MODELING SUSPENDED SEDIMENT AND WATER TEMPERATURE DETROIT LAKE, OREGON

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Abstract: A water temperature and suspended sediment model of Detroit Lake, Oregon was constructed with CE-QUAL-W2 for 2002 and 2003. Input data for the model included lake bathymetry, meteorology, lake outflows, and tributary inflows, water temperature, suspended sediment concentration and total dissolved solids. An important model parameter is the light extinction coefficient. It is affected by suspended sediment in the lake and in turn affects water temperature and the lake heat budget. Three different methods of determining the light extinction coefficient for Detroit Lake are compared; one is derived from light meter measurements taken through the water column, the other two are based on measured Secchi depths. These data were collected at three sites in Detroit Lake at approximately three week intervals from April 2002 through October 2003. A seasonal variation in the light extinction coefficient was observed, with highest values in winter and lowest values in early spring and early fall. Algal blooms also produced higher light extinction coefficients in summer. Light extinction coefficients were similar between all three lake sampling sites when values were low; at higher values, there were larger differences between sites due to the heterogeneity of tributary sediment input and patchiness of algal blooms. The Secchi method, in particular the Williams et al. (1980) equation, was found to be an acceptable alternative to the light meter method for determining Detroit Lake extinction coefficients. The extinction coefficient for Detroit Lake water without suspended sediment (K_{H_2O}) was determined to be 0.21 m^{-1}.

INTRODUCTION

Detroit Lake (Figure 1) is a reservoir on the North Santiam River, 50 miles east of Salem, Oregon. The dam, a 463-foot high concrete structure, was finished in 1953, and the reservoir stores 455,000 acre-ft at full pool. It is used for recreation, flood control, irrigation, power generation and improvement of downstream navigation. The City of Salem takes its primary supply of drinking water from the North Santiam River approximately 28 miles downstream of Detroit Lake. High concentrations of suspended sediment in the river can impair the city's water filtration system, requiring the city to shut off its water intake or add coagulant during some large storms and periods of sustained high levels of turbidity in Detroit Lake. The U.S. Geological Survey has cooperated with the City of Salem since 1998 to monitor and study sediment and turbidity in the North Santiam watershed.

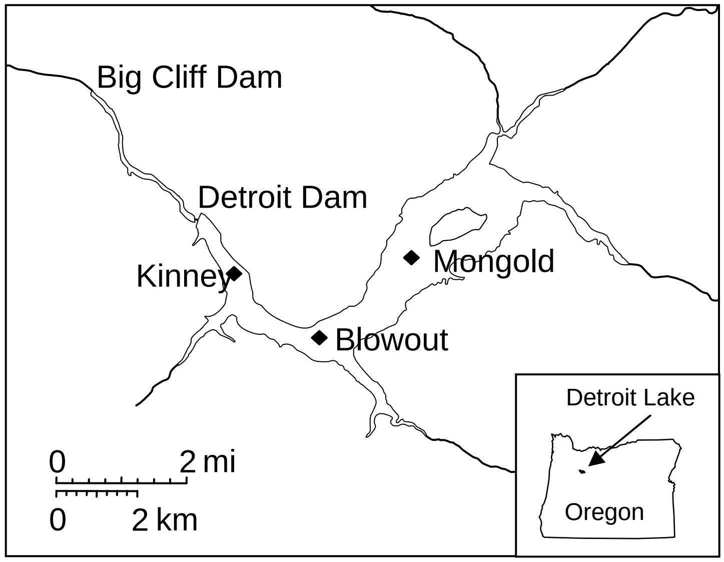

Figure 1 Map of Detroit Lake, Oregon showing the three lake sampling sites.

To help understand the transport and fate of sediment in Detroit Lake, a water temperature and suspended sediment model of the reservoir was constructed with CE-QUAL-W2 version 3.12, a two-dimensional, laterally averaged, hydrodynamic and water-quality model from the U.S. Army Corps of Engineers. Input data for the model included lake bathymetry, meteorology, lake outflows, tributary inflows, and tributary water temperature, suspended sediment and total dissolved solids. Suspended sediment in the tributary inflows was divided into three size classes, based on turbidity-suspended sediment relations developed in Uhrich and Bragg (2003).

