ANALYSIS OF SKYLAB IMAGERY FOR APPLICATION TO THEMATIC MAPPING

Doyle G. Smith
U.S. Geological Survey
Reston, Virginia 22092

Final Report
January 1976

Prepared for
National Aeronautics and Space Administration
Lyndon B. Johnson Space Center
Houston Texas

EREP Investigation No. 501

T-4649B

Original photography may be purchased from:
EROS Data Center
10th and Dakota Avenue
Sioux Falls, SD 57198

Contents

INDEX OF ILLUSTRATIONS

ANALYSIS OF SKYLAB IMAGERY FOR APPLICATION TO THEMATIC MAPPING (SKYLAB EXPERIMENT 501)

INTRODUCTION

The research effort reported in this paper constitutes Skylab Experiment 501 and was performed by members of the U.S. Geological Survey research staff under NASA Contract NAS T-4649B. Skylab photographs and supporting funds were supplied by NASA, and USGS provided manpower and photo-processing facilities.

PREFACE

Since the beginning of the industrial revolution, there has been a need for timely extraction of thematic data for use in resource planning, and this need remains largely unsatisfied, even at present. Reliable thematic data are extracted largely by manual interpretation of photographic images visually correlated to ground-truth data. A few new electronic tools have recently been added to extend man's quantitive ability; but these tools have not, by and large, improved the quality of the output data. Existing combinations of techniques and technology require excessive time for reduction of large volumes of thematic data; and therefore the data are of little value outside the research community.

Purely digital approaches to thematic extraction have yielded the most impressive results thus far but at the expense of rapid throughput capability and economical use of capital hardware investment. In addition, few digital techniques stress maintenance and improvement of geometric fidelity, a prime requisite of both quantitative and qualitative theme extractions. It was, and continues to be, the opinion of the research staff that photographic techniques offer the most promise for economical extraction of high-quality thematic data with maximum geometric fidelity.

OBJECTIVE

The objective of this research was to develop a series of special processing techniques using Skylab photographs, and then to use these techniques to produce a series of subject-oriented thematic graphics which could be conveniently related to the ground and map-type graphics in a format suitable for thematic or time-change analysis. If successful, the project would ultimately lead to a system for providing timely thematic information in the form of maps to users of Skylab or other imagery.

PROCEDURE

Several selected Skylab scenes were processed to determine the capability of isolating four basic themes--ice and snow, open water, vegetation, and mass works of man--and to extract these themes systematically and reliably.

One objective of this experiment was to perform as much of the research as possible by photographic techniques. These techniques were to be supplemented by electronic analog and digital image processing hardware for radiometric analysis and for producing antivignetting and other nonlinear neutral-density filters required to normalize the image radiometry. Unfortunately, the electronic hardware was not available for this project. Consequently the research was carried out with purely conventional photographic techniques and materials.[1,2,3,4]

Only black-and-white film was used for the experiment. Color and color-infrared materials were not employed for three reasons:

1. A spectrophotometric microdensitometer required for essential analytical measurements of color and color opacity was not available for this project.

2. The loss of resolution during image enlargement is much greater for color films than for black-and-white.

---

[1]Philco-Ford, 1971, final report on Image Enhancement of Apollo IX Photographs and Aircraft Photography.
[2]U.S. Geological Survey, 1972, Autographic Theme Extraction, GPO brochure 0-473-697.
[3]Smith, Doyle G., 1973, Autographic Theme Extraction System: 7th UN Regional Cartographic Conference for Asia and the Far East, Tokyo.
[4]Ross, Donald S., 1970, Enhancing Aerospace Imagery for Visual Interpretation: Society of Photo-optical Instrumentation Engineers - 15th Annual Technical Symposium Proceedings.

3. Research photolaboratory facilities were not available for use on this project.

The nominal 9" x 9" enlargements received from NASA were used for most experimental theme extraction because the NASA enlargements, only one or two generations away from the original imagery, were believed to have better resolution and quality than an enlarged copy of a third-generation copy of the original.

Material from two wavebands of the S190A photography was selected as the best potential source of success. The red waveband (0.6-0.7 μm) was selected because it provides high contrast between green vegetation and surrounding rock, sand, concrete, and bare earth. The near-infrared waveband (0.8-0.9 μm) was selected because it provides high contrast between open water and surrounding vegetation, sand, and bare earth. The near-IR region also provides the optimum contrast between urban areas and surrounding water, vegetation, and bare earth.

To extract the thematic information, two principal photographic manipulation techniques were employed--density clipping, and image subtraction by sharp masking. Density clipping is a process whereby only a portion of the density range of a low-gamma photographic film is transferred to a high-gamma film. Exposing light is allowed to pass through a continuous-tone (low-gamma) film onto a piece of high-gamma film. The most transparent areas of the image saturate the high-gamma film emulsion first, followed by more and more dense image areas as the exposure time increases. By changing exposure time, it is thus possible to convert a varying percentage of the low-density image to a latent opaque image, or sharp mask, on the high-gamma film. This image is said to be "clipped" at the upper density level of the low-gamma film beyond which images do not appear on the high-gamma film. This process differs from density slicing, which isolates a portion of the total density range that falls between two density thresholds, upper and lower. Both positive and negative transparencies can be density clipped. (The words negative and positive are used here in the traditional photographic sense; that is, highly reflective objects image dark in the negative and light in the positive.)

Image subtraction by sharp masking involves compositing a density-clipped image in precise register with the original continuous-tone transparency or other sharp masks in order to subtract (mask out) unwanted image information.

Density clipping thresholds were established from microdensimetric measurements of imagery in photographs of the SL2 flight collection that contained the required theme data. The selected photographic images were scanned with a Joyce-Loebl Microdensitometer and a density profile, or trace (figures 1, 2, 3) was produced. Definitive density measurements were provided by immediately overtracing the image density profile with the profile of a calibrated density step tablet. Both profiles were traced at the same microdensitometer aperture, range, magnification, and speed settings, and within minutes of each other; i.e., both the image trace and the step-wedge overtrace were drawn under identical conditions. The following scenes, discussed later in this report, were analyzed:

Flight	Magazine	Frame	Location
SL2	RL 12	136	Missouri
"	RL 08	137	"
"	RL 11	136	"
"	RL 07	137	"
"	RL 17	209	Wyoming
"	RL 14	210	"
"	RL 13	208	"
"	RL 18	209	"
"	RL 13	210	"
"	RL 14	166	Virginia
"	RL 13	166	"
"	RL 18	165	"
"	RL 17	165	"
"	RL 17	166	"
"	RL 18	165	"

Calibrated step-tablet densities were used to extrapolate between the 70 mm copies and the 9" x 9" enlargements, and to transfer definitive densimetric information between the analytic laboratory at Reston, Va., and the photoprocessing facilities at the EROS Data Center, Sioux Falls, S. Dak. The use of an identical step tablet at the EDC photolaboratory also made it possible for the processing staff to extrapolate processing parameters from one printer to another and between light sources.

The density clipping was done by emulsion-to-emulsion contact printing in a vacuum frame. Five density-clipped copies of each selected 9" x 9" image were printed on film. The five clipping thresholds were set at densities of 0.2, 0.5, 0.8, 1.10, and 1.40 and held there for most of the project image processing to maintain a reference during product evaluation. The high-gamma film used for most of the density clipping was Eastman Kodak Kodalith MP Ortho.[5] The clipped images were transferred to Kodaline Reproduction film or color foils when needed for visual aids and display graphics.[6]

DISCUSSION OF RESULTS

Several geographic regions were selected for the research. A scene of Wyoming (plate 1) was selected for extraction of ice and snow. Scenes of St. Louis (plate 5), New York City (plate 8), and Chicago (plate 12) were selected for extraction of mass works of man. The Chesapeake Bay region and adjoining Atlantic seacoast (plates 17 and 18) were selected for extraction of open water. (The images discussed are tabulated in the index of illustrations and accompanying annotated photoindex.)

Ice and Snow Extractions

Ice and snow were the easiest data to extract from the Skylab photographs. These data were density-clipped directly from the high-transmittance region of the black/white film positives of scenes imaged in the 0.6-0.7 μm waveband. This band was selected because it provides high contrast between ice/snow and the evergreen vegetation. Unfortunately, the rock-sand-bare-earth reflectance is also high in this spectral region. This high reflectance produces unwanted signals as does slope aspect, and the extractions therefore contain extraneous data. Narrowing the width of the density band extracted (i.e. lowering the density-clipping threshold) provides smaller areas of theme data, but the reductions appear to be related primarily to the amount of rock and vegetation showing above the snow. A snow extraction (plate 2) was derived from S190B SL2 Wyoming Scene 142 (plate 1), and plates 3 and 4 are density slices derived from the same scene by subtracting information clipped at a lower density threshold from information clipped at a higher density. Equivalent information was obtained by processing S190A Frame 208.

Open-Water Extractions

The open-water extractions obtained from S190A photographs (plates 9, 10, 14, 24, 31, 34) were derived directly from black/white film negatives of imagery obtained in the 0.8 - 0.9 μm waveband. The reflectance of water-borne silt and chlorophyll-producing algae is still sufficiently high in this spectral range to substantially dilute the energy absorption of water that produces an optimum high-contrast land-water boundary. If the extraction band is narrowed to the extent needed to show a satisfactory boundary contrast level, many streams, wetland areas, beach shallows, and delta siltation plumes are lost (plate 9). On the other hand, if the extraction band is widened enough to include all water, the extraction contains extraneous data (plate 10). The band would have to be narrowed and moved to the spectral position of one of the strong water-absorption peaks in order to provide optimum open-water extractions.

Vegetation Extractions

The vegetation extractions were derived by subtracting from the total image (sharp masking) the high-reflectance (snow-ice, sand, bare earth) components extracted from the 0.6 - 0.7 μm waveband and low-reflectance (open water, urban area) components extracted from the 0.8 - 0.9 μm waveband. Therefore the vegetation extractions are degraded by disparities in the content of the other two extractions. The vegetation extractions obtained are of limited cartographic value, as can be seen by comparing the extractions shown in plates 7, 11, 15, and 20 with the accompanying map inserts. Quality can be improved by careful, laborious hand-tweaking of each extractive process, as was done with the materials presented in plates 31 and 32. Unfortunately, this type of processing is not cost and time effective for systematic production. Therefore, careful tailoring of the wavebands in width and spectral position is needed for efficient thematic extraction.

Urban-Suburban Extractions

Extraction of urban-suburban areas lends itself least effectively to systematic processing. Each large city studied--New York, Chicago, Washington, D.C., Baltimore, St. Louis, Miami, Phoenix--has individual spectral reflectance patterns that required hand-tailored processing to isolate the urban characteristics of interest. An example of this spectral-response difference can be seen by comparing Washington with Baltimore in plate 22.

---

[5]Eastman Kodak, 1971, Bulletin for the Graphic Arts, no. 23.
[6]Eastman Kodak, 1974, Tech Bits, v. 3.

The maximum contrast between urban/suburban areas and surrounding countryside is obtained in the 0.8 - 0.9 μm waveband where both bare earth and vegetation reflectances are still fairly high, yet the urban/suburban areas are energy-absorbent. The photographic densities of images of the highly urbanized areas are very close to the water image densities in this spectral band (plates 8 and 13). Thus, clean isolation of one theme from another is rarely possible. In general, clean-cut open-water extractions (plate 31) can be obtained only by individually tailored, cut-and-try processing. The usual consequence of generalized systematic processing is shown in plates 10 and 14, where the heavily urbanized areas tend to density-clip out with the open water. Plate 16 shows an area of suburban expansion around Chicago, but extensive ground examination and evaluation would be required to determine significant characteristics shown by this extraction, if they indeed exist.

Urban/suburban extractions have potential practical applications, and they can be systematically derived, but the processing must be hand-tailored for each case and the extractions obtained are of uncertain quality. It is questionable whether systematic extraction of these themes is more cost or time effective than manual interpretation of an enhanced photoimage. One thing is clear, however: a clean-cut, highly reliable open-water extraction and associated land-water boundary are essential to obtaining valid urban/suburban theme extractions.

Special-Circumstance Extractions

It is occasionally possible to take advantage of a special condition or tool for theme extraction. One of the most powerful special tools is a snowstorm occurring under appropriate conditions. Two examples illustrate its use:

Example A: The boundary line between open water and wetland and some grassland is often difficult and sometimes impossible to define. However, photographs taken just after a snowstorm will often define this line very sharply because the snow will accumulate on grass, shrubs, and fallen leaves, but not on the open water. In plate 23, areas of open water stand out in high contrast to those covered with snow and ice.

Example B: Photographs taken over an inhabited area three or four days after a moderate snowfall will generally show the main transportation routes sharply etched against the snow background because they are plowed out and the snow melts rapidly from the heat-absorbing paved surfaces.

One sample of Example B (plate 25), obtained over central Illinois, was used to extract urban area and transportation net information with limited success. Randomly distributed patches of thin clouds and ground haze, coupled with optical system vignetting (plates 26 and 27) made it necessary to hand-tailor the processing of various areas of each photograph in order to obtain any useful data.

Applications of Theme Extractions

Clean-cut reliable theme extractions provide excellent color-separation plates for small-scale maps (plates 31 and 32 and the Hartford maps that accompany this report). Extractions can also be used as open-window masks, in which case the negative of the extraction is used as a sharp mask registered and composited with the original scene. The negative masks everything but the theme data from the scene and thus permits the original theme data to be further examined and analyzed for subtle (or not-so-subtle) density variations.[7,8] For example, the open-water window of scenes registered with the 0.4 - 0.5 μm waveband images (plates 28 and 29) permits the water images in the scenes to be examined in minute detail so that current patterns and water-borne inorganic sediment plumes can be mapped. Similarly, the open-water window composited with the 0.7 - 0.8 μm waveband images permits the water images to be examined for water-borne chlorophyll-producing organic material.

DISCUSSION OF PROCEDURE

The objective of this project was to establish a systematic processing procedure that could be standardized, more or less mechanized, and described by a reasonably uncomplicated standard operating procedure. But the research project staff was unable to accomplish this objective with the Skylab S190A and S190B materials supplied by NASA. The number of S192 photoimages provided were insufficient as a source of systematic theme extraction. As a consequence, the information obtained from this experiment is limited.

---

[7] Carter, Virginia and Smith, Doyle G., 1973, Utilization of Remotely-Sensed Data in the Management of Inland Wetlands: American Society of Photogrammetry Symposium Proceedings-Management and Utilization of Remote Sensing Data.

[8] Hollyday, Este F., 1974, Improving Estimates of Streamflow Characteristics Using Satellite Imagery: American Society of Photogrammetry Southeastern Regional Conference.

At the outset of the project, we assumed that the source materials available from NASA would be of consistently high quality. This was generally the case. However, the source materials still contain anomalies that are present in nearly all aerospace photographs and that must be compensated for by some technique. The base and maximum densities varied significantly from film magazine to film magazine, as did the shape of the gamma curve. This variation made linear normalization of the image density difficult and often impossible. We had to measure the base and maximum densities of each image frame and then adjust the density clipping thresholds accordingly.

The source materials also contained nonuniform density anomalies that prevented image density normalization. Some anomalies, such as those seen in plate 25, were caused by the optical systems through which the photographs were processed. Others, such as those visible in plates 17 and 18, are caused by atmospheric or Sun-angle conditions in existence at the time the latent images were obtained. Each nonuniform anomaly can be corrected by compositing the image with an individually-tailored nonlinear neutral density filter (density filter of varying shades of gray) that resembles an asymmetric antivignetting filter. The nonlinear filters can be made in two ways: 1) by printing the filter in the form of an unsharp density mask from a clear-field (imageless) photographic frame cycled through the photographic processing system, or 2) by computing the radiometric form of the filter and then electronically printing the filter on photographic film with a digital image processor. Neither clear-field frames nor digital image processor were available for this project.

Optical and radiometric phenomena, Sun-angle effect, specular reflectance, lens/filter vignetting, lighting imbalance in the processing system, and lens decentering cause image anomalies that cannot be entirely eliminated or compensated by conventional photoprocessing techniques. Therefore, some means must be available for making filters that compensate the most systematic of the anomalies. The minimum requirements for system calibration include a full set of clear-field frames for each lens, filter, and aperture combination used to obtain and process the theme imagery. The clear fields can then be used to construct the most basic of the nonlinear filters--those needed to compensate lens/aperture vignetting and light-source decentering.

Theme extraction severely reduces image information because unwanted (nontheme) information is dropped out. Therefore, theme extraction should be performed only after the photographic images have been enlarged up to or beyond the largest scale at which the extraction is to be used. Extraction is most efficient and effective if performed simultaneously with enlargement of the photographs. This approach was employed to generate the extractions shown in plates 31 and 32, which were enlarged from the 70-mm frame to 1:250,000 scale, 11.86X, in two steps. Density clipping was applied during the second stage of enlargement.

