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CLOSE RANGE HYPERSPECTRAL REMOTE SENSING OF WATER COLUMN CONSTITUENTS AND SUBSTRATE EFFECTS

By

Mahtab A. Lodhi

A DISSERTATION

Presented to the Faculty of

The Graduate College at the University of Nebraska

In Partial Fulfillment of Requirements

For the Degree of Doctor of Philosophy

Major: Geography

Under the Supervision of Professor Donald C. Rundquist

Lincoln, Nebraska

February, 1998

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CLOSE-RANGE HYPERSPECTRAL REMOTE SENSING OF WATER

COLUMN CONSTITUENTS AND SUBSTRATE EFFECTS

BY

MAHTAB AHMED LODHI

SUPERVISORY COMMITTEE:

APPROVED	DATE
Fernando R Echavarria Signature	3/05/1998
Dr. Fernando R. Echavarria Typed Name	
David C. Gosselin Signature	2/23/98
Dr. David C. Gosselin Typed Name	
David T Lewis Signature	2/23/98
Dr. David T. Lewis Typed Name	
Donald C. Rundquist Signature	2/23/98
Dr. Donald C. Rundquist Typed Name	
John F. Shroder, Jr. Signature	20/4/98
Dr. John F. Shroder Typed Name	
William J. Wayne Signature	23 Feb 1998
Dr. William J. Wayne Typed Name	

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CLOSE RANGE HYPERSPECTRAL REMOTE SENSING OF WATER COLUMN CONSTITUENTS AND SUBSTRATE EFFECTS

Mahtab Ahmed Lodhi, Ph.D.
University of Nebraska, 1998

Advisor: Donald C. Rundquist

Identifying and measuring amounts of water column constituents is a common application of satellite and close-range remote sensing. The technology provides an efficient and economical means of monitoring water-quality over large areas on a repetitive basis. The approach is especially important in regions where cost or inaccessibility prevents conventional *in-situ* sampling. Suspended sediments and algae are two major substances affecting the quality of surface waters. When suspended in a water column separately or in combination, the substances yield distinct spectral signatures, so their presence in the water column can be detected by means of remote sensing. However, the signal recorded above water bodies, either by satellite, aircraft, or boat-mounted sensors may be a "composite" of water column constituents, substrate effects, and / or atmospheric effects. The use of spectral data for water quality determination becomes difficult when such "peripheral effects" are present.

This study is focused on water column constituents and substrate effects. The general objectives were to: i) analyze, interpret, and relate the upwelling signals to water column constituents where "peripheral effects" are not present; ii) analyze and interpret the "composite signal" from shallow water bodies to determine if substrate effects can be isolated; and iii) analyze the "composite signal" to determine the extent and nature of error introduced into the measurement of water-quality parameters. The research was focused on experiments with sensors positioned at close-range with regard to water bodies.

The signals from two contrasting soil sediments suspended in a water column were distinct in the visible and NIR regions. The wavelength range between 580 and 690 nm was

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found to be optimal for indicating the type of sediment suspended in water, and range between 714 and 880 nm was found to be optimal for estimating the amounts of sediment suspended in water. In general, the substrate impact is greatest in blue-green, and least in the NIR. Reflective substrates generally have a greater impact on the upwelling signal than the absorptive substrates. In eutrophic waters, signals from algal pigments tend to suppress those from bare substrates. In such waters, detection of vegetated substrates is difficult due to identical signatures of pigments and submerged vegetation. Spectral ratios based on both blue-green and red-NIR wavelengths yielded a measure of equilibrium between signals from the substrate and the water column constituents.

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CHAPTER ONE

INTRODUCTION

1. GENERAL BACKGROUND

1.1 Remote Sensing of Water Quality

Although *in-situ* sampling techniques are an integral part of water quality measurements, their utility often is restricted to small areas, as time and cost preclude extensive and frequent data collection over large water bodies. On the other hand, both satellite and close-range remote sensing provide more efficient and economical ways of monitoring water quality over large areas on a repetitive basis.

