

## DSM2 Qual

### Water Quality

The distribution of water quality variables in space and time is computed by solving the one-dimensional advection-dispersion equation in which non-conservative constituent relationships are considered to be governed, in general, by first order rates (see equations on page 3-5). The processes of chemical and biochemical transformations, including interaction among various parameters as represented in the model are shown in Figure 3.1 at the end of this chapter. These constituents include dissolved oxygen, carbonaceous BOD, phytoplankton, organic nitrogen, ammonia nitrogen, nitrite nitrogen, nitrate nitrogen, organic phosphorus, dissolved phosphorus, TDS, and temperature. The conceptual and functional descriptions of the constituent reactions are based generally on QUAL2E (Brown and Barnwell 1987); although in certain instances they were updated based on the work of Bowie et al., (1985). Mass balance equations are written for all quality constituents in each parcel of water (see equations on page 3-5). The reader is referred to Jobson and Scoellhamer (1987) for a description of the Lagrangian formulation which provides the basic framework for DSM2-Qual.

In applying the water quality model, changes in concentration due to advection and dispersion, including changes due to tributaries or agricultural drainage are first computed. Next, concentrations of each constituent in each parcel of water are updated, accounting for decay, growth, and biochemical transformations. New subroutines developed for modeling non-conservative constituents are structured in modular form to facilitate extension for simulation of additional constituents (in the case that such needs arise in the future). Subroutine KINETICS updates constituent concentrations at each time step. A single or any combination of the eleven water quality variables can be modeled to suit the needs of the user. KINETICS is called by the parcel tracking subroutine of DSM2-QUAL for every parcel at each time step. The model has also been extended to simulate kinetic interactions in reservoirs (extended open water bodies encountered in the Delta).

Subroutine CALSCSK builds a source/sink matrix within KINETICS for each non-conservative constituent simulated. For simulation of temperature, a subroutine that computes net transfer of energy at the air-water interface has been adapted from the QUAL2E model with some modification. Required meteorology data (obtained preferably at hourly intervals) include dry bulb and wet bulb atmospheric temperatures, wind speed, atmospheric pressure, and cloudiness.

Physical, chemical, and biological rate coefficients required for KINETICS are read as input. Some of these coefficients are constant throughout the system; some vary by location; and most are temperature-dependent. A list of these coefficients and sample values is provided in chapter 5.

The numerical scheme for updating kinetic interactions was developed considering properties of Lagrangian box models that are most accurate when time steps are small enough to define the dominant temporal variations in flow and concentration. A relatively simple scheme that takes advantage of small time steps—the Modified Euler method—is used to update concentrations. Concentration updating is done at least once in every time step, and more often if the parcel in question has passed a grid point before the current time step is fully accounted for. In the latter case, the reaction time step will be the increment of time remaining to be accounted for—less than the simulation time step (typically 15 minutes). Consequently, reaction time steps remain small, so the Modified Euler scheme for concentration updating is appropriate. Since changes in concentration of any constituent affect the other constituents, tests are included in DSM2-Qual to check whether corrections to constituent concentrations are necessary.