With the Skylab photographs, thematic products of the quality illustrated in plates 31, 32, and accompanying maps can be obtained by experimental, cut-and-try hand-tailored photoprocessing of each individual image; however, the decision as to what represents the optimum product ultimately depends entirely on the judgment of a photointerpreter with experience in evaluating the cartographic quality and content of the theme data.

Clouds and cloud shadows, such as those seen in plates 12 and 18, and slope-aspect shadows of the type seen in plate 33 present problems that remain unsolved. The cloud blemishes can be either opaqued or patched by mosaicking, but the most satisfactory solution is a repetitive-coverage system that can periodically obtain cloud-free images. Images obtained in a narrow waveband that encompasses one of the water-absorbed peaks provide high-contrast open-water theme data that can often be separated from most of the shadows.

Each photographic transparency has a slightly different reference (base) density because of atmospheric and lighting conditions at the time of exposure and because of slight differences in the photochemical and photomechanical processing of each latent image. Therefore it is desirable to establish some image feature that can be used as a base for normalizing each image with reference to standard processing procedures. The base-density level is an unsatisfactory reference because it rarely indicates the radiometric parameters of atmospheric reflection and image illumination. Large, deep, unfrozen bodies of water, if available, provide the most satisfactory reference density for normalizing image radiometry. If the processing of the original latent images and subsequent reproductions is reasonably uniform and consistent, a reference density can be extrapolated to adjacent scenes exposed in the same flight line.

SUMMARY

Approximately 100 frames of Skylab SL2, SL3, and SL4 S190A images, 20 frames of S190B, and 5 frames of S192 were processed during this experiment. With careful screening and processing, the S190A and S190B photographs can be used for extracting data needed for thematic mapping.

Image quality, geometry, and content are adequate for general small-scale mapping.[9,10,11] The widths of the various wavebands and their location in the spectrum are not entirely appropriate for the special requirements of systematic theme extraction. The extraction of any theme requires the highest contrast possible between theme and surrounding imagery. This high-contrast boundary serves two essential purposes: 1) it provides a sharp line for positive image correlation and register from spectral band to spectral band, and 2) it provides the highest possible signal-to-noise ratio between the theme to be isolated and extraneous surrounding image data. In selecting the spectral band or bands in which each theme is to be imaged, either photographically or radiometrically, it is necessary to consider the energy distribution as well as the reflectance characteristics of each theme throughout the spectrum.

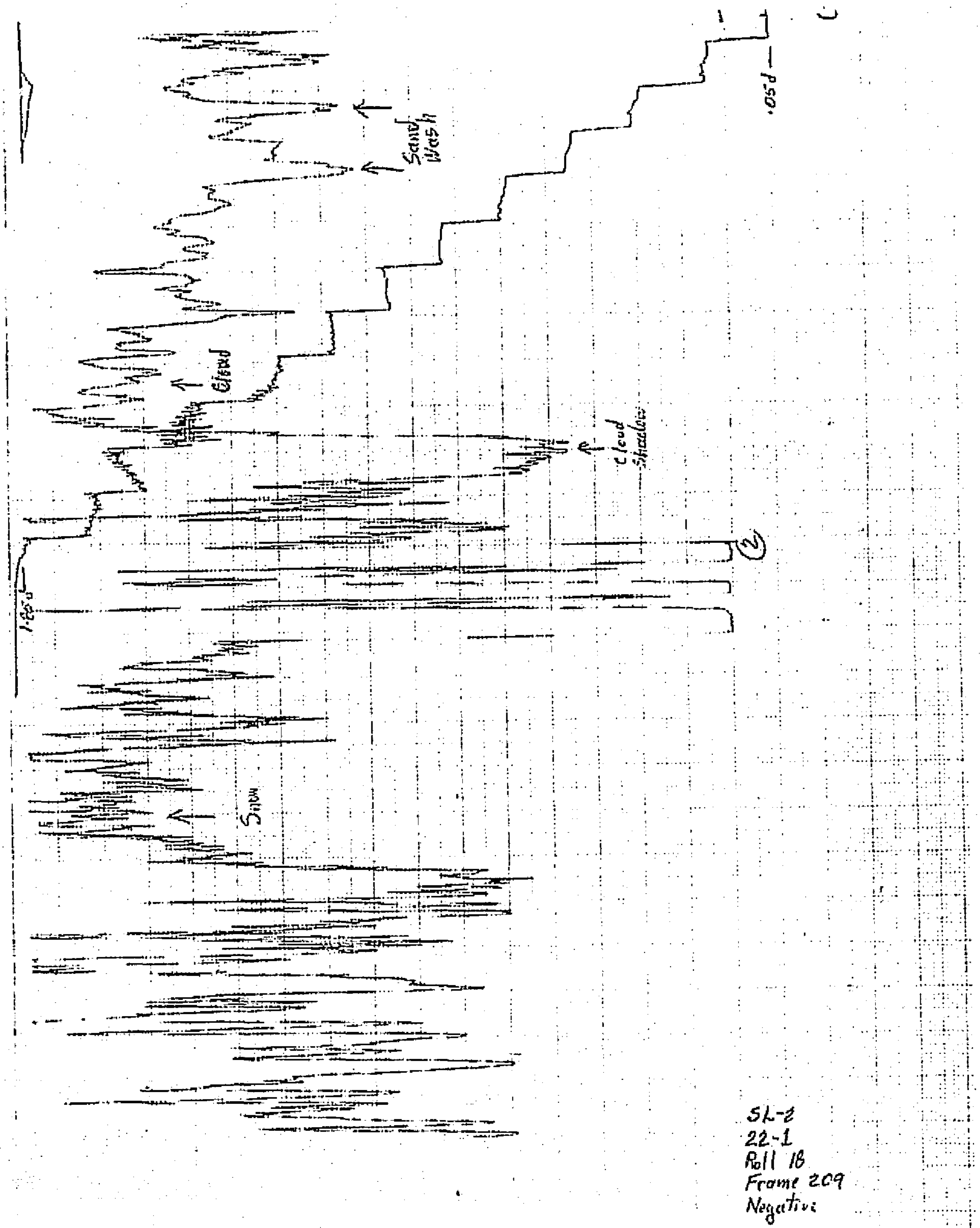
The S192 images are more appropriate from the point of view of waveband width and spectral location; however, linearizing these images during the printing process degrades image resolution and geometry and thus limits use of the photography for cartographic applications.

---

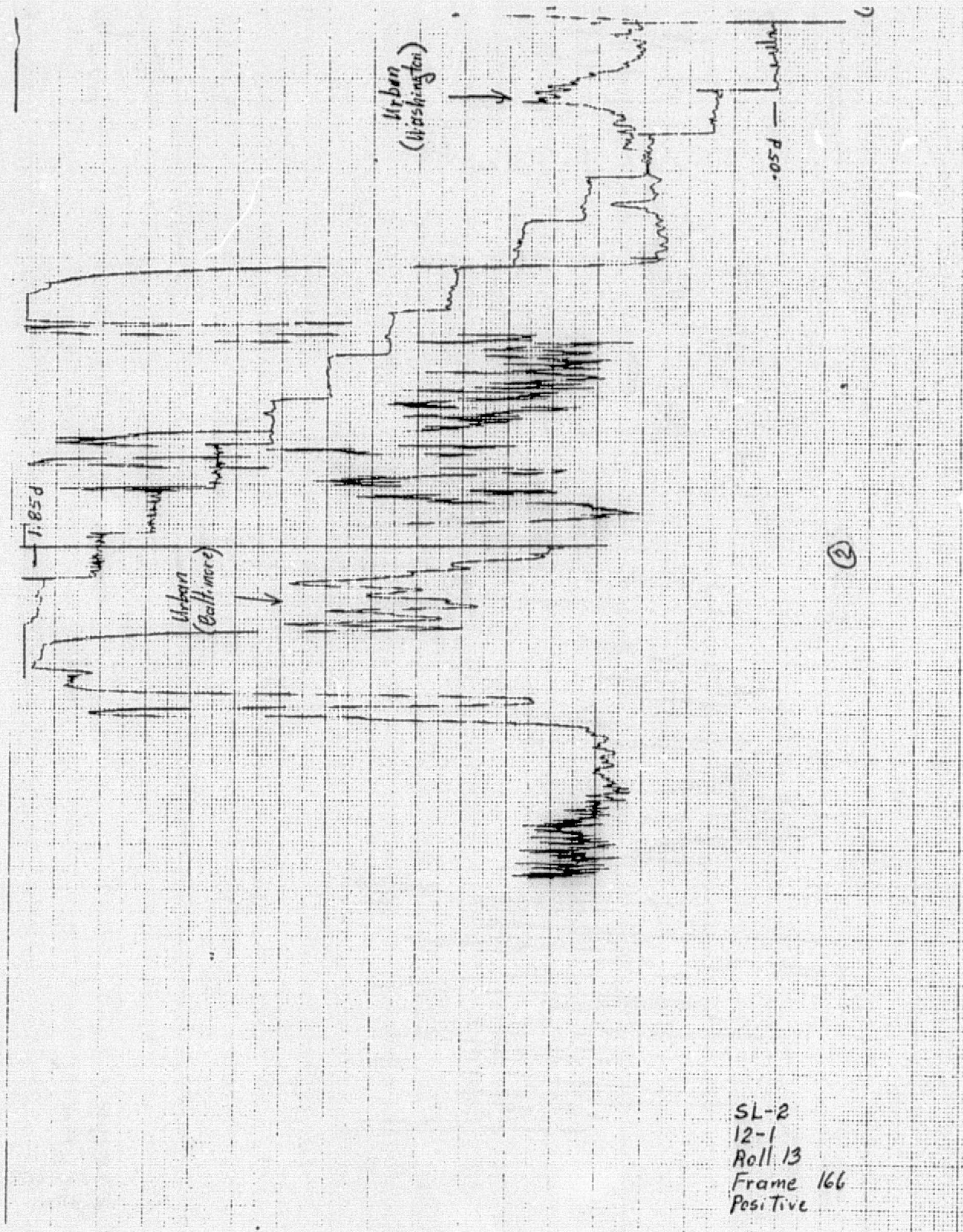
[9] Pilonero, Joseph T., 1975, report on Skylab Experiment 498, Photomapping of the United States.

[10] Kosco, William J., 1975, An Experiment in Cultural Interpretation and Map Revision from Skylab Data.

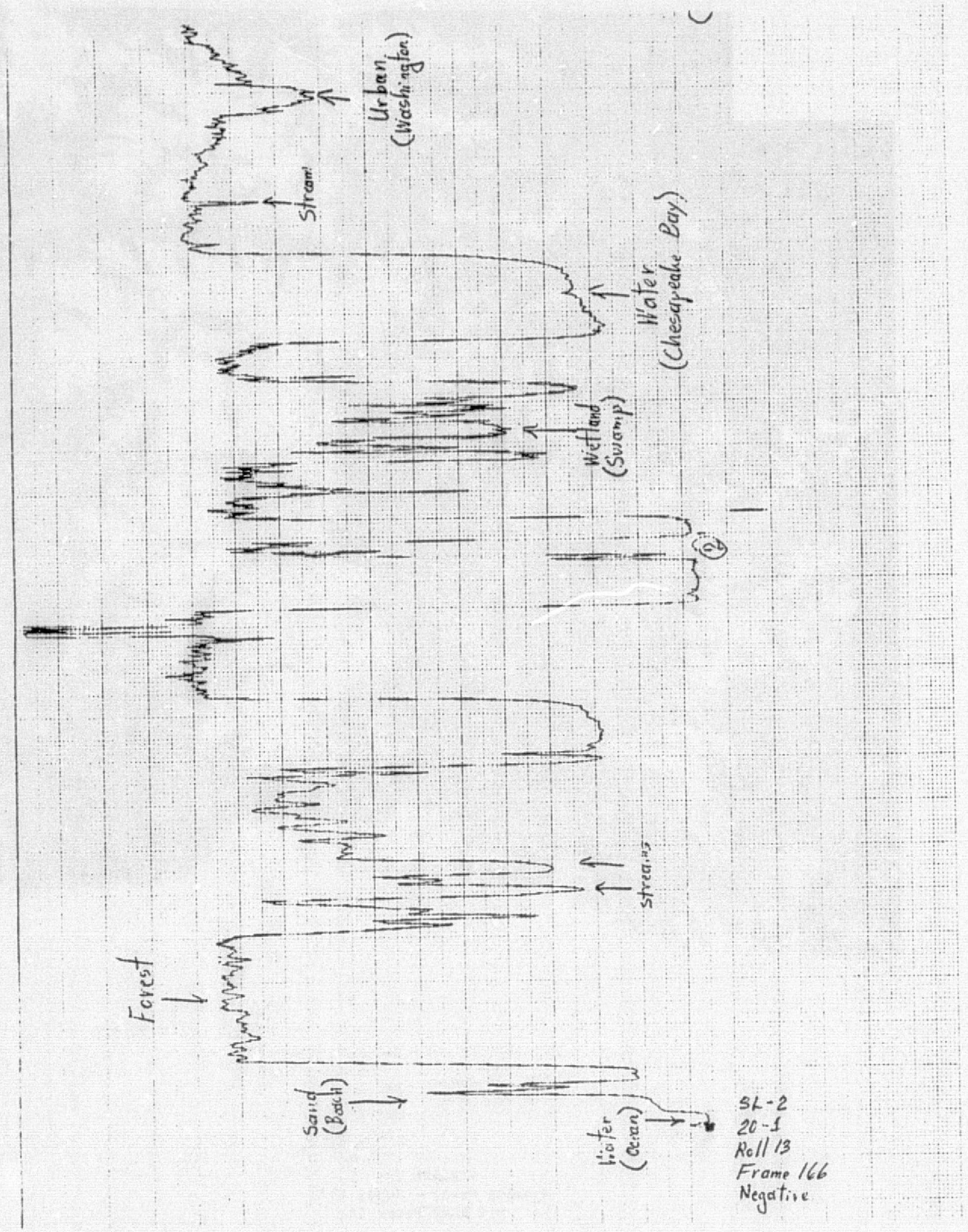
[11] Welch, Roy, 1974-1975, reports on image quality of Skylab photographic imagery.



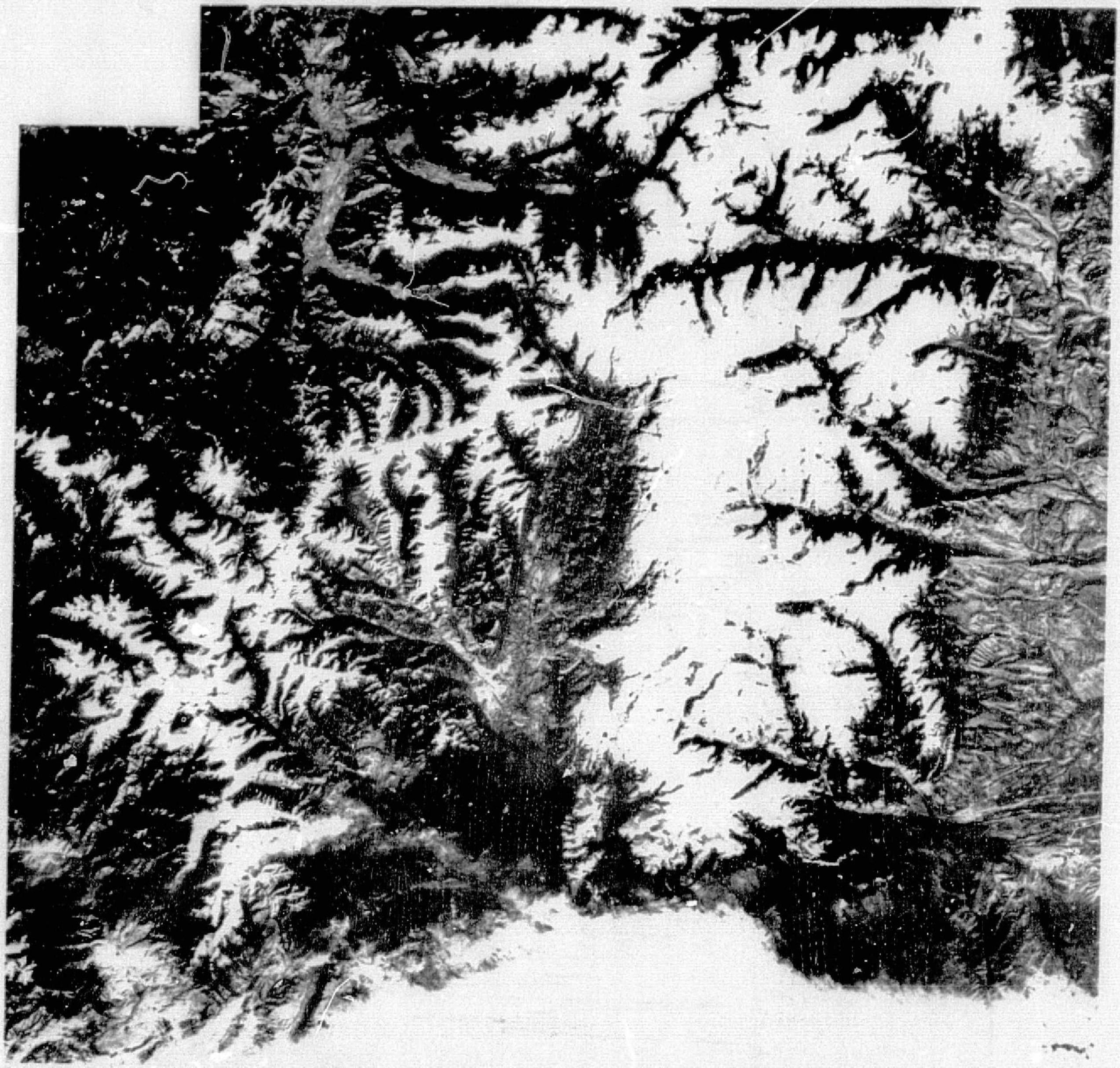
- FIGURE 1 -
Microdensitometer Trace
SL2 RL18 Frame 209



