Turkish J. Eng. Env. Sci.
29 (2005) , 351 – 360.
© TÜBİTAK

The Spectral Reflectance Responses of Water with Different Levels of Suspended Sediment in The Presence of Algae

Murat KARABULUT
Kahramanmaraş Sütçü İmam University, Department of Geography, Kahramanmaraş-TURKEY
e-mail: mkarabulut@ksu.edu.tr
Nihal CEYLAN
Turkish Ministry of Agriculture and Rural Affairs Agricultural Research Institute, Ankara-TURKEY

Received 16.06.2005

Abstract

Examining and measuring levels of suspended sediments of water column is a common application of close range remote sensing, because the technology offers an efficient and economical means of studying water quality problems. The aim of this experiment was to use close range remote sensing to determine the effect of increasing suspended sediment concentration containing different levels of organic matter on algal spectral patterns. The experiment was conducted in a small room with a 65-l volume water container. A Spectron Engineering SE-590 spectroradiometer with a 15° optic was used to take the radiant measurements. The results indicate that the suspended sediment causes increasing spectral response in surface waters. The organic matter content of the suspended sediment has an effect on the spectral reflectance. Therefore, the organic content of the soil present in the water body can be estimated and this property of sediment can help us to recognize the sediment type present in the various layers of the water.

Key words: Suspended sediment, Remote sensing, Water quality, Spectron, Algae

Introduction

Sediments, which fill lakes, reservoirs, and dams, are one of the most important environmental problems throughout the world. High concentrations of suspended sediment in water could shorten the useful life of many reservoirs and dams. Suspended sediment concentration also has an effect on the biologic life in those valuable areas. For example, high concentrations of sediment can reduce the amount of sunlight penetrating through the water columns. This kind of concentration, therefore, causes to decrease in plants and living aquatic animals. Sediments also have a significant impact on the quality of drinking, recreational and industrial water, because it can serve as a carrier and storage agent of many kinds of pollutants such as phosphorus, nitrogen and other kinds of agricultural pollutants (Brown, 1984; Bhargava and Mariam, 1990; Han et al., 1994).

Many studies have been conducted to determine suspended sediment in various water bodies by traditional methods, which are time consuming, expensive and labor intensive. Traditional techniques can also provide only point data, where measurements are obtained at many locations on one or many water bodies such as lakes, dams or reservoirs (Alfoldi, 1982). In contrast, remote sensing is an economical way to monitor water bodies, because it can monitor large areas in a short time on a repetitive basis. It is also easy to update remote sensing data, which allows continuous monitoring of water courses. Resource managers are therefore interested in water quality using such data, because this method provides a synoptic view of water bodies. Thus, satellite remote sensing is an economical way to monitor large areas repetitively (Alfoldi, 1982).

Algal chlorophyll and suspended sediment concentrations (SSC) are one of the many water quality parameters that have been subject to many studies using remote sensing techniques. Chlorophyll is an indicative parameter of trophic status of surface waters, which can result from man-made pollutants. Therefore, this parameter gives important information about water quality such as pollution level of surface waters and distribution of toxic algae (Richardson, 1996).

Suspended sediment is another important parameter that can be easily measured by remote sensing (Alfoldi, 1982). Monitoring suspended sediment helps one to identify the watershed's erosion problems (Engman and Gurney, 1991). The estimation and monitoring of suspended sediments using remote sensing techniques have been performed by different researchers (Bhargava and Marriam, 1990; Han and Rundquist, 1996; Lodhi et al., 1997; Han, 1997; Lodhi et al., 1998). All those papers addressed the presence of suspended sediment causing increased volume reflectance of water areas. Some of those papers discuss the relationship between different soil types in terms of reflectivity differences. The properties of the sediment have an impact on reflectance volume. Such properties of sediments include particle size, organic matter, color and mineral contents. Volume reflectivity was found to increase with decreases in particle size by other investigators (Karabulut, 2004).

The presence of suspended sediment or organic materials causes increasing reflectance in the visible region of the electromagnetic spectrum. However, the reflectance of sediment and water is low in the near infrared (NIR) region unless there are significant amounts of algae present. A positive correlation between suspended sediment concentration and spectral reflectance in the visible and NIR wavelengths was reported in the literature (Alfoldi, 1982).

However, several issues have an impact on reflectance values in water quality studies; these make studies very complex and difficult. These factors are 1) the range of SSC, 2) particle size and shape, 3) the particle mineralogy, 4) the presence of algae, and 5) vertical and temporal variability of SSC (Novo et al., 1989). It is obvious that the isolation or quantification of some or all of the above issues could increase the utility of remote sensing for suspended sediment concentrations in water bodies.

