EFDC1D - A One Dimensional Hydrodynamic and Sediment Transport Model for River and Stream Networks: Model Theory and Users Guide

By

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Abstract

This technical report describes the new one-dimensional (1D) hydrodynamic and sediment transport model EFDC1D. This model can be applied to stream networks. The model code and two sample data sets are included on the distribution CD. EFDC1D can simulate bi-directional unsteady flows and has the ability to accommodate unsteady inflows and outflows associated with upstream inflows, lateral inflows and withdrawals, groundwater-surface water interaction, evaporation and direct rainfall. The model also includes representation of hydraulic structures such as dams and culverts. For sediment transport, the model includes settling, deposition and resuspension of multiple size classes of cohesive and noncohesive sediments. The bed is represented by multiple layers of mixed sediment classes. A bed consolidation model is implemented to predict time variations of bed depth, void ratio, bulk density and shear strength. The sediment bed representation is dynamically coupled to the cross-sectional area representation to account for area changes due to deposition and resuspension.

Table of Contents

1.   Introduction

This document outlines the theoretical and computational aspects of, EFDC1D (Environmental Fluid Dynamics Code - One-Dimensional), a box or control volume based one-dimensional hydrodynamic and sediment-contaminant transport model. The model is implemented in a stand-alone version and also incorporated into HSPF (Hydrologic Simulation Package: Fortran).

Model Features include:

A. Box or reach based spatial data structure, compatible with existing HSPF data structure, for representing one-dimensional channel networks.

B. Utilization of water surface elevation dependent descriptions of channel cross-section area, surface width, wetted perimeter and buoyancy centroid, including representation of overbank regions.

C. Bi-directional unsteady flow and the ability to accommodate unsteady inflows and outflows associated with upstream inflows, lateral inflows and withdrawals, groundwater-surface water interaction, evaporation and direct rainfall. The model includes representation of hydraulic structures such as dams and culverts. Downstream boundary conditions include rating curves and time varying water surface elevation.

D. The model includes a generic one-dimensional transport solver for salinity, temperature and multiple sediment and contaminant classes. Longitudinal dispersive transport is represented. Sources and sinks will be represented consistent with continuity constraints.

E. Buoyancy effects due to salinity and temperature are dynamically coupled with the hydrodynamic component using an equation of state. Temperature transport includes a predictive surface heat exchange formulation representing the effects of solar radiation, long wave back radiation, and latent and sensible heat transfer.

F. For sediment transport, the model includes settling, deposition and resuspension of multiple size classes of cohesive and noncohesive sediments. The bed is represented by multiple layers of mixed sediment classes. A bed consolidation model is implemented to predict time variations of bed depth, void ratio, bulk density and shear strength. The sediment bed representation is dynamically coupled to the cross-sectional area representation to account for area changes due to deposition and resuspension.

The overall approach taken in developing the flow and sediment transport model was to minimize code development by the utilization of existing process subroutines from the multi-dimensional EFDC (Environmental Fluid Dynamic Code) model (Hamrick 1992;

Hamrick 1996; Hamrick and Wu 1997). Process routines from the EFDC model are utilized to satisfy the following requirements:

A. A fully dynamic one-dimensional solver for the momentum and continuity equations with channel cross-section area, surface width, bottom width, wetted perimeter and buoyancy centroid as functions of the water surface elevation.

B. Time varying upstream inflows, and lateral inflows and withdrawals including corresponding sediment loads.

C. Hydraulic control structures and rating curve boundary conditions.

D. Time varying downstream boundary conditions for water surface elevation, salinity, temperature and sediment concentration.

E. A generic one-dimensional transport solver utilizing a monotone, positive definite scheme which minimizes numerical diffusion

F. A fully predictive surface heat exchange formulation which includes evaporation

G. An equation of state relating density to salinity and temperature.

H. A multiple class sediment processes module that incorporates a wide variety of parameterization for settling, deposition and resuspension of cohesive and noncohesive sediments.

I. A multiple layer bed module that includes a bed consolidation solver and parameterizations relating void ratio, bulk and dry density, and shear strength.

Utilizing the above existing routines, code development focused on the main driver program, input and output routines for the stand alone version of the model, interface routines for the HSPF embedded version of the model, and a new hydrodynamic solver optimized for one-dimensional channel network applications. The following sections of this document summarize theoretical and computational formulations of the governing hydrodynamic and transport equations, and model input and output files.

2. Hydrodynamic Equations and Solutions Procedures

The one-dimensional momentum and continuity equations are

$$\partial_t Q + \partial_x \left(\frac{Q^2}{A} \right) = -g(1+b)A\partial_x\zeta - gd_c A \partial_x b + W_s \tau_s - \frac{c_{bp}}{R_h}\left|\frac{Q}{A}\right|Q \tag{2.1}$$

$$\partial_t A + \partial_x Q = q_L + q_S + q_T \tag{2.2}$$

where

A = cross-section area
b = dimensionless buoyancy = $(\rho-\rho_o)/\rho_o$
c_{bp} = dimensionless bottom resistance coefficient over the wetted
     perimeter
g = acceleration of gravity
d_c = distance down from water surface to channel area centroid
Q = discharge
R_h = hydraulic radius
q_L = lateral runoff per unit channel length
q_S = rate of change of cross-sectional area due to sediment bed
     resuspension and deposition
q_T = tributary inflow per unit channel length
W_s = surface width of the channel
ζ = water surface elevation

The centroid depth is determined by

$$d_c = \frac{1}{A}\int_0^W \int_{z_b^*}^{\zeta} (\zeta - z)\,dz\,dy = \frac{1}{A}\int_A (\zeta - z)\,dA \tag{2.3}$$

with the integrals denoting integration across the surface width and over the depth of the channel. For a rectangular cross-section, d_c is equal to one half of the depth. The cross-section area, hydraulic radius, and water surface width are defined as functions of the water surface elevation by tabular functions.

Equations (2.1) and (2.2) are solved using a box or control volume spatial representation.

$$\Delta_{Q:m}\partial_t Q_m + \left(\frac{Q^2}{A}\right)_{A:m} - \left(\frac{Q^2}{A}\right)_{A:m-} = -g\left(1+b_{Q:m}\right)A_{Q:m}\left(\zeta_m - \zeta_{m-}\right) \tag{2.4}$$

$$-g(d_c A)_{Q:m}\left(b_m - b_{m-}\right) + \Delta_{Q:m}(W_s\tau_s)_{Q:m} - \Delta_{Q:m}\left(\frac{c_{bp}}{R_h}\left|\frac{Q}{A}\right|\right)_{Q:m} Q_m$$

3

$$\Delta_{A:m}\partial_t A_m + Q_{m+} - Q_m = \left(Q_L + Q_S + Q_T\right)_m \qquad (2.5)$$

Cross-sectional area, A, water surface elevation, ζ, and buoyancy, b, are defined in continuity control volumes. Discharge, Q, is defined in momentum control volumes which are staggered relative to continuity control volumes, with momentum control volume m being centered at the upstream face of continuity control volume m, as shown in Figure 1. The continuity and momentum control volume lengths are denoted by $\Delta_{A:m}$ and $\Delta_{Q:m}$, respectively. Quantities defined at control volume centers, and determined by interpolation, are denoted by the subscripts $A:m$ and $Q:m$. Quantities at control volumes upstream and downstream are defined by the subscripts $m-$ and $m+$. The source terms in the continuity equation are defined in continuity control volumes by

Q_L = lateral runoff discharge into volume m
Q_S = rate of change of volume m due to bed resuspension and
      deposition and bed consolidation.
Q_T = tributary discharge into volume m

