4.3 Validation of the hillslope model

Various hydrological data have been collected in the Mawddach catchment and are described in previous sections. The hillslope model will now be run for various sub-catchments to check that results are physically realistic and consistent with field observations. Adjustments will be made to model parameters as necessary, to provide the best numerical fit with observed data.

The series of tests simulate the field results for:

- Surface runoff at sites of differing vegetation cover around Hermon,
- Surface runoff and shallow throughflow in periglacial deposits at Tir Penrhos, near Hermon,
- Surface runoff and shallow throughflow in glacial till at Pared yr Ychain,
- Sub-catchment river discharge of the Afon Ty Cerrig at Pared yr Ychain,
- Sub-catchment river discharge of the Afon Wen at Hermon.
- Water table depth and sub-catchment river discharge from the Waen y Griafolen peat blanket bog

Hillslope runoff experiments

Hillslope runoff and shallow stormflows have been monitored around Hermon in the Afon Wen sub-catchment of Coed y Brenin, and at Pared yr Ychain on the slopes of Aran Fawddwy in the upper Wnion valley.

The general design of the soil runoff and throughflow monitoring sites is shown in fig.4.33. Waterflows are collected from a 1m width of hillslope, at the ground surface and at a depth of 1.8m. Water is directed to a gauge where the time that each quantity of 5ml is collected is recorded. The total outflows of surface runoff and shallow stormflow from a 1m contour width of hillslope per hour can therefore be calculated.

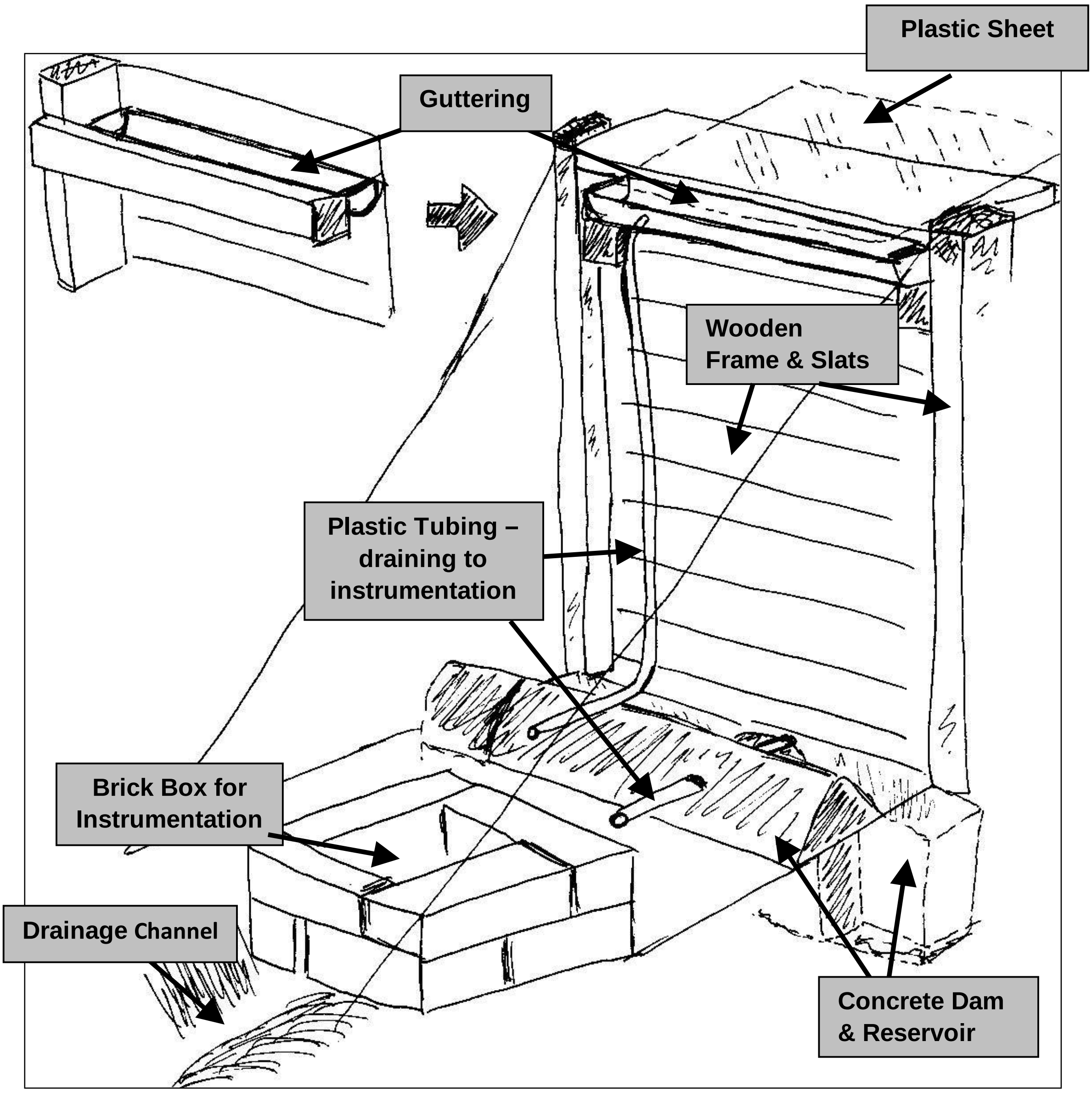


Figure 4.33: Design for the soil throughflow monitoring sites at Hermon, Tir Penrhos and Pared yr Ychain

The hillslope computer model operates on a grid of 50m squares, so data from the runoff monitoring experiments is extrapolated to provide approximate the runoff values from a 50m width of hillslope.

Hermon

The locations of the three hillslope monitoring sites at Hermon, in grassland, a forestry plantation and a clear felled hillslope, are shown in fig.4.34. Surface runoff at the sites was measured for the period 26 July to 1 August 2003, with rainfall totals recorded hourly from a raingauge adjacent to site C.

Figure 4.34: Location of hillslope monitoring sites, Hermon. (A) grassland, (B) forestry plantation, (C) clear felled hillslope. Image by Llion Jones.

The micro-catchment scale of the investigation allows an assumption of uniform rainfall across the catchment area, so the simple rainfall sequence for the Hermon gauge has been used.

The result a run of the hillslope model is shown in fig.4.35, simulating surface runoff at the clear felled hillslope site C. Field data for the three experimental sites are given for comparison.

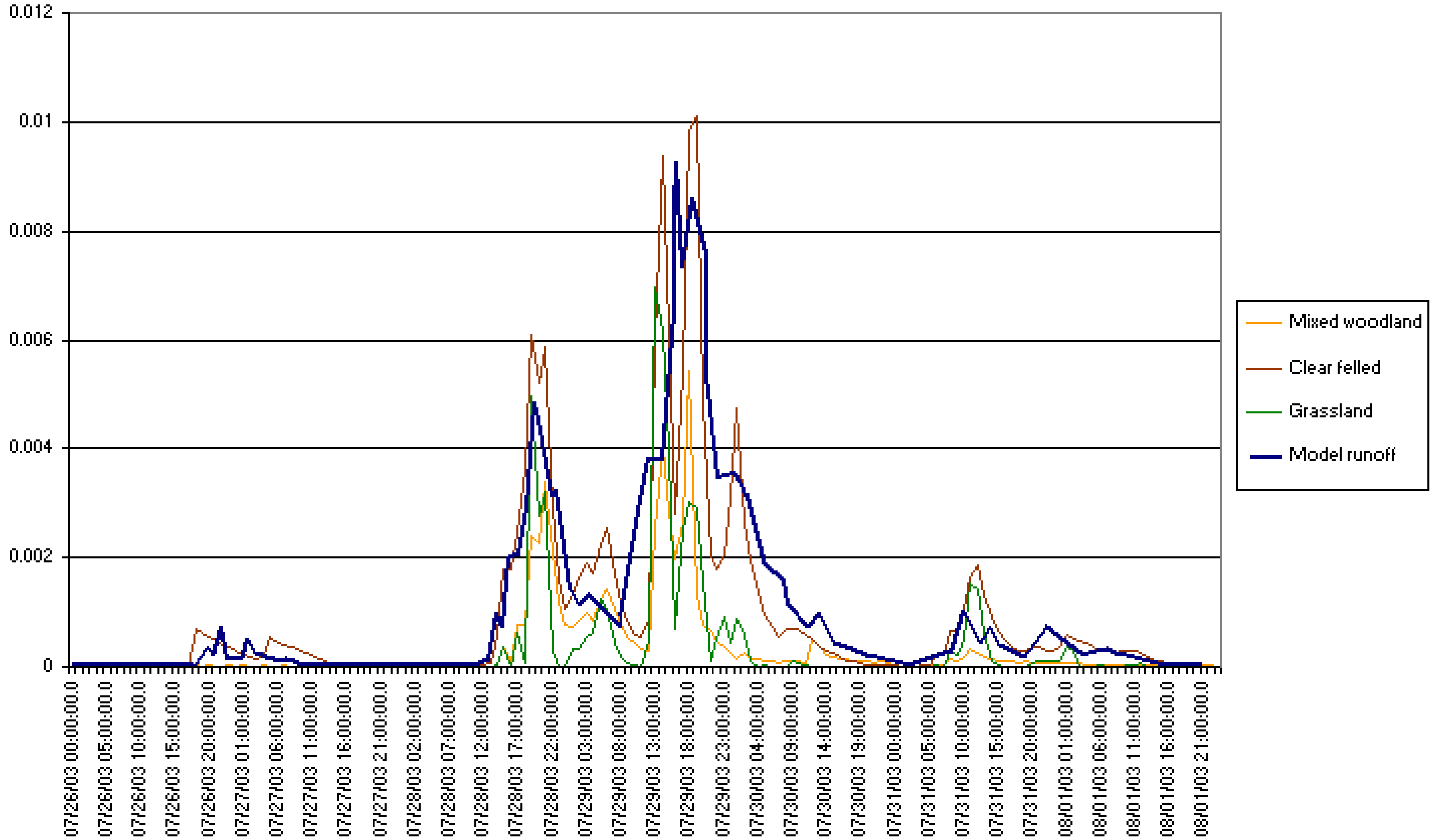


Figure 4.35: Surface runoff at experimental sites, 26 July – 1 August 2003, measured in m^3/contour m/hour, with modelled runoff for the clear felled site C

In addition to surface ronoff, the model computes downslope throughflow in the topsoil and subsoil layers. This flow is shown in fig.4.36.

