Aquatic Ecology **36:** 559–562, 2002.

Inherent and apparent optical measurements in the Hudson/Raritan Estuary

Sima Bagheri[1,*], Machteld Rijkeboer[2,4] and Herman J. Gons[3]
*[1]Department of Civil & Environmental Engineering, New Jersey Institute of Technology, Newark, NJ 07102, USA; [2]Institute for Environmental Sciences, Free University, De Boelelaan 1115, 1081 HV Amsterdam, The Netherlands; [3]Netherlands Institute of Ecology, Centre for Limnology, Rijksstraatweg 6, Nieuwersluis, P.O. Box 1299, 3600 BG Maarssen, The Netherlands; [4]Current address: Netherlands Institute of Ecology, Centre for Limnology, Rijksstraatweg 6, Nieuwersluis, P.O. Box 1299, 3600 BG Maarssen, The Netherlands; *Author for correspondence (e-mail: bagheri@adm.njit.edu)*

Received 17 May 2002; accepted in revised form 11 June 2002

Key words: Bio-optical modeling, Geographic information system (GIS), Remote sensing, Spectral irradiance reflectance, Water quality parameters

Abstract

During an August, 1999 field campaign, measurements were made to establish hydrologic optical properties of the Hudson/Raritan Estuary (New York-New Jersey): 1) concurrent above-and below-surface spectral irradiance; 2) sampling for laboratory determination of inherent optical properties; and 3) concentrations of optically-important water quality parameters. We used a bio optical model based on Gordon et al. (1975) to predict the subsurface irradiance reflectance from optically important water constituents. This model was then validated with the measured reflectance spectra from the field spectroradiometers. Modeling of reflectance is a prerequisite for processing remote sensing data to desired thematic maps. These are key input to the geographic information system (GIS) used to manage the water quality condition of the estuary.

Estuarine/nearshore waters (Case 2) are very complex, being both spatially and temporally heterogeneous. This has created a persistent need for timely information to support a balanced approach to the use and protection of such waters, and numerous efforts are underway to improve the understanding of their physical, chemical, and biological characteristics. One approach uses remote sensing, offering unique advantages for the study of recurrent hydrological phenomena on regional and local scales. Overhead sensors record the color of natural water as spectral reflectance, determined by the composition of the underwater light field (Kirk 1984). The greater the amount and specificity of color information available, the better a remote hydrologic application will generally perform. This is particularly true for estuarine applications, where independent variations of optically-important water quality parameters (WQPs), bottom cover types, and water depths can all occur simultaneously.

The study area-Hudson/Raritan is an extremely complex estuarine system where tidal and wind-driven currents are modified by freshwater discharges from the Hudson, Raritan, Hackensack, and Passaic rivers. Over the last century the estuarine water quality has degraded in part due to eutrophication, which has disrupted the pre-existing natural balance, resulting in phytoplankton blooms of both increased frequency and intensity, increasing oxygen demand and leading to episodes of hypoxia.

The aim of our field campaign was to establish the inherent optical properties (IOPs) of these waters, and use them as input into a bio-optical model of reflectance to estimate the WQPs, total chlorophyll (TCHL), colored dissolved organic matter (CDOM) and total suspended material (TSM). Table 1 lists the sampling stations (1–7), which were selected in di-

Table 1. Sample locations with absorptions of Tripton, CDOM, specific absorption of Phytoplankton, scattering of Seston and concentrations of TSM and TCHL

