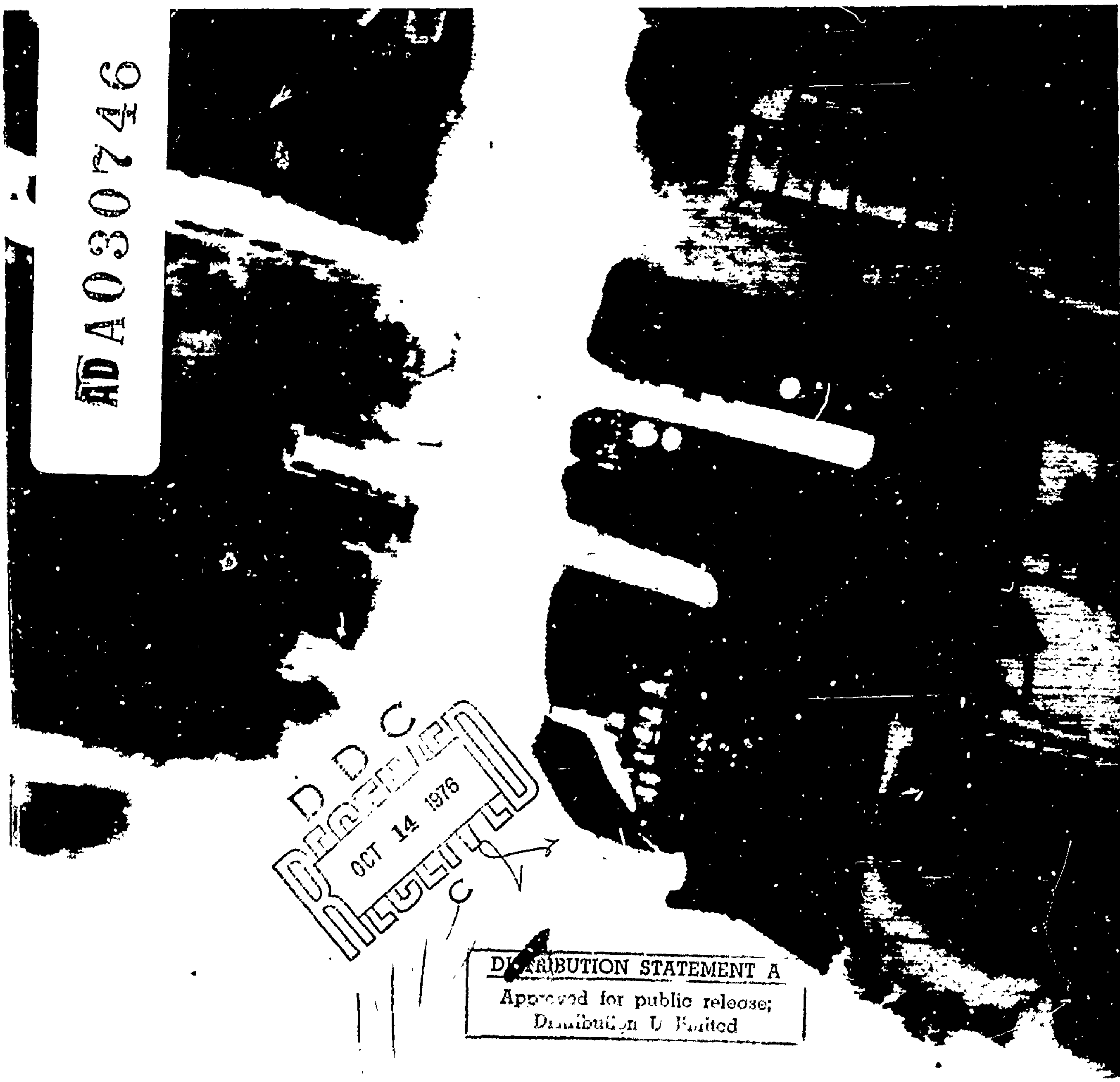
CRREL

Remote sensing of land use and water quality relationships — Wisconsin shore, Lake Michigan



Cover: NASA RS-14 thermal imagery of Fox River, Green Bay, Wisconsin. Note industrial effluent entering river at top of photo, petroleum storage tanks at center of photo, and power plant discharge at mouth of river. Chimneys of power plant and funnel on boat show as bright "hot" spots.

CRREL Report 76-30

Remote sensing of land use and water quality relationships — Wisconsin shore, Lake Michigan

R.K. Haugen, H.L. McKim and T.L. Marlar

August 1976

Prepared for

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

By

CORPS OF ENGINEERS, U.S. ARMY

COLD REGIONS RESEARCH AND ENGINEERING LABORATORY

HANOVER, NEW HAMPSHIRE

Unclassified

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER
(14) CRREL [redacted] 76-30

2. GOVT ACCESSION NO.

3. RECIPIENT'S CATALOG NUMBER

4. TITLE (and Subtitle)
(6) REMOTE SENSING OF LAND USE AND WATER QUALITY RELATIONSHIPS – WISCONSIN SHORE, LAKE MICHIGAN

5. TYPE OF REPORT & PERIOD COVERED

6. PERFORMING ORG. REPORT NUMBER

7. AUTHOR(s)
(10) R.K. Haugen, H.L. McKim [redacted] T.L. Marlar

8. CONTRACT OR GRANT NUMBER(s)

9. PERFORMING ORGANIZATION NAME AND ADDRESS
U.S. Army Cold Regions Research and Engineering Laboratory
Hanover, New Hampshire 03755

10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
NASA SR/T Project 160-75-89-05-10

11. CONTROLLING OFFICE NAME AND ADDRESS
National Aeronautics and Space Administration
Washington, D.C.

12. REPORT DATE
(11) Aug[redacted]976

(12) 53 p.

13. NUMBER OF PAGES
53

14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)

15. SECURITY CLASS. (of this report)
Unclassified

15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Aerial photography	Mapping
Detectors	Monitoring
Infrared detection	Pollution
Lake Michigan	Wisconsin
Land use	

This investigation assessed

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The focus of this investigation was to assess the utility of remote sensing techniques in the study of land use-water quality relationships in an east central Wisconsin test area. The following types of aerial imagery were evaluated for this purpose: high altitude (60,000 ft) color, color infrared, multispectral black and white, and thermal; low altitude (less than 5000 ft) color infrared, multispectral black and white, thermal, and passive microwave. A non-imaging hand-held four-band radiometer was evaluated for utility in providing data on suspended sediment concentrations. Land use analysis includes the development of mapping and quantification methods to obtain baseline data for comparison to water quality variables. Suspended sediment loads in streams, determined from water samples, were related to land

DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE

037 100

Unclassified

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

20 (cont'd).

use differences and soil types in three major watersheds. A multiple correlation coefficient R of 0.85 was obtained for the relationship between the 0.6-0.7 μm incident and reflected radiation data from the hand-held radiometer and concurrent ground measurements of suspended solids in streams. Applications of the methods and baseline data developed in this investigation include: mapping and quantification of land use; input to watershed runoff models; estimation of effects of land use changes on stream sedimentation; and remote sensing of suspended sediment content of streams. High altitude color infrared imagery was found to be the most acceptable remote sensing technique for the mapping and measurement of land use types.

PREFACE

This report was prepared by R.K. Haugen, Geographer, and Dr. H.L. McKim, Research Soil Scientist, of the Earth Sciences Branch, Research Division, U.S. Army Cold Regions Research and Engineering Laboratory, and by T.L. Marlar, Chief, Photo Services Section, Engineering Services Branch, Technical Services Division, CRREL. Funding for the research described in this report was provided by NASA SR/T Project 160-75-89-05-10.

Lawrence Gatto of CRREL technically reviewed the manuscript.

The authors wish to express their appreciation to the following individuals for their considerable contributions to the report, especially in land use mapping and measurement: P.J. Splett, Lawrence Gatto, Carolyn Merry, Michael Hutton, and Martha Greer. Dr. H. Huddleston, University of Wisconsin at Green Bay, provided underflight stream temperature measurements on several occasions. Dr. A. Lind, University of Vermont, provided assistance in the analysis of high altitude thermal imagery and stream color characteristics. The illustrations were drawn by Eleanor Huke.

CONTENTS

ILLUSTRATIONS

TABLES

CONVERSION FACTORS: U.S. CUSTOMARY TO METRIC (SI) UNITS OF MEASUREMENT

These conversion factors include all the significant digits given in the conversion tables in the ASTM *Metric Practice Guide* (E 380), which has been approved for use by the Department of Defense. Converted values should be rounded to have the same precision as the original (see E 380).

Multiply	*By*	*To obtain*
inch	25.4*	millimeter
foot	0.3048*	meter
mile (U.S. statute)	1.609344*	kilometer
square foot	0.09290304*	square meter
square mile	2.589998	square kilometer
degrees Fahrenheit	(°F-32)/1.8	degrees Celsius

* Exact.

REMOTE SENSING OF LAND USE AND WATER QUALITY RELATIONSHIPS – WISCONSIN SHORE, LAKE MICHIGAN

by

R.K. Haugen, H.L. McKim and T.L. Marlar

INTRODUCTION

The Great Lakes are one of the nation's most valuable resources and have been a major factor in the settlement and economic growth of the midcontinental area of both the United States and Canada. The lakes are utilized for many purposes, such as recreation, transportation, waste disposal, water supply, hydroelectric power production, and commercial fishing. A gradual deterioration in water quality caused by these uses has been documented (Beeton 1970), with Lakes Erie and Ontario showing the greatest amounts of pollution and eutrophication. Lake Michigan, the focus of the initial phase of this study, does not exhibit the advanced deterioration of the eastern lakes, but there are serious problem areas in Green Bay and at the southern end of the lake, as well as indications of long-term deterioration in the open waters (Beeton 1970). The seriousness of this condition in Lake Michigan is compounded by its low water turnover rate, compared to the eastern lakes, and most of the major streams which feed Lake Michigan are already polluted.

As land use patterns evolve, generally following a progression from forest to agriculture to urban or industrial uses, stream flow and water quality characteristics also change. The U.S. Army Corps of Engineers, along with its responsibility for the maintenance of inland navigable waterways, is concerned with the environmental impact of pollutants, especially as they affect lakes and streams. Stream sedimentation, a form of pollution which can often be related to economic activity, is of particular interest in this investigation.

Objectives

This investigation examines the feasibility of using remote sensing methods to assess, rapidly and economically on a regional scale, the effect of land use as it influences sediment loading in streams.

To accomplish this objective, the following tasks were completed: 1) the acquisition and evaluation of a large variety of remote sensing imagery, 2) the development of techniques for mapping and quantification of land use patterns, 3) the assessment of the cost effectiveness of these mapping and measurement techniques, and 4) the collection and analysis of water quality samples for comparison to land use characteristics and correlation with signatures identifiable by remote sensing techniques.

Approach and project history

This study was initiated in April 1972. A field trip was taken in May 1972 for an overview of the test area and for the acquisition of data from state and federal agencies in Wisconsin. The initial phase of the study was primarily devoted to acquiring published data and evaluating a variety of imagery provided by NASA in September 1972.

NASA provided imagery for the project by utilizing two aircraft: the General Dynamics RB-57F (later designated the WB-57F), a mid-wing, four-jet engine aircraft capable of altitudes in excess of 60,000 ft, and the Lockheed NP-3, a low-wing, four-engine aircraft designed to carry a variety of sensors at altitudes under 20,000 ft. Some imagery was also acquired by the investigators in a rented Cessna 185, a high-wing, single engine aircraft modified to accommodate an aerial camera. Considerable effort was devoted to experimentation with mapping techniques by using two types of densitometry. The intent was to develop methods for the measurement of land use types directly from imagery. Using color infrared emulsions and filtering, some success was achieved in differentiating U.S. Geological Survey (USGS) Land Use Classification level I, but only where soil color was light. A system of densitometric measurement with hand-drawn overlay maps was eventually developed. This technique provided the necessary data for subsequent comparisons with water quality parameters.

Two methods were used to extract from imag... water quality information that could be correlated to field measurements. The first method was the development of a color classification for streams in the study area, based on a densitometric method. The purpose of the classification was to quantify photographic stream color differences disp' ed in the 1972 high altitude Ektachrome (SO-397) imagery. The results of this approach, howe..., were not sufficiently consistent to be of practical value. During the 1974 missions, ground truth data on reflected and incident radiation in the ERTS (Earth Resources Technology Satellite) MSS spectral bands were obtained. This method provided more reliable results and permitted significant correlation with measured concurrent suspended sediment load' for several major streams in the test area. These data were then compared to measurements of land use and soil types in the individual watersheds for analysis of regional relationships.

In July 1973, a chapter was prepared on land use mapping for the Corps of Engineers Handb *Remote Sensing for Environmental Analysis* (Haugen and Splett 1974). This chapter, based or use mapping procedures developed during the project, provides practical discussion and guiden for land use mapping. ERTS-1 and high altitude color infrared imagery are compared for land use mapping applications within missions of the Corps of Engineers.

STUDY AREA

The Wisconsin shoreline of Lake Michigan, NASA Test Site 311 (Fig. 1), was selected for this investigation for several reasons: 1) the area is predominantly agricultural, with relatively isolated concentrations of urban and industrial land use, so that the contributions to pollution levels of the basic land use types can be readily assessed; 2) the general pollution of Lake Michigan is still low enough so that future benefits from identification of present and potential "trouble spots" can be realized; 3) the streams entering Lake Michigan from the Wisconsin shoreline are relatively short, so that entire watershed areas can be mapped within about 50 miles of the shoreline.

Physical setting

The test area lies within the Eastern Ridges and Lowlands physiographic subprovince of Wisconsin. The eastern portion, the Eastern Ridges, is entirely underlain by the Niagara Cuesta limestone which forms the Door County Peninsula and extends to the southern boundary of Wisconsin, sloping gently toward Lake Michigan. The other major physiographic subprovince is the Lake Winnebago-Green Bay Lowland, a gently sloping plain which contains Lake Winnebago, the Fox River Valley,

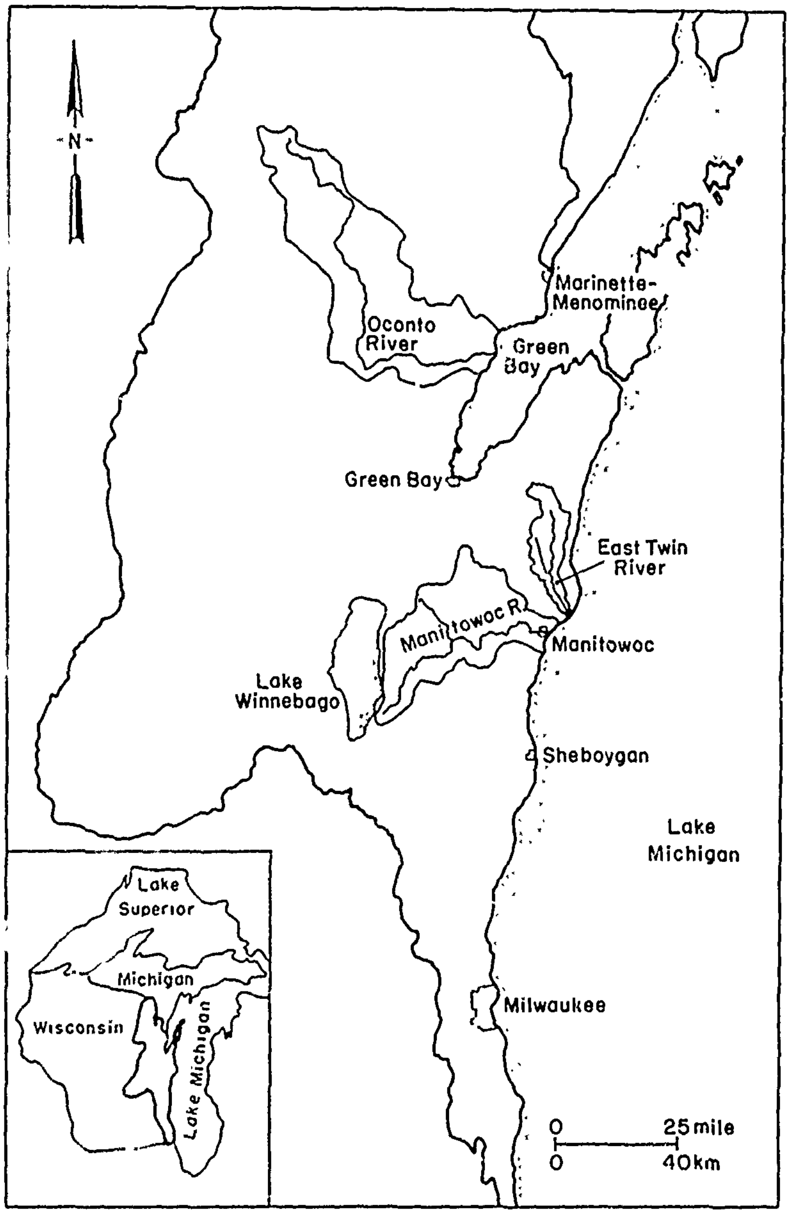


Figure 1. Study area and watershed boundary of Wisconsin rivers draining into Lake Michigan.

and a submerged portion forming Green Bay. The entire landscape of the test area has been extensively modified by Pleistocene glaciation, with glacial deposits forming most of the local relief which ranges up to 200 ft. The Lake Michigan shoreline is formed from tills and lacustrine sediments of higher glacial lakes, resulting in wave-cut cliffs 100-120 ft high in much of the test area. Erosion of these unconsolidated materials continues at the present time, resulting in a large sediment load in the nearshore waters.

The major rivers of the study area are the Fox, Wolf, Menominee, and Oconto which drain into Green Bay, and the East and West Twin, Manitowoc and Sheboygan which drain into Lake Michigan (from north to south along the shoreline). The rivers flowing directly into Lake Michigan do not have sources west of the Niagara Cuesta, with the single exception of the Manitowoc, which is believed to have drained Lake Winnebago during glacial times. Many lakes dot the glacially modified landscape, few of them with an area exceeding 3000 acres. Lake Winnebago, 215 square miles in area, is the largest lake in the state and was formed behind a morainal dam during glacial retreat.