One important parameter in reservoir temperature and sediment models is the light extinction coefficient, a measure of how light is attenuated through the water column. Higher light extinction coefficients mean that there is less light transmitted or that the water is less transparent. The coefficient is affected by suspended sediment and other dissolved and particulate materials in the water column, and in turn affects the heat budget and water temperatures. A low light extinction coefficient allows light to penetrate into deeper water, and less heat is lost in surface exchange. With higher light extinction coefficients, lake surface temperatures increase, deep waters stay cooler, the depth of the mixed layer decreases, and the total heat content of a lake decreases (Hocking and Straskraba, 1999).

There are several approaches to determining the light extinction coefficient. For Detroit Lake, the light extinction coefficient was determined by three methods: one method using a light meter, the other two using a Secchi disk. The light meter method is generally considered more accurate, but Secchi disk methods use less expensive equipment and only require one measurement versus many for the light meter method. In this paper, we compare results from the three methods and examine the seasonal and spatial variation in light extinction coefficients in Detroit Lake from April 2002 through October 2003.

METHODS

<u>Data Collection:</u> Measurements of light intensity in the water column as well as Secchi depths were part of the USGS monitoring program of Detroit Lake from April 2002 through October 2003, and were collected approximately every three weeks. Measurements were made from a boat at three sites in Detroit Lake: Mongold, Blowout, and Kinney (Figure 1).

Light meter measurements were made with a Licor LI-193SA spherical quantum sensor. A light intensity reading was first taken at the surface, then the instrument was lowered through the water column and readings were taken at approximately 1 m intervals until the readings were very low and constant. An example light profile is shown in Figure 2.

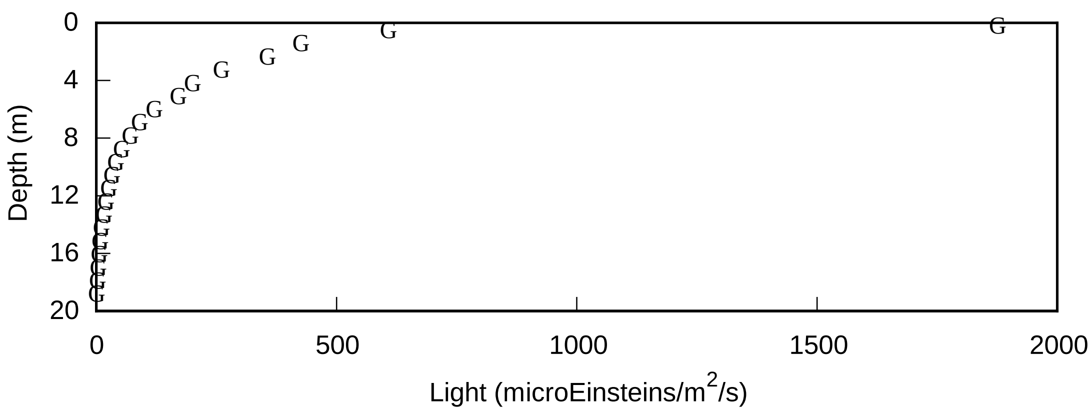

Figure 2 Light profile measured at Kinney in Detroit Lake on May 28, 2003.

Secchi depths were determined by lowering a metal Secchi disk with black and white quadrants into the water and noting the deepest depth at which it could still be distinguished. Typically, multiple measurements were taken and averaged.

<u>Calculation of Light Extinction Coefficients</u> Using light meter data, light extinction coefficients were calculated with the Beer-Lambert law:

$$I_z = I_o e^{-Kz} \tag{1}$$

or

$$\ln\left(\frac{I_z}{I_o}\right) = -Kz \tag{2}$$

where

I_z = light intensity at depth z

I_o = light intensity at water surface

K = extinction coefficient (m^{-1})

z = water depth measured from surface (m)

