3 Light Attenuation

Introduction

Light attenuation is computed using a "partial attenuation model" in which light attenuation is considered as the sum of the contribution from individual components. The components include water itself, colored organic matter, and suspended particles. The selection of components depends on available observations. The contribution from each component depends on local conditions.

Methods

Observations of light attenuation (Ke) and of contributors to attenuation were obtained from the Chesapeake Bay Program on-line data base (http://www.chesapeakebay.net/data/downloads/cbp_water_quality_database_1984_present). Observations were obtained for the years 2000 – 2010 from the Tidal Water Quality Monitoring Program and the Shallow Water Monitoring Program. Contributors included particulate organic carbon (POC), dissolved organic carbon (DOC), volatile suspended solids (VSS), total suspended solids (TSS), salinity (SALT), and chlorophyll 'a' (CHL). DOC and SALT were included as potential indicators of color while the other contributors represented various fractions of suspended solids. Negative values and outliers were removed from the data base, leaving nearly 18,000 observations of KE and contributing factors.

Stepwise regression was employed to evaluate additive models which included various combinations of contributing factors. Superior results (R^2 = 0.623) were obtained for a simple model which related KE to TSS and SALT:

$$Ke = a1 + a2 \cdot TSS + a3 \cdot SALT \qquad (1)$$

in which:

Ke = coefficient of diffuse light attenuation (m^{-1})
a1 = background attenuation (m^{-1})
a2 = attenuation by total suspended solids ($m^2\ g^{-1}$)
a3 = relationship between attenuation and salinity ($m^2\ kg^{-1}$)
TSS = total suspended solids concentration ($g\ m^{-3}$)
SALT = salinity ($kg\ m^{-3}$)

CHL was an additional significant ($p < 0.0001$) contributor to attenuation but the marginal improvement in R^2 was small, 0.012, so CHL was neglected in the model.

After the model was established, residuals were examined by monitoring station. Background attenuation (parameter a1) was adjusted in regions of the Bay which were judged to have significant, consistent, residuals. Additional adjustments to parameter a1 were performed in a few regions based on model-data comparisons following operation of the water quality model (WQM).

Results

Parameter values obtained from regression were: a1 = 1.647 m^{-1}; a2 = 0.0557 $m^2\ g^{-1}$; a3 = -0.0624 $m^2\ kg^{-1}$. The negative value for a3 implies that freshwater is more highly-colored than ocean water. Attenuation due to color diminishes as the fraction of ocean water at the sample location increases. Examination of residuals indicated:

- Negative residuals (observed attenuation less than modeled) near the James, Rappahannock, Potomac and Susquehanna fall lines.
- Negative residuals in the lower Potomac and St. Marys River.
- Positive residuals (observed attenuation greater than modeled) in the York and Mattaponi rivers.
- Positive residuals in the lower James and Elizabeth Rivers.

Adjustments to background attenuation are presented in Table 3-1 for Chesapeake Bay Program Segments as shown in Figure 3-1.

Additional Model Considerations

Observed TSS in the attenuation relationship is the sum of organic and inorganic particulate matter. Multiple WQM state variables must be summed to obtain TSS for use in the relationship. Concentration of inorganic solids is obtained from the WQM as the sum of the fine clay, clay, silt, and sand state variables. Observed organic (volatile) solids correspond to model POC state variables. For idealized organic matter, represented as CH_2O, organic solids concentration would be 2.5 times POC concentration. In reality, this ratio can vary. The appropriate ratio for Chesapeake Bay was obtained by Type II regression (Laws and Archie, 1981) of observed VSS on observed POC. The result indicated organic solids = 2.9 * POC ($R^2 = 0.889$). Model POC is the sum of the three algal groups and three particulate organic carbon variables.

The negative relationship between Ke and SALT can result in negative values for Ke under conditions of high salinity coupled with low TSS. To avoid negative values, a minimum Ke value of 0.15 m^{-1} is imposed.

Comparison of Two Optical Models

The partial attenuation model (PAM) described here replaces an advanced optical model (AOM) employed in the 2010 model study (Cerco et al. 2010). Following parameterization of the PAM and implementation in the WQM, a model run was made for comparison of results with the previous optical model. Computations of Ke were compared using the absolute mean difference statistic developed for the initial Chesapeake Bay model (Cerco and Cole 1994) and utilized thereafter to examine model performance:

$$AMD = \frac{\sum|P - O|}{N} \qquad (4)$$

in which:

AMD = absolute mean difference
O = observation
P = prediction
N = number of observations

The absolute mean difference is a measure of the characteristic difference between individual observations and computations. An absolute mean difference of zero indicates the model perfectly reproduces each observation.

