SECTION 46

APPLICATION OF REMOTE SENSING TO WATER RESOURCES PROBLEMS

by

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INTRODUCTION

BACKGROUND

This paper is a report on research done under a NASA Grant to the University of Wisconsin for Multidisciplinary Research in Space Science and Engineering (NGL 50-002-127) during 1970-71. This research was focused upon the problem of developing remote sensing methods for the detection and monitoring of pollutants in water. It was specifically directed towards the investigation of the application of remote sensing to: (1) Water Quality Monitoring; (2) Detection of Mixing Zone; and (3) Surface Parameters of Large Water Bodies.

It was the intent of this program to achieve the most effective application of funds and personnel available for remote sensing research. This was accomplished by: (1) applying the major thrust of the research effort toward critical problems faced by State and Federal agencies charged with water quality planning and protection; (2) coordinating data acquisition operations on as broad a base as possible in order to make maximum use of the data acquired; (3) involving the appropriate State and Federal agencies with the research effort in order that existing ground truth could be utilized and that positive research results could be made operational in a minimum time; and (4) coordinating information and data dissemination in order that all investigators were kept abreast of developments in related areas.

RELATIONSHIP TO OTHER PROJECTS AND AGENCIES

Since environmental ground truth is so complex and remote sensing data acquisition is costly, it was imperative that related research efforts be coordinated in order to derive maximum benefits from funds and personnel. Therefore, the work done under the remote sensing project funded by NASA's Office of University Affairs was coordinated with related environmental projects. This interdisciplinary approach proved most successful in all phases of the project.

Wisconsin Department of Natural Resources

The Wisconsin Department of Natural Resources is directly concerned with all three areas of interest covered in this investigation. In the case of the Mixing Zone Study, this agency has funded a portion of the research not directly concerned with remote sensing, the development of the mathematical model. In the case of the Water Quality Study, the Department of Natural Resources has cooperated in the definition of the problem and, within the limits imposed by it's own operational requirements, provided ground truth support as requested through the program leader by the principal investigator.

Marine Studies Center

The Marine Studies Center is funded by the National Science Foundation through the University of Wisconsin Sea Grant Program. The Surface Parameters of Large Water Bodies portion of this research was conducted in conjunction with this program. The NASA funds have been used to provide the remote sensing data acquisition and analysis while the Marine Studies Center funds and equipment were used to provide the required ground truth measurements.

National Center for Atmospheric Research

A portion of the aviation support for the Remote Sensing Program has been provided by the National Center for Atmospheric Research. They have provided overflight support in the thermal and photographic region.

International Biological Program

The Lake Wingra Study, as part of the International Biological Program, funded by the National Science Foundation, has as its goal the development of a computer simulation model for complex lake basin ecosystems. As such, a great quantity of ground truth is generated by conventional ground based measurements. The acquisition of the ground truth information was primarily funded by the Lake Wingra Program. NASA funds were used to supplement these measurements, obtain the required remote sensing data, and provided for the analysis of the remote sensing data as they applied to lake ecosystem modeling.

Institute for Environmental Studies

In January of 1970 the Institute for Environmental Studies (IES) was administratively restructured and staffed to provide improved leadership and impetus to the University of Wisconsin's research and teaching efforts in the environmental studies area. IES provides leadership in interdisciplinary environmental research by initiating new and coordinating existing research programs. Thus, IES has provided the administrative organization for the Remote Sensing Program.

The multidisciplinary nature of the Remote Sensing Program can easily be ascertained from the preceding organizational overview. The complex nature of environmental ground truth and the high cost of acquiring and analyzing remote sensing data require that a coordinated interdisciplinary effort be made to insure that each data gathering flight and supporting ground truth acquisition be utilized to the fullest. Furthermore, inasmuch as information gained in one portion of the research is likely to have significant influence upon other efforts, a coordinated organization is essential. Principal investigators from each sub-project are represented on the remote sensing steering committee which serves as the coordination and information distribution element of the program. At the present time the Remote Sensing Program employs some fifteen faculty members and approximately forty students from twelve different departments and/or programs.

WATER RESOURCES PROBLEMS

Because remote sensing techniques offer the capability of covering large areas in a real time scale they can be applied directly to the characterization and monitoring of environmental pollutants -- especially those entering a body of water. Although all water related remote sensing research carried on at the University of Wisconsin can be classified under the heading of applications of remote sensing to "water resource problems" the direction of each individual research project can be best delineated if they are explained separately.

WATER QUALITY RESEARCH*

During the period 1965-1967, Remote Sensing research at the University

*Dr. James P. Scherz, Principal Investigator, Department of Civil and Environmental Engineering and Institute of Environmental Studies.

of Wisconsin in conjunction with the State Department of Natural Resources concluded that reflectance characteristics of water are caused by suspended particulate matter and that these characteristics vary, depending upon the effluent and the receiving water. Work done at Wisconsin under the NASA Multidisciplinary Grant, during the period 1967-1971, concluded that the reflectance characteristics of a pollutant can be positively correlated to suspended solids and that theoretically the solids content can be determined by Remote Sensing technology. Since the solids content and other water quality parameters are at times positively correlated, it may be possible to determine pollutant load in general from the concentrations of solids -- provided the characteristics of an effluent from a particular plant are known.

The present research work and that conducted during the summer and fall of 1971 is directed towards the establishment of a statistical correlation between remote sensing responses and actual water conditions. From the use of spectrophotometers and ground sampling in conjunction with aerial photography, it has been established that in the photographic part of the energy spectrum, the remote sensing response is primarily correlated with the solids in the water (see Figure 1). There is an important depth penetration consideration that must also be considered in that different wavelengths of energy penetrate to different depths into the water. The research work during the summer of 1971 dealt with: (a) establishing a reliable correlation between remote sensing images (reflectance) and the concentration of solids in outfalls from several industrial plants on the Wisconsin River (see Figure 2), and (b) investigating the depth penetration characteristics of color and color infrared film in relation to lakes, rivers, and industrial pollution outfalls. The results of the above research should bridge the gap between aerial remote sensing images and the actual ground conditions on matters relating to water quality; or in other words, the results should determine what is being sensed on the remote sensing images in regard to water quality.

Suspended Solids

The amount of reflectance is directly correlated with the amount of suspended solids but it has been concluded that the laboratory analysis of such wastes at best leaves much to be desired because of the bottom reflection effects of the laboratory sample tube. Actual correlation of suspended solids with images on aerial photographs must be made in the field rather than in the lab, and proper allowance must also be made for bottom effects.

Bottom Effects

There is always some reflectance coming from the bottom of the

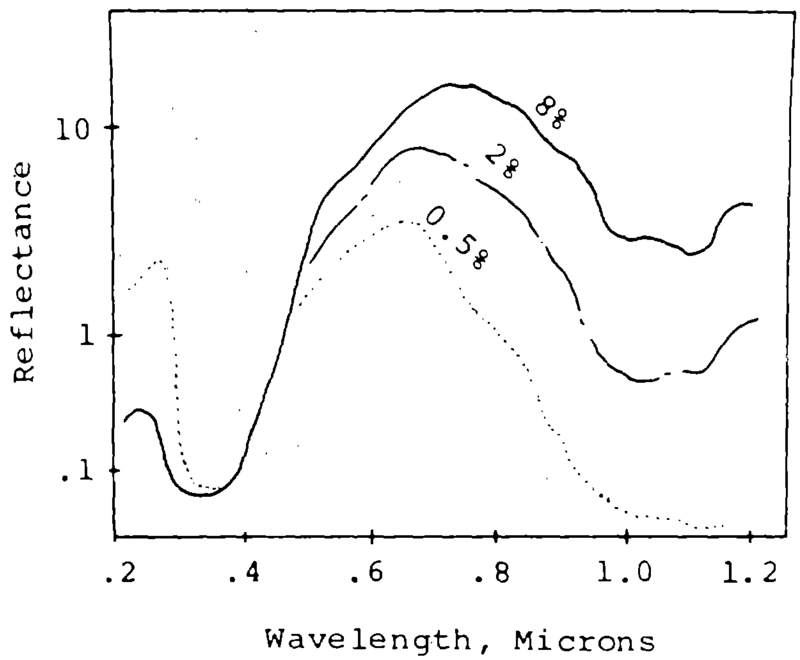

Figure 1.- Change in reflectance of sulfite liquor from Nekoosa, Wisconsin, as a function of concentration of solids.

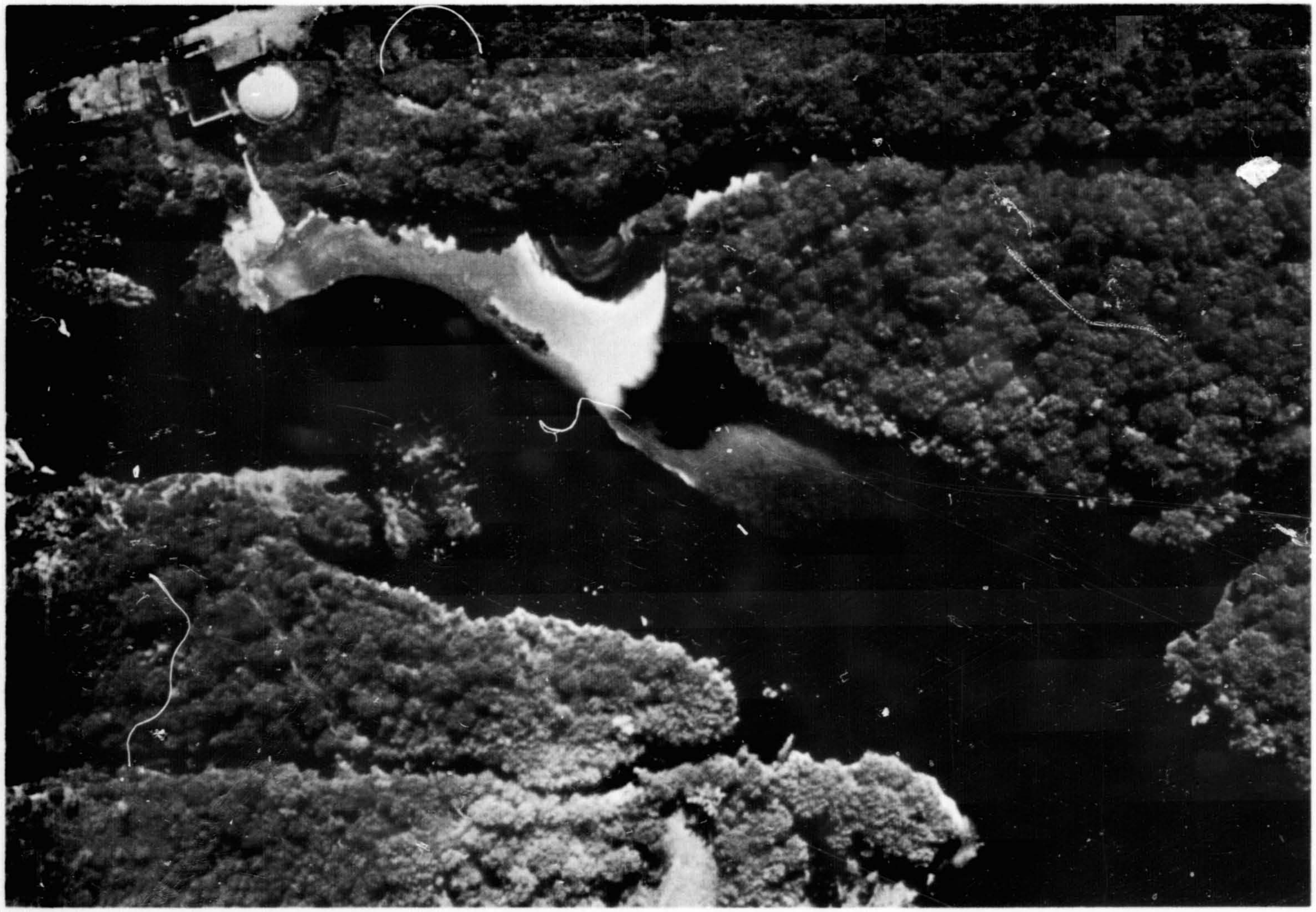

Figure 2.- IR Aerial photograph of paper mill waste entering Wisconsin River near Mosinee, Wisconsin.

sample tube that can make it impossible to exactly extrapolate the laboratory data to predict what will show up on the image without taking into account the bottom effects of both the sample tube and the water site itself. Not enough is now known about these bottom effects to accurately make the correlation between laboratory and the field. Additional work must be done hand in hand between field investigators and laboratory researchers in order to understand these bottom effects and how to deal with them.

