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"SNOWMAPPING IN SOUTHERN NORWAY BY USE OF LANDSAT IMAGERY"

By Johnny Skorve

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" Hydrological Investigations in Norway "
Principal Investigator:
Helge Ødegaard

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15. Abstract

The snowcover in four basins in southern Norway have been studied. By use of data from both 1975 and 1976, it has been possible to observe nearly one complete melting season with the use of Landsat imagery. The observations covers the period middle of May to the end of August. The four basins represent different climatological conditions, and subsequent runoff information is compared with the rate of decrease in areal extent of the snowcover in each basin.

Original photography may be purchased from:
EROS Data Center
Sioux Falls, SD

CONTENT

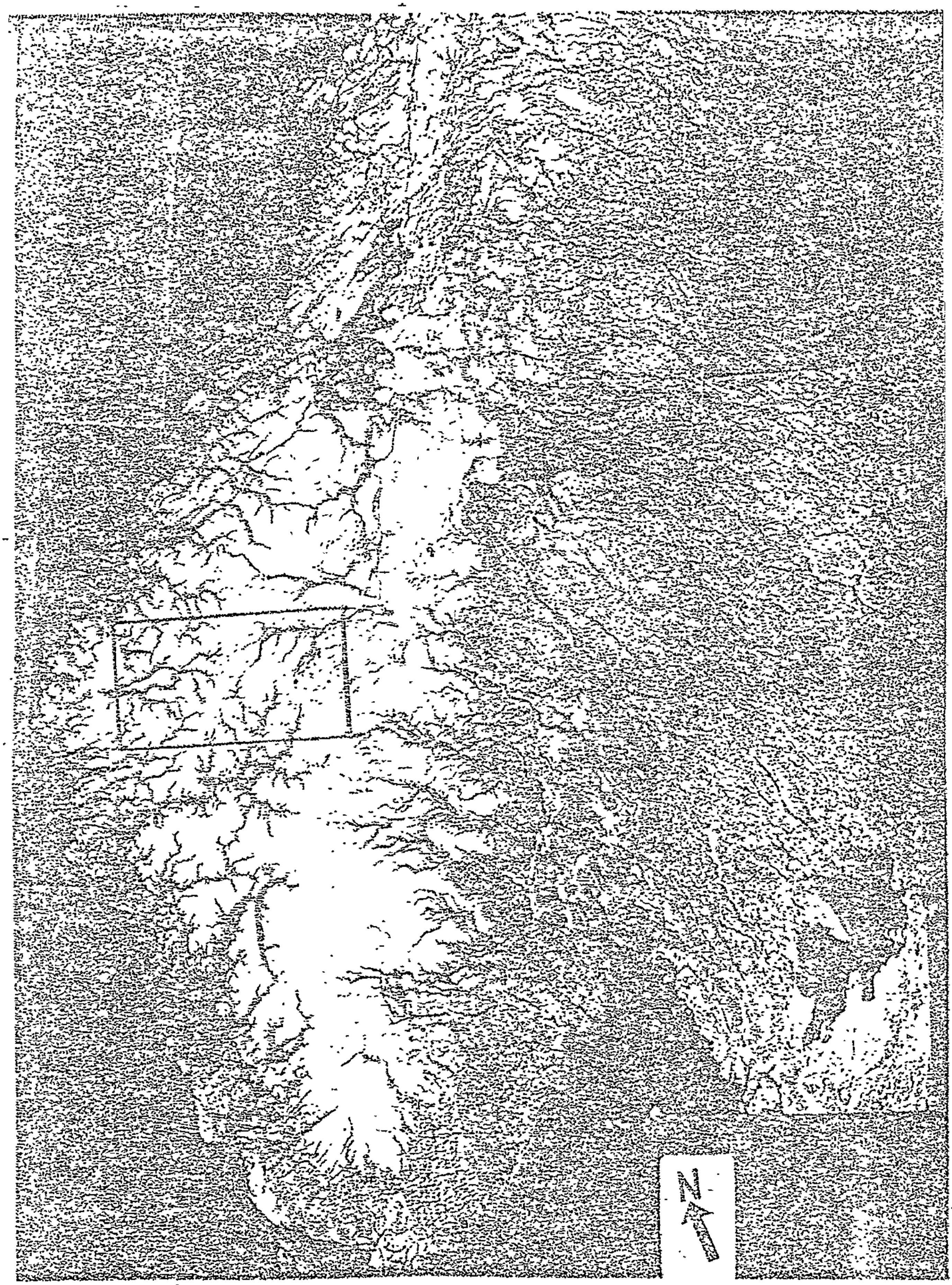

FIG. 1 THE STUDY AREA IS SITUATED WITHIN THE RECTANGLE DRAWN ON THIS UNCONTROLLED LANDSAT-IMAGERY MOSAIC OF NORWAY SOUTH OF THE ARCTIC CIRCLE. (MOSAIC BY JOHNNY SKORVE)

THE BASINS

The areal extent of the four basins in the study area are:

OLDEN	222 km.^{2}
BREIM	626 km.^{2}
JOSTEDAL	634 km.^{2}
BOEVRA	805 km.^{2}

The Boevra and Olden valleys have rivers that run northward, while those of Jostedal and Breim are heading respectively in southern and western direction. FIG. 2,3,4,5 and 6.

GENERAL DESCRIPTION

Four drainage basins in mountainous Norway were selected for a study in snowmapping by use of Landsat imagery. The basins are distributed along an east-west line and they represent different climatological conditions. In the eastern parts of the area the precipitation is only 10-20 percent of the amount in the most western parts. Not only does the climate differ from basin to basin, but also within each one of them, though they are rather small. This is due to the fact that within a relatively short distance, we find both Norways' wettest and driest parts.
All four basins in the study area have glaciers, which complicates the relation between runoff and snowmelt. The difference in climate within the area as a whole has consequences for the pattern of snowmelt.
Landsat imagery show clearly an obvious difference between east and west. In mountain areas SE of the study area, great changes in snowcover took place in the course of 18 days in July 1975, while the snowpattern in the western mountains was much more stable with smaller changes in areal extent. This slower change in snowmelt pattern, makes the area less sensitive to the effect of Landsats' infrequent image coverage because of the 18 days' observation cycle. This is however compensated to some extent by the fact due to the high latitude (61-62^{o}N.) there is some 60 % image overlap on two consequitive days.

Relatively few Landsat images were recorded in 1975 with no scenes later than July 28. This resulted in an incomplete picture of the snowmelting in the western mountain areas since there was still much snow left at the end of July. Fortunately Landsat images were also taken of the study area during the summer of 1976 with two cycles in August. Both 1975 and 1976 summers were sunny and warm and most of the Landsat scenes aquired during these periods were cloud free or nearly cloud free. Both preceeding winters produced considerable more than normal snowpack.

THE GEOGRAPHICAL AND CLIMATOLOGICAL SETTING

The area studied is situated 61.5°N and between 6 and 9°E and it runs nearly perpendicular across the elongated, NNE - SSW oriented Kjoelen mountain range.
The Boevra basin includes the highest mountains in Norway with the Jotunheimen peaks close to 2500m.a.s.l.(8100 feet).The three other basins are closer to the sea and all cover parts of Jostedalsbreen the largest glacier in Norway. The highest parts here are just above 2000 m.a.s.l.(6500feet).
The whole area is dominated by westerly winds resulting in temperate winters and summers. Even during the coldest part of the winter, the average temperature along the outermost part of the coast is above freezing. The precipitation is heavy and inland there are places that get more than 4000 millimeter(160 inches) a year. Going east, the precipitation diminishes rapidly and aprox. 200 kilometer further east the climate is continental with only 300 milli - meter(12 inches) of precipitation annually. FIG.7.

THE TIMBER LINE

In the east and central parts of southern Norway the climatic timber line altitude is between 1000 and 1200 m.a.s.l.(3300-4000 feet), while it is as low as 400 m.a.s.l.(1300 feet) in western coastal areas of southern Norway.

In connection with the use of Landsat for snowmapping, it is very important to recognise the importance of the timber line altitude in Norway. Nearly all of the important basins have most of their areas above the timberline. Therefore, snow in forest-covered areas is not a big problem for users of Landsat data in Norway. This fact makes Landsat imagery more suitable for snowmapping in Norway than for countries at lower latitudes where the timber line is considerably higher than in Norway.

GROUND-BASED DATA ON SNOWCOVER

To get a better understanding of the snow situation, ground based information was used. Data of this type are available on a special snow accumulation maps that the Norwegian Meteorological Institute is issuing on a regular basis.

Snow accumulation is calculated for three levels, 400, 800 and 1200 m.a.s.l.(1300, 2600 and 4000 feet). The isolines on the maps show the per cent of normal snowpack. The last set of maps of a season show the situation at the end of April which is close to the date when snow melting normally starts (FIG. 8, 9, 10 and 11)

Snow data from a few weather stations have also been used. Both winter seasons of 1975 and 1976 have been characterized by heavy snow accumulation in mountain areas in SW Norway. In 1976, parts of the study area got more than double the normal snowpack.

RUNOFF DATA

The runoff data used in this study have been obtained from Limnographic measurements near or at the base of the four basins. The Norwegian Water Resources and Electricity Board provided most of these data, the rest were made available by the Geographical Institute, University of Oslo.
For calculation of the subsequent runoff, a starting point had to be chosen. The date when the runoff rises above the winter level, due to start of snow melting was chosen for this purpose as starting point. The runoff data for 1976 were not available before termination of this study.
The spring increase of runoff due to the start of snowmelting in the four basins was as follows:

BREIM on April 21. 1975
JOSTEDAL on April 24. 1975
BOEVRA on May 6. 1975
OLDEN on May 7. 1975

Subsequent runoff of a basin is calculated as cumulated pentadesums of runoff in $10^6 m^3$ from the dates mentioned above.
Meteorological information for correlation with runoff and snowcover measurements, was selected from one station in the Jostedal basin. The station is situated quite near the geographical center of the four basins used in the study.

Measurements in the Jostedal basin show that during the period 1950-1975 the average annual runoff is $871 \cdot 10^6 m^3$. 90 percent of the annual runoff occurs from May to September. Data show that in this basin the subsequent runoff in 1975 between April 24. and August 1. was $910 \cdot 10^6 m^3$. This shows that the runoff this year was well above average. The same situation was also found in the three other basins. FIG. 19.

