4.4 Results of runs of the integrated model

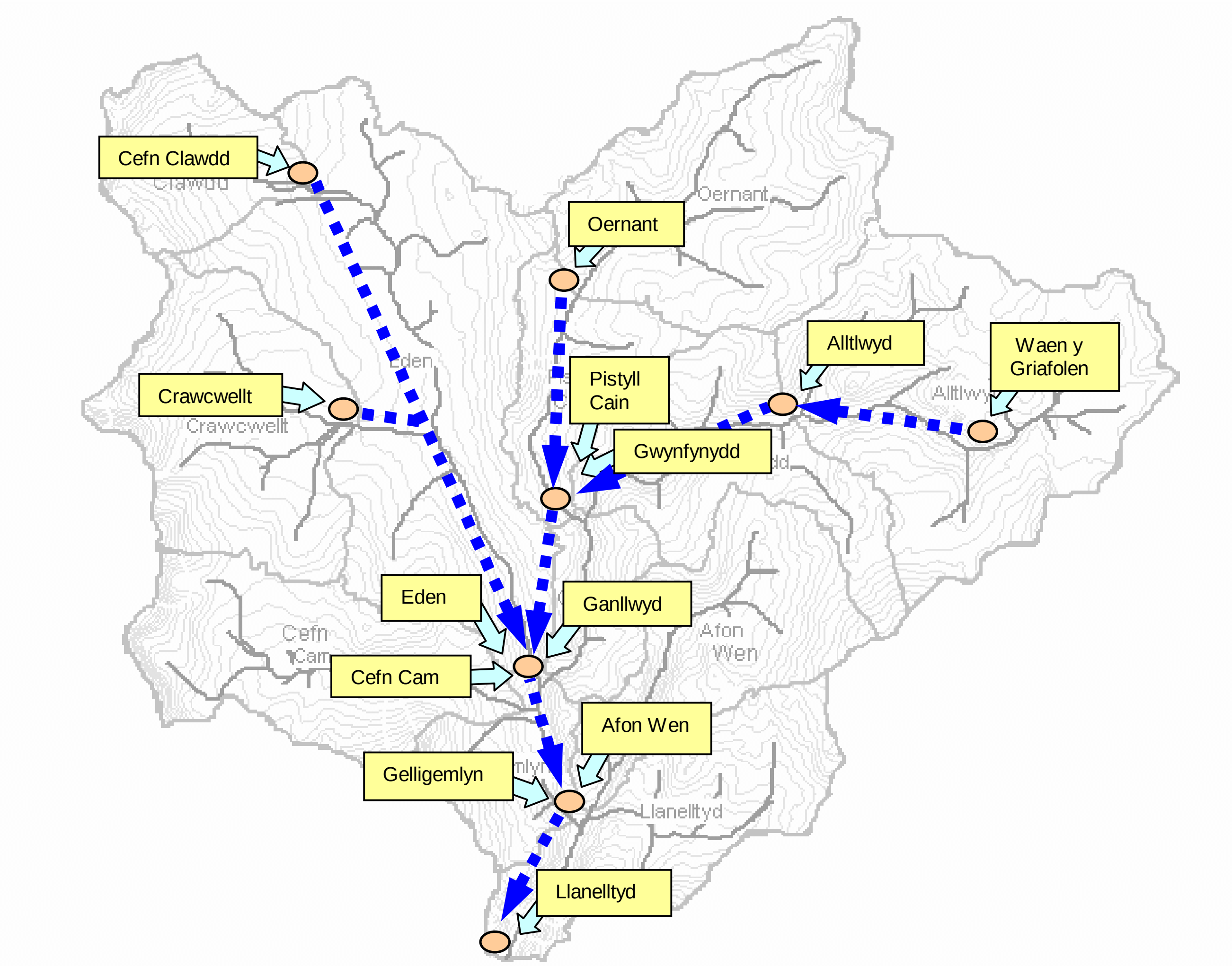
Configuration for distributed processing

Full tests of the integrated hydrological model were carried out for the Mawddach flood events of 3 July 2001 and 3-4 February 2004. Rainfall data was prepare on a 1km grid for the North Wales region using runs of the MM5 meteorological model on a 12-processor Altix minicomputer at Bangor University. This machine is able to simulate 12 hours of world time within 30 minutes of processing time, leaving an adequate forecasting interval. Processing was carried out under remote telnet control from Coleg Meirion-Dwyfor, Dolgellau, where the hydrological model was situated.

Output files from MM5 were downloaded by broadband connection to Dolgellau, where a utility program was used to extract rainfall data from other meteorological output and convert this to ASCII format compatible with the hillslope model.

The hillslope modelling has been coordinated using a set of thirteen Mawddach sub-catchment models and nine Wnion sub-catchment models, as shown in fig.4.51. Computations were carried out for each sub-catchment, to record hillslope surface runoff, shallow throughflow, infiltration to groundwater and open channel flow. An output hydrograph file was created to determine the addition to downstream river flows. To reduce processing time, the sub-catchment models were run simultaneously on a series of networked microcomputers, with output directed to a central fileserver (fig.4.52).

River routing calculations were carried out in a progressive downstream sequence using the program GSTARS in waterflow mode without sediment transport calculations. Output hydrographs for the Afon Wnion at Dolserau and the Afon Mawddach at Gelligemlyn were transferred to the River2D program to simulate overbank flooding in the lower valleys around Dolgellau and Llanelltyd.