Results to date however have shown that one can cancel out the bottom effects by picking the correct part of the spectrum either with filters before taking the photo or by proper choice of wavelengths when working with the microdensitometer-spectrophotometer apparatus during analysis of the color and color IR film. To date it can be concluded that the UV wavelengths reflect only from the surface of the water without penetration and that the IR is absorbed by the water and shows no depth effects and that the blue-green wavelengths penetrate and show the unwanted bottom effects. It appears that by selecting the proper wavelengths one can handle the bottom effect problem and that an understanding of bottom effects is absolutely necessary if one is to look at only the desired water being monitored.

1971 SUMMER RESEARCH

The summer efforts for 1971 consisted of massive correlation efforts between ground truth and simultaneous flights with color and color IR microfilm at four sites on twelve separate days. Ground sampling has been conducted for turbidity, solids, light penetration and color of the industrial waste. The samples have been analyzed at the Institute of Paper Chemistry at Appleton, Wisconsin, and at the Civil Engineering Sanitary Laboratory at the University of Wisconsin, Madison. Several Industrial and Municipal sewage sources on the Fox and Wisconsin Rivers have been photographed and sampled during the summer in order to obtain enough data to get a statistical correlation between the actual pollution and the remote sensing imagery. Primary emphasis was placed on correlation of suspended solids and the density of the image as obtained in relation to that of a standard styrafoam reflectance panel. Secondary emphasis was on seeing to what extent the suspended solids is a real measure of water pollution as indicated by conventional pollution parameters. Figure 3 indicates (in preliminary analysis at .610 microns) a definite correlation between the imagery and suspended solids. This would indicate, in fact, that the suspended solids can be determined from a photograph. Further analysis is in progress to determine the reliability and accuracy of this correlation.

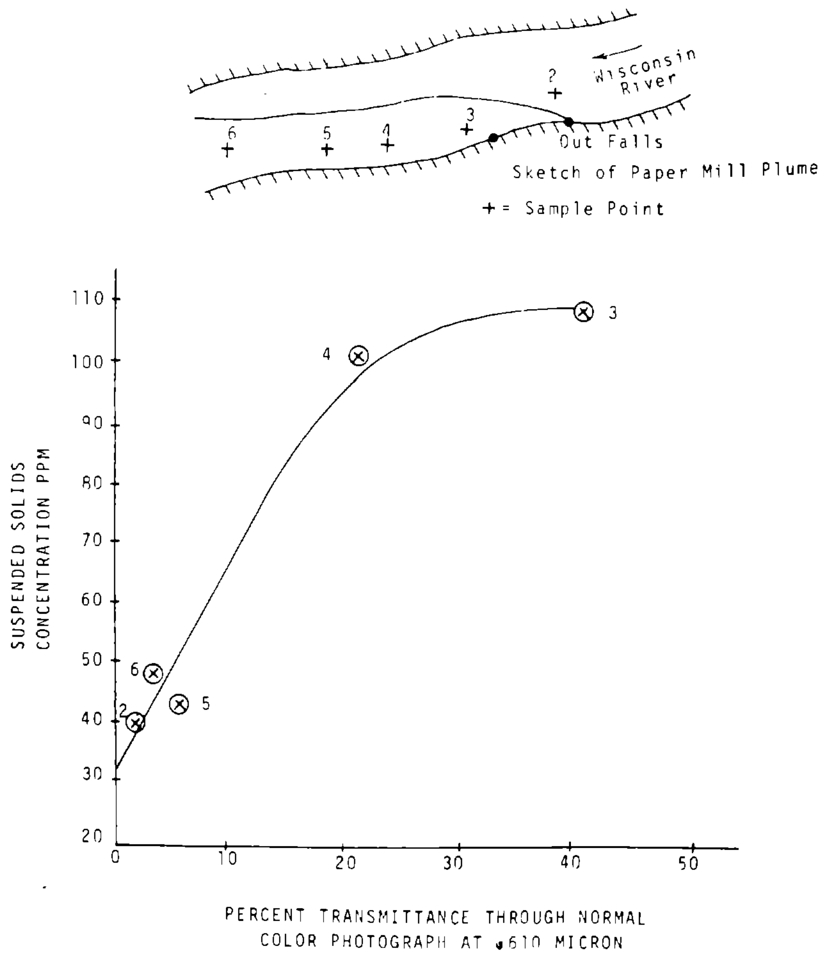

Figure 3.- Graph of suspended solids vs. percent transmittance showing correlation between imagery and suspended solids.

APPLICATION TO MIXING ZONE MONITORING*

The mixing zone is defined as that part of the water region in which pollutants, if they are introduced, are transported and dispersed to concentrations obtainable by total mixing. The mixing zone is a dynamic region, changing continuously in size and shape in response to effluent and water body conditions. The dilution process within the mixing zone is a two-stage process, as shown on the Schematic Diagram (Figure 4). The central objective of our project is the study of the mechanisms of transport and dilution in the mixing zone and the development of a relationship for the extent of the mixing zone as a function of effluent, outfall and water body characteristics. This relationship may be used: (1) in the establishment of definite and rational water quality guidelines; (2) in the development of a sampling and regulation program by governmental agencies; and (3) in the design and location of outfalls by industries and municipalities. In order to accomplish this goal, an integrated program of mathematical and laboratory modelling and field testing is being carried out.

The study now involves the correlation of physical characteristics of pollution as measured on the ground (suspended solids, total solids, dissolved solids, temperature and color) with remotely sensed measurements as reflectance (using film densitometer), emitted radiation (using a PRT-5) and thermal scanning. A related problem is the determination of a 3-dim. picture (basically vertical structure) from such (primarily) surface (2-dim.) indicators. If such correlations can be developed, it will be possible to use remote sensing techniques, together with the established ground techniques, for quantitative measurement of the temporal and spatial presence, character, and concentrations of pollutants in surface waters. In this way the ground and aerial work is complementary and thus permits more effective and accurate monitoring, discovery and characterization.

Field Research

Figure 5 is a graphic representation of the mixing zone characteristics at the Weston Power Plant near Rothschild on 26 August 1970. The high rate of flow on this date (1800 CFS) caused the plume to hug the shore for a long distance. Accompanying strong winds induced strong vertical mixing which in turn caused a slower lateral mixing. On this particular date a good correlation between the boundary of the mixing zone as determined by the aerial photographs and ground sampling is evident. Different flow conditions however may cause a variation in

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*Drs. John A. Hoopes and James R. Villemonte, Co-Principal Investigators, Department of Civil and Environmental Engineering.

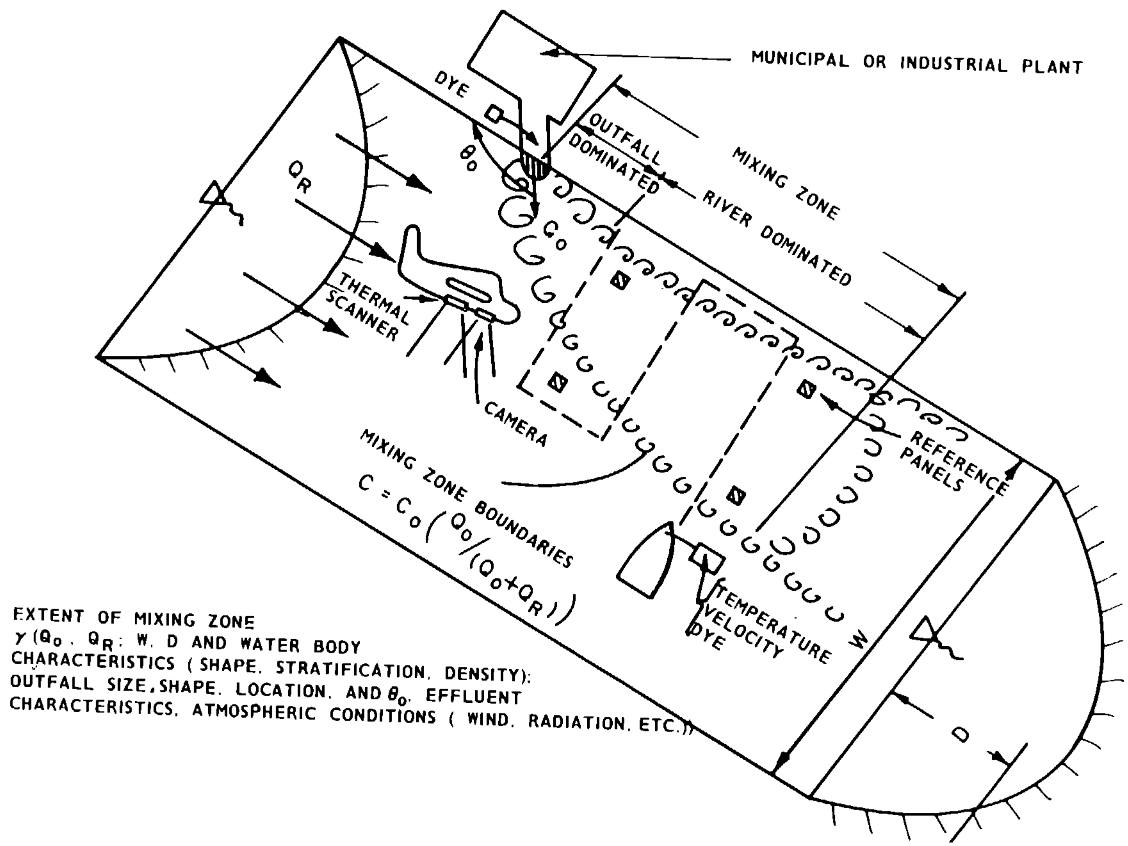

Figure 4.- Schematic diagram of mixing zone parameters.

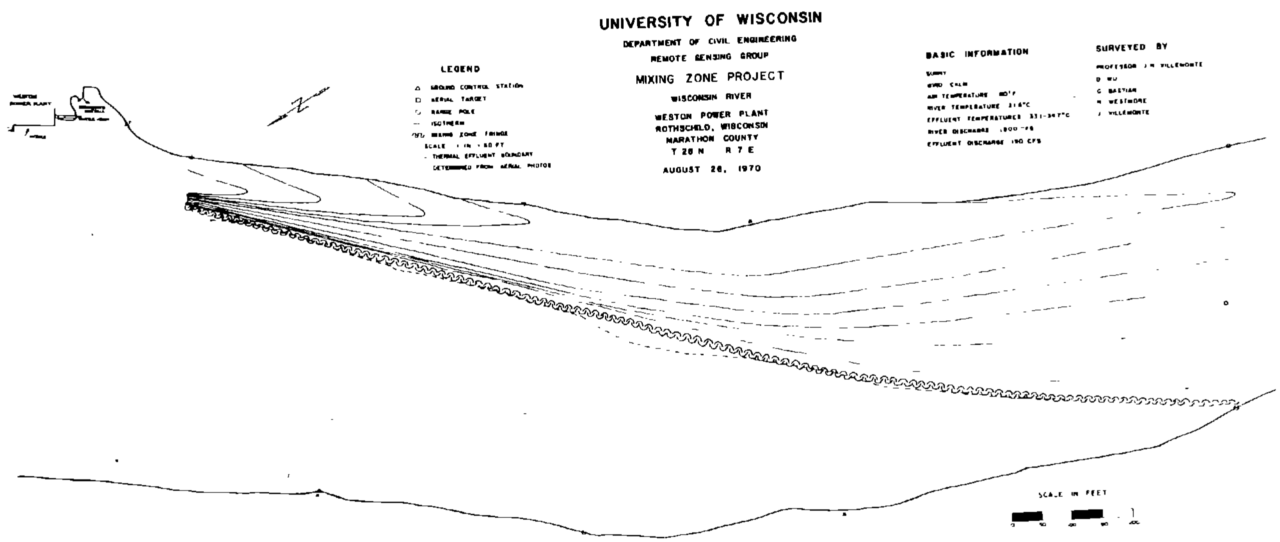

Figure 5.- Graphic representation of mixing zone characteristics of Weston power plant on 26 August 1970.

this correlation. Recent thermal imagery of this location has been linearized and processed for enhancing water temperature variations. Analysis of this imagery is currently in progress.