- FIGURE 2 -
Microdensitometer Trace
SL2 RL13 Frame 166

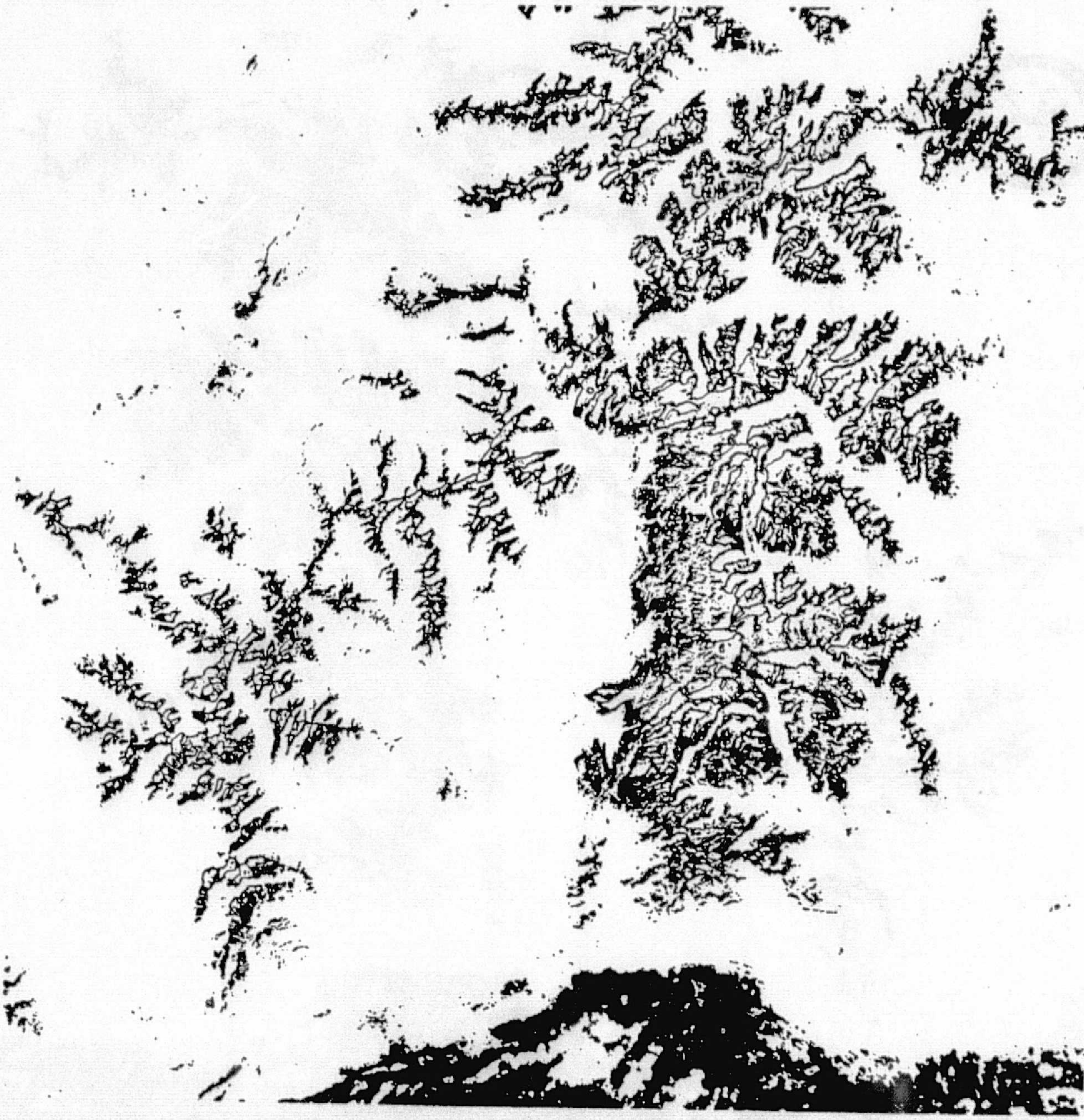


- FIGURE 3 -
Microdensitometer Trace
SL2 RL13 Frame 166



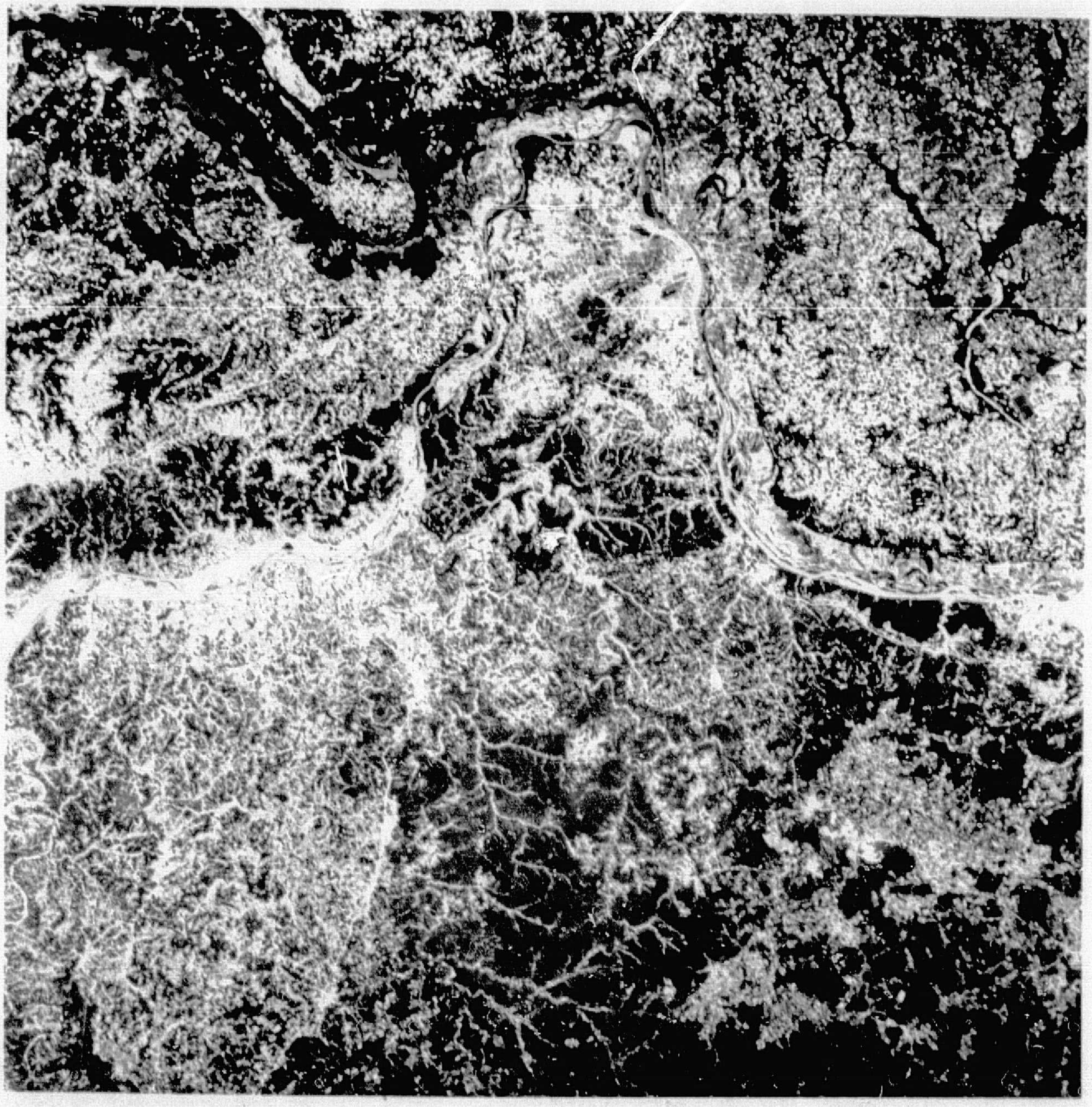
- PLATE 1 -
Wyoming Scene - June, 1973
SL2 RL82 Frame 142

- PLATE 2 -
Snow-Ice Extraction (Black)
Derived from SL2 RL82 Frame 142



- PLATE 3 -
Partial Snow-Ice Extraction (Black)
Derived from SL2 RL82 Frame 142

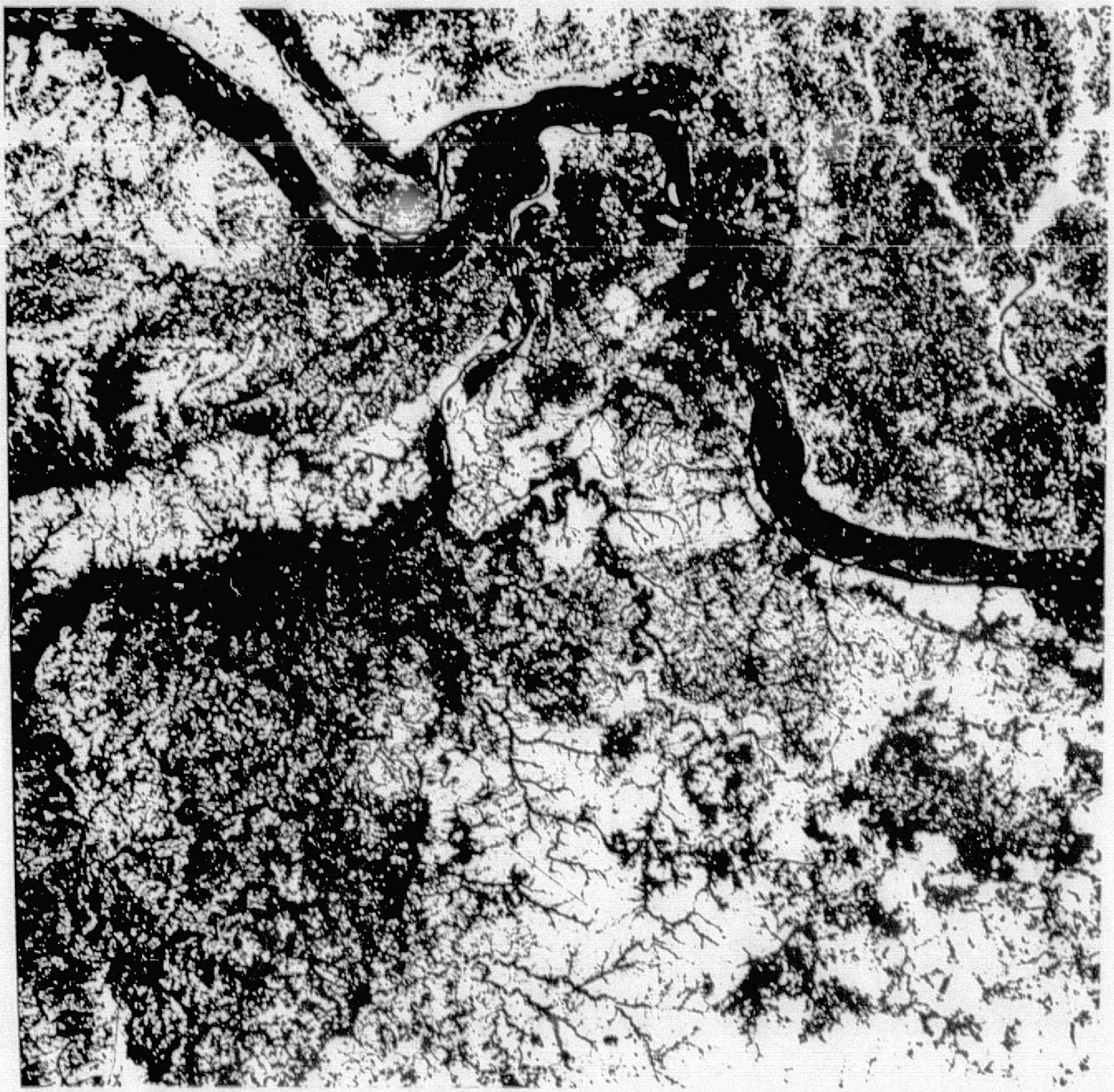
- PLATE 4 -
Partial Snow-Ice Extraction (Black)
Derived from SL2 RL82 Frame 142



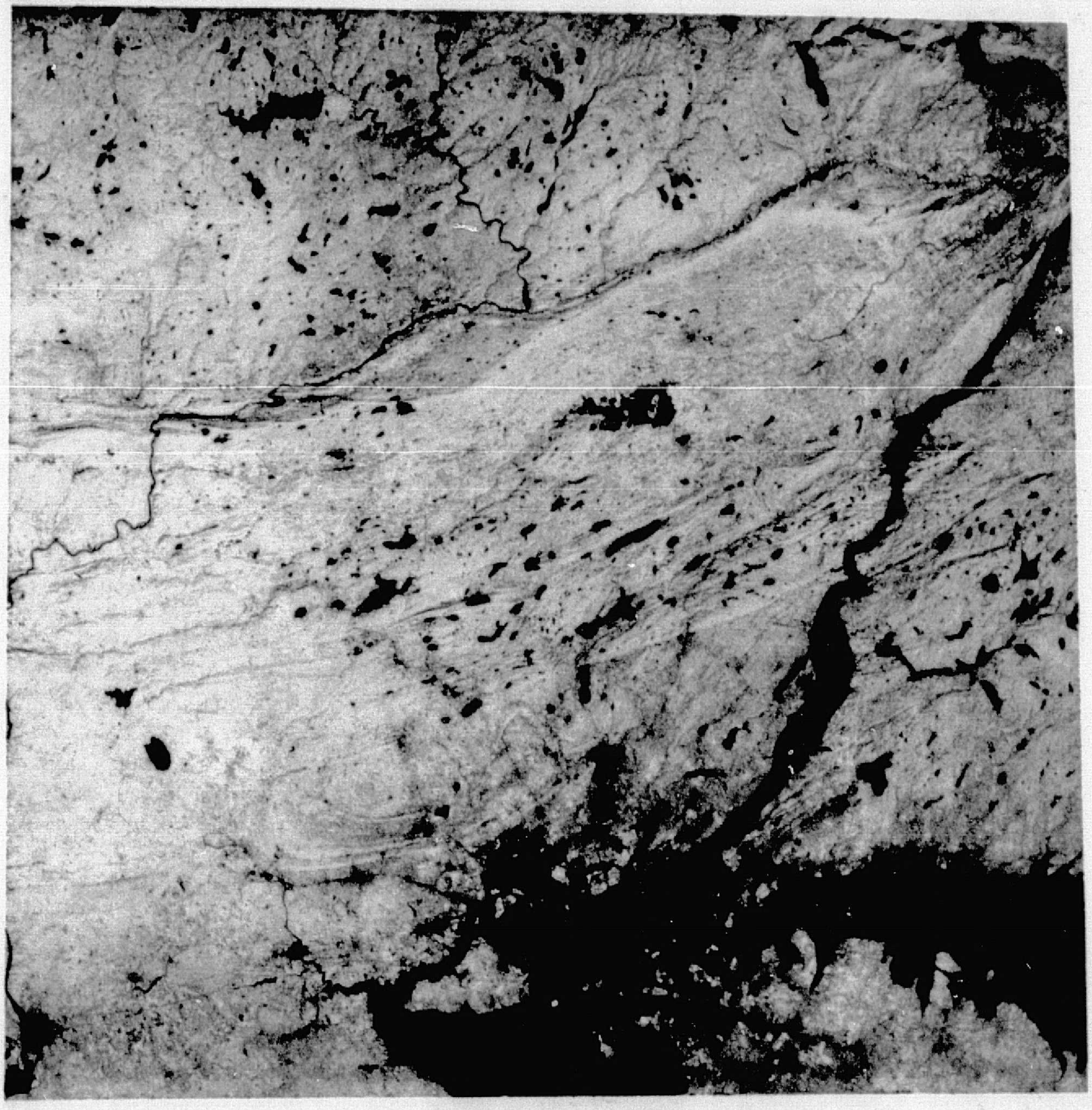
- PLATE 5 -
Missouri Scene - June 1973
SL2 RL12 Frame 136