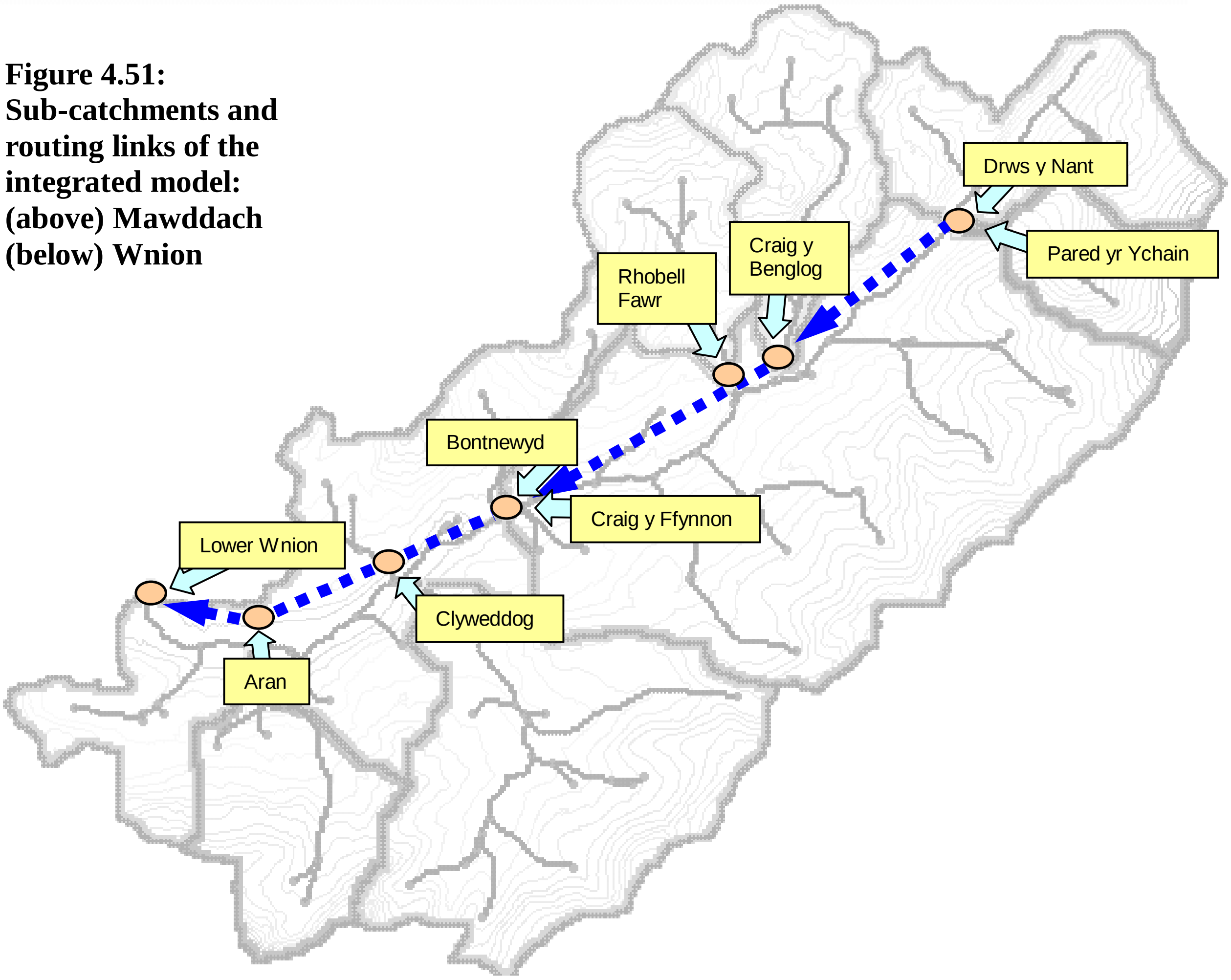


Figure 4.51: Sub-catchments and routing links of the integrated model: (above) Mawddach (below) Wnion

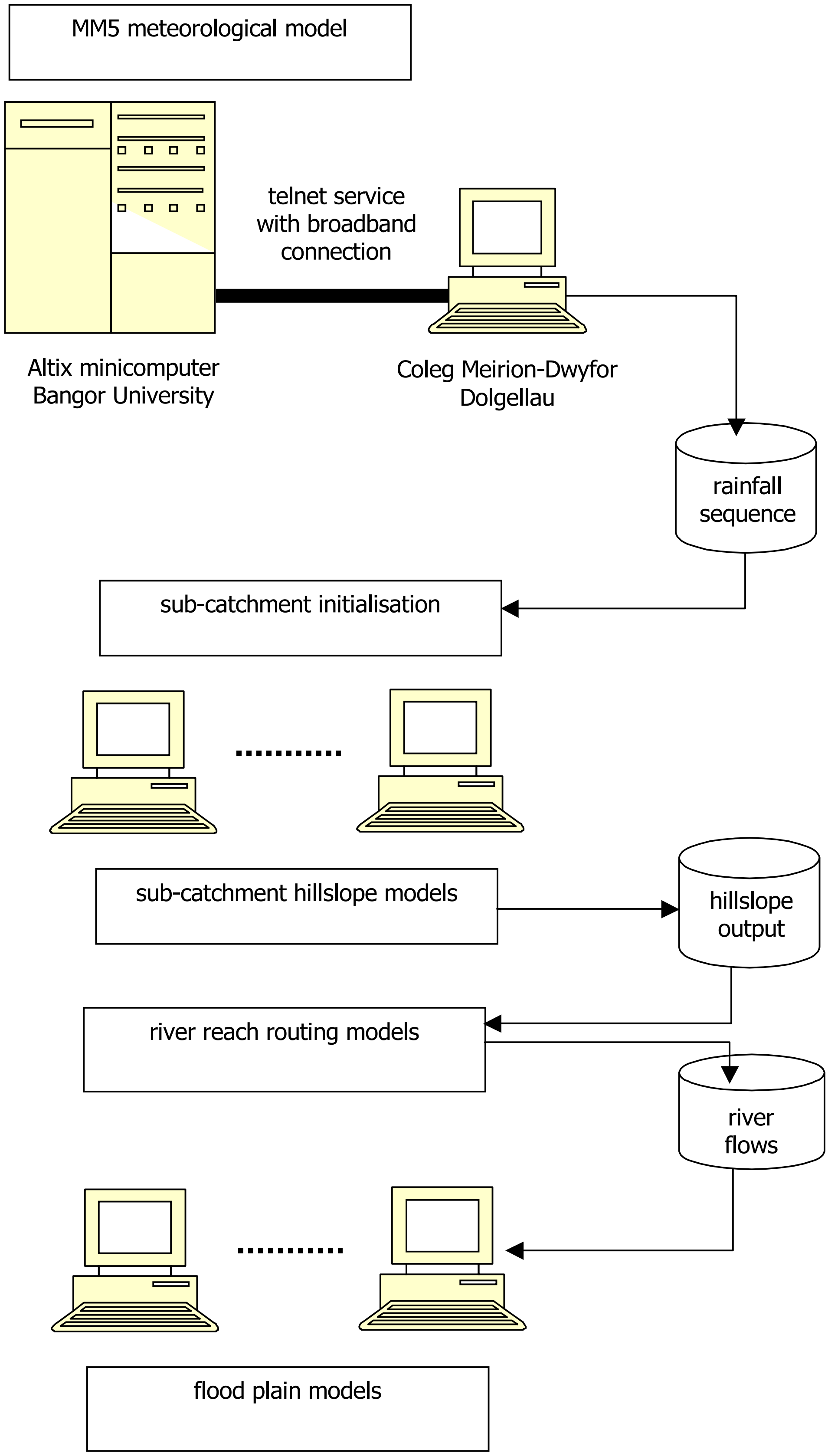


Figure 4.52: Configuration for the Mawddach flood forecasting system

The sequence of operations during a run of the hillslope model are summarised by figs.4.53-4.54:

- Rainfall forecasts generated on a 1km grid by MM5 are applied over the sequence of time steps to the sub-catchment (fig.4.53):

