POLLUTION SURVEILLANCE AND DATA ACQUISITION
USING MULTISPECTRAL REMOTE SENSING[1]

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ABSTRACT

Large scale water resource investigations and effective pollution surveillance programs require the development of additional instrumentation and techniques to supplement existing methods of data acquisition.   As a result, interest is growing in the concept of remote sensing.   Described in this paper is the multispectral sensor concept and its application in water resource studies.

KEY WORDS: remote sensing; water pollution surveillance; industrial wastes;
            water pollution control; instrumentation

INTRODUCTION

The current effort to bring all existing pollution under effective control, and to enhance the quality of our water resources, has provided an added incentive for the development of instrumentation and techniques for detecting and identifying sources of water pollution.   As a consequence, impressive gains have been made in recent years in the development of analytical techniques and continuous monitoring instrumentation.   However, in view of the scope, dynamic nature, and dimension of the pollution control problem, additional techniques are required to detect sources of pollution, identify the pollutant, and to define dispersion patterns.   This is particularly true for large water masses, coastal areas, and large river systems. As a consequence, interest is growing in the concept of remote sensing.

The term remote sensing refers to the acquisition of information about objects or phenomena in our environment through the use of sensory devices at positions away from the subject under investigation.   In this investigation the term is restricted to the use of an airborne system and measurement of interactions in the ultraviolet, visible, and infrared regions of the electromagnetic spectrum.

The amount of information potentially obtainable from remote measurement of electromagnetic energy is quite large.   As Colwell, *et al.* (1963) have emphasized, only four interactions are possible when a photon of any specific energy strikes a substance.   The energy may be absorbed, emitted, scattered, or reflected.   There-fore, in principle, information can be obtained regarding an object provided, of course, that the instrumentation used is capable of defining spectral properties in sufficient detail.

The data acquisition needs in the water pollution control field include infor-mation regarding the following:

1. materials on the surface of the water,
2. materials suspended in the water, and
3. materials dissolved in the water.

Some of this information is at times expressed in broad-term parameters such as sus-
pended solids, total carbon, oils, etc.; and also, of course, in very specific chem-
ical terms.   Additionally, there is a need for information of a strictly physical
nature; such as temperature or data regarding pollution dispersion patterns.   The
information needs are clearly quite extensive and as a result cannot be fully real-
ized with a single sensor system.

The present report deals with one sensor system and presents selected examples
of problems wherein remote sensing can offer a number of unique advantages.

MULTISPECTRAL SENSOR SYSTEM

The instrumental technique used in this investigation involved the use of the
multispectral sensor developed at the University of Michigan (Holter, 1967).

The University of Michigan has pioneered the development of a passive multi-
channel scanner system which is capable of sensing reflected and emitted energy
simultaneously in a number of narrow spectral intervals in the ultraviolet, visible
and infrared region of the solar spectrum.   The system basically consists of a
spectrometer for dispersing the radiation spectrally and filtered detector arrays
placed at the focal points of a double ended optical-mechanical scanner.   Figure 1
shows schematically the system operation.   The scanner uses reflective optics to
collect energy over a wide spectral band between ultraviolet and thermal infrared.
The entrance slit of the spectrometer is placed at the focal plane of the scanner to
insure that space and time simultaneity is achieved for all channels between .4 and
1 μ.   Filtered detectors for the infrared region and the use of short electronic
time delays provide coincident data for the region beyond 1 μ. Additional detectors
and filters can be provided for the ultraviolet region.   Signals from the detectors
are stored on magnetic tape for later image reconstruction and data processing.   As
an integral feature of the system, reference lamps, an input proportional to the sun
energy, and adjustable temperature plates are viewed each revolution of the scanner
mirror.   Thus for the first time (with an optical-mechanical scanner) reproducible
data can be obtained which is referenced to known radiation sources and is capable
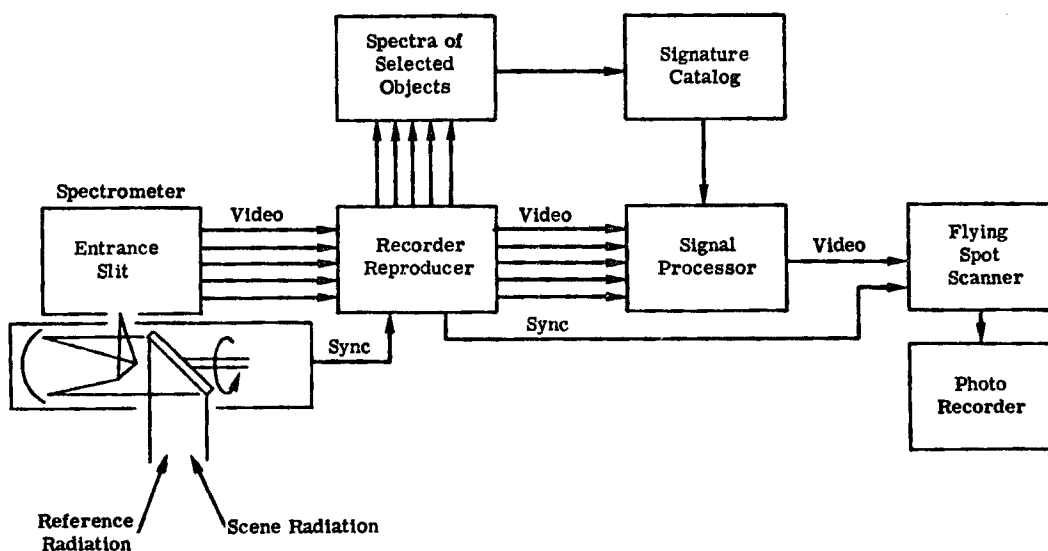

FIGURE 1.   Schematic of multispectral scanner and data processor.

of accounting for changes in solar illumination. These controlled points in each scan line permit the use of sophisticated electronic pattern recognition techniques with both analog and digital computers (Nalepka, 1970).

