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INSTITUTE of HYDROLOGY

FOREST AND WATER RESEARCH, BALQUHIDDER 1988/89

REPORT TO WRc

INSTITUTE of HYDROLOGY

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RESEARCH ON FORESTRY AND WATER RESOURCES, 1988-89

A Report on Work Funded in Part by WRC Contract CS4139RX

by

The Catchment Data Management, Experimental Catchments and Physical Process Studies Sections

of

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Executive Summary

This report has been prepared in response to a one year contract from Water Research Centre relating to specific aspects of the consortium funded study of the effects of upland afforestation on water resources in Highland Scotland.

The report is complementary to the general report prepared for the consortium Steering Committee.

The reasons for the delay in producing both reports relate to staff resignations and initial teething problems with new equipment installed in 1988.

Despite considerable data losses prior to the installation of new logging equipment in September 1988, the results obtained from the Automatic Weather Stations provide further confirmation of higher than expected Penman ET values at altitude. To assist in developing a formal basis for relating these results to altitude and exposure an additional station has been installed in 1989 and proposals to further intensify the networks are under consideration.

The results from the high altitude grass lysimeters for 1988 indicate an evaporation of 81% of Penman ET for the summer months and an estimated 74% of ET for the entire year. There results, together with those from earlier snow interception and heather water use studies, are being incorporated into the simple annual and daily water use models under development at IH.

These water use sub-models will be incorporated into the model being developed to predict seasonal streamflow as they became available. Preliminary work undertaken on the streamflow model has concentrated on identifying the appropriate time step to be used and the snow-melt sub-model. Preparation of files of input data so that the model can be tested initially on the Balquhidder catchments is in hand. A further requirement, that of identifying more accurately the distribution of vegetation cover, has been advanced through the use of aerial infra-red stereo photography.

The water balance and sediment loss studies during this period of changing land use in the catchments were continued through the year, together with the ongoing validation checks on the precipitation and streamflow networks. Despite some 50% of the forest having been felled, no marked trend in water use in the Kirkton has been detected. Sediment losses, particularly suspended sediment, remained high through the year giving annual losses 4.5 times and 1.5 times the pre-disturbance levels from the Kirkton (clear felling) and Monachlye (first planting) catchments. A final analysis of the forest interception study gave an overall interception loss figure of 28% of precipitation and indications that losses from intercepted snow exceed those from rainfall.

Work proposed for the remaining two years of phase 2 of the project includes the continuation of the model development work, an intensification of the study of the relationship of Penman ET to topography and some detailed on-site studies of the energy fluxes involved in the snow melt process in this type of terrain.

Contents

1. Introduction

The Water Research Centre has been a significant supporter of the programme of research on forestry effects on water resources initiated by the Institute of Hydrology in 1981-82. Together with the other members of the funding consortium they have, through their membership of the Steering Committee, participated in identifying the aspects of this series of studies which are considered to be of the most relevance to the Scottish Water Authorities.

A general report on progress is presented by IH each year for discussion at the annual meeting of the Steering Committee. Such a report has been prepared and circulated for the 1988-89 year. This additional report, which should be read in conjunction with the progress report, concentrates on the specific aspects of the project which WRC identified as being of particular interest to their members.

In Contract CS 4139 RX covering the financial year 1988/89, these were identified as:

(a) Continue to study meteorological data, using updated logging systems, to explore further the apparent increase in Penman ET with altitude/exposure in order to provide a basis for extrapolating results to other Highland areas of Scotland.

(b) Commence work on modelling stream flow response in the two catchments, using water use models as the "front end".

(c) Continue the high altitude grassland study for another complete year to provide a more detailed basis for the development of an operational water use sub-model of this vegetation type.

(d) Continue work on validating, simplifying and integrating the forest water use, snow, interception, heather water use and the grass water use sub-models into an overall water use sub-model for application to upland areas.

(e) Prepare a list of recommendations for work proposed for the period 1 April 1989 to 31 March 1990 so that those organisations for whom WRc acts as an agent can discuss and comment on the relevance of the future programme to the Water Industry.

(f) Prepare and submit a report on the above items by 31 March 1989.

Additional comment on these aspects of the project programme is presented in the following sections.

It is regretted that there has been a delay in preparing and presenting both this report and the general report to the Steering Committee. This resulted from a combination of circumstances involving the resignation of a key staff member from the data processing section in February 1989, prolonged teething troubles with new logging systems installed in 1988 and an internal IH reorganisation. Through this difficult period, priority was given to maintaining the continuous data collection. Thus no loss of records has occurred but there have been delays in the processing and analysis of the data and in the production of reports. Following a recruitment exercise, the staff devoted to the project will be back to full strength from October 1989.

2. Meteorological Data

As indicated above and explained in more detail in the general report, a number of problems were experienced with this aspect of the Balquhidder catchments study in 1988-89.

Prior to September 1988 considerable data loss from the weather station network (Figure 2.1) occurred, partly through failures of the old magnetic tape logging systems and partly through individual sensor failures. The effects of the latter were in many cases exacerbated by the former, in that the detection of faulty data from one or more sensors was often delayed by subsequent logger failures.

From September 1988 onwards, data acquisition from the weather stations improved dramatically following the installation of Campbell CR10 processor controlled solid-state loggers. In addition to their greater reliability, the ease with which data can be downloaded and checked meant that sensor failures could be identified and rectified much more quickly. However, this improvement in data acquisition was nullified initially by problems in the calibration and matching of temperature sensors and loggers. That this required a different approach than that used with the previous loggers was not immediately apparent and it was not until June 1989 that the problem was finally solved. Thereafter it was possible to correct retrospectively the temperature and humidity data accumulated since September and recompute the Penman ET estimates.

2.1 PENMAN ET ESTIMATES

The gaps in the data prior to September 1988 made it difficult to carry out detailed between-site comparisons of ET. Complete months of record were not available from the two high altitude sites for the first five months of 1988. The good records obtained for 1988 are listed in Table 2.1.

