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Upland Afforestation and Water Resources

Progress Update 1987/88

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UPLAND AFFORESTATION
AND
WATER RESOURCES

Progress Update 1987/88

by

The Experimental Catchment Studies and
Process Studies Sections

of

The Institute of Hydrology

Contents

1 Introduction

Following the presentation of progress reports on the catchment and process studies at the annual Steering Committee Meeting of the Consortium in May 1987 it was agreed that two further meetings should be held in 1987.

The first of these took the form of a field visit to the Balquhidder catchments and the upland grassland process study site on 9th October 1987 and was attended by representatives of all the funding agencies involved in the programme plus a number of invited guests. Despite a thin covering of snow and subsequent heavy rainfall those who attended were able to see the work in progress in the grassland study and a representative range of the instrumentation in use in the Kirkton and Monachyle catchments. Time precluded a visit to the Upper Monachyle instrumentation sites but the ploughing and drainage techniques applied to the areas to be planted in the lower Monachyle and the felling techniques in use in the Kirkton gave rise to lively discussions.

The second meeting was a two day discussion meeting held in Edinburgh on 10th-11th December 1987. This was attended by representatives from the funding agencies together with invited guests from Universities and other organisations who have a particular interest in the problems being addressed by the research programme. Presentations on all aspects of the catchment studies and the process studies and the results emerging were given by staff of the Institute of Hydrology. These were interspersed with presentations on a range of water quality studies being undertaken within the Balquhidder catchments by independently funded organisations. Following a closed review of the presentations, the funding agencies presented their views on the work and the meeting concluded with a general discussion of the results, their implications and the aspects on which further work was required.

Comprehensive notes on the presentations made at the December meeting were circulated in February 1988. Consequently this progress report does not set out to repeat all the detail presented there. A summary of results and conclusions culled from those presentations is given in the following section. This is followed by two sections in which results emerging since December 1987 from the process studies and the catchment studies are described.

Future work is reviewed in a separate paper also circulated with this report.

2. Summary of Results and Conclusions

The strategy of combining an intensive study of the responses of two representative catchments with detailed studies of the hydrological processes identified as being the key factors controlling these responses has yielded much new information and a better understanding of land use and hydrology in the more extreme upland areas of Britain. This information is being used to extend and improve existing hydrological models. Those improvements already implemented and tested on the Balquhidder catchment data have been shown to be equally valid when applied to less extreme areas elsewhere in Britain. There is every indication that further useful information will emerge from the present phase of clear-felling and initial afforestation on the catchments and the extension of the process studies found necessary as a result of the initial catchment findings.

2.1 CATCHMENT STUDIES

The intensive instrumentation of two catchments at Balquhidder to obtain information on water use by the existing vegetation covers, a heather/grass mix on the Monachyle and 35% mature forest with high altitude grassland above it in the Kirkton, has produced much useful information and some unexpected results. The dense networks of precipitation gauges have given useful insights into the spatial variability of precipitation within this type of rugged terrain. A method of estimating snow input has also been evolved. Accurate, continuous measurement of streamflow over the wide range of flows experienced in the steep flashy streams presented a challenge which has been met successfully and has also provided useful data on the performance of standard structures operating close to or beyond their design limits. Apart from its immediate application in defining water use from the catchments, the flow data obtained will provide valuable information on the flood and low flow characteristics of this type of terrain. Despite a relatively poor data capture rate, the network of Automatic Weather Stations installed to provide estimates of Penman potential evaporation, ET, in the catchments have yielded valuable information on the magnitude and variation with altitude and exposure of ET in these upland conditions. It has been shown that, contrary to previous assumptions, ET is significantly greater in summer on the high altitude exposed areas of the catchments than in the valley bottoms. This suggests that the methods presently employed to obtain regional ET values by extrapolation from low level sites may be significantly underestimating ET for upland areas. Initial analysis of the data on radiation, humidity, temperature and windspeed suggests that the main factors leading to these higher ET values are windspeed and net radiation. The data acquired provide an opportunity to develop a much better understanding of the factors controlling climate in upland areas.

The conclusions from the water balance analyses of the two catchments under their existing vegetation covers were surprising and appeared to contradict existing concepts and model predictions. The heather/grass covered Monachyle was found to have a mean annual water use of 634 mm, relative to an ET estimate of 540 mm and the part forested, part grassland Kirkton a water use of 425 mm relative to an ET of 540 mm. Exhaustive checks on the data, the methods of computing catchment means and the geology of the catchments revealed no sources of systematic error large enough to cast doubt on the conclusions that the water use of the Monachyle was certainly not less than ET whereas that of the Kirkton was significantly lower than ET. An indication of the unexpectedness of the latter result is that the application of the previously accepted Calder & Newson model to the Kirkton would have predicted a water use of 710 mm.

A study of interception loss from the forested area of the Kirkton found that this was within the range found elsewhere in upland Britain, suggesting that the low overall water use of the catchment was due to the high altitude grassland areas. To determine whether water use by these grasses was significantly lower than the Penman ET figures an additional process study was proposed, approved and initiated. This study is not yet completed but initial results suggest that water use by grassland at altitudes above 400 m is indeed lower than Penman ET.

Sediment studies in the Balquhidder catchments during the initial phase of the study were aimed primarily at developing sediment ratings for the catchments under their existing vegetation cover, so that changes in erosion rates resulting from the subsequent operations of land preparation and planting in the Monachyle and clear felling in the Kirkton could be quantified. During the initial phase prior to the felling and planting, mean annual losses of 37 t km^{-2} and 57 t km^{-2} of suspended sediment and 0.1 t km^{-2} and 0.8 t km^{-2} of bedload were observed from the Monachyle and Kirkton respectively. The main sources were the steep tributary streams. The reason for the 50% greater loss from the Kirkton, despite its lower precipitation and flow, was not positively established but most of the material appeared to come from the lower, forested, areas which also contained an established but lightly used network of forestry roads.

Following the start of planting and clear felling in 1986 a marked change in the sediment responses was observed in both catchments. In both cases the range of concentrations occurring at low flows increased dramatically and the maximum concentrations also increased significantly during the second year, the latter occurring in the mid-range of flows rather than at the highest flows.

Concentrations now appear to correlate more readily with rainfall events than with major changes in flow, indicating that much greater quantities of sediment are freely available for transport to the streams in both catchments.. Sources of this additional material have been identified as the 6% of the Monachyle ploughed and the road system in the Kirkton. Material from the plough lines in the Monachyle concentrates in the cut-off ditches and is transported from these to the streams. Heavy usage and regular maintenance of the Kirkton road system has inevitably increased the supply of loose material.

Provisional estimates suggest increases in the range 3-5 times during these initial two years of the planting and felling operations. It will be necessary to continue monitoring through Phase II to determine the duration of these present loss rates and the levels at which they subsequently stabilise.

2.2 PROCESS STUDIES

The primary areas of study in the physical processes have been in the evaporative characteristics of heather, the interception losses from a snow covered forest and, recently, the evaporation from high altitude grassland. In addition a number of smaller studies have been completed including a study of the relationship of low flows to land-use and a study of the effects of forest line thinning on the interception characteristics. The latter found no significant difference in the annual interception losses before and after thinning.

The work on heather moors in Scotland has shown that the interception losses can be large (on average 17% of rainfall). However the transpiration losses are small, smaller than those expected from lowland grassland or forest. As a result of these opposing tendencies, heather will be expected to have an overall evaporation higher than the Penman potential only in the wetter areas (when the rainfall exceeds 1500 mm).

The studies of evaporation from snow intercepted on a forest canopy, undertaken at Aviemore, have shown that potentially large interception losses can occur. Although a snow covered canopy is smoother than a rain wetted one, the large canopy storage capacity means that evaporation can continue long after the snowfall has finished. At Aviemore the proportion of precipitation lost through interception is larger for snow than for rainfall. However there is evidence that this proportion depends on the stand density and for older and less dense forest, such as that at Balquhidder, the interception losses for rain and snow may be similar.

An increasing effort has been devoted to using the process results to calibrate models which will enable the extrapolation of the catchment results to other regions of the UK. Both annual and seasonal models are being produced. The models of forest and heather are now complete (although that for a snow covered forest needs further work). In the light of the Balquhidder catchment results the original model for grass is now felt to be inadequate in high altitude areas and its further development awaits the completion of the high altitude grassland study.

The application of the models to the Monachyle catchment reproduces the high losses observed from this catchment. The application of the models to the Plynlimon catchments shows a good agreement with the grassland Wye catchment (provided a simple temperature correction is applied). In the part forested Severn catchment there is a small discrepancy between the model and catchment results but this is within the expected errors in the two estimates. The application of the models to the Kirkton catchment cannot be made until the grassland study is complete.

3. Recent Developments in the Process Studies

Since the consortium meeting in Edinburgh on 10/11 December 1987 analysis of the 1987 data has continued and the equipment of the high altitude grassland study has been refurbished and reinstalled.

The total water contents in mm calculated from observations made in 1987 are plotted with the daily rainfall in Fig. 3.1. There was good agreement between the data from the two sets of tubes but there were one or two periods when more frequent measurements would have been beneficial. A preliminary analysis of the measurements indicate that there may have been a period towards the end of May when a small deficit was established but there appear to have been no major deficits. This in itself supports the hypothesis of reduced evaporation rates from high altitude grassland. Moreover a comparison of the daily rainfall totals and the changes in soil moisture suggest that transpiration rates throughout the summer are typically only 1 to 2 mm a day. This is in agreement with expectations and the results from the weighing lysimeters but results from continued measurements, if possible at more frequent intervals, will be needed before firm conclusions can be drawn.

The results of the biomass measurements made from April to July 1987 are plotted in Fig. 3.2 which shows a linear increase in the proportion of live biomass as a function of time. This function was used in a simple daily accounting model to predict the seasonal change in soil moisture and the results compared with observations for the period March to July. The model calculates the soil moisture S_{i+1} on day i+1 from:

$$S_{i+1} = S_i - E_i + R_i$$

where S_i is the soil moisture on day i, R_i is the measured rainfall on day i and E_i the evaporation calculated for day, i, as either the Penman E_t, calculated from the Gleann Crotha weather station data, or as the product of E_t and the biomass function $b = 0.00466d + 0.176$ where, d, is the day number.

