THE USE OF LANDSAT-1 IMAGERY FOR WATER QUALITY STUDIES IN SOUTHERN SCANDINAVIA

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ABSTRACT

In order to find out the possibilities of using LANDSAT-1 images for environmental studies, with special references to water quality studies, test areas in southern Scandinavia have been selected.

The MSS images of different bands are compared under the magnification of an Interpretoscope (Zeiss Jena) and densitometric analyses are performed in a Schnellphotometer (Zeiss Jena).

The possibility of tracing pollution plumes is studied in the Oresund outside Copenhagen. The effect of different sewers and the circulation of the polluted water is analysed in various situations.

The variation in reflectivity of a great number of lakes in South and Middle Sweden is studied by means of densitometric analyses and significant regional differences are found. The correlation with in situ measurements of water quality (turbidity and secchi disc transparency) of the sampled lakes (made by the National Swedish Environment Protection Board) is fair good.

INTRODUCTION

In order to find out the possibilities of detecting and determining quantitatively water qualities by means of LANDSAT-1 data, the sewage conditions of Copenhagen in the Oresund and 161 lakes in South and Middle Sweden have been chosen as material to be investigated.

According to spectral experiments accounted for by Fitzgerald (1972), chlorophyllic water reflects most intensively within the band 0.4-0.6 μm, while industrial water pollutions reach their highest reflection in the band 0.6-0.7 μm. Since solar radiation within the MSS bands 4 and 5 have a higher degree of penetrating power into water than within the bands 6 and 7, the former are probably the most suitable channels for water quality detection. The two latter bands are suitable for the detection of surface water quality only.

The investigation has been carried out at the Remote Sensing Division of the Department of Physical Geography, University of Lund, Sweden, within the NASA sponsored project "Evaluation of Data Utility for Earth Sciences from a Methodical Point of View."

METHODS

All the images of the Copenhagen area which have been obtained within the LANDSAT-1 project, have been analysed in an Interpretoscope (Zeiss Jena), whose zoom construction has admitted an adequate choice of enlargement up to 15 times. The types of images that have been investigated, are paper copies and dia-positives of the standard scale 1:1 000 000, which cover the period September 1972-August 1973. From this material four dia-positives (September 1, September 2, 1972, and May 30, August 27, 1973) have been selected and investigated in a microdensitometer (Schnellphotometer G II with Standard-Kompensationsschreiber GI BI), whereby the grey-tone variations in the water outside Copenhagen have been recorded by the plotter unit. A column width of 1 x 1 mm has been used to obtain the required sensitivity to light. As the densitometer measures the transmission of a projection of a dia-positive, which is enlarged 21 times in the projection, the column at a certain moment scans an area 50 x 50 m. The resolution in the images is usually specified 56 x 79 m. However, when the contrasting effect is very good, the resolution may show considerably higher values. For example, it has been possible to detect elongated harbor piers, belonging to a Swedish west-coast town (Halmstad), 50-20 miles wide.

Then the obtained transmission values have been plotted on an image of the Copenhagen area, enlarged from MSS 7, isarithms have been constructed and pollution plumes drawn. In order that the obtained measurement values of the grey-tone variations may be comparable from one image to another, the densitometer has been calibrated to the grey-tone scale contained in each LANDSAT-1 image.

After having examined Swedish lakes in Interpretoscope, they turned out to vary in grey-tone to a lower or higher degree (Fig. 1-2). Since the production of algae and plankton in the lakes of Sweden is greatest in the summer, as large a number of images as possible of South and Middle Sweden were chosen, partly from the turn of month June/July 1973 and partly from the turn of month August/September of the same year. The imagery was analysed in a densitometer for MSS 4 and MSS 5, and thereby the grey-tone of each lake was measured at 5-10 different points and a mean value for each was calculated. For the period June/July, 113 lakes were analysed in MSS 4, while 161 lakes were examined for the period August/September in MSS 4 and the same number in MSS 5. Also in this case, the grey-tone scales were used in order to calibrate the densitometer in such a way that the test results from different images could be compared.

The obtained grey-tone values have been inserted on a map of the lakes of South and Middle Sweden, after which isarithms have been interpolated. The map is constructed in such a way that areas with lakes of the same grey-tone class are reproduced with the same screen pattern, irrespective of if the area in question is represented by one or several lakes, which means that vast land areas situated between classified lakes have been screened, too.

SOURCES OF ERROR

Since analyses of water quality are best carried out using images from MSS 4 and MSS 5, channels in which smoke plumes, clouds and belts of fog also appear most distinctly, it is self-evident that problems of interpretation and pure errors in measurements may occur. Smoke and cloud sheets, even thin ones, of fairly large extension can, however, be detected by means of comparative analyses of images from different MSS bands (Mattson 1973, Svensson et al. 1974). Thin belts of smoke, clouds or fog of limited extension over a water surface are easily misinterpreted as the grey-tone of the water. But, in general, fog or cloud covered water surfaces are recorded by the densitometer with extremely high transmission values, which deviate very much from those of the surrounding water.

In the cases where images from the same period, which partially cover the same areas, can be used, there are also possibilities of detecting and eliminating the effect of smoke, cloud and fog belts on the test results through the exclusion of the higher transmission values (lighter grey-tones) caused by the above mentioned belts.

As mentioned, it is registrations from the band 0.5-0.7 μm that are analysed in order to obtain information about the water quality. Thus, that which has been recorded is radiation, which has penetrated the water surface to a higher or lower degree and has been reflected from substances in the water, alien and/or produced in a natural way. It is also possible that the bottom of shallow lakes have been registered and misinterpreted as the grey-tone of the lake.

Under certain circumstances, however, water surfaces serve as mirrors and reflect the sunlight totally, which produces sunglitter. This sunglitter stands out, e.g. on an aerophoto positive, as light surfaces on the water. This mirror reflection has been pointed out, among others by Strong et al. (1970) in ESSA-9 satellite photos and has been utilized as an indication of water surface roughness and the prevailing wind speed. Sun glitter of this type, however, is not admitted by the multispectral scanner of LANDSAT-1, since the true total reflection point for higher latitudes lies several hundred kilometers from the nadir and the width of the obtained registrations is only 185 km (Stumpf et al. 1974). A certain diffuse surface reflection may occur, but it makes up such a small part of the total reradiation that it need not be considered as a source of disturbance.

RESULTS

<u>Analyses of the pollution situation outside Copenhagen</u>.- The principal part of Copenhagen's waste water is today let out quite unpurified through two main pipes into the eastern part of Kongedybet at a depth of 6-10 m. The pump station at Strandvaenget, from which the three pipes radiate (in Fig. 3 situated to the north), lets out 14.0 million m^3 waste water per annum, while the corresponding figure for Klovermarksvejen's pump station, from which the sewer situated to the south in Fig. 3 comes, is 40.0 million m^3 per annum (Dackman et al. 1971). The quantity of phosphorous and nitrogen from the respective pipes was in 1973 320 tons and 1000 tons respectively 510 tons and 1600 tons (Environment Committee of the Oresund Board 1974). The two pipes from Strandvaenget which are situated furthest to the north, are day-water sewers and are in use only when the supply of rainwater is considerable.