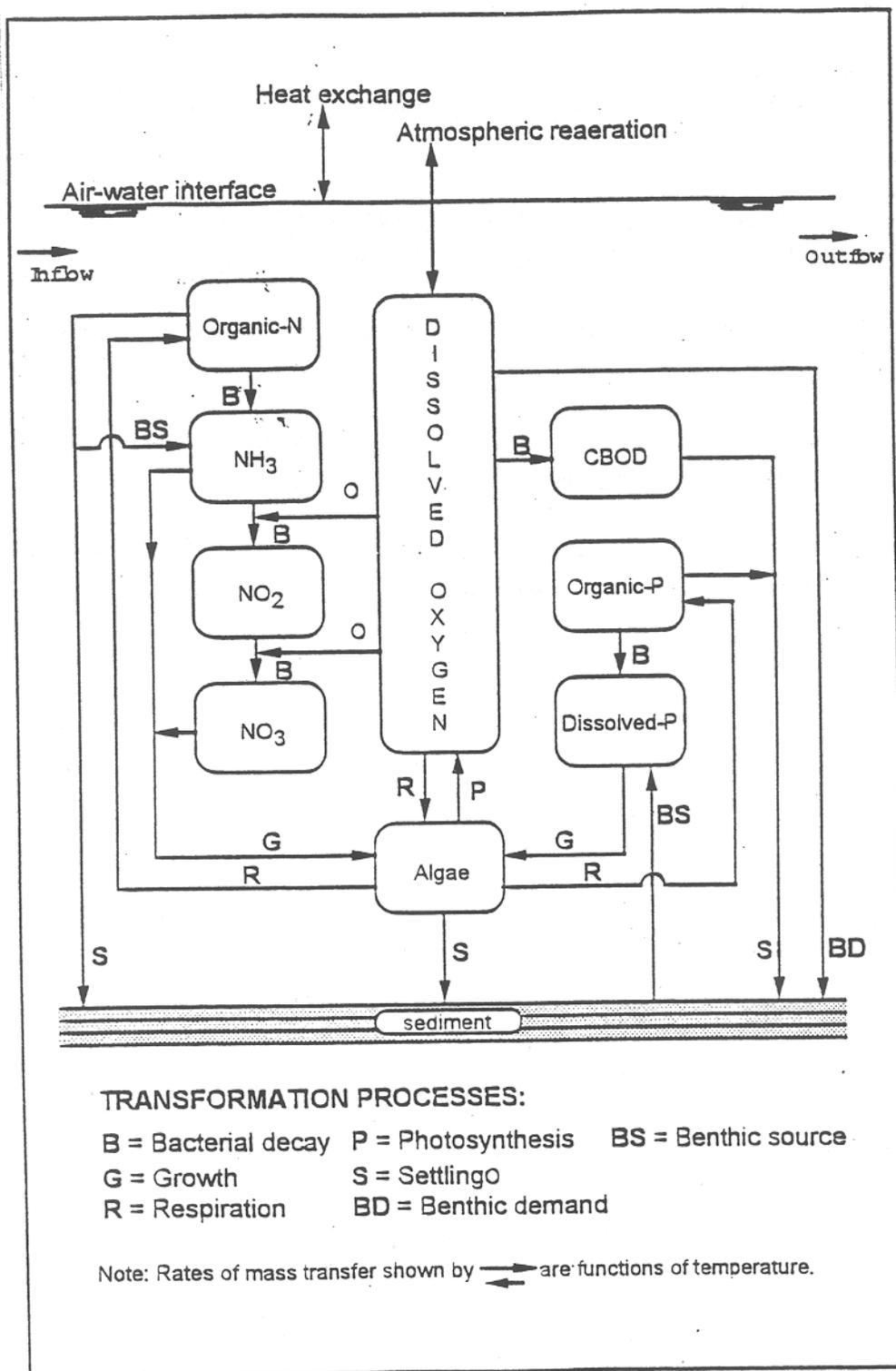
The ability of the model to simulate the dissolved oxygen sag on a reach of the San Joaquin River near Stockton was recently demonstrated. DSM2-Qual was capable of capturing diurnal variations of important constituents such as dissolved oxygen, phytoplankton, temperature, and nutrients under the unsteady conditions of the estuary. Variations were realistic, although lack of a large temporal variation in observed data was somewhat of an impediment to testing the model's full capacity to predict field conditions. Tests of the model's capability to distinguish between alternatives in terms of incremental changes in water quality were encouraging (Rajbhandari 1995). The model has great potential for use as a practical tool for analysis of the impacts of water management alternatives.

To enhance the predictive capability of the model, sensitivity analysis should be performed to determine the relative influence of rate coefficients on model response. Calibrated values of the rate coefficients which are most sensitive should be refined. Also, subject to a consistent expansion of the database, future extensions in the model to add additional variables (such as zooplankton) are likely to result in improvement in model performance. Extension of model to represent sediment transport capability should also be investigated such that a dynamic interaction of sediments with simulated constituents is possible. Other uses of the model would be in providing the spatial and temporal distributions of water quality variables for the Particle Tracking Model, so that aquatic species can be more accurately modeled.

## References

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Figure 3.1 Interaction Among Constituents



## DSM2 Equations for Non-Conservative Constituents

This section lists the equations for each constituent written in a Lagrangian reference frame that moves with the cross-sectional mean velocity. Consequently, the advection term does not appear in these equations.