From these it can be seen that in the 'peak' month of June the ET values from Kirkton High again exceeded those from the low level sites. This was also the case in the particularly mild December 1988 and January 1989 period, when the values from the Upper Monachyle site also exceeded those from Monachyle Glen and Tulloch Farm. The very wet conditions experienced from July to October resulted in depressed ET values for all sites and no conclusive indication of differences in ET. The figures for the much colder and more normal months of February and March 1989 again demonstrate that

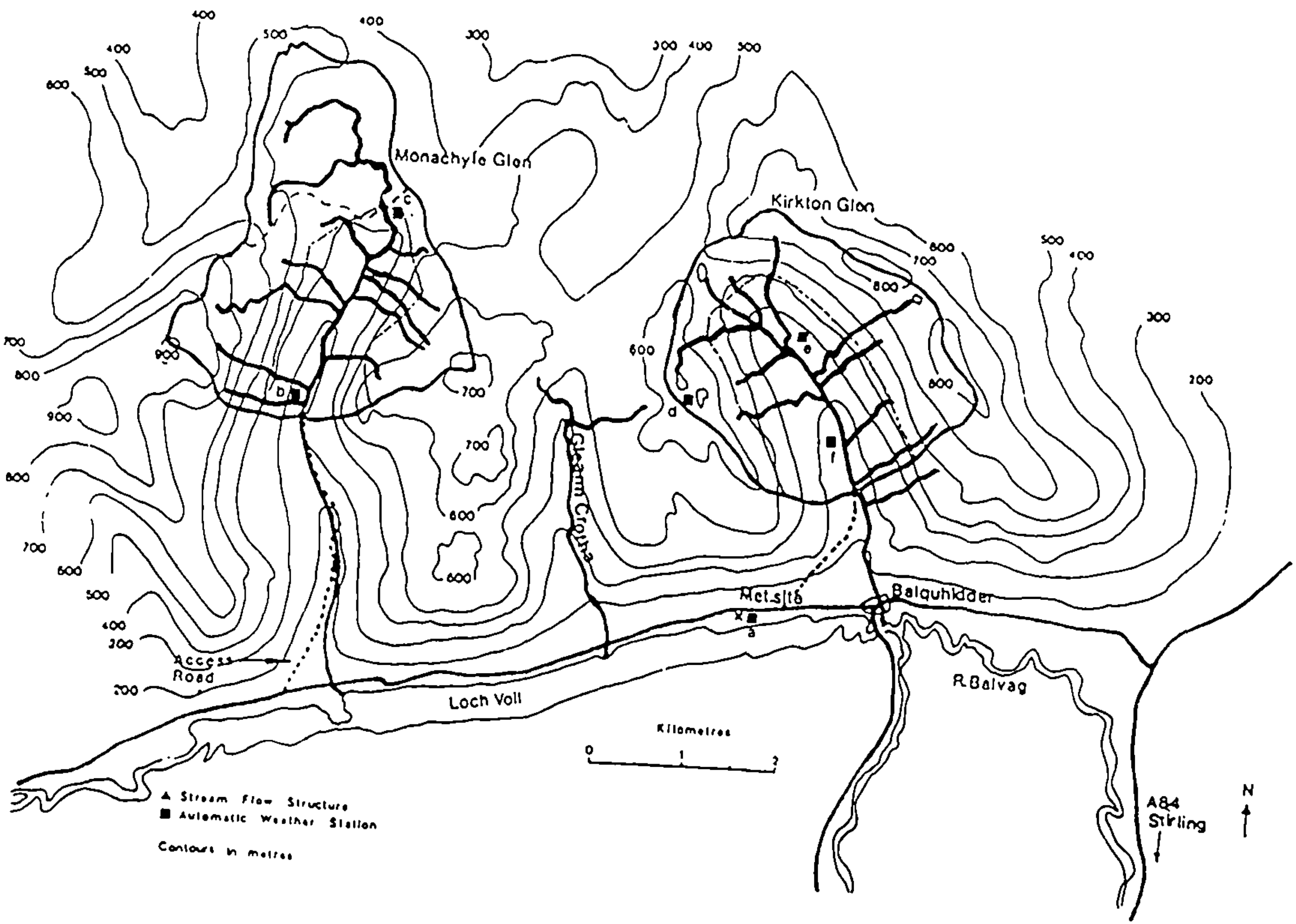

Figure 2.1 *The Automatic Weather Stations at Balquhidder: (a) Tulloch Farm, (b) Monachyle Glen, (c) Upper Monachyle, (d) Kirkton High, (e) Kirkton Forest, (f) Kirkton Cleared Area (installed June 1989)*

values from the Upper Monachyle site were in excess of those from the lower sites. Complete data sets were obtained for the Kirkton High sites for these months, but analysis indicates that the humidity (temperature depression) readings were suspect, possibly due to ice accumulation in the screen.

TABLE 2.1 Monthly Penman ET values from good, complete records from the stations at Tulloch Farm (TF) at 140 m, Monachyle Glen (MG) at 300 m, Upper Monachyle (UM) at 470 m and Kirkton High (KH) at 670 m.

Month	Penman ET Values (mm)			
	TF	MG	UM	KH
1988				
January	8.8	7.3		
February	24.3	-		
March	32.9	27.4		
April	38.7	35.4		
May	64.2	61.7		-
June	83.0	86.3		91.2
July	53.0	54.1		55.2
August	52.5	57.2		55.4
September	41.3	48.5		47.4
October	23.5	22.7	-	20.3
November	8.4	14.1	13.8	15.8
December	16.4	17.9	20.5	24.5
1989				
January	12.6	14.0	23.1	20.1
February	21.8	11.2	23.5	-
March	28.4	27.2	36.8	

2.2 ALTITUDE/EXPOSURE RELATIONSHIPS

Preliminary analysis of the more complete record obtained through the October to March period has produced no evidence so far to contradict the between-site relationships for both Penman and the individual meteorological variables which have been derived from the previous data (see 1988 Report and Blackie, 1987). Obviously the inclusion of at least one season of 'peak' summer data will be necessary to verify this.

