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ENVIRONMENTAL STUDY OF ERTS-1 IMAGERY: LAKE CHAMPLAIN AND VERMONT

A. O. Lind

PRINCIPAL INVESTIGATOR

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DEPARTMENT OF GEOGRAPHY
REMOTE SENSING LABORATORY
UNIVERSITY OF VERMONT
BURLINGTON, VERMONT 05401

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This final report (Type III) presents the results of ERTS-1 imagery analysis performed under NASA contract NAS 5-21753. NASA Identifiers: UN 137; SR 347.

PREFACE AND ACKNOWLEDGMENTS

The findings from the ERTS-1 experiment presented in this report are simply stepping stones leading to larger scale applications and studies of several important environmental and resource features comprising the Lake Champlain region and Vermont. The unique, synoptic, and repetitive coverage provided by ERTS-1 remote sensors has contributed vital information in several resource management areas, as for example in water pollution and flood assessment. Direct resources application of some of the findings is imminent, while others contribute more indirectly, in that they provide a new scale of basic information that could not readily be obtained by "conventional" tools. A contribution to the understanding of the behavior of such a vital resource as Lake Champlain, for example, would provide some basis for future resources decisions. There is little doubt that the ERTS-1 experiment has provided an immeasurable contribution not only to the scientific and resource management communities, but also to the people of Vermont.

The writer is indebted to many persons who have in various ways contributed to this ERTS study. The active participation of Dr. E. B. Henson, Director of the Lake Champlain Studies Center, and co-investigator in the limnological phases of this study was vital. The consultations provided by co-investigators, W. P. Wagner and J. Olson, served to guide aspects of this study in the proper direction. Especially appreciated is the kind, prompt assistance provided by NASA project monitors, Dr. N. Short and Mr. E. Szajna in surmounting technical problems associated with this experiment. Special thanks are due to Mr. James Pelton, Graduate Research Assistant, who provided cartographic expertise and photographic assistance in the laboratory and in the field, and overall assistance in managing details in the laboratory during the course of this project. A large measure of thanks is also due to Mrs. Rita Benjamin who provided the indispensable administrative and clerical support required by a project of this nature.

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I. Introduction

THE EXPERIMENT

The Earth Resources Technology Satellite (ERTS-1) was launched into a near-polar, sun-synchronous orbit with an 18 day cyclic coverage of the same area on the earth's surface. A single frame from its Return Beam Vidicon (RBV) and Multispectral Scanner (MSS) systems covers an area measuring 185 km. square. On a 9 1/2" image derived from these sensors, the resulting scale is 1:1,000,000.

The purpose of the ERTS experiment is to demonstrate that remote sensing from space is a feasible and practical approach to efficient management of earth resources. This goal which was established by the National Aeronautics and Space Administration has been explored in the context of the Vermont environment including Lake Champlain. This report is the culmination of approximately eight months of research activity focusing on resources information derivation from ERTS-1 Imagery. During this short period of time, a number of significant results have been obtained, some of which have direct and imminent applications in the resources management field. Other results are expected to emerge as further studies are made on the continuing flow of remote sensor data

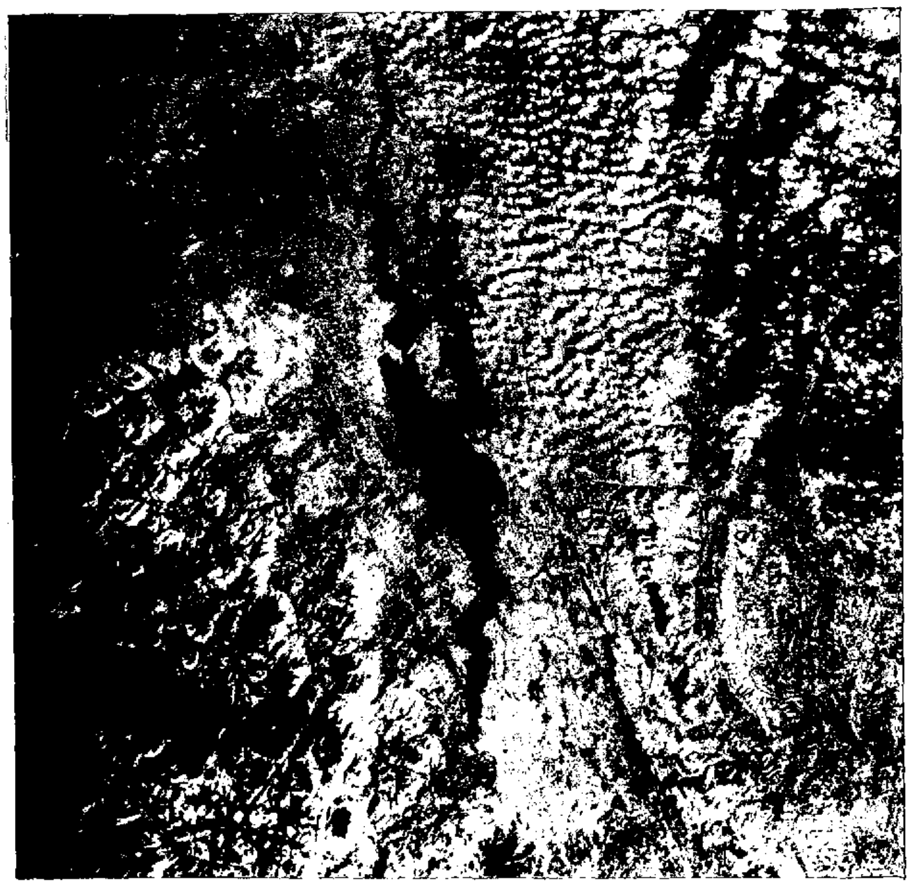

Figure 1. ERTS-1 Scene showing Lake Champlain, the western portion of Vermont, Southern Quebec and the eastern section of Upper New York State in October, 1972 (Image No. 1079-15115). All of the study areas described in this report are contained in this frame.

from space. Even as this report is being prepared, new applications are being investigated.[1]

The results described in the body of this report are grouped into two major categories: a) Lake Champlain and b) Vermont land use. It is in these two broad areas that there exists a need for resources information. On the one hand, Lake Champlain is a vital resource to the region which is being affected by increasing human use. On the other hand, the way in which land in Vermont is used to satisfy both human and ecological needs is a basic concern to planning and implementation of recent land use legislation. Also, of concern is the interaction between land use and the environment, so for example, there remains a basic need to examine such matters as the relationship between the spring flooding of Lake Champlain and land use along its shores. As will be demonstrated in the body of this report, ERTS has contributed the basic data to meet a variety of resource information needs.

In some cases, the synoptic perspective of ERTS with its ability to capture virtually the entire lake and much of Vermont at one instant in time has led to unique resource data contributions. Along with this synoptic feature, the repetitive coverage provided by ERTS has also led to an assessment of seasonal changes

[1]Continuing investigation of ERTS data for resource information is being funded by the State of Vermont, State Planning Office, Montpelier, Vermont.

which are particularly significant in the water resources field. In addition, another service has been provided through ERTS which is of a supplementary nature. Some resources phenomena have been under study and have already been identified and mapped by the use of conventional aerial methods, both photographic and electronic. The table below groups the various results obtained during the course of this study in terms of the above criteria.

TABLE 1

A Classification of ERTS-1 Results
In Terms of Contribution
To Resources Information

Unique Contribution	Supplemental Contribution
Lake Turbidity	Water Pollution
Lake Ice Survey	Agricultural Land Use
Flood Assessment	Forest Land
Algal Blooms*	Wetlands
Lake Outlets*	

Note: Unique contributions relate to essentially large scale phenomena of a dynamic nature which have not been comprehensively mapped prior to ERTS.

*As of the date of this report, not fully confirmed by ground investigation.

ERTS DATA ANALYSIS

This investigation has relied entirely on imagery from the individual spectral bands of the two sensor systems carried aboard ERTS-1. RBV coverage was limited to the first overflight of the region, but this system became inoperable so all subsequent coverage was derived from the MSS system. In spite of the fact that Vermont is cloudy for nearly two-thirds of the average year, a number of excellent imageries were obtained over the course of the investigation which provided useful seasonal data. The number of usable ERTS imageries (mostly cloud-free) available to this investigation may be noted in Table 2. It may be seen that the number of good, cloud-free situations agrees closely with the cloudiness statistics mentioned above.

The basic and most significant ERTS product is the 9 1/2 inch positive transparency format in black-and-white for each of the spectral bands. Whole-frame 70 mm. formats could be ranked as second in importance and positive prints served mainly as communication tools between investigators, public officials, and other interested persons.

Most analysis procedures used in this investigation have relied on secondary data products derived from the

TABLE 2

List of ERTS Imagery Received for Analysis

Dates	Image Numbers	Percent Cloud Cover
July 29	1006 - 15055 1006 - 15054*	75
July 30	1007 - 15113* - **	25
Aug. 16	1024 - 15055	75
Sept. 21	1060 - 15060**	0
Sept. 22	1061 - 15114	75
Oct. 10	1079 - 15115	15
Oct. 27	1096 - 15063**	0
Dec. 2	1132 - 15065**	0
Dec. 20	1150 - 15064	90
Jan. 7	1168 - 15063**	0
Jan. 8	1169 - 15121 **	0
Jan. 25	1186 - 15063**	0
Jan. 26	1187 - 15122	100
Feb. 13	1205 - 15123	100
March 3	1223 - 15125	80
March 20	1240 - 15071	100
March 21	1241 - 15125	70
April 7	1258 - 15071 ** 1258 - 15073	45
April 25	1276 - 15070 ** 1276 - 15073	25
April 26	1277 - 15124	50
May 13	1294 - 15065	97
May 14	1295 - 15124	100

*RBV Imagery; ** Images used in this investigation.

basic source materials described above. The following steps were generally taken in the development of resources information:

1) Initial survey of each 9 1/2 inch positive transparency under magnifying optics illuminated over a light table (Bausch and Lomb Stereozoom 240 scope and Richards imagery light table). Identification of specific phenomena for further analysis.

2) Initial survey of 70 mm. whole frame formats combined in a multispectral viewer (Spectral Data Corp. viewer) for color renditions. Identification of specific phenomena for further analysis.

3) Enlargement of the ERTS scene (9 1/2 inch positive transparency) to a scale suitable for mapping purposes. Depending on the feature initial enlargements ranged from 1.5 to 6X. An enlargement and positive transparency of a particular scene from each band was made using the Polaroid MP-3 copy camera system.

4) Projection of the above enlargement through the multispectral viewer for more detailed analysis and interpretation.

5) Mapping of the information presented on the multispectral viewer screen by direct overlay.

6) Recording (rephotographing) of the multispectral image display on 35 mm. or 70 mm. color film.

Polaroid copies were made for use in interim reports or for draft purposes.

7) Projection of the color transparency onto a base map, used only for lake phenomenon such as turbidity.

8) Study of the resulting information in terms of resources significance.

9) Reporting of significant results to pertinent federal, state, and regional or local agencies.

Interfacing in virtually all of the above steps was information derived from direct ground or lake-level observations, field photography and supplemental support aerial photography of the conventional type. Table 3 below lists the aerial photographic coverage and its principal uses.

TABLE 3

Aerial Photographic Coverage

General Type	Agency or Co. & Date	Principal Use
Hyper-altitude Color IR Black-and-White multiband	NASA Aug. 20, 1972	Land Use Studies
Medium and Low Altitude Color IR Color	NASA Sept. 20, 1972	Land Use Studies
Low Altitude Oblique Black-and-White Pan.	Photo Interpretation Corp. Hanover, N. H.	Lake-Level Documentation

II. ERTS-1 APPLICATIONS: LAKE CHAMPLAIN

Lake Champlain occupies a structural trough between the Green Mountains of Vermont on the east and the Adirondack Mountains of New York on the west. The trough, which includes the Champlain Lowland and the lake itself, widens northward toward the St. Lawrence Valley and narrows toward the south. The lake is 200 km. in length, 18 km. at widest extent and is over 100 meters deep. The morphology of the lake is complicated by large islands in the northern third of the lake basin which effectively creates a series of smaller, somewhat isolated basins interconnected by narrow channels. A portion of the lake, which contrasts strikingly with the main portion, is the long narrow southern leg which is noted for its turbidity. The outlet of the lake is the Richelieu River which drains northward toward the St. Lawrence River through the Province of Quebec, Canada.

The importance of the lake as a resource cannot be overstated. Its uses are varied ranging from water supply to a waste disposal area. Recreation, fishing, transportation, and aestetics all intermingle to produce a resource complex which is not free from problems of a seemingly monumental nature. Conflicts of use are present and a need has recently emerged for information on the basic characteristics of the lake. Limnological studies pertaining to the nature and distribution of the physical and biotic elements have been underway in the Lake Studies Center of the University of Vermont. The large size of the lake made simultaneous observations over the lake surface impractical, so it was not possible to study large scale phenomena without considerable effort in terms of manpower and equipment. The prospects of satellite coverage would seem to circumvent some of these problems, and with the advent of ERTS-1, a series of applications of the type described in this report emerged. Some of the applications described in the following section have a direct bearing on current resource problems now being actively reviewed by resource decision makers. These applications include water pollution and flood assessment. Other applications have resources significance in that they contribute toward filling the resource inventory need, where information is brought to bear on regional and local planning issues as well as directing possible future resource studies. Ice surveys, water quality surveys relating to turbidity and algal blooms, and survey of wetlands connected to the lake are at the moment important resource parameters which may assume resource significance on short notice.

The varied topics covered in this report reflect the wide applicability of ERTS data, and while some of these results have prompted definite future mapping and inventorying project inquiries from various resource-oriented agencies, it should be borne in mind that they have raised additional questions and have opened several new avenues of resource inquiry.

WATER POLLUTION MONITORING USING ERTS IMAGERY

Source of Pollution. The limnological program of the University of Vermont has included a special study of the narrow southern end of Lake Champlain between Fivemile Point and Lapham Point.[1] This part of the lake receives waste water discharge from a new paper mill located on the New York side of the lake just north of historic Fort Ticonderoga.

Water samples have been collected from the study area before and after the plant began operation in early 1971. The waste-water discharge enters the lake through a submerged diffuser pipe which extends northeastward to the middle of the main channel. A sampling grid was established in this area and samples were collected and analyzed for a number of constituents and properties. Isopleth maps derived from the water sampling program conducted after the paper mill began discharging waste water indicate the presence of a plume on the basis of chemical evidence alone. As indicated in Figure 2 , dissolved oxygen, conductivity, and sodium appear to show the pluming effect best. Surface observations in the study area have recorded reddish-brown discolorations of the water due to suspended,paper mill solid wastes. The plume is fairly large and either moves to the east or to mid-lake where

[1]See Appendix B for locations.

