 10. A conductivity value of $2mh^{-1}$ is used for water flows through younger peat. Outflows from the plateau basin are consistent in timing with the recorded outflow hydrograph.

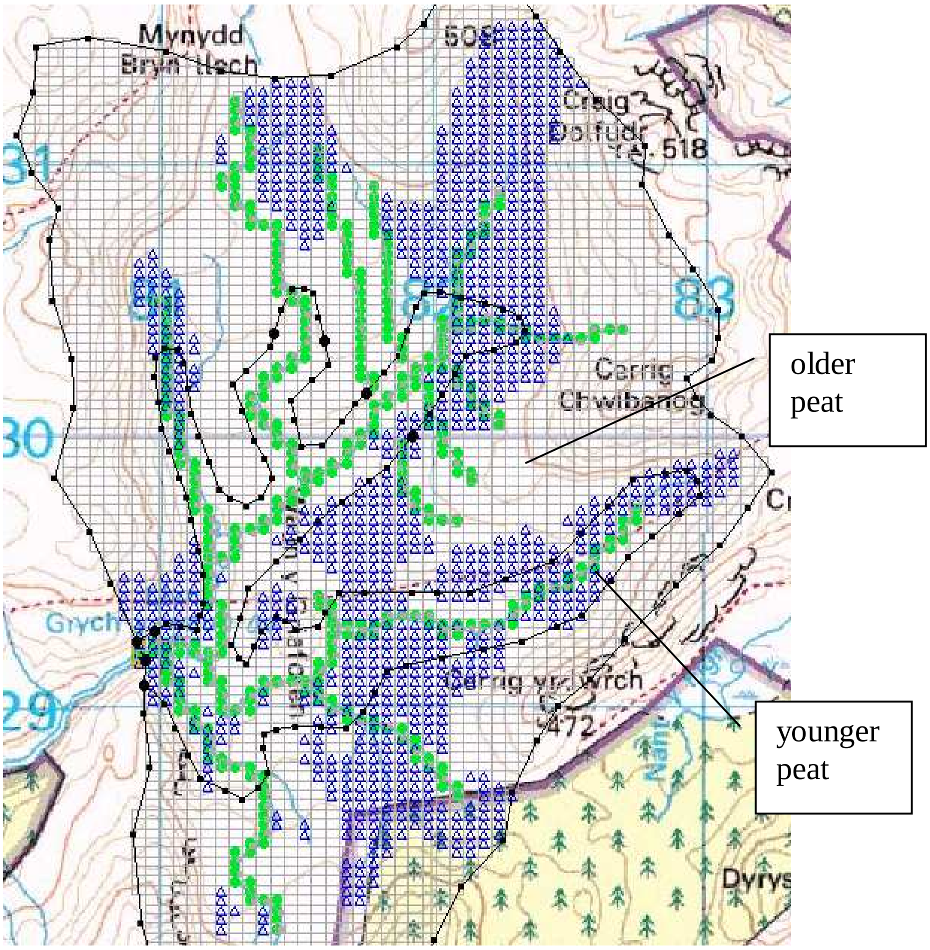


Figure 10. Groundwater model A1 for Waen y Griafolen 2 hours after commencement of the 18 July 2003 storm event. Surface saturation zones are marked by blue triangles. Surface waterflows marked in green. The area modelled as younger peat is outlined in black.

A second model, A2, was run to estimate the effects of the ploughed drainage channels in the central area of the bog. In this model, ploughed channels were assumed to be blocked and reverted to the $2mh^{-1}$ conductivity of younger peat.

A final model, B1, assumes removal of vegetation over the full width of *Sphagnum* and *Juncus* channels, and simulates waterflows in open river courses above a gravel bed (Figure 11).

The stream system of Waen y Griafolen was divided into a series of reaches (Figure 12). The volume of water entering each reach from the surrounding peat during the second hour of the storm event was estimated by the MODFLOW model.