- PLATE 6 -
Missouri Scene - June 1973
SL2 RL07 Frame 137

ORIGINAL PAGE IS
OF POOR QUALITY

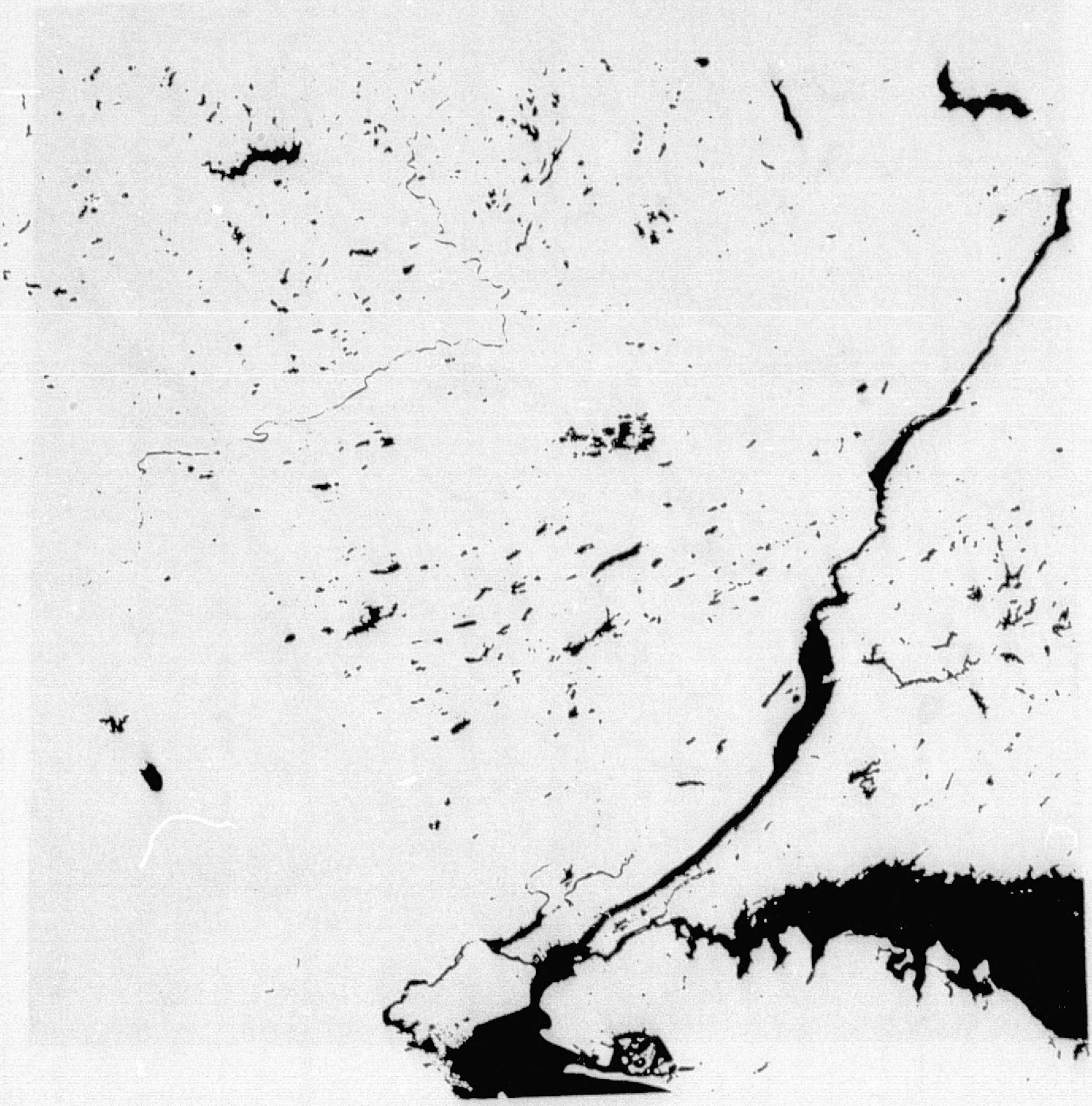


- PLATE 7 -
Vegetation Extraction (White)
Derived from
SL2 RL07 Frame 137 and RL12 Frame 136

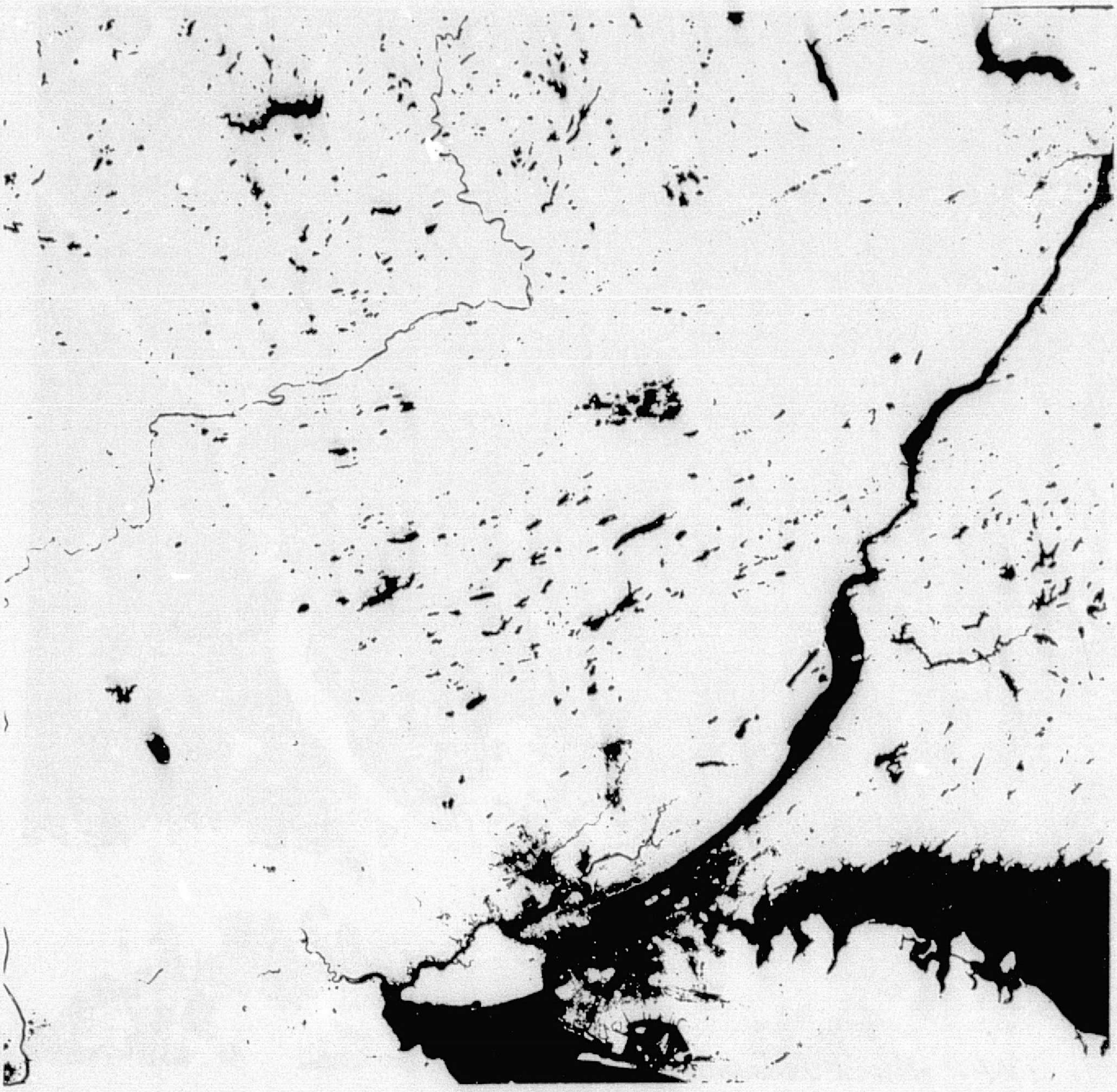


ORIGINAL PAGE IS
OF POOR QUALITY

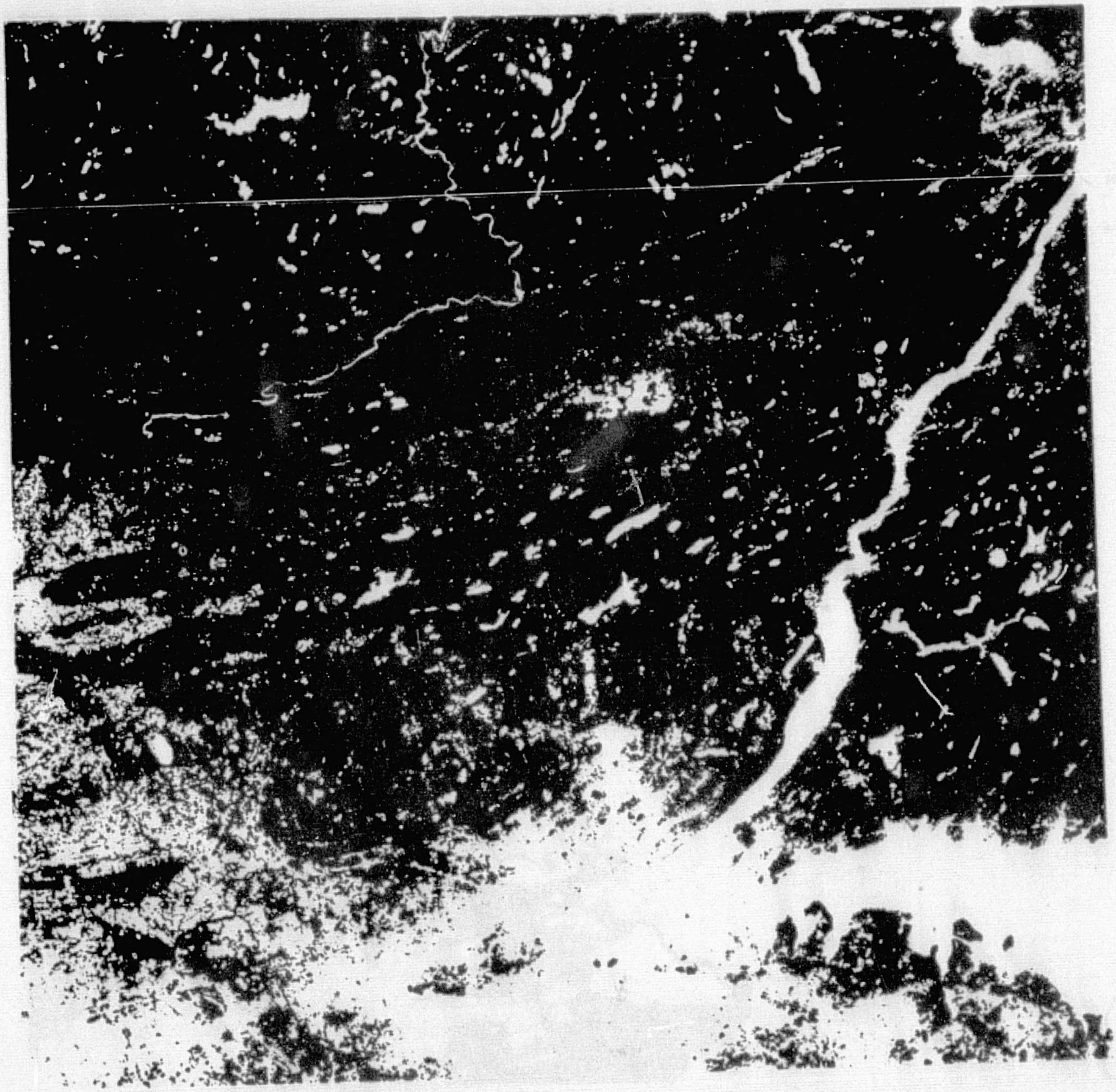
- PLATE 8 -
New York Scene - September 1973
SL3 RL43 Frame 302



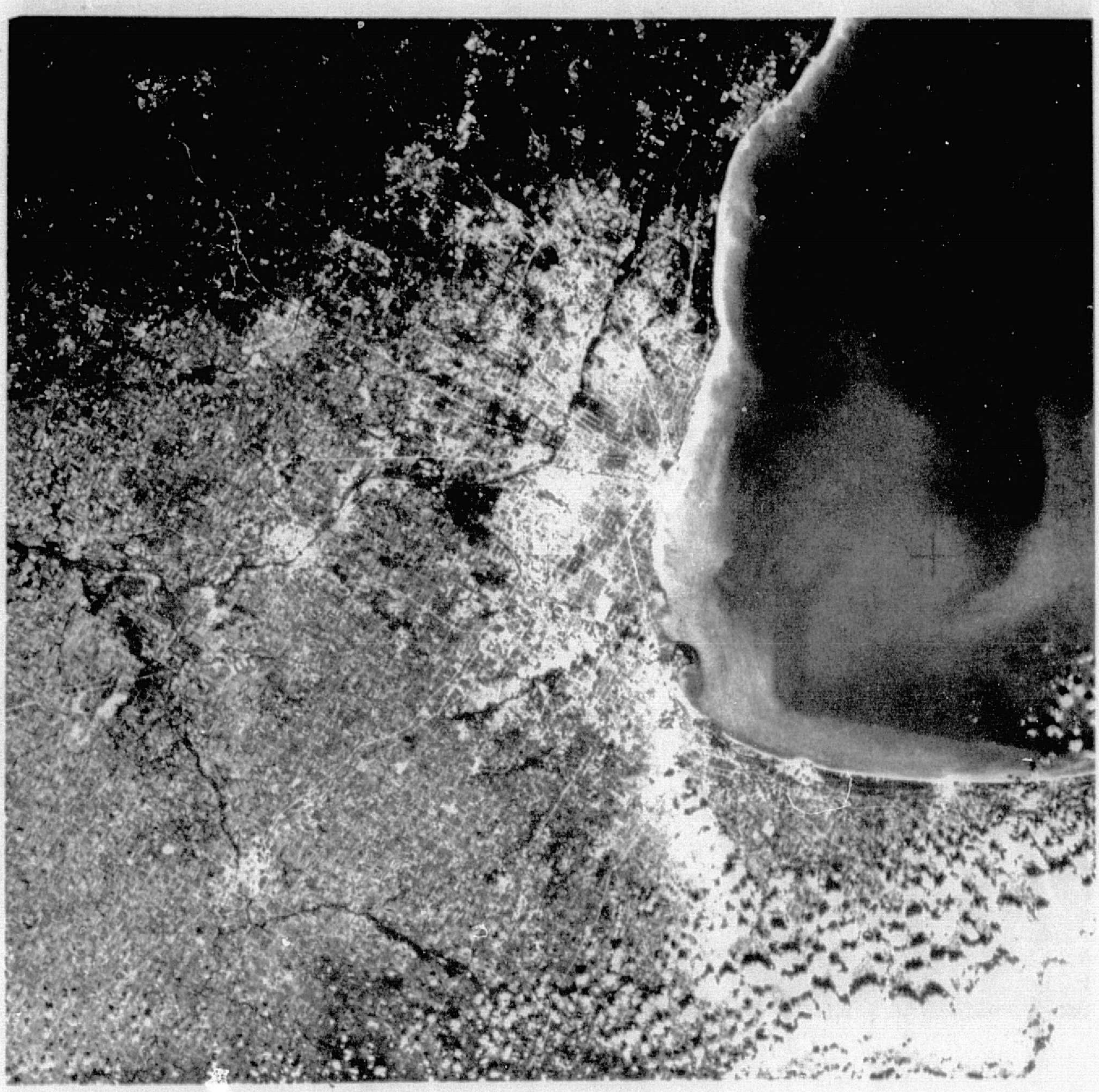
- PLATE 9 -
Open Water Extraction (Black)
Derived from SL3 RL43 Frame 302