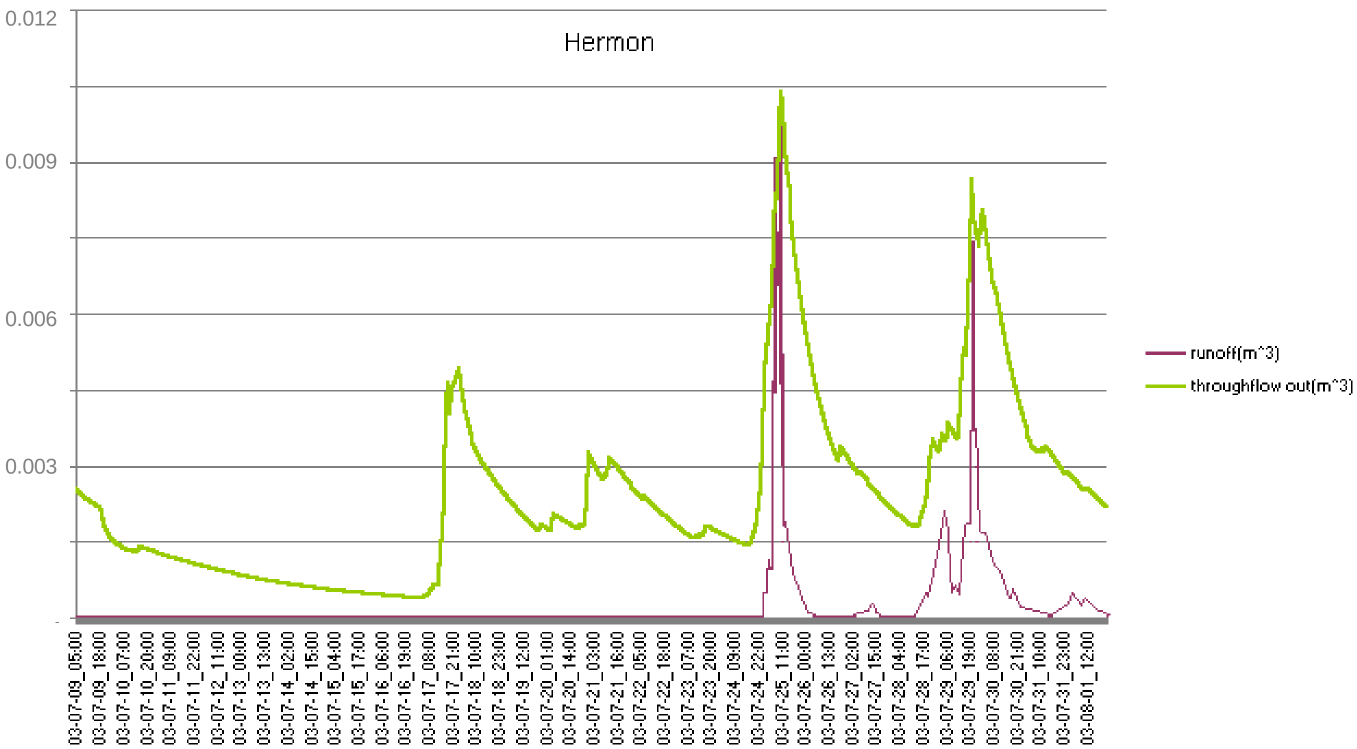


Figure 4.36: Modelled surface runoff and downslope shallow throughflow for Hermon site C, July – August 2003

Runoff is seen to make up a small volume of the total downslope discharge, becoming important only at the most intense periods of storms. Generation of runoff appears to require a high level of soil saturation prior to the onset of storm rainfall.

Within the limitations of the HOST soil classification model being used, hydraulic conductivity was adjusted to produce the best fit with field data in fig.4.35. Alteration of surface roughness made only small differences to runoff rate. Significant changes to both runoff generation and shallow throughflow could be produced, however, by increasing or decreasing the soil thickness represented in the model. It appears that the main effect of forestry on hydrological response within Coed y Brenin is due to the changes in soil depth and texture which occur as plantations mature, rather than changes to ground surface runoff characteristics.

An example plot of surface runoff for the Afon Wen sub-catchment around Hermon is given in fig.4.37 at the peak of a storm event on 25 July 2003. Runoff is restricted to the steep lower valley slopes around Moel Hafodowen and the deeply incised Afon Wen valley. The gentler slopes of Rhobell Fawr are characterised by sub-surface throughflow in soils above low-permeability basalts and diorites.

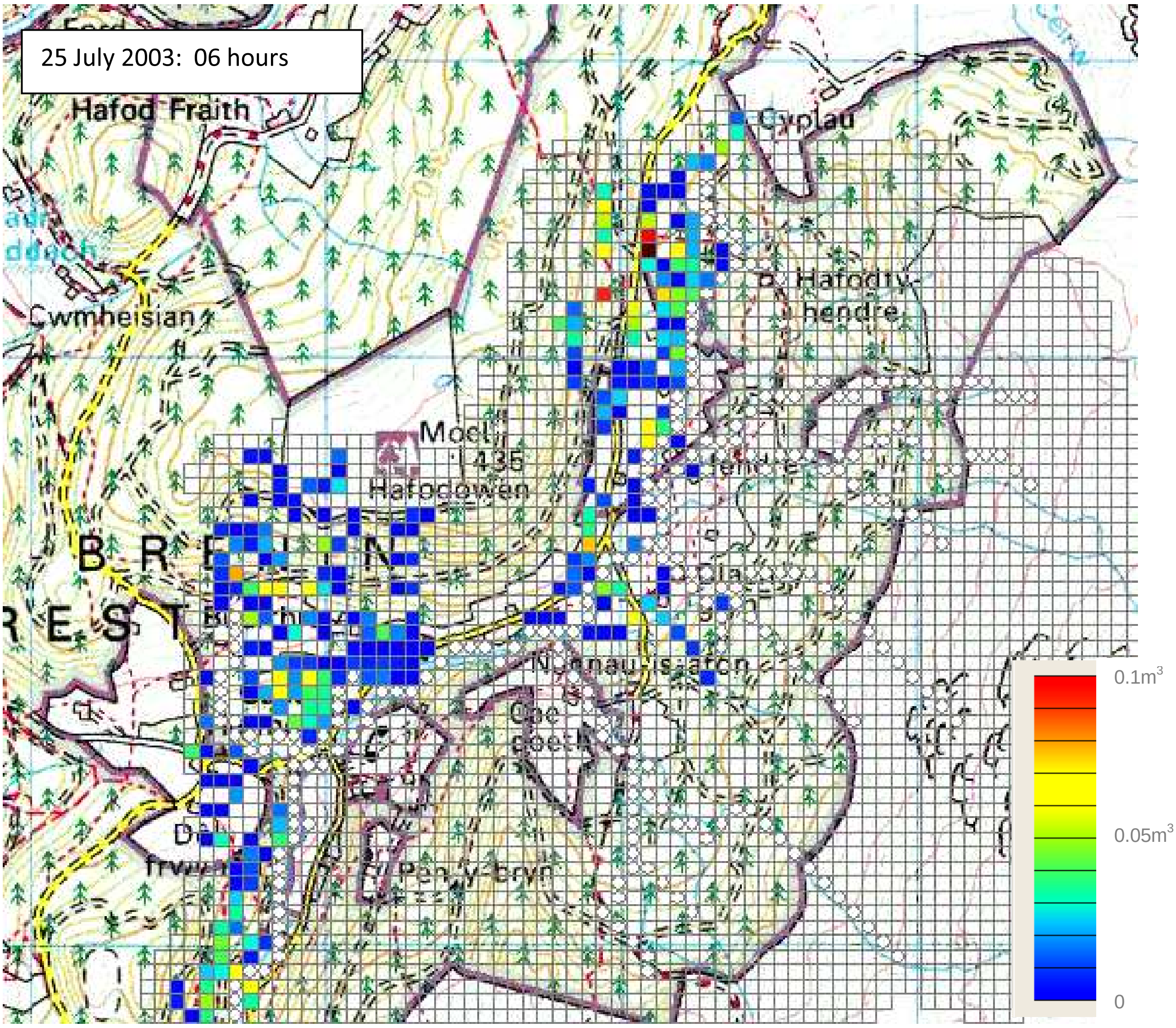


Figure 4.37: Afon Wen sub-catchment, Hermon. Modelled surface runoff for the period 05h-06h, 25 July 2003

Tir Penrhos

A hillslope runoff and throughflow monitoring site was operated at Tir Penrhos, Hermon, from the autumn of 2002 to the summer of 2003. Rainfall was recorded during this period at a gauge adjacent to the monitoring site. This rainfall sequence has been used in the hillslope model.

