THE APPLICATION OF ERTS IMAGERY TO MAPPING SNOW COVER IN NORWAY

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Final Report

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HYDROLOGICAL INVESTIGATIONS IN NORWAY
MAPPING OF SNOW-COVER

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15. Abstract

ERTS images taken over a selected drainage basin in Northern Norway were used to delineate snow lines during the melt season. Image enhancement was made by density slicing with Agfacontour Professional film.

It is concluded that there is no clearcut snowline but snowcivered areas can be fairly accurately mapped and these maps can be put into operational use. The best suited concept is percentage of snow cover within a given basin.
Contour-lines can be made photographicaly around water bodies, along snow-line and at intermadiate points in snow-cower.
Results are useful for water power management.

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OBJECTIVES AND BACKGROUND

Background for snow surveys

The Norwegian Water Resources and Electricity Board (NVE) produce annually 18.000 GWh or 30 per cent of the electric energy in Norway, and operates 40 hydro-electric power-plants in the country.

Snow sampling is made in selected points on a routine basis within all major catchment areas. A programme is being developed to use the reduction of the natural gamma radiation from the ground, recorded from low-flying aircraft. The reduction in such radiation is directly related to the water content of the snow cover (and of soil moisture).

These methods are useful in areas of thick snow cover, but other methods must be used in the melt season to determine the snow cover and the probability for flood damage.

The regular snow-surveys are made in the first week of February and the first week of April.
The winter-production of power and the draw-down of the reservoirs start in November. When the result of the first snow-survey is avaiable in February the first corrections in the production plans are made, and production is divided between the power-plants in the different areas of the country relative to their snow-reservoir and ability to take care of the water during the following summer.

This means that a power-plant with a large amount of snow in February will get a high load and be asked to make room in the reservoir for the expected high snowmelt. The plants with little snow will aim at a low production in the months February thru July. This direction of production takes place in a free market with buyers and sellers, and is possible due to a well developed network of power-lines.
When the result of the snow-survey in April is avaiable new production-plans are made and the load on the different power-plants is reconsidered.

From the melting starts at about May 1. and is complete on August 1. no information can be collected on how the melting takes place. Some years a large amount of water may disappear due to evaporation or filling up of the ground-water reservoir. In this period precipitation is of course recorded and corrected for in the production plans.
But the main problem is that for three months no information is avaiable on what happens to the snow-reservoir.
We feel that if the snow-cover can be photographed from space at certain time intervals a new tool will be avaiable to solve this problem.

In the spring of 1973 low-flying aircrafts had to be used to take oblique pictures from certain basins to determine the amount of snow that was present in the basins, because large amounts of water then stored in the reservoirs had to be routed past the power plants to make room for the expected inflow, to avoid flood damage later in the spring.

Later, when the ERTS images arrived, it proved that they would have been a great help in the planning and decision process, and much of the flying time could have been saved.

It is obvious that images from operational satellittes will be a very valuable tool, and we are now preparing an operational warning system based on remote sensing. We feel that if a receiving station is put into operation in Norway, this can be accomplished.

Test area

In the selection of a test area for the ERTS experiments it was found that an area located in the middle of the country at 66 degrees north was best suited. The work has been delayed because data were not received until late summer 1973. None of the images taken in 1972 could, unfortunately, be used in the work. The material used was collected on ERTS-overflights in the time period June-July 1973.

The test area is the catchment basin for the Upper and Lower Rössåga power plants. The main data are as follows :

Total head	360 m (1181 ft.)
Installation	410 MW
Annual inflow	2990 Mill. m^3 (242.000 acrefeet)
Reservoir capacity	2582 Mill. m^3 (209.000 acrefeet)
Annual production	2470 GWh

The catchment basin has an area of 2114 km^2 (522.000 acres) and a mean elevation of 480 metres (1570 ft.) above mean sea level stretching from 380 to 1400 metres. 5% of the area is covered by the glacier Okstindane. There are a few farms spread around the main reservoir Lake Rössvatn, and there are two meteorological stations in the area, named Tustervatn and Krutaa.

NVE runs approx. 50 snow courses in the area, the water equivalent of the snow pack is determined by conventional gravimetric methods. The inflow into the reservoir from snow-melt is predicted from the snow course data.

The catchment area is a rolling mountain terrain without forest. During the melting of the snow-pack a certain strand-zone is being developed parallell to the shoreline of the main reservoir (elevetaion 380 metres above sea level), and this zone will soon dry up. Above this belt we have an area of wet ground, with only small patches of snow, and wet ground where the snow has just melted but the water has not yet drained away.

Fig. 1 : Oblique air photograph of the snow cover in the Lake Rössvatn basin obtained from lowflying aircraft on June 15, 1973. The banded area of the snow cover is in general located close to the storage reservoir, with an area of partly melted snow and, finally a continuous snow cover at higher elevations. There is definitely no clear-cut snowline!

Fig. 2. Image 1332-10015, MSS 5, contoured at gray-scale level 6 and 10 by the use of Agfa Contour Professional film. Level 10 gives the "snowline" and level 6 delineates the thickest snow cover within snow-covered areas.

The next belt is partly covered with wet snow, and above this we find a continuous snow-covered area with only the highest points bare-blown. Incoming radiation melts the snowlayers from the top and water percolates down making the snow layers isothermal and wet. There is no run-off from the bottom of the snowpack until this saturated situation has been reached.

When the snow cover has been reduced to about 60 centimetres (2 ft.) the sun radiation will start to pass through the snow, so that dark soil is heated and the snow-pack begins to melt from the bottom as well.

There is some loss of water due to evaporation, but also some water gain due to condensation on the surface, but these processes have not been studied in detail.

The snow situation during the spring 1973

This year we had an unusual situation because the reservoirs contained as much as 68 percent of their total capacity, whereas they would normally contain only about 20 percent at this time of the year, i.e. when the snow melt starts.

Already in February we got the first indication that unusually large amounts of snow had accumulated in the basin and that this would create a problem later in the spring, see later.