Statistics were determined using the model-data pairs employed in the model validation time series plots and grouped into systems. Results indicate the AOM and PAM deliver comparable performance in the mainstem Bay (Figure 3-2). For most other regions of the system, AMD is lower for the PAM than the AOM. Only in the Potomac River are results from the AOM superior to the PAM. These results should not be interpreted that PAMs are superior to AOMs. AOMs such as the one employed in the 2010 study are based on rigorous physics and are preferred in applications which emphasize optical properties of surface waters. The less rigorous PAM described here is suitable, however, to describe light attenuation in a study such as this one and is advantageous in terms of computational requirements and data requirements.

References

Cerco, C.F. and Cole, T. M. (1994). “Three-dimensional eutrophication model of Chesapeake Bay,” Technical Report EL-94-4, U.S. Army Engineer Waterways Experiment Station, Vicksburg MS.

Cerco, C., Kim, S.-C. and Noel, M. (2010). “The 2010 Chesapeake Bay eutrophication model,” Chesapeake Bay Program Office, US Environmental Protection Agency, Annapolis MD. (available at http://www.chesapeakebay.net/publications/title/the_2010_chesapeake_bay_eutrophication_model1)

Laws, E., and Archie, J. (1981). “Appropriate use of regression analysis in marine biology,” *Marine Biology* 65, 13-16.

Table 3-1
Adjustments to Background Attenuation

CBPS	Adjustment	CBPS	Adjustment
CB1	-0.4	SBEMH	+0.6
CB2	-0.3	WBEMH	+0.6
CB3	-0.3	LAFMH	+0.6
CB4	-0.3	POTOH	-0.4
CB5	-0.3	YRKMH	+0.5
BOHOH	+0.7	POTTF	-0.4
CHSTF	+0.7	ANATF	-0.4
CHOOH	+0.6	MATTF	-0.4
PAXMH	-0.5	PISTF	-0.4
POTMH	-0.4	MPNOH	+0.5
EBEMH	+0.6	MPNTF	+0.5
ELIPH	+0.6	BSHOH	+0.5