Results for shallow throughflow are given in fig.4.38, with the experimental observations for comparison. The field monitoring site failed to record the peak throughflows which occurred during storm events on 4 December and 30 December when the maximum recording rate of the equipment was exceeded. It is evident that throughflow within the hillslope soil profile was continuing between the periods when discharge was recorded, and would have taken place in subsoil below the depth of emplacement of the catchment dam. Nevertheless, there is a close similarity in the patterns of rise and recession of the modelled and observed flows, providing reassurance for the accuracy of the model.

Surface runoff results for the Tir Penrhos model are given in fig.4.39. Reasonable agreement has been achieved between field observations and the model by adjusting surface roughness coefficients for the hillslope. It is found that surface runoff can vary considerably between adjacent grid squares and time steps, and it is probably not possible to obtain perfect correlation with field measurements when modelling at a grid dimentsion of 50m. It appears, however, that the integrated volume of runoff modelled for the hillslope is realistic.

Model output is given in fig.4.40, showing patterns of downslope shallow throughflow and surface runoff during a storm event in the area of Tir Penrhos on 17 November 2002. Throughflow is extensive in the glacial and periglacial deposits of the deeply incised valleys of Coed y Brenin. Surface runoff is more localised, occurring mainly on lower steep valley sides, and in areas of shallow soils on impermeable bedrock.

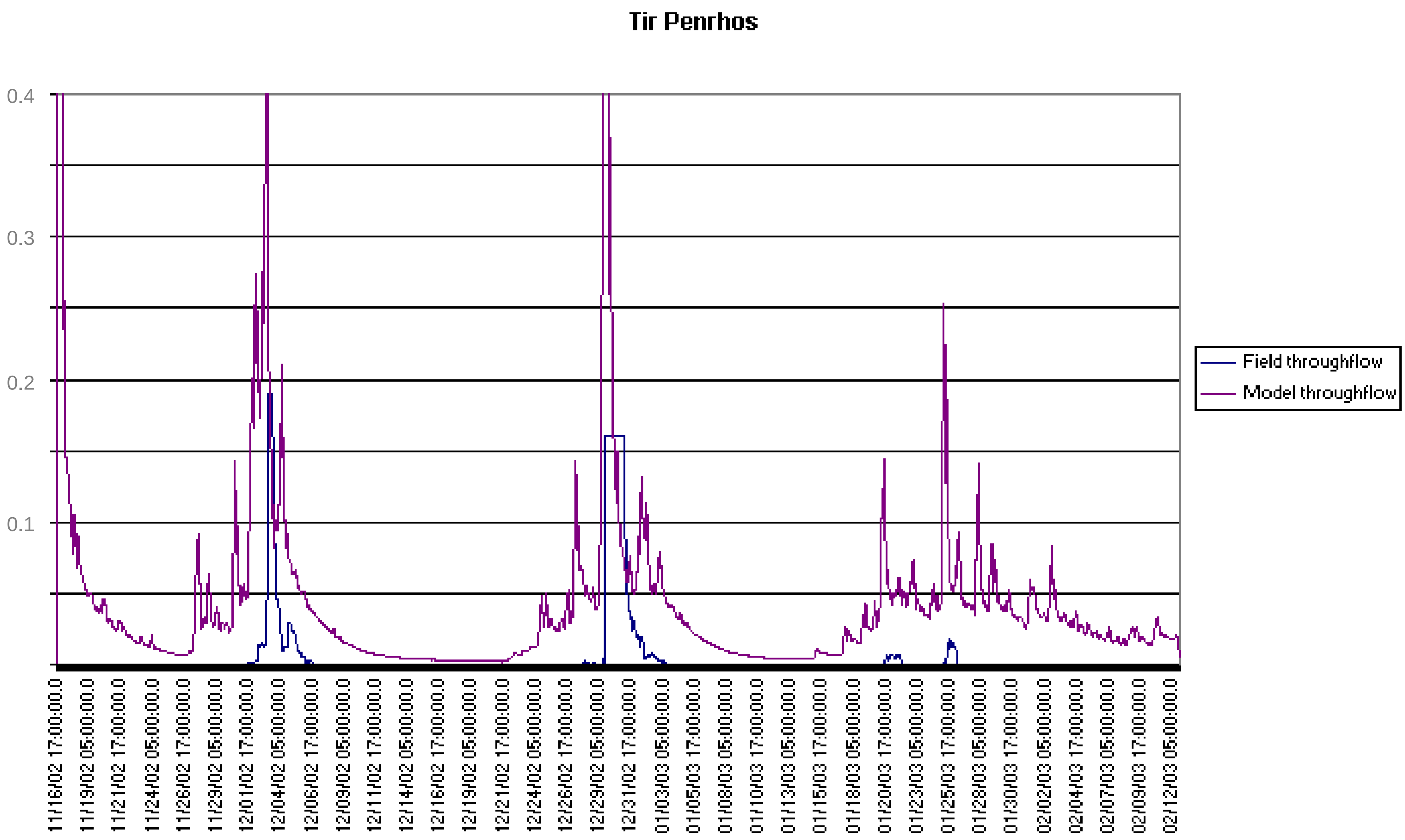


Figure 4.38: Modelled throughflow at Tir Penrhos, Hermon, for the period November 2002 – February 2003, with observed throughflow for comparison

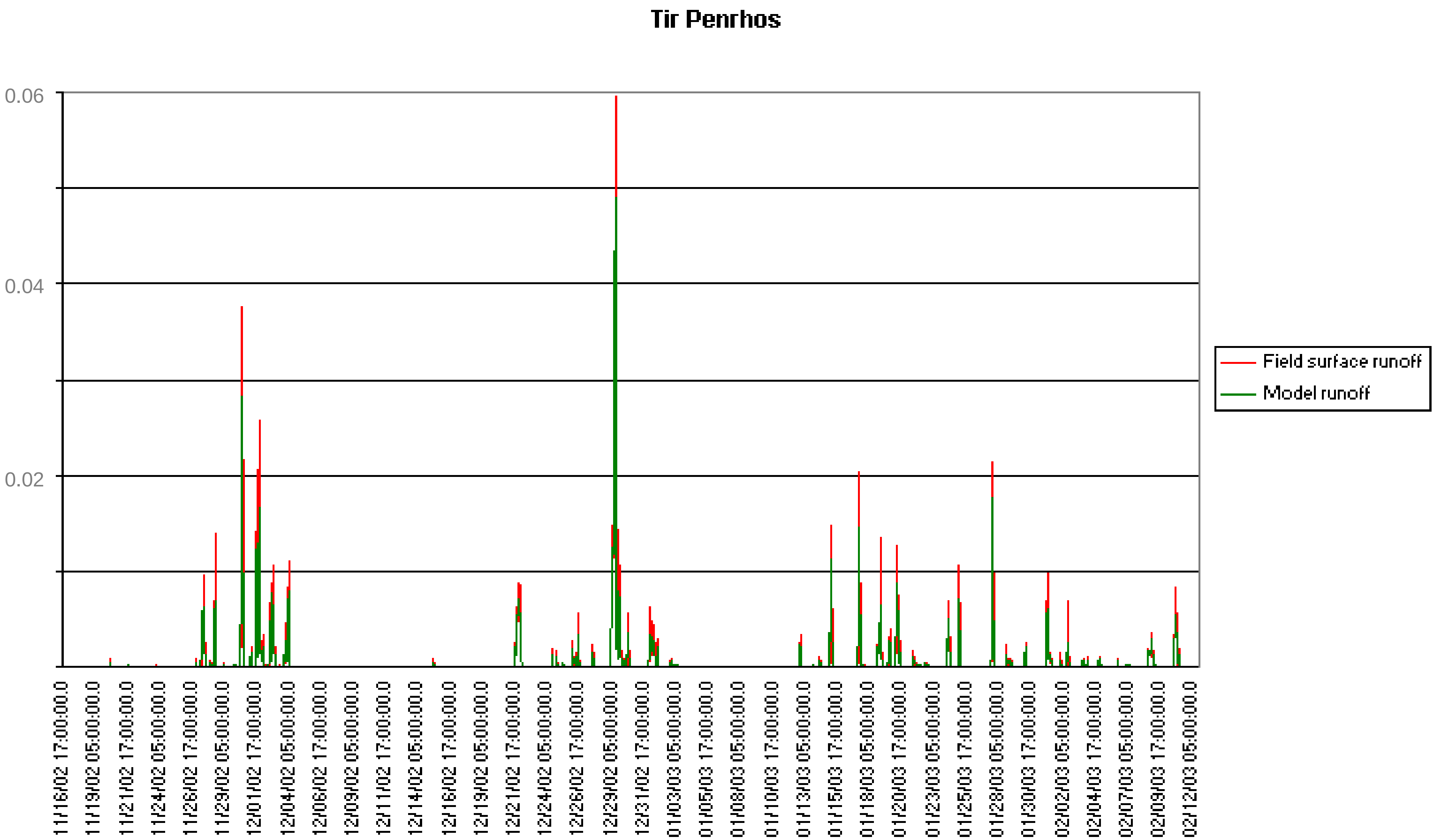


Figure 4.39: Modelled surface runoff at Tir Penrhos, Hermon, for the period November 2002 – February 2003, with observed runoff for comparison

