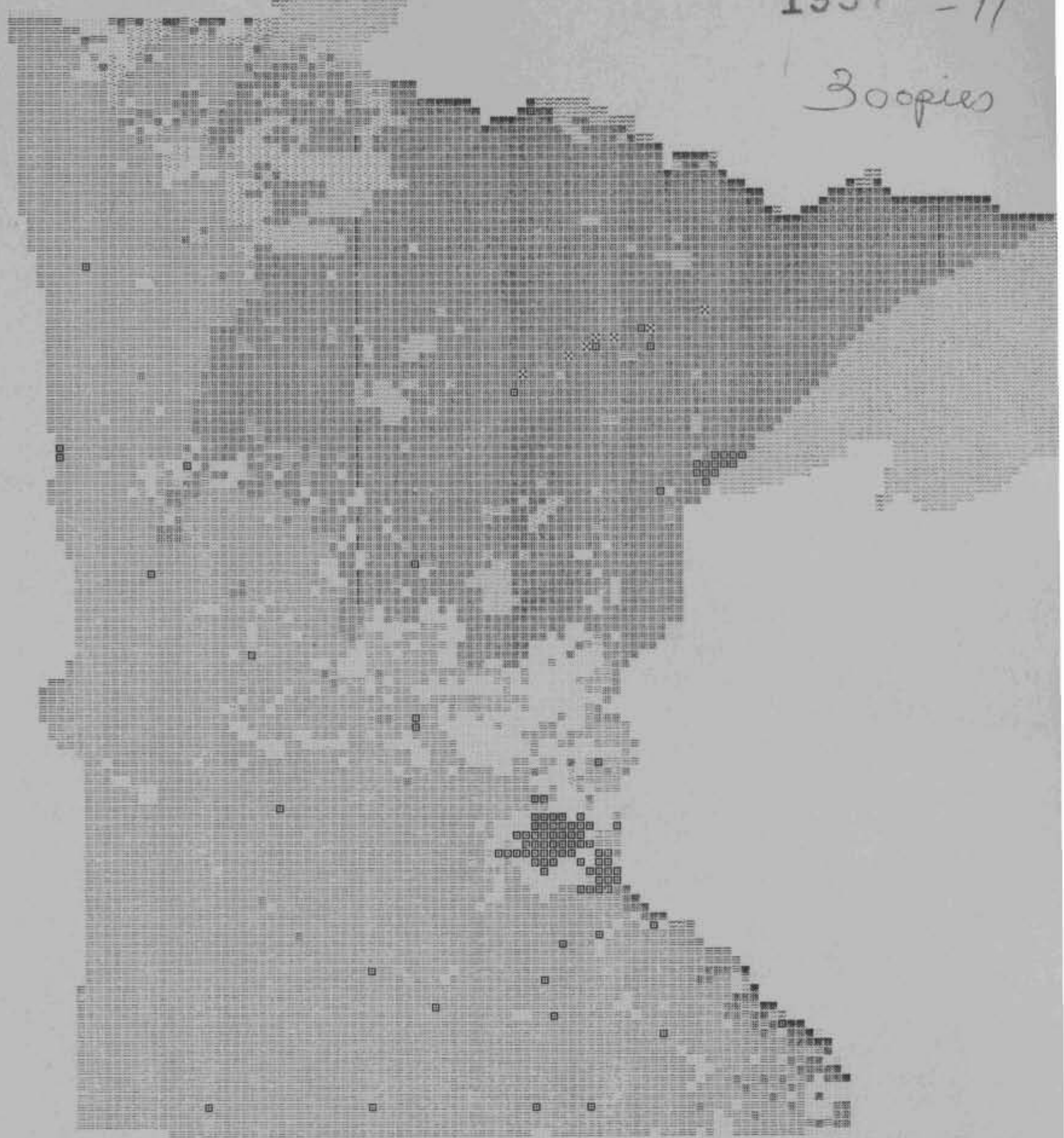
1957 -77

3 copies



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MONITORING SURFACE WATER DYNAMICS IN MINNESOTA

5014

INNESOTA LAND MANAGEMENT
INFORMATION SYSTEM

UNIVERSITY OF MINNESOTA
CENTER FOR URBAN AND
REGIONAL AFFAIRS

STATE PLANNING AGENCY

MONITORING SURFACE WATER DYNAMICS IN MINNESOTA

5014

DWIGHT BROWN
RICHARD SKAGGS
JOHN M. SMILEY
ELIAHU STERN

1975

MONITORING SURFACE WATER DYNAMICS IN MINNESOTA

Dwight A. Brown, Richard Skaggs, John M. Smiley, Eliahu Stern

INTRODUCTION

> Overson Lake is listed on page 296 of 'An Inventory of Minnesota Lakes,' a state publication.
>
> Overson Lake no longer has any water in it, however... The water in Overson Lake disappeared early last month when an unidentified person or persons used dynamite to blow open a short connecting link from the lake to a newly dug 15-foot drainage ditch...A few days before the blast conservation officers had warned...that the lake could not be drained without permit. Was that public water that went down the ditch? Or did the blast release privately owned water creating more cropland for the farm? (Shara, 1974)

Thus begins a recent feature article in the Minneapolis Tribune which illustrates a number of problems related to planning and management of Minnesota's surface water resources.

The first problem concerns the identification and locational documentation of public waters. The second relates to maintenance of an accurate up-to-date inventory. A third problem relates to the monitoring by enforcement personnel of illegal drainage.

The Minnesota Department of Natural Resources (MDNR) is charged with the responsibility of defining and identifying public water in the state. At present the "Minnesota Lakes Inventory" (Bulletin 25) is employed for surface water planning and management. However, Bulletin 25 is now of limited value because of the age of data, the use of basin area without indication of water extent, and the omission of basins under 10 acres. Additional limitations are inherited from the use of existing aerial photography in compiling the inventory. In some counties, only aerial photography taken during 1930's and 1950's dry periods was available, thus allowing some shallow seasonal lakes to escape detection.

Discussions with administrative heads of each division in MDNR and various personnel from The Minnesota State Planning

Agency (MSPA), the Center for Urban and Regional Affairs, University of Minnesota (CURA) and a variety of other state and university centers led to the establishment of a pilot project to examine the cost and utility of ERTS-1 imagery for quickly updating surface water information. A cooperative project was established, based on the results of two studies done in the Geography Department at the University of Minnesota and supported by a NASA grant to the University of Minnesota Space Science Center (Prestin,1974 and Brown and Skaggs,1974). Four areas of the state were indicated by MDNR, the dominant user agency, as tests for the pilot project. Highest priority was given to the copper-nickel study area in Northeastern Minnesota and to the Twin Cities Metropolitan area. Second priority was given to sites in prairie agricultural areas of southwestern Minnesota and the forest-prairie transition zone in west central Minnesota.

The Twin Cities area had been completed by the Department of Geography project but it was deemed useful to produce a complete wall map of the area at a scale compatible with the Twin Cities Metropolitan Council's map series.

The stated needs of field personnel, dealing with permits and enforcement, indicated that the product of the pilot project should be updated 1:24,000 and 1:62,500 scale topographic map overlays that showed the extent of seasonal variations in open surface water verifiable with ERTS-1 imagery. These transparent acetate overlays could then be used by field personnel and could also serve as a locationally accurate data base to be digitized and entered in a water information system. The maps could also provide the basis for producing highly accurate maps at scales as small as 1:125,000. The Twin Cities Metropolitan area was mapped at this scale using a mosaic of 45 topographic maps so that a comparison could be made between the costs of mapping at very large scale and reducing the maps as opposed to remapping at this scale directly from the imagery.

This report will describe the procedures used to produce the two map products described above, detail and compare costs of various products, and compare the map data to that included in existing and traditional sources of information on surface water. Comparisons will be made in lieu of measurements of accuracy because it has become clear to the researchers that these maps, based on multi-season ERTS-1 coverage coupled with good topographic maps, yield a product that far exceeds the quality of any type of "ground truth" now available or potentially available short of an ERTS underflight photographic mission that would rival the corn blight project. Furthermore, the cost of producing this product is very low relative to the cost of producing any of the existing information.

MAPPING PROCEDURES

Three data sources provide the basis for producing the 1:24,000 and 1:62,500 transparent topographic map overlays. They are good quality topographic maps and good quality ERTS-1 MSS system corrected (bulk) color transparencies for two dates. The two dates were selected to maximize the range of observed water area. The maximum and minimum water images were used to produce 35mm ektachrome quad-centered slides from back lighted ERTS-1 transparencies. The single lens reflex camera used was fitted with extension tubes and a through-the-lens-light meter. Total area covered by the slides was 3 to 4 times the quadrangle area in order to minimize optical distortion. The topographic maps were mounted on the wall and the slides were projected with a remote focus, zoom lens slide projector. The use of two people in the operations greatly speeded up the slide registration and mapping procedures.

The maximum geometric discrepancies between the map and projected image were about .1 inch over a 1:24,000 scale map. With the use of base maps other than USGS topographic quadrangles the geometric discrepancies were much larger.

Once the slide image was registered a stable base drafting acetate, with previously drawn USGS water boundaries, was registered over the topographic map. The topographic map was then removed to expose the white wall mounting board, thus maximizing color contrasts. The wall mount mapping procedure was found to be less time consuming in registration and produced a higher contrast image for interpretation than did rear projection drafting tables. The latter are probably less fatiguing for interpreters on long tedious interpretation jobs; but, for this operation image registration time was a significant portion of the total time.

The initial image interpreted and mapped was the maximum aerial extent of open water followed by registration and mapping of the minimum extent of open water image. Once the interpretation procedure was complete, the acetate was taken to a drafting table and registered on the topographic quadrangle. The extent and limits of water were then interpreted and corrected on the topographic map, using the ERTS verified location of water. With this procedure it is possible to exercise judgement and interpret the extent of water in narrows that are not detectable on ERTS, if the level of water can be verified in the two connected wider basins.

Although confusion of plowed fields and cloud shadows with lakes was not a problem with the images used in this study, confusion is known to occur. By using the above method the chance for such error is very small because lakes are restricted to very specific topographic locations. These locations on the map have well defined geometries that would have a very low order of probability of corresponding with plowed fields and cloud shadows.

The next step was final drafting and lettering of the maps so that transparent overlays could be produced for field personnel. Final drafting was done by hand; but, may be done by continuous line plotters if the pencil sheets are digitized for entry into a water information system.

The legends were mass produced on photographic transparencies to enable the production of contact autopositive topographic map overlays.

Figure 1 shows the location of areas where water mapping has been carried out to produce the variety of maps necessary for a reasonable cost analysis. The four areas indicated include new and old topographic maps, both the 1:62,500 and 1:24,000 series, and 5 distinctly different environmental settings. Figure 2 shows the index for each of the quadrangles and reduced versions of the quadrangles are shown in Figures 3-36.

REGIONAL MAPPING

The second phase in this project was to examine the possibility of using the quadrangle maps as a basis for producing larger area maps. Highest priority for this task was given to the Twin Cities Metropolitan area. These quadrangles had already been produced under the project that provided the interpretation procedures used in this pilot project (Brown and Skaggs, 1974).

Early in the research program examining ERTS-1 applications to Minnesota land use ERTS images were used to produce 1:125,000 maps of surface water. For this study a variety of west-central Minnesota counties were mapped with 70mm system corrected band 7 MSS images projected on a county highway map base. Pencil copies of these maps required from 20 minutes to four hours per county depending on size and complexity of the county. Transferring these findings to the Twin Cities area yields a final inked copy at a 1:125,000 scale at 30 man hours. Such a map, while low cost, has several distinct limitations. Few lakes under 20 acres were detected with this mapping procedure. Secondly, the geometry of the county highway maps was not adequate for rapid image registration and mosaicing of multiple county areas. Imprecise lake locations were a result.

There is more detail on the 1:24,000 quads than can be portrayed on the 1:125,000 scale maps. However, it is possible to show more information than was produced in the procedure

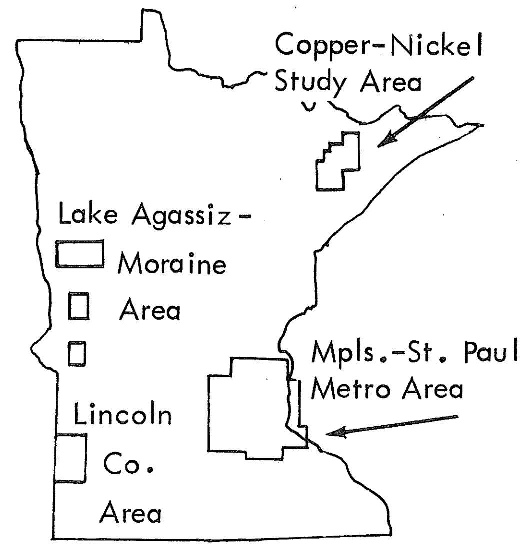
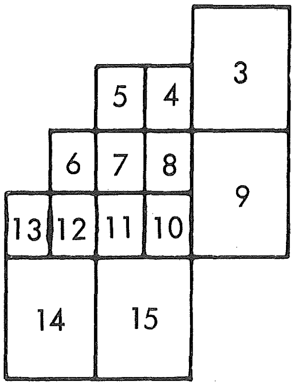
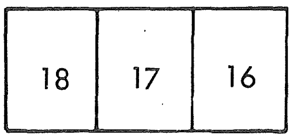


Figure 1. Location of Surface Water Study Areas.



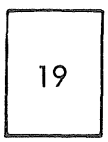
Copper-Nickel Study Area

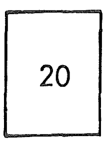
3. Gabbro Lake
4. Kangas Bay
5. Bear Island Lake
6. Isaac Lake
7. Babbitt
8. Babbitt NE
9. Greenwood Lake
10. Babbitt SE
11. Babbitt SW
12. Allen
13. Aurora
14. Markham
15. Brimson



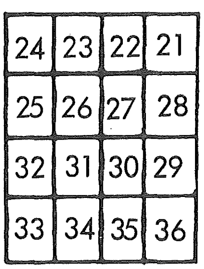
Lake Agassiz-Moraine Area

16. Vergas
17. Pelican Rapids
18. Barnesville
19. Wendell
20. Chokio





Lincoln County Area

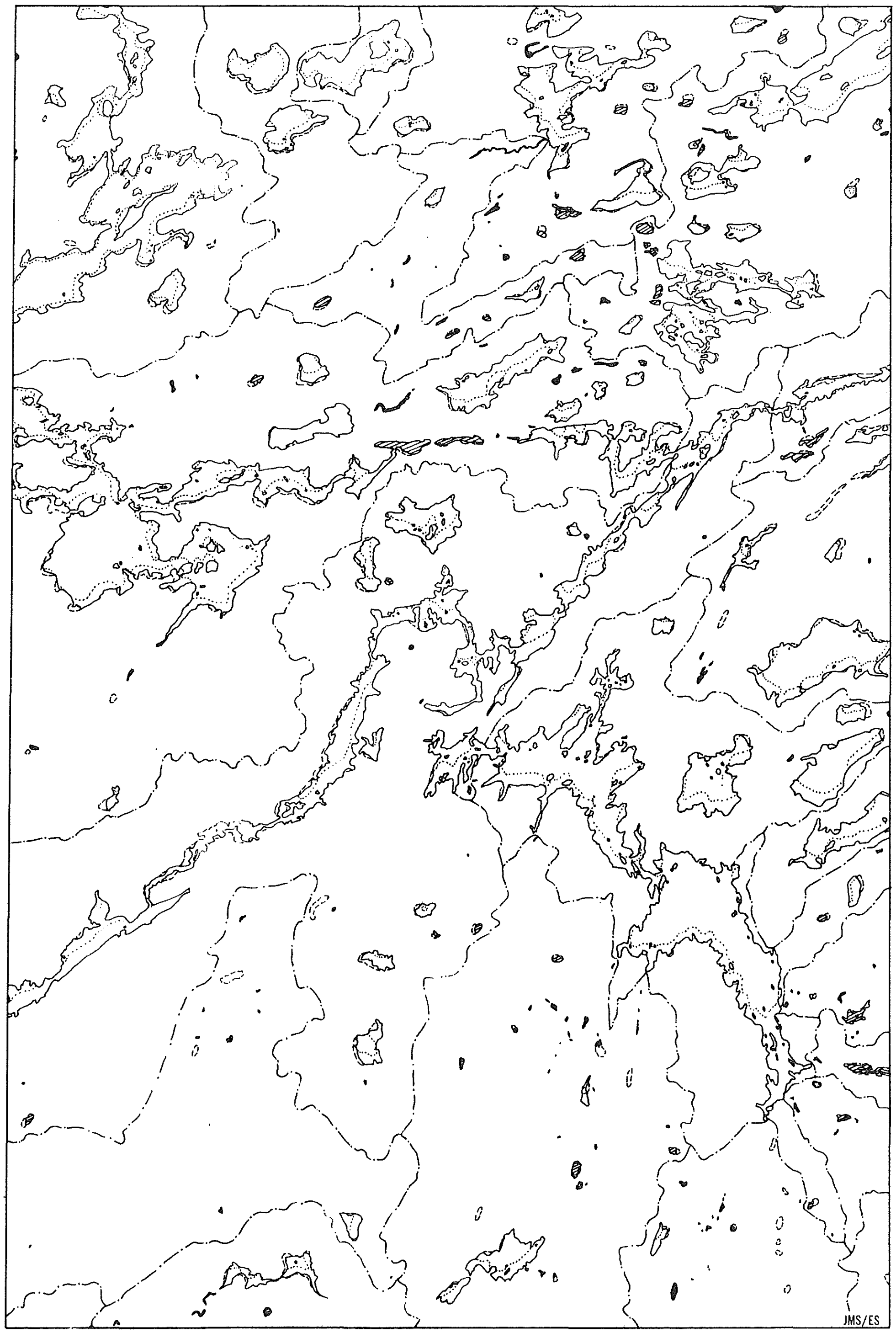


21. Taunton
22. Porter
23. Canby
24. Hendricks
25. Lake Benton NW
26. Lake Benton NE
27. Arco
28. Gislason Lake
29. Dead Coon Lake
30. Tyler
31. Lake Benton
32. Lake Benton SW
33. Elkton
34. Verdi
35. Ruthton NW
36. Ruthton

Figure 2. Location of Figures 3-36.

GABBRO LAKE QUADRANGLE, MINN.