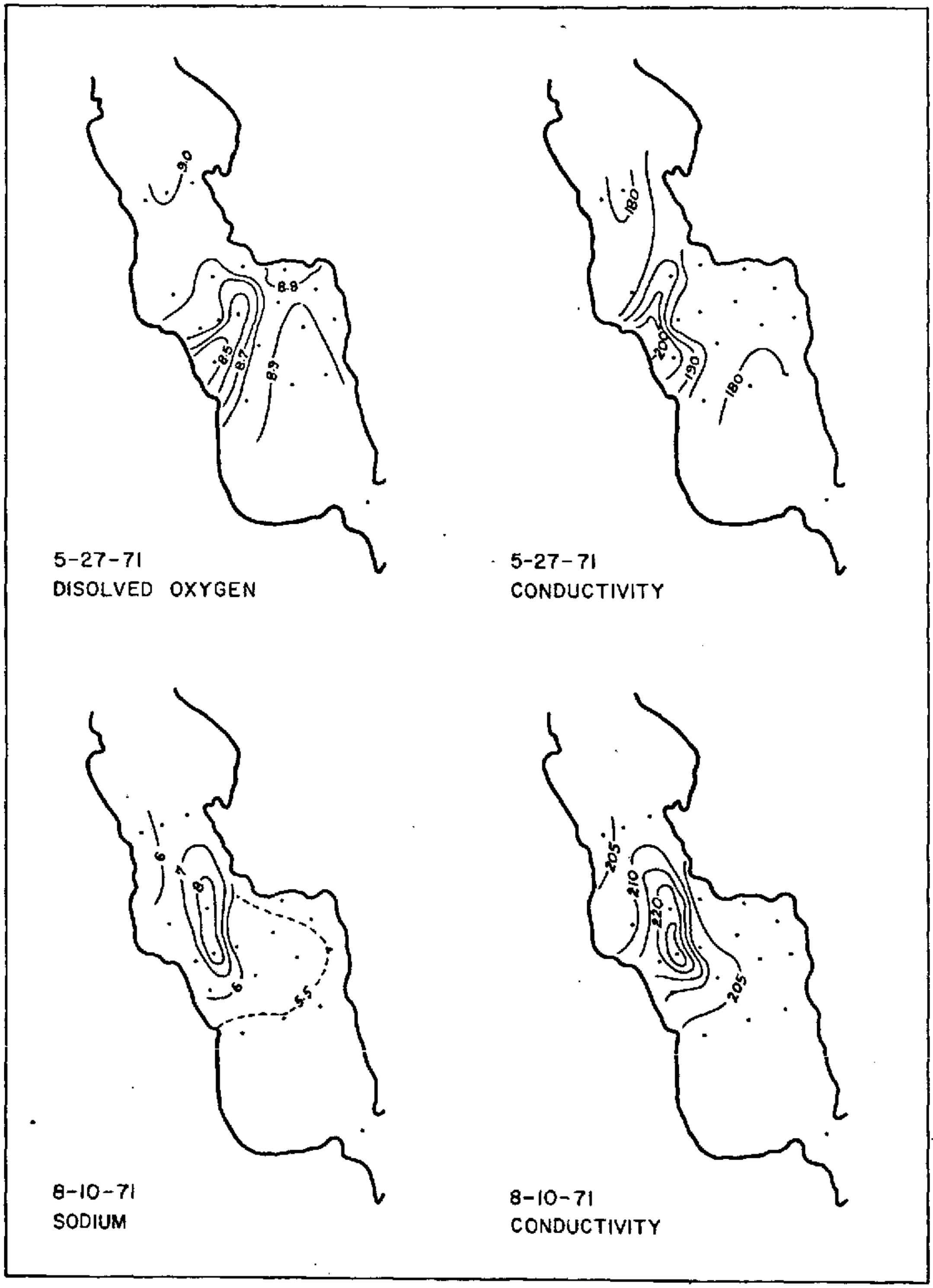

Figure 2. Physical and Chemical Data Showing Pollution Plume Pattern.

it may be transported northward giving the plume a geniculate configuration, or it may simply form a vector path pointing northeast toward Lapham Point on the Vermont shore when the wind is calm and lake currents are slow.

ERTS-1 Imagery and Water Pollution Monitoring. An examination of the 10 October, ERTS-1 coverage of Lake Champlain in MSS bands four and five (500 - 600 nm. and 600 - 700 nm.) was conducted using the 9.5 inch positive transparencies and the variable magnification provided by the Bausch and Lomb 240 Stereozoom optics. ERTS-1 image number 1079-15115 shows the study area described above clearly and under 4X magnification the plume that had been documented by chemical evidence in previous studies was discovered visually on the image. The plume is best seen on MSS band 4 imagery, but may also be recognized on MSS band 5, where it appears as a darker tone in the context of the generally lighter toned, turbid lake water characteristic of this portion of the lake. The MSS band 4 rendition may be seen in Figure 3 as reproduced by Polaroid MP-3 copy camera equipment. An enhanced false-color rendition reveals the plume even more clearly. The enhanced version was produced using enlarged positive transparencies of MSS bands 4, 5, and 6, as viewed through Spectral Data Corporation's multispectral viewer. Photographic reproduction was accomplished with the Polaroid MP-3 copy camera.

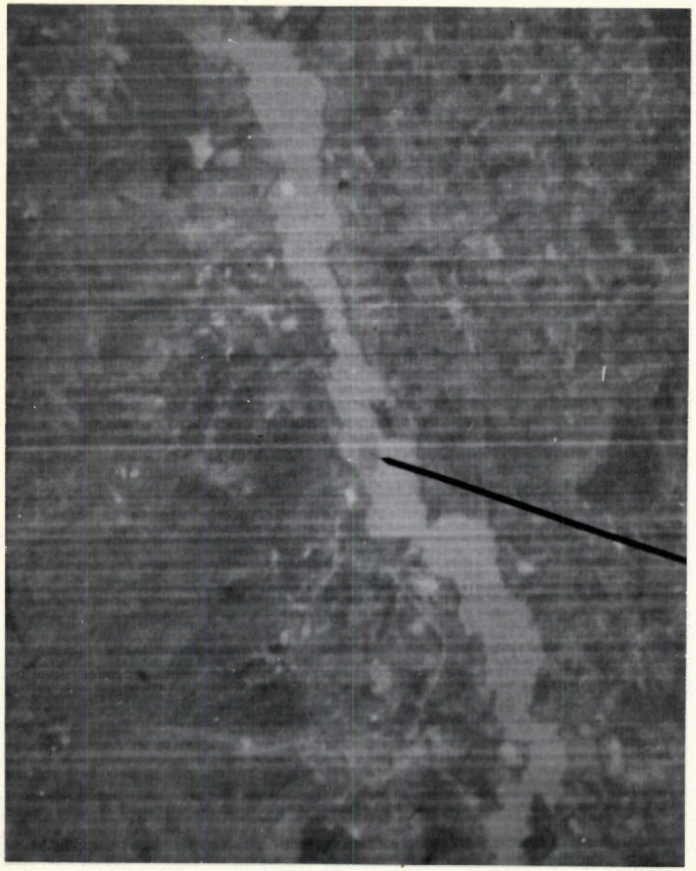

Figure 3. MSS band 4 rendition of International Paper Co. mill discharge into Lake Champlain, October 10, 1972.

Figure 4. MSS band 4 rendition of the plume area, April 7, 1973. Discharge shows under the red dot.

While the plume coverage of October 10 (Image no. 1079-15115) agreed with earlier lake surveys made in the vicinity of the submerged, paper mill, discharge pipe, it was not known what other configurations the plume might take due to seasonal changes in the lake level and lake current intensity. Subsequent coverage of the discharge plume area during the April overflights of ERTS-1 provides additional information and verifies earlier expectations that monitoring of the plume configuration would be possible.

MSS band 4 has again been proved to be the most useful ERTS MSS band for assessing the magnitude and extent of this particular pollution plume. Two subsequent scenes are presented (Figures 4 and 5) representing a distinct seasonal change in the level and current conditions of Lake Champlain as well as contrasting discharge patterns from the paper mill's treatment plant. Both April 7 and 25, 1973, are shown, and at this time, lake levels were at rather high stages (100.4 and 99.4 feet respectively). Low atmospheric transparency on April 25 has a somewhat degrading effect on that image, but detection and recognition of the plume was not seriously affected.

Due to the poor representation of the shoreline on band 4 during April, the position of the plume in the lake had to be determined by superimposing bands 4 and 6 or 7. The near-infrared band provides excellent shoreline definition and

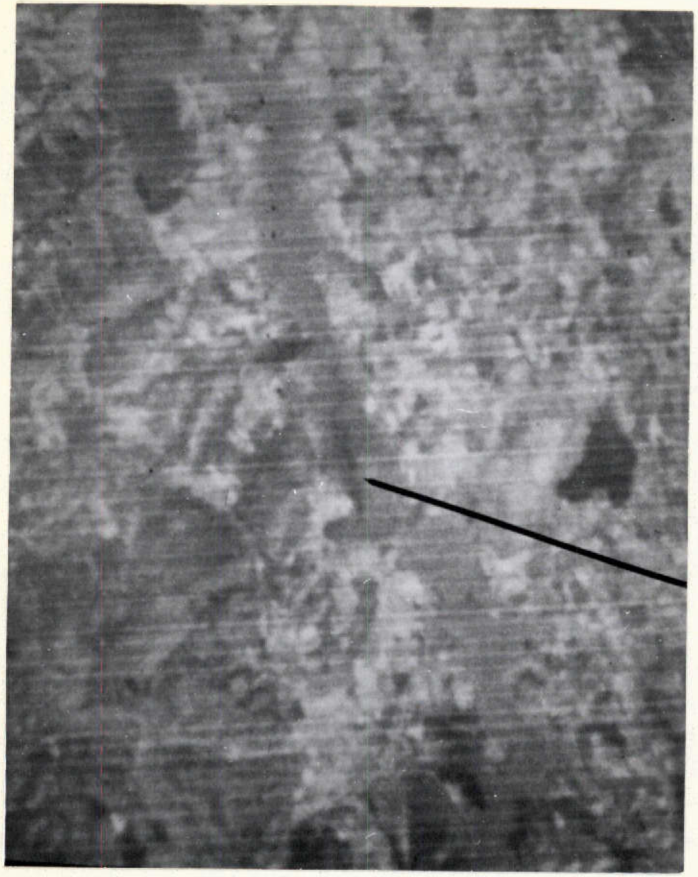

Figure 5. MSS band 4 rendition of the pollution plume area. April 25, 1973. A large plume occurring during high water conditions with moderately strong northward (towards top of photo) current.

Figure 6. MSS band 6 (infrared) rendition of the pollution plume area. This band is used for shoreline delineation thus locating the plume area when superimposed on band 4 (April 25, 1973).

made it possible to note the extent of the plume area. In addition, the near-infrared bands reveal the shoreline position with such clarity that the inundating effects of the spring lake levels on low-lying areas can be assessed. This is in itself a new significant result reported in the following section (p. 21).

Both bands 4 and 6 are shown for the April 25, 1973, view (Image no. 1276-15073: Figures 5 and 6) of that part of Lake Champlain between Fort Ticonderoga and Schoolhouse Bay. This is the turbid, shallow, southern leg of Lake Champlain which has a general north-flowing current throughout most of the year. The plume area on the April 25 imagery extends in a more northerly direction than previously observed and this configuration seems to reflect a stronger north-flowing current in this part of the lake during spring (see Figure 5). Winds recorded at Burlington, Vermont, were from the north at 1000 hours local time and this wind pattern was persistent before and after the overflight of ERTS. The northward trend of the plume area appears to be indicative of the dominating influence of the general lake current.[1] The plume area is somewhat larger than previously observed and represents a fairly high discharge. The plant

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[1]A northerly lake current is indicated by the turbidity discharge pattern where the turbid southern arm empties into the main lake basin. See turbidity section (p. 32).

discharges paper mill wastes at a rate of approximately 21 million gallons per day. The usual high level of general turbidity in the water of this portion of the lake shows as a light tone in the image compared to the darker tone of the plume area which results from the suspended paper mill wastes which produce an overall brownish coloration of the water.

On the April 7 imagery (Image no. 1258-15073) a contrasting view is presented (Figure 4) in which the visible plume is extremely small. The differences in plume extent are related to the nature of the type of effluent being discharged.

<u>Resources Significance</u>. These views of the pollution plume from the International Paper Co. mill located in New York just north of Fort Ticonderoga illustrate that the visible components of the paper mill waste discharge into Lake Champlain can be monitored. The cumulative affect of these images and others to come will be to provide data to construct a model depicting the plume configuration in differing seasons and limnological conditions. Thus, each time ERTS provides an image of the pollution study area, more information is provided to meet that goal. This information can be combined with aircraft data taken under different circumstances.

When the pollution plume observed in the MSS band 4 imagery is compared to the shoreline information clearly seen on the near-infrared bands and transferred to a map base, it becomes apparent that the plume area extends into Vermont. New information based on continuing lake surveys indicates a discernible amount of new sludge deposit on the lake floor. The relationships between the plume area and sludge sedimentation will require further analysis based on a continuing flow of data from ERTS, aircraft and lake surveys. All of this information has a direct bearing on the court suit which Vermont has brought against the International Paper Co. and the State of New York for pollution of its waters. The plume data documented here is available to the State Attorney General's Office, State of Vermont, for possible application in the resources action now in progress at U.S. Supreme Court level. The Attorney General's Office is at this time evaluating the application of the ERTS-derived plume information.[1] The lengthy court suit has recently been opened again after a recess of several months in which opposing parties were attempting to settle out of court.[2]

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[1]Personal communication, Attorney General's Office, State of Vermont (letter) 23 July, 1973.

[2]During the preparation of the final draft of this report, the ERTS data described above was introduced and accepted as evidence (see Appendix C for narrative).

FLOOD ASSESSMENT USING ERTS-1 IMAGERY

Lake Levels Shown by ERTS-Imagery. The seasonal imageries used to assess inundation and shoreline change include autumn and spring scenes which reveal substantial changes in lake level. The well-known property of water to fully absorb near-infrared energy while contrasting land areas tend to reflect such energy in varying amounts leads to a maximum contrast between land and water reflectivity in the infrared bands. Thus, imagery derived from remote sensors using the near-infrared will show water areas as featureless dark gray and land in contrasting medium to light gray when presented on black-and-white positive film. The infrared bands of ERTS-1 currently in use include MSS bands 6 and 7 (700-800 nm. and 800-1100 nm. respectively), and it is imagery from these bands that provides the basic data for the monitoring of lake levels.

The images used to demonstrate the utility of ERTS imagery for lake-level determinations and flood assessment were obtained on October 10, 1972 (low lake-level). These include image numbers 1079-15115, 1258-15071 and 1276-15070 respectively. On October 10, the lake level recorded at the Lake Champlain Transportation Co. gage in Burlington harbor was 95.1 feet (28.99 meters). The higher, spring lake-levels amounted to 100.4 feet (30.60

meters) on April 7 and 99.4 feet (30.30 meters) on April 25. These were also recorded at the Burlington gage mentioned above.[1]

The major changes in shoreline position resulting from the above lake-level changes are most spectacular along low gradient shores such as in deltaic terrain. As the shore gradient steepens, the horizontal displacement becomes smaller. The two examples presented below show a deltaic environment and a steeper gradient shoreline having an estuarine configuration. The former is the Lamoille River delta in Chittenden County while the latter shows the mouths of the Otter Creek-Dead Creek drainage in northern Addison County. Figures 7, 8, and 9 illustrate the seasonal changes in the Lamoille delta region while Figures 10, 11, and 12 show contrasting seasonal changes in northern Addison County.

The extent of inundation in the Lamoille River delta with the lake level at 100.4 feet (30.60 meters) is virtually complete (Figures 8 and 9). Only river-bank levees and sand bars remain above water level. The light-toned "point" showing in the April imagery is a portion of Sand Bar State Park. The remaining portion of the park was inundated. With about a one-foot (0.3 meter) recession in lake level (April 25), more areas emerge as indicated by expansion of the lighter tones along the river banks. High

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[1]Datum for lake levels is mean sea-level.

Figure 7. October 10, 1972 scene at the Lamoille River delta. Lake stage at 95.1 feet (28.99 m.) MSS band 6 rendition.

Figure 8. April 7, 1973 scene of the same area as in Figure 7 showing contrasting flood conditions with lake stage at 100.4 ft. (30.60 m.) MSS band 6 rendition.

Figure 9. Lamoille River delta region on April 25, 1973. Lake stage at 99.4 feet (30.30 m.).