### Dissolved Oxygen

The rate of change in DO concentration is given by:

$$\frac{\partial [O]}{\partial t} = \frac{\partial}{\partial \xi} \left[ E_x \frac{\partial (O)}{\partial \xi} \right] - (k_1 + k_3) L + k_2 (O_s - [O]) - \alpha_5 k_n [NH_3]$$

Diffusion
CBOD
Reaeration
Ammonia oxidation

$$- \alpha_6 k_{ni} [NO_2] + \alpha_3 \mu [A] - \alpha_4 \rho [A] - K_4/d \quad (A.1)$$

Nitrite oxidation
Photosynthesis
Respiration
Benthic demand

where

- [O] = dissolved oxygen concentration, mg/l or, g/m<sup>3</sup>,
- k<sub>1</sub> = CBOD decay rate at the ambient temperature, day<sup>-1</sup>,
- k<sub>3</sub> = rate of loss of CBOD due to settling at the ambient temperature, day<sup>-1</sup>,
- L = CBOD concentration, mg/l,
- k<sub>2</sub> = reaeration coefficient, day<sup>-1</sup>,
- O<sub>s</sub> = dissolved oxygen concentration at saturation, mg/l,
- k<sub>n</sub> = ammonia decay rate at the ambient temperature, day<sup>-1</sup>,
- [NH<sub>3</sub>] = ammonia concentration as N, mg/l,
- α<sub>5</sub> = amount of oxygen consumed in conversion of ammonia to nitrite,

- $\alpha_6$  = amount of oxygen consumed in conversion of nitrite to nitrate,  
 $k_{ni}$  = nitrite decay rate at the ambient temperature, day<sup>-1</sup>,  
 $[NO_2]$  = nitrite concentration as N, mg/l,  
 $\alpha_3$  = amount of oxygen produced per unit of algal photosynthesis,  
 $\mu$  = phytoplankton growth rate at the ambient temperature, day<sup>-1</sup>,  
 $\alpha_4$  = amount of oxygen consumed per unit of algae respired,  
 $\rho$  = phytoplankton respiration rate at the ambient temperature, day<sup>-1</sup>,  
 $[A]$  = phytoplankton concentration, mg/l,  
 $K_4$  = benthic oxygen demand, g/m<sup>2</sup> day<sup>-1</sup>,  
 $d$  = mean channel depth, ft (0.30m),  
 $\xi$  = distance from the parcel, the Lagrangian distance coordinate.

$$\xi = x - x_0 - \int_{t_0}^t u \, d\tau \quad (A.2)$$

$x_0$  = location of the fluid parcel at time  $t_0$ ,

$x$  = Eulerian distance coordinate.

$E_x$  = longitudinal dispersion coefficient,

## DO Saturation

DO Saturation concentration as a function of temperature is:

$$\ln O_{sf} = -139.34411 + (1.575701 * 10^5)/T_k - (6.642308 * 10^7)/T_k^2 + (1.243800 * 10^{10})/T_k^3 - (8.621949 * 10^{11})/T_k^4$$

where  $O_{sf}$  = "freshwater" DO saturation concentration in mg/L at 101 kPa (1 atm); and  $T_k$  = temperature in °K =  $T$  (°C) + 273.15.

Also, to extend the model's applicability to estuaries where salinity intrusion may be significant, the effect of salinity on DO saturation concentration has been incorporated as shown below

$$\ln O_{ss} = \ln O_{sf} - S \left[ 1.7674 \cdot 10^{-2} - (1.0754 \cdot 10^1)/T_k + (2.1407 \cdot 10^3)/T_k^2 \right]$$

where

$O_{ss}$  = "saline water" DO saturation concentration in mg/L at 101 kPa (1 atm); and  $S$  = salinity in ppt. In test simulations using DSM2, where salinity was varied over a range of 5000 to 20,000 ppm, the changes in DO saturation were as much as 15-20%. Such salinity effects are not included in the QUAL2E model package.

The DO saturation value also increases with the increase in atmospheric pressure and is represented in the model by:

$$O_s = O_{ss} P \left[ \frac{[1 - (P_{wv}/P)](1 - \phi P)}{(1 - P_{wv})(1 - \phi)} \right]$$

where

$P$  = nonstandard pressure in atm (101 kPa); and  $P_{wv}$  = partial pressure of water vapor (atm or 101 kPa) calculated from:

$$\ln P_{wv} = 11.8571 - (3840.70/T_k) - (216961/T_k^2)$$

$$\phi = 0.000975 - (1.426 \cdot 10^{-5} T_k) + (6.436 \cdot 10^{-8} T_k^2)$$

$$T = \text{temperature } ^\circ\text{C} = T_k - 273.15.$$

Other terms are as defined previously.