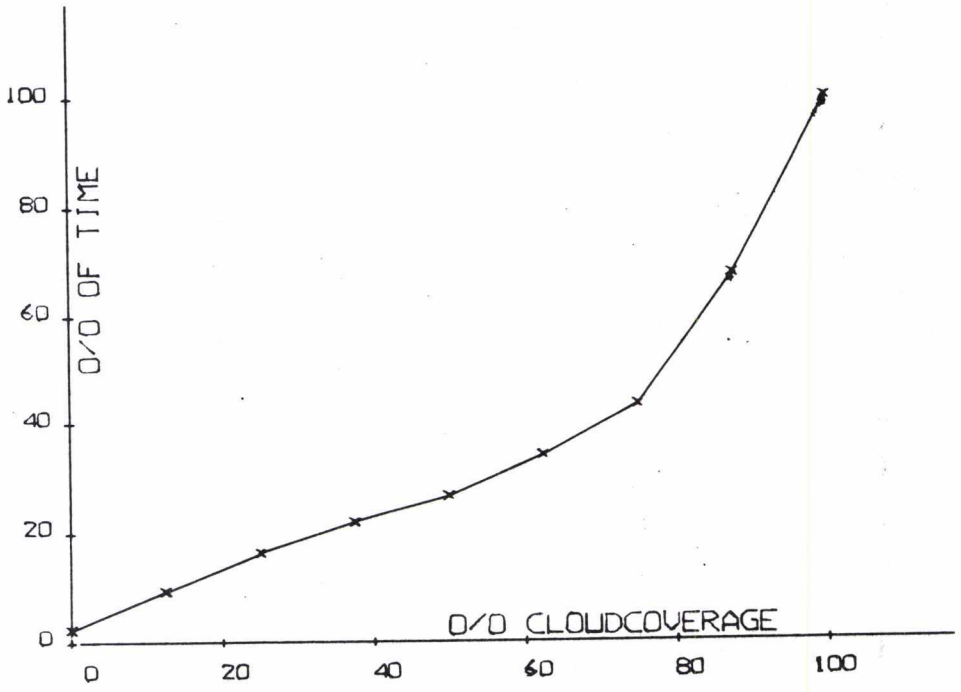

Fig. 3 : Percent cloud cover as recorded at Nerdal meteorological station at 7 a.m. during the period January 1 - August 1, 1973. Only 25 percent of the time the sky had 50 percent or less cloud cover.

The main snow survey was done in April in 44 points. The survey indicated a precipitation of 140 percent.

The unusual hydrologic conditions described above made it necessary to route a considerable part of the stored water past the power station and down to the sea without using it for power generation. This was done because one did not know the melt situation in the mountaineous and remote parts of the basin. It was a risk that if large amounts of snow melted rapidly, the melt water would overfill the reservoir and flood damage below the dam could be a result.

In general, a better knowledge of the snow situation in remote parts of the basin would have made possible a better management of the stored water, and a great part of the "lost" water could have been used for power production.

Snow-line determination

The following ERTS images were available for the study

Date	ID Number
May 16, 1973	- 1297 - 10080
June 2, 1973	- 1314 - 10021
June 20, 1973	- 1332 - 10015
July 8, 1973	- 1350 - 10014

Snow accumulation starts in the fall at the highest points in the landscape, and it was believed that the highest mountains would carry the heaviest snow cover. If this was the case, ERTS images together with point readings of snow depth and density could give a good indication of the total amount of snow stored in the basin. To check this, all separate point-measurements of water equivalent was plotted versus elevation in a diagram (see Fig. 4). The graph indicated that no such relation seems to exist, and the theory had to be discarded.

In this part of the world, the winter snow covers the landscape almost completely down to sea-level and there does not exist any snow line (border between covered and uncovered ground) in the catchment area. It seems therefore that it is not possible to estimate the total amount of snow in an area of this type from ERTS images before the snow-melt has started, and the snow-line is well above the lowest point in the catchment basin. When this situation has been reached, it seems useful to utilize ERTS images to monitor the snow-melt.

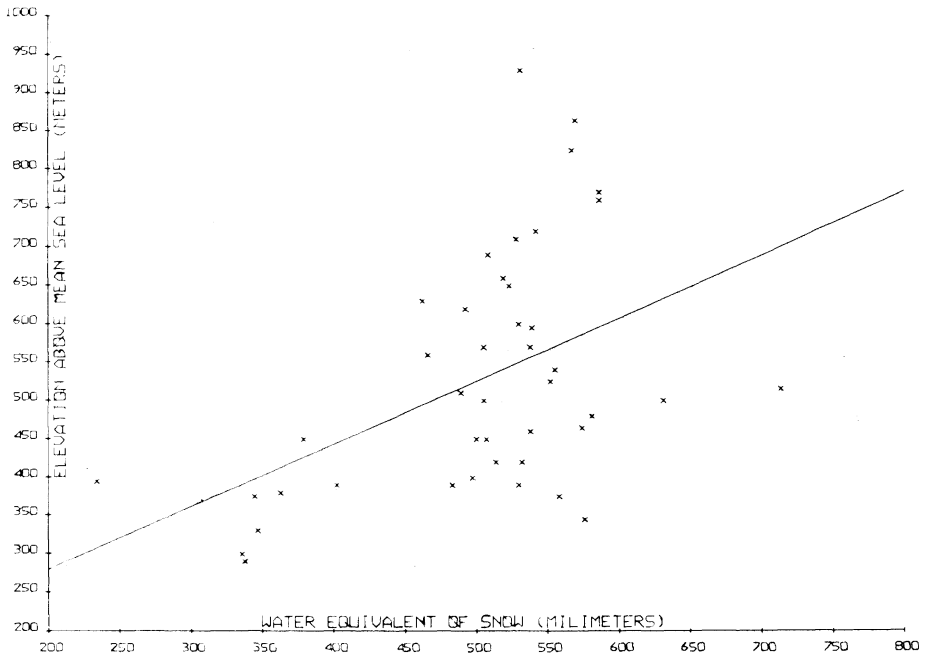

Fig. 4 : Water equivalent of the snow measured at 40 points in the catchment area plotted versus elevation. The points are so scattered that one cannot state any definite relation between snow accumulation and elevation.

TECHNIQUES

Determination of snowline height from ERTS images

The first step was to determine the amount of snow on the ground after the melting had started, and a clearly defined snowline had developed. A hypsographic curve (area in percent as a function of elevation) was constructed for the given basin. From a topographic map (1:100.000) the contour lines at 500, 600, 700, 800, 900 metres above sea level were plotted on clear acetate.

Image 1332-10015 was enlarged to scale 1:100.000 and acetate sheets were overlayed.

From this the mean snowline elevation was determined. Reading off the hypsographic curve this gave the areal extent of the snow cover within the catchment area.

Problems with forest, cloud cover, etc.

It was found that it is very difficult to determine accurately the snowline elevation or the extent of the snow-cover if parts of the area are forested. Therefore, the method is best suited for high mountain areas.

With little snow on the ground it may be difficult to see the difference between old deep snow and a thin layer of new snow. This may be clarified by the use of meteorological data.

