

USE OF NOAA AVHRR DATA FOR SNOW COVER MAPPING IN MOUNTAIN AREAS IN NORWAY.

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ABSTRACT.

In order to operate hydroelectric powerplants in a most profitable way, good predictions of run-off in the snow-melting season is important. This paper describes how NOAA AVHRR satellite imagery in digital format is used for operational snow-cover mapping. The snow-cover information is used in a hydrological model together with terrain elevation data and meteorological data to obtain improved run-off predictions.

BACKGROUND AND OBJECTIVES.

Since the early days of Landsat, the potential of satellite remote sensing for snow cover mapping was realized by Norwegian hydrologists. The Norwegian Hydropower and Electricity Board (NVE) started this work in the seventies in cooperation with IBM Norway which at that time operated a digital image processing service facility (ERMAN-II) in Oslo. The image processing service was in 1983/84 taken over by Fjellanger Widerøe A.S. Utilizing a DIPIX ARIES-II image processing system, Fjellanger Widerøe A.S. has later developed the methods further in close cooperation with the State Power Board (in Norwegian: Statkraft). Instead of Landsat MSS imagery, the most common type of data for the snow-cover mapping has now become NOAA AVHRR imagery. There are several reasons for this: First of all; it is possible to obtain NOAA AVHRR data much more frequently (2 times a day) than is the case with Landsat (every 16th day). Frequent coverage is important, mainly because of the cloud cover problem, as the probability of obtaining cloud-free scenes increases with the acquisition frequency. Frequent coverage is also advantageous when the snow melting monitoring aspect is taken into consideration. Another reason why NOAA AVHRR data is preferred rather than Landsat, is that the 1 x 1 km resolution of the former is considered adequate for the purpose. 80 x 80 m resolution Landsat MSS imagery offers more details, but when the large difference between NOAA AVHRR and Landsat MSS regarding the amount of data is taken into consideration, NOAA AVHRR data is preferable.

However, Landsat MSS (and also SPOT HRV) can be used as reference data ("ground truth") in connection with evaluation of methods based on NOAA AVHRR data.

The main purpose with the satellite-based snow-cover mapping is to improve the run-off predictions obtained from hydrological models. Without snow-cover information obtained from satellites, the model will, in addition to meteorological data, only use snow-cover information from the end of the accumulation period. In order to operate hydroelectric powerplants in the most profitable way, best possible run-off predictions during the snow-melting season is of great importance.

The objective of the snow-mapping project described in this paper is partly to improve the existing methods in terms of accuracy, and partly to improve existing procedures in the direction of operational ("quasi-real-time") use. The term "quasi-real-time" is introduced here to indicate that even though up to 24 hours may elapse from the acquisition takes place at the ground receiving station and until the end-user (the operational manager of the hydroelectric powerplant) has got the snow-cover map and the associated run-off prediction available; the procedure is still to be considered as "real time" compared to other types of satellite remote sensing applications where the time difference between acquisition and completion of final results may be weeks, months and even years.

PROJECT ORGANIZATION.

The snow mapping project is carried out in collaboration between Fjellanger Widerøe A.S. (FW), Norwegian Hydrotechnical Laboratory (NHL) and the State Power Board. Fjellanger Widerøe A.S. is a privately owned aerial surveying and mapping company which is member of the NORWAY MAPPING GROUP. The company also offers services related to digital image processing and applied satellite remote sensing. NHL is part of SINTEF, which is the Foundation for Scientific and Industrial Research at the Norwegian Institute of Technology. The project receives some funding from the so-called "SATMAP"-programme, which is run by the Royal Norwegian Council for Scientific and Industrial Research (NTNF). The State Power Board represents the user, NHL provides the hydrological modelling expertise and FW is to be considered as the industrial/commercial partner. During this year's (1988) melting season, computer facilities at the Norwegian Computing Center (NCC) were also used to a large extent in order to make the procedures as efficient as possible.

The final aim of the project is to develop the snow-cover mapping as a product which can be offered to other users than the State Power Board.