Soil associations in the study area include the Northern and Eastern Sandy and Loamy Reddish Drift Uplands and Plains, Northern Silty Uplands and Plains, Northern Loamy Uplands and Plains, Northern Sandy Uplands and Plains, and the Stream Bottoms and Major Wetlands in the area between the Oconto and Fox Rivers. The major soil associations in the East and West Twin and Manitowoc River Watersheds are the Soils of the Northern and Eastern Clayey and Loamy Reddish Drift Uplands and Plains. Minor soil associations include well to poorly drained sandy soils and poorly drained depressional soils with some peats and mucks.

The climate of the test area is continental, with long and severe winters, especially in the north, and very warm summers. Lake Michigan modifies temperatures in a narrow belt bordering the lake, but the effect is minimized by the general easterly and south-easterly trend of most weather system movements through the areas. The warming effects of Lake Michigan are, therefore, much less for eastern Wisconsin than for western Michigan.

January is the coldest month, with an average temperature ranging from 13°F in the north to 24°F in the south. During July, the warmest month, average temperatures range from 66° to 73°F north to south. The frost-free season ranges from 10 June to 30 August in the north, to 25 April to 20 October in the south. The wettest months are May through September, and annual precipitation totals range from 29 to 33 in., north to south. Snowfall ranges from 60 in. in the north to 30 in. in the south.

Weather conditions in eastern Wisconsin prior to and during aircraft missions and water sampling operations are indicated by the temperature and precipitation data in Appendix A. Generally, the high altitude RB-57F flights required fair weather, with few clouds; however, scattered rain showers preceded the flights in much of the test area. The June 1974 NP-3 nighttime thermal scan was not completed due to heavy ground fog, and weather conditions during September and October 1973 resulted in two canceled missions, which were rescheduled and accomplished during May and June 1974.

Cultural setting

The population within the test area is in the neighborhood of 3,000,000. The largest population concentration is in and around Milwaukee, which is also the economic center of the area. Manufacturing is by far the largest employer within the test area, followed by agriculture, forestry, construction and mining. Over half the northern part of the test area is forest, and wood processing firms are a major part of the region's economy. Much of the wood processing industry is centered in the Fox River Valley. Mining activity primarily includes extraction of clay, limestone, sand and gravel, with some iron ore and granite being mined in the north. The recreation industry is also important, particularly in the northern forested areas.

Agriculture is important throughout the area. Grain crops are dominant in the south, and vegetables, small fruits and horticultural specialities are raised in the central and northeast portions. Some irrigation is practiced with specialty crops. Dairying and related processing industries are found throughout the area.

DOCUMENTED POLLUTION SOURCES IN THE STUDY AREA

There has been considerable activity in the identification and control of aquatic pollution in eastern Wisconsin. Major sources of pollution have been identified, and recommendations for remedial action have been made by the Wisconsin Department of Natural Resources. Three divisions of the U.S. Department of Agriculture (the Soil Conservation Service, the Economic Research Service, and the U.S. Forest Service), are engaged in a cooperative study of flooding and water management problems, the Southeast Wisconsin River Basin Survey.

A map of known aquatic pollution sources (Fig. 2) was compiled from information gathered by the above agencies, especially the Wisconsin Department of Natural Resources, Environmental Protection Division. The point sources of pollution are mapped in five categories: 1) sewage, 2) dairy, 3) cannery, 4) thermal and 5) other types. (As will be discussed in subsequent sections, few of these point sources are visible in the small-scale photography acquired during Mission 205 or Mission 273.)

The largest contributors to polluted waters are inadequate sewage treatment systems. This problem is not unique to the study area, but typifies other areas throughout the United States. Most of the major cities in the study area have sewage treatment plants, but many plants are working at greater capacities than they were designed to handle. Some smaller towns have no treatment plants, and inadequate septic tanks contribute to the problem. Attempts are being made to reduce the excessive amounts of pollutants reaching the streams.

The dairy industry is one of the leading sources of income within the study area. As a result, many dairy processing plants operate in the area, and in most cases, their wastes reach streams with little or no treatment. Dairy farms also add to the pollution of the area because of wastes from their livestock and fields. In other instances, dairy wastes enter existing sewage treatment plants, contributing to the overloading of some of them.

Vegetable and fruit production is an important occupation among farmers in the area; consequently there are canneries that contribute wastes to streams. These wastes add various chemicals from washing operations and increase the organic load.

A limited number of thermal pollution sources exist within the study area. These include electric power generating facilities and sewage treatment plants. The major sources of waste heat are two nuclear power plants, the 527,000-kW plant at Kewaunee and the 597,000-kW plant at Point Beach. These plants are located on Lake Michigan and use water directly from the lake for cooling.

The "other" category of point sources of pollution includes paper-processing factories, which contribute both chemical and organic wastes, industrial plating facilities and tanneries.

EVALUATION OF IMAGERY

Photographic imagery

The flight lines for the RB-57F photographic missions during 1972 are indicated in Figure 3. During 1973, a low altitude thermal scan (Mission 235), was flown with coverage of the coastal portions of the test area along with the Fox River (Fig. 4). An attempted second RB-57F flight in September 1973 was aborted due to unfavorable weather conditions over the test area. The 1972 RB-57F coverage was repeated in 1974 during Missions 273 (3-7 May 1974) and 284 (12 June 1974). Separate flights of these missions were required to cover the test area because of poor weather conditions. A second coverage with the NP-3 aircraft was also obtained on 31 May 1974

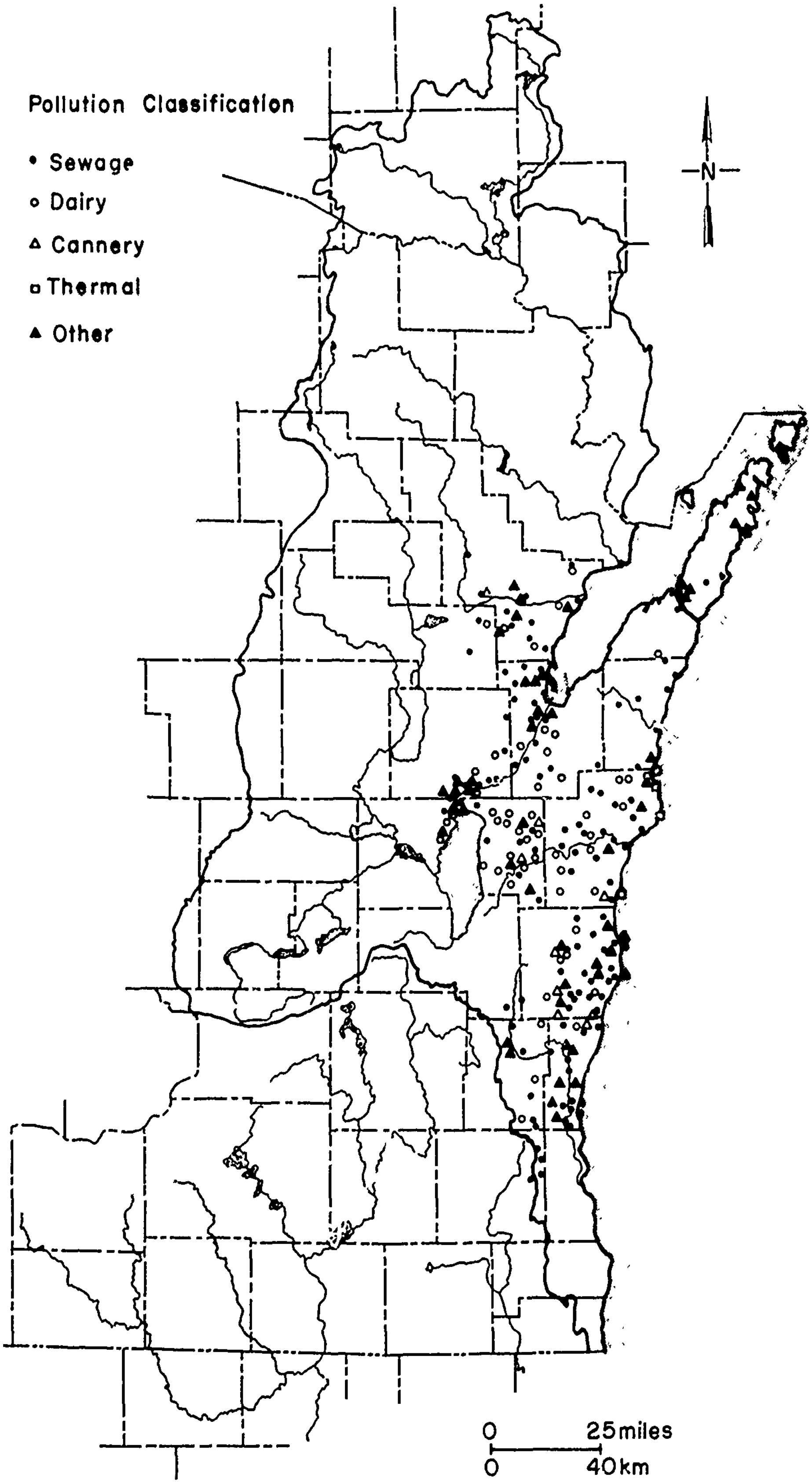


Figure 2. Documented aquatic pollution sources in the study area.

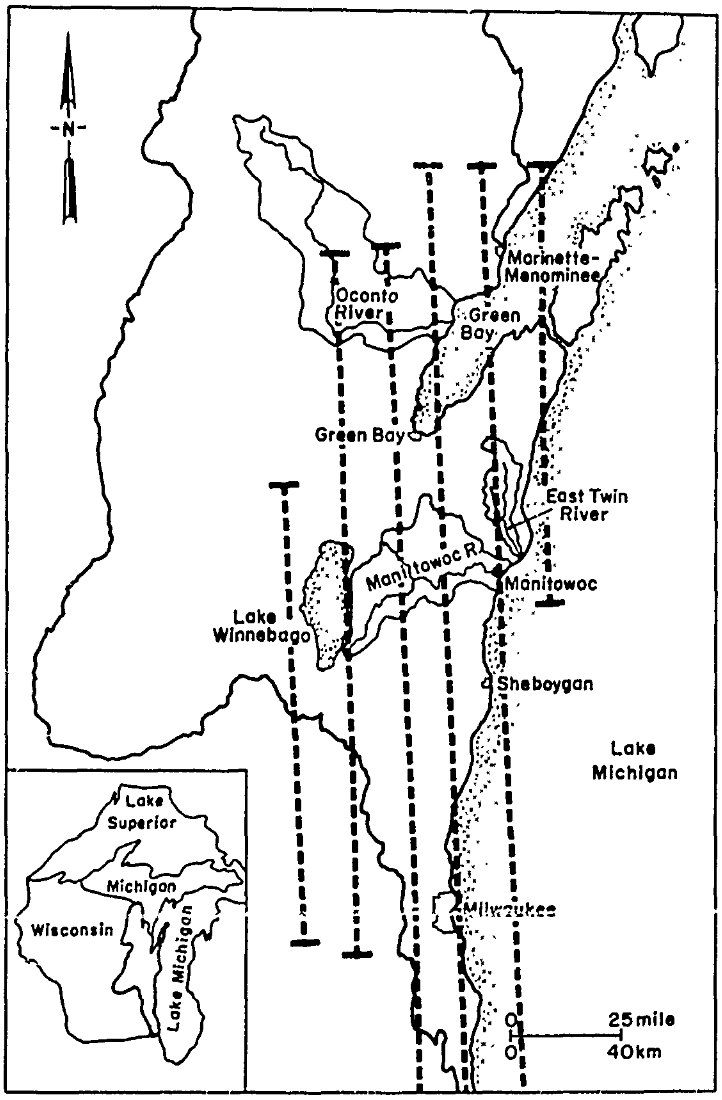


Figure 3. Generalized flight lines for RB-57F photographic missions.

(Mission 272), which included the Wisconsin coast, the Fox, Manitowoc and Sheboygan Rivers. The flight lines for the 1974 photographic and thermal scanning missions are essentially the same as shown in Figures 3 and 4.

The RB-57F aircraft was equipped with two 9-in. format RC-8 cameras (each with a 6-in. lens), a 9-in. format Zeiss aerial camera (with a 12-in. lens), a 70-mm Hasselblad camera (with 40-mm and 80-mm lenses), and an RS-7 thermal scanner filtered for the 10.2- to 12.5-μm spectral region. Imagery from the various cameras consists of 9-in. Ektachrome Type SO-397, 9-in. and 70-mm Aerochrome Infrared Type 2443, and a black and white positive of the RS-7 thermal scanner image. Sequential photography was obtained with the two RC-8 cameras timed for 60% overlap, and the Zeiss camera timed for 22% overlap. As the RB-57F flew at altitudes of 59,000 to 59,800 ft above ground level, the approximate scale of the 9-in. photography was 1:120,000 for the 6-in. lens and 1:60,000 for the 12-in. lens.* Table I shows the imagery acquisition schedule for the duration of the project.

* The exact scale was 1:118,000 for the 6-in. lens and 1:59,000 for the 12-in. lens.

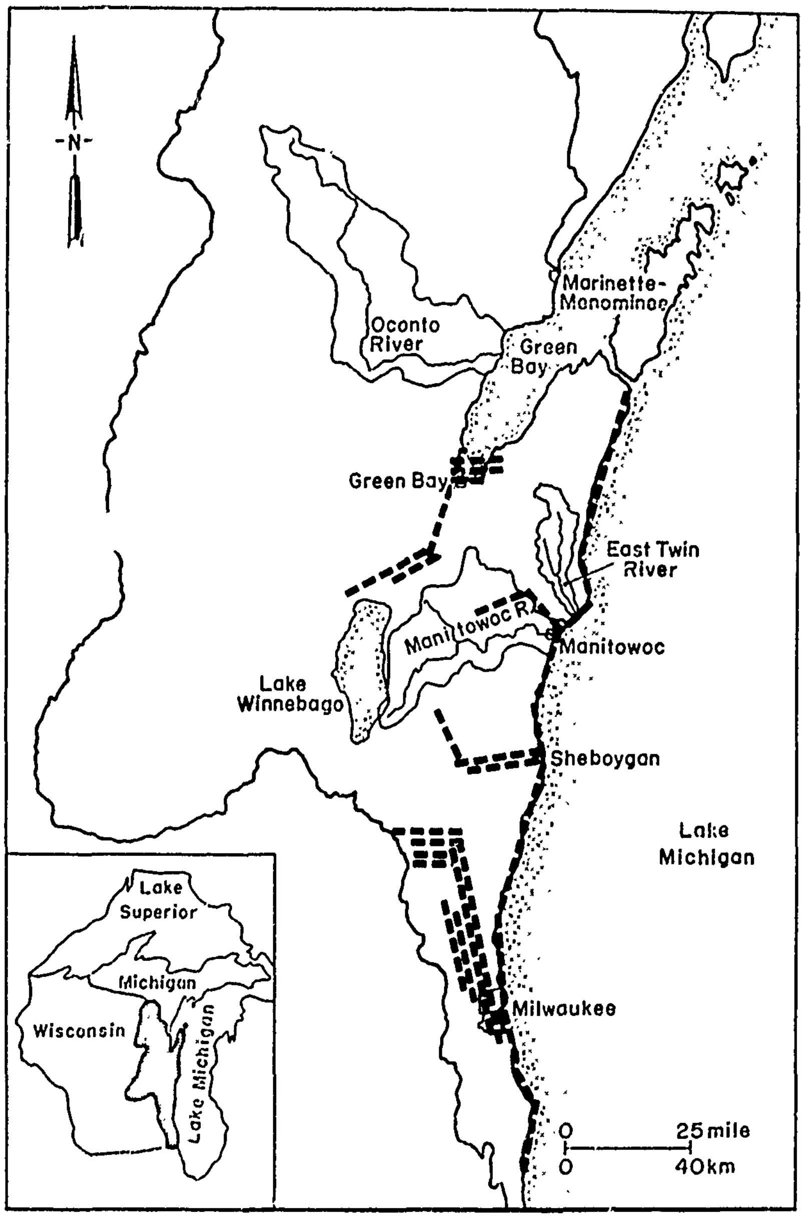


Figure 4. Flight lines for low-altitude thermal scanning missions.

The quality of the photography varied from good to excellent in the 9-in. format, and from poor to excellent in the 70-mm format. Evaluation of each type of imagery obtained for this study should be helpful for planning future missions.

Aerochrome infrared film (9-in. format) was exposed to two cameras (RC-8 and Zeiss) with 6-in. and 12-in. lenses. The 1:120,000 scale colorinfrared photography was used for direct comparison with the non-infrared Ektachrome Type SO-397, which was exposed at the same scale. The 1:60,000 photography was used to verify information derived from the smaller scale photography. Photography was also attempted in 70-mm format with Aerochrome infrared film and with a multispectral 4-camera system. A description of the various photographic formats follows.

Aerochrome Infrared film, type 2443, 9-in. format, 6-in. lens, scale 1:120,000. On the 1:120,000 Aerochrome infrared photography, land use patterns are readily distinguished but individual units are

Table I. Imagery acquisition schedule for NASA and for investigators of this study.

Date	*Aircraft*	*Mission*	*Altitude (ft)*	*Sensor*	*Film type/ wavelength*
Imagery acquisition by NASA					
4 June 1972	RB-57F	205	60,000	RC-8, 6-in. lens	2443
				RC-8, 6-in. lens	SO-397
				Zeiss, 12-in. lens	2443
				Hasselblad, 40-mm lens	2443
				RS-7 - thermal	10-12 μm
24 June 1973	NP-3	235	3,500-4,000	RS-14 - thermal scanner	8-14 μm
				PMIS	K-band
				PRT 5	
3-7 May 1974	RB-57F	273	60,000	RC-8, 6-in. lens	2443
				RC-8, 6-in. lens	SO-397
				Zeiss, 12-in lens	2443
				Hasselblad, 40-mm and 80-mm lenses	2443
				Hasselblad, 4-camera multispectral 40- and 80-mm lenses	2402
31 May 1974	NP-3	272	2,500-4,000	PMIS	K-band
				RS-14	8-14 μm
12 June 1974	RM-57F	284	60,000	Same as Mission 273	
Imagery acquisition by investigators					
3 Oct 1973	Cessna	185	5,000	Hasselblad, 100-mm lens, 4-camera multispectral	PX, 2402
					2443
					EKMS, 2448
7 May 1974	Cessna	185	5,000	Zeiss, 6-in. lens	2443
					PX, 2402

not easily discerned. Water bodies such as lakes, ponds, rivers and streams are easily seen. Patterns are observed in larger water bodies which may be indicators of waterborne pollutants. A wide disparity is noted in the color rendition of water bodies, and it is obvious that factors other than pollution are contributing to tonal appearance. Some of these factors are depth of water, surface roughness, sun angle, and water coloration. This 1:120,000 scale photography is useful in preparing land use maps of a general nature and is excellent for long-term monitoring of urban expansion. However, the detail available at this scale is not adequate to make positive identification of all observed features. The photography obtained in the 9-in. format with the longer focal length lens (12-in.) was used wherever greater detail was needed in the study.

