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Areal precipitation for flood forecasting

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REPORT NO. 8/98 KLIMA

DNMI-REPORT

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ISBN 0805-9918

REPORT NO.

8/98 KLIMA

DATE:

30.01.98

TITLE:

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PROJECT CONTRACTORS:

Norwegian Water Resources and Energy Administration (NVE) (CONTRACT NO: AFoU 03/97-1, PROJECT NO: 3600/1001)
Norwegian Meteorological Institute (DNMI)

SUMMARY:

This report describes the results of a small study on the effect of the density of the station network on estimation of areal precipitation. Different methods were used to estimate areal precipitation for three selected catchments, applying observations from synoptic weather stations as well as observations from the entire network including both synoptic weather stations and precipitation stations.

In the selected situations with high precipitation, the effect using an optimal station network was small. For small and medium size catchments, a denser station network may give better estimates of areal estimation. In large catchments there are small differences in estimates using different station networks. However, a denser network may give valuable information about the precipitation patterns locally within the catchment.

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CONTENTS.

1. INTRODUCTION.

Climatological information like temperature and precipitation are key elements in the hydrological models used for river monitoring and flood forecasting. The hydrological model used for these purposes in Norway is the HBV-model, a conceptual water balance model attempting to describe the conditions in a catchment. The model is a lumped model, describing the whole catchment as one block. There can however be separate models for subcatchments within a large catchment.

In the day to day operation of the models, the Norwegian Water Resources and Energy Administration (NVE) have access to the observations from the *synoptic weather stations* for updating the state of the catchments. This station network is sparse, and will not be representative for the catchment in most cases. In addition to the synoptic weather stations, the Norwegian Meteorological Institute (DNMI) has a denser network of *precipitation stations.* These stations report their readings once a week, so there can be a delay of up to 9-10 days until these data are available in the climatological database at DNMI.

The objective of this investigation is to evaluate the improvement in estimation of areal precipitation applying all possible information, including data for the precipitation stations. The idea is that in a critical situation the precipitation stations could be reporting in real time, as *synoptic precipitation stations.* The precipitation stations do however measure precipitation once a day, while the weather stations observe 2-4 times. Benefits obtained by more frequent readings are not considered in this study

2. DATA AND STUDY AREAS.

Three catchments are selected for this investigation. The information used are daily sums of precipitation in the period 1981-1996 for the stations in and surrounding the selected catchments. Table 1 lists the catchments used in this study. Figure 1 shows a map of the location of the catchments.

Table 1. Catchments analysed.

NVE-nr.	Catchment	River	Area (km^2)
002.142	Knappom	Flisa	1625
002.119	Elverum	Glomma	15426
055.004	Røykenes	Oselv	50

3. METHODS FOR ESTIMATION OF AREAL PRECIPITATION.

There is almost no subject discussed as much in the field of hydrometeorology as estimation of areal precipitation. There is a lot of works carried out in this field, and this report is not attempting to introduce new techniques.

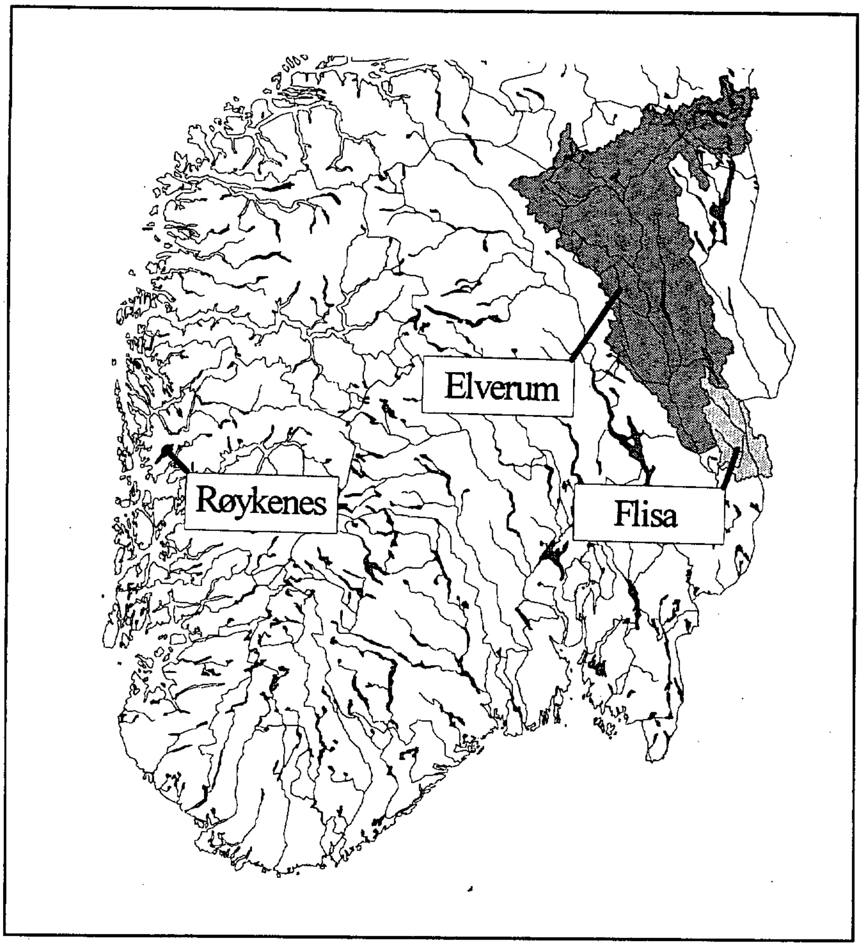

Figure 1: The cathments used for case studies.