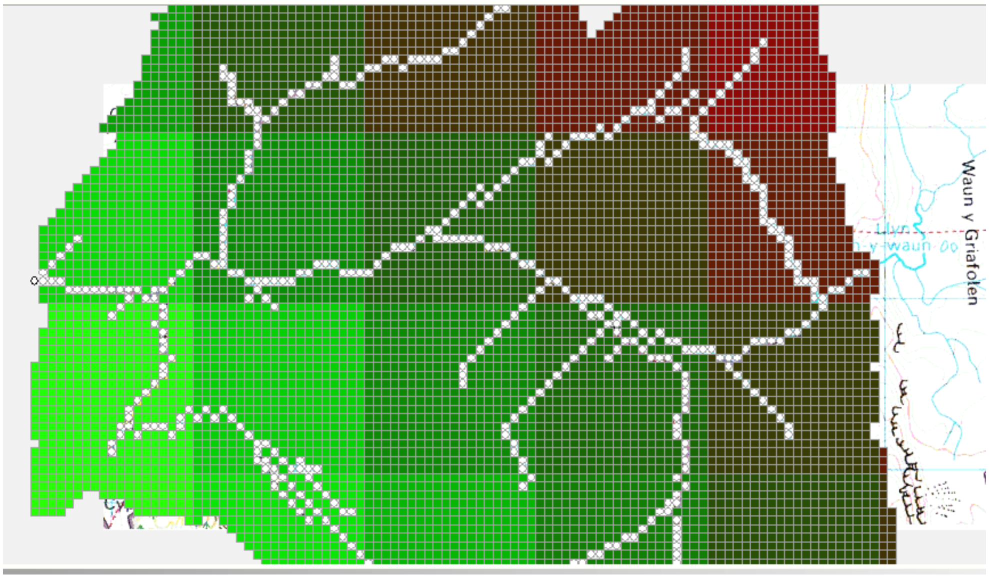


Figure 4.53: Example plot showing a rainfall gradient across the catchment. The 1km resolution of the forecast requires that groups of 20 by 20 grid squares are assigned the same rainfall value during a time step.

- At each time step, a series of hydrological parameters can be displayed (fig.4.57-4.58). This provides a means of checking that the process model is operating in a physically realistic manner, and provides insight into the relative importance of the hydrological processes operating in a particular sub-catchment. Parameters which may be examined are: surface runoff, soil moisture, shallow downslope throughflow, and infiltration to bedrock. The model run may be paused at any stage in order to obtain printouts of parameter plots.
- Water reaching open channel cells through overland flow or downslope throughflow is routed to the sub-catchment outlet, using the kinematic wave method with channel parameters related to stream order as computed by the model. A preview of the outflow hydrograph is provided as a check on model operation, and output flow rates are tabulated for downloading to a data file.

The hillslope modelling software is provided on CD-ROM, and detailed instructions for setting up and running a sub-catchment model are included in Appendix A.

Results from the run of the Integrated Model for 3-4 February 2004

The storm events of 3-4 February 2004 led to extensive flooding around the head of the Mawddach estuary, and have been discussed in chapter 2. Rainfall was related to an established and well defined frontal system tracking in from the Atlantic, and was forecast with a good degree of accuracy by the MM5 meteorological model. Periods of heavy rainfall during the two days, reaching 8mm/h, were separated by drier weather during the night of 3 February (fig.4.54). High quality rainfall predictions were available for the Mawddach catchment at least six hours ahead of the storm events.

Runs of the model have been carried out for the Mawddach and Wnion, with hydrographs generated for gauging points at the outlets of a series of sub-catchments of the river system. A link had previously been demonstrated between river discharge values and the extent of flooding in the lower Wnion and lower Mawddach valleys, so flood predictions can confidently be made from hydrograph data.

Results are presented in fig.4.55 for the Tyddyn Gwladys gauging station in the middle course of the Mawddach, with field data and output from the HEC-1 model for comparison. Relatively close agreement was achieved between the hillslope model and the field data by adjusting the bedrock infiltration rates, hydraulic conductivity and topsoil/subsoil thicknesses for different soil zones. It was observed that the model is very sensitive to changes in these soil parameters, whilst variations in parameters for overland flow and channel routing have a relatively minor effect on the form of the output hydrograph. The timescales for surface flows are sufficiently fast that output from the catchment is effectively controlled by the rate of take up and release of soil water in hillslope processes.

The hillslope model appears to perform well in simulating the medium-timescale processes of water release from hillslope soils and superficial deposits over a period of several days following a storm event. These water flows can have a significant influence on flooding during a sequence of closely spaced rainfall events, as in the case of the February 2004 storms.

