Appendix J: Light Extinction Methodology

This appendix is in connection with Section 3.4.3 in the main report – Light Extinction. It is compiled from DRBC staffs' (Jacob Bransky and Thomas Amidon) presentations to the DRBC's Model Expert Panel and the Water Quality Advisory Committee (WQAC). The appendix is aiming at providing additional information on developing light extinction formulation.

Light extinction refers to how quickly light is attenuated in the water column. It is a critical parameter that influences algal growth, and therefore dissolved oxygen in aquatic systems. Light extinction tends to be site specific and in the Delaware Estuary can range from high levels near the Estuary Turbidity Maximum (ETM, defined as river miles 35-80 for the purposed of this study) to low levels at the extremes of the Estuary near the interface with the Atlantic Ocean or the non-tidal Delaware River (Figure 1). Despite its importance, light extinction is often poorly characterized in models.

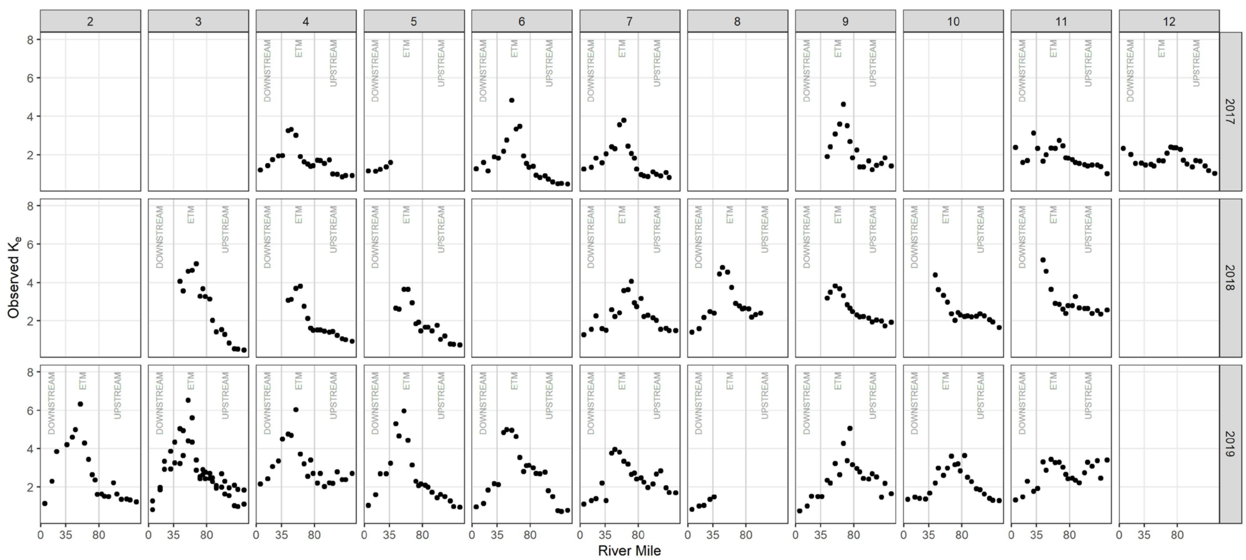


Figure J-1. Observed light extinction (K_e) derived from PAR measurements collected during Delaware Estuary Boat Run monitoring from 2017 - 2019. Each panel represents one Boat Run event with samples being collected from the mouth of the bay (river mile 0) to the head of tide (river mile 134). Columns of panels represent the months (February through December) and rows of panels represent the year.

Light extinction is driven by scattering from solid particles, absorption by dissolved organic material, and self-shading caused by phytoplankton in the water column. In the Delaware Estuary high levels of suspended solids near the ETM complicate the prediction of light extinction by masking the effects of other contributors to light extinction like dissolved organic matter and phytoplankton. Due to the uniqueness of the system, DRBC developed a novel methodology for predicting light extinction in the Estuary based off a series of parameters present in the Eutrophication Model.

DRBC developed a regression model to predict light extinction (K_e). "Observed" K_e was derived from photosynthetically active radiation (PAR) measurements collected during DRBC's Boat Run monitoring program from 2018-2019 (2017 was excluded due to poor data quality). The Boat Run program monthly measures a variety of parameters from the mouth of the bay to the head of tide and provides an excellent dataset for predicting K_e across the entire Estuary. K_e was calculated from PAR measurements using the following equation.

$$K_e = ln\,(\frac{PAR_{surface}}{PAR_{1m\ depth}})$$

To predict K_e, DRBC first evaluated correlation coefficients of several parameters with K_e including chlorophyll a, inorganic suspended solids (ISS), salinity, total suspended solids (TSS), Secchi depth, turbidity, and dissolved organic carbon (DOC) (Figure 2). Several of these parameters correlate closely with K_e but are either not available as state variables in the eutrophication model (Secchi depth, turbidity, and TSS) or are not dynamically predicted by the model (ISS). These parameters were therefore not included in the regression model.