The daily evaporation was also calculated as the products of $E_t\tau$ and $E_t b\tau$ where the temperature function τ is that used by Hall (1987). This assumes that below 5°C there is no transpiration, between 5°C and 10°C there is limited transpiration and that above 10°C transpiration occurs at the Penman rate.

The best fit between observed and predicted soil moisture was obtained when the daily evaporation was given by the triple product. Using E_t alone gave the poorest fit followed by the product $E_t\tau$. Clearly these results do not establish a causal link between temperature, biomass production and evaporation rates. However, they do show again that the soil moisture data are best explained by an evaporation rate significantly less than E_t.

Unfortunately problems with the logging system were encountered for a large part of the operational period of the lysimeters and the more complicated analysis which is required to extract useful data from this period is incomplete.

The lysimeter systems have recently (March 1988) be recommissioned for the 1988 growing season and the old loggers have been replaced with two new Campbell CR10 logging systems. These should improve the reliability and precision of the systems and facilitate data handling.

Work has started using the wet-surface weighing lysimeter system to study the interception characteristics of the grassland. This equipment requires personnel to be on site and so it is proposed that there will be several field trips through the year.

These trips will also be used through the growing period to take biomass samples.

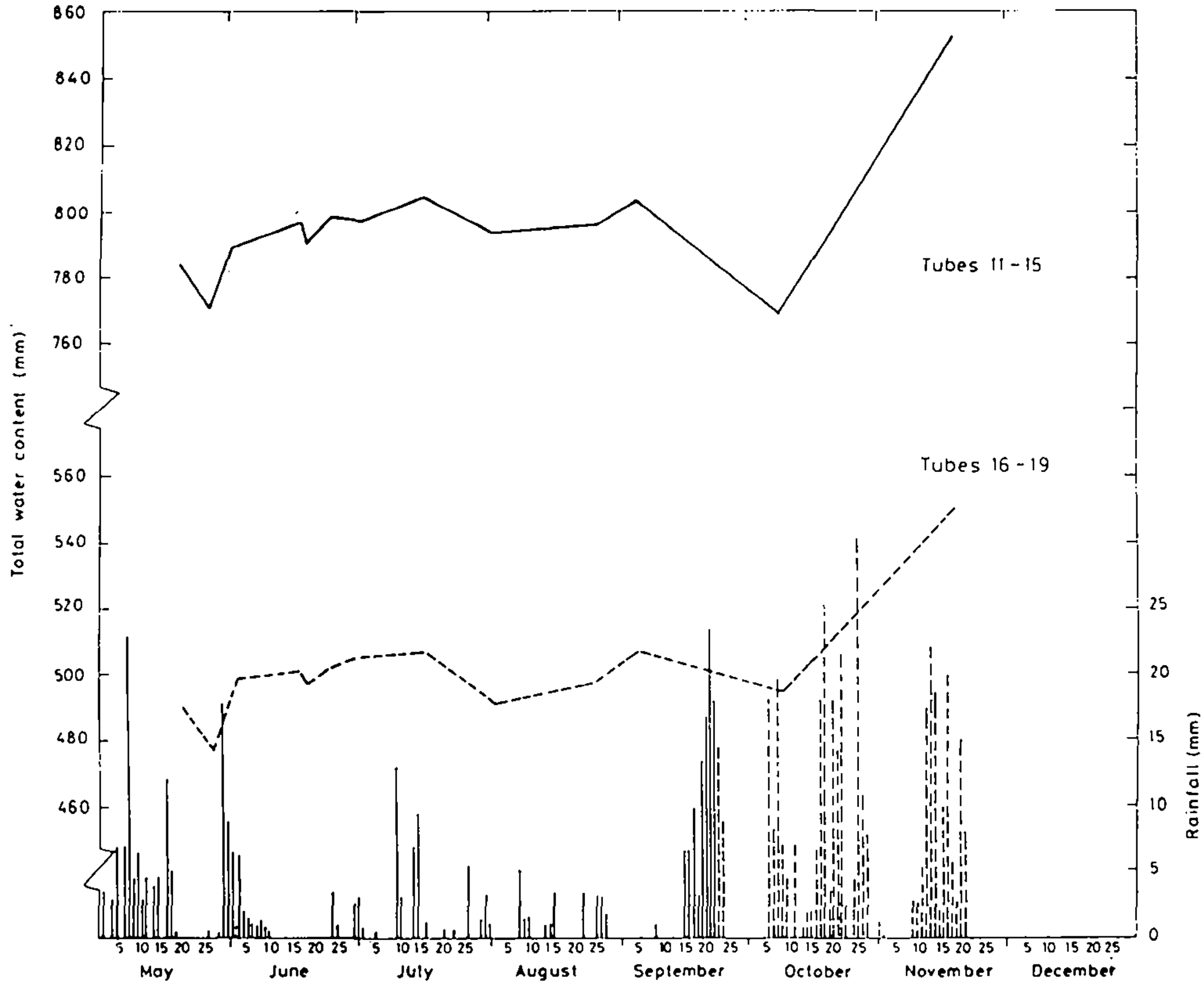


Fig 3.1 Soil moisture and rainfall at the high altitude grassland site in 1987. Rainfall values were measured either at the site or Kirkton High or at the Tulloch Farm manual weather station (shown by broken line)

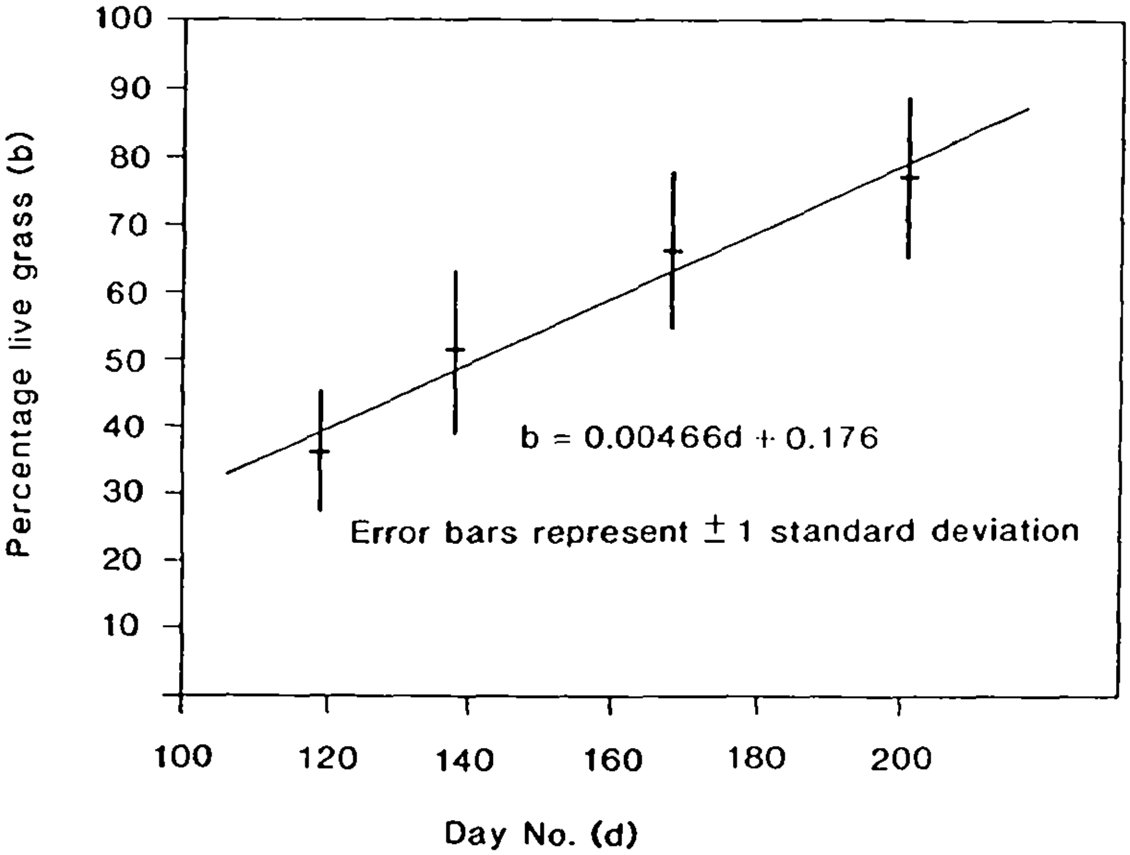


Fig. 3.2 Production of biomass from the high altitude grassland site.

4. Recent Developments in the Catchment Studies

Data collection from the catchment instrument networks and the extensions of these has continued throughout the year. This has resulted in more information now being available from the additional raingauges installed to check on the validity of the basic networks and further, admittedly intermittent, additions to the body of data from the Automatic Weather Stations. Further analysis of these data, in terms of the individual meteorological variables as well as the computed Penman ET values, has begun to yield some insights into the reasons for the higher ET values at the high altitude sites. Sediment sampling was intensified further during 1987 and the ongoing analysis is revealing rather greater changes in sediment yield in Phase II than was first suspected. The water balance results for both catchments have been updated to the end of 1987 and an initial analysis of the upper Monachyle sub-catchment has been carried out. The attention of other sections of the Institute of Hydrology has been drawn to the Balquhidder catchments and initial work is now in hand to use them as testbeds for other Science Vote supported research. This may produce information useful in the interpretation of the catchment and process studies.

4.1 Precipitation

The precipitation gauge networks in both catchments are illustrated in Fig. 4.1.1. Included are the five additional gauges installed in 1986/87 to check on the results obtained in key rainfall domains. These domains are C3Y and C3W in the Kirkton and B3Z and D2W in the Monachyle. The additional gauges installed are C3Y(2), C3Y(3), C3W(2), B3Z(2) and (D2W). The latter differs from the others in that no gauge was previously installed in this domain. All are ground level gauges installed with their grids and orifices parallel to the slope, as for the original gauges. C3W(2) was installed adjacent to a Meteorological Office storage gauge mounted with its orifice horizontal and 30 cms above ground.