Though the complete sets of runoff data for 1976 are not yet available, it is clear that the runoff in 1976 was also well above average. This can be explained by the great amount of snow in the mountains and the considerably warmer and sunnier weather than normal during the summer of 1975 and 1976.

SNOW ON LANDSAT IMAGES

This study has shown that Landsat imagery is very suitable for snowmapping. MSS 4 and 5 proved to be highly redundant, but the latter is best due to better contrast and greater penetration through haze and fog. During winter and early spring there is a rather small difference between MSS 4/5 and MSS 6/7. Later in the year this difference is very great. On Landsat images taken during summer the extent of snow in the MSS 5 band is much greater than in MSS 7.

THE SNOWLINE

In this study the snowline plays a dominant role since it defines the border between snowcovered and snowfree area. To find the size of a snowcovered area, the position of the snowline must be determined. Usually the snowline is not strictly a well-defined and simple line, but rather a transition zone between a completely snowcovered area and bare ground. There are several factors that influence the nature of the snowline, such as season and topography. In mountains during the fall it was possible to get a well defined snowline after the earliest snowfalls of the season. Clearcut snowlines along mountain slopes can also be seen on some Landsat images of Norway obtained during the fall.

TECHNIQUES

The Landsat images used in this study were examined with a Zeiss Interpretoscope which proved to be very suitable instrument for study of this type of satellite imagery. Optical pantographs were used to draw the basin boundaries to the working scale of 1 : 250000. In some special cases this instrument was also used to draw the snowline from 1 : 1 mill. Landsat positiv transparency. However in this study, snowmapping is based on the use of photographic black and white papercopies at a scale of 1 : 250000. FIG. 12 and 13.

Two copies were enlarged for each date and basin. These paperprints were made somewhat darker than normal in order to have the snowcover as white in contrast to the snowfree, dark parts of the landscape. By comparison with MSS 5 1 : 1 mill. transparency, the papercopy that was in the best agreement with it, was selected.

On the selected prints, the basin-boundary was drawn and by planimetry the snowcovered areas were measured. Because the nature of the snowline. dot-planimetry was employed.

The accuracy of the dot-method was tested. One area of known size was measured three times, and the same was done with the snowcover in one basin. The result show that the accuracy of the dot-method is greater than the one with which one can draw a true snowline.

An electronic densitometer and planimeter were made availiable for a day during a demostration. By ajusting the densitometer, we got the snowcovered terrain on the screen as areas of one color. The screen was photographed with 35 mm. color film showing the densitometer picture of snowcover in the Boevra and Jostedal basins on June 22., July 9. and 27. 1975.

Because of the very improvised use of the electronic densitometer, it was not possible to take full advantage of the capacity of the instrument, like electronic planimetry. The reason for this is that no opaque masks outlining the basins were available at short notice. Paperprints of the screen photographs have been measured and are in good agreement with results from the dot-planimetry.

An Additive Color Viewer has been used to make multispectral color images of the study area. These images do not seem to give any substantial new information on the snowcover, compared with black and white MSS 5. However color images are very valuable in providing additional information such as the position of transient snowline on glaciers and suspended sediment loads in lakes and rivers.

ACCOMPLISHMENTS

Inherent in the Landsat system is the ability to observe large areas simultaneously. This is a great advantage because in this way snowcover can be monitored over extensive areas. Most of the weather stations are in the lowland and valleys, while there are only a few up in the vast, inaccessable. high mountain areas. Thus , the in situ information on the snowcover in high mountain areas is quite limited. The Landsat images provide valuable additional information on the snow condition and snowmelting in mountainious Norway.

Ground truth, specially meteorological information, like snowdepth are available from a number of stations. Snowdepth from Boevra basin in 1975 have been tested and the snow distribution on Landsat images agree well with these data.

By combining Landsat images from 1975 and 1976, it has been possible to map the reducion of snowcover successfully from the middle of May to the end of August. In this period most of the snow melting takes place in mountainious Norway.
FIG: 14,15,16 and 17.

SIGNIFICANT RESULTS

During the summer seasons of 1975 and 1976 the snowcover has been successfully monitored and measured in the four basins studied. By use of the elevation distributions for these basins combined with the measured snowcover percentage, the equivalent snowline altitude was calculated. The results are seen in the tables on the next page.

TABLE 1

DATE	BOEVRA	JOSTEDAL	OLDEN	BREIM
MAY 16. 1975	90 %			
JUNE 22. 1975	72 %	78 %	74 %	54 %
JULY 5. 1976	59 %	60 %	68 %	46 %
JULY 10. 1975	59 %	68 %	67 %	32 %
JULY 28. 1975	44 %	58 %	61 %	29 %
AUGUST 9. 1976	29 %	53 %	60 %	27 %
AUGUST 27. 1976	26 %	44 %	46 %	21 %
PERCENTAGE OF THE BASIN COVERED WITH GLACIERS	11	27	36	12

Table 1: Percentage of snowcover in the four basins

TABLE 2

DATE	BOEVRA	JOSTEDAL	OLDEN	BREIM
MAY 16. 1975	580 m.			
JUNE 22. 1975	1000 m.	520 m.	480 m.	700 m.
JULY 5. 1976	1210 m.	890 m.	670 m.	820 m.
JULY 10. 1975	1210 m.	820 m.	740 m.	1000 m.
JULY 28. 1975	1350 m.	910 m.	900 m.	1050 m.
AUGUST 9. 1976	1440 m.	940 m.	970 m.	1100 m.
AUGUST 27. 1976	1480 m.	1030 m.	1220 m.	1240 m.

Table 2: The equivalent snowline altitude in meters above sea level, obtained by combining data on the percentage of snowcover and elevation distributions of the four basins.

Subsequent runoff data have been collected for the basins. Tables showing percentage snowcover versus subsequent runoff have been worked out for 1975. Runoff data for 1976 are not yet available. Because of the lack of complete data on runoff, the analysis of the results have to wait until all data becomes available. This has to be done as a post project work. FIG. 18, 19, 20 and 21.

PROBLEMS

Only some images of all possible Landsat passes in 1975 and 1976 were acquired and therefor the image frequency was not as high as it could have been with maximum utilisation.
Cloud have been a minor problem in this study because most of the images used have been cloudfree. However, in some cases, small clouds were identified and corrected for. Nor do shaddows represent a great problem. The Norwegian mountains are in most areas rather smooth, forming an ondulating landscape. A landscape like this is present in the study area, but rougher terrain is also present, especially in the western parts where the fjords dissect deeply into the mountain massiff. During the period from which Landsat data have been used in this study, the sun angle has been between 35 and 50 degrees. This, and the fact that the snow was mainly confined to higher elevation on the plateau, are the reasons why shaddows were not a real problems.
Misinterpretation caused by high reflective barren terrain is also a minor problem. In the highest parts of the Norwegian mountains, there are quite extensive blockfields where there is very little or no vegitation. These block-fields have in certain areas very high reflection that could be interpreted as snow by unexperienced observers. The most extensive blockfields of this type is found in Finnmark, the northeastern part of Norway. Because of the heavy snowpack in the study area, the majority of these blockfields were snowcovered during most of the

summer 1975 and 1976.
In this study as well as for all use of Landsat imagery the general lack of adequate interpretation instruments in Norway is a problem.

DATA QUALITY AND DELIVERY

The quality of Landsat images used in this study has been very good and the delivery of data has been as expected. In some cases it is considerably easier to distinguish between snow and ice on positive MSS 7 transparencies than on negative MSS 7. This make it difficult to make good positive papercopies if one wants to distinguish between snow and ice.

RECOMMENDATIONS

Satellite observation of snowcover is a valuable tool for water management. However the same can be said of the more general management of the mountain areas since phenological conditions are clearly seen on Landsat imagery. Satellite monitoring of mountain areas are therefore desirable and valuable both for practical and more scientific applications.
This study is based upon images from only a smaller part of all possible Landsat passes over the study area during the meling season. A recommendation to future use of Landsat in snow monitoring, is to exploit fully the coming of a Nordic Landsat station.
Operative use of Landsat data is in many cases like snowmapping, contingent on the users having images available a few days after they have been acquired. The present 6 and 12 days of spacing between Landsat passes together with an east - west overlap between 56 and 71 percent, should provide a useful though not satisfactory basis for semi or complete operational snow monitoring

satellite system.

Snow is easely identifiable on Landsat images and digital processing is not necessary, but it would obviously improve the accuracy.

In the first phase quite simple means should be adequate like enlarging MSS 5 to a suitable, standard scale and with a set of pre-cut basin masks the planimetry work could be performed rapidly.

A set of pre-cut basin masks would also be very useful if an electronic densiometer / planimeter is made available.

One should also take advantage of the progress within the Landsat and other satellite systems. The thermal scanner on Landsat C should, in spite of the lower resolution than the present MSS scanner, give valuable information on the processes of breakdown of snowcover. The use of Landsat C'RBV cameras with high resolution imagery, should make it possible to improve the interpretation. It is desirable to clearify to what degree data from the Heat Capacity Mapping Mission satellite can improve the monitoring of snow.

NOAA satellites do provide a frequent coverage and the VHRR images have a useful resolution. A combination of Landsat and NOAA data could be a good solution for the near future. However, new satellites with sensors which are less affected by weather would surely make monitoring of snow more effective.

CONCLUSION

This study shows that the Landsat images are well suited for snowmapping in mountainious Norway. There is an obvious correlation between the areal extent of snowcover and the amount of water stored in the basins as snow. The 1975 and 1976 situations are not representative compared with normal snowpack and therefore additional satellite observation are desirable.

Accumulated snow-and runoff data over several years will prove to be a valuable tool in water management. Since a small improvement here results in large savings, the satellite observation of snow should continue and be improved.

Johnny Skorve .