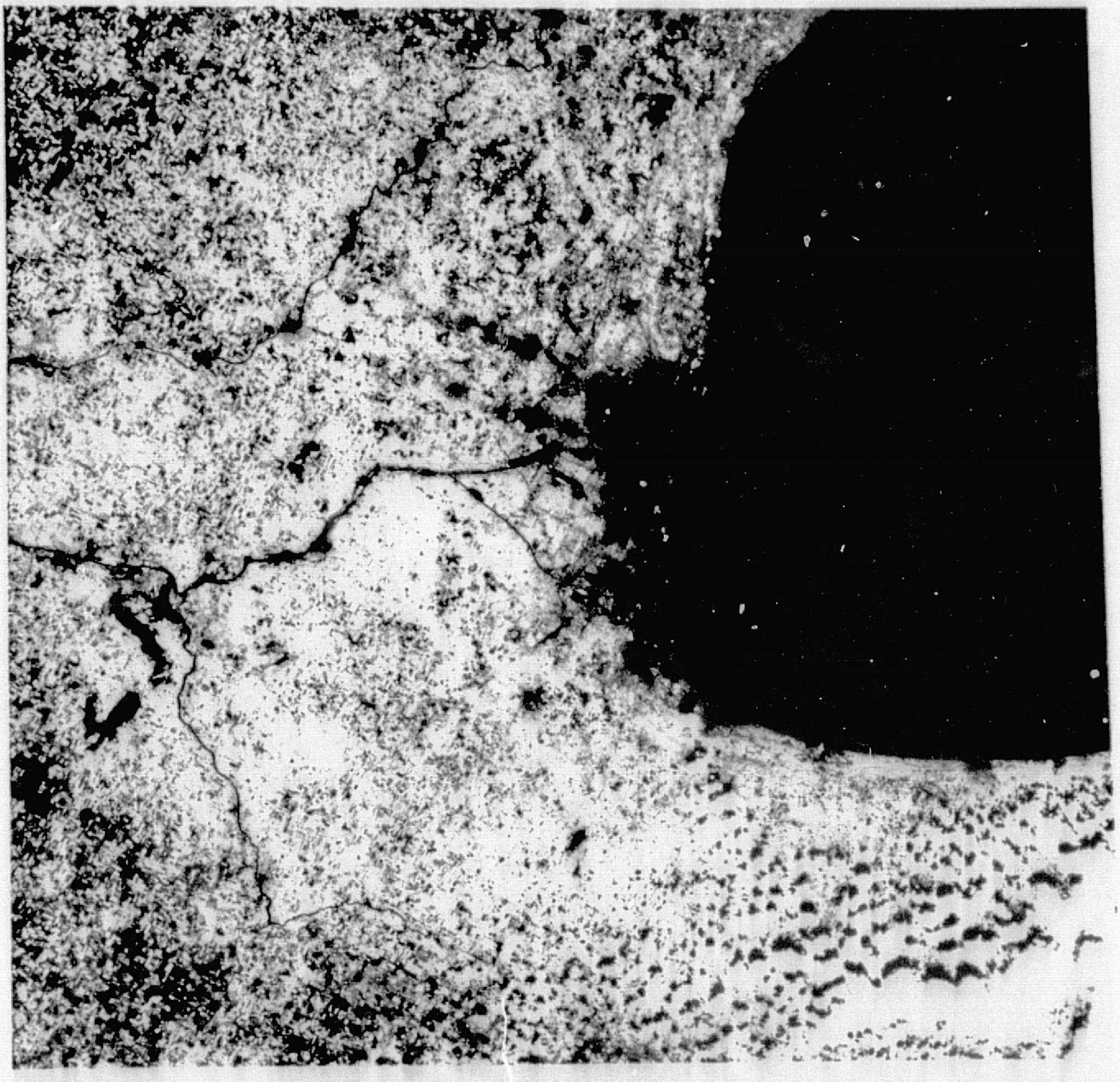
- PLATE 10 -
Open Water and Urban Area Extraction (Black)
Derived from SL3 RL43 Frame 302



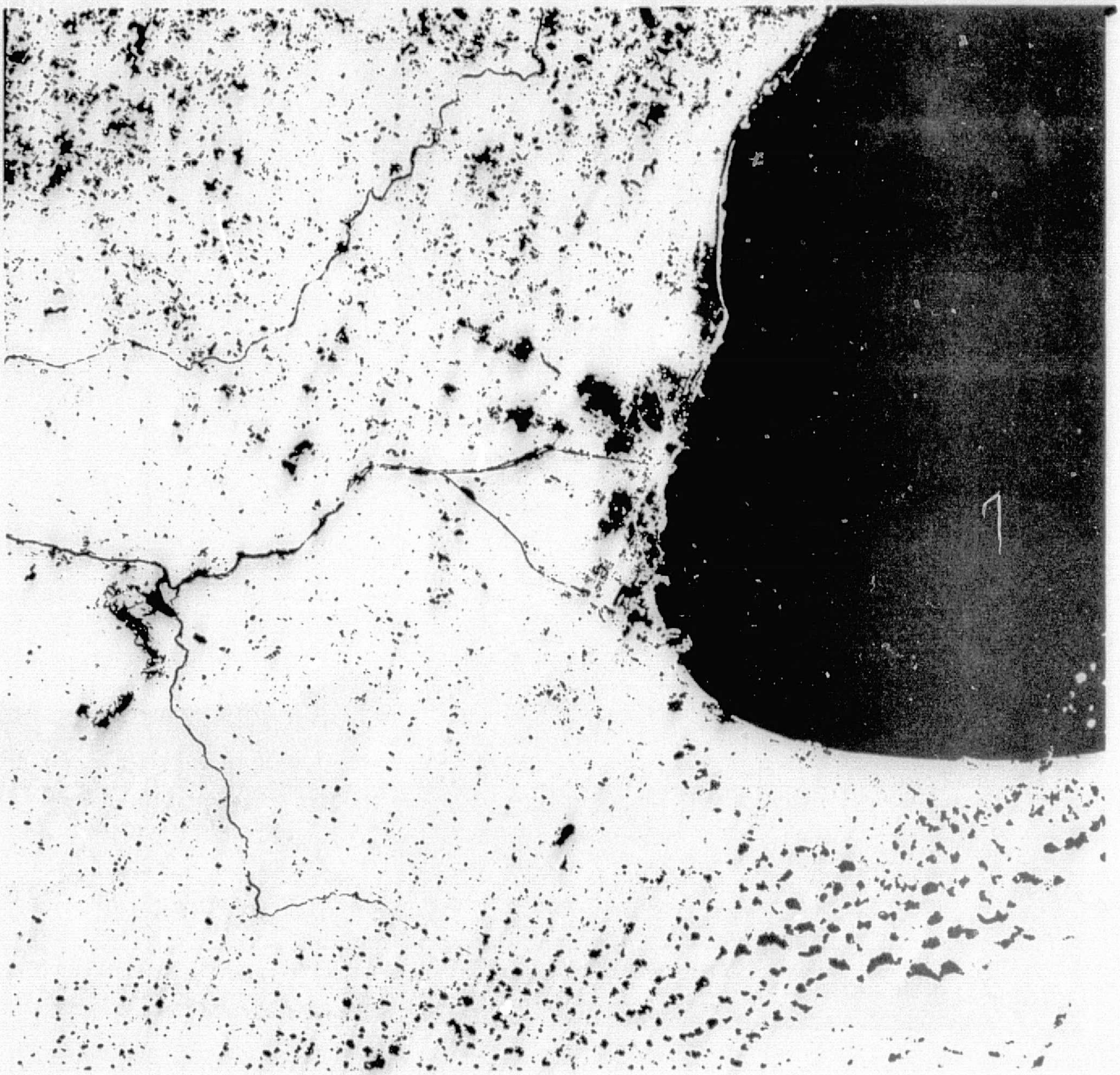
- PLATE 11 -
Vegetation Extraction (Black)
Derived from
SL3 RL Frame and RL43 Frame 302



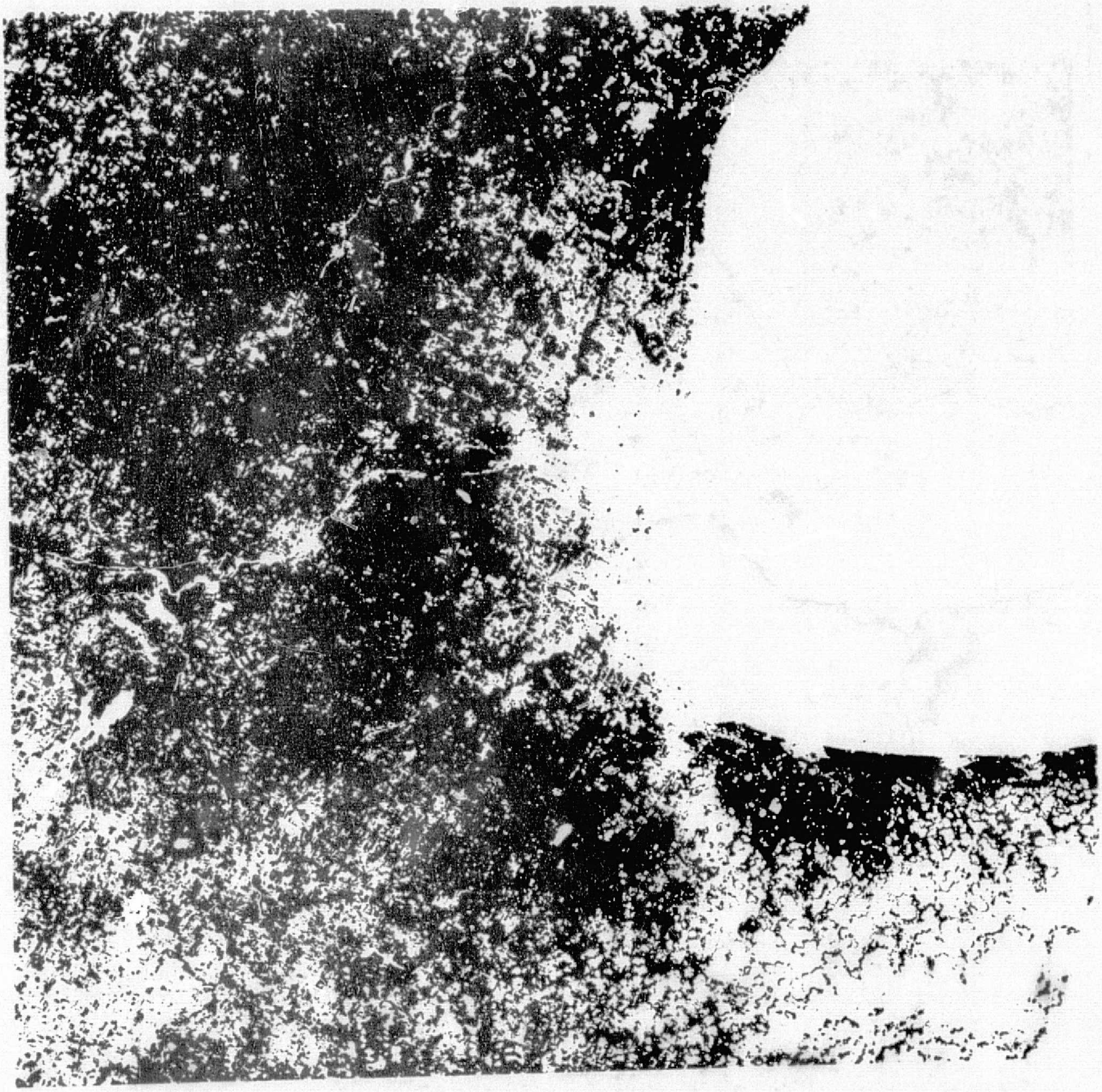
- PLATE 12 -
Illinois Scene - September 1973
SL3 RL48 Frame 200



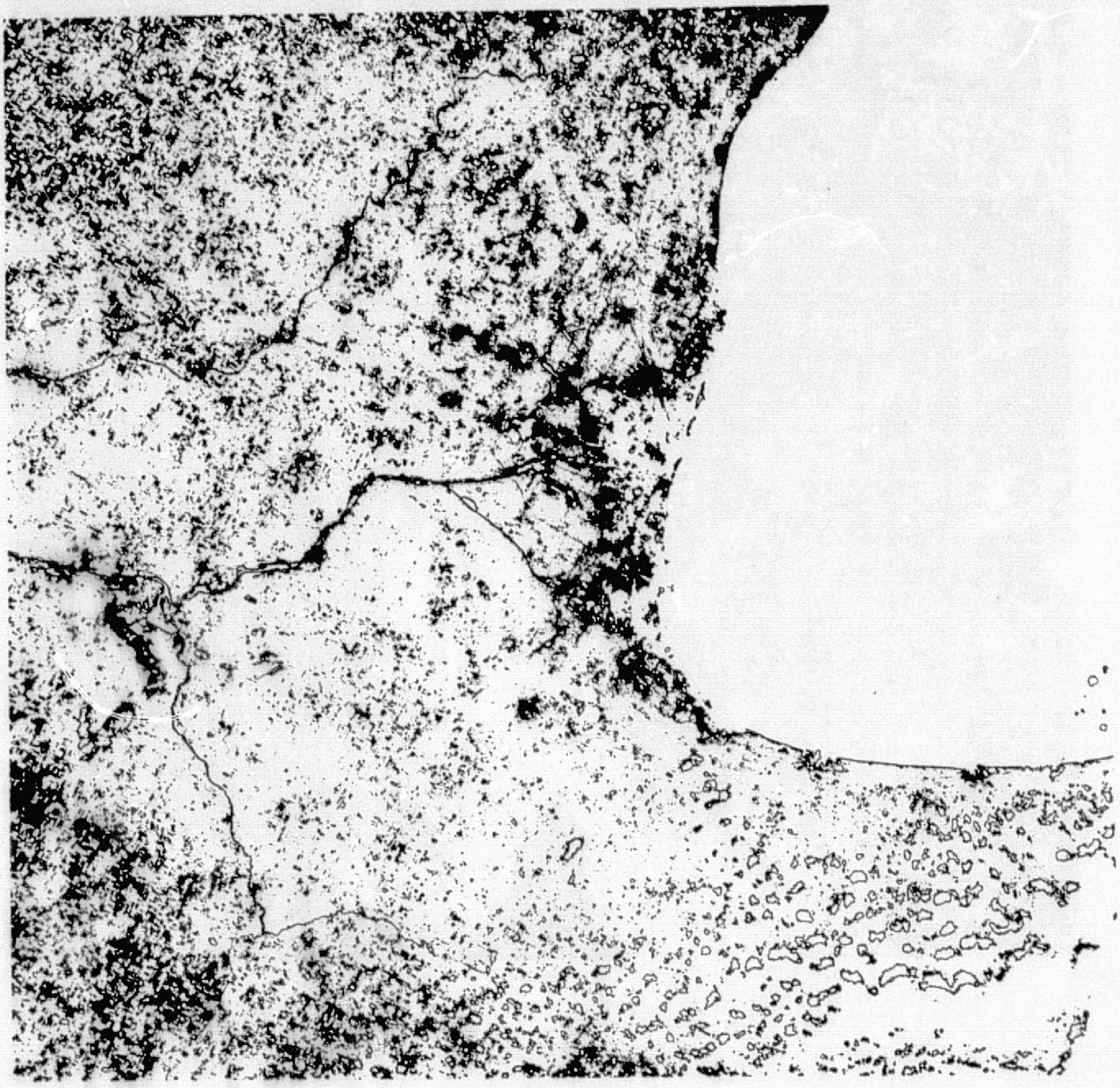
- PLATE 13 -
Illinois Scene - September 1973
SL3 RL43 Frame 200