The rate of change of the continuity control volume due to sediment deposition and resuspension and bed consolidation is given by

$$Q_{S,m} = -W_{B,A:m}\Delta_{A:m}\partial_t B_m \qquad (2.6)$$

where W_B is the channel width over which the deposited sediment bed extends, and B_m is the total thickness of the deposited bed.

a) Continuity control volumes or cells

A(m-1)	A(m)	A(m+1)
ζ(m-1)	ζ(m)	ζ(m+1)
b(m-1)	b(m)	b(m+1)
q(m-1)	q(m)	q(m+1)
C(m-1)	C(m)	C(m+1)
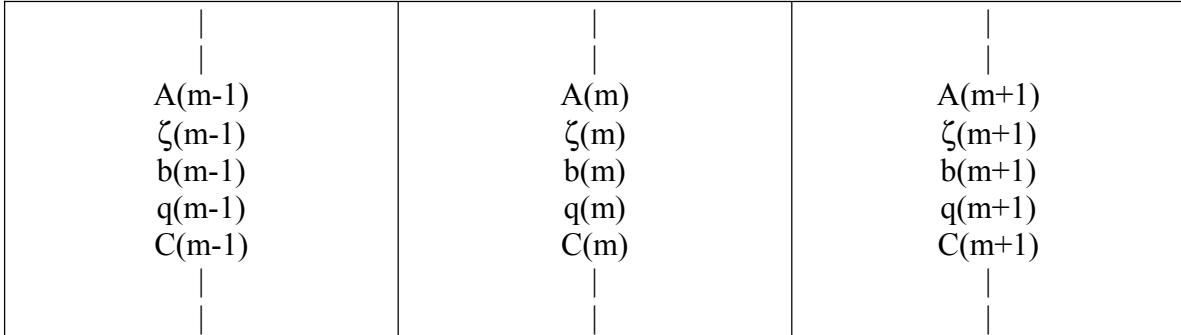
b) Momentum control volumes or cells

| Q(m) | Q(m+1) |
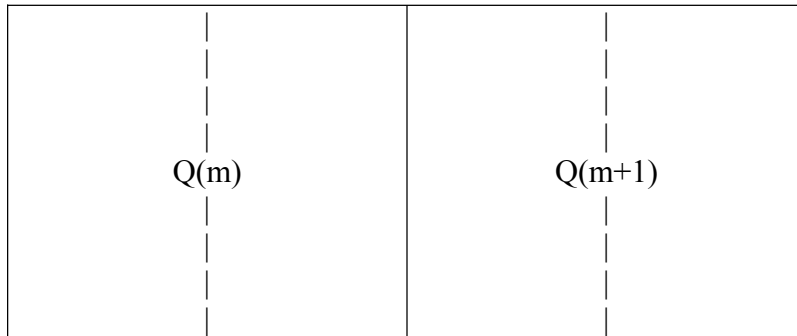
Figure 1.   Continuity and momentum control volumes or cells. Dashed vertical lines indicate positions of momentum volume boundaries in (a) and continuity volume boundaries in (b).

Equations (2.4) and (2.5) are integrated in time, between time levels n and $n+1$, using a two-time level, semi-implicit scheme adopted from the EFDC model. The momentum and continuity equations become

$$\left(1 + \lambda\theta\left(\frac{c_{bp}}{R_h}\frac{|Q|}{|A|}\right)^n_{Q:m}\right)Q_m^{n+1} = \left(1 - \lambda\theta\left(\frac{c_{bp}}{R_h}\frac{|Q|}{|A|}\right)^n_{Q:m}\right)Q_m^n$$

$$-\left(\frac{\theta}{\Delta_{Q:m}}\right)\left\{\left(\frac{Q^2}{A}\right)_{A:m} - \left(\frac{Q^2}{A}\right)_{A:m-}\right\}^n$$

$$-g\left(\frac{\theta}{2\Delta_{Q:m}}\right)\left(1 + b_{Q:m}^n\right)A_{Q:m}^n\left\{\left(\zeta_m - \zeta_{m-}\right)^{n+1} + \left(\zeta_m - \zeta_{m-}\right)^n\right\}$$

$$-g\left(\frac{\theta}{\Delta_{Q:m}}\right)\left(d_cA\right)_{Q:m}^n\left(b_m - b_{m-}\right)^n + \theta\left(W_s\tau_s\right)_{Q:m}^n$$

(2.7)

$$A_m^{n+1} + \left(\frac{\theta}{2\Delta_{A:m}}\right)\left(Q_{m+} - Q_m\right)^{n+1} = A_m^n - \left(\frac{\theta}{2\Delta_{A:m}}\right)\left(Q_{m+} - Q_m\right)^n$$

$$+\left(\frac{\theta}{\Delta_{A:m}}\right)\left(Q_L + Q_S + Q_T\right)_m^n$$

(2.8)

where θ is the time-step. The implicit portion of the solution is represented by rewriting (2.7) and (2.8) in the forms

$$Q_m^{n+1} = F_m - G_m\left(\zeta_m - \zeta_{m-}\right)^{n+1}$$

(2.9)

$$\left(\partial_\zeta A\right)_m^n\zeta_m^{n+1} + D_m\left(Q_{m+} - Q_m\right)^{n+1} = E_m$$

(2.10)

and combining to give a system of linear equations:

$$-D_mG_m\zeta_{m-}^{n+1} + \left(D_mG_m + \left(\partial_\zeta A\right)_m^n + D_mG_{m+}\right)\zeta_m^{n+1} - D_mG_{m+}\zeta_{m+}^{n+1}$$

(2.11)

$$= E_m - D_m\left(F_{m+} - F_m\right)$$

These equations are solved for the new time level water surface elevation. New time level discharges are then determined from (2.9). To guarantee volume continuity, the new time level cross-sectional area is determined from (2.8).

Advective momentum fluxes in (2.7) and (2.9) are determined using simple upwind differences:

$$Q_{A:m}^{n+1/2}\left(\frac{Q}{A}\right)_{A:m}^{n} = \max\left(Q_{A:m}^{n+1/2},0\right)\left(\frac{Q_m}{A_{Q:m}}\right)^n + \min\left(Q_{A:m}^{n+1/2},0\right)\left(\frac{Q_{m+}}{A_{Q:m+}}\right)^n \qquad (2.12)$$

$$Q_{A:m}^{n+1/2} = \frac{1}{2}\left(Q_m^{n+1/2} + Q_{m+}^{n+1/2}\right)$$

The data structure for the hydrodynamic and transport equation solutions is based on a lookup table structure, with the upstream and downstream control volumes, m- and m+ being defined by m-= MM(m) and m+ = MP(m). An additional set of lookup tables are used to define tributary inflow connections in the continuity equation.

At the upstream end of the main channel and each tributary channel, a no flow boundary condition is implemented in the momentum equation and upstream inflow is represented by a lateral source in continuity equation. This type of upstream boundary condition is referred to as a waterfall boundary condition.

Downstream boundary conditions for the solution of the hydrodynamic equations include:

Specified water surface elevation

$$\zeta = \zeta_B(t) \qquad (2.13)$$

where ζ_B is a specified time series or harmonic function.

Specified incoming wave characteristic

$$\zeta - \frac{Q}{W_s\sqrt{g\dfrac{A}{W_s}}} = \phi_B(t) \qquad (2.14)$$

where ϕ_B is a specified time series or harmonic function.

Discharge specified as a function time

$$Q = Q_{BT}(t) \qquad (2.15)$$

where Q_{BT} represents a time series.

Discharge specified as a function of water surface elevation

$$Q = Q_{BC}(\zeta) \qquad (2.16)$$

where Q_{BC} represents a rating curve for the downstream boundary section or a hydraulic control structure.

