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Use of Beam Transmissometer as an Indirect Measure of Suspended Sediment Concentration in the Estuarine Environment: Application and Problems

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Monthly measurements made at 15 stations along the axis of the upper Neuse River estuary show a highly variable degree of correlation between concentration of suspended particulate material (SPM) and attenuation coefficient (c) of light as measured by transmissometer. Coefficients of determination along transect lines ranged from 0.12~0.93 and calibration slopes ranged from 0.50~5.63.

When examined on a station-by-station basis, coefficients of determination ranged from 0.21~0.96 and calibration slopes ranged from 1.04~4.94. Surface calibrations made at individual stations over the full 13-month period were the most consistent of all observations and were considerably better than calibrations made using all of the stations on a given day.

Organic content, which can dominate the suspended sediment load during some months, does not appear to explain the variations in reliability of the calibrations. However, an abundance of large aggregates with time-varying size and shape distributions may be partly responsible for variations in optical properties of the sediments, and thus may confound the relationship between SPM and c in the Neuse River estuary. Time-varying calibrations to account for non-negligible changes in optical properties may not suffice in complex estuarine environments where the *in situ* particle dynamics are poorly understood. However, the best use of Beam Transmissometer will continue to be for applications such as detecting water-column events or for use in situations where wide error bars in establishing SPM concentrations are acceptable.

Introduction

In situ observations of beam transmission are routinely used as a substitute for direct measurements of particle mass or volume. As the most popular optical instrument for making these measurements, the beam transmissometer has been widely deployed in estuaries (Campbell and Spinrad, 1987), in coastal waters and on the continental shelf (Pak and Zaneveld, 1977; Moody *et al.*, 1987), and in the deep sea (McCave, 1983; Gardner *et al.*, 1985). The appeal of transmissometers is in their speed, simplicity, low cost, and general availability. However, use of beam transmission as an indirect measure of sediment mass (or volume) concentration requires that a valid calibration between these variables first be established through regression. In this paper I address questions of reliability of temporal and spatial extrapolation of transmissometer calibrations in an estuarine environment.

The fundamental assumption in determining sediment concentration from beam transmission is that variations in particle size, shape, and refractive index are either negligible, have mutually compensating effects, or can be corrected quantitatively (Baker and Lavelle, 1984; Spinrad, 1986). The importance of particle variables, especially size, has been demonstrated from theory (Jerlov, 1976), controlled laboratory experiments (Baker and Lavelle, 1984), and inferred from field observations (Bishop, 1986; Campbell and Spinrad, 1987; Moody *et al.,* 1987). For example, Baker and Lavelle(1984) have shown that the proportionality constant between beam attenuation and concentration of suspended particulate material can vary by a factor of 10, depending on particle size. Suspended particles 8.5 μm in diameter have been found to attenuate 660 *nm* light 15 times more efficiently than similar particles 48 μm in diameter. Moreover, platy or irregular particles are known to be more effective in scattering light than the same volume of equidimensional particles (Pak *et al.,* 1970) and, for the same particle size and shape, mineral and biogenic skeletal material can be seen to scatter light more effectively than protoplasmic organic matter (Gordon *et al.,* 1980; Zaneveld *et al.,* 1974).

Collectively these and other studies (summarized in Baker and Lavelle, 1984) provide data which clearly indicate that 1) a laboratory calibration alone is insufficient unless the actual properties of particles in suspension are known, 2) a separate field calibration must be made for each particular environment that is studied, and 3) a time-varying calibration needs to be made whenever particle characteristics at a single environment change with time, such as during storms.

In this study I examine the magnitude of the problem of establishing a single calibration slope for the turbidity maximum region of a partially mixed estuary in North Carolina, U. S. A. The specific objective here is to show the spatial and temporal variability in calibration, and its reliability, within a hydrographically-uniform section of a single estuary. I also show the degree of *in situ* variability of natural estuarine suspended particulate material, with the evidence of underwater photographs of particles.

Methods

The field site was a 20-*km* section of the Neuse River estuary, one of two tributary estuarine systems to Pamlico Sound, North Carolina (Fig. 1). The Neuse River drains deeply weathered Piedmont soils, but as a drowned river valley is oversized for the amount of water and sediment that it now carries. Average discharge rate is 150 m^3/sec at the mouth and annual suspended sediment load is estimated(based on data from Giese *et al.,* 1979) to be 2.35×10^5 *t/yr* (Kim, 1990). Although sands from local shoreline erosion form the estuarine margins, bottom sediments throughout most of the estuary are composed of silts and clays(mean disaggregated size 1~3 μm).