The objective of this study is to use close range remote sensing to determine the effect of increasing suspended sediment concentrations containing different levels of organic matter on algal spectral patterns. The hypothesis being tested here is that as suspended sediment concentrations increase with different levels of organic matter, the spectral reflectance pattern of algae can change.

Experimental Design

This laboratory experiment was conducted at the Center for Advanced Landuse Management Information Technologies (CALMIT) spectroradiometry laboratory located at the University of Nebraska (Lincoln), USA.

The tank used for the experiment as a water container had 65-l volume, was made of black polyethylene, and was 0.40 m deep, and was filled with water to 33.02 cm (Figure 1). The tank was painted black to minimize extraneous internal reflectance. The experiment was conducted in a small room painted black to control illumination and eliminate unwanted reflectance from surrounding surfaces. Four 500-W halogen lamps were used to provide light for the experiment. A Spectron Engineering SE-590 spectroradiometer with a 15° optic was used to obtain the radiant measurements from the sediment laden water in the presence of algae (Anabaena spp. Blue-green). The spectroradiometer has the capability of acquiring data in 252 channels (bands) with a spectral range of 368.4 to 1113.7 nm. The sensor was mounted on a platform above the tank. The distance from the tank to the sensor was 68.68 cm. Since the instrument has a 15° optic, the instantaneous field of view (IFOV) was 35.66 cm. The water depth was 33.02 cm. A spectron Lambertian white panel, which reflects 99% of incoming light, was used to calibrate the sensor. A turbidity meter was used to measure turbidity. A small and sensitive laboratory balance was used to weigh the sediment samples.

The first scan was taken over the empty black tank for calibration purposes. The second scan was taken over clear water and then 5 l of water containing a very dense concentration of algae was put into the tank. Clean water was added to the tank both to dilute the algal concentration and to complete the volume of the tank up to 64.345 l. Each sediment increment was weighed to generate 100, 200, 300, 400, 500, 600, 700, 800, 900 and 1000 mg/l of SSC in the water tank, respectively. Before suspension of the sediment sample in the water, the turbidity was measured to get a rough idea about algal concentration and water clarity. A calibration scan was taken before measuring the algae laden water. The first scan was taken for algae. After scanning the algae laden water, 3 types of sediment samples containing different amounts of organic matter were added to the tank. These sediment samples, which were taken from lakes in the Sand Hills region, Nebraska, were dried, sieved and analyzed in terms of organic matter content and particle size prior to the experiment (Table 1). After the addition of each increment of sediment, the water was stirred with a stick manually for 2-3 min at regular intervals to keep the sediment in suspension and to ensure the homogeneous distribution of sediments in the water. The water was not scanned immediately to avoid wave effects; however, scanning was done before the sediment settled and turbidity measurements were obtained after each scan (Table 2).

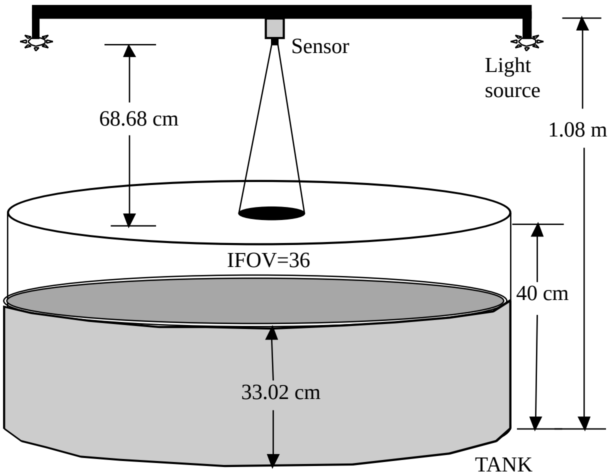

Figure 1. Experimental set-up.

Table 1. Characteristics of the sediment samples.

	Sample Name	Organic Matter (%)	Mean Particle Size (μm)
Experiment 1	Roundup Lake	8.21	63
Experiment 2	Alkali Lake	9.85	63
Experiment 3	Scoonover Lake	13.72	63

Table 2. Turbidity measurements nephelometer turbidity units (NTU).