The results to date from the comparisons in domains C3Y, C3W and B3Z are plotted in Figures 4.1.2, 4.1.3 and 4.1.4. Because it is under snow for long periods insufficient data for analysis has yet been obtained from D2W.

Whilst there is some scatter in the readings in each domain, there is no indication that any of the original gauges differs significantly from the check gauges. It is notable however that the MO standard gauge gives consistently lower readings than either of the ground level gauges in domain C3W.

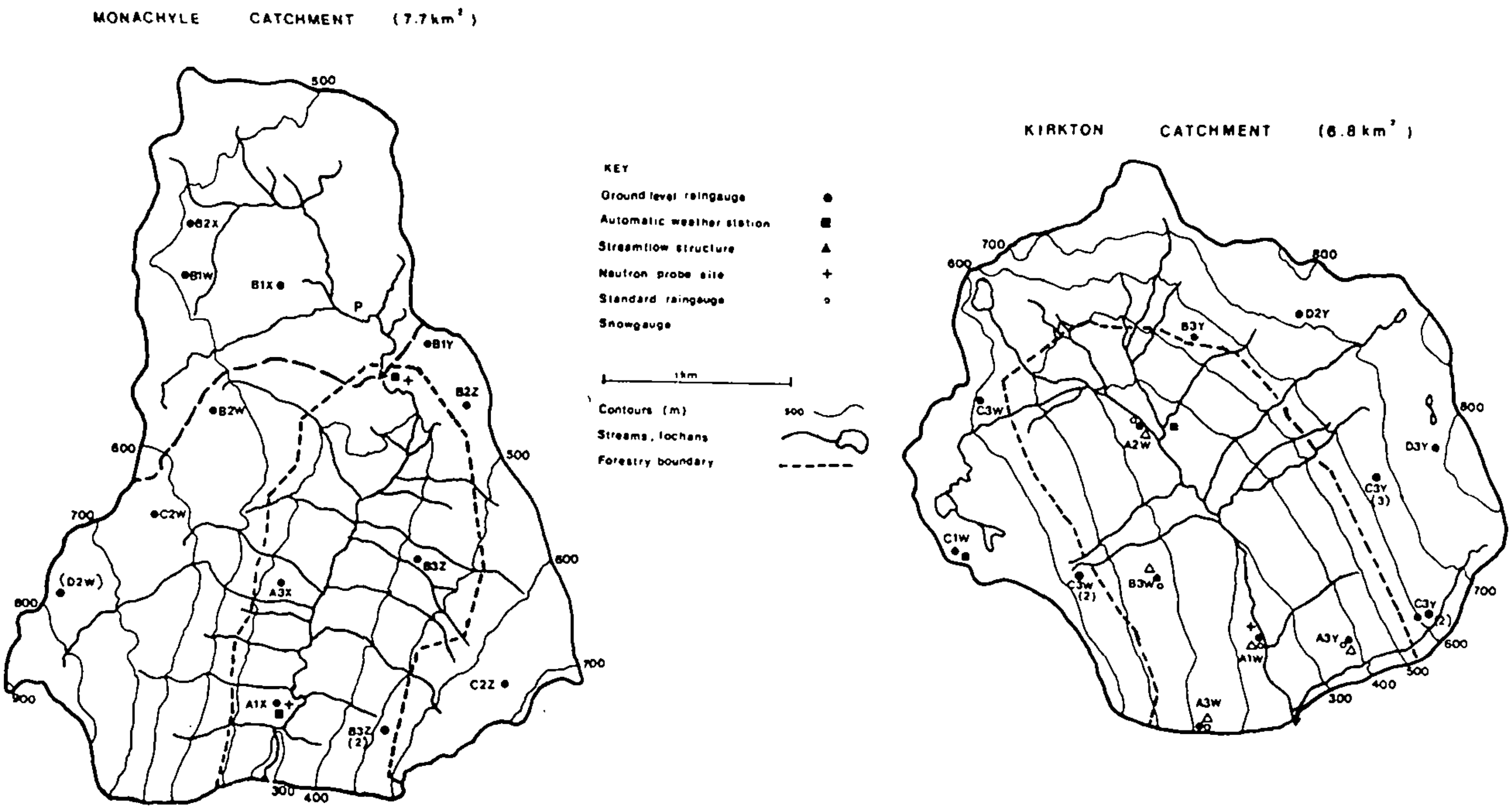


Figure 4.1.1. Instrument networks in Monachyle and Kirkton catchments.

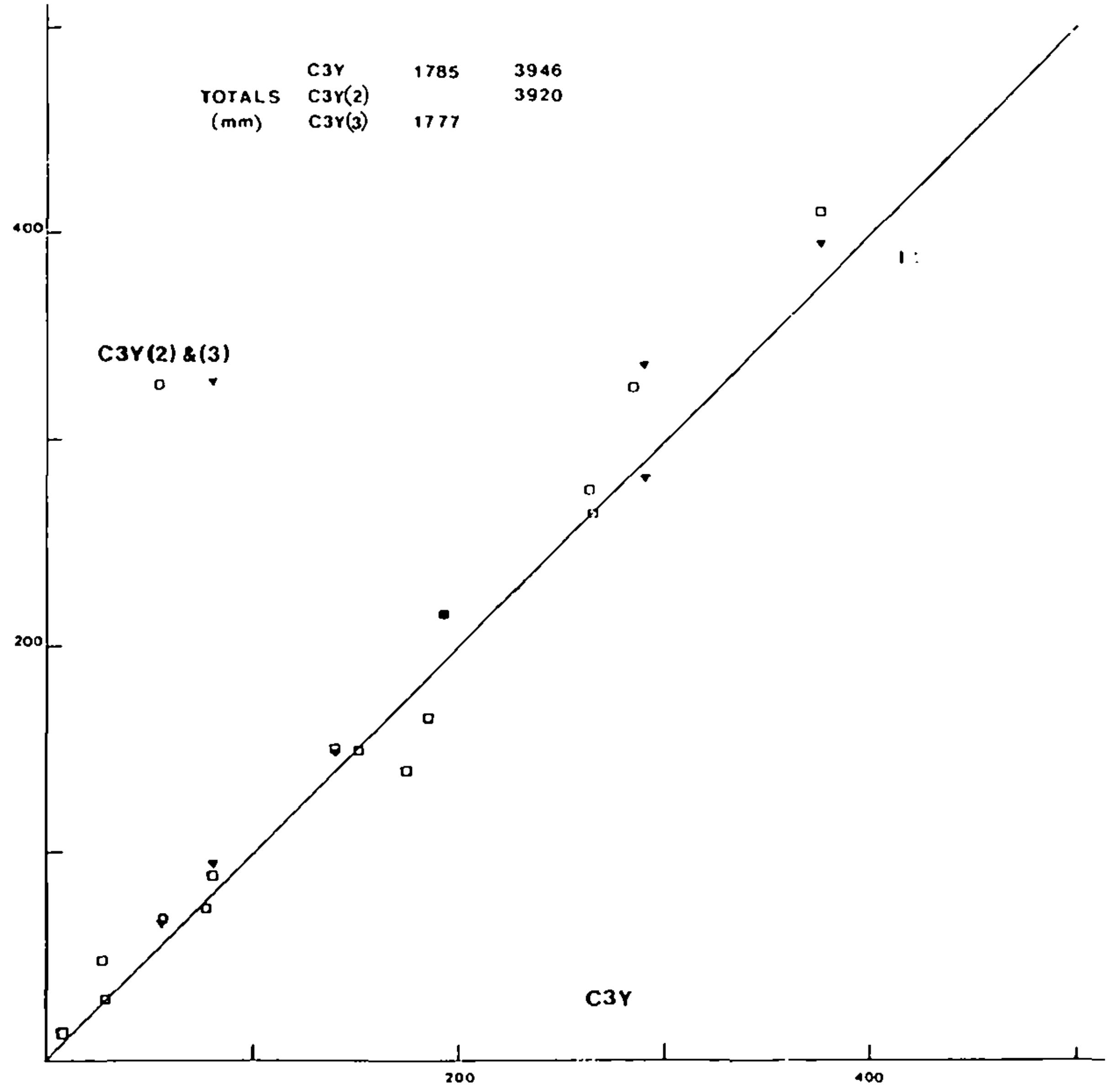


Figure 4.1.2. Comparison of check gauges C3Y(2) and C3Y(3) with network gauge C3Y, Kirkton.

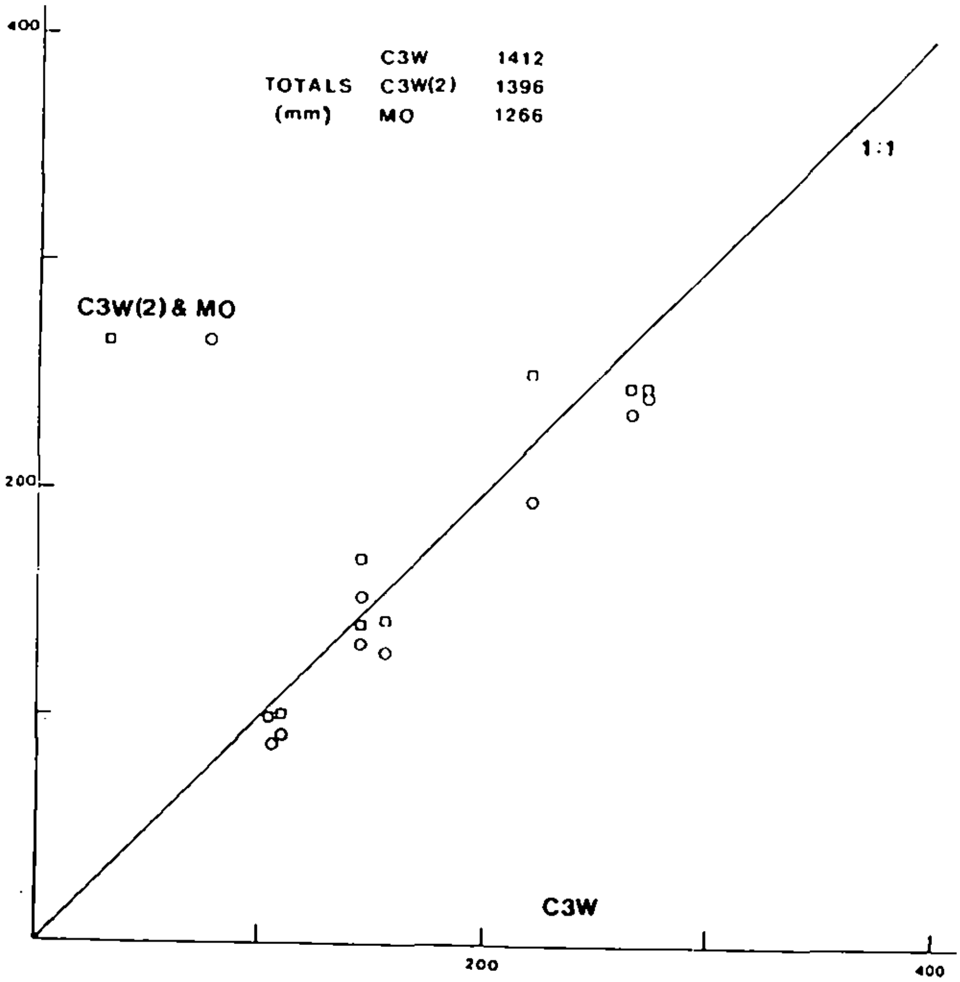


Figure 4.1.3. Comparison of check gauge C3W(2) and Met. Office storage gauge MO with network gauge C3W, Kirkton.