The sun angle may also disturb the interpretation, due to unwanted effects of shadows. The problem of misinterpretation due to clouds can be overcome by comparing two images having different cloud cover (or ideally comparing with a cloud-free image).

Work with Agfacontour film

After that the previously mentioned snowline determination had been done, the positive 70 mm film of the same image (1332-10015, MSS 5) was contact-printed on Agfacontour Professional film with yellow filters separating out level 10 (counted on the gray scale, starting from the left).

When this Agfacontour film was enlarged on photographic paper it gave a sharp equidensity contour line around the snow covered area and it unambigously defined its boundary. The area of the snow patches were measured by a planimeter.

The inflow to the reservoir is continuously computed. It is corrected for the precipitation in the melting period. A curve for inflow vs. percent snow coverage was constructed. This curve will be a good help in the future to determine expected inflow and help preventing flood damage.

Work procedure

We have found that the following procedure will give us a "snow-map" from which the areal extent of snow-cover can be determined.

1) Copy by contact-printing positive 70 mm MSS 7 images onto Agfacontour film, exposed with the contour at level 12 on the gray scale. This will outline all the water bodies, and the result is a "base map" which is used to locate various terrain features and for general reference.
2) Repeat the same procedure twice from MSS 5 - positive - onto Agfacontour film. The exposure-time should be selected so that two copies are obtained giving level 8 and 10 on the gray scale.

Fig. 5 Image 1332-10015, MSS 5 with gray-scale levels 5, 6, 10 and 12 superimposed in the same picture.
Water bodies are outlined (level 12) for reference purposes.

3) The three films so obtained are placed in a photographic enlarger standard type. The films are exposed, one at a time, onto photographic paper (preferably a hard type) and sharp contour-lines are thus obtained. We have used a scale of 1:500.000 for this work. Tick marks or special markings made beforehand, are used to ensure correct registration.

4) The catchment area boundaries are plotted onto the final paper-print, from a topographic map.

5) The areal extent of the snow-cover in the catchment basin is measured (with planimeter). The volume of expected run-off is determined from the curve giving the percentage of snow-cover versus run-off.

Corrections have to be made for misinterpretations originating from clouds and possible shadows from steep mountains in early spring.

ACCOMPLISHMENTS

Experience in the selection of gray-scale levels

The interpretation work made until now has indicated that the following gray-scale levels are useful for the snow survey :

a) to form a "base map", containing water bodies (i.e. shore lines, streams, etc.), the gray scale level 12 should be taken from MSS 7.

b) The gray scale level 10 from MSS 5 gives the boundaries of continuous snow, regardless of the thickness of the snow cover.

c) The iso-density line at gray scale level about 6 from MSS 5 delineates areas of heavy snow cover. These are the areas of highest reflectance.

More information about snow-depth may perhaps be obtained by using MSS 7 for the contouring procedure, but this has not been investigated in detail.

Darkroom technique

Several test series have been made with the contour film to determine the best combination of filters and exposure time to give density lines at intervals which yields maximum information.

By the use of a method of this type it is very important to find a procedure which is relatively easy and which leads to a quick evaluation and, finally, which gives reproducable results.

The sharpest density contour line is obtained with a very yellow exposure light. Two filters of the type Agfa Y 99 have been used in our work for contact printing (described above).

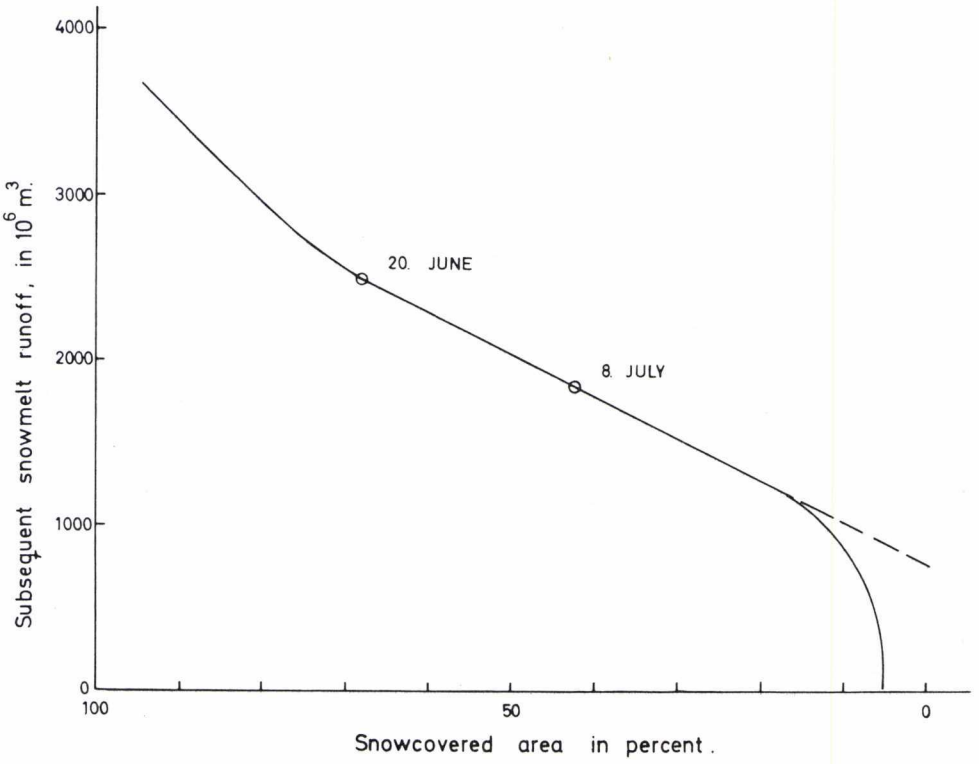

Fig. 6 Subsequent snowmelt runoff as a function of snowcovered area for the catchment basin of Rössåga power plants.

CONCLUSIONS

For the water power authorities, it is desired to find a reliable method to determine the amount of water stored as snow in the mountains in the spring. This is a vital concept for power production and prevention of flood damage. Images obtained from ERTS-1 seems to be well suited for this work. Investigations were made in a test-area in Northern Norway, in the basin "Lake Rössvatn".

Our conclusion is that there is no definite clear-cut "snow-line", which can be easily determined on the ground, by normal field work. The different belts described earlier have been verified by pictures from low-flying aircraft.

For operational use we will in the future, leave the snowline concept and rather use "percentage snow cover" within a given basin.