St	Location	Lat./Long. (degrees)	$a_{tr}(440)$ (m^{-1})	$CDOM_{440}$ (m^{-1})	$a^{*}ph(676)$ (m^2mg^{-1})	$b_{ses}(550)$ (m^{-1})	TSM ($g\ m^{-3}$)	TCHL ($mg\ m^{-3}$)
1	Comptons/PewsCreek	40.45/74.08	0.13	0.12	0.007240	0.98	6	15
2	Keyport Harbor	40.47/74.19	0.35	0.37	0.007812	2.20	26	32
3	Traid Bridge	40.50/74.28	0.29	0.49	0.007131	1.53	13	17
4	Crookes Pt Staten Isl.	40.54/74.14	0.33	0.21	0.007340	2.62	16	37
5	Coney Isl. Pt.	40.57/74.02	0.13	0.10	0.007193	1.02	11	6
6	Sandy Hook Tip	40.49/74.02	0.21	0.15	0.005777	1.27	12	22
7	Shrewsbury River	40.38/73.98	0.50	0.30	0.006250	3.60	21	48

Note: All data were collected during outgoing tides (August 14, 1999).

verse parts of the estuary to have maximum taxonomic variability in phytoplankton community; their IOPs and WQPs data obtained on 8/14/99.

To develop analytical algorithms for estuarine/nearshore (case 2) waters, an optical model needs to link the WQPs to the IOPs, linking these in turn to the subsurface irradiance reflectance (R(0−)). The measurement of R(0−) is therefore the key modeling parameter for deriving atmospherically corrected remote sensing data (Kirk 1994; Dekker et al. 1997).

A) Upwelling and downwelling radiances/irradiances (E_u and E_d) were measured by two different field spectroradiometers. The OL754 was used to compute R(0−) from E_u(0−) and E_d(0−) as measured in water (Bagheri et al. 2000), whereas the PR-650 was used to compute R(0−) from E_u(0−) and E_d(0−) as derived from water-leaving radiance and downward irradiance measured above the water surface (Gons 1999). Comparisons of the reflectance spectra for all stations showed that the results from the two spectroradiometers with different designs differed somewhat, however the ranges of reflectance values were quite consistent (i.e., 1% to 5% R(0−) over the wavelength range of 480 nm to 700 nm). Several features were prominent in the reflectance spectra, such as in the shorter blue wavelengths where absorption by CDOM, tripton (suspended particles other than phytoplankton), and phytoplankton chlorophyll-a caused low reflectance. Beyond 500 nm, reflectance increased allowing better discrimination of local spectral features, such as phytoplankton chlorophyll absorption in the red at 676 nm.

B) To estimate optically-important WQPs coincident with the R(0−) measurements, samples (0.2 to 0.5 m depth) were taken for laboratory analysis. Standard procedures (Rijkeboer et al. 1998) were used to determine concentrations of total chlorophyll-a (TCHL) defined as the sum of chlorophyll-a and phaeopigment (to index phytoplankton abundance) and total suspended matter (TSM). TCHL and TSM were determined according to the Dutch standard methods NEN 6520 (1981) and NEN 6484 (1982) respectively. As shown in Table 1, TCHL varied between 6 mg m^{-3} and 48 mg m^{-3} indicating that sampling did not coincide with any major phytoplankton bloom. Likewise, TSM (6–26 g m^{-3}) was not remarkably high nor low for this time of year. Phytoplankton species were also identified and enumerated in the samples. Moderately abundant were found to be the diatoms Leptocylindrus minimus and Skeletonema costatum. Present in low counts were the dinoflagellates Gyrodinium spec. and Katodinium colundatum.

C) The two IOPs measured directly were spectral absorption (a) and spectral beam attenuation (c), using an Ocean Optics-2000. (Note: Use of this device for measuring IOPs is experimental and has not been referenced in the published literature.) Spectral scattering (b) was then deduced via subtraction of a from c (b = c − a). Absorption data for seston and tripton were determined using the filterpad method of Truper and Yentsch (1967), and are shown in Table 1.

To test the applicability of geophysical forward and inverse modeling, parameters for the Hudson/Raritan Estuary of NY-NJ were derived for input to the Gordon model, originally adapted to inland waters in the Netherlands:

$$R(0-) = r(b_b/(a + b_b)) \tag{1}$$

Where a is the total absorption coefficient, b_b is the backscatter coefficient r is a factor based on the geometry of incoming light and volume scattering in the water.