The pollution situation on September 1, 1972, is evident from Fig. 3. The figures on the plumes indicate the relative transmission, which has been registered by the densitometer on the dia-positive and, accordingly, in a measure of the grey-tone differences within the area. Lighter grey-tones result in higher transmission values. The isolines indicate the distribution and the relative concentration of the pollutions. The other three images that have been analysed show similar conditions, although the spread picture and the distribution of concentration vary somewhat. In general, it can be stated that the plumes on all the images investigated are more or less elongated in a N-S direction along Kongedybet and that the highest transmission values vary between 60% and 80% (Fig. 4-6).

On the images from May 30 and August 27, 1973, there is a very marked plume situated 300-500 miles to the east of the northernmost outlets (the day-water sewers), while the plume at the middle sewer has a very limited expansion. This is interpreted in such a way that the day-water pipes have drained the main part of Strandvaenget's waste water after intensive and/or prolonged precipitation.

Water quality studies of lakes in southern and middle Sweden.- How the difference in grey-tones can vary between two neighboring lakes is illustrated in Fig. 7(cf 1). The diagrams show densitometer profiles drawn over the lakes Vastra and Ostra Ringsjon in Scania for MSS 4 and MSS 5. The transmission values of Lake Vastra Ringsjon (V.R.) are higher than those of the lake Ostra Ringsjon (O.R.). In channel 5, the profiles are more levelled out and the differences between the two lakes are not so pronounced as in channel 4.

The map in Fig. 8 shows land areas with lakes of the same grey-tone class, where the given figures are the transmission values obtained after densitometer analyses. In the hatched area, 161 lakes have been analysed in channel 4 on diapositives from August 26, August 27 and September 4, 1973. Non-hatched areas denote areas where it has not been possible to measure the grey-tones of the lakes owing to too dense cloudiness. The high values in Scania should be noted, likewise those in the area around Lake Roxen and Lake Glan, the Lakes Hjalmaren and Malaren and within an area that stretches down from Lake Vanern towards the area WSW of Lake Vattern. Likewise, the lowest classes, i.e. the area at Bohuslan-Dalsland in north-west and the three areas SE of Lake Vattern.

Then the map can be compared with Fig. 9, which is a compilation by the National Swedish Environment Protection Board of the secchi disc transparency in Swedish lakes. The data basis for this map was collected in August 1972 by the County Administrations of Sweden, who by order of the National Swedish Environment Protection Board and as far as supplies allowed investigated at least 50 lakes in each county among other things with regard to secchi disc transparency, turbidity, color, oxygen content, total phosphorous content, pH and alkalinity (Johansson et al. 1974). Parts of the collected analyses values have kindly been covered by the research laboratory of the National Swedish Environment Protection Board and after continued working up they will be used for comparisons with the spectral properties of the lakes, detected in the densitometer.

A similar image as in Fig. 8 is produced after the analyses of the corresponding material in MSS 5 (Fig. 10). Since more of the radiation reaching water within the band 0.6-0.7 μm, compared with the band 0.5-0.6 μm, is absorbed in the top water layers, the recorded transmission values become considerably lower than the ones within the band last mentioned (MSS 4). Since color radiation within the former band has lower penetrating power into water than within the latter, figure 10 probably reflects to a larger degree the water quality conditions of the surface layers of the examined lakes than figure 8 does.

Figure 11 shows the results of the analyses of LANDSAT images (MSS 4) from the turn of month June/July, 1973 (June 18, July 3) and gives in a general outline the same image as figure 8 except for certain regional differences. Owing to too dense cloudiness over large parts of western Sweden, the measurements are incomplete. It is, however, possible to observe that Scania, the area round Lake Roxen and Lake Glan and the Hjalmaren-Malaren area are depicted with the highest screen classes, while the lowest screen classes can be seen in the Bohuslan-Dalsland-Varmland area. It should be noted that the area to the south-east of Lake Vattern (Fig. 8) which has been labelled with low values, has received far greater extension in figure 11, and that the low values have been replaced by high ones. The differences between the maps can possibly be explained by the fact that the water quality conditions of the investigated lakes probably alternate with the seasons and, therefore, are probably different at the end of August and at the turn of month June/July. Since ground truth information from the latter period is lacking, comparisons between the two maps must be made with certain care.

The results hitherto obtained indicate that there might be a relationship between the grey-tones and secchi disc transparency of the analysed lakes (lighter grey-tones correspond to low secchi disc transparency). Therefore, the grey-tones of the LANDSAT images can primarily be assumed to be a measure of the transparency of the lakes and indirectly a relative measure of the water turbidity, content of algae and plankton on the occasions of the satellite registrations. The transparency of a lake at a certain date can be considered a measure of the biological-chemical conditions of the lake and can probably be correlated to other limnological parameters.

DISCUSSION AND COMPARISONS

Detection of water pollution by means of satellite-borne sensors has been described by among others Watenabe (1973) and Werzenek et al. (1973). Any methodology for a relative analyses or absolute quantification of sewage plumes has, as far as known, not yet been presented in the literature.

Detection of the turbidity and/or chlorophyllic content (algae, plankton) in water bodies has been made in several cases (Bowker et al. 1973, Pluhowski 1973, Svensson 1973). Thus Yarger et al. (1973) has examined the two water reservoirs Perry and Tuttle Creek, Kansas, U.S.A. with regard to grey-tone variations on LANDSAT-1 images and thereby they have been able to find certain connections between grey-tones, quantity of suspended material and secchi disc transparency.

More detailed information about water qualities can probably be derived from LANDSAT data through automation of the procedure of analyses from digital tapes (CCT), whose grey-tone differentiation is almost eight times greater than that of the photographic products (Kritikos et al. 1974). Therefore, at the beginning of 1975, cooperation with the Image Processing Department of the National Defense Research Institute regarding automatic evaluation of MSS computer compatible tapes with respect to information from water bodies was introduced. The results from these experiments are still preliminary and, therefore, only a computer produced microfilm image is presented (Fig. 12). The pollution conditions off Copenhagen on August 27, 1973, are evident from the figure. The grey-tone differentiation of the water has been enhanced and the image has been produced with the help of a Calcomp 835 microfilm plotter.

The possibilities of acquiring continuous information quickly and effectively regarding the quality of different water bodies by means of multispectral images from future operative earth resources satellites are judged to be very good after a further development of existing methods.