Aerochrome Infrared Film, type 2443, 9-in. format, 12-in. lens, scale 1:60,000. The detail observed in this photography is excellent; center markings on highways may be seen, and individual automobiles are seen on highways and in parking lots. Vegetation is readily separated as to type and size. A peculiarity of the imagery is the three-dimensional appearance of the red vegetation signature, a feature that is very helpful in determining relative vegetation heights. The effect is apparently caused by the diffraction characteristics of the red color in the viewing optics. Surface water is contrasted sharply with the background, and drainageways can be traced with relative ease.

Patterns appearing in ground features lead to the speculation (not investigated in the study) that relative surface moisture differences in soils may be seen. Water depth is difficult to estimate but is indicated by changes in the blue rendition of the water. For example, a large swimming pool is shown in the imagery with water that is a very light blue at one end and gradually becoming dark blue at the opposite end. This color gradation is affected by other factors than depth, however, and is not a reliable indicator in all instances.

Aerochrome Infrared, type 2443, 70-mm format (2¼-in. square), 40- and 80-mm lenses, 12 + 30B filter. This photography was taken on two days. On 3 May 1974 it was exposed with 40-mm lenses on the Hasselblad cameras and on 7 May 1974 it was exposed with 80-mm lenses on the same cameras. The usefulness of the two days' photography varied considerably. Large patterns such as urban areas, large lakes or ponds and streams could be seen, but finer detail needed for land use mapping was missing. The probable cause of such poor resolution was atmospheric attenuation coupled with exposure variances. The 70-mm format was more difficult to work with than larger formats and was considered the least desirable for land use mapping.

70-mm Hasselblad multi-spectral imagery. The NASA 4-camera Hasselblad system was used with Wratten 24 and 45 filters and 2402 and 2442 (IR) film to obtain black and white photography of the test areas which would approximate the various spectral bands obtained in the ERTS-1 imagery (blue, green, red and near IR). The 2402 film with a Wratten 24 filter produced the best result for single band viewing and was the only band considered suitable for gross land use mapping (level 1). Color reconstruction of selected scenes was attempted using the multi-spectral viewer, but the usefulness of this technique (optical mixing) was limited due to the quality of the photography. It is possible to emphasize natural and cultural features by using the multi-spectral viewer, but in no instance was more information obtained from this technique than could be obtained from the larger color transparencies.

Conclusions. It was found in this study that the aerial photography does not give enough information to allow direct monitoring of point sources of water pollution. It does, however, provide information on gross pollution in water bodies, primarily in those cases where the pollution contrasts with the normal coloration of the water. The ability to do detailed land use and drainage mapping from this scale photography is its principal asset. Smaller scale photography is also useful in land use mapping, when supplemented with adequate larger scale photography for detail checking.

Thermal imagery

Patterns indicative of thermal pollution are generally recognized as thermal plumes emanating from point sources such as industrial areas, thermoelectric generating plants (with both nuclear and conventional fuels), and sewage treatment plants. The detection of thermal plumes is possible on small-scale thermal imagery (such as from an RS-7 scanner), but no quantitative assessment of actual temperature differences is possible, since calibrated temperature data are not available. The evidence of thermal pollution is therefore based entirely on relative tone signatures; for example, the rendition of dark tones on a positive film indicates cool temperatures, while light tones indicate warm temperatures.

RS-7 thermal imagery. The thermal imagery for this study was first obtained with the RS-7 infrared scanner, which is sensitive to the 10.2- to 12.5-μm spectral range, the far-infrared region of the spectrum. Most thermal imagery is acquired at night to avoid the effect of reflected radiation and at altitudes under 10,000 ft so that the resolution will be sufficient for the detection of thermal point sources. For this study, however, high-altitude, daytime RS-7 imagery was obtained on an experimental basis. In terms of the objectives of this study, little evidence of thermal pollution patterns could be seen. The only clearly identifiable man-made plume on the original imagery was the plume of the Point Beach Nuclear Power Plant (located at point 4, Fig. 5) where thermal differences could be seen extending about two miles southward of the plant.

Figure 5. RS-7 high-altitude thermal imagery of study area.

The plumes of several rivers entering Lake Michigan and Green Bay include the Milwaukee, the Fox, and the Menominee Rivers, points 3, 7, and 1, respectively, in Figure 5. It is normal for the water of rivers entering Lake Michigan and Green Bay to be warmer than the lake water during the spring and early summer seasons, and differences as high as 20°F were measured by the investigators. Therefore, it is difficult (if not impossible) to estimate how much of the relative warmth of these rivers is due to natural causes and how much is from industrial sources. Low-altitude, nighttime thermal scans would provide much more information on this type of problem.

A noticeable aquatic thermal pattern is illustrated at point 2 (Fig. 5). This pattern is interpreted to be related to major circulation systems within Green Bay, as the confinement of the pattern to the water area suggests that the signal did not result from atmospheric temperature differences. The original RS-7 imagery provided numerous patterns related to lake currents and long shore currents in Lake Michigan. The effect was similar to current turbidity patterns seen in the same areas on ERTS MSS bands 4 and 5 at approximately the same scale as the RS-7 imagery.

Thermal patterns on the land surface were complex. The most readily distinguishable patterns were found over forested areas (for example, point 7, Figure 5) which contrasted with those from cleared agricultural areas and small lakes. Urban areas were not distinct, but always gave a light tone on the original imagery, suggesting a "heat island" effect. An example is the city of Sheboygan (point 5). Tonal differences of the urban areas compared to the surrounding countryside resemble ERTS MSS band 7 in appearance.

One of the most noticeable terrestrial patterns on the RS-7 imagery is a dark swath with a northwest to southeast orientation, located between Green Bay and Lake Winnebago (point 6). The probably cause of this cold signal is judged to be precipitation occurring shortly before the time of flight, resulting in higher soil moisture content in this area. The only weather stations located within the dark-toned area are Brillion and Kewaunee, which reported 0.68 and 0.69 in. of precipitation, respectively, on 4 June (see App. A).

RS-14 thermal imagery. RS-14 imagery was obtained during Missions 272 and 273, which were flown on 31 May and 12 June 1974 at approximately 2100 to 2400 hours local time (flight lines are indicated in Figure 3). RS-14 imagery was also attempted for Mission 235 (June 1972) but ground fog obscured the results. Aircraft coverage of the Fox River was at 2500 ft (radiometric altitude); the rest of the coverage, including that of the Lake Michigan shoreline and the Manitowoc, Sheboygan and Milwaukee Rivers was at approximately 3500 ft (radiometric altitude). This study focused primarily on the RS-14 imagery of the Manitowoc River and briefly on the larger scale coverage of the Fox River. Data resulting from the PRT-5 radiometric thermometer intended for correlation with the RS-14 imagery were not received from NASA.

The RS-14 thermal scan provided imagery in the 8- to 14-µm wavelengths. The imagery was acquired at night so that only emitted thermal radiation would be recorded. The clarity of the thermal imagery acquired during Mission 272 is excellent. Except for the presence of scan lines, much of the imagery approaches photographic quality in terms of information content available for interpretation.

The primary consideration in this study was the application of RS-14 thermal imagery to the Corps of Engineers mission work. The acquisition of thermal imagery is considerably more expensive than that of photographic imagery. This discussion compares the information content of the thermal imagery with color infrared photographic imagery acquired during Mission 273.

Details of the RS-14 thermal scan of the Manitowoc River were compared with a 1:60,000 scale color infrared photograph acquired 23 days prior to the thermal scan (7 May). Figure 6 is a negative rendition of this RS-14 imagery. Very little water detail is visible in either type of imagery except at the wider portions near the river mouth. On the RS-14 imagery, temperature differences

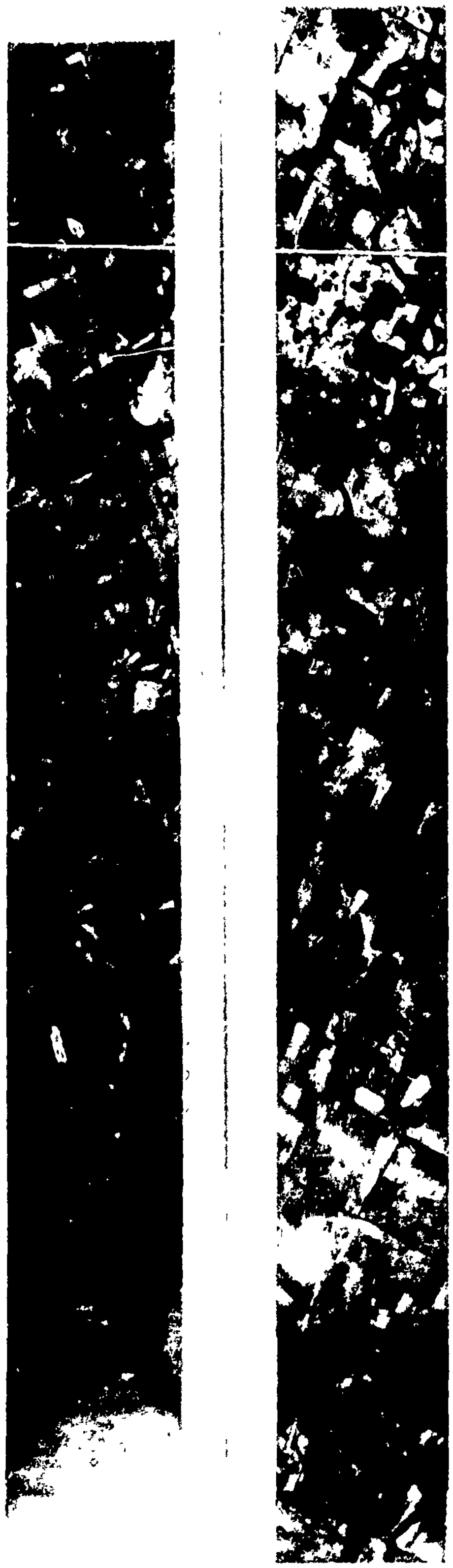


Figure 6. RS-14 Imagery of the Manitowoc River (negative rendition).

attributed to the mixing of cooler lake water with that of the river can be detected as a gradual shading from the harbor area to approximately one mile upstream. This differentiation is not observable in the color infrared imagery. An indication of a warm signature resulting from sewage plant effluent is visible near the harbor entrance on the RS-14 imagery but not on the imagery from the Zeiss camera. This small plume was readily detectable, however, on color infrared imagery acquired by the investigators at an aircraft altitude of 5000 ft two months (7 May 1974) prior to this flight.

Details of drainage and apparent soil moisture differences are as evident as those on the color infrared photograph used for comparison. Agricultural land use patterns, such as differentiation of field boundaries, roads and other cultural patterns, are readily apparent on the RS-14 imagery. Apparent differences in surface materials on roads were noted on the RS-14 imagery but not on the color infrared. The RS-14 imagery of the urbanized area of Manitowoc displayed considerable detail, particularly street patterns and large building structures.

A section of the Fox River between Neenah and Menasha is shown to illustrate the clarity of wetlands delineation on the RS-14 imagery (Fig. 7). A black and white reproduction of an RC-8 color infrared image of the region is also shown to provide a geographic reference. The warm shallow water within the wetlands and in a small stream entering the wetland area provide detail generally not available on photographic imagery.

The analysis of the RS-14 thermal imagery, as compared to color infrared photographic imagery, indicates that many of the patterns displayed on the thermal imagery are readily detectable on photographic imagery, especially color infrared emulsions. In cases where relative temperature information is desired for a land or water surface, there is no substitute for the thermal scanner, but, for most purposes, sufficient information can be obtained much more economically with aerial photography. For instance, the photographic identification of effluents in water bodies can be done whenever the effluent enters a water body with a different turbidity or color. There were few cases where effluent plumes identifiable on

a. RS-14. b. RC-8.

Figure 7. RS-14 and RC-8 imagery of the Fox River between Neenah and Menasha.

on the RS-14 imagery did not create an identifiable signature on either high altitude color or color infrared imagery. In the study area, color infrared and/or color imagery acquired at a similar scale to the thermal imagery could be used to locate most types of effluents. However, details of the plumes, such as the size and concentration within mixing zones, would be far better depicted by thermal imagery.

Conclusions. Although much detail on land use patterns is portrayed in the thermal imagery, its application in a mapping program should be limited to a few specialized areas. For general mapping efforts the low resolution, narrow field of coverage, lack of geometric control and high expense preclude the use of thermal imagery. For specialized applications, however, the thermal scanner may be the only feasible sensor; for example, the delination of impervious areas within a city, or differentiation of small drainage patterns within a wetlands area must be done with a scanner.

PMIS imagery

On 31 May and 24 June 1973, the NASA NP-3 aircraft flew the RS-14 infrared scanner and the passive microwave imaging system (PMIS) over the test area. The PMIS is a recently developed sensor which has not been tested for many potential remote sensing applications. A variety of microwave sensors have been used to measure parameters of water or ice surfaces, and several federal agencies have sponsored successful research on determination of sea state, water surface temperature, water salinity, oil pollution of water surfaces, and sea mapping.

PMIS system characteristics. Passive microwave systems do not provide their own energy source. These sensors respond to the energy emitted and reflected from surfaces scanned by the sensor. The sum of these types of energy constitutes the brightness temperature of an object. Emitted and reflected energy have an inverse relationship, with their sum being equal to one. Thus, objects which are good reflectors of energy, such as metal roofs and areas of concrete, are generally poor emitters of energy – and vice versa.

The greater variance of reflectivity in any given area, as opposed to variance in emissivity, causes reflected energy to make up the major portion of a microwave signal recorded during daylight hours. Nighttime imagery records mostly emitted energy. This variance in reflection and emission causes the differences perceivable on the imagery. According to the *Earth Observations Aircraft Remote Sensing Handbook* prepared by NASA (1972), the airborne PMIS gathers brightness temperature data (10.69 GHz, in kelvins) from two scanning antennae, one for vertical polarization and one for horizontal polarization. Black and white images on a video monitor and digital magnetic tapes are generated aboard the aircraft.

The imagery supplied for evaluation in this study was a computer-processed false color rendition of the scene scanned by the PMIS, each color representing a temperature range of about 4 K. A total of 64 colors were used. A computer printout of the area represented by the color transparency was supplied with the temperature for each footprint (color segment) given.

The PMIS imagery was acquired on a single flight line of the NASA NP-3 aircraft at an average altitude above the terrain of 4300 ft. The flight line was centered on the Fox River, which drains Lake Winnebago and discharges into Green Bay about 40 miles to the northeast. The land use patterns along the Fox River covered by the PMIS swath include most of the land use categories to be found in the eastern Wisconsin test area and form a good basis for examining the applicability of PMIS imagery to patterns in the Great Lakes region. Recent studies conducted at the University of California, Santa Barbara, have suggested that passive microwave imagery could be useful for general land use mapping.

The PMIS system was found in this study, however, to have severe limitations as a remote sensing tool for land use mapping. These limitations include low resolution and small area coverage. The

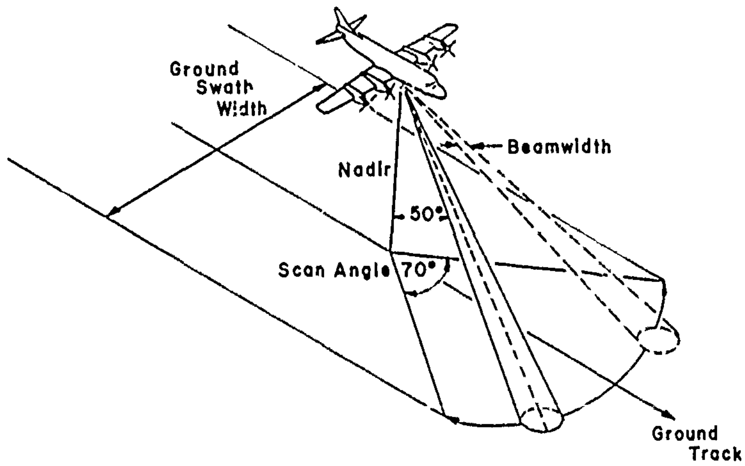
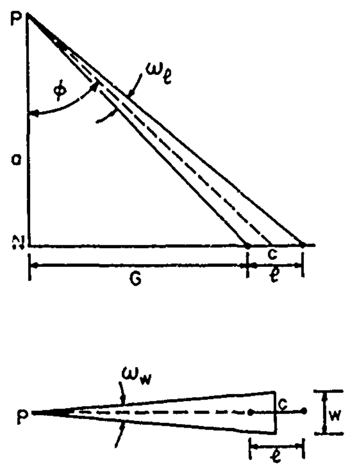


Figure 8. PMIS scanning geometry (diagrammatic).



P = location of aircraft (scanner)
c = ground position, or center of scanner's field of view
a = altitude of aircraft above that of footprint
N = nadir of aircraft at elevation of footprint
G = horizontal distance from N to near edge of footprint along Nc
$= a \tan(\phi - \theta/2)$
$= 1.118a$
ℓ = horizontal length of footprint in direction of Nc
$$= a\left[\tan\left(\phi - \frac{\theta}{2}\right) - \tan\left(\phi - \frac{\theta}{2}\right)\right]$$
$= 0.108a$
$\phi = 49.5°$
ω_ℓ = vertical angular field of view = 2.6°
ω_w = horizontal angular field of view = 1.6°
$\overline{pc} = a \sec 49.5° = 1.539a$
$$w = 2\left(\overline{pc} \tan \frac{\omega_w}{2}\right) = 0.0430a$$

Figure 9. PMIS scanning geometry, and formulae for footprint determination.

scanning geometry of the PMIS system is shown in Figure 8, and the formula for determining the size of the PMIS footprint is shown in Figure 9. Applying the formula to the imagery evaluated in this report, the following dimensions are obtained: footprint length, 464 ft; footprint width, 185 ft; aircraft nadir to footprint, 5035 ft. It is interesting to note that from an altitude of 4300 ft the PMIS footprint size is slightly narrower but considerably longer than the 264-ft circle which composes a single unit (pixel) for the ERTS multispectral scanner from an altitude of 496 miles. The PMIS imagery evaluated has somewhat less resolution than the satellite MSS sensor.