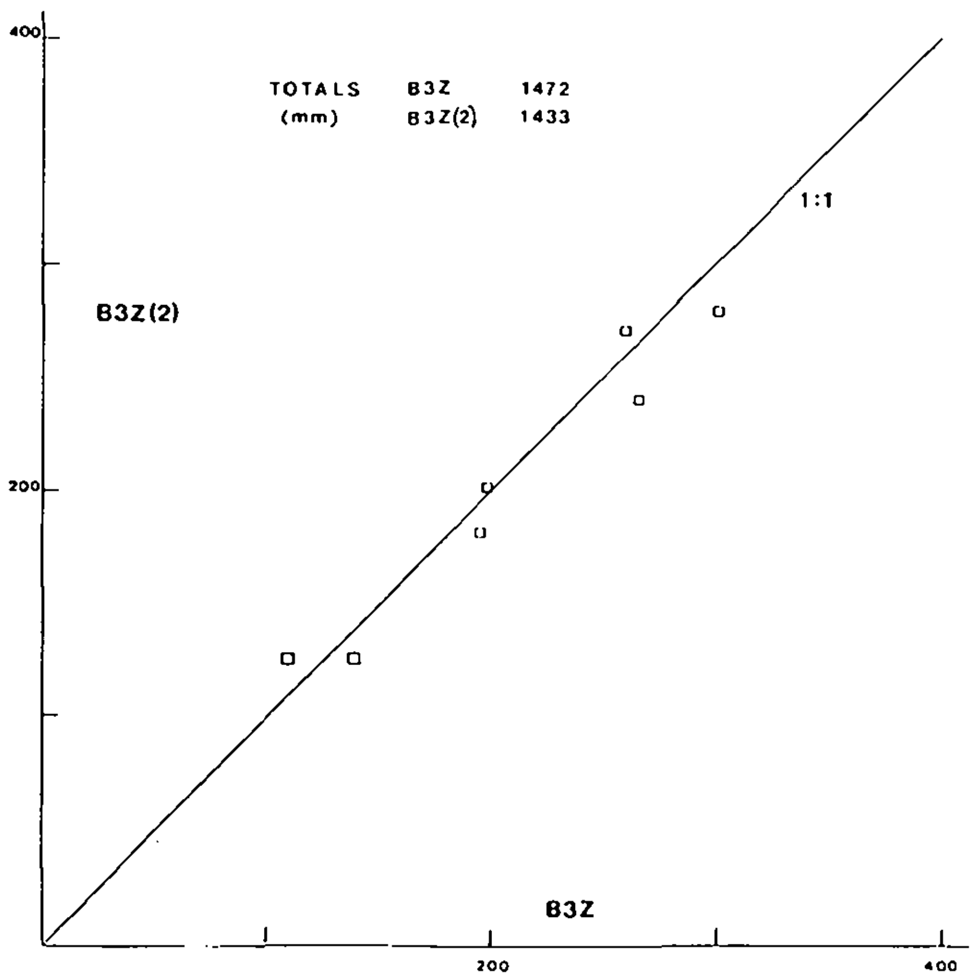


Figure 4.1.4. Comparison of check gauge B3Z(2) with network gauge B3Z, Monachyle.

4.2. Meterorological Data

Collection of meteorological data from the four original AWS and the additional one installed above the forest canopy in the Kirkton in 1986 has continued to be beset by the development of faults in individual sensors and occasional malfunctioning of the loggers. Because of the time lag between the removal of the tapes from the loggers and availability of translated and processed data these faults can continue undetected for long periods. To counteract this the mag. tape loggers are being replaced with processor controlled solid state systems in autumn 1988. 'Real' data can be obtained from these in a very much shorter time using a PC. This should result in a much better return of data in future.

Analysis of Penman ET values for complete months up to 1985 (Blackie, 1987) revealed stable, well defined relationships between the stations which were used to infill missing months and so produce annual estimates of ET from the high altitude exposed sites at Kirkton High and Upper Monachyle (see Fig. 4.1.1). Data from the 'complete' months obtained in 1987 gave no indication of any significant changes in these relationships.

During the past year some analysis of the individual variables has been undertaken. This is summarised in Figs. 4.2.1 to 4.2.5 in which monthly mean daily values of solar, net, temperature, saturated humidity deficit and windspeed for complete months from each site are plotted against the Tulloch Farm site. These indicate surprisingly close values of solar radiation at all sites but marked differences in the other variables. The general trends are in the same sense as those identified by Johnson (1985). The similarity in the between-site relationships from year to year helps to explain the stable between-site Penman relationships. Comparison of the slopes of the regression lines in the above figures suggests that factors other than altitude are involved. The presence of snow at some stations and not others during the winter months undoubtedly plays a part but factors such as low cloud and differences in soil moisture in the summer months must have some influence.

Clearly, however, the reason for the higher Penman ET values at the high altitude stations is that they experience much higher net radiation and wind speed, which suggests that exposure rather than altitude is the significant factor.

More complete runs of data and further analysis is required before any generally applicable model of climatic variation can be formulated as a basis for estimating catchment mean Penman ET values.

This work has revealed that a few of the monthly ET values previously considered to be acceptable must be discarded. Revised estimates of annual ET for each of the four sites are listed in Table 4.2.1. Insignificant good data have been obtained from the Kirkton forest site so far to present ET values for it.

For the present the similar values derived from the two exposed sites have been used as reference values in the water balance analysis.

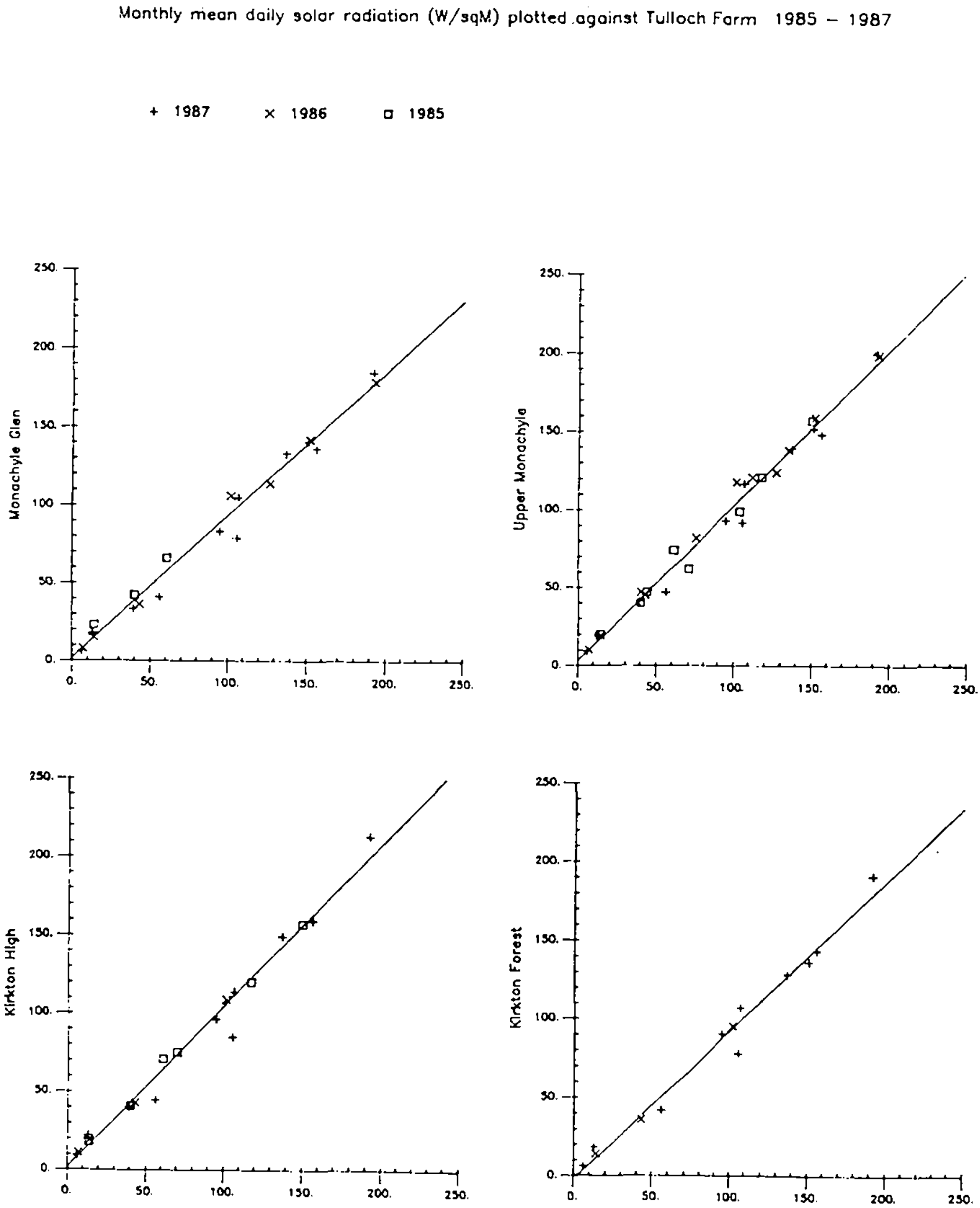


Figure 4.2.1 *Between-site solar radiation relationships*

Monthly mean daily net radiation (W/sqM) plotted against Tulloch Farm 1985 - 1987