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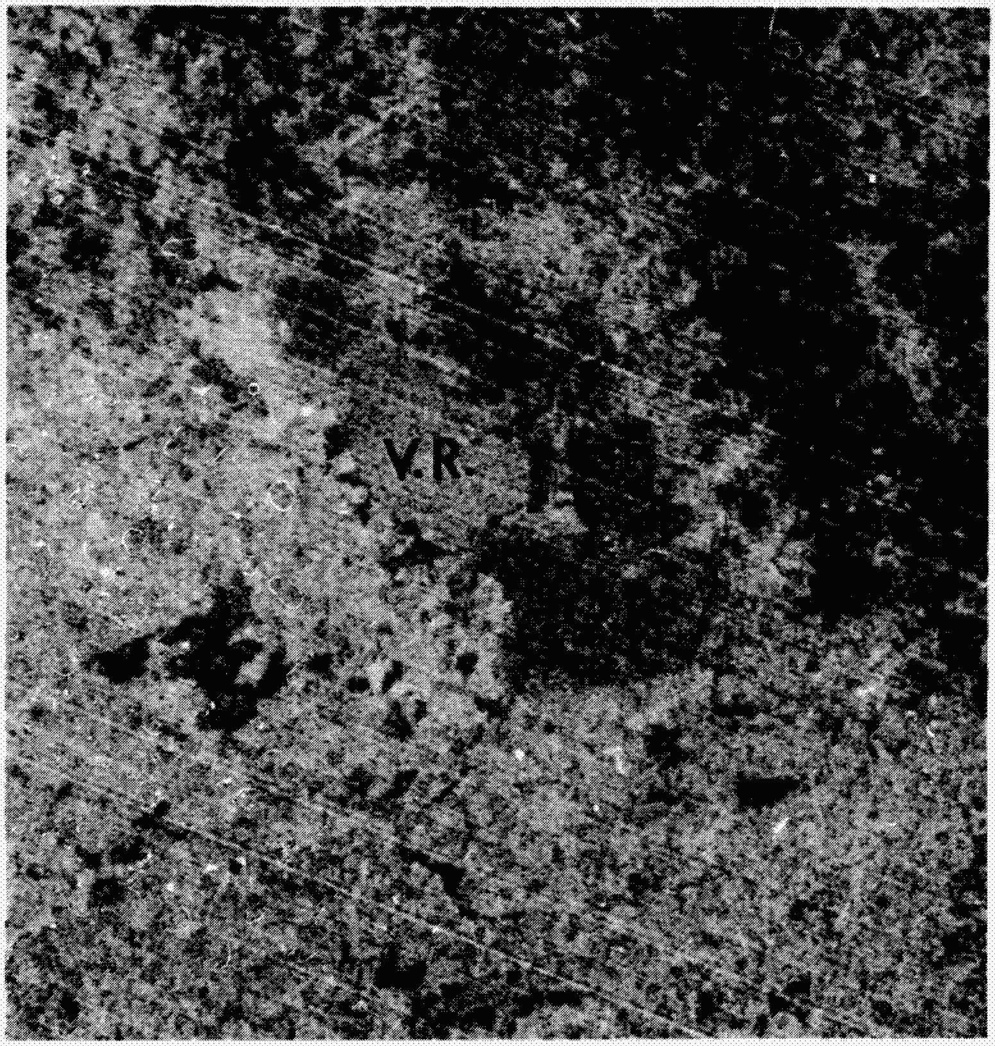

Figure 1.- LANDSAT-1 image (MSS 4) of Lake Ostra Ringsjon (O.R.) and Lake Vastra Ringsjon (V.R.) in Scania registered on August 27, 1973. Appr. scale 1:650,000.

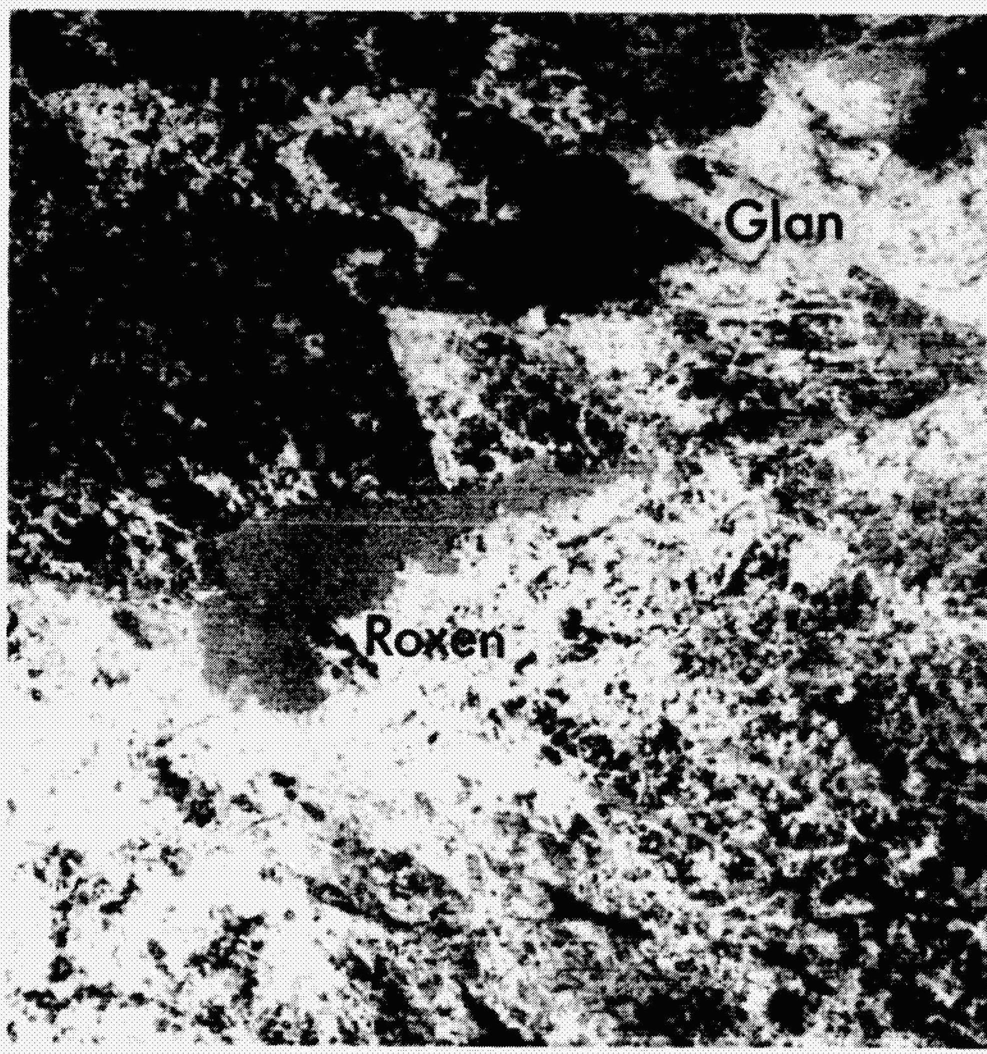

Figure 2.- LANDSAT-1 image (MSS 4) of the Lakes Roxen and Glan in Ostergotland, registered on August 27, 1973. Appr. scale 1:650,000.