The generation of a spectrum for each element permits machine recognition of classes of objects whose spectral characteristics are similar within certain electronic decision levels. As part of on-going research, the University of Michigan is engaged in a spectral measurement program to identify the spectral characteristic of objects and determine their mean and variance statistics for a class of similar objects. In the field of water pollution control it is believed that remote spectral measurements can be used to detect and identify effluent discharges.

In order to determine spectral characteristics, the airborne data recorded on magnetic tape is electronically digitized and then stored in a computer. The analog to digital converter consists of a high accuracy (13 bit and sign) successive approximation converter capable of providing samples in 10 microseconds. The data is formated and coded into 48 bit words for a CDC-1604 computer. Special computer programs have been written to edit the digital tapes and format the data for use with FORTRAN programs. Selected portions of the objects mapped are used as training areas for which the spectral characteristics are computed. Once computed, a computer generated spectral curve can be made that is referenced to the incoming solar spectrum or to other objects in the scene. In some cases, ground reflectance standards are used to provide absolute reflectance calibration.

The spectral properties are then available for use with the computer to perform spectral matching operations to enhance the detection of selected objects of similar properties or to map the different concentration of an effluent.

The electronic format of the data also permits a voltage sampling operation (for any selected band) in order to display small density differences. For example, the mixing zones of a thermal discharge into a river or lake can be studied readily by quantizing the data in the 8-13.5 μ band into one half degree steps, color coding each step, and combining the set into one color composite display. Each color represents the isotherm for a chosen temperature level. The use of two adjustable reference plates in the scanner system insures optimum recording and accurate reconstruction of the apparent temperature patterns.

Many other computer programs have been devised and are employed in processing the multispectral data for particular applications.

APPLICATIONS

Detection and identification of any object is possible only if there is a significant contrast in physical or chemical properties between the object being examined and its background. In the case of effluent discharges into the aquatic environment; from power plants, industrial sources, and municipal sources, there is normally some significant difference between the effluent and the receiving body of water which can be detected by the system described above. Additionally, the very large discrimination capability of the sensor system allows for the characterization of the target, at least in terms of broad parameters. Described in the sections which follow are selected examples which serve to define areas of application wherein remote sensing technology offers a number of advantages.

TEMPERATURE ANALYSIS

Temperature is one parameter which is closely related to water pollution and is of interest in virtually all studies dealing with the aquatic environment. Fortunately, surface determinations can readily be made in the 8-13.5 μ region throughout the day or night to an accuracy of 0.5°C. This ability has been clearly demonstrated by a number of investigators. However, the important difference between what has been reported in the past and the present investigation, centers around the in-

creased instrument capability due to the calibration and correlation with other por-
tions of the spectrum.

An added feature of the University of Michigan system is the calibration lamp
and controlled thermal sources that are recorded for each scan line.   This feature
allows for greater sensitivity in temperature determinations and thermal contour
development.

Shown in Figure 2 is a portion of a thermal plume discharging from a power
plant. The general distribution of the warm water being discharged is clearly visi-
ble in the lower panel. Using the computer processing technique referred to earlier,
the airborne thermal data was used to develop temperature contours.   Shown in the
figure are selected temperature levels in the plume area.

In addition to applicability in thermal pollution studies; the speed, mobility,
and ability to completely and virtually instantaneously map large water areas can be
of great importance in a variety of other water resource investigations.   For exam-
ple, the movement of water masses can be followed and defined. This can be accomp-
lished in terms of a number of physical-chemical characteristics.   However, if in a
given situation a temperature difference exists between the two water bodies, moni-
toring can easily be done in the 8-13.5 μ range during hours of daylight or dark-
ness. An example is shown in Figure 3.   In this situation the progression of a cold
water release from an upstream dam was defined.   The dark area represents water ap-
proximately 3°C colder than the light areas shown.

EFFLUENT OUTFALLS

The ability to detect small temperature differences can also be used to locate
effluent outfalls including submerged outfalls; provided of course, that the volumes
discharged are of sufficient magnitude to alter the temperature of the receiving
waters.   Detection on the basis of other effluent characteristics is also possible.
However, in virtually all cases there is a temperature difference between the efflu-
ent and the receiving body of water which can serve as a basis for detection. Moni-
toring in the 8-13.5 μ region of the electromagnetic spectrum can be done during the
day or night and hence provides an expanded capability for pollution surveillance.

Shown in Figure 4 (lower panel) is the plume from a 3 M.G.D. municipal waste
treatment plant discharging from a submerged outfall. In this case, the variations
in emitted power level are probably due to a change in temperature and emissivity
due to a change in water quality.

UNDERWATER FEATURES

It is generally recognized that in examining any scene, certain components of a
target can be best defined by their response within selected narrow spectral bands.
This fact is clearly illustrated in Figure 5 which demonstrates the capability of
the system in locating and mapping underwater features in clear water.   The imagery
shown was obtained at the south end of Biscayne Bay in Florida and shows maximum
overall light penetration in seawater in the 0.55 to 0.58 μ bandwidth, with Ceasar
Creek clearly defined in the 0.62 to 0.68 μ bandwidth (Polcyn and Rollin, 1969).

