Mechanisms of flooding in the Mawddach catchment

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Abstract A research project is in progress to model flooding in the Mawddach catchment, North Wales. A range of field investigations has been carried out to help in the selection of appropriate computer models. Rainfall distribution recorded at 22 raingauges does not correlate well with ground elevation, suggesting instead that maximum precipitation is generated at valley heads where maximum uplift of air masses occurs. Streams within the Mawddach catchment have their sources in upland blanket bogs; water table monitoring shows the water storage capacity of older humified peat to be very limited, with saturation possible during a single storm event. Large thicknesses of glacial and periglacial deposits infill river gorges in the catchment; saturation of these deposits can create conditions for rapid runoff and flooding downstream. Temperature monitoring of river bed sediments has identified resurgence of groundwater after prolonged rainfall. It is concluded that surface water and groundwater interactions are essential for the modelling of antecedent effects on storm runoff. Surface water models predict that floodplain forestry within the catchment can provide significant temporary storage for peak discharge, reducing flood levels downstream.

Key words blanket bog; flooding; flood plain forestry; groundwater; North Wales; rainfall distribution.

BACKGROUND TO THE PROJECT

The Mawddach river system drains a mountainous area of north-west Wales, reaching Cardigan Bay through the Mawddach estuary. The town of Dolgellau at the head of the estuary has experienced regular flood events through historical times (Barton, 2002). In July 2001, an estimated 300-year maximal flood caused extensive damage to bridges and roads in the catchment. Climate change models suggest that such extreme events will become increasingly frequent (Skaugen *et al.* 2003).

Following the 2001 flood, a research programme was initiated to investigate mechanisms of flooding within the Mawddach catchment. The overall aims of the project are to improve short-term flood prediction, and to make recommendations for catchment management to reduce flood risk. Field data have been used to develop hypotheses for hydrological mechanisms, which are currently being investigated by computer modelling.

RAINFALL DISTRIBUTION

A grid of 22 continuous-recording raingauges has been established across the Mawddach and Wnion catchments, extending from near sea level (Dolgellau 8m, Llanbedr 16m) to the higher slopes of the mountain hinterland (sites on Rhinog Fawr at 490m and Aran Fawddwy at 505m). 18 storm events occurring during the period October 2002 to November 2004 have been recorded in detail. Rainfall distributions during individual storm events often follow a similar pattern, with highest rainfall concentrations occurring in a zone inland of the Rhinog mountain range: from Trawsfynydd in the north, through the Coed y Brenin forest to Rhobell Fawr and the Aran mountains in the south east. The example shown in fig. 1 is typical: a frontal system, tracking north-eastwards, crossed the catchment between 0500 and 1100 hrs on 28 April 2003, with precipitation occurring at warm and cold fronts.