Several interpretative approaches were used in the evaluation of the PMIS imagery. The initial approach was to visually match the major patterns of the PMIS imagery with those seen on Aerochrome IR transparencies and black and white prints of the study area. A Bausch and Lomb Zoom Transfer Scope (ZTS) was used to match the scales of the imagery for visual comparison and interpretation. It was anticipated that major patterns identified on the photography as forest or agricultural land, or as residential or industrial areas, would correlate with the microwave imagery.

Table II. Typical PMIS signatures.

Temperature range (K)	*Polarization*	*Interpreted phenomena*
50-82	Vertical	
	Horizontal	
83-122	Vertical	
	Horizontal	Water, agricultural land
123-226	Vertical	Water, wetlands, industrial areas (metal roofs)
	Horizontal	Water, wetlands, residential areas, industrial areas (metal roofs)
227-258	Vertical	Boat berths, residential areas, industrial areas (metal roofs), agricultural areas, heavily vegetated areas, isolated metal-roofed buildings, trailer parks, bare soil areas
	Horizontal	Residential areas, industrial areas (metal roofs), agricultural areas, heavily vegetated areas
259-300	Vertical	Industrial areas, residential areas
	Horizontal	Residential areas

It was not possible to identify the major patterns on the PMIS imagery. The only dependable pattern agreement was with the land-water boundaries representing the Fox River and the shore of Green Bay. In some cases other kinds of differentiation could be observed, for instance, the boundary between the central business district in the city of Green Bay and the established residential areas with many trees. Wet areas and small ponds produced a distinctive signature on the PMIS imagery and could be compared to the photo record for shape and size. However, such relationships were not consistent from place to place, and pattern interpretation based on the PMIS imagery without conventional photography as ground truth was not feasible.

An attempt was made to correlate the PMIS computer printouts to color transparencies. A direct correlation could not be made, and in many cases, a unique footprint shown in the color transparency could not be located on the digital printout for the corresponding scan line. Nevertheless, it was possible in most cases to correlate a particular cultural or natural feature as shown on the color infrared with outstanding footprints on the PMIS imagery. A summary of interpreted relationships is shown in Table II. Possible causes of problems in correlation are: 1) individual scan lines are not properly synchronized with the computer printout, 2) the imagery may show unique segments when the brightness temperatures do not change significantly, or 3) the time index printed on the imagery or the time indication on the computer printout may be incorrect. The best method of evaluation was a simple visual comparison of the PMIS imagery to conventional photography.

Evaluation of PMIS imagery. The particular PMIS computer imagery evaluated in this project did not provide satisfactory results for the purposes of investigating land use. Wetlands were visible on the imagery, but the possibility of confusing such terrain with various other phenomena that produce similar tonal signatures was too great to be overlooked. One cluster of buildings would appear as a white or pink area on the imagery, while a similar group of adjacent buildings would not be represented at all. Of two adjacent ponds of similar size, one would be visible and the other not shown. On the basis of color or tone signature, heavily vegetated areas could not be separated from residential or industrial areas. In some cases, land could not be distinguished from water on the microwave imagery. Some roofs showing white on the imagery could be mistaken for ponds, as water also may be white on the imagery. This type of identification problem dominated correlative attempts based upon color and tone on the PMIS imagery.

Figure 10. Comparison of high-altitude color infrared imagery (a) with PMIS imagery (b).

With regard to possible practical applications of the PMIS as a remote sensing tool in the eastern Wisconsin test area, it would appear there are severe limitations, especially for terrestrial applications. These limitations include low resolution, small area coverage, difficulties of scan line identification, and problems with numerical correlation of the colors represented on the imagery. This negative evaluation did not, however, apply to the traditional applications of passive microwave sensors which are primarily related to water surfaces.* The few areas of wetlands or fill were for the most part detectable. A comparison of PMIS imagery with RC-8 photographic imagery is shown in Figure 10. The scale of the PMIS imagery in Figure 10 is slightly smaller in its long axis compared to the RC-8 photographic image, so that comparable points do not register exactly left and right. Although both originals were in color, this black and white reproduction provides considerable information on signature comparability. The major water bodies, Green Bay and the Fox River, are easily defined in both types of imagery. The residential areas (point 4, Fig. 10) appear as a warm (dark) signal in the PMIS, probably due to dense tree growth. The central business district of Green Bay (point 2) gives a mixed signal. The arc of cold (light) signals just below this point is an error, due to a tilt of the sensing aircraft at this point. Paper mills (point 3) provide a cold PMIS signal, and are highly reflective in the photographic wavelengths.

For land use mapping and other terrestrial applications in the eastern Wisconsin test area, the PMIS does not appear to be a practical tool. The only clear advantage it has over other available sensors is that imagery can be acquired under adverse weather conditions. Although more detailed processing at the PMIS ground data station and imagery acquired at a lower altitude would provide more detail, it appears unlikely that the PMIS could provide data for land use mapping comparable, for most practical applications, to either thermal scanning or photographic sensors.

LAND USE ANALYSIS

The initial step in the land use analysis portion of this study was to determine mapping criteria which would permit a quantitative comparison to water quality measurements. Most urban and many agricultural point sources can be directly related to a potential for pollution, but meaningful areal measurements cannot be obtained. Although changes in number and types of point sources will occur as land use patterns evolve, the size of the site or land area occupied by a typical point source is not directly related to the intensity or type of pollution. The development of a data base for land use/water quality comparisons was, therefore, restricted to land use categories that lend themselves to area measurements rather than enumeration of point sources. This investigation was then focused on the regional relationship of land use categories to sediment loading in streams.

The USGS Land Use Classification System was selected for use in this investigation. The benefits of this system are described (Anderson et al. 1972) as:

> The classification system utilizes the best features of existing widely used classification systems to the extent that they are amenable to use with remote-sensing, and it is open-ended so that regional, state, and local agencies may develop more detailed land use classification systems, at third and fourth levels, to meet their particular needs and at the same time remain compatible with each other and with the national system.

An outline of the system is shown in Table III. This system is adaptable to three levels of organization. Levels I and II are readily mapped from most types of aircraft photography and require a minimum of ground truth data for verification. The only extensive ground truth needed would be that required for some level III land use mapping. Level II mapping was accomplished on a small area

* The use of PMIS for the differentiation of soil moisture was not sufficiently tested, due to the uniformity of soil type within the Fox River valley.

primarily to compare content and efficiency of mapping from ERTS-1 vs high altitude aircraft imagery (Haugen and Splett 1974). The only level III* categories utilized were to differentiate between open agricultural land and that with a cover crop.

For land use mapping, the color infrared imagery was primarily acquired from the RC-8 camera (6-in. lens), with an approximate scale of 1:120,000. (Although Zeiss 1:60,000 photography provided the greatest detail, mission restrictions precluded complete area coverage with this camera.) The RC-8 color infrared transparencies were contact printed to obtain black and white negatives and were enlarged to a print scale of 1:63,360 for use with acetate watershed outline maps prepared from USGS 15-minute topographic maps. Interpretation was done directly on the acetate overlays. These 9-x 9-in. color transparencies were placed on a nearby light box for constant reference during the mapping on the black and white enlargements.

Analysis of 1972 imagery

The East and West Twin River watersheds were selected for the initial mapping effort because the photography showed obvious color-density differences between the two streams, which suggested apparent variations in sediment load. The object was to correlate the apparent changes in sediment load to land use. Since the 1:120,000 color infrared imagery provided the greatest amount of information on land use differences, it was used for land use interpretation. Basic details such as roads, streams and watershed boundaries were transferred directly from the base map to an acetate overlay with predrawn linear features to provide control for distortions on the black and white photo enlargements. Colors were chosen for the manuscript map, based on their optical density, to allow measurement of areas through color densitometer planimetry. The photo base map and the manuscript land use map are illustrated in Figures 11 and 12. Unfortunately the colors most suitable for color densitometry do not reproduce well in black and white photography, so that the categories are difficult to discern in the illustration.

The instrument used was an Antech model A-12 densitometer, which consists of a black and white TV camera especially modified for uniform sensitivity across its entire scan area, a color TV receiver, and an electronics package including a digital planimeter. The instrument converts density levels into different voltages which are then displayed as discrete colors and/or numerical values. The range of density values examined is adjustable, and the assignment of specific colors to given density values is operator-controlled. A "color window" feature permits the analysis of a variable-size square or rectangular area within the scanned area. The planimeter feature provides a direct readout of the proportion of the window in a given color or density level. Using the densitometer planimetry method, 97-99% accuracy is achieved, provided the initial mapping is correct.

The color window must be calibrated to correspond to a known area on the acetate or base map. Since the mapping was done at a scale of 1 in. = 1 mile, a grid network (Fig. 13) representing 16 in.^{2} on the base map, or about 10,240 acres on the ground, was established. This block size was selected because it yielded maximum results in terms of accuracy and size measurement. The grid was applied to the Twin Rivers watersheds and the resulting measurements are indicated in Tables IV and V.

In the above analysis an experiment was accomplished by using the color densitometer to measure land use areas directly from the color and color infrared imagery. Color filters were employed to emphasize tonal patterns and to vary contrast differences indigenous to the imagery. The obvious advantage of this procedure is that manual mapping of land use is eliminated and data for comparison to stream sedimentation and other water quality measurements can be obtained directly. Also, maps of land use can be compiled by simply photographing the individual sections on the densitometer screen.

---

* The level III classification in this system is used to further subdivide level II categories. The choice of categories within level III is made by the investigator to fit the objectives of his study.

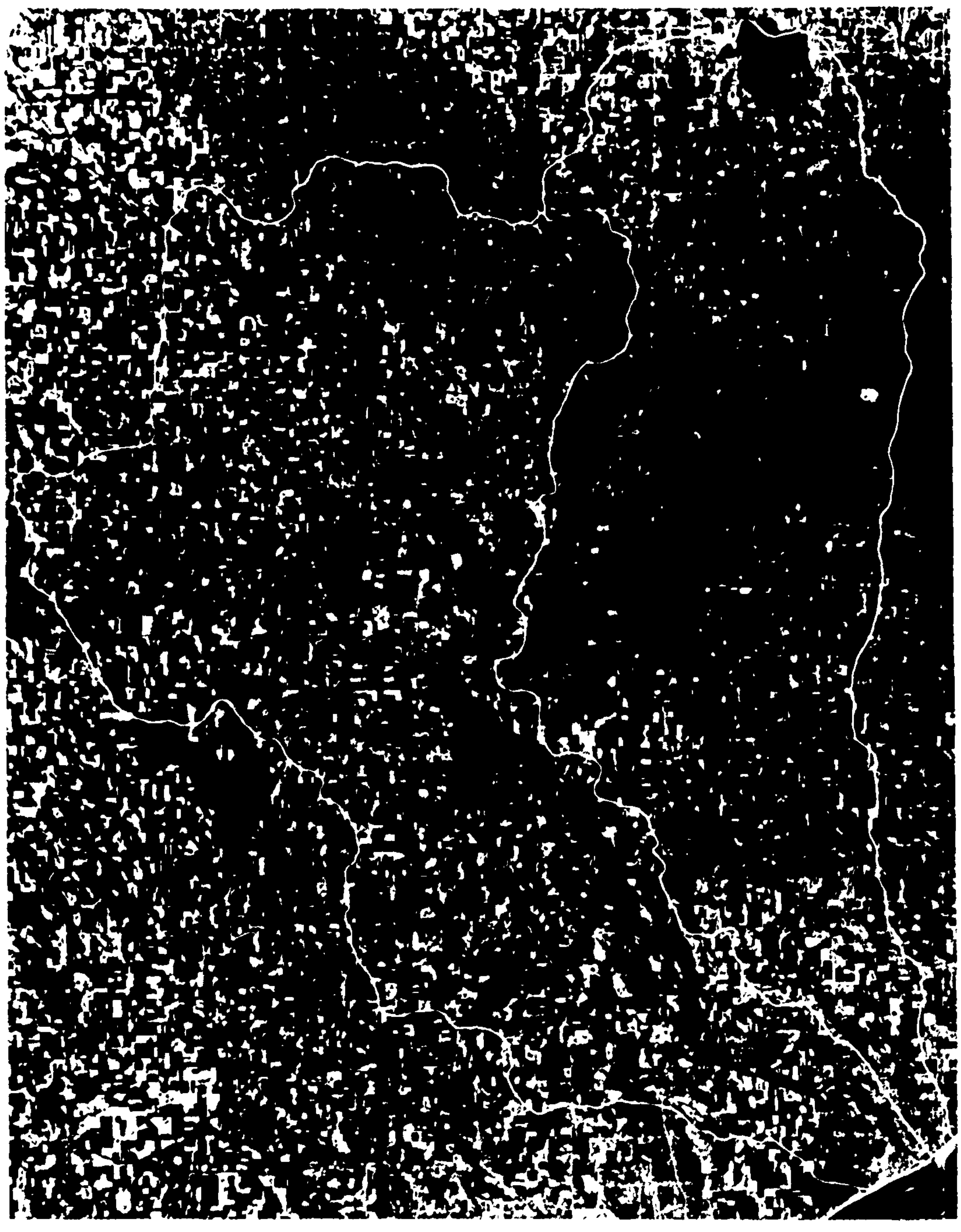


Figure 11. Photo base map with watershed outlines of East and West Twin Rivers.

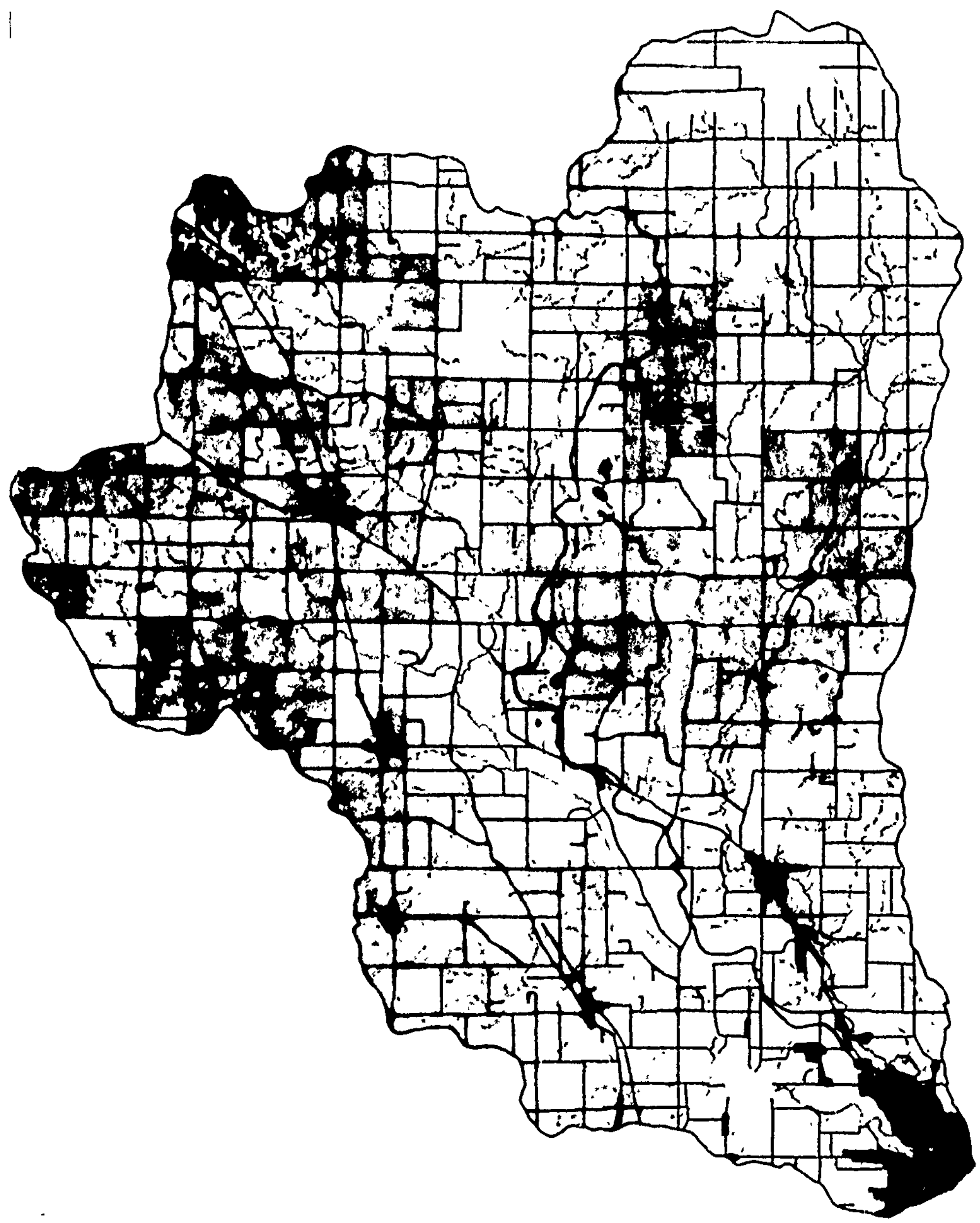


Figure 12. Black and white reproduction of manuscript land use map.

The direct measurement of land use areas from the photography proved to be feasible only for limited areas. Only those areas with light-toned soils provided sufficient color density contrast between open fields and vegetation. Other land use categories, notably forests and roads, almost always could be distinguished and directly measured. However, the method was not considered feasible because all level I categories could not be measured exactly from place to place within watershed areas.