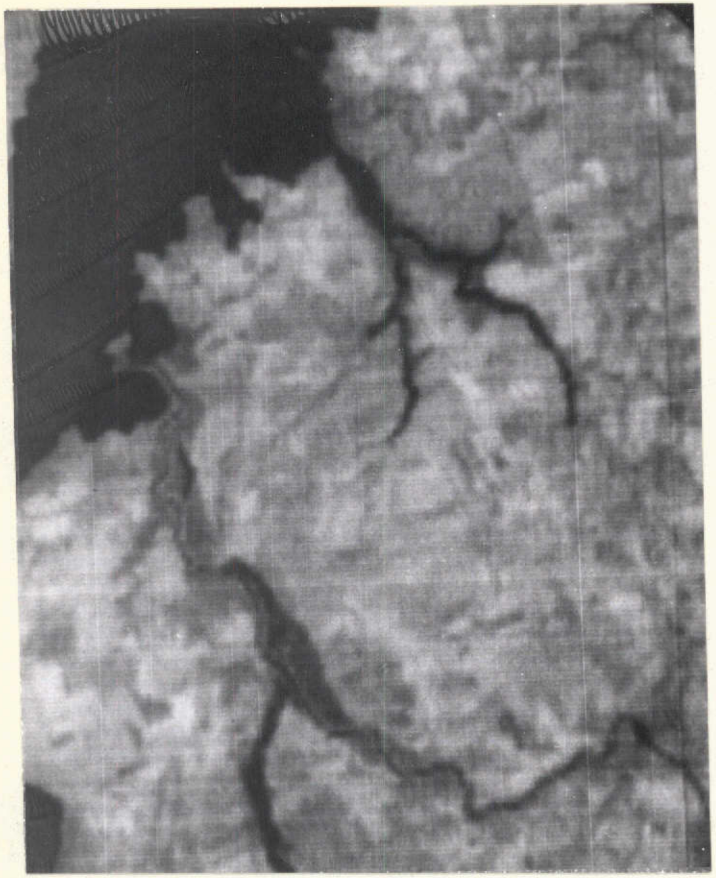

Figure 10. Otter Creek-Dead Creek area on October 10, 1972. MSS band 6 rendition. Lake at low water stage.

Figure 11. Otter Creek-Dead Creek area on April 7, 1973, showing inundation. MSS band 6 rendition. Cropland areas are affected by the high water.

Figure 12. Otter Creek-Dead Creek area on April 25, 1973. MSS band 6 rendition.

oblique aerial photos taken on May 19, 1972 (Lake stage, 101.5 ft.) during the spring flooding of the Lamoille delta (Figures 13 and 14) shows that all of the delta terrain is inundated with the exception of the Sand Bar Point area. The extent of inundation observed on the aerial photos is in agreement with flooding extent as seen on ERTS imagery.

The Otter Creek-Dead Creek area is characterized by a moderately to gently sloping shore gradient resulting in less horizontal change in shoreline as lake level changes. However, seasonal changes are readily apparent by comparison of the ERTS scenes and slight changes in level such as occurred between April 7 and April 25 are also detectable. In this area, cropland has been inundated besides the generally low wetlands found in the valleys.

Preliminary experiments indicate these shoreline changes can be plotted directly onto existing U.S. Geological Survey topographic maps with little difficulty. These shoreline plots provide information that was not possible to obtain previously since topographic information on existing maps is insufficient to locate projected lake levels from gage data alone. Since ERTS has provided a basis for assessing flooding and shoreline change, the aerial extent of these can now also be mapped and applied in resource management decisions.

Resource Problems of High Lake-Levels. Seasonal lake-level changes in Lake Champlain have recently been a

Figure 13. Oblique aerial photo of inundation during spring of 1972 (May 19, 1972). Lake stage is 101.5 ft. View is toward the southeast. (Photo by Photographic Interpretation Corp.)

Figure 14. Oblique aerial photo of inundation looking northeastward (May 19, 1972). (Photo by Photographic Interpretation Corp.)

topic of much concern among various resource management bodies and local shore residents since above-normal and record high lake-levels have caused flooding problems in low-lying areas affecting both agricultural and resort activities as well as lake transportation. In addition, wildlife habitats in major preserves such as in the delta region of the Lamoille River have been adversely affected by the high lake-levels.

Seasonal lake-levels may vary by as much as nine feet (2.74 meters) with the highest levels coming during the spring months as snow melt combines with runoff from frontal rains. The heavy spring runoff is rapidly reflected in lake levels which attain their highest mark in April when they may reach or exceed the 100-foot level. Above normal precipitation has combined with the spring runoff to bring about generally high lake-levels through the course of the year, and this has prompted some interest in adopting controlling measures for regulating lake-levels. Since the outlet of Lake Champlain is the Richelieu River in Canada, such questions become the jurisdiction of the International Joint Commission. This body has resource management powers and it has begun studies relating to the problem. The Lake Champlain Commission is another agency with an interest in lowland flooding. Among the kinds of information that will be needed are: 1) nature and extent of inundations 2) seasonal lake volume differences and 3) shore changes resulting from lake-level changes. These questions are essentially interdependent and it was anticipated at the outset of this ERTS investigation that satellite imagery, with its synoptic feature of viewing a large area at one time and its periodic coverage, might become a viable tool for lake-level investigations. The recently received April ERTS coverage of Lake Champlain has provided the seasonal contrast desired. Seasonal differences between low lake-levels occurring in October of last year and high lake-levels of the following spring (April, 1973) amount to nearly 5 1/2 feet (1.67 meters). These differences are readily apparent on ERTS imagery and will form the basis for a lake-wide survey of flooding and shoreline change. Special interest in this survey has been expressed by the Lake Champlain Committee.[1]

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[1]Personal communication from the Vermont Co-chairman of the Lake Champlain Committee, Mr. William Cowles.

TURBIDITY

Sources and Characteristics of Turbidity. Streams and bank erosion contribute large quantities of sediments in the fine silt and clay sizes. The narrow southern leg of Lake Champlain extending southward from Crown Point (see Figure 2) is characteristically turbid, while the main section of the lake to the north is generally free from high turbidity levels. The boundary between the turbid waters from the south and the relatively clear main lake is found just north of Crown Point. The average northward flow of lake water from the turbid southern portion is estimated at 1,400 cfs. Other sources of turbidity include active shore erosion, especially where older lacustrian sediments are exposed to wave attack. These areas have turbid offshore waters reflecting the process of shore erosion and generally their contribution to offshore turbidity seems to exceed that of the larger rivers emptying into Lake Champlain. The areal distribution of turbidity in the lake is strongly dependent on the interactions of the wind-wave-current system, and turbidity patterns observed from ERTS must be interpreted in light of these interactions as well as water temperature and density.

Turbidity Patterns from ERTS-1 Imagery. The visible portion of the spectrum has provided the most information on turbidity and in terms of the specific sensor-band combination, this corresponds to the RBV 2 and MSS 5 bands. Analysis of the turbidity patterns is aided by the inclusion of the green band (RBV 1, MSS 4) and one of the near-infrared bands in a multispectral viewer. Enlargement of the scene to a scale of 1:125,000 or 1:84,000 allows for the superposition of the ERTS-derived information onto a base map.

Different patterns of turbidity appear in the Crown Point area when viewed at different times. The first scene examined was provided when the Return Beam Vidicon system (RBV) was in operation during July 30, 1972 (Image No. 1007-15113). Three additional scenes were provided by the Multispectral Scanner System (MSS) which replaced the RBV system. These scenes and appropriate image numbers are as follows: October 10, 1972 (1079-15115), April 7, 1973 (1258-15073) and April 25 (1276-15073).

These four scenes are shown in Figures 15 to 18 in the rendition of the RBV band 2 or the MSS band 5. Varying patterns of turbidity are revealed which correlate with wind and current relationships, so for example, during calm conditions and very light winds which occurred on July 30, 1972 (Figure 15). The boundary is fairly abrupt indicating that the turbid water flowing out of the southern leg of the lake is sinking as fast as turbid water is entering. A seasonal contrast is provided by the April 7

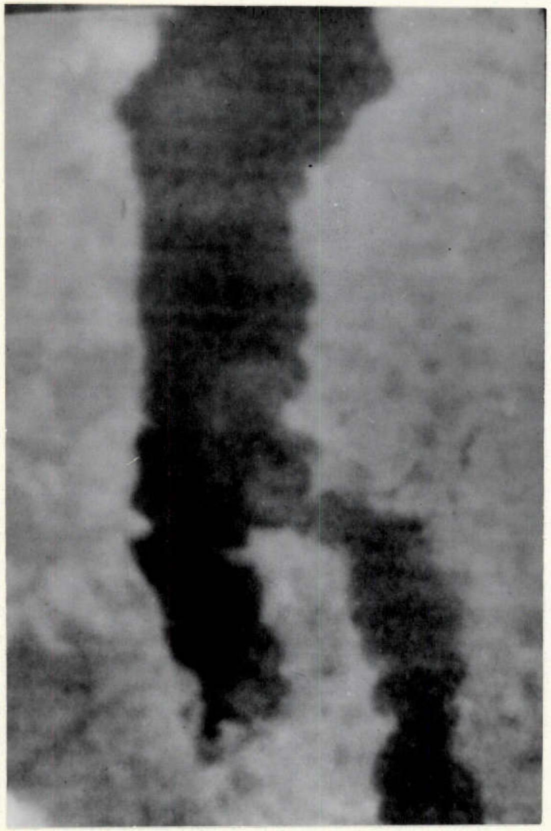


Figure 15. Turbidity at Crown Pt., July 30, 1972. Light and variable winds. RBV band 2 rendition.

Figure 16. Turbidity at Crown Pt., October 10, 1972. Moderate southerly winds, MSS band 5 rendition.

Figure 17. Turbidity of Crown Pt. April 7, 1973. Moderate northerly winds and high lake level conditions. MSS band 5 rendition.

Figure 18. Turbidity at Crown Pt. April 25, 1973. Moderate northerly winds and high lake level conditions. MSS band 5 rendition.

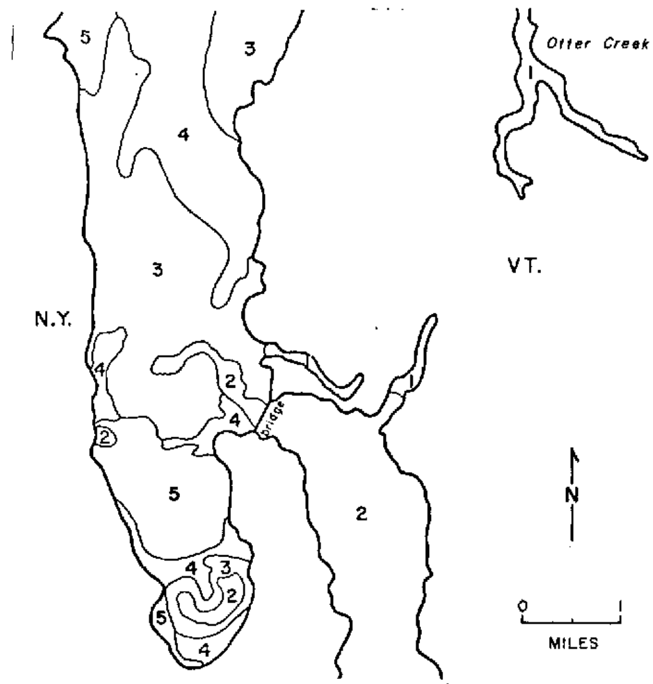


Figure 19. Relative turbidity map of the Crown Point area. The degree of turbidity is indicated by numbers ranging from 1 to 5. 1 = Extremely turbid, 2 = Highly turbid, 3 = Moderately turbid; 4 = Slightly turbid, 5 = Negligibly turbid.

Map derived from April 7 Image, Fig. 17.

ERTS coverage which shows a significant northward extension of turbid waters into the main lake. At this time, the turbid water from the southern leg of the lake is considerably warmer than the main lake, thus the turbid water flows at the surface until it reaches a state of thermal equilibrium when it becomes heavier than the main lake water and begins to slowly sink.

The surface patterns of turbidity in this spring scene reflect the influence of northerly winds which deflects the main stream of turbid water toward the west side of the lake. Turbidity along portions of the east shore of the lake is due to shore erosion of older lacustrian clays. The fetch available for northerly winds is considerable, hence wave attack is intense on these shores. In addition, the lake stage is at "flood" level which serves to accelerate the erosion process. (See p. 21 for discussion of lake stages and inundation.)

The turbidity pattern differences observed from ERTS have been observed in part on numerous occasions from the surface, but it was not possible to document the entire area affected until ERTS imagery became available. Although turbidity measurements have been made showing a substantial difference in the water of the main lake where Secchi disc readings range from 4 to 6 meters and the turbid section where disc readings are less than one meter, the exact relationship between the tonal signatures observed on ERTS-1 imagery and the specific relationship to turbidity levels remains to be investigated. However, during the period of this investigation, only a sample of the range of turbidity patterns have been observed, but it is expected that future ERTS scenes will provide data relating to a wider range of wind-wave-current situations.

Resources Significance. In view of the fact that Lake Champlain is a vital resource to Vermont and the region, data relating to water quality becomes particularly relevant for resource planning. Turbidity affects water quality significantly and therefore it becomes pertinent to examine the nature and distribution of turbidity throughout the lake. ERTS-1 imagery provides the synoptic and repetitive coverage necessary to map turbid areas of the lake. Correlating these to the environmental factors affecting such patterns, provides the necessary limnological information for resources decisions. The scale of information provided by ERTS covers all of the lake. Such a synoptic view would not be practical by ground-level observations alone.

For the moment, direct applications of ERTS-derived turbidity data is limited to limnological studies, but changes in the information needs of various lake and water-oriented agencies occur on short notice. The location of water intakes for water supplies would demand turbidity information of the type provided by ERTS. Preliminary turbidity maps can be prepared at this point to satisfy current information needs. It is anticipated that a series of turbidity maps derived from ERTS data will be included in an atlas of Lake Champlain.

LAKE ICE DEVELOPMENT AS SHOWN BY ERTS IMAGERY

Winter Conditions and ERTS Coverage. It was anticipated that ERTS-1 imagery would provide some data on ice conditions in Lake Champlain which might lead to developing a model of the lake freezing process during winter as well as the progression of melting in spring. Weather conditions during these periods involves a high incidence of cloudy-weather associated with cyclonic storms and fronts, thus for the winter of 1972-73, one good ERTS scene was obtained. At such a rate, it would appear that in order to document the lake ice freeze-thaw cycles adequately from ERTS, approximately three winter cycles might be needed. However, since the one ERTS scene obtained during the past winter is of excellent quality and shows considerable variation in the tone, pattern, and arrangement of ice features, some indication of ice development can be interpreted from this variation. The lake generally freezes over completely by mid-February, and it is only a rare occurrence when the lake does not completely freeze. No usable ERTS data are available for documenting the thaw process for the lake.

Ice Patterns Shown by ERTS Imagery. Figure 20 shows a slightly enlarged (1:800,000) scene from the one good winter ERTS image. This figure is the MSS band 5 rendition of January

Figure 20. Lake ice development on Lake Champlain, January 8, 1973. 1 = Smooth Ice; 2 = Rough Ice; 3 = Open Water.

8, 1973, (Image No. 1169-15121. Further enlargement of this scene by 2 to 3X would allow for mapping ice extent and type on base maps of the lake. The MSS band 5 image provided maximum contrast, whereas the infrared bands (MSS bands 6 and 7) provided much less by way of ice detail. As would be expected, the infrared bands provide maximum contrast for shoreline location.

The tonal variations as seen in Figure 20 appear to relate directly to the age of the ice and its previous history, as well as to areas of open water. However, it was not possible to differentiate between new ice in the process of forming or new, thin, ice and open water. This was reaffirmed by field observations and photographs. The weather conditions attending the ERTS scene were ideal for rapid formation of new ice with daily temperature ranges of -10° to +10° F. Areas of new ice observed from the ground had formed in several areas, but apparently the reflectance difference between the new, thin, ice and adjacent open water was negligible. Investigation of image enhancement procedures will be required in order to see if the differences can be brought out sufficiently to define the ice-water margins. The general area of open water can be recognized by the evaporation clouds over the main portion of the lake (bottom center of Figure 20).

The age and conditions of formation of lake ice is indicated by its tonal signature, so that dark gray-tones of smooth, relatively new ice, progress toward lighter gray-tones indicative of older ice with some wind-swept snow cover. Rougher textures in some areas are due to wind-jammed ice floes which freeze together to form rough ice. These variations in ice types were documented by ground-level photography on the day ERTS overflew the lake (Figures 21 and 2 2).

In general, the progression of freezing may be determined by the progression of gray tones described above which indicates that the northeast sector of the lake, with its numerous bays and shallow water, freezes first. The portion of the lake south of Grand Isle remains open the longest. The detailed pattern of ice development can now be mapped and compared with future ERTS scenes and applied to resource considerations and planning for additional lake studies.

Figure 21. Ground-Level view of smooth lake ice. January 10, 1973.

Figure 22. Ground-Level view of rough lake ice. January 10, 1973.