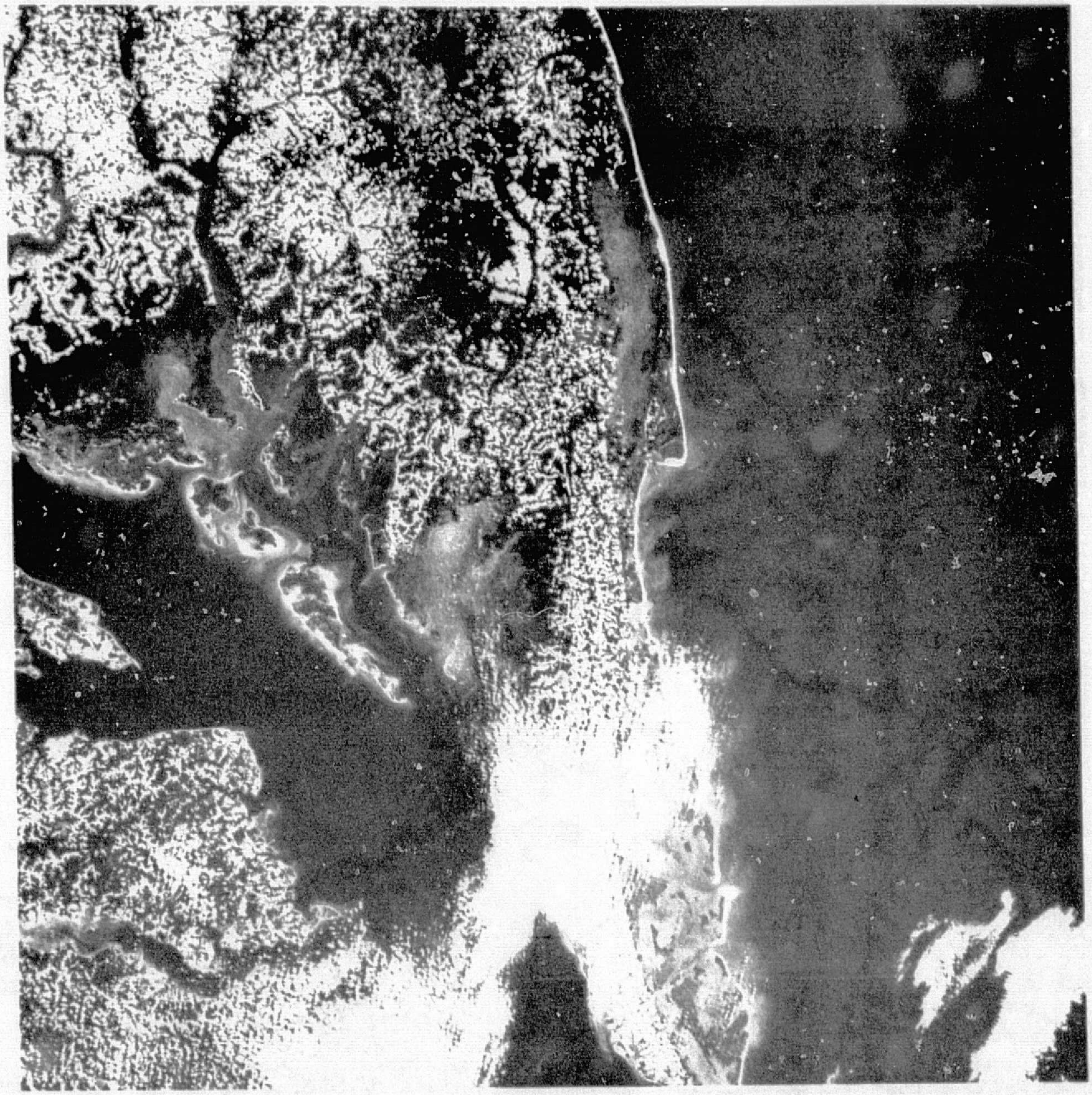
- PLATE 14 -
Open Water Extraction (Black)
Derived from SL3 RL43 Frame 200



- PLATE 15 -
Vegetation Extraction (Black)
Derived From
SL3 Frame 200, RL43 and RL48



- PLATE 16 -
Suburban Area Theme Extraction
Derived from SL3 RL43 Frame 200

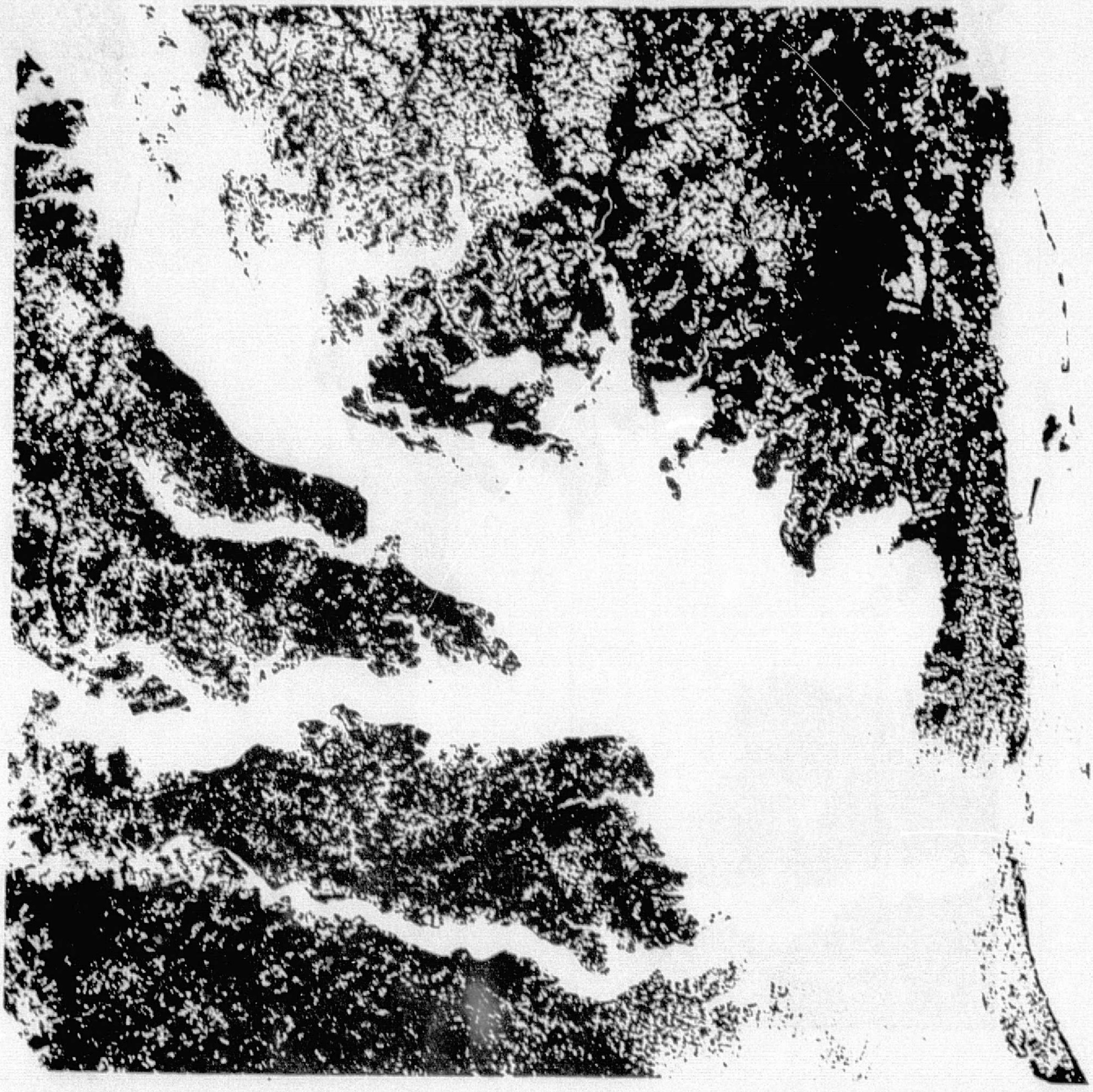


- PLATE 17 -
Virginia Scene - June 1973
SL3 RL18 Frame 167

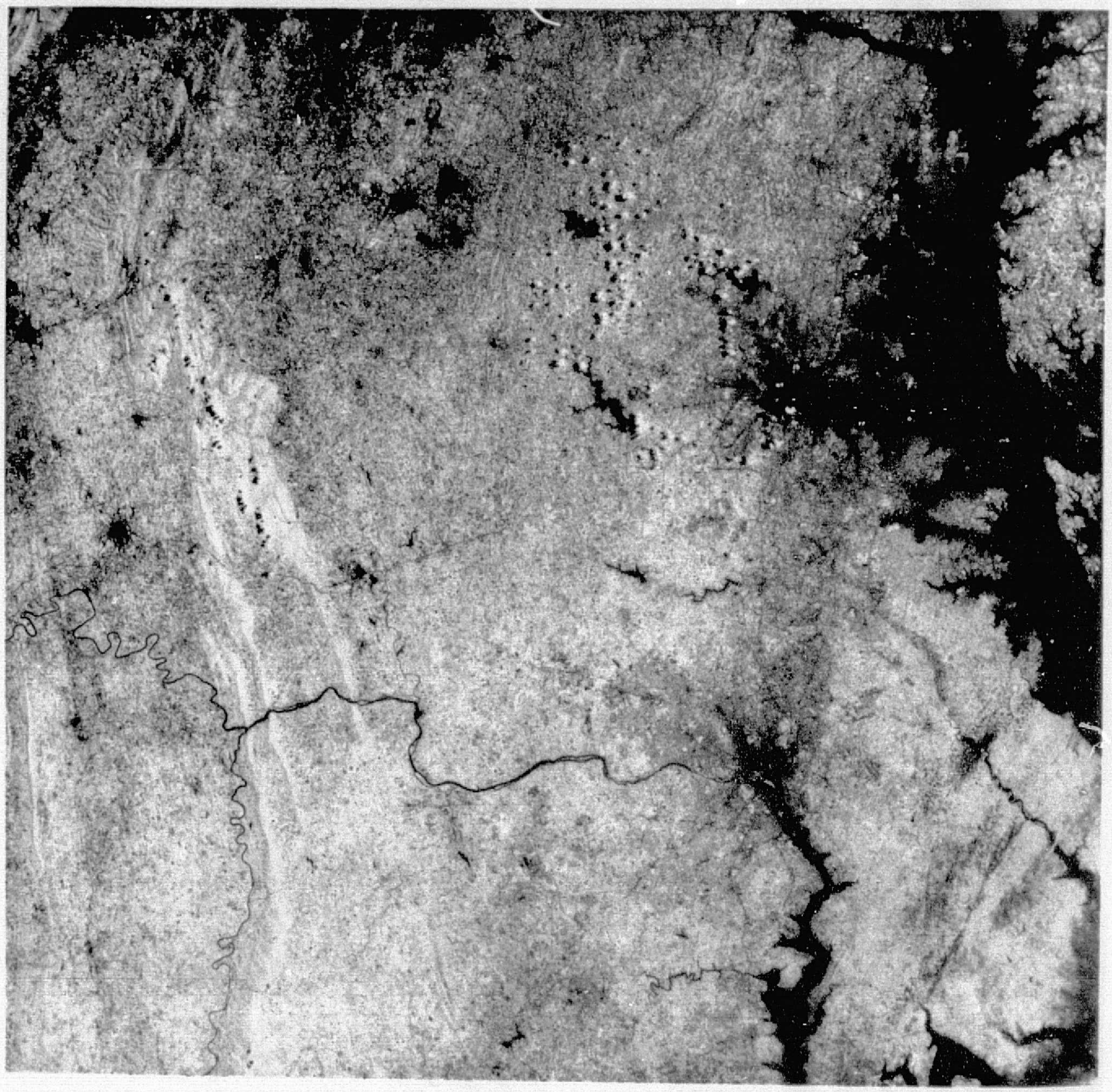
\- PLATE 18 -
Virginia Scene - June 1973
SL2 RL14 Frame 168

- PLATE 19 -
Open Water Theme Extraction (Black)
Derived from SL2 RL14 Frame 168

- PLATE 20 -
Vegetation Theme Extraction (Black)
Derived From
SL2 RL18 Frame 167 and RL14 Frame 168

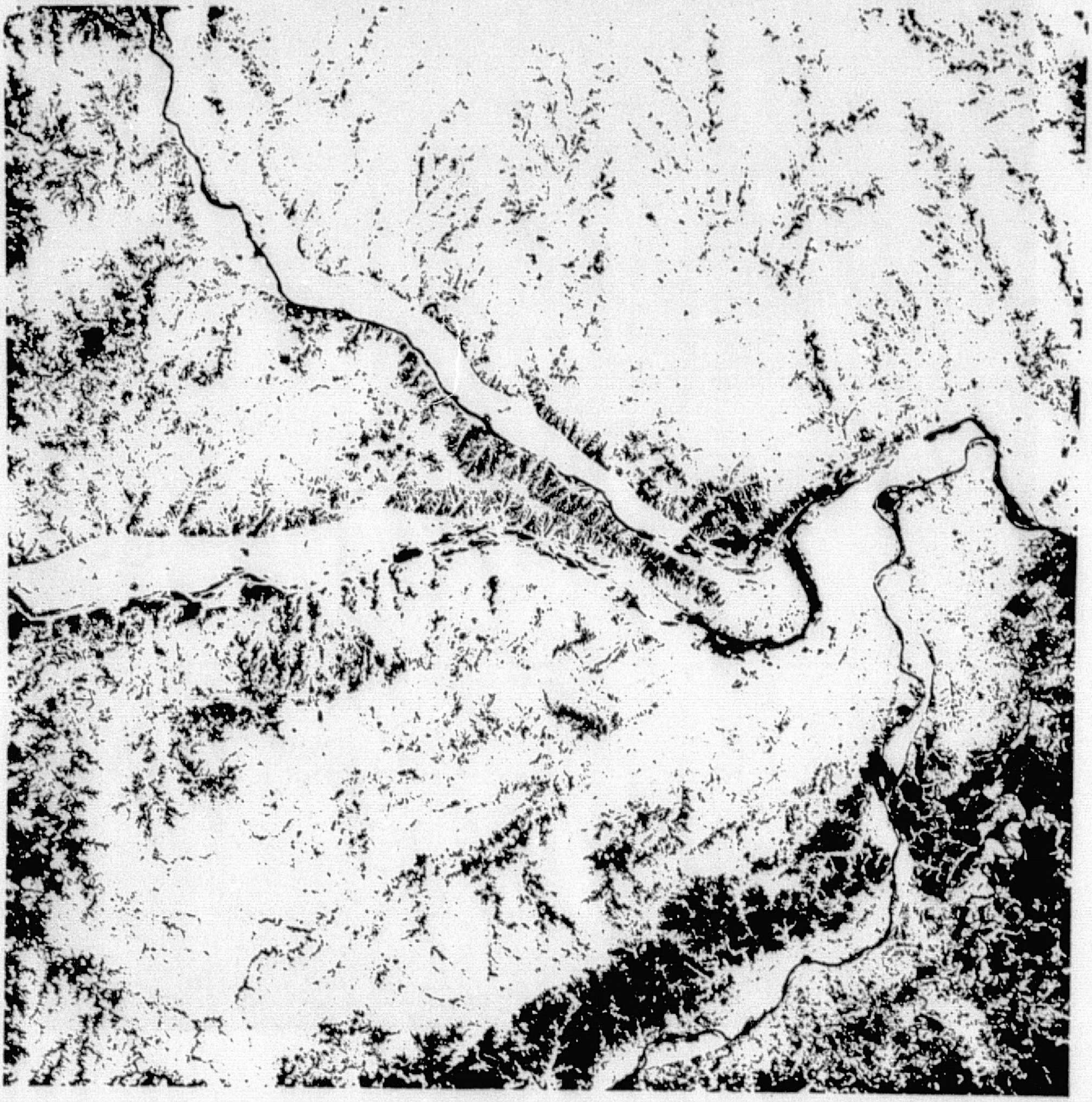


- PLATE 21 -
Vegetation Theme Extraction
Derived from
SL2 RL14 Frame 167 and RL17 Frame 166