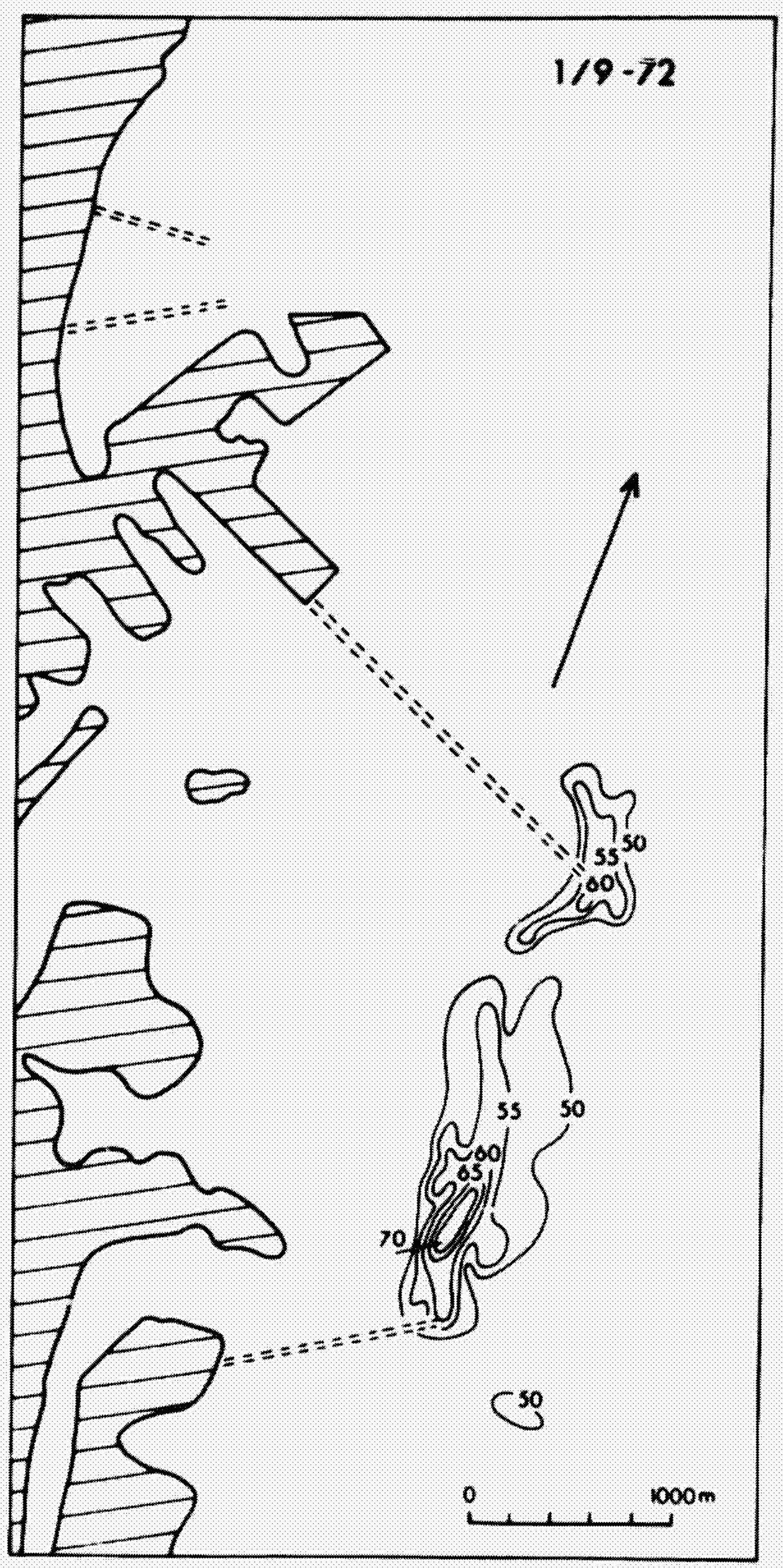

Figure 3.- The pollution plumes outside Copenhagen on September 1, 1972, according to densitometer analysis of LANDSAT-1 diapositive (MSS 5). The figures denote the relative transmission.

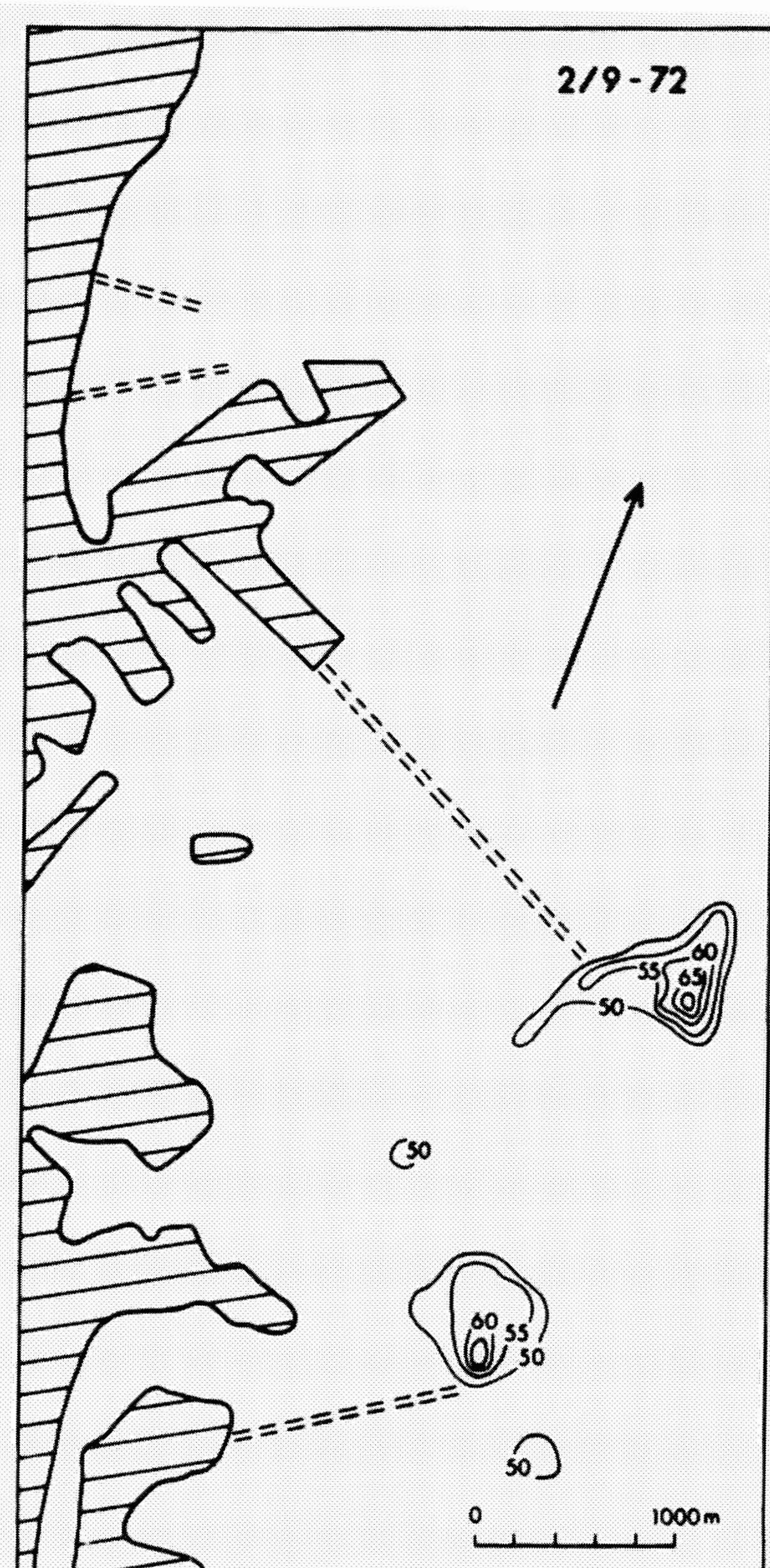

Figure 4.- The pollution plumes outside Copenhagen on September 2, 1972, according to densitometer analysis of LANDSAT-1 diapositive (MSS 5). The figures denote relative transmission.