CHANGES OF VISIBLE OPEN WATER



1 0 1 mile

—·—·— Watershed boundaries

——— Lake boundaries 1957 U.S.G.S. Topographic Sheet

■ Undetectable but existent on U.S.G.S. sheet

– – – – Maximum visible change 5-28-73

▨ Detectable on 5-28-73 only

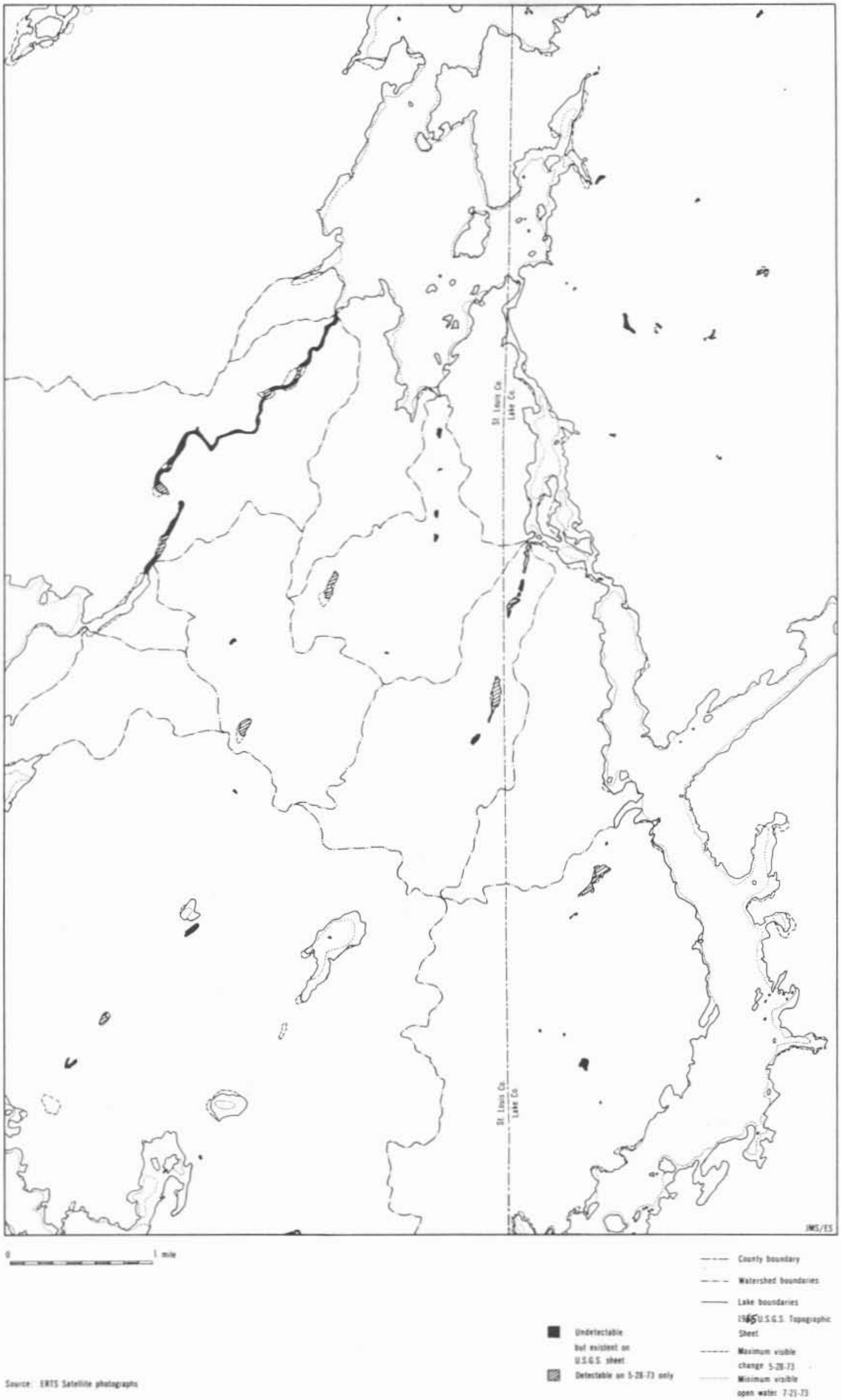
· · · · · · · Minimum visible open water 7-3-73

Source: ERTS Satellite photographs

Figure 3.

KANGAS BAY QUADRANGLE, MINN.

CHANGES OF VISIBLE OPEN WATER

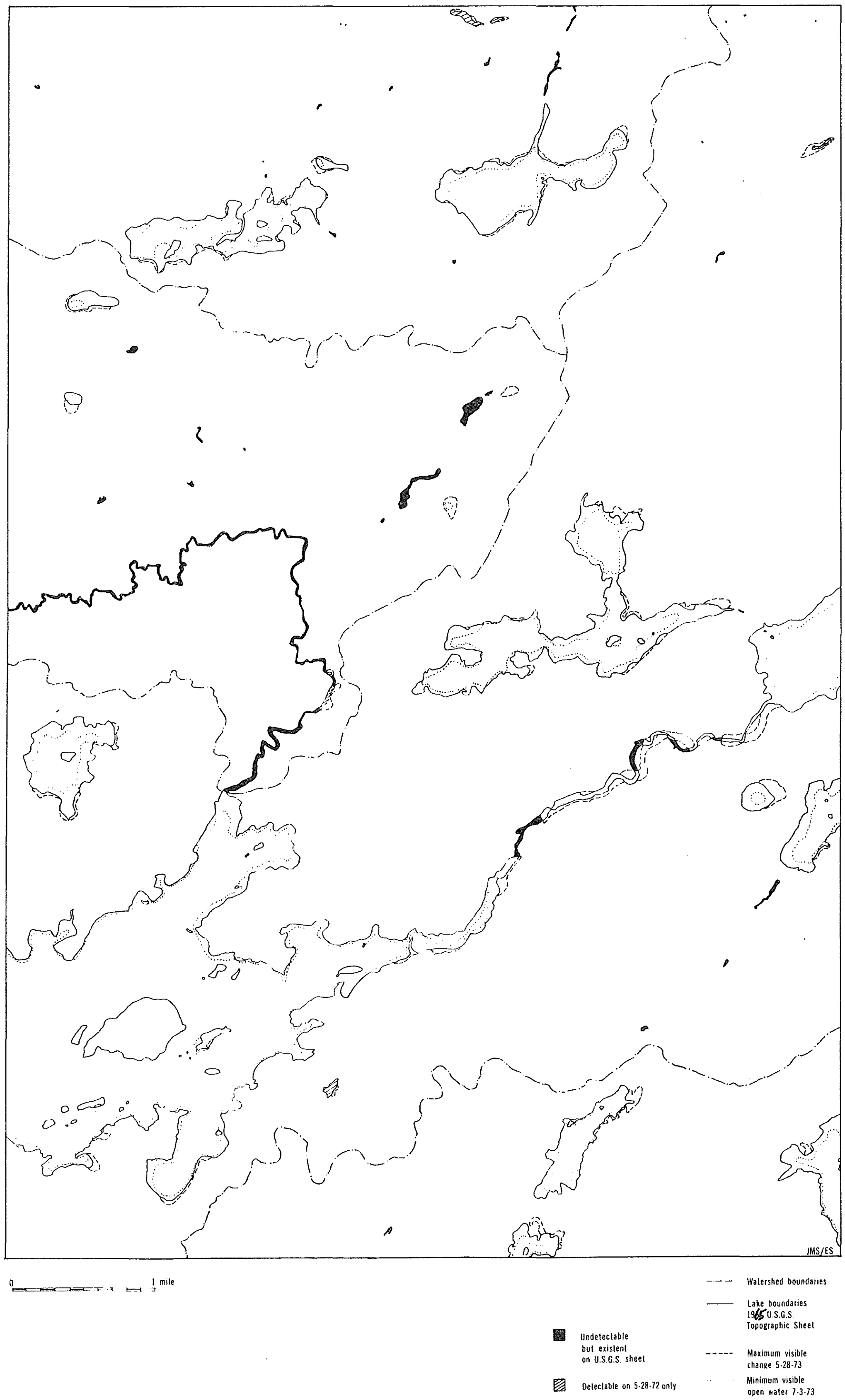


Source: ERTS Satellite photographs

Figure 4.

BEAR ISLAND QUADRANGLE, MINN.

CHANGES OF VISIBLE OPEN WATER

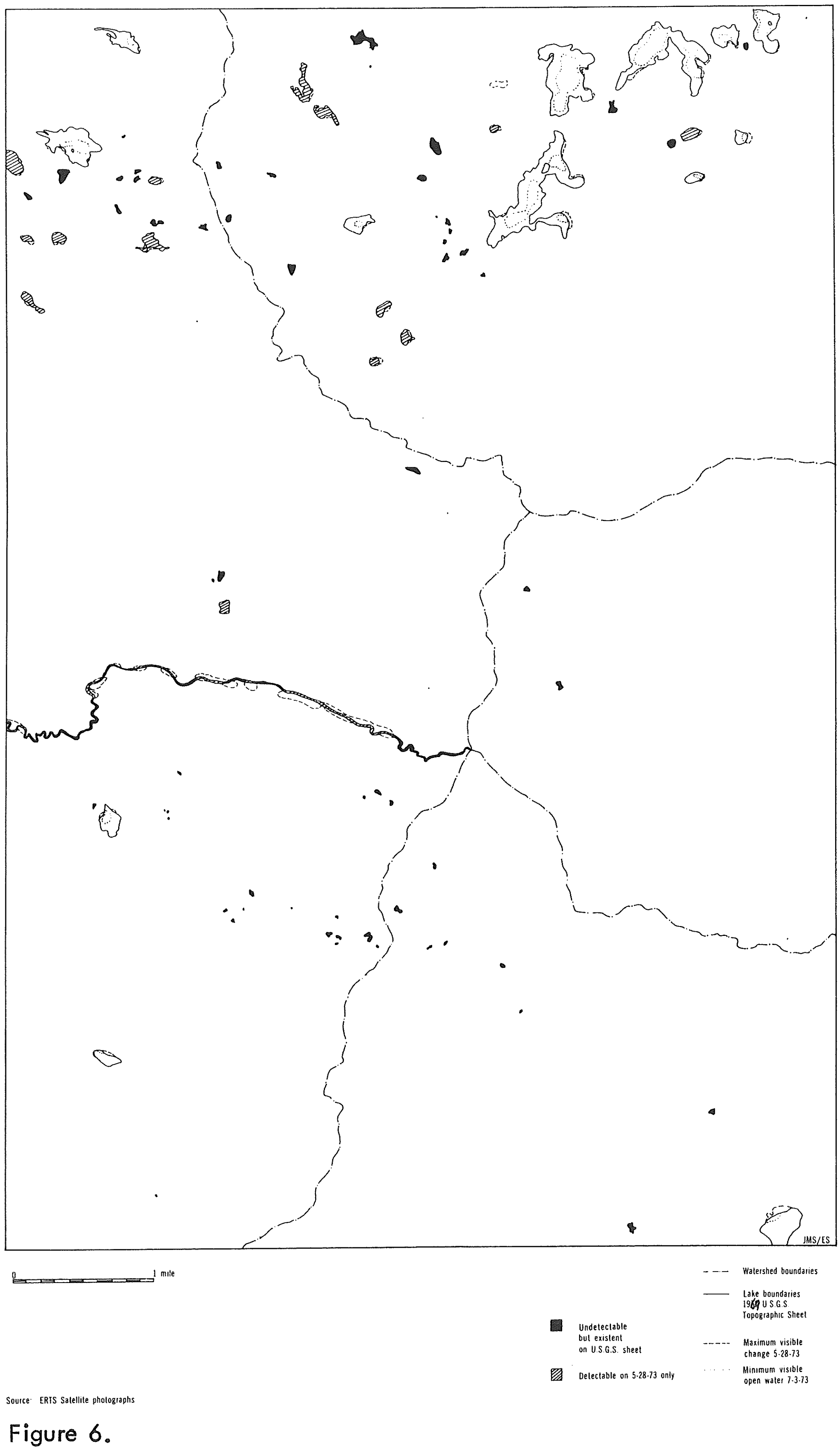


Source: ERTS Satellite photographs

Figure 5.

ISAAC LAKE QUADRANGLE, MINN.

CHANGES OF VISIBLE OPEN WATER

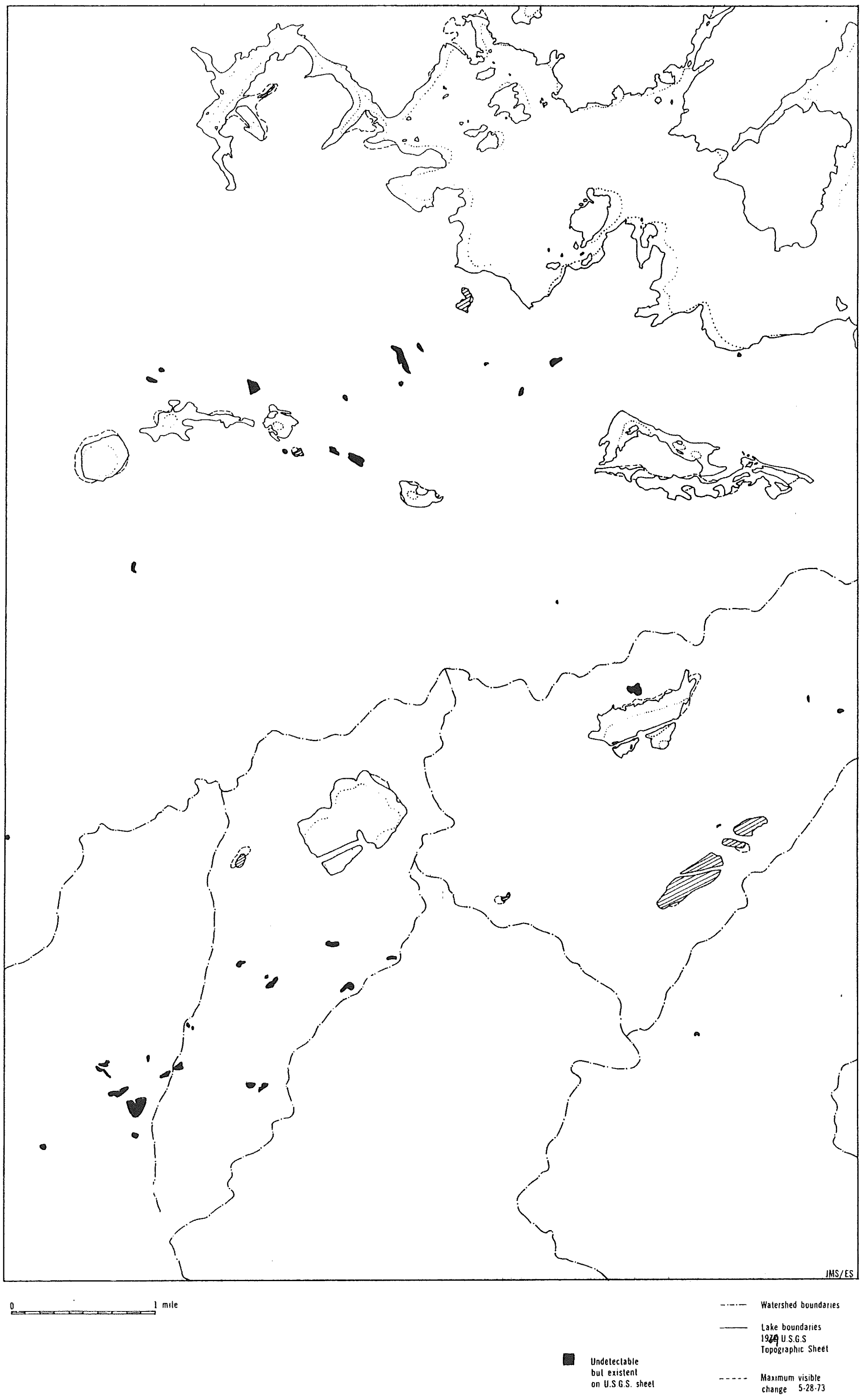


Source: ERTS Satellite photographs

Figure 6.

BABBITT QUADRANGLE, MINN.

CHANGES OF VISIBLE OPEN WATER

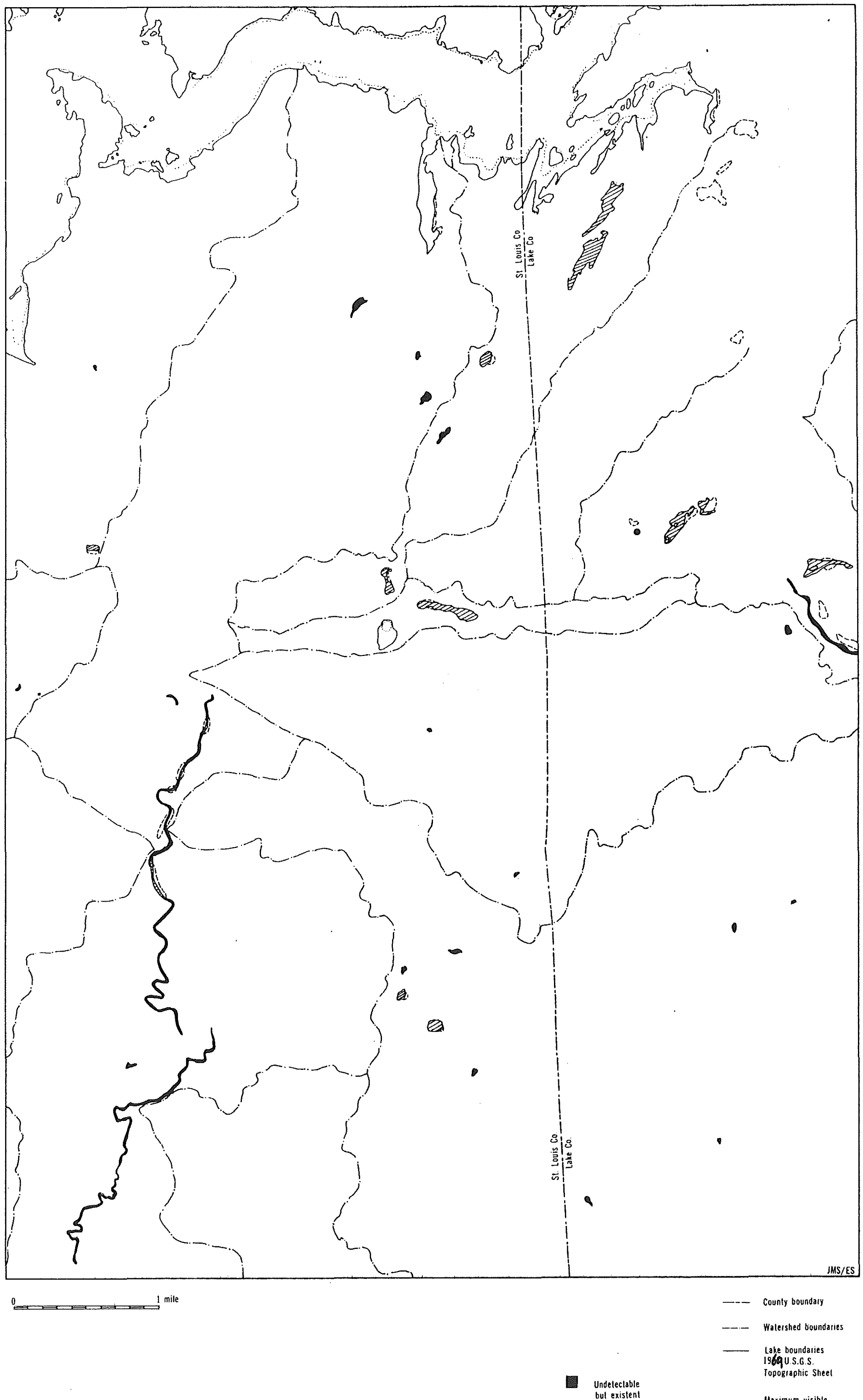


Source: ERTS Satellite photographs

Figure 7.

BABBITT NE QUADRANGLE, MINN.

