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# DEVELOPMENT OF IMPROVED METHODS OF SNOWMELT FORECASTING

**Annual Progress Report to The Scottish Office for the period November 1995 to October 1996**

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## 1. Introduction

This is the second progress report of The Scottish Office project "Development of improved methods of snowmelt forecasting", begun in March 1995 and employing data from IH's experimental catchments in Balquhidder, Scotland. The Balquhidder experimental catchments were established in 1981 to study the effects of forestry on water resources. Precipitation falling as snow is difficult to measure in the catchments and no explicit measurement of falling snow, as opposed to lying snow, had previously been undertaken. Under The Scottish Office Project the Institute of Hydrology installed a Double Fenced Intercomparison Reference (DFIR) gauge for this purpose. This method is regarded by WMO as a reference standard against which all other methods of measurement can be related. Section 4 presents the final results of the DFIR field trial and its performance against existing gauges, including consideration of wind turbulence effects.

The report begins with a review of other field monitoring activities and database management in support of the modelling work (Section 2). Initial results on modelling the Balquhidder catchment flows under snowmelt conditions are reported in Section 3. The report ends with a review of liaison activities related to the project.

## 2. Field monitoring and database management

A plan for snow surveys was developed, including occasional traverses up the Monachyle valley and more frequent point measurements in the vicinity of the Lower Monachyle AWS site and DFIR gauge. A total of 40 sampling points are involved in the snow traverse, at which depth and water equivalent would be determined. Data would be used to monitor the changing volume of snow stored in the catchment. Table 2.1 summarises the snow surveys carried out according to this plan during the winter of 1995/96.

River flow and automatic weather station (AWS) data have now been transferred to the modelling database at Wallingford through to June 1996. Table 2.2 provides a summary of these data holdings. Lack of snow water equivalent data from snow cores in data transferred to Wallingford prompted a review of the field notebooks used to log these data. This brought to light data for the snowy period January/February 1984 for which regular daily snow depth measurements were taken at Tulloch Farm, together with about 10 water equivalent measurements. Corresponding hourly weather station data for 1984 were obtained, as indicated in Table 2.2. These data have been used in a preliminary model study reported in the next section.

**Table 2.1 Snow survey visits carried out during the 1995/96 winter**

| Date | Snow depth<br>mm | Snow density<br>g cm⁻³ | Snow water equivalent<br>mm | Snow line<br>m |
|---|---|---|---|---|
| 13 December 1995 | 0 | 0 | 0 | 1000 |
| 22 December 1995 | 69 | 0.15 | 10.35 | - |
| 29 December 1995 | 110 | 0.15 | 16.5 | - |
| 4 January 1996 | 50 | 0.4 | 20 | 400 |
| 11 January 1996 | 10 | 0.4 | 4 | 600 |
| 18 January 1996 | 0 | 0 | 0 | 1000 |
| 21 January 1996 | 0 | 0 | 0 | 1000 |
| 24 January 1996 | 0 | 0 | 0 | 500 |
| 26 January 1996 | 45 | 0.04 | 1.8 | - |
| 27 January 1996 | 40 | 0.15 | 6 | - |
| 29 January 1996 | 70 | 0.16 | 11.2 | 200 |
| 31 January 1996 | 52.6 | 0.16 | 8.4 | 200 |
| 6 February 1996 | 351 | 0.11 | 39 | - |
| 7 February 1996 | 300 | 0.13 | 39 | - |
| 10 February 1996 | 314 | 0.22 | 69 | - |
| 14 February 1996 | 192 | 0.3 | 57.6 | 100 |
| 13 March 1996 | 150 | 0.12 | 18 | - |

**Table 2.2 Summary of Balquhidder data transferred to Wallingford**

| Data type | Station name | Period |
|---|---|---|
| AWS (hourly) | Tulloch Farm† | January 1990 - May 1994 |
| | Auchleskine (moved from above) | May 1994 - June 1996 |
| | Kirkton High‡ | January 1990 - June 1996 |
| | Lower Kirkton | January 1990 - June 1996 |
| | Lower Monachyle | January 1990 - June 1996 |
| | Upper Monachyle† | January 1990 - June 1996 |
| River flow - hourly | Kirkton Weir | January 1983 - Dec 1989 |
| - 15 minute | | January 1990 - June 1996 |
| - hourly | Lower Monachyle | January 1983 - Dec 1989 |
| - 15 minute | | January 1990 - June 1996 |
| - hourly | Upper Monachyle | January 1987 - Dec 1989 |
| - 15 minute | | January 1990 - June 1996 |