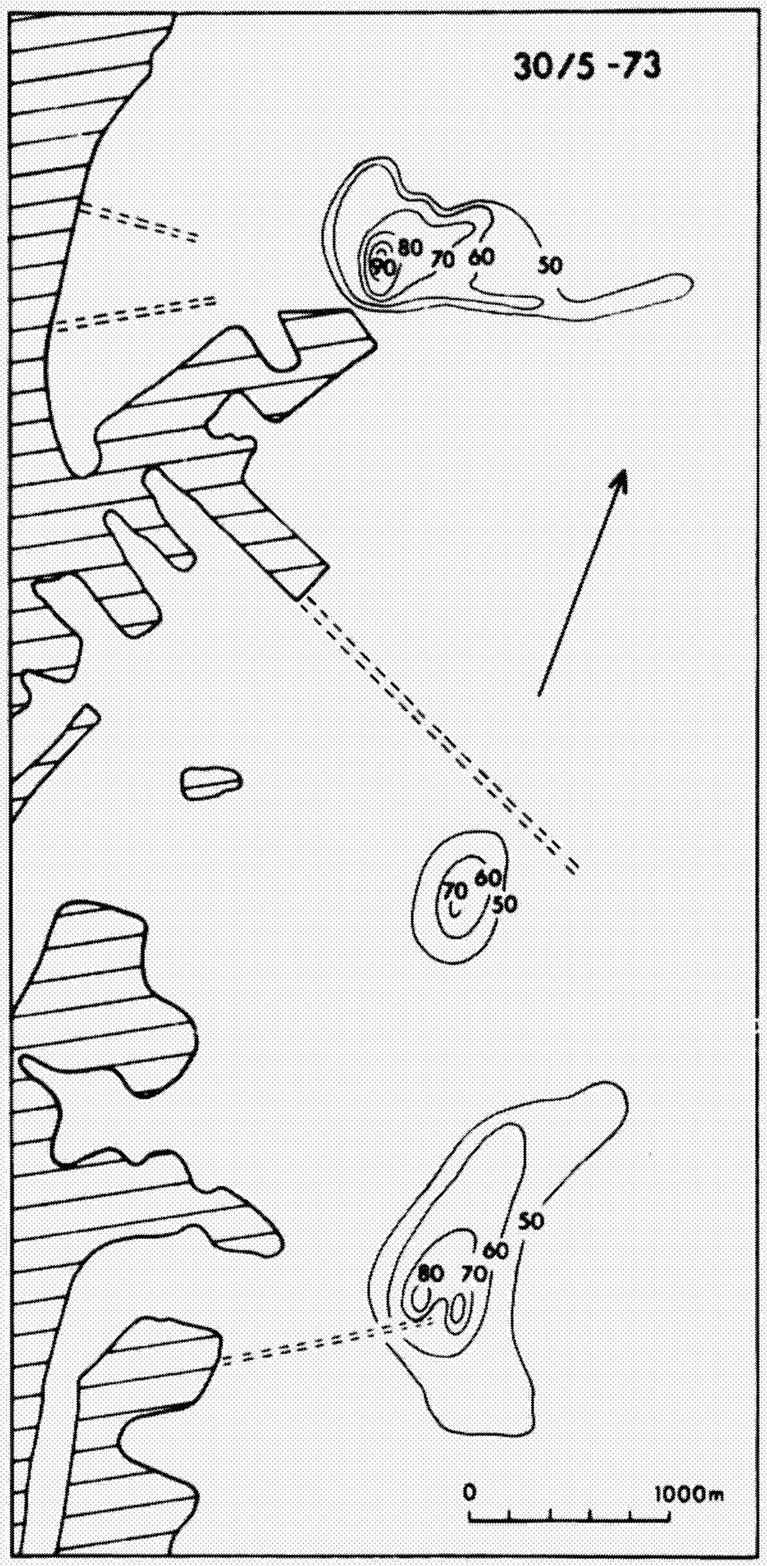

Figure 5.- The pollution plumes outside Copenhagen on May 30, 1973, according to densitometer analysis of LANDSAT-1 dia-positive (MSS 5). The figures denote the relative transmission.

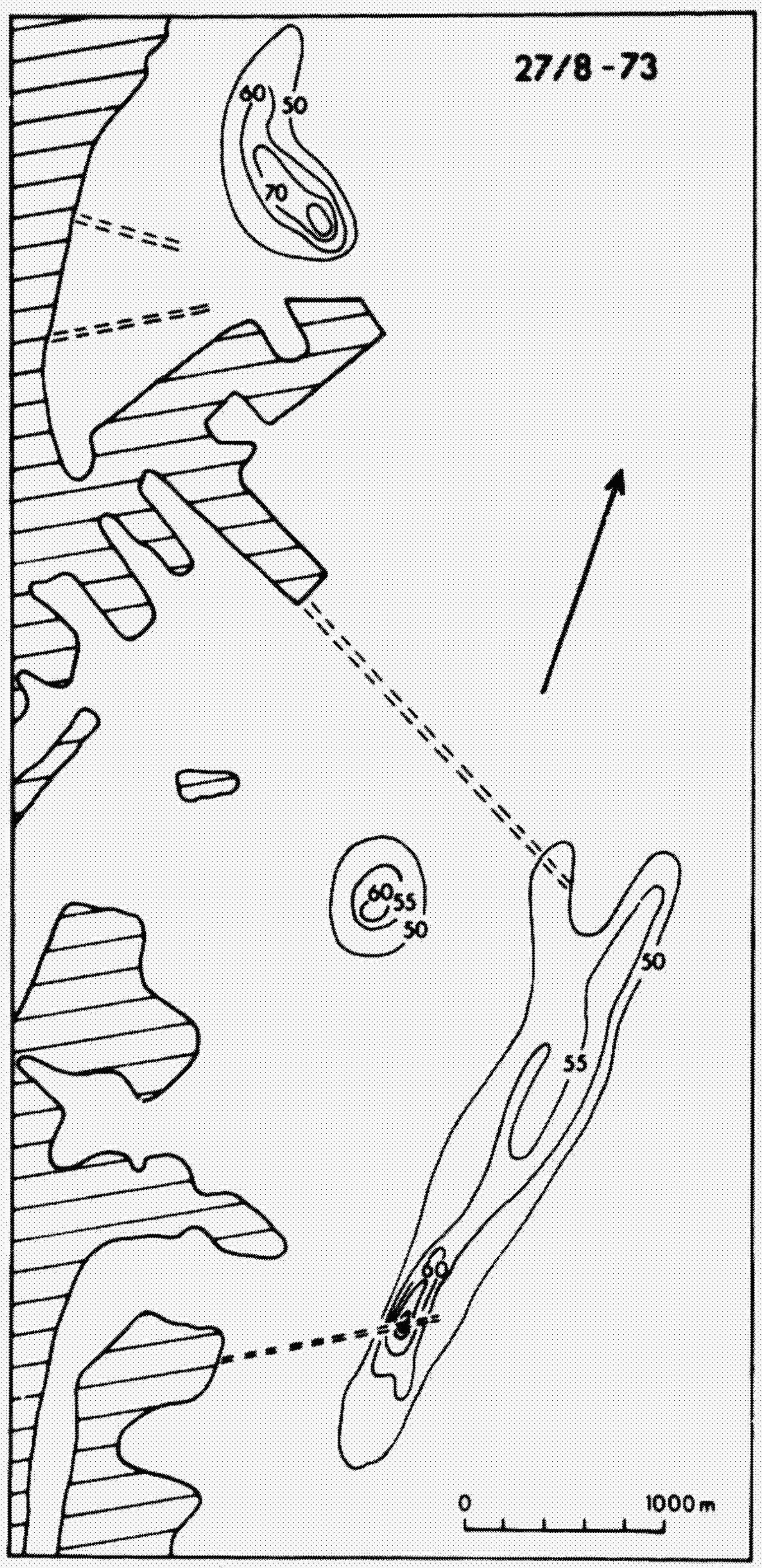

Figure 6.- The pollution plumes outside Copenhagen on August 27, 1973, according to densitometer analysis of LANDSAT-1 diapositive (MSS 5). The figures denote the relative transmission.

