

**USF-CMHAS Hydraulic  
and Water Quality Model  
(HYDQUAL)  
Documentation**

**August, 1999**

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Publication Report:  
No. CMHAS GO/99

**Bernard E. Ross, Mark A. Ross and Patrick D. Tara  
Center for Modeling Hydrologic and Aquatic Systems  
Department of Civil and Environmental Engineering  
University of South Florida  
Tampa, Florida**

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## **PART 1: TECHNICAL DOCUMENTATION**

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USF-CHMHAS Hydraulic and Water Quality Model  
Part 1: Technical Documentation

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# 1.0 INTRODUCTION AND BACKGROUND

In 1989, the Southwest Florida Water Management District, SWFWMD, and the Pinellas County Environmental Management Department, completed a Surface Water Improvement and Management Plan (SWIM) for Lake Tarpon and the surrounding watershed. The SWIM plan objectives were to gain a better understanding of the lake ecosystem so that more informed management decisions could be made. Studies included the examination of nutrient loading and recycling characteristics, phytoplankton communities and dynamics, and basic trophic status. The SWIM study consultant, King Engineering Associates, Inc. (KEA), contracted with the Center for Modeling Hydrologic and Aquatic Systems (CMHAS) at the University of South Florida (USF) to develop a water quality model to help quantitatively evaluate nutrient management alternatives and possible regulatory actions concerning Lake Tarpon. Part 3 describes the preliminary calibration and application of the model within the limited scope and budget of this study. Subsequent calibration, adaptation for structure operations and predictive simulations were the subject of later studies (Walker, 1993, Rahgozar, 1994, Ross and Tara, 1996).

## 1.1 Model Background

Coastal Florida lakes and estuaries, are considerably different from their northern counterparts. First, Florida lakes are characteristically shallow (typically <10 ft), wind-driven, and well-mixed. Water quality is, therefore, highly dependent on lake geometry and surface stresses in addition to inflows and outflows. The prevailing and dominant winds, lake or estuary orientation, and natural shelter all factor into this dependence. The lack of appreciable seasonal variability and shallow nature negate overturning, which can be the dominant water quality and circulation process for deeper lakes and reservoirs in temperate latitudes. Second, the semi-tropical climate creates unique, highly productive (trophic), and complex biological communities. Lastly, natural and man-made nutrient stress to receiving systems in Florida is primarily in the form of non-point sources (runoff and aeolian) and benthic nutrient exchanges, providing a mechanism to continuously or episodically recycle nutrients from accumulated historical loading.

The nature of Florida receiving systems and cost-benefit considerations lend credibility to the continued popular application of two-dimensional, vertically-integrated water-quality models. This level of detail is often most appropriate and therefore recommended for engineering and/or management evaluations of non-point and point source impacts to lakes, estuaries or other planar receiving systems. A zero (box) or one-dimensional (river) model is insufficient for relating spatial variability of loading response within the system. Conversely, three dimensional water quality models are costly and controversial and may not provide any significantly improved system representation for engineering and management evaluations. Furthermore, exhaustive and problematic data requirements, proprietary codes, and high user-familiarity requirements prove cumbersome or prohibitive for technology transfer from model developers to users who will ultimately be interested in management-comparative applications. Two-dimensional models abound in the literature, however, two-dimensional models produced for temperate receiving waters are not always readily applicable to unique conditions described for Florida. For this

reason, the USF-CMHAS 2D Hydraulic and Water Quality Model (HYDQUAL) continues to remain popular, receiving widespread application. The USF-HYDQUAL model is based on well documented and established modeling principles and was developed specifically for the application to shallow, high trophic Florida lakes and estuaries with balanced or nutrient-limited conditions.

The engine of the USF-HYDQUAL 2D Model consists of two components: a 2-D vertically-integrated hydraulic model and a 2-D nutrient budget/eutrophication model. The model links both these codes into one complete interactive hydraulic/water quality program. However, the codes can be run separately or in combination with support of other models. To complete the modeling packaging, additional couplings have been made. A model interface links the 2D model, a non-point source (NPS) nutrient loading model, and a Geographic Information System (GIS). The NPS model, which was specifically developed for a study of Lake Tarpon (Halley et al. 1992), uses watershed data analyzed with a GIS to provide hydrographs and nutrient loads to the lake from non-point source rainfall runoff.

## 1.2 Model Objective

The most common objectives of a typical model simulation are to predict hydraulic conditions of storms and manage impacts from point and non-point source (stormwater runoff and aeolian) loading to a lake or estuary system, to further aid in the understanding of unique physical, chemical, and biological processes of a receiving water system, and to prevent or reverse further degradation of water quality or scour and depositional conditions around structures. Scientists, engineers, and environmental managers have generally agreed that the key means by which water quality is maintained or improved is the specific management of pollutant inputs, together with evaluating nutrient affects on eutrophication. To help meet this need, the USF-CMHAS model uses a mass transport/nutrient budget approach to track nutrient concentrations. This requires simulating not only the hydraulic transport of constituents, but also the chemical and biological dynamics that affect them. Nitrogen and phosphorous chemical constituents considered by limnologists and coastal scientists to be most important to primary productivity and ecological condition of the system are included in detail. However, present modeling capabilities dictate that many physical and biological influences are poorly understood and are, therefore, poorly accounted for in the model (e.g., secondary predation).

The fully dynamic hydraulic portion of the model simulates storm or tidal time-scale influences of the following parameters:

- ⊞ Gravity forces
- ⊞ Coriolis effects
- ⊞ Baroclinic (density-driven) circulation
- ⊞ Depth and roughness dependent bed functional conditions
- ⊞ Wind driven circulation including seiching
- ⊞ Freshwater inputs from tributaries, point- and non-point sources
- ⊞ Variable boundary conditions with tidal influences
- ⊞ Variable sub-grid features such as bridge piers, docks, and oyster bars
- ⊞ Limited flow structures including gated opening

The water quality portion of the model simulates storm event response time scales of the following parameters:

- ☒ Salinity (S)
- ☒ Phytoplankton-algal biomass (A)
- ☒ Chlorophyll-a (Chl-A)
- ☒ Organic nitrogen (Org-N)
- ☒ Ammonia nitrogen (NH<sub>3</sub>)
- ☒ Nitrite-nitrate nitrogen (NO<sub>2</sub>-NO<sub>3</sub>)
- ☒ Organic phosphorus (Org-P)
- ☒ Orthophosphate (PO<sub>4</sub>)
- ☒ Biochemical Oxygen Demand (BOD)
- ☒ Dissolved Oxygen (DO)
- ☒ Benthic Nutrient Exchange (NER)
- ☒ Sediment Oxygen Demand (SOD)

The NPS model provides the landform derived source loading of all of the Nitrogen and Phosphorous series, as well as BOD and DO.

In addition, a trophic state index (TSI) has been added to the water quality model. As with all of the above listed parameters, the trophic state of a lake or estuary can be determined both spatially and temporally. The inclusion of a (TSI) strengthens the model application as a management tool as it provides a simple, yet quantitative way to track the direction of changes in trophic condition due to variations in chemical/biological response. The index is based on analysis of resultant parameters (e.g., algae biomass or light extinction) but is a simple representation that can be understood by the general public when presented by scientists, engineers, or environmental managers who must make decisions affecting the aquatic environment.

The sediment transport algorithms provide for storm event, scour, and deposition analyses, fully documented in a separate report (Vincent et al., 1992). The model also provides for Lagrangian particle tracking for transport studies. The model is completely modular, providing for separate and simultaneous simulations of hydraulics, water quality, and sediment transport as well as separate modules for non-point source and one-dimensional tributary loading.

## **2.0 THE NON-POINT SOURCE LOADING MODEL**

### **2.1 Overview**

The non-point source (NPS) loading model generates pollutant loadings from precipitation runoff using modified SCS Hydrologic Methods (McCuen 1982). A weighted averaging approach, using the GIS generated basin characteristics and contributing pollutant concentrations, is combined with the calculated runoff volume to determine the estimated nutrient load to the lake or estuary for each of the target constituents.

The NPS model is an event simulation model consisting of two parts. First, a total unit hydrograph along with an average pollutograph (for each nutrient) is determined for each of the subbasins. Hydrographs and pollutographs can be generated for any storm depth and duration. Secondly, the total nutrient load, in pounds, is calculated for each subbasin and each constituent. Knowledge of the total loads from subbasins with complex landuse coverage can be useful management information for identifying and quantifying high loading areas which may significantly contribute to lake eutrophication. These areas can be easily targeted for remediation and consideration of possible stormwater management alternatives.

### **2.2 NPS Model Theory and Equations**

In the first section of the NPS model, a triangular unit hydrograph is determined for each of the microbasins within a subbasin. The individual microbasin hydrographs are then added together to give the total curvilinear hydrograph for the subbasin. The addition takes place at every major time ordinate for every microbasin hydrograph. The major time ordinates for the triangular unit hydrograph are the time to the start of runoff (the origin), time to peak, and the time to the end of runoff (the time base). Lastly, a time lag for each microbasin discharge to the subbasin outfall is also considered, thereby taking into account the microbasin's proximity to the outfall. The time lag for each microbasin is added to the above times to reference the discharge to the outfall.

In addition to the discharge value, an average pollutant concentration is calculated at each of the time periods mentioned above. This will provide a curvilinear pollutograph for the average nutrient concentrations contributed from each subbasin that is used by the receiving water model. The hydrographs and pollutographs generated are defined using the following parameters.

1) The **VOLUME OF RUNOFF** is calculated from the SCS curve number and the user defined rainfall depth in inches.

$$Q = \frac{[P(\frac{200}{CN}) + 2]^2}{[P(\frac{800}{CN}) + 8]}$$

where:

Q = runoff volume (inches)  
P = rainfall depth (inches)  
CN = SCS curve number for the microbasin

2) The SCS equation to calculate basin **STORAGE** is

$$S = \frac{1000}{CN} + 10$$

where:

S = surface storage capacity

3) The **TIME LAG** of the microbasin is defined as the time from the center of mass of rainfall excess to the peak discharge. It is calculate utilizing the SCS Lag Method. The maximum hydraulic length utilized here is estimated from the GIS average hydraulic length as described below.

$$T_l = \frac{HL^{0.8} (S + 1)^{0.7}}{1900 (y)^{0.5}}$$

where:

T<sub>l</sub> = time lag of the microbasin (hours)  
HL<sub>max</sub> = hydraulic length (feet)  
S = storage volume (inches)  
y = average slope (percent)

4) The **Maximum Hydraulic Length** is estimated by finding the longest path from the microbasin from the following equation:

$$HL_{max} = \frac{A_{mb}}{HL_{avg}} \% HL_{avg}$$

5) The **TIME TO PEAK** discharge is the time from the start of runoff to the peak discharge and is assumed to be related to storm duration, D, and microbasin time lag, T<sub>l</sub>.

$$T_p = \frac{D}{2} + T_l$$

where:

- T<sub>p</sub> = time to peak discharge (hours)
- D = storm duration (hours)
- T<sub>l</sub> = time of concentration (hours)

6) The **TIME BASE** is the total duration of the runoff and is related empirically to T<sub>p</sub>,

$$T_b = 5(T_p)$$

7) The **PEAK FLOW** is estimated based on the area of the microbasin and its respective runoff volume at the time to peak. The constant represents a 256 shape factor for the typical Florida landscape.

$$q_p = \frac{256A_{mb}Q_{mb}}{T_p}$$

where:

- A<sub>mb</sub> = microbasin area (mi<sup>2</sup>)
- Q<sub>mb</sub> = microbasin runoff volume (inches)

As previously mentioned, the first section of the NPS model also generates an average curvilinear pollutograph of the nutrient loadings with respect to time. At each major time ordinate, the flow (QCFS) is interpolated from all the relevant microbasin hydrographs. This interpolated flow (IQ) is multiplied by the respective pollutant concentrations. These products are then added together and divided by the total flow at that time step to determine the weighted average concentrations. The general equation is:

$$C_{sb}(t) = \frac{\sum (SQ_{mb}(C_{mb}))}{\sum SQ_{mb}}$$

where:

- C<sub>sb</sub>(t) = average subbasin nutrient concentration for each constituent varied with time (mg/l)
- SQ<sub>mb</sub> = total flows at each time interval (cfs)
- C<sub>mb</sub> = pollutant concentration (mg/l)

The total nutrient loads, in pounds, are determined in the second section of the NPS model. The runoff volume ( $Q_{mb}$ ), the area ( $A_{mb}$ ), and a conversion factor (144.9664), are multiplied together with the respective pollutant concentrations for each microbasin. These are summed to generate a weighted average total pollutant load for the subbasin.

$$WC_{sb} = \sum_j (15)Q_{mb}A_{mb}C_{mb}$$

## 2.3 Data Requirements

The only input parameters that the user is required to designate are the rainfall depth (in inches), the storm duration (in hours), and the antecedent condition (wet, medium, dry). The GIS will supply all the remaining parameters in the MICCHAR.DAT file. The storm depth, duration, and antecedent condition can be designated for the model using the Lake Tarpon Management Model Interface.

## 2.4 NPS Model Output

The output file of the NPS model that is used by the USF-CMHAS 2D Lake model is named FILENAME.NPS. This file consists of the flows and concentrations for various times for each subbasin, and is fashioned in a format compatible with the 2D model lake model. In addition, simple evaluation of non-point source loading is provided to the user through the output post-processor contained within the interface, or by importation of the \*.NPS file into any spreadsheet software to generate curvilinear hydrographs and pollutographs. All pollutant loading rates and loads for each subbasin are contained in the FILENAME.PLD file. This file is not used by the 2D model and exists strictly for use by the environmental manager to pinpoint and quantify high to low loading basins.

## 3.0 THE USF-CMHAS 2D HYDRAULIC MODEL

### 3.1 Overview

The two-dimensional vertically-integrated hydraulic model used to simulate the circulation in lakes or estuaries was originally developed in 1969 by Dr. Bernard E. Ross at the University of South Florida. Initially the model was used to simulate the hydraulics of Tampa Bay (Ross 1971). The hydraulics model is based on well established methodologies stemming from the original work of Platsman (1968). The work of Reid and Bodine (1968), who used a similar hydraulic model to predict storm surges in Galveston Bay, Texas, and, Miyazaki's (1965) model of the storm surge of hurricane Carla (1961) in the Gulf of Mexico also helped establish the early framework for the USF model.

Over the years, graduate students at the University of South Florida have revised and extended the hydraulic model to increase applicability, speed, and accuracy. Ghioto (1973) formulated most of the original code for application to Tampa Bay. Mass transport in the form of a salinity model (uncoupled, i.e., salinity did not influence the hydraulics) was added to the Fortran code by Schwartz (1972). Linked stormwater runoff calculations were introduced by the work of Copeland (1973), and a basic water quality model was formulated in the same year by Armstrong (1973). The hydraulic model was subsequently linked to the predecessor of the USF-CMHAS 2D water quality model in 1984 (Ross et al 1984). In the 1984 version, the components were run separately and sequentially. Later versions resulted in dynamic coupling of the two codes to reduce run time and storage requirements. The present version allows for simulation of either coupled or sequential hydraulics.