The main question to be solved in the estimation of areal precipitation, is the representativity of the precipitation observations related to the catchment. In many cases the information of precipitation is limited to one single station close to the catchment, or if you are lucky, inside the catchment. In hilly terrain as in Norway, the representativity in altitude is also of importance, as most of the stations are located in the lower altitude levels of the catchments.

Different techniques for estimation of areal precipitation are used in this study. The most simple is to use the data from one single weather station, and assume this as representative for the total catchment. This is not a good method, and is a result of «what's available».

A slightly more sophisticated method is the «Thiessen polygons». This is a nearest neighbour technique. A polygon is created around each station having a measurement. The polygon is constructed so that the station within the polygon is the nearest for all possible points within the area. The areal precipitation for each polygon is set to the observed value for the station inside the polygon. For the catchment, the areal precipitation is calculated by estimating the weight of each Thiessen polygon based on the contribution to the catchment (Area of Thiessen polygons inside the catchment divided by the catchment area). This approach gives discrete representation of the precipitation field.

Application of linear interpolation gives a continuos representation of the precipitation. In this investigation, triangular surfaces between the observation stations are formed, and the slope of these gradients are used to estimate the precipitation values for each gridcell within the catchment.

The most advanced technique used in this study is kriging. This is a statistical approach utilising the spatial covariance in the observed precipitation. The method gives estimates for the gridcells within the catchment. Interpolation considering topography is not applied in this study.

4. PROCEDURE.

The dataseries were investigated finding the ten highest observed precipitation events at each station for a given number of days. These events are analysed individually to estimate its corresponding areal precipitation. In this report a few of these events, representing different types of precipitation events are shown.

In addition, information of the largest runoff volumes in the rainflood season, is used to find precipitation events causing high runoff.

5. RESULTS.

002.142 Knappom

Map of the study area defined for Knappom is shown in figure 2. Altogether, 24 stations were used in the analysis. In the HBV-model for this catchment, the weather station Flisa (WS06040) is used for estimation of areal precipitation. This station is situated just outside the catchment, not far from the runoff station Knappom. In addition, three precipitation stations are running within the catchment (P06440, P06490 and P06550).

In addition to this method, the Thiessen method (applying weather stations only as well as all stations), triangular surfaces and kriging were applied (the latter two can only be applied using all stations).

The events studied were selected from the ten highest values at the weather station at Flisa and the three precipitation stations within the catchment. Table 2 shows the results for three different episodes.

Table 2: Areal precipitation (mm) for 002.142 Knappom by different techniques.

Event no.	Date	V06040	Thiessen (WS)	Thiessen (All)	Triangular	Kriging
1	25.8.1996	61.8	65.9	58.7	59.4	59.6
2	22.6.1985	39.4	32.5	14.5	17.3	8.9
3	19-20.6.1991	49.5	49.3	57.3	56.0	56.2

WS = weather stations, All = all available stations

1.) 25.8.1996.

Map of this situation is shown in figure 3. This is the highest 1-day precipitation measured at WS06040 Flisa in the period 1957-96. The entire catchment got high precipitation amounts, and the difference in areal precipitation between the methods is not large.

2.) **22.6.1985.**

This is an event which shows another pattern (figure 4). It is only the southern parts of the area getting more than 10mm of precipitation. The highest values are observed at the weather station at Flisa (WS06040). This precipitation pattern results in large variation between the different methods. For this situation kriging performs badly, due to the scattered characteristics of the precipitation, high values at a few stations, and low values for the rest. When establishing the spatial structure function (variogram), the high values will be given little weight, and thereby suppressed in the following interpolation.

3.) **19-20.6.1991**

This is a 2-day event, which also resulted in flood discharge in the Flisa river. The event showed a quite uniform precipitation pattern throughout the area. The highest value was observed at station P06440, and the areal precipitation is higher using all stations compared to the information offered by the weather stations.

For some events, there are large differences between estimated areal precipitation applying all available stations and the estimate from weather stations only. These differences mainly occur in weather situations with convective precipitation (showers). An «accidental» hit at a station by a shower may give an overestimation of areal precipitation, if this event is not suppressed by measurements at other stations. However, in such situations, showers are likely to occur everywhere within the catchment, and may not be observed at any of the stations.

<u>002.119 Elverum.</u>

The Elverum catchment and the stations used in this analysis is shown in figure 5. This is a large catchment, 15426 km^2. Four synoptic stations are well within the catchment, and one is situated at the divide. Altogether 53 stations are used for this catchment, 23 of them are located within the catchment.

The single weather station approach for estimation of areal precipitation was not applied, instead the average precipitation from the four synoptic weather stations within the catchment is used as a reference value.

A few episodes are studied closer, and these are summarised in table 3.

Table 3: Selected precipitation events for 002.119 Elverum.

Event no.	Date	Aver. of WS	Thiessen (WS)	Thiessen (All)	Triangular	Kriging
1	1.8.89	60.8	55.8	54.2	54.5	54.1
2	12.9.84	14.3	15.8	13.3	13.6	13.4
3	28.5.-3.6.95 («Vesleofsen»)	66.7	64.2	66.7	66.7	66.7