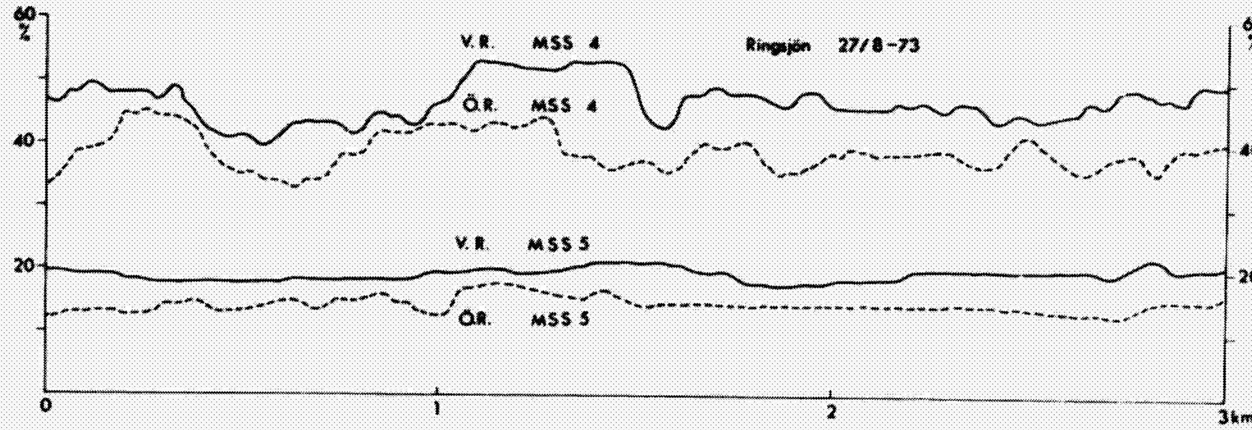

Figure 7.- Densitometer profiles of Lake Vastra Ringsjon (V.R.) and Lake Ostra Ringsjon (O.R.) in Scania on the basis of LANDSAT-1 images (MSS 4, MSS 5) registered on August 27, 1973.

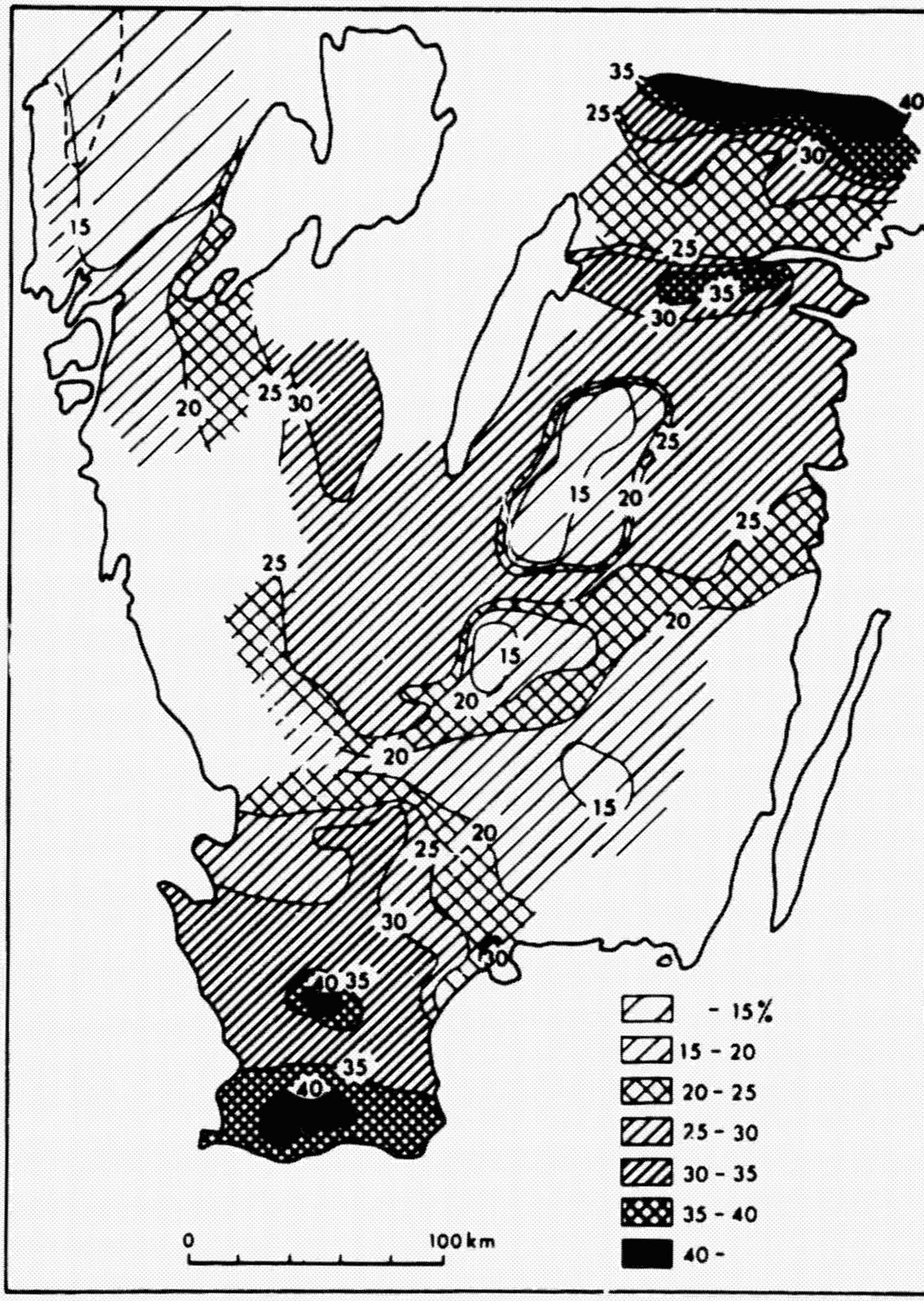

Figure 8.- Map of land areas with lakes of the same grey-tone where the given figures represent transmission values gained after densitometer analysis of LANDSAT-1 images (MSS 4) registered on August 26, 27 and September 4, 1973.