	Experiment 1	**Experiment 2**	**Experiment 3**
Tap Water	0.86	0.86	0.86
Algae	2.65	3.15	2.84
100 mg/l SSC	7.62	33.1	31.2
200 mg/l SSC	17.7	49.6	44.8
300 mg/l SSC	25.7	83.1	83.3
400 mg/l SSC	31.5	97.6	134.0
500 mg/l SSC	48.1	123.0	136.0
600 mg/lSSC	50.1	182.0	166.0
700 mg/lSSC	72.4	219.0	212.0
8000 mg/l SSC	86.7	250.0	241.0
900 mg/l SSC	91.6	298.0	302.0
1000 mg/l SSC	106.0	339.0	358.0

Reflectance factors were calculated as a simple ratio using the following formula (Han and Rundquist, 1994):

$$R_{(\lambda)} = L_{(\lambda)}/S_{(\lambda)} * Cal_{(\lambda)} * 100 \tag{1}$$

Where λ is the wavelength, $R_{(\lambda)}$ is the reflectance factor, $L_{(\lambda)}$ is the radiance measured from the water's surface, $S_{(\lambda)}$ is the radiance from the spectron Lambertian white panel, and $Cal_{(\lambda)}$ is the calibration factor for the white panel.

Results and Discussion

Two spectral profiles were generated at the start of our analysis to represent turbidity measurements for algae in pure water (Table 2, Figure 2). Although the sensor has the capability to measure spectral reflectance between 368.4 and 1113.7 nm, the spectral reflectance pattern for algae laden water is only detectable between 400 and 900 nm. Figure 2 shows the variation in the reflectance value with respect to the various wavelengths with algae laden water having a turbidity value of about 2.65 and 3.15 NTU for experiments l and 2, respectively. Initially, they exhibit a rather sharp increase of reflectance with increasing wavelengths in green and NIR regions. In contrast, in the red spectrum a very steep decrease in reflectance is observed. The above pattern of responses can be easily generalized for all 3 experimental designs.

In the presence of an algae concentration, blue light (400-450 nm) was strongly absorbed by the algal pigments. Thus, at wavelengths of 400-450 nm, reflectance values for the 3 experiments showed similar spectral patterns on the curves. The characteristic and pronounced red chlorophyll, an absorption feature, which appeared near 582-653 nm (that has minimum absorption at around 618 nm) the first time, is readily apparent in the figures 2 and 3 (Gitelson, 1992; Han et al., 1994). The lower reflectance values in the red wavelength region centered at 600-650 nm for all 3 experiments is due to chlorophyll absorption by living cells. The apparent reflectance peak in the green spectrum (centered between 500 and 550 nm) is the result of low absorption of algal chlorophyll and other factors. The cause of the higher reflectance values in the near infrared wavelength (centered between 650 and 750 nm, a near infrared peak at 707.9 nm) might be the fluorescence of algal pigments (Han et al., 1994).

In this experiment, the spectral response of the different levels of suspended sediment load in algae laden water was measured in terms of percentage reflectance. As the suspended sediment concentration increased from 100 to 1000 mg/l, reflectance also increased at all wavelengths between 400 and 900 nm. Reflectance values increased at all wavelengths for all 3 sediment types as SSC increased (Figures 3-5). The highest spectral reflectance measurements were obtained for experiment 3 between 9 and 10% (Figure 5), containing the highest level of organic matter (13.724%). This was followed by experiments 2 and 1 in that order. For experiment 2 the maximum values of spectral reflectance were between 7% and 8 %, having 9.85% organic matter. The lowest spectral reflectance measurements were acquired for experiment 1 (between 5% and 6%), which has the lowest organic matter content (8.21%). The spectral patterns presented in Figures 2 and 3 look similar to each other. The spaces between the lines get smaller with increasing suspended sediment concentration except for in experiment 1, which shows a different pattern.

The Scoonover Lake sediment, which had more organic matter, resulted in higher volume reflectance at all wavelengths compared with other sediment types (Figure 5). A reflectance difference of about 4% was noted between Roundup Lake and Scoonover Lake samples. For experiments 2 and 3 the reflectance curves were similar to each other. A reflectance difference between these sediment types is only around 1%.

For the Roundup Lake, the experiment curve represents 3 notable spectral patterns. Figure 3 can therefore be clearly divided into 3 phases or wavelength groups. Sediment loads of 100-400 mg/l showed similar reflectance values, i.e. 1-1.5%. On the other hand, sediment loads of 500-600 mg/l had reflectance values between 1.5% and 3.2%. For loads greater than 700 mg/l, reflectance values continued to increase. Peak reflectance values shifted slightly to the longer wavelengths.