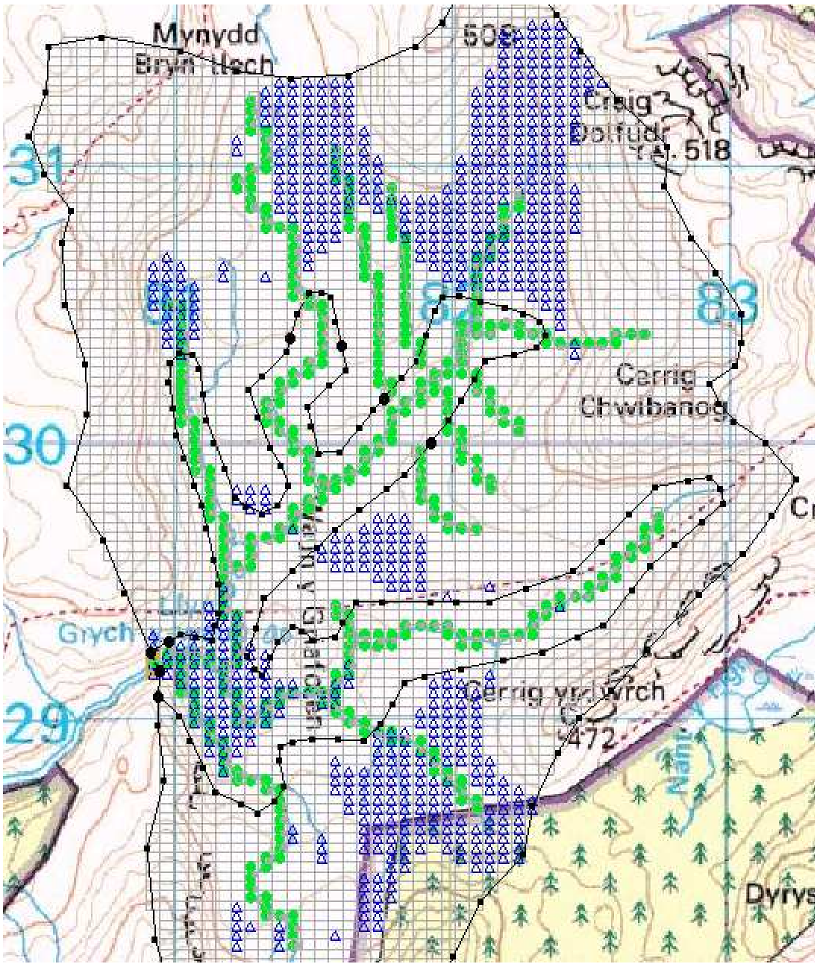


Figure 11. Groundwater model B1 for Waen y Griafolen 2 hours after commencement of the 18 July 2003 storm event. The area of younger peat is outlined in black.

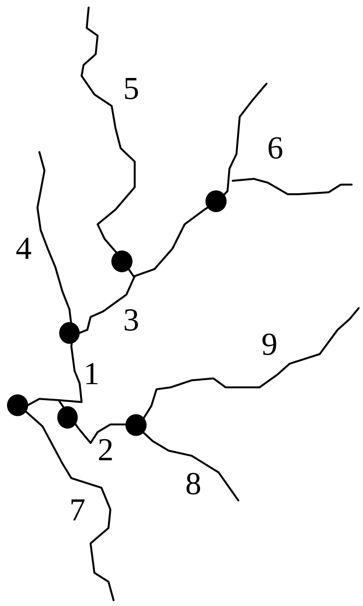


Figure 12. Key to numbered river reaches listed in Table 3.

RESULTS

Comparison between models A1 and A2 showed water flows in ploughed drainage channels to have negligible effects beyond the local reach, and no effect on water volumes at the basin outlet.

Water flows estimated by MODFLOW for models A1 and B1 in the second hour of the storm event are given in Table 3.

Reach	Model A1 *Sphagnum /Juncus* infilled channels	Model B1 Open gravel bed channels
1	13 207	33 197
2	1 237	9 585
3	5 356	5 368
4	2 519	3 565
5	3 744	4 864
6	4 633	5 062
7	1 979	1 724
8	2 851	4 753
9	3 088	1 396
Total flow	38 614	69 514

Table 3. Modelled water flows (m^3) entering surface streams from peat during hour 2 of the 18 July 2003 storm event. Numbering of river reaches is given in Figure 12.

Modelling predicts that removal of younger peat in *Juncus* and *Sphagnum* zones would lead to an increase in the severity of flash flood responses due to the loss of temporary water interception capacity. In an extreme case of complete removal of younger peat from channels, peak discharge from the basin could be almost doubled. Comparison of Figures 10 and 11 suggests that loss of *Juncus / Sphagnum* peat would lead to a reduction in aerial extent of surface saturation within older peat during storm events. This could result in the drying out of *Erica* communities and the onset of peat hag erosion. Drier grassland and *Trichophorum* communities may then invade the *Erica* moorland.

The *Juncus / Sphagnum* communities are seen as fragile. Management options to protect channel vegetation are recommended, which could include the blocking of surface streams to encourage a distributed water flow and maintain saturated ground conditions. A favourable area for *Sphagnum* bog regeneration has been identified above low permeability lake clay deposits near the basin outlet (Figure 1).

Consideration should be given to stabilising the river course as it leaves the blanket bog through a boulder channel over glacial moraine. Increased fluvial erosion at this point would lower base levels and reduce the area of saturation suitable for *Sphagnum* ecosystems.

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