PROSPECTIVE APPLICATIONS

Problem Areas. Two lake phenomena observed from ERTS remain to be more adequately documented from ground or lake-level, and at the time of writing of this report, such documentation was lacking. In the case of algal blooms, which were detected on the first RBV coverage (July 29) of the lake, no opportunity was available to track down this highly elusive feature. Also, algal blooms figure most significantly during the warmer months of the year when conditions for phytoplankton are ideal. The imagery available to this investigation effectively straddles the ideal time for observations on algal blooms, but since this is a matter of basic interest to ongoing limnological studies, observations are planned for future summers.

A second phenomena, which was discovered late in the investigatory phase, deals with an overflow or high water outlet leading from the upper portion of Mississquoi Bay at the northern end of Lake Champlain across the Alburg peninsula into the Richelieu River. The channel pattern seen on spring 1973 ERTS coverage strongly suggests that there is some flow of an undertermined amount through this outlet. A review of available topographic sheets indicates such a possibility. A highly localized geographic terminology apparently exists for the area which is known as the "overflow." Investigations are planned to more fully study this possible outlet which has not appeared as yet in any scientific literature dealing with Lake Champlain. This general area has special significance now, since there is considerable discussion regarding the establishment of controlling works relating to high lake-levels. (See p. 21.)

Algal Blooms. Mass concentrations of algae and diatoms are not uncommon in the warmer months of the year and the extent and distribution of such masses would bear significantly on limnological questions of lake enrichment which in turn relates to water quality and pollution. The presence of mass concentrations of algae may potentially be detected in either the near infrared or the green, visible band. The July 29 coverage of ERTS (Image No. 1007-15113) revealed no significant tonal variations in the near infrared indicating that the main mass of algae was sufficiently below the surface to allow for full absorption of infrared energy. Some tonal variations were detected in the band 1 image which corresponds to the green spectral region. These did not appear again in the adjacent red band. The suspected algal blooms are shown in Figure 23 which is an enlarged portion of the RBV scene.

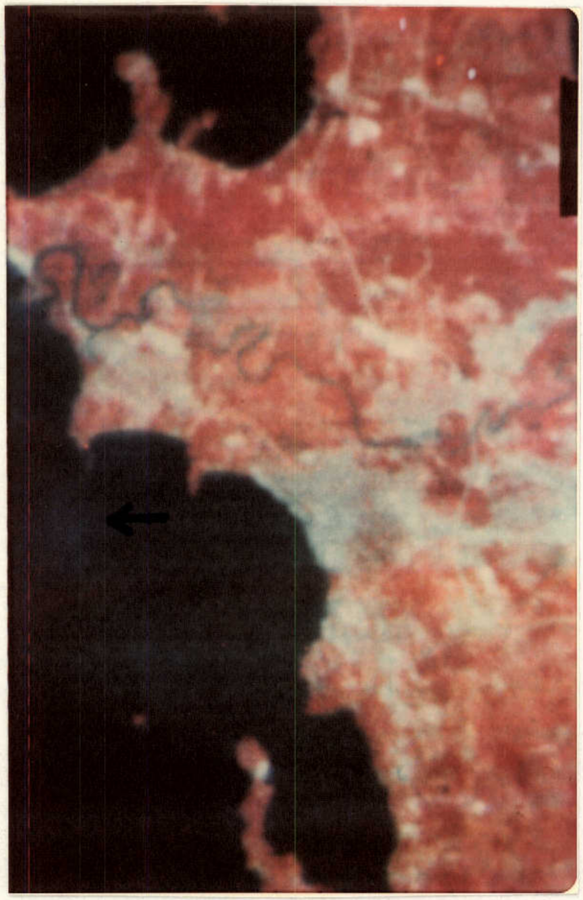


Figure 23. Suspected algal blooms RBV band 1, 30 July, 1973.

Figure 24. Possible overflow channel during high lake stages. January 10, 1973, MSS band 5 rendition.

The Overflow. The channel thought to provide an outlet for Lake Champlain during high lake levels is seen in Figure 24 which is an enlarged scene from the winter coverage of January 8, 1973 (Image No. 1169-15121). Although the major portion of the channel is a wooded wetland, definite indications that water occupies the channel area is seen in the near-infrared bands from the April ERTS coverage when the lake stages were close to 100 feet (see p.21 for discussion of lake levels). The nature and magnitude of flow are unknown, so investigation of the area is necessary in order to provide a reasonably accurate water budget for the lake. As indicated before, the resources significance of these suspected channels has recently been magnified in the search for possible solutions to the high lake levels which have occurred over the past three years.

III. LAND USE APPLICATIONS OF ERTS-1 IMAGERY

As a result of recent legislative activity within the State of Vermont, a new state-wide land use and capability plan has been proposed which is officially and popularly known as Act 250. Prior to the development of this legislation, a large effort of state-wide land use mapping was required. The data for the land use mapping project were begun in 1972, but the data were several years old and consisted of large scale aerial photographs of 1962 and 1968 vintage. In view of the significant changes in land use that have occurred in some portions of the state due to recent land developments for residential and recreational facilities, significant updating is already required at broad scales. Moreover, the initial mapping project, which this investigator directed, was hindered by poor imagery for several large areas making the photo-interpretation task especially difficult and the information quality poor. Thus, it seemed especially pertinent to investigate the potential of ERTS data for application to the larger scale considerations of land use mapping, or more appropriately, land use map updating.

Land use applications also figure significantly in a second area of interest related to water resources. For studies relating to the water budget of the Lake Champlain basin, the consumptive use of water by the changing state of vegetative cover in croplands and forest lands is a necessary consideration. Runoff potentials from different kinds of land surfaces (land use areas) could be estimated more accurately with seasonal data provided by ERTS.

Vermont poses some special problems in land use mapping which appear to also be common to other sections of the New England region and possibly other portions of the East. Land holdings in farms are generally small and individual fields are generally small. Moreover, there is little regularity in field pattern which is understandable in view of the metes and bounds system of land surveying which prevails in this region. These factors would seem to militate against any field by field inventory from ERTS in the case of agricultural lands.

In order to evaluate the applicability of ERTS-derived data in land use mapping, four test areas were established which represent a range of conditions. These areas are identified in Figure 25 and generally contain the following characteristics (Table 4).

TABLE 4

Land Use Test Area Characteristics

Area	Name	Features
A	North Hero	Insular, Agricultural
B	Burlington	Urban
C	Cedar Swamp	Agricultural, Wetlands
D	Mt. Mansfield	Forest Lands

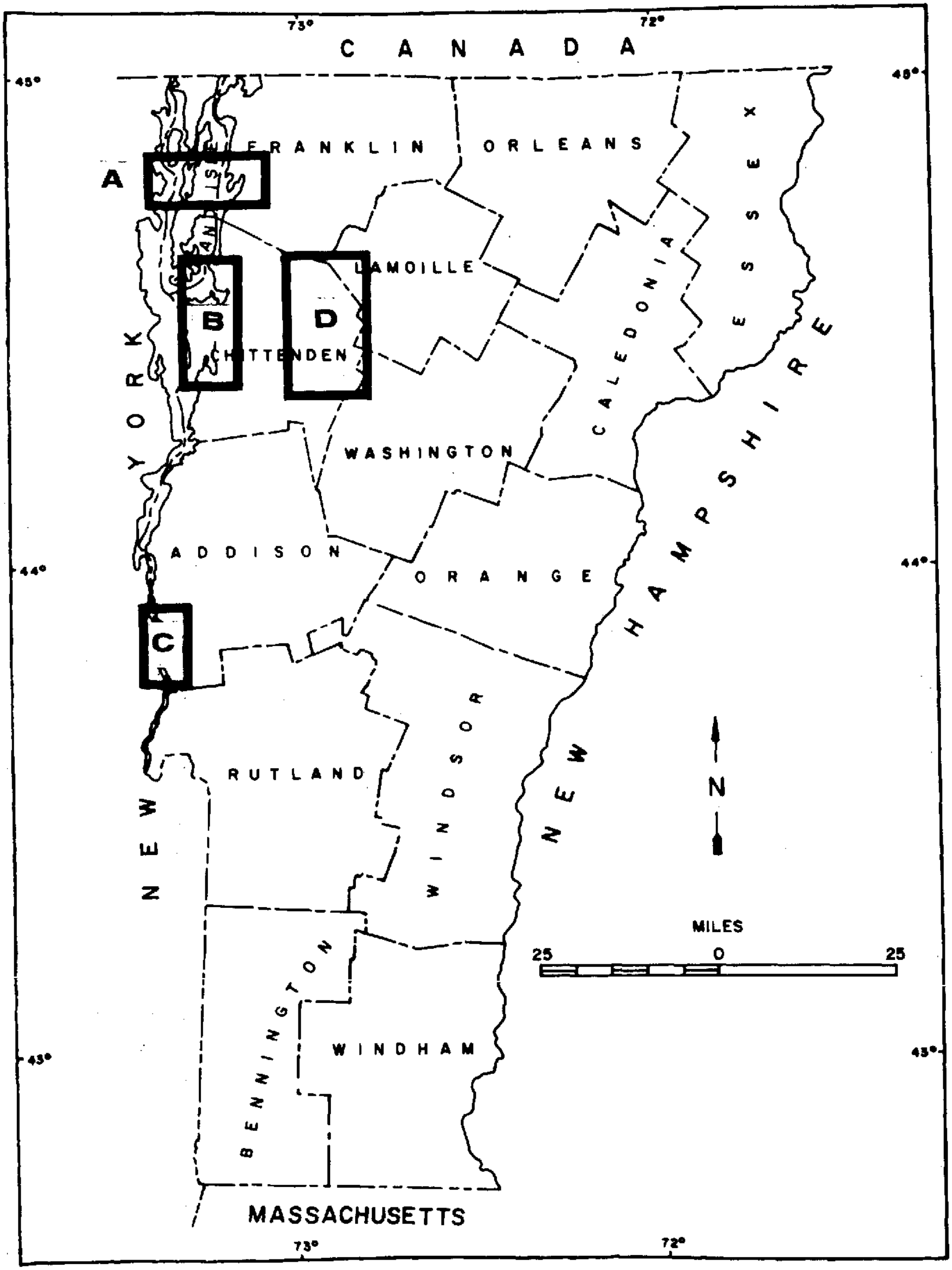


Figure 25. Land Use Test Areas.

Test areas A and C comprise agricultural areas and were inventoried in detail by ground survey in conjunction with aerial photographs. Areas B and D were photographed in detail by NASA aircraft. Supplemental ground photography was also obtained to further document land use characteristics and field mapping of selected areas was undertaken to assist in verifying the ERTS-derived land use information.

AGRICULTURAL LAND USE

Agricultural Activity. The single most important agricultural activity in the region is dairying, and in support of this, agricultural lands are used for the production of fodder crops or are permanent pastures. Orchards are important locally in parts of the Champlain Lowland. No great variety of crops is produced at a large scale, so the only row-crop of significance is corn, which is grown for mainly grain and silage. Hay crops and some minor cereal grains, such as oats, are cover crops which occur widely. In the latter group, alfalfa is also significant.

Individual family-owned farms of relatively small size characterize most of the study areas and within the farm units, field sizes are generally on the order of 20 to 40 acres. Terrain conditions often limit croplands and pasture, and woodlots or orchards intermingle with the other agricultural uses.

ERTS Imagery. The timing of ERTS coverage appears to be of critical importance for land use mapping in rural areas where the reflectance characteristics of the vegetative cover changes with season. Because land-use mapping in agricultural areas requires special attention to vegetative cover characteristics, all ERTS spectral bands, and particularly the near-infrared, contain significant data. Therefore, analysis of ERTS data for land use patterns virtually requires a multispectral viewing technique. In addition, substantial scene enlargement (4 X) is required to gain as much detail as possible and to compensate for the generally small field sizes.

The first ERTS data received for this task were RBV scenes from July 29, 1972 (Image No. 1007-15113). These scenes provided the basis for differentiating two major land use classes, namely, agricultural land (cropland and pasture) and woodlands. These were delineated on base maps of the two agricultural land-use study areas.

Upon receipt of fall coverage (October 10, 1972, Image No. 1079-15115), the major categories were again mapped, but with considerably greater ease, and also it became apparent that this coverage provided a fairly significant difference in terms of reflectance between cover crops (including pasture) and row crops (entirely corn). These scenes are reproduced in Figures 26 and 27 which shows a considerably enlarged portion of the MSS scene as projected through a multispectral viewer.

The winter ERTS coverage from January 8, 1973 (Image 1169-15121) offered additional assistance because of a considerably prominent reflectance difference between open areas which were covered with a few inches

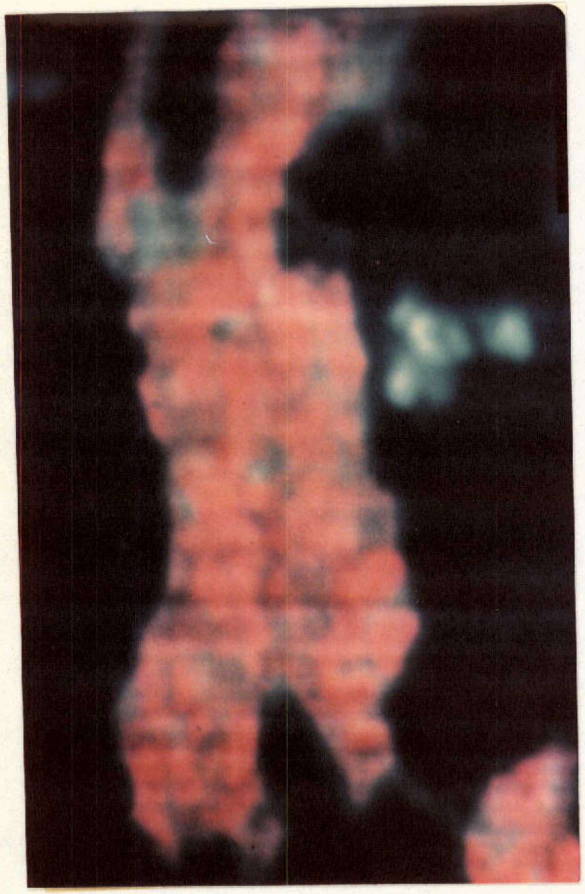


Figure 26. Enlarged ERTS Scene, North Hero Test Area, October 10, 1972.

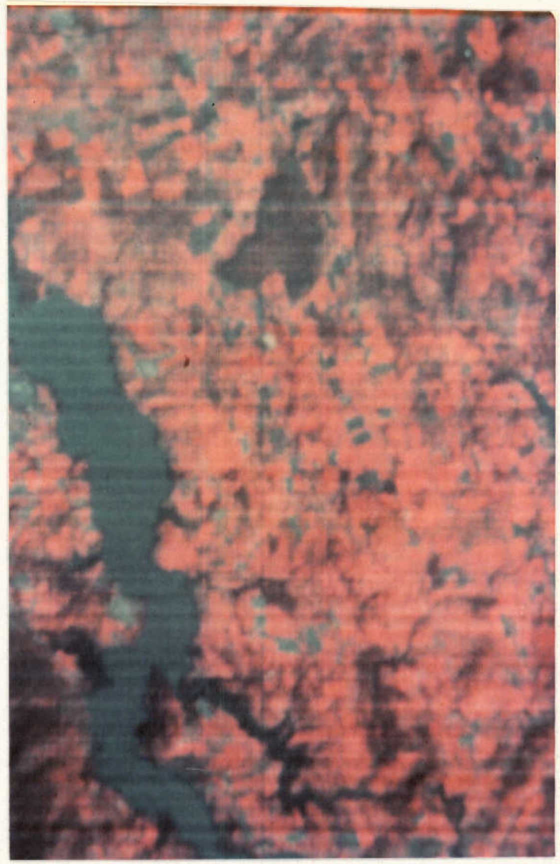


Figure 27. Enlarged ERTS Scene, Cedar Swamp Test Area. October 10, 1972.