To move on from determining between site relationships to examining the reasons for them, in terms of altitude and exposure, is the next step. The network of four sites in current use samples a range of altitudes but each site has very different exposure conditions. This is typified in Figure 2.2 where

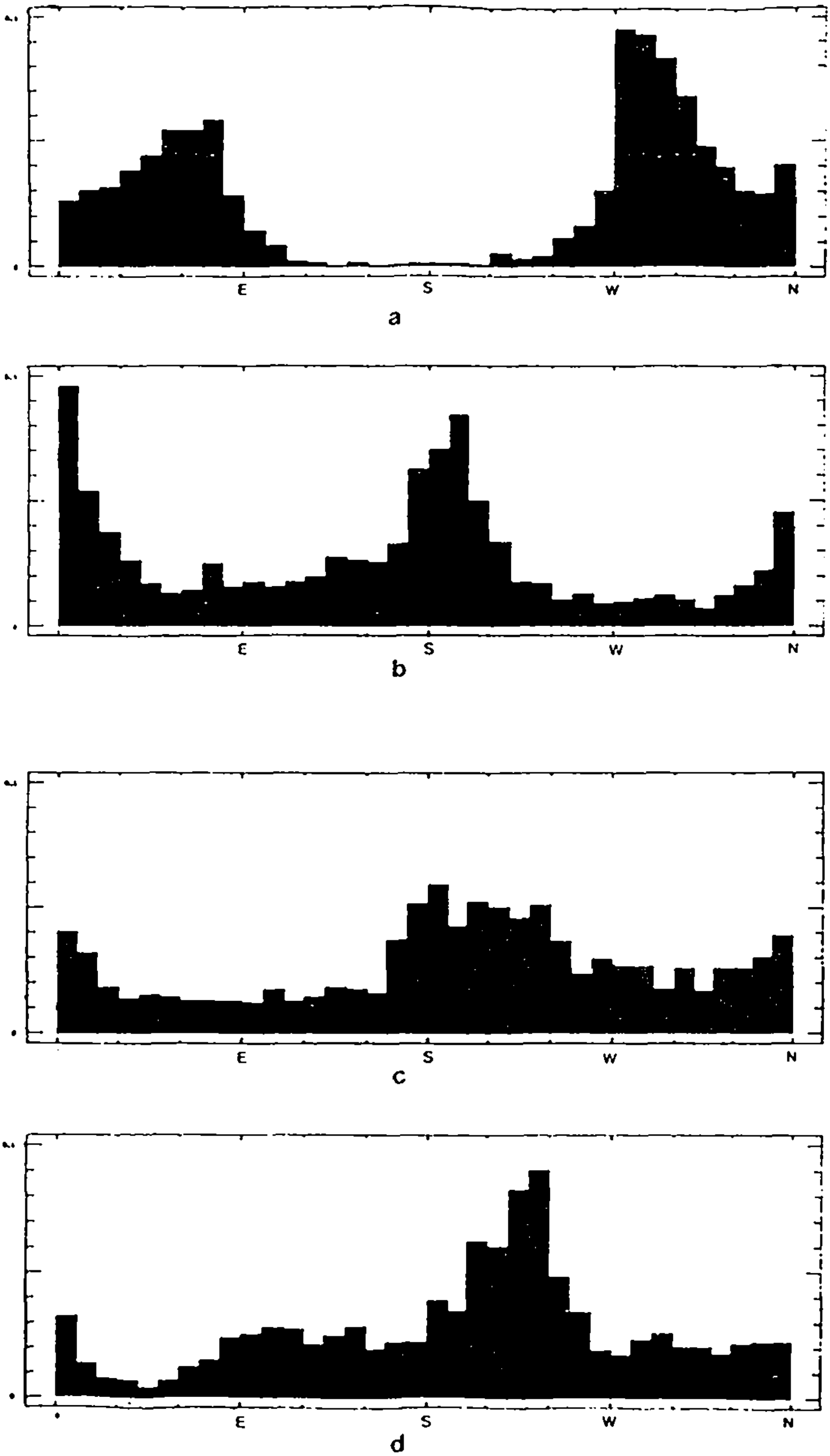

Figure 2.2 *Frequency distributions of wind directions from AWS at (a) Tulloch Farm, (b) Monachyle Glen, (c) Upper Monachyle, (d) Kirkton High*

the radically differing wind direction frequencies at the four sites are illustrated. That for the east-west valley bottom site at Tulloch Farm is effectively displaced by 90° compared with that for the north-south valley bottom site at Monachyle Glen.

An attempt to extend the network in this respect was made in 1986 when a fifth station was installed at a valley bottom site in the Kirkton. This, however, had of necessity, to be mounted on a tower above the forest canopy. The (relatively sparse) data captured from this station are of value in determining conditions at canopy level. Because of the very different roughness, net radiation, temperature and humidity profiles being sampled over the canopy as compared with the 'grass' at the other sites, the data are of limited value in network analysis. To counteract this, an additional valley-bottom station was installed in June 1989 in a clearfelled area in the lower Kirkton, as shown in Figure 2.1. Whilst this Kirkton Cleared Area site will expand the network there is a requirement, for example, to include sites at similar exposures but at a range of altitudes. A proposal to extend this aspect of the study has been submitted for NERC consideration on the basis that building on the existing information in this location may yield altitude/ exposure models that can be applied more generally.

At present the information obtained from the existing network indicates strongly that, in typical Scottish Highland topography, the presumed altitude decrease of Penman ET does not occur. The need to replace this with a better defined relationship is recognised and proposals have been made as to how this might be achieved.

3. Streamflow Modelling

Preliminary work on the choice and development of appropriate versions of the IH suite of catchment models (Blackie and Eeles, 1985) for application to the Balquhidder catchments is in hand.

3.1 CHOICE OF TIME-STEP

This work includes identification of the most appropriate time-step to be used in the models. Ideally, with catchments of this size and response characteristics, an hourly time-step would be used. Problems arise, however, in setting up the input precipitation data at this time interval. During summer snow free periods, this can be done by time-distributing the storage gauge data using the recording raingauges attached to the AWS and the rainfall event recorders. In snow conditions and in freezing conditions, however, the time distribution data from these sources is very unreliable.