METHODOLOGY.

The methodological elements in the snow-mapping project can be described as follows:

Reception of image data at the ground receiving station and transfer of data to the analyst/ user environment.

Geometrical rectification and registration of the image data to a geographical reference system.

Processing and analysis of the digital image data in order to, for each pixel to obtain a value giving the percentual degree of snow-cover. (The relative area of each pixel covered by snow).

Integration of the snow-cover data and terrain elevation data with meteorological data in a hydrological model giving run-off prediction.

Cartographic presentation of the snow-cover distribution.

The different methodological elements which are illustrated in Figure 1, are also described in more detail below.

Reception and Transfer of Data.

The Tromsø Satellite Station (TSS), formerly denoted Tromsø Telemetry Station, has the capability of receiving NOAA AVHRR data. This station is located in the city of Tromsø in Northern Norway. TSS is equipped with digital image processing equipment of the type I2S. At TSS a NOAA AVHRR scene in its initial format consists of 1440 lines, each line being 2048 pixels long. The area of interest in the snow mapping project, which comprises only a limited part of the mountain areas in Southern Norway, is rather small compared to a whole NOAA AVHRR scene. For this reason the first step in the image processing procedure carried out at TSS, is to "cut out" a smaller subarea of the whole scene, with the size of about 600 lines by 600 pixels. Such an image covers the whole of Southern Norway, which is a much larger area than the one of interest for the snow-cover mapping. The reason why the subscene covering almost the complete Southern Norway is used, is the need to obtain good Ground Control Points located in snow-free areas for the geometrical rectification. (The geometrical rectification is treated in detail in the next paragraph). At TSS the I2S image processing system is used for the generation of subscenes which are appropriately located for use in the snow-cover mapping project. The subscenes are then transferred from the I2S system to the disc of a ND (Norsk Data) - 570 computer also at TSS. By the aid of the ND-specific software for file transfer between ND-computers, "COSMOS", the NOAA AVHRR subscene image file is then transferred via the DATAPAK (X.25) telecom network to a ND-5800 computer located at the Norwegian Computing Centre in Oslo. From the ND-5800 the data-