CHANGES OF VISIBLE OPEN WATER

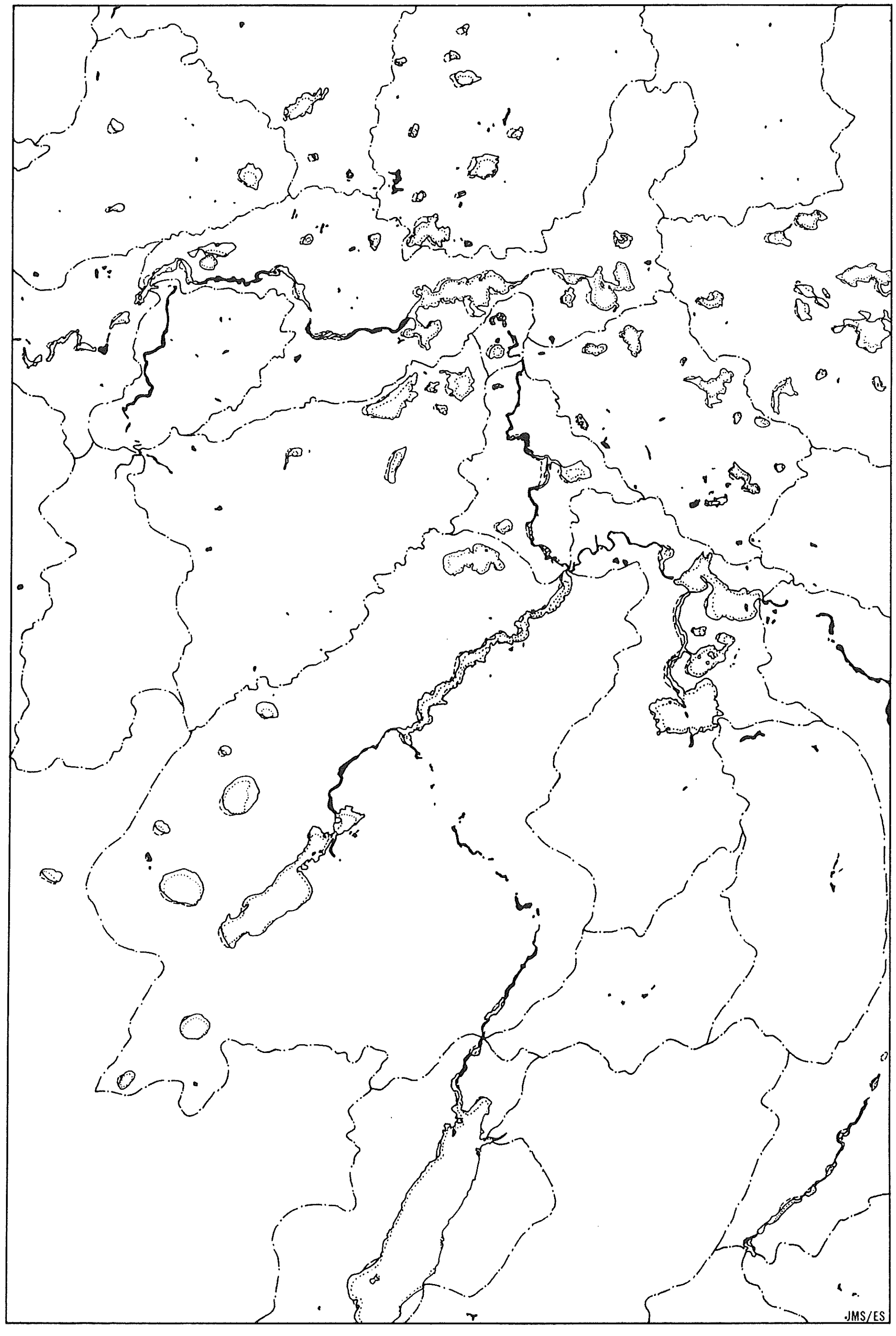


Source: ERTS Satellite photographs

Figure 8.

GREENWOOD LAKE QUADRANGLE, MINN.

CHANGES OF VISIBLE OPEN WATER



1 0 1 mile

——·—— Watershed boundaries

———— Lake boundaries 1974 U.S.G.S. Topographic Sheet

■ Undetectable but existent on U.S.G.S. sheet

– – – – Maximum visible change 9-18-72

▨ Detectable on 9-18-72 only

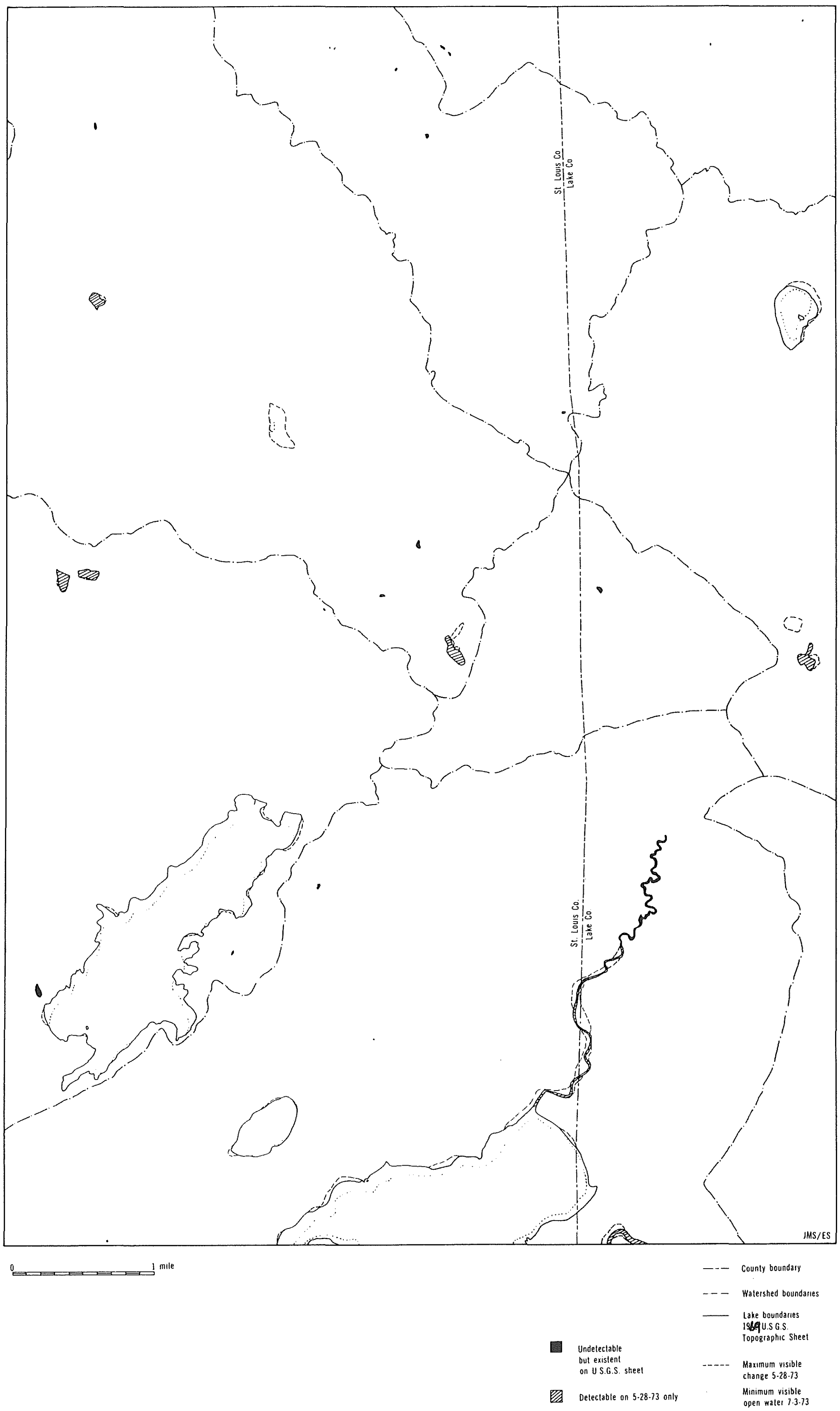
········ Minimum visible open water 7-21-73

Source: ERTS Satellite photographs

Figure 9.

BABBITT SE QUADRANGLE, MINN.

CHANGES OF VISIBLE OPEN WATER

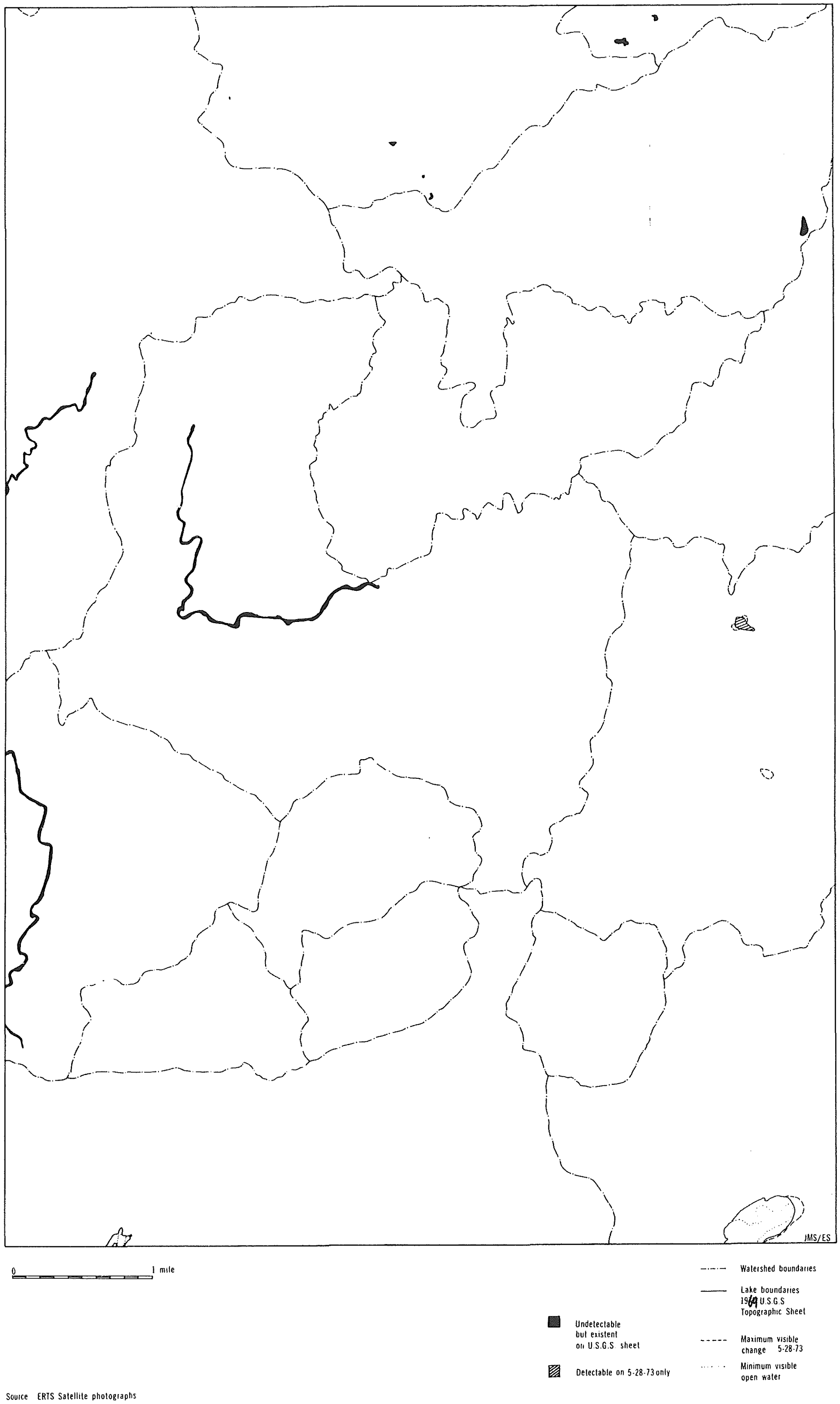


Source: ERTS Satellite photographs

Figure 10.

BABBITT SW QUADRANGLE, MINN.

CHANGES OF VISIBLE OPEN WATER

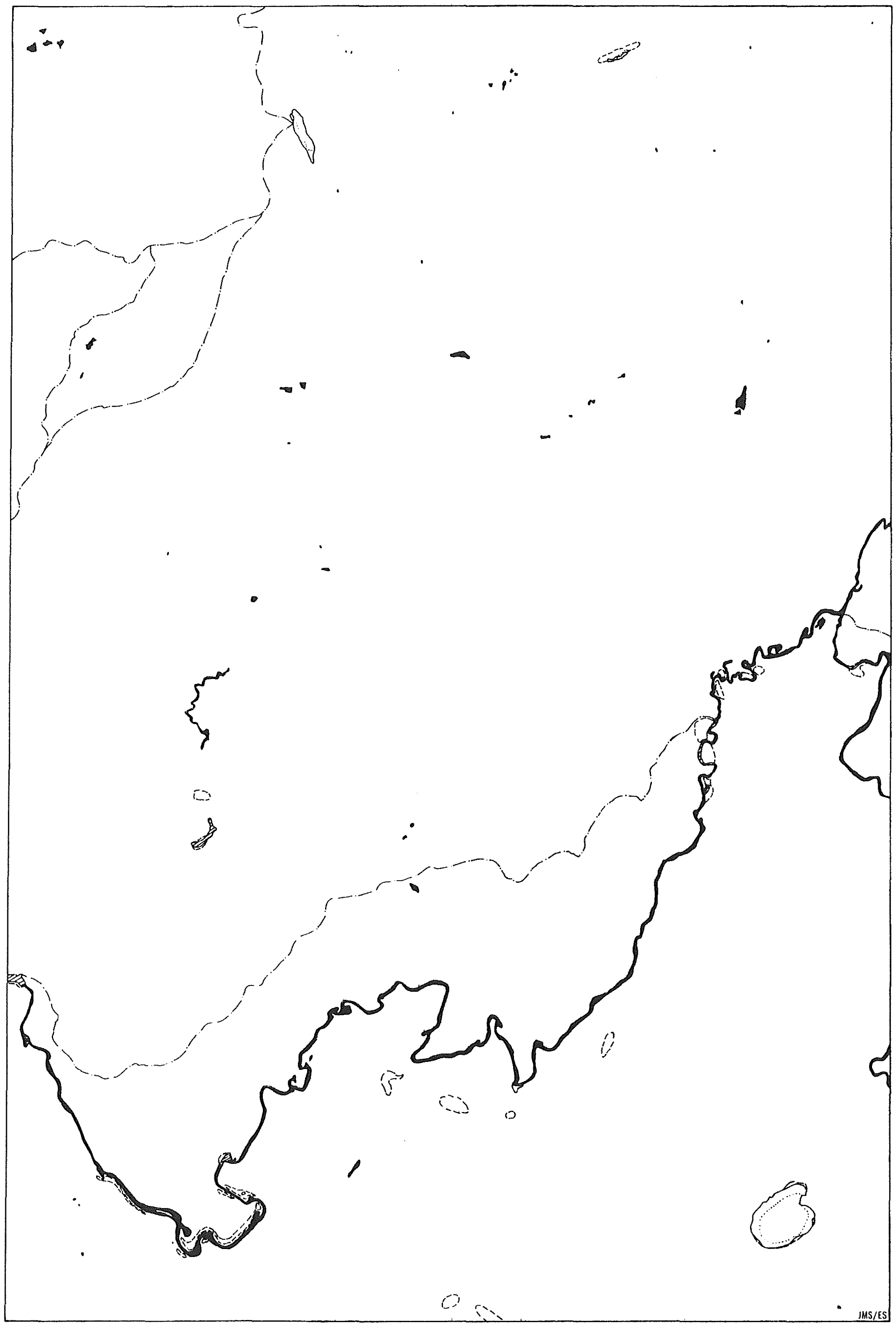


Source ERTS Satellite photographs

Figure 11.

ALLEN QUADRANGLE, MINN.

CHANGES OF VISIBLE OPEN WATER



0 1 mile

Watershed boundaries

Lake boundaries
1969 U.S.G.S. Topographic Sheet

Undetectable but existent on U.S.G.S. sheet

Maximum visible change 5-28-73

Minimum visible open water 7-21-73

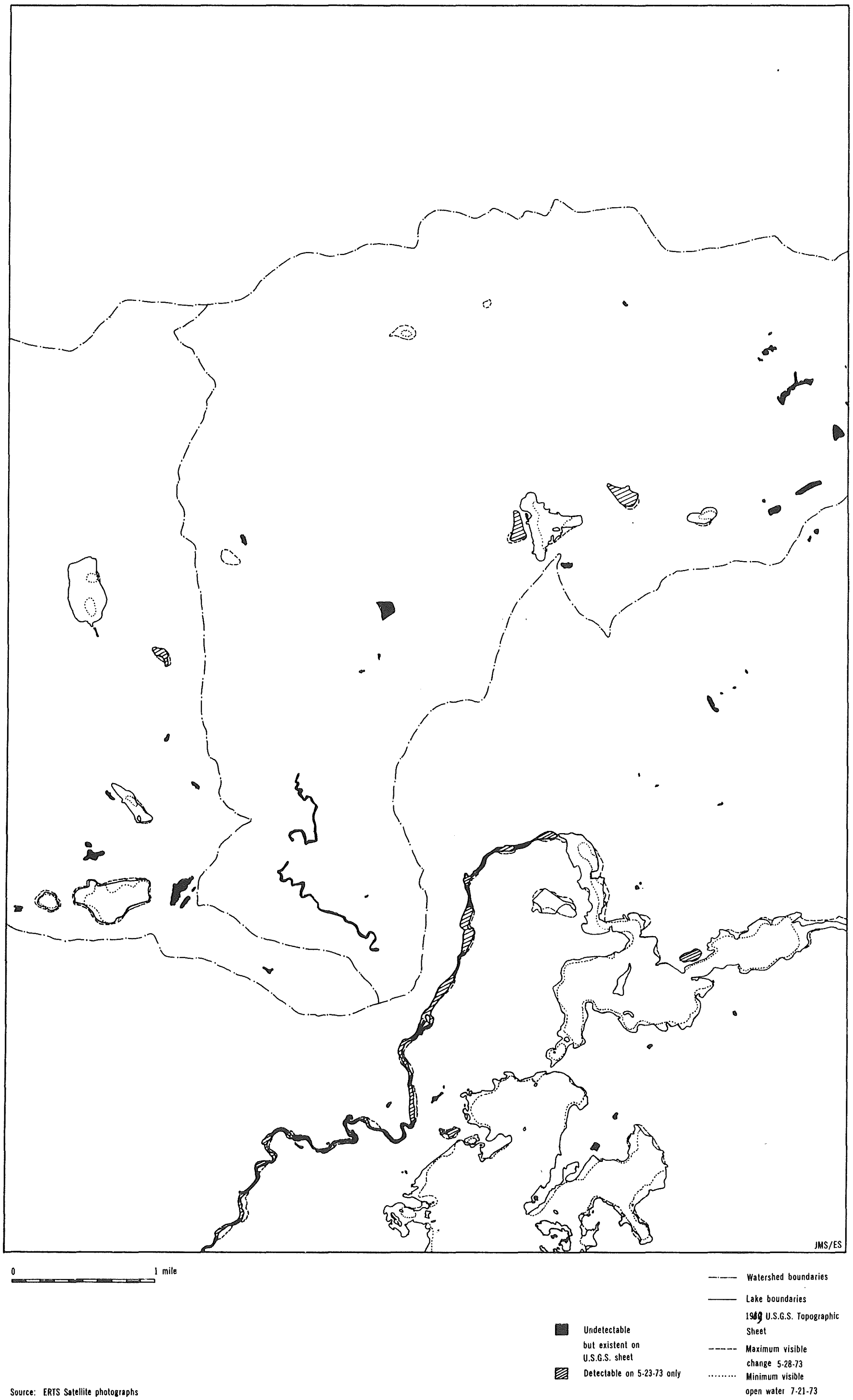
Detectable on 5-28-73 only

Source: ERTS Satellite photographs

Figure 12.

AURORA QUADRANGLE, MINN.