For water balance purposes the distribution on a daily basis is carried out using the daily read gauge at the Tulloch Farm site. This time-step will be used initially and the possibility of using the fine time scale to explore the detailed response characteristics over short snow-free periods will be explored.

3.2 PENMAN ET INPUTS

In a 'lumped' catchment model it is necessary to input a good estimate of the catchment mean ET. With the range of ET values obtained within each catchment and the uncertainty over how to interpret these in terms of altitude and exposure the definition of catchment mean ET is not yet resolved. Whilst this presents some difficulty, the fact that the seasonal trends in ET are closely similar at each site means that even an arbitrary choice of mean values should enable preliminary modelling work to go ahead. A more important problem may be the degree of infilling needed to produce complete ET data sets for each catchment.

3.3 SNOW MELT SUB-MODEL

A number of variations on the 'degree day' type of snow-melt sub-model are available. Using these in lumped models of catchments with the altitude and precipitation ranges found in the Balquhidder catchments presents some difficulties. These are exacerbated by the frequency with which the winter situation in the catchments comprises rainfall in the lower reaches and snow accumulation at altitude. It is hoped to undertake some field studies of snowmelt in the Upper Monachyle catchment in the next two winters.

3.4 CROP WATER USE SUB-MODELS

Whilst considerable progress is now being made in modifying and updating these on the basis of the process studies results, some sub-sections such as those relating to high altitude grassland have yet to be finalised. This sub-section is of such critical importance in the Balquhidder context that it is considered unwise to attempt to run the models without this component.

3.5 VEGETATION COVER IN THE CATCHMENTS

To apply the sub-models it is necessary to have fairly detailed information on the distribution of each vegetation type within the catchments. General information on these distributions and accurate estimates of the forested areas have been obtained from ground survey. The proportions which are 'grass' dominated and heather dominated are, however, not easy to determine without very detailed ground survey. To speed up this assessment some infra-red stereo-photographic coverage was obtained from overflights by the NERC survey aircraft late in 1988. This is now being analysed. It is hoped that more extensive coverage will be obtained in 1989.

4. High Altitude Grassland Study

The results obtained from this study during the 1988 field season from late March to the end of September are presented in some detail in the general report. These are summarised here in the cumulative plots of total evapotranspiration from the lysimeters and of Penman ET for the site in Figure 4.1 and in the series plots of the ratio of total evapotranspiration to ET and of rainfall in Figures 4.2 and 4.3.

The overall ratio of total evapotranspiration to Penman ET of 0.81 through this active growing season indicates that 'grass' at this altitude does indeed use water at a lower rate than ET. Figure 4.2 suggests that during dry periods the rate is very much lower than this but increases to rates higher than ET during rainfall periods. The implication is that the rate of loss of intercepted water is considerably higher than ET.

During the 1988 field season mean daily temperatures were below the physiologically critical figure of 6°C for all of April and the first few days of May. Biomass composition, expressed as the ratio of live grass to total biomass, was also monitored through the season. This ratio rose rapidly from 0.35 in mid April to a peak of 0.67 in mid-July and declined thereafter.

On the basis of 25% of the annual Penman ET occurring in the winter months, October to March, and the actual evaporation equalling 60% of ET during this time (based on an extrapolation of April 1988, Figure 4.2) an annual evaporation of 384 mm (74% of Penman ET) is estimated for the upper parts of the Kirkton catchment for 1988.

These data are now being analysed on a finer time-scale to identify the relative importance of the factors contributing to the overall water use.

A further season of data collection is now under way. It is hoped that this will produce more information on the interception loss rates which appear from the 1988 data to be much higher than anticipated.