Oslo, May 25. 1977

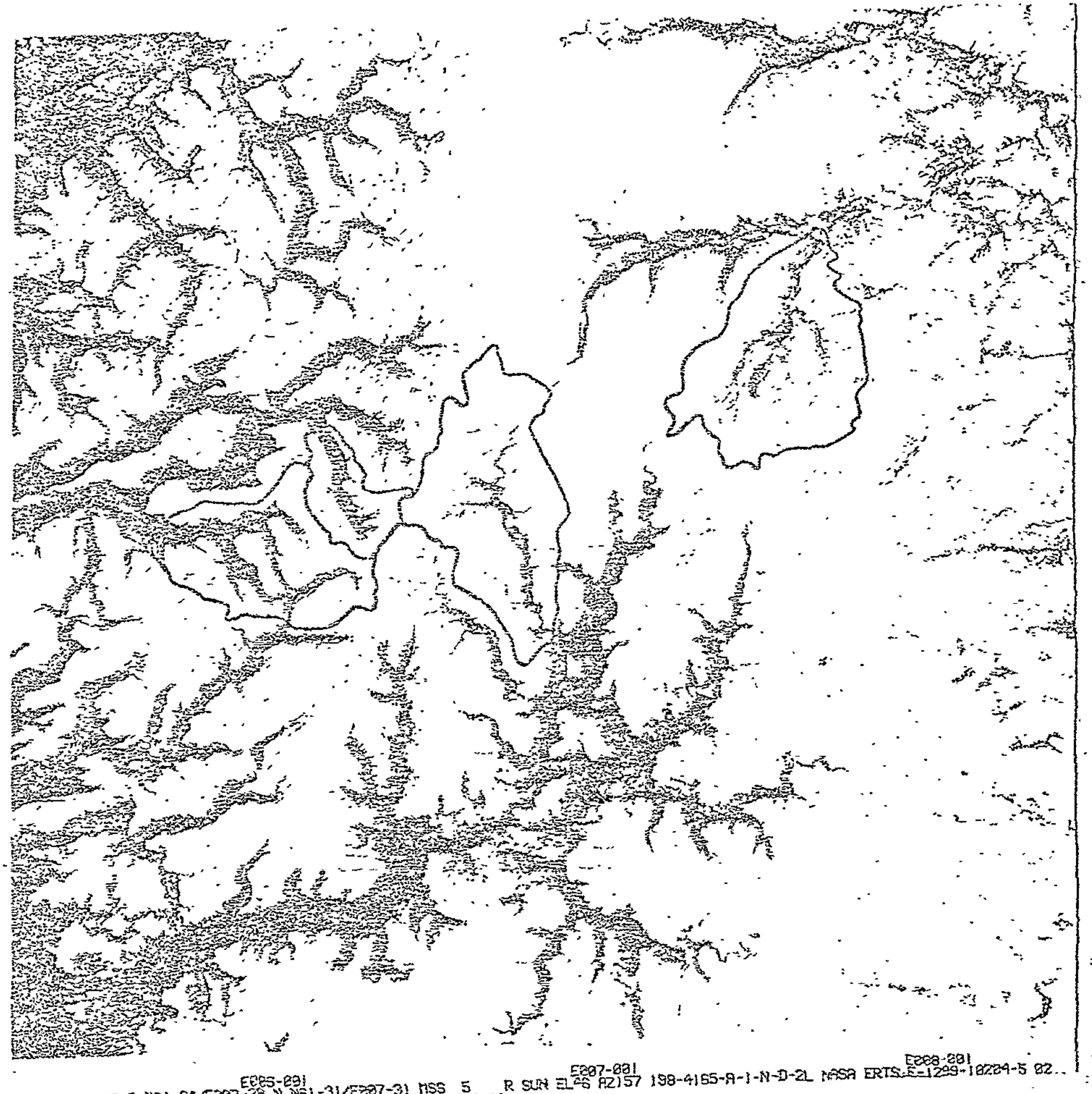

FIG. 2 THIS LANDSAT MSS 5 IMAGE FROM MAY 18.1973 SHOW THE SNOW SITUATION DURING SPRING IN SOUTH-WESTERN NORWAY. THE BOUNDARIES OF THE FOUR BASINS STUDIED, HAVE BEEN DRAWN. FROM LEFT TO RIGHT: BREIM, OLDEN, JOSTEDAL AND BOEVRA.
SCALE 1:1 MILL.
ID: 1299 -10204