### 3.2 The Equations of Motion and Continuity

The hydraulic model is based on the equations of motion and continuity, which are derived directly from the Navier-Stokes equations for incompressible, viscous flow, and the principle of conservation of mass, respectively. Detailed derivations for the vertical integration of the Navier-Stokes equations for flows that do not exhibit appreciable vertical stratification in density are given in Ross et al (1984). Application of density driven circulation terms have since been added and included in the summary below. The vertically-integrated equations of motion in the x and y Cartesian coordinate directions are:

$$\frac{MU}{M_t} + \frac{1}{D} \frac{MU^2}{M_x} + \frac{1}{D} \frac{MUV}{M_y} + SV + \frac{1}{D} \frac{MP}{M_x} + gD \frac{MH}{M_x} + \frac{gD^2 MD}{D M_x} + X + D \frac{f^* Q^* U}{D^2}$$

$$\frac{MV}{M_t} + \frac{1}{D} \frac{MV^2}{M_y} + \frac{1}{D} \frac{MUV}{M_x} + SU + \frac{1}{D} \frac{MP}{M_y} + gD \frac{MH}{M_y} + \frac{gD^2 MD}{D M_y} + Y + D \frac{f^* Q^* V}{D^2}$$

The vertically-integrated continuity equation is:

$$\frac{\partial H}{\partial t} + \frac{\partial MU}{\partial x} + \frac{\partial MV}{\partial y} = R$$

where:

- t = time (sec)
- x,y = horizontal Cartesian coordinates (southward, eastward)
- U,V = the depth averaged transport components (cfs/ft width) in the x and y directions
- H = height of the water w.r.t NGVD or MLW (ft)
- z<sub>0</sub> = the bottom elevation w.r.t. NGVD or MLW (ft)
- R = source and sink terms (cfs/ft<sup>2</sup>)
- D = total water depth (ft) (H - z<sub>0</sub>)
- D = density of water, which is a function of salinity and temperature (lb/ft<sup>3</sup>)
- P = atmospheric pressure (lb/ft<sup>2</sup>)
- g = the acceleration due to gravity (ft/s<sup>2</sup>)
- X,Y = the x and y components of the wind stress per unit of mass of water (ft<sup>2</sup>/s<sup>2</sup>)
- S = the Coriolis factor (1/s)
- f = the bottom friction factor (dimensionless)
- Q = resultant transport (cfs/ft width)

The above equations are solved to find the height, H(x,y,t), and the depth-integrated transports, U(x,y,t) and V(x,y,t). The transport components are defined by the equations:

$$U(x,y,t) = \int_{Z_0}^H u(x,y,z,t) dz \quad \text{and} \quad V(x,y,t) = \int_{Z_0}^H v(x,y,z,t) dz$$

where:

- u,v = velocity components in the x and y directions (ft/sec)

The continuity equation, which states that a gradient in transport plus external inflows within a system will result in a change in volume with time, results in water level predictions. This is the equation in which sources and sinks are introduced into the model. Examples of sources include inflows from non-point overland flow, groundwater inflows, rainfall, or point sources such as stormwater outfalls, creeks, or

rivers. Sinks, such as withdrawal structures or small outlet canals, can be treated as negative sources.

The equations of motion provide the transport predictions calculated as accelerations caused by a variety of normal and shear stress gradients. Accelerations resulting from gradients in advected momentum, caused by adjacent boundaries or channels, are determined by the first two terms in the right-hand side of the equation. In most cases, convective acceleration terms are quite small in magnitude when compared to the other terms, except in the vicinity of structures or channels where significant velocity gradients exist.

The third term introduces the effects on flow due to the rotation of the earth, i.e., Coriolis accelerations. A Coriolis factor ( $S$ ), which is twice the value of the vertical component of the earth's rotation, is a function of the latitude of the computational point and the angular acceleration of the earth. The Coriolis factor is multiplied by the velocity to determine Coriolis accelerations. The factor,  $S$  is calculated as:

$$S = 2T \sin N$$

where:

- $T$  = the angular velocity of the earth (1 radian/sec)
- $N$  = the latitude of the computational point, ie. node center (degrees)

Accelerations caused by atmospheric pressure gradients are handled by the fourth term in the equation of motion. Such a gradient will result in the movement of water from high to low pressure areas, and an increased water level (surge) in the low pressure region.

The most significant term in the equation of motion is the gradient in water surface introduced by the fifth term. Losses in velocity head at the point of entry of point sources and sinks result in local gradients in elevation head of the water surface. This determines the overall gravitational circulation in the lake.

The sixth term is the minor circulation caused by horizontal density gradients associated with temperature and/or salinity differences.

The drag force that wind exerts on the water surface of the lake is introduced in the seventh term of the equation of motion. Stresses on the water surface due to the wind can be attenuated or strengthened depending upon several complex factors, including variability of wind speed and wave energy, that are difficult to model. Fortunately, the most significant factor influencing wind driven circulations, the wind speed, is commonly measured and easily included in the model equations (Fischer et al 1979). The USF-CMHAS 2D hydraulic model uses wind speed to calculate the effect of surface shear on transport based on the work by Van Dorn (1953):

$$X' = KW^2 \cos(\theta)$$

$$Y' = KW^2 \sin(\theta)$$

where:

- ( = the angle between the wind velocity vector and x-axis
- W = the magnitude of the wind velocity
- K = a non-dimensional wind friction variable

For a wind velocity (W) that is less than the critical wind velocity (usually about 10 mph), then  $K = 1.1 \times 10^{-6}$ . For  $W > W_c$ , then K is found using the equation below:

$$K = K_1 + K_2 \left(1 + \frac{W_c}{W}\right)^2$$

where:

- $K_1 = 1.1 \times 10^{-6}$
- $K_2 = 2.5 \times 10^{-6}$

The last term introduces the effects of bottom friction on transport. The friction factor (f) in the transport equation is calculated by:

$$f = \frac{gn}{(1.49)^2 D^{\frac{1}{3}}}$$

where:

- n = Manning's roughness coefficient
- g = the acceleration due to gravity (32.2 ft/s<sup>2</sup>)
- D = water depth (ft)

In the USF-CMHAS 2D hydraulic model, Manning's coefficient is calculated as a function of depth for both the x and y directions using the Reynolds number. The Reynolds number is also determined within the model based on average depth and convective accelerations. Manning's n is determined by:

$$n = \frac{g \bar{U}^2}{(1.486)^2 D^{\frac{4}{3}}}$$

where:

- $\bar{U}$  = the Reynolds number

and 1.486 is a conversion factor from metric to English units.

### 3.3 Numerical Solution of the Equations

To use the equations of motion, continuity, and nutrient transport in a simulation of an aquatic system, a conversion must be made from the differential form of the equations to a more usable discrete algebraic form that is solved numerically (ie., by computer). This method of solution, called finite differencing, allows results to be calculated in discrete elements. Conversion of the equations of motion and continuity to the finite difference solution can be found in Ross et al (1984). Basically, the model is an explicit finite difference form written to capitalize on the array processing capabilities of the new vector processors.

To solve the numerical equations in a two-dimensional model, the study area must first be broken into discrete elements of time and space. Transforming the continuous nature of a waterbody to a discrete system involves superimposing a grid, with cell lengths and widths,  $DX$  and  $DY$ , over the study area. Each cell in the grid has a location defined by  $I$ , increasing north to south, and  $J$ , increasing west to east. Input data (bottom elevation, SOD/NER) and results (transports, height, concentrations) will be specified by  $I, J$  location. The bottom and water surface elevations,  $Z(I, J)$  and  $H(I, J)$  respectively, are defined in the center of each grid. The transport  $U(I, J)$  is defined to be positive southward, originating at the north edge of the cell, and  $V(I, J)$  is positive when moving in the eastward direction and originates from the west edge. Terms affecting these transports in the  $x$  and  $y$  directions, such as friction and depth are defined on the same edge as the respective transport. Sources and sinks are applied in the center of the cell, as they directly affect the height (Devine 1991).

An explicit numerical method is used to solve the equations of motion and continuity (Reid and Bodine 1968). Explicit solutions require that  $H(I, J)$ ,  $U(I, J)$ , and  $V(I, J)$  determined at the each timestep, be calculated from values determined at the beginning of the timestep. However, the numerical solutions to the equations of motion and continuity are not conveniently solved simultaneously, i.e.,  $H(I, J)$  cannot be solved at the same time as  $U(I, J)$  and  $V(I, J)$ . Therefore,  $H(I, J)$  at time  $t+DT$  is found from  $H(I, J)$  at time  $t$  and transports  $U(I, J)$  and  $V(I, J)$  calculated at time  $t$ . Then,  $U(I, J)$  and  $V(I, J)$  at time  $t+DT$  are calculated from  $U(I, J)$ ,  $V(I, J)$  at time  $t$  and  $H(I, J)$  determined at time  $t+1DT$  (Devine 1991). To illustrate this further, the continuity equation, as it appears in the model code, is shown below:

$$H(I, J)^{t+1} = H(I, J)^t + DT \frac{U(I, J)^t + U(I, J)^t}{DX} \\ + DT \frac{V(I, J)^t + V(I, J)^t}{DY} + DT R(I, J) \frac{DX}{DY}$$

An explicit scheme requires that the timestep,  $DT$ , for the hydraulic model, must be small enough to ensure numerical stability. Therefore,  $DT$  should be smaller than the time it takes a wave to travel through the grid. For two-dimensional flows with different grid dimensions in the  $x$  and  $y$  directions, the following stability condition (the CFL condition) must be satisfied:

$$DT \# \frac{DX}{U_{\max} \sqrt{2gD_{\max}}} \quad \text{and} \quad DT \# \frac{DY}{V_{\max} \sqrt{2gD_{\max}}}$$

where:

g = the acceleration due to gravity (ft/sec<sup>2</sup>)  
D<sub>max</sub> = the maximum depth in the grid cell (ft)

### 3.4 Features of the Hydraulic Model

The USF-CMHAS Hydraulic model has several features to expand application of the model. First, the model has a particle tracking routine which calculates the location of a particle initially placed at a user-specified location in the model grid. This routine keeps a record of the particle path throughout the duration of the simulation, and thus enables the model user to follow the circulation in the water body.

Another property of the hydraulic model is the capability to incorporate sub-grid features into the hydrodynamic calculations. Sub-grid features may represent structures, channels, or obstructions in the waterbody that are smaller than the grid size but produce an appreciable change in transport. Examples include causeways, islands, weirs, dams, bridge pilings, and docks. The user must specify the number of sub-grid features, as well as the location and dimension of each.

The hydraulic model is also capable of incorporating inlets, canals, and other flow constricting structures into the model grid with a partial land routine. This feature allows the user to designate which grid cells are positioned on the canal shoreline and have both water and land within the cell. The location and percentage of land in the cell must be designated by the user (see Section 5.2).

The hydraulic model may be used to simulate flow through a tidal or nontidal water body. For tidally-driven water bodies, the location of open-water segments must be designated by the user. A time-series of tides as well as time lags, leads, and amplitude-adjustment parameters for the tide function must be specified (see Section 4.2).

### 3.5 Hydraulic Model Output

The output of the hydraulic model consists of water level, H(I,J), velocity and direction (U(I,J,t) and V(I,J,t)) at user selected time intervals. These values can be displayed for every grid (map form), or at specific locations within the lake. To produce mapped output, the user must specify the time interval (in hours) at which results are to be written to the map output file, FILENAME.HMP. The time interval input variable, [THPRNT], is contained in the hydraulic data set. Hydraulic output can also be produced for specific locations within the waterbody and contained in the FILENAME.PTS file. These stationary observation points, called VQMETERS, must be identified by (I,J) grid location in the HYDQUAL.DAT file. Again, the user must specify the time interval (in hours) at which to write the output file with the input variable [VQMETER]. All user-specified parameters described in this paragraph are discussed in detail in Chapter 5.0 of this report.

## 4.0 THE USF-CMHAS 2D WATER QUALITY MODEL

### 4.1 Overview

The USF-CMHAS 2D Water Quality Model was first developed at the Department of Civil Engineering and Mechanics at the University of South Florida in the early 1980's (Ross et al 1984). Originally driven by output from the hydraulic model, requiring separate simulations and large disk storage, the two codes have been linked, thereby greatly reducing the run times. The water quality model includes all of the important chemical processes of the phosphorus and nitrogen cycles, as well as biological process related to phytoplankton nutrient uptake and release, nutrient recycling, and oxygen dynamics. It also simulates benthic processes and a measure of the overall condition of the waterbody via a trophic state index routine. Much of the framework of the model was derived from a comprehensive review of the state-of-the-art in water quality modeling, published by the USEPA (1985).

### 4.2 Mass Transport Equation and Numerical Solution

The water quality model is based upon the vertically-integrated mass transport equation. A derivation and detailed discussion of this equation starting with a basic mass balance is presented in Ross et al (1984). The two-dimensional mass transport equation is shown below:

$$\frac{MC}{M_t} + \frac{1}{D} \left( \frac{M}{M_x} (DE_x \frac{MC}{M_x}) \right) - \frac{1}{D} \left( \frac{M}{M_y} (DE_y \frac{MC}{M_y}) \right) + U \frac{MC}{M_x} + V \frac{MC}{M_y} - \frac{M_p}{D} - \frac{N_p}{D}$$

where:

C = vertically-averaged concentration

U = vertically-averaged transport in the x-direction

V = vertically-averaged transport in the y-direction

E<sub>x</sub>, E<sub>y</sub> = dispersion coefficients

M<sub>p</sub> = vertically-averaged external source/sink flux

N<sub>p</sub> = vertically-averaged internal source/sink flux (rate of production or decay)

The first two terms in the mass transport equation represent the net diffusive/dispersive flux. Diffusion is the movement of a constituent due to turbulent mixing caused by wind, waves, and currents,

and dispersion is the additional mixing that occurs from the finite grid scale and timesteps used in the model. The dispersion coefficients that are used in the USF-CMHAS 2D Lake Model are very simple formulations that incorporate the effects of both current and wind induced mixing, simply:

$$E = E_C + E_W$$

where:

$E_C$  = the current-induced mixing coefficient (ft<sup>2</sup>/sec)

$E_W$  = the wind-induced mixing coefficient (ft<sup>2</sup>/sec)

The current mixing coefficient ( $E_C$ ) is calculated using an equation similar to one derived by Holley and Harleman (1965) for longitudinal flow. In the model, homogeneous turbulence is assumed so that the final current-induced diffusivity equations for the x- and y-directions become:

$$E_{C_x}(i,j) = K n_{ij}^5 u_{R_{ij}}^5 D_{ij}^{-5/6}$$

where:

$$E_{C_y}(i,j) = E_{C_x}(i,j)$$

K = a coefficient between 0 and 100

D = the water depth (ft)

$u_R$  = the resultant velocity  $(u^2 + v^2)^{1/2}$

n = Manning's roughness coefficient

The wind-induced diffusivity is determined following an equation developed by Elder (1959) for two dimensional, steady, uniform flow in an infinitely wide channel. Elder's relationship was originally formulated to describe the diffusivity in terms of the shear stress along the wall of the channel. However, it has been speculated that the diffusivity resulting from application of the wind shear to the free surface can be determined as simply:

$$E_W = 5.9D \sqrt{\frac{J_w}{D}}$$

where:

$J_w$  = the wind-induced shear stress at the surface (ft<sup>2</sup>/sec)

D = the mass density of the water (lbm/ft<sup>3</sup>)

The square root term is commonly referred to as the shear velocity, having units of length/time. The stress felt by the upper layers of the water surface is a function of many complex factors that are extremely difficult to model including the wind variability, the length of the fetch, and wave development and dissipation. Fortunately, the largest influence is the wind speed, which is an input parameter to most water quality models. Fischer et al (1979) gives the following equation for calculating the wind-induced shear stress:

$$J_w = C_D D_A W^2$$

where:

- $C_D$  = a dimensionless drag coefficient
- $D_A$  = the density of air (lbm/ft<sup>3</sup>)
- $W$  = the velocity of the wind (ft/sec)

The drag coefficient incorporates the effects on wind shear due to all of the more complex parameters mentioned previously. The value of  $C_D$  has been found to be constant at a value of  $1.0 \times 10^{-3}$  for wind speeds below the critical value of 16.4 ft/sec, and to vary linearly between  $1.0 \times 10^{-3}$  and  $1.5 \times 10^{-3}$  for velocities between 16.4 and 49.2 ft/sec, respectively. When speeds are greater than the critical value, the model calculates the new drag coefficient using the following equation:

$$C_{D_{new}} = (C_D) \left( \frac{W}{W_c} \right)^5$$

where:

- $C_D$  =  $1.0 \times 10^{-3}$
- $W_c$  = the critical wind speed

The third and fourth terms in the depth-averaged mass transport equation are the advective transport terms, and represent the amount of constituent that is being moved into or out of the system by the depth-averaged transport. This motion is caused by currents, wind, and inflows or outflows to the system (Ross et al 1984). The transports used to move the aquatic constituents are calculated by the hydraulic model and have been discussed previously. The last two terms represent the sources and sinks, and vary depending upon the chemical or biological parameter modeled. These terms are be discussed in detail later in this documentation.