It can be seen that the location of minimum and maximum reflectance values for green, red and NIR wavelengths tends to shift toward longer wavelengths as the suspended sediment concentration increased from 100 to 1000 mg/l. This pattern is more noticeable for experiment 1 due to the continuing effect of algae. As SSC increased from 0 to 300 mg/l, reflectance values were relatively uniform at most wavelengths between 400 and 900 nm (Figures 3-5).

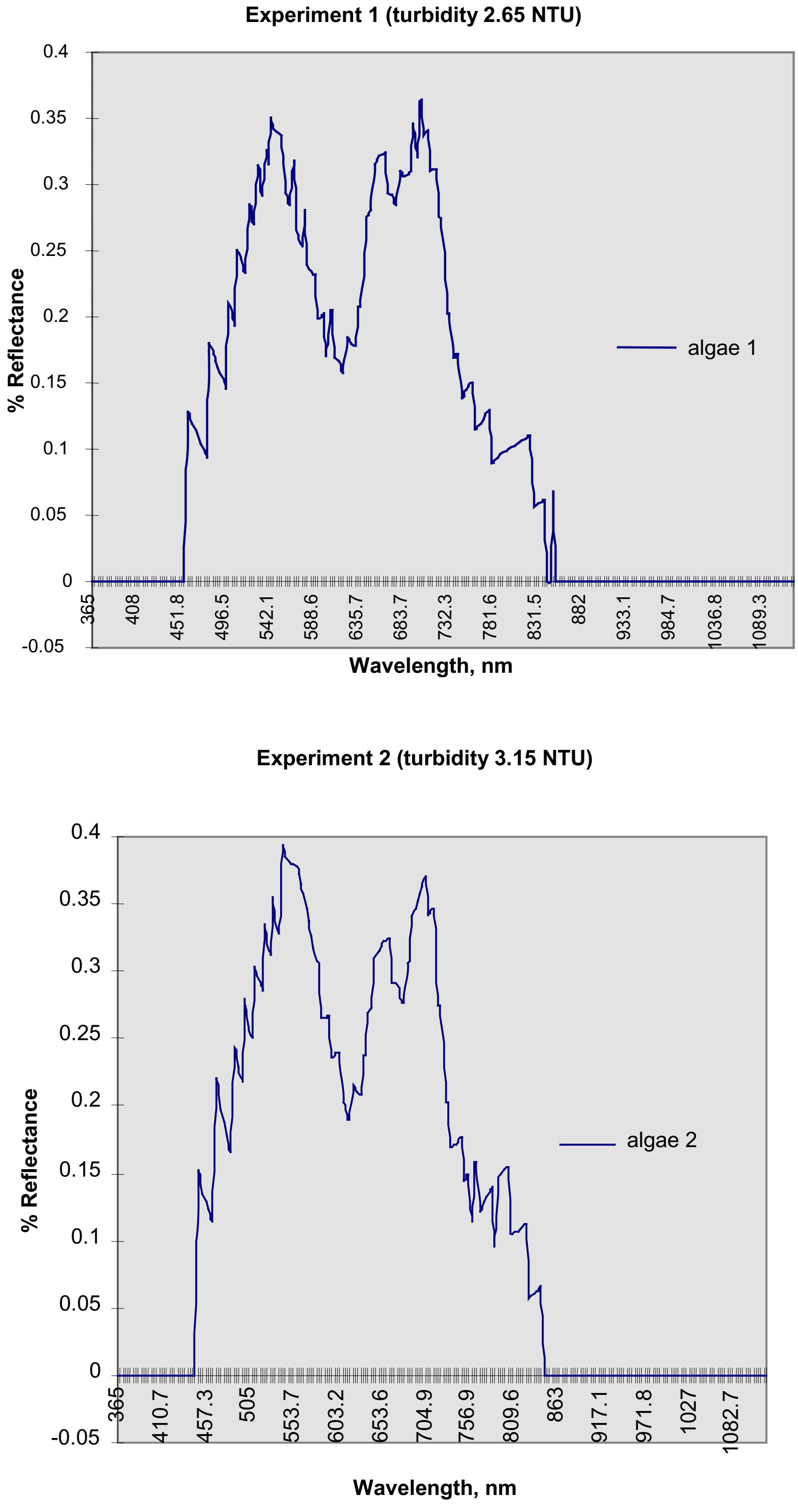

Figure 2. Turbidity measurements for experiment 1 (2.65 NTU) and 2 (3.15 NTU).