3. Transport Equations and Solution Procedures

The transport equation for a dissolved or suspended material, represented by the concentration, C, is

$$\partial_t(AC) + \partial_x(QC) = \partial_x(AD_C\partial_xC) + q_LC_L + q_SC_S + q_TC_T + W_BJ_{CB} - W_SJ_{CS}$$ (3.1)

where

C = concentration (salinity, temperature, or suspended sediment)
C_L = concentration of lateral runoff inflow
C_S = concentration associated with pore water component of water column-sediment bed
    exchange
C_T = concentration of tributary inflow
D_C = longitudinal dispersion coefficient
W_S = surface width of channel
W_B = bed depositional width of channel
J_{CS} = surface outflux of C
J_{CB} = bed influx of C

When C represents temperature, the last two terms on the right of (3.1) are retained and account for net water surface heat flux and convective heat flux from the bed, respectively. When C represents suspended sediment, the next to the last term on the right of (3.1) is retained and represents sediment resuspension and deposition, with the term q_sC_s set to zero.

Equation (3.1) is solved by a fractional step method at the same time-step as the hydrodynamic equations. With C defined in the continuity control volumes, the first step is:

$$A_m^{n+1}C_m^* = A_m^nC_m^n - \left(\frac{\theta}{\Delta_{A:m}}\right)Q_{m+}^{n+1/2}C_{Q:m+}^n + \left(\frac{\theta}{\Delta_{A:m}}\right)Q_m^{n+1/2}C_{Q:m}^n$$

$$+\left(\frac{\theta}{\Delta_{A:m}\Delta_{Q:m+}}\right)(AD_C)_{Q:m+}^n(C_{m+} - C_m)^n - \left(\frac{\theta}{\Delta_{A:m}\Delta_{Q:m}}\right)(AD_C)_{Q:m}^n(C_m - C_{m-})^n$$ (3.2)

$$+\left(\frac{\theta}{\Delta_{A:m}}\right)\left(Q_L^nC_L^n + Q_S^nC_S^n + Q_T^nC_T^n\right)_m$$

where

$$Q^{n+1/2} = \frac{1}{2}\left(Q^{n+1} + Q^n\right)$$ (3.3)

It is noted that (3.2) is consistent with the continuity equation (2.6) that it reduces to when all concentrations are set to unity. The second step is given by

$$A_m^{n+1} C_m^{n+1} = A_m^{n+1} C_m^* + \theta \left(W_B J_{CB} - W_S J_{CS} \right)_m^{n+1}$$ (3.4)

The surface and bottom fluxes are defined at the new time level to maintain a positive concentration when J_{cs} represents the settling or deposition of suspended sediment. The advective fluxes in (3.2) are given by a weighted upwind-central difference form

$$Q_m^{n+1/2} C_{Q:m}^n = F_u \left(\max\left(Q_m^{n+1/2}, 0\right) C_{m-}^n \right) + F_u \left(\min\left(Q_m^{n+1/2}, 0\right) C_m^n \right)$$
$$+ \frac{F_c}{2} Q_m^{n+1/2} \left(C_{m-}^n + C_m^n \right)$$ (3.5)

where the flux weights, F_u and F_c, are determined by a flux limiter that insures a monotone and positive definite solution while also reducing numerical diffusion associated with upwind flux.

4.   Heat Transport Formulation

For thermal transport and temperature simulations, the water surface heat flux for the transport equation (3.1), when C represents heat ($C = \rho_w c_{pw} T$) is:

$$J_{TS} = \varepsilon \sigma T_s^4 \left(0.39 - 0.05 e_a^{1/2}\right)\left(1 - B_c C_c\right) + 4\varepsilon \sigma T_s^3 \left(T_s - T_a\right) \tag{4.1}$$

$$+ c_h \rho_a c_{pa} \sqrt{U_w^2 + V_w^2}\left(T_s - T_a\right) + c_e \rho_a L \sqrt{U_w^2 + V_w^2}\left(e_{ss} - R_h e_{sa}\right)\left(0.622 p_a^{-1}\right) - I_S$$

where c_{pw} is the specific heat of water. The heat fluxes on the right hand side of (4.1) are based on the NOAA Geophysical Fluid Dynamic Laboratory's atmospheric heat exchange formulation (Rosati and Miyakoda 1988). The first two terms represent net longwave back radiation where

T_s = water surface temperature
T_a = atmospheric temperature
ε = emissivity
σ = Stefan-Boltzman constant
e_a = atmospheric vapor pressure in millibars
C_c = fractional cloud cover
B_c = empirical constant equal to 0.8.

The third term is the convective or sensible heat flux where

c_h = dimensionless transfer coefficient on the order of 10^{-3} in magnitude,
ρ_a = atmospheric density,
c_{pa} = specific heat of air.

The last term represents latent heat transfer where

c_e = dimensionless transfer coefficient on the order of 10^{-3} in magnitude,
L = latent heat of evaporation
e_{ss} = saturation vapor pressures in millibars corresponding to the water surface
        temperatures
e_{sa} = saturation vapor pressures in millibars corresponding to the atmospheric
        temperature
R_h = fractional relative humidity
p_a = atmospheric pressure in millibars

The incident shortwave solar radiation, I_s, at the water surface (watts/m^2) is given by

$$I_s = 0.5 I_o \left(1 - A_\alpha + \tau^{\sec \psi}\right)\left(1 - \alpha\right)\left(1 - 0.62 C_c + 0.0019 \beta\right) \tag{4.2}$$

where

I_o = shortwave solar radiation at the top of the atmosphere
A_α = water vapor plus ozone adsorption coefficient (0.09)
τ = atmospheric attenuation coefficient (0.7)
ψ = zenith angle
α = surface albedo
β = solar noon angle in degrees.

The bottom heat flux is given by:

$$J_{TB} = c_{hb}\rho_w c_{pw}\sqrt{u_1^2 + v_1^2}\,(T_B - T) - I_B \tag{4.3}$$

where

T_B = bed temperature
ρ_b = bed bulk density
c_{pb} = specific heat of the water-solid bed mixture
c_{hb} = dimensionless convective heat exchange coefficient on the order of 10^{-3}.

The remaining irradiance at the sediment bed-water interface being adsorbed into the sediment bed is

$$I_B = rI_S \exp(-\beta_f H) + (1 - r)I_S \exp(-\beta_s H) \tag{4.4}$$

where

β_f = fast scale attenuation coefficient (1/meters)
β_s = slow scale attenuation coefficient (1/meters)
r = a distribution fraction between zero and one

For shallow water environments, r is set to one and β_f generally falls within the range of 0.2 to 4 per meter. The thermal balance for the bed is given by

$$\partial_t \left(\rho_b c_{pb} H_b T_b\right) = I_b - c_{hb}\rho_w c_{pw}\sqrt{u_1^2 + v_1^2}\,(T_b - T) \tag{4.5}$$

where H_B is the thermal thickness of the bed. Equation (4.5) serves to couple the bed with the water column.

5.   Noncohesive Sediment Settling, Deposition and Resuspension

Noncohesive inorganic sediments settle as discrete particles, with hindered settling and multiphase interactions becoming important in regions of high sediment concentration near the bed.   At low concentrations, the settling velocity for the jth noncohesive sediment class corresponds to the settling velocity of a discrete particle:

$$w_{sj} = w_{soj} \tag{5.1}$$

Useful expressions for the discrete particle settling velocity that depend on the sediment density, effective grain diameter, and fluid kinematic viscosity are provided by van Rijn (1984b):

$$\frac{w_{soj}}{\sqrt{g' d_j}} = \begin{cases} \dfrac{R_{dj}}{18} & : \quad d_j \leq 100\mu m \\[2mm] \dfrac{10}{R_{dj}}\left(\sqrt{1+0.01R_{dj}^2} - 1\right) & : \quad 100\mu m < d_j \leq 1000\mu m \\[2mm] 1.1 & : \quad d_j > 1000\mu m \end{cases} \tag{5.2}$$

where d_j is the sediment diameter, and

$$g' = g\left(\frac{\rho_{sj}}{\rho_w} - 1\right) \tag{5.3}$$

is the reduced gravitational acceleration and

$$R_{dj} = \frac{d_j \sqrt{g' d_j}}{v} \tag{5.4}$$

is the sediment grain densimetric Reynolds number.