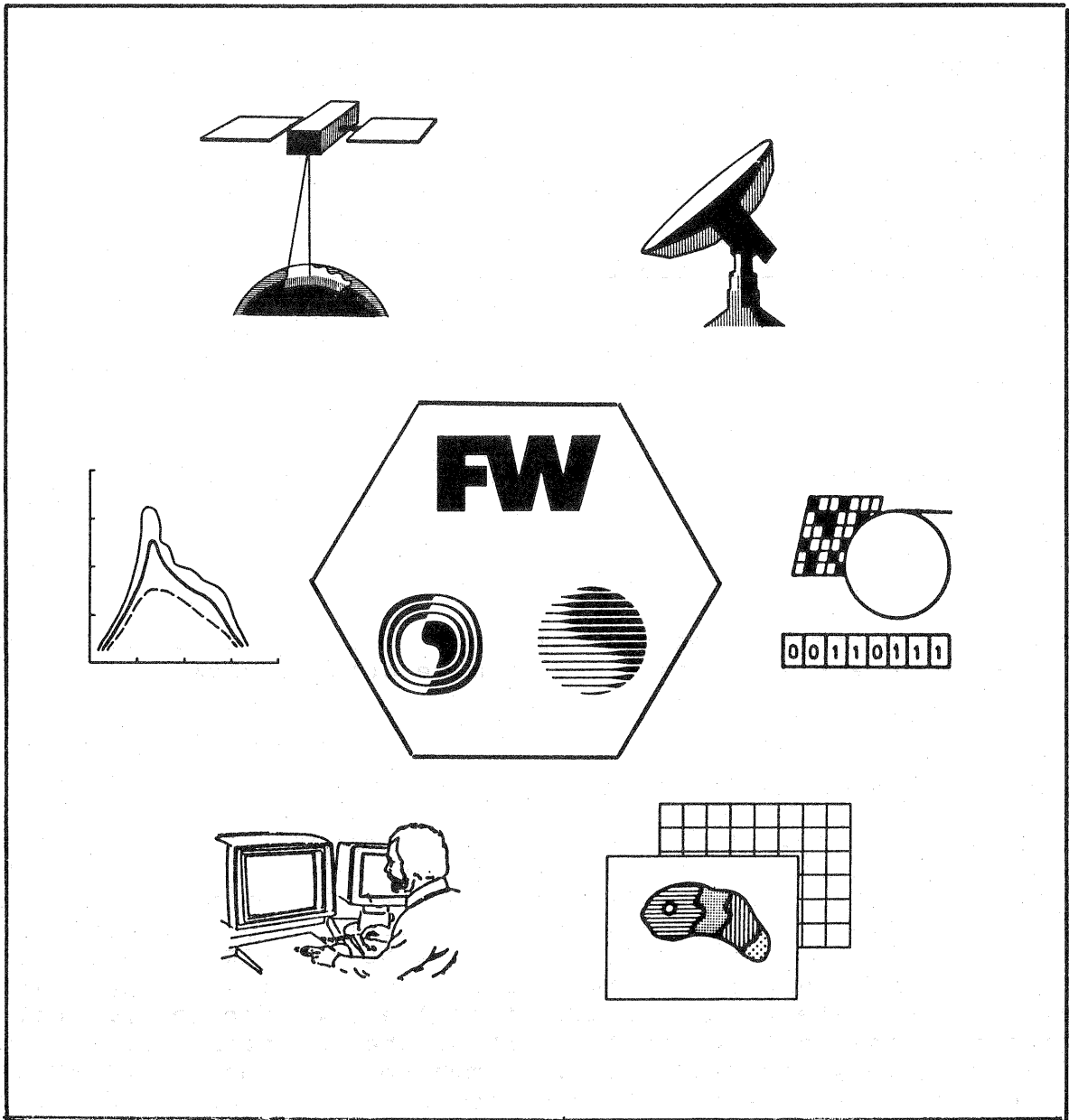


Figure 1. Illustration showing the different elements involved in the snow-cover mapping project. From top left and clockwise: Satellite remote sensing, data reception at ground station, transfer of data, geometrical rectification and cartographical presentation, digital image processing and analysis, hydrological modelling and preparation of run-off hydrographs. Note the logos of the participants in the project in the central hexagon; in addition to Fjellanger Widerøe, Norwegian Hydrotechnical Laboratory (lower left) and State Power Board (lower right).

set is then transferred to a Context Vision GOP-300 image precessing system, also located at the NCC. On this system the digital image is geometrically rectified, subareas covering the actual catchment-areas are defined and eventually the images are interactively analysed in order to obtain the distribution within the catchment areas of the percentual snow-cover. In this last part of the image analysis procedure, an experienced hydrologist contributes to the analysis, resulting in a clearly defined linear relationship between pixel-values and percentual snow-cover. The image processing procedures mentioned above, are described in more detail in the paragraphs following below.

In the final processig stage, the snow-cover data is transferred via a diskette to a PC-system in order to be used in hydrological modelling together with terrain elevatation data. PC-based software is also used for generation of snow-cover line maps (in black and white), well suited for distribution by telefax to the different hydro-electric powerplants for which the melt-water from the mountain areas will play an important role.

Geometrical rectification.

NOAA AVHRR data is normally delivered from TSS without any geometrical correction. Initially an attempt was made by FW to correct the imagery by using the image to grid rectification module included in the ARIES-II software package. With this module it is possible to save the map coordinates defined in a rectification process. The idea was that the same map coordinates (i.e. the same set of GCP's) could be used for different images (from different dates) but covering the same area. In practice, it became clear however, that this did not work out quite well. GCP's which could be defined well in an image acquired at one date, could in some cases be rather difficult to define in an image acquired at another date. It therefore seemed to be a need for a more flexible solution.