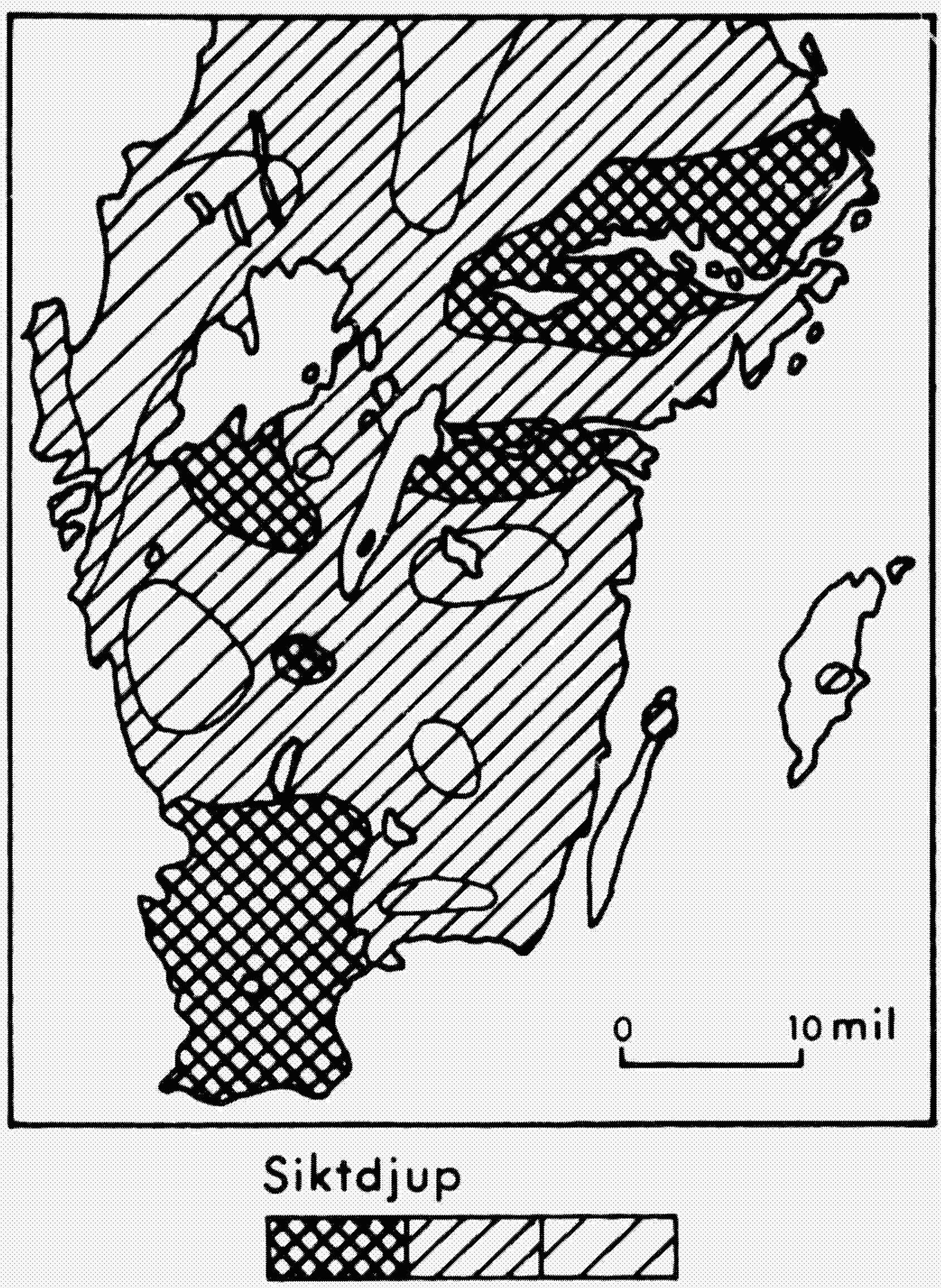

Figure 9.- The secchi disc transparency of Swedish lakes based on a compilation of the National Swedish Environment Protection Board (after Johansson et al. 1974).

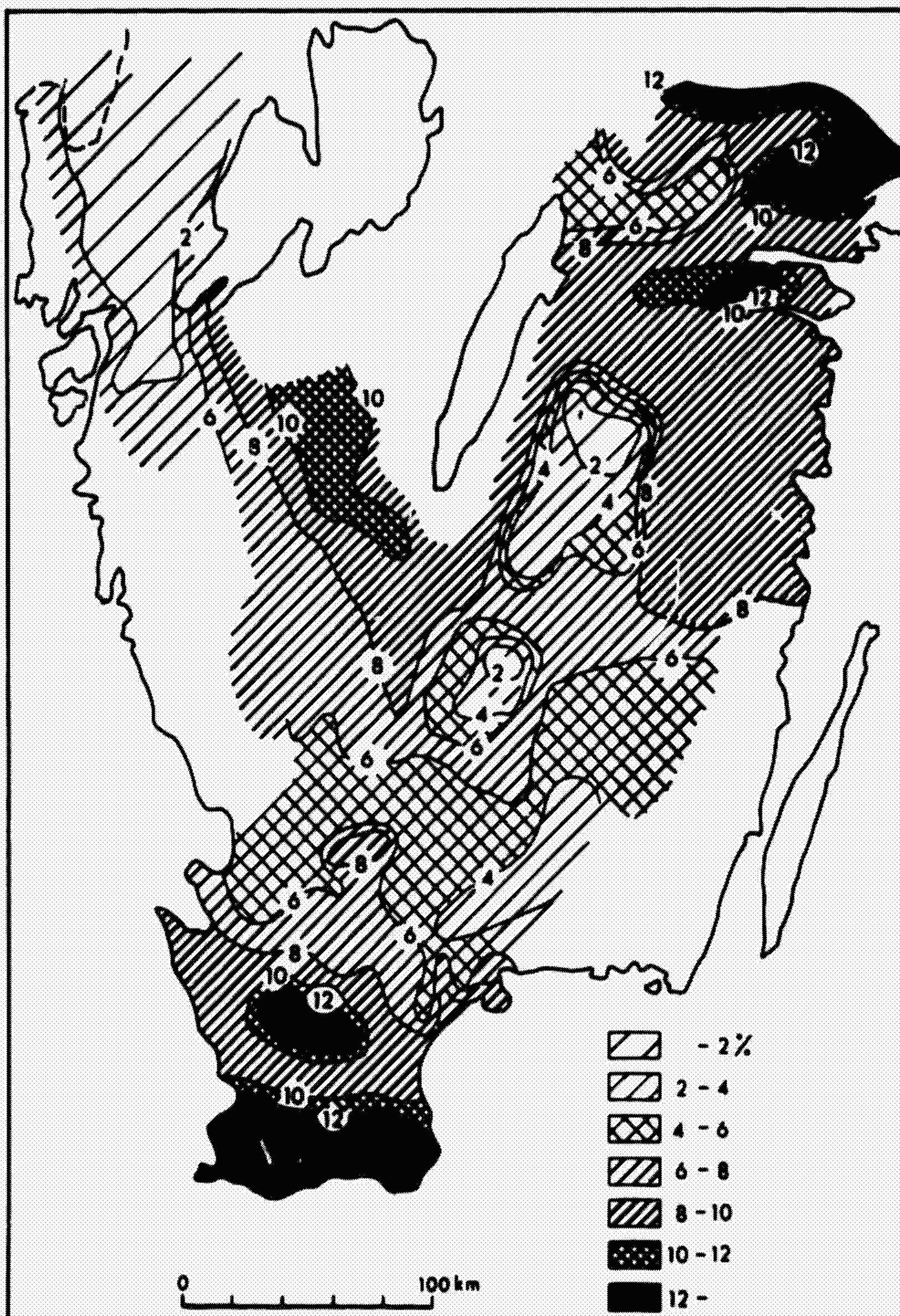

Figure 10.- Map of land areas with lakes of the same grey-tone class where the given figures represent transmission values gained after densitometer analysis of LANDSAT-1 images (MSS 5) registered on August 26, 27 and September 4, 1973.