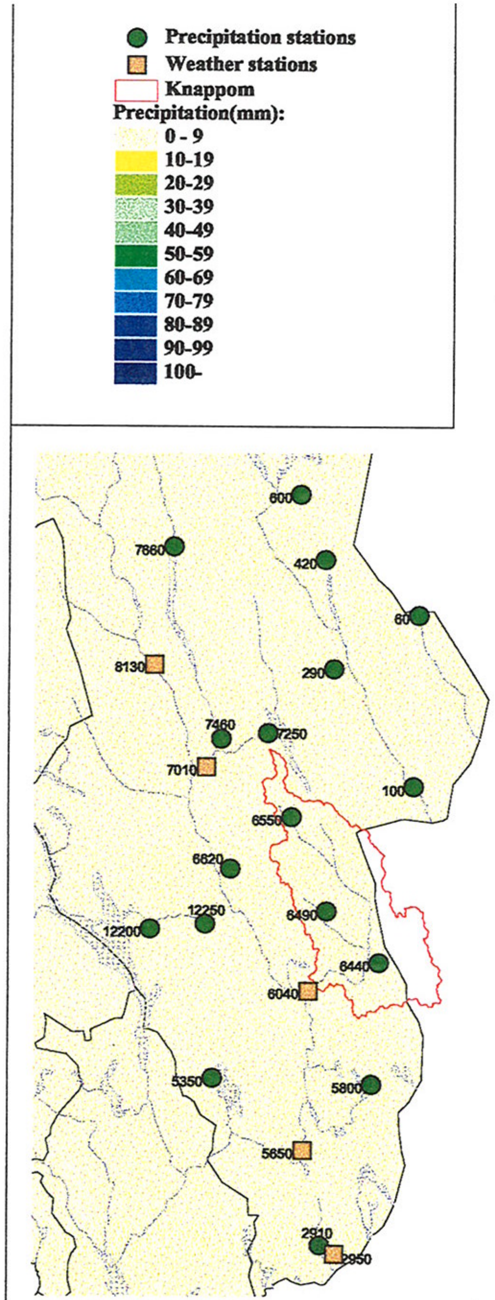

Figure 2: Stations used in the case study for the Knappom catchment.

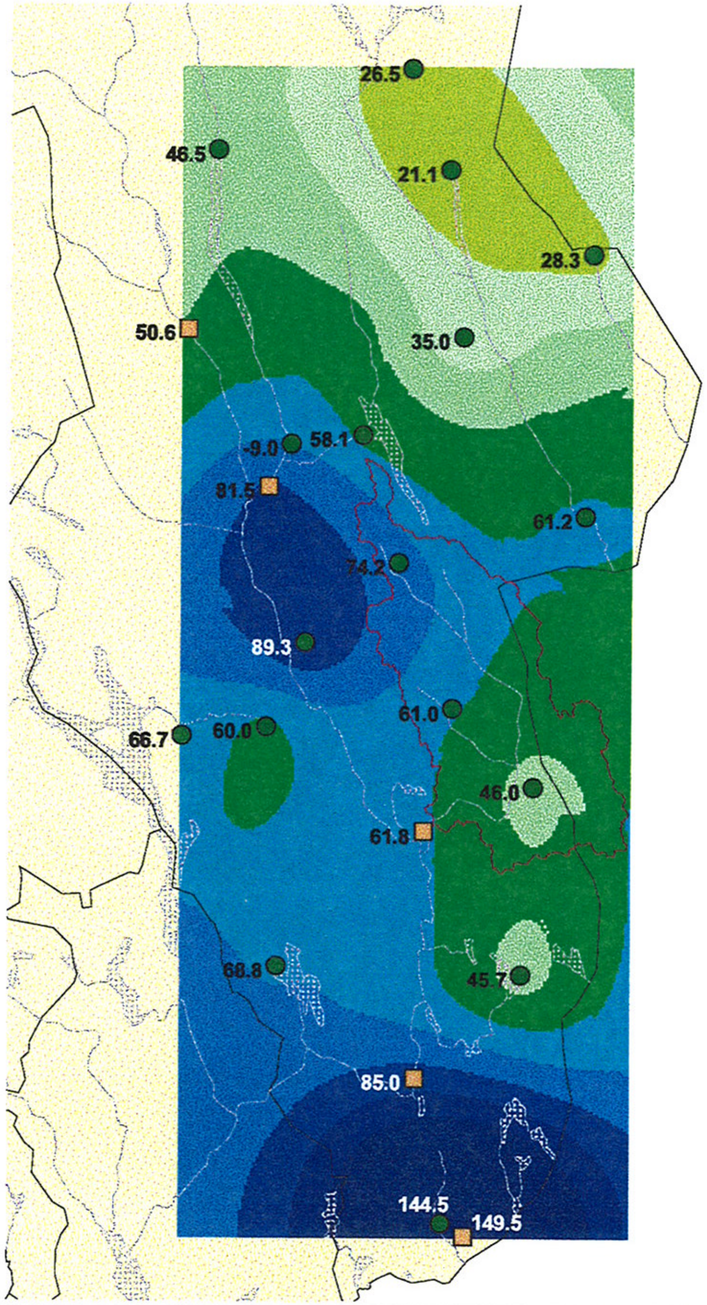

Figure 3: The distribution of 1-day precipitation 25.8.1996. The field is analysed by applying kriging.