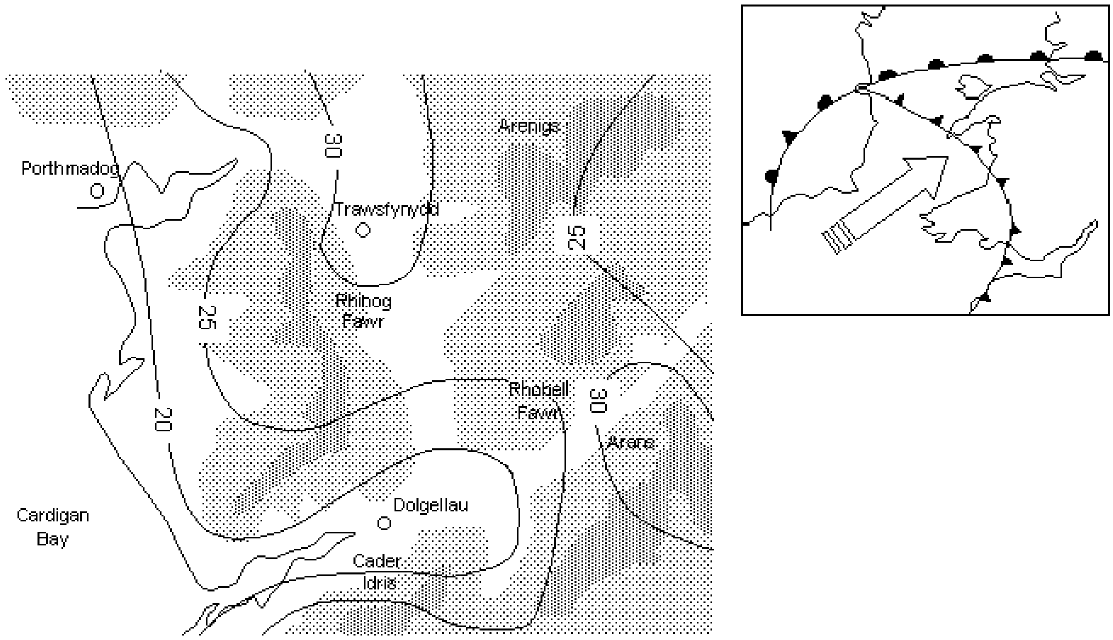


Fig. 1 Rainfall(mm) for 28 April 2003

Total rainfall inland during this storm exceeded rainfall in the coastal zone by a factor of two; during other storm events an inland total up to four times the coastal total has been recorded.

It is suggested that air masses approaching from the west are deflected around the mountain mass of the Rhinogs and funnelled along the estuaries of the Dwyryd at Porthmadog in the north, and the Mawddach at Dolgellau in the south. A theoretical model is being developed which locates maximum precipitation at the steep heads of the inland valleys where the wet air masses are forced to rise most rapidly. This model is currently being tested by means of the US NCAR mesoscale weather modelling system, MM5 (Dudhia, 2005).

CATCHMENT CHARACTERISTICS

The Mawddach and Wnion catchments extend around the southern and eastern sides of the Harlech Dome, a complex Caledonian fold structure in Lower Palaeozoic rocks. Resistant Lower Cambrian grits form the Rhinog mountains near the core of the dome, surrounded by a ring of softer Upper Cambrian sediments (Fig. 2). The outer flanks of the dome are composed of Ordovician volcanics and interbedded sediments which give rise to the mountainous terrains of Cader Idris, the Arans, Rhobell Fawr and the Arennigs.

The Dome structure is cut along its margins by fracture zones aligned north to south, and south-west to north-east, which have had a strong influence on the orientation of the main streams within the catchment.