Experiments with density slicing indicates that the areas of thin snow can be easily distinguished from areas of deep snow, and the areal extent of both types of snow cover be measured. The density-sliced ERTS images can be used to calculate the total amount of snow that is still present in the basin.

This is a most valuable information for the management of water reservoirs, particularly if the potential water yield from the snow is of a critical size compared with the capacity of the reservoir. ERTS images will then, on an operational basis, be invaluable to monitor the snow melt in remote parts of the basin, for the benefit of the week-to-week management of the reservoir during the critical months in the spring.

Cost-effective benefits.

ERTS-data represent a source of information that can not be produced in any other way today.
We have made attempts to collect data about the snow-cover by field measurement on the ground, but has not succeded.
The snowline-elevation is not constant throughout the area but is a function of the prevailing winds during snow-accumulation, exposure to wind, heating from sun etc.
It is also difficult to move around on the snow-surface when it is in the melting stage. It will not carry a snow-scooter or snow-track because of the open space in the snow-layer. All neccessary transport has to take place in the night time when temperature drops below freezing and the snow-surface becomes hard.
For theese reasons it is difficult to observe the snow-line on the ground and make observations.

We have in critical periods been using small planes from local aero-clubs. They will take oblique pictures from a low altitude at certain points, but will not be able to cover the whole area. This makes if difficult to analyze the material.
Use of high altitude aircraft is expensive because they are not avaiable in the area, there is no airports near by that can handle them, and weather conditions will be uncertain.

It is very difficult to determine an economical value for space-acquired data during a critical period and cost benefit data. The yearly production of electricity at the Rössåga power-plants is 2470 GWh (2470 million kWh). If the use of such data could prevent 1 GWh from being spilled and instead routed through the power-plants the value of this increased production of energy is on the first hand aprox. 40.000,- N. kr. ($ 6.000,-). but will have an even higher value for the country. In such a situation 10 GWh could easily be saved for production.

If this volume of water is not taken out of the reservoir before it is completely filled and has to be routed over the spill way at a time with a high inflow to the reservoirs, this could lead to damage which could otherwise have been prevented. The type of damage expected would be erosion and washing out of valuable soil, closing of highway, possible damage to bridge and highway.
It is again difficult to set a value, but it could easily reach an amount of 200.000,- N.kr. ($ 30.000,-).

FUTURE ACTIVITIES

Our continued work in this field will be to determine which snow-depths or the amounts of water content that is represented at the different gray-scale levels, and how MSS 5 and MSS 7 compare in this respect. This requires field observations and simultaneous ERTS overflights.

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IAEA - SM - 129/13, p. 191-210.

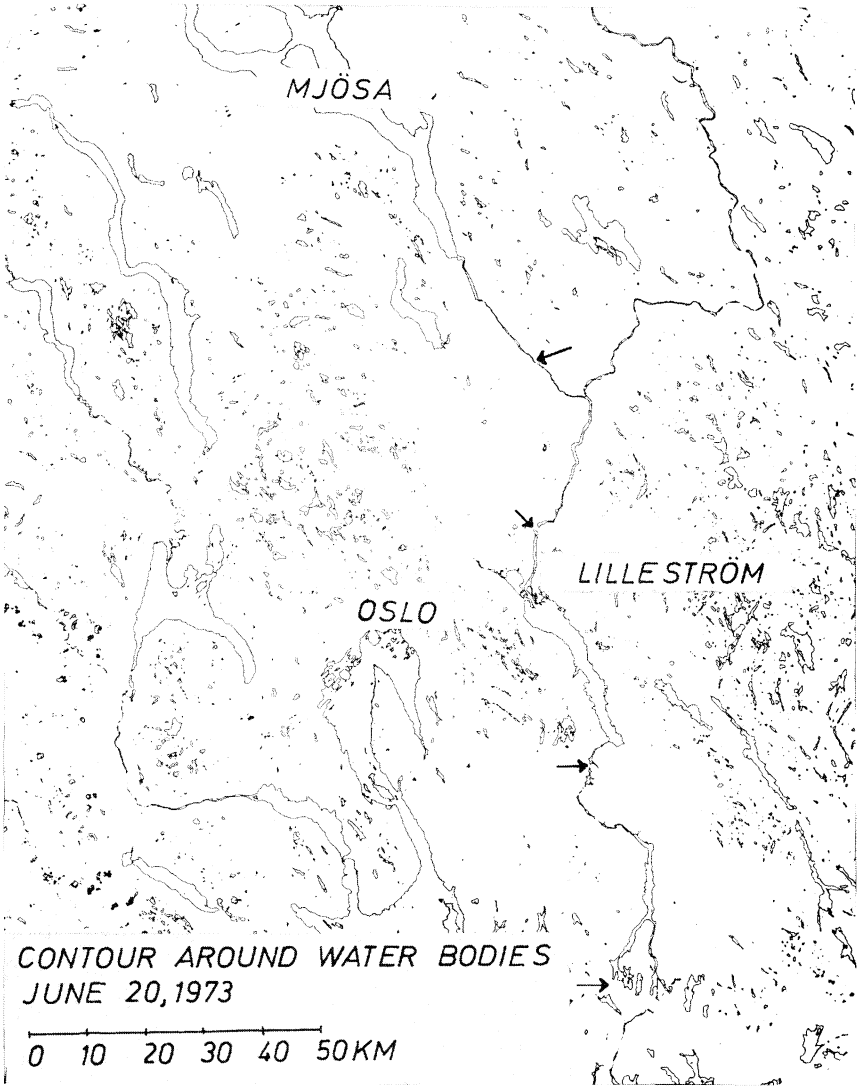

Fig. 7 : Contouring of image 1332-10033, MSS 7 on Agfacontour Professional film. Level 13 on the gray scale surround all water bodies. The smallest rings represent lakes with a diameter of approx. 200 metres, points indicate lakes with a diameter of approx. 100 metres. Arrows point to dams and hydro-electric installations where water is routed through pipes and tunnels.

Fig. 8 : Second-order contouring of image 1245-13412, MSS 7 (March 25, 1973) showing sea-ice between Greenland and Spitsbergen. White surface is snow-covered ice and open water. Dark areas indicate ice where the snow is washed off due to wave action. Arrows point to sun-reflections on water surface. This might be a manifestation of internal waves in the sea with a surface wave length of approx. 25 km.

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APPENDICES

REPORT OF ERTS IMAGERY SHOWING SNOW-EXTENT DECREASE, RIVER FLOODING AND SEDIMENT TRANSPORTATION IN RIVERS, LAKES AND FJORDS.

INTRODUCTION.