Over a 13-month period (February, 1988~February, 1989), monthly profiles of current speed and direction, salinity, temperature, light transmission, and suspended particulate material concentration were obtained by simultaneously deploying an InterOcean S4 electromagnetic currentmeter with temperature and salinity sensors, Sea Tech optical transmissometer, a camera system, and a submersible pump for bringing water samples to the surface. The stations covered that part of the estuary where the typical salinity range was 0~15‰ and where a turbidity maximum, when present, would be expected to occur.

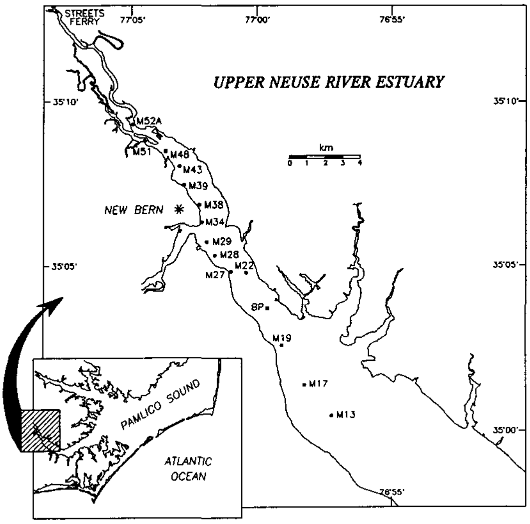

Fig. 1. Map showing the location of stations in the upper Neuse River estuary.

At each station, a water-column profile was made at 1-*m* intervals from near-bottom (50 *cm* above bed) to surface. Beam transmission was recorded aboard ship using a strip chart recorder(Primeline, Model 6723) for real-time observations and a data logger (Metrosonics, dL-714) for digital acquisition.

The camera system consisted of a Nikon N2000 camera with motor drive, a Micro Nikkor F2.8 lens, and two MV substrobes. The camera was enclosed in a small Ikelite housing and suspended over the side of the ship by bridle. Photographs were taken with Plus X Pan film using an F-stop of 22 and a shutter speed of 1/125 *s*. A slab of water 4.2 *cm* ×6.3 *cm*×15 *cm*(397 cm^3) was photographed and aggregates as small as 10 *μm* could be detected.

Water samples were stored in 500 *ml* plastic bottles until they could be filtered in the laboratory, usually within 48 *hr* of collection. Approximately 400 *ml* of each sample was filtered through a preweighed 0.45 *μm* Millipore filter (type HA, 47 *mm* diameter) using standard gravimetric techniques. Filter pads were rinsed twice with 10 *ml* of distilled water to remove any residual salt. They were then air dried for at least 72 *hr* under controlled room temperature and humidity before reweighing. Because of its potential role in attenuation of light, an estimate of sediment organic content was also made. Filter pads were ashed at 500℃ for 5 *hr* in aluminum petri dishes with full covers(Manheim *et al.*, 1970). All dry weights were converted to units of *mg/l*.

Calibration slopes were established through linear regression using sediment concentration as the dependent (Y) variable. The independent (X) variable, beam attenuation coefficient, was determined from transmission data provided by the data logger. The transmissometer, which measures the intensity of a collimated monochromatic light beam after the beam has been transmitted through a known length (5 *cm*) of water column, provides information on attenuation, c, through the relationship

$$I(r)=I(0)\ e^{-cr} \qquad (1)$$

where I(0) and I(r) are the light intensities at the source and at a distance r (in *m*) from the source. Beam transmission, the ratio of received to source light intensity, I(r)/I(0), is given

$$T=e^{-cr} \qquad (2)$$

and the attenuation coefficient is thus determined from beam transmission by the relationship

$$c=-\ln T/r \qquad (3)$$

In general, the transmission values have contributions from absorption and scattering by pure water, by suspended particles, and by dissolved organic material. However, the Sea Tech transmissometer used in this study has a light source (660 *nm* wavelength) that effectively eliminates the absorption from dissolved materials so that any attenuation is due to water and sediment only.

Results and Discussion

Fig. 2 shows the seasonal relationship between suspended material, freshwater discharge, and salinity. Average suspended particulate material concentrations are of the order 5~25 *mg/l* with monthly variations that correlate well with freshwater

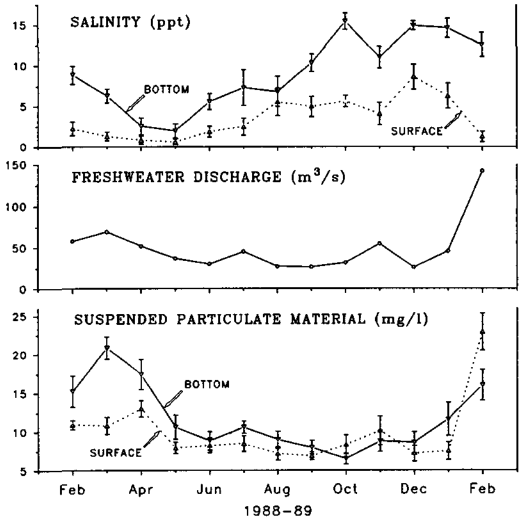

Fig. 2. Monthly variation in mean salinity, 5-day averaged freshwater discharge, and mean suspended particulate material concentration. Error bars represent 95% confidence intervals.

discharge. Concentrations are nearly always higher near the bottom. During most months the vertical salinity gradient is 5~10‰ and the upstream limit of salt intrusion migrates over approximately 20 *km* of the estuarine axis.