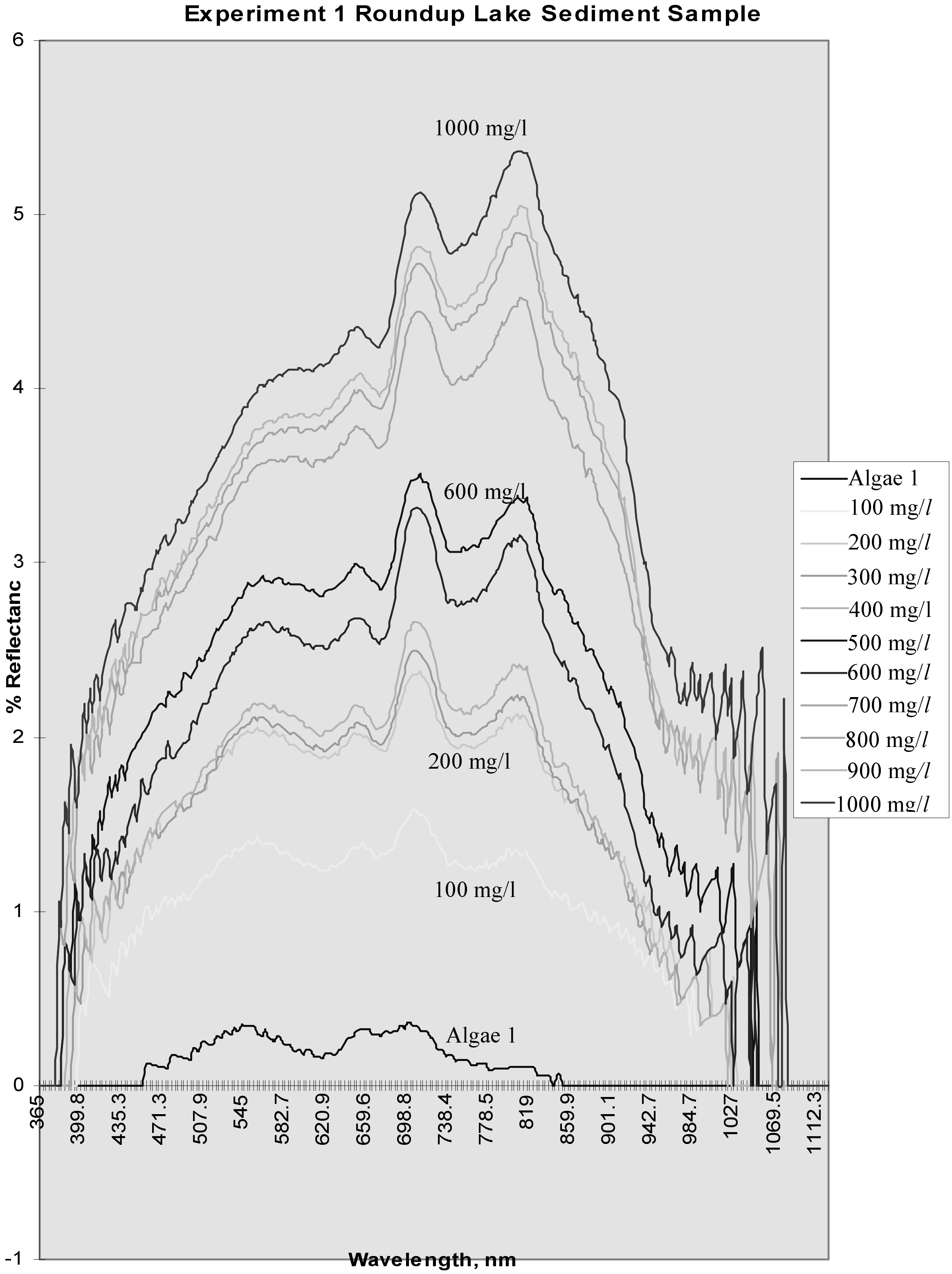

Figure 3. Surface reflectance for experiment 1 with varying SSC.