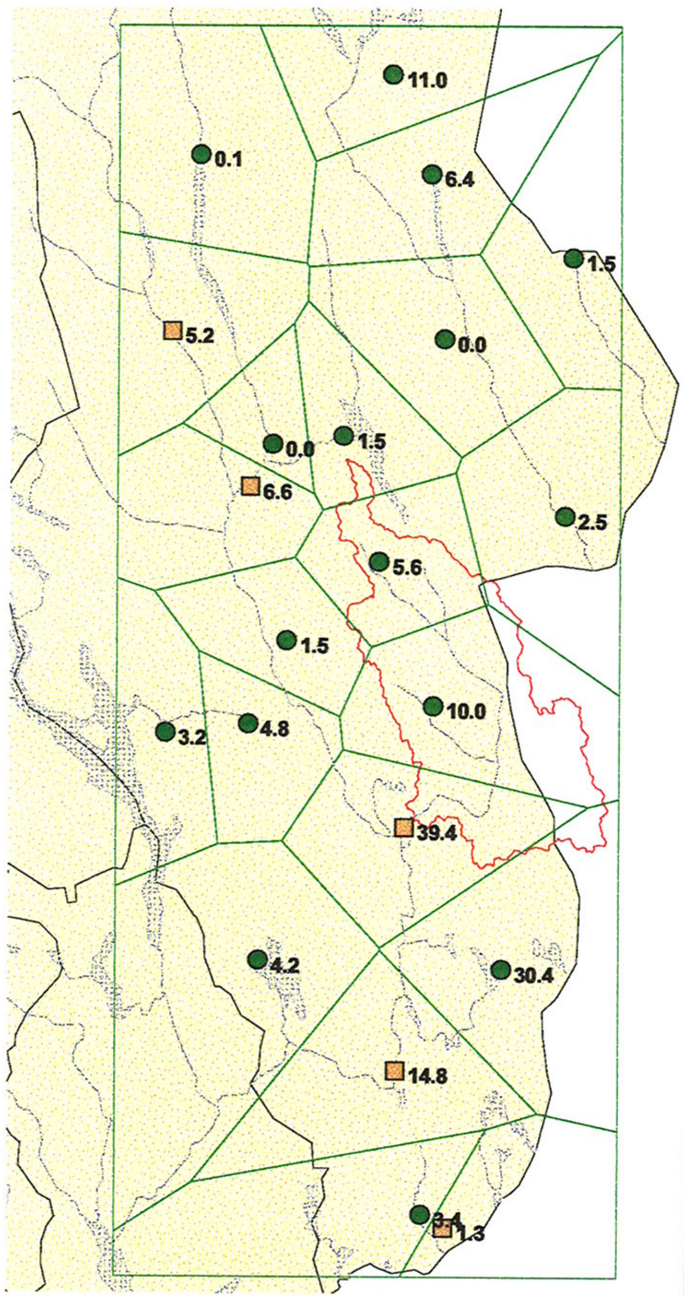

Figure 4: Distribution of the 1-day precipitation 22.6 1991. The map is showing the Thiessen polygons for this event.

1). **1.8.89**

A map of this situation is shown in figure 6, with the fields interpolated by kriging and the observed station values. This map shows one of the advantages using spatial interpolation techniques, giving an impression of the spatial variation of the event which can be important for subjective evaluation of the condition. However, the conditions are quite the same in the area, and a difference of 1.6 mm between the two Thiessen polygons approaches is negligible.

2). **12.9.84**

This event is included as an example of relatively strong precipitation in a part of the catchment. The precipitation distribution is shown in figure 7. The differences are negligible.

3.) **«Vesleofsen» (28.5-3.6.95)**

By curiosity, the precipitation sum for the week of the most severe floodings in this area is investigated. The precipitation fields as estimated using kriging is presented in figure 8. The estimate of areal precipitation would have been the same applying arithmetic mean for the four weather stations as by using more sophisticated spatial methods. This is of course a coincidence, but it shows some of the problems with areal precipitation estimates. The Thiessen estimate using the weather stations is 2.5 mm lower, i.e. a neglible difference. In this situation the whole catchment was exposed to relatively high amounts of precipitation. This itself was not the flood generating process. The flood was a result of snow melt, relatively high temperatures and the precipitation.

Since this is a large catchment, local variability will have less influence on the areal precipitation, and the representation of areal precipitation is not that sensible as for smaller catchments in areal precipitation estimations.

055.004 Røykenes

This is a small catchment, 50 km^2, situated south of Bergen in western Norway. Eight stations are selected for the analysis for this catchment, as shown in figure 9.

Kriging cannot be used for this catchment, since the number of stations is too low for estimating the variogram, which is the structure function used for estimating the interpolation weights. If only weather stations are used, the entire catchment is located inside the Thiessen polygon of WS50540 for most events.

The results for two different events are summarised in table 4.

Table 4. Estimated areal precipitation for 055.004 Røykenes for selected precipitation events.

Event no.	Date	WS 50540	Thiessen (WS)	Thiessen (All)	Triangular	Kriging
1	27.10.95	104.4	104.4	94.9	95.7	-
2	27.12.94	74.0	74.0	42.4	35.2	-