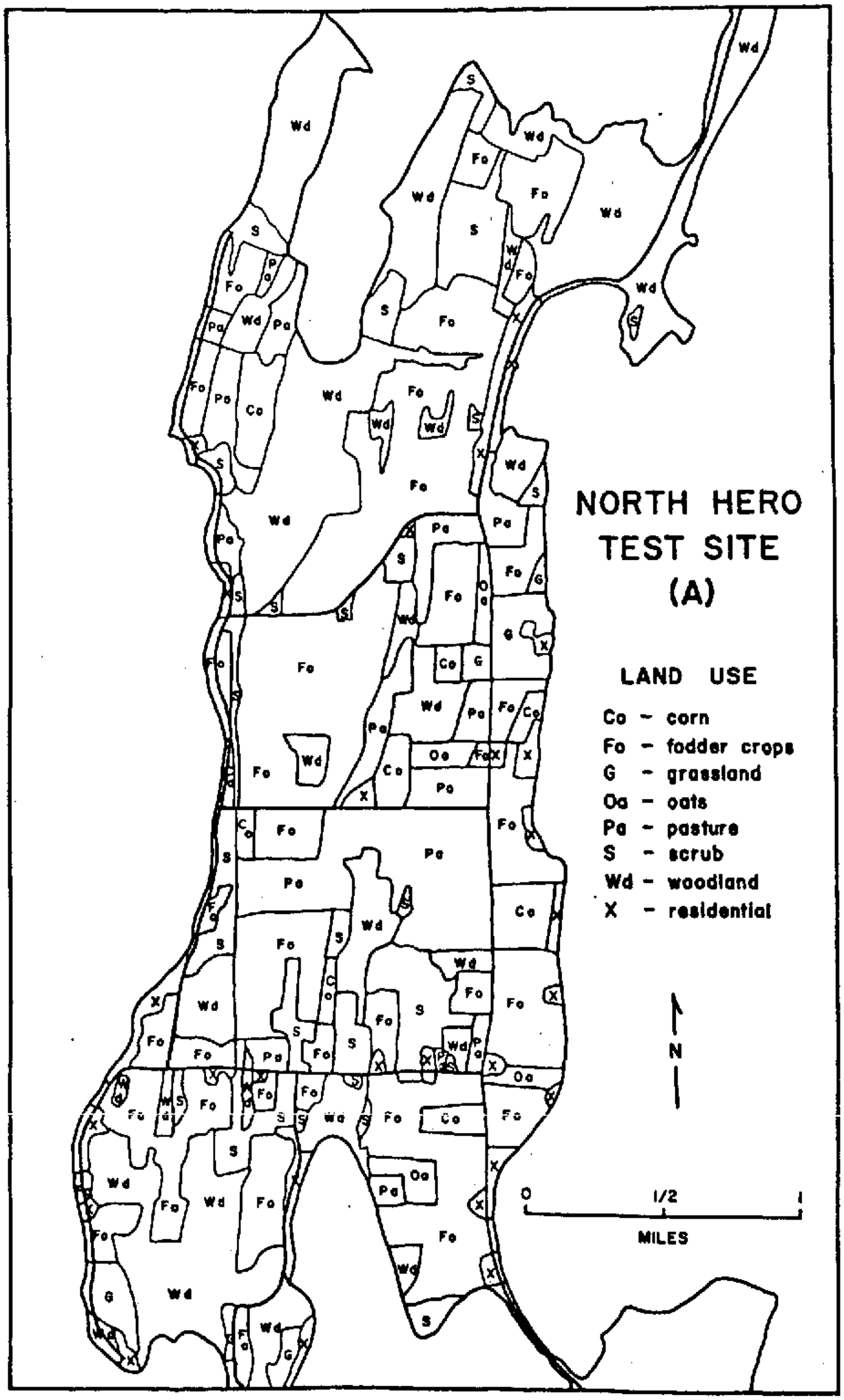


Figure 28. Detailed Field Survey, North Hero Test Area.

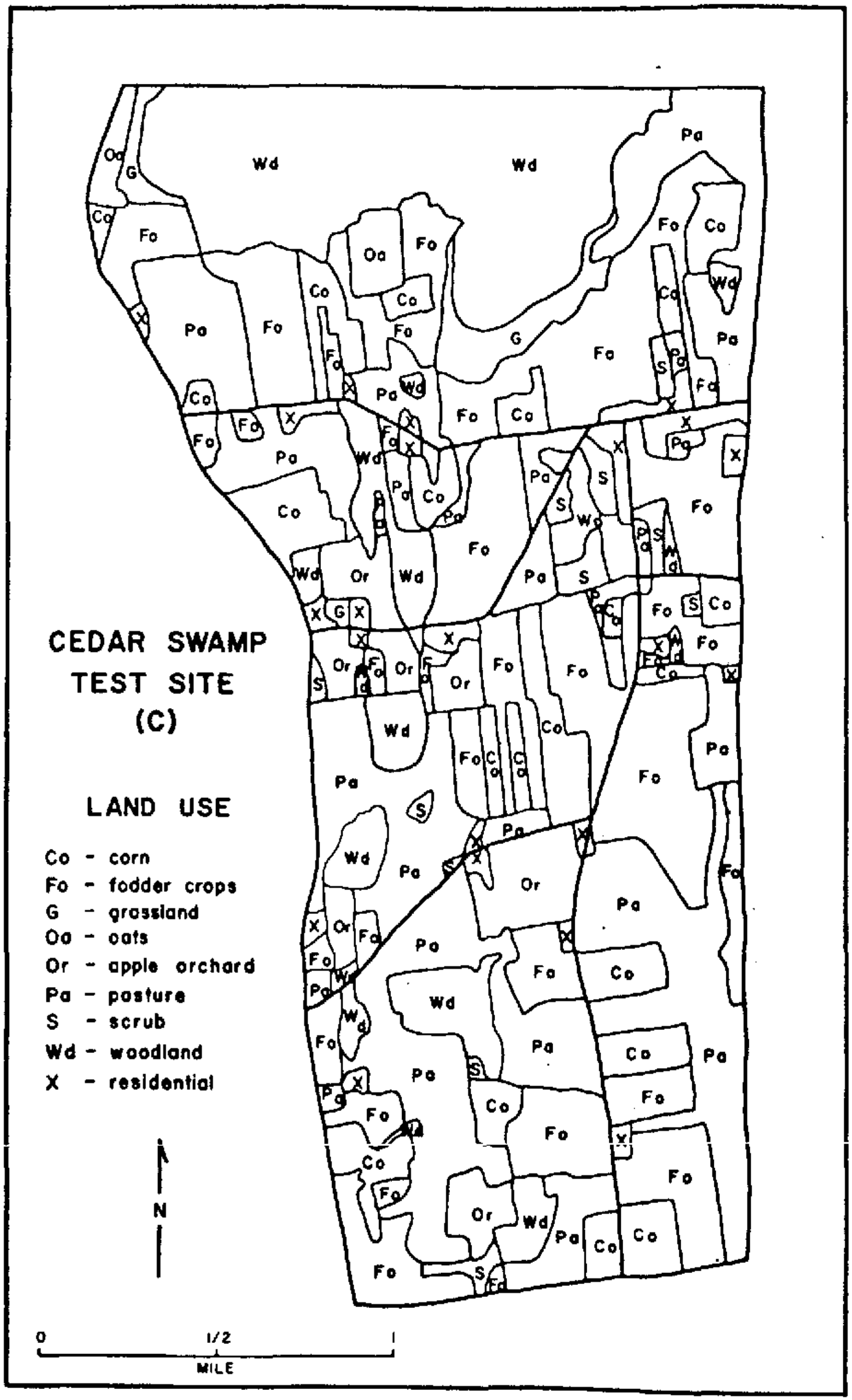


Figure 29. Detailed Field Survey, Cedar Swamp Test Area.

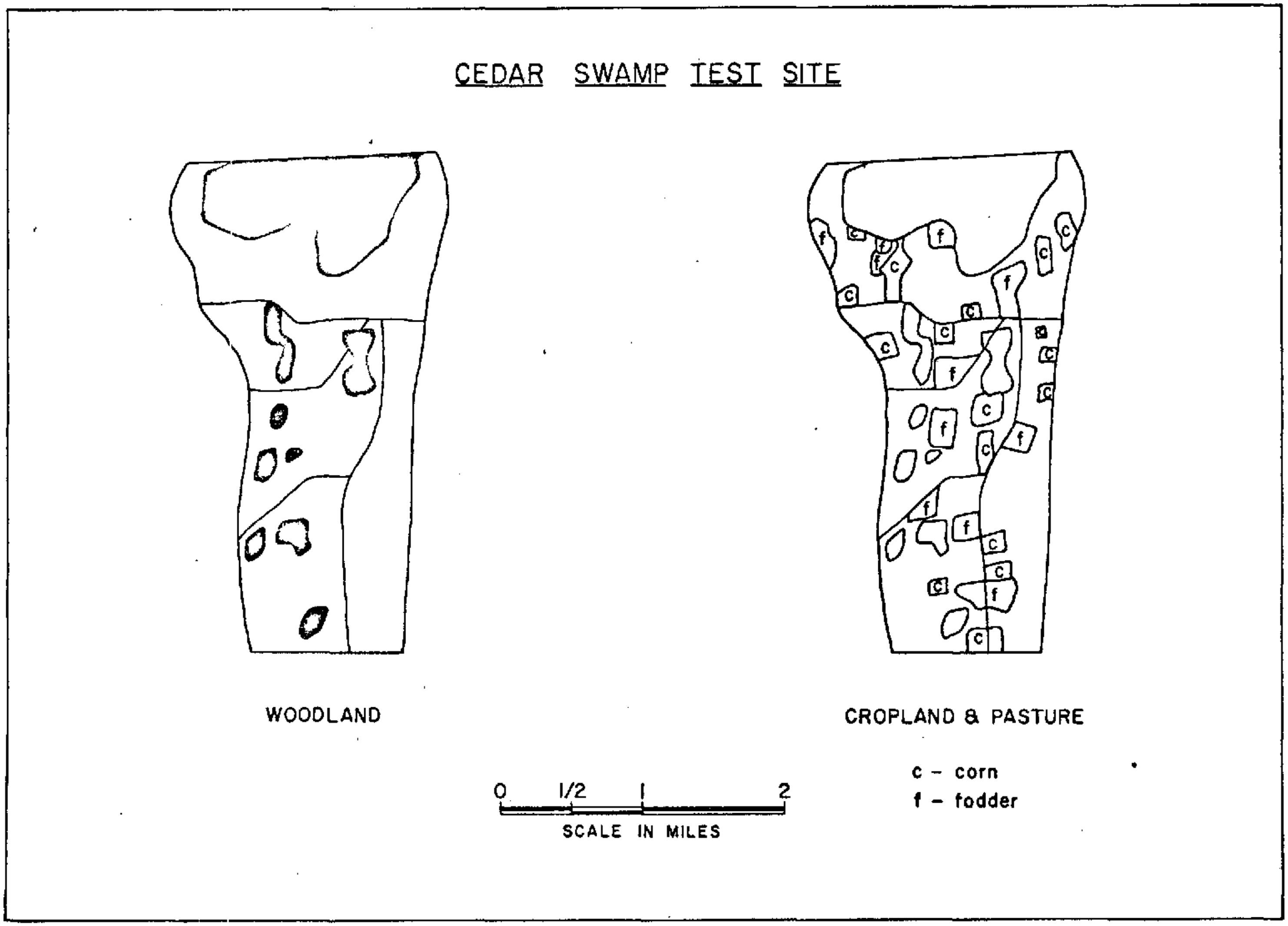


Figure 31. Land Use From ERTS.

of snow and the forested areas, which were rendered in dark tones because of the dense cover of bare branches in the lowland deciduous forests. Thus, seasonal coverage from summer, fall, and winter, contributed in a cumulative way to a final land use map. (See Figures 30 and 31.)

An attempt was made to examine the relative accuracy of mapping land use from ERTS following the above procedures. ERTS derived maps were compared to detailed field surveys with the results summarized in Table 5 below.

TABLE 5

Comparative Land Use Data

ERTS vs Ground Truth

Land Use Class	Acreage Ground Truth	Acreage ERTS	Percent of Total Area Ground Truth	Percent of Total Area ERTS	Percent Difference
All woodland	1508	1303	40	36	13.5
All agricultural	2111	2225	56	61	5.0
Other (Residential)	156	120	4	3	23.0
TOTAL	3775	3648	100	100	3.3

Attempts to define land-use at lower classificatory levels were successful only in the agricultural land use division where a distinction between cover crops (including pasture) and row crops (corn) could be made. The comparative results for finer divisions are shown in the following table.

TABLE 6

Comparative Land Use Data for Lower Order Classes

Land Use	Acreage Ground Truth	Acreage ERTS	Percent of Total Area Ground Truth	Percent of Total Area-ERTS	Percent Difference
Woodland	1179	1226	31	34	3.8
Scrub	329	77	9	2	76.5
Cover crops (includes pasture)	1984	2246	53	61	11.5
Row crops (corn)	127	102	3	3	19.6
Fodder only	1394	365	37	10	73.8

From the above table it is apparent that a woodland-scrub differentiation is particularly difficult, and interpretation of ERTS data greatly underestimates scrub areas. Overall, however, the inclusion of scrub with woodland provides a very good comparison. The differentiation of cover crops vs. row crops is also feasible and with a larger sample, the differences would become less. However, attempting to separate fodder crops from pasture produces a large difference which apparently results from the fact that many fields of fodder crops had been cut and would therefore appear similar to pasture lands. This problem might be resolved by use of early summer imagery (June) when fodder crops, such as hay (timothy, alfalfa, etc.) and sudan grass.

In sum, ERTS provides reasonably reliable land-use data on a broad scale, which provides a useful tool for updating and inventorying land use at the accuracies acceptable to most small scale mapping problems.

<u>Resources Significance</u>. As indicated earlier, a major land use mapping project for the State of Vermont was conducted recently using 1962-1968 aerial photographic data. For the agricultural study areas identified above, the data are essentially 10 years old. A comparison of the small scale maps resulting from the State project and ERTS maps showed some increase in woodland acreage. This agrees with known changes in land use over the period where most marginal pasture lands have reverted to scrub and woodland. A correction in the land use inventory was made on the basis of ERTS coverage which agreed with field

checks in the area. These changes are of special interest to the State Planning Office which is charged with maintaining the land use inventory.

Aside from the direct applications which can be made on short notice for maintaining a land use inventory, an additional application is under serious consideration in the water resources field. In this context, what is of special interest is the consumptive uses by vegetation and runoff characteristics associated with particular major land use classes. Of particular value here, are the seasonal data provided by ERTS along with its synoptic coverage of virtually the entire drainage basin of Lake Champlain. A project of this scope is now under serious consideration.

URBAN LAND USE

<u>The Burlington Test Site</u>. The largest urban area in Vermont is found in Chittenden County which contains the City of Burlington (population 40,000) and several suburban communities. The test area shown in Figure 32 comprises a portion of the urban area which extends into the urban fringe zone and surrounding rural area. The major objective with respect to the ERTS imagery is to delimit the urbanized or built-up areas. The urban fringe zone is currently an area of rapid change involving conversion of rural uses to urban (residential) uses. It would appear that periodic updating of land uses would be especially important in these areas of rapid change.

<u>ERTS Imagery</u>. An intial attempt to map urban areas from the RBV data which were available earlier in the investigation proved successful. For this mapping task, enlargements of the individual RBV bands were projected through a multispectral viewer providing a sufficiently wide range of color-tones to differentiate the following land use classes:

a) Built-up area - low intensity
b) Built-up area - high intensity
c) Non urbanized - (woodland and cropland)

The result of the mapping is presented in Figure 32 which agrees very closely with data obtained from NASA support aerial photography and ground observations. The overall differentiation between urban built-up areas and non-urbanized, rural areas is extremely close with an estimated error of only 5 percent. The differentiation within urban areas is however more difficult with a corresponding increase in error. ERTS-1 imagery provides a reliable basis for at least separating built-up areas from non-built-up areas. This is in itself a contribution which has resource significance as described in the previous section.