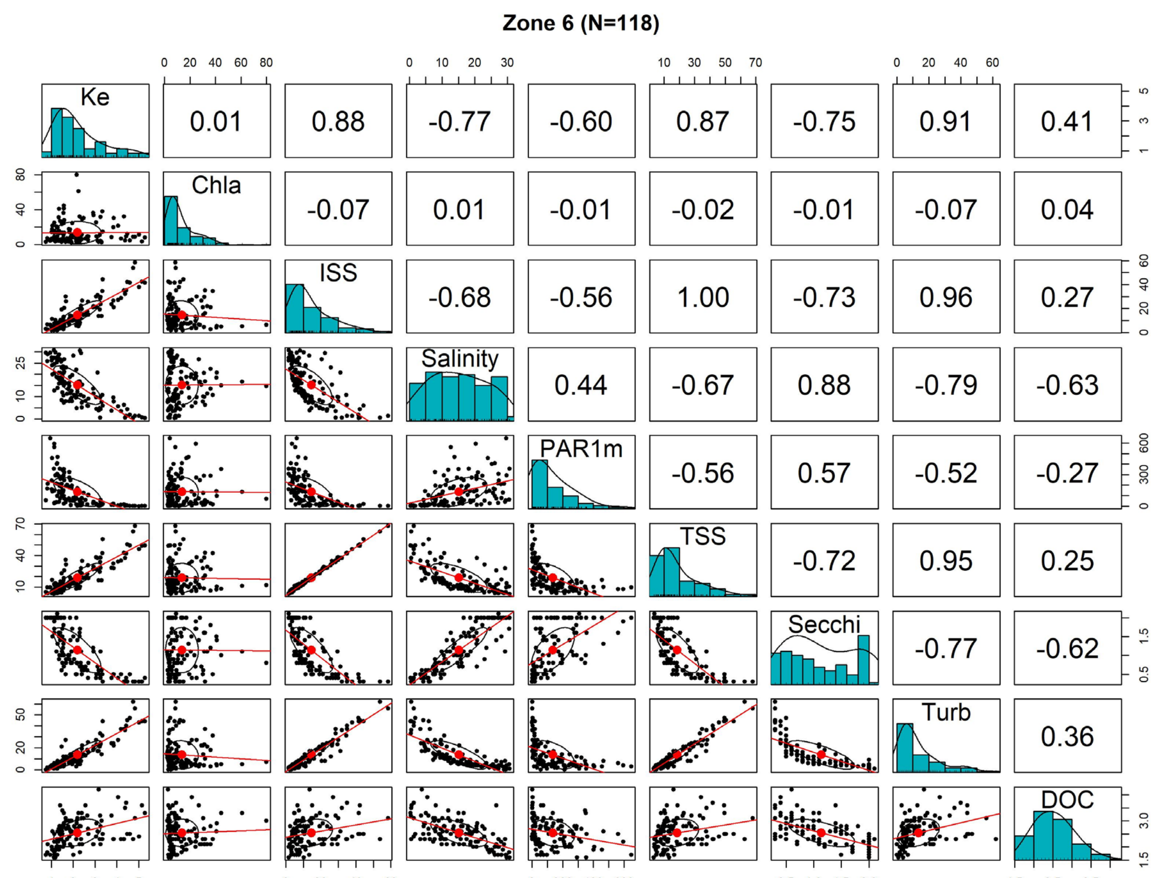


Figure J-2. Correlation of selected parameters with observed K_e in Zone 6 of the Delaware Estuary. Zone 6 was chosen for illustrative purposes, but correlations were calculated in each zone of the Estuary.

The final parameters chosen to predict K_e using a regression model were chlorophyl a (to represent phytoplankton self-shading), dissolved organic carbon (to represent absorption and color) and salinity (as a surrogate for suspended solids to represent scattering). While salinity does not have a direct effect on K_e, it is strongly negatively correlated to suspended solids in the lower portion of the Estuary and is accurately predicted by the eutrophication model. At the mouth of the bay, salinity is high and suspended solids are low. At the ETM, salinity is low and suspended solids are high. Upstream of the ETM, salinity is near zero which effectively removes this term from the equation in this section of the river which generally has lower levels of suspended solids than the ETM. These patterns allowed us to use salinity as a surrogate for suspended solids in the predictive model.