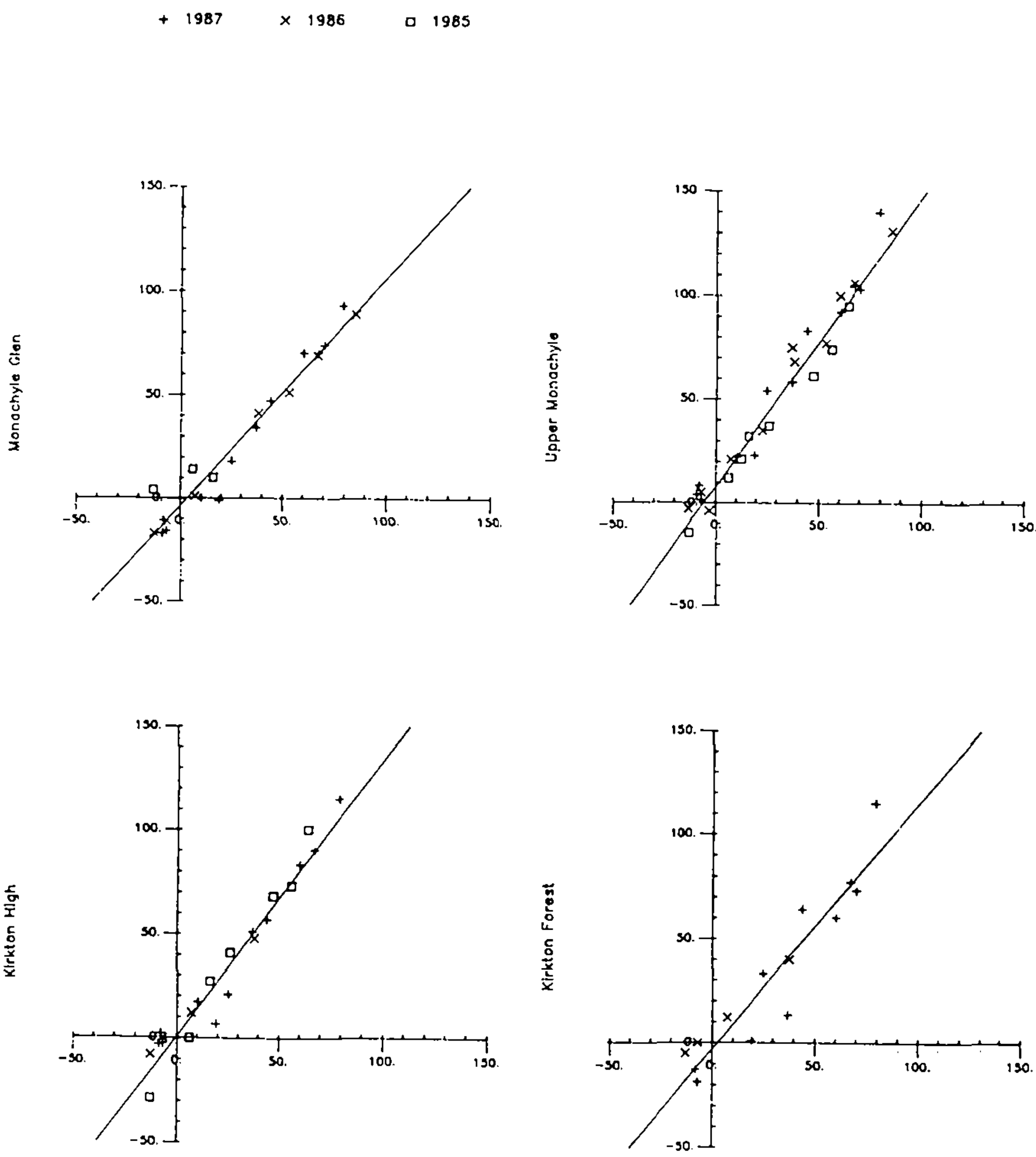


Figure 4.2.2 Between-site net radiation relationships

Monthly mean daily Temperature (Deg C) plotted against Tulloch Farm 1985 – 1987

+ 1987 × 1986 □ 1985

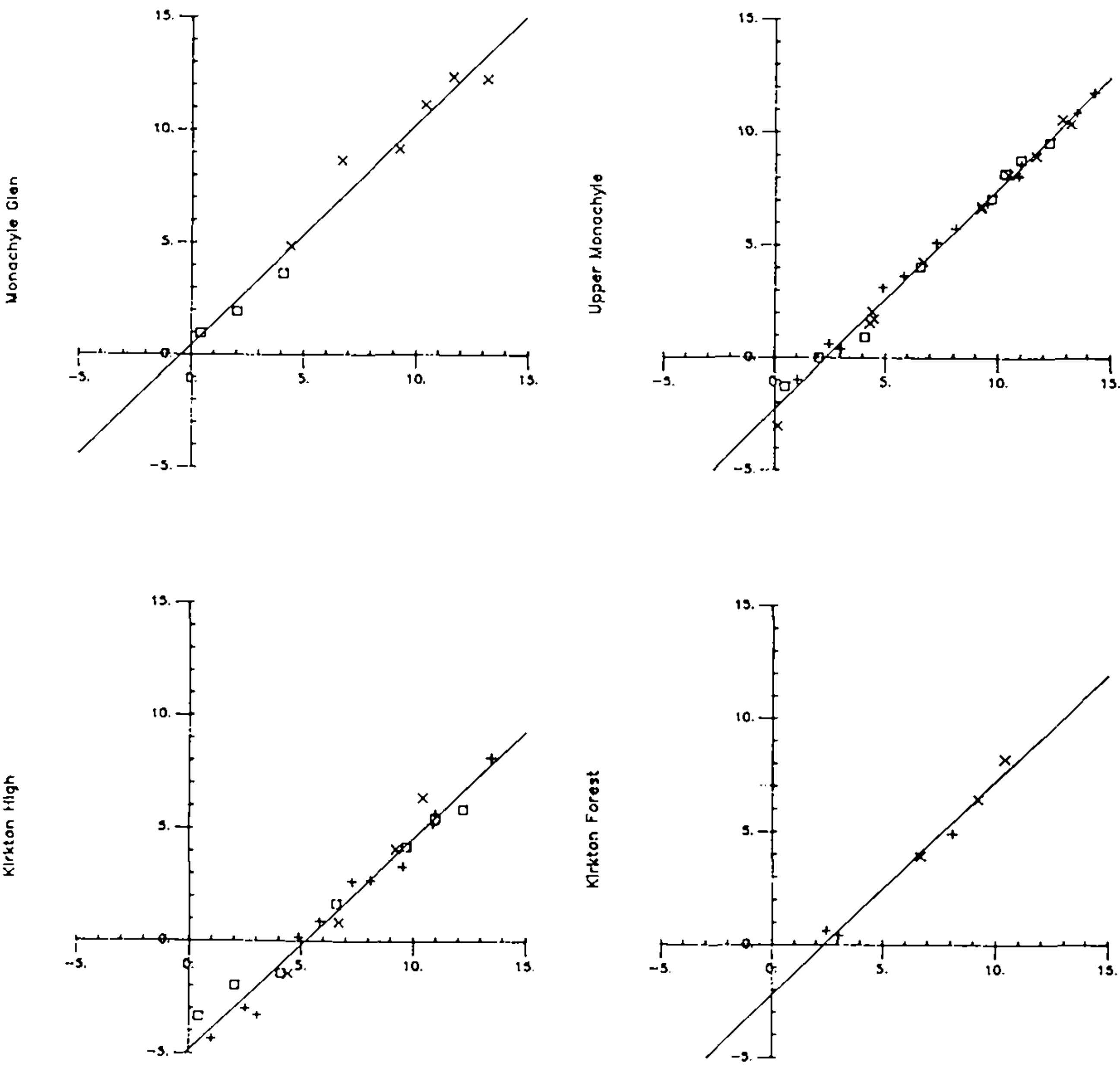


Figure 4.2.3 Between-site temperature relationships

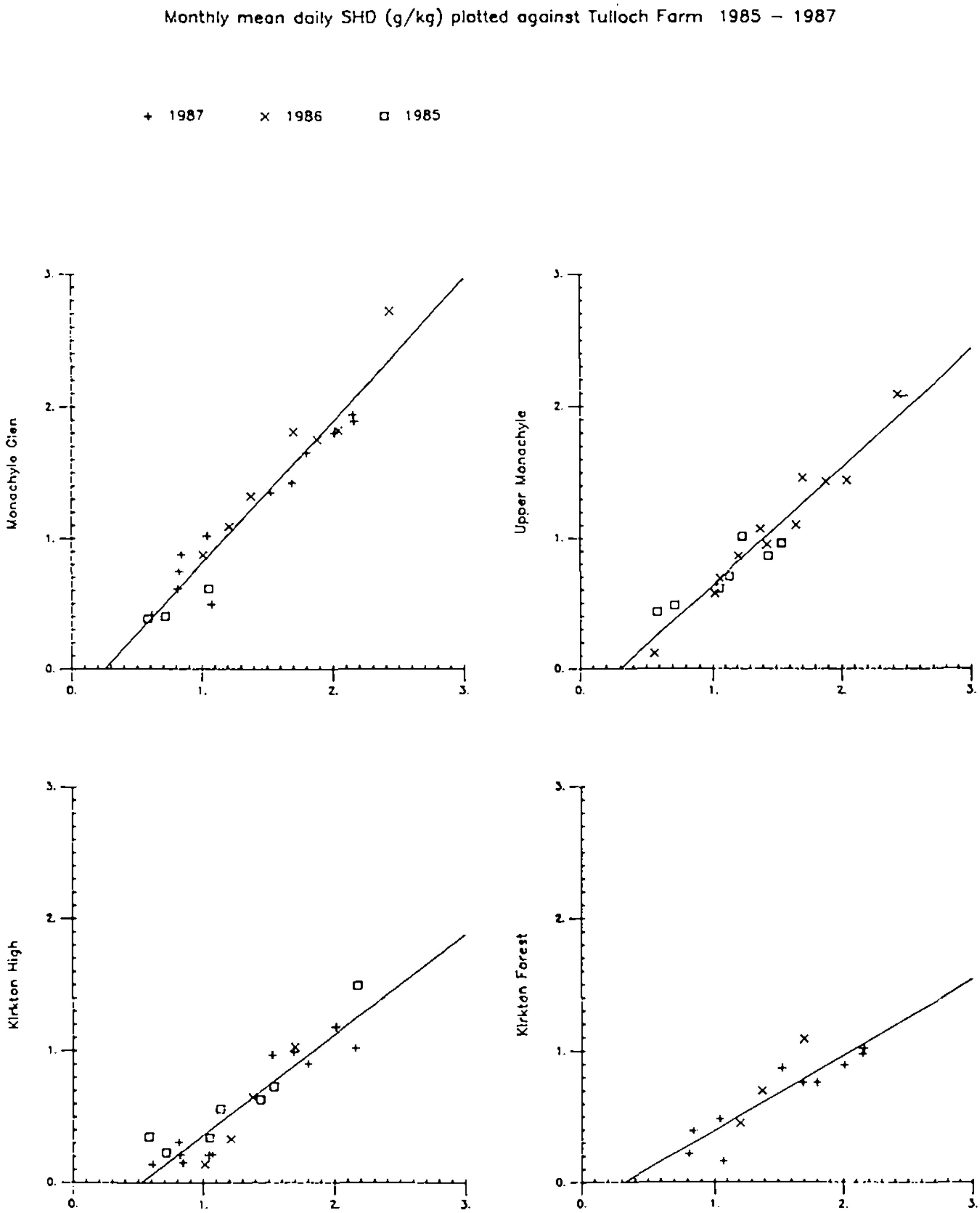


Figure 4.2.4 Between-site saturated humidity deficit relationships

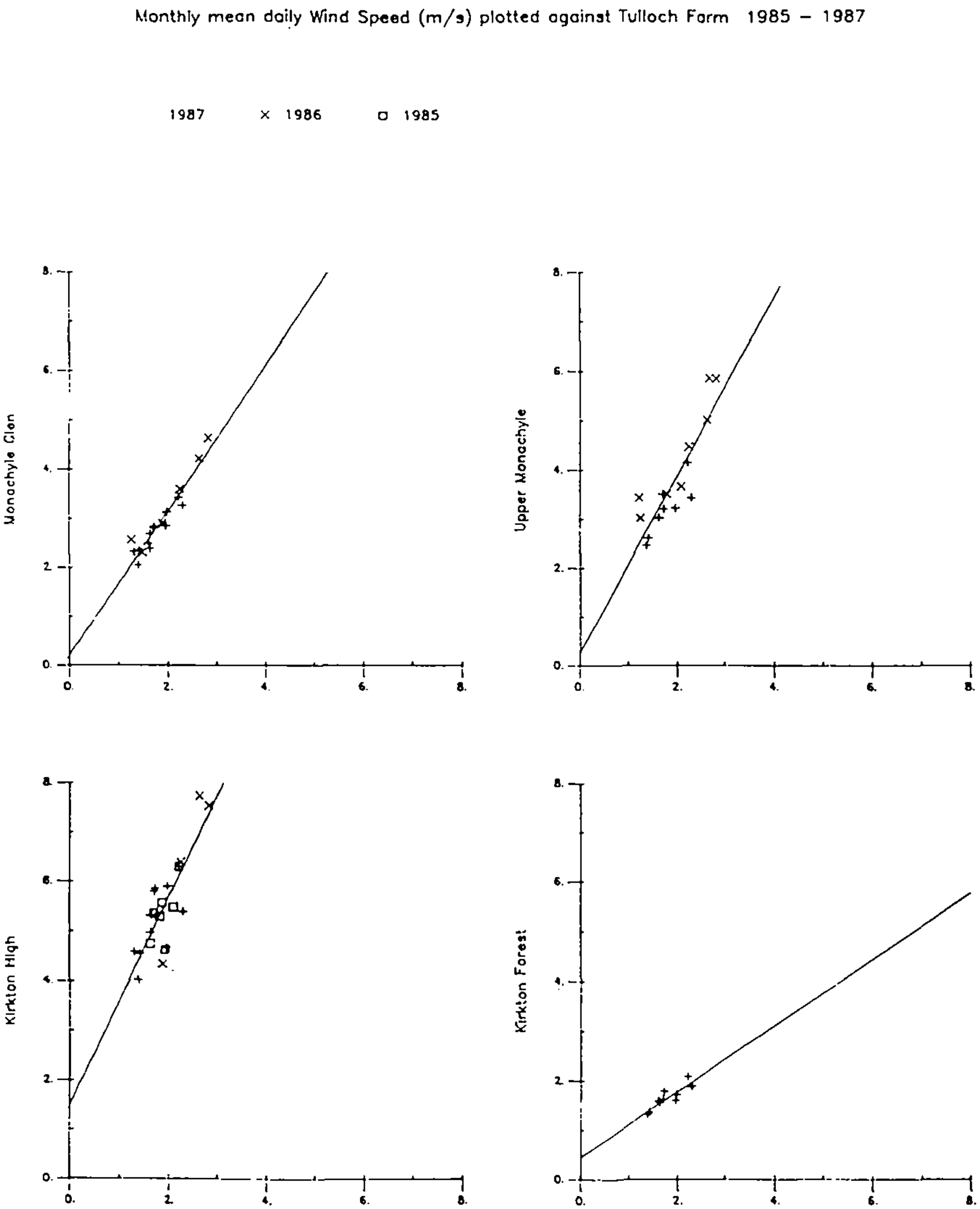


Figure 4.2.5 Between-site windspeed relationships

TABLE 4.2.1 Estimated Annual Penman ET Totals (mm)

	1983	1984	1985	1986	1987	1983-85 means	1983-87 means
Kirkton High (670 m)	522	635	446	558	492	534	531
Upper Monachyle (470 m)	(540)*	634	464	584	492	546	543
Monachyle Glen (300 m)	495	557	392	458	443	481	469
Tulloch Farm (140 m)	438	504	370	415	415	437	428

* Estimated from the other stations

4.3 Sediment Yields

Estimation of sediment yields from catchments on the basis of intermittent sampling methods and the relationship of these observations to flows is fraught with uncertainty. Nevertheless considerable advances have been made in refining the methods applied to these catchments. The provisional figures for yields during Phase I (1983-85), prior to the land use changes, presented in December 1987 have been corrected for logarithmic bias in the rating curves. The revised figures are presented in table 4.3.1, together with provisional estimates for the first two years of Phase II.

An indication of the difficulty of estimating these yields accurately is given by Fig 4.3.1 where the envelopes of points obtained (~ 300 per annum) are illustrated. Fig. 4.3.1 also indicates the significant change in sediment response since the start of felling (Kirkton) and planting (Monachyle) operations in 1986. The ranges of concentrations at low flows have increased dramatically and maximum concentrations have also increased, these being observed to occur in the low to medium range of flows. Comparison with rainfall data (Fig. 4.3.2.) suggests that rainfall intensity, implicitly an indicator of surface water movement, is a better basis for estimating sediment loss than streamflow in the present catchment conditions.