The next approach to land use mapping involved hand-colored overlays on frosted acetate, but with three important differences from the original effort on the Twin Rivers watersheds. First, a subcategory was created to distinguish "open" agricultural land, essentially areas of bare soil where crops had not yet reached sufficient density (maturity) to produce a signature on the color infrared

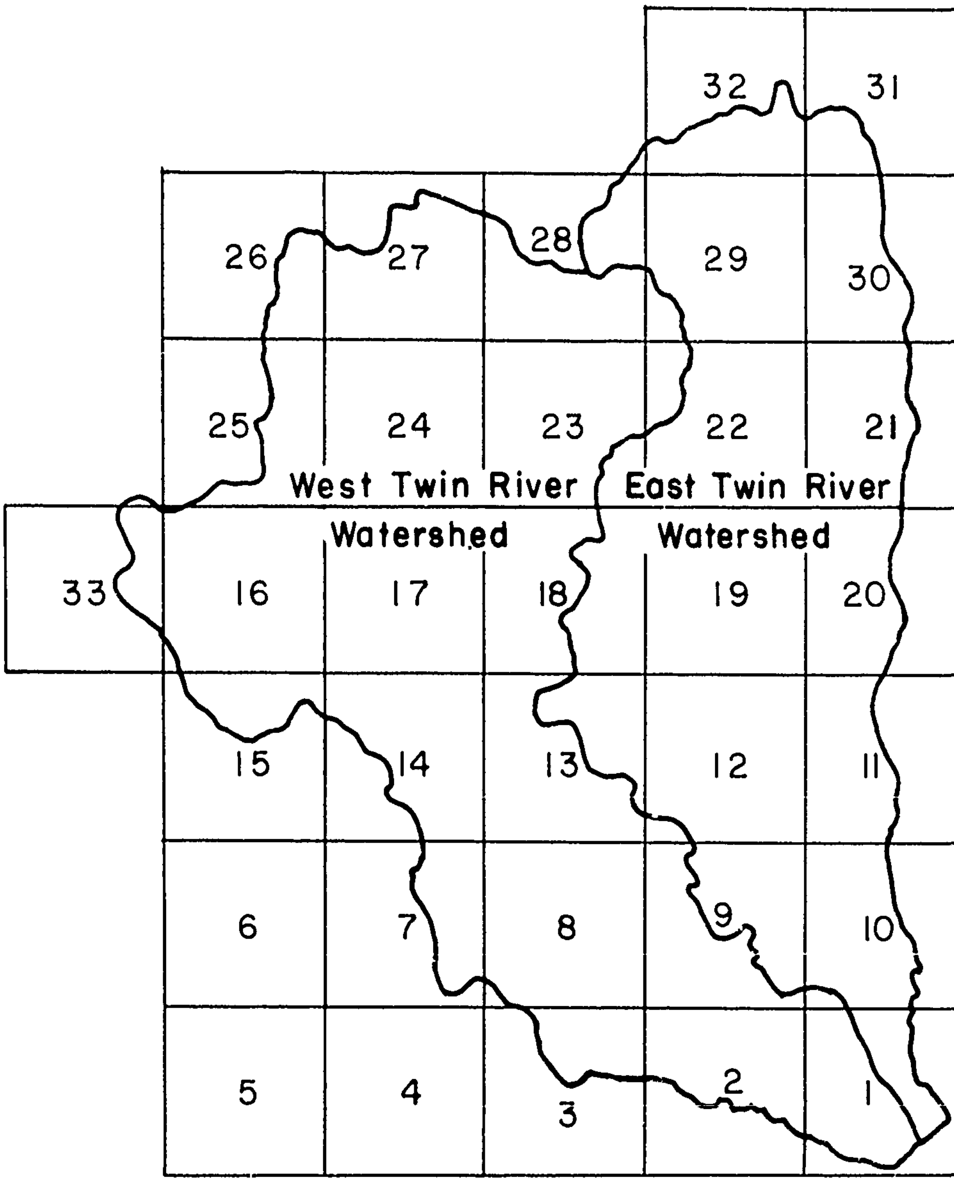


Figure 13. Grid used for densitometer measurement.

imagery. (All other agricultural land was designated as "closed.") Open land, being more subject to erosion, would contribute more directly to turbidity differences in streams. The turbidity differences were apparent in the imagery and could be measured by the analysis of water samples. Secondly, this mapping effort was done directly on an overlay of the 1:120,000 color infrared imagery. The geometric control originally provided by USGS base maps was not believed critical to the measurement of land use areas. The smaller scale, together with the procedure of mapping directly from the color infrared imagery, was considerably faster. The third difference was the production of a strip map which furnished a sampling of land use units representative of the watershed area. Two grids – one with two square miles, and one with eight square miles – were prepared for equal sampling to include at least one mile on each side of the stream. The small grid square was used where the stream was more or less straight; the larger grid was used where streams bifurcated or where major curves were encountered.

Table III. Land use classification system for use with remote sensor data.

Level I	*Level II*
01. Urban and built-up land	01. Residential
	02. Commercial and services
	03. Industrial
	04. Extractive
	05. Transportation, communications and utilities
	06. Institutional
	07. Strip and clustered settlement
	08. Mixed
	09. Open and other
02. Agricultural land	01. Cropland and pasture
	02. Orchards, groves, bush fruits, vineyards, and horticultural areas
	03. Feeding operations
	04. Other
03. Rangeland	01. Grass
	02. Savannas (palmetto prairies)
	03. Chaparral
	04. Desert shrub
04. Forest land	01. Deciduous
	02. Evergreen (coniferous and other)
	03. Mixed
05. Water	01. Streams and waterways
	02. Lakes
	03. Reservoirs
	04. Bays and estuaries
	05. Other
06. Nonforested wetland	01. Vegetated
	02. Bare
07. Barren land	01. Salt flats
	02. Beaches
	03. Sand other than beaches
	04. Bare exposed rock
	05. Other
08. Tundra	01. Tundra
09. Permanent snow and icefields	01. Permanent snowfields and icefields

Two watersheds were mapped and measured using this procedure, the Oconto (1060 square miles) and the Manitowoc (557 square miles). The Oconto, located in the northern part of the test area, is in a predominantly forested area with few apparent sources of aquatic pollution. The Manitowoc watershed had a proportionment of land use categories typical of the eastern Wisconsin test area. Measurements of land use areas for the Oconto and Manitowoc watersheds were determined by use of the strip mapping method. This technique resulted in a mapping area approximately one-third of the total watershed.

Table IV. Area of land use types, East Twin River watershed (84,697 total acres).

Measured block (Fig. 13)	*Forest* %	*Forest* Acres	*Urban* %	*Urban* Acres	*Agriculture* %	*Agriculture* Acres	*Other** %	*Other** Acres	
1		471		1301		860		72	
10		1608		184		4413		420	
9		850		522		2775		102	
13		503		0		1577		123	
12		2826		0		6093		317	
11		993		0		3052		358	
20		922		358		4547		287	
19		3686		10		5642		481	
18		707		0		2028		225	
23		236		0		358		10	
22		2458		0		5673		113	
21		1782		0		5243		277	
30		1341		0		4024		440	
29		3389		0		5335		543	
28		348		0		778		51	
32		1065		0		635		307	
31		266		0		297		113	
Totals	28	23,452	3	2375	64	53,330	5	5,257	84,697

* This category includes watershed boundary lines, roads, rivers, etc.

There is a bias in the use of strip mapping for measurement of land use categories within a watershed, because land use within two miles of a stream is not necessarily representative of the proportions of land use within the entire watershed. However, for purposes of studying the relationships among land use practices, stream sedimentation and other water quality measurements, it can be argued that the resultant data from this procedure are pertinent.

Analysis of 1974 imagery

Several changes in the mapping approach were made, based on experience gained in utilizing the 1972 imagery for the mapping effort described above. Instead of using colors on a single overlay map as in the initial procedure, greater measurement accuracy could be achieved with the densitometer/planimeter by delineating land use with black ink on separate overlays for each category. Although mapping with colors is the more rapid method, boundaries are not as distinct and measurement with the densitometer is more difficult. This is due to the unavoidable density differences in the colored patterns on acetate and also to the similarity of color densities.

The East Twin River watershed was selected as a test area for this mapping approach. This watershed is small (approximately 131 square miles) compared to the Oconto and Manitowoc watersheds, and water samples were obtained at several locations along the East Twin River. The 1974 color imagery was used to prepare a black and white photographic base map at a scale of 1:63,360. The 1974 color infrared imagery was overexposed and could not be utilized for enlargement.

Five acetate overlay maps were prepared for the East Twin River watershed at a 1:63,360 scale representing agriculture (open), agriculture (closed), forest, urban, and water. This total watershed map provided an accurate basis for evaluation of previous and future mapping techniques. A reproduction of the base photo map together with overlay for agriculture ("open") is shown in Figure 14.

Table V. Area of land use types, West Twin River watershed
(106,205 total acres).

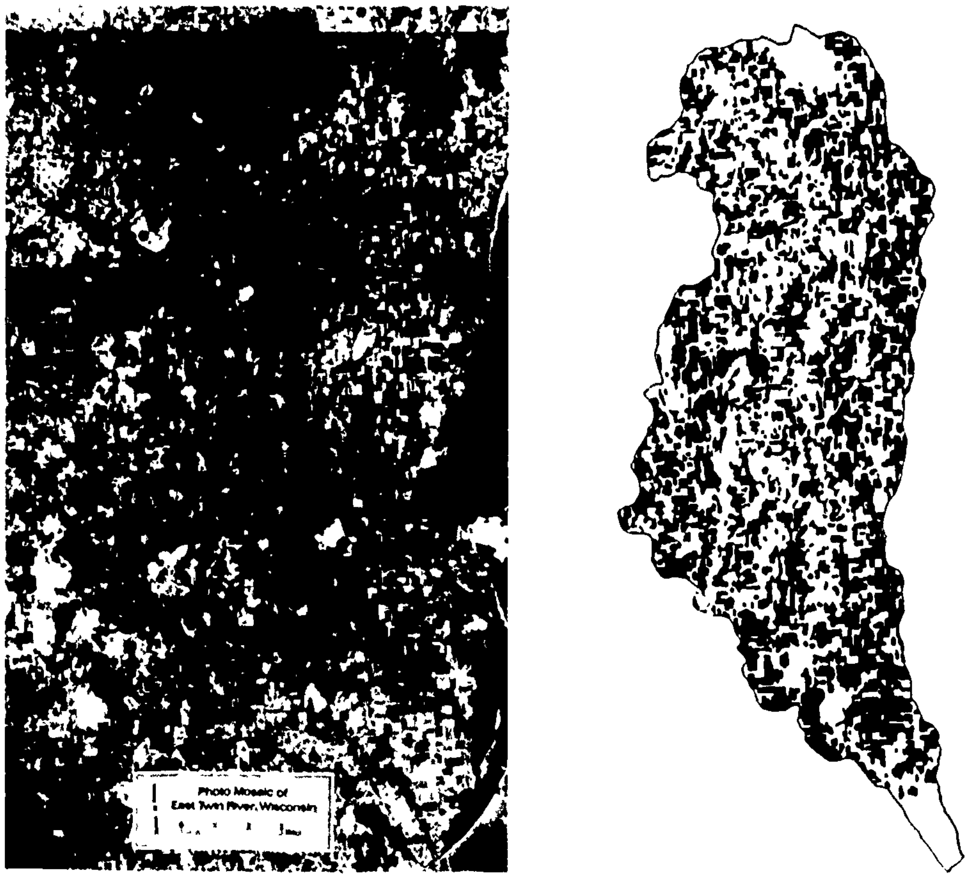
Measured	*Forest*		*Urban*		*Agriculture*		*Other**		
block	*%*	*Acres*	*%*	*Acres*	*%*	*Acres*	*%*	*Acres*	
1		1608		1638		1556		625	
2		1925		430		4076		358	
3		922		0		2252		717	
7		696		287		2396		819	
15		819		0		2488		297	
14		1137		573		6154		225	
8		1751		522		7393		522	
9		655		10		3553		388	
12		614		0		102		10	
13		2990		92		4014		625	
16		1864		0		7905		205	
17		2171		840		6728		317	
18		1475		0		4618		164	
25		666		0		3553		143	
24		1577		0		6738		1034	
23		2488		0		5612		522	
22		20		0		789		0	
28		963		0		1864		92	
29		41		0		133		0	
27		819		369		3717		72	
26		584		0		789		225	
		0		0		92		0	
33		215		0		1382		0	
Totals	22	16,000	4	4761	67	77,904	6	7,360	106,025

* This category includes watershed boundary lines, roads, rivers, etc.

The time required to map an entire watershed at the 1:63,360 scale was too great with regard to the principal objective of obtaining quantitative land use data for several representative watersheds.

Therefore, a second sampling technique was devised and tested for precision against the totally mapped East Twin River watershed. One square mile (one section) was established as the sampling unit. A computer-generated listing of random numbers was obtained to provide a 25% sample for grid matrices of 3x3, 4x4, 6x6, and 12x12 units. The different sizes were necessary to provide a "best fit" when the grids were systematically overlaid on the irregularly shaped watershed. The grid is illustrated in Figure 15. The grids were applied to a watershed mosaic composed of USGS topographic maps. The random numbers, identified as to row and column for each grid, were used to locate the square-mile sample areas. Frequently roads, conspicuous on the imagery, followed section lines. The exact location of a section-sized area was varied slightly from the location indicated by the grid, so as to conform to these boundaries for ease in subsequent mapping. For the East Twin River watershed the 25% sample provided 36 one-mile squares to be mapped.

Measurement was done with the color densitometer as previously described. In this case, two factors contributed to greater measurement accuracy: 1) the color window could be calibrated to conform exactly to the one-square-mile size, and 2) the black ink patterns created only one density level so that the density settings of the instrument remained constant. To verify the sampling method, all East Twin River watershed map overlays were measured using larger grid squares and the results



a. *b.*

Figure 14. Photo mosaic of East Twin River watershed with (a) base map and (b) overlay for agricultural (closed) land.

were .d. These results indicated that the 25% sample was within 8% of the values obtained fre , .otal sample for all categories and within 4% for the majority of categories. The bias experienced with the strip mapping approach was avoided.

For the mapping and measurement of the Oconto and Manitowoc watersheds, the 25% sample approach was also used. Overlay maps were produced from the 1:120,000 color infrared imagery. This imagery, although over-exposed, contained enough detail to permit direct interpretation. Further timesaving resulted from combining the mapped categories on a single sheet of acetate. Seven separate borderless squares, representing each of the categories, were mapped in columnar form on an acetate overlay. This permitted mapping all factors within the section sequentially, and provided a systematic basis for the subsequent densitometer measurement of areas. In this manner, level I mapping of a square-mile section could be accomplished in approximately 7 to 15 min, depending on the number of categories present and pattern complexity. An illustration of these overlays is shown in Figure 16.

SOILS OF MANITOWOC, EAST TWIN AND OCONTO RIVER WATERSHEDS

Assessment of the soils was needed to examine the relationship among land use, soil association and stream sedimentation. The soil information used in this investigation was obtained from soil surveys and maps prepared by the U.S. Department of Agriculture. Details on soil association,

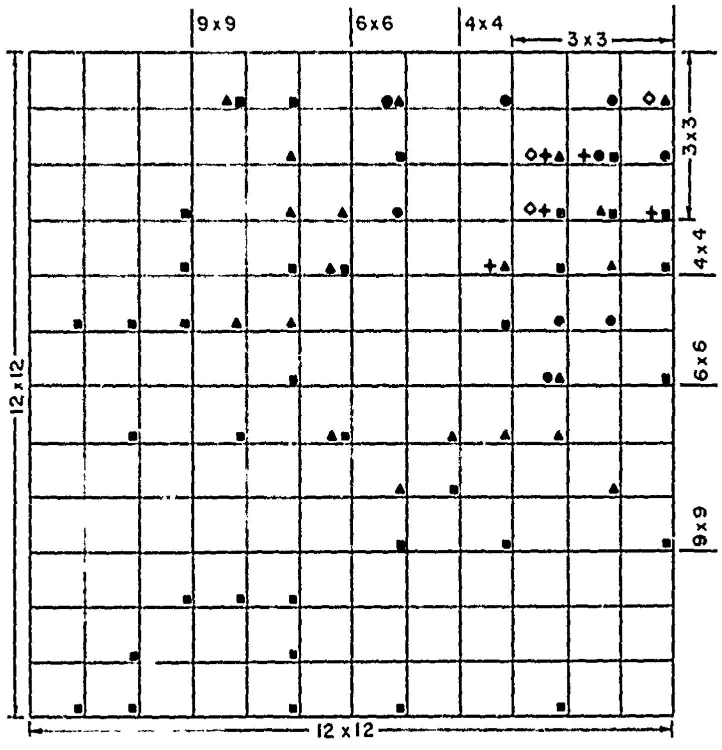


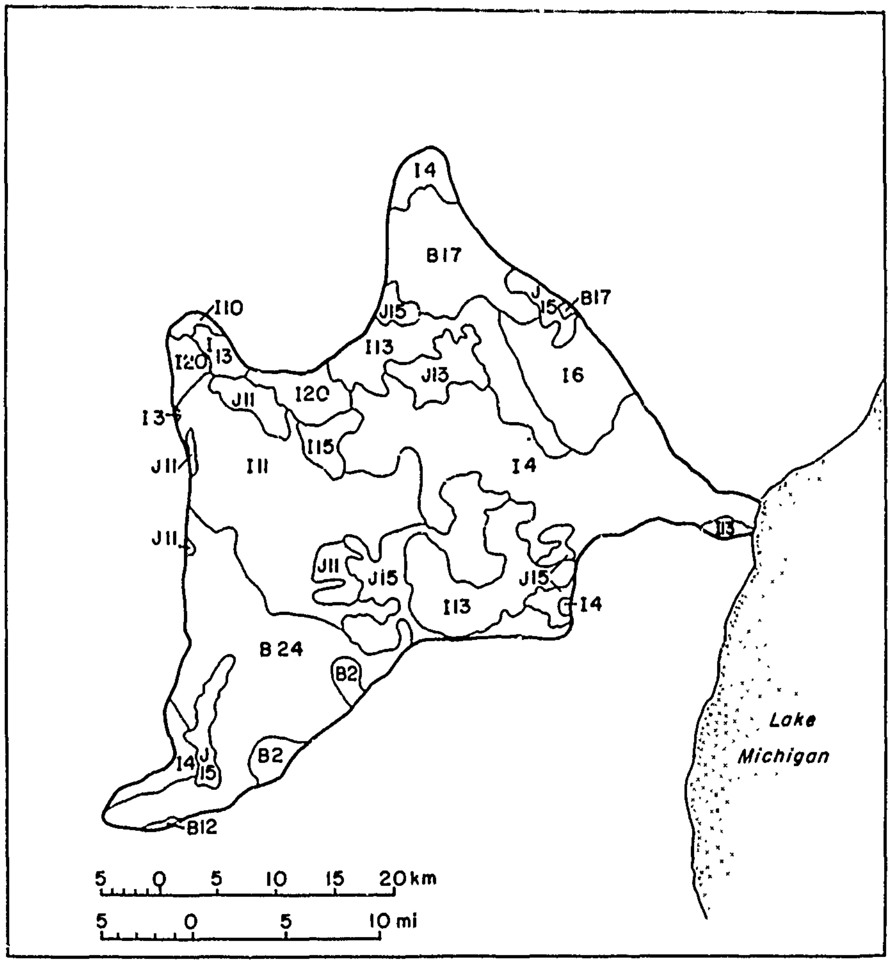
Figure 15. Grid matrices for a 25% random sample of variously sized mapping units.