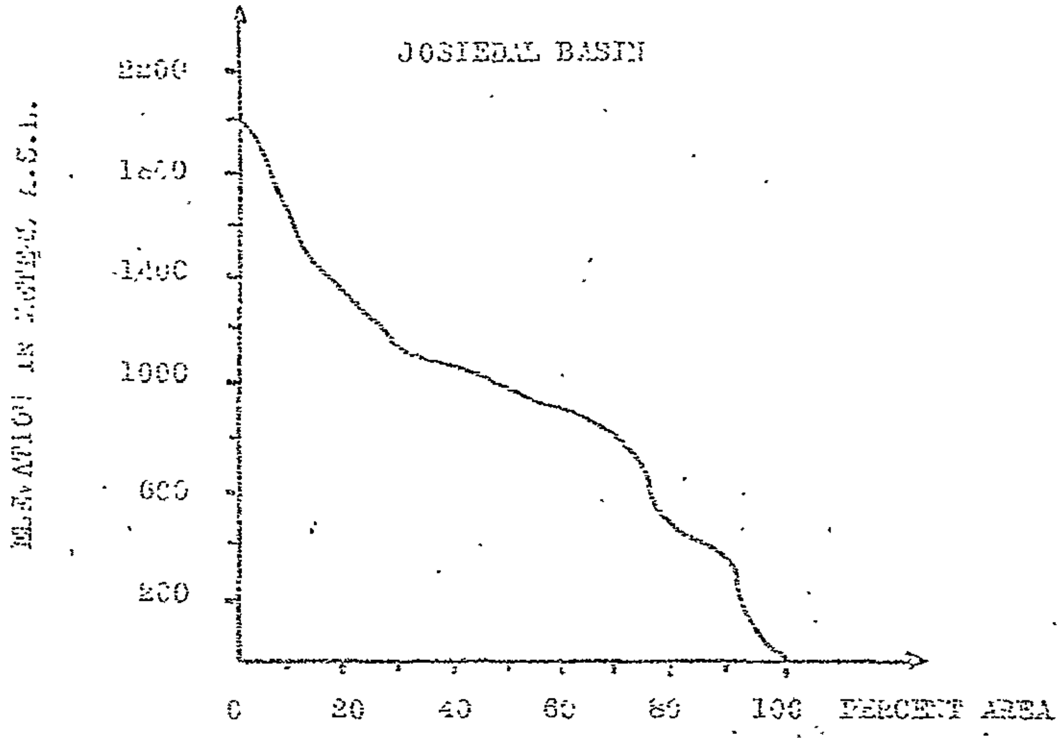

FIG. 3 ELEVATION DISTRIBUTION

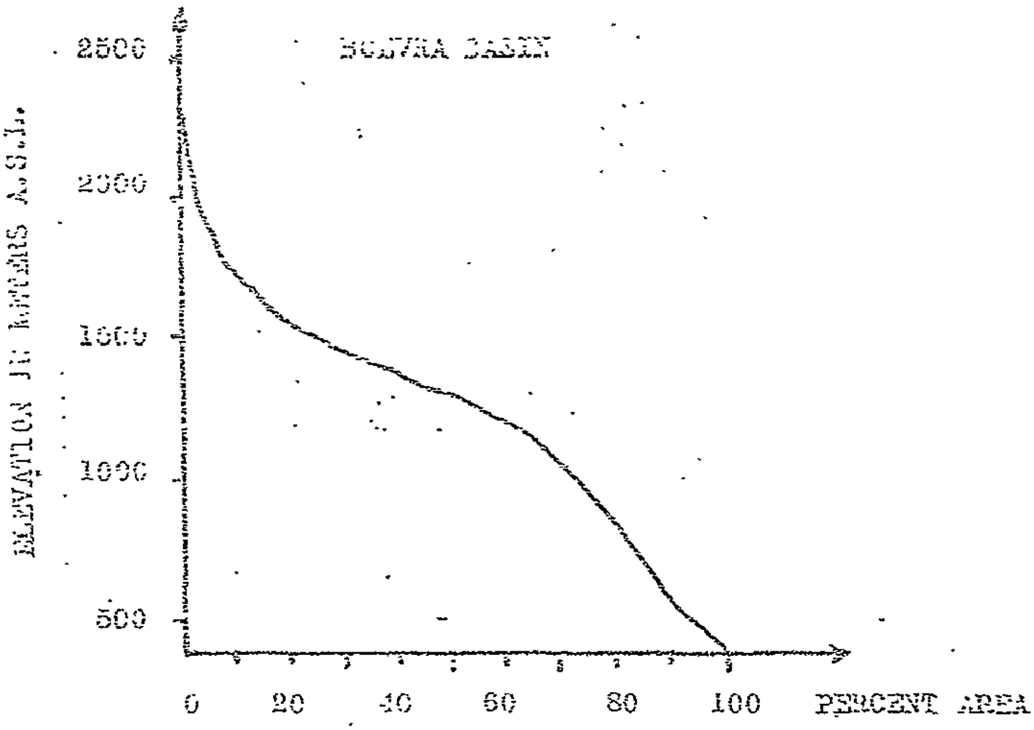

FIG. 4 ELEVATION DISTRIBUTION

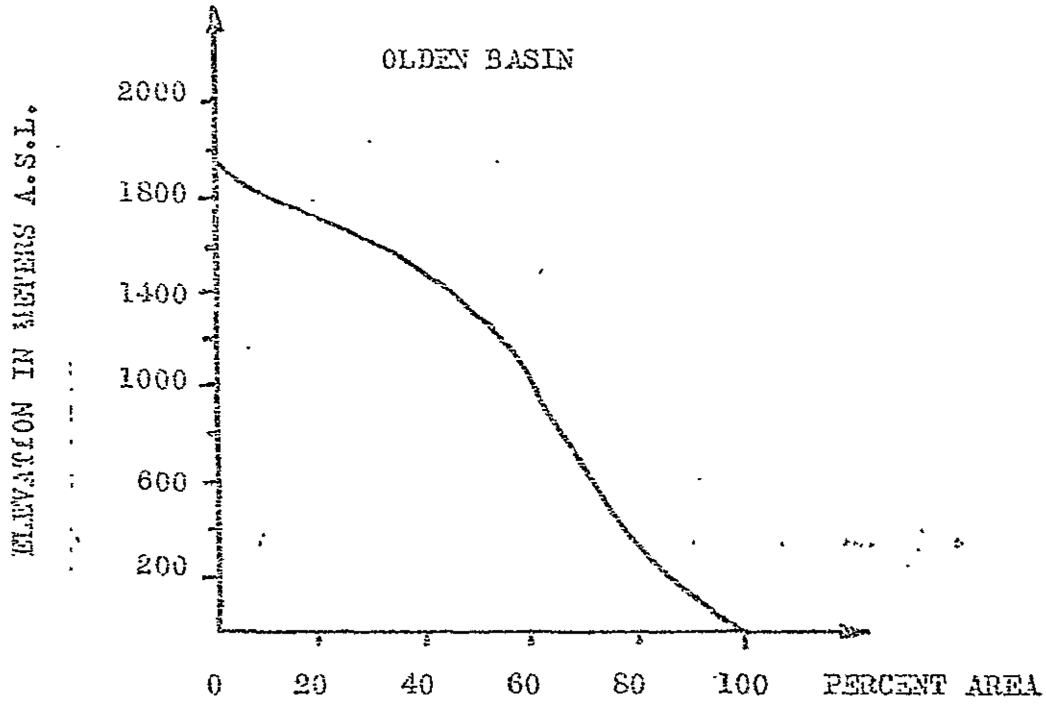

FIG. 5 ELEVATION DISTRIBUTION

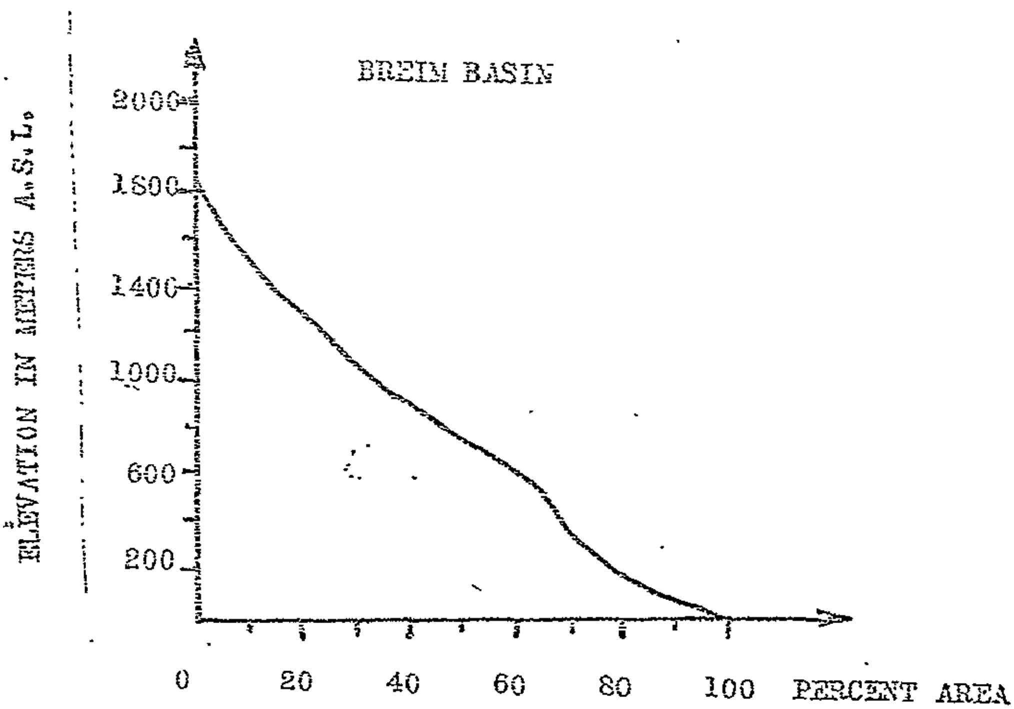

FIG. 6 ELEVATION DISTRIBUTION

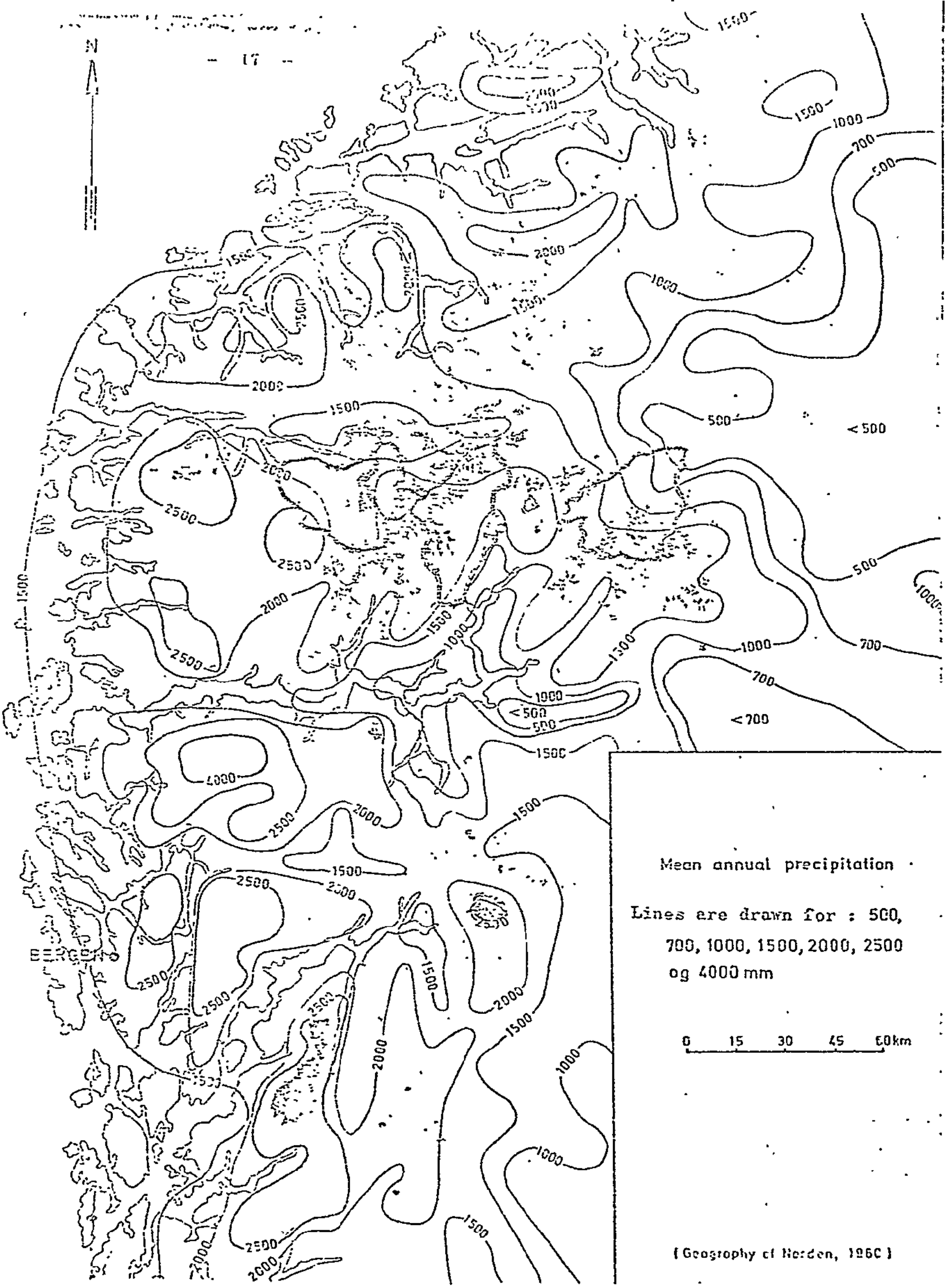

FIG.7 THE FOUR BASINS IN THE STUDY IS DRAWN ON THIS MEAN ANNUAL PRECIPITATION MAP OF SOUTHWESTERN NORWAY. FROM LEFT TO RIGHT: BREI[illegible], OLDEN, JOSTEDAL AND BOEVRA.

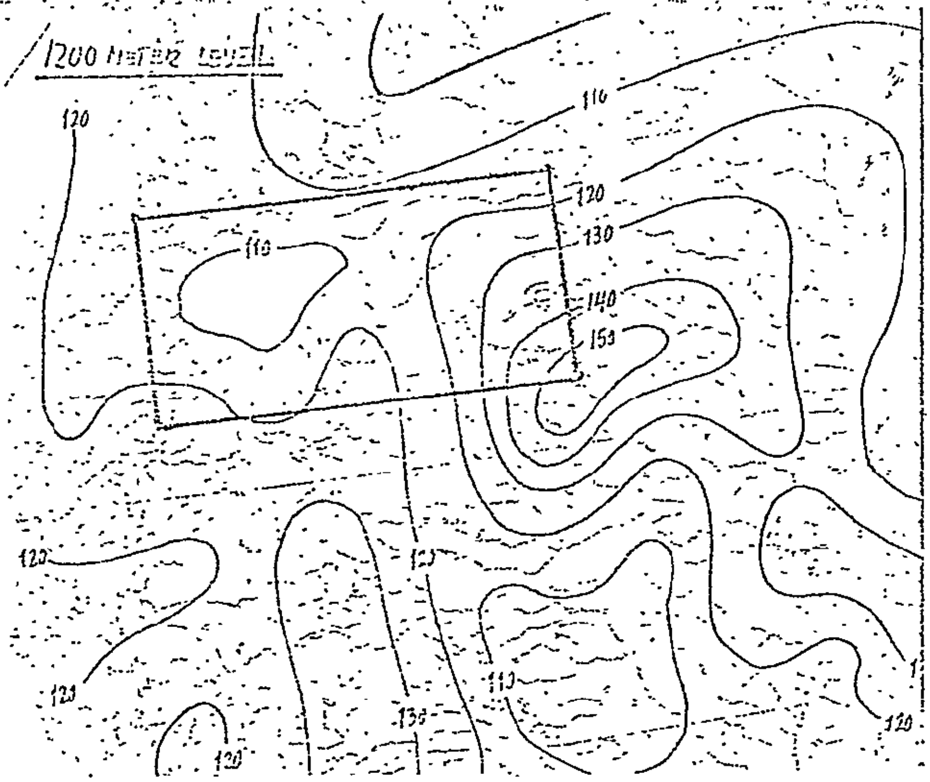

FIG. 8 THE ISOLINE MAP SHOW PERCENT OF NORMAL SNOWPACK IN THE 1200 METER A.S.L. ON APRIL 30. 1975. THE STUDY AREA IS SITUATED WITHIN THE RECTANGLE.