In July 1973 the ERTS-investigators at the Norwegian Power Board received the first satellite imagery of Norway taken this spring. At the beginning of October, ERTS pictures covering the period from the middle of May to the beginning of July, have been received. This report is based on 70 mm. film of ERTS images taken during this period.

RESULTS.

SNOW-COVER

Test measurements of some selected sites on ERTS images of Norwegian mountain regions, show that changes in snow-cover can be determined within areas of only a few square kilometers. The information from this type of mapping, can by combination with hydrological data for a given river basin, be used to obtain better and more exact estimates of the water volume stored here.

Beside determination of the position of the snowlines and their motion with time, ERTS imagery is very valuable in observing the break up of lake ice. On images of Norway all stages of ice break up is found.

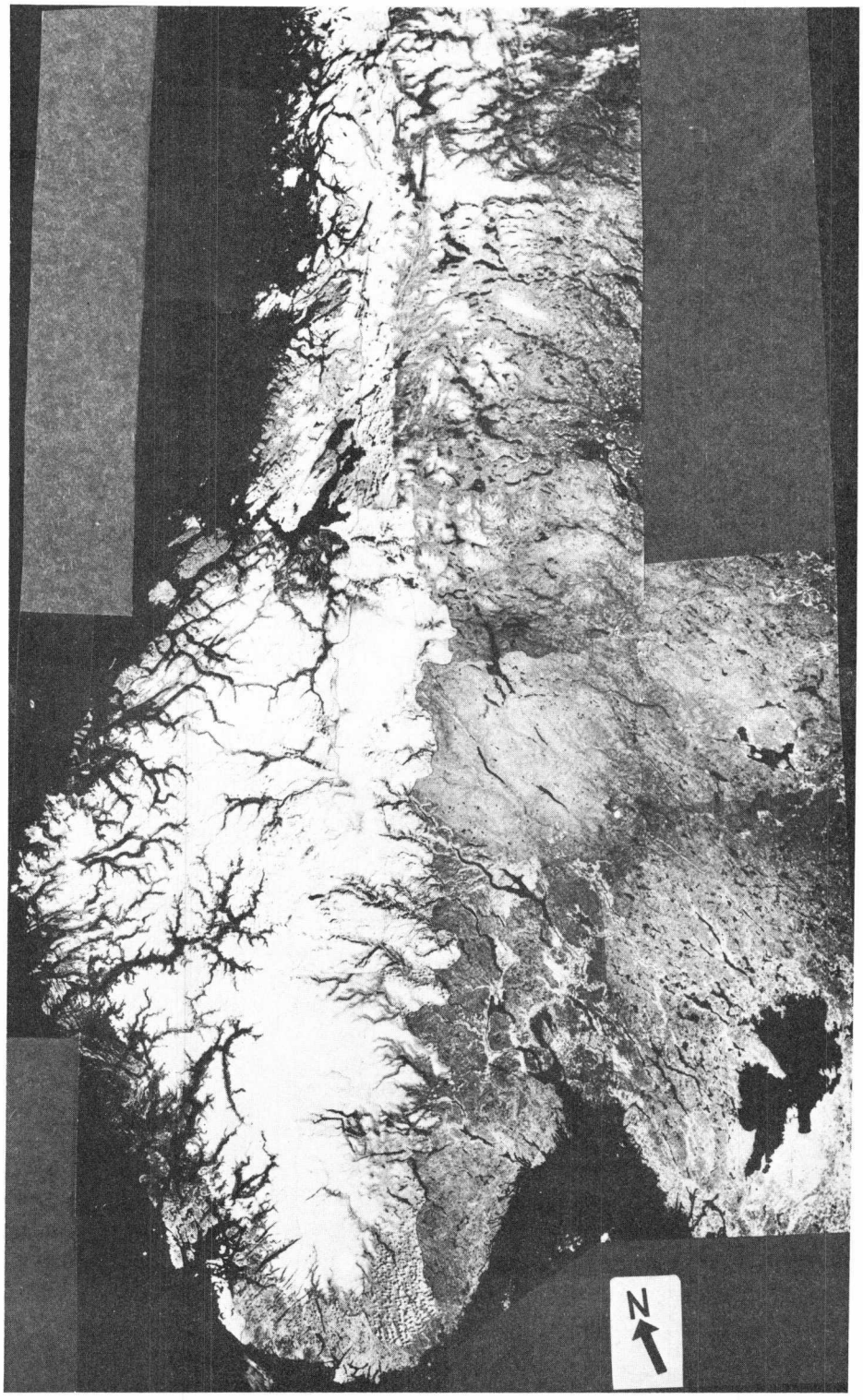

Fig. 1 Uncontrolled ERTS-mosaic of Norway south of the polar circle. The MSS 7 band was used here and it shows the extent of snow-cover during May - June 1973. The mosaic was made by Johnny Skorve.

In some scenes the snow-cover have a rather different appearance in the MSS 5 compared with the MSS 7 band. The MSS 5 is generally best for snow-mapping, but by combining MSS 5 and 7, it is possible to obtain information about where the snow-cover is melting and wet. The MSS 7 band has proved to be of great value in certain cases. With a thin cloud-cover, the snow is conciderably more obscured in the MSS 5 than in the MSS 7 band. By use of the more transparent MSS 7 band, it is possible to determine the extent of snow-cover through thin layers of clouds.

RIVER FLOODING.

Fig. 2 One aprox. 95 x 160 km section of scene No. 1314 - 10032 in the MSS 7 band. This scene is of June 2. 1973. The main inundiated areas shown here are:

1. Tynset - Alvdal.
2. Koppang.
3. Oestamyra.
4. Finstadsjoen.
5. Langsjoen.
6. Gudbrandsdal river near Losna

The coordinates of the picture-center are: 61^{o} 48´N, 11^{o}00´E

Strong snow-melting in the mountains during the latter part of May, 1973 resulted in flooding and extensive inundation in central parts of southern Norway. Figure 2 ERTS I passed over this part of Norway simultanously with the flood culmination. In the Tynset area the flood crest was reached only a few hours before ERTS on June 2. provided a cloud free image of this and other flooded areas in the same part of the country. Scene No. 1314-10032. Being 62°N, the overlapping of the ERTS images is so good that we obtained ERTS coverage of the Tynset area also on June 4. During the following cycle two new ERTS images was taken on June 20. and 22. No. 1332 - 10031 and 1334 - 10141.