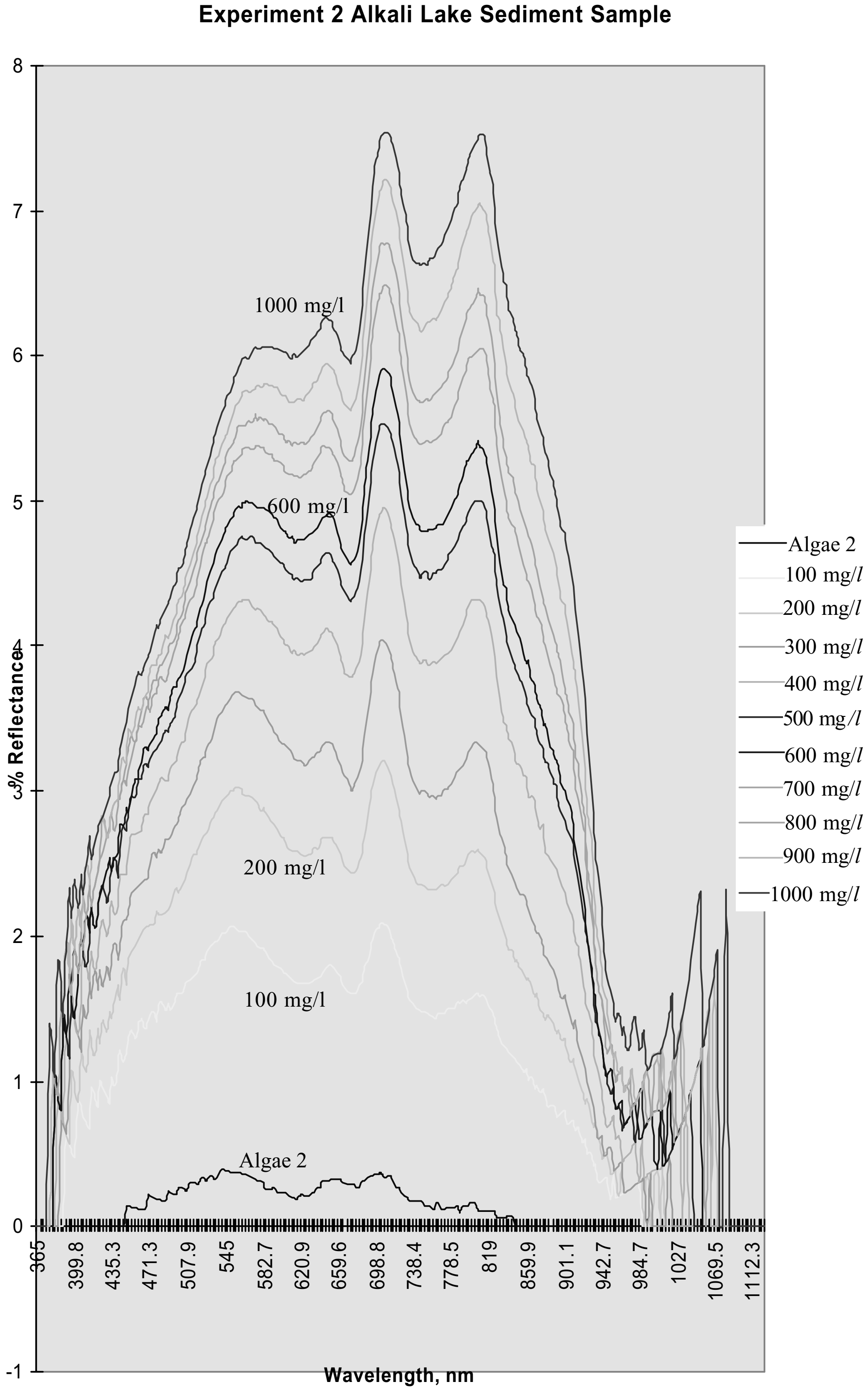

Figure 4. Surface reflectance for experiment 2 with varying SSC.