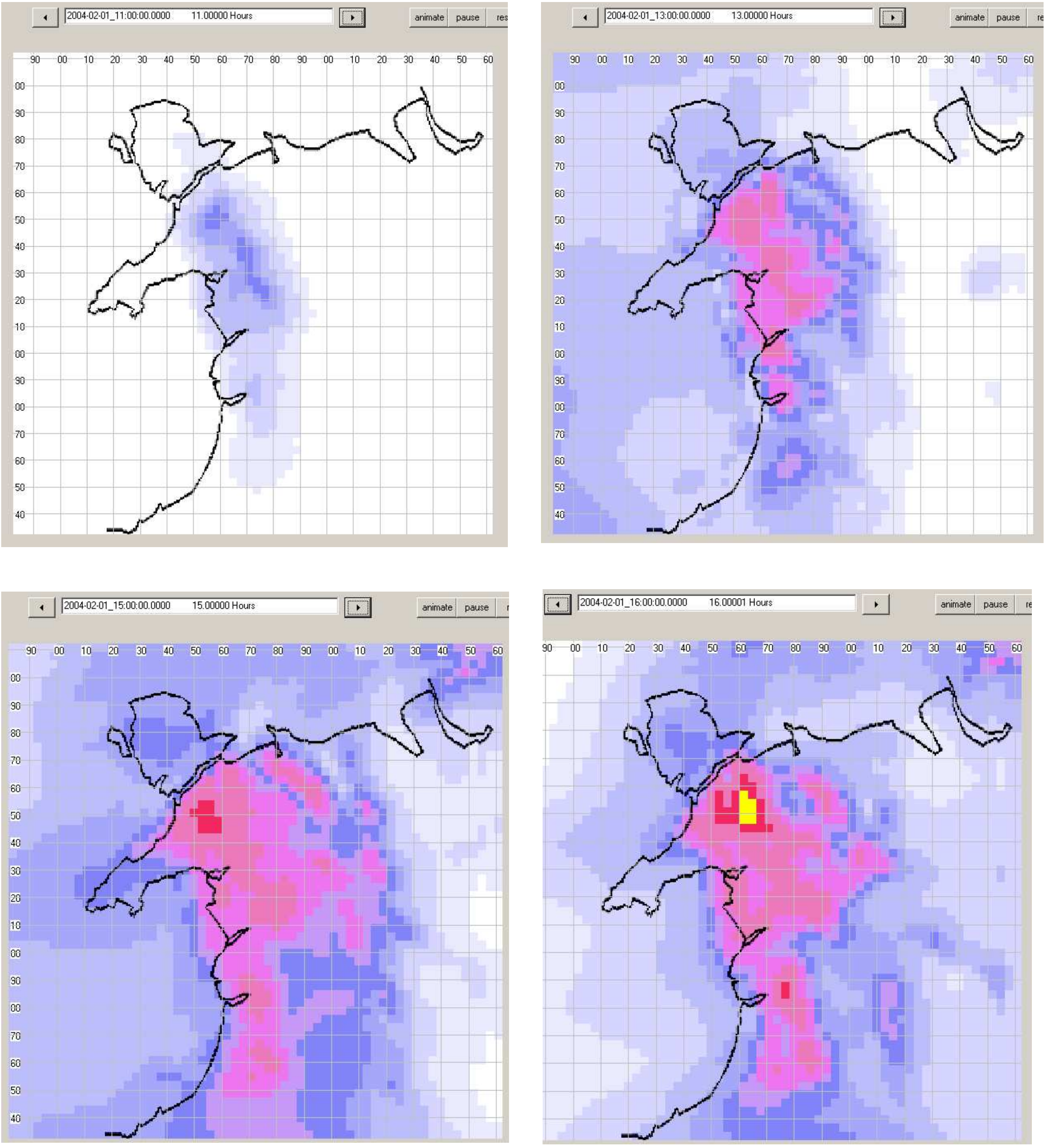


Figure 4.54: Example time-frames from the predicted rainfall sequence over North Wales, 3-4 February 2004, reformatted for input to the Mawddach hillslope model

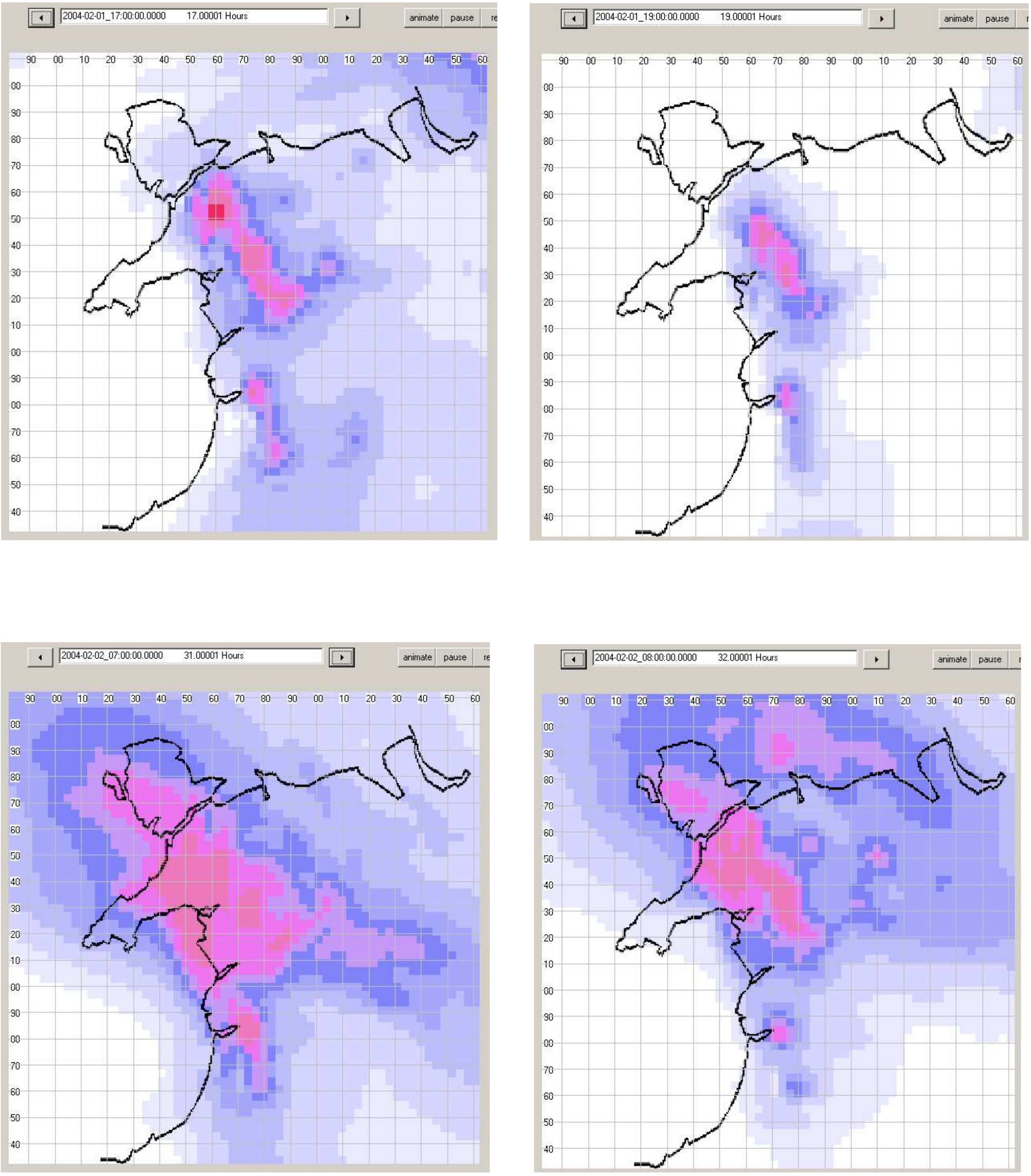


Figure 4.54 (cont.): Example time-frames from the predicted rainfall sequence over North Wales, 3-4 February 2004, reformatted for input to the Mawddach hillslope model