LEGAL ASPECTS OF WATER POLLUTION DETECTION THROUGH REMOTE SENSING*

One obvious domestic use for remote sensing devices is as an aid in water pollution detection. For the past two and a half years the University of Wisconsin's Remote Sensing Program of the Institute for Environmental Studies has been conducting research on the remote sensing of water pollution. As part of this study, aerial surveillance of a number of industrial firms heavily polluting Wisconsin's rivers has been undertaken, frequently supplemented with ground samples.

Standing alone, however, such efforts are largely self-contained. They do not lead to the abatement of pollution nor do they constitute proof, in a strict legal sense, of pollution. It was because of this aspect of the Remote Sensing Program that Professor Scherz of the Civil Engineering School suggested that remote sensing evidence be tested in a court of law.

Through the cooperation of the United States Attorney for the Western District of Wisconsin and the Department of Natural Resources remote sensing data was used in the spring of 1971 in an actual criminal case against a creamery polluting a major tributary of the Wisconsin River (United States vs. Wisconsin Dairies Cooperative, 71 Cr. 56, W.D. Wisc.; filed 14 April 1971). Since the case ended with a plea of *nolo contendere*, an admission of guilt for the purposes of the case, the data gathered was not actually used in court. Other cases, however, are currently being developed. It is expected that they will result in remote sensed data being used in a disputed case so that its reliability will be judicially established.

REFLECTANCE AND TRANSMITTANCE CHARACTERISTICS OF SELECTED GREEN AND BLUE-GREEN UNIALGAE*

The two-fold purpose of these sets of experiments was to evaluate

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**Drs. William C. Boyle and Lorne C. Gramms, Co-Principal Investigators, Department of Civil and Environmental Engineering.

the feasibility of using the reflectance and transmittance characteristics of unialgae to differentiate between green and blue-green algae and to formulate eutrophication indices from the derived data. Two types of green algae, Selenastrum and Chlorella, and two types of blue-green algae, Microcystis and Anabaena, were evaluated in this study. The reflectance and transmission characteristics of these algae were recorded between .375 and .8 microns.

Experimental Design and Results

A two-level, four factor factorial design for each of the four algal cultures was performed. The dependent variables were transmittance and reflectance properties of the suspensions. Independent variables for each unialgal suspension included algal concentration, suspension depth, SiO_2 concentration, and the length of the experimental chamber.

The results of our experiments can be summarized by considering four general areas: (1) algal species differentiation, (2) algal concentration estimation, (3) effects of particulate interference, and (4) effects of phosphorous deficiency on the reflectance measurements.

Algal Species Differentiation Figure 6 shows the reflectance spectra of the four types of algae. As can be seen in the diagram, the green algae have a characteristic absorption at .650 microns, while the blue-green algae do not. From this we have been able to find a method of differentiating between the two types of algae by measuring the ratio of the reflected light at .650 microns to the intensity at .625 microns. We have been able to conclude that the ratio is greater than one for the blue-green and less than one for the green algae.

In order to assess the possibility of determining algal suspension concentrations using certain wavelengths or ratios of wavelengths, two of the algae, Selenastrum and Anabaena, were studied in detail at different algal concentrations.

Algal Concentration Estimation Figure 7 depicts curves of the reflectance spectra of the algal Selenastrum for four different concentrations. Investigations of the reflectances indicate that for Selenastrum the reflectance at .550 microns was approximately halved for each doubling of the concentration of the algae. The results for Anabaena showed a similar but not identical relationship.

Effects of Particulate Interference In order to study the effects of turbidity of the water on the reflectance spectra of these algal, an amount of fine sand was added to the experimental mixtures. The curves in Figure 8 represent the reflectance spectra of Anabaena at different concentrations with and without the SiO_2 added. The results were somewhat discouraging. It was found that for low concentrations of the algal (4 mg/l) the reflected signal decreased with the addition of SiO_2, but the converse was found for the higher concentration. The reflected signal was greater with the addition of the SiO_2 for the 8 mg/l concentration of the Anabaena. Thus, the effect of turbidity could cause false reflectance measurements.

Even though the SiO_2 changed the reflectance and transmittance properties, it did not change the characteristic ratio of the intensities between the green and blue-green algal. Thus we can still qualitatively distinguish between the two types of algal independent of turbidity.

Effects of Phosphorous Deficiency The removal of phosphorous from the growth media had a pronounced effect on the spectral reflectance properties of the experimental algal cultures. The graphs in Figure 9 depict the results of this experiment. In general the limited phosphorous media resulted in increased intensity of the reflectance spectra.

AQUATIC MACROPHYTES AS EUTROPHICATION INDICATORS*

Aquatic macrophytes as well as algae can be used as eutrophication indicators. Eutrophication of the Madison area lakes is primarily due to the infusion of nutrients from many varied sources including agricultural runoff and storm sewer drainage.

Background

Lake Wingra, which is situated within the Madison city limits, is the site of several intensive ecosystem studies as part of the International Biological Program (IBP). The primary productivity of the aquatic macrophytes is one component of this systems study which is being analyzed by biomass sampling and net photosynthesis studies. The possibilities of using remote sensing techniques to save time and effort in the biomass studies are of particular interest to investigators in the remote sensing program and in the biological systems study. These possibilities are being examined at the present time by comparing the collected ground data and aerial photographs taken during the past summer. This joint effort has been fruitful in increasing the efficiency of future production estimates, in providing data not readily available from more traditional methods, and in providing for the ultimate modeling of this aquatic ecosystem.

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*Dr. Michael S. Adams, Principal Investigator, Department of Botany.

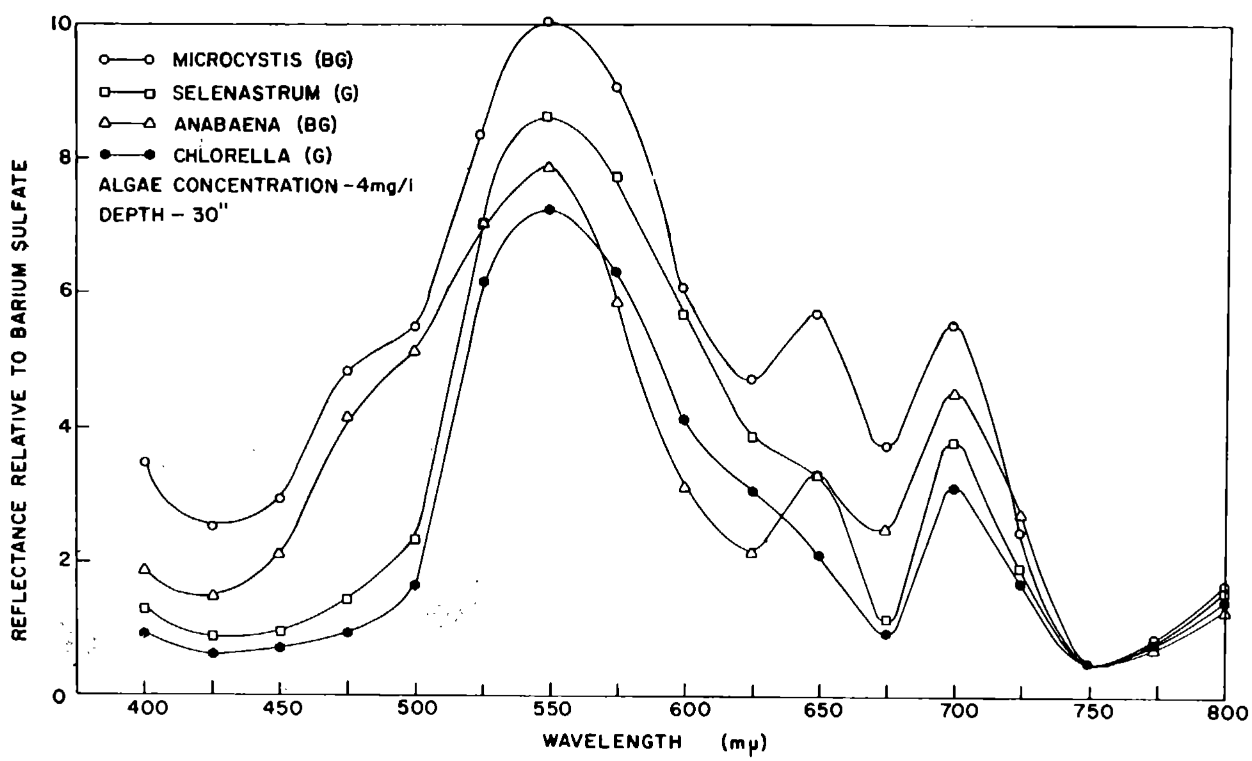

Figure 6.- Reflectance spectra of two green and two blue green algae.

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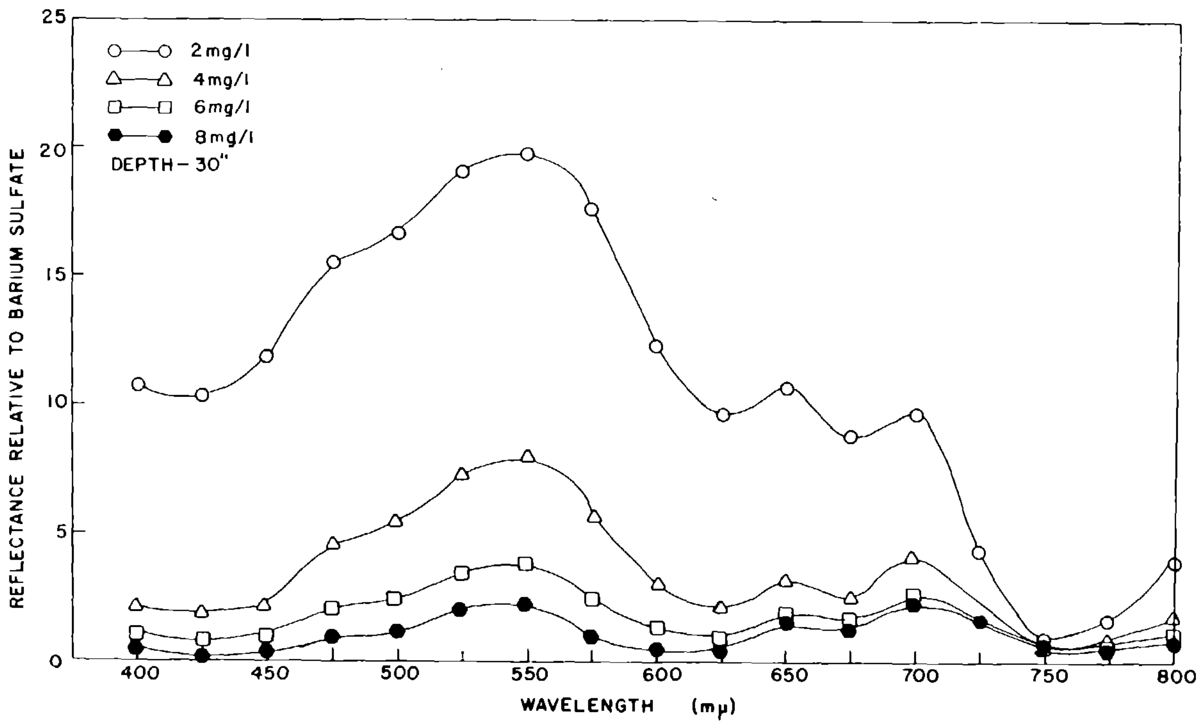

Figure 7.- Reflectance spectra of algal *Selenastrum*.