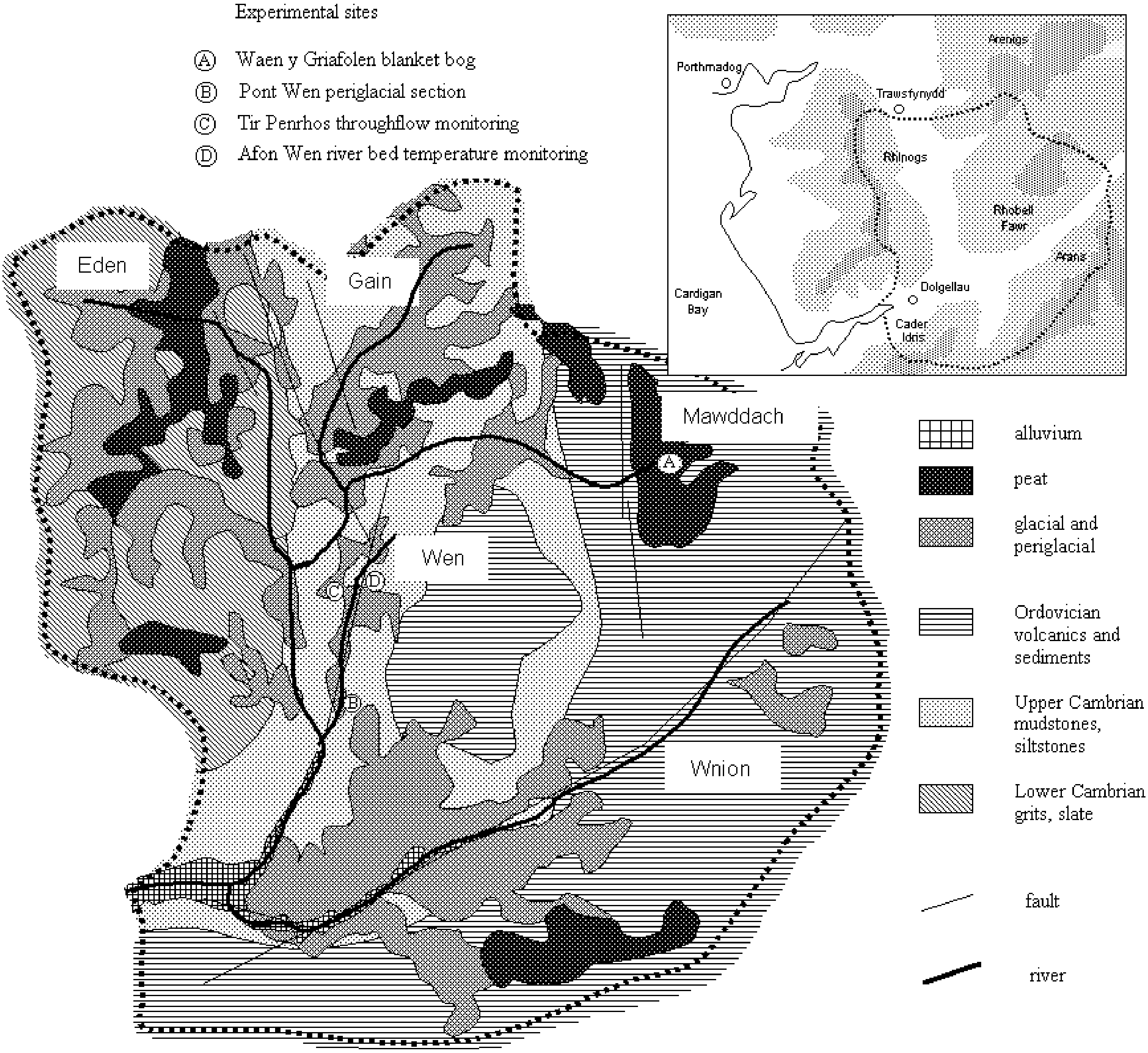


Fig. 2 Geology of the Mawddach and Wnion catchments

Upland blanket bogs

Extensive areas of blanket bog form the source regions of the main tributaries of the Mawddach, and have a particular significance since several lie within the zone of maximum precipitation for the catchment. A detailed study has been made of one of these, Waen y Griafolen, at the head of the Mawddach itself (Awissa, 2003).

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 Summary of geophysical observations at Waen y Griafolen

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	

The shallower structure above the sandy till has been investigated by an auger survey using a grid of 40 sample points. A contrast occurs between zones of older humified peat with a *Calluna* – *Vaccinium* association, and younger active *Sphagnum* peat.

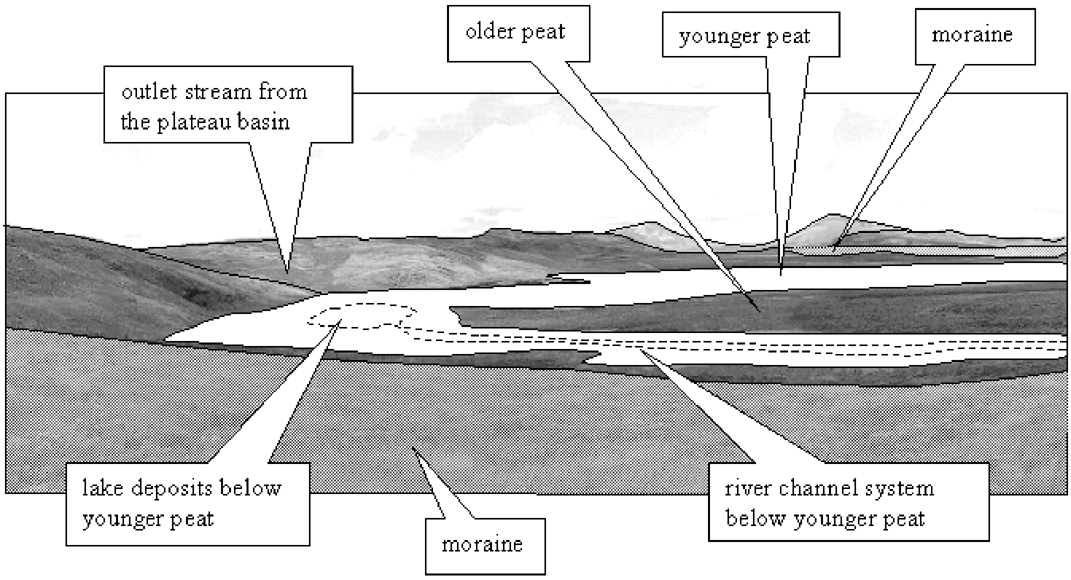


Fig. 3 Waen y Griafolen blanket bog

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. 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).