During 1986 land preparation for planting began in the Monachyle. The combination of the latest guidelines in planting practices with the topography, soils and geology of the catchment meant that on 60% of the catchment area was ploughed. Plough lines terminated some 20 m from the main water course and cut-off drains were dug across the ends of the furrows at slope angles of less than 3°, most of these also terminating well before drainage lines. Planting in non-cultivated areas has caused virtually no soil disturbance. Whilst sediment movement was observed in the plough lines immediately, this was not at first finding its way much beyond the ends of the cut-off ditches. However, as accumulations from the plough lines increased, these concentrations of loose material began to be transported into the water courses, resulting in the 3-5 fold increases in the stream sediment loads indicated in Table 4.3.1. This concentrating effect of the cut-off ditches raises questions on whether this is the best approach to containing sediment movement. The plough lines are now being recolonised with a vegetation cover but large quantities of sediment in the ditches are still easily transportable.

In the Kirkton the reasons for the higher sediment loads during Phase I were not positively identified. It is worth noting however that an established though lightly used road system was present in the forested area throughout, whereas no roads are present in the Monachyle. This road system was upgraded in late 1985 and extended to include two timber stacking areas when felling started. Timber extraction to the roads, by cable crane and by tracked vehicles driven on brash mats, has caused minimal soil disturbance. Use of the roads has increased dramatically however with some 4 lorry loads of timber moving out each day, necessitating on-going road repairs and maintenance. Thus the main source of the 1986 5-fold increase in readily transportable sediment appears to be the road system.

40% of the forest has now been felled and the remaining 60% is scheduled for removal by 1990. During this period second crop planting will begin on the earliest cleared areas. Removal of the mature forest means the removal of the 32% interception loss, so that the sparsely vegetated cleared areas will experience greater direct rainfall impact as the present brash covering decays and presumably greater surface water flow. Any effect of this on erosion rates has been swamped so far by the large increases in loss from the roads but should become more apparent as the area cleared increases.

TABLE 4.3.1 Annual sediment loads (tonnes), adjusted for bias. Bedload given as > 1 mm and also total load in brackets.