## Reaeration

O'Connor and Dobbins (1956) equation is used:

$$k_2 = (D_m \bar{u})^{0.5} d^{-1.5}$$

(at 20°C)

where  $D_m$  = molecular diffusion coefficient = 0.000081 ft<sup>2</sup>/hour,  $\bar{u}$  = the mean velocity (ft/s), and  $d$  = average stream depth (ft).

## Carbonaceous Biochemical Oxygen Demand (CBOD)

Accounting also for the removal of CBOD that may be due to settling of organic particles, the rate of change of CBOD due to both biochemical oxidation and settling can be expressed as:

$$\frac{\partial L}{\partial t} = \frac{\partial}{\partial \xi} \left[ E_x \frac{\partial L}{\partial \xi} \right] - (k_1 + k_3) L \quad (\text{A.3})$$

Terms are as defined previously.

## Algae (Phytoplankton)

The rate of increase in algal biomass is computed by:

$$\frac{\partial [A]}{\partial t} = \frac{\partial}{\partial \xi} \left[ E_x \frac{\partial [A]}{\partial \xi} \right] + [A] (\mu - \rho) - \sigma_1 \frac{[A]}{d} \quad (\text{A.4})$$

$\sigma_1$  = phytoplankton settling rate at ambient temperature,  
ft/day,

[A] = phytoplankton concentration, mg/l.

$$\mu = \mu_{\max} (FL) \text{ Min} \left( \frac{N}{K_N + N}, \frac{P}{K_P + P} \right) \quad (\text{A.5})$$

- $\mu_{\max}$  = maximum algal growth rate at the ambient temperature, day<sup>-1</sup>,  
 N = inorganic nitrogen concentration (NO<sub>3</sub> + NH<sub>3</sub>), mg/l,  
 $K_N$  = nitrogen half saturation constant, mg/l,  
 $K_P$  = phosphorus half saturation constant, mg/l,  
 $K_L$  = half saturation constant for light, Kcal.m<sup>-2</sup>.s<sup>-1</sup> or Btu/ft<sup>2</sup> -hr (light intensity at which phytoplankton grows at half the maximum rate),  
 FL = algal growth limitation factor for light.

$$FL = \left(\frac{1}{\lambda d}\right) \ln \left[ \frac{K_L + I}{K_L + I e^{-\lambda d}} \right] \quad (A.6)$$

Equation (A.6) is obtained when the variation of light intensity with depth represented by the relationship shown below is substituted in the Monod expression for light and integrated over the depth of flow.

$$I_z = I \exp(-\lambda z) \quad (A.7)$$

where

- I = light intensity at the surface, Kcal.m<sup>-2</sup>.s<sup>-1</sup> or Btu/ft<sup>2</sup> -hr,  
 $I_z$  = light intensity at a given depth (z), Kcal.m<sup>-2</sup>.s<sup>-1</sup> or Btu/ft<sup>2</sup> -hr,  
 z = depth variable, ft,  
 $\lambda$  = light extinction coefficient, ft<sup>-1</sup>.

The light extinction coefficient is usually defined as the linear sum of several extinction coefficients representing each component of light absorption (Bowie et al., 1985). The light extinction coefficient ( $\lambda$ ) will be computed using the expression:

$$\lambda = \lambda_0 + \lambda_1 \alpha_7 [A] + \lambda_2 (\alpha_7 [A])^{2/3} \quad (A.8)$$

where

- $\lambda_0$  = non-algal portion of the light extinction coefficient, ft<sup>-1</sup>,

- $\lambda_1$  = linear algal self shading coefficient,  $\text{ft}^{-1}(\mu\text{g-Chla/l})^{-1}$ ,  
 $\lambda_2$  = nonlinear algal self shading coefficient,  $\text{ft}^{-1}(\mu\text{g-Chla/l})^{-2/3}$ ,  
 $\alpha_7$  = conversion factor,  $(\mu\text{g-Chla/mg [A]})$ .

Other terms are as previously defined.

### Chemical Oxidation: Nitrogen Series

The differential equations representing transformations of organic nitrogen to ammonia, ammonia to nitrite, and nitrite to nitrate are presented below.