† Also 1984 to complement Jan-Feb 1984 snow survey data

## 3. Snowmelt modelling

The First Report reviewed progress on transferring historical data for Balquhidder into the modelling database at IH but work had not progressed to modelling *per se*. A review of these historical data revealed that there was a lack of consecutive daily snow core samples, measuring snow depth and water equivalent, needed to support snowmelt modelling. An important exception was the snowy period from 9 January to 28 February 1984 for which suitable records are available. Ten observations of water equivalent were made between 15 January and 5 February. Preliminary model results have been obtained for this event and are reported on below.

The NRA R&D Note 402 "Development of improved methods of snowmelt forecasting" provides details of the model used in this initial investigation. The model is based on the PDM (Probability Distributed Model) catchment model for transforming rainfall (and any drainage melt from the snowpack) and evaporation to catchment runoff. This is coupled to the PACK snowmelt model which represents the processes of melt together with melt storage and drainage, and the effects of partial snow cover. Results reported here relate to the simplest form of model which uses a simple temperature index control on melt and with no subdivision of the catchment into elevation zones.

The PDM catchment model has been first calibrated and validated using hourly rainfall and flow data for a snow-free period . An excellent calibration fit, accounting for 93% of the flow variation ($R^2$=.93), was obtained for the period 5 November to 1 December 1984. Using the resulting calibrated model over the period 1 to 31 December 1984, without recalibration, as an independent validation test resulted in 92% of the flow variation being accounted for by the model simulated flows. The snowmelt model was then calibrated to the daily snow water equivalent values obtained by snow coring at the snow survey location (Tulloch Farm), giving an $R^2$ value of 0.91. The fitting procedure followed that described in R&D Note 402, where the modelled snowpack was corrected to agree with the measured water equivalent values during accumulation periods and assessed without correction only during melt periods free of snowfall. As a consequence few values are included in forming the $R^2$ assessment. Results are displayed graphically in Figure 3.1.

The combined model used to predict catchment flows gauged at the Lower Monachyle gave an $R^2$ of 0.36. However, with further calibration this was increased to give a good $R^2$ value of 0.73. To put this result in perspective, if the catchment rainfall-runoff model alone is used with no consideration of the presence of snow an $R^2$ as low as 0.46 is obtained. The corresponding simulated hydrographs, obtained without and with the effect of snow taken into account, are shown in Figure 3.2. It should be highlighted that these are very preliminary first results and, for example, the spurious modelled flow peak on 27 January 1984 needs further investigation.