CHANGES OF VISIBLE OPEN WATER

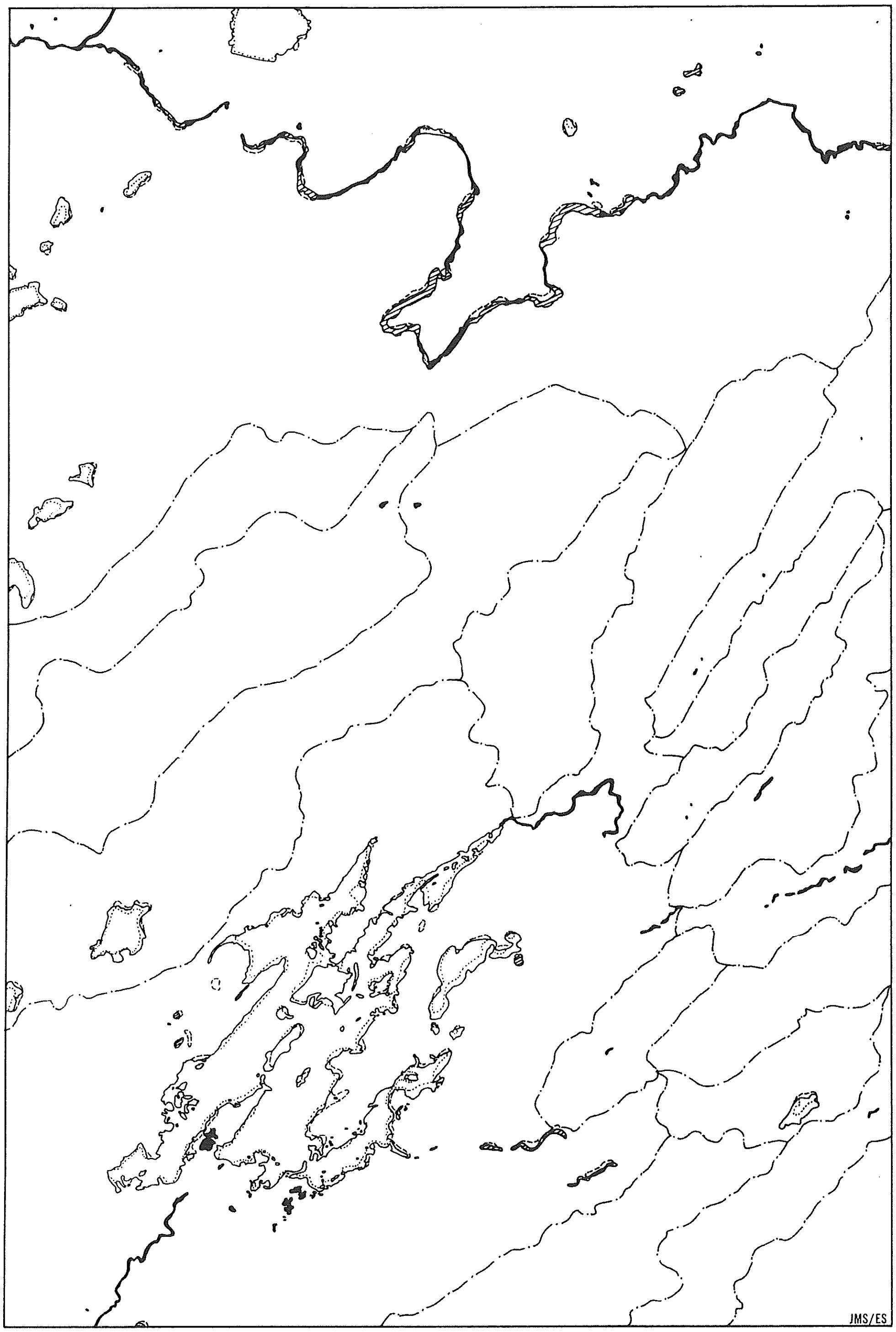


Source: ERTS Satellite photographs

Figure 13.

MARKHAM QUADRANGLE, MINN.

CHANGES OF VISIBLE OPEN WATER



1 0 1 mile

Watershed boundaries

Lake boundaries
1957 U.S.G.S.
Topographic Sheet

Undetectable
but existent
on U.S.G.S. sheet

Maximum visible
change 9-18-72

Minimum visible
open water 7-21-73

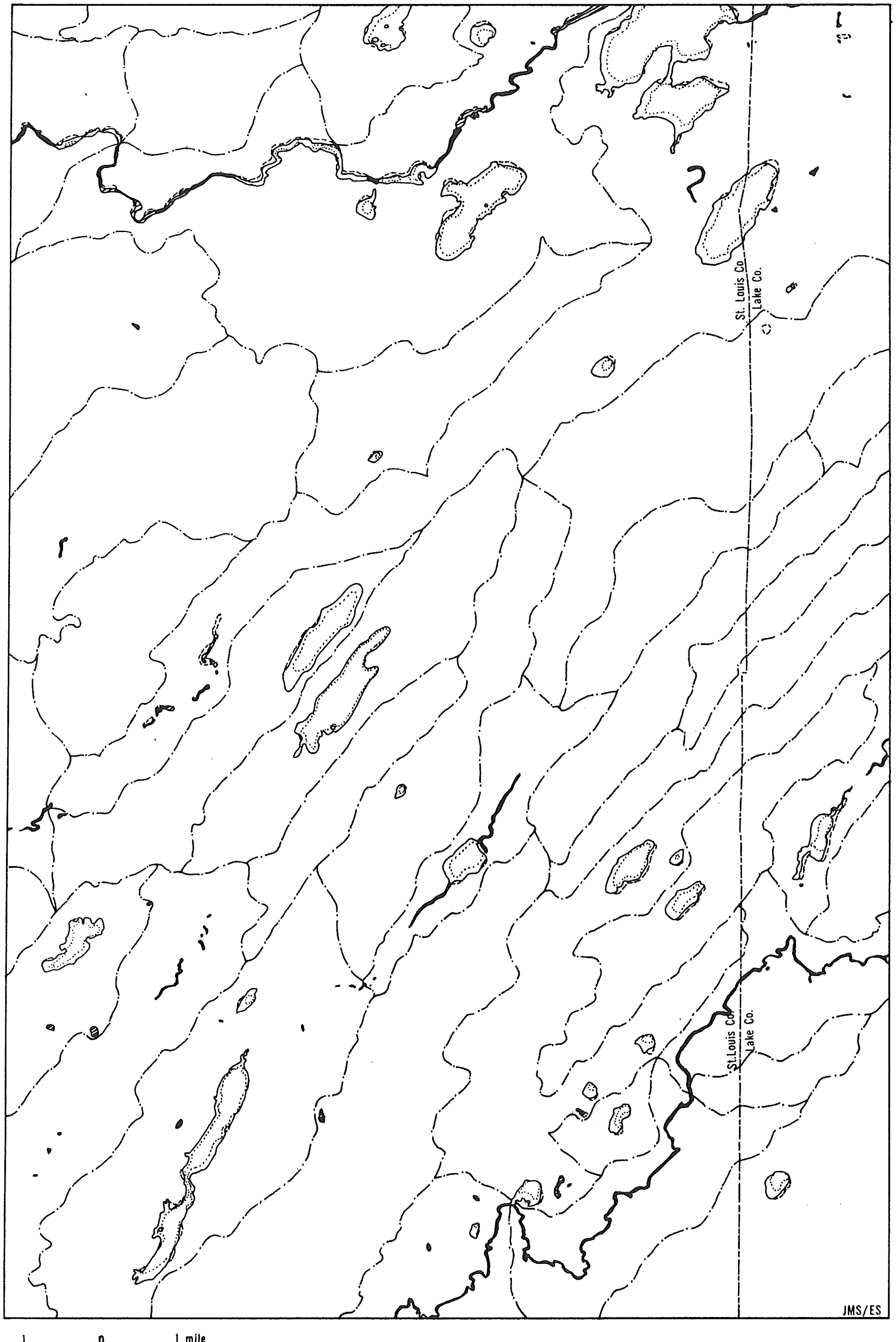
Detectable on 9-18-72 only

Source: ERTS Satellite photographs

Figure 14.

BRIMSON QUADRANGLE, MINN.

CHANGES OF VISIBLE OPEN WATER



County boundary

Watershed boundaries

Lake boundaries 1957 U.S.G.S. Topgraphic Sheet

Maximum visible change 9-18-72

Minimum visible open water 7-21-73

Undetectable but existent on U.S.G.S. sheet

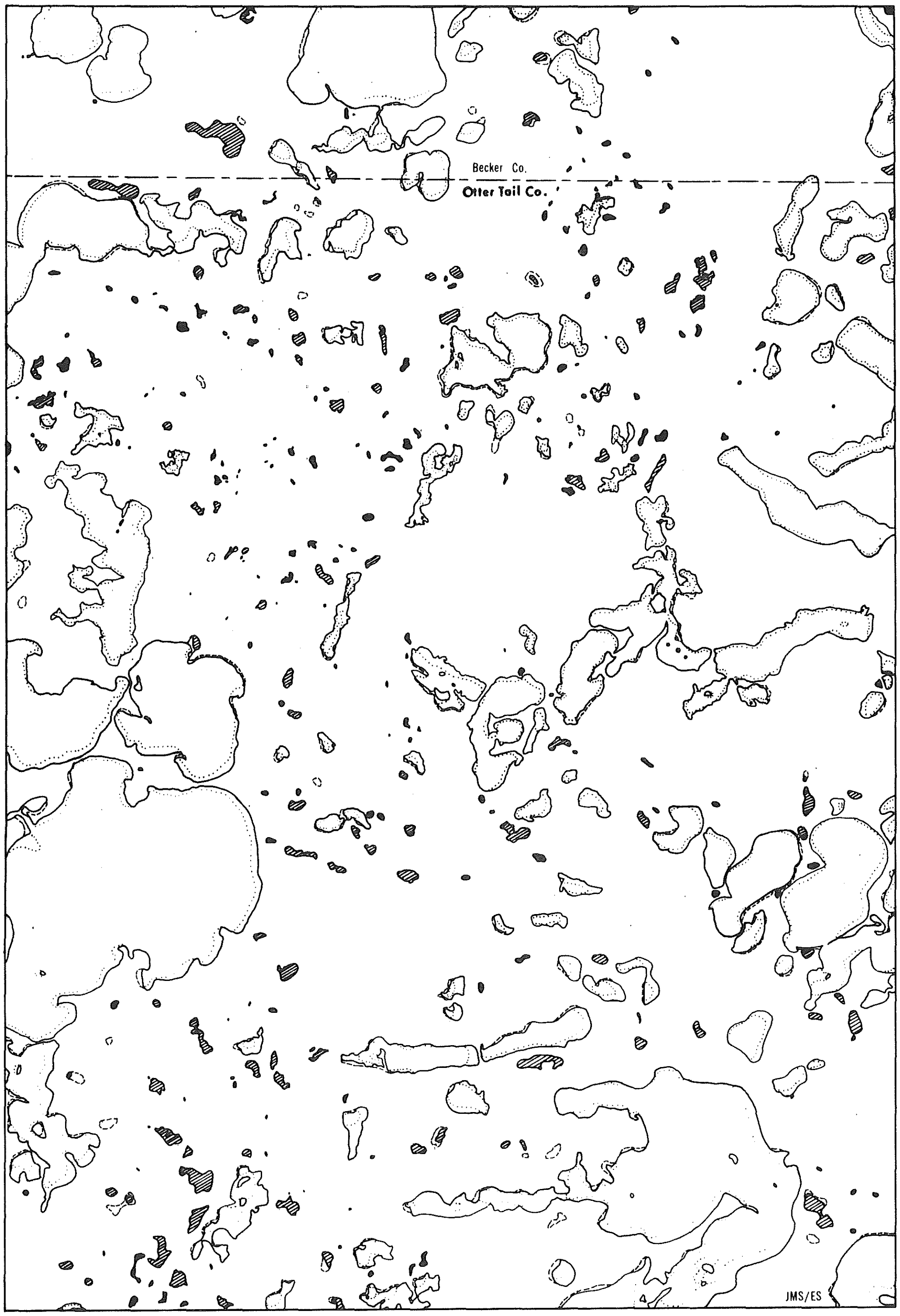
Detectable on 9-18-72 only

Source: ERTS Satellite photographs

Figure 15.

VERGAS QUADRANGLE, MINN.

CHANGES OF VISIBLE OPEN WATER



0 1 2 mile

County Boundary

Watershed Boundaries

Lake Boundaries

1912 U.S.G.S. Topographic Sheet

Maximum visible open water 6-30-74

Minimum visible open water 8-28-73

Undetectable but existent on U.S.G.S. sheet

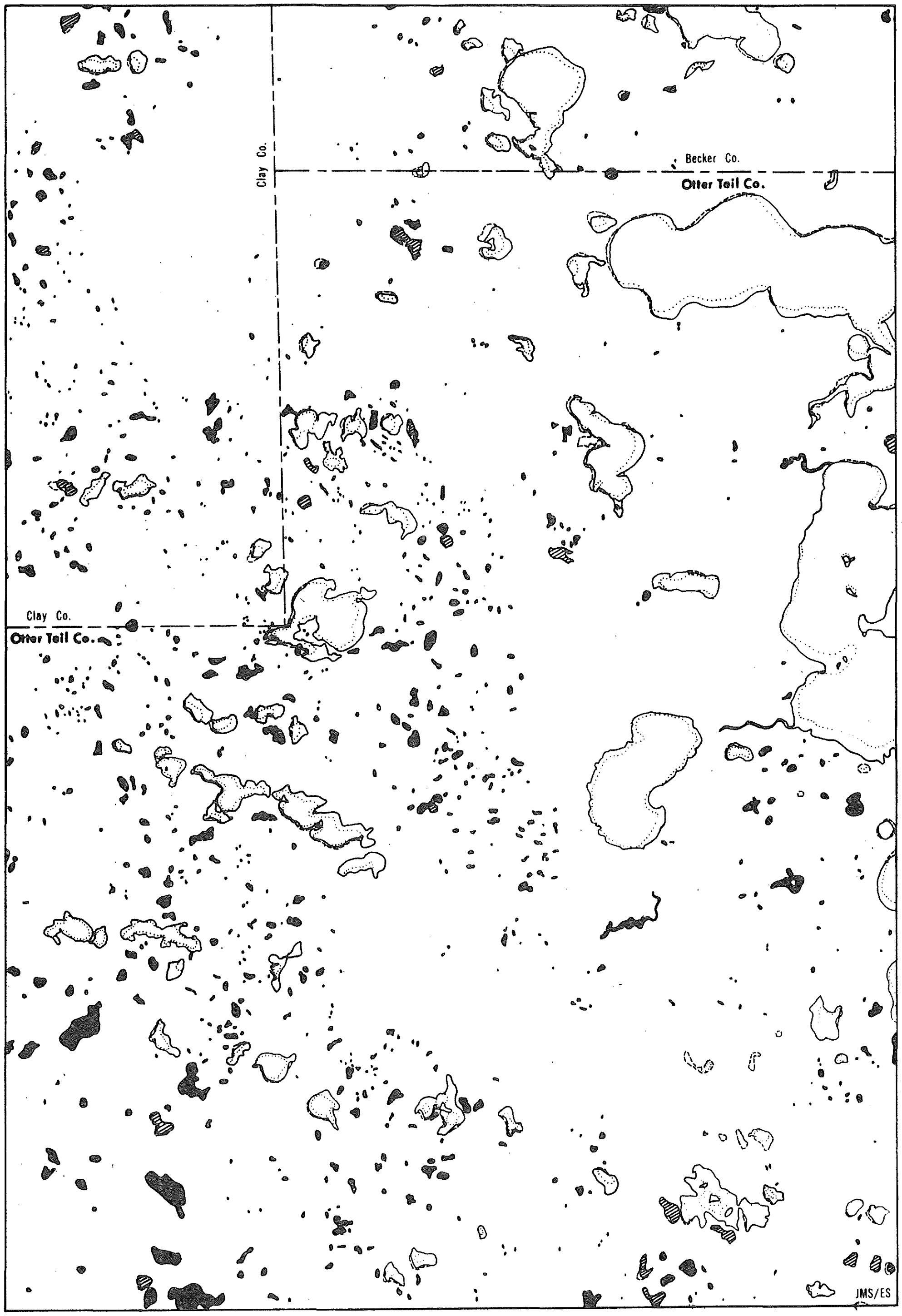
Detectable on 6-30-74 only

Source: "ERTS MSS Imagery"

Figure 16.

PELICAN RAPIDS QUADRANGLE, MINN.

CHANGES OF VISIBLE OPEN WATER



0 1 2 mile

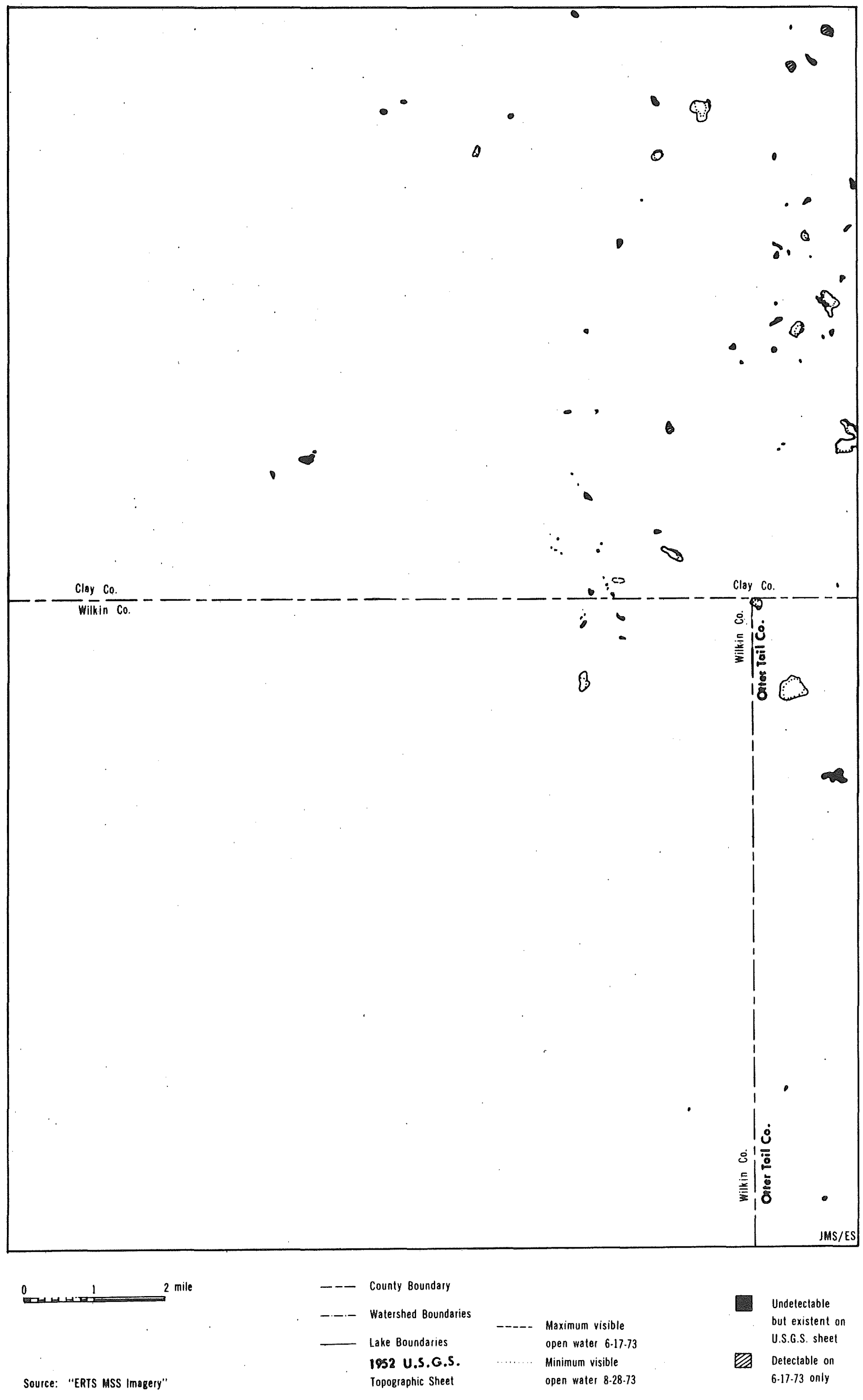
----	County Boundary
-·-·-	Watershed Boundaries
——	Lake Boundaries 1914 U.S.G.S. Topographic Sheet
-----	Maximum visible open water 6-17-73
·····	Minimum visible open water 8-28-73
■	Undetectable but existent on U.S.G.S. sheet
▨	Detectable on 6-17-73 only

Source: "ERTS MSS Imagery"

Figure 17.

BARNESVILLE QUADRANGLE, MINN.

CHANGES OF VISIBLE OPEN WATER



Source: "ERTS MSS Imagery"

Figure 18.