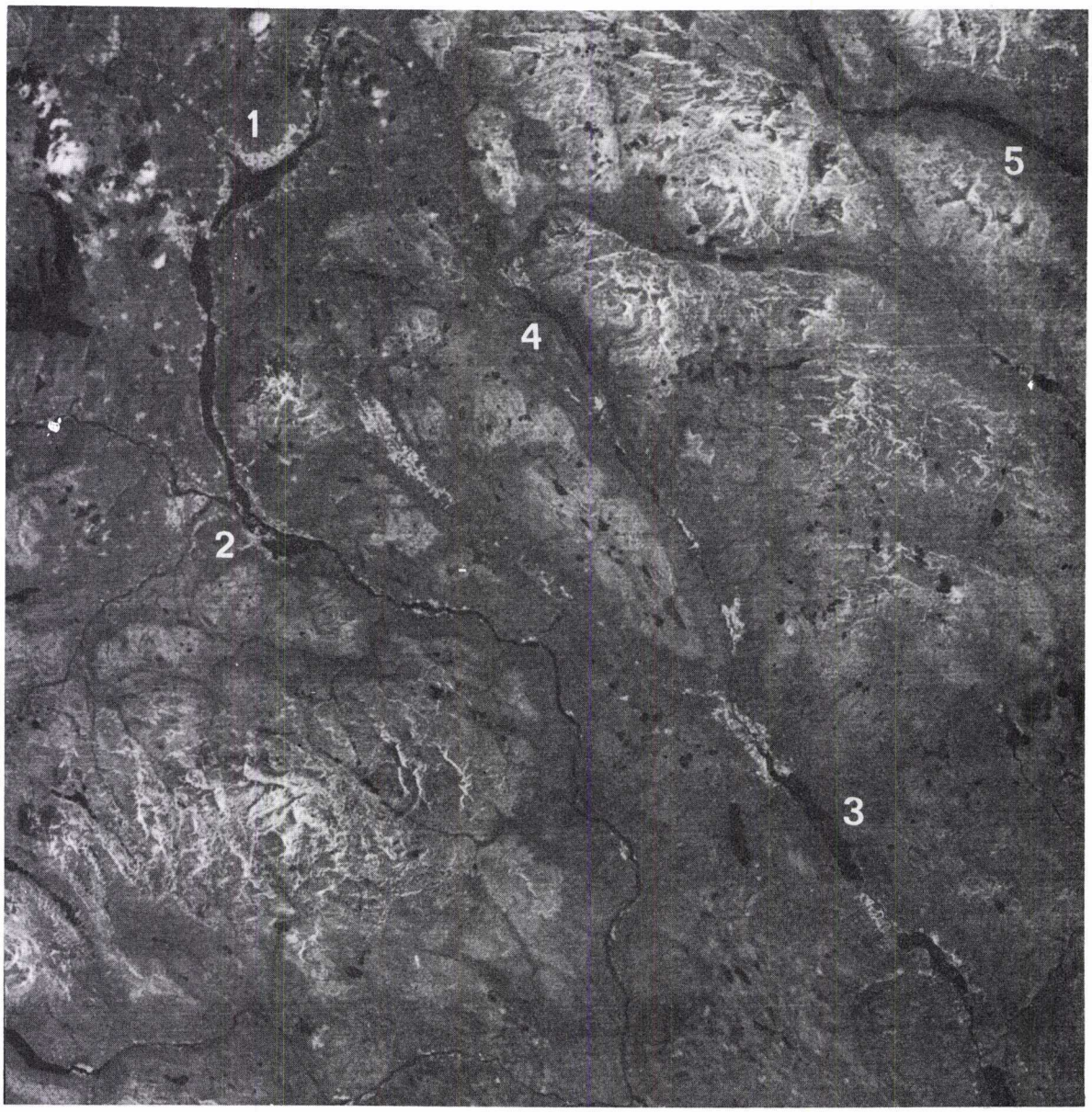

Fig. 3. One aprox. 70 x 70 km. section of scene No. 1314 - 10032 in the MSS 7 band of June 2. 1973. The main inundiated areas shown here are:

1. Tynset.
2. Alvdal.
3. Oestamyra.
4. Lake Finstadsjoen.
5. Lake Langsjoen.

The coordinates of the picture center are: 62°05´N, 10°55´E.
Compare this with scene No. 1332 - 10031 of June 20. of the same area.

At the time of maximum inundation, the Glomma river formed an elongated lake nearly 30 km. long from Tynset to Alvdal. Figure 3. The ERTS image of June 4. No. 1316 - 10142 show a marked retreat of the inundation compared with the situation 48 hours earlier. It is possible to see that the lowering of the water level resulted in the formation of a complicated pattern in the flat areas around Tynset and Alvdal. This is believed to be the highest parts emerging and forming small islands