Like the hydraulic model, the numerical solution to the mass transport equation is determined using a finite difference method. The solution is developed using the grid system outlined in the documentation of the hydraulic model. The concentration,  $C(I,J)$ , and the dispersion coefficients,  $E_x(I,J)$ , and  $E_y(I,J)$ , are defined in the center of the grid, while transports are described on the north-south and east-west edges. Point and non-point source concentrations and chemical and biological processes are applied directly to  $C(I,J)$ . The conversion of the numerical equation from the differential form is presented in Ross et al (1984).

In general, the timestep for the water quality model is not the same as that used in the hydraulic

model. Again, the timestep must be small enough to ensure numerical stability for the model. In this case stability dictates that a parcel of water should not pass through the grid before the model updates the finite difference solution. Therefore, DT should be smaller than the time it takes a particle to travel through the grid. For two-dimensional flows, the following conditions must be satisfied:

$$DT < \frac{DX}{U_{\max}} \quad \text{and} \quad DT < \frac{DY}{V_{\max}}$$

## 4.3 Discussion of Constituents Modeled

The following section is a detailed discussion of the source/sink terms of the mass transport equation for all constituents simulated in the water quality model. Some concepts, such as point and non-point sources, settling, and temperature dependence exist in almost all of the mass transport equations and are handled in the same way for each constituent. Instead of discussing these for every constituent a general documentation of each concept is below.

### 4.3.1 Point Sources

Point sources are calculated simply as:

$$Q_C = \sum_{s=1}^S q_s C_s$$

where:

- $Q_C$  = source rate of constituent (mg/l-ft/sec)
- $q_s$  = specific discharge of source or sink  $s$  (ft/sec)
- $C_s$  = concentration of constituent in  $s$  (mg/l)
- $S$  = the number of sources within a grid

The source rate ( $Q_C$ ) is added to a single grid in the model, however multiple point sources can exist in one location. Point sources can be time-varying, in which case the model will perform linear interpolation between the user specified times, flows, and concentrations. In this capacity, the model can use measured hydrographs and pollutographs as input. If only one time and flow is specified, the source is considered to be constant throughout the simulation period. For negative sources (i.e., sinks) the user is not required to specify concentrations as the model uses concentrations calculated at the sink location. All data values are specified in the "FILENAME.PS" input file.

### 4.3.2 Non-Point Sources

Non-point source hydrographs and pollutographs are calculated by the NPS Loading Model and contained in the FILENAME.NPS file. The water quality model reads-in the discharge and concentration for each subbasin, as well as the subbasin/lake boundary locations determined by the GIS. Q's and C's are specified at up to 30 points in time for each constituent. The user may either assign equal distribution to the lake model grids that receive runoff from a subbasin or define a percentage array in order to distributed runoff unequally (see Section 5.1.7).

### 4.3.3 General Temperature Dependence

To correct temperature dependent parameters an exponential response is assumed (i.e., growth, decay, consumption, or uptake increases exponentially with temperature increase). First, the maximum rate is determined using a reference temperature of 20EC. The temperature correction coefficient then adjusts this maximum rate for the ambient temperature of the surface water system. For all temperature dependent parameters, the correction coefficient and the ambient temperature are specified by the user (see Chapter 5.0). The temperature corrected rate or coefficient is found using the Arrhenius equation (USEPA 1985):

$$R(T) = R(20) \cdot 2^{(T-20)/10}$$

where:

- R(T) = temperature corrected rate or coefficient
- 2 = temperature correction coefficient
- T = ambient temperature (EC)

### 4.3.4 General Settling

Settling is included as a sink for almost all of the constituents modeled. Most water quality models, including the USF-CMHAS 2D, rely on literature or measured values for the rate best suited to the parameter modeled. This user specified settling rate is multiplied by the concentration of the constituent to determine the total loss due to settling.

### 4.3.5 ALGAE (A)

To simulate algal dynamics in a lake, a model must incorporate as many as possible of the external physical, chemical, and biological parameters that affect algae growth and death. While technology has not advanced enough for the inclusion of all factors that affect algae growth, the most significant ones are utilized, if even in a very simplistic way. The USF-CMHAS model includes such physical parameters as

temperature, physical transport, and sunlight. Chemical and biological parameters included are the limiting nutrients and zooplankton consumptive mortality.

To add to the complexity of algal processes, many species of phytoplankton exist which differ in internal physical and biological characteristics. The USF-CMHAS model simulates the dynamics of the total phytoplankton population and, after calibration for overall lake conditions, has no capacity to distinguish between algal species. All rates and constants used to simulate algae should be indicative of values for total phytoplankton.

### Temperature Dependence

The ambient temperature of the water affects the algae concentration by influencing growth and respiration rates, and zooplankton grazing rates. As explained previously, temperature corrections for all of these parameters are performed using the Arrhenius relationship explained previously in this report.

Total algae is modeled using the vertically-integrated mass transport equation shown:

$$\frac{M(AD)}{M_t} = \left( \frac{M(UA)}{M_x} + \frac{M(VA)}{M_y} \right) - \left( \frac{M}{M_x} (E_x \frac{M(AD)}{M_x}) + \frac{M}{M_y} (E_y \frac{M(AD)}{M_y}) \right) - \mu AD - D_r AD - F_s A - D_{gz} AD$$

where:

- A = depth-averaged concentration of algae (mg/l)
- D = total water depth (ft)
- $\mu$  = temperature dependent specific growth rate of algae (1/day)
- $D_r$  = temperature dependent respiration rate of algae (1/day)
- $F_s$  = settling rate of algae (1/day)
- $D_{gz}$  = temperature dependent grazing rate of zooplankton on algae (1/day)

The generation and decay of algae biomass in the mass transport equation are presented in the last four terms. These terms are the sources and sinks of algae, and constitute the difference between gross growth and net growth (or growth minus death).

## Growth

Algal growth ( $\mu$ ) is a function of a user defined maximum growth rate adjusted by temperature, the availability of light, and limiting nutrients, simply:

$$\mu = \mu_{\max} f(T) f(L) f(N, P)$$

where:

$\mu_{\max}$  = maximum algal growth rate at 20°C (1/day)

$f(T)$  = temperature correction factor for algal growth

$f(P, N)$  = growth limiting function for available phosphorus and nitrogen nutrients

$f(L)$  = growth limiting function for light

The modeling of algae growth as shown above is in a multiplicative form, and any inhibition of growth should be represented in this equation. A multiplicative approach assumes that the decrease in several of the limiting factors will cause a more drastic reduction in growth than would a decrease in just one of the growth dependent parameters.

## Limiting Nutrients

Florida waterbodies are unique from northern lakes in that primary productivity is limited by nitrogen as well as phosphorus (Brezonik 1976). Nutrient bioassays performed on phytoplankton existing in Lake Tarpon have confirmed this (Vargo 1991). In the USF-CMHAS model, the limiting nutrients are ammonia, nitrate, and ortho-phosphate, which are the forms taken directly into the algal cell.

The calculation of the nutrient limitation factors for nitrogen and phosphorus are based on standard Michaelis-Menten kinetics which assume a hyperbolic growth curve. The Michaelis-Menten nutrient limitation equation is:

$$\mu = \mu_{\max} \left( \frac{S}{K_s + S} \right)$$

where:

$S$  = concentration of limiting nutrient (mg/l)

$K_s$  = nutrient half-saturation constant (mg/l)

The half-saturation constant included in this equation is defined to be the concentration of the limiting nutrient at which the algal growth rate is exactly one-half the maximum value. At high nutrient concentrations the limitation coefficient will approach a value of one and algae growth will proceed at nearly

the maximum rate. At very low nutrient concentrations, the half-saturation constant in the denominator will greatly decrease the growth rate, demonstrating the limiting effects. Half-saturation constants are specified by the model user.

## Light

The effects of light upon algal growth are calculated using a combination of the Beer-Lambert law which describes the attenuation of light due to depth and algal shading, and the Steele Formulation which determines the effect of light levels on photosynthesis. The latter equation is the most commonly used photoinhibition relationship, and is based on a curve in which the growth rate increases linearly at low light intensities and then peaks at some optimum light level. As solar intensity increases beyond this peak, growth begins to decrease as photosynthesis is inhibited (USEPA 1985).

$$I = I_o e^{-k(d)}$$

The Beer Lambert Law:

$$f(L) = \frac{I}{I_s} \left( 1 + \frac{I}{I_s} \right)$$

The Steele Formulation:

The resulting depth integrated equation used in the model is:

$$f(L) = \frac{ef_p}{(d)} \left( e^{-\frac{I_o}{I_s} k(d)} - e^{-\frac{I_o}{I_s} k(d)} \right)$$

where:

- $f_p$  = photoperiod or time of daylight (hundredths)
- $($  = light extinction coefficient constant (1/day)
- $d$  = depth (ft)
- $I_o$  = average light intensity at the surface (Langley/day)
- $I_s$  = saturation light intensity (Langley/day)

The light extinction coefficient ( $($ ) is a constant that accounts for the attenuation of light due to

$$( = (o \% c_1 A$$

turbidity in the water caused not only by algae, but other suspended matter as well. It is calculated as follows:

where:

$C$  = light extinction coefficient for suspended matter other than algae (1/ft)

$c_1$  = light extinction coefficient relating for algal shading (1/ft)

$A$  = algae concentration (mg/l)

## **Respiration**

Respiration is defined to be the non-predatory death of algae and is considered an important process in the return of organic nutrient forms to the inorganic pool (USEPA 1985). With algae respiration, additional organic matter becomes available for chemical/bacteriological oxidation, thereby significantly contributing to carbonaceous oxygen demand. In the USF-CMHAS model, respiration is simulated with a user-defined, temperature dependent respiration rate, which is multiplied by the algae concentration to determine the total loss.

## **Predatory Mortality**

As algal predators are not explicitly modeled, such losses are incorporated in the model by assuming that zooplankton consumption of algae is directly proportional to the phytoplankton concentration. Simply, an increased presence of algae biomass in the food chain will be met with increased algal losses due to predatory grazing. A user-specified, temperature dependent zooplankton grazing rate is multiplied by the algae concentration to determine predatory losses.

### 4.3.6 Chlorophyll-a (Chl-a)

The concentration of chlorophyll-a (that which is contained within the algae biomass only) can be calculated as a function of the total algae biomass, simply:

$$(CHL) = \alpha_{CHL} A$$

where:

CHL = concentration of chlorophyll-a ( $\mu\text{g/l}$ )

$\alpha_{CHL}$  = ratio of chlorophyll-a to the total algae biomass  
( $\mu\text{g Chl-a/mg A}$ )

A = depth averaged algae concentration ( $\text{mg/l}$ )

The user must specify the chlorophyll-a/algae biomass ratio.

### 4.3.7 Carbonaceous Oxygen Demand (CBOD)

Biochemical Oxygen Demand (BOD) is a measure of the oxygen need of the aquatic system. Oxygen is used in the oxidation of both carbonaceous and nitrogenous waste materials, and for micro and macrophyte respiration (Thomann and Mueller 1987). If high levels of aquatic plants, organics, and ammonia exist in the sediments and/or water column, BOD will increase and lead to a decline in aquatic health.

Because oxygen is used for both carbonaceous and nitrogenous materials, BOD is often divided into two separate fractions: (1) a carbonaceous BOD (CBOD) which measures the amount of oxidizable organics present, and (2) nitrogenous BOD (NBOD) which represents the amount of oxidizable nitrogen. The USF-CMHAS water quality model simulates CBOD explicitly and NBOD via the nitrogen balance. Sources include both point and non-point inflows and algal matter not assimilated by zooplankton, while sinks consist of settling and carbonaceous oxidation (decay) processes. While the NBOD is not explicitly included, nitrification (the oxidation of ammonia to nitrite to nitrate) is simulated in both the ammonia and nitrate subroutines.

The CBOD is typically measured using a test which indicates the amount of oxygen utilized over a 5-day test period (CBOD5). The results can then be converted to the ultimate CBOD (CBODU), which is used in the modeling equations. CBOD5 is converted to CBODU using the following equation:

$$C_U = (C_5) / (f_{U/5})$$

where:

$C_U$  = ultimate CBOD concentration ( $\text{mg/l}$ )

- $C_5$  = 5-day CBOD concentration (mg/l)
- $f_{U/5}$  = ratio of CBODU to CBOD5 (mg CBODU/ mg CBOD5)

In the model the  $f$  ratio is defined by the user.

The effects of low dissolved oxygen concentrations on CBOD decay are handled by a low DO correction factor ( $f_1$ ) that is based on the Michaelis-Menten formulation described previously for limiting nutrients, simply:

$$f_1 = \frac{O}{O + K_o}$$

where:

- $O$  = depth averaged dissolved oxygen concentration (mg/l)
- $K_o$  = oxygen half-saturation constant for CBOD decay (mg/l)

As with limiting nutrients, the half-saturation constant is specified by the model user.

As stated previously, the oxygen demand exerted by algal matter unassimilated by zooplankton is included. Not all of the algae consumed by the predator is successfully assimilated in the organism's intestine, thus the organics and nutrients released back into the water column are available for participation in oxidation and other chemical reactions proceeding in the water column (USEPA 1985). (This mechanism is an important pathway for nutrient recycling in aquatic systems, and it is included not only in the CBOD calculations, but throughout this model.) In the simulation, the amount of phytoplankton consumed by zooplankton is calculated and then decreased by the amount successfully assimilated using a user-specified assimilation efficiency parameter. The remaining, unassimilated matter is considered available for oxidation.

### Temperature Dependence

The ambient temperature of the water affects the CBOD by influencing algae respiration rates, zooplankton grazing rates, and carbonaceous oxidation rates. Temperature corrections for all of these parameters are performed using the Arrhenius relationship described previously in this report.