INDUSTRIAL EFFLUENTS

As indicated earlier, an important feature of the instrumental system used in
this investigation is the ability to examine a scene in 17 bands distributed between
0.3 and 13.5 μ. This means that in addition to the detection capability referred to
above, the system serves as a 17 channel spectrometer with electronic processing
features.   Shown in Figures 6-9 are a few examples of multispectral imagery of in-
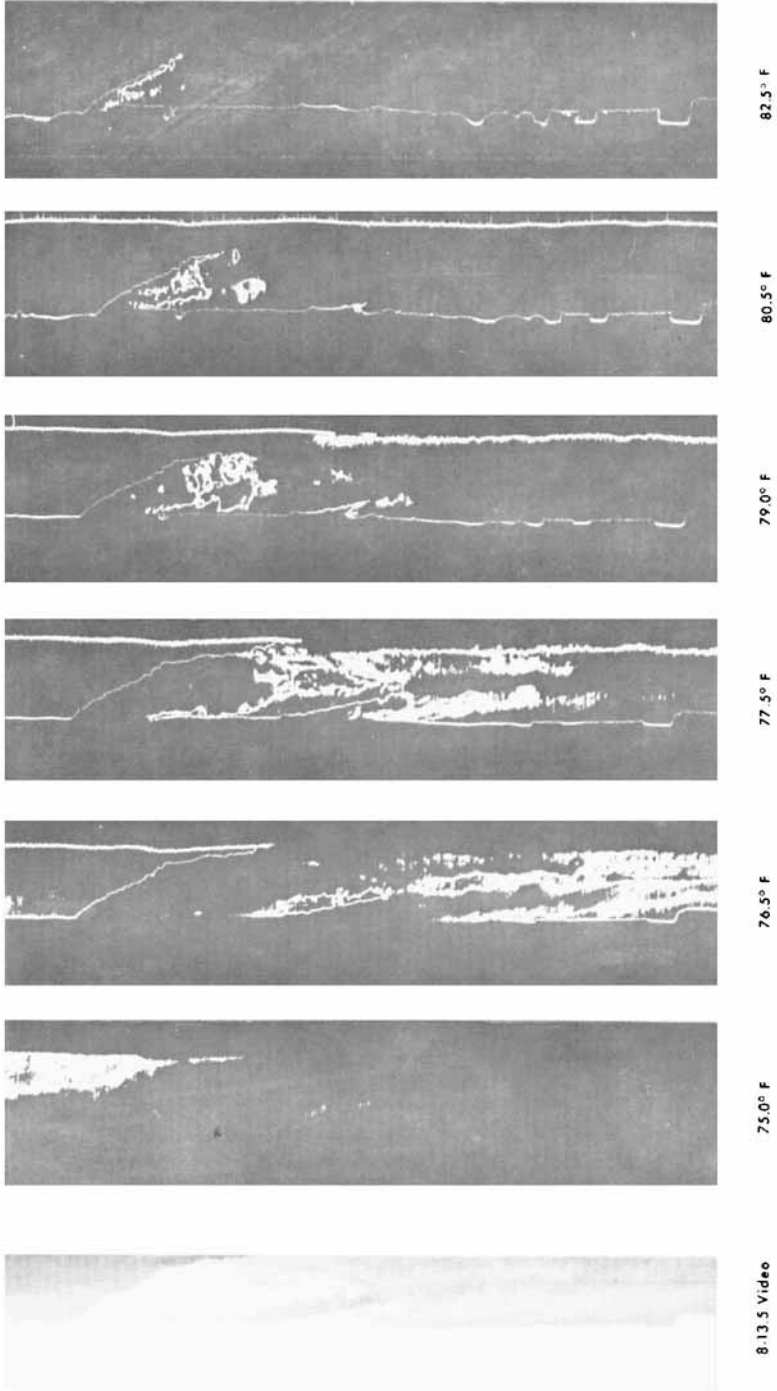dustrial discharges.