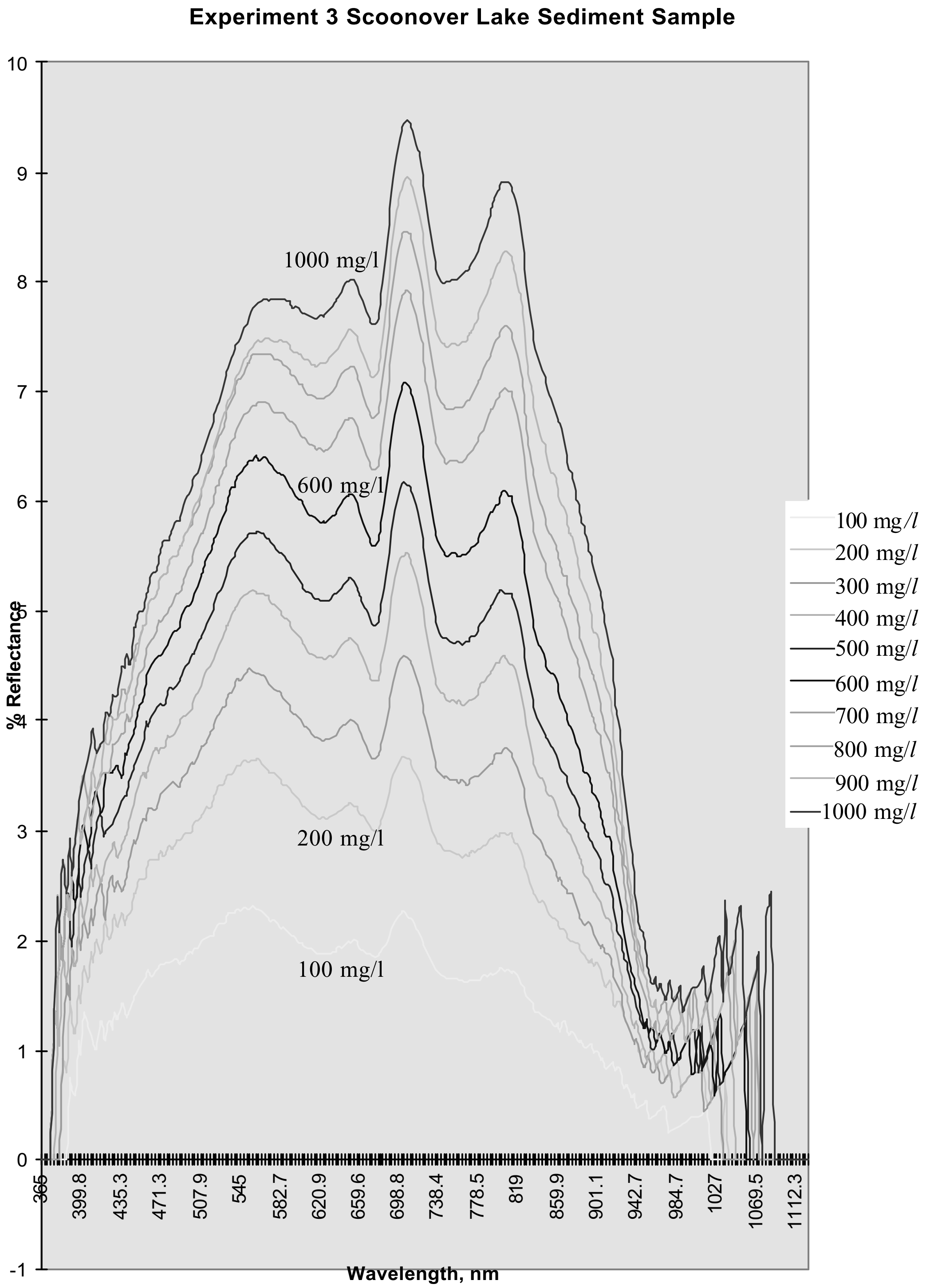

Figure 5. Surface reflectance for experiment 3 with varying SSC.

However, experiment 1 showed a reflectance curve slightly different than the others. For all 3 experiments the pattern of reflectivity increase was easily noticeable. These findings are in agreement with previous studies (Han et al., 1994). In experiments 2 and 3 the red and NIR reflection peak value represented little or no effect from increasing SSC. This indicates that the location of the red minimum and NIR peak value can be primarily controlled by the concentration of algae in the water and not sediment amount, because, with regard to the spectral residual from the algae signal, it can be seen that the addition of sediments would not eliminate the primary characteristics of chlorophyll in water. It appears that red is inversely related to chlorophyll, whereas the NIR is directly related to chlorophyll. More specifically, at SSC densities less than 400 mg/l the shift of the NIR peak is more noticeable. The results also showed that increasing sediments, which contain more organic matter, appeared to have similar additive effects at both the red and NIR wavelengths for experiments 2 and 3.

Correlation coefficients (r) were computed to describe the relationship between SSC and reflectance values at each of the 172 wavelengths, beginning at 397.1 and ending at 901.1 nm. All the correlation coefficient values were statistically significant, indicating a higher correlation between spectral reflectance and increasing suspended sediment concentrations ($r > 0.90$, $P = 0.000$).

Conclusions

The aim of this study was to measure the effects of SSC on penetration of light through water columns, which is vital for aquatic organisms and vegetation, using remote sensing. The analysis at 10 levels of SSC, ranging from 100 to 1000 mg/l and 3 types of sediment applied to tap water containing high amount of algae, led us to conclude:

1) The additive effects of SSC on percent reflectance values from algae laden water occur at all wavelengths between 400 and 900 nm,

2) Increasing suspended sediment concentration cannot eliminate the prominent spectral pattern of algae. This spectral pattern can be seen even when the suspended sediment concentration is 1000 mg/l.