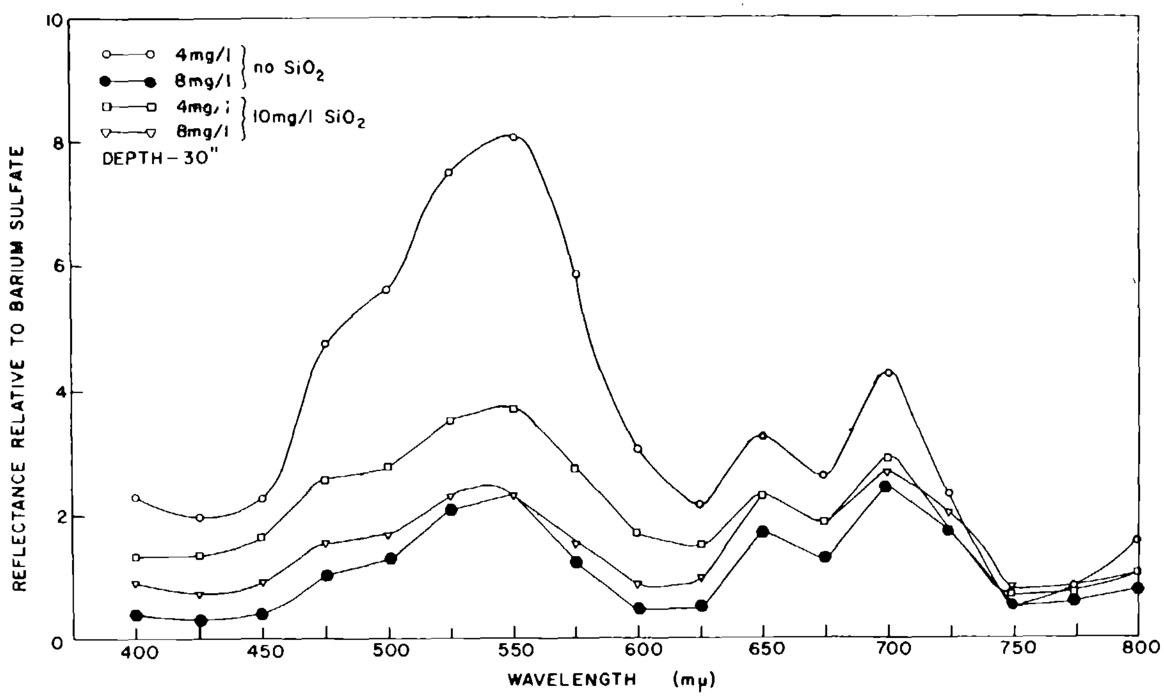

Figure 8.- Reflectance spectra of algal <u>Anabena</u>.

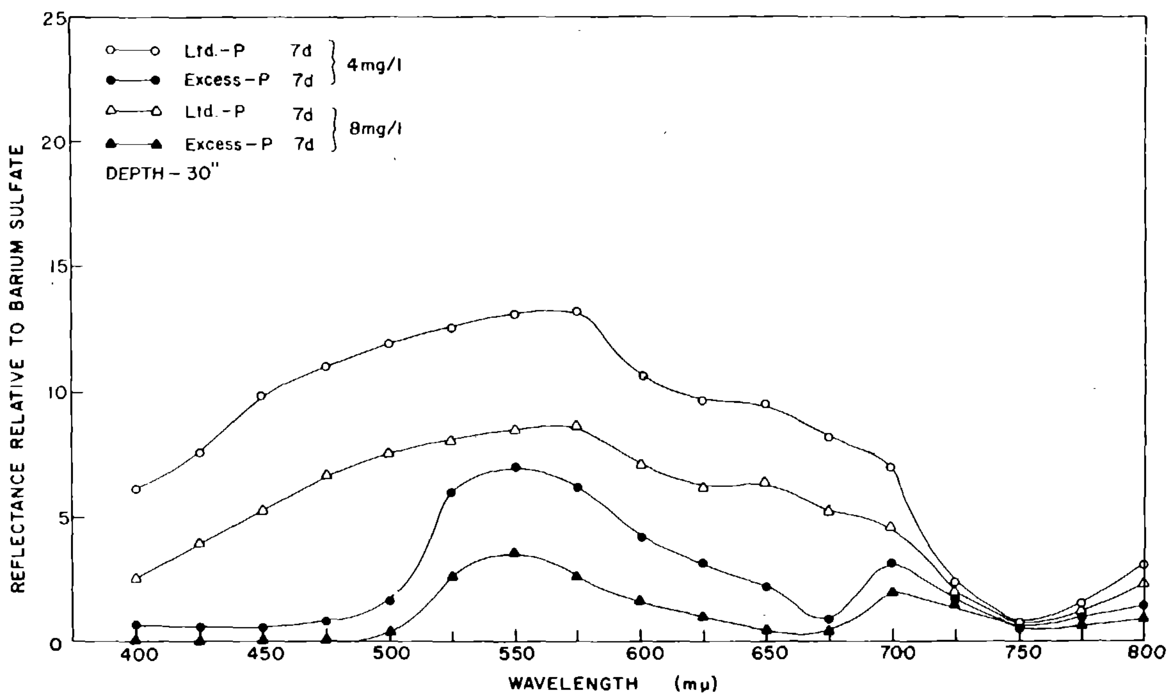

Figure 9.- Increased intensity of reflectance spectra in limited phosphorous media.

Figure 10.- IR Aerial photograph of west end of
L. Wingra taken in August, 1971.

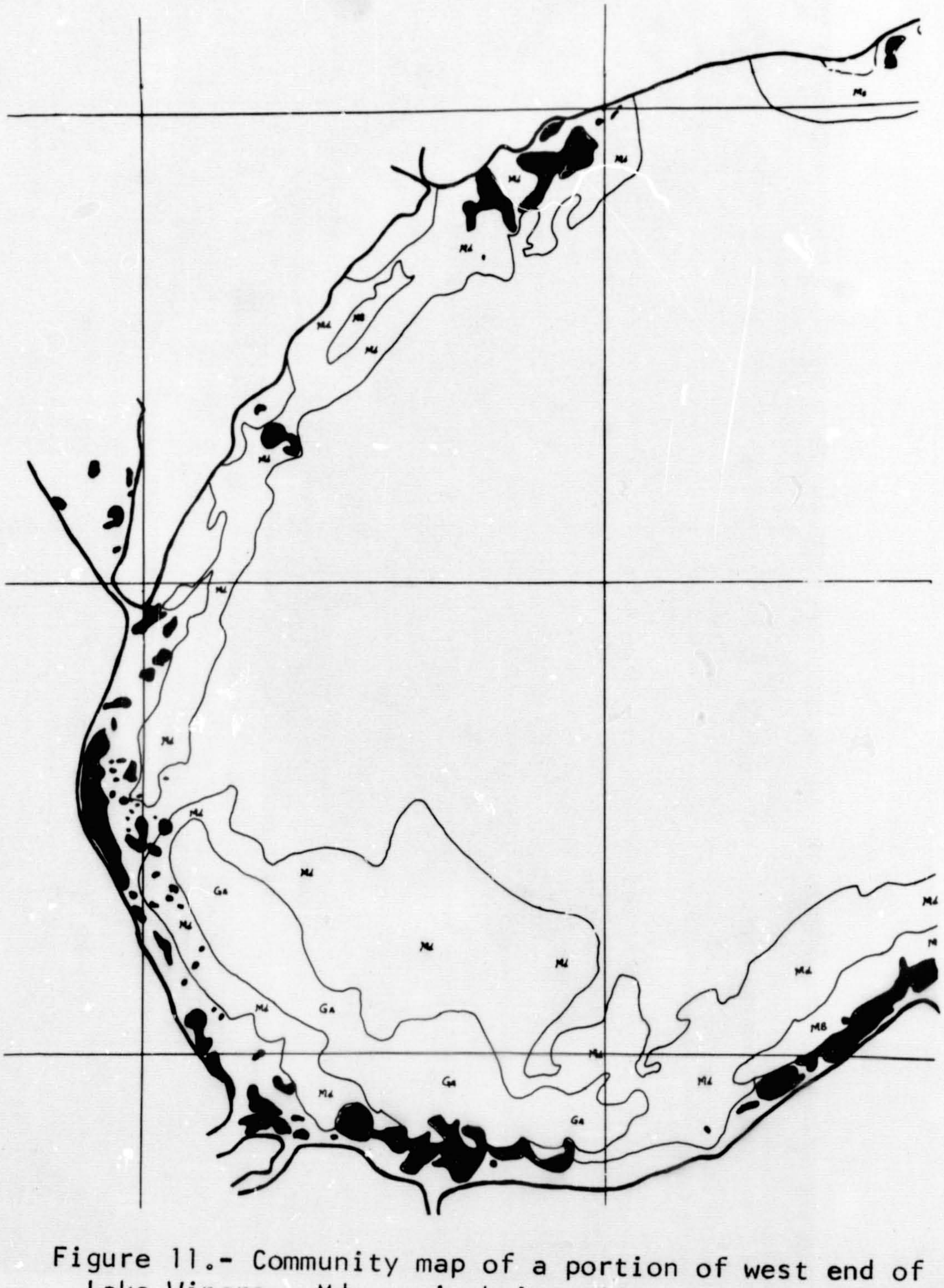

Figure 11.- Community map of a portion of west end of Lake Wingra. Md= myriophylum, GA= green algae overgrowth, MB= marl.

Applications of Remote Sensing

The color and infrared slides taken during the summer of 1971 have revealed several valuable uses for remote sensing of the lake and suggest further research. Color IR photographs are valuable in determining the physiological state of aquatic plants. The encrustment of plant leaves with carbonates, the senescense of plant tissue and the life cycle stages are easily discernible.

The appearance of the *Myriophyllum spicatum L.* communities is very pronounced in the aerial photographs. Figure 10 is a color IR aerial photo of the west end of Lake Wingra taken in August of 1971. With the aid of vertical photographs taken this season, the various communities have been mapped. A portion of the August map showing Myriophyllum and water lily communities with mat of green algae is shown as Figure 11. Information from the analysis of these maps can be used to make biomass and productivity estimates when used in conjunction with other biological data. The aerial photographs will also be correlated with the annual cycle of plant growth and community development. The infrared film is particularly effective in differentiating the marl bottom from vegetation. Marl is calcium carbonate which is precipitated out in hard water lakes. In regular color film the marl appears green but appears white in color infrared, thereby distinguishing it from vegetation. During the growing season the *Myriophyllum* becomes progressively encrusted with diatoms as well as calcium carbonate. In the infrared photographs the weed beds appear lighter due to this, and thus the accumulations can be monitored. Thermal imagery shows some application to the macrophyte study and is currently undergoing analysis.

The major effort of this past summer has been to correlate the biomass measurements taken last year with the vertical photographs, using both mapping techniques and intensive ground sampling. Remote sensing techniques are definitely applicable to the study of aquatic macrophytes and future work will be undertaken to further correlate imagery data with lake eutrophic state.

SURFACE PARAMETERS OF LARGE BODIES OF WATER*

The application of Remote Sensing to the measurement of the Surface Parameters of large water bodies is a multidisciplinary effort supported by the National Aeronautics and Space Administration program and the University of Wisconsin Sea Grant Program in conjunction with the University of Wisconsin Marine Studies Center. During the past year the

*Drs. Theodore Green III and Robert A. Ragotzkie, Co-Principal Investigators, Marine Studies Center.

direction of this project has been toward data acquisition during the summer and preliminary analyses of this data during the past fall.

The two geographical areas studied this past year were the Southern Lake Superior coast along the Keweenaw Peninsula and the Western Coastal Zone of Lake Michigan with special emphasis placed upon a nuclear power plant near Manitowoc, Wisconsin (Figure 12). Thermal scanner data were acquired at 5 other power plants along the coast in conjunction with the Wisconsin Department of Natural Resources.