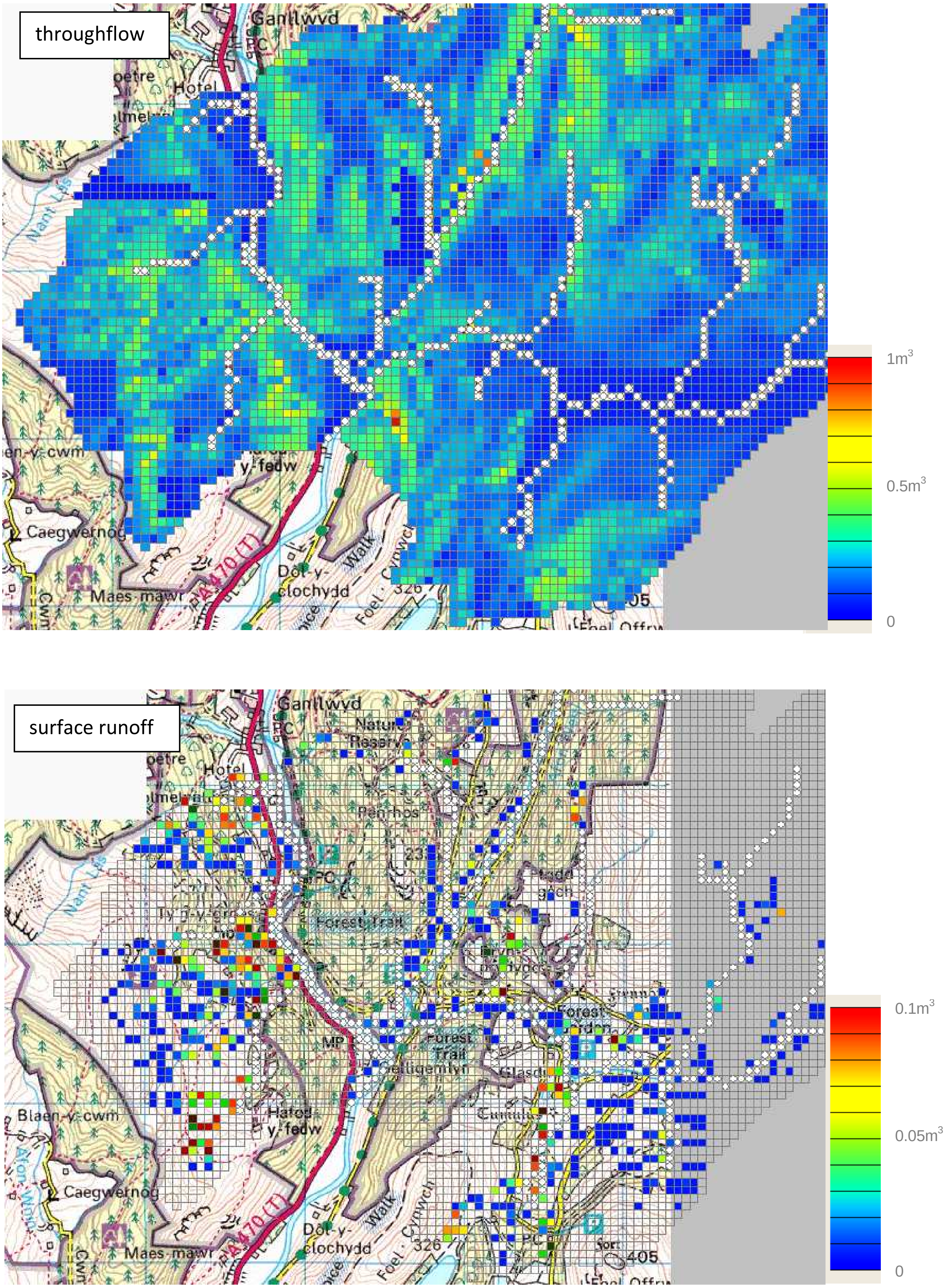


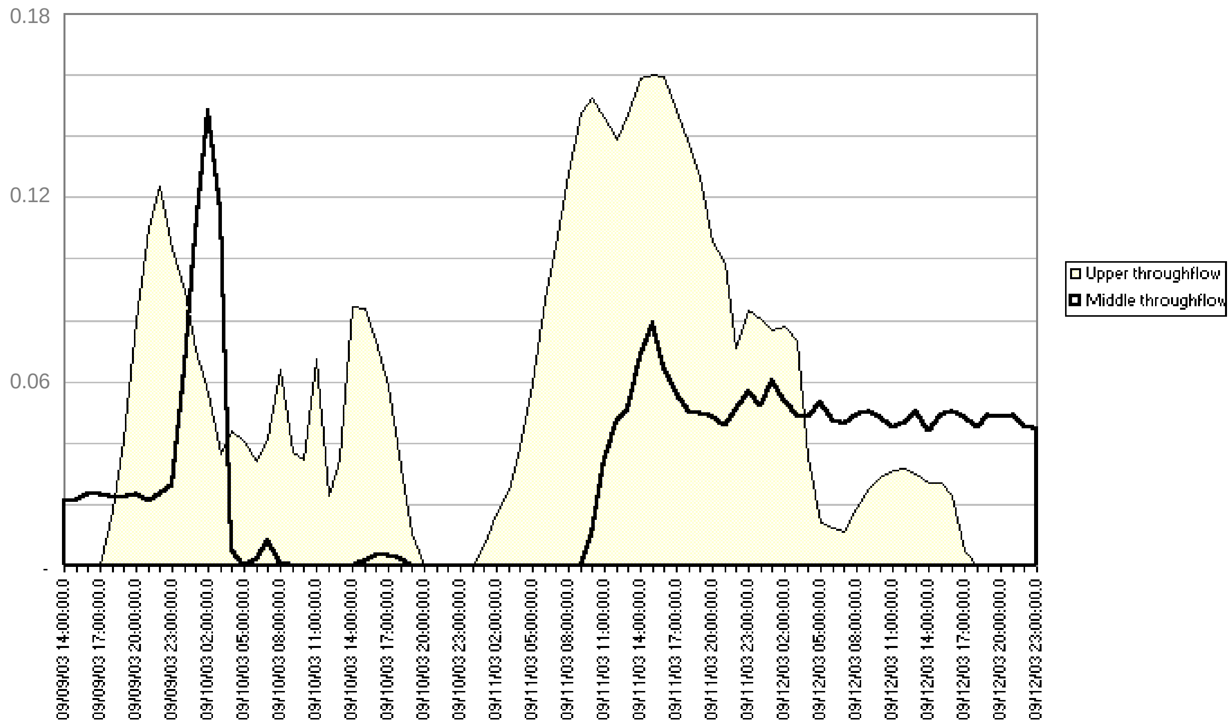
Figure 4.40: Relative rates of throughflow and surface runoff for the lower Afon Wen sub-catchment, 17 November 2002, 21h-22h

Pared yr Ychain

Runoff and throughflow monitoring has been carried out at hillslope sites in young forestry plantations at Pared yr Ychain in the upper Wnion valley. The lower and upper monitoring sites are marked at locations A and B in fig.4.41.

Figure 4.41: Location of runoff and throughflow monitoring sites, Pared yr Ychain.
Image by Llion Jones

The hillslope model was run to simulate throughflows at sites A and B during two storm events on 9 and 11 September 2003. Results from the field observations and model are shown in fig.4.42.