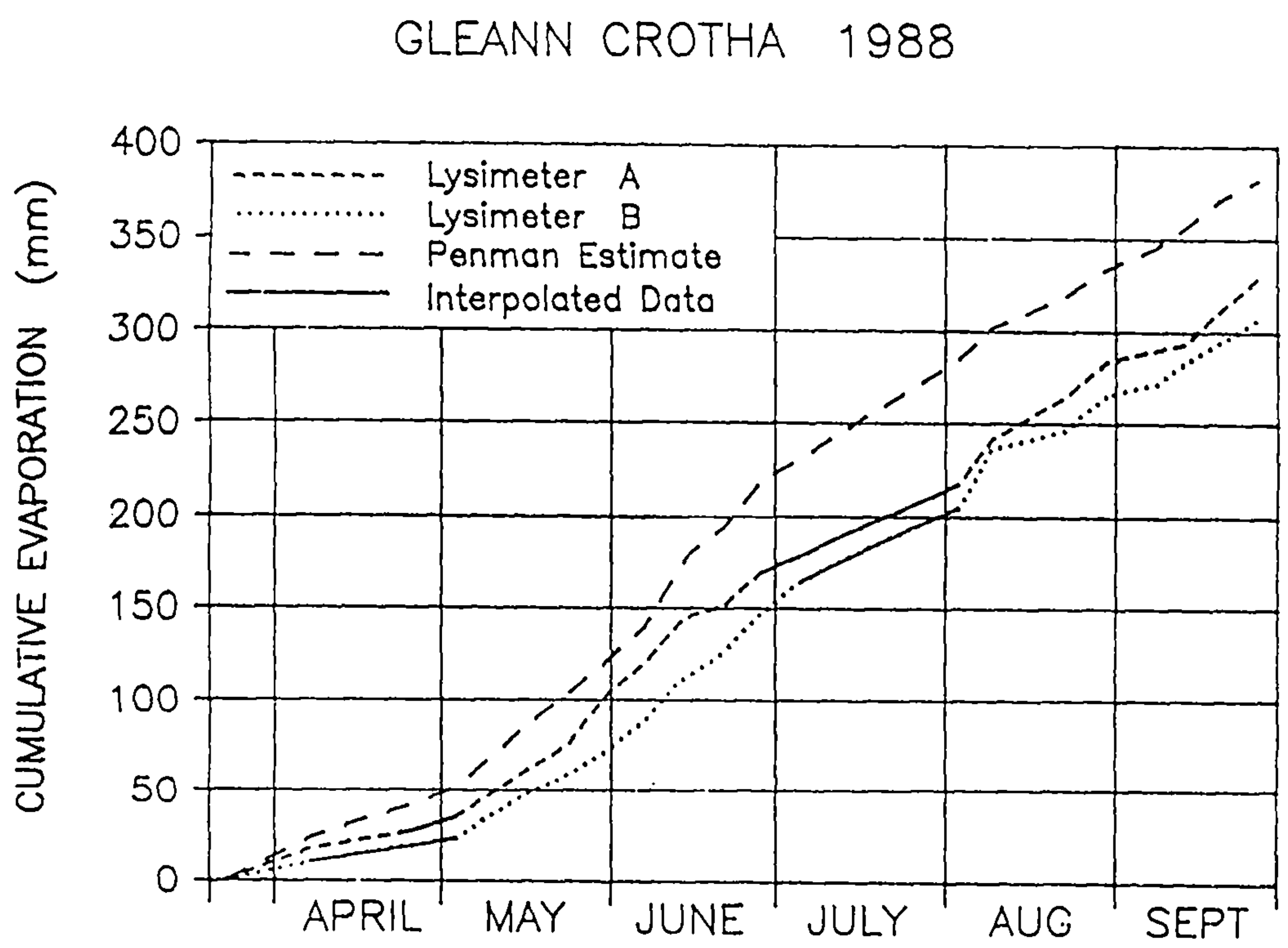

Figure 4.1 Gleann Crotha 1988

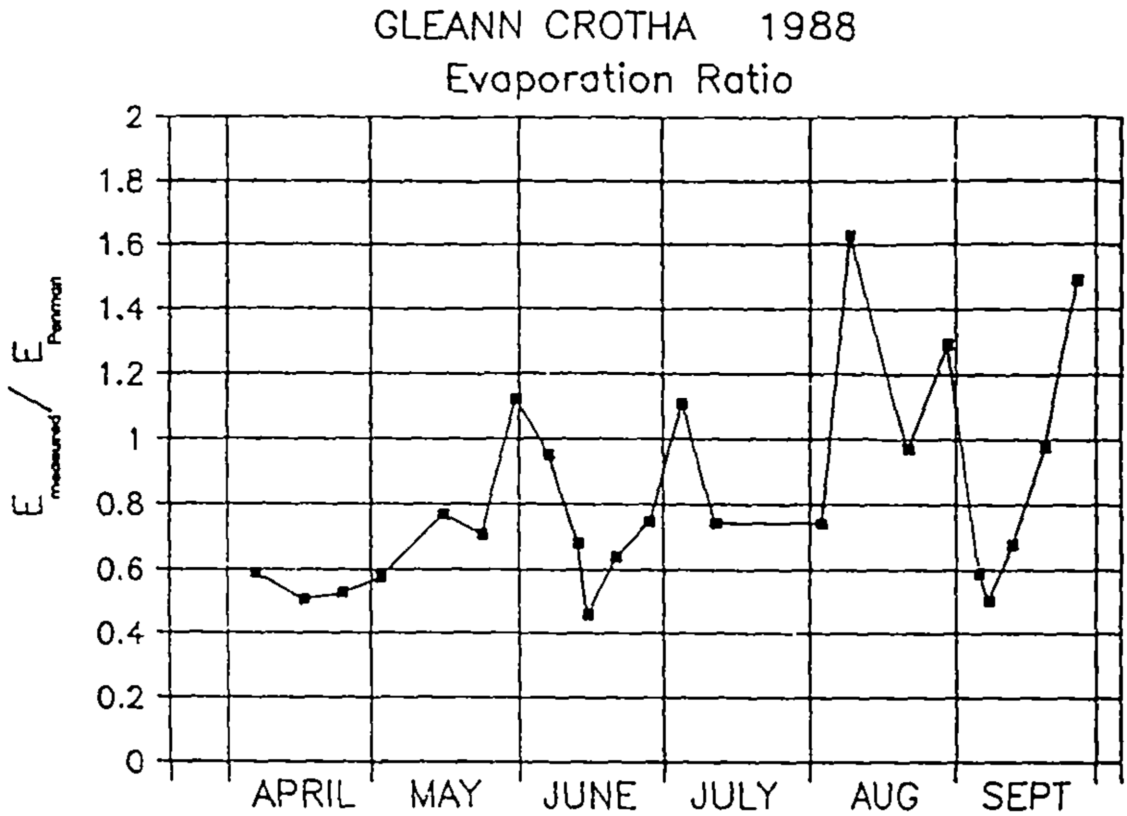

Figure 4.2 Gleann Crotha 1988

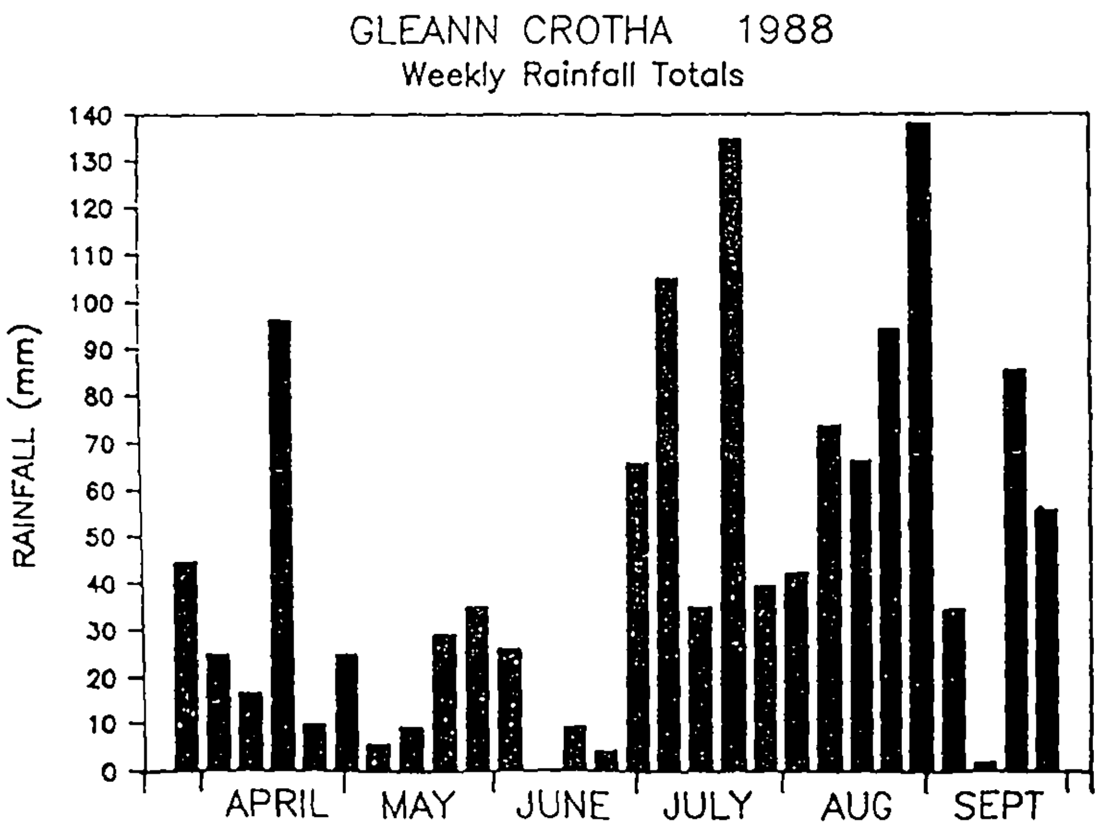

Figure 4.3 Gleann Crotha 1988, week;y rainfall totals

5. Development of Process Sub-models

Models to predict evaporation from different vegetation types range from the extremely sophisticated to the very simple. Generally the more sophisticated are more accurate and more generally applicable. However the more complex models require very detailed input meteorological data and are very sensitive to errors in these data. For areas, such as the Scottish Highlands, where meteorological data sets are very limited there is a need to develop simpler models of vegetation water use which require only rudimentary meteorological data. Any such simplification will necessitate a reduction in the physical realism of the models and will require careful validation against good sets of water use data.

The first such water use model for use in the UK uplands was that devised by Calder and Newson (1979). This model had a number of limitations: principally it could only estimate for forest and grass, it would work only on an annual basis and it was not calibrated for areas where snow is a significant factor. Over the last 10 years the model has been extended to overcome some of these limitations:

1. Measurements of the interception of snow by forest canopies has shown that losses from snow covered canopies are at least as large as from rain covered canopies and to a first approximation can be treated similarly.

2. Following measurements in Scotland there is now a sub-model describing the evaporation from heather moor.

3. A daily model has been developed for forest and heather.

The daily model was tested with the catchment data from the Monachyle, a predominantly heather catchment, with very encouraging results. However it became evident that it would not work for the mixed forest and high altitude grassland cover in the Kirkton catchment. The main hypothesis for the problems experienced with the water use from this catchment is the slow growth of the high altitude grassland which will suppress the transpiration. A very simple correction to the Penman formula, based on mean air temperature, was presented last year. The corrected value agreed very well with the mean annual water use from the grassland Wye catchment in mid Wales. The results from the high altitude grassland lysimeters in Balquhidder for 1988 (presented in section 4) show an evaporation of 75% of Penman for the whole year, in agreement with the simple annual correction. More work is needed to develop these results into a seasonal model.

To summarise, the development of a seasonal model to describe the water use from upland heather, grass and coniferous forest is well advanced. There are just two areas which need attention viz. the incorporation of the high altitude grassland lysimeter results into the simple daily model and the development of a simple daily snow model. For the latter a number of sets of observations of snow evaporation have been obtained with which to develop the model and plans to take additional measurements to validate the model at Balquhidder during the next two winters have been prepared.