At higher concentrations under hindered settling conditions, the settling velocity is less than the discrete velocity and can be expressed in the form

$$w_{sj} = \left(1 - \sum_i^I \frac{S_i}{\rho_{si}}\right)^n w_{soj} \tag{5.5}$$

where ρ_s is the sediment particle density with values of n ranging from 2 (Cao *et al.* 1996) to 4 (Van Rijn 1984). The expression (5.5) is approximated to within 5 per cent by

$$w_{sj} = \left(1 - n\sum_i^I \frac{S_i}{\rho_{si}}\right) w_{soj} \tag{5.6}$$

for total sediment concentrations up to 200,000 mg/liter. For total sediment concentrations less than 25,000 mg/liter, neglect of the hindered settling correction results in less than a 5 per cent error in the settling velocity, which is well within the range of uncertainty in parameters used to estimate the discrete particle settling velocity.

Noncohesive sediment is transported as bed load and suspended load. The initiation of both modes of transport begins with erosion or resuspension of sediment from the bed when the bed stress, τ_b, exceeds a critical stress referred to as the Shield's stress, τ_{cs}. The Shield's stress depends upon the density and diameter of the sediment particles and the kinematic viscosity of the fluid, and can be expressed in empirical dimensionless relationships of the form:

$$\theta_{csj} = \frac{\tau_{csj}}{g' d_j} = \frac{u_{*csj}^2}{g' d_j} = f(R_{dj}) \tag{5.7}$$

Useful numerical expressions of the relationship (5.7), provided by van Rijn (1984b), are:

$$\theta_{csj} = \begin{cases} 0.24\left(R_{dj}^{2/3}\right)^{-1} & : \quad R_{dj}^{2/3} < 4 \\ 0.14\left(R_{dj}^{2/3}\right)^{-0.64} & : \quad 4 \le R_{dj}^{2/3} < 10 \\ 0.04\left(R_{dj}^{2/3}\right)^{-0.1} & : \quad 10 \le R_{dj}^{2/3} < 20 \\ 0.013\left(R_{dj}^{2/3}\right)^{0.29} & : \quad 20 \le R_{dj}^{2/3} < 150 \\ 0.055 & : \quad R_{dj}^{2/3} \ge 150 \end{cases} \tag{5.8}$$

A number of approaches have been used to distinguish when a particular sediment size class is transported as bed load or suspended load under specific local flow conditions characterized by the bed stress or bed shear velocity:

$$u_* = \sqrt{\tau_b} \tag{5.9}$$

where τ_b is the kinematic bed stress (dynamic stress divided by water density). The approach proposed by van Rijn (1984a) is adopted in the EFDC model and is as follows. When the bed velocity is less than the critical shear velocity

$$u_{*csj} = \sqrt{\tau_{csj}} = \sqrt{g' d_j \theta_{csj}} \tag{5.10}$$

no erosion or resuspension takes place and there is no bed load transport. Sediment in suspension under this condition will deposit to the bed as will be subsequently discussed. When the bed shear velocity exceeds the critical shear velocity but remains less than the settling velocity,

$$u_{*csj} < u_* < w_{soj} \tag{5.11}$$

13

sediment will be eroded from the bed and transported as bed load. Sediment in suspension under this condition will deposit to the bed. When the bed shear velocity exceeds both the critical shear velocity and the settling velocity, bed load transport ceases and the eroded or resuspended sediment will be transported as suspended load. These various transport modes are further illustrated by reference to Figure 2, which shows dimensional forms of the settling velocity relationship (5.2) and the critical Shield's shear velocity (5.10), determined using (5.8) for sediment with a specific gravity of 2.65. For grain diameters less than approximately 0.130 mm (130 μm) the settling velocity is less than the critical shear velocity and sediment resuspends from the bed when the bed shear velocity exceeds the critical shear velocity will be transported entirely as suspended load. For grain diameters greater than 0.130 mm, eroded sediment is transported as bed load in the region corresponding to (5.11), and then as suspended load when the bed shear velocity exceeds the settling velocity.
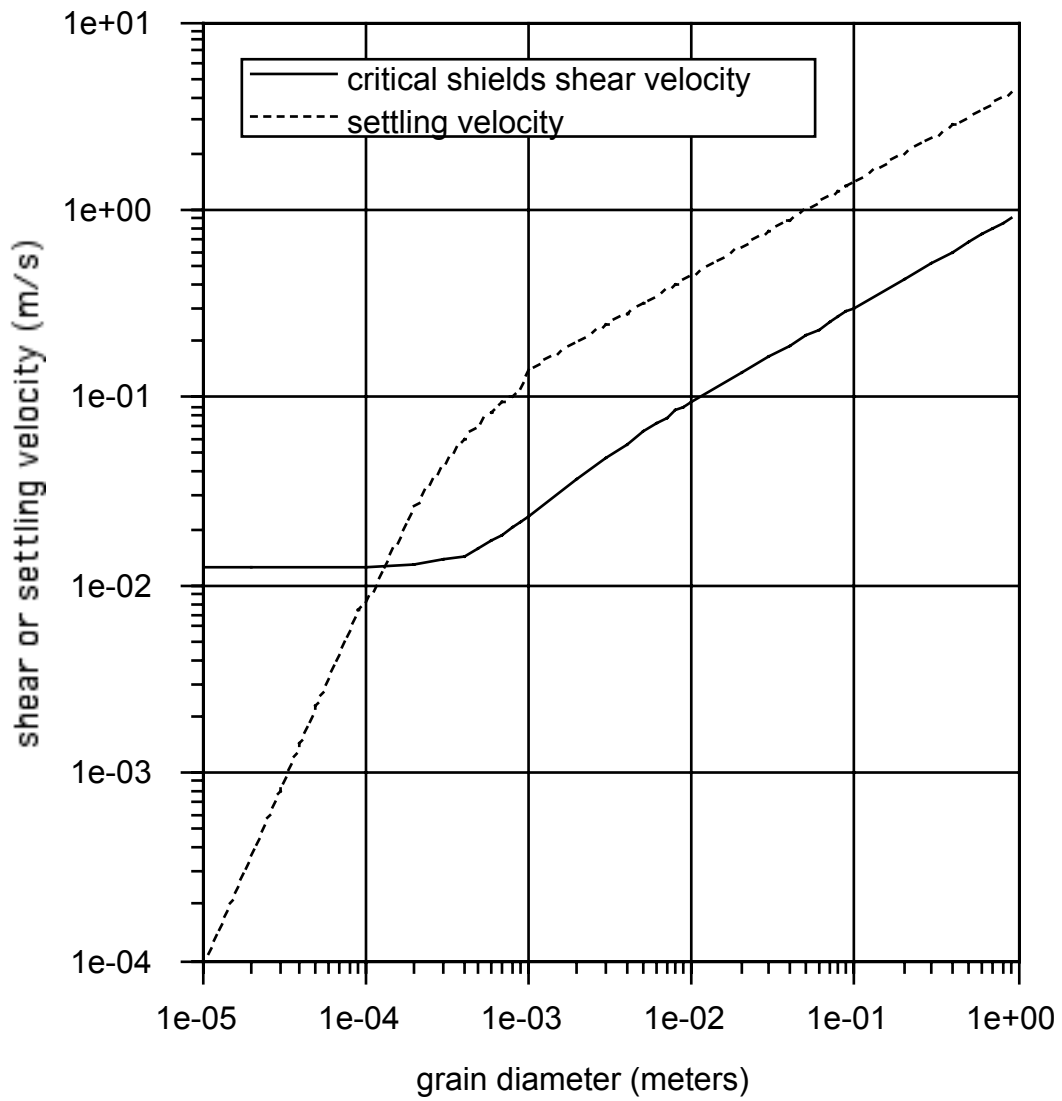
Figure 2.   Critical Shield's shear velocity and settling velocity as a function of sediment grain size.