	Suspended		Bedload	
	Kirkton	Monachyle	Kirkton	Monachyle
1983	483	337	6 (20)	< 1 (2)
1984	292	296	5 (13)	< 1 (2)
1985	386	228	6 (17)	< 1 (2)
1986*	1965	1027	Not available	
1987*	986	860	Not available	

* provisional figures

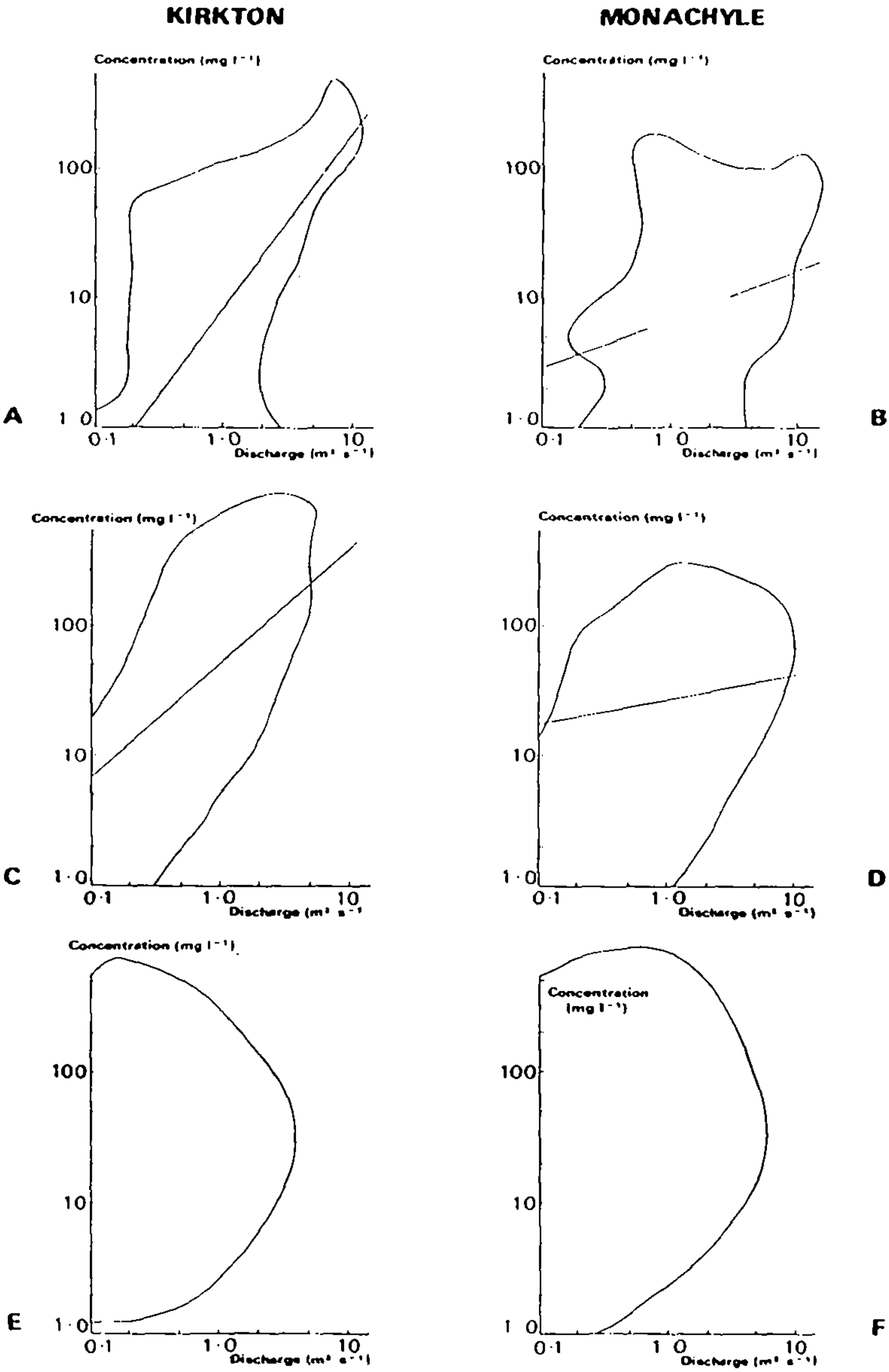


Figure 4.3.1 *Suspended sediment/discharge relationships*
A, B 1983-85; C, D 1986; E, F 1987

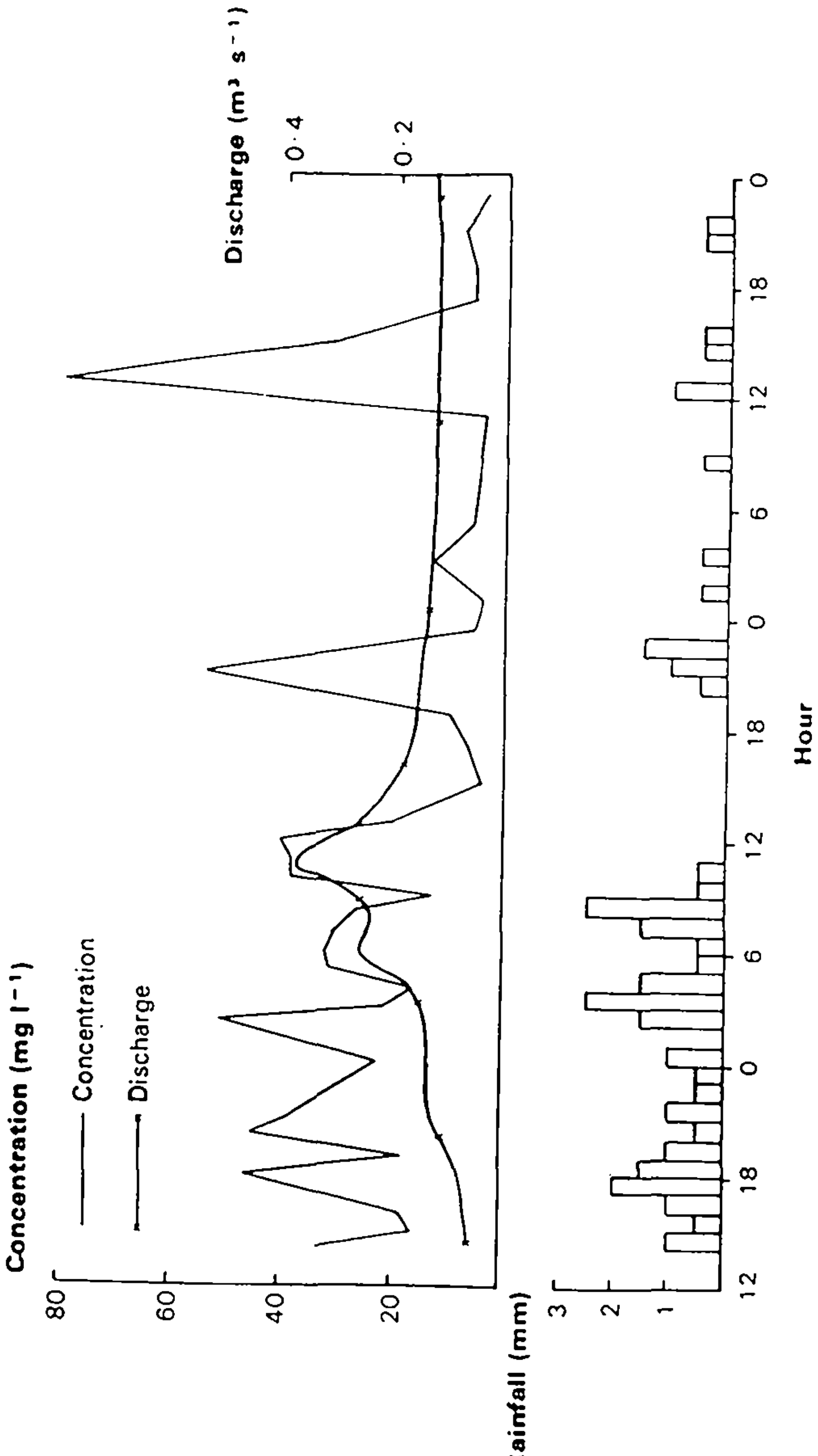


Figure 4.3.2 *Kirkton suspended sediment, flow and rainfall 29-31 May 1987*

4.4 Catchment Water Balances

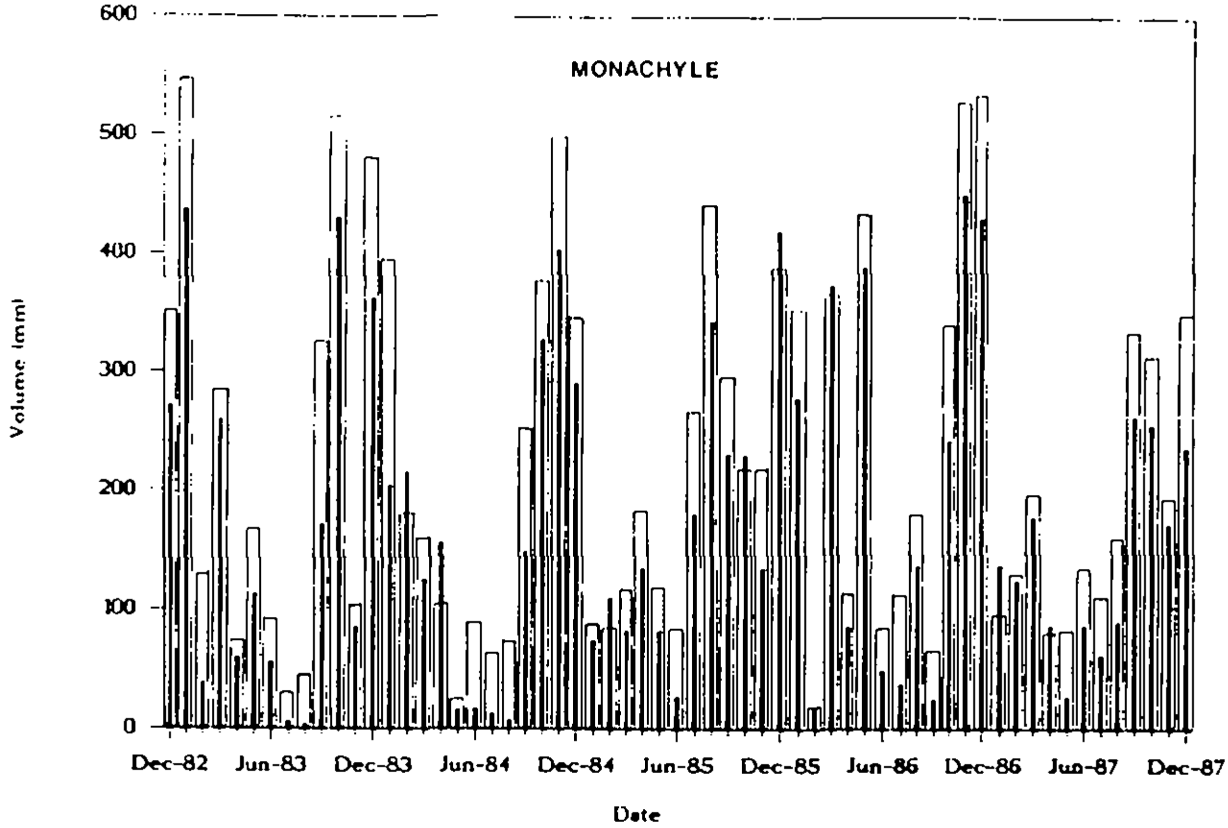
Catchment water balances for the Monachyle and Kirkton to the end of 1985 and their implications were discussed at length at the December meeting. The time series plots of P and Q and the annual water balances are updated with the inclusion of the 1987 figures in Figure 4.4.1 and Table 4.4.1