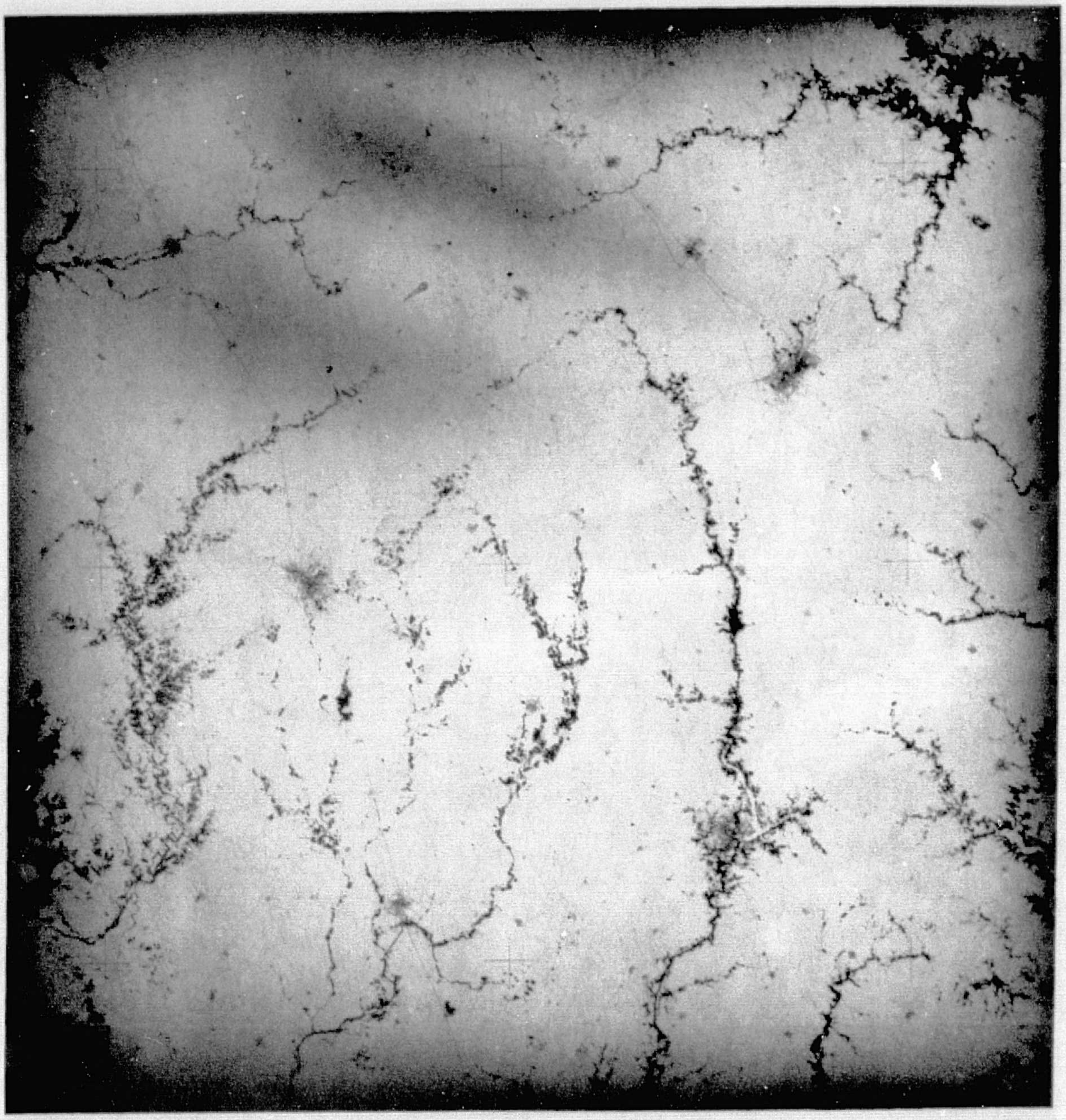


\- PLATE 22 -
Maryland Scene - September 1973
SL3 RL20 Frame 195

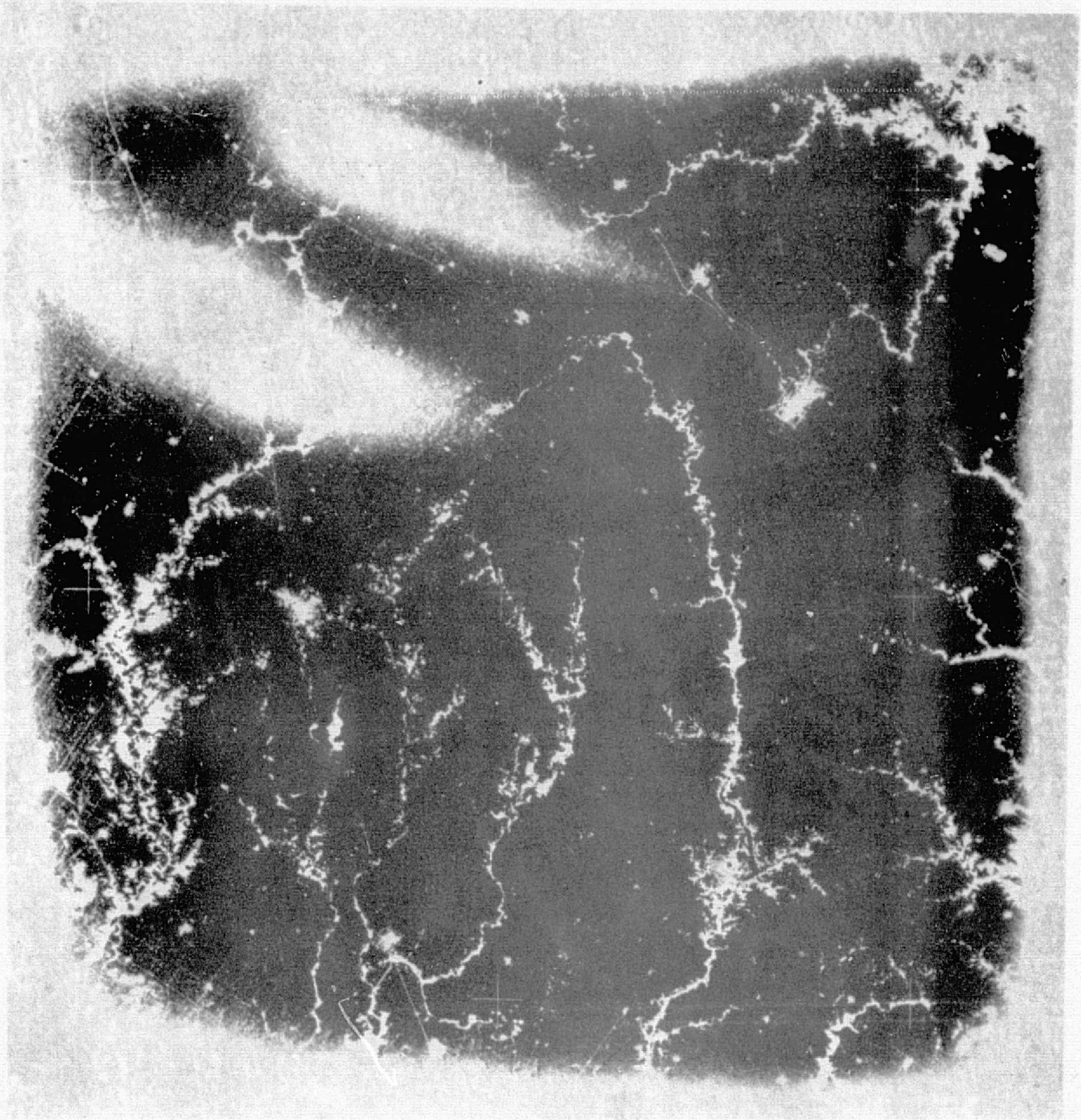
- PLATE 23 -
Illinois Scene - February 1974
SL4 RL65 Frame 292



- PLATE 24 -
Open Water Theme Extraction (Black)
Derived from SL4 RL65 Frame 292

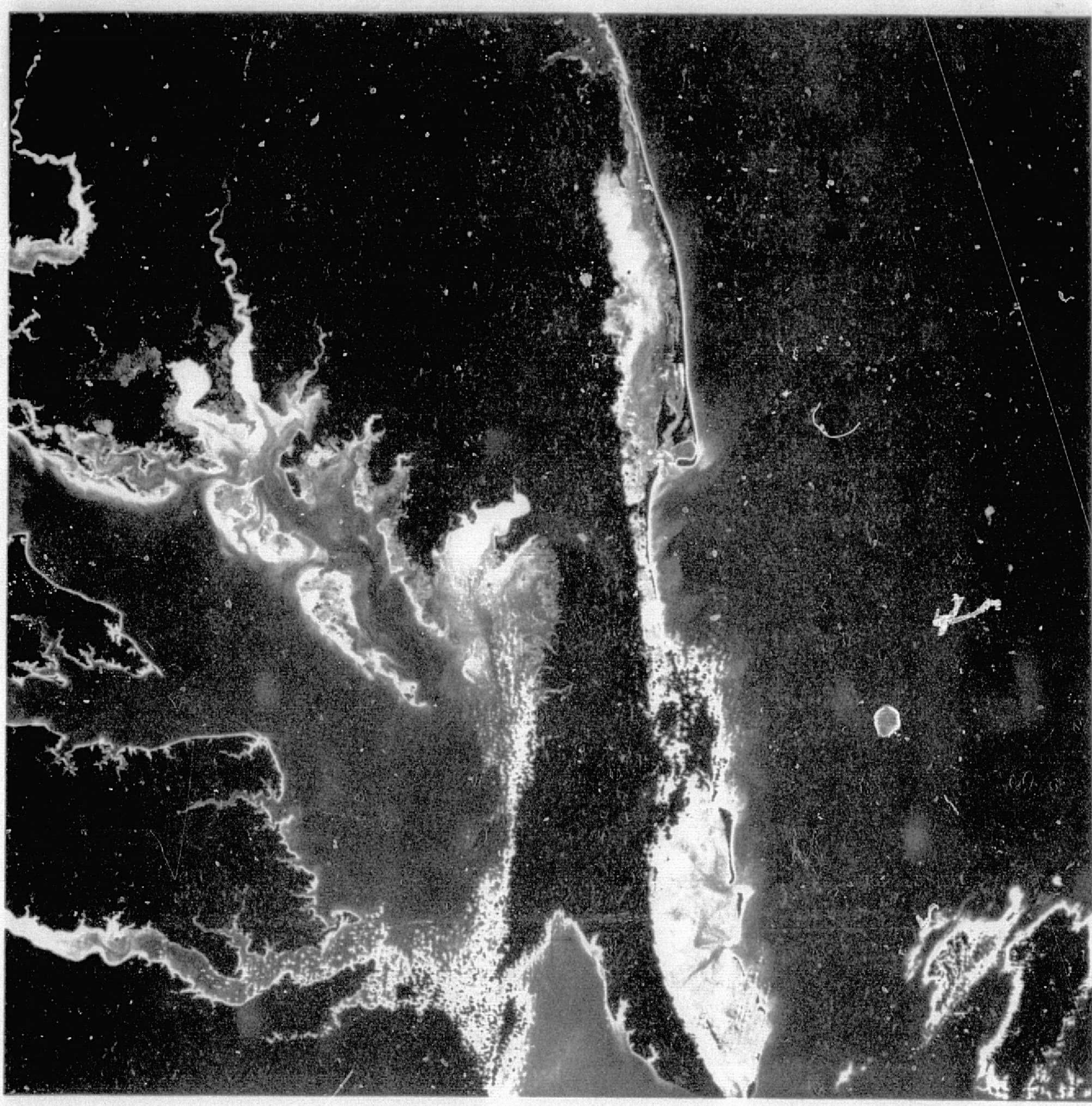


- PLATE 25 -
Illinois Scene - February 1974
SL4 RL65 Frame 295

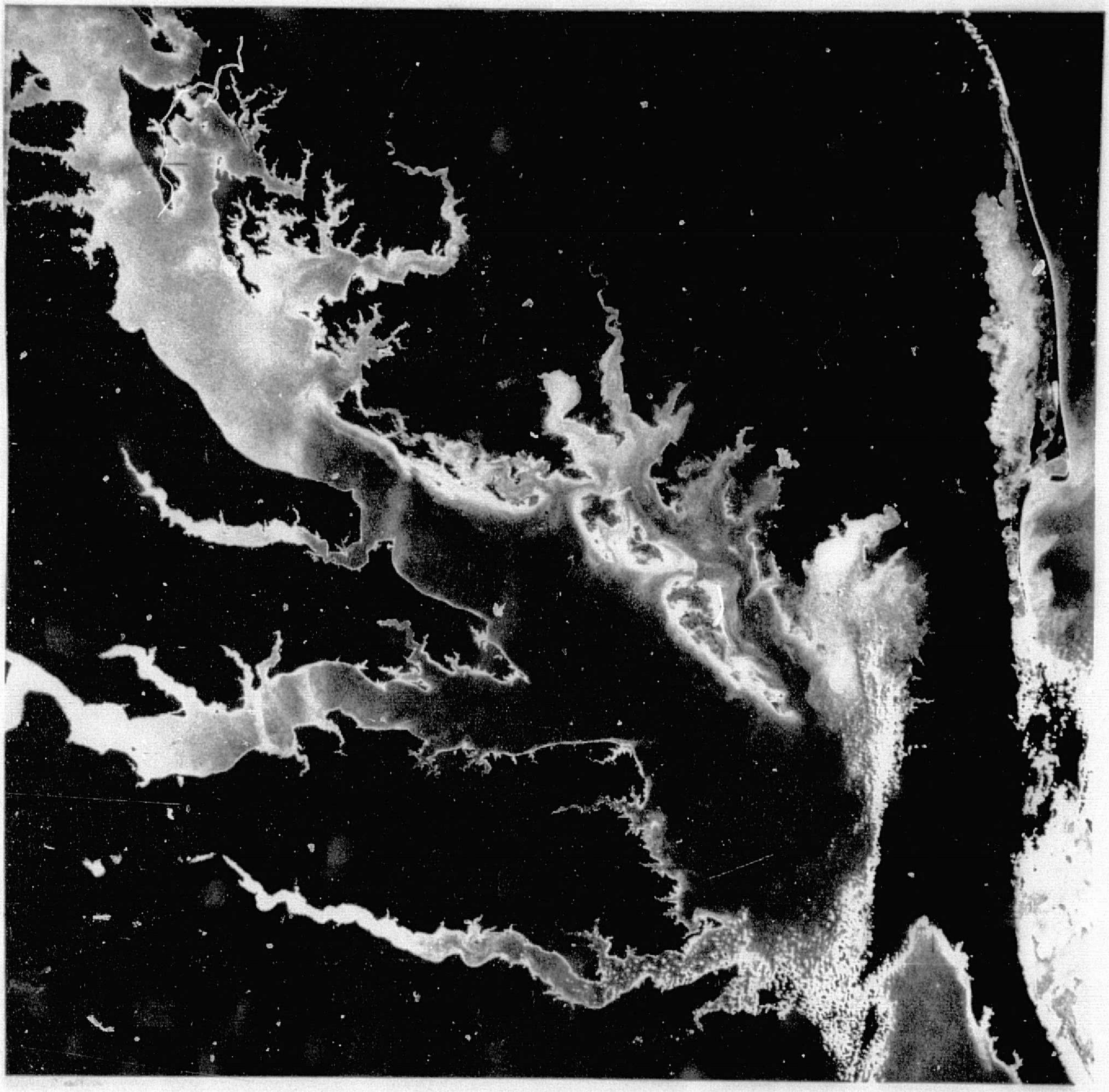


- PLATE 26 -
Vignetted Transportation Route Extractions (White)
Derived from SL4 RL65 Frame 295

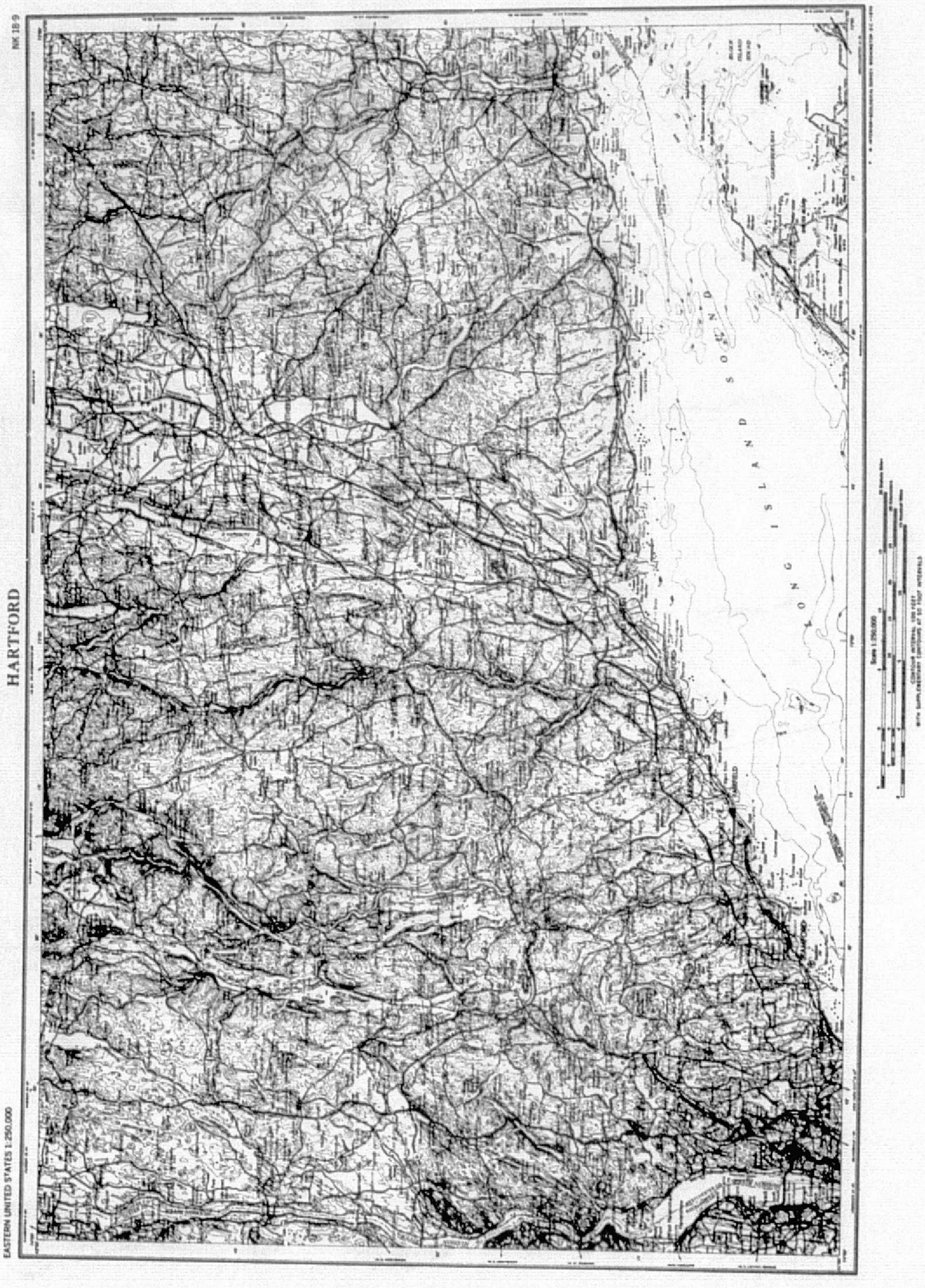
- PLATE 27 -
Vignetted Transportation Route Extractions (White)
Derived from SL4 RL65 Frame 295