Figs. 3~5 show scatter plots of suspended particulate material concentration (SPM) versus attenuation (c) over all stations for the full 13 months of observations. Slightly more than one-half of the total variation in suspended sediment concentration can be explained by regression of SPM on c (r^2= 0.56). Although surface and bottom calibration slopes are nearly identical, the correlation between c and SPM is better at the surface (r^2=0.65) than at the bottom (r^2=0.48). The widest scatter of data occurs at sediment concentrations above about 15 *mg/l*, reflecting the especially poor correlation at higher concentration values which were observed near the bottom. Given the time and space scales over which the 1300 pairs of simultaneous measurements were made, the scatter in data is not surprising. A more realistic approach, presented in the following paragraphs, is to examine the data by month and by station, in addition to depth in the water column.

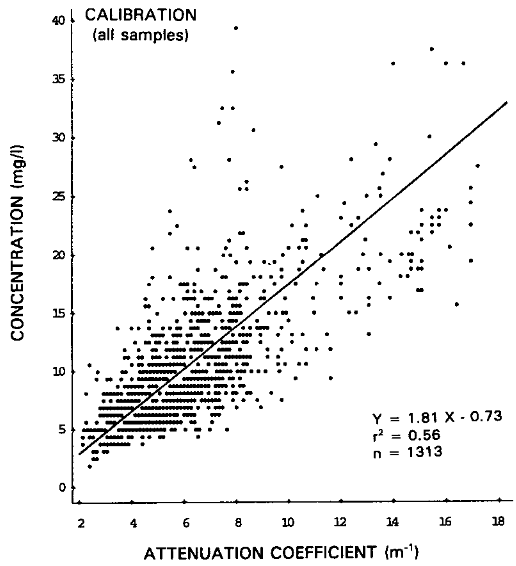

Fig. 3. Relationship between SPM concentration and attenuation coefficient for all pairs of simultaneous observations ($p<0.0001$).

Correlation Analysis by Month: Table 1 provides a summary of the coefficients of determination (r^2) and the calibration slopes on a month-by-month basis. Values of r^2 ranged widely from 0.12~0.87

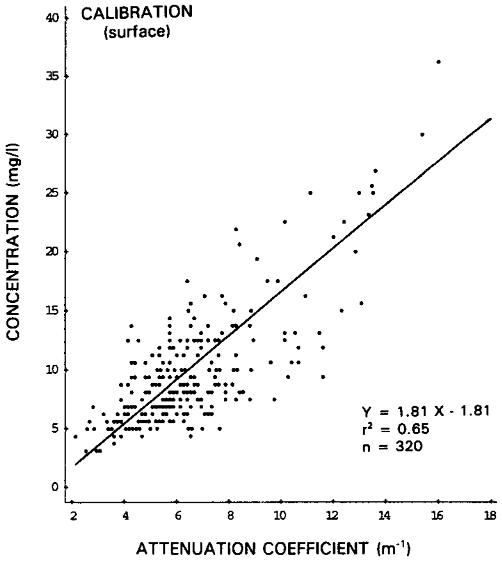

Fig. 4. Relationship between SPM concentration and attenuation coefficient for surface observations only($p<0.0001$).

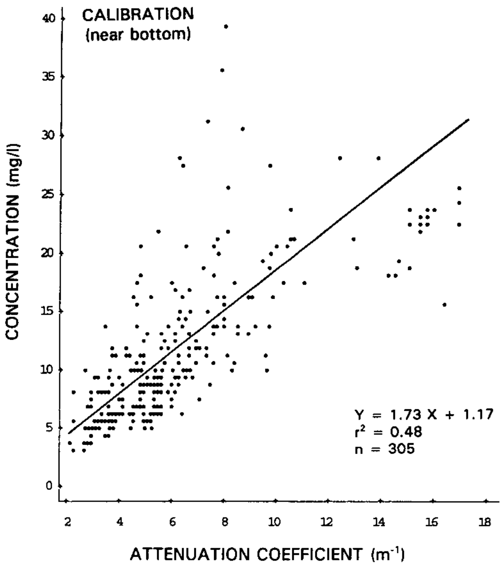

Fig. 5. Relationship between SPM concentration and attenuation coefficient for bottom observations only ($p<0.0001$).

at the surface, 0.19~0.95 at the bottom, and 0.07~0.80 using samples from all levels. The surface and bottom averages and standard deviations were essentially the same, suggesting that the overall ability to calibrate was neither better nor more consistent at one level than the other. Although there was no apparent seasonal pattern in degree of correlation, comparison to Fig. 2 shows that surface values bear some relationship to freshwater discharge in that the three highest r^2 values (July and November, 1988, and February, 1989) occurred during periods of higher discharge. Steeper and more variable calibration slopes at the bottom indicate a wider range of optical properties close to the bed.