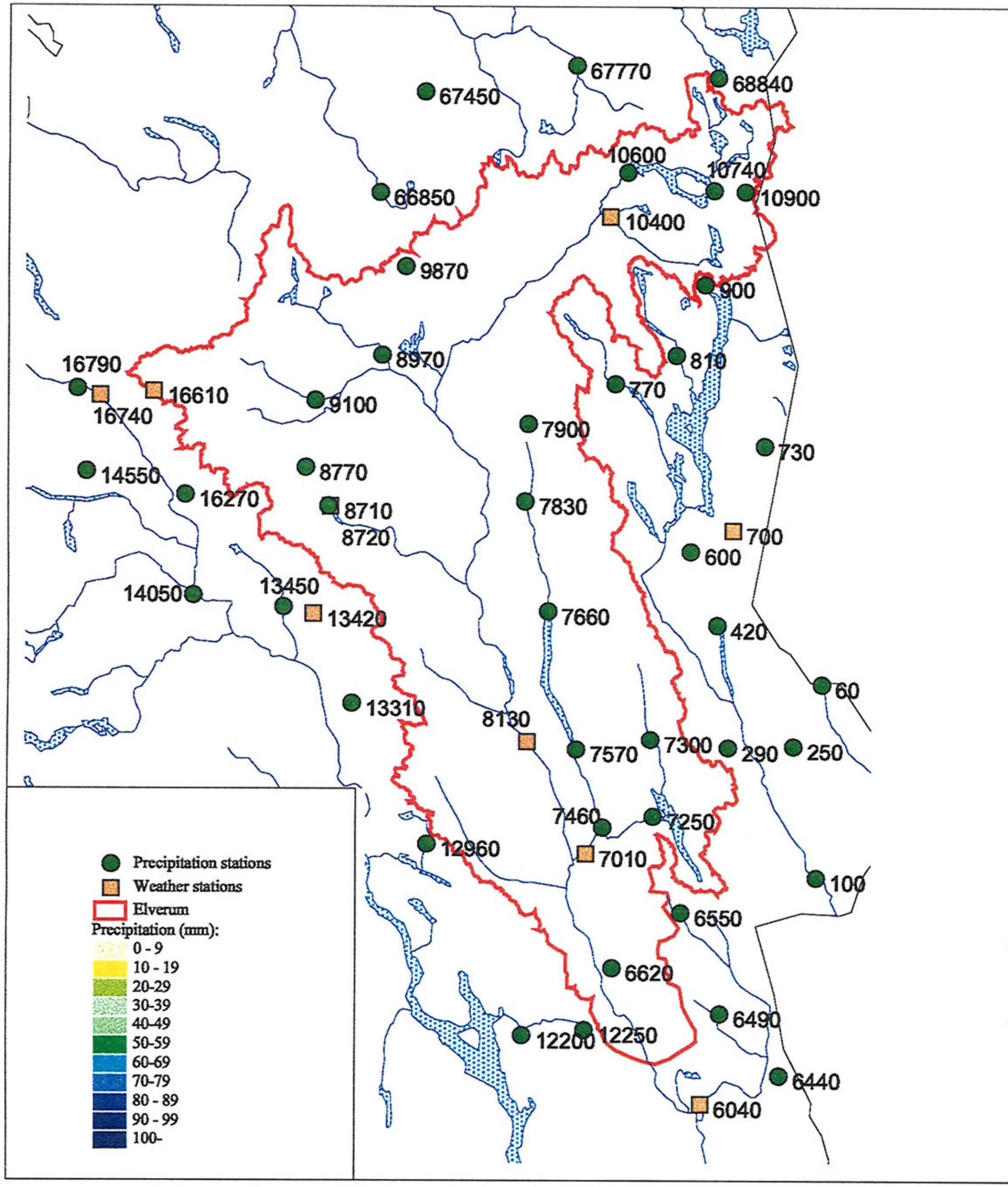

Figure 5: Stations used for estimation of areal precipitation for the Elverum catchment.

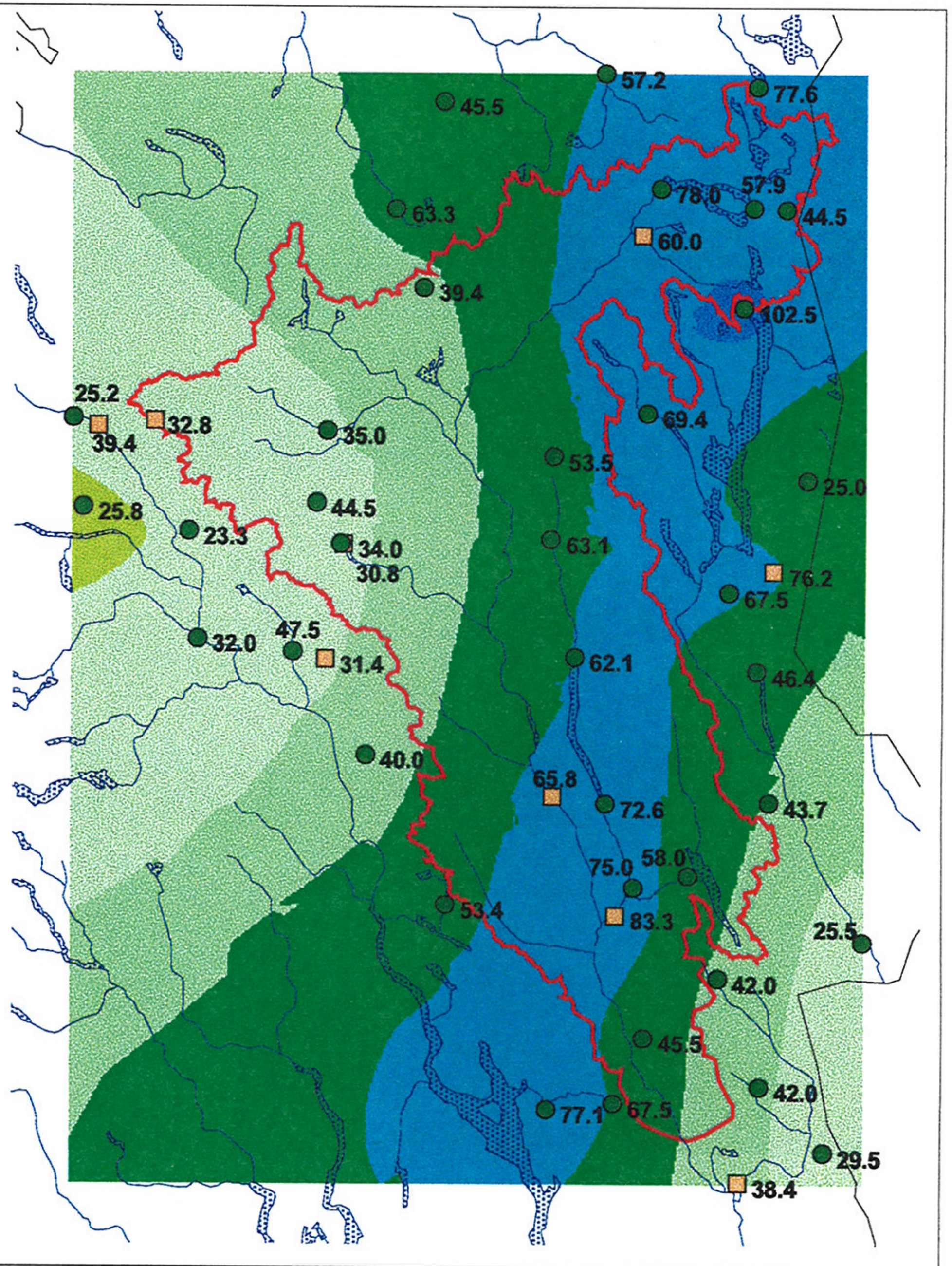

Figure 6: The distribution of 1-day precipitation 1.8.89. The analysed field is estimated by applying kriging.

