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Field Measurements of the Spectral Response of Natural Waters

Turbid river water had a higher spectral response than clear lake water in the red and near-infrared portions of the spectrum

Introduction

Aerial surveys and conventional photo-interpretation techniques have been used to obtain information on water quality (Strandberg, 1966; Schneider, 1968; James, 1971). With the advent of Landsat-1 (formerly called the Earth Resources Technology Satellite, ERTS) and the development of automatic pattern-recognition techniques for analyzing remotely-sensed multispectral data, it has been possible to discriminate several spectrally different classes of water (Landgrebe *et al.*, 1972; Mausel *et al.*, 1976; Tarnocai and Kristof, 1976). To date, though, it has been difficult to relate these different spectral classes of water to specific water quality parameters. It is possible that these different spectral classes of water are closely related either to different levels of turbidity or to reflectance effects from the bottom of shallow and clear bodies of water. Therefore, it is important to have a better understanding of the optical characteristics of natural waters, such as their spectral transmittance, reflectance, and scattering.

In the past, the optical behavior of natural waters has been studied under laboratory conditions (Scherz *et al.*, 1969), in which the illumination and geometry of measurements are different from those encountered in field measurements.

The purpose of this investigation was to study the optical behavior of natural waters in the field. Specifically, the objectives were (1) to measure *in situ* the spectral response (air-water interface reflectance and water-volume scattering) of turbid river water and relatively clear lake water, and (2) to determine the influence of the bottom reflectance on the spectral response of river water. A

Abstract: *The spectral response (air-water interface reflectance and water-volume scattering) of turbid river water (99 mg/litre suspended solids) and relatively clear lake water (10 mg/litre suspended solids) was measured in situ with a field spectroradiometer. The influence of the river bottom on the spectral response of the water also was determined by using a modified Secchi disc approach.*

The results indicated that turbid river water had a higher spectral response than clear lake water (≈6 percent) in the red (0.6 - 0.7 μm) and near-infrared (0.7 - 0.9 μm) portions of the spectrum. Also, the reflectance characteristics of the river bottom did not influence the spectral response of the turbid river water when the water was deeper than 30 cm.

Photogrammetric Engineering and Remote Sensing,
Vol. 43, No. 5, May 1977, pp. 595-598.

TABLE 1. CONDITIONS DURING COLLECTION OF SPECTRAL DATA AT THE WABASH RIVER AND LAKE MONROE TEST SITES.

Site	Date	Time (Local)	Sky Conditions (Cloud Cover)	Suspended Solids (mg/litre)	Water Depth (cm)
Wabash River	7/11/73	12:00 noon	Clear	99	60
Lake Monroe	6/10/73	10:00 am	Clear	10	>400

field spectroradiometer and a modified Secchi disc approach were used in the experiment.

It is hoped that the results obtained from this and similar investigations will aid in the interpretation of the large quantities of multispectral data collected from aerial and space platforms and thus increase the capability to detect and monitor effectively and quantitatively the quality of water resources.

MATERIALS AND METHODS

The spectral data for this experiment were collected at two different test sites: the Wabash River near Lafayette, Indiana (turbid water) and Lake Monroe, located approximately 10 miles south of Bloomington, Indiana (clear water). Table 1 shows the date, time, sky condition, suspended solids (inorganic), and depth of the water for the two different test sites. The analysis of the water samples was conducted by Dr. John M. Bell of the Purdue Environmental Engineering Laboratory.

The measuring instrument was an Exotech Model 20-C field spectroradiometer mounted on a Hi-Ranger mobile tower. This instrument consists of two separate units: a short wavelength unit and a long wavelength unit, each of which can be operated individually. In this experiment only the short wavelength unit was used. The spectral ranges and detector types of the short wavelength unit are summarized in Table 2. The Exotech 20-C has two selectable fields of view (FOV): 0.75° and 15°. The scan rate can be varied from 0.5 to 30 seconds per scan, and its spectral resolution is 0.017 μm at half bandwidth in the visible and 0.032 μm at half bandwidth in the near and middle infrared portions of the spectrum. Detailed specifications for the instrument have been described by Silva *et al.* (1971) and Robinson *et al.* (1973).