Image to image registration would represent such a flexible solution, assuming a sufficiently good quality of the reference image. Some attempts were made with a NOAA AVHRR image already rectified by input of UTM coordinates. This image was however deemed to have inadequate quality for the purpose. The idea of using Landsat MSS data to generate a "synthetical" 1 km resolution image was then tested out with good result. As input for the "synthetical" image was used part of a digital Landsat MSS based mosaic covering the whole of Norway, which had formerly been produced for FW by NRSC/RAE at Farnborough in the UK. The resolution of the mosaic is 300 x 300m and it is geometrically corrected to UTM zone 32. The 300 x 300m resolution mosaic subarea was transformed to a 1 x 1 km reference image, located in such a way that the pixel centers coincided with the nodes in the UTM 1 km grid. Since the MSS based mosaic had already been transferred to the UTM grid, a first order polynomial was used for the transformation. The coefficients of this polynomial was determined by selection of

ground control points. Figure 2 gives an illustration of this procedure, and Figure 3 shows the relationship between the line/pixel coordinates and the UTM coordinates. When this registration or georeferencing had been obtained, thematic image files with masks defining the different catchment areas of interest could be produced without difficulties. Terrain elevation for each node in the UTM grid was obtained from the State Mapping Authority in digital raster format. In this way, the satellite data, the terrain elevation data and the mask defining the actual catchment area could be considered as different features in a raster-based geographical information system, and then be used further in connection with the hydrological modelling.

Determination of percentual snow-cover.

The basic idea behind the NOAA AVHRR based snow mapping is that a relationship between pixel-value and percentual snow cover can be established. The method used to establish this relationship is rather straightforward and simple. Never the less, experience so far has shown that the method is sufficiently accurate for the purpose. It is assumed that there in the near infrared channel (channel 2) of the NOAA AVHRR data exists a direct linear relationship between pixel value and percentual snow-cover. By determining with interactive image analysis the pixel value in areas where the snow-cover is 100% (upper parts of glaciers are well suited for this purpose) and areas where the snow-cover is known to be 0%, the relationship can, because of the assumed linearity, easily be established. When the 0% snow cover reference pixels are selected; it is of great importance that these pixels are taken from areas with a "background-reflectivity" similar to the "background-reflectivity" in the partly snow-covered areas.

Use of the data in hydrological modelling.

As soon as the pixel-value/ degree of snow-cover relationship is established, the original pixel-values can be used as input in the hydrological model together with the coefficients in the linear transformation equation. It is also possible to use the transformed pixel-values (i.e. the percentual snow-cover) directly in the model. The model then uses the terrain elevation data to calculate the average degree of snow-cover within selected height intervals. Together with meteorological data this information eventually results in a run-off hydrograph.

Cartographic presentation of the results.

When the pixel-values have been transformed to percentual snow-cover values, it is very easy by the aid of a digital image processing system to perform a pseudo-colour density slice on the data. In the project the following intervals were used in connection with the cartographic presentation: <10%, 11-30%, 31-50%, 51-70%, 71-90% and >90%. In this way a "nice-looking" colour image can be easily produced on the colour monitor of the image display system. A requirement which was heavily stressed by the State Power Board, was that the result in cartographic form could be quickly distributed to the hydroelectric powerplants. If these plants had been equipped with digital image processing facilities linked together in a network, the image distribution task could have been very easily solved. As this was not the case, the snow-cover maps representing the final result of the presentation-oriented process, had to be distributed to the powerplants by ordinary telefax equipment. Such equipment is not suited for transfer of colour imagery. The solution of this problem was to represent the snow-cover map as a black and white line-drawing, with different patterns representing the different snow-cover classes. An example of such a map is shown in Figure 4. A map like this is generated in the following way:

1. The classified data, (6 snow-cover classes) is transferred via a diskette to an Amstrad PC1512 system providing the GEM software facility.
2. The classified image is then represented in colours on the screen of the PC-system. By using the cursor, which is controlled by the system's mouse, the boundaries between the snow-classes are interactively defined. (This process can be considered as a vectorization process).
3. The modified image, now consisting of the boundary lines only, is captured and treated further by the interactive CAD-like software GEM PAINT. With this software it is rather easy to fill the areas corresponding to the different classes with selected patterns. It is also possible for the user to edit the patterns, such that the best possible result for a certain application can be obtained. When a satisfactory map is shown on the screen, a hard-copy can easily be produced and brought to the telefax for further transmission.