A borehole with continuous monitoring of water table depth has been established within older humified peat in the central area of the bog. An example graph is given in fig. 3. The older peat was found to have an unexpectedly small buffering effect, with the water table rising by 1cm per hour and the peat reaching saturation within a single storm event. Watertable decline during a dry period is at a slower rate of about 1cm per day.

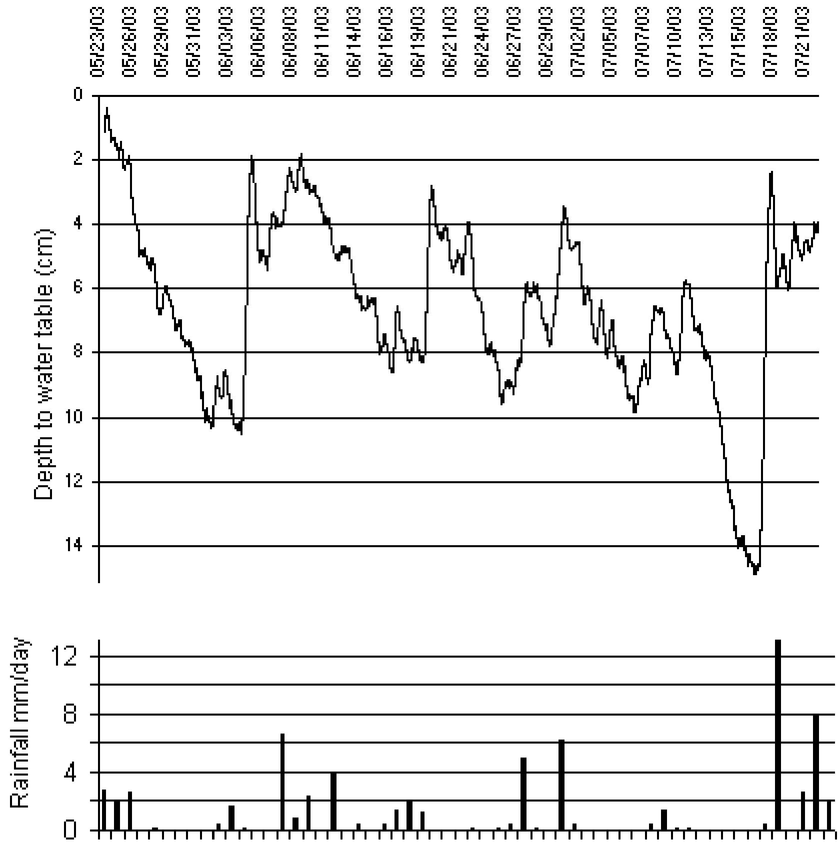


Fig. 4 Water table monitoring at Waen y Griafolen

A theoretical model is being developed for the hydrology of the blanket bog, which attributes the main controlling influence to the zones of active *Sphagnum* peat. Storm runoff from the older peat is rapid, but water then passes slowly through the *Sphagnum* zones which have a significant buffering capacity.

The Mawddach gorges

Rivers within the Mawddach catchment exhibit an unusual stepped long profile due to Tertiary plateau erosion. The middle courses of the main tributaries run through deep gorges as they descend steeply to the head of the estuary. The orientation of gorges is largely controlled by a series of north-south fracture zones in the bedrock. This topography is exemplified by the Afon Wen (Fig. 5), where a particular study of surface runoff-groundwater relations has been carried out.