Correlation Analysis by Station: Table 2 provides a summary of the coefficients of determination and calibration slopes on a station-by-station basis. Both variables displayed a narrower range than when examined by month. Surface and bottom r^2 values ranged from 0.46~0.96 and 0.21~0.93, respectively, and the total using all levels ranged from 0.34~0.93. Surface values at each station showed generally good correlations(avg. $r^2=0.75$) and a low standard deviation (0.12) when averaged over all stations; in only three instances were the r^2 values lower than 0.70. Surface and bottom calibration slopes were similar and also less variable when examined on a station-by-station basis. However, despite the similarity in calibration slopes, the r^2 values did not covary between surface and bottom and the differences were often quite large. Moreover, Fig. 6 shows in a summary plot the lack of any clearcut relationship between suspended particulate concentration and the coefficients of determination or the calibration slopes.

The most significant aspects of Tables 1 and 2 are 1) the wide variations in calibration slope, 2) the inconsistent and often poor fit of data to the regression (calibration) curves, and 3) the fact that more uniform calibration slopes and higher r^2 values (at the surface) can be obtained by calibrating over a relatively long period of time than over a relatively modest distance. Thus, it is easy to dismiss the attempts to establish experimental calibrations over all stations (Table 1) as unrealistic because of inherent spatial variations, even on a given day. Presumably, the calibration slopes in Table 1 vary widely and have low r^2 values because of substantial variations in particle properties within the 20 km stretch over which the measurements were made. The implication, given that surface and bottom correlation coefficients in Table 1 are 0.70 only 25% of the time, is that towing a transmissometer for the purpose of making quick regional surveys, at least in the Neuse River estuary, will not provide an accurate measure of suspended particulate material concentration.

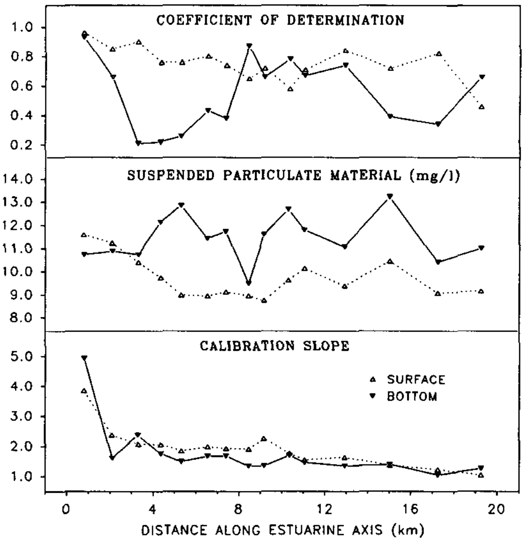

Fig. 6. Data from Table 2 plotted along the estuarine axis showing their lack of relationship to SPM concentration. Note the difference in covariance between surface and bottom coefficients of determination and calibrations slopes.

The relatively uniform calibration slopes and high correlation coefficients at the surface, over the full 13 months at each station (Table 2), are perhaps surprising in light of the overall poor correlations in Table 1. In fact, the high r^2 values in Table 2 would suggest that surface particle characteristics do not vary significantly over time. The uniform optical properties which allow such good correlations can probably best be explained by the dominance of terrigenous sediment input at the surface, which is not complicated by incoming bottom

Table 1. Calibration slopes and coefficients of determination between c and SPM, summarized by month ($p<0.05$ for all surface and near-bottom R^2 values and $p<0.01$ for all total R^2 values, except as noted). *$p<0.06$, **$p<0.04$.

DATE	SURFACE			NEAR-BOTTOM			TOTAL		
	# SAMP	R^2	SLOPE	# SAMP	R^2	SLOPE	# SAMP	R^2	SLOPE
2/25/88	11	0.52	1.94	10	0.38	2.77*	51	0.47	2.02
3/18/88	25	0.49	0.99	22	0.36	0.82	101	0.75	1.11
4/21/88	28	0.20	0.96	26	0.64	0.81	104	0.46	1.66
5/13/88	30	0.65	1.14	30	0.44	2.29	111	0.30	1.11
6/13/88	30	0.12	0.80	30	0.69	3.14	124	0.41	2.05
7/28/88	30	0.79	1.00	30	0.19	0.65	116	0.34	0.86
8/20/88	30	0.33	0.50	23	0.40	0.72	112	0.26	0.59
9/26/88	15	0.42	0.62	13	0.61	0.94	59	0.07	0.51**
10/27/88	24	0.45	1.99	25	0.70	2.21	104	0.51	1.63
11/22/88	27	0.87	1.67	26	0.69	5.20	122	0.55	1.90
12/22/88	28	0.69	2.00	29	0.95	5.31	127	0.61	3.40
1/27/89	27	0.69	1.91	26	0.31	2.50	114	0.46	2.45
2/28/89	15	0.85	4.05	15	0.93	5.63	68	0.80	3.67
AVERAGE		0.54	1.51		0.56	2.63		0.46	1.77
STD. DEV.		0.23	0.90		0.23	1.69		0.19	0.94