At both tests sites, several spectra of the water were recorded from an altitude of 6 metres (20 feet). A field of view of 15° was used, which covered an area of approximately 162 cm in diameter on the water surface. This part of the investigation was performed in order to determine and compare the spectral characteristics of turbid and relatively clear water under natural undisturbed conditions.

In order to determine the effect of the river bottom reflectance on the spectral response of the water at the Wabash River test site, a modified Secchi disc approach was utilized. A 38 by 38 cm square aluminum plate painted with white Krylon plastic paint on one side and with black Krylon plastic paint on the other side was placed at different depths in the water ranging from 0 to 30 cm. The aluminum plate was sandblasted before painting to increase the diffuse reflectance characteristic of its surface. Both the white and black paints have a known reflectance which is nearly constant throughout the visible and near-infrared portions of the spectrum. The spectral reflectance of the white painted surface was approximately 83 percent throughout the visible and near-infrared wavelengths (Figure 2), and that of the black painted surface was practically zero. From six to eight spectra were then taken of both sides of the plate from an altitude of 6 metres (20 feet) and through the narrow field of view (0.75°) which covered an area of approximately 8 cm in diameter.

The target was viewed along the normal in order to avoid any specular component from the surface of the painted plate, and the re-

TABLE 2. SPECTRAL RANGES AND DETECTOR TYPES OF THE EXOTECH 20-C SPECTRORADIOMETER—SHORT WAVELENGTH UNIT.

Spectral Regions	Wavelength (μm)	Detector
Ultraviolet and Visible	0.38–0.72	Silicon
Near Infrared	0.70–1.30	Lead Sulfide
Middle Infrared	1.30–2.50	Lead Sulfide

sulting spectra were normalized by comparing them to the spectrum of the incoming solar radiation and to the spectral reflectance of a known standard (pressed barium sulfate). This procedure enabled the calculation of the bi-directional spectral reflectance factor $R(\lambda)$ with respect to a perfect diffusing (Lambertian) surface. The $R(\lambda)$ curves shown in Figures 1 through 4 were determined by using Equation 1 and are expressed in percent.

$$R(\lambda) = \frac{L_1(\lambda)}{L_2(\lambda)} \rho_b(\lambda) \qquad (1)$$

Where $L_1(\lambda)$ is the measured spectral radiance of the target,
$L_2(\lambda)$ is the measured spectral radiance of the pressed barium sulfate, and
$\rho_b(\lambda)$ is the published spectral reflectance of pressed barium sulfate.

Results

A comparison of the spectral characteristics of turbid river water (99 mg/litre of suspended solids) and of lake water (10 mg/litre of suspended solids) is shown in Figure 1. The spectral response of the turbid water was very similar to that of the clear water (≈1.5 percent) in the green portion of the spectrum (0.50 - 0.55 μm), whereas in the yellow, red, and near-infrared regions (0.55 - 0.90 μm) the spectral response of the turbid and clear waters differed by approximately 6 percent. In the near-infrared portion of the spectrum, the clear lake water was essentially black, whereas the turbid river water had a spectral response of approximately 5 percent.

The effects of the reflectance characteristics of the white and black plate on the spectral response of the turbid water are shown in Figures 2 and 3. In Figure 2 one can see how the influence of the white plate on the spectral response of the river water decreases as the depth of the plate increases from 3 to 20 cm. The spectral response of the water when the white plate was placed at 20 cm below the water surface or deeper was equal to the spectral response of the river without the plate.

When the black plate was placed at 3 and 6 cm under the turbid water, the spectral response of the water was practically zero. Only as the black plate was lowered to 10, 20, and 30 cm below the water surface was the instrument able to detect and record the spectral response of the turbid water as illustrated in Figure 3. The spectral responses of the water when the black plate was placed at 20 and 30 cm below the water surface differed from each other by less than 1 percent. Furthermore, when the white and black plates were placed at 20 cm below the water

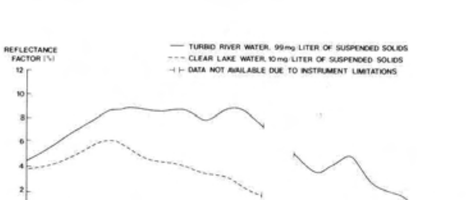

Fig. 1. Spectral characteristics of turbid river water and clear lake water.

