ON THE UNIVERSALITY OF THE POOLE AND ATKINS SECCHI DISK–LIGHT EXTINCTION EQUATION*

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INTRODUCTION

The solar radiation passing downwards at depth Z in a body of water is classically described by the equation

$$I_Z = I_O\, e^{-KZ} \tag{1}$$

where I_O is the irradiance just beneath the water surface and K is an extinction coefficient. Where instrumentation has not been available to measure I_Z directly, it has often been calculated from eqn (1) with K values obtained from correlations with Secchi disk depth, Z_{SD}.

Poole & Atkins (1929) developed one of the earliest such formulations:

$$K = \frac{1{\cdot}7}{Z_{SD}} \tag{2}$$

Recently, however, this equation has been questioned and alternatives proposed (Graham 1966; Holmes 1970). The data used in these attempts to improve upon eqn (2) have spanned the range of turbid to clear ocean water ($1{\cdot}9\ \text{m} \leq Z_{SD} \leq 35\ \text{m}$). In this paper we present K and Z_{SD} measurements made in turbid desert ponds over the Secchi disk depth range to a lower limit of 0·09 m. A more comprehensive evaluation is then made of eqn (2).

EXPERIMENT

On 26 clear days during the year April 1971 to March 1972, K and Z_{SD} measurements were made in a small man-made pond filled with renovated sewage water of the Flushing Meadows reclamation project at Phoenix, Arizona (Bouwer 1970). The Z_{SD} measurements were made with a 20-cm-diameter Secchi disk observed from above the surface without a submersible viewer. The K determinations were made from incoming and reflected solar radiation measurements above the water surface and irradiance measurements beneath the surface. The first two of these measurements were obtained from an upright Eppley pyranometer and an inverted Kipp solarimeter, respectively, while the underwater measurements were made with the thermopile radiometer described by Idso (1972).

The K determinations were made from these measurements as follows. On several of the clear days detailed profiles were obtained for the irradiance at depth increments of

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the order of 5–10 cm. These profiles all gave exact exponential extinction rates which indicated a surface absorption of the net solar radiation of 48%. Thus, K was routinely calculated as

$$K = \frac{\ln[0{\cdot}52(I\downarrow - I\uparrow)] - \ln(I_{0{\cdot}2})}{0{\cdot}2\ \text{m}} \tag{3}$$

where $I\downarrow$ and $I\uparrow$ were the daily totals of incoming and reflected solar radiation, respectively, and $I_{0{\cdot}2}$ was the daily total downward solar radiation flux measured at 20 cm depth.

RESULTS AND DISCUSSION

The results of our determinations of K and Z_{SD} at Flushing Meadows are plotted on a log-log scale in Fig. 1, along with data of the three studies previously cited, plus a few

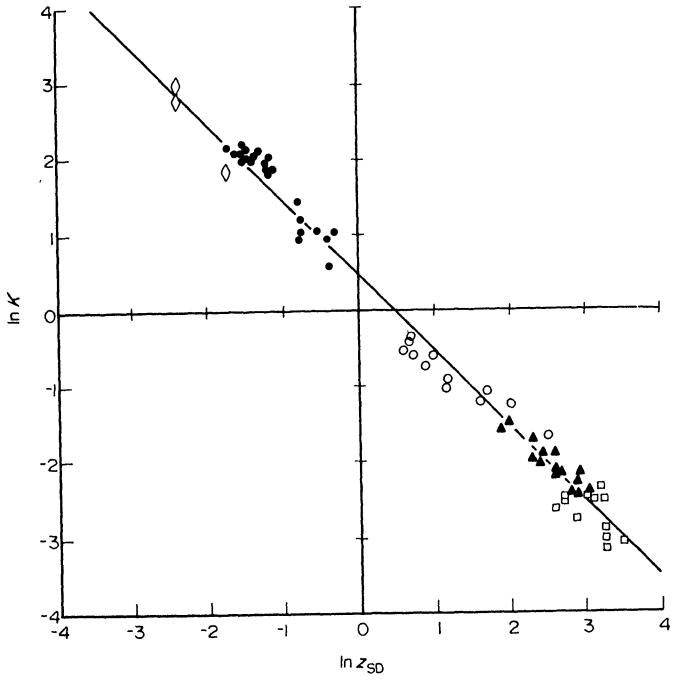
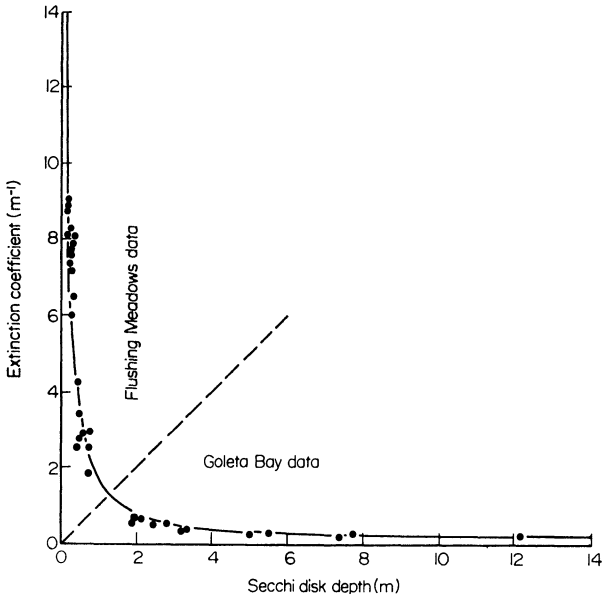


FIG. 1. Natural logarithm of light extinction coefficient in m^{-1} plotted as a function of the natural logarithm of Secchi disk depth in m. ●, Flushing Meadows; ◇, Little Triste Pond; ▲, Poole & Atkins (1929); □, Graham (1966); ○, Holmes (1970).

measurements in a second desert pond supplied by Professor G. A. Cole (personal communication). The solid line is a similar representation of Poole and Atkins' original equation (2). It is readily observed that this equation successfully fits the data over the entire turbidity range ($0{\cdot}09\ \text{m} \leq Z_{SD} \leq 35$ m). Indeed, a linear regression run upon the K predictions of eqn (2) and the actual measurements of K derived from the combined data used in constructing Fig. 1 yields a slope of 1·02 and correlation coefficient of 0·99.

This shows that the Poole and Atkins (1929) equation is completely general and may serve as a universal relation between K and Z_{SD} in naturally occurring waters of all degrees of turbidity. When eqn (2) is plotted as in Fig. 2, however, it is noted that



FIG, 2. Extinction coefficient plotted as a function of Secchi disk depth for the data of Holmes (1970) in Goleta Bay and our data from Flushing Meadows. The solid line is a plot of eqn (2).

although the predictions from the equation and the measured data do agree equally well along both arms of the hyperbola, there is a greater possibility for error as large turbidities are approached, due to the almost vertical aspect of the plot of eqn (2) as the origin is approached. Nevertheless, the Poole and Atkins equation does possess a universality that should provide a sufficiently accurate estimate of light extinction in all types of water for many biological studies lacking detailed light profile measurements.

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