In the EFDC model, the preceding set of rules is used to determine the mode of transport of multiple size classes of noncohesive sediment. Bed load transport is determined using a general bed load transport rate formula:

$$\frac{q_B}{\rho_s d \sqrt{g'd}} = \Phi(\theta, \theta_{cs})$$ (5.12)

where q_B is the bed load transport rate (mass per unit time per unit width) in the direction of the near bottom horizontal flow velocity vector. The function Φ depends on the Shield's parameter

$$\theta = \frac{\tau_b}{g'd_j} = \frac{u_*^2}{g'd_j}$$ (5.13)

and the critical Shield's parameter defined by (5.7) and (5.8). A number of bed load transport formulas explicitly incorporate the settling velocity. However, since both the critical Shield's parameter and the settling velocity are unique functions of the sediment grain densimetric Reynolds number, the settling velocity can also be expressed as a function of the critical Shield's parameter with (5.12) remaining an appropriate representation.

A number of bed load formulations developed for riverine prediction (Ackers and White 1973; Laursen 1958; Yang 1973; Yang and Molinas 1982) do not readily conform to (1) and were not incorporated as options in the EFDC model. Two widely used bed load formulations that do conform to (5.12) are the Meyer-Peter and Muller (1948) and Bagnold (1956) formulas and their derivatives (Raudkivi 1967; Neilson 1992; Reid and Frostick 1994) that have the general form

$$\Phi(\theta, \theta_{cs}) = \phi(\theta - \theta_{cs})^{\alpha} \left(\sqrt{\theta} - \gamma \sqrt{\theta_{cs}} \right)^{\beta}$$ (5.14)

where

$$\phi = \phi(\theta_{cs}) \quad or \quad \phi(R_d)$$ (5.15)

The Meyer-Peter and Muller formulations are typified by

$$\Phi = \phi(\theta - \theta_{cs})^{3/2}$$ (5.16)

while Bagnold formulations are typified by

$$\Phi = \phi(\theta - \theta_{cs}) \left(\sqrt{\theta} - \gamma \sqrt{\theta_{cs}} \right)$$ (5.17)

with Bagnold's original formula having γ equal to zero. The Meyer-Peter and Muller formulation has been extended to heterogeneous beds by Suzuki *et al*. (1998), while

16

Bagnold's formula has been similarly extended by van Niekerk *et al*. (1992). The bed load formulation by van Rijn (1984a) has the form

$$\Phi = \phi\left(\theta - \theta_{cs}\right)^{2.1}$$
$$\phi = \frac{0.053}{R_d^{1/5}\theta_{cs}^{2.1}}$$

(5.18)

and has been incorporated into the CH3D-SED model and modified for heterogeneous beds by Spasojevic and Holly (1994). Equation (5.18) can be implemented in the EFDC model with an appropriately specified ϕ. A modified formulation of the Einstein bed load function (Einstein 1950) that conforms to (5.12) and (5.14) has been presented by Rahmeyer (1999) and will be later incorporated into the EFDC model.

The procedure for coupling bed load transport with the sediment bed in the EFDC model is as follows. First, the magnitude of the bed load mass flux per unit width is calculated according to (5.12) at horizontal model cell centers, denoted by the subscript c. The cell center flux is then transformed into cell center vector components using

$$q_{bcx} = \frac{u}{\sqrt{u^2 + v^2}} q_{bc}$$

$$q_{bcy} = \frac{v}{\sqrt{u^2 + v^2}} q_{bc}$$

(5.19)

where u and v are the cell center horizontal velocities near the bed. Cell face mass fluxes are determined by downwind projection of the cell center fluxes

$$q_{bfx} = \left(q_{bcx}\right)_{upwind}$$

$$q_{bfy} = \left(q_{bcy}\right)_{upwind}$$

(5.20)

where the subscript *upwind* denotes the cell center upwind of the x normal and y normal cell faces. The net removal or accumulation rate of sediment material from the deposited bed underlying a water cell is then given by:

$$m_x m_y J_b = \left(m_y q_{bfx}\right)_e - \left(m_y q_{bfx}\right)_w + \left(m_x q_{bfy}\right)_n - \left(m_x q_{bfy}\right)_s$$

(5.21)

where J_b is the net removal rate (gm/m^2-sec) from the bed, m_x and m_y are x and y dimensions of the cell, and the compass direction subscripts define the four cell faces. The implementation of (5.19) through (5.21) in the EFDC code includes logic to limit the out fluxes (5.20) over a time-step, such that the time integrated mass flux from the bed does not exceed bed sediment available for erosion or resuspension. When this formulation is implemented in the one-dimensional model, the x direction is presumed aligned along the channel, with the y fluxes set to zero. The scale factors m$_x$ and m$_y$ then correspond to the cell length, Δ, and the sediment bed width, W_B, respectively.

Under conditions when the bed shear velocity exceeds the settling velocity and critical Shield's shear velocity, noncohesive sediment will be resuspended and transported as suspended load. When the bed shear velocity falls below both the settling velocity and the critical Shield's shear velocity, suspended sediment will deposit to the bed. A consistent formulation of these processes can be developed using the concept of a near bed equilibrium sediment concentration. Under steady, uniform flow and sediment loading conditions, an equilibrium distribution of sediment in the water column tends to be established, with the resuspension and deposition fluxes canceling each other. Using a number of simplifying assumptions, the equilibrium sediment concentration distribution in the water column can be expressed analytically in terms of the near bed reference or equilibrium concentration, the settling velocity and the vertical turbulent diffusivity. For unsteady or spatially varying flow conditions, the water column sediment concentration distribution varies in space and time in response to sediment load variations, changes in hydrodynamic transport, and associated nonzero fluxes across the water column-sediment bed interface. An increase or decrease in the bed stress and the intensity of vertical turbulent mixing will result in net erosion or deposition, respectively, at a particular location or time.

To illustrate how an appropriate suspended noncohesive sediment bed flux boundary condition can be established, consider the two-dimensional, in the vertical plane, form of the sediment transport equation,

$$\partial_t (HS)S + \partial_x (HuS) + \partial_z (wS) = \partial_z \left(\frac{K_v}{H} \partial_z S + w_s S \right) \tag{5.22}$$

where u and w are the along channel and vertical velocities respectively, K_v is the vertical diffusion coefficient, H is the water depth, and z is the dimensionless vertical coordinate varying from 0 at the bed to 1 at the water surface. For nearly uniform horizontal conditions, (5.22) can be approximated by:

$$\partial_t (HS) = \partial_z \left(\frac{K_v}{H} \partial_z S + w_s S \right) \tag{5.23}$$

Integrating (5.23) over the depth gives

$$\partial_t \left(H\bar{S} \right) = J_0 \tag{5.24}$$

where the over bar denotes the mean over the depth. Subtracting (5.24) from (5.23) gives

$$\partial_t (HS') = \partial_z \left(\frac{K_v}{H} \partial_z S + w_s S \right) - J_0 \tag{5.25}$$