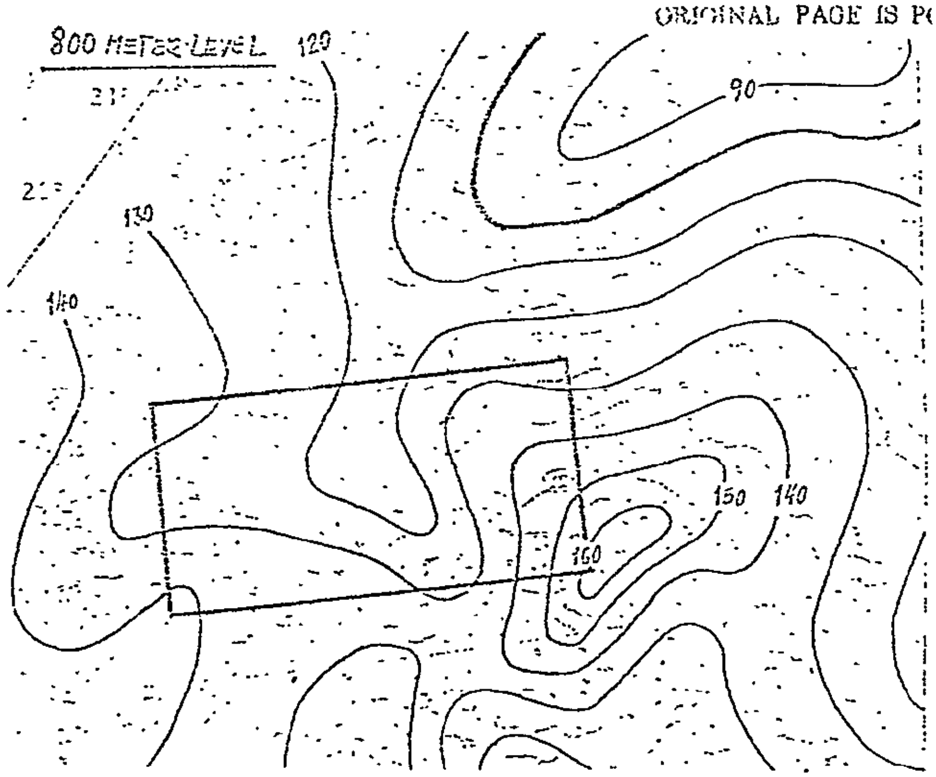

FIG.9 THE ISOLINE MAP SHOW PERCENT OF NORMAL SNOWPACK IN THE 800 METER A. S. L. ON APRIL 30. 1975. THE STUDY AREA IS SITUATED WITHIN THE RECTANGLE.

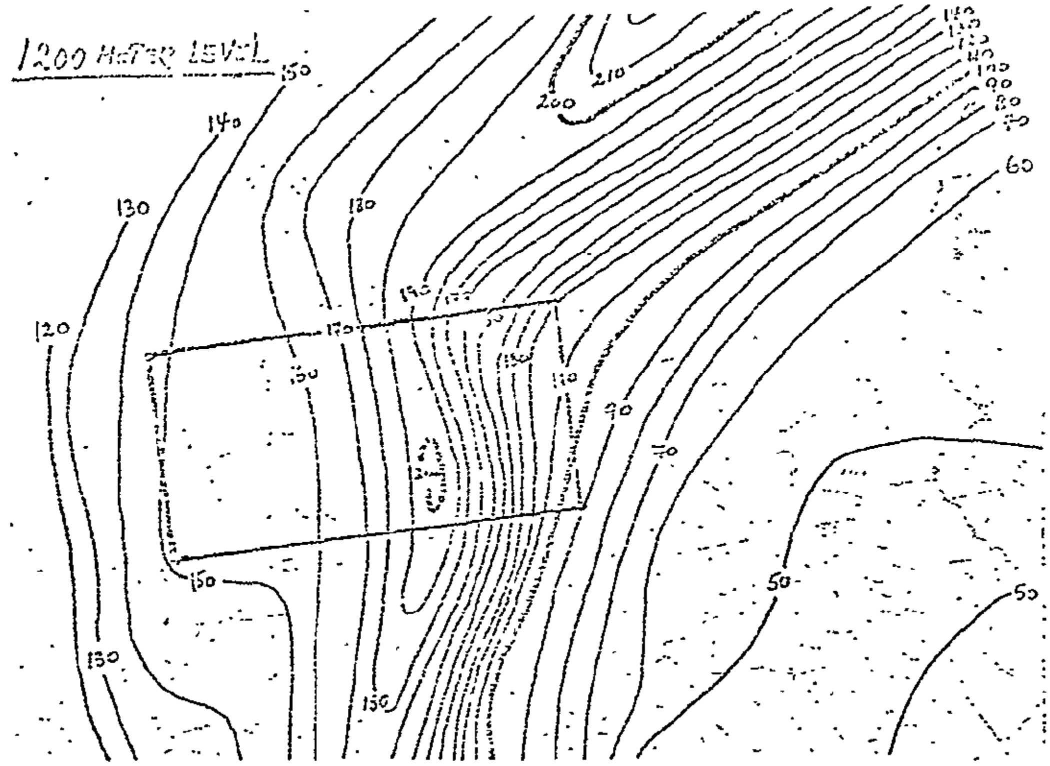

FIG: 10 THE ISOLINE MAP SHOW PERCENT OF NORMAL SNOWPACK IN THE 1200 METER A.S.L. ON APRIL 30, 1976. THE STUDY AREA IS SITUATED WITHIN THE RECTANGLE.

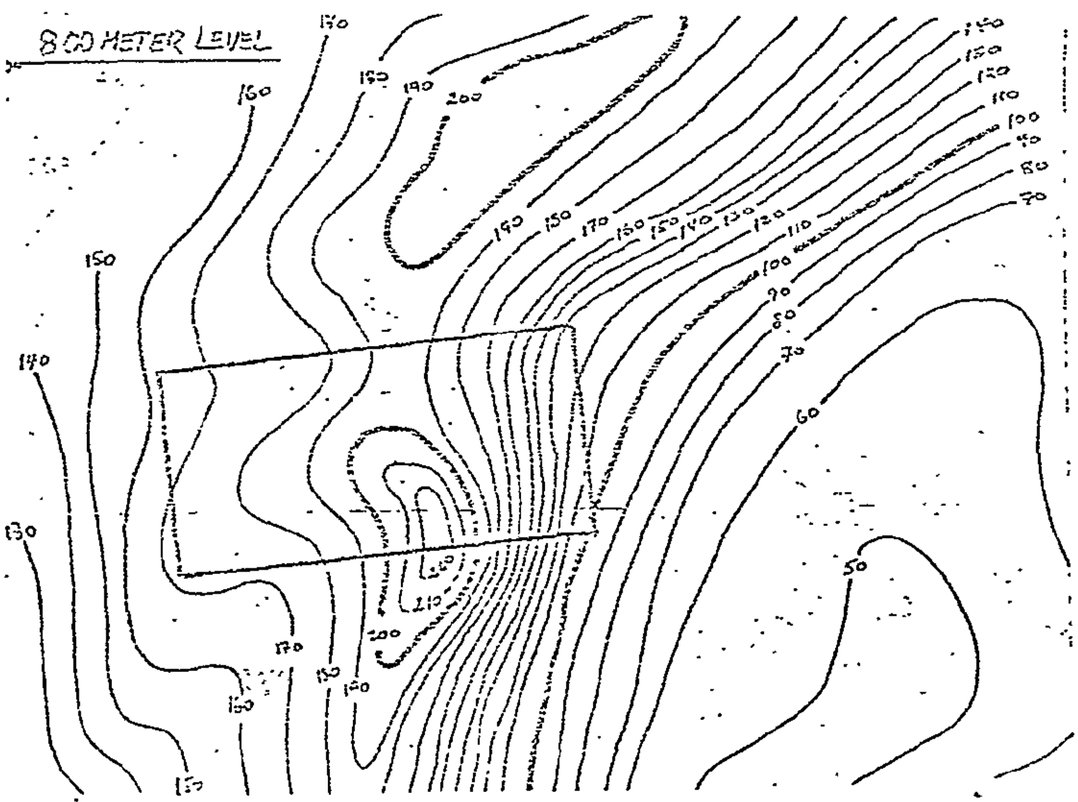

FIG. 11 THE ISOLINE MAP SHOW PERCENT OF NORMAL SNOWPACK IN THE 1200 METER A.S.L. ON APRIL 30, 1976. THE STUDY AREA IS SITUATED WITHIN THE RECTANGLE.