The vertically-integrated mass transport equation for ultimate carbonaceous biochemical oxygen demand is shown below:

$$\frac{M(CD)}{M_t} + \frac{M(UC)}{M_x} + \frac{M(VC)}{M_y} = \frac{M}{M_x} (E_x \frac{M(CD)}{M_x}) + \frac{M}{M_y} (E_y \frac{M(CD)}{M_y})$$

$$Q_c f_1 C_{CD} + F_c C^0 (1 - O_z) D_G = C^0 AD$$

where:

- $C$  = vertically-averaged concentration of ultimate carbonaceous biochemical oxygen demand (CBOD)(mg/l)
- $D$  = water depth (ft)
- $Q_C$  = source rate of CBOD from point and non-point sources and sinks (mg/l-ft/sec)
- $f_i$  = low dissolved oxygen correction factor for the decay of CBOD
- $\$C$  = temperature dependent first-order decay rate of CBOD due to oxidation (1/day)
- $F_C$  = settling rate of CBOD (1/day)
- $O_Z$  = zooplankton assimilation efficiency (mg assim/mg grazed)
- $D_G$  = temperature dependent zooplankton grazing rate(1/day)
- " $c$  = fraction of algae biomass that is carbon (mg C/mg A)
- $A$  = vertically averaged algae concentration (mg/l)

### 4.3.8 The Phosphorus Cycle

Phosphorus is one of the most important nutrients required for zooplankton and phytoplankton growth. While most parts of the world have only modest amounts of naturally occurring phosphorus, Florida sediments contain large deposits which can consistently elevate concentrations in lakes and receiving waters. More importantly, urbanization has greatly added to the concentrations of phosphorus in receiving waters through stormwater and wastewater effluent, in many cases increasing the trophic status (Kramer 1972).

The USF water quality model simulates two forms of phosphorus, dissolved organic phosphorus (OrgP) and inorganic orthophosphorus, ( $PO_4$ ). In the aqueous phosphorus cycle, dissolved inorganic forms are converted to organic compounds primarily through assimilation of  $PO_4$  by algae and eventual release of OrgP during algal respiration. The cycle is completed as the OrgP is transformed back to  $PO_4$  through various chemical and biological mechanisms (Mitchell 1974 and Thomann and Mueller 1987). All three of these steps in the cycle are included in the model.

#### Temperature Dependence

The ambient temperature of the water affects phosphorus concentrations by influencing algae growth and respiration rates, zooplankton grazing rates, decay, and uptake rates. Temperature corrections

are made using the Arrhenius relationship described previously in this report.

### Organic Phosphorus (OrgP)

The USF-CMHAS model does not distinguish between dissolved and particulate fractions of nutrients, thus the OrgP simulated should be regarded as a total value. Sources include point and non-point inputs, as well as OrgP released into the water column after algal respiration or zooplankton assimilation. Sinks include decay to PO<sub>4</sub> and settling. The vertically-integrated mass transport equation for OrgP is:

$$\frac{M(P_1 D)}{M_t} = \frac{M(UP_1)}{M_x} + \frac{M(VP_1)}{M_y} + \frac{M}{M_x} (E_x \frac{M(P_1 D)}{M_x}) + \frac{M}{M_y} (E_y \frac{M(P_1 D)}{M_y})$$

where:

$$\frac{M(P_1 D)}{M_t} = \frac{Q_{P_1}}{D} + \frac{O_Z}{D} A + \frac{D_G}{D} P_1 + \frac{\$_{P_1}}{D} P_1 + \frac{F_{P_1}}{D} P_1$$

P<sub>1</sub> = vertically-averaged concentration of organic phosphorus (mg/l)

D = water depth (ft)

Q<sub>P1</sub> = source rate of organic phosphorus from point and non-point sources and sinks (mg/l-ft/sec)

O<sub>Z</sub> = fraction of algae biomass which is P (mg P/mg A)

D = temperature dependent respiration rate of algae (1/day)

A = vertically-averaged concentration of algae (mg/l)

O<sub>Z</sub> = zooplankton assimilation efficiency (mg asm/mg grazed)

D<sub>G</sub> = temperature dependent zooplankton grazing rate (1/day)

\$<sub>P1</sub> = temperature dependent first-order decay rate of organic phosphorus to orthophosphate (1/day)

F<sub>P1</sub> = settling rate of organic phosphorus (1/day)

### Orthophosphate (PO<sub>4</sub>-P)

The modeling of orthophosphate includes sources such as point, and non-point inflows, and benthic exchange, and the decay of organic phosphorus to PO<sub>4</sub>. The only sink modeled is the assimilation of PO<sub>4</sub> by algae. The vertically-integrated mass transport equation for orthophosphate is:

$$\frac{M(P_2D)}{Mt} + \left( \frac{M(UP_2)}{M_x} - \frac{M(VP_2)}{M_y} \right) - \frac{M}{M_x} (E_x \frac{M(P_2D)}{M_x}) - \frac{M}{M_y} (E_y \frac{M(P_2D)}{M_y})$$

$$Q_{P_2} - \frac{P_2 D}{O_{P_2}} \mu A$$

where:

- P<sub>2</sub> = vertically-averaged concentration of orthophosphorus (mg/l)
- D = water depth (ft)
- Q<sub>P<sub>2</sub></sub> = source rate of orthophosphate from point and non-point sources and sinks (mg/l-ft/sec)
- \$<sub>P<sub>1</sub></sub> = temperature dependent first-order decay rate of organic phosphorus to orthophosphate (1/day)
- O<sub>P<sub>2</sub></sub> = benthic source rate for orthophosphate (mg P/m<sup>2</sup>/day)
- " = fraction of algae biomass which is P (mg P/mg A)
- μ = temperature dependent algae growth rate (1/day)
- A = vertically-averaged concentration of algae (mg/l)

### 4.3.9 The Nitrogen Cycle

One of the principal limiting nutrients in Florida waters is nitrogen. The USF-CMHAS model includes the three nitrogen forms which most directly affect primary productivity: (1) organic nitrogen (OrgN), (2) ammonia (NH<sub>3</sub>), and (3) nitrite-nitrate (NO<sub>2</sub>-NO<sub>3</sub>) which are modeled jointly. Three pathways in the nitrogen cycle are incorporated in the source and sink terms of the transport equation for these nutrients. The first pathway is the assimilation of NH<sub>3</sub> and NO<sub>3</sub> by phytoplankton, converting inorganic to organic forms. Second, upon algal respiration or zooplankton excretion, the process of

ammonification converts OrgN to NH<sub>3</sub>. The final pathway used in the model is nitrification, or the oxidation of NH<sub>3</sub> to NO<sub>2</sub> and eventually NO<sub>3</sub>.

### Nitrogen Assimilation (NO<sub>3</sub> or NH<sub>3</sub> to OrgN)

A fixed stoichiometry approach is used to simulate nitrogen uptake by the algae community. It is assumed that the nutrient composition of the algal cell remains constant, therefore nutrient uptake is directly proportional to the algae concentration in the water column. In this way the rate of nutrient uptake only increases at times of algal growth. The equation for nitrogen uptake is simply:

$$\frac{MN}{M_A} \cdot \gamma \cdot \mu_N \mu A D$$

where:

- N = nitrogen assimilated (mg/l)
- γ = ammonia preference factor
- μ<sub>N</sub> = fraction of algae biomass which is nitrogen (mg N/mg A)
- μ = algae growth rate at 20EC (1/day)
- A = concentration of algae (mg/l)
- D = water depth (ft)

Ammonia is the preferred form of nitrogen for algal consumption. During the model simulation, the two nutrients are prioritized using an ammonia preference factor, γ, which partitions the uptake of nitrogen between NH<sub>3</sub> and NO<sub>3</sub> (USEPA, 1985). γ is calculated using the following equation:

$$\gamma = \frac{N_2}{(N_2 \% (1 + \epsilon) N_3)}$$

where:

- N<sub>2</sub> = vertically-averaged ammonia concentration (mg/l)
- N<sub>3</sub> = vertically-averaged nitrite-nitrate concentration (mg/l)
- ε = preference rate of ammonia over nitrate (hundredths)

### Ammonification (OrgN to NH<sub>3</sub>)

The process of ammonification returns organic nitrogen to the inorganic nitrogen pool as ammonia, and is simulated with the organic nitrogen release during algal respiration and zooplankton excretion. This process is modeled using first order kinetics as a decay of organic nitrogen to ammonia, thus is included as a sink of OrgN and a source of NH<sub>3</sub>. The modeling equation is simply:

$$\frac{MN_1}{M_t} = \$_{N_1} N_1 D$$

where:

$N_1$  = vertically-averaged concentration of organic nitrogen as nitrogen (mg/l)

$\$_{N_1}$  = temperature dependent first-order decay rate of organic nitrogen to ammonia (1/day)

$D$  = water depth (ft)

### Nitrification (NH<sub>3</sub> to NO<sub>2</sub>-NO<sub>3</sub>)

Nitrification is a two-stage process which converts reduced forms of nitrogen to more oxidized forms. Nitrifying bacteria first oxidize ammonia to create nitrite, then other species of bacteria further oxidize the nitrite to nitrate. Many models, including the USF model, reduce these two reactions to a one-stage approach which assumes that all nitrite will be converted to nitrate (USEPA 1985). Nitrification is simulated as a decay of ammonia resulting in the joint constituent nitrite-nitrate (NO<sub>2</sub>-NO<sub>3</sub>). (This nomenclature is a reminder of the single reaction approach.) Since first-order kinetics are used, the need to explicitly include the nitrifying bacteria population is eliminated (Thomann and Mueller 1987). This population is included indirectly in the decay rate, which is indicative of the rate of oxidation performed by the microorganisms.

In the USF-CMHAS model, the rate of decay of ammonia is dependent upon the ambient temperature and the amount of ammonia and oxygen available. To account for the reduction in nitrification when oxygen concentrations are limited, a low DO correction factor based on the Michaelis-Menten formulation is included (USEPA 1985 and Brezonik 1972). Like the half-saturation constants for the nutrient limitation of algal growth,  $K_O$  must be specified by the model user. The equation for the low DO correction factor is below:

$$f_2 = \frac{O}{O + K_O}$$

where:

$f_2$  = low dissolved oxygen correction factor for nitrification

$O$  = depth average concentration of dissolved oxygen (mg/l)

$K_O$  = oxygen half-saturation constant for nitrification (mg/l)

Nitrification is simulated in the USF model using the equation below:

$$\frac{MN_2}{M_t} = f_2 \$_{N_2} N_2 D$$

where:

$N_2$  = vertically-averaged concentration of ammonia as N(mg/l)

$f_2$  = low-dissolved oxygen correction factor for decay of  $NH_3$

$\$_{N_2}$  = temperature dependent rate of biological oxidation of  $NH_3$  to nitrate (1/day)

$D$  = water depth (ft)

## Temperature Dependence

The ambient temperature of the water affects the concentration of all nitrogen forms by influencing algae growth and respiration rates, zooplankton consumption rates, decay and uptake rates. Any parameter in the transport equations that are described as being temperature dependent are corrected using the Arrhenius relationship described previously in this report.

## Organic Nitrogen (OrgN)

Sources of OrgN includes benthic, point and non-point, and that released during algal respiration and after zooplankton feeding. Sinks include ammonification and settling. As the model does not distinguish between dissolved and particulate fractions nutrients, all concentrations OrgN should be regarded as a total value. The vertically-integrated mass transport equation for OrgN is:

$$\frac{M(N_1 D)}{Mz} \cdot \left( \frac{M(UN_1)}{Mx} + \frac{M(VN_1)}{My} + \frac{M}{Mx} \left( E_x \frac{M(N_1 D)}{Mx} \right) + \frac{M}{My} \left( E_y \frac{M(N_1 D)}{My} \right) \right)$$

$$\frac{Q_{N_1}}{N_1} \left( 1 - \mu_z \right) D_G - \mu_{N_1} A D + F_{N_1} N_1 D$$

where:

$N_1$  = vertically-averaged concentration of organic nitrogen as nitrogen (mg/l)

$D$  = water depth (ft)

$Q_{N_1}$  = source rate of organic nitrogen from point and non-point sources (mg/l-ft/day)

$\mu_{N_1}$  = fraction of algae biomass which is N (mg N/mg A)

$D$  = temperature dependent respiration rate of algae (1/day)

$A$  = vertically-averaged concentration of algae (mg/l)

$\mu_z$  = zooplankton assimilation efficiency (mg assim/mg grazed)

$D_G$  = temperature dependent zooplankton grazing rate on algae (1/day)

$\mu_{N_1}$  = temperature dependent first-order decay rate of organic nitrogen to ammonia (1/day)

$F_{N_1}$  = settling rate of organic nitrogen (1/day)

### Ammonia (NH<sub>3</sub>)

The simulation of NH<sub>3</sub> includes processes such as assimilation, ammonification, nitrification, settling, and benthic exchange. Point and non-point sources are also included. The vertically-integrated mass transport equation for ammonia is:

$$\frac{Q_{N_2}}{N_2} - \mu_{N_2} N_2 D + f_2 \mu_{N_2} N_2 D + \mu_{N_2} A D + F_{N_2} N_2$$

where:

$N_2$  = vertically-averaged concentration of ammonia as N (mg/l)

- D = water depth (ft)
- $Q_{N_2}$  = source rate of ammonia from point and non-point sources (mg/1-ft/day)
- $\$_{N_1}$  = temperature dependent first-order decay rate of organic nitrogen to ammonia (1/day)
- $f_2$  = low-dissolved oxygen correction factor for decay of ammonia
- $\$_{N_2}$  = temperature dependent rate of biological oxidation of ammonia to nitrate (1/day)
- $O_{N_2}$  = benthic source rate for ammonia (mg N/m<sup>2</sup>/day)
- $a$  = ammonia preferential consumption factor
- $\mu$  = temperature dependent algae growth rate (1/day)
- $''_N$  = fraction of algae biomass which is N (mg N/mg A)
- A = vertically-averaged concentration of algae (mg/l)
- $F_{N_2}$  = settling rate of ammonia (1/day)

### Nitrite-nitrate (NO<sub>2</sub>-NO<sub>3</sub>)

Nitrite-Nitrate is simulated with the inclusion of processes such as assimilation, nitrification, and benthic exchange. Point and non-point sources of NO<sub>2</sub>-NO<sub>3</sub> are included. The vertically-integrated mass transport equation for nitrate is:

$$\frac{M(N_3D)}{M_t} + \left( \frac{M(UN_3)}{M_x} + \frac{M(VN_3)}{M_y} \right) \frac{M}{M_x} (E_x \frac{M(N_3D)}{M_x}) + \frac{M}{M_y} (E_y \frac{M(N_3D)}{M_y})$$

$$= Q_{N_3} + f_2 \$_{N_2} N_2 D + O_{N_3} (1 + a) ''_N \mu A D$$

where:

- $N_3$  = vertically-averaged concentration of nitrate as N (mg/l)
- D = water depth (ft)

- $Q_{N3}$  = source rate of nitrate from point and non-point sources (mg/l-ft/day)
- $f_2$  = low-dissolved oxygen correction factor for decay of ammonia
- $\$_{N2}$  = temperature dependent rate of biological oxidation of ammonia to nitrate (1/day)
- $O$  = benthic source rate for nitrate (mg N/m<sup>2</sup>/day)
- $a$  = ammonia preferential consumption factor
- $\mu$  = temperature dependent algae growth rate (1/day)
- $''_N$  = fraction of algae biomass which is N (mg N/mg A)
- $A$  = vertically-averaged concentration of algae (mg/l)

### 4.3.10 Dissolved Oxygen (DO)

The amount of dissolved oxygen (DO) in a waterbody is commonly used as an indicator of trophic state. Low concentrations of DO indicate high oxygen demand and possibly a eutrophic environment. In the USF-CMHAS model, sources of DO include point and non-point inputs, reaeration from the atmosphere, and the oxygen produced during algal photosynthesis. DO sinks consist of algal respiration, oxygen demand from the benthic community, CBOD, and nitrification.