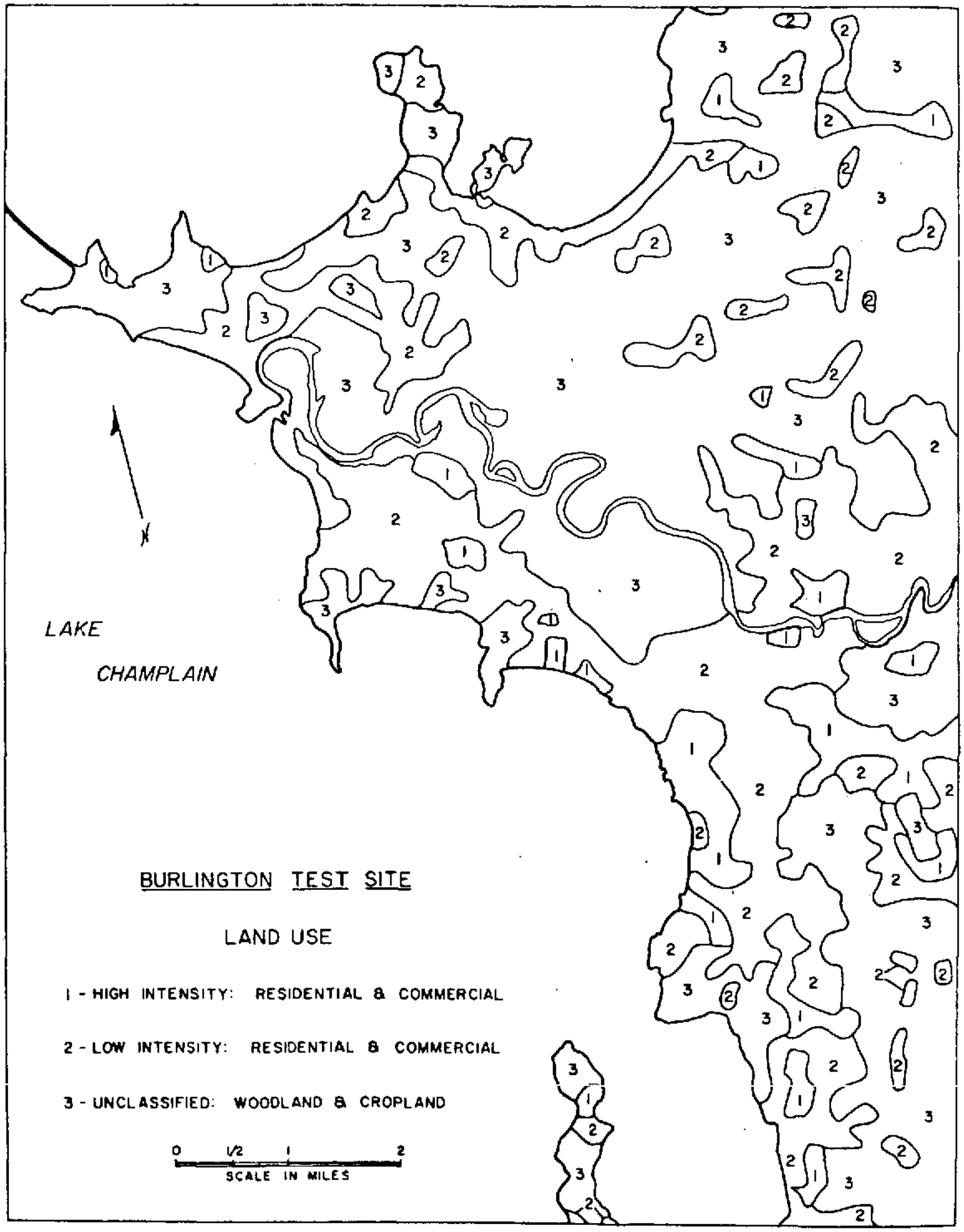


Figure 32. Urban Land Use From ERTS. See Fig. 23 for ERTS image of the urban area included above.

FOREST LANDS

The Mount Mansfield Test Area. Testing the applicability of ERTS-derived land use data in a mountainous, forested region is a major concern since much of Vermont is so characterized. The test area shown in Figure 33 straddles the main topographic axis of the Green Mountains and contains the highest peaks in Vermont (Mt. Mansfield, 4,393 feet). This is a heavily forested region which also contains significant resort activities, primarily related to skiing. This area offers sufficient elevational contrasts to provide for a range of forest types. Deciduous forests consisting of a birch, beech, maple association occupy lower slopes while the summit regions have a coniferous association of spruce-fir. Mixed forest stands are often at lower elevations and contain mainly white pine. These stands represent various regrowth stages after a major removal of forest cover.

ERTS-1 Imagery. This area was last to be mapped among all of the test areas, and by that time the January 8 ERTS coverage was available (Image No. 1069-15121). As indicated previously, the snow cover occurring at that time enhanced the differences between forest and non-forest so that an initial step was to map this boundary using enlargements of the scene. It was not possible to differentiate forest groups, i.e. deciduous vs. coniferous or mixed due to the strong tonal shadows resulting from low sun angle.

The differentiation of forest types shown in Figure 33 was based on fall coverage provided in the October 10, 1972 MSS scenes (Image No. 1079-15115). A multispectral viewer was necessary since all bands were used in the mapping process. The overall mapping effort produced good results for identification of: a) coniferous forest, b) deciduous forest, c) mixed forest, and d) non-forested lands. Comparison of the results with field observations and aircraft imagery are in substantial agreement and it can be concluded that ERTS derived data may be used for identification and mapping of major forest types.

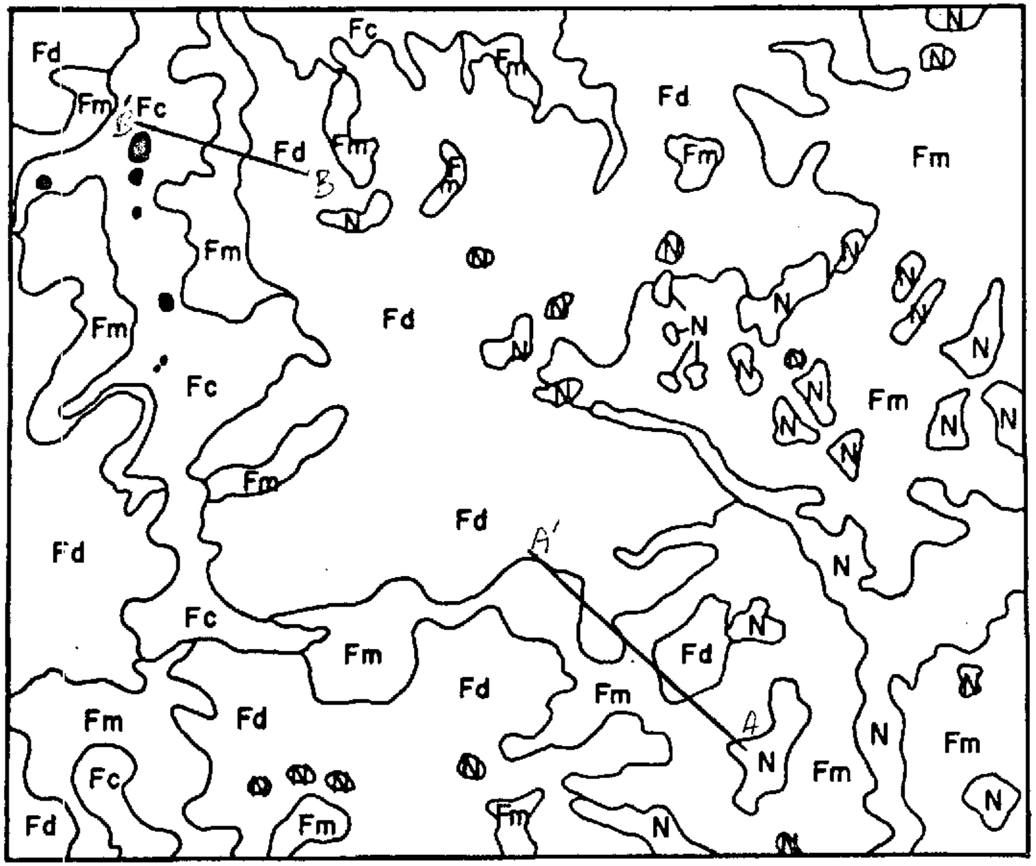


Figure 33. Forest Land Type from ERTS. Key to Symbols: N = Non-forested, Fd = Deciduous Forest, Fc = Coniferous Forest, Fm = Mixed Forest. Line A - A' corresponds to center of field of view in Figure 34; B- B' to Figure 35.

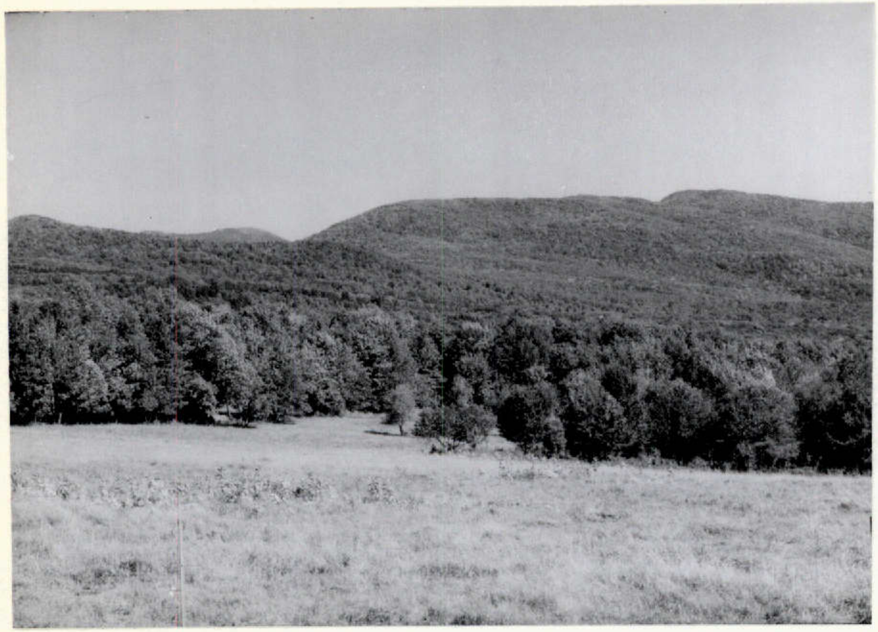


Figure 34. View across mixed forest in foreground, deciduous forest in middle vale area and mixed forests in the distance. See Figure 33.

Figure 35. View towards Mt. Mansfield with deciduous forest in foreground, mixed forest on upper slopes grading into coniferous forest at crest. See Figure 33.

IV. SUMMARY OF RESULTS

NASA RESOURCE CATEGORIES AND APPLICATIONS

The results described in the previous section of this report fall under diverse discipline and sub-disciplinary fields as defined by NASA. In terms of major disciplinary categories, the results obtained thus far come under:

Group 1	Agriculture/Forestry/ Range Resources
Group 2	Land Use Survey and Mapping
Group 4	Water Resources
Group 7	Environment

Each of these major disciplinary headings is further divided into sub-disciplines. Table 7 lists the specific NASA categories that apply to the results obtained during the course of this investigation. This table also summarizes the nature of the resource application at the time of writing of this report.

TABLE 7

Result Summary by NASA Resource

Category and Application

Resource Element Identified in This Report	Pertinent Resource Categories	Application
Water Pollution	7.C. Lake and River Pollution Surveys 4.D. Limnology	Legal suit. Vt. vs. N.Y. & International Paper Co.
Lake Levels & Flood Assessment	4.F. Flood Assessment & Prediction 4.D. Limnology	For engineering & planning purposes regarding lake level control
Turbidity	4.D. Limnology 4.M. Turbidity (Other)	Lake studies Lake shore erosion Water quality Water supply planning
Lake Ice	4.I. Lake Ice Surveys 4.D. Limnology	Lake studies Recreation
Algal Bloom	4.D. Limnology 7.C. Lake & River Pollution Surveys	Lake studies Water quality investigation
Lake Overflow Channel	4.D. Limnology 4.C. Wetlands Survey	Lake studies Engineering & planning related to lake level control
Agricultural Land Use	1.A. Crop Survey & Mapping 2.A. Land Use Classification	Updating general land use maps Land use studies for planning
Urban Land Use	2.A. Land Use classification	Updating general land use maps Land use studies for planning
Forest Land Type	2.a. Land Use Classification	Updating general land use maps Land use studies for planning

EVALUATION OF ERTS-1 IMAGERY

There is a continual need to evaluate remote sensor outputs to determine their application for specific tasks. For the varied results described in this study, different combinations of spectral band imagery or, in some cases, specific band imagery was used. Table 8 summarizes the relative value of ERTS spectral bands by a ranking procedure and comments on the application of multispectral viewing of all bands simultaneously.

From the single band point of view, the 600-700 nm. (red) and the two infrared bands (700-800 and 800-1100 nm.) are particularly important. These correspond to MSS bands 5 (red) and 6 and 7 (infrared). MSS band 4 (500-600 nm.) assumes its importance principally in the multispectral viewing process, but on two occasions ranks first from the single band point of view.

TABLE 8

Evaluation of ERTS Imagery

Single Band and Multispectral

Resource Element	Individual Spectral Band Rank* MSS: 4	5	6	7	Multispectral Combination in Color
Water Pollution	1	2	0	0	Helpful Necessary for detailed mapping
Lake Levels & Flood Assessment	3	2	1	1	Unnecessary
Turbidity	2	1	0	0	Helpful Necessary for detailed mapping
Lake Ice Survey	2	1	3	3	Essential
Algal Bloom	1	2	0	0	Essential
Lake Overflow Channel	3	2	1	1	Unnecessary
Agricultural Land Use	3	2	1	1	Essential
Urban Land Use	3	2	1	1	Essential
Forest Land Type	3	2	1	1	Essential

Key to Ranks:
- 0 = No Data
- 1 = Best individual band imagery may be used for detailed study-mapping
- 2 = Useful rendition for general survey, but not for detailed investigation
- 3 = Poorest rendition and difficult to use without assistance of other bands