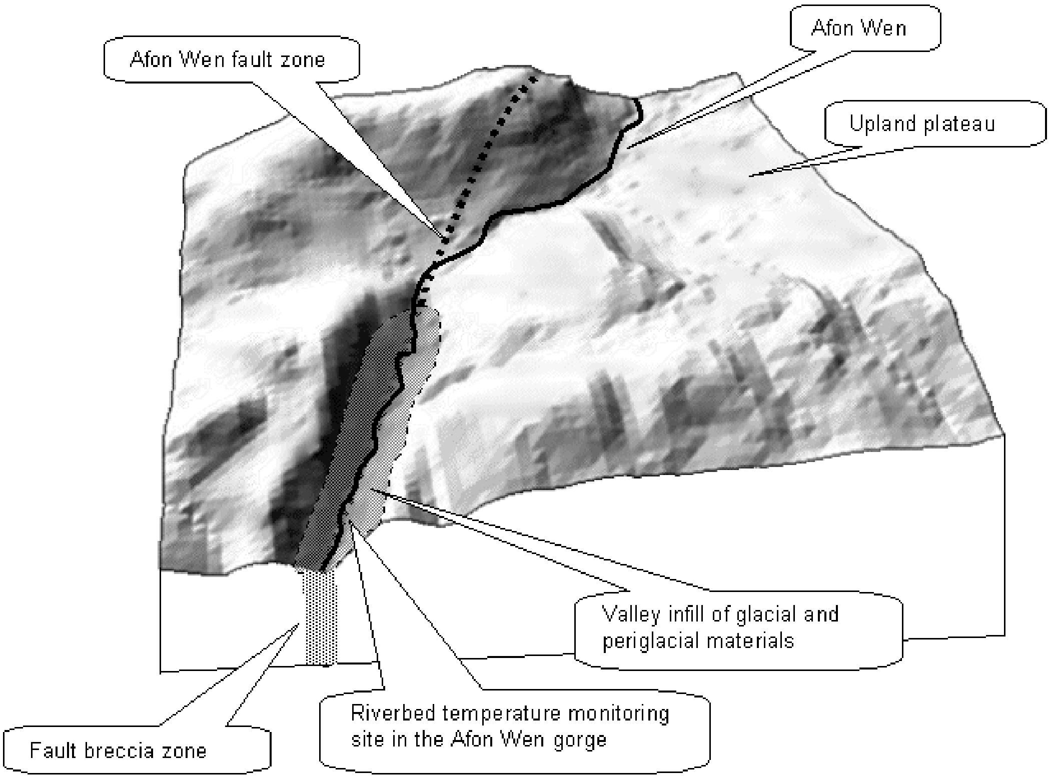
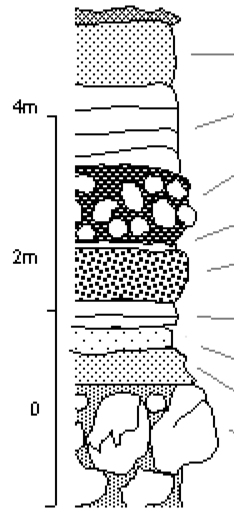


Fig. 5 Block diagram of the Afon Wen sub-catchment

The Afon Wen sub-catchment, in common with the remainder of the Mawddach basin, has been extensively glaciated and exhibits thick sequences of glacial and periglacial valley infill. Sediments at Pont Wen, 1km above the confluence of the Afon Wen and Mawddach, have been sampled and an analysis of particle size and sorting carried out to infer modes of origin (fig. 6).



forest brown earth			
grey sandy clay	SOLIFLUCTION	Zone III	Sub-Boreal
iron cemented cobble band	RIVER CHANNEL	Zone II	Atlantic
yellow clay	LAKE BED		
unstratified sandy gravel	FLUVIAL REDEPOSITION OF SOLIFLUCTION MATERIAL		
fine gravelly sand			
silty clay	FLUVIAL		
sandy gravel	SOLIFLUCTION	Zone I	Boreal
boulder clay	VALLEY GLACIER	Late Devensian	

Fig. 6 Stratigraphic sequence at Pont Wen.

Hillslope throughflow

Five throughflow experimental sites have been established in the middle section of the Afon Wen catchment around the village of Hermon. Timbered exposures cut into hillsides allow the continuous recording of surface runoff and throughflow at a depth of 1m in the periglacial sequence.