Scattering driven by suspended solids at the ETM controls light extinction dynamics in this portion of the Estuary and masks the effects self-shading and dissolved organic carbon. Because of this, DRBC developed a unique methodology to spatially derive coefficients and intercepts depending on location throughout the Estuary. Coefficients for the various parameters were parametrized using data from the following sections of river:

- The salinity coefficient (as a surrogate for suspended solids) was parameterized using data downstream of river mile 35 (the lower extent of the ETM) and resulted in a value of -0.097,
- The chlorophyll a and DOC coefficients were parameters from data only in areas where they would be expected to have a meaningful effect on K_e (i.e., upstream and downstream of the ETM, < river mile 35 and > river mile 80) and resulted in values of 0.014 and 0.345 respectively.

The above methodology results in the following equation to predict K_e:

$$K_e = K_{e\_int} + (0.014 \times Chla) + (0.345 \times DOC) - (0.097 \times Salinity)$$

This methodology does not use data from within the ETM to parametrize any of the coefficients due to the overwhelming effect of suspended solids in this part of the Estuary. To counteract this and better capture high K_e values in the ETM we also used a spatially unique strategy to calculate intercepts (K_{e_int} in the above equation). At each Boat Run station, a unique intercept was calculated. First, chlorophyll, DOC, and salinity were used to predict K_e for each sample in the dataset and a unique intercept representing the difference between observed K_e and the predicted K_e was calculated representing the amount of K_e unexplained by these parameters. These sample-specific intercepts were than averaged by Boat Run station to calculate site-specific intercepts (Figure 3). The addition of these spatially variable intercepts helps capture the high K_e values that occur in the ETM. Curves were then fit to the site-specific intercepts to allow for prediction of a unique intercept at any river mile in the estuary. An exponential fit was used outside of the ETM while a linear fit was used within the ETM (Figure 4) resulting in the following equation for K_{e_int}.

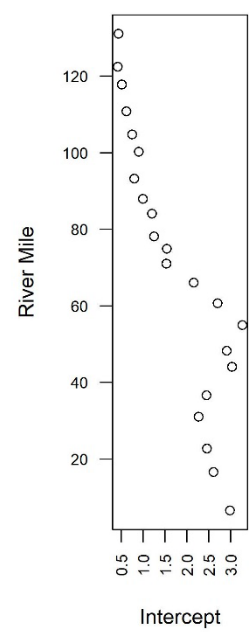


Figure J-3. Site specific intercepts calculated for prediction of K_e.

$$K_{e\_int}\ as\ f(RM) = 3.5944 \times e^{(-0.016*RM)} + Max\left[0, \left(1.7549 - 0.069 \times ABS(54.9 - RM)\right)\right]$$