As was indicated in December the P-Q estimates of water used by both catchments during 1983-85 period are not significantly affected by the absence of an estimate of the storage difference, ΔS. Consideration of the possible systematic errors in P and Q following the revision of the ratings of both streamflow structures and the checks on the raingauge networks showed that these were unlikely to account for the between-catchment differences. It also suggested that the departures of P-Q from ET in both catchments were probably significant.

The P-Q values for 1986 and their relationships with ET are very similar to the 1983-85 means. The 1987 values are lower for both catchments both in absolute terms and relative to ET. Consideration of the conditions at the beginning and end of the year indicates that both catchments were wet but flows were higher at the end. However snow cover was greater at the beginning. Estimation of both the sign and the magnitude of ΔS over the year is difficult therefore and at this stage the significance of these P-Q values can not be fully assessed. It is interesting to note however that annual precipitation in both catchments in 1987 was the lowest experienced in the study.

The upper Monachyle sub-catchment yielded streamflow data for part years only until 1986 because of freezing of the structure float well for long periods during winter. Experiments with the use of pressure transducers to determine water level in the forecourt proved successful and a complete flow record was obtained for 1987.

Water balance data for the part year periods prior to 1986 and for the complete year of 1987 are compared with these from the complete Monachyle catchment in table 4.4.2. Also listed are values for the 'lower' Monachyle, obtained by area weighted subtraction of the two data sets. 'Lower' in this context does not relate to altitude. The 'lower' part contains both the highest and lowest altitude areas of the catchment, with a mean very similar to the upper sub-catchment. As can be seen from table 4.4.2 P,Q and P-Q are very similar for both parts of the catchment. Whilst it is interesting to note that the maximum difference in P-Q occurred in 1986 when the lower part of the Monachyle was undergoing partial ploughing and drainage it is doubtful whether the difference can be regarded as significant.



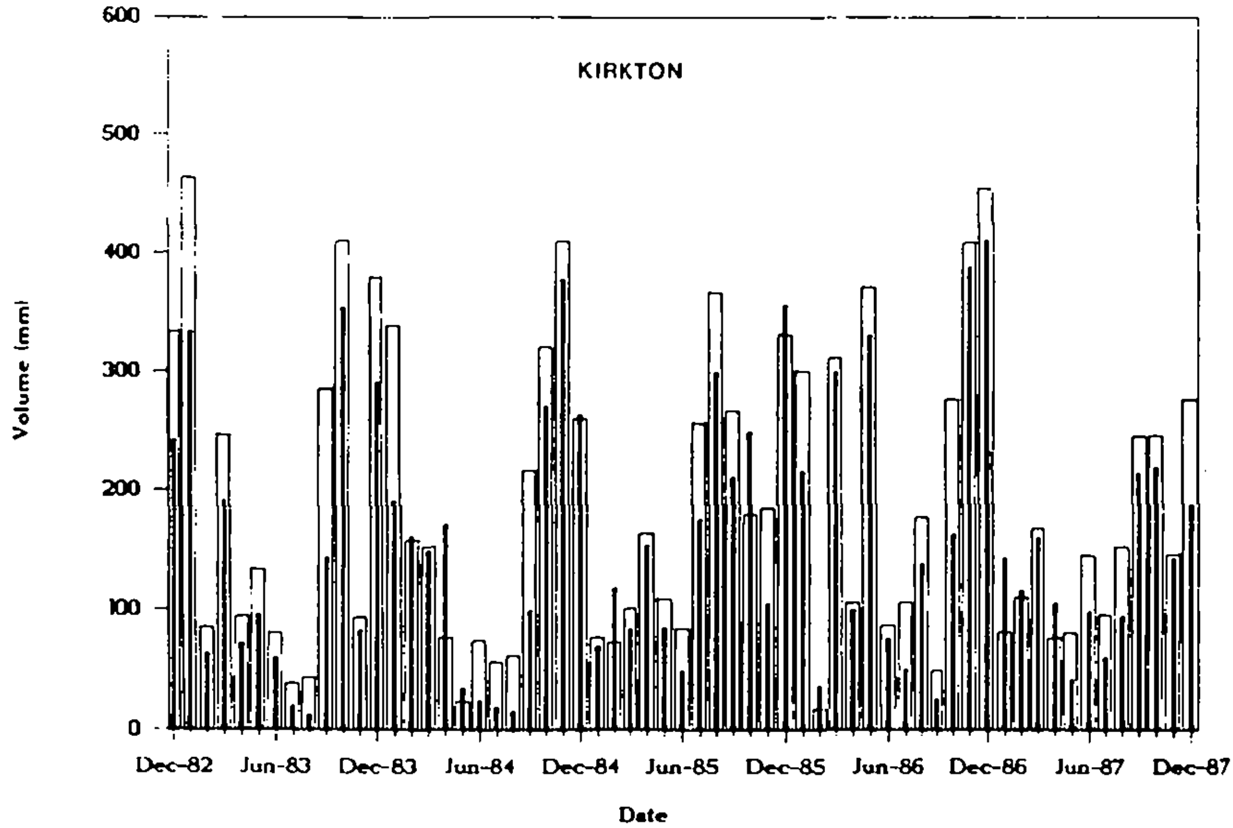


Figure 4 4 1 Monthly precipitation and streamflow

TABLE 4.4.1 Annual totals (mm) of Precipitation (P), Streamflow (Q), Estimated Water Use (P-Q) and Penman Potential Evaporation (ET))

	MONACHYLE (Heather/grass)				KIRKTON (Forest + Grass)			
Period	P	Q	P-Q	ET	P	Q	P-Q	ET
PHASE I, CONTROL PERIOD								
1983	2811	2028	783	540*	2368	1721	647	522
1984	2582	1929	653	634	2162	1781	381	635
1985	2520	2056	464	464	2208	1960	248	446
Means	2638	2004	634	546	2246	1821	425	534
PHASE II, LAND USE CHANGES								
1986	3147	2522	625	584	2684	2242	442	558
1987	2198	1724	474	492	1841	1592	249	492
Means	2673	2123	550	538	2263	1917	346	525

TABLE 4.4.2 Comparison of P, Q and P-Q for Periods when Upper Monachyle Flow Data were Available (mm)

	MONACHYLE			UPPER MONACHYLE			'LOWER' MONACHYLE		
Period	P	Q	P-Q	P	Q	P-Q	P	Q	P-Q
8/83-11/83	995	693	302	996	726	270	994	679	315
5/84-10/84	887	530	357	885	523	362	888	534	354
4/85-12/85	2225	1788	437	2237	1863	375	2221	1758	463
Means			365			335			377
4/86-12/86	2405	1850	555	1443	1815	628	2390	1865	525
1987	2198	1724	474	2236	1757	479	2183	1711	472
Means			515			553			499

5. Other studies

Future developments of the process and catchment studies are discussed in a paper circulated separately from this report.

In addition to these, IH is currently undertaking two additional studies based on the Balquhidder catchments. These do not form a part of the Consortium funded programme but are aspects of Science Vote funded research which could have been carried out elsewhere. Since the outcome could have relevance to the Balquhidder studies, the teams involved have agreed to use the catchments as a focus of their operations.

One such project is concerned with the development of remote sensing techniques. These techniques can improve knowledge of the geological structure of an area. Differences in the vegetation cover can be recognised by the differences in the reflectance characteristics. Thus heather can be distinguished from grass. However, the differences change through the growing season. Also the aspect of the land surface the vegetation is on affects the reflectances. The resolution of the remotely sensed data affects the results as the data represents the mean reflectance within an area. For the satellites SPOT and LANDSAT 5 this is 20 m and 30 m respectively. This means that the land cover classification works best when the differences in land cover occur in large, distinct, uniform blocks. Problems can occur when an area is a mixture of types but it is sometimes possible to assess the percentage occurrence of the component types. Remotely sensed data will be used in the Balquhidder catchments to try and distinguish between areas with grass and heather covers. In addition, differences in the wooded areas can also be established as well as different agricultural land uses. The data available for this are a LADNSAT 5 TM image acquired on the 17 March 1985 and a SPOT XS image acquired on 17 April 1987.

A request has also been made that the catchments should be included in the NERC airborne campaign in 1988 using infrared photography. However, this has been accepted only on a reserve basis and so cannot be guaranteed.

The second project is concerned with the further development of the eddy correlation technique for obtaining direct measurements of evapotranspiration. The 'Hydra' instrument developed by the Institute of Hydrology has now been used experimentally in a number of locations internationally to sample evapotranspiration by a variety of vegetation types ranging from annual crops to Amazonian rain forest. A perceived limitation of its use is that it normally requires to be mounted over the vegetation on level terrain with a level upwind 'fetch' In seeking sites on which to explore its limits in terms of sloping terrain the high altitude grassland slopes of the Kirkton catchment were suggested. This site has the advantage that results can be compared with the grassland study results and the catchment data.

An experimental rig has now been installed on the upper eastern slopes of the Kirkton catchment and will be operated through summer 1988. If the results show promise a more intensive exercise may be mounted in 1989.

6 References

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