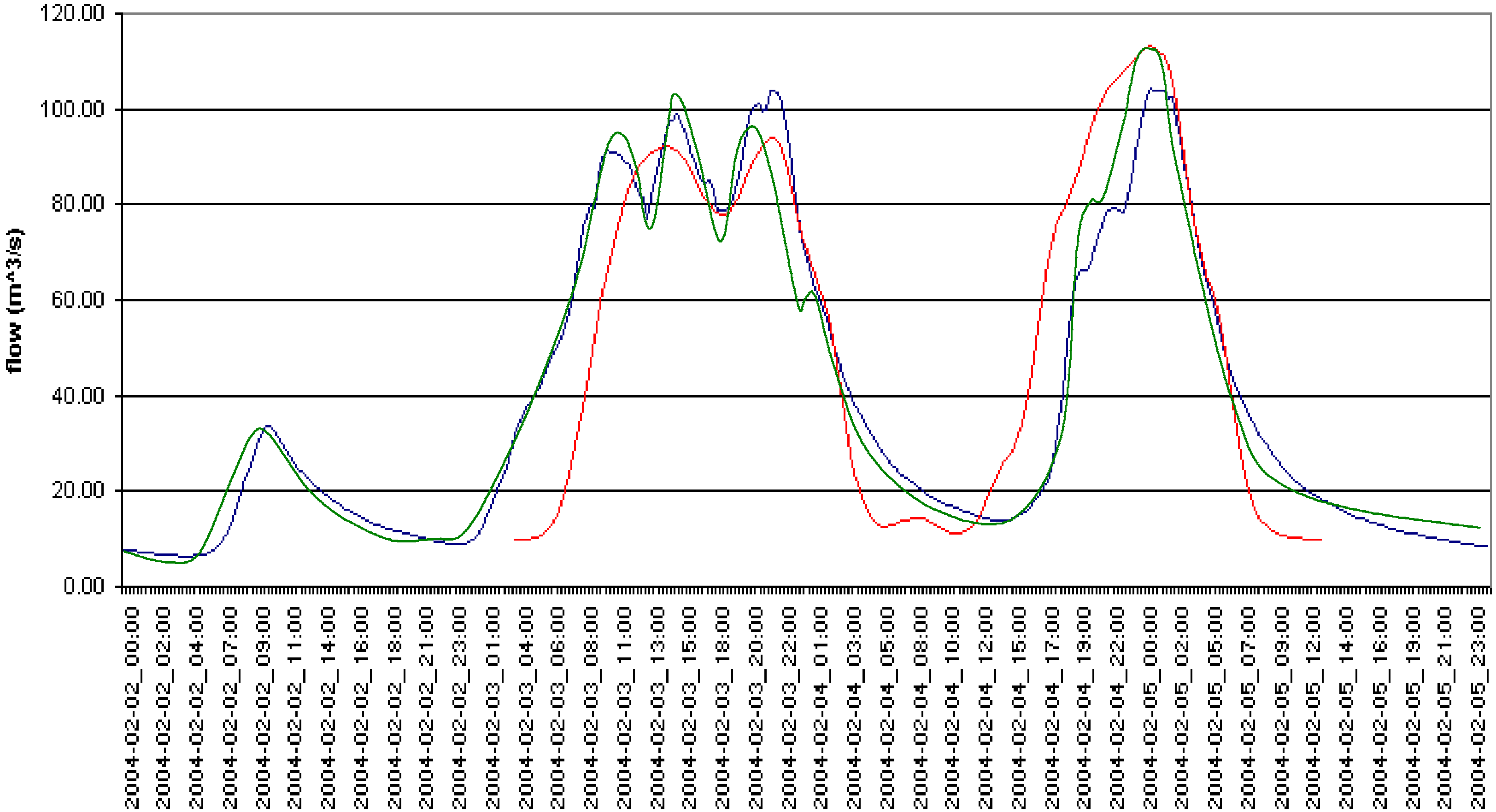


Figure 4.55: Hydrographs for Tyddyn Gwladys, Afon Mawddach, for the period 2-5 February 2004. Black: hydrograph recorded at the gauging station. Green: simulation using MM5 and the hillslope model. Red: simulation using HEC-1 and catchment raingauge data.

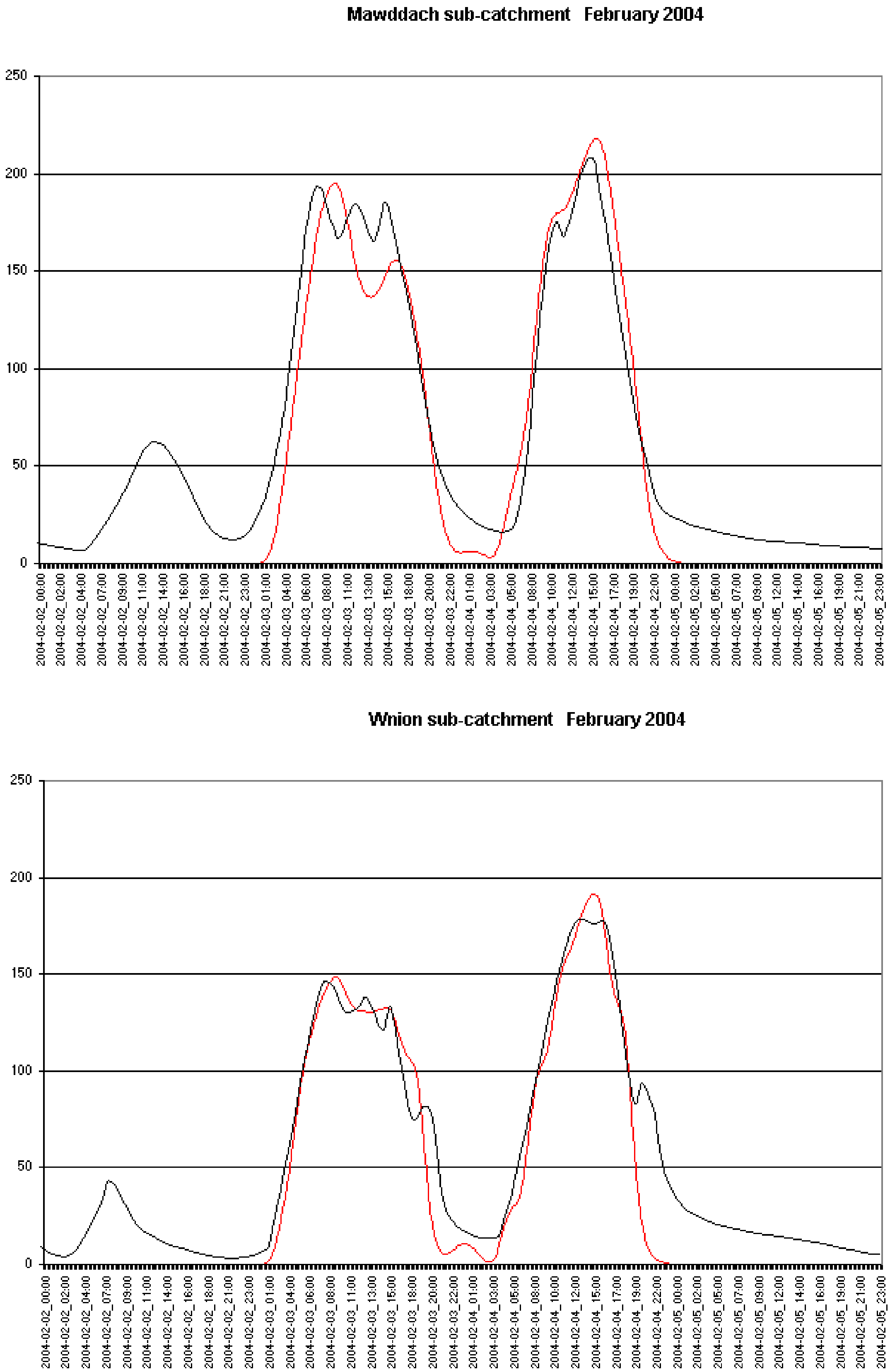


Figure 4.56: Comparison of the MM5 – hillslope model (black) and the HEC-1 model (red) for the Rivers Mawddach and Wnion at the tidal limits close to their confluence: 2-5 February 2004.