WENDELL QUADRANGLE, MINN.

CHANGES OF VISIBLE OPEN WATER

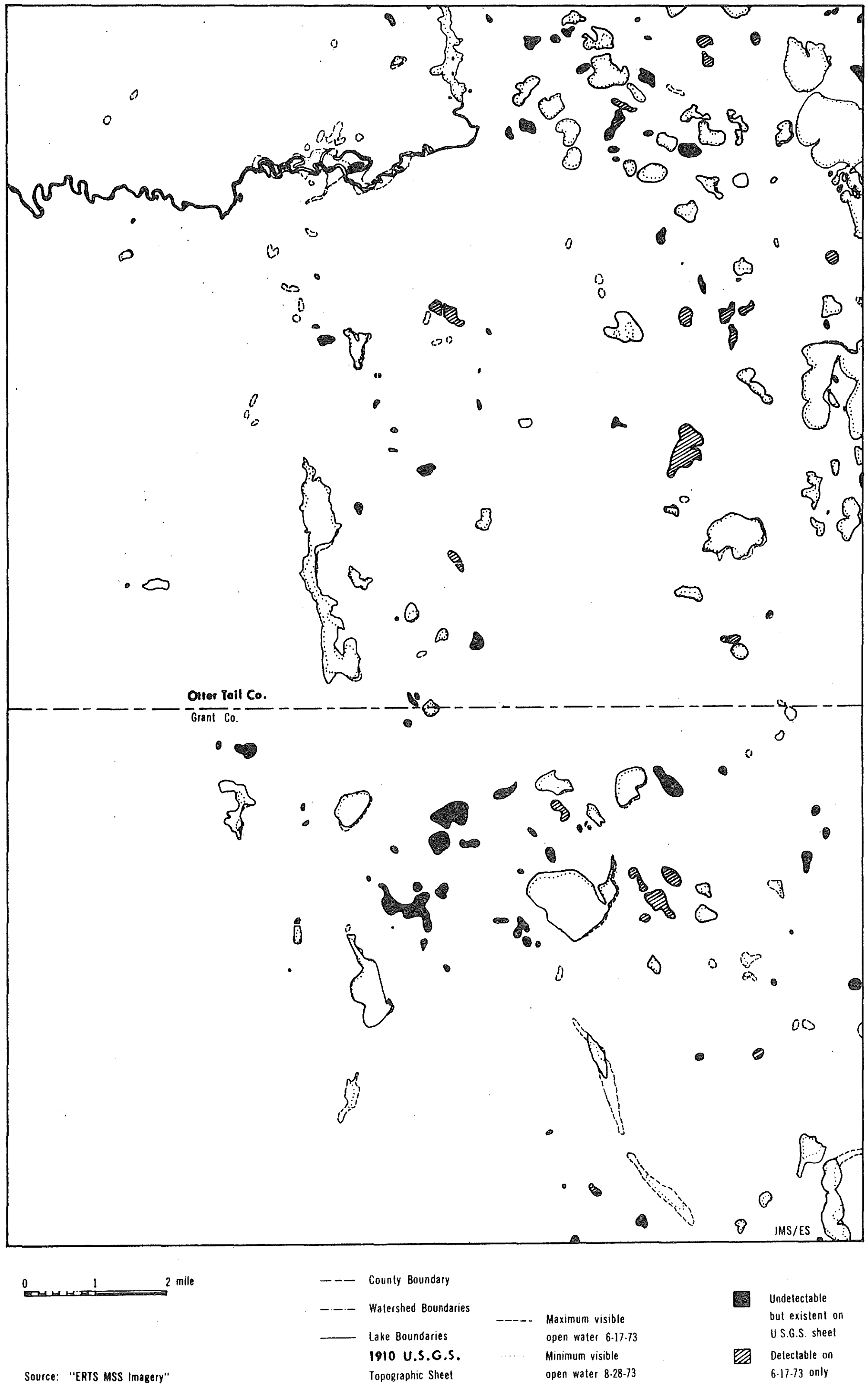


Figure 19.

CHOKIO QUADRANGLE, MINN.

CHANGES OF VISIBLE OPEN WATER

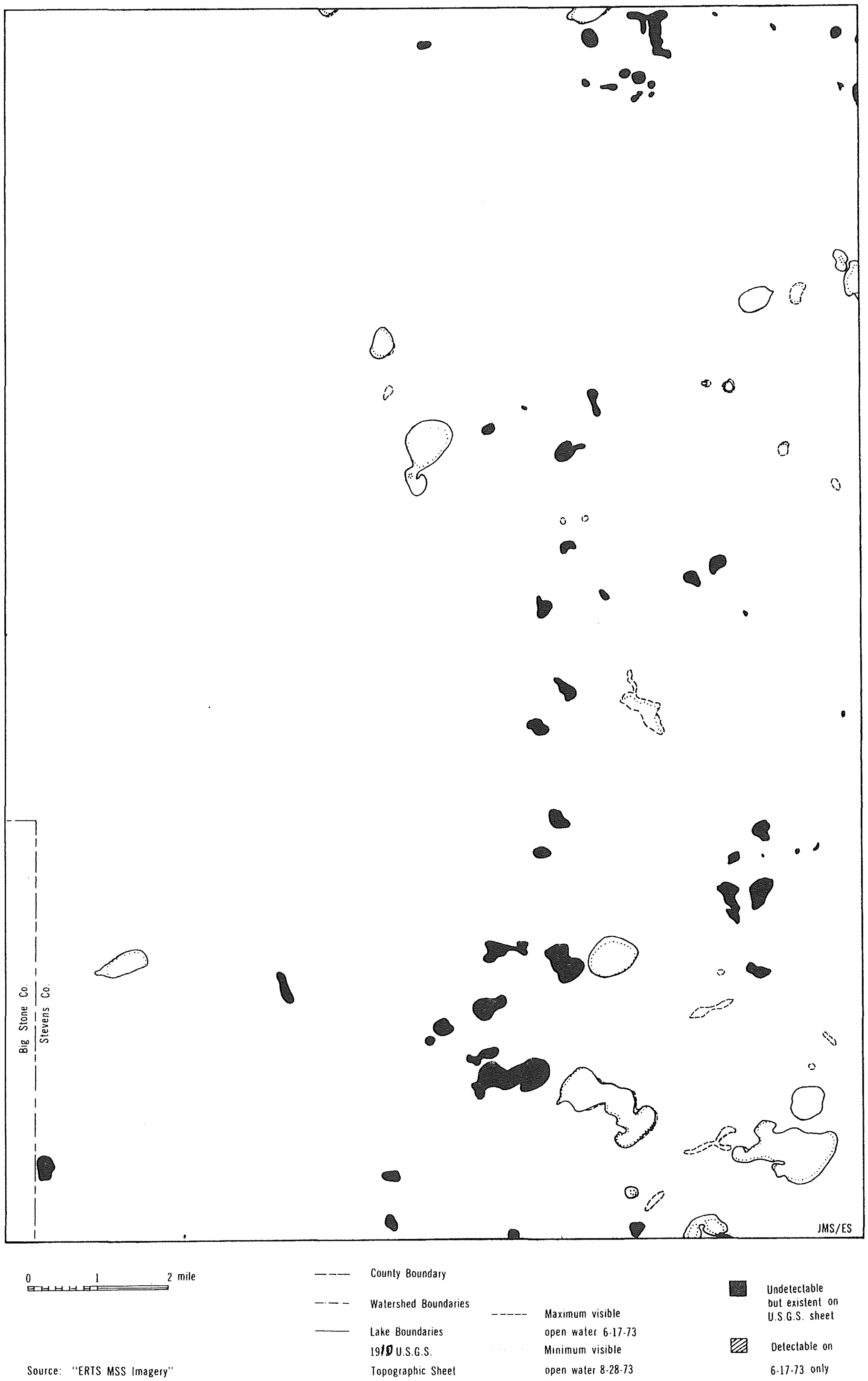
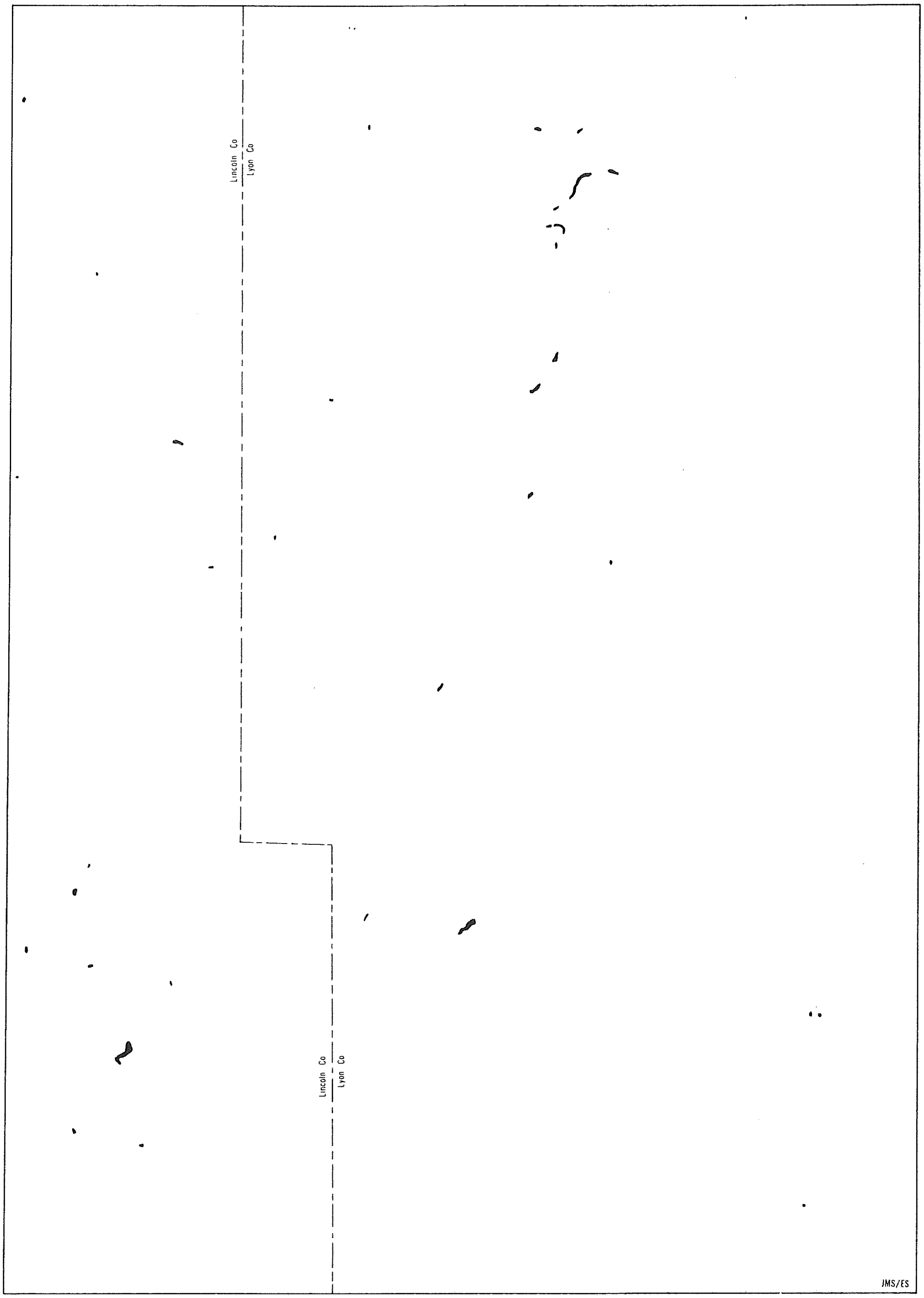


Figure 20.

TAUNTON QUADRANGLE, MINN.

CHANGES OF VISIBLE OPEN WATER



0 1 mile

Source "ERTS MSS Imagery"

--- County Boundary

— — Watershed Boundaries

—— Lake Boundaries 1967 U S G S Topographic Sheet

----- Maximum visible open water 6-17-73 Minimum visible open water 8-28-73

Undetectable but existent on U S G S sheet

Detectable on 6-17-73 only

Figure 21.

PORTER S.W. QUADRANGLE, MINN.

CHANGES OF VISIBLE OPEN WATER

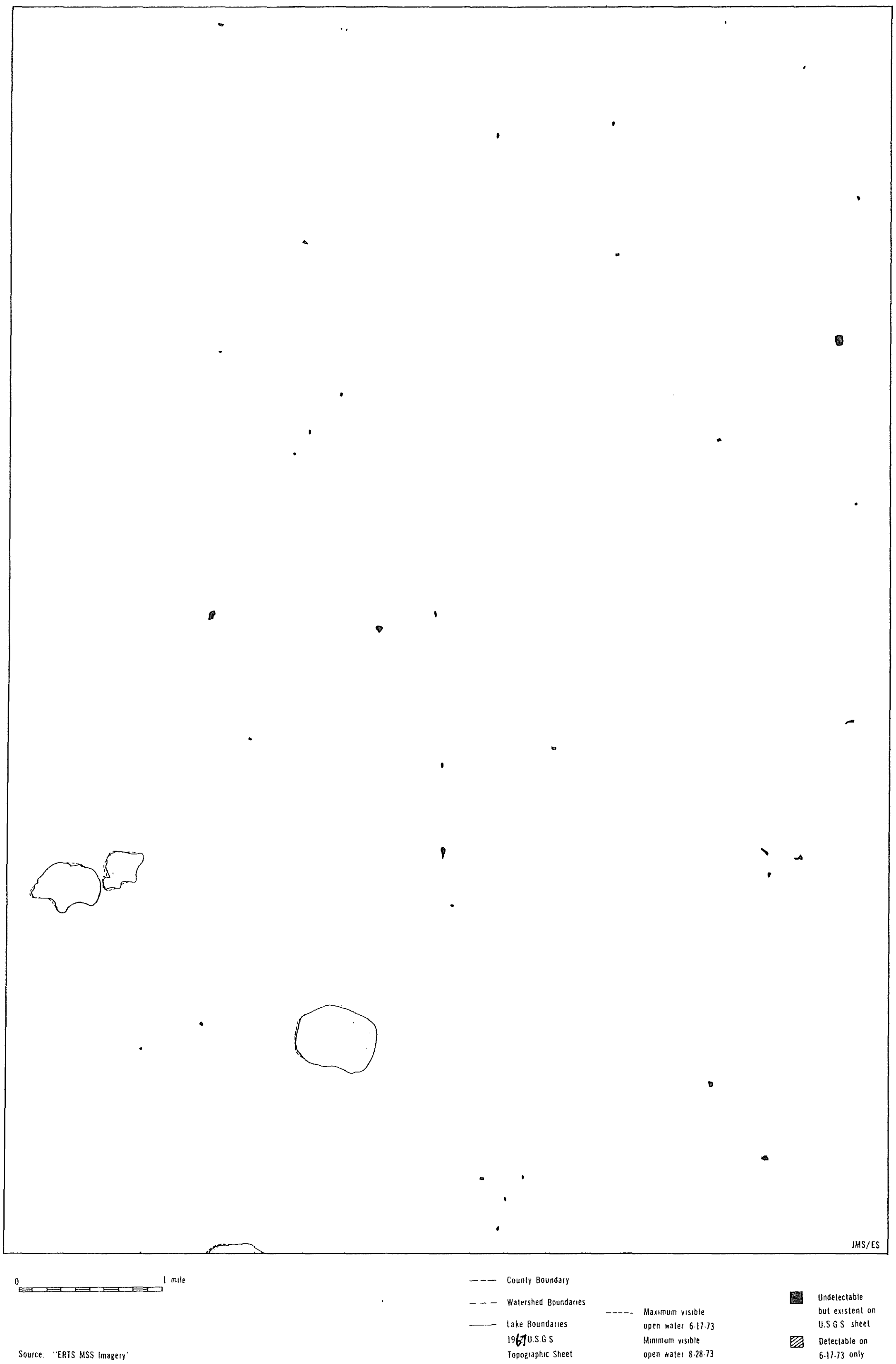


Figure 22.

CANBY S.E. QUADRANGLE, MINN.