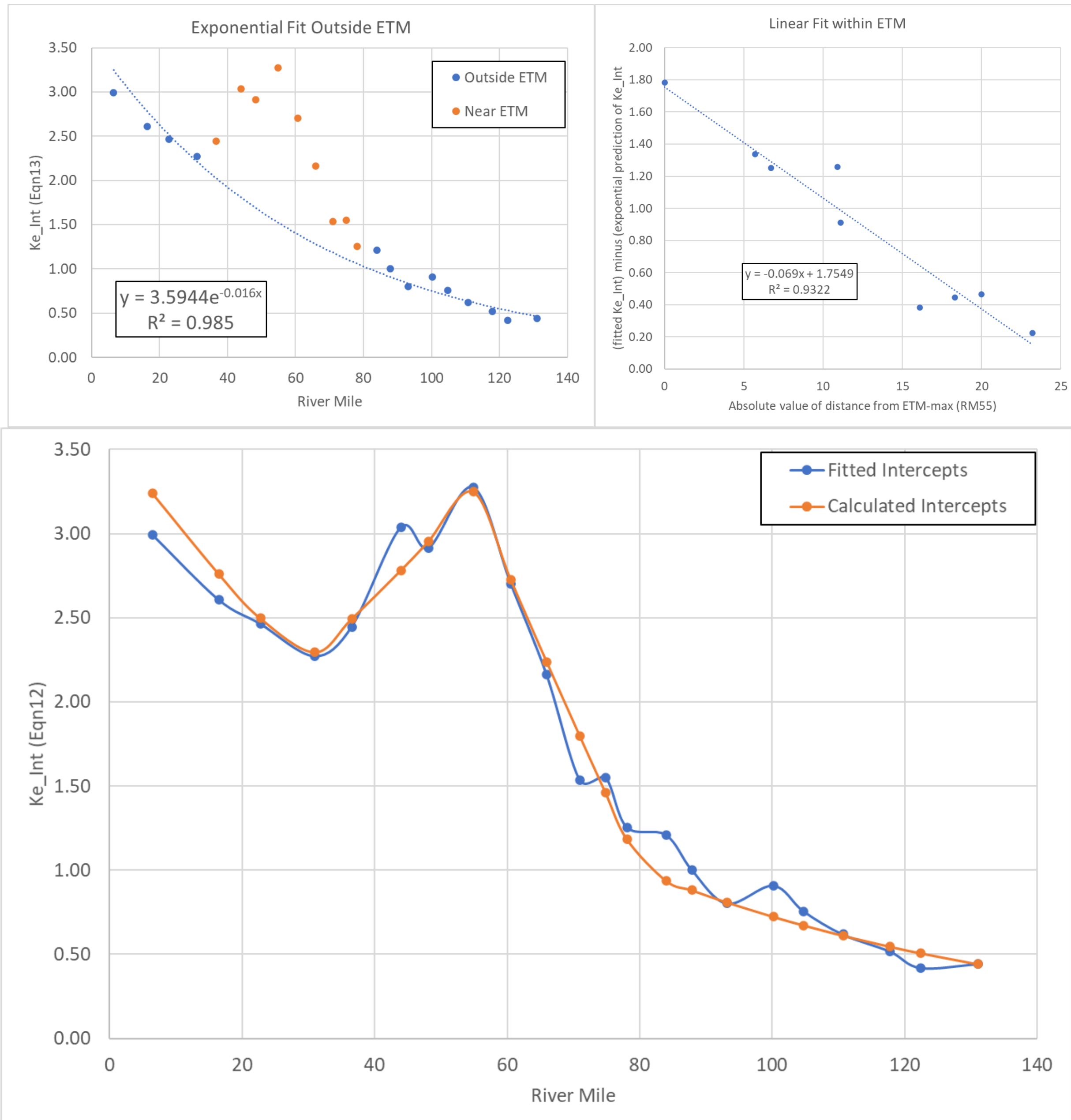


Figure J-4. Curve fitting to predict site-specific intercepts by river mile. Top panels show exponential fit to data outside ETM and linear fit to data within ETM. Bottom panel shows fitted vs calculated intercepts. Regression of fitted vs calculated intercepts results in R^2 = 0.9829.

In summary, the above methodology allows DRBC to derive K_e estimates from model state variables by leveraging spatially unique relationships between state variables and K_e as well as spatially unique intercepts. Diagnostic plots show fit of predicted K_e values against observed values (Figures 5 and 6).