#### Temperature Dependence

The ambient temperature of the water affects the DO concentration by influencing algae growth rates, reaeration rates, and oxidation rates. Temperature corrections for all of these parameters are performed using the Arrhenius relationship.

The mass transport equation for dissolved oxygen is:

$$\frac{M(OD)}{M_t} + \frac{M(UO)}{M_x} + \frac{M(VO)}{M_y} - \frac{M}{M_x} (E_x \frac{M(OD)}{M_x}) - \frac{M}{M_y} (E_y \frac{M(OD)}{M_y})$$

$$+ k_r (O_s - O) D - \mu A D + \mu_{(OR)} D A D$$

$$+ f_1 \$_C C D + f_2 \mu_{(ON)} \$_{N2} D + O_0$$

where:

- $O$  = vertically-averaged concentration of oxygen (mg/l)
- $D$  = water depth (ft)
- $k_r$  = reaeration rate of oxygen (1/day)
- $O_s$  = saturation concentration of oxygen (mg/l)
- $\mu_{OG}$  = oxygen production per unit algae growth (mg O/mg A)
- $\mu$  = algae growth rate (1/day)
- $A$  = algae concentration (mg A/L)
- $\mu_{OR}$  = oxygen demand per unit of algae respired (mg O/mg A)
- $D$  = algae respiration rate (1/day)
- $f_1$  = low DO correction factor for the decay of CBOD
- $\$C$  = decay of BODC (1/day)
- $C$  = BODC concentration (mg C/L)
- $f_2$  = low DO correction factor for the decay of ammonia
- $\mu_{ON}$  = oxygen demand per unit of ammonia oxidized (mgO/mgN)
- $\$N$  = decay of organic nitrogen to ammonia (1/day)
- $\$N_2$  = decay of ammonia to nitrates (1/day)
- $N_2$  = ammonia concentration (mg  $N_2$ /L)
- $O_O$  = benthic oxygen demand (mg O/L - ft/day)

## Reaeration

Reaeration is the replenishment of the supply of DO in the water column due to transfer of oxygen from the atmosphere across the surface of the water. As seen in the transport equation, reaeration is modeled using an equation which implies that the mass transfer of oxygen across the surface is directly proportional to the difference between the ambient DO and saturation DO concentrations, simply (USEPA 1985):

$$F_O = k_r(O_s - O)$$

where:

- $F_O$  = flux of DO across water surface (mg/area/time)
- $O$  = DO concentration (mg/l)
- $O_s$  = saturation DO concentration (mg/l)
- $k_L$  = reaeration coefficient (length/time)

The saturated DO concentration varies with changes in atmospheric pressure, temperature, and salinity. In Florida it can be assumed that the receiving water is at or very close to sea level, thus the effects of pressure are negligible and need not be considered. The USF-CMHAS model determines  $O_s$  using an equation from the RECEIV-II water quality model developed by Raytheon Company (USEPA 1985):

$$C_s = \exp\left[173.0722 + 21.8492\left(\frac{T}{100}\right) + 249.6339\left(\frac{T}{100}\right) + 143.3483\left(\ln\frac{T}{100}\right) + S(0.033096 + 0.014259\left(\frac{T}{100}\right) + 0.0017\left(\frac{T}{100}\right)^2)\right]$$

where:

- $S$  = salinity concentration (ppt)
- $T$  = temperature (K)

For the simulation of freshwater lakes, the portion of this equation in which saline effects are calculated reduce to zero.

The reaeration coefficient is calculated using the Langbein and Durum equation (USEPA 1985), while wind effects are calculated with the assumption that surface transfer increases as wind velocity increases. The reaeration coefficient is calculated using the equation shown below:

$$k_{20E} = \frac{7.6U}{d^{1.33}} \frac{k_w V_w}{d}$$

where:

- $k_{20}$  = reaeration coefficient at 20EC (1/sec)
- $d$  = depth (ft)
- $U$  = current velocity (ft/s)
- $k_w$  = wind reaeration coefficient (1/sec)
- $V_w$  = wind velocity (ft/s)

### 4.3.11 Trophic State (TSI)

Trophic state indices (TSI) are quantitative scales of the trophic status of a waterbody. The indices were mainly developed to help convey the health of a lake to the general public in manner that is simple and easy to understand, and to assist environmental managers in decisions that will affect aquatic systems. Most of the indices that have been developed use the physical, chemical, and biological characteristics of the waterbody that traditionally have been used to describe aquatic health as trophic indicators. The USF water quality model calculates trophic state using a TSI based on an index developed by Carlson (1977) for the classification of northern lakes. The Carlson index was revised for application to Florida lakes by researchers at the University of Florida (Huber et al 1982).

The index used in the USF-CMHAS model is based upon the most useful and common measurement of trophic state, phytoplankton. This algal-based TSI comprised of trophic indicators such as chlorophyll-a, Secchi depth, and limiting nutrients which have been mathematically related to algae growth through a series of regression relationships. Derived using data from 573 Florida lakes, the index was scaled such that a doubling in algae growth would correspond to a 10 unit increase in trophic state.

The chl-a TSI was determined by regression analyses with algae and chl-a data, simply:

$$TSI(Chla) = 10(1.68 + 1.44\ln Chla)$$

where Chla is the chlorophyll-a concentration in  $\mu\text{g/L}$ .

The nutrient TSI can be calculated for phosphorus limited, nitrogen limited, or nutrient balanced lakes. The LTMM user must specify which nutrient based TSI is to be used in the model interface.

Phosphorus limited TSI:

$$TSI(TP) = 10(2.36\ln TP + 2.38)$$

where TP is total phosphorus concentration in  $\mu\text{g/L}$ .

Nitrogen limited TSI:

$$TSI(TN) = 10(5.96 - 2.15 \ln TN)$$

where TN is the total nitrogen concentration in mg/l.

The nutrient-balanced TSI is calculated using the following set of equations:

$$TSI(TNB) = 10(5.6 - 1.98 \ln TN)$$

$$TSI(TPB) = 10(1.86 \ln TP + 1.84)$$

and

$$TSI(N\&bal) = 0.5[TSI(TNB) + TSI(TPB)]$$

The same type of regression analysis performed with Secchi depth and chl-a data yielded the final index:

$$TSI(SD) = 10(6.0 - 3.0 \ln SD)$$

where SD is Secchi depth in meters.

This method of calculating the TSI(SD) has been criticized because it is based on the assumption that algae is the dominant cause of light absorption in the water column. However, many Florida lakes are naturally colored due to detritus and other organics or wetland runoff, which would make suspended substances other than algae the major light inhibition factor. To create an index that is more sensitive to other causes of light attenuation, a relationship that relates the Secchi depth to an overall light extinction coefficient is used in the USF-CMHAS 2D model. As stated in Section 4.3.10, the water quality program calculates the light extinction coefficient with consideration to both algal shading effects and any other light absorbent materials in the water column, simply:

$$C = C_o + c_1 A$$

where:

- $C_0$  = light extinction coefficient for suspended matter except algae (1/ft)
- $c_1$  = light extinction coefficient relating algae concentration and shading (1/ft/mg algae)
- $A$  = algae concentration (mg/l)

The relationship between SD and the overall light extinction has been documented by Brown (1984) and Thomann and Mueller (1987). This equation is:

$$SD = \frac{\ln\left(\frac{I}{I_0}\right)}{C_0 + c_1 A}$$

where:

$I/I_0$  = the percentage of light penetration at the Secchi depth

This equation and the light extinction calculation are combined in the USF-CMHAS 2D Lake Model to determine the value of SD that is used for the Secchi depth index. The value of %L can vary greatly depending upon the function of the waterbody. For solid waste streams and highly turbid waters where only 10-20% of the total light penetrates to the Secchi depth, %L can range from 2.3 to 1.6. For most lakes used for recreational purposes (those without overt turbidity problems), %L will have a lower value.

In the USF-CMHAS 2D Model, %L and the light extinction coefficients are user-specified. Due to the variability in the cause of turbidity in Florida lakes, all of these values are extremely site specific and it is highly recommended that they be determined experimentally. However, if laboratory analysis is not possible, these coefficients can be found using the above two equations and several on-site measurements of SD and algae concentration that have been taken at various times during the year. Still, another equation is needed to find the value of the overall light extinction (Brown 1984). This expression is simply:

$$\text{euphotic zone} = 1\% \text{ light depth} = \frac{4.6}{C}$$

Brown states that a good estimate of the euphotic zone is approximately three to four times the measured Secchi depth. However, in most shallow Florida lakes the entire depth of the lake can be considered as residing within the euphotic zone. The result of the above equation ( $C$ ) can then be inserted into the Secchi depth/light extinction relationship to determine %L. Finally, the light extinction components can be found using two forms of this relationship, simply:

$$C_o = \left( \frac{\%L}{SD} + c_1 \right) A$$

$$c_1 = \left( \frac{\%L}{SD} + C_o \right) \frac{1}{A}$$

If algae concentration has not been measured, then chlorophyll-a data can be converted with the user-specified chl-a/algae biomass ratio that must be designated in the water quality data set (see Section 5.3.5).

For the final calculation of the trophic state of the lake, the three subindices, TSI(SD), TSI(chl-a), TSI(nutr), are calculated at every water quality model timestep and averaged to obtain an overall TSI in each grid. This approach uses the assumption that statistically each indicator contributes equally to the variability in the overall TSI.

From the standpoint of trophic state terminology, the Huber TSI only differentiates between non-eutrophic and eutrophic lakes. Because many different interpretations of trophic nomenclature exist and there is no widely accepted numerical scale for each class, Huber refrained from giving separate trophic levels in the index a title (e.g., mesoeutrophic, oligoeutrophic). Even without the benefit of class names, this strictly numerical index is simply scaled and can be easily understood. In general, major trophic states are delineated at every ten units (i.e., 10, 20, 30, etc...), and any number below 60 is considered non-eutrophic. To define this cut-off value, Huber used individual indicator values that were considered indicative of eutrophication. For example, the Florida Department of Environmental Regulation considers a chlorophyll-a concentration of 20 mg/m<sup>3</sup> as the "desirable upper limit", which gives a TSI(chl-a) value of 60. Table 1.8 displays indicator values for each trophic level.

**Table 1.8** TSI Indicator Values for Trophic Levels\*

TSI(i)	chl-a (µg/l)	SD (m)	TP limited	TN limited	balanced	balanced
			TP (µg/l)	TN (mg/l)	TP (µg/l)	TN (mg/l)
0	0.3	7.4	2.7	0.06	2.7	0.06
10	0.6	5.3	4.1	0.10	4.6	0.10
20	1.3	3.8	6.3	0.16	7.9	0.16
30	2.5	2.7	9.6	0.25	13.5	0.27
40	5.0	2.0	15.0	0.40	23.0	0.45
50	10.0	1.4	23.0	0.64	39.5	0.74
60	20.0	1.0	34.0	1.02	67.7	1.23
70	40.0	0.72	52.0	1.62	116.0	2.04
80	80.0	0.51	80.0	2.58	198.0	3.4
90	160.0	0.37	122.0	4.11	340.0	5.6
100	320.0	0.26	185.0	6.54	581.0	9.3

\* Source: Huber et al, "A Classification for Florida Lakes, 1982, (modified)

## 4.4 Water Quality Model Output

The water quality model is capable of producing both mapped and specific location output for all constituents modeled. The mapped output consists of the concentration of constituent in each grid within the lake and is contained in the FILENAME.QMP file. The user can specify which constituents are to be mapped in the model run with the logic input variable [LOUT] which must be designated for all constituents in the water quality model (see "Water Quality Model Logic Parameters"). The variable [LOUT] must be given a value of either 1, map concentrations, or 0, no map output. The user can also specify the time interval to produce concentration maps with the input variable [TQPRNT] (see "Section 5.3.1").

Specific locations within the waterbody, called VQMETERS, can be designated as stationary points at which depths, velocities and directions, and concentrations of all constituents are observed. For example, in the preliminary model runs of Lake Tarpon, the post-storm event stations were designated as VQMETERS and all output was compared to actual measured data. Again, the user must specify the time interval at which to write the output file, FILENAME.PTS, with the input variable [VQMETER]. In addition, the user must designate the name and I,J location of the observation point (see "Common Model VQMETER Parameters").

A water quality summary file, FILENAME.QSM, that tabulates the chemical and biological processes that occurred during the model run is also produced as model output. A total value, summed

throughout the model run, for growth, respiration, decay, settling, production, benthic sources, and point/non-point sources is displayed for all applicable constituents.

## **5.0 USF-CMHAS 2-D MODEL DATA REQUIREMENTS**

The USF-CMHAS 2D model input data is distributed between three main data files: (1) HYDQUAL.DAT, the hydraulic/water quality common data set, (2) HYD.DAT, the hydraulic model data set, and (3) QUAL.DAT, the water quality model data set. All of these main data files include temporal parameters to specify modeling and output times and logic parameters that turn a feature of the model on or off. In addition, point and non-point source information is detailed in the FILENAME.PS and FILENAME.NPS files.

### **5.1 Common Model Data**

The HYDQUAL.DAT file contains all parameters that are used by both the hydraulic and water quality models. The first 8 characters in the first line of the common data set define the FILENAME of the hydraulic simulation. The remaining characters in the first line are comments. All input specifications are listed in the FILENAME.OUT file.

In the common data set, the size of the model grid and the date and duration of simulation are specified, sources (point/non-point) are designated, and model output locations are assigned. All common input parameters are listed and described on the next few pages. Tables with a brief description of parameters and sources from which they can be obtained are provided as well.

## 5.1.1 Temporal Parameters

**Table 1.9** Common Model Temporal Parameters

PARAMETER NAME	DESCRIPTION	Lower Limit	Upper Limit
NYR	year of simulation	N/A	N/A
NMON	starting month of simulation	1	12
NDAY	starting day of simulation	1	31
NHR	starting hour of simulation	0	23
NMIN	starting minute of simulation	0	59
RUNTIME	duration of simulation (hours)	0	N/A
STARTUP	time of simulation to start producing output (model time)	0	runtime
TMETER	time interval (hours) to output VQMETER data	0	N/A

<b>NYR</b>	The starting year of simulation.
<b>NMON</b>	The starting month of simulation.
<b>NDAY</b>	The starting day of simulation.
<b>NHR</b>	The starting hour of simulation.
<b>NMIN</b>	The starting minute of simulation.
<b>RUNTIME</b>	The duration of simulation in hours. The RUNTIME parameter specifies the total hours of simulation.
<b>STARTUP</b>	The time to start producing output.
<b>TMETER</b>	The time interval in hours to output VQMETER data. (See Section 5.1.4)

## 5.1.2 Logic Parameters

Logic parameters are used to turn a feature on (1) or off (0) in the model. This is provided to save time when certain options are not necessary for a simulation.