Using Secchi depth data, light extinction coefficients can be calculated with several equations. Two of these equations were applied to the Detroit Lake data. One commonly applied method is the Poole and Atkins equation (Poole and Atkins, 1929; Isdo and Gilbert, 1974):

$$K = \frac{1.7}{z_S} \tag{3}$$

where

z_S = Secchi depth

The other Secchi depth equation, referenced by the CE-QUAL-W2 manual, is by Williams et al. (1980):

$$K = \frac{1.1}{z_S^{0.73}} \tag{4}$$

All three of these methods calculate a light extinction coefficient that considers together the effect of all constituents (dissolved constituents, algae, suspended solids) that affect light extinction. The model CE-QUAL-W2 separates out these constituents as follows:

$$K = K_{H_2O} + K_{ISS} + K_{POM} + K_a \tag{5}$$

where

K_{H_2O} = extinction from water and dissolved constituents
K_{ISS} = extinction from inorganic suspended sediments
K_{POM} = extinction from suspended particulate organic matter
K_a = extinction from algae

To determine K_{H_2O} for Detroit Lake, a regression was calculated between light extinction coefficients and suspended sediment concentration (which includes inorganic suspended sediment, particulate organic matter and algae) in the top 10 m of the water column; K_{H_2O} is the extinction coefficient when suspended sediment concentration is zero. Measured suspended sediment concentration was determined from detailed turbidity profiles taken at the same time as light measurements, and regressions between suspended sediment and turbidity in Detroit Lake.

RESULTS

Results from the light meter method for the three Detroit Lake sites are shown in Figure 3. Light extinction coefficients were highest in December through February when winter storms brought suspended material into the lake. There were also some higher extinction coefficients in summer, probably due to algal blooms. Dissolved oxygen and pH profiles provided additional evidence for algal blooms in Detroit Lake at that time of year. The lowest light extinction coefficients occurred in late spring and early fall. When light extinction coefficients were low, there was very little difference in coefficients between sites. When light extinction coefficients were higher, there were greater differences between the three sites in Detroit Lake, probably due to the spatial heterogeneity of sediment input from tributaries and patchiness of algal blooms.

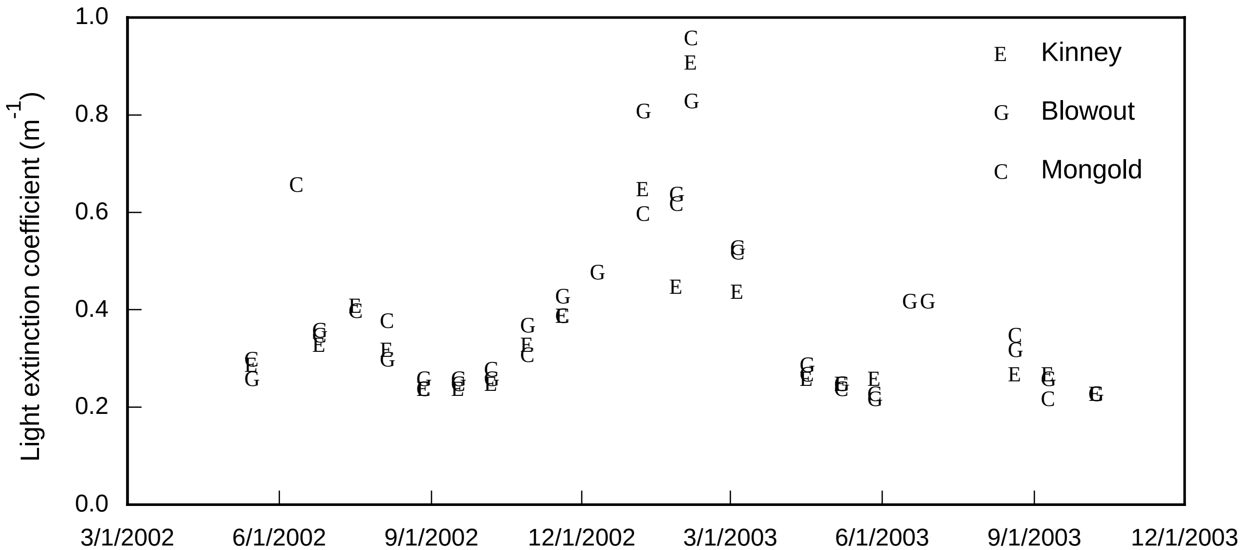

Figure 3 Light extinction coefficients at Detroit Lake sites using the light meter method.