FIGURE 2. Thermal contour of Detroit Edison Plant; 13 August 1969; 0900 hrs.,; altitude 1000'; sky condition, moderate haze and cloudy.
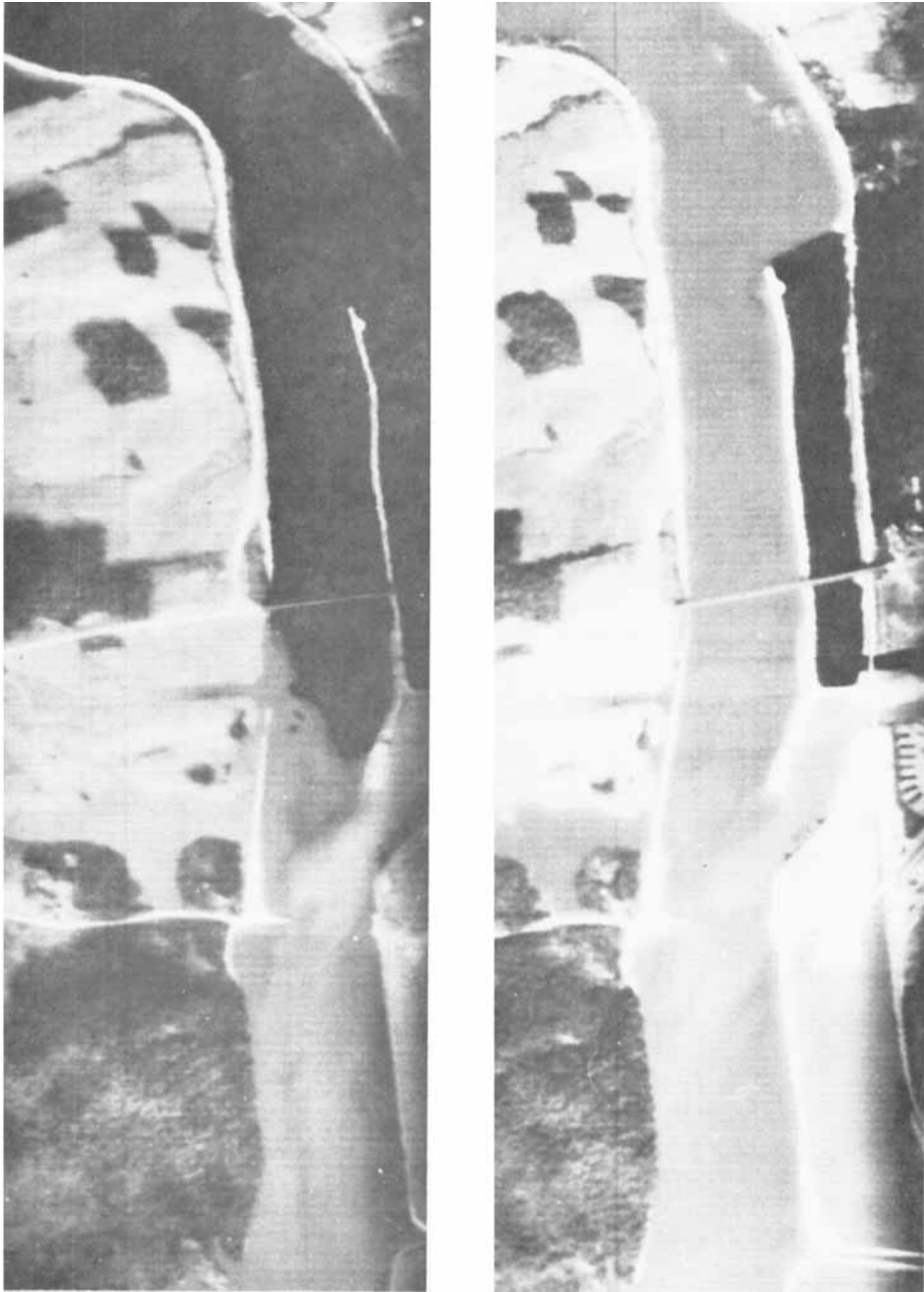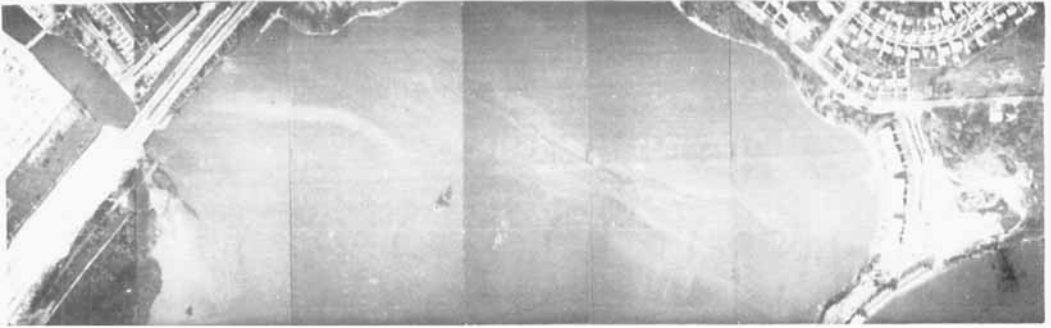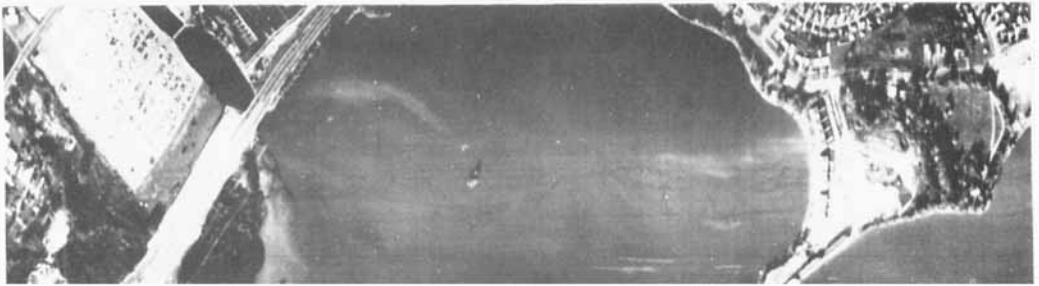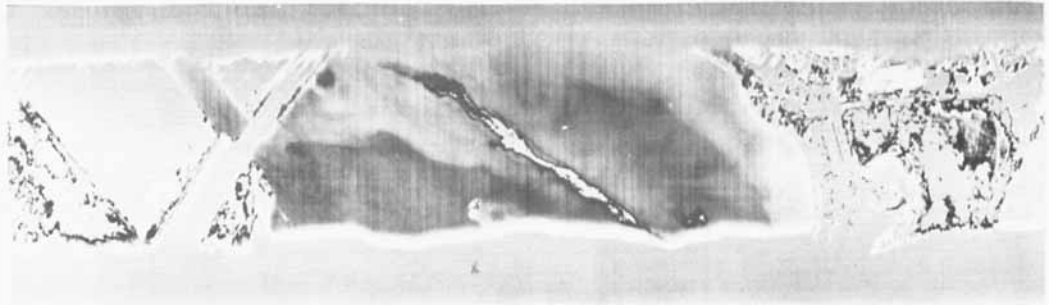
FIGURE 3. Position of cold water mass.