Figure 16. Example of separate overlay mapping for a single square-mile section. Numbers refer to land use categories.

topography, parent material and classification (according to the 7th approximation) can be obtained from the legend of the Overlay Soil Map of Wisconsin (Wisconsin Geological and Natural History Survey 1968).

Manitowoc River watershed

The approximate percentages of the principal soil groups that occur in the Manitowoc River watershed (Fig. 17) are: soils of the Southeastern Upland (20%), soils of the Northern and Eastern Clayey and Loamy Reddish Drift Uplands and Plains (50%) and soils of the Stream Bottoms and Major Wetlands (30%). The Southeastern Upland soils, developed in loess, sand or loamy till, are located in the headwater area of the watershed. The parent material for the soils found on the Reddish Drift Uplands and Plains is primarily clay and silt. These soils occur in the central and lower reaches of the drainage system on 2% to 12% slopes. The Stream Bottom and Wetland Soils are located throughout the watershed on level plains and are usually poorly drained. The parent materials for these soils are glacial sandy outwash and organic materials, calcareous clayey lacustrine sediments and sandy and loamy glacial drift.



Legend

B Soils of the Southeastern Upland

B 2 - Hochheim, Teresa and Brookston silt loam
B12 - Teresa, Hochheim and Nenno silt loam (rolling)
B17 - Teresa, Onaway, Fox and Salter silt loam and loams
B24 - Teresa, Hochheim and Nenno silt loam (gently undulating)

I Soils of the Northern and Eastern Clayey and Loamy Reddish Drift Uplands and Plains

I 4 - Kewaunee, Hortonville, Manawa and Poygan silt loam and silty clay loam
I 6 - Onaway loam; Teresa, Hortonville, Fox and Casco loams
I10 - Kewaunee, Manawa and Poygan silty clay loam
I13 - Kewaunee, Manawa, Poygan and Hortonville loams and silt loams Tustin loamy sand
I15 - Kewaunee, Kolberg and Manawa silt loam and loams
I20 - Kewaunee, Oshkosh, Manawa and Poygan silty clay loam

J Soils of the Stream Bottoms and Major Wetlands

J 4 - Newton, Plainfield and Morocco sand and loamy sand, and shallow peat soils
J11 - Zittau, Poygan, Poy and Borth loams and silty clay loam
J13 - Raw acid sedge and woody peat soils with thin moss covering. Cable and Freer silt loam
J15 - Slightly acid to alkaline sedge and woody peat and muck soils. Pella, Poygan and Brookston silt loam and silty clay loam

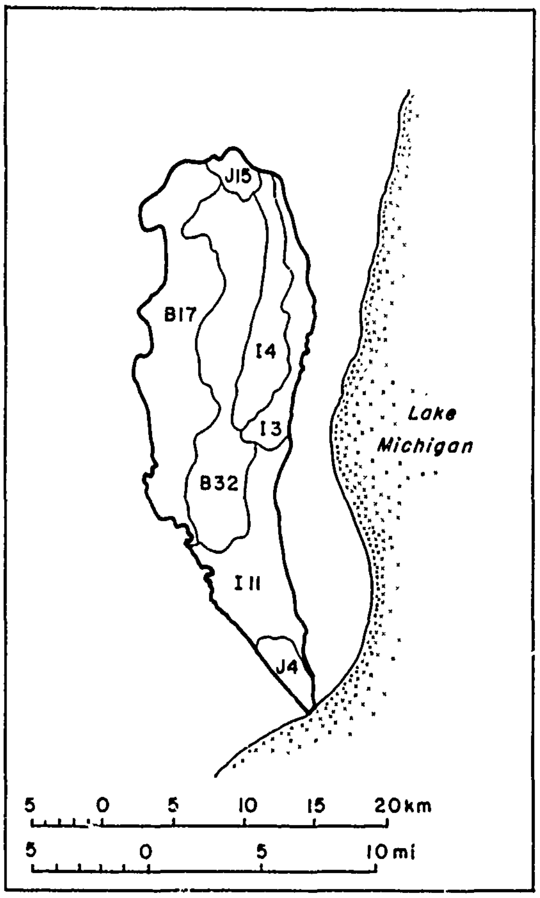
Figure 17. Soil groups of the Manitowoc River watershed.

East Twin River watershed

The same soils groups that appear in the Manitowoc watershed occur in the East Twin River Watershed (Fig. 18), but the percentages differ as follows: soils of the Southeastern Upland (55%), soils of the Northern and Eastern Clayey and Loamy Reddish Drift Uplands and Plains (40%) and soils of the Stream Bottoms and Major Wetlands (5%). The distribution of these soils is similar to that of the Manitowoc.

Oconto River watershed

The Oconto is the largest of the three watersheds and contains the greatest number of soils. The approximate percentages of the principal soil groups (Fig. 19) are: soils of the Southeastern Upland



Legend

B Soils of the Southeastern Upland

B17 - Teresa, Onaway, Fox and Salter silt loam and loams
B32 - Plano and St. Charles (stratified substratum), Warsaw and Fox silt loam

I Soils of the Northern and Eastern Clayey and Loamy Reddish Drift Uplands and Plains

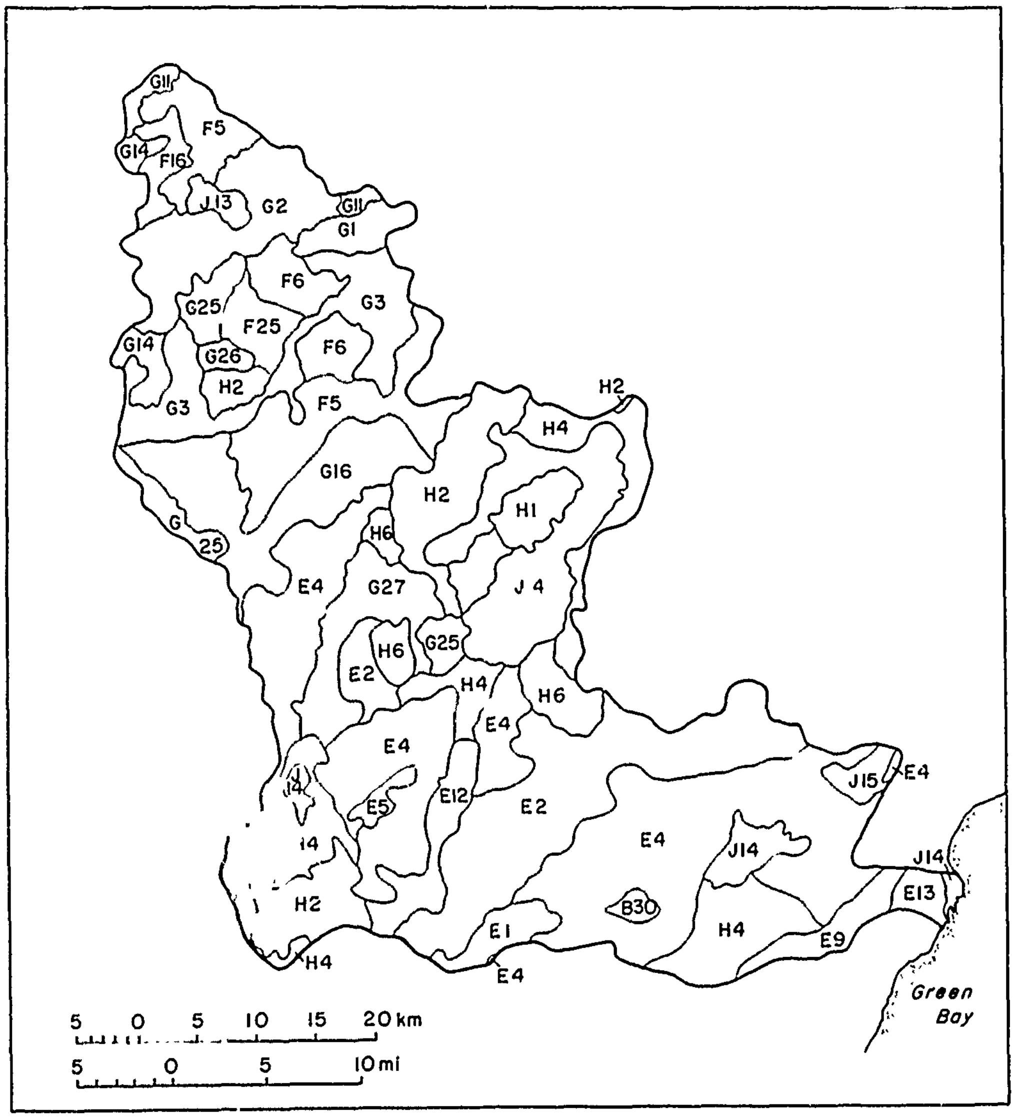
I 4 - Kewaunee, Hortonville, Manawa and Poygan silt loam and silty clay loam
I11 - Kewaunee, Manawa and Poygan silt loam and loams
I13 - Kewaunee, Manawa, Poygan and Hortonville loams and silt loam; Tustin loamy sand

J Soils of the Stream Bottoms and Major Wetlands

J 4 - Newton, Plainfield and Morocco sand and loamy sand; shallow peat soils
J15 - Slightly acid to alkaline sedge and woody peat and muck soils; Pella, Poygan and Brookston silt loam and silty clay loam

Figure 18. Soil groups of the East Twin River watershed.

and Plains (5%), Soils of the Northern Loamy Upland and Plains (22%), soils of Northern Sandy Upland and Plains (17%), and soils of Stream Bottoms and Major Wetlands (7%). Generally the silty and loamy soils occur on moderate to steep slopes in the headwater regions. Coarse-grained deposits are found in the gently rolling and level plain positions in the central portion of the watershed. Finer textured soils (silts and clays) are found in the lower reaches of the river.



Legend

B Soils of the Southeastern Upland

B30 - Fox and Casco loams. Boyer sandy lo.

E Soils of the Northern and Eastern Sandy and Loamy Reddish Drift Uplands and Plains

E 1 - Emmet loamy sand; Onaway loams; Omega loamy sand
E 2 - Onaway and Solona loams; Emmet and Underhill sandy loam Angelica loams
E 4 - Onaway, Underhill, Emmet, Alban and Solona loams
E 5 - Solona, Onaway, Angelica and Wauseon loams
E12 - Shawano, Keowns, Granby and Au Gres loamy sand and sandy loam
E13 - Shawano and Granby loamy sand and sandy loam, peat and muck soils

F Soils of the Northern Silty Uplands and Plains

F 5 - Stambaugh and Goodman silt loam; Padus and Iron River loams
F 6 - Antigo and Norrie silt loam, Onamia and Kennan loams
F16 - Stambaugh silt loam Padus and Iron River loams, peat soils
F25 - Antigo and Brill silt loam; Onamia loams

G Soils of the Northern Loamy Uplands and Plains

G 1 - Gogebic and Iron River loams, stony, with bedrock outcrops
G 2 - Iron River and Pence loams; Goodman, Monico and Stambaugh silt loam, peat soils; some areas are stony
G 3 - Iron River and Pence loams; Vilas sand, and peat soils
G11 - Iron River, Padus and Pence loams; Vilas sand, and peat soils
G16 - Padus and Pence loams; Omega sand, Stambaugh silt loam, and peat soils
G25 - Pence and Padus loams; Stambaugh silt loam; Vilas and Omega sand
G26 - Onamia and Chetek loams and sandy loam, Antigo silt loam, and peat soils
G27 - Pence sandy loam; Vilas sand, Stambaugh and Padus loams, and peat soils

H Soils of the Northern Sandy Uplands and Plains

H1 - Vilas, Omega and Hiawatha loamy sand and sand, Pence sandy loam, and peat soils
H2 - Vilas, Omega and Hiawatha loamy sand and sand, and peat soils
H4 - Omega and Vilas loamy sand and sand; Pence sandy loam, and peat soils
H6 - Omega and Vilas loamy sand and sand, Chetek and Pence sandy loam, and peat soils

J Soils of the Stream Bottoms and Major Wetlands

J13 - Raw acid sedge and woody peat soils with thin moss covering, Cable and Freer silt loam
J14 - Acid sedge peat and muck soils; Au Gres, Newton and Moroceo sand and loamy sand
J15 - Slightly acid to alkaline sedge and woody peat and muck soils, Pella, Poygan and Brookston silt loam and sandy clay loam

Figure 19. Soil groups of the Oconto River watershed.

WATER QUALITY DATA

Although the primary source of information on water quality throughout the study was laboratory analysis of water samples collected in the field, efforts were also made to derive water quality information by remote sensing means. The initial attempt was the attempt to develop a water color classification based on stream colors observable in the 1972 1:120,000 scale Ektachrome (SO-397) imagery. Some of the shortcomings of this imagery for the purposes of pollution identification have already been discussed. Its small scale, the effects of atmospheric attenuation, and the loss of contrast and detail due to two generations of reproduction (internegative and duplicate positive transparency) of the imagery supplied by NASA all serve to lessen the amount of information which may be derived. It was decided, however, that sufficient color detail and uniformity existed in this imagery to make possible comparisons for land use classification.

Water mass color determinations were done according to the Densitometer-Munsell system of color notation (Rib 1968). This technique permits the determination of the Munsell notation with a transmittance densitometer so that errors involved with matching of color chips are eliminated. The measurements were made with a Macbeth TD-504 Quantalog transmission densitometer, fitted with a custom-made 0.75-mm aperture so that measurements could be made of some of the smaller streams. The instrument is normally supplied with 1- and 2-mm apertures. The measurement technique for each point consists of separate readings through each of four Wratten filters: 106W (visual), 92 (red), 93 (green), and 94 (blue). The raw measurements are converted to Munsell values of hue, chroma, and intensity according to the procedures outlined by Rib (1968).

The feasibility of correlating tonal variations of aerial imagery with turbidity measurements for local areas has been demonstrated (Sherz et al. 1969 and Lillesand 1975). The effort in this study was to attempt a more general relationship that could be applied, on a regional basis, primarily for correlation with agricultural land use. The results of numerous measurements of color signatures of streams throughout the study area indicated that this approach was probably not feasible. Although there was sufficient uniformity of color representation of the major streams within the 1972 color imagery, the color balance of the 1974 imagery of the same locations was completely different. In the comparison of streams where gross differences in the level of turbidity or suspended solids were known to exist (for example, the Fox as compared to the Oconto Rivers), differences could be seen on all the imagery. But in general, it had to be concluded that the representation of stream color in high altitude aerial photography displayed far more variation due to factors other than turbidity in the streams than it did for these parameters.

To provide a more direct basis for comparing water quality parameters to signatures contained in remote sensing imagery, multispectral measurements of reflected and incident light were made in conjunction with water sampling during Mission 235. A non-imaging hand-held four-band Exotech ERTS Ground Truth Radiometer was employed.

Multiple correlation analysis indicated that reflectivity of the streams sampled is related linearly to incident and reflected radiation in ERTS MSS band 5 (Fig. 20). A multiple correlation coefficient R of 0.85 and a standard error of estimate for suspended solids in streams of 3.8 mg/l was obtained. The measurement and estimated values are shown in Table VI. The range of suspended solid concentrations during the test period was low, 2-20 mg/l, but the high correlation with radiated and incident light measurements suggests that the relationship would also exist for higher concentrations of suspended sediment in the streams. Further sampling of a wider range of suspended sediment concentrations with concurrent incident and radiated light measurements would permit the estimation of stream sediment loads based on digital density measurements of remote sensing imagery in the 0.6- to 0.7-μm wavelength for this test area.

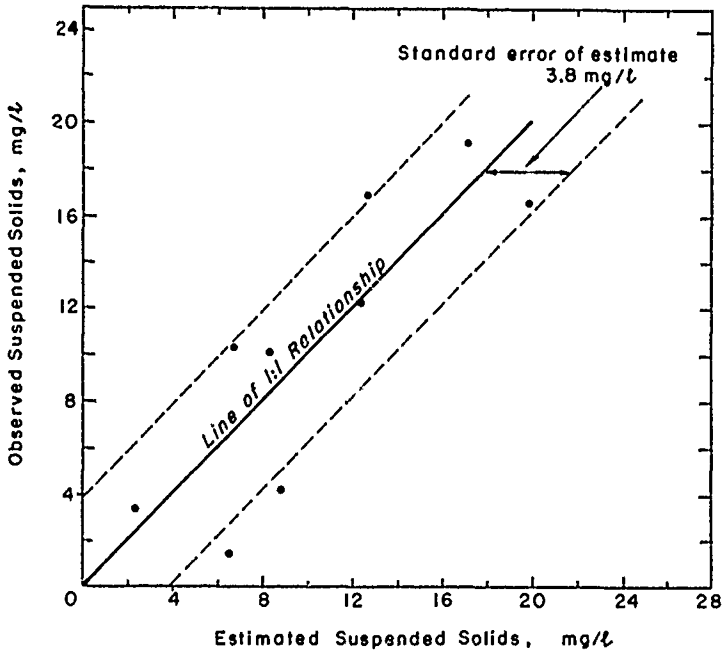


Figure 20. Relationship of ERTS MSS band 5 incident and reflected radiation to measured suspended solids.

Table VI. Comparison of spectral measurements* and suspended sediment load at water sampling sites.