Finally, the models that are being developed require either annual mean or daily meteorological observations. This is now no problem for Balquihidder but may pose a problem for the extrapolation to other areas of Highland Scotland.

6. Summary of Other Work 1988/89

In addition to the aspects of the year's work highlighted in the above sections, data collection continued in the catchments as did checking of the precipitation networks and analyses of the catchment water balances, sediment yields and forest interception data. Details of these aspects of the project are given in the general report. Some important points are summarised here to put the work described in this report in context and to indicate the present state of understanding of the catchment systems.

6.1 PRECIPITATION NETWORKS

Further work on the representativeness of individual gauges revealed that the domain C3Y above the tree line on the steep eastern side of the Kirkton catchment required to be split into two domains. The more northerly part of this domain receives significantly more precipitation. The original gauge, situated close to the southern end of the domain, was found to be unrepresentative even of this part of the domain. It is estimated that the effect of this gauge in the past has been to depress the catchment mean precipitation estimate by between 1% and 1.6% (23-36 mm). No significant errors were found in the other large domains checked in the catchments but a gauge in the high altitude D2W domain on the west side of Monachyle indicated that the absence of a gauge in this domain previously may have resulted in a 1.7% (46 mm) underestimate in the catchment mean precipitation. Both these figures are within the uncertainty limits on the catchment mean estimates, but their effect on the P-Q estimates of catchment water use would be to raise these by approximately 8% in both catchments.

6.2 CATCHMENT WATER BALANCES

The higher than average rainfall in the July-October 1988 period (July was the wettest month of the year) resulted in annual P and Q totals in both catchments second only to those of 1986 in the period of record. P-Q estimates of catchment water use in 1988 did not differ significantly from those of the previous two years, giving once more a between-catchment difference of some 200 mm.

6.3 SEDIMENT LOSSES

Sediment losses from both catchments in 1988 continued significantly higher than in the Phase I pre-disturbance period. First estimates for suspended loads were 255 t km^{-2} from the Kirkton and 58 t km^{-2} from the Monachyle, respectively, 4.5 times and 1.5 times the pre-disturbance loads. Bedloads were found to be very similar to the pre-disturbance loads. The plough lines in the Monachyle are now revegetating which should reduce losses from this source but the losses from the road surfaces appear likely to continue through the clear-felling period in the Kirkton.