Conventional Photo Mosaic

Narrow Band Scanner Imagery 0.55 to 0.58μ
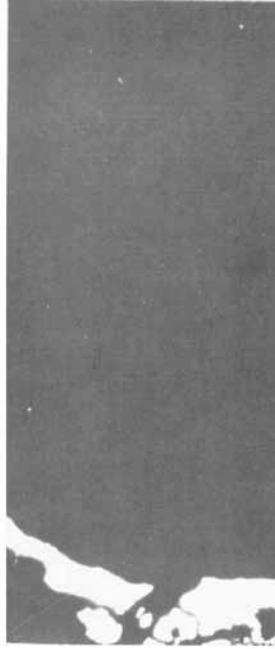

Enhanced Scanner Imagery 8.0 to 14.0μ

FIGURE 4. Municipal waste treatment plant discharge.

.55 to .58 μ

.62 to .68 μ

.80 to 1.00 μ

.40 to .44 μ

.50 to .52 μ

FIGURE 5. Underwater features.
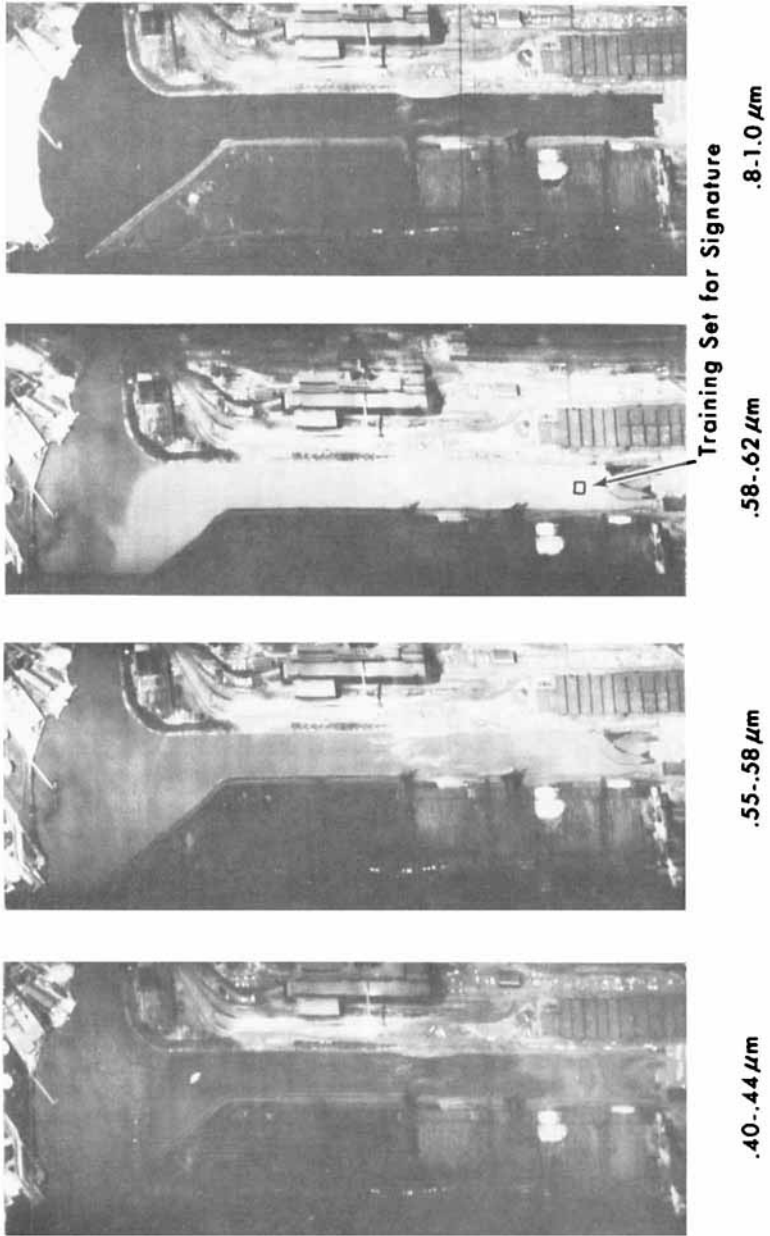