Stream/Sampling site	*Date/ Local time*	*Reflected radiation band* 1	2	3	4	*Incident radiation band†* 1	2	3	4	*Suspended solids (mg/l)* Meas.	Est.**
Oconto River Hwy 141	2 May 1974 1530	0.04	0.05	0.03	0.00	0.30	0.38	0.30	0.34	3.4	2.2
Oconto River Stiles	2 May 1974 1600	0.10	0.12	0.08	0.04	0.30	0.40	0.32	0.36	1.4	6.2
Manitowoc River Clark's Mills	3 May 1974 1120	0.12	0.20	0.10	0.02	0.58	0.70	0.18	0.08	10.3	6.9
Manitowoc River Mill Road	3 May 1974	0.22	0.32	0.18	0.08	0.66	0.82	0.64	0.64	16.9	12.6
Manitowoc River Harbor	3 May 1974 1300	0.30	0.42	0.20	0.08	0.56	0.80	0.64	0.80	16.5	19.2
East Twin River Mishicot	3 May 1974 1330	0.14	0.42	0.14	0.06	0.60	0.74	0.60	0.78	4.1	8.8
Fox River Wrightstown	3 May 1974 1030	0.16	0.24	0.14	0.00	0.16	0.16	0.16	0.60	19.1	17.2
Fox River Green Bay	2 May 1974 1315	0.16	0.20	0.11	0.00	0.28	0.32	0.24	0.28	12.2	12.4
East Twin River Choto	3 May 1974 1500	0.16	0.20	0.08	0.02	0.46	0.60	0.46	0.56	10.1	8.3

*Spectral range of bands: 1 (0.5-0.6 μm); 2 (0.6-0.7 μm); 3 (0.7-0.8 μm); 4 (0.8-1.1 μm).

†Reflectance measurements are based on a 2-mW full scale reading (2 mW/cm^2); incident measurements are based on a 10-mW full scale reading (10 mW/cm^2).

**Estimated according to $y = 4.54+62.5X-14.5X_2$, where y = estimated suspended solids (mg/l), X_1 = reflected 0.6-0.7 μm radiation ($mW/cm^2 \times 5$), X_2 = incident 0.6-0.7 μm radiation (mW/cm^2).

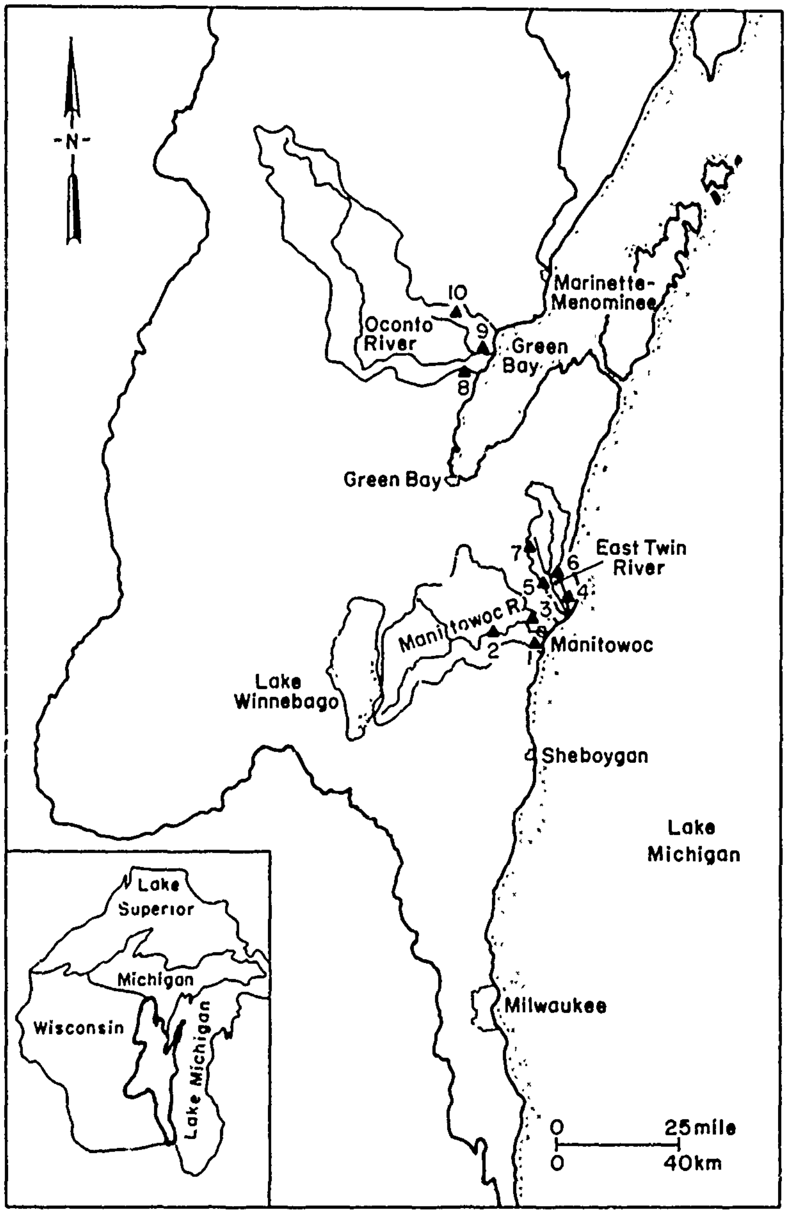


Figure 21. Field sampling sites for suspended solids.

Water samples were taken in June and October 1973 and May 1974 as part of the ground truth for the NASA photo mission. Suspended solids were determined at CRREL according to procedures used by the Wisconsin Department of Natural Resources, Division of Environmental Protection and the U.S. Department of Agriculture. A location map of the field sample sites is shown in Figure 21.

Manitowoc River

The June 1973 Manitowoc River suspended solids data varied from 30 mg/l to 105 mg/l with an average of 70.1 mg/l (Table VII). The total precipitation, measured at local testing sites immediately preceding and during the sampling period, 19-21 June, averaged 0.45 in. (see App. A). During October 1973 the suspended solids in the Manitowoc River decreased to an average of 6.3 mg/l. The samples were obtained on 8 October, and for the six days, 3-8 October, only 0.1 to 0.2 in. of

Table VII. Average daily water quality data: Manitowoc River, June and October 1973 and May 1974.

Sampling site	*Turbidity (JTU)**	*Suspended solids (mg/l)*	*Organic matter (mg/l)*	*Nonorganic (%)*	*Organic (%)*
June 1973					
Clark Mills (2)	43	81.8	25.4	69	31
Mill Road (3)	39	29.8	9.6	69	32
Clark Mills (2)	18	63.4	18.6	71	29
Mill Road (3)	52	105.4	16.2	85	15
		Avg 70.1			
October 1973					
Hwy. 141 (3)	2	5.0			
Harbor (1)	5	7.6			
		Avg 6.3			
May 1974					
Harbor (1)	10	16.5			
Mill Road (3)	10	16.9			
Clark Mills (2)	2	10.3			
		Avg 14.3			

* JTU – Jackson Turbidity Units.

precipitation occurred in the watershed. In May of 1974 the average amount of suspended solids in the river was 14.3 mg/l. For the six days up to and including the sampling date of 3 May the precipitation averaged 0.2 in. The suspended solids data for the same monthly time periods from 1965-1968 indicate the same trend as the data obtained from this study.

East Twin River

Suspended solids determinations were made at four sample sites in the East Twin River (Fig. 20). The average suspended solid concentration from the 21 June 1973 sampling was 35.4 mg/l (Table VIII) and precipitation during the preceding seven days was 0.39 in. The October data were collected on the 8th when the suspended solids averaged 13.0 mg/l and precipitation for 3-7 October was 0.28 in. The May sampling, taken on 3 May, yielded 4.1 mg/l of suspended solids. The precipitation totaled 0.22 in. for the six days from 28 April to 3 May. These data compared favorably with those obtained by the Wisconsin Department of Natural Resources (1965-1968).

Oconto River

The three water sampling sites for the Oconto River are shown in Figure 20. The 19 June 1973 samples yielded an average of 61.9 mg/l of suspended solids (Table IX). The total precipitation from all measuring sites during 14-18 June was 0.15 in. In October 1973 and May 1974 the water samples collected contained very little suspended solids and much of this was in organic form. These data correspond to data taken during similar intervals in 1965-1969 (Wisconsin Dept. of Natural Resources 1968).

Table VIII. Average water quality data: East Twin River, June and October 1973 and May 1974.

Sampling site	*Turbidity (JTU)**	*Suspended solids (mg/l)*	*Organic matter (mg/l)*	*Nonorganic (%)*	*Organic (%)*
June 1973					
Mishicot (5)	12				
Tisch Mills (6)	18	28.6	8.6	70	30
Two Rivers (4)	15	39.6	8.2	79	21
Co. Rd. B (7)	26	38.0	16.4	57	43
Strangeville		Avg 35.4			
October 1973					
Hwy. 42 (4)	20+	22.4			
Mishicot (5)	4	3.7			
		Avg 13.0			
May 1974					
Mishicot (5)	2	4.08			

* Jackson Turbidity Units.

Table IX. Average water quality data: Oconto River, June and October 1973 and May 1974.

Sampling sites	*Turbidity (JTU)*	*Suspended solids (mg/l)*	*Organic matter (mg/l)*	*Nonorganic (%)*	*Organic (%)*
June 1973					
City	24	52.6	9.2	83	17
Hwy. 141	35	71.2	16.8	76	24
		Avg 61.9			
October 1973					
Hwy. 141	2	2.2	1.5	59	41
May 1974					
Hwy. 141	22	3.4			
Stiles	2	1.4			
		Avg 2.9			

LAND USE/STREAM SEDIMENTATION RELATIONSHIPS

The land use maps prepared from the NASA RB-57F imagery for the Manitowoc, East Twin River and Oconto watersheds indicate that the agricultural land composes the majority of the land area in the Manitowoc and East Twin River, 74% and 66% respectively, but only 27% of the land in the Oconto watershed. (The major unit in the Oconto watershed is forest, making up 50% of the landscape.) When these percentages are compared to the suspended solids data taken from the Manitowoc, East Twin and Oconto River watersheds, the results show that as the percentage of agricultural land increases, the amount of sediment in the stream increases (Table X).

Table X. Land use, suspended solid, soils and precipitation data for the Manitowoc, East Twin, and Oconto River watersheds.

Watershed	*Total square miles*	*Agr (open) (%)*	*Agr (closed) (%)*	*Forest (%)*	*Urban (%)*	*Wetlands and water (%)*	*Other (%)*	*Suspended solids average (mg/l)*	*Soil texture*	*Total precip five days preceding mission (in.)*
Manitowoc	505	35	39	17	2	5	2	14.6	Fine	0.2
East Twin	166	36	30	18	5	2	9	4.1	Medium to fine	0.2
Oconto	966	18	9	50	1	16	6	2.4	Coarse	0.1

Supporting data for this relationship also can be found in the soils data. The finer textured soils and the largest percentage of these soils can be found in the Manitowoc watershed. The head-water area of the East Twin contains medium- to fine-grained surface sediment, but toward the mouth of the river there are finer grained soils. However, in the Oconto the soils are primarily developed in sandy and loamy deposits which are very coarse-grained. Also, in this watershed there is a large percentage of organic soil, so that the suspended solids tend to contain a large percentage of organic matter. The Manitowoc River had the largest amount of particulate matter per liter during the test. These data reveal that the Manitowoc watershed has the greatest percentage of agricultural land and the finest textured soils. In contrast, the Oconto has the smallest percentage of agricultural land, the coarsest textured soils and the lowest amount of suspended solids in the stream.

RESULTS AND CONCLUSIONS

The primary focus of this report has been to examine the feasibility of using remote sensing methods to rapidly and economically assess, on a regional scale, the effect of land use as it influences sediment loading of streams. A test area, consisting of several major watersheds in eastern Wisconsin, was selected for the development and evaluation of techniques to achieve this objective.

Sensor evaluation

A variety of aerial remote sensors were applied to the test area for evaluating and developing data pertinent to the assessment of the relationships between land use patterns and the sediment load in streams. By far the most useful imagery supplied by NASA for the investigation was the color infrared photography acquired at 60,000 ft with 9-in. format RC-8 and Zeiss cameras. This combination of sensors was judged to be adequate for any regional scale land use mapping effort to level II of the USGS land use classification, and with appropriate ground truth support, level III detail is feasible.

Sensor evaluation included the following:

High altitude RS-7 thermal scanner. This imagery, acquired during daylight hours at an altitude of 60,000 ft provided a small scale (1:1,000,000) thermal map of much of the study area. General land use patterns could be observed as well as large water circulation patterns in Lake Michigan and Green Bay. The detection and mapping of major circulation patterns in large water bodies would be the primary recommended application for this sensor for high altitude operation.

RS-14 thermal scanner. This imagery, in the 8-14 μm range, was acquired for the Wisconsin shoreline and several watershed areas at altitudes range from 2500 to 3500 ft. It was compared for information content with color infrared photographic imagery obtained during other missions. Analysis indicated that many of the patterns displayed on the thermal imagery are readily detectable on color infrared or color imagery. Recommended specialized applications, however, include monitoring and mapping details of effluent plumes for size and concentration, and differentiation within wetlands or impervious urban settings, or wherever relative temperature information is desired. For general mapping efforts, the lack of geometric control, narrow field of view, and high expense would appear to preclude the use of this sensor.

High altitude multi-spectral 70-mm (Hasselblad) photography. This sensing tool did not provide significant data input for the study. The small 70-mm format is difficult to work with, and the multispectral and color infrared imagery acquired with the Hasselblads did not contain any information that was not more easily obtained from the 9-in. format cameras. Although the acquisition cost of 70-mm imagery is somewhat less than the cost of 9-in. format imagery, interpretation for most purposes is more difficult and time-consuming and would probably offset any economy gained by the lower original cost.

High altitude color (SO 397). This imagery was usable for most purposes of this study, but was surpassed in utility by the 9-in. format color infrared (2443) emulsion. Densitometric determinations of Munsell color equivalents were made at a large number of sample points. The results of this correlation effort were considered indecisive because of: 1) the wide variation in the general color balance of the imagery from flight to flight, 2) the loss of density detail on the duplicate imagery provided by NASA as compared to originals, and 3) the influence of many uncontrollable variables on photographic color, such as the angle and intensity of sunlight and atmospheric haze. It is believed that the method of correlating SO-397 imagery to water quality parameters could be developed to apply to small area, single flight line surveys, but it does not appear feasible for regional area surveys or with high altitude imagery.

PMIS. The PMIS (Passive Microwave Imaging System) imagery was acquired on Mission 235 on the Fox River valley at an altitude of 4300 ft. Because PMIS is a new sensor, and few terrestrial applications have been demonstrated for it, considerable effort was devoted to the interpretation and evaluation of the imagery. Other than land-water boundaries, it was not possible to consistently identify major patterns on a 64 color photographic rendition of the PMIS scanning data. Further, exhaustive attempts to correlate individual segments of the PMIS scan between the computer-generated false color imagery and the digital computer printout provided were unsuccessful, although signatures of individual scan segments could be correlated with photographic color infrared imagery for some types of features (such as large buildings with metal roofs or small impoundments in agricultural areas). Consequently there are severe limitations concerning the PMIS as a remote sensing tool for terrestrial phenomena in a region such as the eastern Wisconsin test area.

Land use analysis

The principal objectives of the land use analysis portion of this investigation were to develop a data base reflecting regional differences within the test area for comparison with stream sediment loading data, and to determine the most efficient and effective approaches to land use mapping based on the imagery provided by NASA.

The USGS Land Use Classification System for Remote Sensing was incorporated because it is widely used, is compatible with most other classifications, and is sufficiently flexible to accommodate specialized applications. Although initial mapping efforts were confined to level I of the system, subsequent mapping incorporated levels II and III to provide more pertinent data on the erosion potential of agricultural land. Following the final mapping, comparisons were made with the earlier strip mapping efforts of the Oconto and Manitowoc watersheds and regional differences were noted. The strip map approach has a built-in bias which can vary, depending upon the land use development history and the nature of the terrain. The application of this mapping approach should be confined to cases where prior information is obtainable on general distribution of land use types within the watershed. A flow diagram of the land use mapping effort is shown in Figure 22.

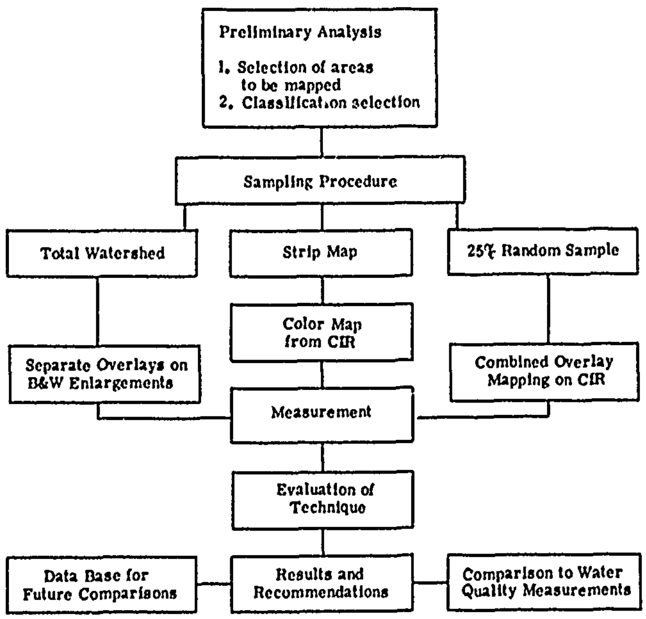


Figure 22. Flow diagram of land use mapping and analysis.

Mapping approaches

Various approaches to the actual mapping of land use were tested, but all incorporated the USGS classification system. The ability to measure mapped areas rapidly was a first requirement for any of the mapping procedures. The measurement device in all cases was the planimeter component of a color densitometer. This required that all mapped categories be distinguishable on the basis of their gray scale density.

The first large watershed map was done in color on frosted acetate and included only level I of the USGS classification. A concurrent attempt was also made to measure land use categories directly from color or color infrared imagery using the densitometric method. This method worked for level I mapping categories only in limited areas with light toned soils.

The second method applied to obtain land use data involved sampling rather than mapping the entire watershed. Colored acetate strip maps were made of two large watersheds, the Manitowoc and the Oconto. The sampling grid was constructed so that the sample included at least one mile of land on either side of any stream. This made up approximately one-third of the entire watershed area.

The third method involved a dual approach; one watershed, the East Twin River was measured first for the entire watershed area and then on the basis of a 25% random sample. The land use of this watershed was mapped in its entirety on six separate clear acetate overlays. The mapping was accomplished in ink to simplify the densitometric measurement and the results of this comparison were that all the major mapping categories (Agriculture Closed, Agriculture Open, and Forest) were within 4% of being equal. Larger differences were noted for categories such as Urban and Water where the area involved was quite small. Based on this comparison, it was decided that for subsequent mapping efforts the 25% random sample approach would provide sufficiently accurate data and result in greater efficiency.

