The Light Module

1. Solar Radiation

Solar radiation delivers a spectrum of light differentially propagated through the water column. WASP8 considers wavelengths from ultraviolet through infrared, divided into discrete wavebands. These wavebands drive various processes important to water quality:

- Heat balance
- Algal growth
- Chemical photolysis
- Nanochemical photolysis
- Bacterial death

Total solar radiation is divided into three broad classes:

Table 1. Total solar radiation divided into wave classes

Wave Class	Color	Wavelengths, nm	Fraction of Total
1	ultraviolet	295 – 379	0.036
2	visible	380 – 724	0.464
3	infrared	725 – 2500	0.500

These three classes are used in the heat balance equations in the WASP8 Temperature module, and in the bacterial death equations in the Eutrophication and Toxicant modules. Visible light is equated to photosynthetically active radiation (PAR), which is used in the Eutrophication module to drive algal growth.

Ultraviolet and visible solar radiation are further divided into 10 wavebands: These wavebands are used to drive the chemical and nanochemical photolysis equations in the WASP8 Toxicant module. Table 2 summarizes how WASP divides solar radiation into ultraviolet, visible, and infrared wave bands, with fractions of the total radiation by latitude.

Table 2. Ultraviolet and visible wavebands, with fractions by latitude

Index	Color	Wavelength [nm]	Latitude						
			0° N	10° N	20° N	30° N	40° N	50° N	60° N
1	uVb med	295 – 304	0.00015	0.00015	0.00013	0.00011	0.00008	0.00006	0.00004
2	uVb high	305 – 314	0.00142	0.00139	0.00132	0.00120	0.00104	0.00085	0.00067
3	uVa low	315 – 334	0.00845	0.00839	0.00825	0.00801	0.00766	0.00721	0.00681
4	uVa med	335 – 354	0.01141	0.01137	0.01126	0.01108	0.01082	0.01052	0.01054
5	uVa high	355 – 379	0.01723	0.01718	0.01706	0.01686	0.01655	0.01619	0.01630
6	violet	380 – 449	0.07626	0.07617	0.07593	0.07550	0.07482	0.07394	0.07443

7	blue	450 – 494	0.06664	0.06663	0.06659	0.06652	0.06639	0.06616	0.06644
8	green	495 – 569	0.10386	0.10388	0.10394	0.10402	0.10406	0.10390	0.10285
9	yellow-orange	570 – 619	0.06546	0.06549	0.06556	0.06566	0.06576	0.06568	0.06422
10	red	620 – 749	0.14914	0.14934	0.14995	0.15106	0.15282	0.15550	0.15769

WASP determines the fraction of total radiation in each waveband for a specified latitude by interpolation. Each waveband is attenuated separately through the water column as discussed in Section 4. Photochemical reactions are driven by these discrete wavebands, with different rate constants assigned for each.

WASP8 uses time series of total radiation along with waveband fractions to deliver solar radiation to the water surface. The total radiation can be input by the user or calculated internally by the model. The waveband fractions can be specified or default values.

2. Input Total Radiation

There are two options to specify total solar radiation reaching the water surface – user input light and internally-calculated diel light. This option is specified in the Constants section, Light group. The default is 0, Calculated diel light.

Option 0, Calculated diel light
Light option 0 is driven by internally-calculated light based on latitude, longitude, day of year, and time of day. The latitude and longitude of the water body are input in the Constants section, General group. The simulation day and time are kept internally based on the simulation start day and time and the calculation time step. Calculated light represents clear sky radiation, I_{clear}, in W/m^2.

Option 1, User input diel light
Light option 1 is driven by up to 4 specified time series of hourly (or less) surface light fluxes. WASP8 assumes that these input functions represent the total spectrum of solar radiation [W/m^2]. Each time step, the model reads the total radiation and applies this total to each surface segment.

The appropriate solar radiation time function for each segment (1 – 4) is specified in the Parameter Data section, Environmental group. The solar radiation time functions are entered in the Time Functions section. If the data represent a fraction of the total (i.e., visible or PAR light) or if the data are expressed in alternate units, then the user must enter an appropriate scale factor in the "Solar Radiation Multiplier [unitless or watts/m2]" located in the Parameter Data section, Environmental group. To convert from PAR light to total radiation, the multiplier should be 2.155.

Option 2, User input daily light, calculated diel light
Total daily light flux – Light option 2 is driven by up to 4 specified time series of total daily surface light fluxes [W/m^2]. Each new simulation day, the model reads the total

daily radiation for that day, I_{Tot}. Each time step through the diel cycle, the model calculates and applies a portion of the daily total radiation to each surface segment.

The appropriate solar radiation time function for each segment (1 – 4) is specified in the Parameter Data section, Environmental group. The solar radiation time functions are entered in the Time Functions section. If the data are expressed in alternate units, then the user must enter an appropriate scale factor in the "Solar Radiation Multiplier [unitless or watts/m2]" located in the Parameter Data section, Environmental group.

Default diel light distribution – The default diel cycle is based on latitude, longitude, day of year, and time of day. The model calculates the total clear-sky radiation for the day ($I_{ClearDay}$), and the clear sky radiation for each time step through the day ($I_{ClearSky}$). The instantaneous solar radiation flux is the input total daily flux (I_{Tot}) times the diel ratio for that time step:

$$I = I_{Tot} (I_{ClearSky} / I_{ClearDay})$$

The latitude and longitude of the water body are input in the Constants section, General group. The simulation day and time are kept internally based on the simulation start day and time and the calculation time step.