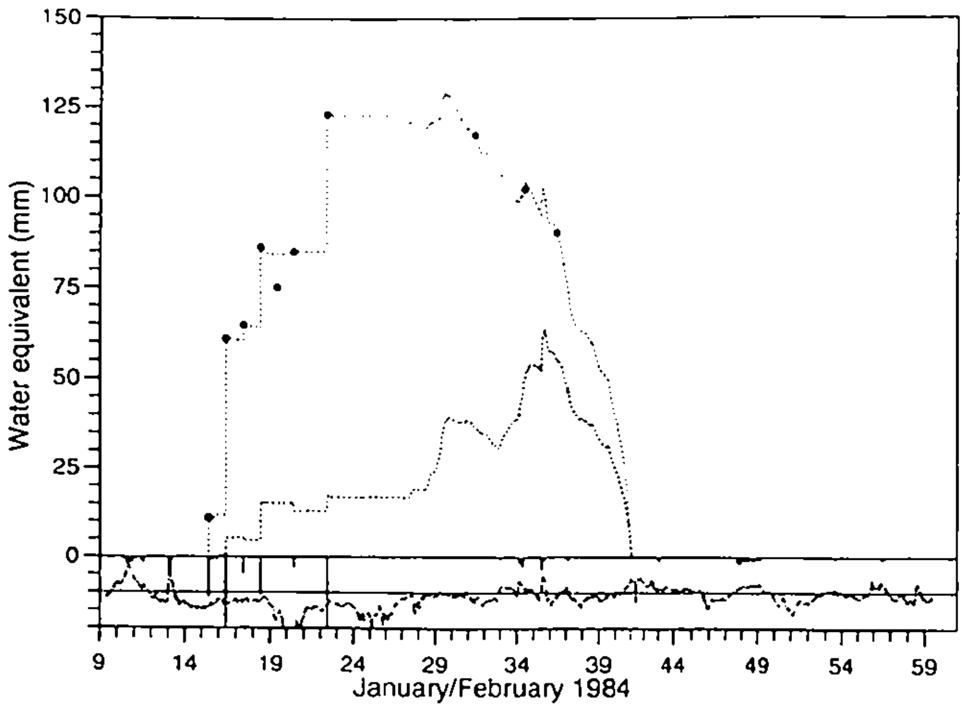



**Figure 3.1** **Preliminary model simulations of snow water equivalent at Tulloch Farm, 9 January to 28 February 1984. The total and melt component of the pack are shown along with the snow survey measurements (large dots). The negative axis shows rainfall/inferred-snowfall and temperature fluctuations (about a zero line at -10) on a proportional scale.**

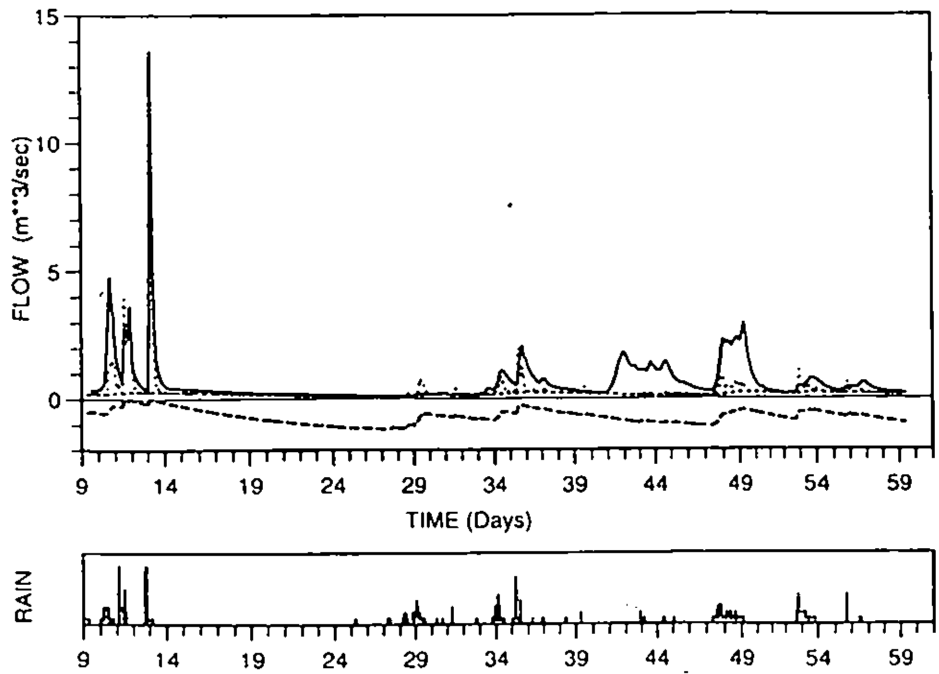
## 4. Field trial of the WMO Double Fenced Intercomparison Reference snow gauge

### 4.1 Introduction

The Balquhidder experimental catchments were established in 1981 to study the effects of upland afforestation on water resources in Highland Scotland. The nature of the Balquhidder catchments is significantly different to other UK experimental catchments, such as Plynlimon, in that they have a more rugged relief and coarser vegetation and experience a high proportion of annual precipitation falling as snow. Consequently the measurement of snow proves critically important.

Precipitation falling as snow is difficult to measure in the catchments. The large surface to weight ratio of snow makes snowfall vulnerable to wind turbulence. Standard raingauges with gauge rims above the ground surface are known to increase passing wind turbulence, further aggravating snowfall measurement. Also, raingauges used with the rims level to the ground surface, although reducing the effect of wind turbulence on the catch, are vulnerable to drifting snow.