#### Organic Nitrogen

$$\frac{\partial[\text{N-org}]}{\partial t} = \frac{\partial}{\partial \xi} \left[ E_x \frac{\partial[\text{N-org}]}{\partial \xi} \right] + \alpha_1 \rho[\text{A}] - k_{\text{n-org}} [\text{N-org}] - \sigma_4 [\text{N-org}] \quad (\text{A.9})$$

where

- $[\text{N-org}]$  = concentration of organic nitrogen,  $\text{day}^{-1}$ ,  
 $k_{\text{n-org}}$  = rate constant for hydrolysis of organic nitrogen to ammonia nitrogen at the ambient temperature,  $\text{day}^{-1}$ ,  
 $\alpha_1$  = fraction of algal biomass, which is nitrogen,  
 $\sigma_4$  = organic nitrogen settling rate at the ambient temperature,  $\text{day}^{-1}$ .

#### Ammonia Nitrogen

$$\frac{\partial[\text{NH}_3]}{\partial t} = \frac{\partial}{\partial \xi} \left[ E_x \frac{\partial[\text{NH}_3]}{\partial \xi} \right] + k_{\text{n-org}} [\text{N-org}] - k_{\text{n}}[\text{NH}_3] + \frac{\sigma_3}{d} - f\alpha_1 \mu[\text{A}] \quad (\text{A.10})$$

where

- $\sigma_3$  = benthic release rate for ammonia nitrogen at the ambient temperature,  $\text{mg/m}^2\text{day}^{-1}$ .

f = fraction of algal uptake of nitrogen which is ammonia.

$$= \frac{p[\text{NH}_3]}{p[\text{NH}_3] + (1-p)[\text{NO}_3]} \quad (\text{A.11})$$

p = preference factor for ammonia nitrogen (0 to 1.0).

### Nitrite Nitrogen

$$\frac{\partial[\text{NO}_2]}{\partial t} = \frac{\partial}{\partial \xi} \left[ E_x \frac{\partial[\text{NO}_2]}{\partial \xi} \right] + k_n [\text{NH}_3] - k_{ni} [\text{NO}_2] \quad (\text{A.12})$$

### Nitrate Nitrogen

$$\frac{\partial[\text{NO}_3]}{\partial t} = \frac{\partial}{\partial \xi} \left[ E_x \frac{\partial[\text{NO}_3]}{\partial \xi} \right] + k_{ni} [\text{NO}_2] - (1-f) \alpha_1 \mu [A] \quad (\text{A.13})$$

## 3.5 Phosphorus Transformation

### Organic Phosphorus

$$\frac{\partial[\text{p-org}]}{\partial t} = \frac{\partial}{\partial \xi} \left[ E_x \frac{\partial[\text{p-org}]}{\partial \xi} \right] + \alpha_2 \rho [A] - k_{\text{p-org}} [\text{p-org}] - \sigma_5 [\text{p-org}] \quad (\text{A.14})$$

where

- [p-org] = concentration of organic phosphorus, mg/l,
- $\alpha_2$  = fraction of algal biomass which is phosphorus,
- $k_{\text{p-org}}$  = organic phosphorus decay rate at the ambient temperature,  $\text{day}^{-1}$ ,
- $\sigma_5$  = organic phosphorus settling rate at the ambient temperature,  $\text{day}^{-1}$ .

### Dissolved Phosphorus

$$\frac{\partial[\text{PO}_4]}{\partial t} = \frac{\partial}{\partial \xi} \left[ E_x \frac{\partial[\text{PO}_4]}{\partial \xi} \right] + k_{p\text{-org}} [\text{PO}_4] - \alpha_2 \mu [A] + \frac{\sigma_2}{d} \quad (\text{A.15})$$

where

- $[\text{PO}_4]$  = concentration of inorganic or dissolved phosphorus, mg/l,  
 $\sigma_2$  = benthic release rate for dissolved phosphorus at the ambient temperature,  $\text{mg/m}^2 \text{ day}^{-1}$ .