Remote sensing for water quality involves the measurement of electromagnetic energy transmitted through, absorbed by or reflected from a water body. In order to quantify these three interactions, an understanding of the optical properties, *inherent* and *apparent*, of water bodies is essential (Smith and Baker, 1978).

1.2 Inherent Optical Properties

Inherent properties, which are independent of changes in the radiance distribution and specify the true scattering and absorbing characteristics of the medium, are dependent upon both dissolved and suspended material in the water (Preisendorfer, 1976). They also are linearly related to the chemical properties of water (Hakvoort, 1994). The absorption coefficient (α) and the volume scattering function (β) are the two main *inherent* optical properties. The (α) is the loss of photons from a beam of light by

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absorbing pigments and other materials per unit distance. The (β) describes the angular distribution of photons that are re-directed from a beam of light.

1.2 Apparent Optical Properties

Apparent properties are dependent on both the radiance distribution at a particular location and the dissolved or suspended material in the water. They are not related linearly to the chemical properties of water. The attenuation coefficient of irradiance (a), which provides the direct measure of the penetration of radiant energy in water, is an example of an apparent optical property. Reflection R (λ), also an *apparent* optical property, is the ratio of upwelling to downwelling radiance. It is a function of, among other factors, the suspended and dissolved constituents in water. Other *apparent* properties include color, transparency, and Secchi depth.

1.3 Transmission of Visible Light through Water Column

Visible light occupies the approximate wavelength range from 400 nm to 700 nm, and encompasses blue, green and red colors. Compared to turbid water, clear water absorbs very little incoming energy at wavelengths shorter than 700 nm, and transmission is relatively high. The maximum transmittance for clear water occurs at about 460 nm (blue-green) and it decreases significantly as wavelength increases. In clear water, transmission in the red region is almost 70 times less than that of the blue region. In surface waters, the maximum transmittance is dependent not only on wavelength but also on the type and the amount of suspended materials. Transmittance decreases with both increasing wavelength and turbidity.

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1.4 Absorption and Scattering of Visible Light in Water

Visible energy entering surface waters attenuates through the processes of absorption and scattering within the water column, and only a small portion of the incident energy is backscattered from the water volume. The absorption is a consequence of a selective effect of colored dissolved organic matter (CDOM), also known as *gilvin*, *gelbstoff* or *yellow substances* and the relatively unselective effect of suspended particulate materials such as phytoplankton, phaeopigments, detritus, and degradational products. These dissolved materials absorb electromagnetic energy more strongly in the blue wavelengths than in the green or red wavelengths (Bricaud et al., 1981; Kirk, 1976, 1980, 1983; Kishino et al., 1985; Mitchell and Kiefer, 1988; Roesler et al., 1989). When CDOM is present in small quantities, the attenuation of electromagnetic energy is lowest in the green wavelengths; and in waters with large amounts of such substances, the attenuation is lowest in the red wavelengths (water is more transmissive) than in the blue or green. The phytoplankton pigments show absorption maxima in the blue spectral region at ~ 445 nm, and in the red at ~ 670 nm. These contrasting absorption characteristics of phytoplankton pigments and the CDOM can be exploited for the purpose of quantifying variable amounts of phytoplankton pigments in waters containing both of these materials. The attenuation of energy by CDOM is entirely due to absorption and the scattering is negligible (Morel and Prieur, 1977; Gordon and Morel, 1983; Tassan, 1988) whereas the attenuation by pigments and detritus material is due to the combined action of absorption and scattering. Thus in surface waters, as water transparency diminishes, the amount of reflected energy from the water volume, that can

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be recorded by a sensor will increase in longer wavelengths, emanating from increasingly shallow optical depths (Hutchinson, 1957).