To establish values for r and b_b for a specific location, knowledge of the volume scattering function is required. Vos et al. (1998) demonstrated that a practical solution for determination of the volume scattering function is to estimate r and b_b by comparing modeled R(0−) to measured R(0−) values. In this study, the values for factor r varied between 0.30–0.38 and were based on the field data and calculations made by fitting measured R(0−) spectra to measured IOPs. The IOPs a and b_b were assumed to be linear functions of the WQPs. This allowed the concentration-specific IOPs (SIOP) to be introduced that link the concentrations of all optically relevant components to the subsurface irradiance reflectance. Using Beer's law, the total absorption coefficient – a – can be written as sum of the absorption by phytoplankton (CHL), tripton (TSM) and colored dissolved organic matter ($CDOM_{440}$). It should be noted that the 440 nm wavelength was chosen since it was corresponded approximately to the midpoint of first chlorophyll-a absorption band (Kirk 1994). The backscattering (b_b) is used here which is based on the conversion of the scattering coefficient to the backscattering coefficient. The volume scattering function of Petzold (Kirk 1994) is assumed to be valid, therefore b_b was obtained as 0.019b. For pure water, this ratio is 0.5 but for seston measurements depends on the composition of the water (Morel and Prieur 1977).

$$a = a_w + a^*_{TSM}TSM + a^*_{ph}CHL + a^*_{CDOM}CDOM_{440} \quad (2)$$

$$b_b = 0.5b_w + b_b{}^*_{TSM}TSM \quad (3)$$

Where:

a_w = absorption of pure water

a^*_{ph} = specific absorption of the phytoplankton

b_w = scattering of pure water

$b_b{}^*_{TSM}$ = specific backscatter of TSM

a^*_{TSM} = specific absorption of TSM

a^*_{CDOM} = specific absorption of CDOM

NOTE: The asterisks denote that a and b_b are specific inherent optical properties per unit concentration denoted by the subscript.

The a and b coefficients of all stations (Table 1) were averaged to produce one set of representative values for each WQP and were used as the input values in bio-optical modeling. Using (Equation 1), R(0−)s were modeled for stations 3 and 4 (Figures 1a & 1b), which had TCHL of 17 and 37 mg m^{-3}, respectively (Table 1). Station 3 was located within estuarine waters while Station 4 was at the mouth of the Raritan River having much more fresh water influence. The modeled spectra (Figure 1b) exhibited several distinctive peaks around 530–600 nm, 650 nm and 700–710 nm.

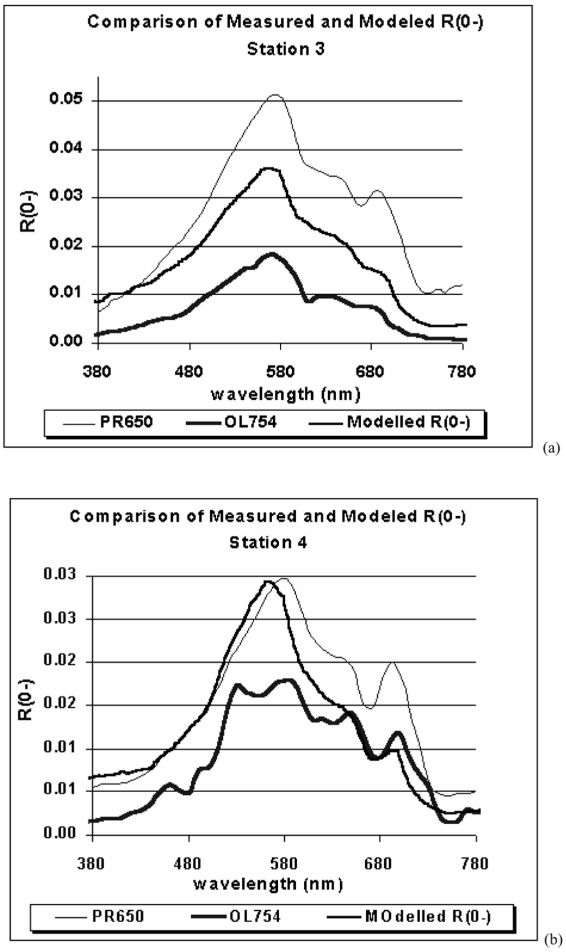

Figure 1. Comparisons of Modeled R(0-) and Measured (in water) R(0-) using OL754 & PR650 spectroradiometers for (a) Station 3 (Traid Bridge) and (b) Station 4 (Crookes Pt Staten Isl.)