Assuming that the rate of change of the deviation of the sediment concentration from the mean is small

$$\partial_t (HS') << \partial_t \left(H\bar{S} \right) \tag{5.26}$$

allows (5.26) to be approximated by

$$\partial_z \left(\frac{K_v}{H} \partial_z S + w_s S \right) = J_0 \tag{5.27}$$

Integrating (5.27) once gives

$$\frac{K_v}{H} \partial_z S + w_s S = -J_0 (1 - z) \tag{5.28}$$

Very near the bed, (5.28) can be approximated by

$$\frac{K_v}{H} \partial_z S + w_s S = -J_0 \tag{5.29}$$

Neglecting stratification effects the near bed diffusivity is approximately

$$\frac{K_v}{H} = K_o q \frac{l}{H} \cong u_* \kappa z \tag{5.30}$$

Introducing (5.30) into (5.29) gives

$$\partial_z S + \frac{R}{z} S = -\frac{R}{z} \frac{J_o}{w_s} \tag{5.31}$$

where

$$R = \frac{w_s}{u_* \kappa} \tag{5.32}$$

is the Rouse parameter. The solution of (5.31) is

$$S = -\frac{J_o}{w_s} + \frac{C}{z^R} \tag{5.33}$$

The constant of integration is evaluated using

$$S = S_{eq} \quad : \quad z = z_{eq} \quad and \quad J_o = 0 \tag{5.34}$$

which sets the near bed sediment concentration to an equilibrium value, defined just above the bed under no net flux condition. Using (5.34), equation (5.33) becomes

$$S = \left(\frac{z_{eq}}{z} \right)^R S_{eq} - \frac{J_o}{w_s} \tag{5.35}$$

19

For nonequilibrium conditions, the net flux is given by evaluating (5.35) at the equilibrium level

$$J_o = w_s \left(S_{eq} - S_{ne} \right) \tag{5.36}$$

where S_{ne} is the actual concentration at the reference equilibrium level. Equation (5.36) clearly indicates that when the near bed sediment concentration is less than the equilibrium value a net flux from the bed into the water column occurs. Likewise when the concentration exceeds equilibrium, a net flux to the bed occurs.

For the relationship (5.36) to be useful in a numerical model, the bed flux must be expressed in terms of the transport model's representation of sediment mean concentration. For application in an one-dimensional or two-dimensional model, (5.35) can be integrated over the depth to give

$$J_o = w_s \left(\overline{S}_{eq} - S \right) \tag{5.37}$$

where

$$\overline{S}_{eq} = \frac{\ln\left(z_{eq}^{-1}\right)}{\left(z_{eq}^{-1} - 1\right)} S_{eq} : R = 1$$

$$\overline{S}_{eq} = \frac{\left(\left(z_{eq}^{-1}\right)^{1-R} - 1\right)}{(1-R)\left(z_{eq}^{-1} - 1\right)} S_{eq} : R \neq 1 \tag{5.38}$$

defines an equivalent layer mean equilibrium concentration in terms of the near bed equilibrium concentration. The corresponding quantity in the sediment transport equation (3.1) is

$$J_{CB} = J_{SB} = w_s \left(\overline{S}_{eq} - \overline{S} \right) \tag{5.39}$$

An alternate formulation for one-dimensional and two-dimensional, depth averaged, model applications retain the complete form of (5.28):

$$\frac{K_v}{H} \partial_z S + w_s S = -J_o (1 - z) \tag{5.40}$$

A more general form for the vertical diffusivity is:

$$\frac{K_v}{H} = K_o q \frac{l}{H} \cong u_* \kappa z (1 - z)^\lambda \tag{5.41}$$

Introducing (5.41) into (5.40) gives

20

$$\partial_z S + \frac{R}{z(1-z)^\lambda} S = -\frac{R(1-z)^{1-\lambda}}{z} \frac{J_o}{w_s}$$

<div align="right">(5.42)</div>

A close form solution of (5.42) is possible for λ equal to zero. Although the resulting diffusivity is not as reasonable as the choice of λ equal to one, the resulting vertical distribution of sediment is much more sensitive to the near bed diffusivity distribution than the distribution in the upper portions of the water column. For λ equal to zero, the solution of (5.42) is

$$S = -\left(1 - \frac{Rz}{(1+R)}\right)\frac{J_o}{w_s} + \frac{C}{z^R}$$

<div align="right">(5.43)</div>

Evaluating the constant of integration using (5.43) gives

$$S = \left(\frac{z_{eq}}{z}\right)^R S_{eq} - \left(1 - \frac{Rz}{(1+R)}\right)\frac{J_o}{w_s}$$

<div align="right">(5.44)</div>

For nonequilibrium conditions, the net flux is given by evaluating (5.44) at the equilibrium level

$$J_o = w_s\left(\frac{(1+R)}{1 + R(1 - z_{eq})}\right)(S_{eq} - S_{ne})$$

<div align="right">(5.45)</div>

where S_{ne} is the actual concentration at the reference equilibrium level. Since z_{eq} is on the order of the sediment grain diameter divided by the depth of the water column, (5.45) is essentially equivalent (5.35). To obtain an expression for the bed flux in terms of the depth average sediment concentration, (5.44) is integrated over the depth to give

$$J_o = w_s\left(\frac{2(1+R)}{2 + R(1 - z_{eq})}\right)(\overline{S}_{eq} - \overline{S})$$

<div align="right">(5.46)</div>

where

$$\overline{S}_{eq} = \frac{\ln(z_{eq}^{-1})}{(z_{eq}^{-1} - 1)} S_{eq} : R = 1$$

$$\overline{S}_{eq} = \frac{(z_{eq}^{R-1} - 1)}{(1 - R)(z_{eq}^{-1} - 1)} S_{eq} : R \neq 1$$

<div align="right">(5.47)</div>

The corresponding quantity in the sediment transport equation (3.1) is

$$J_{CB} = J_{SB} = w_s \left(\frac{2(1+R)}{2+R(1-z_{eq})} \right) \overline{S}_{eq}$$

(5.48)

When multiple sediment size classes are simulated, the equilibrium concentrations given by (5.38) and (5.47) are adjusted by multiplying by their respective sediment volume fractions in the surface layer of the bed.

The specification of the water column-bed flux of noncohesive sediment has been reduced to specification of the near bed equilibrium concentration and its corresponding reference distance above the bed. Garcia and Parker (1991) evaluated seven relationships, derived by combinations of analysis and experiment correlation, for determining the near bed equilibrium concentration as well as proposing a new relationship. All of the relationships essentially specify the equilibrium concentration in terms of hydrodynamic and sediment physical parameters

$$S_{eq} = S_{eq}(d, \rho_s, \rho_w, w_s, u_*, \nu)$$

(5.49)

including the sediment particle diameter, the sediment and water densities, the sediment settling velocity, the bed shear velocity, and the kinematic molecular viscosity of water. Garcia and Parker concluded that the representations of Smith and McLean (1977) and Van Rijn (1984b) as well as their own proposed representation perform acceptably well when tested against experimental and field observations.

Smith and McLean's formula for the equilibrium concentration is

$$S_{eq} = \rho_s \frac{0.65 \gamma_o T}{1 + \gamma_o T}$$

(5.50)

where γ_o is a constant equal to 2.4E-3 and T is given by

$$T = \frac{\tau_b - \tau_{cs}}{\tau_{cs}} = \frac{u_*^2 - u_{*cs}^2}{u_{*cs}^2}$$

(5.51)

where τ_b is the bed stress and τ_{cs} is the critical Shields stress. The use of Smith and McLean's formulation requires that the critical Shields stress be specified for each sediment size class. Van Rijn's formula is

$$S_{eq} = 0.015 \rho_s \frac{d}{z_{eq}^*} T^{3/2} R_d^{-1/5}$$

(5.52)

where z_{eq}^* ($= H z_{eq}$) is the dimensional reference height and R_d is a sediment grain Reynolds number. When Van Rijn's formula is selected for use in EFDC1D, the critical Shields stress in internally calculated using relationships from Van Rijn (1984b). Van Rijn suggested setting the dimensional reference height to three-grain diameters. In the

EFDC1D model, the user specifies the reference height as a multiple of the largest noncohesive sediment size class diameter.