Suspended sediment causes an increased spectral response in surface waters. The organic matter content of the suspended sediment has an effect on the spectral reflectance. High organic matter leads to high spectral reflectance.

Distinct differences in reflectance values corresponding to different SSC values are observed between 400 and 900 nm wavelength. This range can therefore be used to monitor a wide variation in turbidity levels. The Roundup Lake sediment, with the lowest organic content, shows the lowest reflectance value, whereas Scoonover Lake sediment, with the highest organic content, shows the highest reflectance value. Therefore, the organic content of the soil present in the water body can be estimated and this property of sediment can help us to recognize the sediment type present in the various layers of the water.

Similar experiments can be conducted using remote sensing data taken over reservoirs, lakes or other water surfaces to simulate the natural conditions of water bodies. Water quality research can be performed preferably on water bodies that have a sedimentation problem. Using sediment samples for studying the remote sensing of water quality will be also helpful in the case of shallow water bodies to consider bottom effects. These results would constitute a very helpful database for the interpretation of satellite images of specific surface water. The experiment introduced in this research highlights the importance of examining the effects of suspended sediment containing different levels of organic matter on the trophic status of water.

Acknowledgments

We extend our sincere appreciation to Dr. Donald C. Rundquist for helping us to develop the idea. We would like to thank Dave Deny for helping us to obtain the spectral reflectance measurements. Thanks must also go to Mahtab Lodhi for providing sediment samples.

References

Alfoldi, T.T., "Remote Sensing for Water Quality Monitoring", In Remote Sensing for Resource Management, Edited by C. J. Johannsen and J. L. Sanders (Ankey, Iowa: Soil Conservation Society of America), 317-328, 1982.

Bhargava, D.S. and Mariam, D.W., "Spectral Reflectance Relationships to Turbidity Generated by Different Clay Material", Photogrammetric Engineering and Remote Sensing, 56: 225-229, 1990.

Brown, L.R., "The Global Loss of Topsoil", Journal of Soil and Water Conservation, 39: 162-165, 1984.

Engman, E.T. and Gurney, R.J., "Water Quality", Remote Sensing in Hydrology, Great Britain: Cambridge Press, 175-192, 1991.

Gitelson, A.A., "The Peak Near 700 nm on Radiance Spectra of Algae and Water: Relationships of Its Magnitude and Position With Chlorophyll Concentration", International Journal of Remote Sensing, 13, 3367-3373, 1992.

Han, L., Rundquist, D.C., Liu, L.L. and Fraser, R.N., "The Spectral Responses of Algal Chlorophyll in Water With Varying Levels of Suspended Sediment", International Journal of Remote Sensing, 15, 3707-3718, 1994.

Han, L. and Rundquist, D.C., "The Response of Both Surface Reflectance and the Underwater Light Field to Various Levels of Suspended Sediments: Preliminary Results", Photogrammetric Engineering & Remote Sensing, 60, 1463-1471, 1994.

Han, L. and Rundquist, D.C., "Spectral Characterization of Suspended Sediments Generated Form Two Textures Classes of Clay Soil", International Journal of Remote Sensing, 17, 643-649, 1996.

Han, L., "Spectral Reflectance With Varying Suspended Sediment Concentrations in Clear and Algae-laden Waters", Photogrammetric Engineering & Remote Sensing, 63, 701-705, 1997.

Karabulut, M., "An Examination of Surface Water Using Close Range Remote Sensing Techniques", proceeding on 3rd GIS Days in Turkey, October 6-9, 2004 (in Turkish).

Lodhi, M.A., Rundquist, D.C., Han, L. and Kuzila, M.S., "The Potential for Remote Sensing of Loess Solis Suspended in Surface Waters", Journal of American Water Resources Association, 33, 111-117, 1997.

Lodhi, M.A., Rundquist, D.C., Han, L. and Kuzila, M.S., "Estimation of Suspended Sediment Concentration in Water Using Integrated Surface Reflectance", Geocarto International, 13(2), 11-15, 1998.

Novo, E.M., Hansom J.D. and Curran, P.J., "The Effect of Sediment Type on the Relationship Between Reflectance and Suspended Sediment Concentration", International Journal of Remote Sensing, 10, 1283-1289, 1989.

Richardson, L.L., "Remote Sensing of Algal Bloom Dynamics", BioScience, 46, 492-501, 1996.