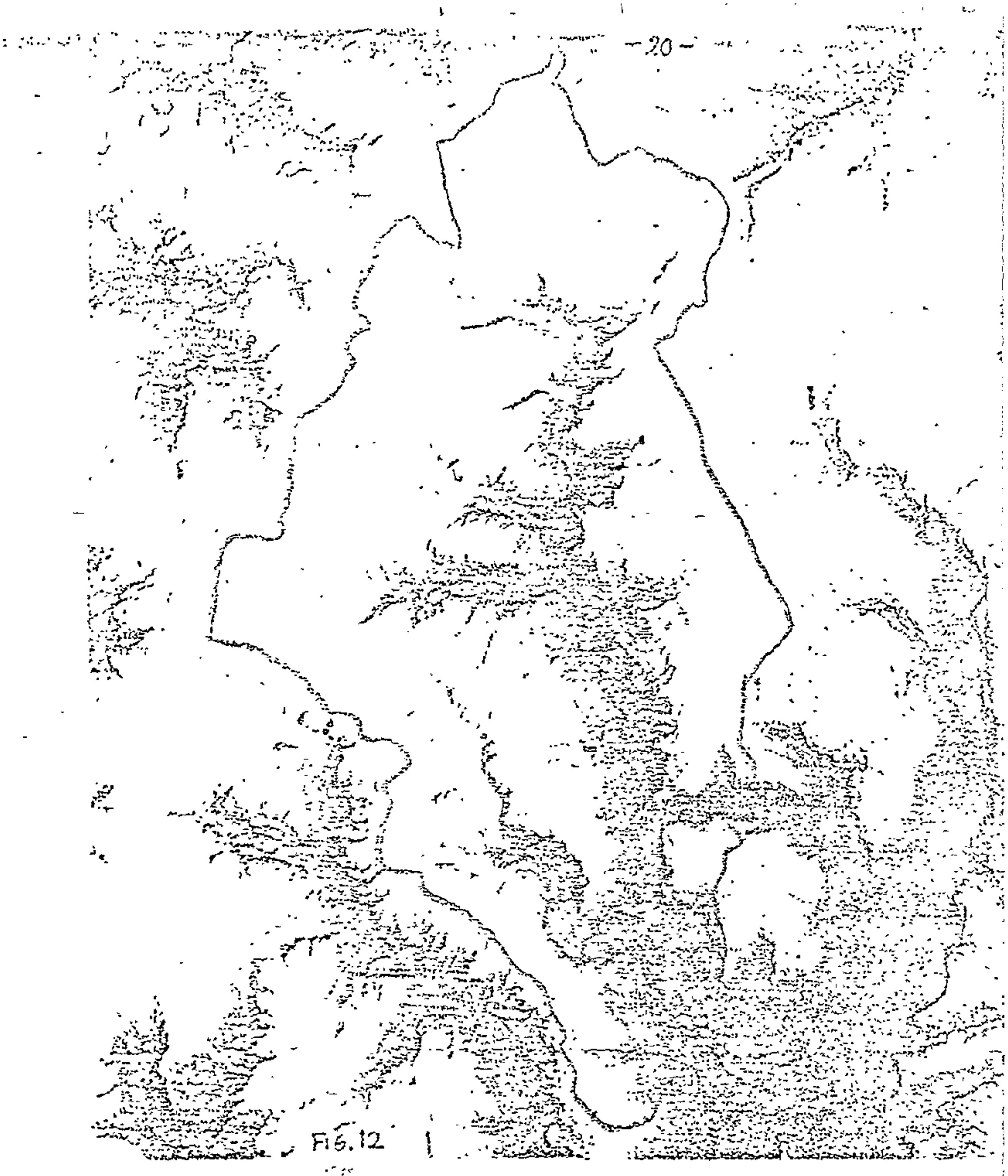

FIG. 12

FIG. 12 and 13 : AN EXAMPLE OF HOW THE SNOWCOVER DECREASE IN SIZE WITHIN THE STUDY AREA DURING THE SUMMER MELTING. THE SEPARATION IN TIME IS 68 DAYS.

FIG. 12 THE JOSTEDAL BASIN SHOWN ON AN MSS 5 ENLARGEMENT OF LANDSAT IMAGE FROM JULY 5, 1976.

SCALE: 1 : 250000

ID : [illegible]

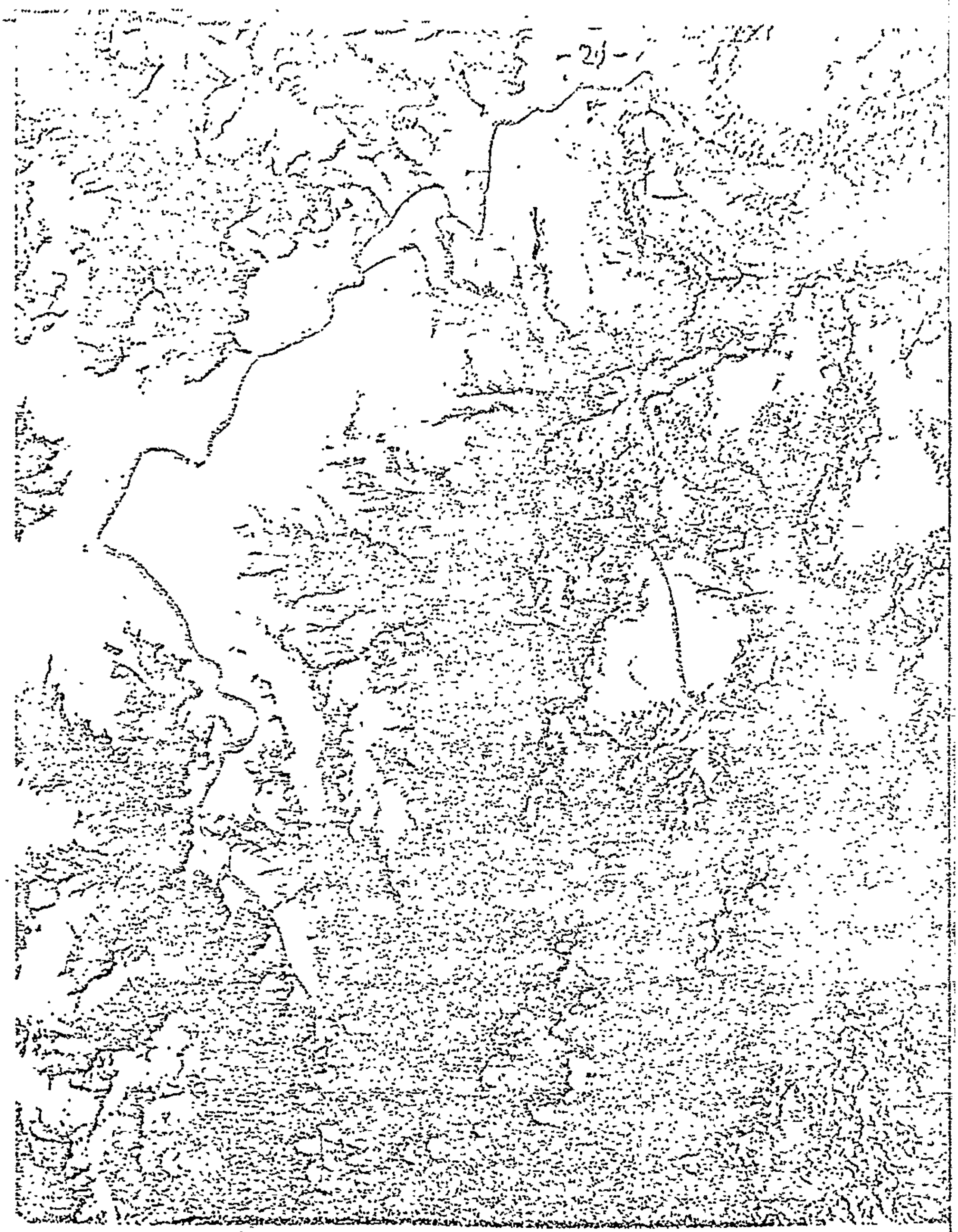

FIG. 18 : THE JOSTEDAL BASIN SHOWN ON AN MSS 5 ENLARGMENT OF LANDSAT IMAGE FROM AUGUST 27. 1976.
SCALE: 1 : 250000
ID : [illegible]