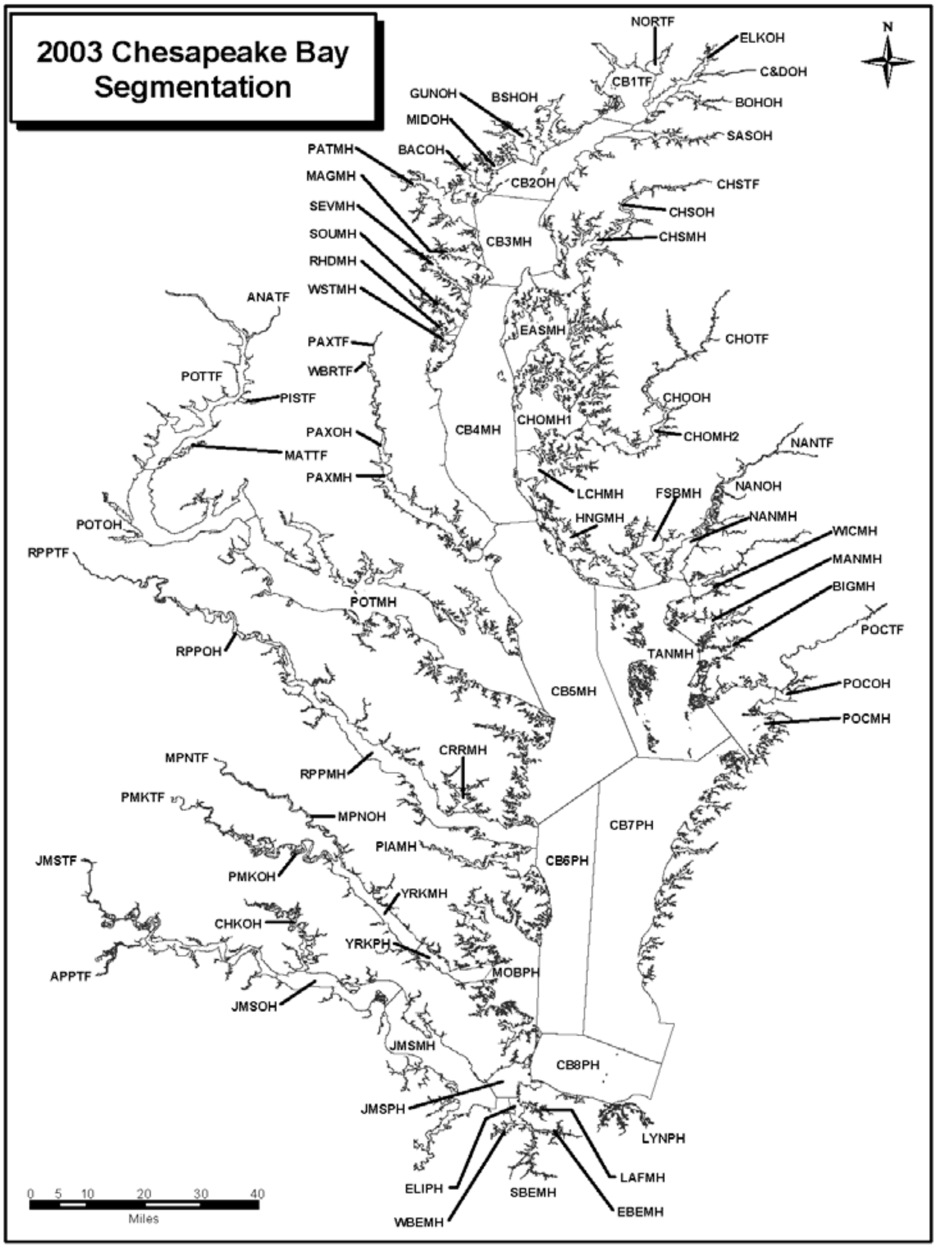

Figure 3-1. Chesapeake Bay Program Segments. Background attenuation was adjusted on segment-wide basis for segments listed in Table 3-1.

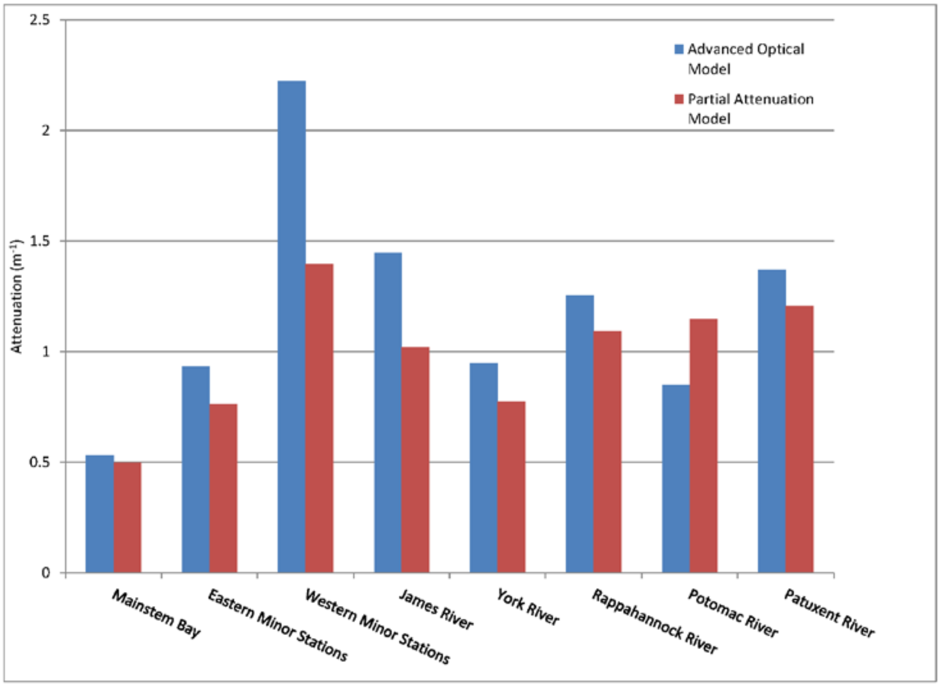

Figure 3-2. Light attenuation absolute mean difference statistic for the partial attenuation model vs. the advanced optical model.