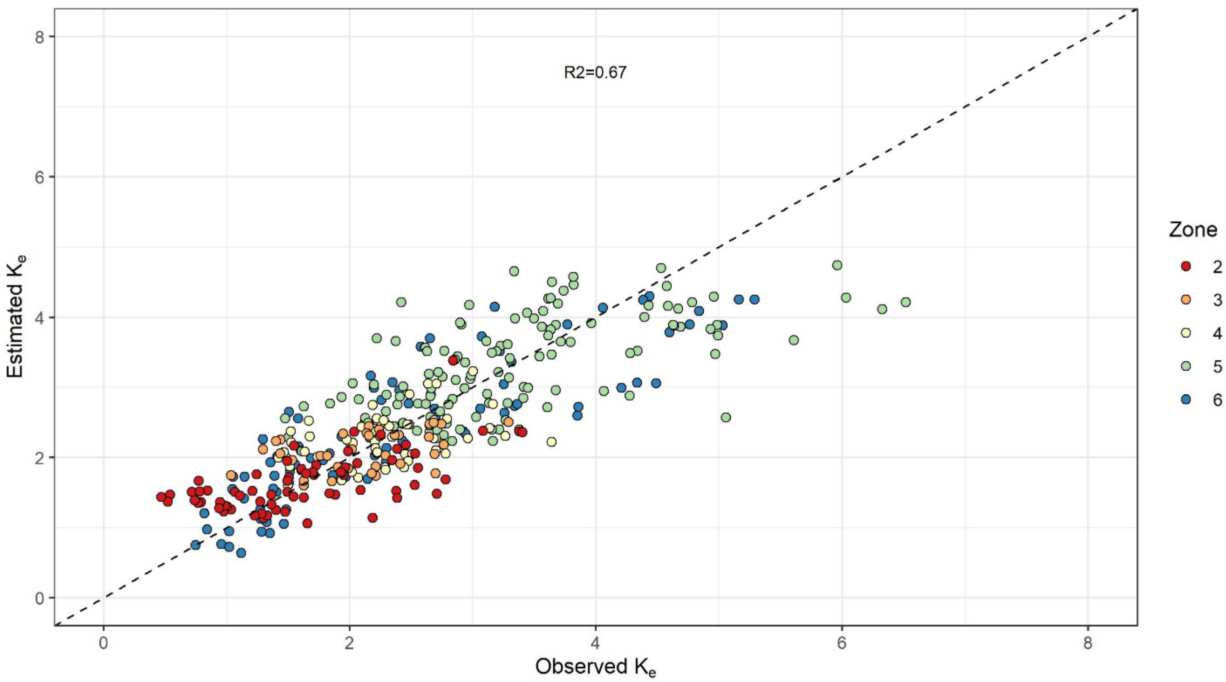
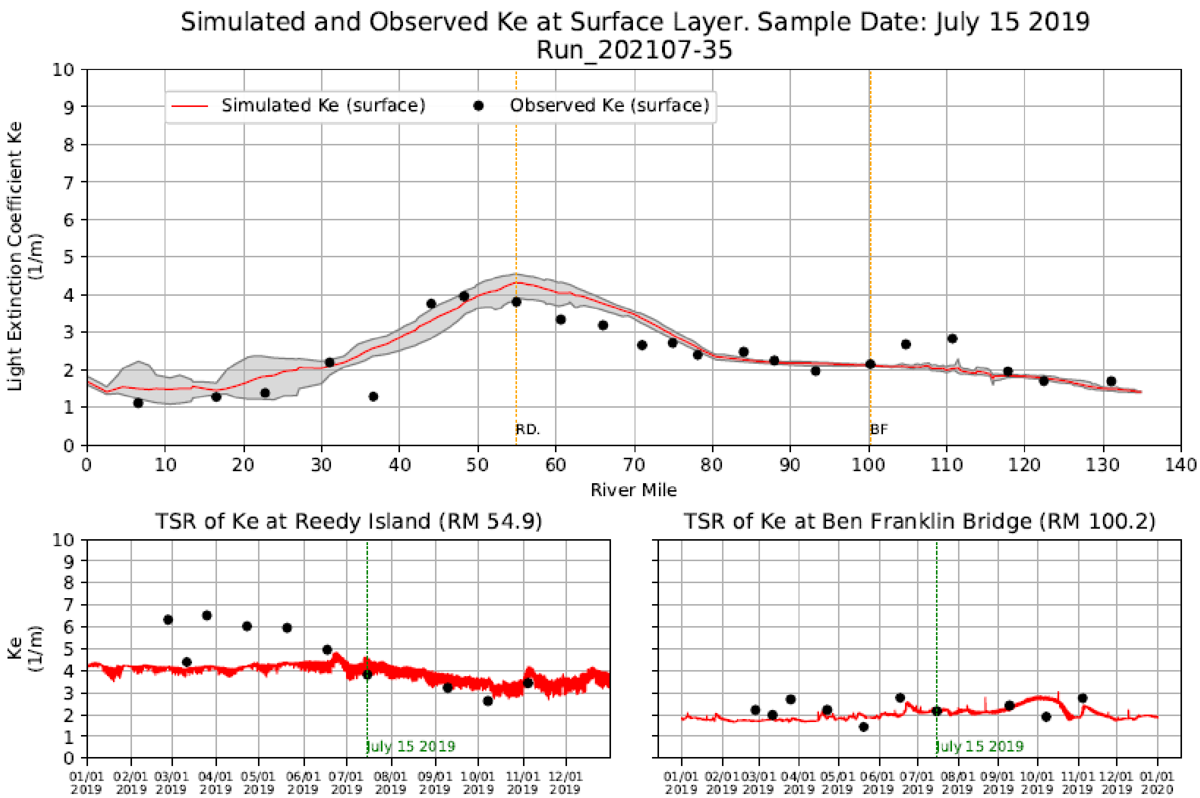


Figure J-5. One-to-one plot showing observed vs estimated K_e



Simulated and Observed Light Extinction Coefficient Ke
Model results from 07/15/2019 were used in this analysis.

Figure J-6. Example observed vs. estimated K_e in the eutrophication model