Lake Superior-Keweenaw Current Study

The Keweenaw Current is the dominant feature of the water circulation in Lake Superior. This current is analagous to the Gulf Stream in the Atlantic Ocean; although it varies considerably in strength, it is strongest in the latter part of July and early August. From this study we hope to generate a better understanding of the mixing processes of near shore currents in large bodies of water. This project provides a unique opportunity to develop methodology to study a major current of varying magnitude with an emphasis upon the coastal waters mixing into the lake. A thorough understanding of this mixing process is imperative for making reasoned decisions regarding the future location and design of waste product outfalls, including those of a thermal nature. To preserve the purity of our coastal waters, it is important that waste products dumped into lakes and oceans are speedily diluted to a safe concentration.

Experiment and Results.- In the past this current has been studied using airborne radiometric methods. In our experiments this past summer we have used a thermal line scanner to map the current temperature and extent, and photogrammetric techniques to precisely measure the surface velocity structure near Eagle Harbor, Michigan. Figure 13 is a graphic representation of these results. To measure the velocity, drift cards were distributed in the water in lines perpendicular to the coast. These were photographed from an aircraft using a precision aerial mapping camera approximately every 8 minutes for several hours. The measured photo coordinates were entered into a computer and the actual ground coordinates as a function of time were then calculated for the drift cards using photogrammetric modeling techniques. The velocity structure of the current was then calculated.

The simultaneous radiometric and thermal line scanning used to map temperature distributions and the extent of the Keweenaw Current provide a measurement of relevant small scale parameters which are not available by other means and are vital to the investigation of the dynamic structure of lake currents.

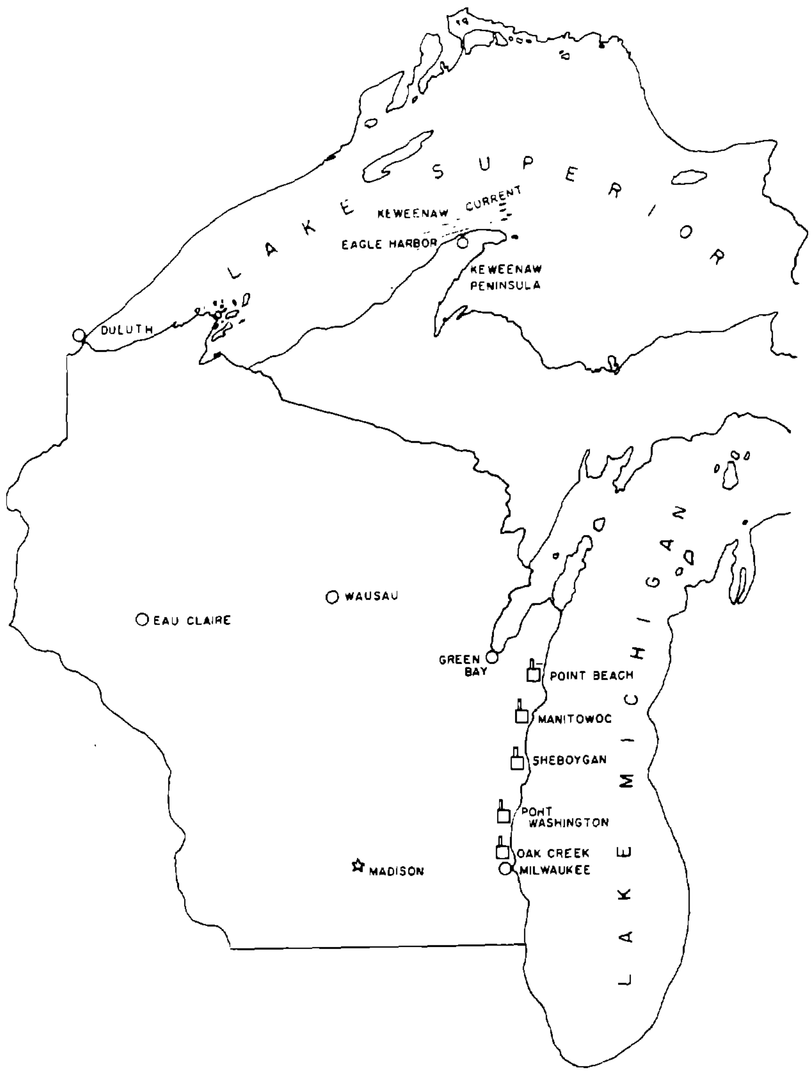

Figure 12.- Map of Wisconsin showing relative position of power plants.

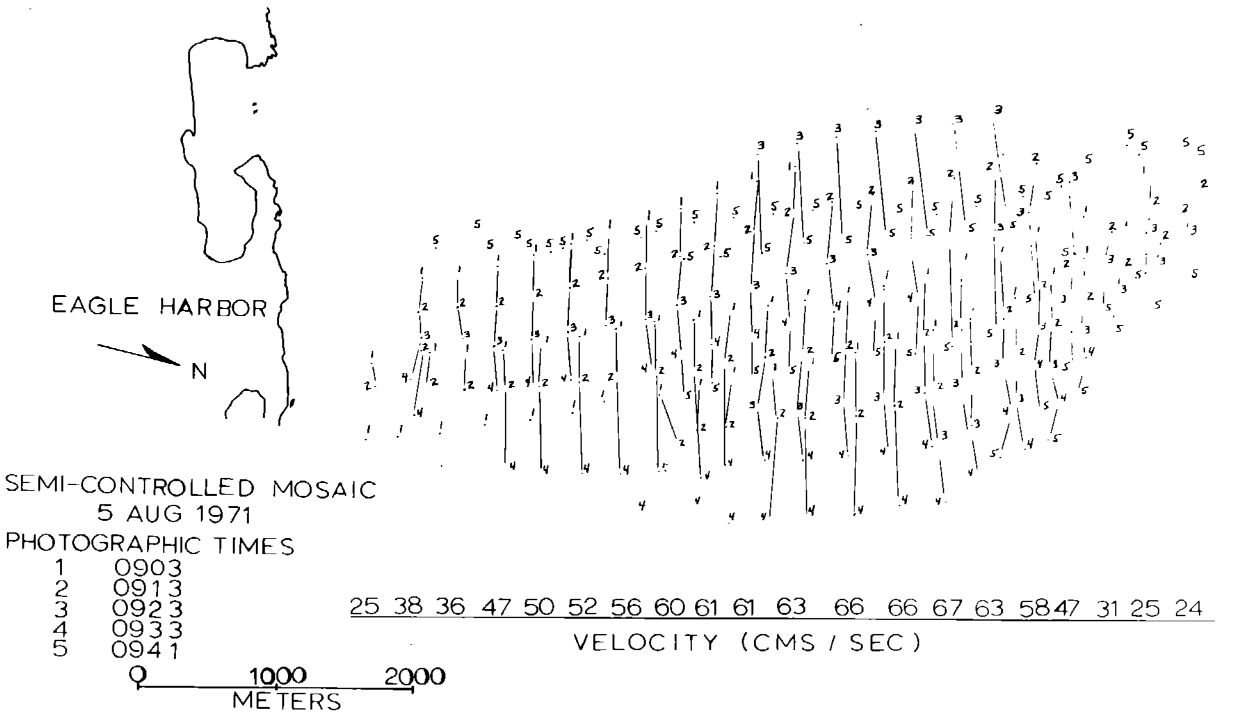

Figure 13.- Semi-controlled mosaic of current velocity structure off Eagle Harbor.

LAKE MICHIGAN COASTAL ZONE*

Thermal line scanner imagery of a portion of the Western Coastal zone of Lake Michigan was acquired in September 1971 on four consecutive days. We were mainly interested in the nearshore circulation and the surface details of the thermal discharges of power plants into the lake.

A prominent feature of the thermal imagery of the coastal zone is the relatively sharp demarcation between the cold nearshore water and the warmer offshore water (see Figure 14). From supporting color and color IR photography of the coast (flown by a NASA RB 57 at 60,000 feet), we suspect that there is not only a sharp thermal gradient but also a sharp discontinuity in the concentrations of suspended solids in the offshore waters as illustrated in Figure 15. Concurrent wind data suggest that these contrasts are due to upwelling, and that the scanner may be used to investigate coastal upwelling in lakes. Figure 16 depicts the thermal imagery of a portion of the coast for the three successive days. Further experiments are planned this spring and summer to closely monitor the changes in thermal structure. We plan to measure this coastal thermal structure every few hours to determine the time scale of the upwelling and its sensitivity to the wind speed and direction.

Thermal imagery of the power plant discharges along the western coast of Lake Michigan was obtained during the same experiment. Emphasis was placed on studying the Point Beach Nuclear Power Plant plume in detail. This plant is located on Lake Michigan approximately five miles north of Two Rivers, Wisconsin, and produces 500 megawatts of power while operating at half capacity. A total of 350,000 gallons of heated water is discharged each minute into the lake near shore. We attempted to measure both the thermal and velocity structures of this plume.

Using precise analytical photogrammetric techniques, the positions of many drogues at various times set for different depths were calculated. Figure 17 shows the results of analyzing one of the several experimental runs over this plume.

Figure 18 shows a thermal line scanner image of the Point Beach Power Plant thermal plume. To us, the most interesting features of this thermal picture are the thermal fronts moving concentrically outward from the outfall in a wave-like fashion. Since we have thermal pictures of the plume every five minutes, we can follow each of the fronts as it moves outward. From this (neglecting turbulent mixing) we may estimate the velocity structure of the plume.

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*Drs. Theodore Green III, Robert A. Ragotzkie, and Paul R. Wolf, Co-Principal Investigators, Marine Studies Center and Dept. of Civil and Environmental Engineering.

Figure 14.- Print of thermal imagery showing sharp demarcation between cold nearshore and warmer offshore water on western coast of L. Michigan.

Figure 15.- High altitude photograph showing discontinuity in concentration of suspended solids.