Results of the Secchi methods were compared to results from the light meter (Figure 4) for the same date and location. At low values of the light extinction coefficient, both Secchi methods produced light extinction values close to those determined by the light meter method. At higher extinctions, the Williams et al. (1980) method produced values closer to those of the light meter method.

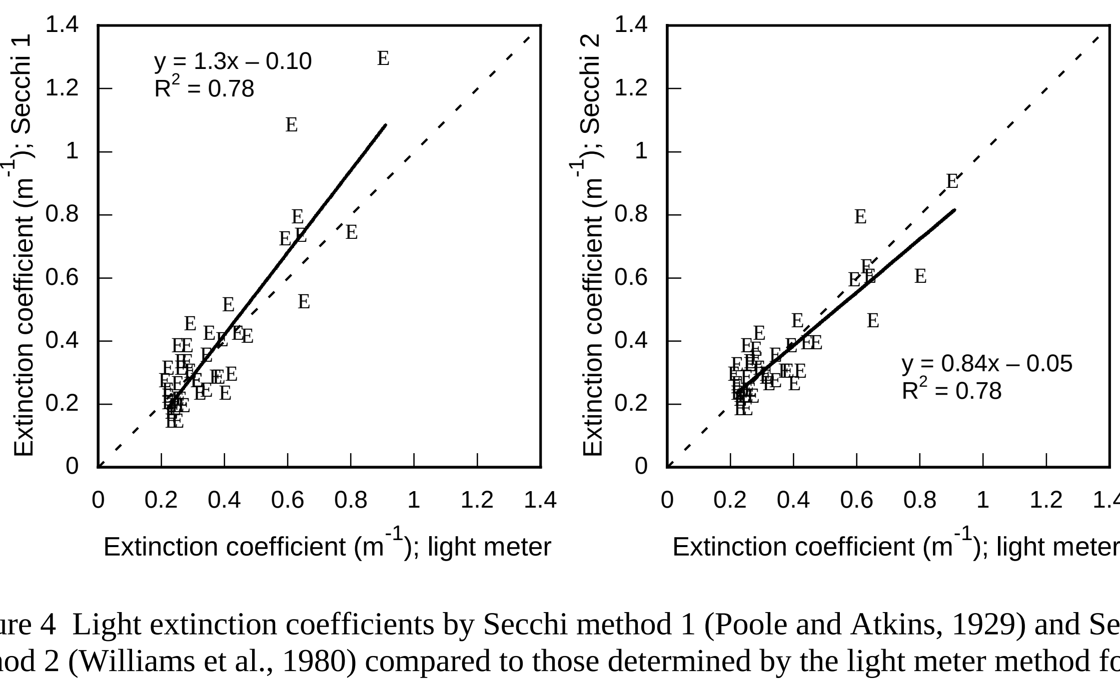

Figure 4 Light extinction coefficients by Secchi method 1 (Poole and Atkins, 1929) and Secchi method 2 (Williams et al., 1980) compared to those determined by the light meter method for the same date and location in Detroit Lake. The dashed line represents a one-to-one ratio.

The extinction coefficient for water, K_{H_2O}, was determined to be 0.21, 0.15, and 0.22 m^{-1} with the light meter, Poole and Atkins (1929), and Williams et al. (1980) methods, respectively. The extinction coefficients for the Williams et al. (1980) Secchi method and the light meter method were most similar.

SUMMARY

Light extinction coefficients are affected by suspended sediment and are critical for modeling water temperature in lakes. Light extinction coefficients in Detroit Lake were highest in winter due to tributary sediment input during storms, and also high during summer algal blooms. Low extinction coefficients were present in Detroit Lake in early spring and early fall. Light extinction coefficients were determined by three methods for purposes of comparison. The light meter method is generally thought to be most accurate, but the Secchi method, especially using the Williams et al. (1980) equation, was found to be an acceptable surrogate for the light meter method in Detroit Lake, and could be used if, for example, equipment or time was scarce. The extinction coefficient for water, 0.21 m^{-1} determined by the light meter method, was used in Detroit Lake water temperature and suspended sediment modeling.

ACKNOWLEDGEMENTS

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