FIGURE 6. Multispectral imagery; automotive plant pickling liquor discharge.
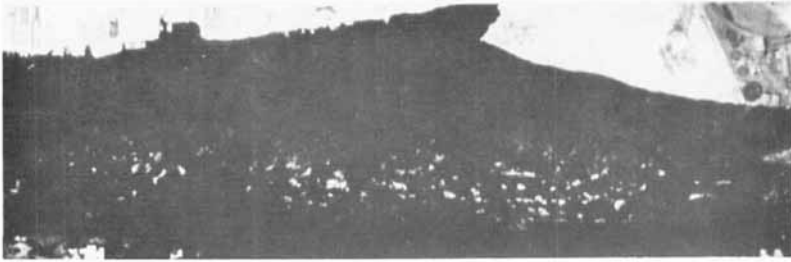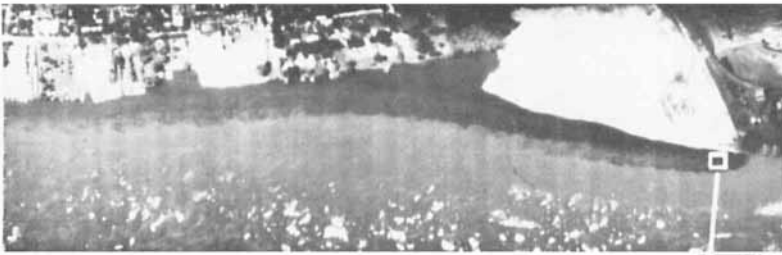
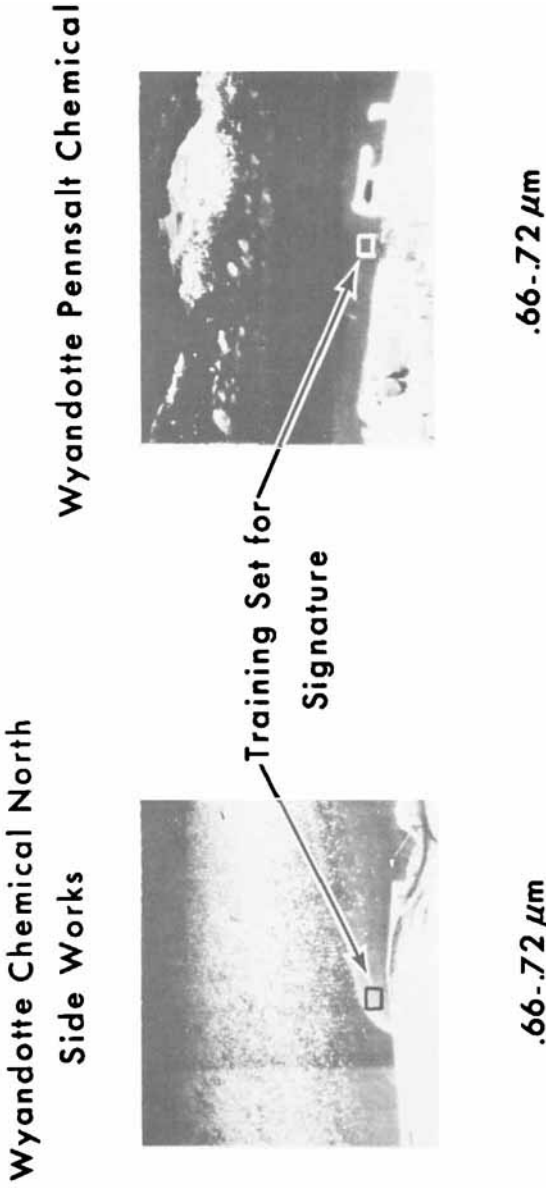FIGURE 7. Multispectral imagery; steel mill.
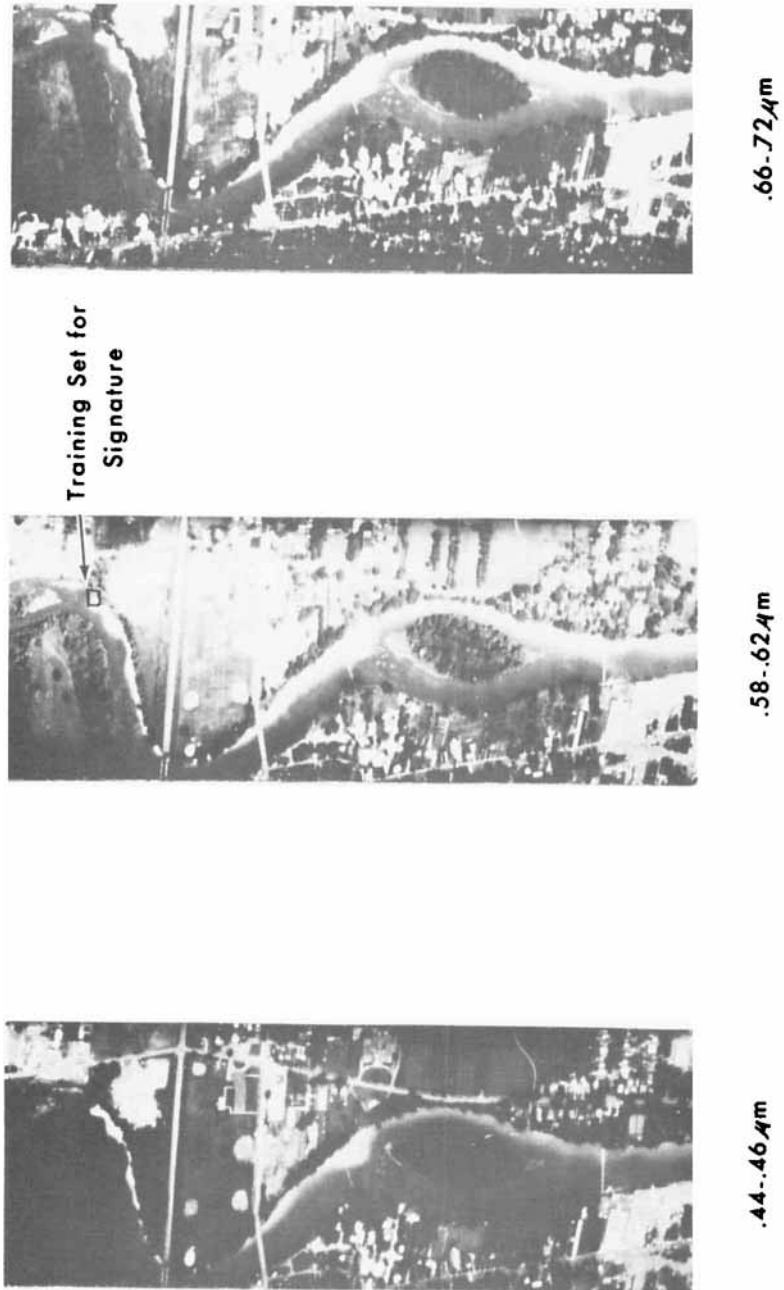
FIGURE 8.   Chemical plant effluent.