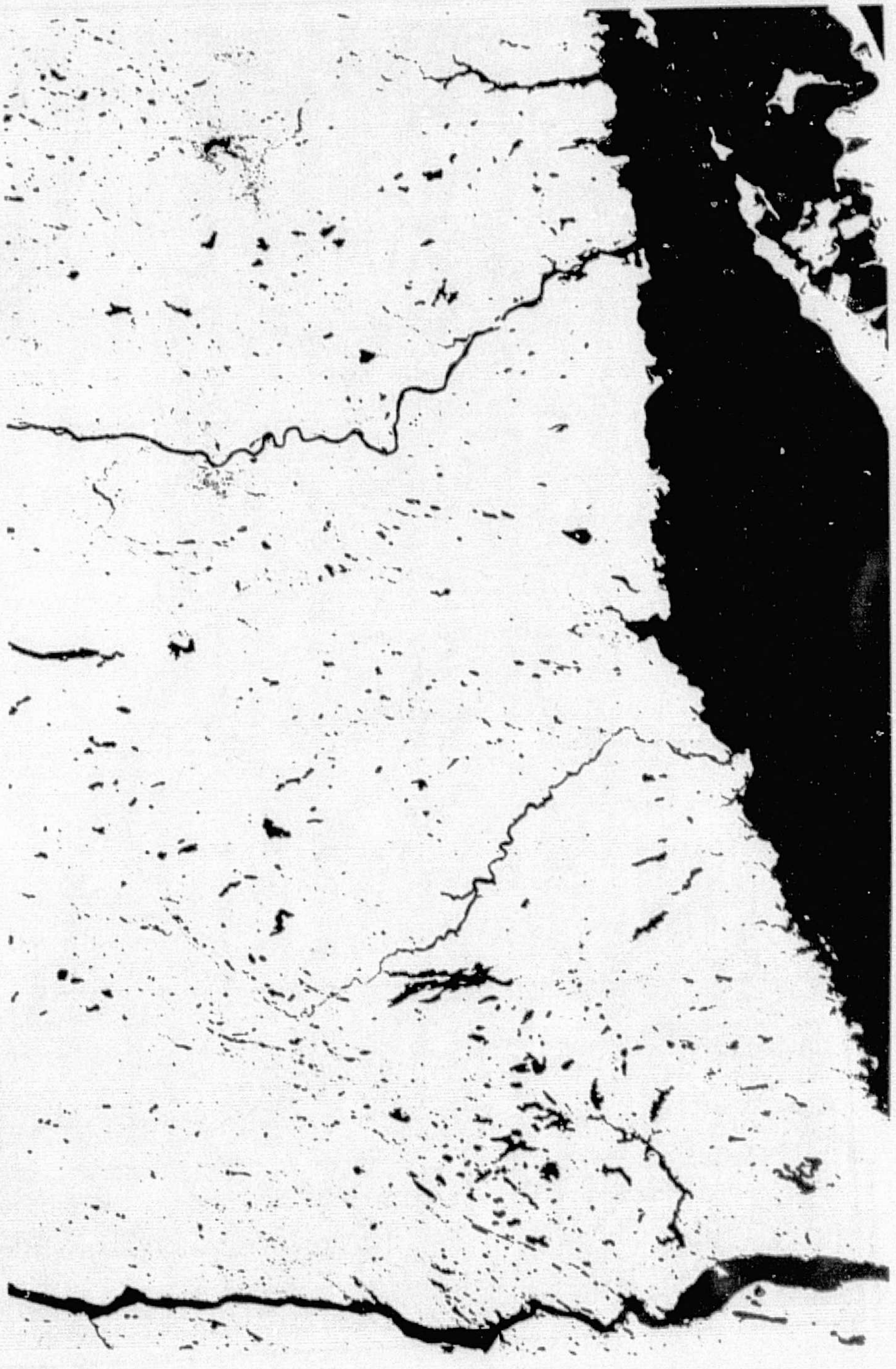
- PLATE 28 -
Open Water Window Mask
Composited with
SL2 RL18 Frame 165



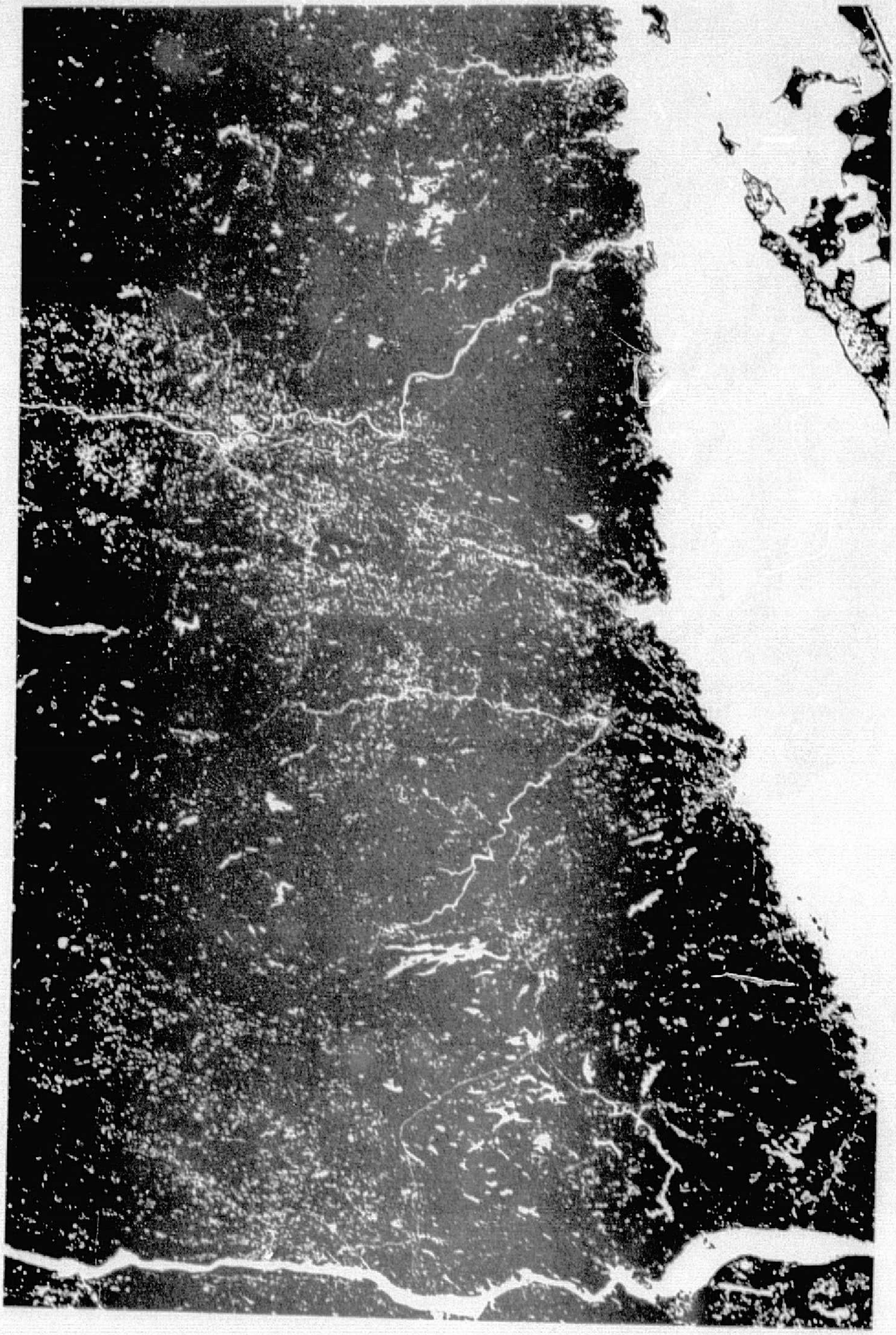
- PLATE 29 -
Open Water Window Mask
Composited with
SL2 RL18 Frame 166



- PLATE 30 -
Hartford, Connecticut
Line Information
Map Overlay

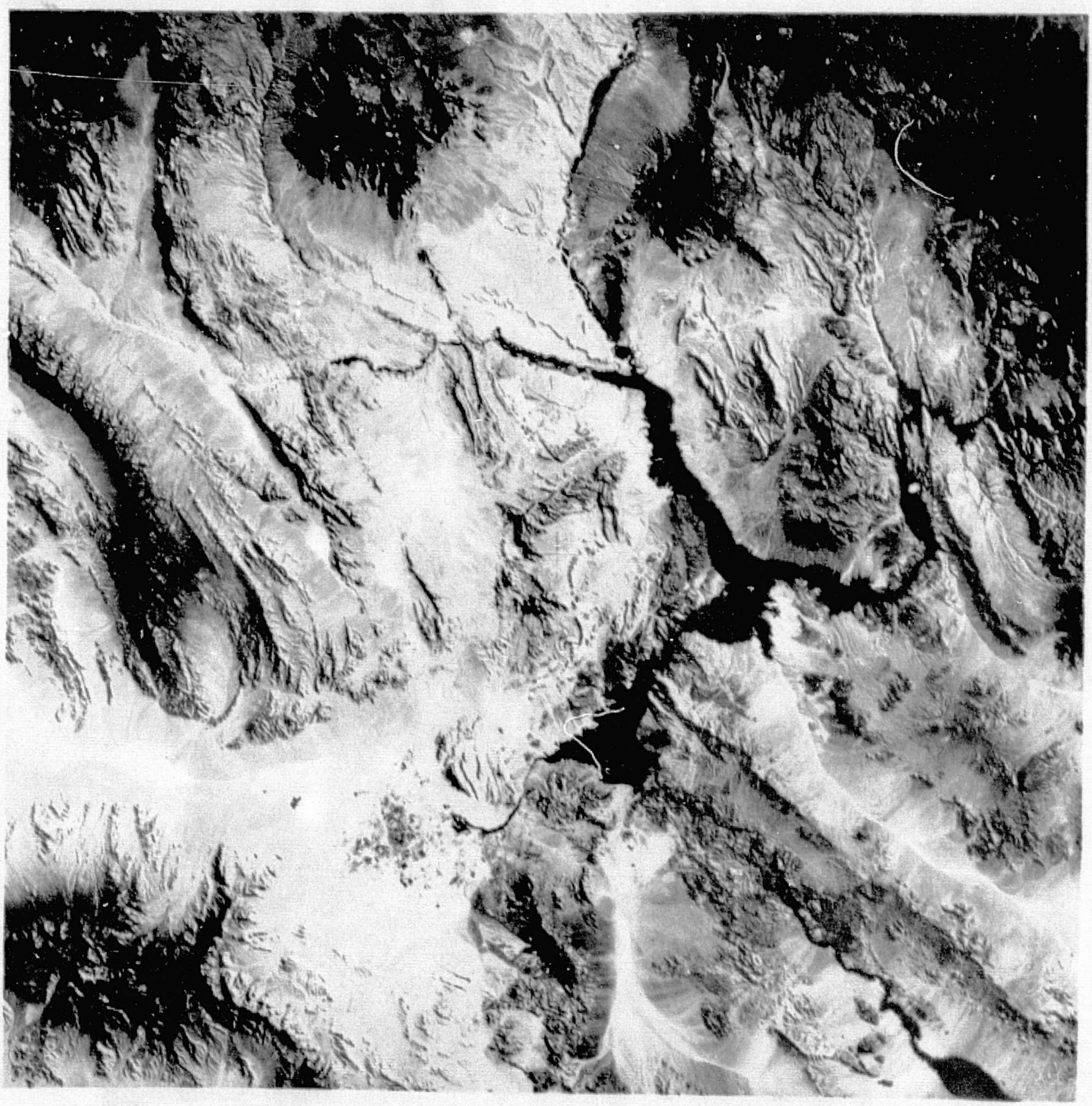


- PLATE 31 -
Hartford, Connecticut Map Overlay
Open Water Theme Extraction (Black)
Derived from
SL2 RL44 Frames 302 and 304

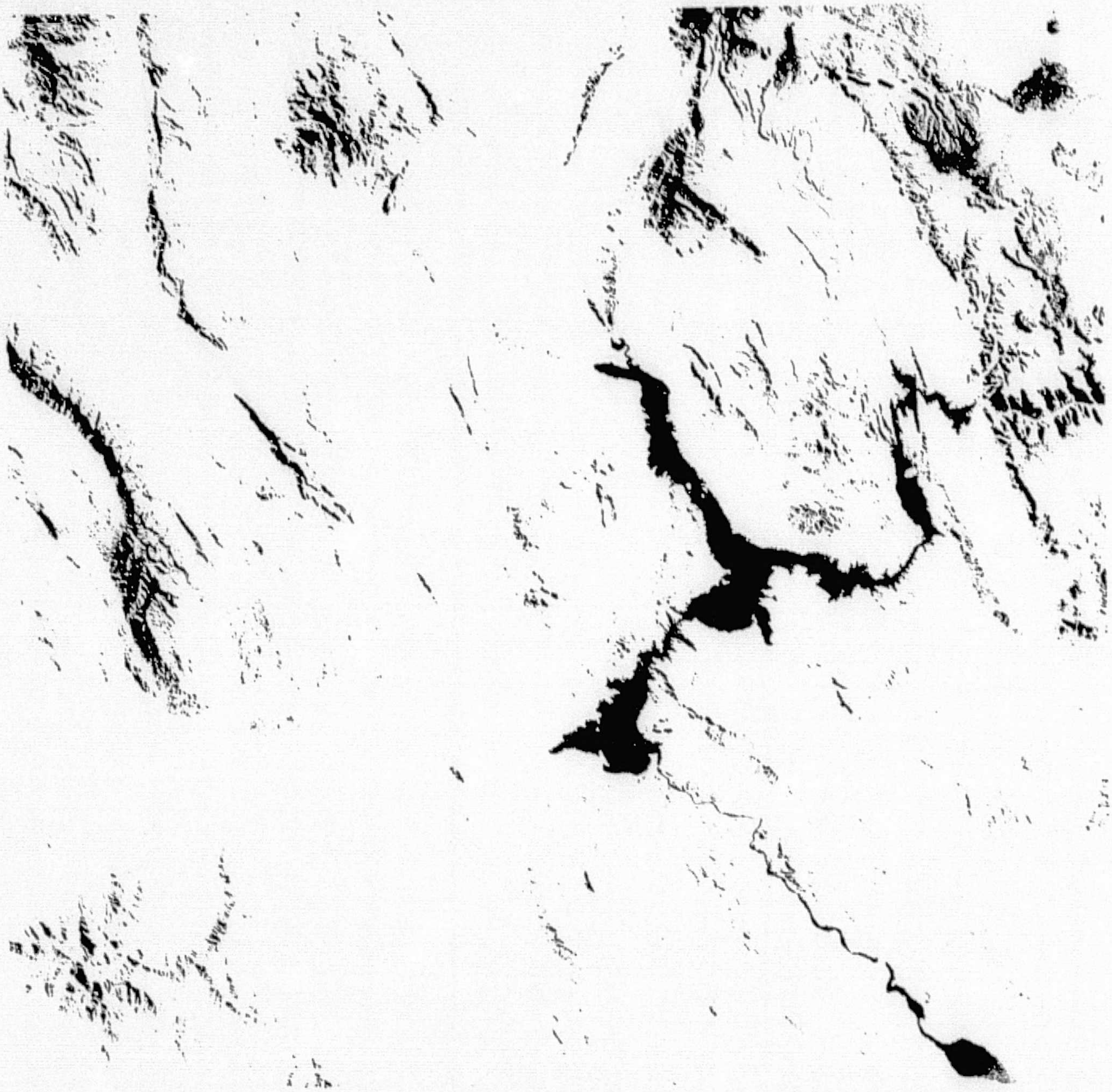


- PLATE 32 -
Hartford, Connecticut Map Overlay
Vegetation Theme Extraction (Black)
Derived from
SL2 RL44 Frames 302 and 304
RL47 Frames 302 and 304

ORIGINAL PAGE IS
OF POOR QUALITY



- PLATE 33 -
Arizona Scene - September 1973
SL3 RL29 Frame 060



- PLATE 34 -
Open Water Theme Extraction (Black)
Derived from SL3 RL29 Frame 060