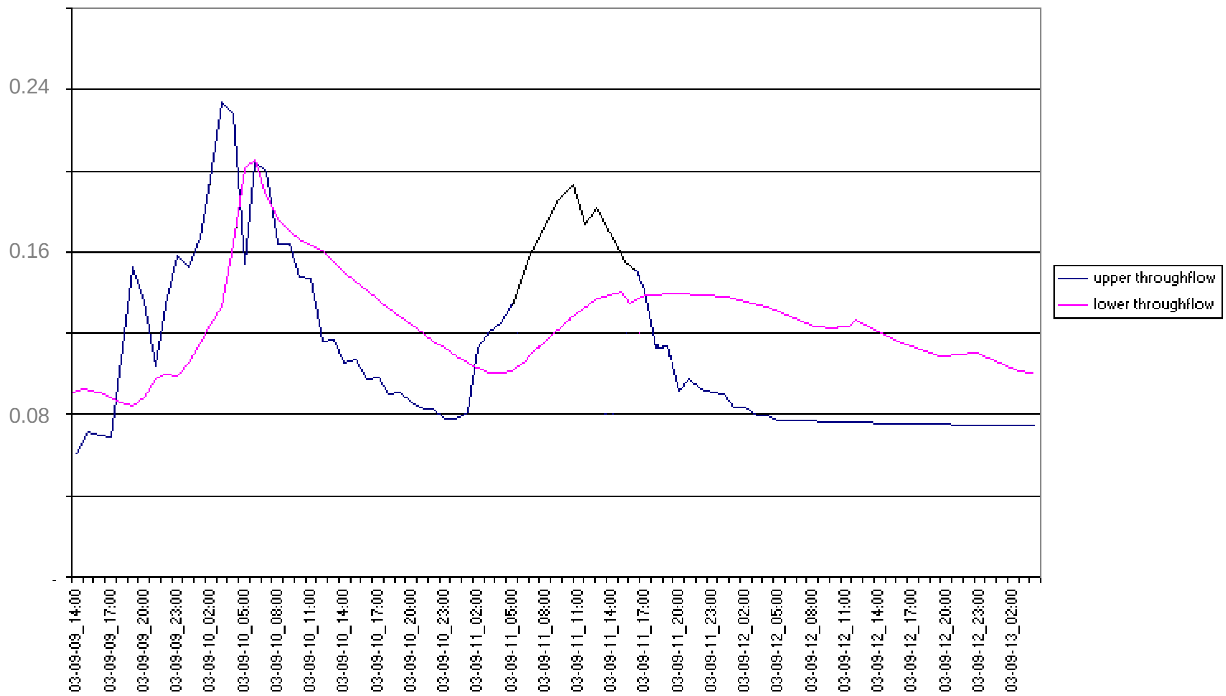


Figure 4.42: Throughflow at Pared yr Ychain hillslope sites, storm events of 9 and 11 September 2003. (above) field observations, (below) model.

As in the case of measurements at Tir Penrhos, it is evident that some throughflow has passed below the collecting dams at sites A and B and was not recorded. Nevertheless, the main features of the flow patterns are reproduced in the model:

- During each storm event, high volumes of throughflow appear first at the upper site and reach the lower site approximately three hours later. This may represent the slow saturation of the sandy boulder clay drift deposits occupying the floor of the Ty Cerrig valley.
- High levels of throughflow persist longer at the lower site as the superficial deposits drain slowly downslope at the end of the rainfall event.

Differences in the heights of the successive storm throughflow peaks occur between the field observations and the model. It may be possible to obtain a better correspondence through adjustment of the hydrological properties of the HOST soil class representing glacial till. However, an important simplifying aspect of the HOST system is that one class should represent all soils developed on glacial till within the Mawddach basin. Further field data would be needed to assess possible variability of hydrological responses by till deposits with different source materials and textures.

Fig.4.43 gives a comparison of throughflow and surface runoff for a storm event of 24 July 2003. Throughflow rates are modelled as appreciably lower in the areas of glacial till, whilst surface runoff from these areas is noticeably higher. This is consistent with field observations during storms.

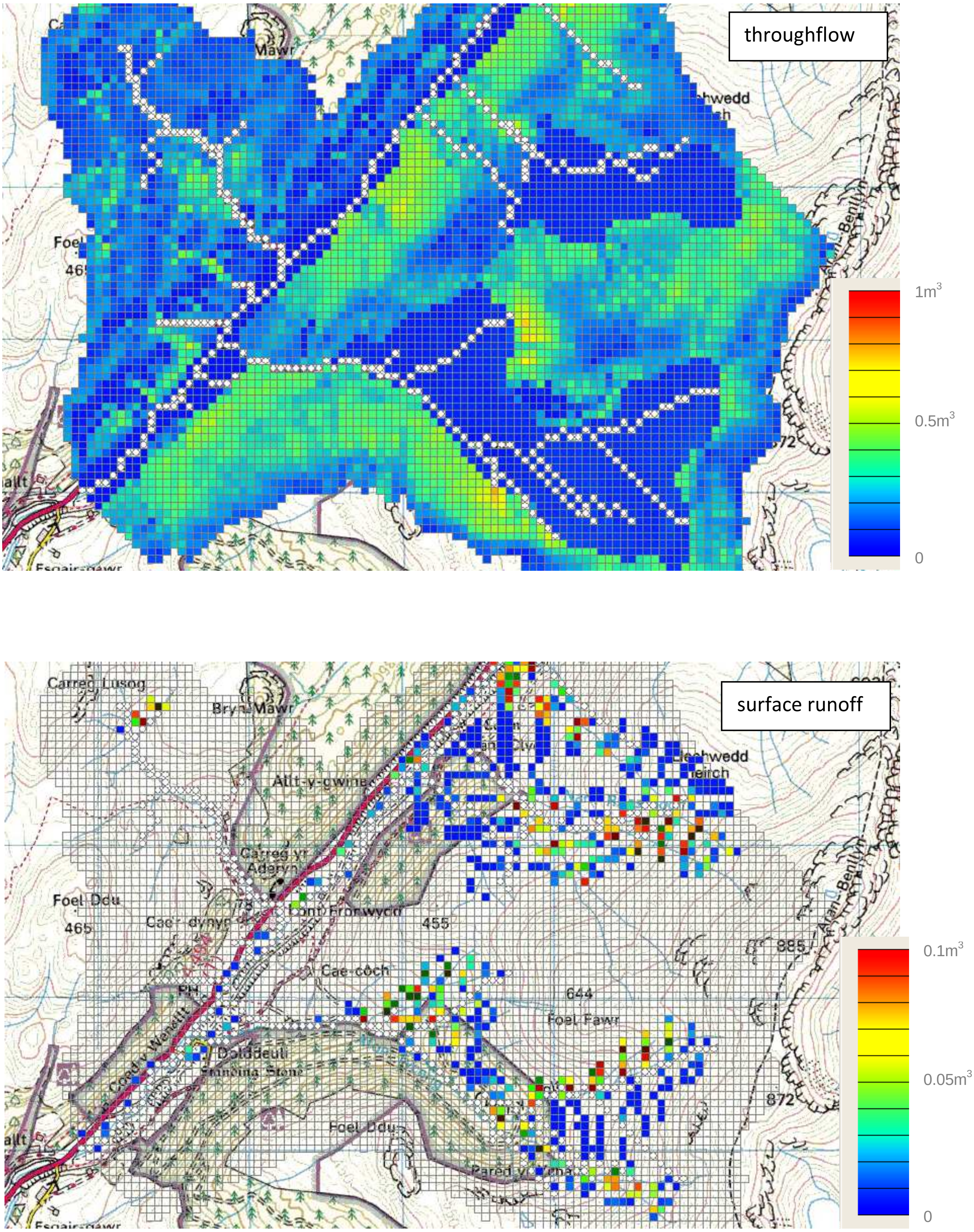


Figure 4.43: Relative rates of throughflow and surface runoff for the upper Wnion valley, 24 July 2003, 08h – 09h

Channel routing

Following the work of Lee and Chang (2005), an algorithm was developed within the hillslope model to classify surface streams according to stream order. Headwaters are designated as first order streams. Where two first order streams converge, a second order stream is produced. Similarly, the convergence of two second order streams produces a third order stream. Hydrological parameters are assigned to first, second and third order streams to produce a best fit with recorded hydrographs at the outlets of sub-catchments.

Afon Ty Cerrig

The computer generated stream classification for the Nant Ty Cerrig sub-catchment is given in fig.4.44. The model hydrograph for outlet point A is presented in fig.4.45, with the recorded hydrograph for comparison. Agreement with the model for flood events is satisfactory, although the recesion curves in the modelled graph are rather too steep.