**Table 1.10** Common Model Logic Parameters

PARAMETER NAME	DESCRIPTION	Lower Limit	Upper Limit
		0=OFF	1=ON
LHYD	logic variable to omit hydraulic model simulation	0	1
LQUAL	logic variable to omit water quality model simulation	0	2
LSRC	logic variable to omit point sources	0	1
LNPS	logic variable to omit non-point sources	0	1
LNPSAR	logic variable to omit non-point source location array	0	1

**LHYD** A logic variable to omit hydraulic simulation. A value of 0 turns the hydraulic model off. A value of 1 allows hydraulic simulation to proceed. Note: if the user omits the hydraulic simulation, a hydraulic output file must be included to run the water quality model (see LUIN in section 5.2.2).

**LQUAL** A logic variable to control water quality simulation. A value of 0 turns the water-quality model off. A value of 1 allows the water quality simulation to proceed with all constituents. A value of 2 allows the water quality simulation to proceed with salinity only (ie., hydraulics with density circulation).

**LSRC** A logic variable to omit point sources. A value of 0 turns the point-source routines in both the hydraulic and water quality models off. A value of 1 allows point sources to be included. Note: if the user omits point sources, then point source parameters do not need to be designated for simulation. If a value of 1 is specified, then these parameters must exist within the FILENAME.PS file, created with the aid of the interface preprocessor (see section 5.1.6).

**LNPS** A logic variable to omit non-point sources. A value of 0 turns the non-point source routines in both the hydraulic and water quality models off. A value of 1 allows inclusion of non-point sources. Note: if the user omits non-point sources, then NPS parameters do not need to be designated for simulation. If a value of 1 is specified, then these parameters must exist within the FILENAME.NPS file, created by the NPS or other stormwater runoff model. The user has the option to append this file (see section 5.1.7).

**LNPSAR** A logic variable to omit the non-point source location array. A value of 0 signifies that the array should not be read as data input. A value of 1 allows the array to be read as data. The non-point source location array is created by the GIS.

### 5.1.3 Spatial Parameters

Spatial parameters describe the grid orientation, size, and shape, thus establishing the spatial dimensionality of the model.

**Table 1.11** Common Model Spatial Parameters

PARAMETER NAME	DESCRIPTION	Lower Limit	Upper Limit
M	number of rows in model grid (in the x-direction)	1	140
N	number of columns in model grid (in the y-direction)	1	110
DX	north-south grid size (ft)	N/A	N/A
DY	east west grid size (ft)	N/A	N/A
RLAT	latitude of the northwest corner of the grid (decimal degrees)	0	90
AECLKW	angle of grid clockwise (north from true north)	0	360

- M** The number of rows in the model grid corresponding to the x-direction (positive vertically downward) and U velocity component. M may not exceed 140.
- N** The number of columns in the model grid corresponding to the y-direction (positive from left to right) and V velocity component. N may not exceed 110.
- DX** The north-south grid cell size in feet. Note: if the grid cell size is changed, then the timesteps for both the hydraulic and water quality models must be reviewed and changed if needed (see DTHYD in section 5.2.1 and/or DTQUAL in section 5.3.1).
- DY** The east-west grid cell size in feet. Note: if the grid cell size is changed, then the timesteps for both hydraulic and water quality models must be reviewed and changed if needed (see DTHYD in section 5.2.1 and/or DTQUAL section 5.3.1).
- RLAT** The latitude (in decimal degrees) of the northwest corner of the grid.
- AECLKW** The angle (in decimal degrees) of the grid north (negative x-axis) from due north. Clockwise is considered positive for this angle.

## 5.1.4 VQMETER Parameters

A VQMETER is defined as a stationary observation point within the model grid at which both hydraulic and water quality output is recorded. A VQMETER can exist at any grid cell within water body, but location and angle must be specified by the user. The model limits the number of VQMETER's designated during a simulation to thirty.

**Table 1.12** VQMETER Parameters

	DESCRIPTION	Lower Limit	Upper Limit
NVQPTS	number of VQMETERs	0	30
IJNAME(L)	name of VQMETER (L)	N/A	N/A
IVQPTS(L)	I grid cell location for VQMETER, L	0	M
JVQPTS(L)	J grid cell location for VQMETER, L	0	N
KVQPTS(L)	k grid cell face for VQMETER, L	0	4
ANGLE(L)	compass direction for positive flow for VQMETERs (degrees)	0	360

- NVQPTS** The number of VQMETER's designated for the simulation. NVQPTS cannot be larger than 30. If NVQPTS is 0, then the following variables do not need to be included in the data set.
- IJNAME** The user-defined, four-character identification name and/or number of the individual VQMETER's.
- IVQPTS** The I (north to south) grid cell location of the VQMETER.
- JVQPTS** The J (west to east) grid cell location of the VQMETER.
- KVQPTS** The K side location of the VQMETER (1=top, 2=left, 3=bottom, 4=right, 0=center). K values may be assigned as either positive or negative numbers. If K is negative, main and secondary channel velocities are reported separately in the output files. If K is positive, the average velocity across the entire width of the cell face is reported (average of the main channel, secondary channel, and barrier velocities, if applicable). If K is 0, the average of the velocities and direction at each of the four faces is reported as output.
- ANGLE** If K=0, an angle must be defined by the user in order to establish the direction of positive flow. If the ray at the specified angle is plotted on a compass rose, then the line perpendicular to the plotted ray divides positive from negative flow directions. For

example, if ANGLE is equal to 90, then all velocity directions from 0 to 180 degrees will be considered positive flows (e.g., inflows) and velocity directions between 180 and 360 degrees will be negative (e.g., outflows).

## 5.1.5 Wind Parameters

Winds are applied in the hydraulic and water quality models at user-designated times throughout the simulation. The user must specify the time, speed, and angle of the wind. Winds are applied over the entire model grid.

**Table 1.13** Common Model Wind Parameters

PARAMETER NAME	DESCRIPTION	Lower Limit	Upper Limit
NWPTS	number of times when wind is specified for the run	0	200
WT	time (K) of wind (model time)	N/A	N/A
WS	wind speed at time K (knots)	0	N/A
WA	compass angle from where the wind blows at time K (decimal degrees)	0	360

**NWPTS** The number of times during the simulation that wind is specified. The times do not have to be at regular intervals, as the model linearly interpolates the winds between specified times. If NWPTS is 0, then the following variables do not need to be included in the data set.

**WT** The time of the wind condition in hours.

**WS** The speed of the wind at WT in knots.

**WA** The compass angle of the wind in decimal degrees. This angle is measured from the direction the wind blows, NOT the direction that the wind is blowing.

## 5.1.6 Point Source Parameters

Point sources and sinks (PS) are defined as a flow into or out of the water body at a specific location. Examples include stormwater outfall pipes, power plant intake pipes, and dams or gates. In the USF-CMHAS 2D model, sinks are defined as negative point sources (i.e., a negative discharge). Point sources are added to the lake in a single grid cell, however more than one source can exist in a cell. A maximum of 60 point sources can be designated for a simulation. For each point source, an identification number, grid-point location, and time-varying flow rates and concentrations must be

designated by the user. All point source information is contained in the FILENAME.PS file. Each point source can have up to 15 records describing the discharge and concentration as a function of time. The model will perform linear interpolation between the user-specified times, flows, and concentrations.

**Table 1.14** Point Source Parameters

PARAMETER NAME	DESCRIPTION	Lower Limit	Upper Limit
NUMPS	point source identification number	1	60
IPS(L)	I grid location of point source L	0	M
JPS(L)	j grid location of point source L	0	N
TIME(K,L)	time (K) of point source discharge L (hours)	0	runtime
QPS(K,L)	discharge value at time K of point source L (cfs)	0	N/A
QPSC(K,L)	point source, L, concentration of algae (mg/l)	0	N/A
QPSP(K,L)	point source, L, concentration of BODCU (mg/l)	0	N/A
QPSPO4(K,L)	point source, L, concentration of OrgP (mg/l)	0	N/A
QPSN(K,L)	point source, L, concentration of PO <sub>4</sub> (mg/l)	0	N/A
QPSNH3(K,L)	point source, L, concentration of NH <sub>3</sub> (mg/l)	0	N/A
QPSNO3(K,L)	point source, L, concentration of NO <sub>2</sub> -NO <sub>3</sub> (mg/l)	0	N/A
QPSOX(K,L)	point source, L, concentration of DO (mg/l)	0	N/A
QPSBOD5(K,L)	point source, L, concentration of BODC5 (mg/l)	0	N/A

- NUMPS** The point source identification number. If NUMPS does not change, the model will continue to linearly interpolate for flows and concentrations. Therefore, the last point source in the model will remain constant if Q's and C's do not have a value of zero. It is suggested that an extra point source, with the flow and all concentrations having a value of 0, be added at the end of the .PS file to eliminate any possibility of error.
- IPS** The I (north to south) grid cell location of the point source (L).
- JPS** The J (west to east) grid cell location of the point source (L).
- TIME** The time (K) of the point source discharge in hours. This time is designated as X number of hours after the start of the simulation.
- QPS** The discharge of the point source, L, at time, K, in cfs.
- QPSC** The point source, L, concentration of CBODU in mg/l.
- QPSP** The point source, L, concentration of OrgP in mg/l.
- QPSPO4** The point source, L, concentration of PO<sub>4</sub> in mg/l.

<b>QPSN</b>	The point source, L, concentration of OrgN in mg/l.
<b>QPSNH3</b>	The point source, L, concentration of NH <sub>3</sub> in mg/l.
<b>QPSNO3</b>	The point source, L, concentration of NO <sub>2</sub> -NO <sub>3</sub> in mg/l.
<b>QPSOX</b>	The point source, L, concentration of DO in mg/l.
<b>QPSBOD5</b>	The point source, L, concentration of CBOD5 in mg/l.

## 5.1.7 Non-point Source Parameters

In the USF-CMHAS model, a non-point source is defined as the overland flow resulting from rainfall runoff. Non-point sources can be added at just one grid or several, depending upon the size of the subbasin outfall. As stated previously, the NPS Model determines the hydrographs and pollutographs and assigns them to the subbasin from which they originate. The 2D model performs a linear interpolation between the flows and concentrations determined by the NPS model.

The user has the capability to change the non-point source data contained in the FILENAME.NPS file. Non-point sources must be defined by location, time, flow, and concentration.

**Table 1.15** Non-Point Source Parameters

PARAMETER NAME	DESCRIPTION	Lower Limit	Upper Limit
KSRC(L)	non-point source, L, type (runoff, rainfall, or groundwater)	0	N/A
NSRC(L)	non-point source, L, identification number	0	35
I(L)	I grid location of non-point source L	0	M
J(L)	J grid location of non-point source L	0	N
TIME(K,L)	time, K, of non-point source, L, discharge (model time)	0	runtime
Q(K,L)	discharge of non-point source L (cfs)	0	N/A
CA(K,L)	non-point source, L, concentration of algae (mg/l)	0	N/A
CC(K,L)	non-point source, L, concentration of BODCU (mg/l)	0	N/A
CP(K,L)	non-point source, L, concentration of OrgP (mg/l)	0	N/A
CPO4(K,L)	non-point source, L, concentration of PO <sub>4</sub> (mg/l)	0	N/A
CN(K,L)	non-point source, L, concentration of OrgN (mg/l)	0	N/A
CNH3(K,L)	non-point source, L, concentration of NH <sub>3</sub> (mg/l)	0	N/A
CNO3(K,L)	non-point source, L, concentration of NO <sub>2</sub> -NO <sub>3</sub> (mg/l)	0	N/A
COX(K,L)	non-point source, L, concentration of DO (mg/l)	0	N/A

**KSRC** The type of non-point source, L. In the future, the model will identify and model different types of non-point sources (e.g., rainfall, runoff, or groundwater). At this point in time however, this feature is not available.

**NSRC** The user-defined identification number of non-point source, L.

<b>I</b>	The I (north to south) grid location of non-point source, L.
<b>J</b>	The J (west to east) grid location of non-point src, L.
<b>TIME</b>	The time, K, of non-point source, L, discharge condition.
<b>Q</b>	The discharge of the non-point source at TIME.
<b>CA</b>	The non-point source, L, algae concentration in mg/l.
<b>CC</b>	The non-point source, L, CBOD concentration in mg/l.
<b>CP</b>	The non-point source, L, OrgP concentration in mg/l.
<b>CPO4</b>	The non-point source, L, PO <sub>4</sub> concentration in mg/l.
<b>CN</b>	The non-point source, L, OrgN concentration in mg/l.
<b>CNH3</b>	The non-point source, L, NH <sub>3</sub> concentration in mg/l.
<b>CNO3</b>	The non-point source, L, NO <sub>2</sub> -NO <sub>3</sub> concentration in mg/l.
<b>COX</b>	The non-point source, L, DO concentration in mg/l.

### 5.1.8 Common Model Arrays

The only array that must be defined for the common model data set contains the locations of the non-point source loading subbasins. Multiple grid locations can receive the same non-point source as overland flow can enter the lake at various locations. The model takes the nps conditions (flows, concentrations, and outfall subbasin number) at the lake shore and divides the loading by the number of grids existing in the subbasin.

**Table 1.16** Common Model Arrays

PARAMETER NAME	DESCRIPTION	Lower Limit	Upper Limit
NPSLOC(I,J)	non-point source location array	M	N
NSPRCNT(I,J)	non-point source percent array	M	N

**NPSLOC(I,J)** The non-point source subbasin grid locations. This array directs the flow from the subbasins (calculated by the NPS model) into the model lake grids that receive flow from the designated subbasins. The NPSLOC(I,J) is generated by the GIS and placed into the HYDQUAL.DAT file by the data preprocessor. The model user can omit use of this array with the LNPSAR logic variable (see LNPSAR in section 5.1.2).

**NPSPRCNT(I,J)** The non-point source percent array will allow the user to divide flow unequally among grids existing in the subbasin. At this time, input of the non-point source percent array is not available.

## 5.2 Hydraulic Model Data

The USF-CMHAS 2D hydraulic model requires specification of model timestep and output time intervals, bottom elevations, sub-grid features (i.e., gates and partial land grids), particle tracking points, and tidal, water level, or flow data definition for each open water boundary. In addition, several logic parameters are included in the hydraulics data set that can turn-on calculations of lower order terms in the equations of motion, thus decreasing simulation times. All hydraulic model input parameters are listed and described on the next few pages. Tables with a brief description of parameters and sources from which they can be obtained are provided as well.

### 5.2.1 Temporal Parameters

The temporal parameters for the hydraulic model set model timesteps and output intervals.