FIGURE 9. Multispectral imagery; container manufacturing.

Inspection of the above figures shows that each effluent is more clearly de-
fined by examination at its optimum wavelength; and, hence, dispersion patterns of
the effluent are best determined within a particular spectral band width.

Using the multispectral scanner concept, the optimum wavelength is automatical-
ly determined; and in addition, the interactions of radiation with the effluent at
other positions in the electromagnetic spectrum are also determined. This is shown
in Figures 10 and 11. Each effluent type and receiving body of water has its unique
spectral characteristics which serve to differentiate it from other sources.

It is clear that when a photon of energy strikes a liquid, one of the inter-
actions which occur is scattering. The selective scattering which takes place is,
of course, affected by the concentration, shape, and size of suspended solids. A
decrease in concentration will result in a decrease in back-scattered light. Figure
12 illustrates this point. The degree of back-scattering is reduced at a position
100 ft. below the outfall in the effluent plume; as well as in an adjacent area in
the Detroit River. In this particular case, the optimum spectral position for
defining variations in suspended solids concentration is about .64 μ. Using the
computer techniques referred to earlier, suspended solids contours could be easily
developed. Work is currently in progress to further explore the techniques of sus-
pended solids measurement using the methods described together with other instru-
mental concepts.

OTHER NONCONTACT MEASUREMENT TECHNIQUES

The present report describes one instrument and one approach to the problem of
measurements in the aquatic environment. This instrumental technique will undoubt-
edly be further refined and expanded in the near future. However, it is clear that
all measurement needs cannot be fully realized using this approach, and that addi-
tional concepts will have to be explored. The authors are currently engaged in
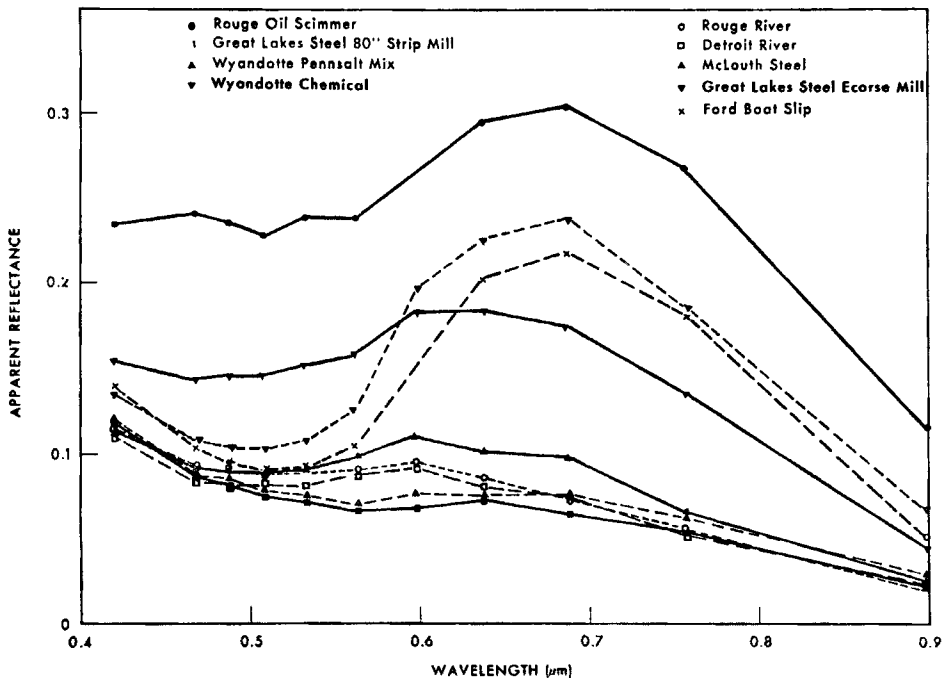