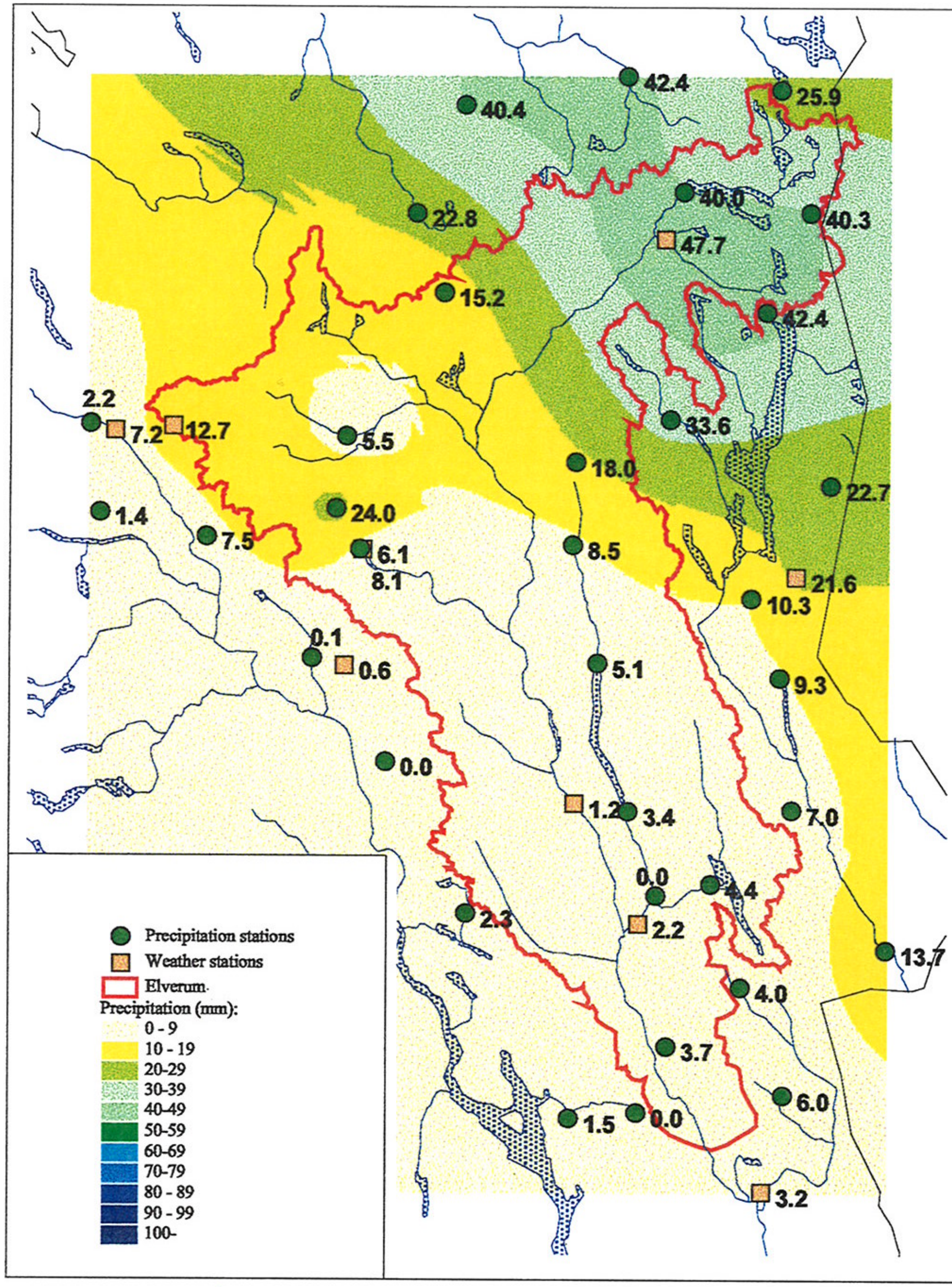

Figure 7: The distribution of 1-day precipitation 12.9.84. The analysed field is estimated by applying kriging.