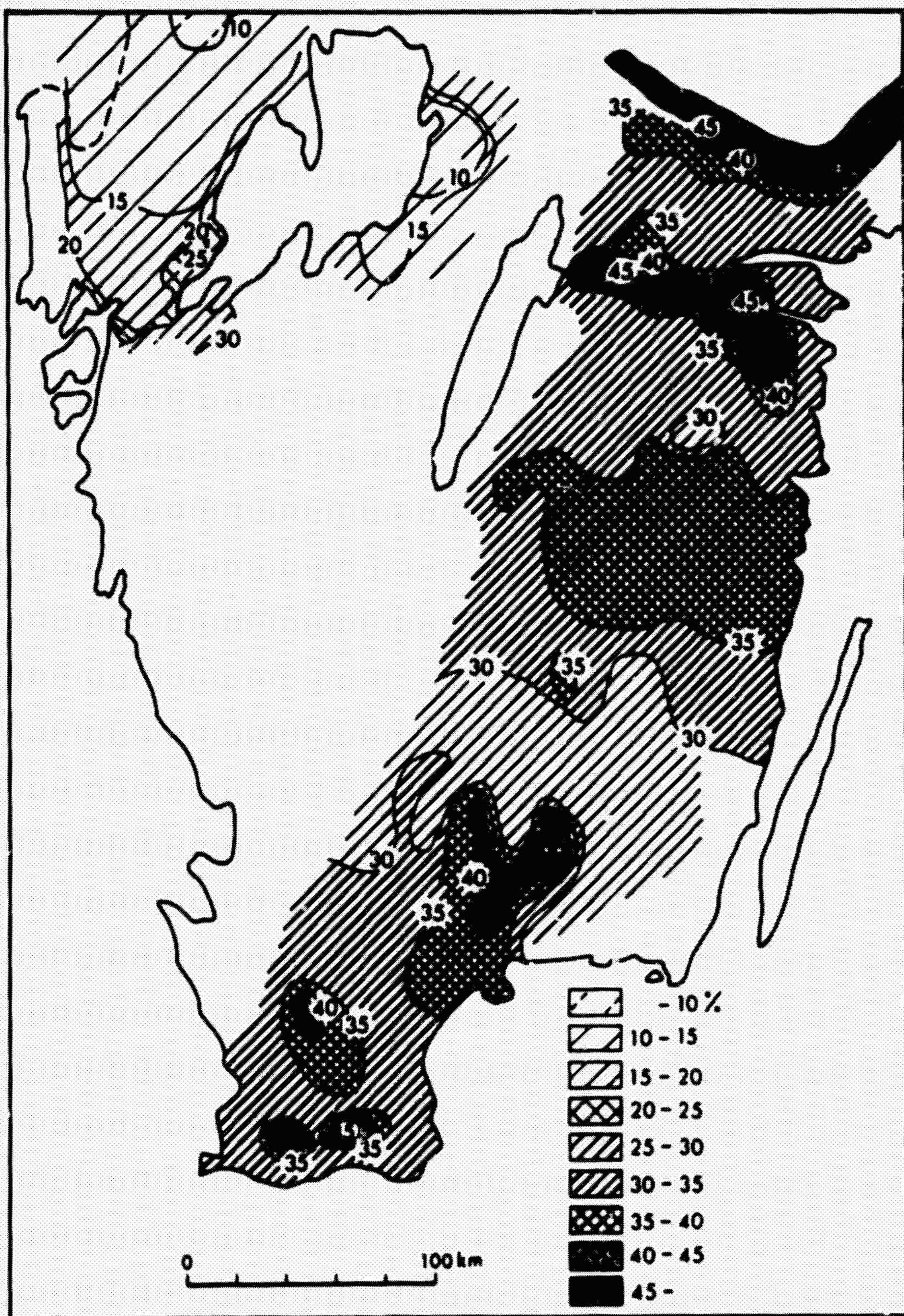

Figure 11.- Map of land areas with lakes of the same grey-tone class where the given figures represent transmission values gained after densitometer analysis of LANDSAT-1 images (MSS 4) registered on June 18 and July 3, 1973.

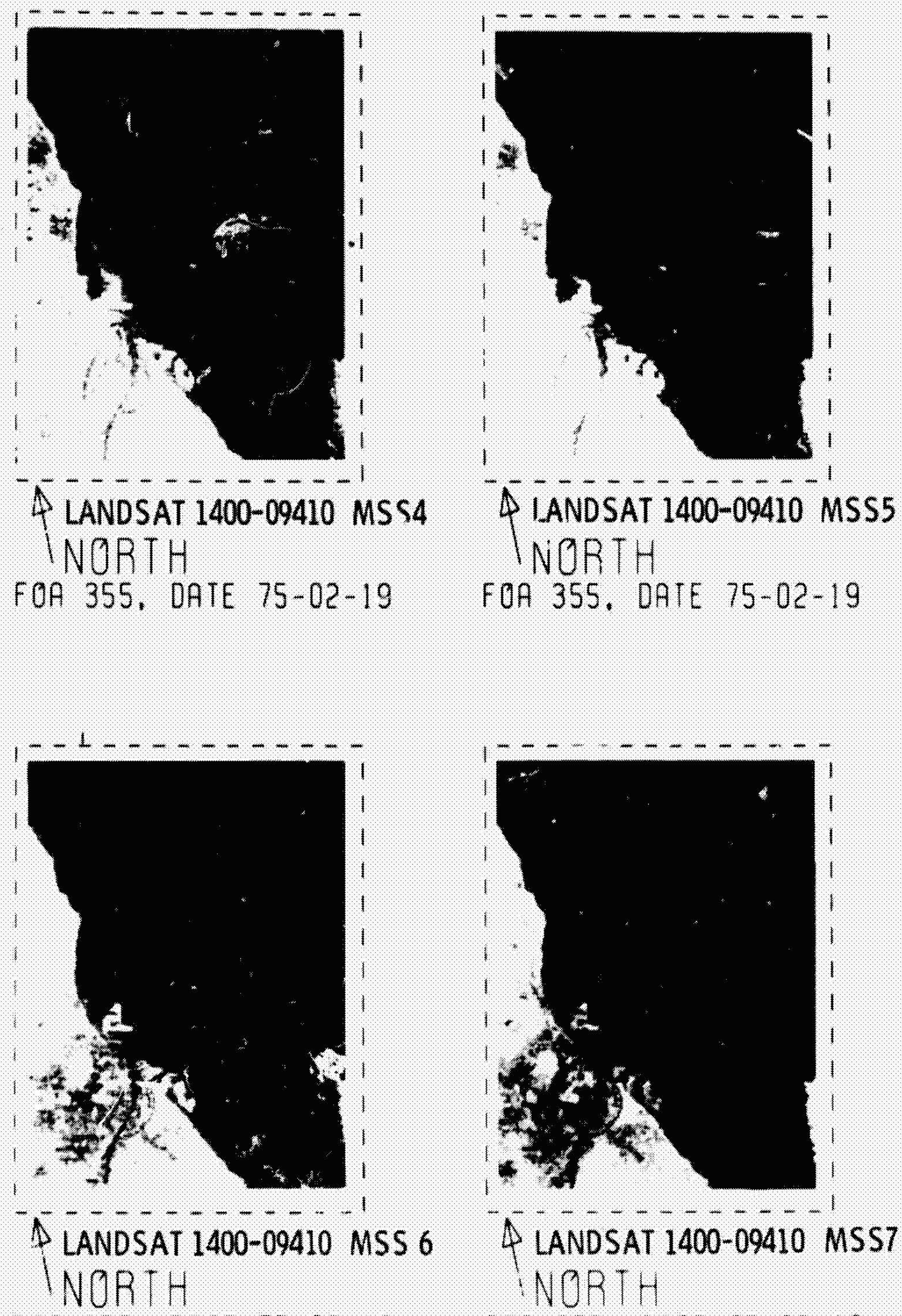

Figure 12.- The pollution conditions outside Copenhagen on August 27, 1973. The grey-tone differentiation of the water has been enhanced and the image has been produced with the help of a Calcomp 835 microfilm plotter. Appr. scale 1:250,000.