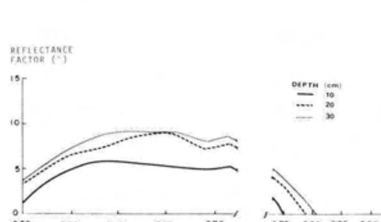

Fig. 3. Spectral response of a black plate submerged at different depths in turbid water.

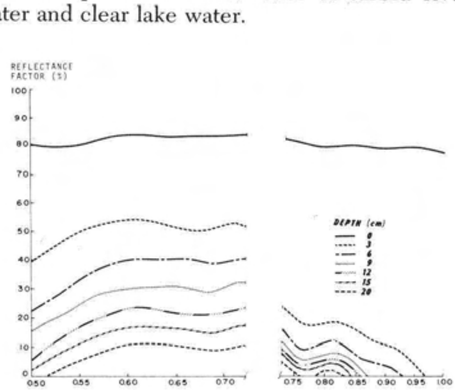

Fig. 2. Spectral response of a white plate submerged at different depths in turbid water.

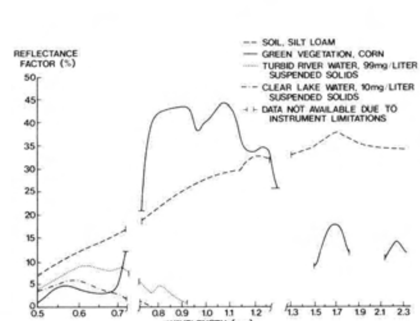

Fig. 4. Spectral characteristics of clear lake water, turbid river water, soils, and vegetation.

surface or deeper, the spectral response of the turbid water was essentially equal to the spectral response of the water without the plates.

A comparison of the spectral characteristics of major ground cover types, i.e., water (clear and turbid), soils, and vegetation is illustrated in Figure 4. This comparison shows the portions of the reflective spectrum where the spectral responses of the major ground cover types may be more readily discriminated in remote sensing applications. The spectral data for the soils and vegetation in Figure 4 were also obtained *in situ* with the Exotech 20-C field spectroradiometer and were made available to the authors by Dr. M. E. Bauer, research agronomist at the Laboratory for Applications of Remote Sensing (LARS).

Discussion

The results indicate that the greatest difference between the spectral responses of turbid (99 mg/litre of suspended solids) and clear waters (10 mg/litre of suspended solids) occur in the 0.6 to 0.9 micrometre region of the spectrum, which corresponds to bands 5 (0.6 - 0.7 μm), 6 (0.7 - 0.8 μm), and 7 (0.8 - 1.1 μm) of the Landsat-1 and Landsat-2 multispectral scanners. These results suggest that any of these three bands of the Landsat scanners could be used to discriminate between turbid and clear water. The best discrimination could be accomplished using band 5(0.6 - 0.7 μm) where the difference between the spectral responses of turbid and clear waters were found to be the greatest (Figure 1). Similar investigations (Weisblatt *et al.*, 1973; Barker, 1975) also have indicated that the spectral response in band 5 of the Landsat-1 system is linearly related to levels of turbidity (suspended solids).

It is also significant that, for turbid bodies of water ($\approx$100 mg/litre of suspended solids), the bottom reflectance does not affect the spectral response of the water if the bottom is deeper than 30 cm.

At present, the authors are conducting a similar investigation on lakes having a range of different water quality characteristics (suspended inorganic and organic solids, and algae concentrations), different depths, and different natural bottoms. It is hoped that the results from the research and the preliminary results reported in this paper will aid in the interpretation of the various spectral classes of water that can be mapped from Landsat multispectral scanner data and computer-aided analysis techniques.

Acknowledgment

This work was supported by the National Aeronautics and Space Administration (NASA) contract NAS9-13301.

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