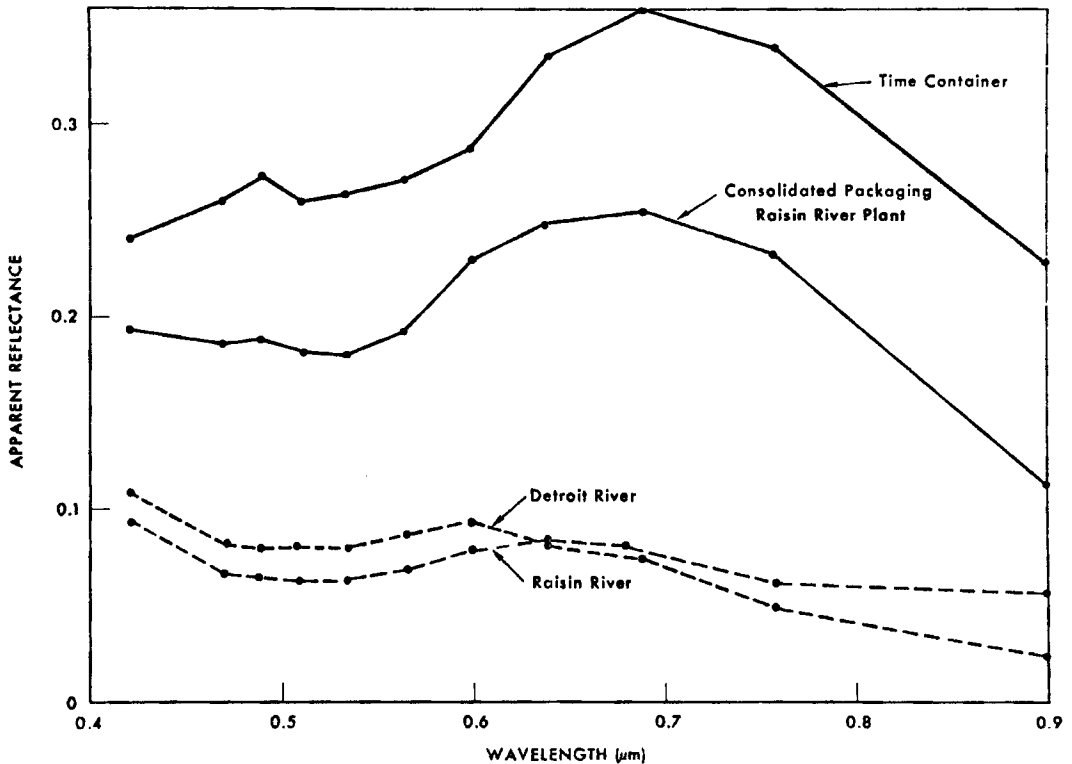FIGURE 10. Spectra comparison: Rouge and Detroit Rivers.

FIGURE 11. Spectra comparison: Raisin River.

laboratory studies dealing with noncontact measurements of specific chemical con-
stituents.   One technique which is certain to be used extensively in the future for
noncontact data acquisition involves analysis on the basis of fluorescence.   This
analytical technique could be used for the detection and identification of sub-
stances such as rhodamine dye, chlorophyll, lignin-sulfonates, and many other sub-
stances which possess the property of fluorescence.   Recent reports which describe
the Fraunhofer line discriminator (Stoertz, *et al.*, 1969) and laser induced emis-
sions (Hickmann and Moore, 1970) indicate that airborne fluorescence measurements
are feasible.

CONCLUSIONS

The added sophistication which the multispectral system provides in terms of
range of spectral discrimination and electronic processing, clearly indicates that
this system can be used to collect a wide variety of data which is of significance
in water pollution control and water quality evaluation.   As a result, the prelimi-
nary data collected to date encourages a continued research effort to fully define
the capabilities of this system and related instrumentation.   Research is needed to
develop spectra for a wide range of pollutants and substances, to define the limits
and extent of ground control required, to define the limitations of the system, and
to evaluate a number of environmental factors.   Additionally, other instrumental
concepts must be considered including the use of "active" systems.

The field of remote sensing is still very much in its infancy; however, the
prospects are very exciting.   The advantages which a fully developed remote sensing
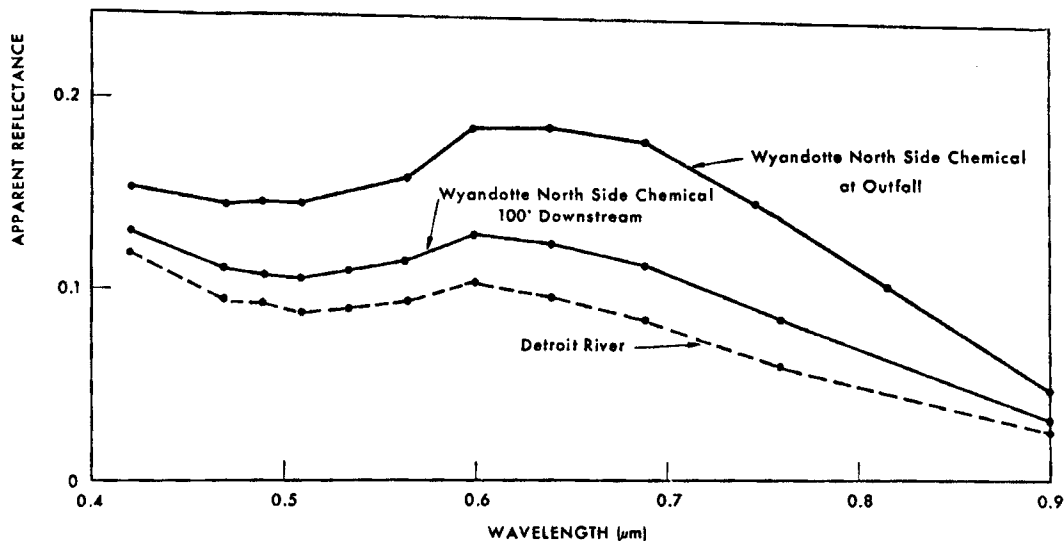technology could offer the field of water quality management are obvious.   Speed of

FIGURE 12.   Spectral variation due to variation in suspended solids concentration.

data acquisition, mobility, accessibility, and large area coverage, are some charac-
teristics of an airborne system which could provide a new dimension in data acquisi-
tion.   As a consequence, it is a virtual certainty that in the near future remote
sensing techniques will be used for pollution monitoring, study of dynamic condi-
tions in the aquatic environment, and other large scale water resource investiga-
tions.

ACKNOWLEDGEMENTS

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