(a) Snow ignored




(b) Snow accounted for

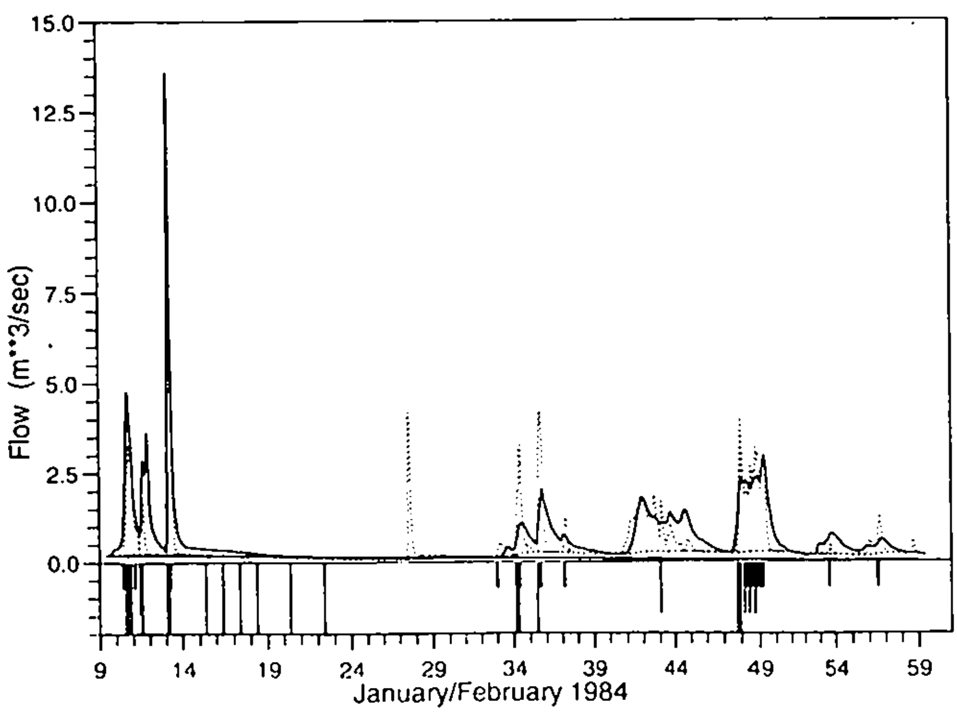



Figure 3.2 Preliminary model results obtained without and with the effect of snow taken into account. Observed flow: black line; Modelled total flow: dotted line; Modelled baseflow: grey dashed line; Modelled soil moisture deficit (negative dimensionless scale): dashed line; Rain/inferred snow (dimensionless scale): grey/black histograms.

The water balance study at Balquhidder has relied upon regular snow pack surveys to determine the inputs of snowfall. The difficulty of this method is the short-lived nature of many snowfall events in Britain, the unknown quantity of snow lost to melt and the redistribution of lying snow by wind. Consequently, the combination of snowpack surveys and storage gauges offers a potentially better solution.

In 1985 the WMO initiated an intercomparison of international methods of solid precipitation measurement (Goodison *et al*, 1989). The work noted that it was possible to incur significant differences in precipitation measurement arising from variations in measurement technique. The WMO intercomparison set out to determine a reference standard to which all measurement techniques could be related. The gauge decided upon, developed in Russia, was the Double Fence Intercomparison Reference (DFIR) comprising a Tretyakov gauge surrounded by two snow fences. After testing in numerous locations, specifications were set for the gauge design and siting. The results of the intercomparison over the period 1986 to 1993 at 11 stations in Canada, the USA, Russia, Germany, Finland, Romania and Coatia are reported in Yang et al (1995).

During the winter of 1995/96 a field trial of the DFIR in the Balquhidder catchment was carried out to test its performance against existing raingauges. The installation of the gauge and final results of the trial are reported below.

## 4.2 WMO Double Fenced Intercomparison Reference (DFIR) Gauge

The DFIR gauge consists of a Tretyakov storage gauge, mounted on a 3 metre high vertical post, surrounded by two octagonal fences, 4 and 12 m in diameter, providing the wind shield (Figure 4.1). The design specification for the gauge requires 300 metres of surrounding level ground for its siting. This excludes many sites in Highland Scotland where snow inputs are significant. A site in the Monachyle glen at Balquhidder was chosen as the location for the