CHANGES OF VISIBLE OPEN WATER

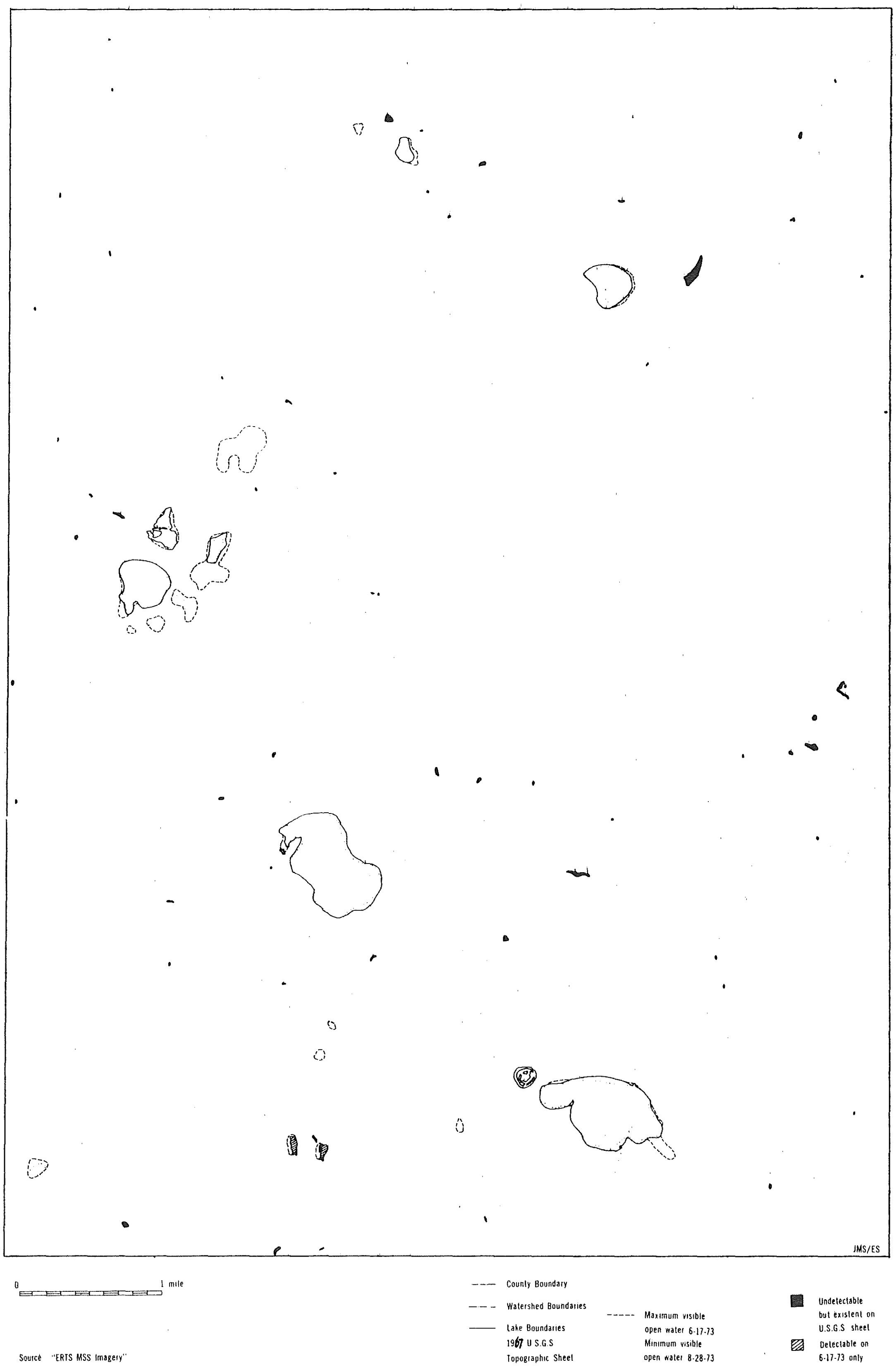
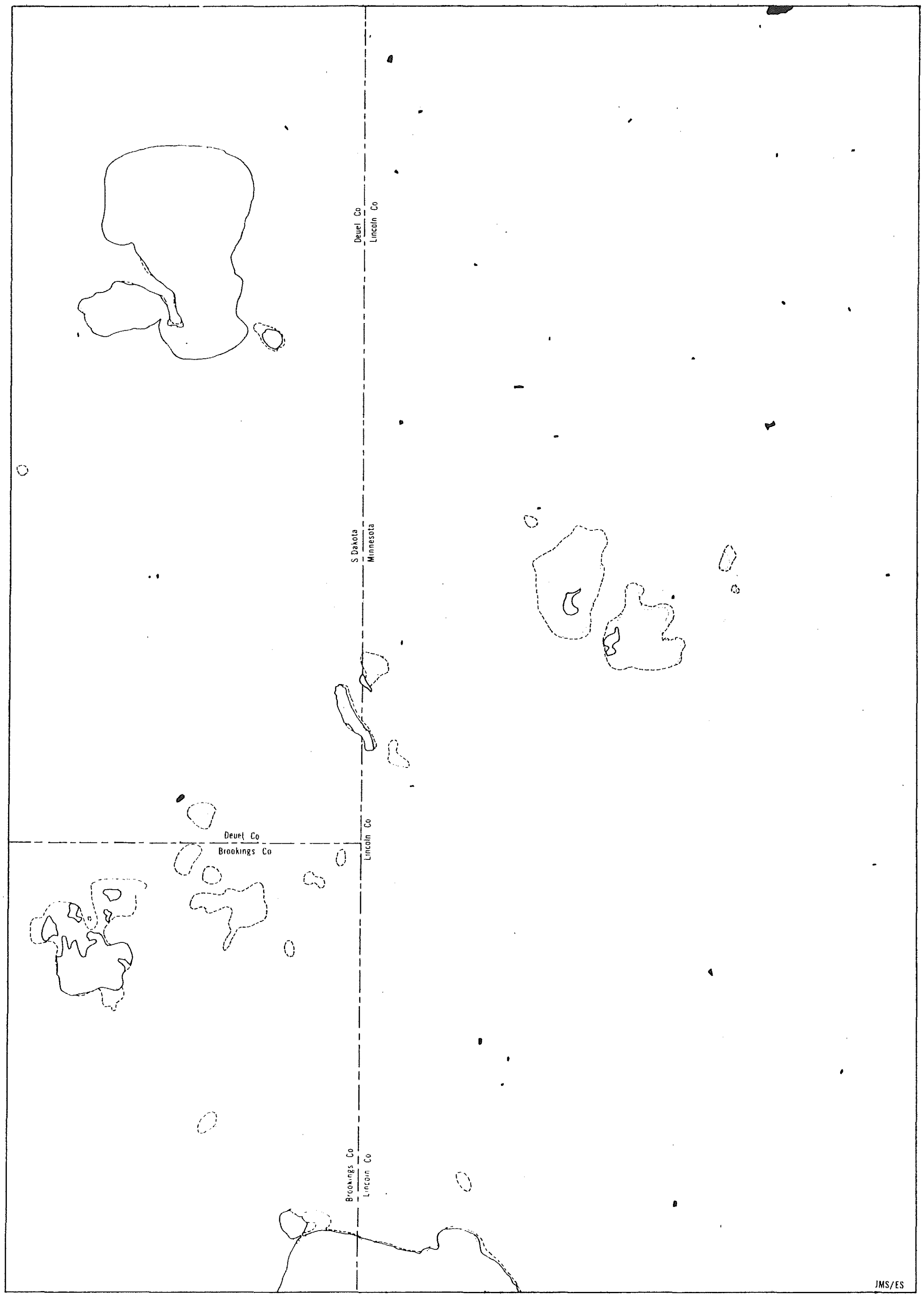


Figure 23.

HENDRICKS QUADRANGLE, MINN. -S. DAKOTA

CHANGES OF VISIBLE OPEN WATER



0 1 mile

Source "ERTS MSS Imagery"

—— County Boundary

— — — Watershed Boundaries

—— Lake Boundaries 1967 U S G S Topographic Sheet

- - - - - Maximum visible open water 6-17-73 Minimum visible open water 8-28-73

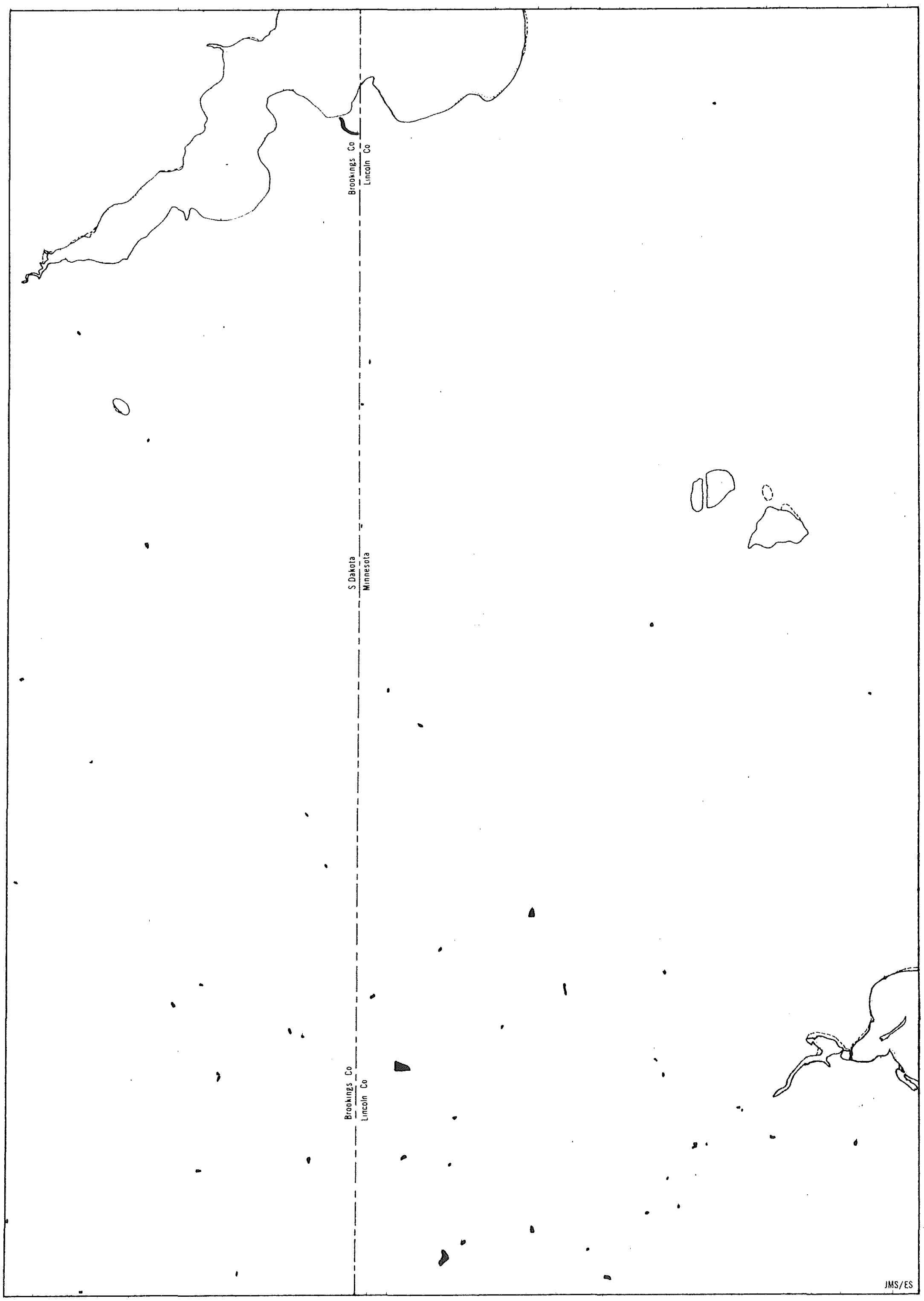
Undetectable but existent on U S G S sheet

Detectable on 6-17-73 only

Figure 24.

LAKE BENTON N.W. QUADRANGLE, MINN.-S.DAKOTA

CHANGES OF VISIBLE OPEN WATER



0 1 mile

County Boundary

Watershed Boundaries

Lake Boundaries 1967 U S G S Topographic Sheet

Maximum visible open water 6-17-73

Minimum visible open water 8-20 73

Undetectable but existent on U.S.G.S. sheet

Detectable on 6-17-73 only

Source "ERTS MSS Imagery"

Figure 25.

LAKE BENTON N.E. QUADRANGLE, MINN.

CHANGES OF VISIBLE OPEN WATER

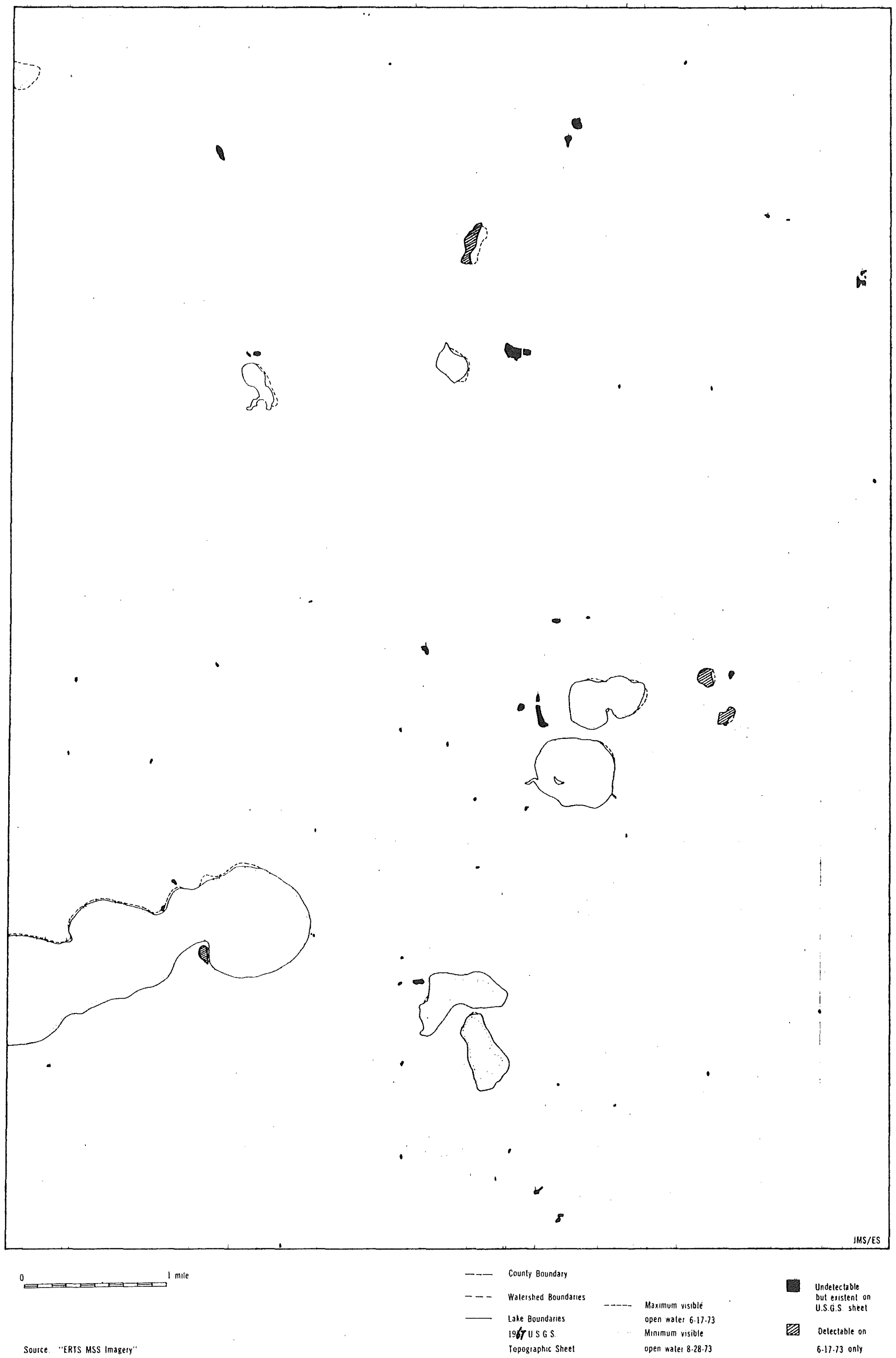
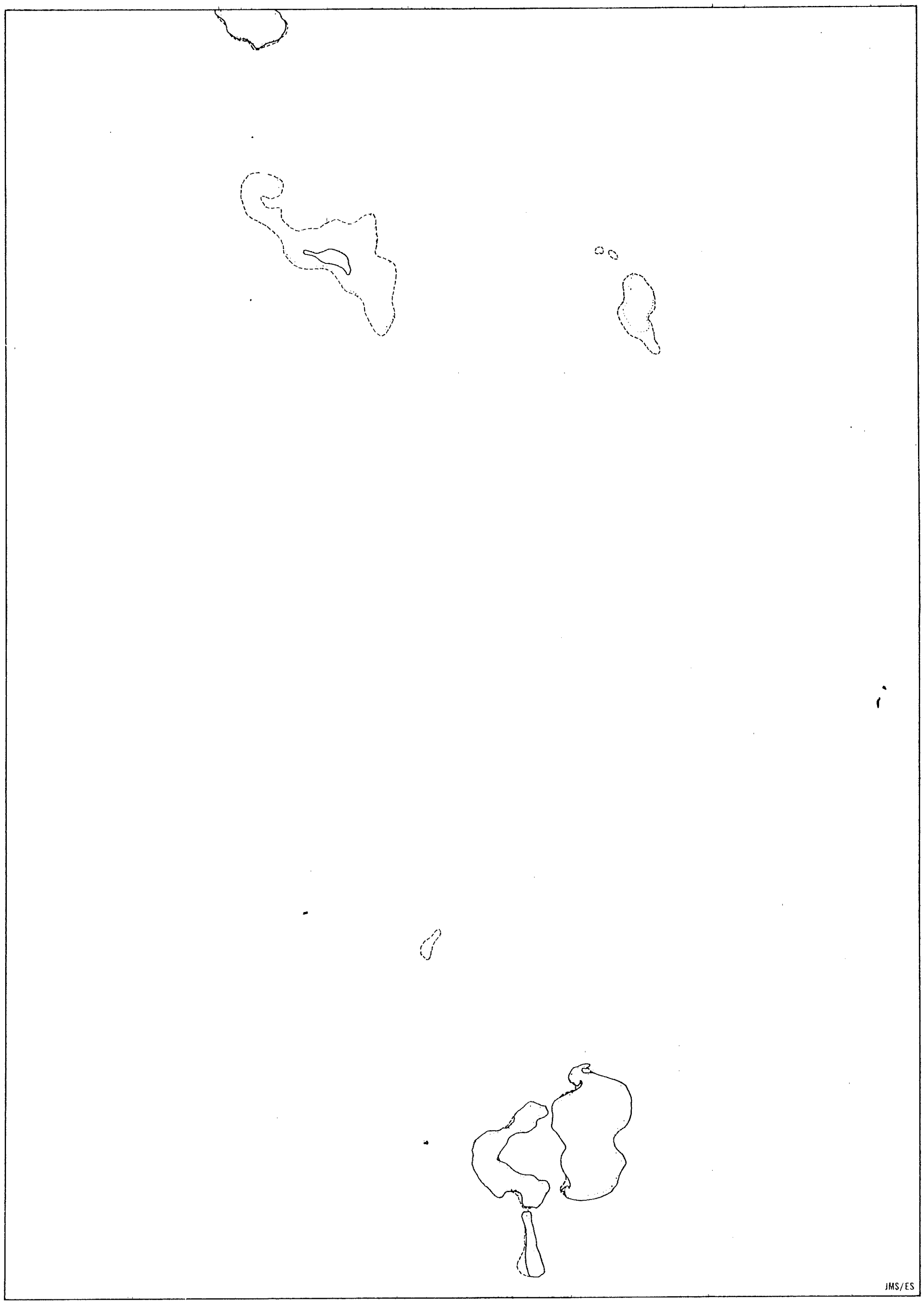


Figure 26.

ARCO QUADRANGLE, MINN.

CHANGES OF VISIBLE OPEN WATER



0 1 mile

--- County Boundary

- - - Watershed Boundaries

——— Lake Boundaries
1963 U S G S
Topographic Sheet

----- Maximum visible
open water 6-17-73
Minimum visible
open water 8-28-73

Undetectable
but existent on
U.S.G.S. sheet

Detectable on
6-17-73 only

Source: "ERTS MSS Imagery"

Figure 27.

GISLASON LAKE QUADRANGLE, MINN.