APPENDIX A

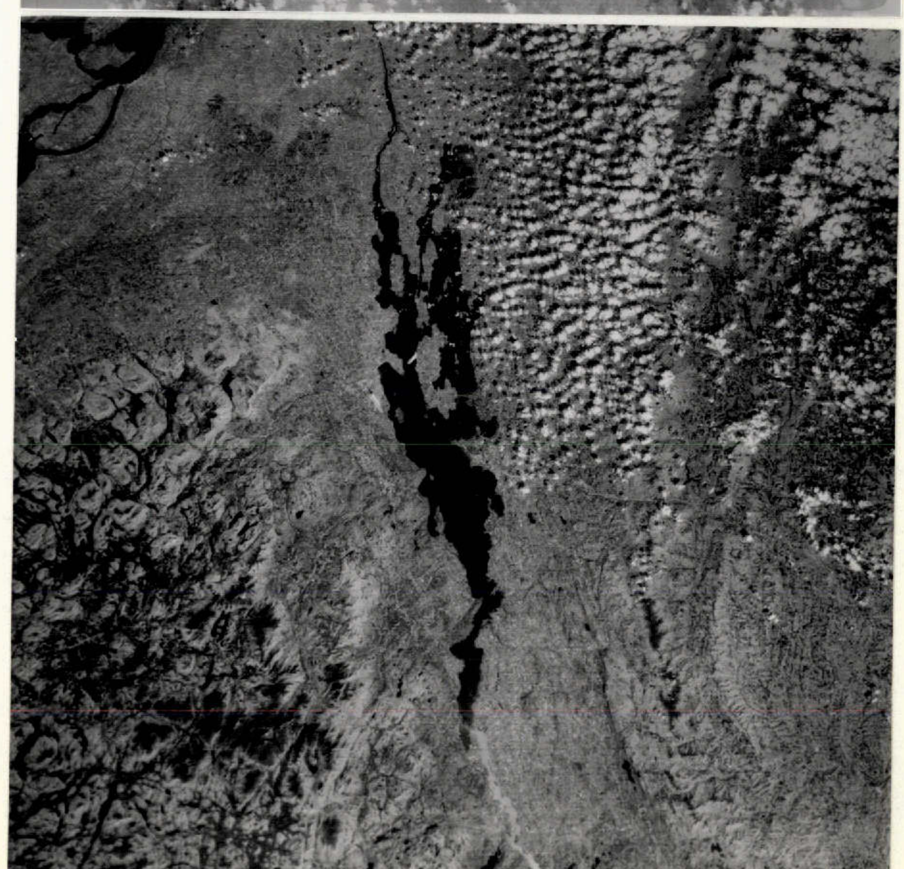
CATALOG OF ERTS IMAGERY

BY DATE*

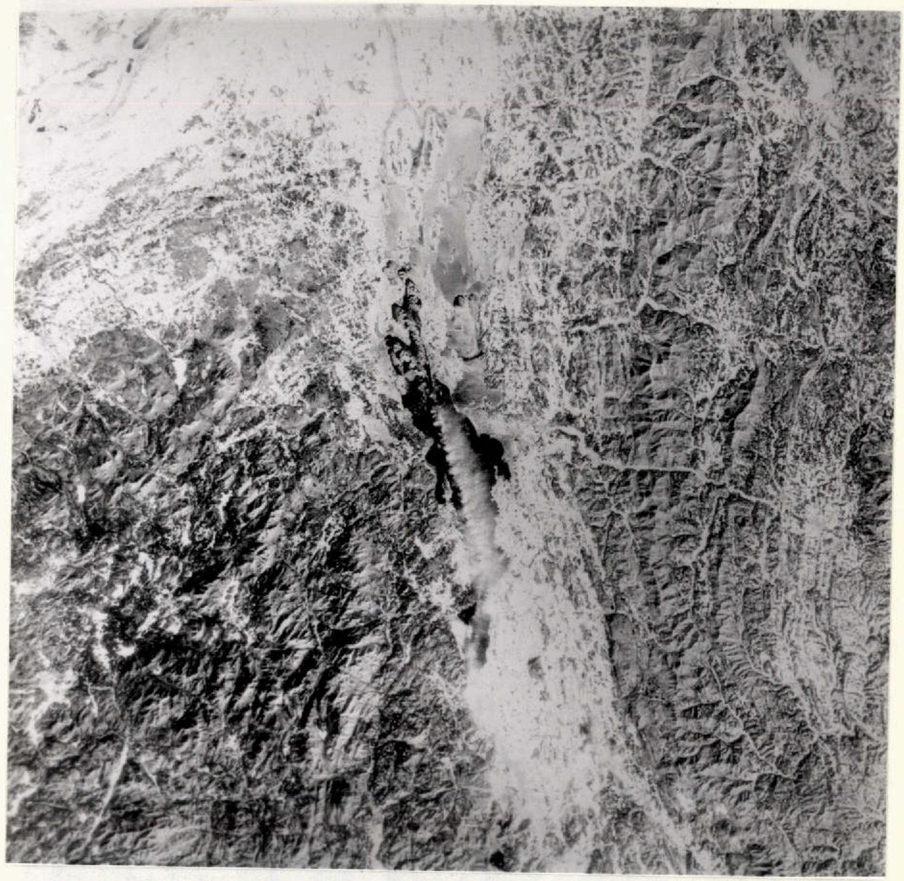
*See Table 2 for image numbers.