Table 2. Calibration slopes and coefficients of determination between c and SPM, summarized by station($p<0.05$ for all surface and near-bottom R^2 values and $p<0.01$ for all total R^2 values).

STATION	SURFACE			NEAR-BOTTOM			TOTAL		
	# SAMP	R^2	SLOPE	# SAMP	R^2	SLOPE	# SAMP	R^2	SLOPE
M52A	20	0.96	3.85	20	0.93	4.94	73	0.93	4.22
M51	21	0.85	2.37	22	0.66	1.60	116	0.78	2.19
M48	20	0.90	2.07	19	0.21	2.37	85	0.66	2.47
M43	22	0.76	2.06	21	0.22	1.74	85	0.53	2.15
M39	21	0.76	1.84	22	0.26	1.48	81	0.34	2.00
M38	22	0.80	1.98	20	0.43	1.66	71	0.54	1.85
M34	20	0.74	1.92	17	0.38	1.67	69	0.49	2.02
M29	20	0.64	1.91	21	0.07	1.34	64	0.72	1.53
M28	23	0.72	2.25	21	0.66	1.34	96	0.63	1.09
M27	22	0.58	1.76	20	0.78	1.69	134	0.73	1.54
M22	23	0.71	1.54	22	0.67	1.45	98	0.66	1.39
BP	22	0.84	1.63	21	0.74	1.34	89	0.74	1.37
M19	23	0.72	1.36	22	0.39	1.38	88	0.43	1.32
M17	20	0.82	1.22	17	0.34	1.04	70	0.51	1.10
M13	14	0.46	1.04	14	0.66	1.25	55	0.57	1.19
AVERAGE		0.75	1.92		0.55	1.75		0.62	1.83
STD. DEV.		0.12	0.63		0.23	0.90		0.15	0.76

flow from Pamlico Sound, and by the absence of any resuspension effects in the upper part of the water column. On the other hand, failure to obtain good correlations between SPM and c during previous 25-*hr* anchor station experiments, even at the surface (Wells, 1989; Wells and Kim, 1989), may have been a result of episodic or high frequency events that altered the optical properties of particles on short time scales, but not in such a way as to influence less frequent monthly data taken over a year. In other words, the high-frequency variability in particle properties, which previously led to low r^2 values, may have been much greater than the low-frequency monthly or seasonal variability measured here.

Underwater Photographs of Aggregated Particles: Although properties of inorganic sediments on the bottom appear quite uniform along the estuarine axis (Kim, 1990), this is probably not the case for inorganics in the water column. Current meter and salinity records show the presence of two-layer estuarine circulation, migration of the flow convergence zone, and salinity variations that may influence the degree of particle aggregation along the transect. *In situ* photographs of particles using an underwater camera have revealed that in fact there is always a varying abundance of large aggregates (>100 μm) in the water column, especially near the bottom (Fig. 7A to 7D). These four photographs show the variation in size and shape of *in situ* large aggregates at different stations (A; St.43, B; St.28, C; St.BP, and D; St.13) during same observation period (Dec. 19, 1988). Frame size is 63 $mm \times 42$ mm. The maximum size of aggregates, measured directly from photographs, ranges from hundreds of microns to several millimeters, diameters that are one or two orders of magnitude larger than typical 'salt flocs' (Kim, 1990). The size and abundance of large aggregates in the water column