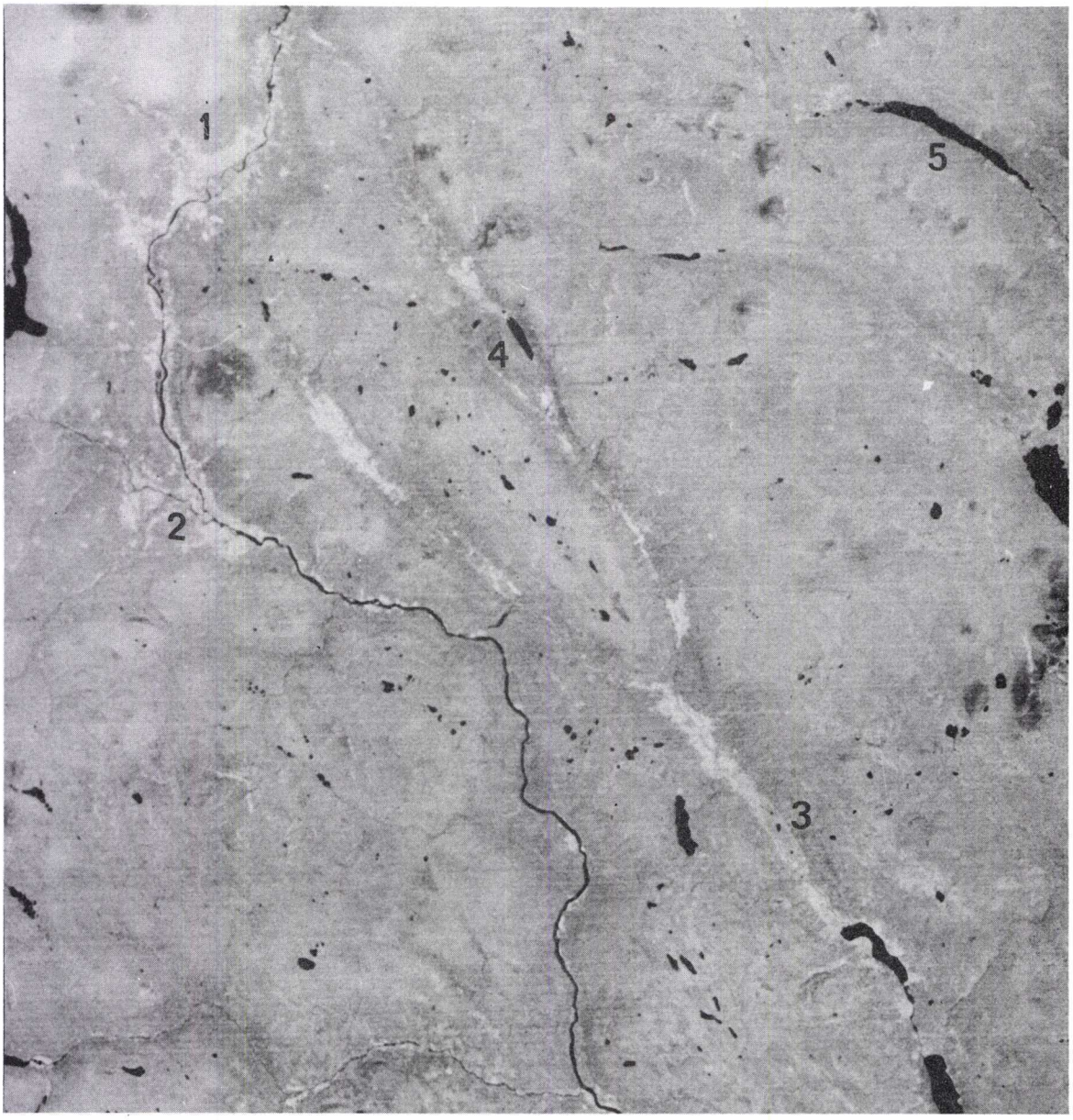

Fig. 4. One aprox. 70 x 70 km. section of scene No. 1332 - 10031 in the MSS 7 band of June 20. 1973.

1. Tynset.
2. Alvdal.
3. Oestamyra.
4. Lake Finstadsjoen.
5. Lake Langsjoen.

The coordinates of the picture center are: $62^{o}05'N$, $10^{o}55'E$.

and peninsulas. The impression from inspection of the ERTS image is confirmed by the following table:

The following measurements were made at Auma, just south of Tynset, at about 08:00 in the morning.

AUMA (TYNSET)	WATER STAGE	DISCHARGE
JUNE 1.	4.33 m	485 m^3/s.
JUNE 2.	4.80 m	647 m^3/s.
JUNE 3.	4.23 m	469 m^3/s.
JUNE 4.	3.93 m	368 m^3/s.
JUNE 20.	2.79 m	132 m^3/s.
JUNE 22.	2.78 m	130 m^3/s.

The flood was not restricted to the Tynset - Alvdal area, in many other places extensive inundation is found on ERTS images taken June 2. The main inundiated areas are:

1. Tynset - Alvdal
2. Koppang, aprox. 80 km. south of Tynset.
3. Oestamyra in the Rena river valley north of Storsjoen lake where a 8 km. long flood lake was formed.
4. Lake Finstadsjoen east of Alvdal, more than dubble its length in the northernly direction.
5. Lake Langsjoen west of lake Femund increased its size conciderably.
6. The Gudbrandsdal river flooded its valley north of lake Mjoesa. The inundation was greatest north of Losna, between Kvam and Ringebu.

With cloudfree pictures from both June 2. and 20., it is easy to compare the situation on these dates. Figure 4 A more detailed study of the flooding as see on ERTS imagery will be initiated. During this phase groundbased and oblique low altitude arial photographs taken during the flood will be used in interpretating the ERTS images.

SEDIMENT IN RIVERS, LAKES AND FJORDS.

ERTS images of Norway taken June 2. show very clearly suspended sediment in connection with the spring flooding. Figure 5 and 6. It is possible to observe variation in the sediment density, distribution and motion.