The State Power Board has also expressed interest for the possibility of storing the snow-cover maps in digital format on diskettes, and display the maps in colours by the aid of ordinary PC-equipment. The PC1512 in combination with the GEM software, offers a possibility to solve also this problem in a rather straightforward way.

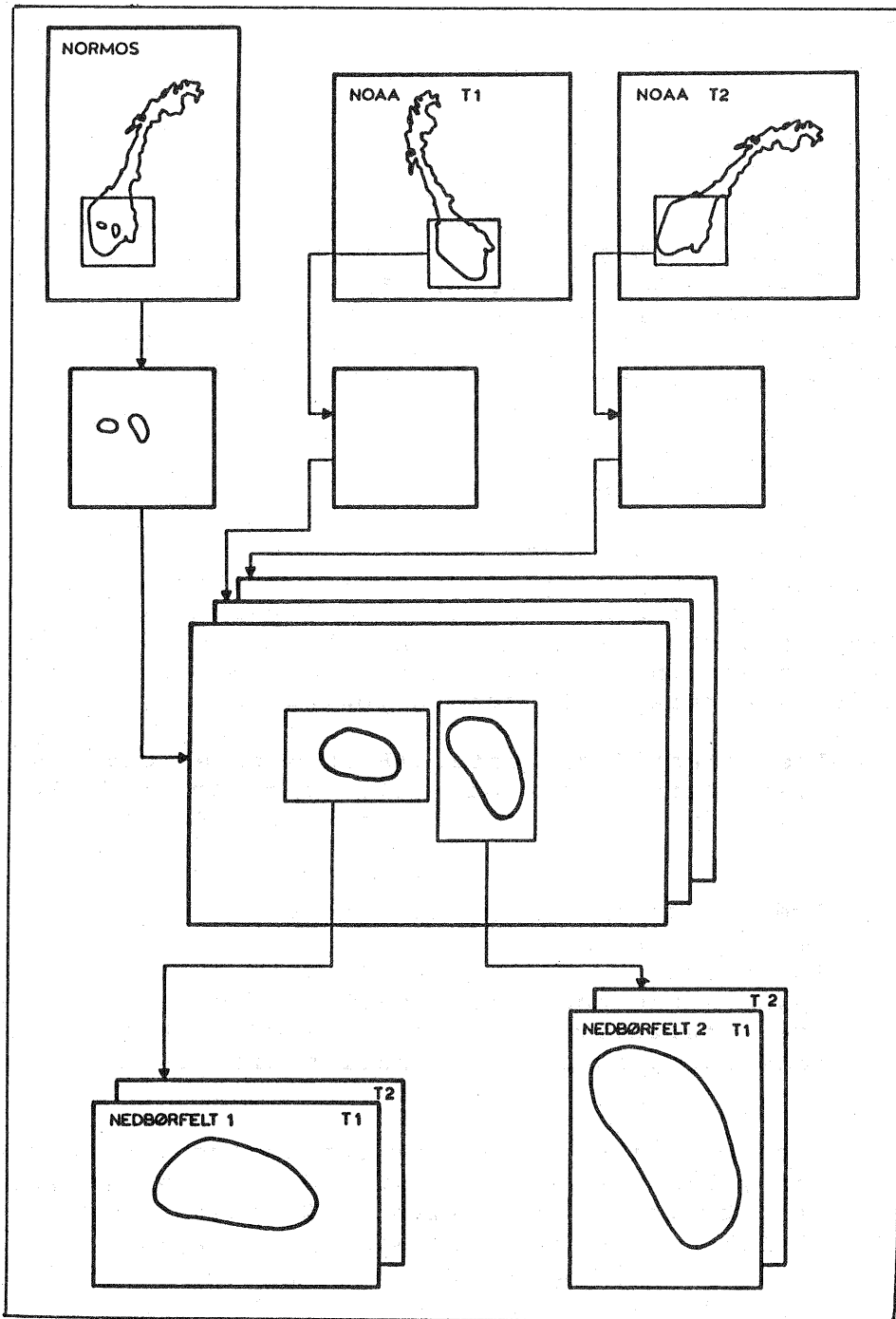


Figure 2. Illustration showing how the digital mosaic derived from Landsat MSS data (here denoted NORMOS) was used as a basemap