Graphical output from the hillslope program is useful in the investigation of hydrological process. Figures 4.57-58 illustrate hydrological responses of the Allt Lwyd sub-catchment during the storm event of 3 February 2004:

Fig.4.57 shows the expanding area of saturation-excess runoff during the storm, with low intensity runoff extending upwards from the Allt Lwyd valley to the slopes of Rhobell y Big during the period of maximum rainfall intensity.

Fig.4.58 (upper) shows an example of block diagram output by the program. Soil saturation is illustrated, with saturation reaching 100% on the Waen y Griafolen blanket bog and along the Allt Lwyd valley. High value close to saturation are seen on the hilltop plateau surfaces above Waen y Griafolen and on the gentle slopes of Rhobell Fawr. Lower saturation levels are modelled for the steep sides of the glaciated valleys.

Fig.4.58 (middle) illustrates downslope throughflow within the soil horizons. Throughflow is greatest within scree and other periglacial deposits which blanket the Allt Lwyd valley.

Fig.4.58 (bottom) shows downwards infiltration to bedrock. The model records low values in the areas of valley floor glacial tills.

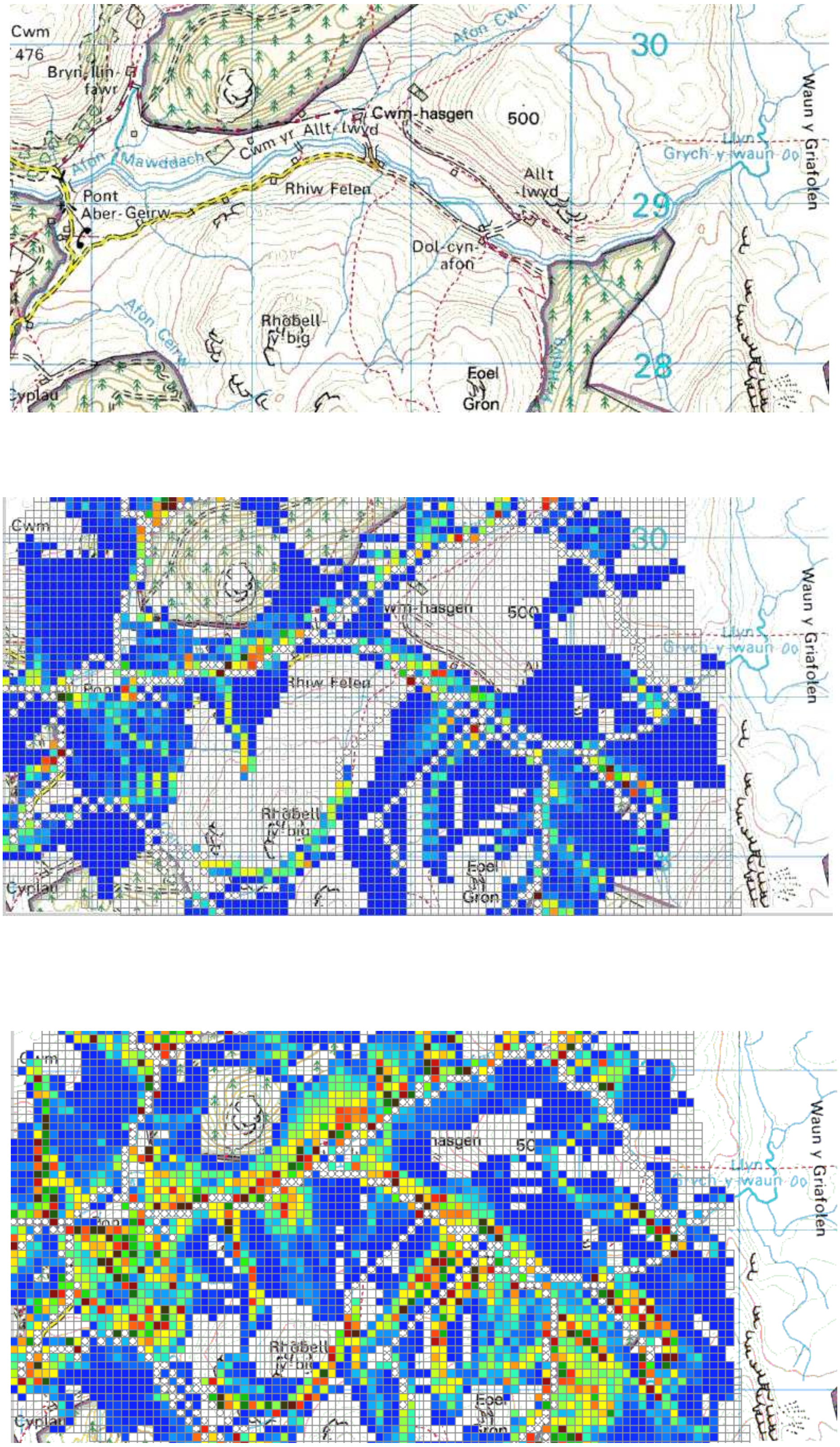


Figure 4.57: Changing extent of surface runoff in the Allt Lwyd sub-catchment during the storm event of 3 February 2004: (upper) 00:00h, (middle) 01:00h, (lower) 02:00h.