Land use/sedimentation relationships

The analysis of the relationships between stream sedimentation and land use practices indicated that the amount of suspended solids measured from water samples increased with the percentage of agricultural land within the watershed. Soils and precipitation data were also compared to the suspended solids measured for the various streams.

The use of high altitude color or color infrared imagery to characterize sediment loading of individual streams did not appear practical in the quantitative sense. The effects of image duplicating, processing, photo color balance, atmospheric haze, and time of day of the imagery all served to decrease the informational content of the high altitude aerial images. Only major differences among the streams were observable, and these were evident only in some of the imagery. Attempts to measure and characterize stream color differences using the Densitometer-Munsell system of notation (Rib 1968) were not sufficiently consistent to be of value. However, a comparison of multispectral measurements made with a hand-held radiometer in conjunction with water sampling during Mission 235 was successful. A multiple correlation coefficient R of 0.85 was obtained between incident and reflected radiation in the ERTS MSS band 5 (0.6-0.7 μm) and measured suspended solids concentrations in the streams. A trial application of the universal soil loss equation (USDA 1965) did provide estimates of soil loss that correlated with observable and measurable differences in turbidity of the East and West Twin Rivers, but it was apparent that refinement was necessary for the input data to the universal soil loss equation to provide meaningful results for the variety of streams in the test area.

Cost effectiveness analysis

A cost effectiveness analysis was performed on the various land use mapping approaches. The results are summarized in Table XI. The strip mapping approach, using colored pencil on a single acetate overlay of original scale photography, provided the fastest method of obtaining land use measurements. Including analysis, 0.4 hours per square mile was required. For the areas sampled with a 25% random sample and a combined sequential overlay map, 1.1 and 1.3 hours were spent per square mile of sample. The 25% sample of the East Twin River Watershed required slightly more time – 3.2 hours per square mile of sample – because the mapping was done on separate overlays. The results of the cost effectiveness analysis are similar to those shown in a NASA-sponsored study by Vegas (1973), although the mapping objectives were more general than this application.

Table XI. Cost effectiveness analysis (in hours).

	East Twin		*Manitowoc*	*Oconto*	
Area mapped	*25%*	*Total*	*25%*	*25%*	*Strip*
Enlargements	1.5	1.5	2	3	
Overlays	4	4	8	8	
Sampling	8		20	20	16
Mapping					
Separate	29	65			
Combined			120	155	40
Measurement	8	12	30	35	35
Tabulation of data	4	16	20	30	10
Analysis	60	60	60	60	30
Hours/no. of sq mile samples	114.5/ 36	158.5/ 144	260/ 150	311/ 250	131/ 344
Hours/square mile	3.2	1.1	1.7	1.2	0.4

RECOMMENDATIONS AND APPLICATIONS

This investigation has addressed two primary areas of application for remote sensing techniques: 1) the mapping and quantification of land use, and 2) the relationship of land use to stream sedimentation.

The application for land use mapping based on aerial or satellite imagery has been well documented in the literature. Conflicting demands for land utilization resulting from normal economic growth together with many legislative requirements indicate clearly that more data on land use will have to be generated and continually updated. The evaluation of a wide variety of imagery types in this study led to the conclusion that high altitude color infrared imagery was the most universally acceptable for the mapping and measurement of land use types. Based on this imagery a rapid and cost effective approach to the mapping and measurement of land use categories was demonstrated. The basic mapping approach developed in this investigation is now a part of the Corps of Engineers Handbook on *Remote Sensing of the Environment* (Haugen and Splett 1974).

The comparison of land use to stream sedimentation demonstrated that a relationship could be shown based primarily upon data derived by remote sensing means. This type of data is necessary for the prediction of impact on streams and harbors of land use changes within a watershed. Thus, remote sensing techniques can solve a major problem in defining land use-stream sedimentation relationships – the sparseness of published water quality data, especially for streams away from major population centers.

The collection of data on water quality, especially sediment load, could be accomplished quickly and with minimum expense if a data bank were developed which would include incident/reflected radiation measurements with each water sample made. With an adequate sampling over a regional area and throughout a representative range of national conditions, monitoring of stream sediment loads by remote sensing methods could be instituted as a practical and efficient technique.

SELECTED BIBLIOGRAPHY

Anderson, J.R., E.E. Hardy and J.T. Roach (1972) A land use classification system for use with remote sensor data. U.S. Geological Survey Circular 671, Washington, D.C.

Aschmann, H. (1971) Prolegomena to the remote sensing of environmental quality. *The Professional Geographer*, vol. 23, no. 1, p. 59-63.

Barrow, T.L. (1972) Contingency mission plan, Mission 205, test site 311, Lake Michigan (Wisconsin shoreline). NASA Manned Spacecraft Center, Houston, Texas, MSC-05996.

Beeton, A.M. (1970) Statement on pollution and eutrophication of the Great Lakes. University of Wisconsin, Center of Great Lakes Studies, Milwaukee, Wisconsin, Special Report 11.

Conrod, A.C. and K.A. Rottweiler (1971) Water quality measurements with airborne multispectral scanners. Paper presented at the Joint Conference on Sensing of Environmental Pollutants, Palo Alto, California, November 8-10, 1971, AIAA Paper no. 71-1096.

Haugen, R.K. and P.J. Splett (1974) Land use mapping. In *Remote sensing of the Environment*, Office of the Chief of Engineers, Washington, D.C., chapter 5, p. 5-1 - 5-17.

Kelly, K.L. (1958) ISCC-NBS color-name charts. Supplement to Research paper RP2911, Central notations for the revised ISCC-NBS color-name blocks, National Bureau of Standards, Washington, D.C.

Klooster, S.A. and J.P. Scherz (1974) Water quality by photographic analysis. *Photogrammetric Engineering*, vol. 15, no. 8, p. 927-935.

Lillesand, T.M., F.L. Scarpace and J.L. Clapp (1975) Water quality in mixing zones. In *Photogrammetric Engineering and Remote Sensing*, p. 285-298.

National Aeronautics and Space Administration (1971) Remote measurement of pollution. National Aeronautics and Space Administration, NASA SP-285, Washington, D.C.

National Aeronautics and Space Administration (1972) *Earth observations aircraft remote sensing handbook.* NASA.

North, G.W. (1971) Remote sensing of environmental quality. Paper presented at the United Nations International Workshop for Earth Resources Survey Systems. Department of the Interior, U.S. Geological Survey, Washington, D.C.

Rib, H.T. (1968) Color measurements. In *Manual of color aerial photography*, American Society of Photogrammetry, p. 12-24.

Scarpace, F.L. and T. Green, III (1972) The use of a thermal line scanner in the remote sensing of water pollution. The University of Wisconsin Sea Grant Program, Madison, Wisconsin, Technical Report 13.

Scherz, J.P., D.R. Graff and W.C. Boyle (1969) Photographic characteristics of water pollution. *Photogrammetric Engineering*, vol. 35, p. 38-43.

U.S. Department of Agricultural (1926) Soil survey of Manitowoc Country, Wisconsin. Series 1926, no. 34.

U.S. Department of Agricultural, Agricultural Research Service and Purdue Agricultural Experiment Station (1965) Predicting rainfall-erosion losses from cropland east of the Rocky Mountains. Agricultural handbook no. 282.

U.S. Department of Commerce (1972) Climatological data, monthly summarized station and divisional data, Wisconsin, May and June, vol. 77. U.S. Department of Commerce, National Climatic Center, Asheville, N.C., (5&6), p. 65-77.

Vegas, P.L. (1973) A detailed procedure for the use of small scale photography in land use classification. NASA Earth Resources Laboratory Report 031.

Welch, R. (1971) Remote sensing for water pollution control. *Photogrammetric Engineering*, vol. XXXVII, no. 12, p. 1285-1286.

Wisconsin Department of Natural Resources (1965-71) Pollution investigation reports of the major watersheds of eastern Wisconsin, including those draining into Green Bay. Department of Natural Resources, Division of Resource Development, Madison, Wisconsin.

Wisconsin Department of Natural Resources (1965-68) State of Wisconsin surface water quality monitoring data. Department of Natural Resources, Division of Environmental Protection, Madison, Wisconsin.

Wisconsin Geological and Natural History Survey (1968) Legend for overlay soil map of Wisconsin. Soil Survey Division, Wisconsin Geological and Natural History Survey, Madison, Wisconsin.

APPENDIX A. PRECIPITATION AND TEMPERATURE DATA

Table AI. Precipitation and temperature data for East Twin River Watershed.

Precipitation (inches)

1972

Station	May 29	May 30	May 31	June 1	June 2	June 3	June 4
Kewaunee	--	--	--	--	--	T	.69
Green Bay	.06	.13	--	.01	--	.97	--
Two Rivers	.17	.84	--	T	--	--	.05

[illegible]perature (°F)

[illegible] (max/min)

Station	May 29	May 30	May 31	June 1	June 2	June 3	June 4
Kewaunee	--	--	--	69/38	61/45	70/46	71/50
Green Bay	74/48	58/41	71/39	83/53	83/50	88/55	75/52
Two Rivers	61/48	61/43	58/39	80/42	80/49	62/47	72/52

Precipitation (inches)

June 1973

Station	14	15	16	17	18	19	20	21
Kewaunee	--	.08	--	.20	.10	--	.05	--
Green Bay	--	.26	.04	.05	--	T	.01	.15
Two Rivers	--	T	.15	.01	--	--	.06	--

Temperature (°F)

June 1973 (max/min)

Station	14	15	16	17	18	19	20	21
Green Bay	83/55	80/58	80/58	80/59	80/56	82/63	77/58	73/58
Kewaunee	73/54	68/54	64/50	60/50	66/49	72/53	77/58	74/56
Two Rivers	69/53	67/54	70/54	65/50	62/49	67/51	73/51	75/47

Precipitation (inches)

October 1973

Station	3	4	5	6	7	8	9	10	11	12
Green Bay	T	.43	--	.01	--	--	.63	.02	.19	.06
Kewaunee	--	--	--	--	--	--	--	--	--	--
Two Rivers	T	.09	--	--	.04	--	--	--	.80	.03

Temperature (°F)

October 1973 (max/min)

Station	3	4	5	6	7	8	9	10	11	12
Green Bay	75/46	64/44	69/41	67/44	62/54	74/54	73/59	81/62	79/61	70/52
Kewaunee	--	--	--	--	--	--	--	--	--	--
Two Rivers	62/47	61/42	70/40	69/46	60/59	64/53	61/55	66/54	67/53	67/57

Precipitation (inches)

1974

Station	April 28	April 29	April 30	May 1	May 2	May 3	May 4	May 5	May 6	May 7
Two Rivers	.10	--	.14	--	--	.03	--	.35	.07	--
Kewaunee	--	--	--	--	--	--	--	.89	--	--
Green Bay	--	T	--	--	T	.17	00	1.15	--	--

Temperature (°F)

May 1974 (max/min)

Station	29	30	31
Two Rivers	60/46	60/45	66/47
Kewaunee	61/47	55/44	65/45
Green Bay	65/49	61/44	69/49

Table AII. Precipitation and temperature data for Manitowoc River Watershed.

Precipitation (inches)

1972

Station	May 29	May 30	May 31	June 1	June 2	June 3	June 4
Appleton	.49	.35	--	--	--	.05	--
Brillion	--	.77	.01	--	--	.60	.68
Chilton	.23	.61	--	--	--	.28	T
Green Bay	.06	.13	--	.01	--	.07	--
Manitowoc	.22	.58	--	--	.03	--	.02

Temperature (°F)

1972
(max/min)

Station	May 29	May 30	May 31	June 1	June 2	June 3	June 4
Appleton	71/50	56/44	68/40	79/53	81/54	85/61	75/56
Chilton	83/64	71/43	67/39	79/52	85/55	84/60	78/52
Green Bay	74/48	58/41	71/39	83/53	83/50	88/55	75/52
Manitowoc	67/55	65/42	65/41	80/43	77/52	82/54	81/55

Precipitation (inches)

June 1973

Station	14	15	16	17	18	19	20	21
Appleton	--	.20	.05	.10	--	--	.05	.08
Brillion	--	--	.35	.10	.11	--	.05	--
Chilton	--	T	.25	.15	--	--	.05	--
Green Bay	--	.26	.04	.05	--	T	.01	.15
Manitowoc	--	--	.15	.03	--	--	.04	--

Temperature (°F)

June 1973 (max/min)

Station	14	15	16	17	18	19	20	21
Appleton	81/58	80/65	82/58	78/58	78/56	80/61	73/61	70/61
Chilton	84/52	83/53	84/64	81/63	80/53	81/61	81/53	75/55
Green Bay	83/55	80/58	80/58	80/59	81/56	82/63	77/58	73/58
Manitowoc	81/55	72/54	80/55	70/54	69/52	84/51	82/57	76/57

Precipitation (inches)

October 1973

Station	3	4	5	6	7	8	9	10	11	12
Appleton	T	.11	--	.02	.02	--	.82	.02	.50	.03
Brillion	.18	.05	--	--	.07	--	--	.18	.86	.02
Chilton	--	.20	--	--	.10	--	.15	.05	.75	T
Green Bay	T	.43	--	.01	--	--	.63	.02	.19	.06
Manitowoc	.02	.07	--	--	.21	--	--	--	--	T

Temperature (°F)

October 1973 (max/min)

Station	3	4	5	6	7	8	9	10	11	12
Appleton	73/55	64/47	68/43	62/48	61/52	73/55	71/62	78/63	78/63	70/55
Chilton	73/48	72/50	68/46	67/41	62/51	70/53	73/60	79/60	78/62	72/60
Green Bay	75/46	64/44	69/41	67/44	62/54	74/54	73/59	81/62	79/61	70/52
Manitowoc	67/50	61/52	69/42	64/41	61/52	67/60	64/59	69/59	69/61	67/59

Precipitation (inches)

1974

Station	28	29	30	1	2	3	4	5	6	7
Appleton	--	.03	--	--	T	.04	--	.35	.02	--
Brillion	--	--	--	--	--	.04	--	--	.59	--
Chilton	--	--	--	--	--	--	--	.11	.16	--
Green Bay	--	T	--	--	T	.17	--	1.15	--	--
Manitowoc	--	T	--	--	--	.03	--	.28	.09	--

Temperature (°F)

May 1974 (max/min)

Station	29	30	31
Appleton	68/54	65/49	69/51
Brillion	--	--	--
Chilton	66/55	68/45	68/51
Green Bay	65/49	61/44	69/49
Manitowoc	67/55	61/46	74/49

Table AIII. Precipitation and temperature data for Oconto River Watershed.

Precipitation (inches)

1972

Station	May 29	May 30	May 31	June 1	June 2	June 3	June 4
Breed	.10	.56	--	--	--	--	--
Crivitz High Falls	--	1.40	--	--	--	--	--
Lakewood	.80	.18	--	T	T	--	--
Oconto	T	.39	--	--	.05	--	--
Shawano	.27	.06	--	--	--	--	--

Temperature (°F)

1972 (max/min)

Station	May 29	May 30	May 31	June 1	June 2	June 3	June 4
Breed	84/60	67/41	70/28	82/42	82/44	89/47	89/39
Crivitz High Falls	86/68	72/42	68/36	72/46	76/43	76/50	86/49
Lakewood	79/52	75/40	70/30	81/47	81/46	87/50	82/43
Oconto	73/42	58/34	68/43	--	85/47	81/51	90/49
Shawano	84/51	67/42	72/32	80/48	84/46	88/45	87/44

Precipitation (inches)

June 1973

Station	14	15	16	17	18	19	20	21
Breed	--	--	T	.14	.03	.04	.11	--
Crivitz High Falls	--	--	T	--	--	T	.10	--
Lakewood	--	.04	T	.46	--	--	.03	.03
Oconto	--	--	T	.05	.12	--	.03	--
Shawano	--	--	--	T	--	.06	.04	--

Temperature (°F)

June 1973 (max/min)

Station	14	15	16	17	18	19	20	21
Breed	85/49	85/47	83/61	75.54	78/56	84/60	83/57	75/51
Crivitz High Falls	94/30	86/62	89/66	80/55	71/54	73/60	82/58	76/56
Lakewood	83/45	83/59	75/58	73/51	75/56	81/60	78/55	73/52
Oconto	78/50	83/55	81/60	72/56	74/57	75/59	80/57	72/54
Shawano	81/48	80/57	75/64	78/53	78/53	76/54	80/61	80/51

Precipitation (inches)

October 1973

Station	3	4	5	6	7	8	9	10	11	12
Breed	T	.17	.06	--	.07	--	--	.22	.56	.19
Crivitz High Falls	--	.32	--	--	T	--	.54	1.10	.10	--
Lakewood	--	.10	--	--	.03	--	.84	.09	.15	.03
Oconto	--	.10	.36	--	.07	--	--	.39	.27	--
Shawano	--	.11	--	--	.05	--	1.09	--	.29	--

Temperature (°F)

October 1973 (max/min)

Station	3	4	5	6	7	8	9	10	11	12
Breed	75/40	72/49	68/29	70/28	62/49	73/54	73/59	76/52	78/56	75/60
Crivitz High Falls	73/40	74/42	72/30	70/29	73/33	70/60	66/54	75/58	75/64	72/54
Lakewood	73/40	70/47	68/32	65/30	60/48	72/52	68/57	70/58	74/60	68/58
Oconto	65/44	73/44	65/37	70/37	65/37	62/52	69/55	68/59	77/59	75/62
Shawano	73/49	70/45	69/30	68/30	60/46	72/49	72/54	76/55	78/53	78/53

Precipitation (inches)

1974

Station	April 28	April 29	April 30	May 1	May 2	May 3	May 4	May 5	May 6	May 7
Breed	.03	.07	.03	.06	--	.22	--	.10	.23	--
Crivitz High Falls	T	T	--	.04	--	.31	--	.04	T	--
Lakewood	.12	.03	T	--	--	--	--	.26	.02	--
Oconto	--	--	--	T	--	.16	--	.18	.36	--
Shawano	--	--	--	--	--	.03	--	.55	.04	--

Temperature (°F)

May 1974

Station	29	30	31
Breed	72/53	72/37	71/47
Crivitz High Falls	75/57	71/44	70/45
Lakewood	73/55	65/40	70/46
Oconto	63/54	69/44	59/47
Shawano	63/55	68/47	70/49