6.4 FOREST INTERCEPTION

Final results from the forest interception study in the Kirkton catchment indicate an overall interception loss of 28% of precipitation, with the net precipitation comprising 69% throughfall and 4% stemflow. Losses during a prolonged period of snow accumulation were 37%, with an estimated peak storage on the canopy of 22 mm water equivalent, some 10 times greater than the canopy capacity for liquid storage.

6.5 OTHER STUDIES

The project continues to play host to other groups carrying out independent studies on the Balquhidder catchments on aspects of water chemistry, its effects on fish life and on nutrient cycling. Precipitation, streamflow and meteorological data are provided to these groups on request and the resident staff at Balquhidder devote considerable time to assisting in sample collection.

Demand for the services of the HYDRA direct evaporation measuring system overseas precluded the proposed testing on the Kirkton slopes in 1989.

7. Future Work 1989/91

In the discussion document "A review of Future Objectives in the Research Programme" circulated to the Consortium Steering Committee before the 1988 meeting the proposed objectives for the period to 1991 were identified. These met with general agreement from the Consortium and form the basis of the present work programme from the project. This is summarised under the "immediate objectives" section of Figure 7.1 which is taken from the above discussion document.

Despite the set-backs experienced in early 1989 this programme is still running close to schedule.

Continuation of the catchment data collection until the present phase of land

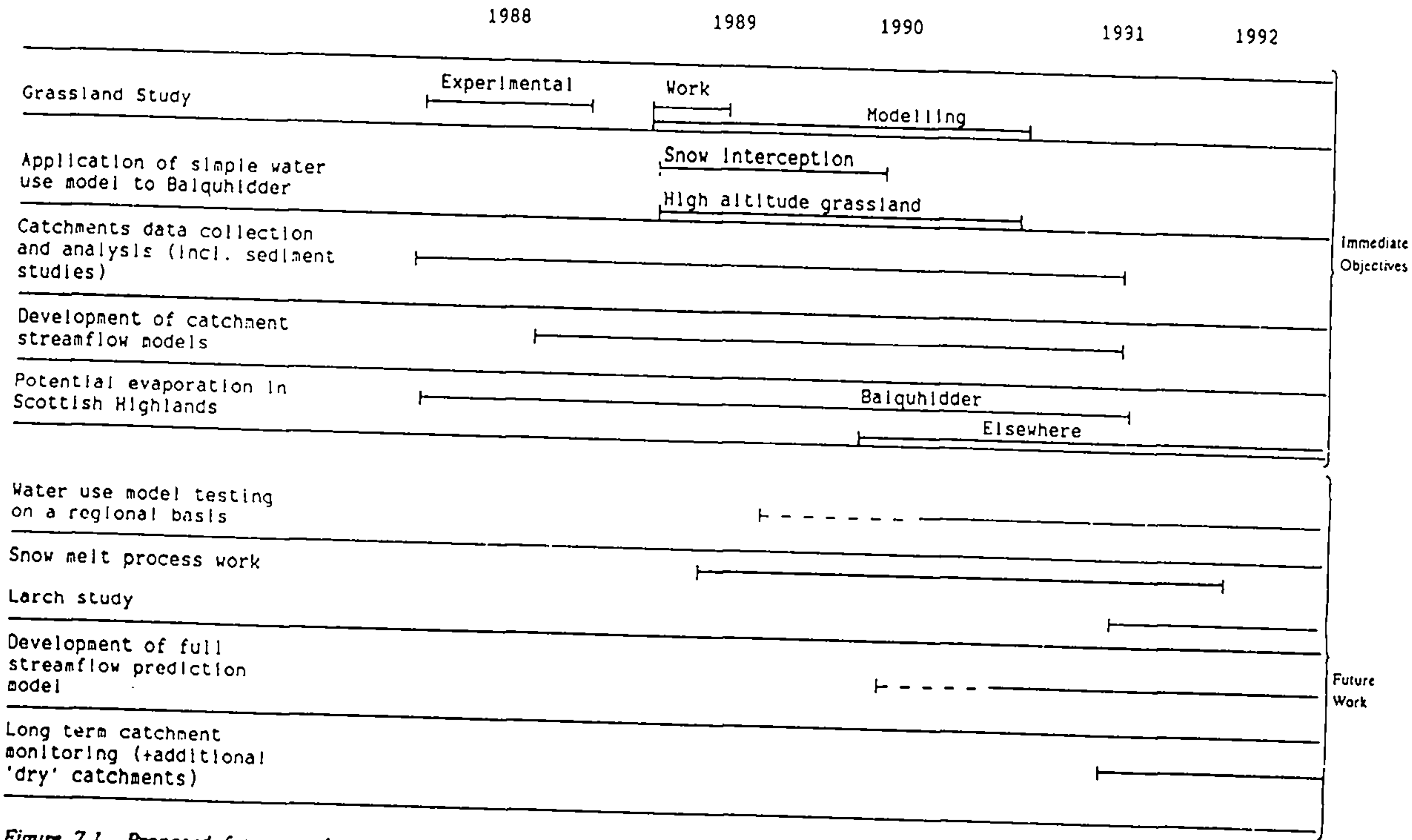

Figure 7.1 Proposed future work

use changes is completed in 1991 is considered to be essential to ensure that the effects on water use, streamflow responses and sediment loss are fully quantified. As part of this exercise checks on the precipitation networks and the streamflow structure ratings will continue, the latter using newly acquired electro-magnetic current-meters capable of measuring much lower velocities than their mechanical predecessors. This will make it possible to check the ratings at much lower flow rates than has been possible hitherto.

The main part of the grassland lysimeter study will be completed in 1989. In the latter part of 1989 and during 1990 more emphasis will be placed on identifying the interception losses from both dormant and actively growing grass. It is proposed to leave the lysimeters on site in 1990 but operate them only as drainage lysimeters so that cumulative checks on water use will still be obtained.

Data collection from the AWS networks in the catchments will be continued. The additional site in the lower Kirkton (section 2.2) should help to clarify the relationships between the meteorological variables and altitude and exposure in this area. A proposal to increase the network density in the Kirkton is under consideration for additional NERC Science Budget support.