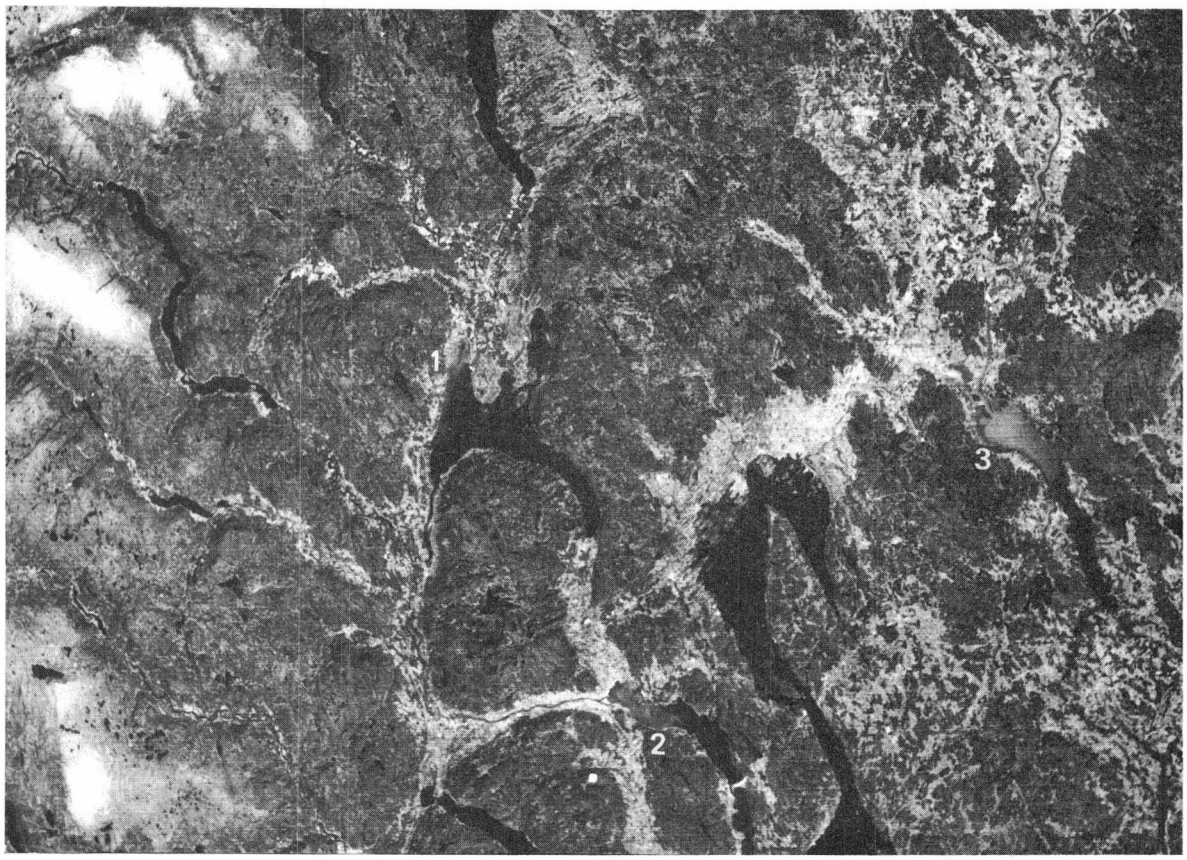

Fig. 5. MSS 5 image of scene No. 1314 - 10035 of June 2. 1973. In this aprox. 95x125 km. section, sediment plumes are clearly seen in:

1. Lake Tyrifjorden.
2. Drammensfjorden.
3. Lake Oeyern.

In the left part of the picture, snow can be seen in the following mountain areas, from north to south:

1. Vassfaret.
2. Norefjell.
3. Blefjell.

The coordinates of the picture-center are: $60^{o}03'$N, $10^{o}25'$E.

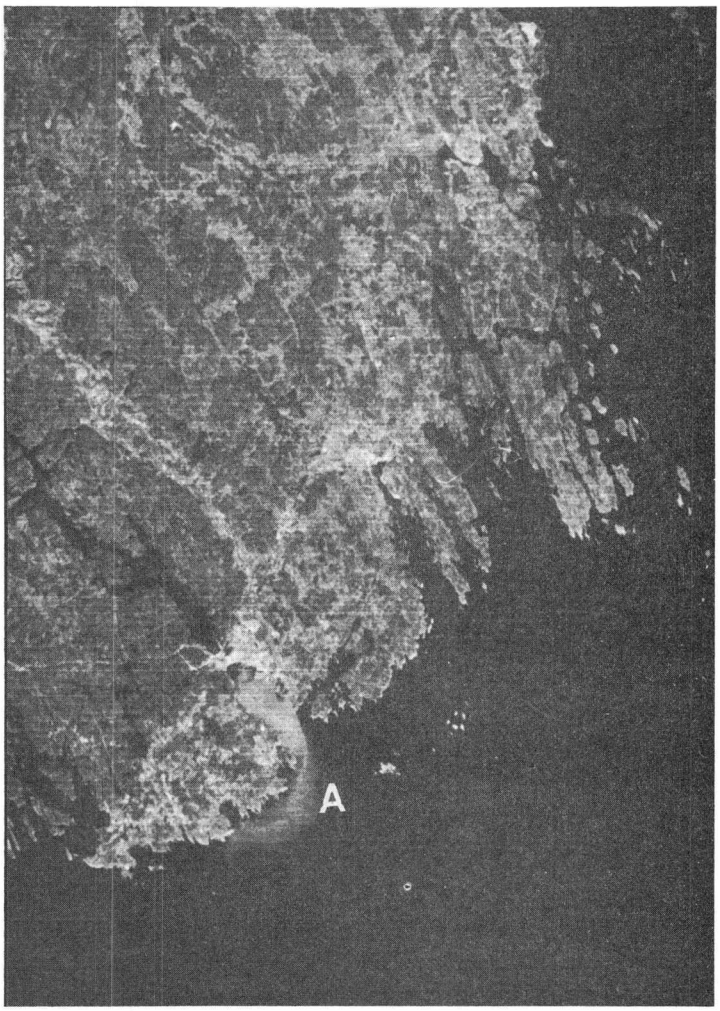

Fig. 6. MSS 5 image of scene No. 1314 - 10041 of June 2. 1973. This 45 x 65 km. section shows parts of outer Oslofjorden and Skagerak.
A is marking the river-plume from Numedalslågen emerging out Larviksfjorden and curving to the west reaching Skagerak.

The coordinates of the picture-center are: $59^{o}05'N$, $10^{o}10'E$.

Major sediment plumes have been detected in the following lakes and fjords:

1. Lake Oeyern, where we find the greatest and most dense plume of sediment. It extends about 12 km. from the mouth of Glomma.
2. Drammensfjorden, where the river plume of the Drammenselven river is about 12 km. long and has a rather complex pattern.

3. Tyrifjorden, where the river plumes from the Storelva and Sokna rivers run along the western shore for about 20 km. from Ask to Vikersund.
4. Larviksfjorden. Here the plume of the Numedalslagen river is filling the whole fjord except for the extreme part just south of the town of Larvik.
   The plume emerges out of the fjord and curves gently about 90 degrees to the west into the Skagerak, and it can be traced for at least 15 km.
5. Trondheimsfjorden. north of the city of Trondheim is filled with sediments but its true extent cannot definitivly be established because of obscuring clouds.
6. Lusterfjorden in western Norway. This is one of the innermost arms of the long Sognefjord. The heaviest an sediment consentration is found in the Gaupne fjord, an arm of Lusterfjord. The Jostedals river is transporting glacial sediment from the eastern side of the Jostedal glacier into the Gaupnefjord. Glacial sediment can also be seen in Tunsbergdal lake in front of the Tunsbergdal glacier.

On ERTS images of June 20. of southeastern Norway, the prominent appearence of river plumes have disappeared, except at lake Oeyern, where the highest concentration is found in the Lillestroem area.

COLOR ENHANCEMENT.

I^2S color enhancement have proved valuable in differentiating between snow and clouds, since certain color combinations give them different colors. Color enhancement has also been used by combining two positive MSS 5 transparencies of the same area taken during two different cycles. Overlapping each other, the two are given different colors and areas that were snow-covered on the first date and free of snow on the latter are highlighted, and its area can be measured.

Observing the breakup of ice on lakes, color enhancement is far superior to the use of single black and white copies. Subtle color differences make it possible to observe in more details the different stages of the ice breakup.

The color enhancement technique has the same advantages when stydying suspended sediment in rivers, lakes and fjords. By such enhancement one can observe smaller differences in sediment densities and more details in the current pattern and motion of the suspended sediment.
By use of Agfacontour film in combination with I^2S color enhancement on a small part of scene 1336 - 10260 showing the Lusterfjord in western Norway, the pattern of sediment densities and distribution are more clearly defined compared with what can be seen on the ordinary image.

Johnny Skorve

ERTS investigator

Oslo, November 9th 1973.