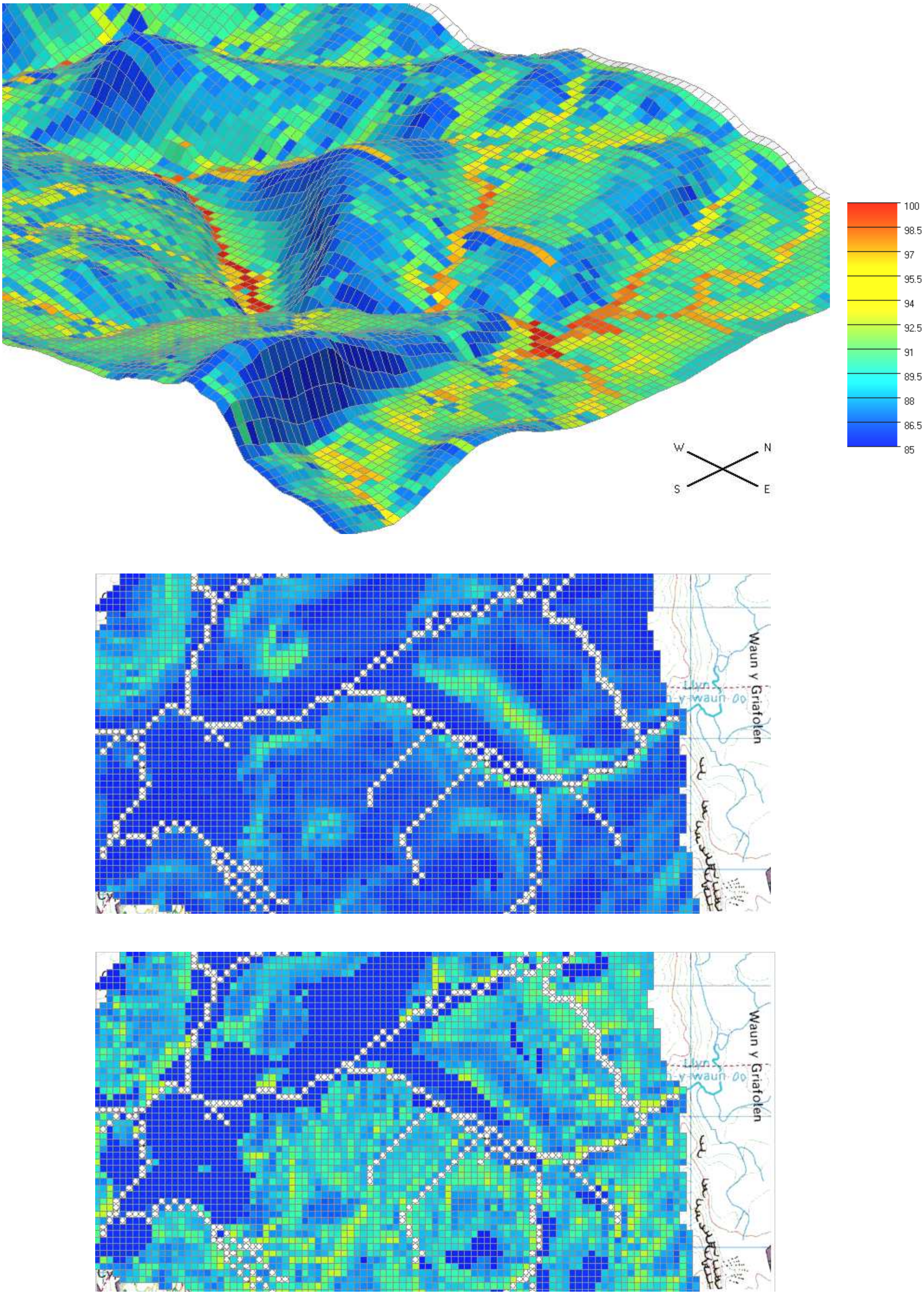


Figure 4.58: Hydrological responses in the Allt Lwyd valley during the storm event of 3 February 2004. (upper) Soil saturation, (middle) downslope throughflow, (lower) infiltration to bedrock.

Results from a run of the Integrated Model for 3 July 2001

The major flood on the Afon Mawddach on 3 July 2001 was the result of intense thunderstorm activity along a squall line across North and Mid Wales. The distribution of the centres of intense rainfall along the squall line was affected by random convective motion, so precise forecasting was difficult in the period before the Mawddach storm.

Several alternative convective modelling schemes are available within the MM5 meteorological package, and it was found that these had differing degrees of success in predicting the storm rainfall distribution. The most accurate results were obtained by the Anthes-Kuo scheme, and were used to produce the rainfall distributions for the hillslope model (fig.4.59). Results from running the model are shown in fig.4.60, with data from the gauging station observations and the HEC-1 model for comparison. The hillslope model using the MM5 forecast initially produced flood peaks substantially lower than actually occurred during the flood event, although the high flow rates which would have been predicted several hours ahead would have been a cause for concern. It should be noted, however, that the HEC-1 model was based on raingauge data collected during the storm event plus a conjectured rainfall sequence for the central point of the convective storm, then applied to the model as a hind cast. A second run of the hillslope model was carried out, using the same gauge data as input in place of the MM5 forecast. A much closer correspondence to the recorded maxima was then obtained.

It is important to distinguish the two ways in which the model has been tested:

- In *hindcasting* mode, to check that model results are consistent with observed hillslope waterflows and recorded river hydrographs. This required the use of a sequence of rainfall data to describe the actual storm event as accurately as possible.
- In *forecasting* mode, using only the data that would have been available some six hours ahead of a storm event, as a means of assessing the ability of the modelling system to predict flooding.