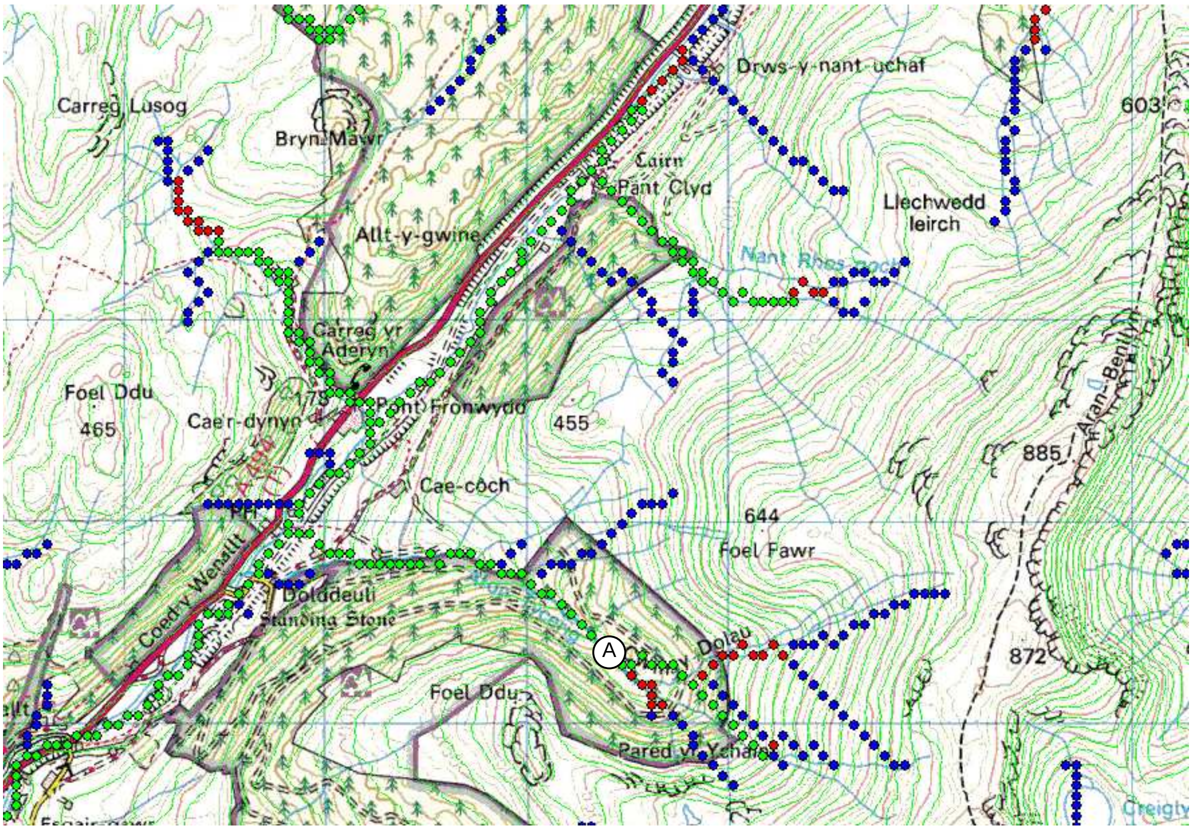


Figure 4.44: Stream classification for the upper Wnion valley. First order streams are shown in blue, second order in red, and third order in green.

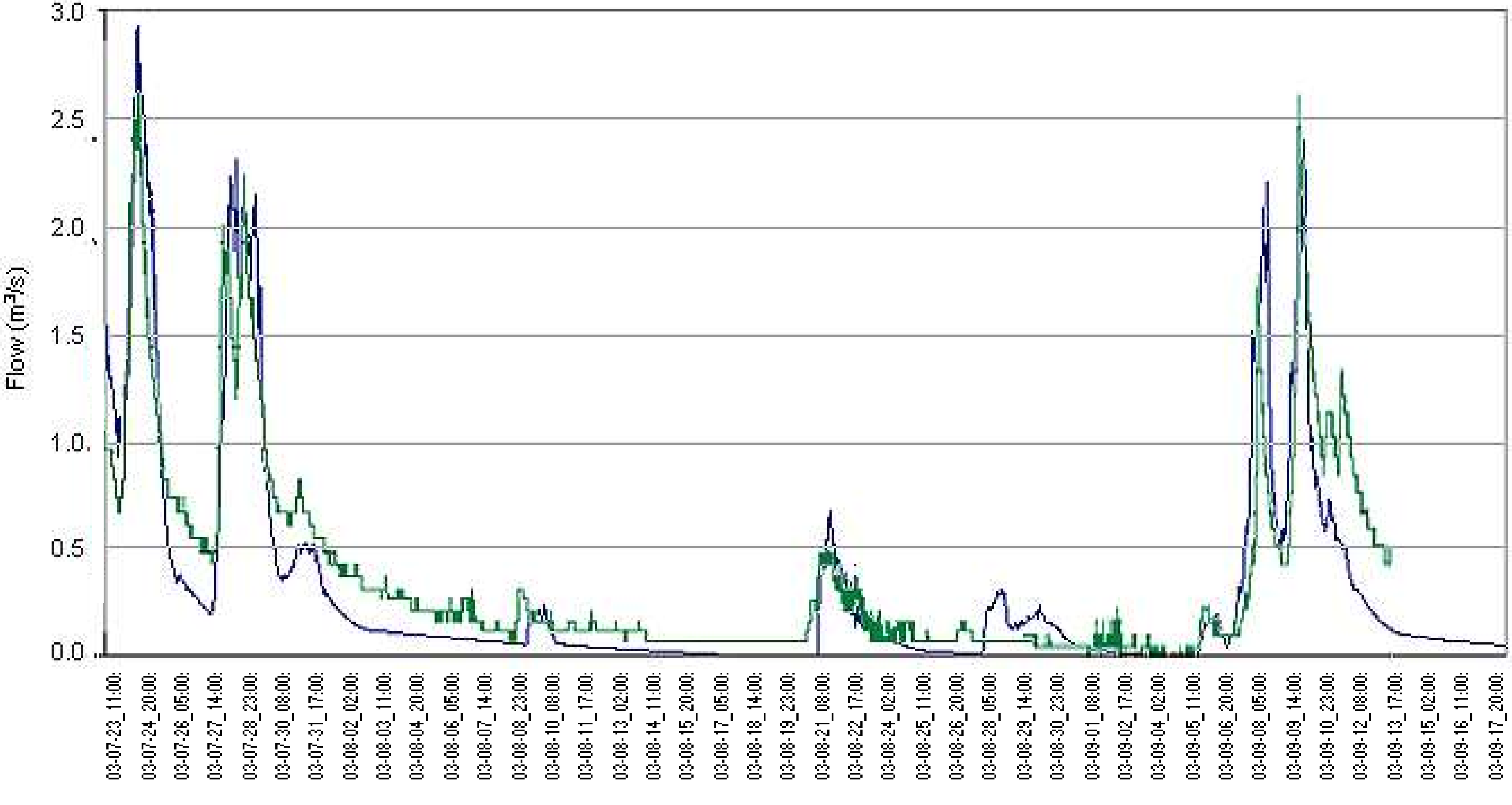


Figure 4.45: Modelled hydrograph (black) and recorded hydrograph (green) for the Afon Ty Cerrig at location A (fig.4.44) for the period July 2003 – September 2003

Afon Wen

Hydrographs were recorded on the Afon Wen near the village of Hermon during the winter of 2002-3. Stream order classification was carried out by the hillslope model (fig.4.46) and a hydrograph simulation carried out for the recording period. The results are presented in fig.4.47 with the field data for comparison. The model has been successful in picking out the main features of the hydrograph pattern, particularly for the major storm events. Some minor hydrograph peaks apparent in the model were not recorded in the field; it is uncertain whether this was due to limitations in the hydrograph recording equipment, or whether some buffering effect occurred within the river system to prevent an increase in discharge on the river at Hermon. The recession curves for the recorded hydrograph are in this case steeper than in the model. This may be due to a loss of drainage water to groundwater store within the steep gorge section of the Afon Wen after the peak of a flood event has passed.

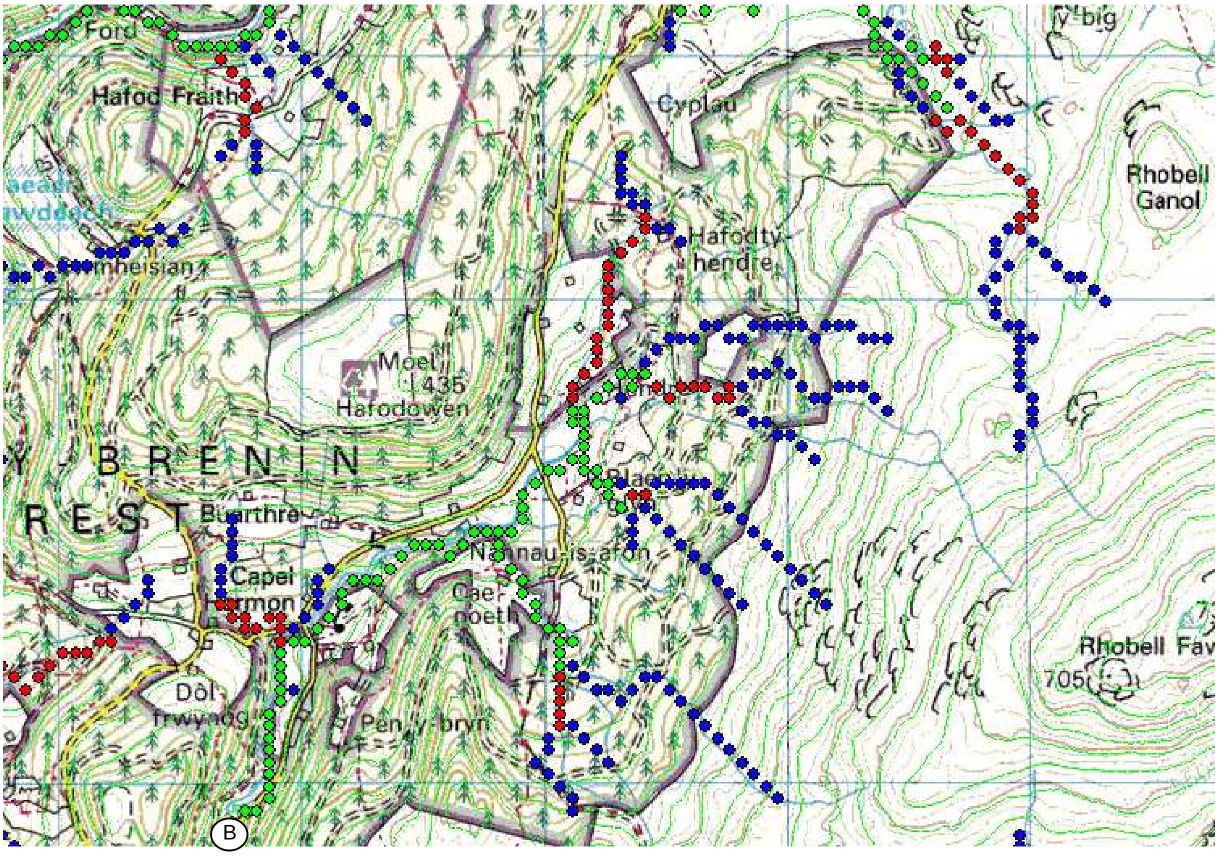


Figure 4.46: Stream classification for the upper Afon Wen. First order streams are shown in blue, second order in red, and third order in green.

