Secchi Depth and HydroLight

Curtis Mobley **12 Nov 2004**

Several users of HydroLight have requested that HydroLight output the Secchi depth, z_{SD}. I have therefore added a routine to compute z_{SD} whenever the HydroLight run covers at least the visible wavelengths 400-700 nm. These notes outline the computations and give a few warnings for the user.

The HydroLight Secchi depth calculations are based on the definitive article on this topic, "Secchi disk science: Visual optics of natural waters" by R. W. Preisendorfer, *Limnol. Oceanogr*. 31(5), 909-926, 1986 (referenced as RWP below. As a poignant aside, this was Rudy's last paper, which I sent to L&O after his death.). This article *must* be read and understood by anyone wishing to make or interpret Secchi depth measurements.

The Secchi depth is given by RWP Eq. (55):

$$z_{SD} = \frac{\Gamma}{\alpha + K} \qquad [\mathrm{m}] \qquad \text{(RWP.55)}$$

Here α is the depth average over 0 to z_{SD} of the *photopic* beam attenuation coefficient, which is computed from the beam attenuation coefficient $c(z,\lambda)$ as follows. The depth-dependent $\alpha(z)$ is given by RWP Eq. (21) [in the modern notation of *Light and Water*, referenced as L&W]

$$\alpha(z) = \frac{\int_\Lambda L_u(z,\lambda)\, c(z,\lambda)\, \bar{y}(\lambda)\, d\lambda}{\int_\Lambda L_u(z,\lambda)\, \bar{y}(\lambda)\, d\lambda} \qquad [\mathrm{m}^{-1}] \qquad \text{(RWP.21)}$$

where $\bar{y}(\lambda)$ is the photopic luminosity function [L&W Table 2.1]. The upwelling radiance L_u is used in (RWP.21) on the assumption that we are looking straight down through the water to see the Secchi disk. The depth-averaged $\alpha(z)$ is then given by

$$\alpha = \frac{1}{z_{SD}} \int_0^{z_{SD}} \alpha(z)\, dz\,. \qquad \text{(RWP.46b)}$$

The downwelling plane illuminance E_{dv} is computed from the downwelling plane irradiance $E_d(z,\lambda)$ by RWP Eq. (15) or L&W Eq. (2.7):

$$E_{dv}(z) = \int_\Lambda E_d(z,\lambda)\, K_m\, \bar{y}(\lambda)\, d\lambda\,, \qquad [\mathrm{lumen\ m}^{-2}] \qquad \text{(RWP.15)}$$

where K_m = 683 lumen/Watt. K, depth-averaged diffuse attenuation function for the illuminance, is then given by RWP Eq. (38), which is equivalent to

$$K = -\frac{1}{z_{SD}} \ln\left[\frac{E_{dv}(z_{SD})}{E_{dv}(0)}\right] \qquad [\mathrm{m}^{-1}] \qquad \text{(RWP.38)}$$

Finally, Γ is the coupling constant, to be discussed below. The integrals over wavelength should, in principle, be performed over 380-770 nm, although 400-700 gives acceptable accuracy.

Note that it is not possible to use these equations as they stand to compute z_{SD} because RWP.46b and RWP.38 cannot be evaluated until z_{SD} is known. We therefore proceed as follows. The value of α at the surface, i.e. at depth z = 0, and the value of K as obtained from E_{dv} at depth 0 and at the first depth of the HydroLight printout are used in RWP.55 to obtain a first estimate for z_{SD}. Equations RWP.46b and RWP.38 are then used to compute the depth-averaged α and K for the initial estimate of z_{SD}. These depth averaged values are then used in RWP.55 to obtain an updated estimate of z_{SD}, and new α and K are computed. This process is repeated until z_{SD} changes by less than some ϵ (taken to be 0.01) between iterations. If the H run does not go at least as deep as z_{SD}, then the initial estimate based on the near-surface α and K is given in the output, along with a warning that the H run needs to be repeated with a deeper output depth. The details can be seen in subroutine Secchi on file Secchi.f.

It should be noted that the final value of z_{SD} will depend slightly on the wavelength and depth resolution of the HydroLight run, since the wavelength integrations of RWP.21 and RWP.15, as well as the depth integrations, use linear interpolations of values at the available wavelengths and depths. These resolution effects have not been studied in any detail.