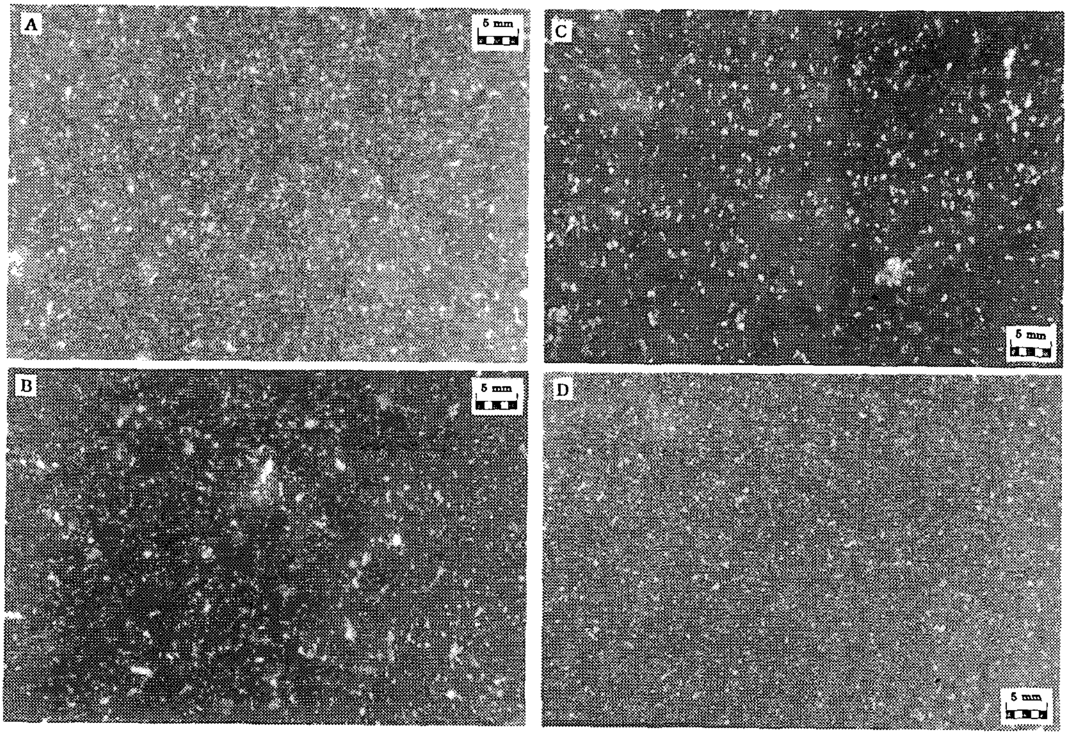

Fig. 7. Photographs showing *in situ* large aggregates and their variation in size and shape at different stations (A; St. 43, B; St. 28, C; St. BP, and D; St. 13) during same observation period (Dec. 19, 1988). Frame scale is 63 $mm \times 42$ mm.

are highly variable due to their extreme fragility, rapid settling and resuspension, and possible association with salt flocs which can be building blocks for the aggregates. During the examination of particles photographed by underwater camera, the effect of salinity was observed as a rapid increase in the amount of large aggregates at the fresh-salt water boundary (near St. 28 and St. BP), suggesting the importance of salt flocs in the building of large aggregates.

The effects of current speeds on the particle size distribution are expected in two ways; high shear stress in the water column tends to destroy the fragile aggregates while resuspension from the bottom due to high current speed tends to increase the amount of large aggregates (Eisma, 1986). However, further studies are required before the details of particle size distribution can be understood.

Underwater photographs from a nearby field site at Cape Lookout Bight have shown that the population of large aggregates which exists in shallow water can be highly dynamic. During one 25-*hr* experiment, near bottom aggregate abundance ranged from 1700~5300 per liter, mean diameter ranged from 0.17~0.50 *mm* and the percent of total particle mass accounted for by large aggregates ranged from 5~95% (Wells, 1989). Moreover, variations in particle shape are also known to occur on short time scales (Wells and Shanks, 1987). Large aggregates are often comet-shaped and, when magnified on a digitizing table, appear visually to be composed of fragile strings of smaller, more spherical particles.

Large aggregates, which have been shown to be optically inactive and relatively unimportant in the attenuation of light (Campbell and Spinrad, 1987), are extremely important in how the total particle mass is packaged, and therefore may confound any simple linear relationship between SPM and c. Notwithstanding the importance of small light scatterers, the large aggregate population can provide one explanation for the difference in calibration slopes and goodness of fit. This is because of their tremendous effect on particle mass but apparently only minor effect on the attenuation of light. Since a single spherical aggregate 0.3 *mm* in diameter (in coastal North Carolina) contains on the order of 1000 individual mineral grains (A. L. Shanks, pers. comm.), any temporal or spatial variations in aggregate size, shape, or abundance would require contemporaneous calibration adjustments. At present I do not know how to make such calibration adjustments since size distributions in estuaries cannot be accurately determined except by *in situ* methods. Moreover, it is doubtful that techniques to increase resolution, such as calibration diagrams (Spinrad, 1986), can be applied to estuarine systems such as the Neuse where consistent empirical calibrations are not yet possible.