### Temperature

The transport equation for heat as the constituent is:

$$\frac{\partial C_h}{\partial t} = \frac{\partial}{\partial \xi} \left( E_x \frac{\partial C_h}{\partial \xi} \right) + s \quad (\text{A.17})$$

Where

- $C_h$  = concentration of heat ( $\text{HL}^{-3}$ )  
which can be represented as

$$C_h = C\rho T \quad (\text{A.18})$$

where

- $C$  = specific heat of water ( $1 \text{ btu/lb-}^\circ\text{F}$  or  $1 \text{ cal/g-}^\circ\text{C}$ ),  
 $\rho$  = density of water,  $62.4 \text{ lb/ft}^3$  or  $1\text{g/cm}^3$ ,  
 $T$  = water temperature, (deg C).

Other terms are as defined previously.

The source/sink term (s) accounts for heat exchanged through the air-water interface. Substituting equation (A.18) into equation (A.17) and representing s in the form of the net energy flux ( $Q_n$ ) into the water surface finally leads to:

$$\frac{\partial T}{\partial t} = \frac{\partial}{\partial \xi} \left( E_x \frac{\partial T}{\partial \xi} \right) + \frac{Q_n}{\rho c d} \quad (\text{A.19})$$

where

d = hydraulic depth of the water body.

Table A.1 Temperature Coefficients For Reaction Rates

Constituent	Reaction type	Temperature coefficient	Variable (FORTRAN)
BOD	decay	1.047	thet(1)
	settling	1.024	thet(2)
DO	reaeration	1.024	thet(3)
	SOD	1.060	thet(4)
ORGANIC-N	decay	1.047	thet(5)
	settling	1.024	thet(6)
AMMONIA-N	decay	1.083	thet(7)
	benthic source	1.074	thet(8)
NITRITE-N	decay	1.047	thet(9)
ORGANIC-P	decay	1.047	thet(10)
	settling	1.024	thet(11)
DISSOLVED-P	benthic source	1.074	thet(12)
ALGAE	growth	1.047	thet(13)
	respiration	1.047	thet(14)
	settling	1.024	thet(15)

### IV.C.3.7 Components of Heat Exchange at the Air-Water Interface

Heat exchanges through the air-water interface depend upon both the internal hydromechanical behavior of the water body and the physics of its interaction with the overlying air mass.

Meteorological factors such as solar radiation, wind, humidity, pressure, and cloudiness figure prominently in the many physical processes involved. Accounting for the most important of these processes the rate of energy transfer is computed as:

$$Q_n = Q_{sn} + Q_{at} - Q_{ws} - Q_e - Q_h \quad (A.20)$$

where

- $Q_n$  = net heat energy transfer across the air-water interface,
- $Q_{sn}$  = net short wave solar radiation flux,
- $Q_{at}$  = net long wave atmospheric radiation flux,
- $Q_{ws}$  = water surface back radiation flux,
- $Q_e$  = evaporative heat flux,
- $Q_h$  = sensible heat flux.

All the above terms are in units such as Btu/ft<sup>2</sup>-day or cal/cm<sup>2</sup>-day. A table (Table A.2) on unit conversion of various terms appearing on this section is provided at the end of this section. The remainder of this section describes how each of the heat components is represented in the model.

#### Net Short Wave Solar Radiation, $Q_{sn}$

The net incoming solar radiation is short wave radiation which passes directly from the sun to the earth's surface. The attenuating effects of the absorption and scattering of the light in the atmosphere due to cloud cover and the reflection from the water surface must be considered in the computation of the solar radiation that penetrates the water surface. It may be represented by:

$$Q_{sn} = Q_o a_t (1 - 0.65 C^2) (1 - R_s) \quad (A.21)$$

where

- $Q_o$  = solar radiation intensity at the top of the atmosphere, a function of location and time,
- $a_t$  = atmospheric transmissivity term,
- $C$  = cloud cover in tenths of sky covered, from 0.0 to 1.0,

$R_s$  = reflectivity of the water surface, a function of the solar altitude of the form:

$$R_s = A\alpha^B \quad (A.22)$$

where

$\alpha$  is the solar altitude in degrees and A and B are functions of cloudiness. Values for A and B are shown below (as reported in the QUAL2E manual).

Cloudiness C	0		0.1-0.5		0.6-0.9		1.0	
	Clear		Scattered		Broken		overcast	
Coefficient	A	B	A	B	A	B	A	B
	1.18	-0.77	2.20	-0.97	0.95	-0.75	0.35	-0.45

The reader is referred to the QUAL2E manual (Brown and Barnwell, 1987) for details on the representation of the atmospheric transmission term ( $a_t$ ) and  $Q_o$ .