7/30/72

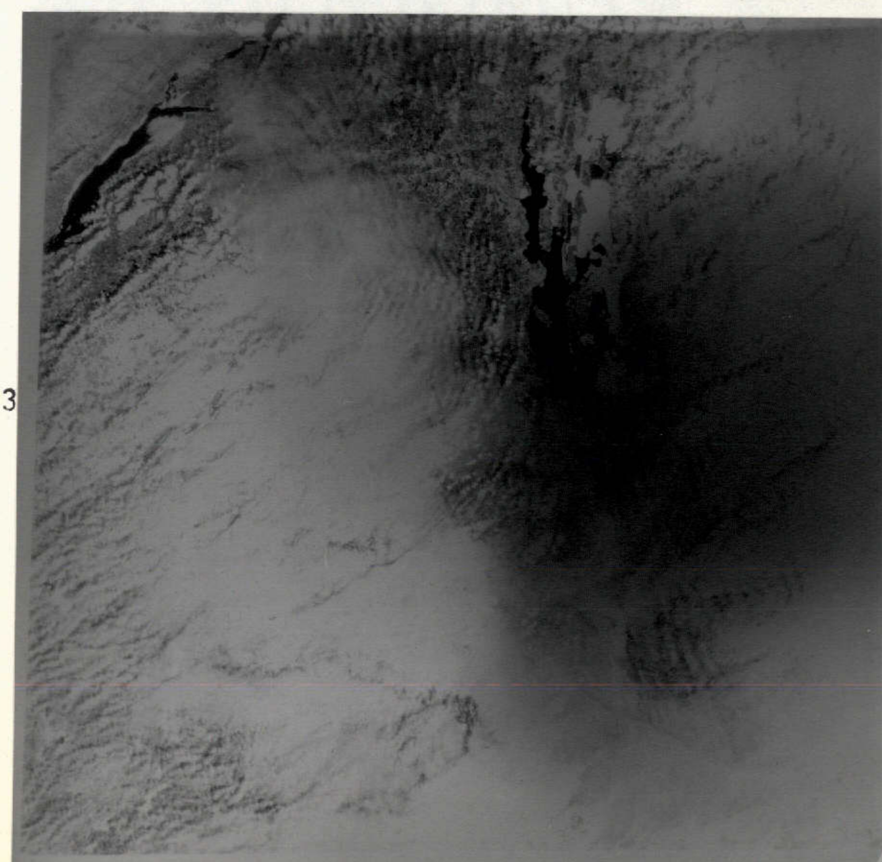
10/10/72



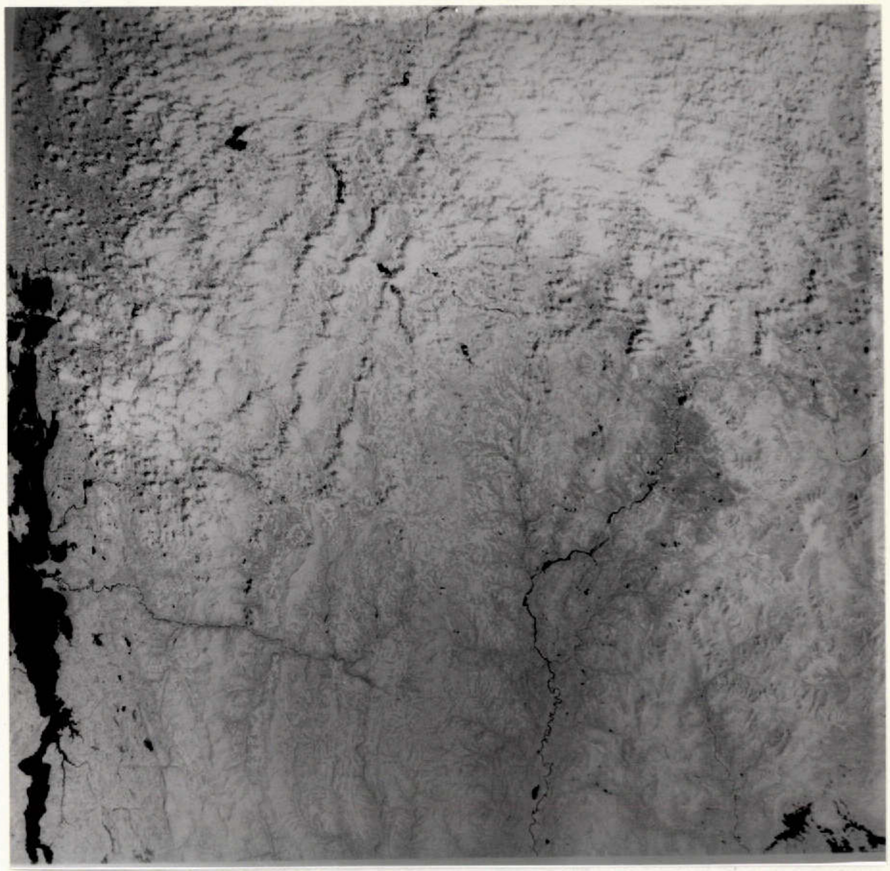
1/8/73



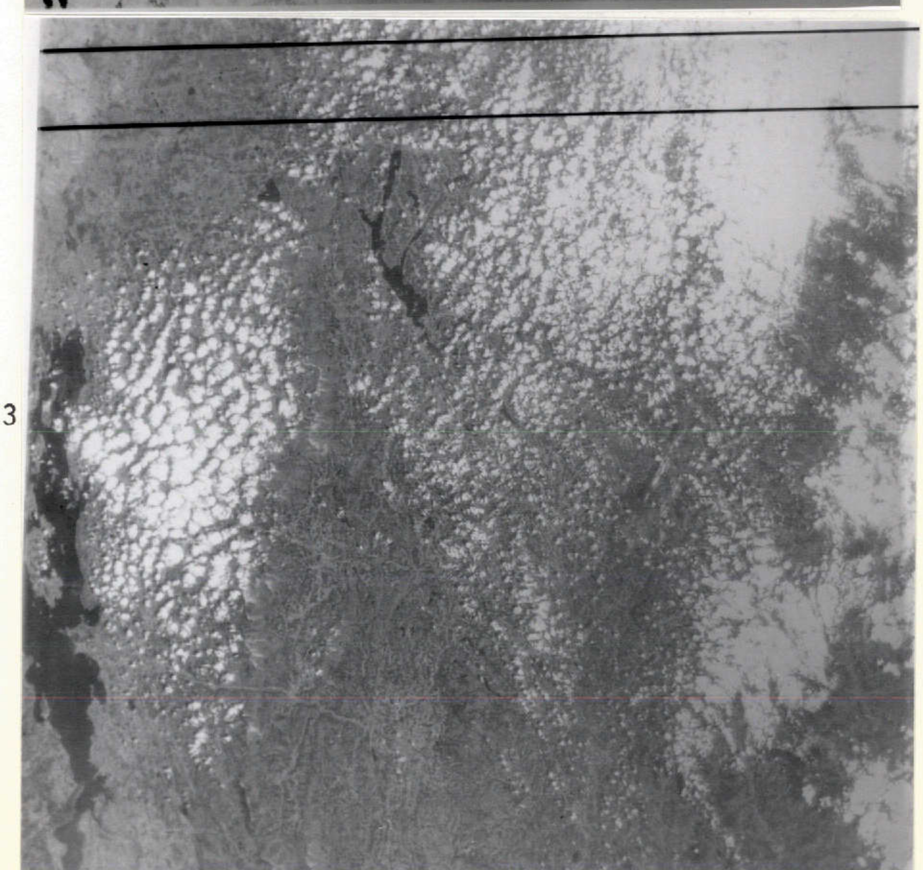
3/21/73



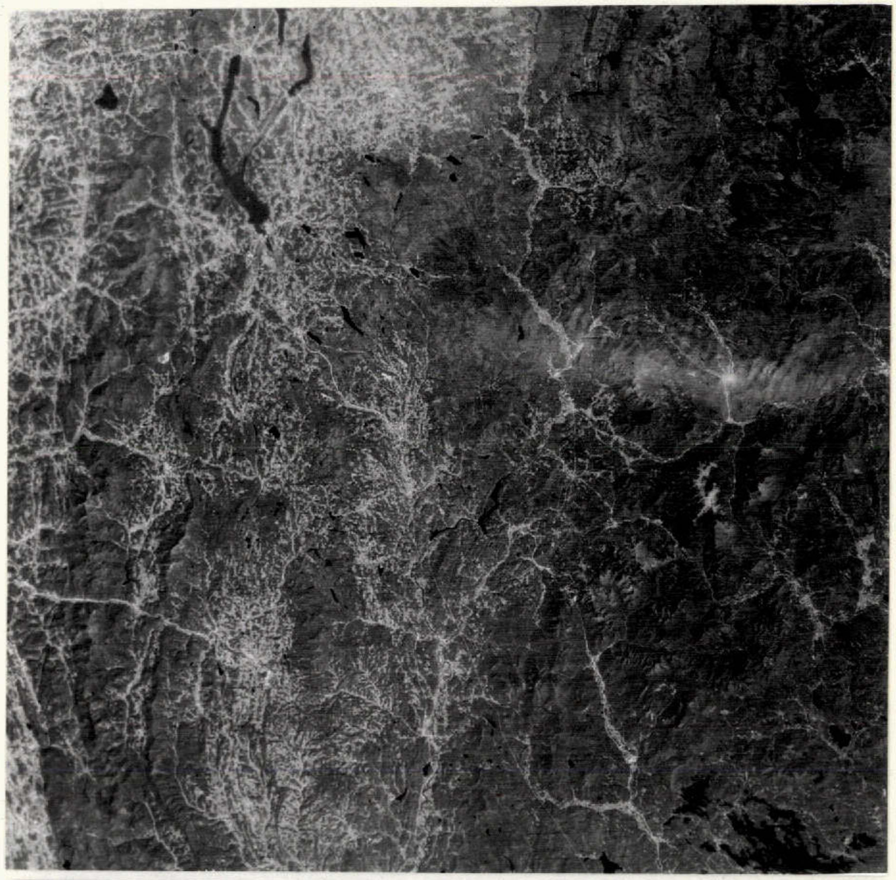
4/7/73



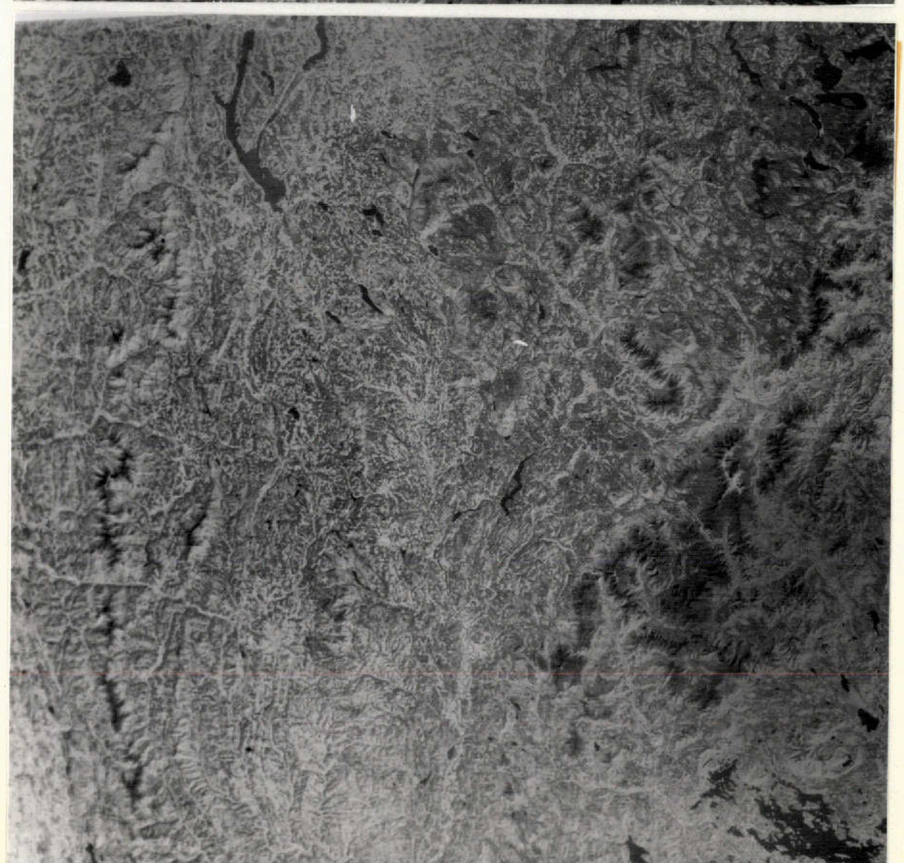
4/25/73



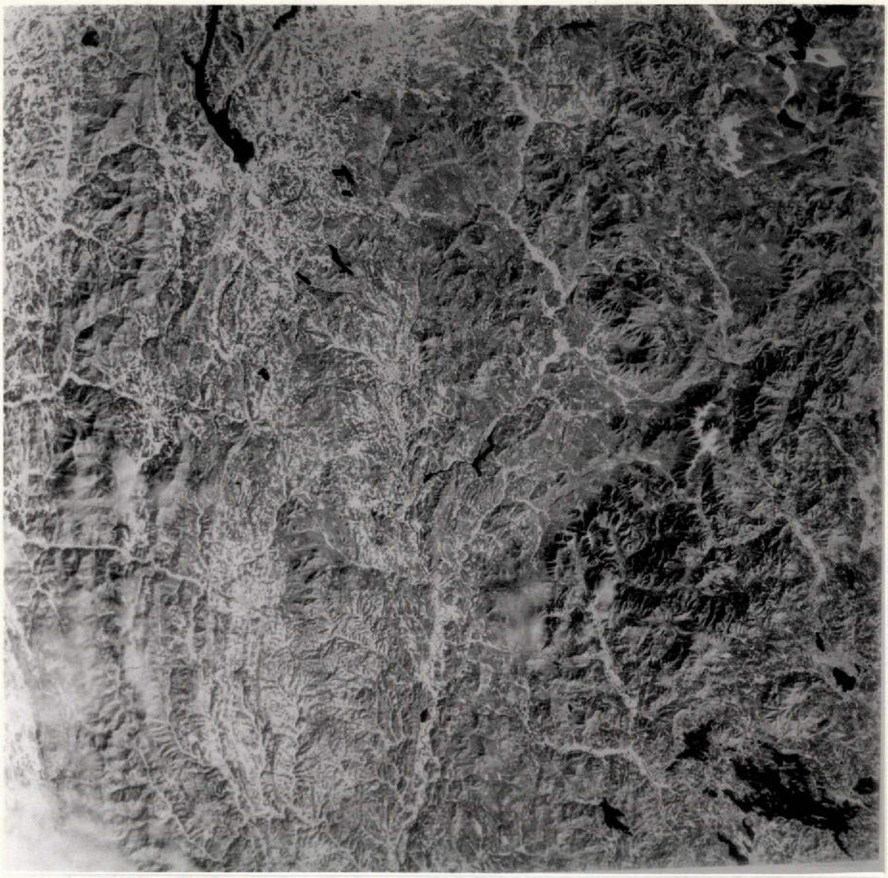
9/21/72



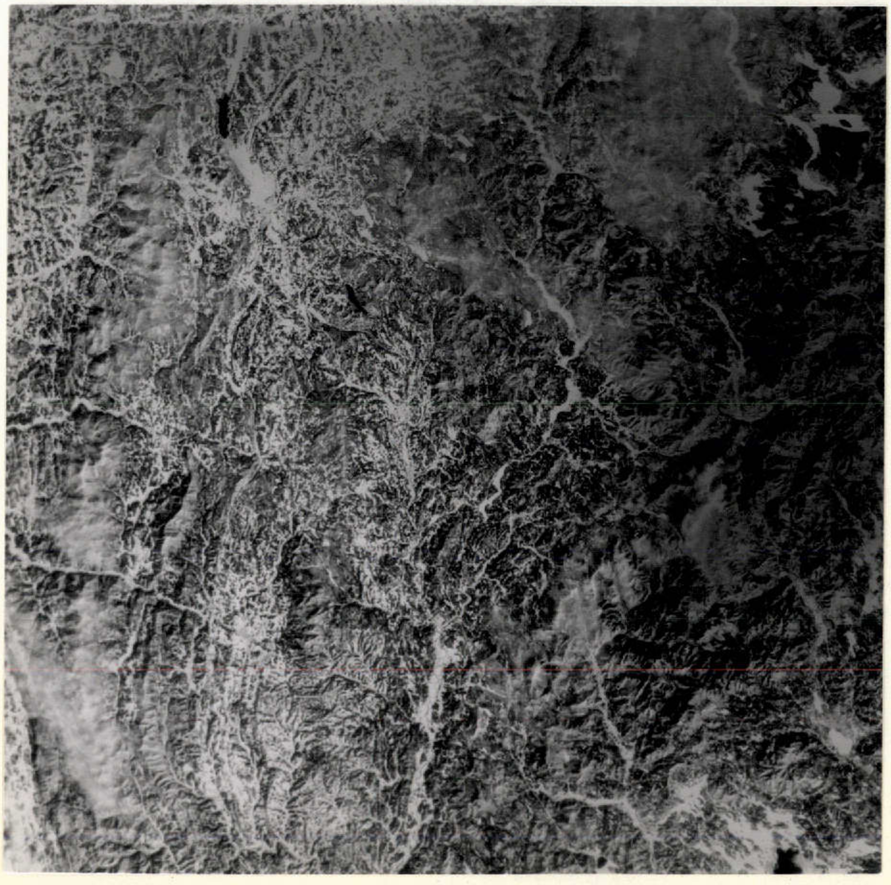
10/27/72



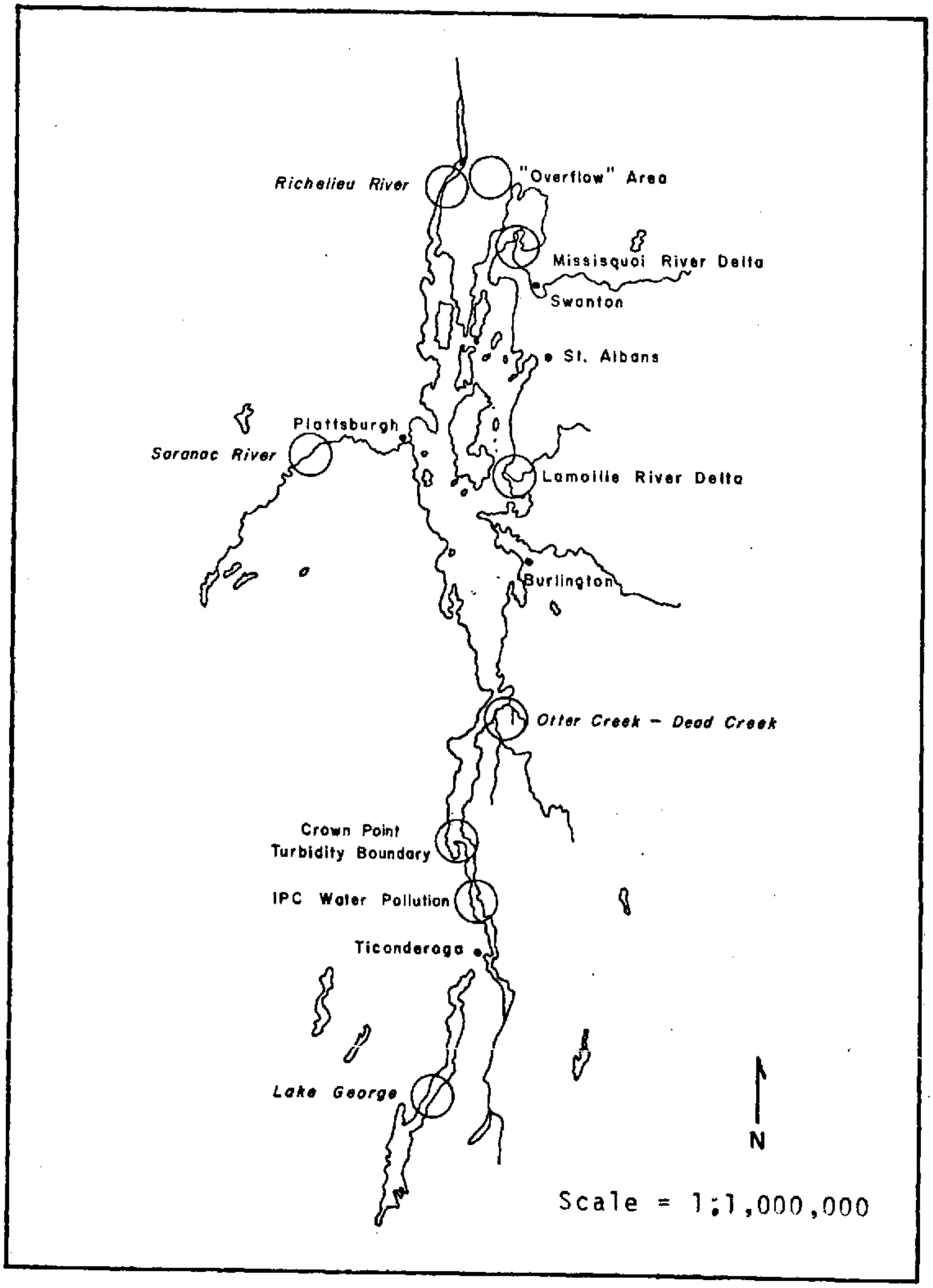
12/2/72



1/7/73



1/25/73



Appendix B. Location Map for Water Resources Features.

APPENDIX C

APPLICATION OF ERTS-1 IMAGERY IN THE VERMONT-NEW YORK DISPUTE OVER POLLUTION OF LAKE CHAMPLAIN

This application was based on ERTS-derived information obtained during the contract period, therefore it is included with this final report even though application of the data did not take place until October 1973.

NASA Contract
NAS 5-21753

UN 137
SR 347

Pollution Monitoring with ERTS-1. Prior to the expiration of the University of Vermont contract with NASA (June 30, 1973), three ERTS-1 images from different dates were used to document the effluent pattern emanating from the large International Paper Company Mill north of Fort Ticonderoga, New York. These imageries include October 10, 1972; April 7, 1973; and April 25, 1973. Documentation and discussion of the images was presented in two earlier reports and a symposium paper.[1]

Variations in the paper mill discharge pattern were observed for the three dates in question and one interpretation given for this variation was that there were contrasting rates of discharge for weekend operation producing a minimal effluent plume (April 7). Actual discharge information recently obtained do not corroborate that interpretation, so that the extent of the plume becomes a function of what waste materials are included in the effluent besides the various environmental factors that have a direct affect on the lake water such as wind and current direction and magnitude.

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[1]Significant Result Reports:

E. B. Henson and A. O. Lind, Nov. 1972. Pollution Detection in Lake Champlain Using ERTS-1 Imagery.

A. O. Lind and E. B. Henson, June, 1973. Pollution Monitoring in Lake Champlain Using ERTS-1 Imagery.

NASA Symposium Paper:

A. O. Lind, E. B. Henson, and J. Pelton, 1973. Environmental Study of ERTS-1 Imagery: Lake Champlain and Vermont.

While the relationship between effluent composition and lake surface plume pattern is a matter for further study waiting for specific effluent data, it has nevertheless been possible to observe the pattern of water degradation on ERTS imagery and to document this pattern by mapping. A composite map showing the plume extent on each of the three dates mentioned earlier is presented in Figure 36.

<u>The Pollution Problem</u>. The State of Vermont is currently suing both the International Paper Company and the State of New York for degrading the waters of Lake Champlain in Vermont. The state's suit is being presented before special U.S. Supreme Court Master Ammi Cutter and has so far generated some 14,000 pages of court transcript. This particular case would seem to rank among the precedent setting variety since other states who now have or develop similar problems may find it desirable to resolve their problems through court action if other means fail.

The Attorney General of Vermont has expressed interest in the ERTS-1 imagery showing the extent of the International Paper Co. plume in the southern portion of Lake Champlain since it reveals that the degraded water pattern extends toward Vermont. The composite map (Figure 36) was prepared by superimposing enlarged ERTS imagery of the appropriate dates onto a U.S.G.S. topographic map (Fort Ticonderoga, New York quadrangle, 1:62,500)

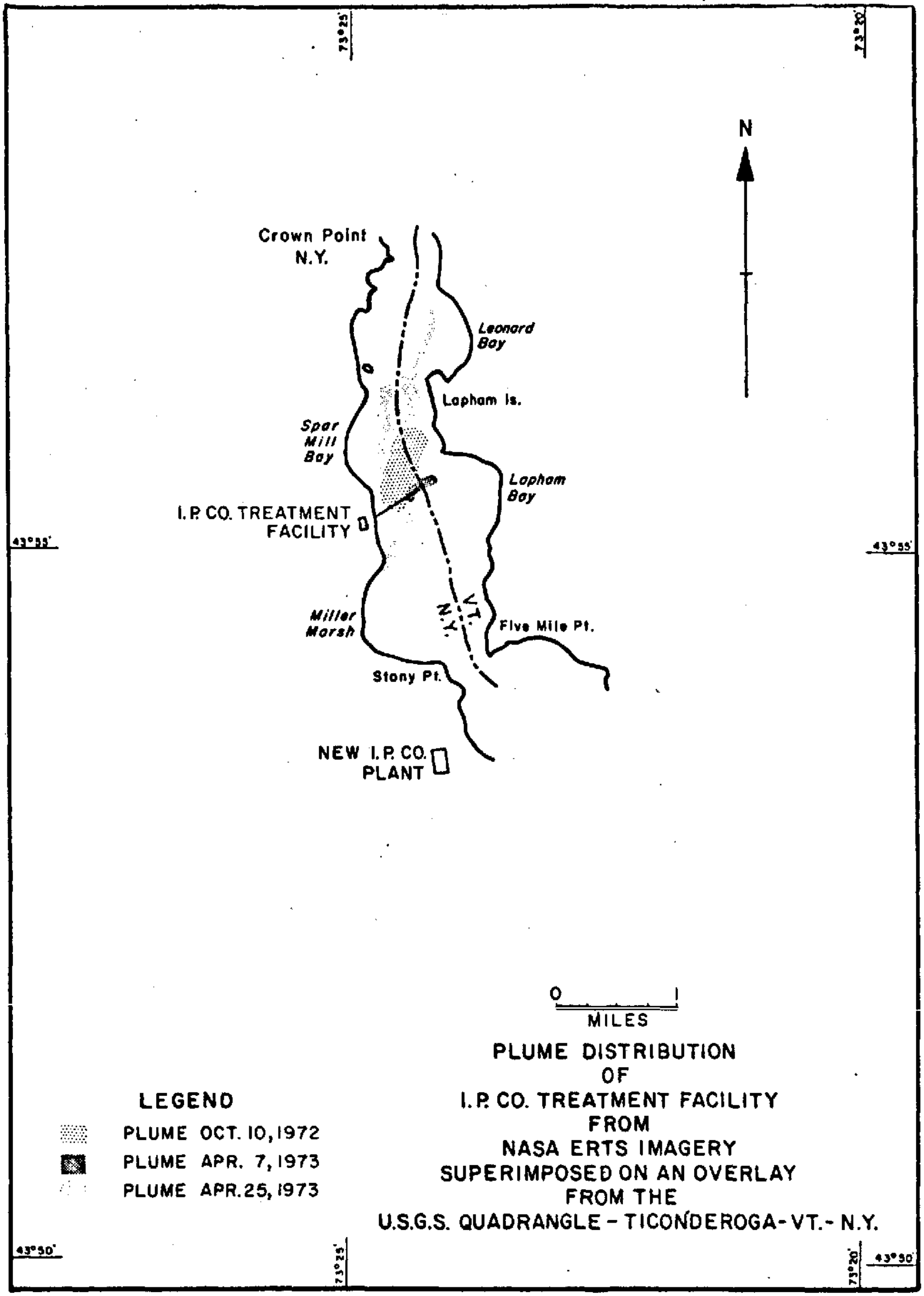
73°25'
73°20'
N
Crown Point
N.Y.
Leonard
Bay
Lapham Is.
Spar
Mill
Bay
Lapham
Bay
I.P. CO. TREATMENT
FACILITY
43°55'
43°55'
VT.
N.Y.
Miller
Marsh
Five Mile Pt.
Stony Pt.
NEW I.P. CO.
PLANT
0
1
MILES
PLUME DISTRIBUTION
OF
I.P. CO. TREATMENT FACILITY
FROM
NASA ERTS IMAGERY
SUPERIMPOSED ON AN OVERLAY
FROM THE
U.S.G.S. QUADRANGLE - TICONDEROGA - VT. - N.Y.
LEGEND
PLUME OCT. 10, 1972
PLUME APR. 7, 1973
PLUME APR. 25, 1973
43°50'
73°25'
73°20'
43°50'

Figure 36

Summary. ERTS-1 imagery and a composite map derived from ERTS-1 imagery were presented as evidence in a U.S. Supreme Court case involving the pollution of an interstate water body (Lake Champlain). A pollution problem generated by a large paper mill forms the basis of the suit (Vermont vs. International Paper Co. and State of New York) and ERTS imagery shows the effluent pattern on the lake surface as extending into Vermont during three different times.