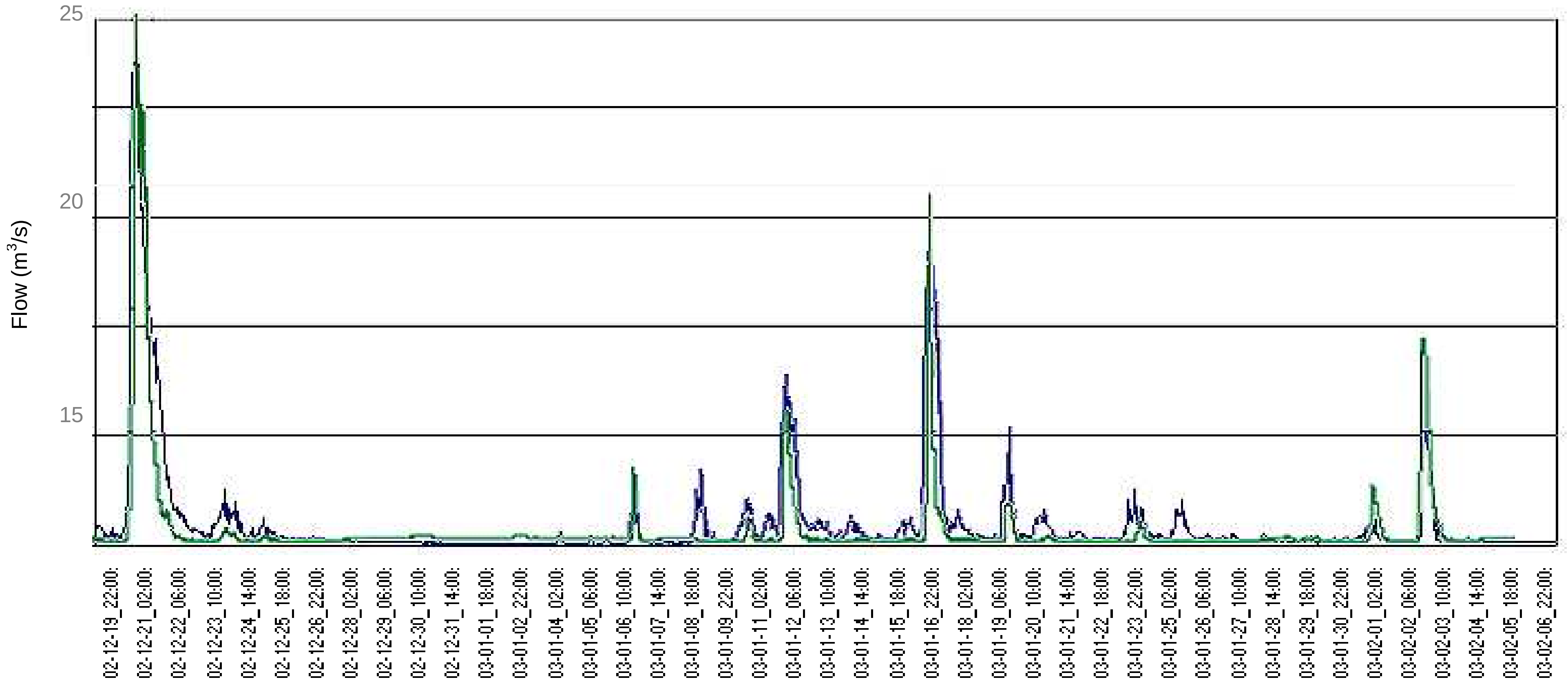


Figure 4.47: Modelled hydrograph (black) and recorded hydrograph (green) for the Afon Wen, Hermon at location B (fig.4.46) for the period December 2002 – February 2003

Waen y Griafolen

A hydrological study was carried out on the Waen y Griafolen peat blanket bog during 2003. This study included the monitoring of water levels in the peat, and the recording of hydrographs on the outlet stream (fig.4.48).

Water flow simulations have been carried out using the Mawddach hillslope model, to determine whether the soil/subsoil throughflow and runoff functions provided by the program are adequate to model storm events on the bog.

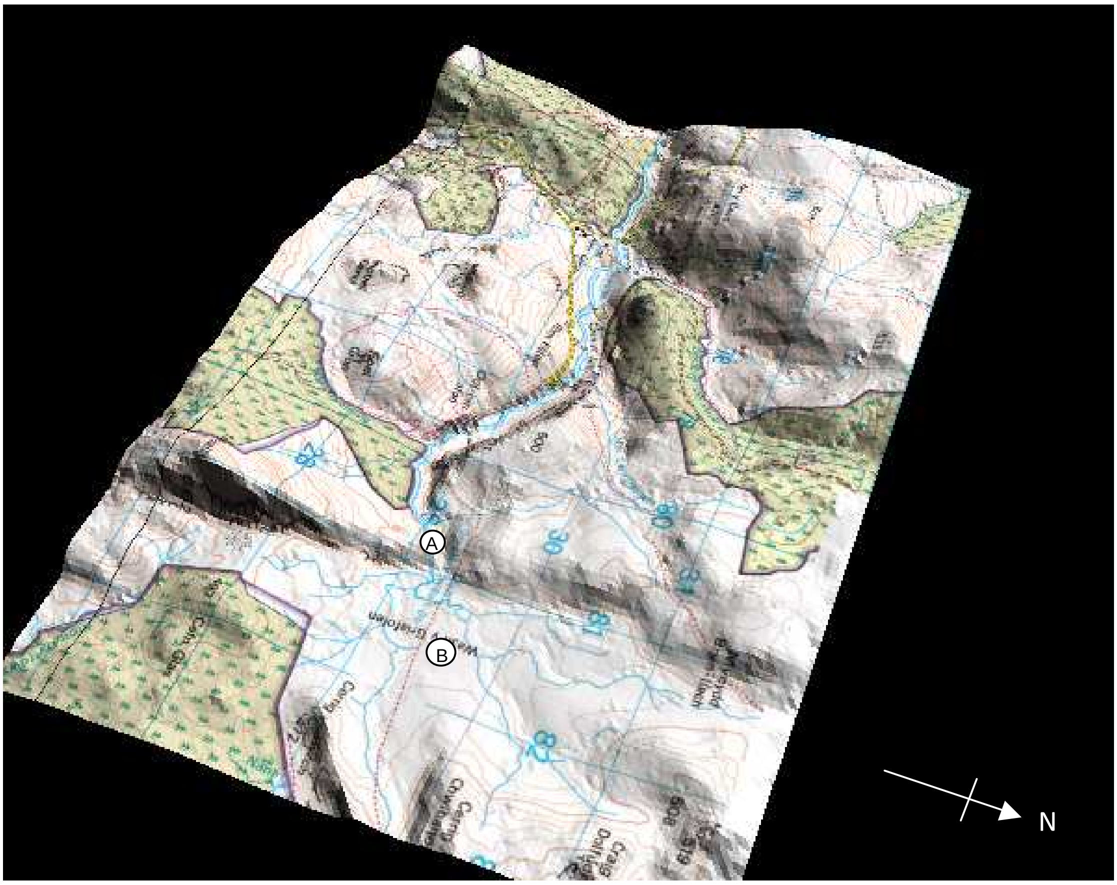


Figure 4.48: Waen y Griafolen blanket bog. Water table monitoring was carried out at borehole B, with monitoring of the outlet stream at A. Image by Llion Jones

Model output is given in fig.4.49 for a rainfall event of 4 June 2003:

Sub-surface throughflow is very low over most of the blanket bog, despite the peat being close to saturation. Explanations may be the low permeability of the older humified and gelatinous peat, combined with the very gentle gradient of much of the bog. The only areas of significant throughflow are at the base of the western escarpment, and around the heads of the stream valleys cutting into Cerrig Chwibanog to the east.

Surface runoff is widespread across the surface of the raised bog, reaching high volumes in places. It is evident that the peat rapidly saturates during prolonged rainfall, leading to extensive saturation-excess overland flow as the main mechanism for water release from the bog.

The modelled hydrograph for the outlet stream is given in fig.4.50, and is consistent with the limited hydrograph recordings available from fieldwork. Comparison with the borehole water levels show that a period of repeated high river levels corresponds with a period of saturation of the central peat area.