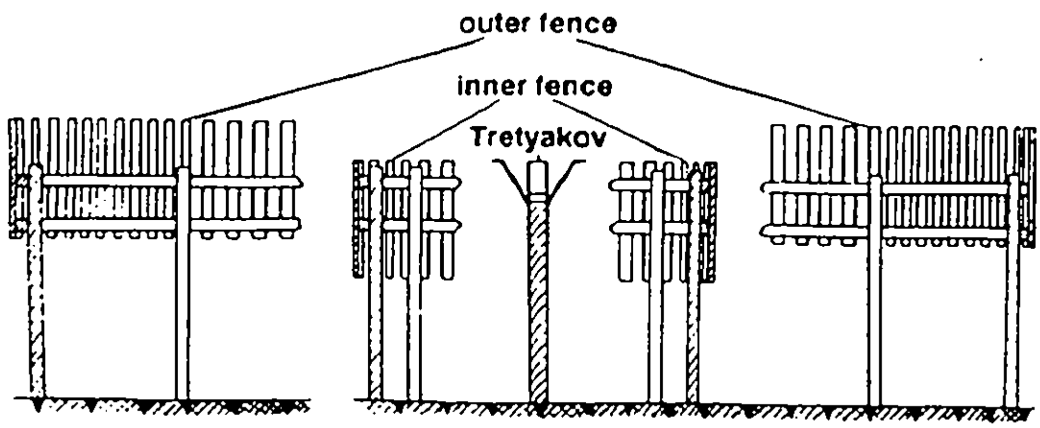



Figure 4.1 WMO Double Fenced Intercomparison Reference (DFIR) Gauge

gauge. To allow for easy access during the winter months, the gauge was sited on a river terrace in the glen bottom. This had the added benefit of being situated near to existing raingauges and an automatic weather station.

Installation of the gauge proved difficult. Lack of ease of installation is one cause that would inhibit its widespread use. Also, although additional bracing was added to the construction over and above that required by the specification, the gauge did not survive the winter. The design of the DFIR makes it susceptible to extreme conditions, such as those experienced in the Highlands of Scotland. Even when managed under experimental catchment conditions, as is the case with Balquhidder, the gauge proved impractical to maintain.

### 4.3 Performance of the DFIR

Although the DFIR gauge did not survive the entire 1995/96 winter, it did experience some heavy snowfall periods which allowed for comparison with existing gauges, with wind speed data from a weather station being available to support the interpretation of results. The DFIR gauge performance was judged against the catch of the existing Meteorological Office Mk II gauge. This gauge had previously provided the standard method for precipitation measurement in the catchments (Johnson, 1989).

The DFIR gauge was measured at the same time as the Meteorological Office Mk II gauge on frequent visits to the catchment. Figure 4.2 shows the relationship between the two gauges when displayed as a scatter plot. Whilst a good relationship exists between the two gauge measurements, the Mk. II gauge consistently records the greater amount. A regression analysis, with the line constrained to pass through the origin, yielded a slope of 0.72 and a squared correlation coefficient of 0.95. Thus factoring Mk II gauge values by .72 provides

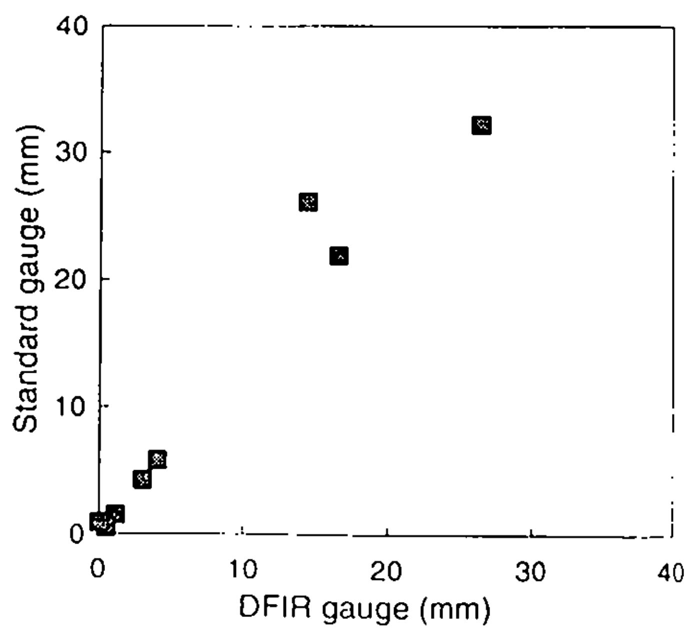



Figure 4.2 Comparison of DFIR and Met Office Mk II gauge measurements of precipitation

good agreement with the DFIR gauge values. The higher catch from the Mk II gauge might imply that it is more susceptible to drifting snow at ground level. This was certainly evident in one of the comparisons, when the Mk II gauge measured 0.9mm while the DFIR gauge for the same period failed to measure any precipitation. This highlights the advantage of the DFIR collector being 3 metres above ground level.