**Table 1.17** Hydraulic Model Temporal Parameters

PARAMETER NAME	DESCRIPTION	Lower Limit	Upper Limit
DTHYD	hydraulic model timestep (seconds)	0	N/A
TDAVG	time between updates of average depth (hours)	0	N/A
TMANN	time between updates of Manning's friction coefficient (hours)	0	N/A
TFRIC	time between updates of friction terms (hours)	0	N/A
THPRNT	time between hydraulic output reports (hours)	0	N/A
TUVD	time between updates of velocity and depth output (hours)	0	N/A
TTROUT	time between particle tracking output (hours)	0	N/A

**DTHYD** The hydraulic model timestep in seconds. To ensure model stability, DTHYD must conform to the stability criteria described in section 4.3, namely:

$$DT < \frac{DX}{U_{\max} \%2\sqrt{gD_{\max}}} \quad \text{or} \quad DT < \frac{DY}{V_{\max} \%2\sqrt{gD_{\max}}}$$

<b>TDAVG</b>	The time between updates of average depth in hours. TDAVG should be a multiple of DTHYD and a fraction of the water quality timestep, DTQUAL. It is not necessary, especially in more static waterbodies such as lakes, to calculate average depth at every timestep. To decrease model simulation times, depth can be calculated at time intervals specified by TDAVG. If TDAVG is zero or one, depths are updated each timestep (see DTQUAL in section 5.3.1).
<b>TMANN</b>	The time between updates of Manning's friction coefficient in hours. TMANN should be a multiple of DTHYD. It is not necessary, especially in more static waterbodies such as lakes, to calculate Manning's n every timestep. To decrease model simulation times, Manning's n is calculated at time intervals specified by TMANN.
<b>TFRIC</b>	The time, in hours, between updates of the friction terms in the numerical solution of the equations of motion. TFRIC should be a multiple of DTHYD. It is not necessary, especially in more static waterbodies such as lakes, to calculate the effects of friction every timestep. To decrease model simulation times, friction terms are updated at time intervals specified by TFRIC.
<b>THPRNT</b>	The time between production of the mapped hydraulic output in hours. THPRNT should be some multiple of DTHYD. Due to computer disk storage constraints, hydraulic map output should not be written to the map output file frequently unless the run is a short diagnostic simulation. Also, a voluminous amount of output may be generated which is relatively useless for static waterbodies such as lakes. To decrease the amount of output to a reasonable and useful quantity, hydraulic results are written to a file at relatively infrequent time intervals specified by THPRNT.
<b>TUVD</b>	The time between updates of velocity and depth output reports in hours. TUVD should be some multiple of DTHYD. It is not necessary, especially for more static waterbodies such as lakes, to keep continuous records of UVD's. To decrease the amount of UVD output to a reasonable and useful quantity, results are written to a file at infrequent time intervals specified by TUVD.
<b>TTROUT</b>	The time between particle tracking point output in hours. TTROUT should be some multiple of DTHYD. It is not necessary to update particle movement in the waterbody every interval when using short timesteps, therefore tracking output is calculated less frequently to save computer run time at time intervals specified by TTROUT (See section 5.2.3 for more information).

## 5.2.2 Logic Parameters

Logic parameters are used to turn a feature on (1) or off (0) in the model. This is provided to save time when certain options are not necessary for a simulation.

**Table 1.18** Hydraulic Model Logic Parameters

PARAMETER NAME	DESCRIPTION	Lower Limit	Upper Limit
		0=OFF	1=ON
LDRY	logic variable to check for grids going dry	0	1
LCONV	logic variable to omit convective terms	0	1
LCOR	logic variable to omit Coriolis terms	0	1
LUIIN	logic variable to specify UVD input (0, 1, 2) see LUVD section 6.2.2	0	2
LBAR	logic variable to omit baroclinic terms	0	1
LTIDE	logic variable to omit tides	0	1

**LDRY** A logic variable for dry grid cells. If LDRY equals 1, the model checks for dry cells (i.e., due to low water levels) and activates an error trapping feature. Basically, all cells are tested to find any that have a water level of less than 0.01 ft. If so, the dry cells are "shut off" to save computer run time until the water level returns to over 0.01 ft. If LDRY equals 0, then the model does not check for dry grid cells, allowing numerical errors (division by zero) to occur at dry grid locations.

**LCONV** A logic variable for the convective terms in the numerical solution of the equations of motion. In many waterbodies, the convective terms do not significantly affect the overall circulation and can be neglected, at a great time savings. If LCONV equals 0 the convective terms are omitted. A value of 1 provides for the calculation of the terms (see section 3.2 for an explanation of the convective terms).

**LCOR** A logic variable for the Coriolis terms in the numerical solution to the equation of motion. In small waterbodies Coriolis accelerations do not greatly affect the overall circulation and can be neglected. A value of 0 for LCOR omits the Coriolis terms, and a value of 1 provides for the inclusion of the terms (see section 3.2 to refer to the Coriolis terms).

**LUIIN** A logic variable to designate the use of UVD input files. A value of 0 omits the use of UVD output. A value of 1 signifies that a UVD output file should be written at the end of a simulation. A value of 2 specifies that a UVD file should be read for model restart and appended to the final results when the simulation is complete.

**LBAR** A logic variable to omit or include baroclinic terms. If the baroclinic terms are included, the water quality model must be turned on because variations in salinity must be simulated.

**LTIDE** A logic variable designating tidal conditions, i.e., whether tides are specified for the waterbody. If LTIDES has a value of 1, then tidal parameters are included in the data file, and the tide function is activated in the model. A value of 0 signifies that there is no tidal boundary in the waterbody, and tidal parameters do not need to be specified. However,

if LTIDE is equal to 0, the water level parameter, HSTART, needs to be designated by the model user. (For more information see Section 5.2.6.)

### 5.2.3 Particle Tracking Parameters

The USF-CMHAS 2D model has the capability to track Lagrangian particle movement within the waterbody as the simulation proceeds. The user must specify the initial location of the particle, as well as the time to start tracking (for more information, see Section 5.4).

**Table 1.19** Particle Tracking Parameters

PARAMETER NAME	DESCRIPTION	Lower Limit	Upper Limit
NTRPTS	number of tracked particles	0	30
TRNUM	particle identification number	0	30
TT(I)	time to begin particle tracking for particle, I	0	runtime
ITR(I)	I grid location of particle, I	0	M
JTR(I)	J grid location of particle, I	0	N
XT(I)	location (x-direction) within starting grid of tracked particle, I (ft)	0	DX/2
YT(I)	location (y-direction) within starting grid of tracked particle, I (ft)	0	DY/2

- NTRPTS** The number of tracking points. NTRPTS cannot be larger than thirty. If NTRPTS is set to 0, then the following variables do not need to be included in the data set.
- TRNUM** The particle identification number (from 1 to 30).
- TT(I)** The starting time for tracking of the particle in hours.
- ITR(I)** The starting I, column, (north to south) grid location for the particle.
- JTR(I)** The starting J, row, (west to east) grid location for the tracing particle.
- XT(I)** The location within the grid cell of the particle from the grid cell node in the x-direction in feet. The maximum/minimum allowable value is  $\pm DX/2$ .
- YT(I)** The location within the grid cell of the particle from the grid cell node in the y-direction in feet. The maximum/minimum allowable value is  $\pm DY/2$ .

## 5.2.4 Gate Parameters

A gate is a sub-grid detail which decreases the cross-sectional area of a grid cell and results in obstruction of flow on one or more cell boundaries. Examples of gates include barriers such as bridge pilings and oyster bars, or channels cut through shallow water. The user must specify the location and size of the gate.

**Table 1.20** Gate Parameters

PARAMETER NAME	DESCRIPTION	Lower Limit	Upper Limit
NGATES	number of gates	0	300
IG(L)	I grid location of gate L	0	M
JG(L)	J grid location of gate L	0	N
KG(L)	side for gate L, (1=north, 2=west, 3=south, 4=east)	1	4
CH1DEP(L)	main channel depth (ft) for gate L	N/A	N/A
CH1WID(L)	main channel width (ft) for gate L	0	DX or DY
CH2DEP(L)	secondary channel depth (ft) for gate L	N/A	N/A
CH2WID(L)	secondary channel width (ft) for gate L	0	DX or DY
BARH(L)	barrier height of gate L (ft)	N/A	N/A

- NGATES** The number of gates. NGATES cannot be larger than 300. If NGATES is 0, then the following variables do not need to be included in the data set.
- IG(L)** The I column (north to south) grid location of the gate.
- JG(L)** The J row (west to east) grid location of the gate.
- KG(L)** Indicator of gate location within the grid cell. Set KG to 1, 2, 3, or 4 to indicate whether the gate is on the top, left, bottom, or right side of the cell, respectively.
- CH1DEP(L)** The depth (ft) of the main channel. CH1DEP is negative relative to the datum used (e.g., NGVD, MLW).
- CH1WID(L)** The width (ft) of the main channel.
- CH2DEP(L)** The depth (ft) of the secondary channel. CH2DEP is negative relative to the datum used (e.g., NGVD, MLW).
- CH2WID(L)** The width (ft) of the secondary channel.

**BARH(L)** The barrier height (ft). BARH is positive above the datum used and negative below. If the KG(L) is 1 or 3, the barrier width is equal to the east-west grid size (DY) minus the sum of the main and secondary channel widths (CH1WID+CH2WID). If KG(L) is 2 or 4, the barrier width is equal to the north-south grid size (DX) minus the sum of the main and secondary channel widths (CH1WID+CH2WID).

### 5.2.5 Partial Land Parameters

Land, such as lake shoreline, islands, and causeways, can also be treated as a sub-grid feature by specifying the percentage of land within a grid cell. Location of the partial land grid must also be noted. Note: the effect of utilizing the partial land feature on the hydraulic model is similar to having smaller grid cells at the shoreline, causeway, etc... A smaller cell size may require a smaller timestep. Therefore, this feature cannot be used carelessly as it could cause instabilities in the model. (For more information, refer to Section 3.4.)

**Table 1.21** Partial Land Parameters

PARAMETER NAME	DESCRIPTION	Lower Limit	Upper Limit
NDELH	number of partial land grids	0	50
IH(L)	I grid location for partial land grid L	0	M
JH(L)	J grid location for partial land grid L	0	N
PLAND(L)	percentage of land in partial land grid L	0	100

**NDELH** The number of grids that are partially land. NDELH cannot be larger than 50. If NDELH is 0, then the following variables do not need to be included in the data set.

**IH(L)** The I column (north to south) grid location for the partial land cell.

**JH(L)** The J column (west to east) grid location for the partial land cell.

**PLAND(L)** The percentage of land in the partial land grid in percent.

### 5.2.6 Tidal and Water Level Parameters

The tidal driving function is an important feature of the hydraulic model when applied to coastal embayments and estuaries. Tidal parameters are included as follows:

**Table 1.22** Tidal and Water Level Parameters

PARAMETER NAME	DESCRIPTION	Lower Limit	Upper Limit
HSTART	initial water level (ft)	N/A	N/A
NOWSEGS	number of open-water segments for tide function	0	6
NTIDES	number of tide functions provided	0	6
KSTRT	For sides 2 and 4, I location for start of open-water boundary;	0	M
	For sides 1 and 3, J location for start of open-water boundary.	0	N
KSTOP	For sides 2 and 4, I location for end of open-water boundary	0	M
	For sides 1 and 3, J location for end of open-water boundary	0	N
DTSTRT	time shift of tide function for KSTRT (minutes)	0	N/A
DTSTOP	time shift of tide function for KSTOP (minutes)	0	N/A
HAMP	amplitude multipliers for tide function	N/A	N/A
REFOFF	vertical shift of tide function (ft)	0	N/A
AMPOFF	average water level of tide function (ft)	N/A	N/A

- HSTART** The initial water level at start of the simulation in feet. HSTART is specified in applications to lakes or reservoirs where no tides are present. HSTART is positive above the datum and negative below.
- NOWSEGS** The number of open-water segments for the tide function. Up to 6 open-water segments may be designated by the user.
- NTIDES** The number of tide functions designated by the user.
- KSTRT** The I or J grid location of the first cell on the open water boundary.
- KSTOP** The I or J grid location of the last cell on the open water boundary.
- DTSTRT** The time shift for KSTRT of the tide function in minutes.
- DTSTOP** The time shift for KSTOP of the tide function in minutes.
- HAMP** The amplitude multipliers for the tide function.
- REFOFF** The vertical shift, in feet, of the tide function.
- AMPOFF** The average water level, in feet, of the tide function.

## 5.2.7 Hydraulic Arrays

**Table 1.23** Hydraulic Model Arrays

PARAMETER NAME	DESCRIPTION	Lower Limit	Upper Limit
Z(I, J)	Array of bottom elevations and topography	N/A	99.0

**Z(I,J).** The array of bottom elevations and topography, in feet, with respect to the datum used (e.g., MLW, GCLWD, or NGVD). Bottom elevations for water cells are negative. Land elevations are positive and may not exceed 99.0 feet. Flow within the water body as well as across land surfaces can be simulated by the model. The array can be generated by the GIS or may be user defined. The array can be conveniently updated by the model user.

## 5.3 Water Quality Model Data

The USF-CMHAS 2D water quality model requires input to specify timestep and output time intervals, initial and open water boundary concentrations, benthic SOD/NER arrays, and constituent rates and constants. In addition, several logic parameters are included in the water quality data set that can turn-off the writing of mapped output files for any constituent. All water quality model input parameters are listed and described on the next few pages. Tables with a brief description of parameters and sources from which they can be obtained are provided as well.

### 5.3.1 Temporal Parameters

**Table 1.24** Water Quality Model Temporal Parameters

PARAMETER NAME	DESCRIPTION	PARAMETER SOURCE		
		GIS	DEFAULT	USER
DTQUAL	water quality model timestep (minutes)			X
TQPRNT	time between mapped water quality output (hours)			X

**DTQUAL** The water quality model timestep in minutes. To ensure model stability, DTQUAL must meet stability requirements described in section 4.2, "Mass Transport Equation and Numerical Solution". DTQUAL should be less than either  $DX/(2*U_{max})$  or  $DY/(2*V_{max})$ . DTQUAL should be an integer increment of the hydraulic timestep (DTHYD) or the hydraulic UVD output (TUVD).

**TQPRNT** The time between updates of the water quality model mapped output files in hours. TQPRNT should be some multiple of DTQUAL. Due to the voluminous nature of these files and disk storage constraints, water quality mapped output should not be written to an output file at small time increments. To control the amount of output to a reasonable and useful quantity, water quality results should be written to a file at infrequent time intervals (about 10 to 20 times during the run) specified by TQPRNT.

### 5.3.2 Logic Parameters

Logic parameters are used to turn a feature on (1) or off (0) in the model. This is provided to save time when certain options are not necessary for a simulation. A logic variable (on/off key) used for selecting output exists for each water quality parameter described in the table below. A value of 0 omits output for the constituent, while a value of 1 requires output to be written to the various output files. Note: the constituent logic parameters do not omit the simulation of constituents. They designate only whether output for the constituents is to be produced.

**Table 1.25** Water Quality Model Logic Parameters

PARAMETER NAME	DESCRIPTION	PARAMETER SOURCE		
		GIS	DEFAULT	USER
ALGAE	logic variable that requests output for algae (1=ON, 0=OFF)		X	X
CBOD	logic variable that requests output for CBOD (1=ON, 0=OFF)		X	X
ORGP	logic variable that requests output for OrgP (1=ON, 0=OFF)		X	X
PO4	logic variable that requests output for PO <sub>4</sub> (1=ON, 0=OFF)		X	X
ORGN	logic variable that requests output for OrgN (1=ON, 0=OFF)		X	X
NH3	logic variable that requests output for NH <sub>3</sub> (1=ON, 0=OFF)		X	X
NO2NO3	logic variable that requests output for NO <sub>2</sub> -NO <sub>3</sub> (1=ON, 0=OFF)		X	X
OXYGEN	logic variable that requests output for DO (1=ON, 0=OFF)		X	X
TSI	logic variable that requests output for TSI (1=ON, 0=OFF)		X	X
TSILIM	designation of limiting nutrient (1=N, 2=P, 3=BALANCED)			X
LBENTHIC	logic variable that omits the benthic SOD/NER arrays (0,1,2) 0 = do not include benthic data, 1 = constant SOD/NER's over time 2 = temporally varied SOD/NER's		X	X
LBENMOD	designation of spatial variation of SOD/NER arrays (1 = constant, 2 = spatially varied)		X	X

**TSILIM** A logic variable that designates the nutrient limiting condition of the lake, and determines how the TSI is calculated. A value of 1 signifies a nitrogen limited conditions, 2 designates phosphorus limited conditions, and a value of 3 specifies nutrient balanced conditions. This parameter is required only to select the appropriate TSI equation for the waterbody (see section 4.3.11).