in connection with the rectification of the NOAA AVHRR imagery. T1 and T2 denotes different times. "NEDBØRFELT" is the Norwegian word for catchment area.

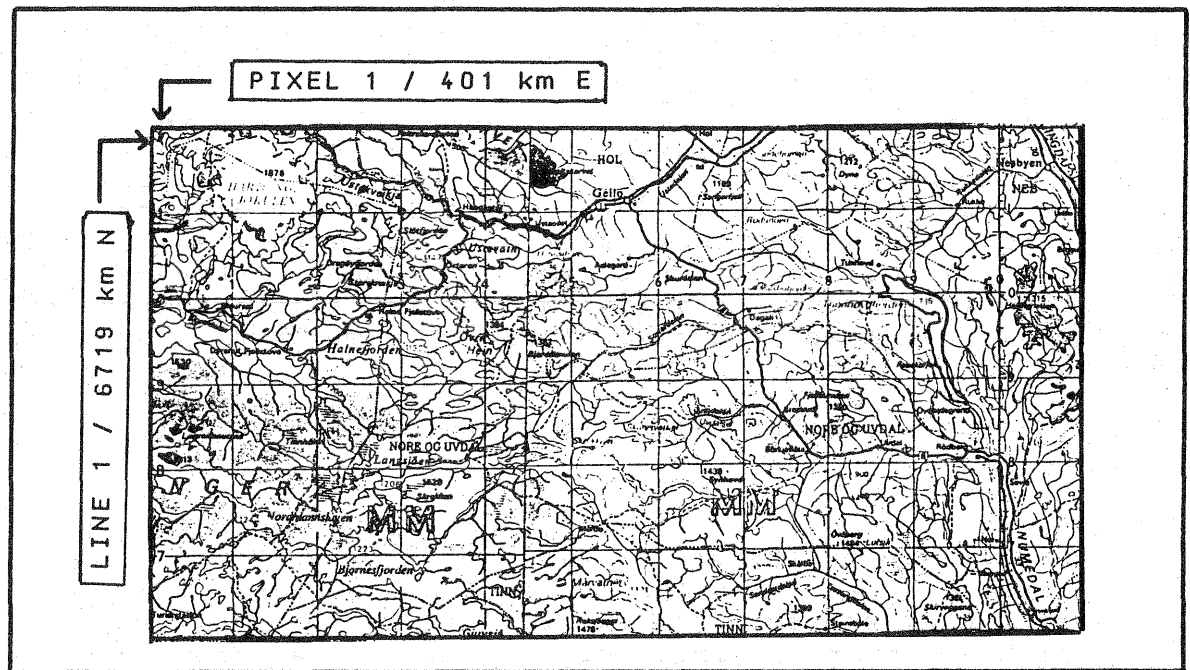


Figure 3. Map covering the catchment area "Nore". This map is to be considered as an image with 60 lines and 110 pixels. In the local reference system, the pixel in the NW corner is denoted 1,1. The central point of this pixel has the position 401 km E, 6719 km N in the UTM zone 32 coordinate system.