A major design feature of the DFIR is reduction of the effect of wind on the catch through the use of two wind shields. To assess its effectiveness, the ratio of measurements from the two types of gauge was plotted with respect to wind speed and the result is shown in Figure 4.3. No clear relationship is evident from the limited data set covering only a restricted range of wind speeds.

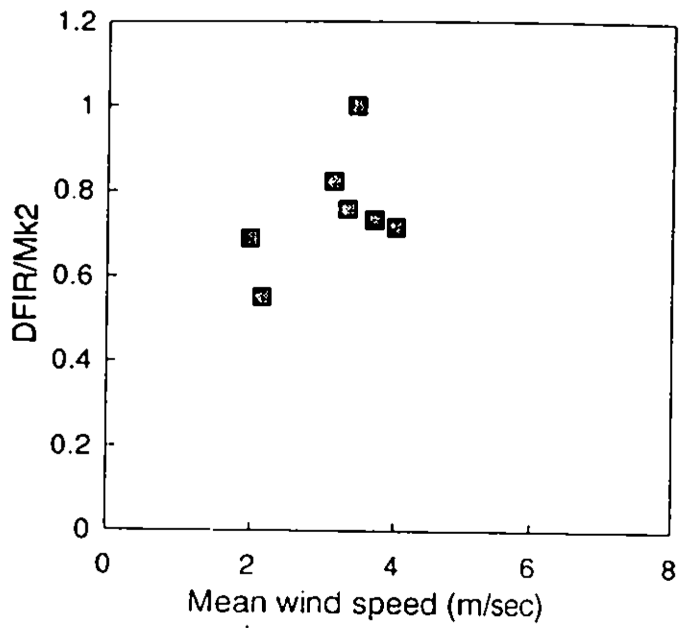



**Figure 4.3 Wind speed dependence of the ratio of DFIR to Met Office Mk II gauge measurements of precipitation**

## 4.4 Conclusion

The field trial of the DFIR snow gauge in Balquhidder aimed to assess the effectiveness of this WMO standard snow precipitation gauge for use in Highland Scotland. The trial reached the following conclusions:

(i) the installation of the DFIR is not practical for snow precipitation measurement in the Highlands of Scotland and is susceptible to extreme conditions;

(ii) the DFIR catch was on average 0.72 of the Met Office Mk II gauge catch, possibly implying that the design of the gauge, being 3m above ground level, is effective in reducing the effect of drifting snow on gauge catch; and

(iii) the limited data collected over the trial period was insufficient to establish a clear relationship between wind speed and standard gauge catch, using the DFIR gauge as a reference.

Overall, the field trial of the DFIR showed initial signs of the effectiveness of the gauge but highlighted the impracticality of its design for the measurement of snow in the Scottish Highlands.

## 5. Liaison

A Project Review Meeting, bringing together Stirling and Wallingford staff involved in the project, was convened at the IH Stirling Office on 12 January 1996 following a field visit to Balquhidder the previous day. The minutes of this meeting was passed to The Scottish Office for information. In particular, this meeting highlighted the difficulty of sustaining a snow survey programme of adequate frequency in the Balquhidder catchments, given available resources. Automated measurement of the water equivalent of lying snow, using a weighing snow board based on load cell technology, was proposed. Unfortunately, The Scottish Office were unable to make budgetary provision for a trial of this idea.

IH Scotland continued their external liaison activities under the newly formed Scottish Snow Group. A second meeting of the Group was convened in December 1996 and a newsletter called "Snow" was started together with the collation of a "Snow Inventory for Scotland". The latter would provide sources from where further information might be sought. A third meeting of the Group is planned for 11 December 1996.

On 26 September 1996 an Environment Agency sponsored seminar on "Improved Methods of Snowmelt Forecasting" was held at IH to assist in the dissemination of the results reported in NRA R&D Note 402. This was attended by The Scottish Office and two SEPA representatives. In the afternoon a joint NRA/Scottish Office Project meeting was convened to discuss progress to date under the new contracts.

## References

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