**LBENTHIC** A logic variable that omits benthic SOD/NER arrays. If LBENTHIC is equal to 0, then no benthic parameters are used in the simulation. If LBENTHIC is set to 1, then temporally constant benthic nutrient fluxes are used. A value of 2 for LBENTHIC specifies the use of time-variable benthic nutrient fluxes. If this parameter has a value of 1 or 2, then the logic parameter LBENMOD must be specified as well (see LBENMOD). NOTE: this feature of the water quality model is not available at this time.

**LBENMOD** A logic variable that specifies the spatial characteristics of benthic data. A value of 1 for LBENMOD sets all SOD/NER's in the model grid cells to a single value, thus no spatial variation is used throughout the run. If LBENMOD is equal to 2, benthic nutrient fluxes can be spatially varied throughout the model grid. NOTE: this feature of the water quality

model is not available at this time.

### 5.3.3 Initial Conditions

The overall initial concentration in the waterbody at the start of the simulation must be specified for all constituents. This concentration is designated by the model at the center of every grid cell inside the waterbody boundaries.

**Table 1.26** Water Quality Model Initial Conditions

PARAMETER NAME	DESCRIPTION	PARAMETER SOURCE		
		GIS	DEFAULT	USER
ALGAE	initial concentration of algae (mg/l)			X
BODU	initial concentration of BODCU (mg/l)			X
ORGP	initial concentration of organic phosphorus (mg/l)			X
ORTHP	initial concentration of orthophosphate (mg/l)			X
ORGN	initial concentration of organic nitrogen (mg/l)			X
NH3	initial concentration of ammonia (mg/l)			X
N2N3	initial concentration of nitrate (mg/l)			X
DOAVG	initial concentration of dissolved oxygen (mg/l)			X
TEMP	ambient water temperature (EC)			X
SALIN	water salinity (ppt)			X

- ALGAE** The initial concentration of algae in mg/l.
- BODU** The initial concentration of BODU in mg/l.
- ORGP** The initial concentration of OrgP in mg/l.
- ORTHP** The initial concentration of PO<sub>4</sub> in mg/l.
- ORGN** The initial concentration of OrgN in mg/l.
- NH3** The initial concentration of NH<sub>3</sub> in mg/l.
- N2N3** The initial concentration of NO<sub>2</sub>-NO<sub>3</sub> in mg/l.
- DOAVG** The initial concentration of DO in mg/l.
- TEMP** The average ambient water temperature in EC, at the start of the simulation.
- SALIN** The initial salinity of the waterbody in ppt.

### 5.3.4 Boundary Conditions

When an open water boundary is included in the model, the concentration of all constituents at the boundary must be specified. The boundary location (north, south, east, west) must be specified as well. In general, a closed lake will not have any open water boundaries, but an estuary will have one or more.

**Table 1.27** Water Quality Model Boundary Conditions

PARAMETER NAME	DESCRIPTION	PARAMETER SOURCE		
		GIS	DEFAULT	USER
ALGAE	boundary concentration of algae (mg/l)			X
BODU	boundary concentration of BODCU (mg/l)			X
ORGP	boundary concentration of organic phosphorus (mg/l)			X
ORTHP	boundary concentration of orthophosphate (mg/l)			X
ORGN	boundary concentration of organic nitrogen (mg/l)			X
NH3	boundary concentration of ammonia (mg/l)			X
N2N3	boundary concentration of nitrate (mg/l)			X
DOAVG	boundary concentration of dissolved oxygen (mg/l)			X
DORNG	range of dissolved oxygen concentration at boundaries (mg/l)			X

- ALGAE**      The open water boundary concentration of algae in mg/l.
- BODU**      The open water boundary concentration of BODU in mg/l.
- ORGP**      The open water boundary concentration of OrgP in mg/l.
- ORTHP**     The open water boundary concentration of PO<sub>4</sub> in mg/l.
- ORGN**      The open water boundary concentration of OrgN in mg/l.
- NH3**        The open water boundary concentration of NH<sub>3</sub> in mg/l.
- N2N3**      The open water boundary concentration of NO<sub>2</sub>-NO<sub>3</sub> in mg/l.
- DOAVG**     The open water boundary concentration of DO in mg/l.
  
- DORNG**     The allowed range of DO concentration at the open water boundaries in mg/l. This provides for the more natural user specified diurnal fluctuation of DO along the boundary during the run.

## 5.3.5 Algae Parameters

**Table 1.28** Algae Parameters

PARAMETER NAME	DESCRIPTION	PARAMETER SOURCE		
		GIS	DEFAULT	USER
GROMAX	maximum specific growth rate of algae at 20EC (1/day)		X	X
RESP	respiration rate of algae at 20EC (1/day)		X	X
GRAZE	grazing rate for algae at 20EC (1/day)		X	X
ZOOEFF	zooplankton assimilation efficiency (mg assimilated/mg grazed)		X	X
HSATP	phosphorus half-saturation constant (mg P/l)		X	X
HSATN	nitrogen half-saturation constant (mg N/l)		X	X
SETA	settling velocity of algae (ft/day)		X	X
FC	fraction of the algae biomass which is carbon (mg C/mg A)		X	X
CHL	ratio of chl-a to algae biomass ( $\mu\text{g chl-a/mg A}$ )		X	X
TCOGRO	temperature coefficient for the algal growth rate		X	X
TCORSP	temperature coefficient for the algal respiration rate		X	X
TCOGRZ	temperature coefficient for the algal grazing rate		X	X

**GROMAX** The maximum specific growth rate of algae at 20EC (1/day). GROMAX describes the maximum growth rate when sufficient light and nutrient concentrations are present (see section 4.3.5)

**RESP** The respiration rate of algae at 20EC (1/day). This is the rate of non-predatory mortality of algae (see section 4.3.5).

**GRAZE** The grazing rate of zooplankton on algae at 20EC (1/day). GRAZE is the consumption rate of algae from zooplankton feeding (see section 4.3.5).

**ZOOEFF** The zooplankton assimilation efficiency (mg algae assimilated/mg algae consumed per day). The ZOOEFF parameter defines the ability of zooplankton to successfully digest consumed algal matter. The amount not digested is returned to the water column as organic matter (see section 4.3.5).

**HSATP** The phosphorus half-saturation constant for algal growth (mg/l). HSATP is one-half the concentration of phosphorus required for maximum algal growth (see section 4.3.5).

**HSATN** The nitrogen half-saturation constant for algal growth (mg/l). HSATN is one-half the concentration of nitrogen required for maximum algal growth (see Section 4.3.5).

**SETA** The average settling velocity of algae community modeled (ft/day) (see Section 4.3.4).

<b>FC</b>	The carbonaceous fraction of the algae biomass (mg C/mg A).
<b>CHL</b>	The ratio of chl-a to algae biomass ( $\mu\text{g}$ chl-a/mg A).
<b>TCOGRO</b>	The temperature correction coefficient for algal growth (see Section 4.3.3).
<b>TCORSP</b>	The temperature correction coefficient for algal respiration (see Section 4.3.3).
<b>TCOGRZ</b>	The temperature correction coefficient for algal grazing (see Section 4.3.3).

### 5.3.6 The Oxygen and CBOD Parameters

**Table 1.29** Oxygen and CBOD Cycle Parameters

PARAMETER NAME	DESCRIPTION	PARAMETER SOURCE		
		GIS	DEFAULT	USER
DKC	decay rate of CBOD due to oxidation (1/day)		X	X
SETC	settling rate of carbonaceous BOD (1/day)		X	X
BODU5	ratio of ultimate CBOD to 5-day CBOD (mg CBODU/mg CBOD5)		X	X
OXGROW	oxygen production per unit of algae growth (mg O/mg A)		X	X
OXRESP	oxygen demand per unit of algae respired (mg O/mg A)		X	X
OXC	oxygen demand per unit of carbon algae (mg O/mg C)		X	X
OXNH3	oxygen demand per unit of ammonia oxidation (mg O/mg N)		X	X
HSATOC	DO half-saturation constant for CBOD decay (mg O/l)		X	X
TCOC	temperature coefficient for the decay of CBOD		X	X
TCOREA	temperature coefficient for the reaeration rate of oxygen		X	X
WINDCO	wind coefficient for reaeration of oxygen		X	X

- DKC** The decay rate of CBOD due to oxidation at 20EC (1/day).  
**SETC** The settling rate of CBOD (1/day) (see section 4.3.4).  
**BODU5** The ratio of ultimate CBOD to 5-day CBOD (mg CBODU/mg CBOD5).  
**OXGROW** The oxygen production per unit of algae growth (mgO/mgA).  
**OXRESP** The oxygen demand per unit of algae respired (mg O/mg A).  
**OXC** The oxygen demand per unit of carbon algae (mg O/mg C).  
**OXNH3** The oxygen demand per unit of NH<sub>3</sub> oxidation (mg O/mg N).  
**HSATOC** The DO half-saturation constant for CBOD decay (mg/l).  
**TCOC** The temperature correction coefficient for the decay of CBOD.  
**TCOREA** The temperature correction coefficient for oxygen reaeration.  
**WINDCO** The wind coefficient for reaeration of oxygen.

### 5.3.7 The Phosphorus Cycle

For more information on how organic and orthophosphorus are modeled, see Section 4.3.8.

**Table 1.30** Phosphorus Cycle Parameters

PARAMETER NAME	DESCRIPTION	PARAMETER SOURCE		
		GIS	DEFAULT	USER
DKP	decay rate of organic phosphorus (1/day)		X	X
SETP	settling rate of organic phosphorus (1/day)		X	X
FP	fraction of the algae biomass which is phosphorus (mg P/mg A)		X	X
TCOP	temperature coefficient for the decay of organic phosphorus		X	X

- DKP** The decay rate of OrgP to PO<sub>4</sub> at 20EC (1/day).  
**SETP** The settling rate of OrgP (1/day) (see Section 4.3.4).  
**FP** The phosphorus fraction of the algae biomass (mg P/mg A).  
**TCOP** The temperature correction coefficient for the decay of OrgP.

### 5.3.8 The Nitrogen Cycle

For more information on how the nitrogen constituents are modeled, see Section 4.3.9.

**Table 1.31** Nitrogen Cycle Parameters

PARAMETER NAME	DESCRIPTION	PARAMETER SOURCE		
		GIS	DEFAULT	USER
DKN	decay rate of organic nitrogen to NH <sub>3</sub> at 20EC (1/day)		X	X
DKNH3	decay rate of ammonia to nitrate at 20EC (1/day)		X	X
SETN	settling rate of organic nitrogen (1/day)		X	X
SETNH3	settling rate of ammonia (1/day)		X	X
FN	fraction of the algae biomass which is nitrogen (mg N/mg A)		X	X
PRF	algal preference rate of ammonia over nitrate (hundredths)		X	X
HSATON	DO half-saturation constant for nitrification (mg O/l)		X	X
TCON	temperature coefficient for the decay of organic nitrogen		X	X
TCONH3	temperature coefficient for the decay of ammonia		X	X

- DKN** The decay rate of OrgN to NH<sub>3</sub> at 20EC (1/day).
- DKNH3** The decay rate of NH<sub>3</sub> to NO<sub>2</sub>-NO<sub>3</sub> at 20E (1/day).
- SETN** The settling rate of OrgN (1/day) (see Section 5.3.4).
- SETNH3** The settling rate of NH<sub>3</sub> (1/day) (see Section 5.3.4).
- FN** The nitrogenous fraction of the algae biomass (mg N/mg A).
- PRF** The algal preference factor for NH<sub>3</sub> over NO<sub>2</sub>-NO<sub>3</sub> (hundredths).
- HSATON** The DO half-saturation constant for nitrification (mg/l). HSATON is used in the correction factor for the rate of nitrification (decay of ammonia to nitrates) when very low levels of DO are present.
- TCON** The temperature correction coefficient for the decay of OrgN.
- TCONH3** The temperature correction coefficient for the decay of NH<sub>3</sub>.

### 5.3.9 Light Parameters

For more information on the simulation and use of light parameters in the model, see the "Light" subtitle in Section 4.3.5.

**Table 1.32** Light Parameters

PARAMETER NAME	DESCRIPTION	PARAMETER SOURCE		
		GIS	DEFAULT	USER
SECEXT	constant relating Secchi depth to light extinction		X	X
PHOTO	percent of day which is sunlight (hundredths)		X	X
EXTL1	light extinction coefficient for suspended matter (1/ft)		X	X
EXTL2	light extinction coef. for algae (1/ft/mg A)		X	X
XLIGHT	avg. light intensity at the water surface (langleys/day)		X	X
XSATLI	saturation light intensity (langleys/day)		X	X

- SECEXT** The constant relating Secchi depth to the light extinction coefficients.
- PHOTO** The percent of day which is sunlight (hundredths). This parameter is a function of the time of year (winter, spring, summer, fall).
- EXTL1** The light extinction coefficient for all suspended matter other than algae (1/ft). EXTL1 describes the reduction of light penetration due to suspended sediments or detritus.
- EXTL2** The light extinction coefficient for algae only (1/ft). EXTL2 describes the reduction of light penetration due to phytoplankton only.
- XLIGHT** The average light intensity at the water surface (langleys/day). XLIGHT is used to define relative cloudiness or haziness that will reduce algae growth.
- XSATLI** The saturation light intensity (langleys/day). XSATLI is the optimum light intensity at the surface of the water.

### 5.3.10 Water Quality Benthic Arrays

**Table 1.33** Water Quality Model Arrays

PARAMETER NAME	DESCRIPTION	PARAMETER SOURCE		
		GIS	DEFAULT	USER
DBENOX(I,J)	sediment oxygen demand array (mg/m <sup>2</sup> /day)	X		X
DBENP2(I,J)	PO <sub>4</sub> benthic nutrient exchange rate array (mg/m <sup>2</sup> /day)	X		X
DBENN2(I,J)	ammonia benthic nutrient exchange rate array (mg/m <sup>2</sup> /day)	X		X
DBENN3(I,J)	nitrate benthic nutrient exchange rate array (mg/m <sup>2</sup> /day)	X		X

**DBENOX(I,J)** The array of sediment oxygen demand in mgO/m<sup>2</sup>/day. This array is generated by the GIS. Modifications to the array can be made using the GIS or the Data Preprocessor.

**DBENP2(I,J)** The array of PO<sub>4</sub> benthic nutrient exchange rates in mg P/m<sup>2</sup>/day. A positive value denotes a release into the water column. This array is generated by the GIS. Modifications to the array can be made using the GIS or the Data Preprocessor.

**DBENN2(I,J)** The array of NH<sub>3</sub> benthic nutrient exchange rates in mg N/m<sup>2</sup>/day. A positive value denotes a release into the water column. This array is generated by the GIS. Modifications to the array can be made using the GIS or the Data Preprocessor.

**DBENN3(I,J)** The array of NO<sub>2</sub>-NO<sub>3</sub> benthic nutrient exchange rates in mg N/m<sup>2</sup>/day. A positive value denotes a release into the water column. This array is generated by the GIS. Modifications to the array can be made using the GIS or the Data Preprocessor.

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