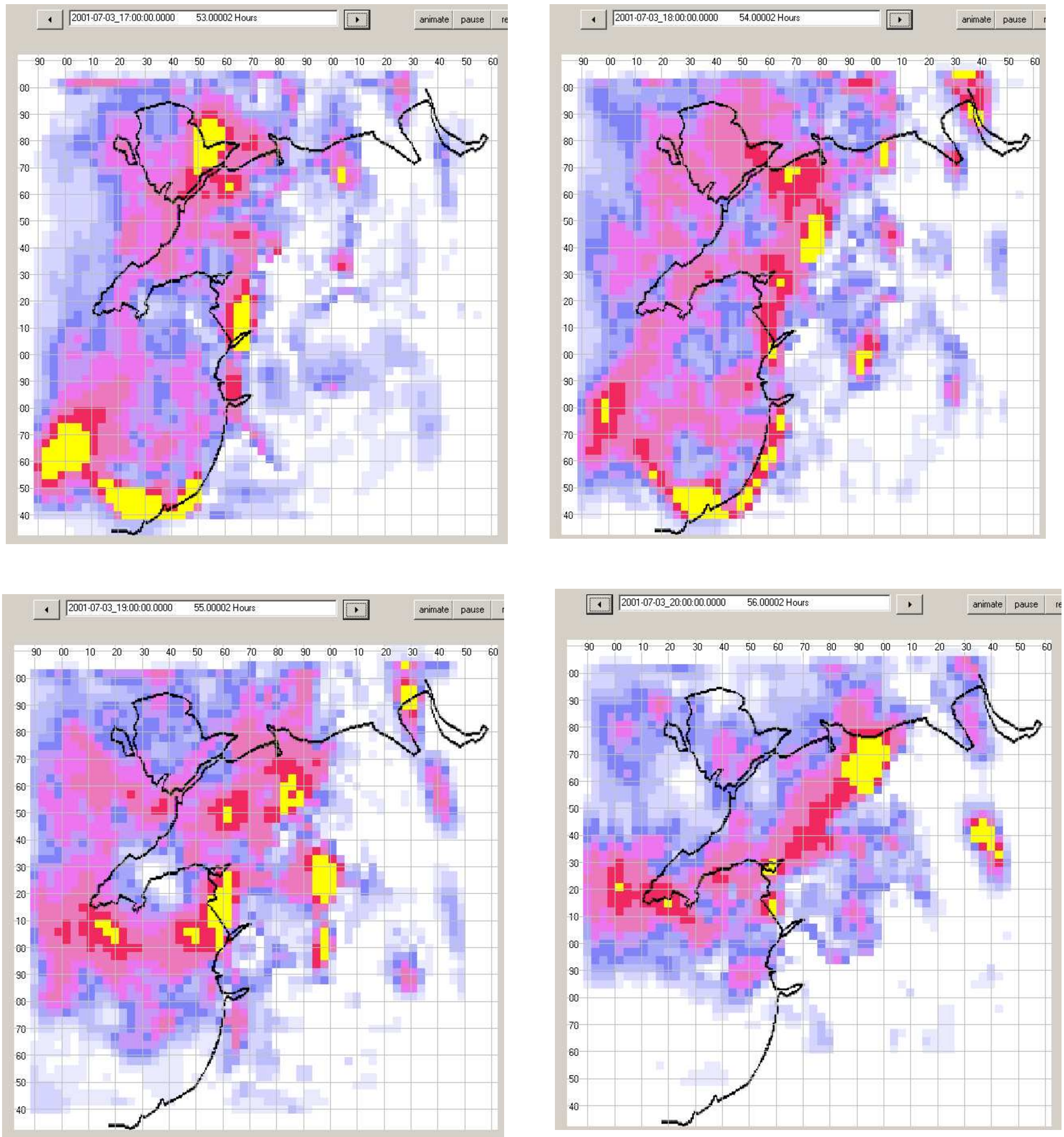


Figure 4.59: Example time-frames from the predicted rainfall sequence over North Wales, 3 July 2001, reformatted for input to the Mawddach hillslope model.

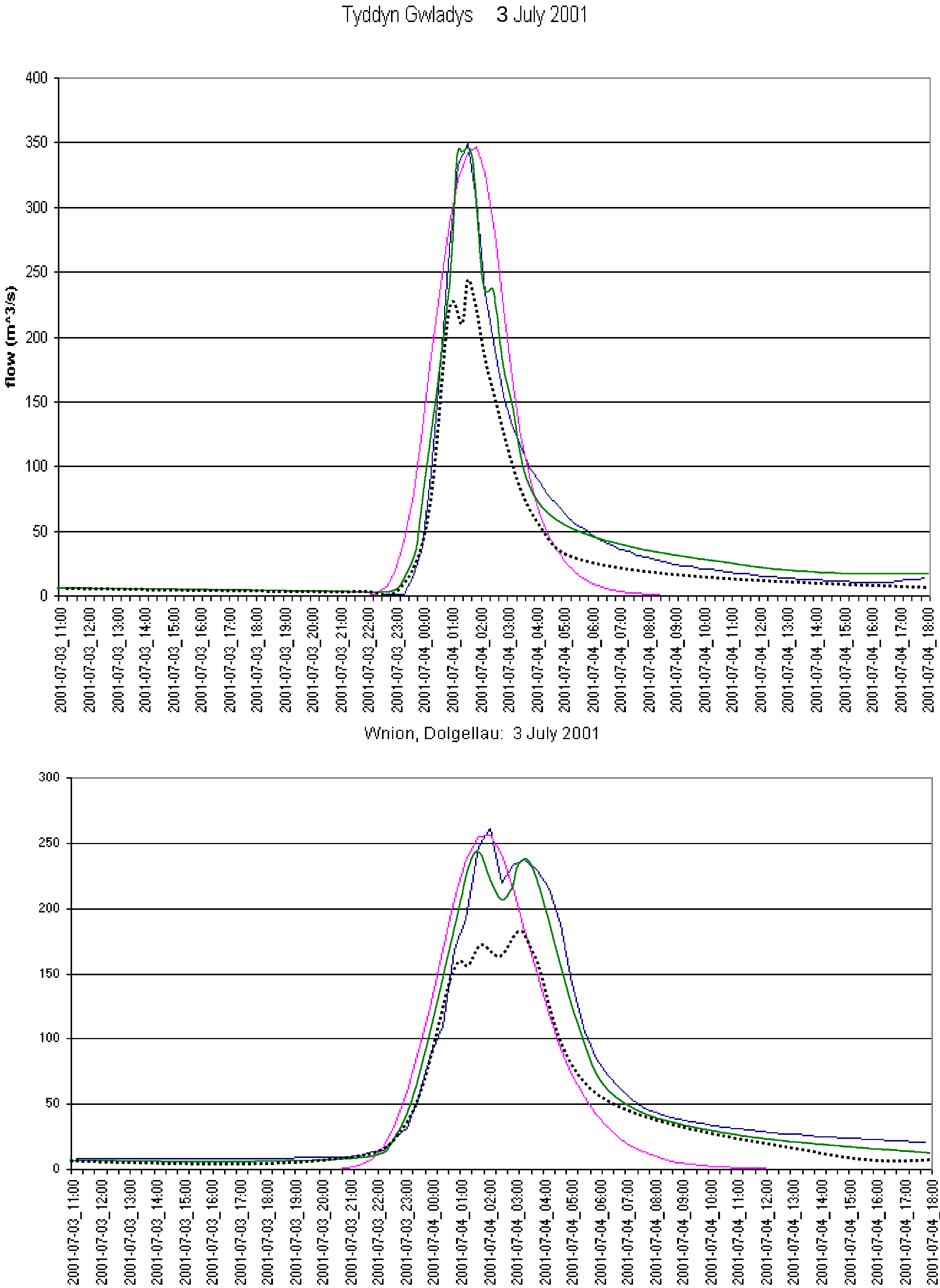


Figure 4.60: Hydrographs for Tyddyn Gwladys on the Afon Mawddach and Dolgellau on the Afon Wnion, 3 July 2001. (black solid) recorded hydrographs, (black dotted) hillslope model with MM5 forecast, (green) hillslope model with raingauge data, (red) HEC-1 model with raingauge data.

Summary

- Testing of the MM5 hillslope integrated model has been carried out for the flood events of 3 July 2001 and 3-4 February 2004.
- The model can be run by a combination of parallel and distributed processing to ensure that forecasts are obtained sufficiently quickly to provide a practically useful predictive tool.
- The hillslope model can be calibrated satisfactorily by adjustment of the soil depths and hydrological properties of the HOST soil classes.
- Results for the frontal storms of 3-4 February using MM5 and the hillslope model show an improvement on the synthetic hydrographs produced by the HEC-1 model. The problem of over-rapid fall in river level following a flood event has been addressed in the hillslope model by the incorporation of throughflow processes.
- Graphical output from the hillslope model allows the monitoring of hydrological processes during a storm event: surface overland flow, shallow stormflow, and infiltration to bedrock.
- Convective rainfall processes operate with a high degree of randomness, making it difficult to forecast the exact locations where storm cells will develop. As might have been anticipated, the modelling of the convective storms of 3 July 2001 presented some difficulty for MM5. Although extreme water levels would not have been predicted by the model, some serious flooding would nevertheless have been anticipated when MM5 rainfall data was applied to the hillslope module.
- In the convective storm of July 2001, the intensity of the rainfall caused runoff to occur by an infiltration-excess mechanism, despite dry ground conditions. This process was successfully modelled by the hillslope software..