Garcia and Parker's general formula for multiple sediment size classes is

$$S_{jeq} = \rho_s \frac{A(\lambda Z_j)^5}{\left(1 + 3.33 A(\lambda Z)^5\right)} \tag{5.53}$$

$$Z_j = \frac{u_*}{w_{sj}} R_{dj}^{3/5} F_H \tag{5.54}$$

$$F_H = \left(\frac{d_j}{d_{50}}\right)^{1/5} \tag{5.55}$$

$$\lambda = 1 + \frac{\sigma_\phi}{\sigma_{\phi o}} (\lambda_o - 1) \tag{5.56}$$

where A is a constant equal to 1.3E-7, d_{50} is the median grain diameter based on all sediment classes, λ is a straining factor, F_H is a hiding factor and σ_ϕ is the standard deviation of the sedimentological phi scale of sediment size distribution. Garcia and Parker's formulation is unique in that it can account for armoring effects when multiple sediment classes are simulated. For simulation of a single noncohesive size class, the straining factor and the hiding factor are set to one. The EFDC1D model has the option to simulate armoring with Garcia and Parker's formulation. For armoring simulation, the current surface layer of the sediment bed is restricted to a thickness equal to the dimensional reference height.

6.   Cohesive Sediment Settling, Deposition and Resuspension

The settling of cohesive inorganic sediment and organic particulate material is an extremely complex process. Inherent in the process of gravitational settling is the process of flocculation, where individual cohesive sediment particles and particulate organic particles aggregate to form larger groupings or flocs having settling characteristics significantly different from those of the component particles (Burban *et al.* 1989, 1990; Gibbs 1985; Mehta *et al.* 1989).   Floc formation is dependent upon the type and concentration of the suspended material, the ionic characteristics of the environment, and the fluid shear and turbulence intensity of the flow environment. Progress has been made in first principles mathematical modeling of floc formation or aggregation, and disaggregation by intense flow shear (Lick and Lick 1988; Tsai *et al.* 1987). However, the computational intensity of such approaches precludes direct simulation of flocculation in operational cohesive sediment transport models for the immediate future.

An alternative approach, which has met with reasonable success, is the parameterization of the settling velocity of flocs in terms of cohesive and organic material fundamental particle size, d; concentration, S; and flow characteristics such as vertical shear of the horizontal velocity, du/dz, shear stress, $A_v du/dz$, or turbulence intensity in the water column or near the sediment bed, q. This has allowed semi-empirical expressions having the functional form

$$W_{se} = W_{se}\left(d, S, \frac{du}{dz}, q\right)$$

(6.1)

to be developed to represent the effective settling velocity. A widely used empirical expression, first incorporated into a numerical model by Ariathurai and Krone (1976), relates the effective settling velocity to the sediment concentration:

$$w_s = w_{so}\left(\frac{S}{S_o}\right)^a$$

(6.2)

where a is an empirical constant and the o subscript denotes a reference value. Depending upon the reference concentration and the value of α, this equation predicts either increasing or decreasing settling velocity as the sediment concentration increases. Equation (6.2) with user-defined base settling velocity, concentration and exponent is an option in the EFDC1D model. Hwang and Mehta (1989) proposed

$$w_s = \frac{aS^n}{\left(S^2 + b^2\right)^m}$$

(6.3)

based on observations of settling at six sites in Lake Okeechobee. This equation has a general parabolic shape with the settling velocity decreasing with decreasing concentration at low concentrations, and decreasing with increasing concentration at high concentrations. A least squares regression analysis for the parameters a, m, and n in (6.3)

24

was shown to agree well with observational data. Equation (6.3) does not have a dependence on flow characteristics, but is based on data from an energetic field condition having both currents and high frequency surface waves. A generalized form of (6.3) can be selected as an option in the EFDC1D model.

Ziegler and Nisbet (1994, 1995) proposed the following formulation to express the effective settling as a function of the floc diameter, d_f:

$$w_s = a d_f^b \tag{6.4}$$

with the floc diameter given by:

$$d_f = \left(\frac{\alpha_f}{S\sqrt{\tau_{xz}^2 + \tau_{xz}^2}} \right)^{1/2} \tag{6.5}$$

where S is the sediment concentration, α_f is an experimentally determined constant and τ_{xz} and τ_{yz} are the x and y components of the turbulent shear stresses at a given position in the water column. Other quantities in (6.4) have been experimentally determined to fit the relationships:

$$a = B_1 \left(S\sqrt{\tau_{xz}^2 + \tau_{xz}^2} \right)^{-0.85} \tag{6.6}$$

$$b = -0.8 - 0.5\log\left(S\sqrt{\tau_{xz}^2 + \tau_{xz}^2} - B_2 \right) \tag{6.7}$$

where B_1 and B_2 are experimental constants. This formulation is also an option in the EFDC1D model.

A final settling option in EFDC1D is based on that proposed by Shrestha and Orlob (1996). The formulation in EFDC1D has the form

$$w_s = S^\alpha \exp(-4.21 + 0.147G) \tag{6.8}$$
$$\alpha = 0.11 + 0.039G$$

where

$$G = \sqrt{(\partial_z u)^2 + (\partial_z v)^2} \tag{6.9}$$

is the magnitude of the vertical shear of the horizontal velocity. It is noted that all of these formulations are based on specific dimensional units for input parameters and predicted settling velocities and that appropriate unit conversions are made internally in their implementation in the EFDC1D model.

Water column-sediment bed exchange of cohesive sediments and organic solids is controlled by the near bed flow environment and the geomechanics of the deposited bed. Net deposition to the bed occurs as the flow-induced bed surface stress decreases. The most widely used expression for the depositional flux is:

$$J_o^d = \begin{cases} -w_s S_d \left(\dfrac{\tau_{cd} - \tau_b}{\tau_{cd}} \right) = -w_s T_d S_d & : \quad \tau_b \leq \tau_{cd} \\[4mm] 0 & : \quad \tau_b \geq \tau_{cd} \end{cases}$$

(6.10)

where τ_b is the stress exerted by the flow on the bed, τ_{cd} is a critical stress for deposition that depends on sediment material and floc physiochemical properties (Mehta *et al.*1989), and S_d is the near bed depositing sediment concentration. The critical deposition stress is generally determined from laboratory or *in situ* field observations and values ranging from 0.06 to 1.1 N/m^2 have been reported in the literature. Given this wide range of reported values, in the absence of site specific data the depositional stress is generally treated as a calibration parameter. The critical depositional stress is an input parameter in the EFDC1D model.