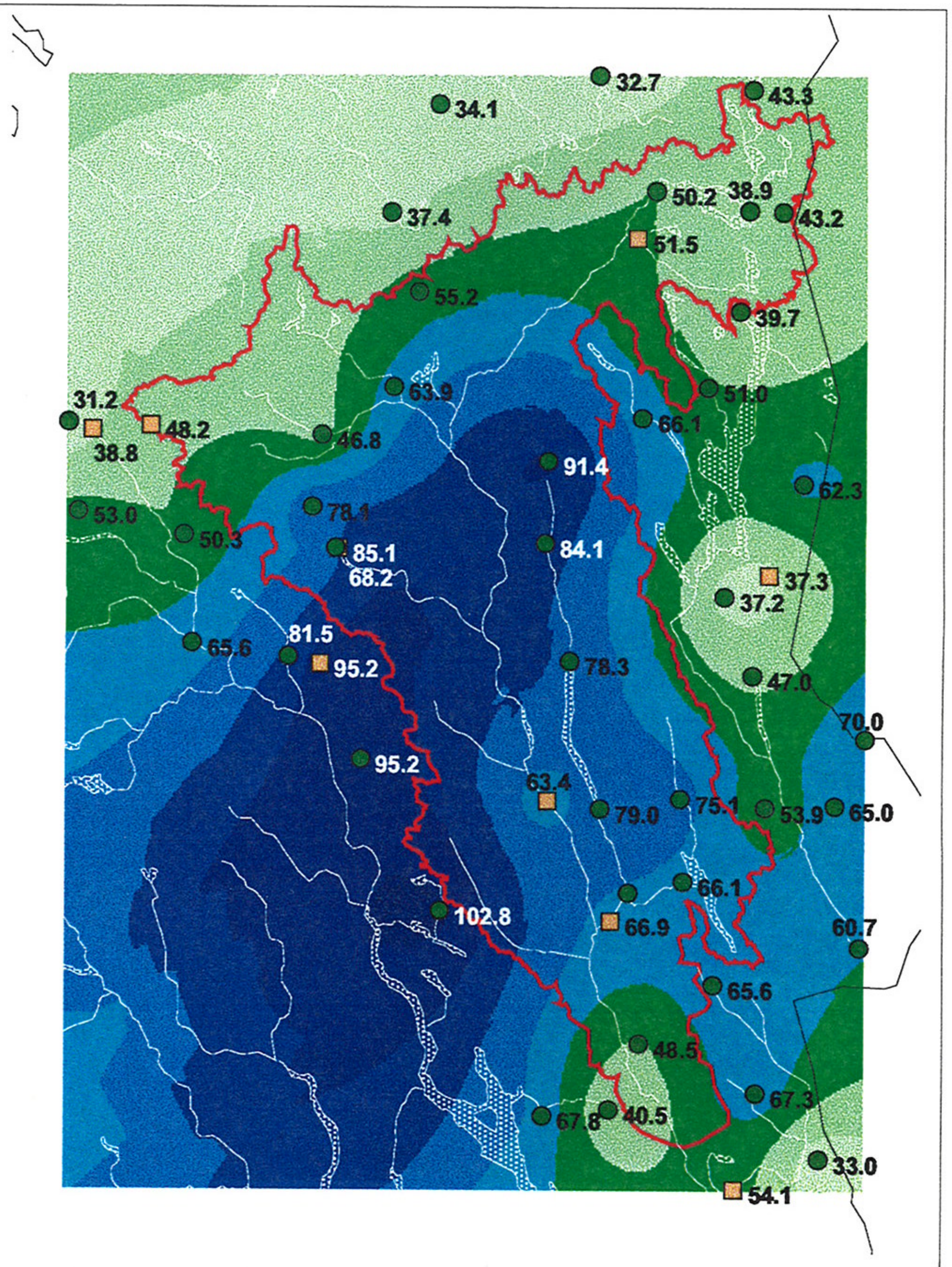

Figure 8: The distribution of 7-day precipitation 3.6.95. The analysed field is estimated by applying kriging.

These two events are quite different. In the first event (figure 10) the precipitation is increasing eastwards from the coast. There is also less precipitation in the south than in north.

The difference between the methods are small. The second event (figure 11) has one high precipitation measurement at WS50540, but the other stations have lower precipitation sums.

As a consequence, areal precipitation estimated from WS50540 is too high compared to the estimates using all available stations. This is especially the case in the second event, where WS50540 has considerably higher precipitation than the other stations.

6. DISCUSSION AND CONCLUSIONS.

This little study has been focused on the effect of the density of station network in estimating the areal precipitation. The synoptic weather station network as well as additional information from the denser precipitation station network have been utilised to evaluate the sensitivity in areal precipitation estimation due to extended spatial description of the precipitation events.

Different standard methods for estimating the areal precipitation have been applied:

- Thiessen polygons
- Linear interpolation
- Kriging

Three catchments have been selected for case studies. The events analysed are selected from daily precipitation sums in the period 1981-1997. Also events for 2-7 days have been studied. Attempts to study precipitation events connected to flood situations has been made, but there are no obvious connection between seasonal or annual maximum runoff (which was the information available) and corresponding precipitation events with large precipitation.

In the analysis, areal precipitation is estimated both using observations from the synoptic weather stations only, as well as the synoptic weather and precipitation stations. The differences in estimated areal precipitation from these two data can be considerable, depending upon the weather situation.

For small and medium size catchments, there can be an improvement in areal precipitation estimations applying the total station network. The catchment of 002.142 Knappom is one example, where the present use of one single precipitation station may give large errors. For large catchments, like 002.119 Elverum the effect of applying precipitation stations in addition to the synoptic weather stations is smaller. In such large areas, local anomalies in the precipitation patterns will be suppressed by the larger scale mean conditions in the other parts of the catchment. The local information made available by the extended station network can however be of interest for the hydrologists evaluating the conditions in different parts of the catchments.

The results depend on the configuration of the station network, a small catchment without weather stations in its neighbourhood will get better estimates applying all available stations, while in other cases, a weather station located inside the catchment is sufficient for giving the