Organic Content of Suspended Particles: During some months, organic material dominates the suspended sediment load and presumably the optical properties of sediments within the estuary. Examination of organic content during each observation period reveals that organics increase downstream (Kim, 1990) and display substantial overall monthly variations (Fig. 8). However, variation in organic content or in the organic-inorganic ratio does not appear to offer an explanation for low or inconsistent r^2 values. For example, comparison of Table 1 and Fig. 8 shows that 1) the best monthly SPM-c correlation was established in November 1988,

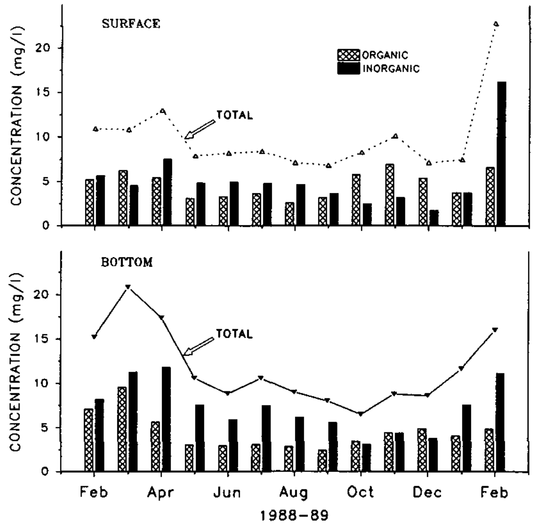

Fig. 8. Monthly variation in combustible organic matter at the (a) surface and (b) near bottom.

when organic material dominated the surface sediments, but that essentially the same degree of correlation was achieved in February 1989, when organic content was a much lower percentage of the sediment load, and 2) the very poor correlations, both at the surface and bottom, occurred over a wide range of SPM and organic-inorganic ratios.

Regardless of the exact cause, the most troubling practical aspect of highly variablecalibration data is the inability to know *a priori* whether a reliable calibration can be established. Without collecting extensive empirical data, it is simply not possible to know from one day or one station to the next, when or to what degree the transmissometer can fulfill its role as a fast substitute for direct measurements of SPM. This lack of knowledge clearly diminishes the utility of the transmissometer, regardless of how it is deployed. Even at the surface, where calibration slopes are relatively uniform and r^2 values are relatively high at most stations, there are questions concerning utility of the calibration. This is because, in terms of boundary layer processes, most of the interest is near the bottom where calibrations still remain poor. Questions concerning the effects of high frequency events on calibration slopes, such as during storms (Moody *et al.*, 1987), also remain unanswered and present a potential problem. I therefore emphasize, as have several previous researchers, the need for careful time varying calibrations. I add the cautionary note here that even this may not suffice in the complex estuarine environment where there is a great need for fast and reliable estimates of SPM concentration. However, I believe that further research on *in situ* size, shape and abundance distributions, especially for large aggregates, may offer hope for overcoming the calibration problems described in this paper. Until then, the best use of beam transmission data will continue to be for applications such as detecting water-column events or for use in situations where wide error bars in establishing SPM concentrations are acceptable.

Conclusions

1. Beam transmission appears to be providing little consistent or interpretable information on SPM concentration in the upper Neuse River estuary. Monthly coefficients of determination(concentration versus attenuation) along transect lines were found to range from 0.12~0.93 and calibration slopes to range from 0.50~5.63. Over an annual cycle at individual stations, coefficients of determination were found to range from 0.21~0.96 and calibration slopes to range from 1.04~4.94.
2. Surface calibrations at individual stations, based on data collected at monthly intervals for 13 months, are considerably better than calibrations made over all stations on a single day. Comparing results to previous data collected at tidal cycle frequency suggests that surface sediments may exhibit a narrower range in optical properties when sampled at monthly intervals over a full annual cycle than when sampled at higher frequencies.
3. Variations in organic content or in the organic-inorganic ratio cannot explain the variations in reliability of the calibration. However, an abundant and highly variable population of large aggregates may confound the simple linear relationship between SPM and c, and therefore could be responsible for the inconsistent calibrations.
4. At our present level of understanding, frequent empirical calibrations must be made, even for fair-weather applications. However, the inability to establish valid calibrations along transect lines indicates that spatial monitoring or contouring of SPM using beam transmission is not possible in the Neuse River estuary. The best use of beam transmission data continues to be for the detection of water-column events, or in other situations where wide error bars in relating c to SPM are acceptable.

Acknowledgements

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References

Baker, E. T. and J. W. Lavelle. 1984. The effect of particle size on the light attenuation coefficient of natural suspensions. Journal of Geophysical Research 89, 8197~8203.

Bishop, J. K. B. 1986. The correction and suspended particulate matter calibration of Sea Tech transmissometer data. Deep-Sea Research 33, 121~134.

Campbell, D. E. and R. W. Spinrad. 1987. The relationship between light attenuation and particle characteristics in a turbid estuary. Estuarine, Coastal and Shelf Science 25, 53~65.

Eisma, D. 1986. Flocculation and de-flocculation of suspended matter in estuaries. Neth. J. Sea Res., 20, 183~196.