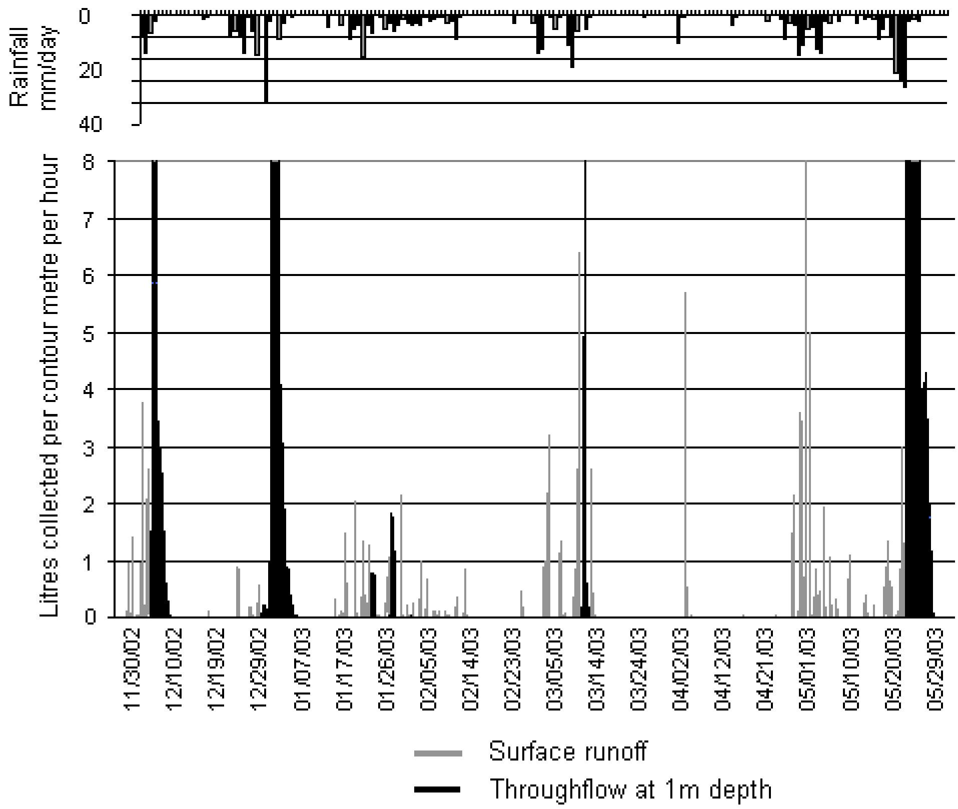


Fig. 7 Throughflow experimental site at Tir Penrhos

The example data from Tir Penrhos illustrates typical drainage conditions. After dry periods, infiltration into the periglacial sequence readily occurs, and rainfall events generate only surface runoff at the monitoring sites. A continuing wet period of a week or more can lead to the saturation of the periglacial sediments, so that further storm rainfall is accompanied by large volumes of throughflow at shallow depth. It is significant that the shallow throughflow events recorded at Tir Penrhos exactly correspond with periods of flooding of farmland in the lower Mawddach valley some 5km downstream.

River bed temperature monitoring

Investigations have been carried out to estimate the extent of river flow/groundwater interaction within the gorge section of the Afon Wen. Two continuous-recording thermometers have been installed in river bed gravel, with one at the gravel surface and the other buried at a depth of 1.6m, close to the bedrock interface. During dry periods, changes in river temperature are reflected about 6 hours later by similar changes in the deep gravel temperature, suggesting slow downward movement of water through the river bed gravels and into underlying bedrock fractures (fig. 8(a)). After a prolonged period of wet weather the situation is reversed. Changes in deep temperature are reflected some 3 hours later by changes in the temperature of the upper gravel, suggesting resurgence of groundwater from bedrock fractures permeating upwards through the river bed sediment (fig. 8(b)).

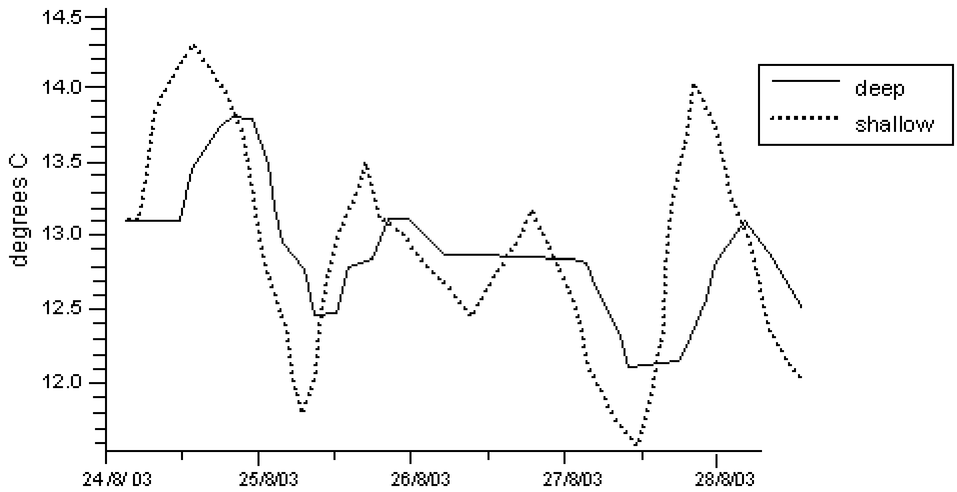


Fig. 8(a) Afon Wen river bed temperatures: following a period of low rainfall in August 2003