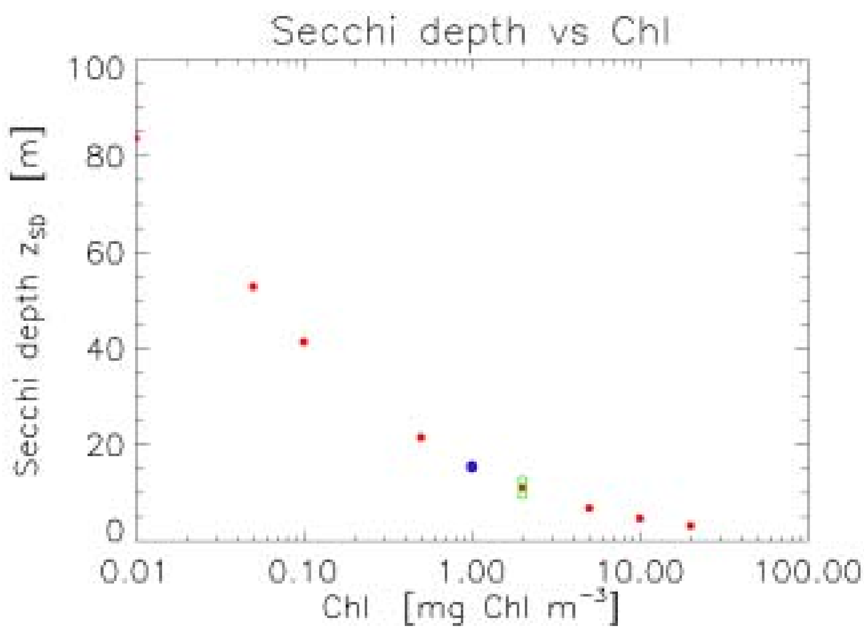
As explained in RWP, the coupling constant Γ depends on factors such as the *photopic* reflectance of the Secchi disk, the *photopic* reflectance of the water, the observer's visual acuity, and sea surface effects. RWP Table 2 shows Γ values from less than 6 to more than 9. However, for many instances, Γ varies from 7 to 9, with 8 being a reasonable guess for typical observing conditions and a disk of 85% photopic reflectance in water of 2% photopic reflectance. The code therefore uses $\Gamma = 8$ as the default. The Γ value is easily changed in Secchi.f.

Because of the uncertainties in Γ and all of the other uncontrolled variables inherent in Secchi depth measurements (the observer's eyesight, surface effects, the seldom (if ever!) measured photopic reflectances of the disk and the water, etc.), only the most naive would consider z_{SD} to be a meaningful quantity of better than, perhaps, ±10% accuracy for a given observer, or between observers. I would not be surprised if HydroLight-computed z_{SD} values disagree with actual observations by a larger factor, even if the IOPs are known accurately for input to the HydroLight run. However, I do not have any data that allow comparison of HydroLight-predicted and measured z_{SD} values for various IOPs and observation conditions.

Figure 1 shows the HydroLight-predicted z_{SD} as a function of the chlorophyll concentration *Chl*, as computed using

- the HydroLight "classic" IOP model for Case 1 waters
- the particle backscatter fraction is $b_b/b = 0.01$
- no surface effects (script T = 1 in RWP), i.e. the observer is viewing the disk from just below the surface
- sun at 30 deg zenith angle, clear sky, wind = 5 m/s
- the HydroLight run was 400-700 nm, with various depth resolutions for the different *Chl* cases

The red dots are for $\Gamma = 8$ and the conditions listed above. The blue circles for *Chl* = 1 show the range of z_{SD} obtained for b_b/b = 0.005 to 0.020. The green circles for *Chl* = 2 show the range z_{SD} for Γ = 7 and 9. I shall leave it to the interested HydroLight user to further investigate the dependence of z_{SD} on water composition and observation conditions.



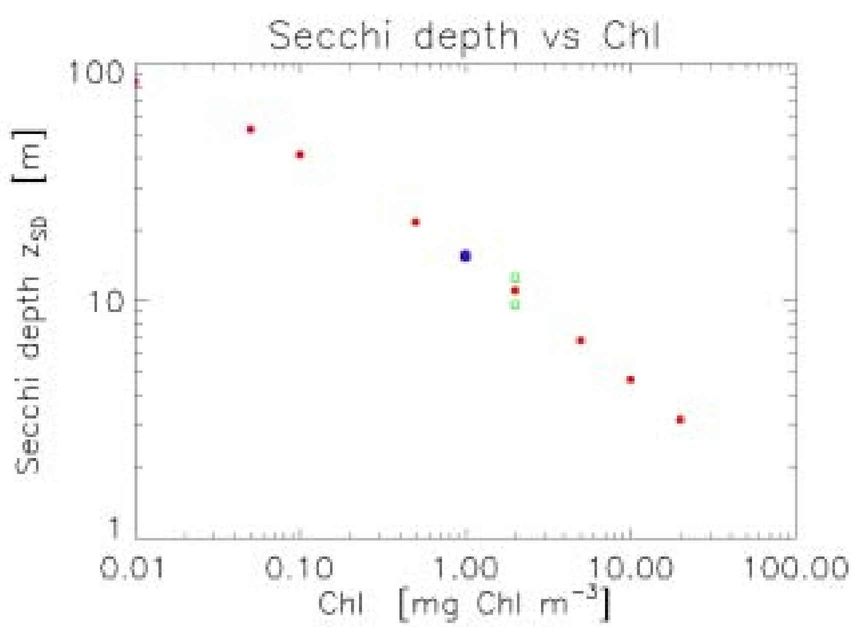


Fig. 1. HydroLight-computed Secchi depth as a function of chlorophyll concentration for Case 1 water.