Development of the process sub-models and the catchment models will continue along the lines indicated in sections 3 and 5. The objective will be to test these against the data obtained from the two catchments over phases 1 and 2 of the project. Thereafter they will be used to assess the effects of upland land use modification in other areas.

Other work which has been proposed for the Balquhidder catchments during the period to 1991, includes the following items. These are subject to the levels of interest expressed and funding made available by NERC Science Budget and the Consortium members.

(a) Increase the AWS network density (as described above) to make this site a test-bed for identifying the interactions of upland topography and the meteorological variables.

(b) Install instrumentation at a site in the Monachyle to study in detail the energy fluxes involved in the snowmelt process.

(c) Subject to international demand on the equipment making it possible, to install the IH HYDRA system over high altitude grassland to provide additional information on water use.

8. References

Blackie, J.R. 1987. The Balquhidder catchments, Scotland: the first four years. *Trans. Roy. Soc. Edinburgh: Earth Sciences*, 78, 227-239.

Blackie, J.R. and Eeles, C.W.O. 1985. Lumped catchment models. In: Hydrological Forecasting. Eds. Anderson, M.G. and Burt, T.P. Wiley, Chichester, 311-345.

Calder, I.R. and Newson, M.D. 1979. Land use and upland water resources in Britain - a strategic look. *Water Resources Bulletin*, 15. 1628-1639.

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The demand for long-term scientific capabilities concerning the resources of the land and its freshwaters is rising sharply as the power of man to change his environment is growing, and with it the scale of his impact. Comprehensive research facilities (laboratories, field studies, computer modelling, instrumentation, remote sensing) are needed to provide solutions to the challenging problems of the modern world in its concern for appropriate and sympathetic management of the fragile systems of the land's surface.

The **Terrestrial and Freshwater Sciences** Directorate of the Natural Environment Research Council brings together an exceptionally wide range of appropriate disciplines (chemistry, biology, engineering, physics, geology, geography, mathematics and computer sciences) comprising one of the world's largest bodies of established environmental expertise. A staff of 550, largely graduate and professional, from four Institutes at eleven laboratories and field stations and two University units provide the specialised knowledge and experience to meet national and international needs in three major areas:

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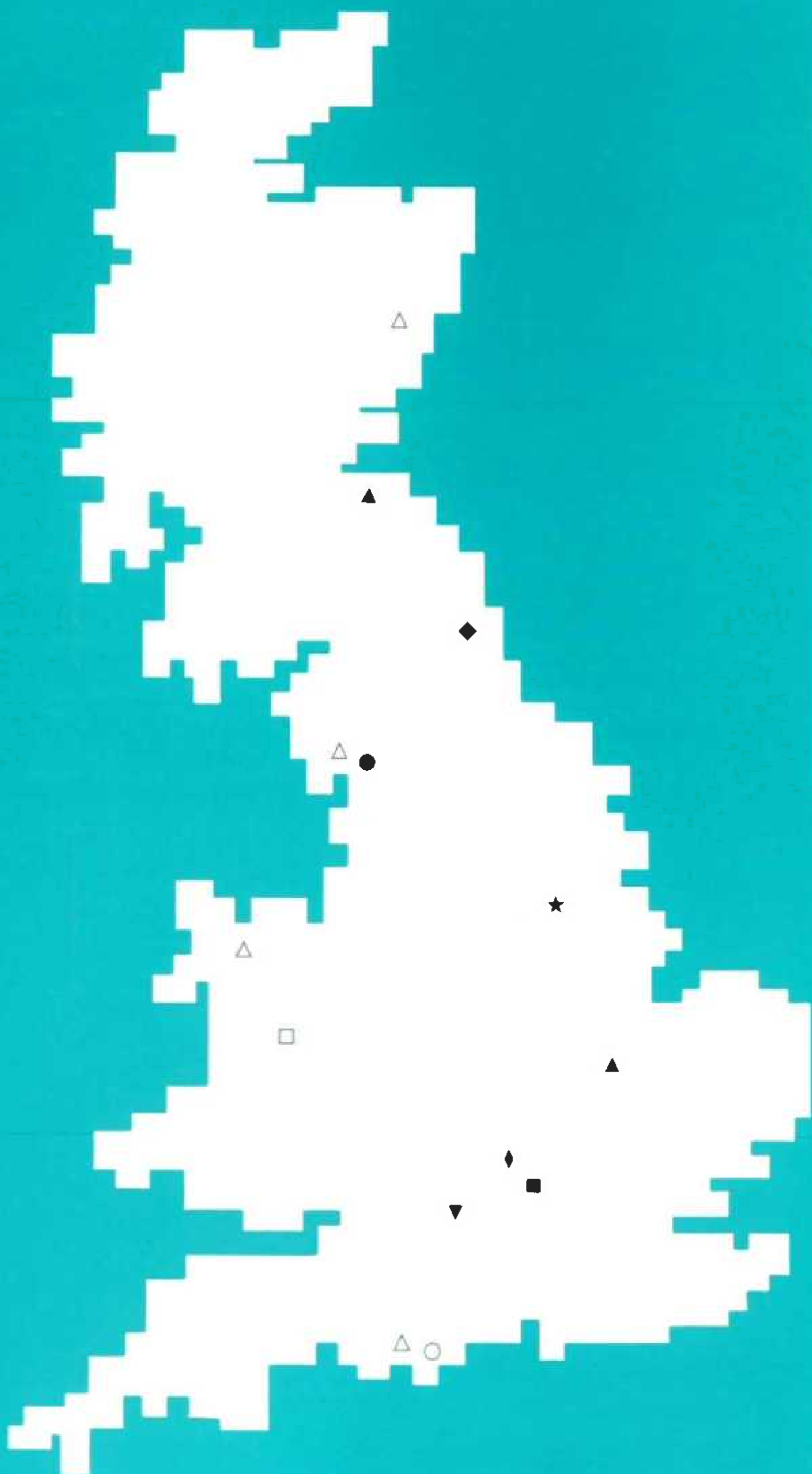

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