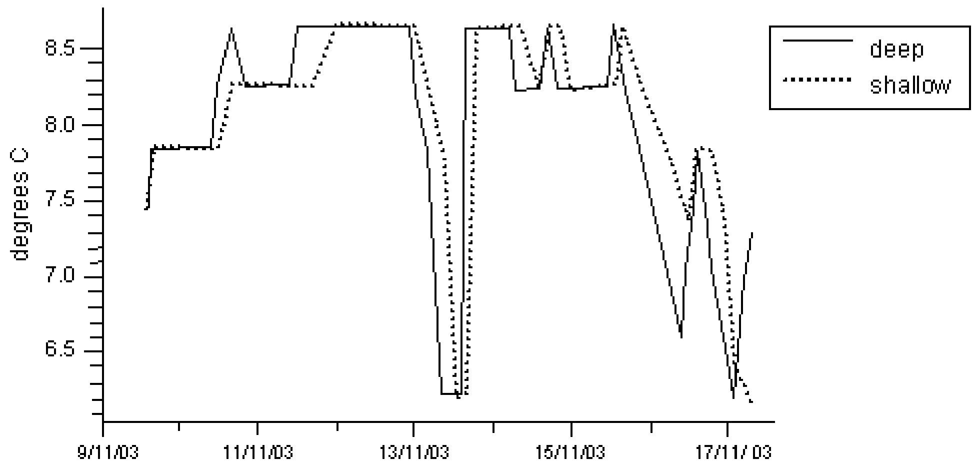


Fig. 8(b) Afon Wen river bed temperatures: period of groundwater saturation with resurgence during storm events on 13 November and 16 November 2003

A theoretical model is being developed to relate antecedent conditions to the onset of flooding from the Afon Wen. During normal conditions, groundwater pathways exist through periglacial deposits and bedrock fracture zones which provide a storage and buffering effect for inflows of rainwater. After a significant period of wet weather, however, the periglacial deposits and bedrock fractures become saturated; storm rainfall runs off rapidly into the river and is routed immediately downstream. River flows are augmented in some reaches by resurgence from river bed fracture zones.

Modelling strategy

A modelling strategy is now being implemented which incorporates the processes identified from field investigations outlined above:

- The MM5 meteorological modelling system simulates rainfall patterns over the mountainous terrain which are in close agreement with the raingauge data recorded.
- Groundwater–surface water interaction is crucial to the modelling of antecedent conditions and saturation-excess flood generation in the catchment. Modflow is being used as the groundwater model.
- Rainfall output from MM5 linked as an input to Modflow may provide effective simulation of the groundwater response to an extended sequence of rainfall events. A Fortran module is being developed to carry out this linkage.

Floodplain forestry

The Mawddach river system flows through the extensive Coed y Brenin forest. It was thought that areas of floodplain forestry might provide significant temporary storage for flood water, which reduces peak flows and releases water during the falling stage of the hydrograph. To investigate this hypothesis, detailed field surveying and computer modelling were carried out for three floodplain sites on the Mawddach: Tyddyn Gwladys and Cefn

Deuddwr in the gorge section, and Gelligemlyn in the lower Mawddach valley (O Connell, 2004).

Computer modelling used the River2D software package (Blackburn and Steffler, 2002) which allows the input of parameters for both bed roughness and the lateral turbulence generated by trees obstructing floodplain flow. It was estimated that forestry at the two upstream sites increases water depth during flood events by 0.5m compared to a grassland floodplain, representing a significant total storage capacity through the whole river system. This result is consistent with flood plain modelling carried out elsewhere (Thomas and Nesbit, 2004).

The lower site investigated at Gelligemlyn is not currently forested. A computer model for dense woodland suggests that temporary water storage depths on the floodplain could be increased by up to 1.2m, and the peak discharge on the Mawddach could be delayed by over 20 minutes downstream (fig. 9.)