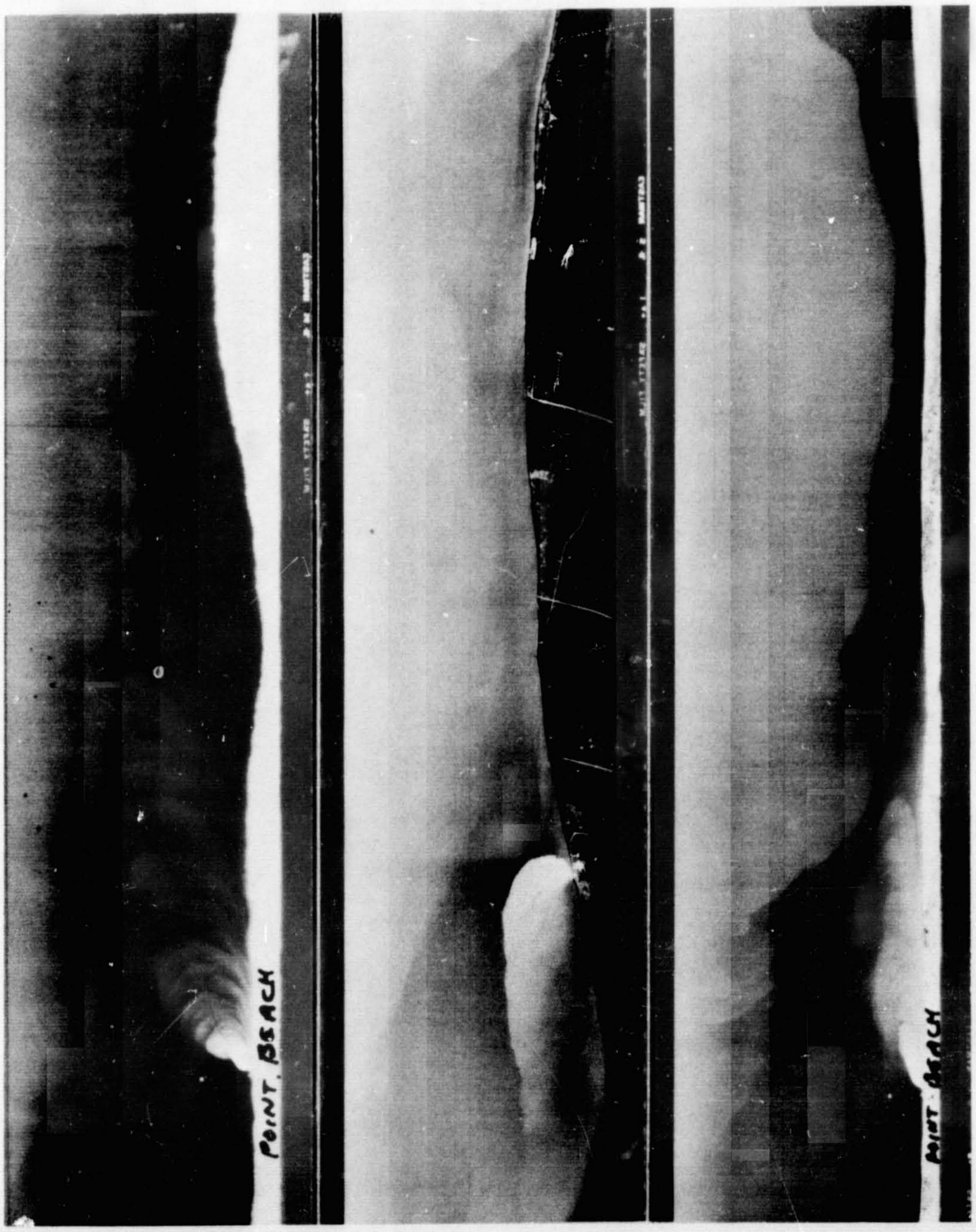

Figure 16.- Thermal imagery of Point Beach plume on three successive days.

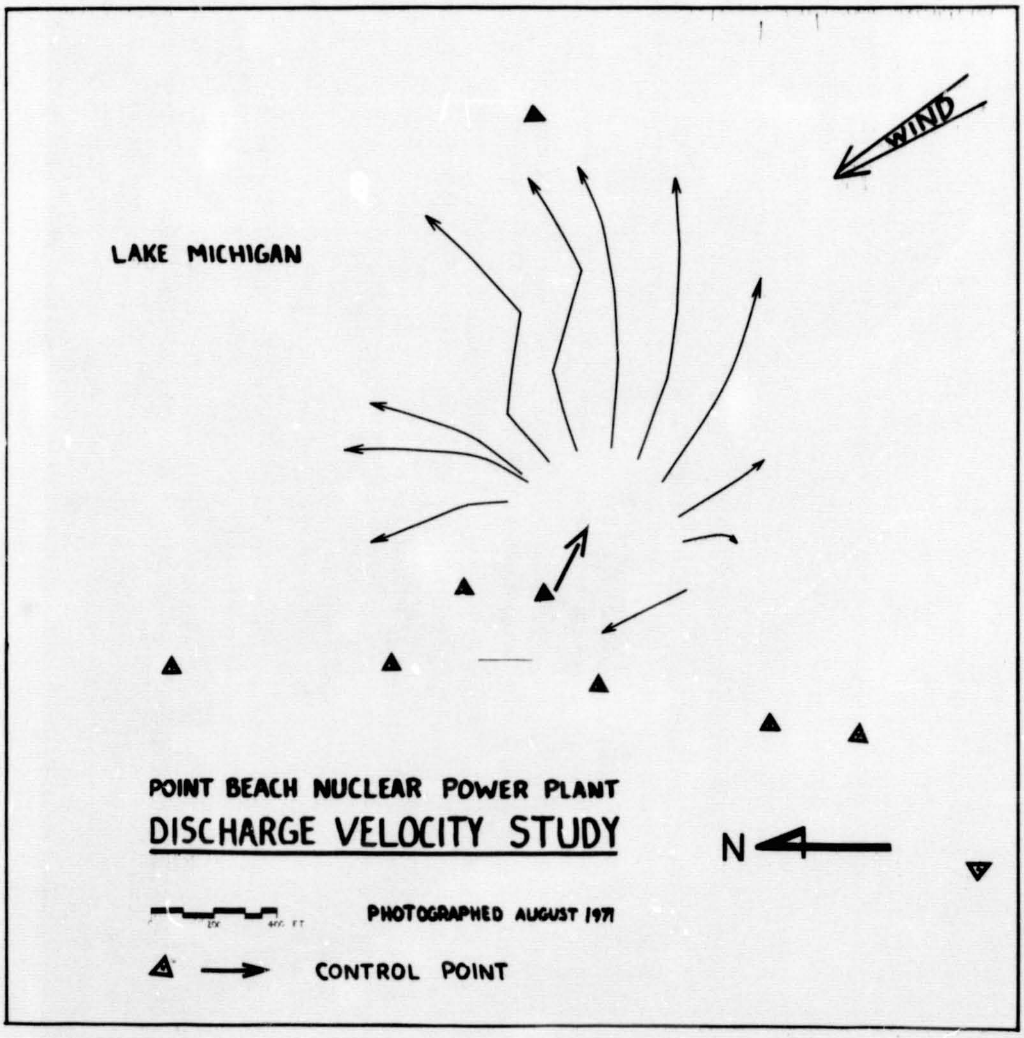

Figure 17.- Graphic representation of drogue positions over time.

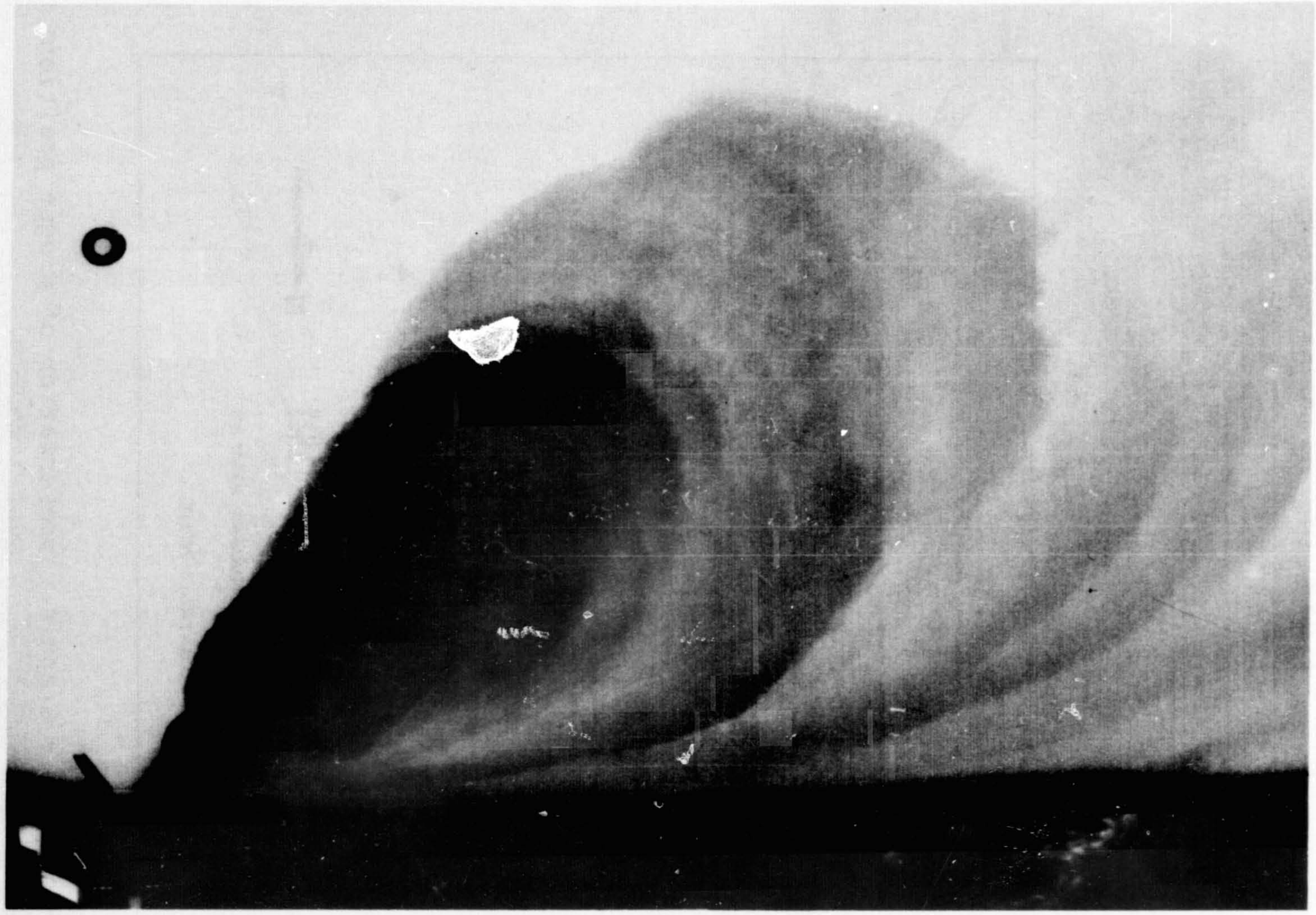

Figure 18.- Thermal line scanner image of Point Beach nuclear power plant plume.

Figure 19 shows a schematic of the plume velocity structure. This is a preliminary analysis based upon tracings of successive thermal fronts from projections of the thermal imagery. Digitized information from this thermal imagery has been analyzed and Figure 20 illustrates the temperature contours of this plume at the same time as the velocity structure shown in Figure 19.

Figure 21 shows the same plume, but was flown at 5000 feet. Wave-like thermal fronts extend several miles south of the plant but are by no means unique to the Point Beach power plant. Figure 22 shows a similar structure at the power plant near Sheboygan, Wisconsin. We have reason to suspect that these thermal fronts are not just surface phenomena. Figure 23 depicts a recording of the temperature at a fixed point in the middle of the Point Beach plume at a depth of 6 feet. The periodic variation of 2 to 3^{o}C may indicate the passage of a thermal front. Plans are now underway to erect a permanent platform in the plume with the capability of recording the temperature at many depths as well as the velocity of the current.

ADDITIONAL RELATED RESEARCH

APPLICATION OF REMOTE SENSING TO HYDROGEOLOGY*

In continuation of our research on the application of remote sensing in the evaluation of shallow ground water flow systems, two landfill sites in the city of Madison, Wisconsin, were overflown with a Daedalus thermal scanner and PRT-5 (8-14μ) at altitudes between 1600-1800 feet. Simultaneously with the thermal flights, ground truth information was gathered and the data obtained are now being correlated with the imagery obtained by the thermal sensor. An analysis is being made of such masking effects as: vegetation and color of soils; depth to the water table; topography; diurnal soil temperature variations; heat conduction originated by the decomposition of the refuse. Extensive ground water flow system evaluations, both physical and chemical, had already been accomplished at these two sites using conventional ground based techniques.

Our research so far has led to the conclusion that remote sensed thermal imagery (8-14μ) can be a valuable tool in rapid reconnaissance of ground water discharge into surface water bodies. In particular, the color separation processing of original analog data from magnetic tape corresponding to thermal levels has shown itself to be especially useful. Despite the abundance of masking effects, principally vegetation,

*Dr. David A. Stephenson, Principal Investigator, Associate Professor of Geology and Geophysics, Chairman - Water Resources Management Program.