CHANGES OF VISIBLE OPEN WATER

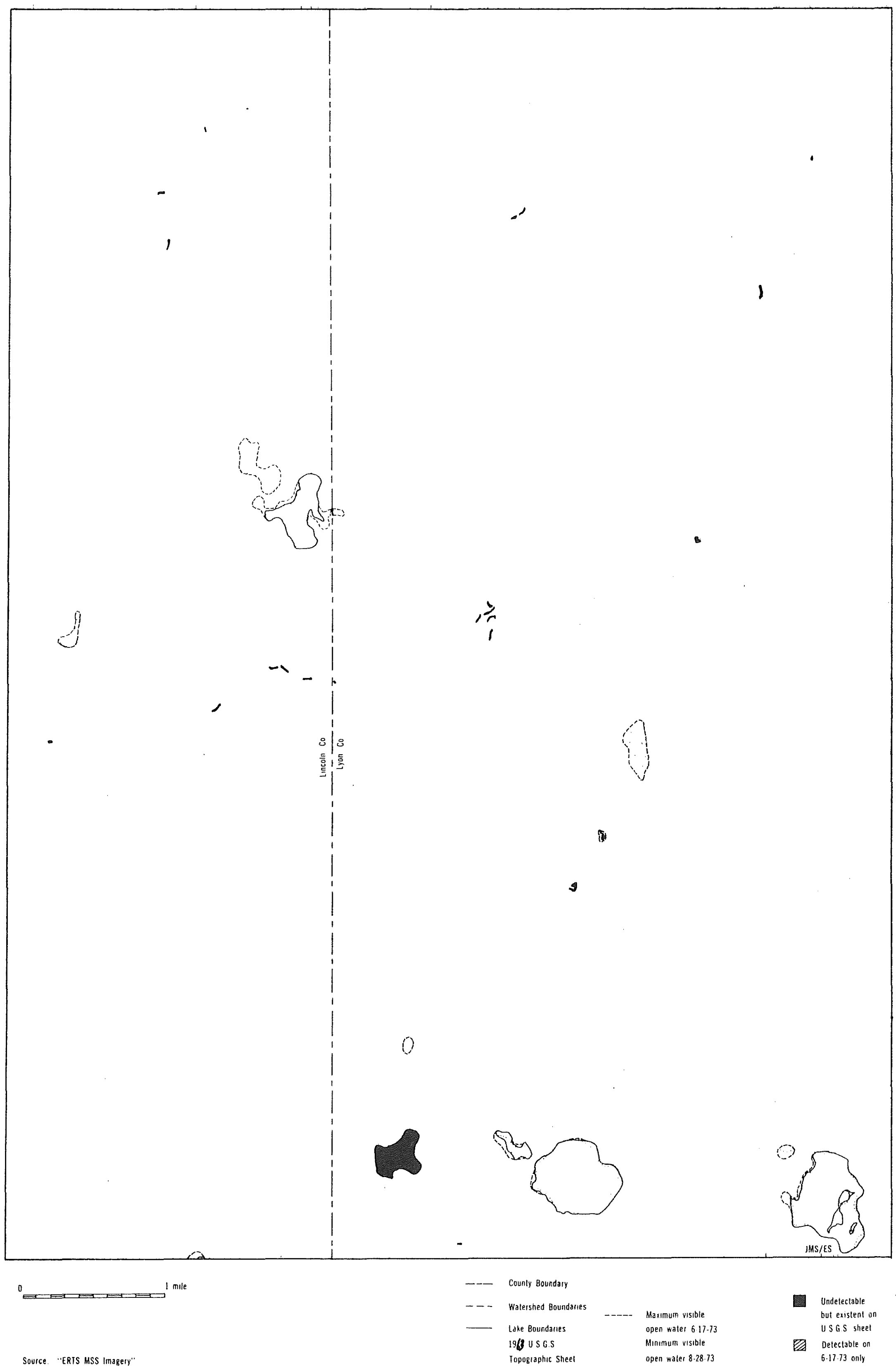
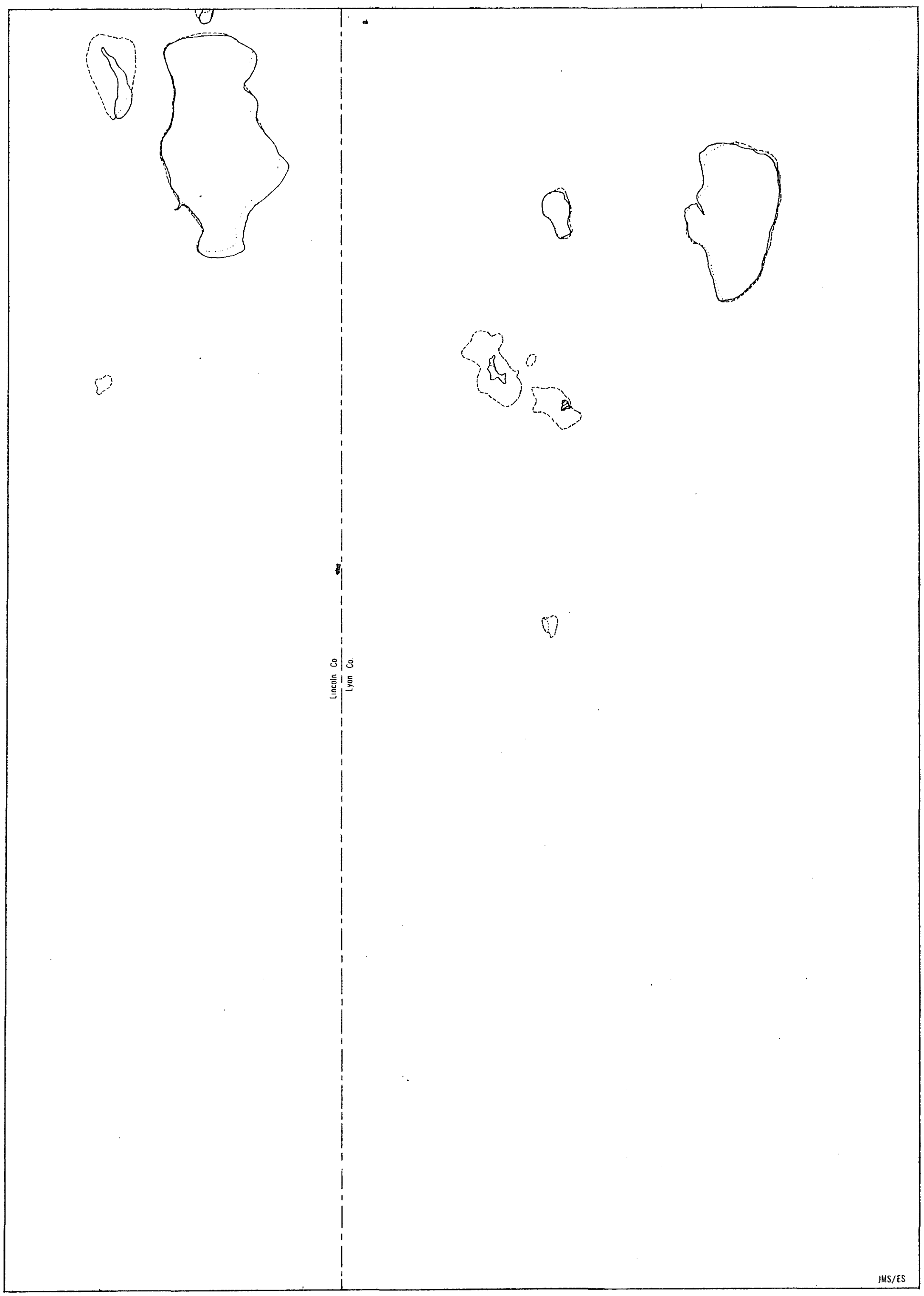


Figure 28.

DEAD COON LAKE QUADRANGLE, MINN.

CHANGES OF VISIBLE OPEN WATER



0 1 mile

Source: "ERTS MSS Imagery"

County Boundary

Watershed Boundaries

Lake Boundaries 19[6]3 U.S.G.S. Topographic Sheet

Maximum visible open water 6-17-73

Minimum visible open water 8-28-73

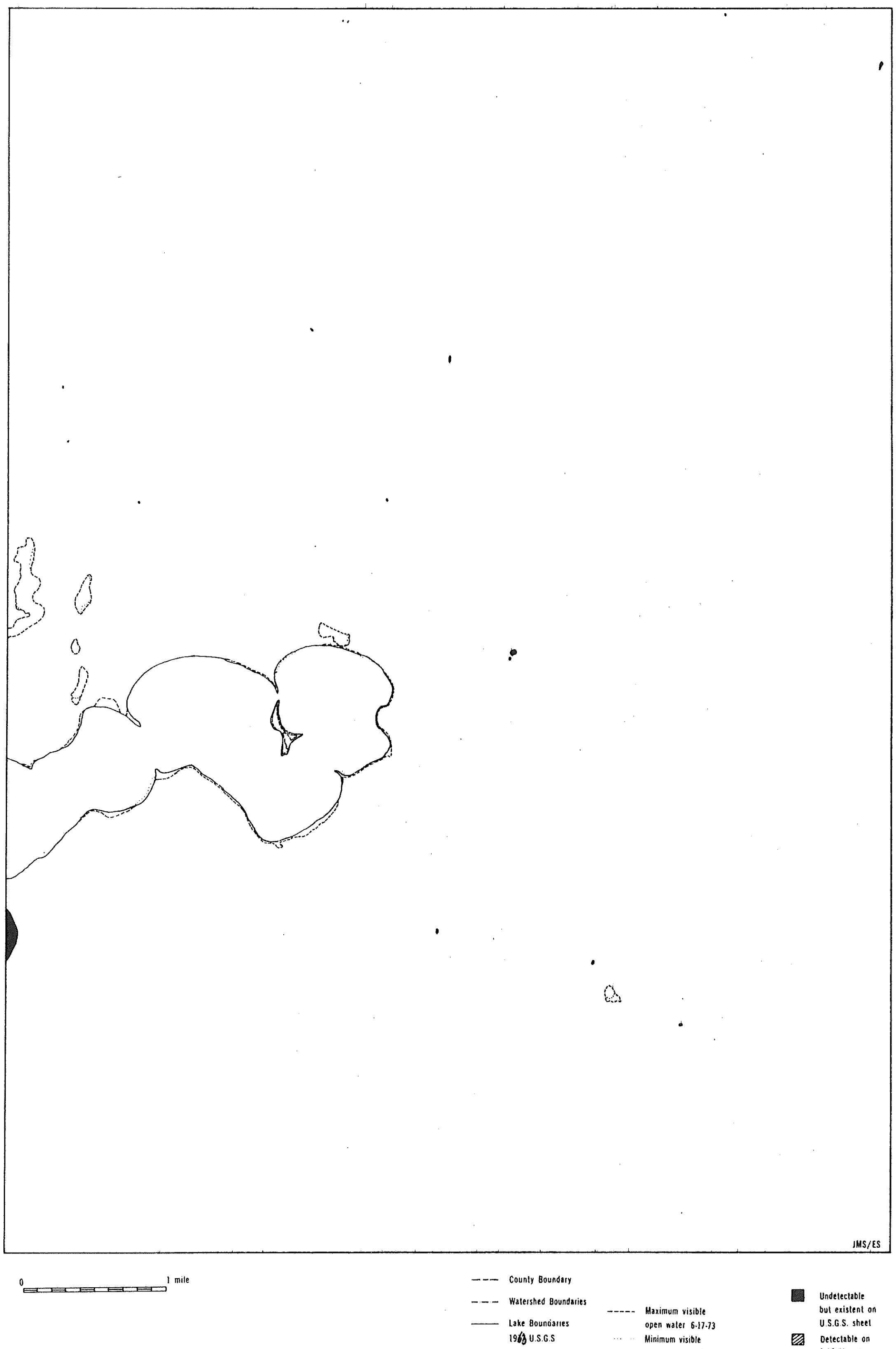
Undetectable but existent on U.S.G.S. sheet

Detectable on 6-17-73 only

Figure 29.

TYLER QUADRANGLE, MINN.

CHANGES OF VISIBLE OPEN WATER

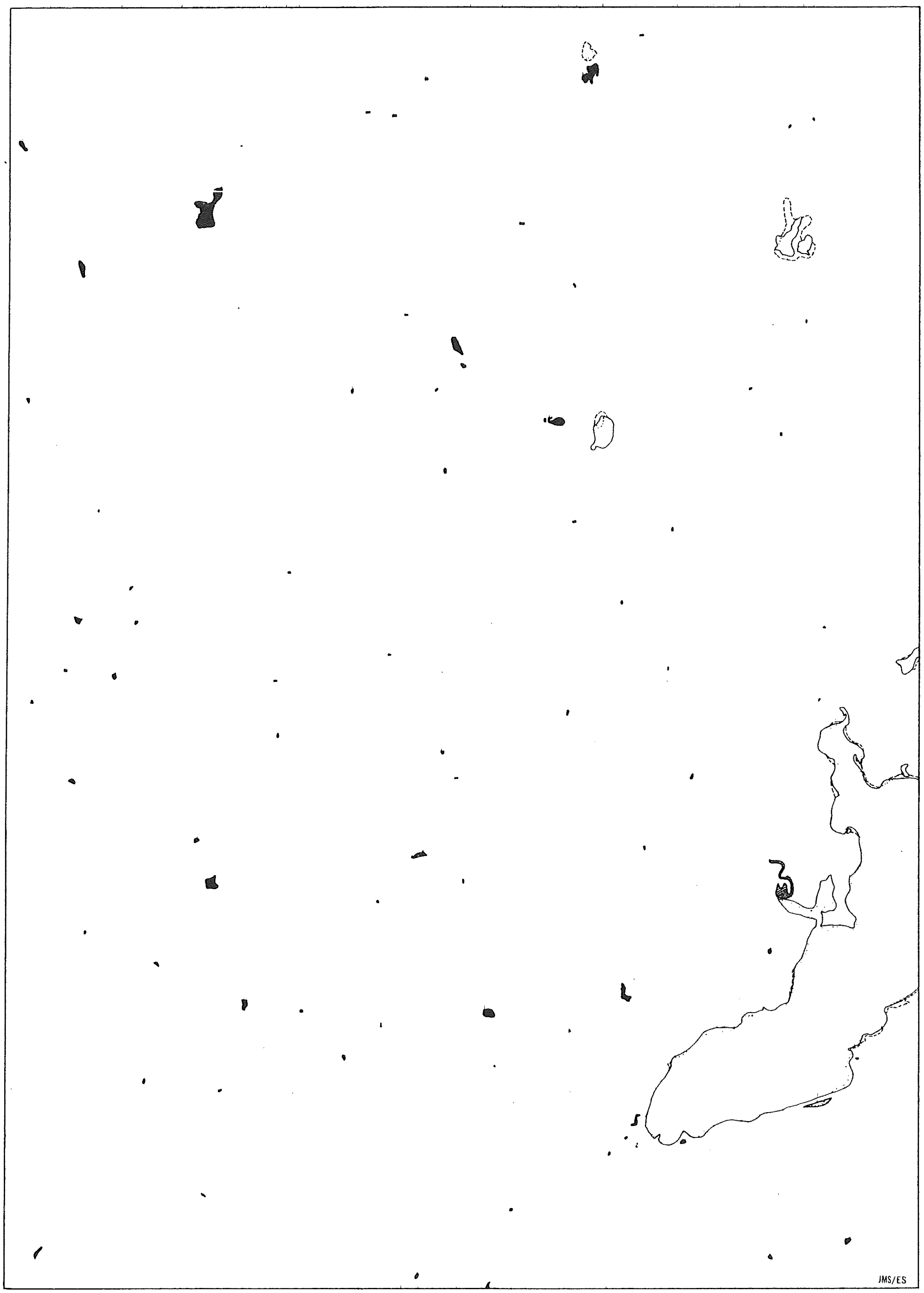


Source: "ERTS MSS Imagery"

Figure 30.

LAKE BENTON QUADRANGLE, MINN.

CHANGES OF VISIBLE OPEN WATER



0 1 mile

Source "ERTS MSS Imagery"

County Boundary

Watershed Boundaries

Lake Boundaries 1967 U S G.S Topographic Sheet

Maximum visible open water 6-17-73

Minimum visible open water 8-28-73

Undetectable but existent on U S G.S. sheet

Detectable on 6-17 73 only

Figure 31.

LAKE BENTON S.W. QUADRANGLE, MINN. -S. DAKOTA

CHANGES OF VISIBLE OPEN WATER

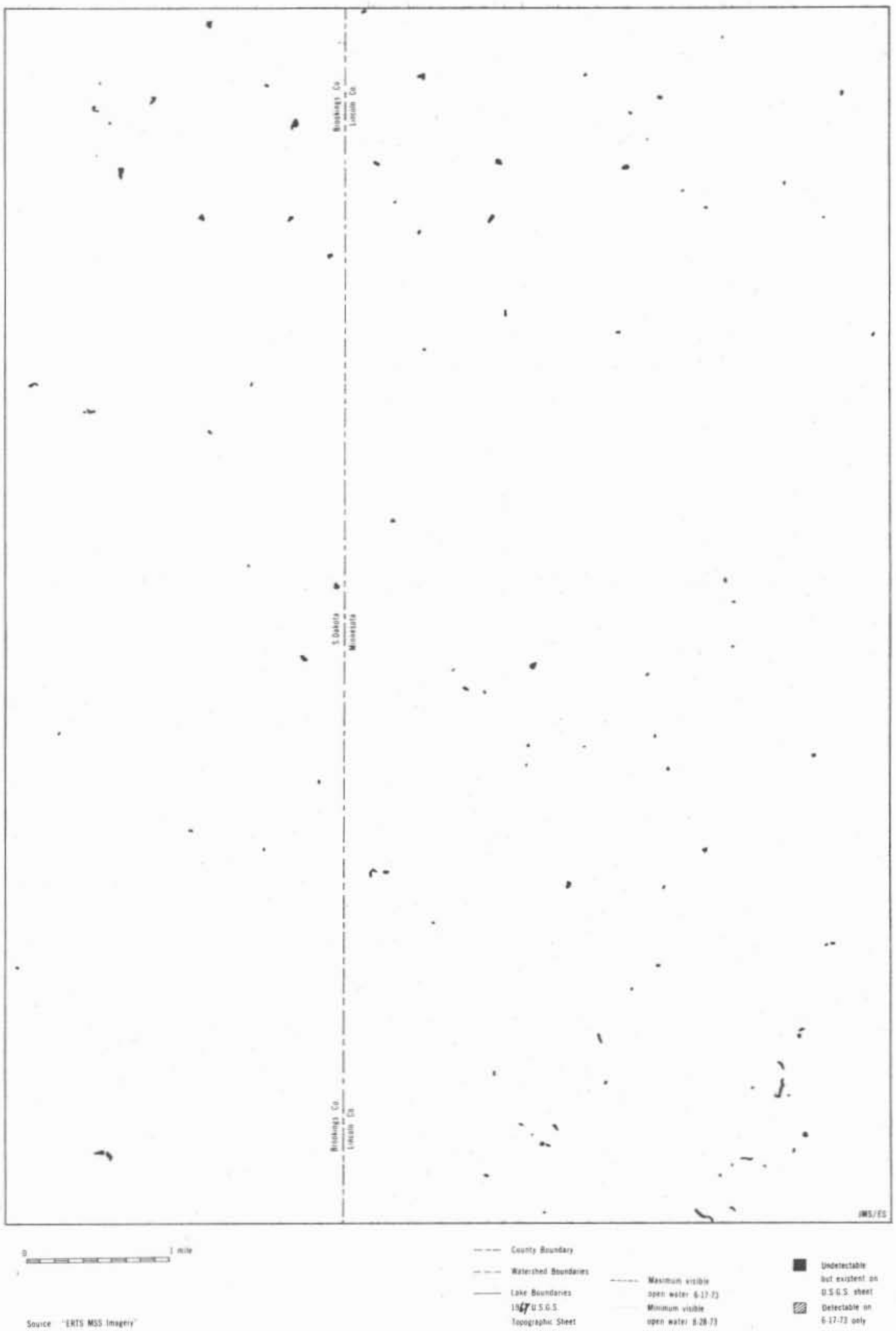


Figure 32.