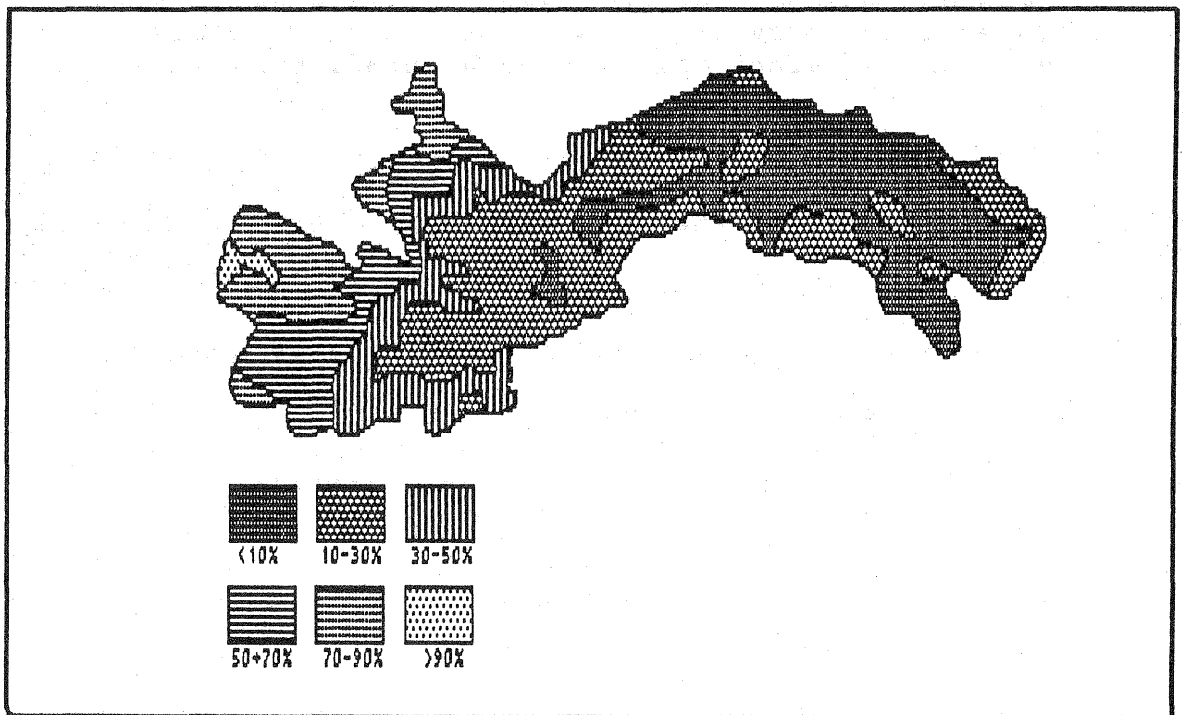


Figure 4. Map showing the distribution of snow-cover classes in the catchment area "Nore" produced by unsophisticated PC equipment.

UNFORESEEN PROBLEMS AND PROBLEMS REMAINING TO BE SOLVED.

The initial intention was that a certain level of operationality should have been reached during the snow melting season of this year (1988). Due to technical problems with the computer equipment both at FW and the NCC in this period, the situation as of May 27. 1988 is that preparation and distribution of the the snow-cover map within the "quasi-real-time" limit of 24 hours has not yet been achieved. The procedures are however established, and it is anticipated that some "quasi-real-time" operations will be completed during the remaining part of the melting season.

The intention with the project is also to go in depth with the following issues:

To test the accuracy of the pixel-value/snow-cover relationship by the use of Landsat MSS and SPOT HRV reference data. (On the 16. of June in 1986, the NOAA AVHRR sensor, the Landsat MSS sensor and the SPOT HRV sensor acquired cloud-free data from a mountain area in South Norway practically at the same time. These interesting data-sets are now available to the project).

To develop methods for correction of illumination-differences caused by the orientation of the terrain surface.

To develop methods which makes it more easy to differentiate between snow - covered and cloud-covered areas, since this can be a problem in some images.

The aim is to accomplish the snow mapping project within the present year, 1988.

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