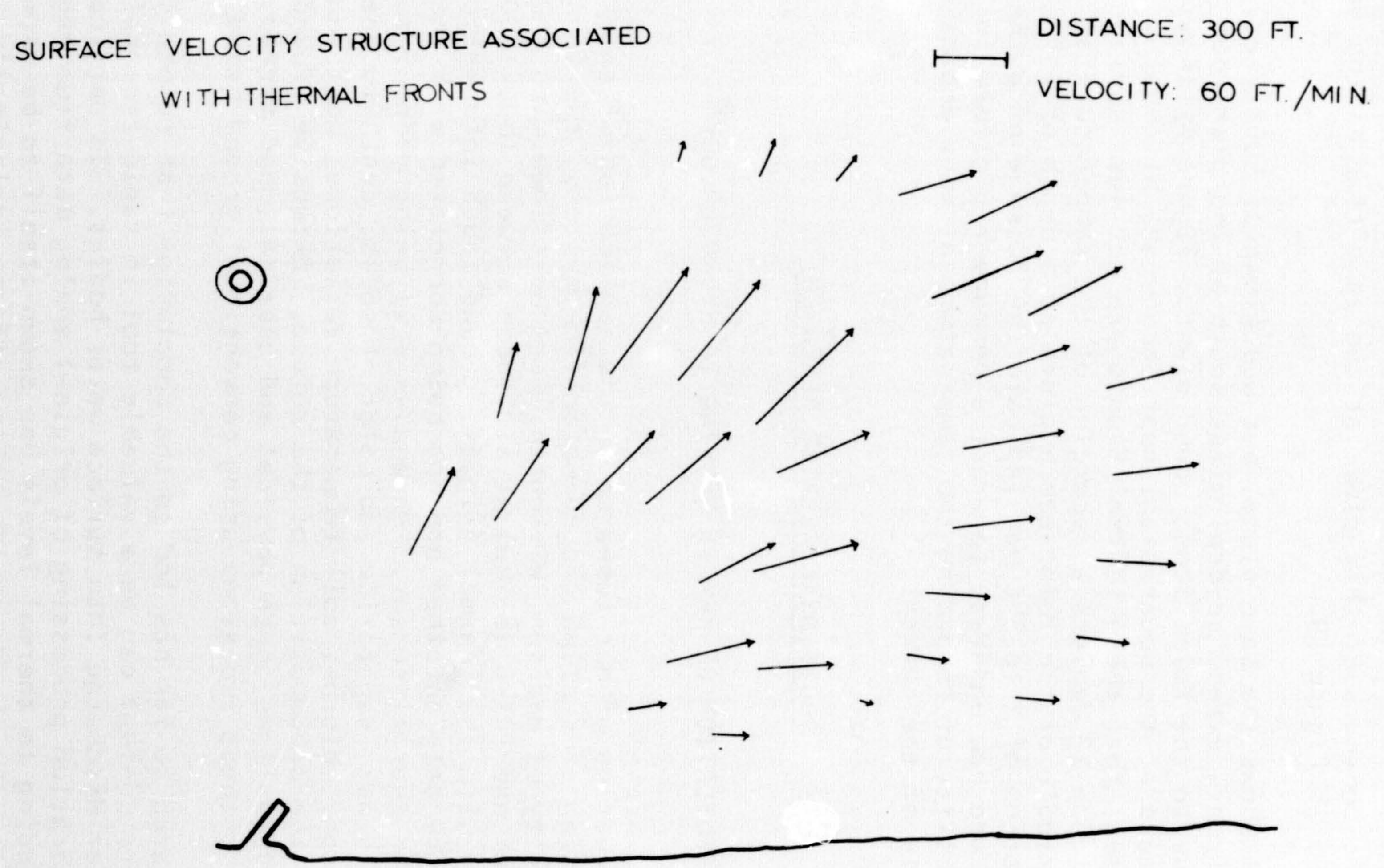

Figure 19.- Schematic diagram of Point Beach plume velocity structure.

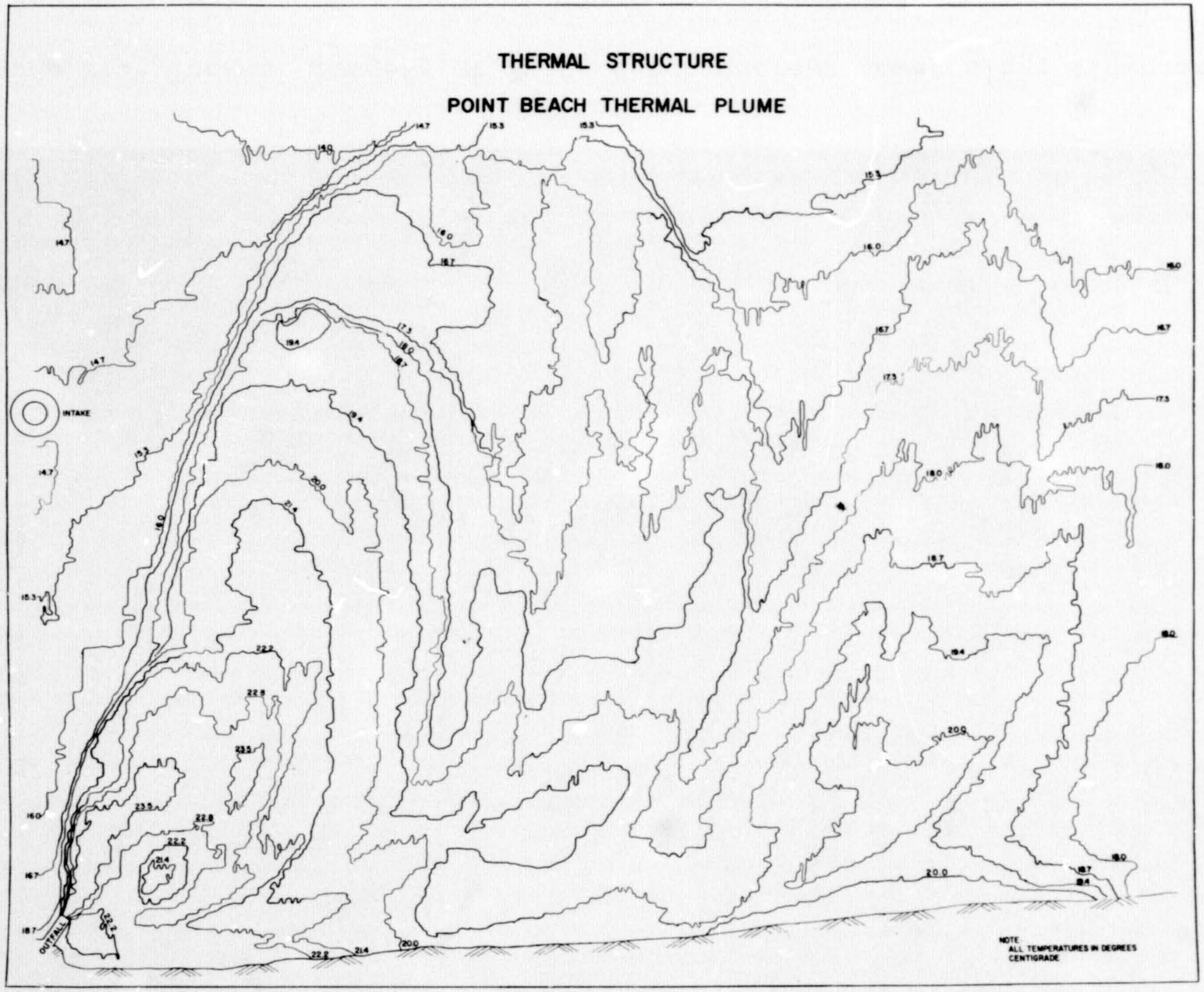

Figure 20.- Temperature contours simultaneous with velocity structure shown in Figure 19.

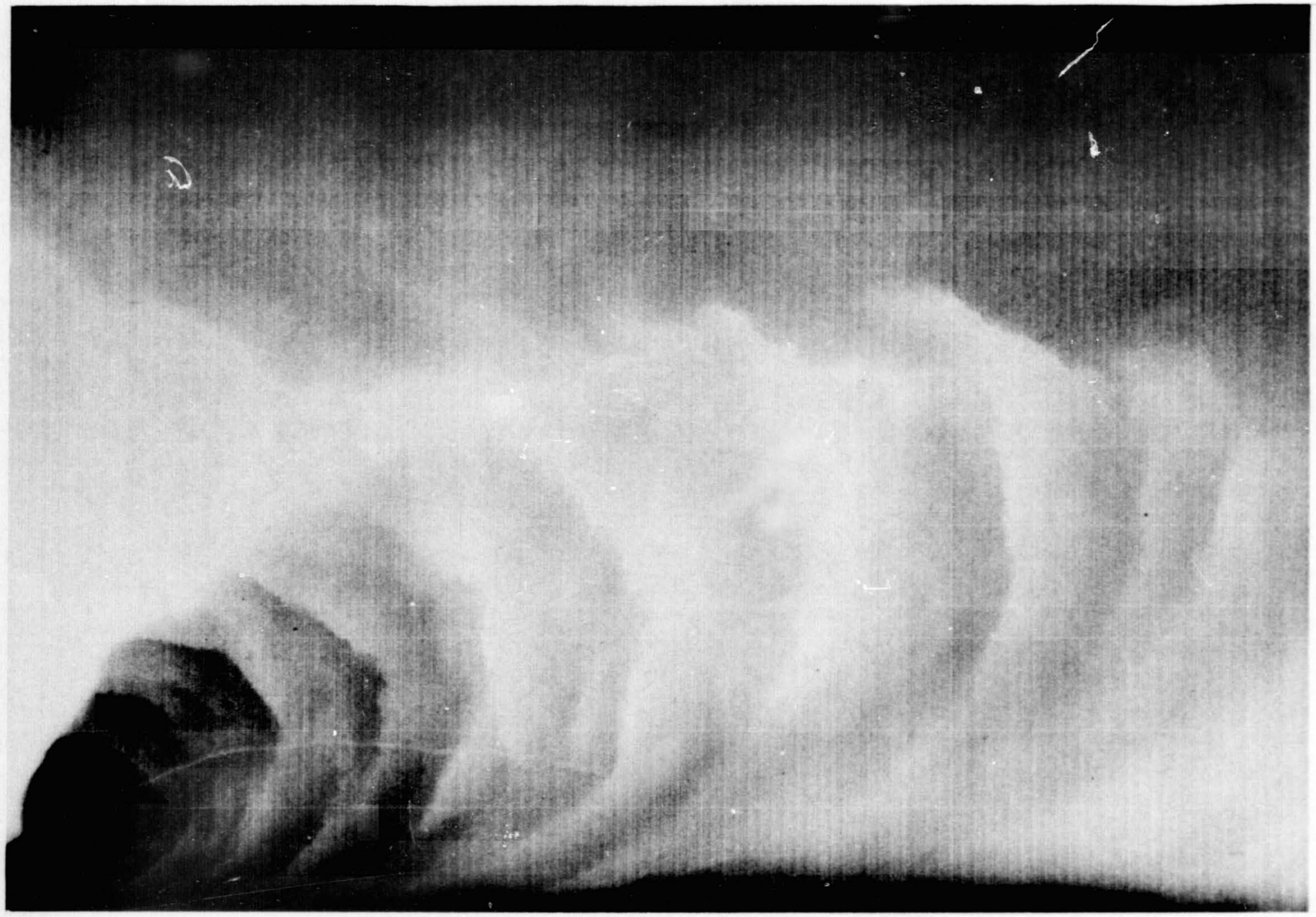

Figure 21.- Thermal imagery of Point Beach nuclear power plant flown at 5000 feet.