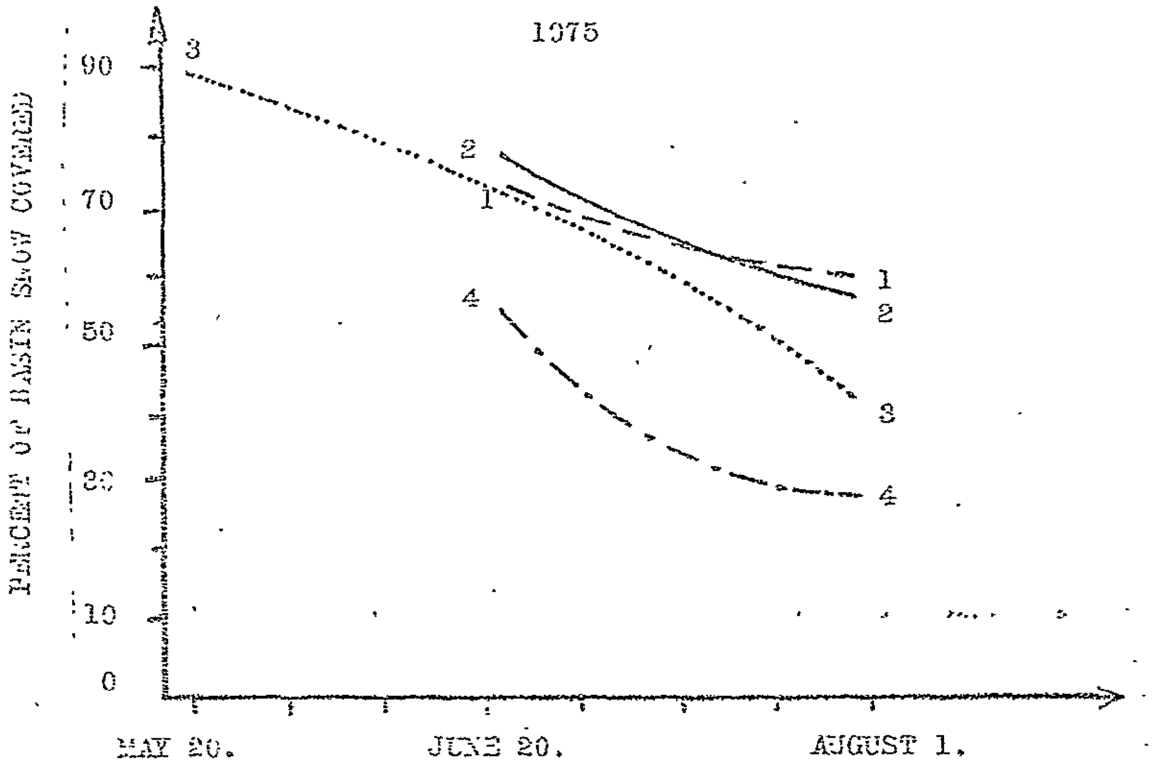

FIG.14 SNOW EXTENT VARIATION IN FOUR NORWEGIAN BASINS
1: OLDEN
2: JOSTEDAL
3: BOEVRA
4: BREIM

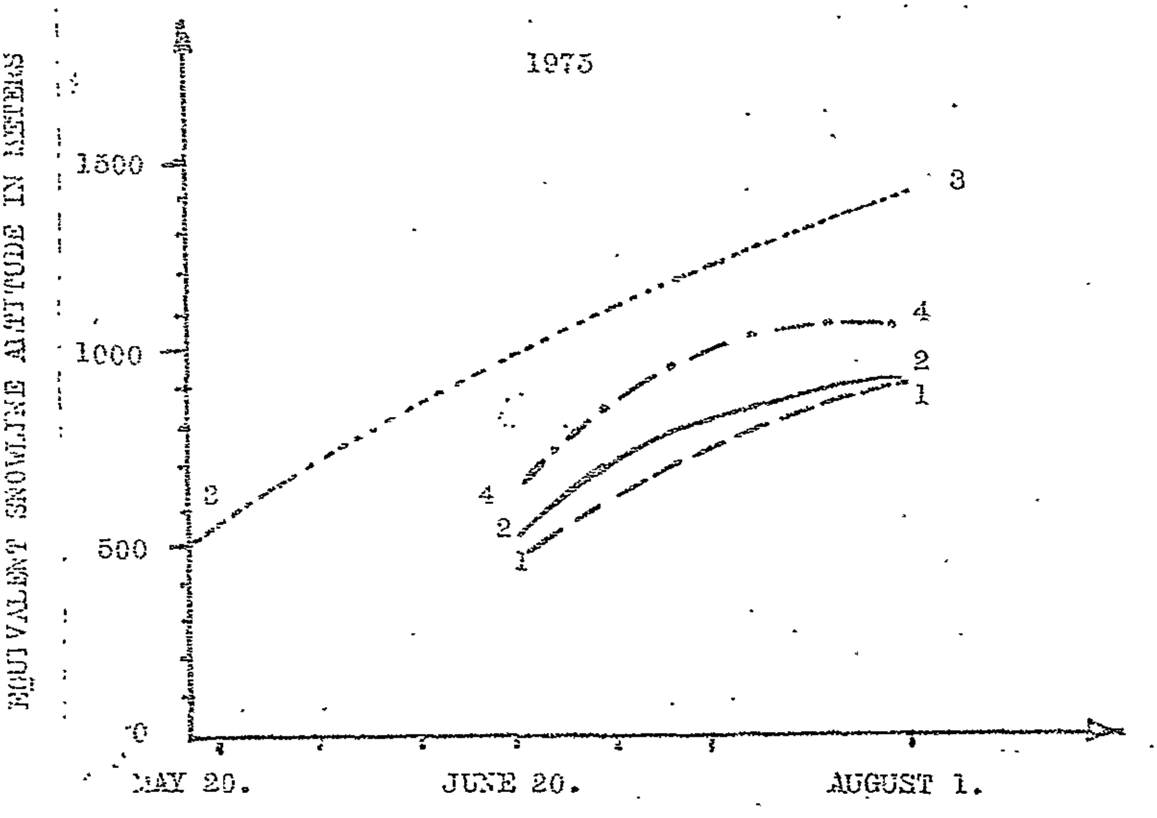

FIG. 15 VARIATION OF EQUIVALENT SNOWLINE ALTITUDE WITH TIME IN THE FOUR BASINS : 1. OLDEN
2. JOSTEDAL
3. BOEVRA
4. BREIM

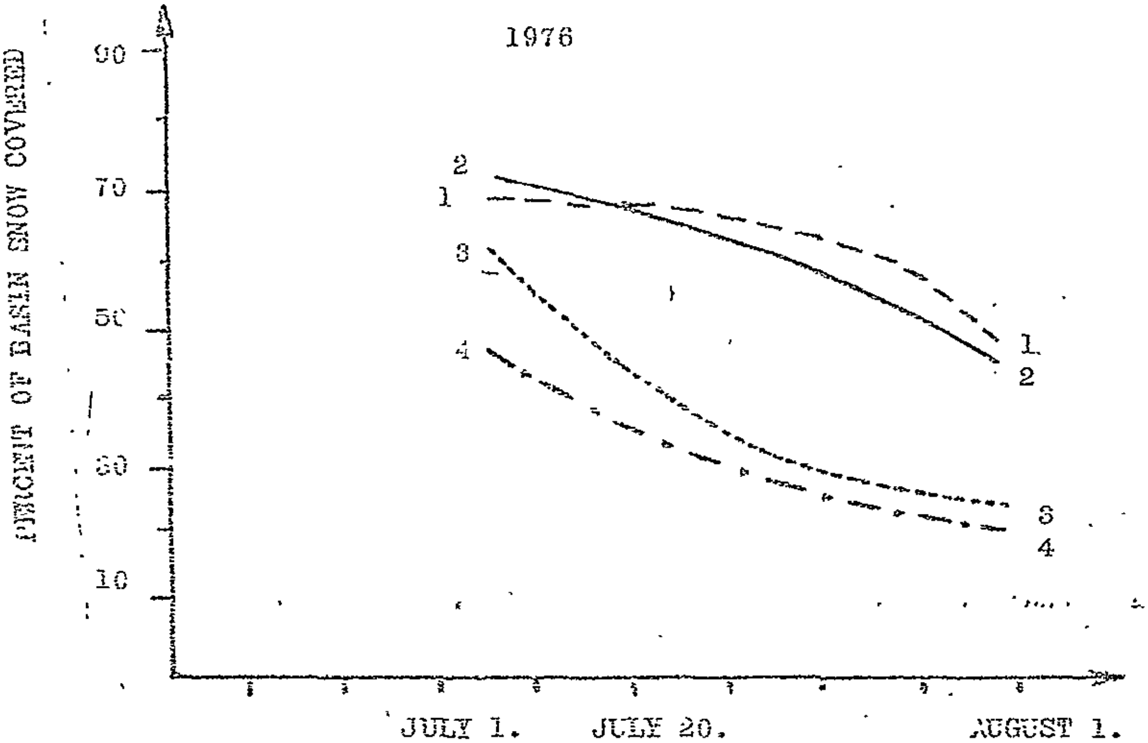

FIG.16 SNOW EXTENT VARIATION IN FOUR NORWEGIAN BASINS

1: OLDEN

2: JOSTEDAL

3: BOEVRA

4: BREIM

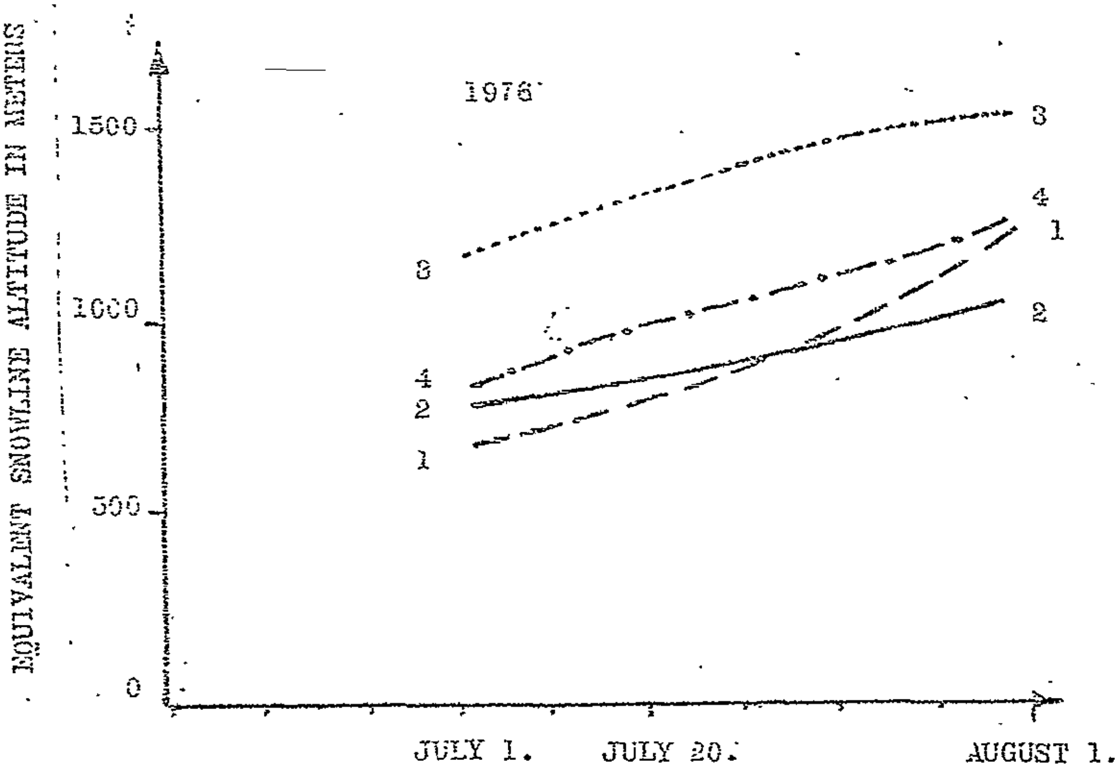

FIG.17 VARIATION OF EQUIVALENT SNOWLINE ALTITUDE WITH TIME IN THE FOUR BASINS: 1. OLDEN, 2. JOSTEDAL, 3. BOEVRA, 4. BREIM . .