Gardner, W. D., P. E. Biscaye, J. R. V. Zaneveld and M. J. Richardson. 1985. Calibration and comparison of the LDGO nephelometer and the OSU transmissometer on the Nova Scotian Rise. Marine Geology 66, 323~344.

Giese, G. L., H. B. Wilder and G. G. Parker. 1979. Hydrology of major estuaries and sounds of North Carolina. Water Supply Paper 2221, U. S. Geological Survey, 108 p.

Gordon, H. R., J. M. Smith and J. R. V. Zaneveld. 1980. Introduction to ocean optics. SPIE Ocean Optics IV 208, 14~55.

Jerlov, N. G. 1976. Marine Optics. Elsevier, New York. 231 p.

Kim, S. Y. 1990. Physical processes and fine-grained sediment dynamics in the Neuse River estuary, North Carolina. Ph. D. Dissertation. Univ. of North Carolina, Chapel Hill, North Carolina, 128 p.

Manheim, F. T., R. H. Meade and G. C. Bond. 19 70. Suspended matter in surface waters of the Atlantic continental margin from Cape Cod to the Florida Keys. Science 167, 371~376.

McCave, I. N. 1983. Particulate size spectra, behavior, and origin of nepheloid layers over the Nova Scotian continental rise. Journal of Geophysical Research 88, 7647~7666.

Moody, J. A., B. Butman and M. H. Bothner. 1987. Near-bottom suspended matter concentration on the continental shelf during storms: estimates based on *in situ* observations of light transmission and a particle size dependent transmissometer calibration. Continental Shelf Research 7, 609~628.

Pak, H. and J. R. V. Zaneveld. 1977. Bottom nepheloid layers and bottom mixed layers observed on the continental shelf off Oregon. Journal of Geophysical Research 82, 3921~3931.

Pak, H., G. F. Beardsley, Jr., G. R. Heath and H. Curl. 1970. Light-scattering vectors of some marine particles. Limnology and Oceanography 15, 683~687.

Spinrad, R. W. 1986. A calibration diagram of specific beam attenuation. Journal of Geophysical Research 91, 7761~7764.

Wells, J. T. 1989. *In situ* measurements of large aggregates over a fluid mud bed. Journal of Coastal Research SI5, 75~86.

Wells, J. T. and S. Y. Kim. 1989. Sedimentation in the Albemarle-Pamlico lagoonal system: synthesis and hypotheses. Marine Geology 88, 263~284.

Wells, J. T. and A. L. Shanks. 1987. Observations and geologic significance of marine snow in a shallow-water partially enclosed marine embayment. Journal of Geophysical Research 92, 13,185~13,190.

Zaneveld, J. R. V., D. M. Roach and H. Pak. 1974. The determination of the index of refraction distribution of oceanic particulates. Journal of Geophysical Research 79, 4091~4095.

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강하구에서의 부유물질농도 결정을 위한 광전도측정기의 이용 및 문제점

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광전도측정기(Beam Transmissometer)를 이용한 간접적인 부유물질농도결정의 신뢰도와 문제점을 조사하기 위하여, Neuse 강 (미국 North Carolina주) 하구의 15개 정점에서 13개월에 걸쳐 매월 광전도도와 부유물질의 농도를 측정, 상관관계를 분석하였다. 부유물질농도(SPM)와 광감쇄계수(Beam Attenuation Coefficient, c) 간의 상관계수(Coefficient of Determination, r^2) 및 상관함수의 기울기(a)는 월별(r^2: 0.12~0.93, a: 0.53~5.63) 및 정점별(r^2: 0.21~0.96, a: 1.04~4.94)로 극심한 변동폭을 보였으나, 표층이 저층보다 밀접한 상관관계를 보였으며, 해수의 영향이 연중 거의 미치지 않는 최상류지점에서 가장 높은 상관계수($r^2=0.96$)를 나타내었다.

계절별로 다양한 변화를 보이는 부유물질의 유기물함량은 SPM과 c 간의 함수관계에 중요한 영향을 미치지 않으나, 시간적, 공간적으로 다양하게 변화하는 부유물질응집체(aggregate)에 의해 부유입자의 광학적 특성 (입도, 모양 및 광굴절지수 등)이 변화하게 되며, 따라서 SPM과 c의 관계를 복잡하게 하는 것으로 생각된다.

광전도측정기의 효과적인 이용을 위해서는 정확한 보정이 필요하나, 부유입자의 광학적 특성이 다양하게 변화하는 강하구와 같은 환경에서는 시간적, 공간적으로 빈번한 보정으로도 신뢰도 높은 상관관계의 획득이 불가능하다. 그러나 광전도측정기의 최선의 용도는 수괴의 탁도의 급격한 변동을 감지하는데 있으며, 부유입자의 광학적 특성이 비교적 균일한 외해에서나 혹은 오차범위를 허용할 수 있는 상황에서는 매우 유용하게 사용될 수 있다.