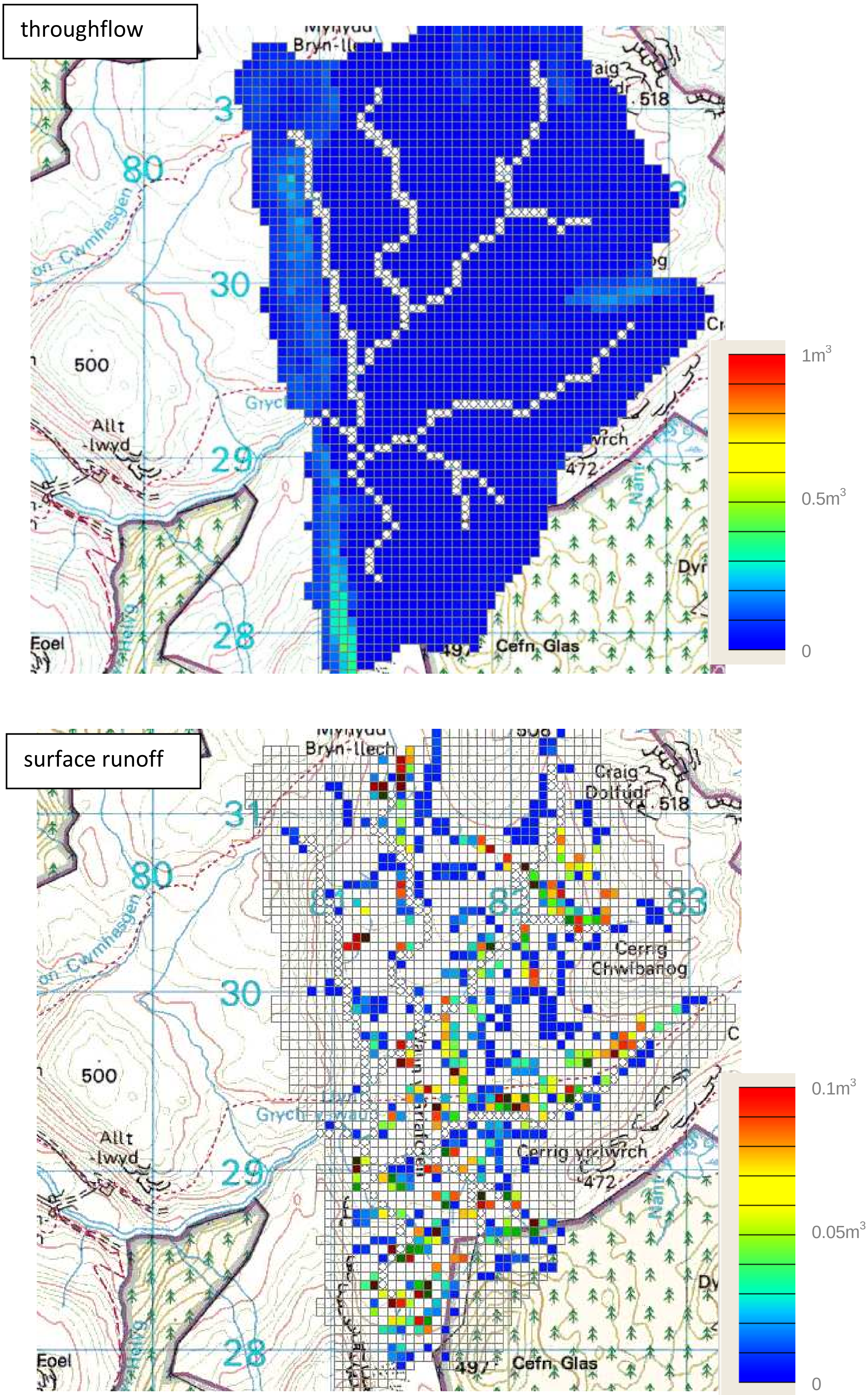


Figure 4.49: Relative rates of throughflow and surface runoff for Waen y Griafolen, 4 June 2003, 20h-21h

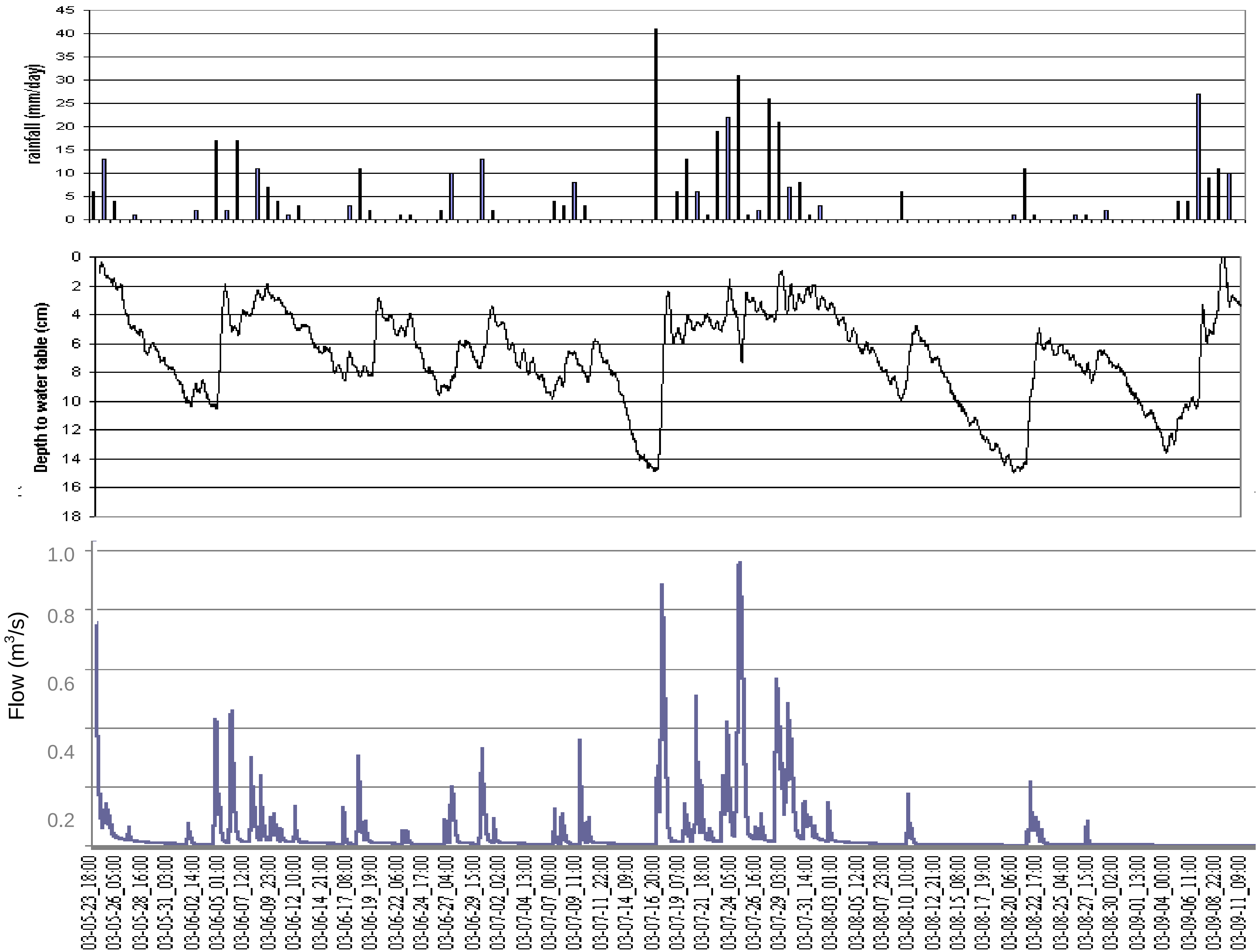


Figure 4.50: Comparison of borehole water levels on the Waen y Griafolen blanket bog and the modelled river discharge of the outlet stream

Summary

- The Mawddach hillslope model is consistent with field observations, and has provided additional insight into hydrological processes operating in the catchment. The model provides numerical results for hillslope runoff, shallow throughflow and river discharge which are close to measured data.

- Modelling confirms field observations that storm throughflow is the critical process responsible for the majority of flood events on the Mawddach. In most areas of the catchment, surface runoff is rarely observed except for brief periods during intense storm events. However, substantial areas of surface runoff may occur on blanket peat and glacial till. The model demonstrates the expanding zones of saturated soil at the base of hillslopes where surface runoff is generated during storm events.

- The hillslope model is able to simulate changes in soil and subsoil saturation over extended periods, and demonstrates the critical dependence of frontal rainfall flood events on antecedent hydrological conditions within the catchment. Convective thunderstorms can, however, produce rainfall rates which locally exceed the rate at which water can enter even dry soils, causing infiltration-excess overland flow.

- Modelling supports field observations that the principal effect of forestry on hydrology in the Mawddach catchment is through the development of increased depth of soils. Forestry effects on hillslope flow through simple surface roughness are of lesser significance.

- The model provides insight into the movement of waves of soil water downslope through superficial deposits on a scale of several hours in the course of a storm event.

- The Mawddach hillslope model appears suitable for use in a flood prediction system where frontal rainfall dominates. In particular, the model is able to handle antecedent soil moisture conditions effectively, and thereby identify periods of high potential flood risk within the catchment.