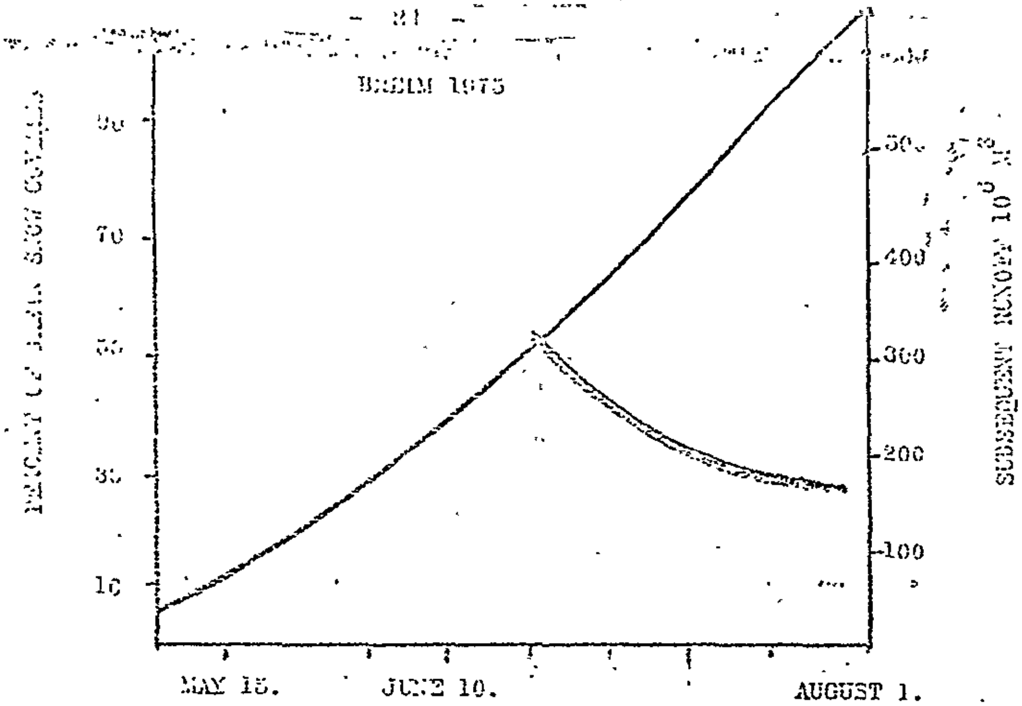

FIG. 18 VARIATION IN SNOWCOVER VERSUS SUBSEQUENT RUNOFF

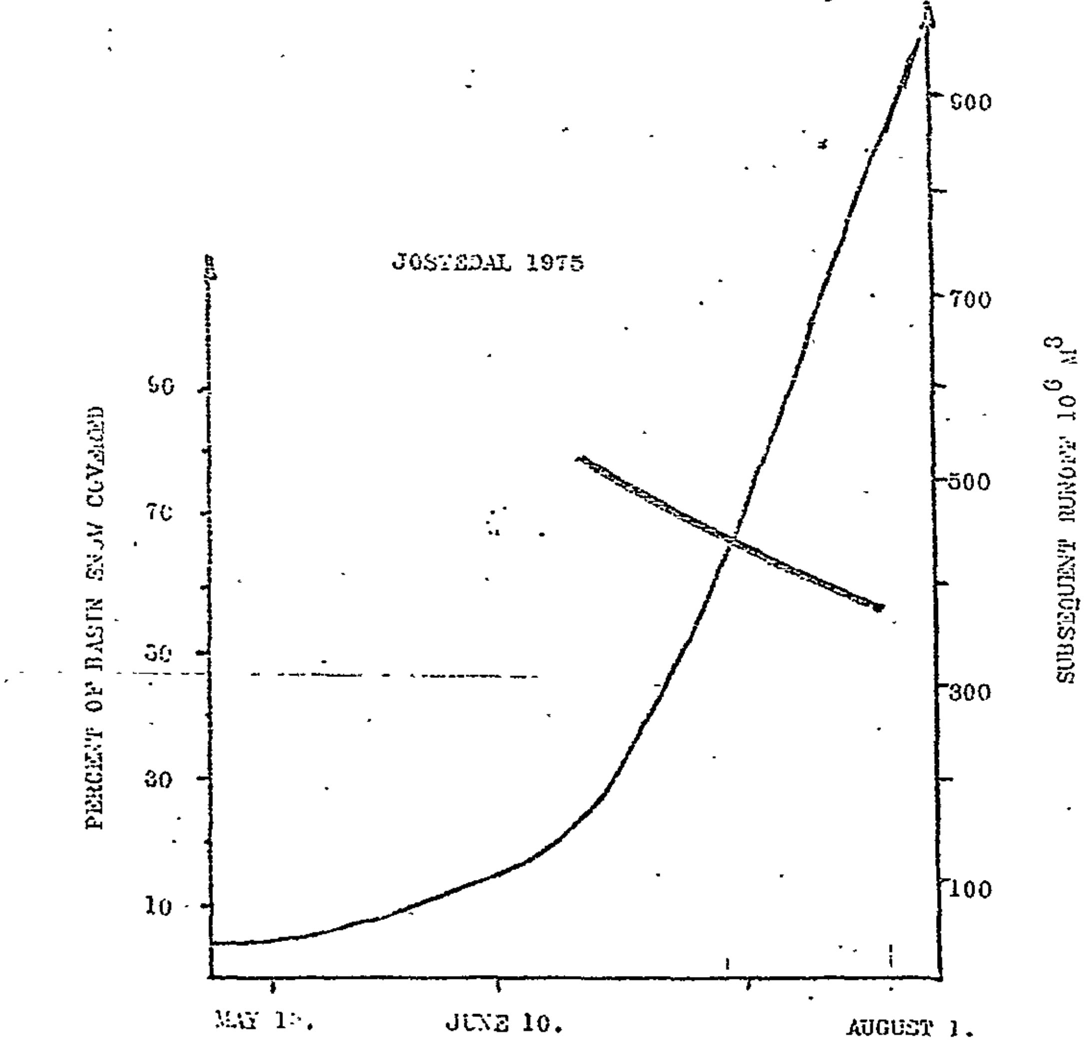

FIG. 19 VARIATION IN SNOWCOVER VERSUS SUBSEQUENT RUNOFF

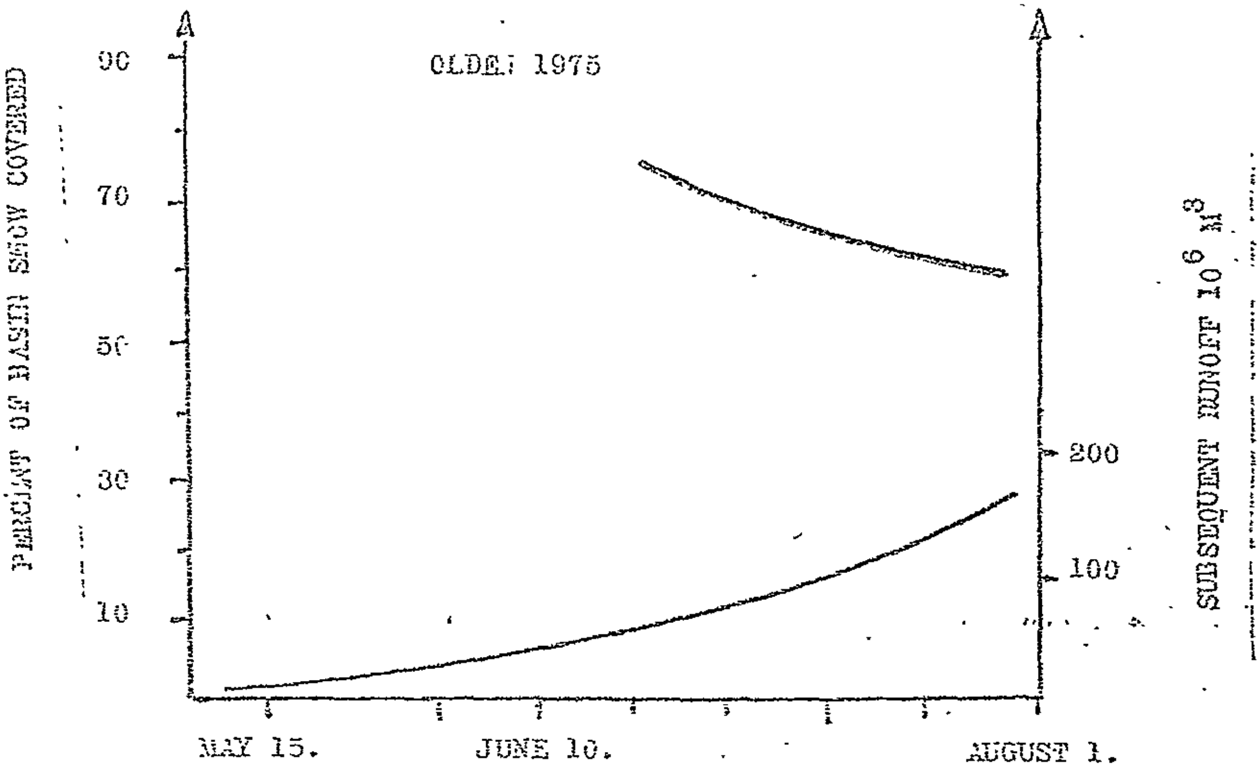

FIG. 20 VARIATION IN SNOWCOVER VERSUS SUBSEQUENT RUNOFF

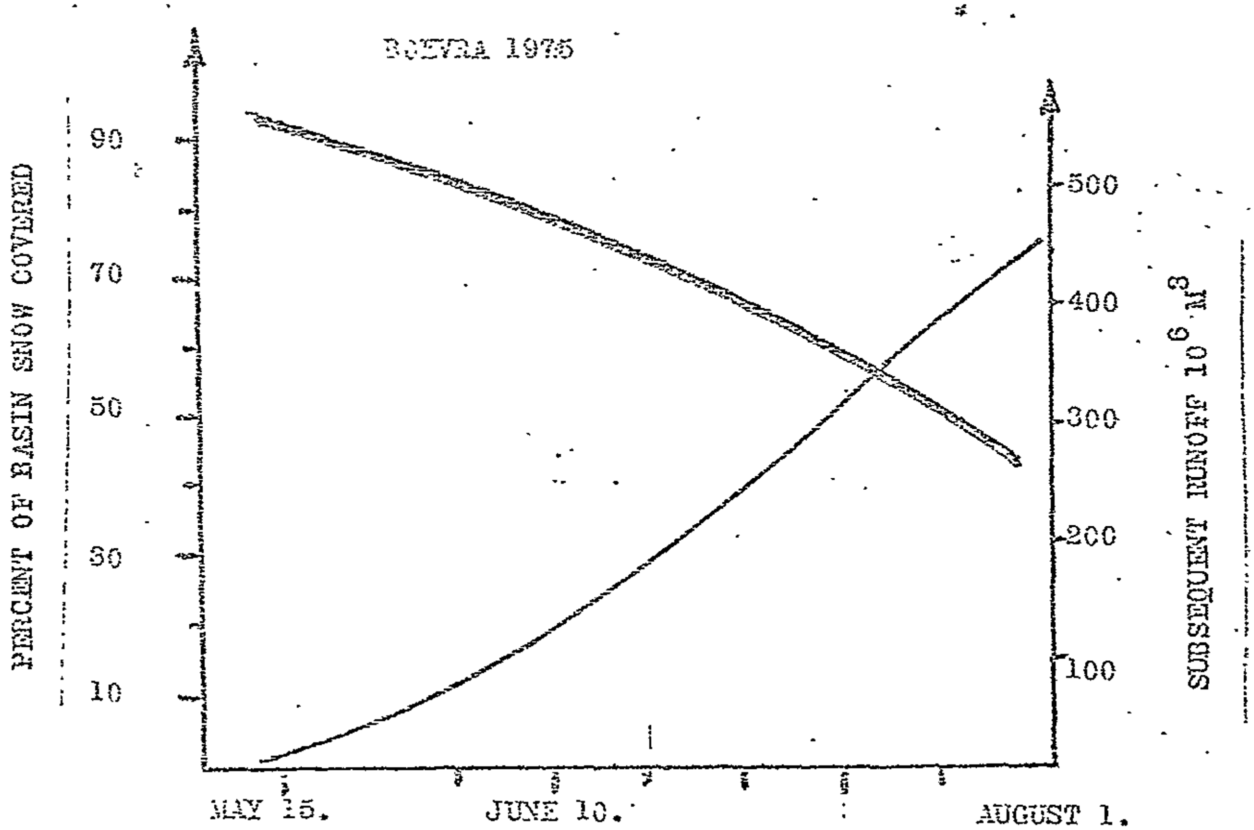

FIG. 21 VARIATION IN SNOWCOVER VERSUS SUBSEQUENT RUNOFF