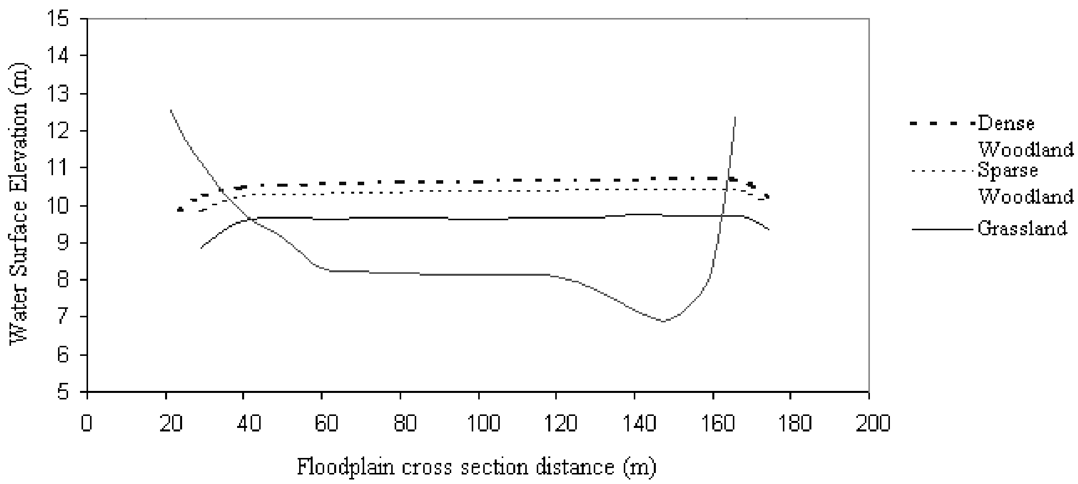


Fig. 9 Simulation of the July 2001 flood event for the Mawddach valley at Gelligemlyn, showing peak water surface elevations for different vegetation scenarios. (after O Connell, 2004)

CONCLUSIONS

Rainfall distribution across the catchment does not correlate well with ground elevation. It is proposed that air masses are funnelled along major valleys and maximum precipitation is generated where uplift occurs at valley heads.

A number of streams within the Mawddach catchment have their sources in upland blanket bogs. The water storage capacity of older humified peat is very limited, with saturation occuring within a single storm event. Throughflow within the blanket bogs is concentrated in zones of younger *Sphagnum* peat.

Large thicknesses of glacial and periglacial deposits occur within the gorges of the Mawddach catchment. The saturation of these deposits following a period of prolonged rainfall creates conditions for rapid runoff and flooding downstream. Prolonged periods of rainfall also lead to saturation of bedrock fractures, with resurgence of groundwater into river channels causing further increases in river discharge.

Areas of floodplain forestry within the catchment, either existing or possible for development, can provide significant temporary storage capacity for peak flood discharge, reducing flood levels downstream.

A computer modelling strategy has been developed which combines high resolution rainfall distribution patterns generated by MM5 and groundwater modelling with Modflow, to produce simulations of groundwater responses for extended sequences of rainfall events which should be consistent with mechanisms identified in the field.

REFERENCES

Awissa, F.T. (2003) Water flow in the peat bog at Waen y Griafolen. MSc Dissertation, University of Wales, Bangor.

Barton, J. (2002) Flooding: past, present and future. A case study of Dolgellau and the Mawddach catchment. MSc Dissertation, University of Wales, Bangor.

Bellamy, D. (1986) *The Wild Boglands*. Country House, Dublin.

Blackburn J. and Steffler, P.M. (2002) River 2D two dimensional depth averaged model of river hydrodynamics and fish habitat. University of Alberta.

Dudhia J. *et al.* (2005) PSU/NCAR mesoscale modelling system. Tutorial class notes and user's guide: MM5 modelling system version 3. National Centre for Atmospheric Research, Boulder Colorado.

O Connell J. (2004) Assessing the potential of floodplain woodland in flood amelioration. MSc Dissertation, University of Wales, Bangor.

Skaugen T., Astrup M., Roald L. and Førland E. (2003) Scenarios of extreme daily precipitation for Norway under climate change. *Nordic Hydrology* **35**(1), 1-13.

Thomas H. and Nesbit T.R. (2004) An assessment of the hydraulic impact of floodplain woodland. Forestry Commission.