Alternate diel light distribution – An alternative user-controlled diel option is applied if a daylight fraction time function f_{day} is specified. In this case, the total daily radiation is distributed through daylight hours (between dawn and dusk) using a half-sine curve with a maximum value at noon.

$$I_{max} = I_{tot} \pi / (2 f_{day})$$

$$I = I_{max} \sin(\pi \tau_{day})$$

where I_{tot} is the total daily radiation [W/m^2], f_{day} is the fraction of day that is daylight (0.2 – 0.8) and τ_{day} is normalized time between sunrise and sunset, expressed as fraction of the daylight interval. Sunrise is 0, noon is 0.5, and sunset is 0. I is 0 during nighttime hours.

The "Fraction Daily Light (fraction)" is input in the Time Functions section. The simulation day and time are kept internally based on the simulation start day and time and the calculation time step.

3. Light Attenuation Above Water Surface

Input solar radiation can be attenuated by cloud cover, canopy shading, ice cover, and water surface reflectance.

Cloud cover – Internally-generated light (Option 1) represents clear sky radiation, and must be attenuated by user-specified cloud cover [fraction of sky].

$$I = I_{clear} * 0.65 * Cloud^2$$

The appropriate cloud cover time function for each segment (1 – 4) is specified in the Parameter Data section, Environmental group. The cloud cover time functions (0 – 1) are entered in the Time Functions section.

Canopy shading – Near surface light can be diminished by vegetative shading. Light beneath the canopy must be attenuated by user-specified vegetative shading [fraction of light intercepted].

$$I_s = I * (1 - Shade)$$

The appropriate canopy shading time function for each segment (1 – 4) is specified in the Parameter Data section, Environmental group. The canopy shading time functions (0 – 1) are entered in the Time Functions section.

Water surface reflectance – A fraction of light reaching the water surface, I_s, is reflected. Light at the top of the water column, I_0, is reduced by the fraction of light reflected:

$$I_0 = I_s * (1 - \beta_w)$$

The default reflectance is 0.06. The user can input an alternate value in the Constants section, Light group.

Attenuation in ice – When ice forms on the water surface, the surface light, I_s, is attenuated by reflectance of the ice surface (albedo), absorption by the surface (β_i), and light extinction through the ice thickness, h_i.

$$I_0 = I_s * (1 - albedo) * (1 - \beta_i) * exp(-\gamma_i h_i)$$

The default values for albedo, surface absorption, and ice extinction coefficient (γ_i) are 0. The user must input appropriate values in the Constants section, Water temperature group.

Surface ice cover fractions can be input in the Parameter Data section, Environmental group and the Time function group. Together, these inputs give the fraction surface areas covered by ice.

$$F_{ice} = SG_{ice} * TF_{ice}$$

Ice thickness is calculated by the temperature module. If water temperature and ice are not being simulated, then the "Minimum ice thickness before ice formation is allowed" is applied as an average thickness. This is input in the Constants section, General group.

4. Light Attenuation through Water Column

Within the water column, light is attenuated with depth following the Beer-Lambert equation:

$$I_z = I_0 * exp(-K_{e\lambda} z)$$

Where $K_{e\lambda}$ is the light extinction coefficient [1/m], λ is the wavelength index, and z is depth below the surface [m].

The light extinction coefficients are calculated internally as a function of background water, algal chlorophyll *a*, DOC, and solids:

$$K_{e\lambda} = K_{w\lambda} + K_{chl,\lambda} \times Chl^{exp,\lambda} + K_{DOC,\lambda} \times DOC + K_{solid,\lambda} \times TSS$$

Where Chl is algal chlorophyll [ug/L], DOC is total dissolved organic carbon [mg/L], and TSS is total suspended solids [mg/L]. In the toxics module, DOC fractions are simulated as state variables. In the eutrophication module, CBOD fractions are simulated as state variables and DOC fractions are calculated from CBOD.

The default coefficients by wavelength are:

Table 3. Light attenuation coefficients by waveband

Index	Color	Water [1/m]	Chlorophyll [(1/m)/(ug/L)]	DOC [(1/m)/(mg/L)]	Solids [(1/m)/(mg/L)]
1	uVb med	0.151	0.103	6.22	0.34
2	uVb high	0.109	0.0816	5.40	0.34
3	uVa low	0.0805	0.069	4.59	0.34
4	uVa med	0.0512	0.057	3.40	0.34
5	uVa high	0.0340	0.053	2.54	0.34
6	violet	0.0169	0.039	1.266	0.34
7	blue	0.0166	0.0262	0.514	0.34
8	green	0.0475	0.0143	0.289	0.34
9	yellow-orange	0.217	0.0063	0.115	0.34
10	red	1.007	0.0065	0.0	0.34
11	infrared	2.07	0.0	0.0	0.34

The chlorophyll exponent by wavelength defaults to 1. The coefficients for total ultraviolet and total visible light are calculated internally as the weighted sum of their component wavebands (1 – 6 for ultraviolet, 7 – 10 for visible).

The user can enter alternate coefficients for visible light in the Constants group, Light section. If multiple fractions of DOC or CBOD are simulated, then the user can enter a set of light extinction coefficients for each DOC fraction.

In the eutrophication module, the user can choose to specify segment-specific light extinction coefficients for visible light. Segment specific values can be input in the Parameter Data section, Environmental group. An associated time function can be input in the Time Functions section. The light extinction coefficients for each segment at each time step will be the product of the input parameters and time function.

If the user simulates macro algae in the eutrophication module, then an additional light extinction term considers macro algal shading:

$$K_{e,MA} = K_{MA} \times MA$$

Where $K_{e,MA}$ is the macro algae shading coefficient [1/m], MA is the macro algae biomass [g_{DW}/m^3], and K_{MA} is the coefficient [$(1/m)/(g_{DW}/m^3)$], specified in the Constants section, Macro Algae group. This extinction coefficient is applied below the macro algae canopy height, which can be on the water surface or at a specified elevation above the bottom.