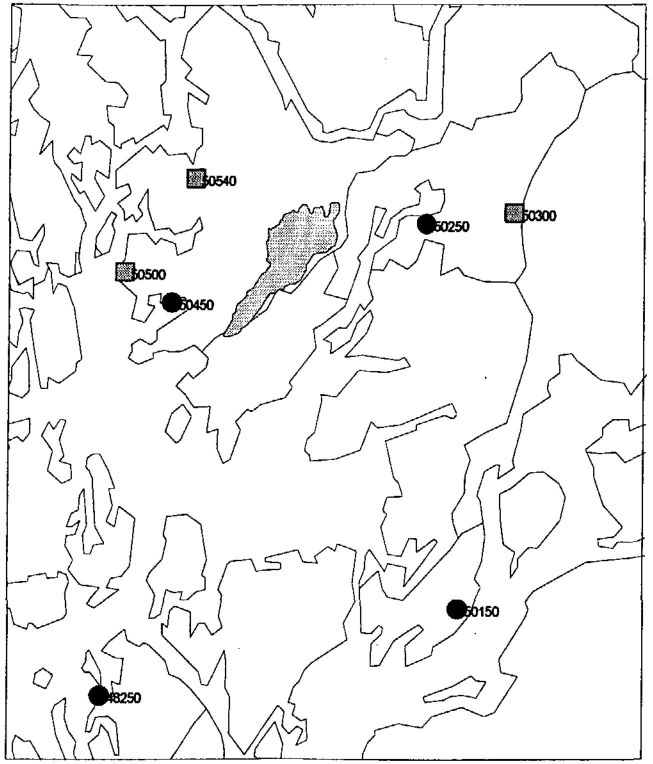

Figure 9: Stations for estimating areal precipitation for the Røykenes catchment.

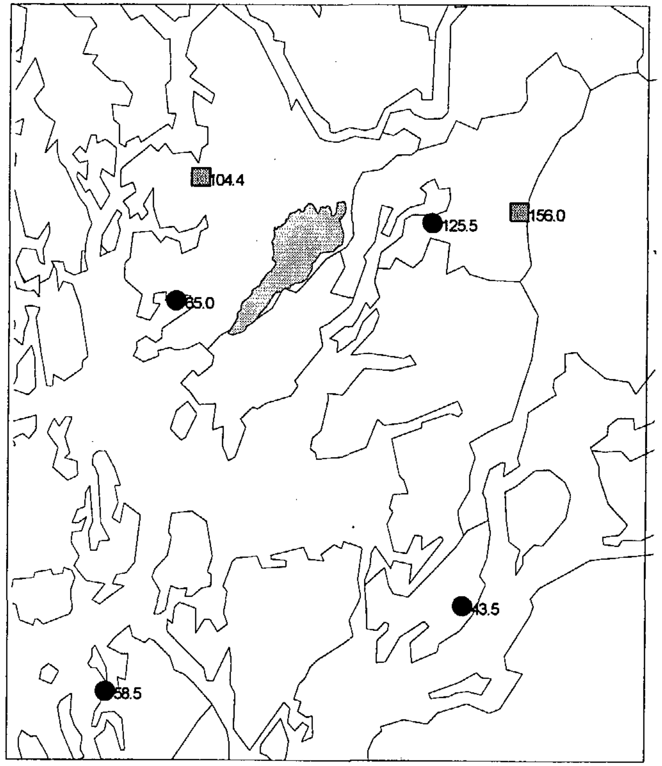

Figure 10: The distribution of the 1-day precipitation 27.10.95.

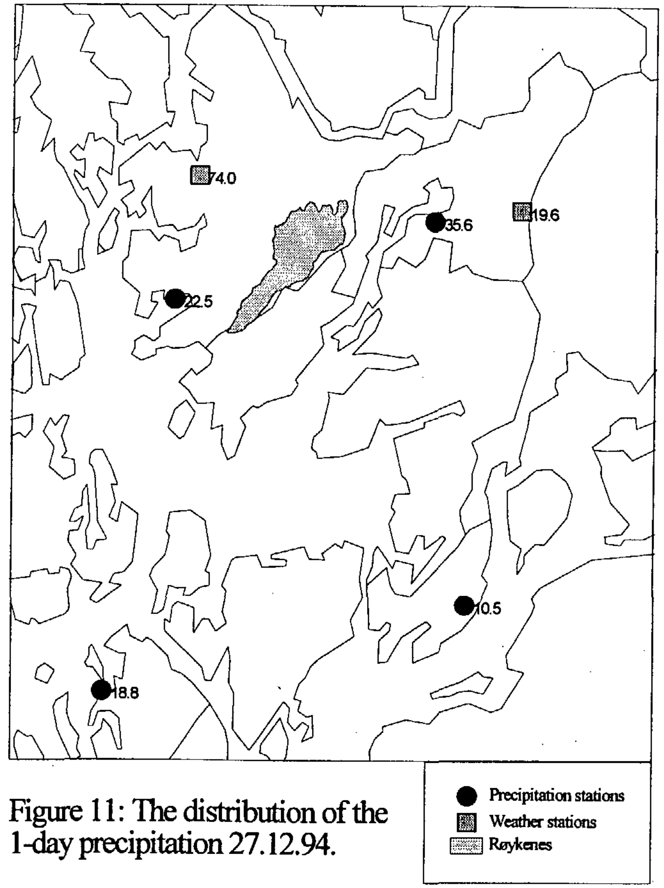

Figure 11: The distribution of the 1-day precipitation 27.12.94.

best estimate. A survey of the optimal network observing precipitation for each catchment of interest should be carried out.

The different methods for estimating areal precipitation showed small differences, and the traditional Thiessen polygons should be applied due to its simplicity.

Spatial variations due to topography is not considered in this study. There are variation in precipitation influenced by topographical effects which not are likely to be covered by the station network alone. Further studies should be carried out in order to establish spatial relations that covers also orographic effects.

For flood purposes, the intensity of precipitation may be an important factor. In the present observing program, with measurements in 6-24 hours intervals, such information is not easily accessible. However, information from the increasing network of real-time reporting automatic weather stations may improve the monitoring of precipitation in critical flood conditions.

ACKNOWLEDGEMENTS.

Thanks to Lars Evan Petterson, Thomas Skaugen and Hans Christian Udnæs at the Norwegian Water Resources and Energy Administration for providing information about floods, catchment boundaries and the use of climatic information in the flood forecasting.

The project is partly funded by the Norwegian Water Resources and Energy Administration (Contract no: AFoU 03/97-1, Project no: 3600/1001).