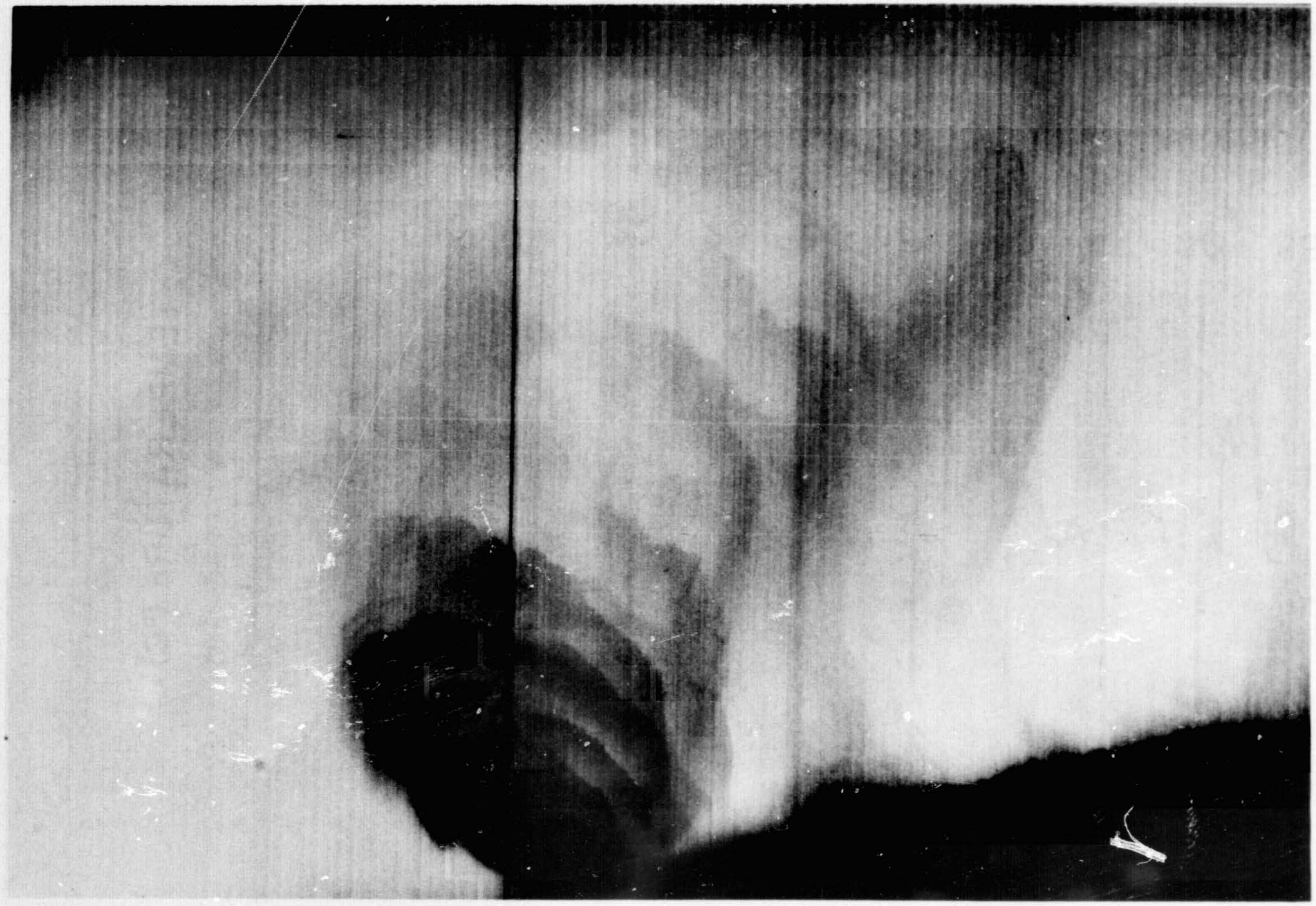

Figure 22.- Thermal imagery of power plant near Sheboygan, Wisconsin.

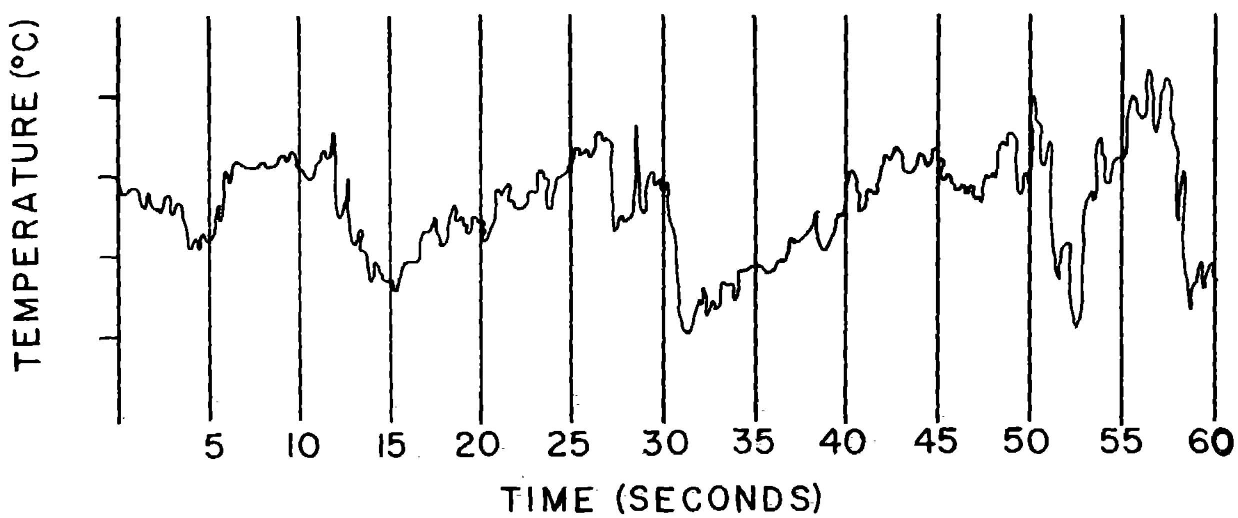

Figure 23.- Recording of temperature at a fixed point in middle of Point Beach plume at a depth of 6 feet.

springs discharging into Wingra Creek, which borders the Olin Avenue landfill site, were detected in the "color separated" imagery. The "normal black and white thermal image" fails to reveal to the naked eye these springs. They could only be detected with the time-consuming use of a scanning densitometer.

Whether thermal sensors (8-14μ) can help in locating ground water discharge zones will depend principally on the type or absence of vegetative cover, and on the time of the year. From the point of view of reducing the masking effects of vegetation, early spring, or whenever the spring thaw occurs, seems to be the best period of the year. The reduction in vegetative cover effects will probably compensate for the fact that the contrast between surface and ground water temperatures is smaller than in the summer or winter.

The possibility that the remote sensors investigated -- thermal IR, color and infrared color film -- can be used for the evaluation of different quality ground water discharges into surface water bodies is very small. In the two landfill sites studied, the water that infiltrates into the refuse and is later discharged into adjacent surface water bodies is too diluted to be detectable by present available remote sensors; in fact, it is even difficult to detect using conventional ground based instruments. The possibility that the water that infiltrates into the refuse becomes warmer and would therefore be detectable when discharged into a surface water body seems to be rather limited, since much of the heat conducted by the ground water along its "flow line" has probably been dissipated by the time it is discharged into a surface water body.

DETERMINATION OF OIL FILM THICKNESSES USING REMOTE SENSING TECHNIQUES*

The purpose of the study was to determine the feasibility of measuring the depth of an oil slick by employing Remote Sensing techniques. A constraint imposed was: that the materials and equipment used be easily obtainable, inexpensive and fairly simple to use. Because of this constraint the photographic portion, 0.375 microns to 0.800 microns, of the electromagnetic spectrum was chosen for use in the study. A three camera bank was utilized so that simultaneous photographs could be made with the three film and filter combinations selected for study. Agfachrome CT-18, no filter; Kodak Ektachrome-X, exposed through a polarizing filter turned to maximum polarization; and

*Dr. James P. Scherz, Principal Investigator, Department of Civil and Environmental Engineering and Institute for Environmental Studies.

Kodak Infrared Aero Film, Type 8443, exposed through a #15 Wratten filter, were the combinations chosen.

Photographs were taken on a bright, clear day and on a cloudy, overcast day to see what affect these conditions would have on the final results and to also see if the procedure had an all weather capability. A hoop was floated on the surface of Lake Monona in Madison and filled with varying amounts of oil. Each successive depth of oil was then photographed using the three camera bank. The hoop was used as the reflectance standard against which reflectance values for the increasing depths of oil were compared. This gave a percent reflectance value which could be plotted against wavelength for each different depth of oil. The percent reflectance readings were obtained by analyzing the transparencies developed from the three films. The equipment utilized was a Gamma Scanning Microdensitometer Assembly Model 700-10-80 and a Gamma Scientific Model 2020 Spectrophotometer. It was hoped that a correlation between percent reflectance and oil depth could be found that would enable an interpreter to accurately estimate the depth of an oil slick.

Analysis of the transparencies obtained showed, that for the oil used, Mobil Oil, 20W, and accurate estimation of a slick's depth can be made. The two film and filter combination will enable an investigator to secure reliable results no matter what the sky conditions are at the site of the spill. Generally, on a bright day, Agfachrome CT-18 films, no filter, will prove the most useful for detecting and delineating the slick visually. Ektachrome-X film, exposed through a polarizing filter did not yield meaningful results. Kodak Infrared Aero Film, Type 8443, will provide the best correlation between reflectance readings and oil depths during the machine analysis of the transparencies. On a cloudy day, all three films will sharply delineate the extent of the spill visually. The infrared film will again be the best film for providing the correlation between percent reflectance and the depth of the oil spill during machine analysis. The agfachrome film can provide a check on the depth of thin oil films. The Ektachrome-X proved to be of little value.

USE OF REMOTE SENSING TO IDENTIFY HYDROLOGICALLY ACTIVE SOURCE AREAS*

Hydrology, by the most accepted definition, is a discipline dealing with the origin, properties, movement and distribution of water on and beneath the surface of the earth. Application of remote sensing tech-

*Dr. Dale D. Huff, Principal Investigator, Department of Civil and Environmental Engineering.

niques to hydrology should therefore be a process by which characteristics of objects connected with the origin, properties, movement and distribution of water on and beneath the surface of the earth are obtained without physically touching them.

A review of the available literature indicates that infrared photography and thermal imagery have been used fairly extensively in ground water explorations and water quality studies. At the present time, however, there has been little or no effort made to determine parameters of the hydrological cycle using remote sensing techniques.

In the recent past a new idea called the "source area concept" has been added to the study of runoff hydrology. Proposed by Hewlett in 1961 as a better way to interpret and explain storm and base flows from forested watersheds, this concept has now gained some headway through the efforts of many engineers and hydrologists in applying it to local situations. While outlining this concept as it is known today, this research is analyzing the possibility of using remote sensing techniques for locating such source areas.

Successful identification of these hydrologically "active" areas by means of remote sensing techniques will not only help in developing a more accurate "runoff generation model" but will also have numerous uses in the following fields of studies: (1) Water quality; (2) Water and land management; and (3) Erosion and soil conservation.

CONCLUSIONS

Based upon the results of the past years' research effort by the University of Wisconsin's Remote Sensing Program, the following conclusions were reached concerning the applications of remote sensing to water resources problems.

1. Remote sensing methods provide the most practical method of obtaining data for many water resources problems.
2. Effective use of remote sensing research funds can be achieved by cooperative efforts with other environmental research efforts and agencies.
3. The multi-disciplinary approach is essential to the effective application of remote sensing to water resource problems.
4. There is a correlation between the amount of suspended solids in an effluent discharged into a water body and reflected energy. However, bottom effects may mask the signal if not properly accounted for.
5. Remote sensing provides for more effective and accurate monitoring, discovery and characterization of the mixing zone of effluent discharged into a receiving water body.
6. It is possible to differentiate between blue and blue-green algae

by comparing the ratios of reflected light at 0.650 microns and 0.6250 microns.

7. The reflectance at 0.550 microns is approximately halved for each doubling of algae Selenastrum and Anabaena concentration. However, this effect is masked by turbidity.
8. Multiband photography provides for rapid mapping of aquatic macrophytes.
9. Simultaneous radiometric, photogrammetric, and thermal line scanning can be used to provide measurement of relevant parameters which are not available by other means and are vital to the investigation of the dynamic structure of lake currents.
10. The velocity structure of some thermal plumes may be obtained from sequential thermal imagery by tracing the propagation of thermal fronts in the plume.
11. It is unlikely that photography or thermal IR can be used to evaluate the quality of ground water discharges into surface water bodies.
12. Kodak Infrared Aero Film, Type 3443 can be used to obtain accurate estimates of oil slick depth for Mobil Oil, 20W.