Figures 1a and 1b demonstrate the applicability of the modeling approach used. There was a reasonable match between corresponding spectra for stations 3 and 4. The only discrepancies were primarily in the 615–645-nm region because of phycobilipigments not fully accounted-for in our procedure. Thus some signals due to cyanobacteria appear to have influenced the measured R(0−) but not the modeled R(0−).

This work provides a baseline of field and laboratory measurements that will have significance for future work on the underwater light field and remote sensing methodologies for the Hudson/Raritan Estuary. Currently there is no systematic management tool for monitoring of pollution in the Hudson/Raritan Estuary. The establishment of estuarine IOPs is a critical factor in application of such a tool. The production of thematic maps of WQPs for input to GIS are important because of limited capability to monitor conditions in the estuary using conventional methods.

Acknowledgements

This project was funded by the National Science Foundation (BES-9806982). Support of the NASA Headquarters and the AVIRIS Experiment Team is greatly appreciated. Review of the manuscript by Dr A. Dekker is appreciated.

References

Bagheri S., Rijkeboer M., Pasterkamp R. and Dekker A.G. 2000. Comparison of the field spectroradiometers in preparation for optical modeling. 2/23-2/27/2000. 9th Aviris Workshop, JPL, Pasadena, CA, USA.

Dekker A.G., Hoogenboom H.J., Goddijn L.M. and Malthus T.J.M. 1997. The relationship between inherent optical properties and reflectance spectra in turbid inland waters. Remote Sens. Rev. 15: 59–74.

Gons H.J. 1999. Optical teledetection of chlorophyll a in turbid inland waters. Env. Sci. Tech. 6.

Gordon H.R., Brown O.B. and Jacobs M.M. 1975. Computed relationships between Inherent and apparent optical properties of a flat homogeneous ocean. Appl. Optics. 14: 417–427.

Kirk J.T.O. 1994. Light and photosynthesis in aquatic ecosystems. University Press, Cambridge, 401.

Kirk J.T.O. 1984. Dependence of relationship between inherent and apparent optical properties of water on solar altitude. Limnol. Oceanogr. 29: 350–356.

Morel A. and Prieur L. 1977. Analysis of variations in ocean color. Limnol. Oceanogr. 22: 709–722.

NEN 6484 1982. Water: Determination of the content of not dissolved material and its ignition residue. Nederlands Normalisatie instituut, Delft, The Netherlands, (in Dutch).

NEN 6520 1981. Water: Spectrophotometric determination of chlorophyll a content. Nederlands Normalisatie instituut, Delft, The Netherlands, (in Dutch).

Rijkeboer M., Dekker A.G. and Hoogenboom H.J. 1998. Reflectance spectra with associated water quality parameters measured in Dutch waters (Speclib-TK-database). Institute for Environmental Studies, The Netherlands, E98/12.

Truper H.G. and Yentsch C.S. 1967. Use of glass fiber filters for the rapid preparation of in vivo absorption spectra of photosynthetic bacteria. J. Bact. 94: 1255–1256.

Vos R.J., Dekker A.G., Peters S.W.M., Rossum G.V. and Hooijkaas L.C. 1998. RESTWAQ2, part II. Comparison of remote sensing data, model results and in-situ data for the Southern Frisian Lakes. Rep. num. NRSP-2 98-08b. Netherlands Remote sensing Board (BCRS); Programme Bureau; Rijkswaterstaat Survey Department.