If turbid coastal or inland waters are rich in suspended sediment, backscattering from particles is the dominant factor. Reflectance in these waters is low in the blue region of the spectrum (400 – 500 nm), but at wavelengths longer than 500 nm, reflectance is affected markedly by the type, particle size, and the level of particulate matter within the water column. Water bodies with relatively high concentrations of suspended sediment have high reflectance in the wavelength region between 500 to 710 nm. At longer wavelengths, the attenuation of light by water becomes dominant, and reflectance decreases. The spectral range roughly between 710 to 880 nm (NIR) has been considered appropriate by some for monitoring reflectance changes due to the differing nature of turbidity-causing material (Han and Rundquist, 1994).

1.5 Bottom Effect on the Optical Properties of Water Column

Where water transparency and depth permit electromagnetic radiation to reach to the bottom, the composite upwelling signal from a water body can include reflectance from the surface, from the water column, and also from the bottom. The intensity and the pattern of this "bottom effect" on the spectrum of volume reflectance depends on both the color and the composition of the bottom, and also on the type of water column constituents. In remote sensing studies that deal with bathymetry or mapping of bottom features, it is essential that the lake bottom is visible to the sensor. In this case, bottom effects are considered useful information and are the desired objective. However, in remote sensing studies for water-quality measurements, bottom effects are considered to

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be undesirable peripheral effects, which can introduce "noise" in the upwelling composite spectral signal. In this case, reflectance backscattered from the bottom is a source of error when interpreting remotely sensed data.

2. THE PROBLEM

Identifying and measuring amounts of water column constituents is a common application of remote sensing. The intention is to be able to use aircraft and satellite sensors to infer water-quality, in automated fashion, over a wide expanse of geographic space. This approach is especially important in regions where cost or inaccessibility prevents conventional *in-situ* sampling.

Sediment suspended in lakes and reservoirs not only degrads the quality of the water for drinking, recreational, and industrial purposes, but also has a significant impact on the aquatic ecosystems. Sediment transports adsorbed toxic substances, thereby limiting light availability and photosynthesis. Suspended sediment and associated organic material support filter-feeding pelagic and benthic communities. Thus, pesticides associated with these sediments represent a pathway for entry into the food chain (Bergamaschi et al., 1997). Remote sensing can facilitate the monitoring of suspended sediment transported by watershed runoff into lakes and reservoirs.

Various investigators either have successfully established statistical correlation between the spectral data and suspended sediment concentration (SSC) in surface waters or have developed algorithms for this purpose (Alfoldi and Munday, 1978; Amos and Alfoldi, 1979; Curran and Novo, 1988; Aranuvachapun and Walling, 1988; Lyon et al., 1988; Doerffer et al., 1989; Bhargava and Mariam, 1991; Ritchie et al., 1990; Goodin et

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al., 1993; Mayo et al., 1993; Han and Rundquist, 1994). All of these investigators documented relationships between reflectance and SSC in surface waters. However, only a few analyzed spectral data for suspended sediment derived from different types of soils.

The signal recorded above water bodies, either by satellite-based sensors or boat-mounted spectroradiometers, does not represent solely the water column constituents. Rather it may be a "composite or volume signal," and includes signals from single or multiple constituents accumulated in the water column, backscattering from the bottom, and atmospheric effects (in case of satellite or aircraft-based sensors). The use of spectral data for interpretation and analysis of water quality becomes complicated when such "peripheral effects" are present.

Substrate effects on the upwelling signal from water bodies have been studied by several researchers (McCluney, 1974; Scherz and Van Domelon, 1975; Bartolucci et al., 1977; Whitlock et al., 1978; Hollinger et al., 1985; Lyon et al., 1992; Montovani and Cabral, 1992; Estep, 1994; Rundquist et al., 1995). Based on these studies, some generalizations can be made. For example, bottom effects decrease with increasing amounts of suspended matter because of increased attenuation of light in the water column. Scattering material present within the water column "re-directs" photons, and increases the likelihood of their being absorbed. Additionally, different types of bottoms exhibit significant differences in reflectance. For example, light-colored sandy bottoms tend to have higher reflectance than do bottoms consisting of silt, clay, sediment high in organic matter, and vegetated substrates.

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