ELKTON QUADRANGLE, MINN.-S. DAKOTA

CHANGES OF VISIBLE OPEN WATER

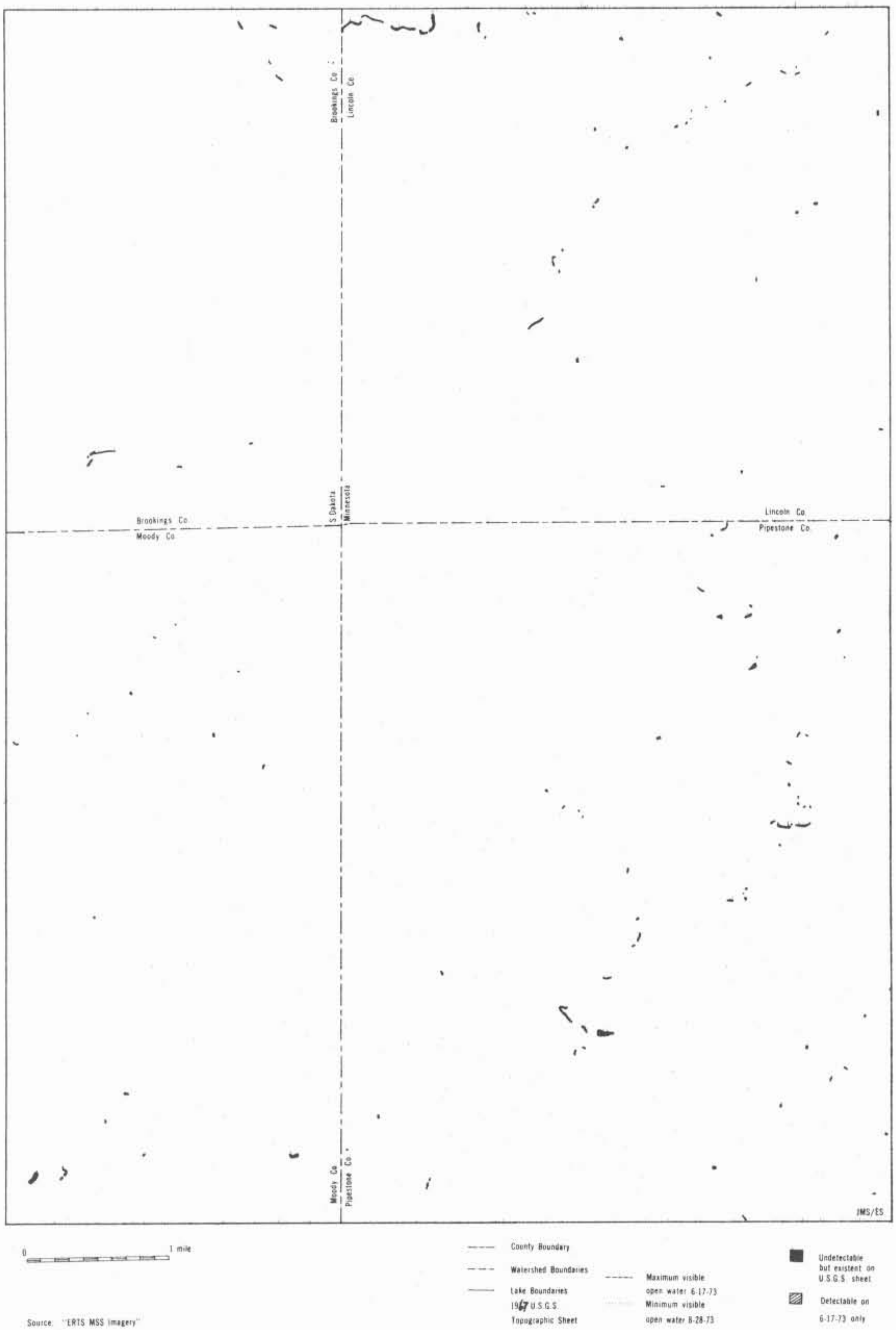
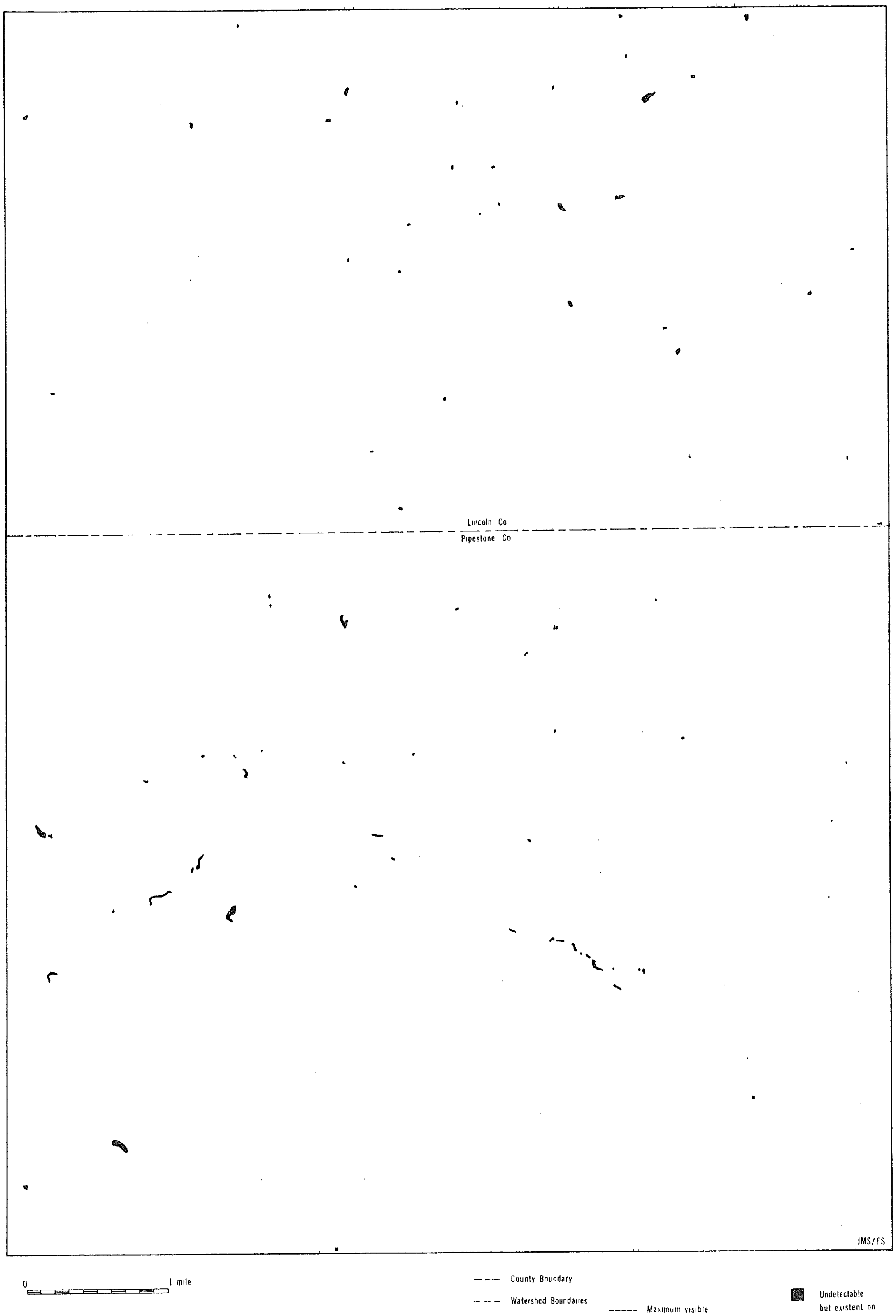


Figure 33.

VERDI QUADRANGLE, MINN.

CHANGES OF VISIBLE OPEN WATER



Source: "ERTS MSS Imagery"

Figure 34.

RUTHTON N.W. QUADRANGLE, MINN.

CHANGES OF VISIBLE OPEN WATER

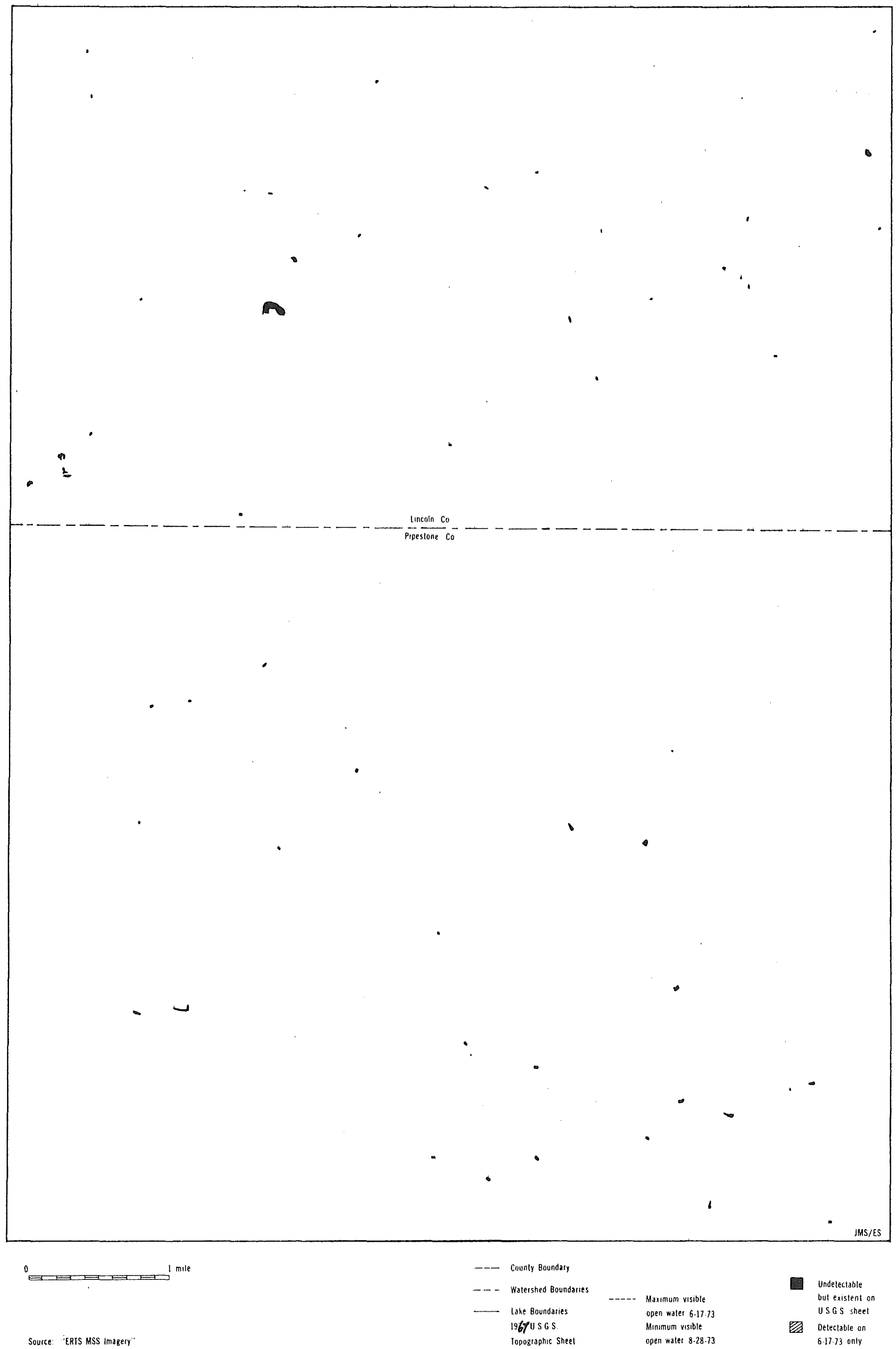


Figure 35.

RUTHTON QUADRANGLE, MINN.

CHANGES OF VISIBLE OPEN WATER

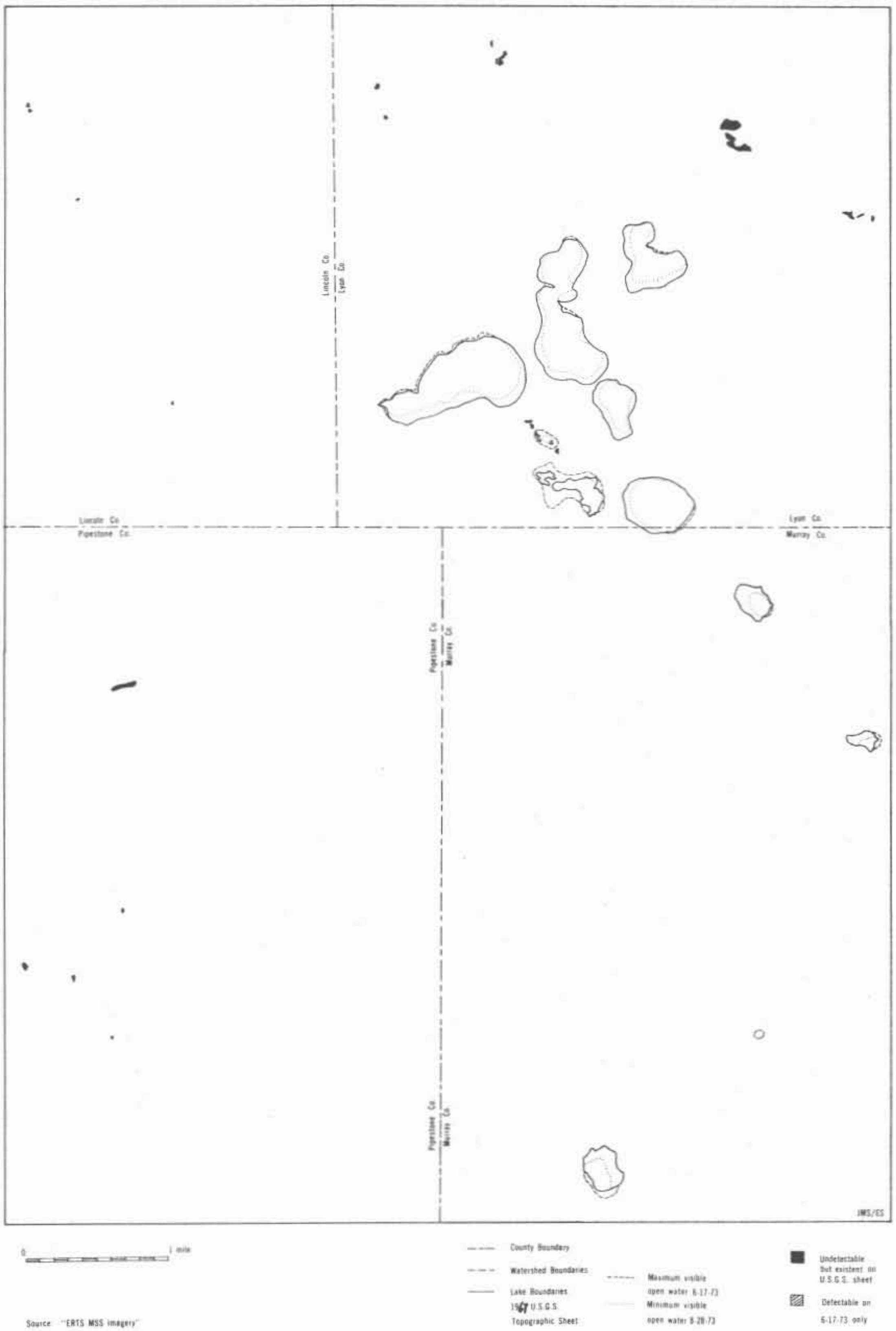


Figure 36.

number of lakes that are reduced in size or dry and are not so indicated in Bulletin 25. Column 5 shows the number of basins listed in Bulletin 25 as affected by drainage and dry and column 6 indicates how many of these affected basins had significant water areas at some time during the period of ERTS coverage from August 72 through July 74. Columns 7 and 8 indicate the reduced and empty status of basins reported as affected by drainage.

Similar comparison for the 1912 vintage 1:62,500 scale Chokio Minnesota Quadrangle (Stevens Co.) indicates that only 20 of the 118 lakes over 10 acres were detectable on ERTS-I images. Sixty four basins in Bulletin 25 were not indicated with water on the 1912 quadrangle. One additional lake on the quad was not included in either Bulletin 25 or on the ERTS imagery. The portions of 16 1:24,000 scale quadrangles that cover Lincoln County contain 9 lakes detected from ERTS-I images that are neither on the quads nor in Bulletin 25. Of the 118 Lincoln Co. basins included in Bulletin 25, 66 are not present on the ERTS verified quadrangles.

Differences between Bulletin 25 and ERTS verified water maps stem largely from two factors. First is the use of existing areal photography to map basins. Available aerial photography, at the time Bulletin 25 was being compiled, was single season and seldom taken in the spring, the normal period of maximum water. Second is the age of the existing aerial photography used. Some photography is now over 30 years old, and for some counties, it was taken during prolonged dry periods. The photography used for the Metropolitan 7 county area in this evaluation is now 21-25 years old. These products placed severe limitations on the mapping of seasonally wet basins and their age may account for considerable changes resulting from manipulation of basins.

CONCLUSIONS

The findings of this research indicate that ERTS-1 products described above. It was deemed desirable to attempt to maximize the detail and include even the smallest open water bodies that are portrayed on topographic quadrangles. Secondly, the normal water levels, portrayed on the USGS quads, should be included and supplemented by information on the seasonal maximum water.

To satisfy the data requirements for this map, the 45 quadrangles for the 7 county Metropolitan Area were photographically reduced to 1:125,000 scale and mosaiced. It was considered desirable to eliminate the watershed boundaries and the seasonal minimum water extent shown on the quads, thus necessitating redrafting. The Metropolitan Minneapolis-St. Paul Area map in the map pocket shows the final product. The solid black areas shows the water indicated on topographic maps that was not detectable during the July 1972-July 1974 period of ERTS coverage. Many of the smaller water bodies shown in black are too small for detection by ERTS. Those lakes greater than 10 acres shown in black should be seen with a high degree of reliability with ERTS-1 images and can be considered to lack open water surface during the times of data collection by the satellite. The blue pattern extending beyond the black normal water line indicates seasonal inundation interpreted from ERTS-1 images.

COST PROJECTIONS

The experience gained in producing the quadrangles shown in Figures 3-36 and the 45 quads used to produce the Metropolitan Minneapolis-St. Paul Area map indicates that the cost of producing quadrangle overlays varies significantly throughout the state. Labor for the complete maps ranges from 5.25 to 22.25 man hours. Labor requirements are generally higher in areas with many or highly irregular lakes. The 1:62,500 (15') series quads are more expensive than the 1:24,000 (7.5') series; but, of course they individually cover 4 times more area. There are approximately 425 15' quad areas in Minnesota, mostly mapped in the 7.5' series. The labor required for each 15 minute area averages about 25 hours or a total of 10,625 man hours to complete the entire state.

Supply costs would run approximately \$50 per 15' area or about \$21,250 for the state. Equipment costs would be under \$2,000 for an operation large enough to complete the job in one calendar year.

Labor requirements for the Metropolitan Minneapolis-St. Paul Area map in the pocket were 180 hours. The cost includes mosaicing the 45 reduced quadrangles, drafting the two plates for the printer, and editing the proof. The 180 hours by this method seems quite high in comparison with the 30 hours for the county maps interpreted directly from ERTS-1 70mm positives of band 7. It must be remembered that the direct mapping process included only one piece of information, was lower in locational accuracy, did not contain topographic map data, and did not include many lakes smaller than 20 acres.

EVALUATION

Comparison of verified surface water topographic maps with Bulletin 25 yields a multitude of discrepancies when compared on a lake by lake basis for the seven county metropolitan area. The data for this comparison are shown in Table 1. Because of the 10 acre limit in Bulletin 25 only water features of that size are considered here. It should be pointed out that Bulletin 25 is an inventory of basins capable of holding water and not of water area. It has annotations for basins that are affected by drainage, partially dry, and dry at the time of the aerial photography used in the inventory.

The first column of Table 2 indicates the number of 10 acre or larger lakes detected on ERTS-1 for which there were no basins listed in Bulletin 25. These lakes probably represent enlargements of small lakes missed because of their condition on single season aerial photography, dominantly taken during prolonged dry periods. The 126 lakes for the 7 county area does indicate a 13% increase in the number of basins. The third and fourth column indicate the

TABLE 1. Comparison of Twin Cities Metropolitan Area Map with an Inventory of Minnesota Lakes, Bulletin 25

			Mapped Lakes ≥ 10 Acres Listed in Bulletin 25 as Not Affected by Drainage or Dry		Mapped Lakes ≥ 10 Acres Listed in Bulletin 25 as Affected by Drainage or Dry			
County	Mapped Lakes ≥ 10 Acres not in Bulletin 25	Number of Basins in Bulletin 25	Reduced in Size	Empty Basins	Total Listed	Affected but Wet	Reduced in Size	Empty Basins
Anoka	15	143	1	6	55	31	7	17
Carver	30	128	0	1	73	25	5	43
Dakota	16	83	2	1	8	2	0	6
Hennepin	32	200	2	12	39	18	3	18
Ramsey	14	82	4	1	31	6	6	9
Scott	14	144	0	6	92	36	3	53
Washington	5	168	1	6	6	3	1	2
Metropolitan Area Total	126	948	10	33	304	121	25	148

can serve as a low cost extender of existing and topographic maps and photography for examining seasonal variations in visible open surface water. The ERTS-I materials alone are capable of providing rapid reconnaissance analysis of open surface water resources. Coupled with good topographic quadrangles, the interpretation of surface water from ERTS-1 images can provide far more detailed surface water information than now exists in Minnesota for lakes larger than 5 acres. Smaller water bodies are not detectable with any reasonable degree of reliability and other data sources must be sought where these water features are of concern.

REFERENCES

Brown, D.A. and Skaggs, R.H., 1974, "Remote Sensing Applications to Hydrology in Minnesota": A Study of Minnesota Forests and Lakes Using Data from Earth Resources Technology Satellites," Space Science Center, University of Minnesota, p. 81-94.

Prestin, Steven J., 1974, Management of Hydrographic "Features in West-Central Minnesota from ERTS-1 Imagery": A Study of Minnesota Forests and Lakes Using Data from Earth Resources Technology Satellites, Space Science Center, University of Minnesota, p. 99-195.

Shara, Ron, 1974,"Lakes Drained - Was That Public Water," Minneapolis Tribune, Sunday, October 13, 1974, p. 1f.

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