#### Net Atmospheric Radiation, $Q_{at}$

Some short-wave radiation from the sun plus radiation emitted by the ground or water surfaces enters the earth's atmosphere and is partly absorbed by water vapor, carbon dioxide, ozone and other atmospheric gases. These constituents, in turn, emit long wave radiation back to the ground and water surfaces, and outward to space. Such radiation is called atmospheric radiation. It is a function of absolute air temperature, cloudiness and water surface reflectivity (Orlob and Marjanovic, 1989) and is expressed as:

$$Q_{at} = C_{at} \sigma (T_a + 460)^6 (1 + 0.17 C^2)(1 - R_a) \quad (A.23)$$

where

$C_{at}$  = Swinbank's coefficient approximately equal to  $2.89 * 10^{-6} \text{ } ^\circ\text{R}^{-2}$ ,

$\sigma$  = Stefan-Boltzman constant =  $1.73 * 10^{-9} \text{ Btu/ft}^2\text{/hr/}^\circ\text{Rankine}^4$ ,

- $T_a$  = temperature of the radiating air mass, °F,  
 $R_a$  = water surface reflectivity of long wave radiation = 0.03.

Water Surface Back Radiation,  $Q_{ws}$

The loss of energy from a water body by long wave radiation is expressed by the Stefan-Boltzman Fourth Power Radiation Law for a black body as:

$$q_{ws} = \epsilon \sigma (T_s + 460)^4 \quad (A.24)$$

where

- $\epsilon$  = emissivity of the water surface; i.e., ratio of an actual radiation to that of a black body = 0.97,  
 $T_s$  = water surface temperature, °F.

Evaporative Heat Flux,  $Q_e$

The evaporative heat loss occurs due to water changing a liquid state to a gas state (vapor) and the heat loss associated with the latent heat of vaporization.

$$Q_e = \gamma L_v E \quad (A.25)$$

where

- $\gamma$  = specific weight of water, lb/ft<sup>3</sup>,  
 $L_v$  = latent heat of vaporization, Btu/lb,  
 $E$  = evaporation rate, ft/hr, often expressed as

$$(a+bW) (e_s - e_a) \quad (A.26)$$

where

- $a, b$  = constants,  
 $W$  = wind speed, miles/hr, measured 6 ft. above the water surface,  
 $e_s$  = saturation vapor pressure of the air (in. of Hg) at the temperature of the water surface, as given by  
 $e_s = 0.1001 \exp (0.03T_s) - 0.0837$   
 $e_a$  = water vapor pressure (in. of Hg) at a height of 6 feet above the water surface, given as

$$e_a = e_{wb} - 0.000367 P_a (T_a - T_{wb}) [1.0 + (T_{wb} - 32)/1571]$$

Other terms are as defined earlier.

$e_{wb}$  = saturation vapor pressure (in. of Hg) at the wet bulb temperature,

$T_{wb}$  = wet bulb temperature °F,

$P_a$  = local barometric pressure, in. of Hg.

### Sensible Heat Flux, $Q_h$

Sensible heat is transferred between air and water by conduction and transferred away from the air-water interface by the same mechanisms as for evaporation. It is convenient to relate sensible and evaporative heat fluxes using Bowen's ratio in the form:

$$Q_h = Bq_e$$

where

$$B = \text{Bowen's ratio} = 0.01 \frac{T_s - T_a}{e_s - e_a} \frac{P_a}{29.92} \quad (\text{A.27})$$

Table A.2 Unit Conversion Related to Heat Equations  
(Bowie et al., 1985)

1 BTU/ft <sup>2</sup> /day	0.131 watt/m <sup>2</sup>	0.271 Ly/day	0.113 kcal/m <sup>2</sup> /hr
Ly/day	0.483 watt/m <sup>2</sup>	3.69 BTU/ft <sup>2</sup> /day	0.42 kcal/m <sup>2</sup> /hr
kcal/m <sup>2</sup> /hr	1.16 watt/m <sup>2</sup>	2.40 Ly/day	8.85 BTU/ft <sup>2</sup> /day
1 mb	0.1 kp	0.769 mm Hg	0.03 in Hg
1 mm Hg	1.3 mb	0.13 kp	0.039 in Hg
1 in Hg	33.0 mb	25.4 mm Hg	3.3 kp