Since the near bed depositing sediment concentration in (6.10) is not directly calculated, the procedures of Chapter 5 can be applied to relate the near bed depositional concentration to the bottom layer or depth average concentration. Using (5.33) the near bed concentration during times of deposition can be determined in terms of the bottom layer concentration for two-dimensional, in the vertical plane, and three-dimensional model applications. Inserting (6.10) into (5.33) and evaluating the constant at a near bed depositional level gives

$$S = \left(T_d + (1 - T_d) \frac{z_d^R}{z^R} \right) S_d$$

(6.11)

For use in a two-dimensional, depth averaged, or one-dimensional application, (6.11) is integrated over the total depth to give

$$S_d = \left(T_d + \frac{\ln(z_d^{-1})}{(z_d^{-1} - 1)} (1 - T_d) \right)^{-1} \overline{S} : R = 1$$

$$S_d = \left(T_d + \frac{\left((z_{eq}^{-1})^{1-R} - 1 \right)}{(1 - R)(z_d^{-1} - 1)} (1 - T_d) \right)^{-1} \overline{S} : R \neq 1$$

(6.12)

The corresponding quantities in the one-dimensional sediment transport equation (3.1) are

$$J_{CB} = J_{SB} = -\left(T_d + \frac{\ln\left(z_d^{-1}\right)}{\left(z_d^{-1}-1\right)}\left(1-T_d\right) \right)^{-1} w_s \overline{S} : R = 1$$

$$J_{CB} = J_{SB} = -\left(T_d + \frac{\left(\left(z_{eq}^{-1}\right)^{1-R}-1\right)}{(1-R)\left(z_d^{-1}-1\right)}\left(1-T_d\right) \right)^{-1} w_s \overline{S} : R \neq 1 \tag{6.13}$$

An alternate formulation for depth averaged and one-dimensional model applications is obtained by combining (6.10) with (5.43). The constant of integration is evaluated at a near bed depositional level to give

$$S = \left(1 - \frac{Rz}{(1+R)} \right)T_d S_d + \left(1 - \left(1 - \frac{Rz_d}{(1+R)} \right)T_d \right)S_d \frac{z_d^R}{z^R} \tag{6.14}$$

Integrating (6.14) over the depth gives

$$S_d = \left(\left(\frac{2+R(1-z_d)}{2(1+R)} \right)T_d + \frac{\ln\left(z_d^{-1}\right)}{\left(z_d^{-1}-1\right)}\left(1-\left(\frac{1+R(1-z_d)}{(1+R)}\right)T_d\right) \right)^{-1} \overline{S} : R = 1$$

$$S_d = \left(\left(\frac{2+R(1-z_d)}{2(1+R)} \right)T_d + \frac{\left(z_d^{R-1}-1\right)}{(1-R)\left(z_d^{-1}-1\right)}\left(1-\left(1-\frac{Rz_d}{(1+R)}\right)T_d\right) \right)^{-1} \overline{S} : R \neq 1 \tag{6.15}$$

The corresponding quantities in the one-dimensional sediment transport equation (3.1) are

$$\frac{J_{SB}}{w_s\overline{S}} = -\left(\left(\frac{2+R(1-z_d)}{2(1+R)} \right)T_d + \frac{\ln\left(z_d^{-1}\right)}{\left(z_d^{-1}-1\right)}\left(1-\left(\frac{1+R(1-z_d)}{(1+R)}\right)T_d\right) \right)^{-1} : R = 1$$

$$\frac{J_{SB}}{w_s\overline{S}} = -\left(\left(\frac{2+R(1-z_d)}{2(1+R)} \right)T_d + \frac{\left(z_d^{R-1}-1\right)}{(1-R)\left(z_d^{-1}-1\right)}\left(1-\left(1-\frac{Rz_d}{(1+R)}\right)T_d\right) \right)^{-1} : R \neq 1 \tag{6.16}$$

It is noted that the assumptions used to arrive at the relationships (6.12) and (6.15) are more tenuous for cohesive sediment than the similar relationships for noncohesive sediment. The settling velocity for cohesive sediment is highly concentration dependent and the use of a constant settling velocity to arrive at (6.12) and (6.15) is questionable. The specification of an appropriate reference level for cohesive sediment is difficult. One possibility is to relate the reference level to the floc diameter using (6.5). An alternative is to set the reference level to a laminar sub-layer thickness

$$z_d = \frac{v(S)}{Hu_*} \tag{6.17}$$

27

where $\nu(S)$ is a sediment concentration dependent kinematic viscosity, and the water depth is included to nondimensionalize the reference level. A number of investigators, including Mehta and Jiang (1990) have presented experimental results indicating that at high sediment concentrations, cohesive sediment-water mixtures behave as high viscosity fluids. Mehta and Jaing's results indicate that a sediment concentration of 10,000 mg/L results in a viscosity ten times that of pure water, and that the viscosity increases logarithmically with increasing mixture density. Use of the relationships (6.12) and (6.16) is optional in the EFDC1D model. When they are used, the reference height is set using (6.17) with the viscosity determined using Mehta and Jaing's experimental relationship between viscosity and sediment concentration.

Cohesive bed erosion occurs in two distinct modes, mass erosion and surface erosion. Mass erosion occurs rapidly when the bed stress exerted by the flow exceeds the depth varying shear strength, τ_s of the bed at a depth, H_{me} below the bed surface. Surface erosion occurs gradually when the flow-exerted bed stress is less than the bed shear strength near the surface but greater than a critical erosion or resuspension stress, τ_{ce} which is dependent on the shear strength and density of the bed. A typical scenario under conditions of accelerating flow and increasing bed stress would involve first the occurrence of gradual surface erosion, followed by a rapid interval of mass erosion, followed by another interval of surface erosion. Alternately, if the bed is well consolidated with a sufficiently high shear strength profile, only gradual surface erosion would occur. Transport into the water column by mass or bulk erosion can be expressed in the form

$$J_o^r = J_{SB} = \frac{m_{me}(\tau_s \le \tau_b)}{T_{me}}$$ (6.18)

where J_o is the erosion flux, J_{SB} represents the bed source term in (3.1), m_{me} is the dry sediment mass per unit area of the bed having a shear strength, τ_s, less than the flow-induced bed stress, τ_b, and T_{me} is a somewhat arbitrary time scale for the bulk mass transfer. The time scale can be taken as the numerical model integration time-step (Shrestha and Orlob 1996). Observations by Hwang and Mehta (1989) have indicated that the maximum rate of mass erosion is on the order of 0.6 gm/s-m^2 that provides a means of estimating the transfer time scale in (6.18). The shear strength of the cohesive sediment bed is generally agreed to be a linear function of the bed bulk density (Mehta *et al*. 1982; Villaret and Paulic 1986; Hwang and Mehta 1989)

$$\tau_s = a_s \rho_b + b_s$$ (6.19)

For the shear strength in N/m^2 and the bulk density in gm/cm^3, Hwang and Mehta (1989) give a_s and b_s values of 9.808 and -9.934 for a bulk density greater than 1.065 gm/cm^3. The EFDC1D model currently implements Hwang and Mehta's relationship, but can be readily modified to incorporate other functional relationships.

Surface erosion is generally represented by relationships of the form

$$J_o^r = w_r S_r = \frac{dm_e}{dt} \left(\frac{\tau_b - \tau_{ce}}{\tau_{ce}} \right)^\alpha \quad : \quad \tau_b \geq \tau_{ce} \tag{6.20}$$

or

$$J_o^r = w_r S_r = \frac{dm_e}{dt} \exp\left(-\beta \left(\frac{\tau_b - \tau_{ce}}{\tau_{ce}} \right)^\gamma \right) \quad : \quad \tau_b \geq \tau_{ce} \tag{6.21}$$

where dm_e/dt is the surface erosion rate per unit surface area of the bed and τ_{ce} is the critical stress for surface erosion or resuspension. The critical erosion rate and stress and the parameters α, β, and γ are generally determined from laboratory or *in situ* field experimental observations. Equation (6.20) is more appropriate for consolidated beds, while (6.21) is appropriate for soft partially consolidated beds. The base erosion rate and the critical stress for erosion depend upon the type of sediment, the bed water content, total salt content, ionic species in the water, pH and temperature (Mehta *et al.* 1989) and can be measured in laboratory and sea bed flumes.

The critical erosion stress is related to but generally less than the shear strength of the bed, which in turn depends upon the sediment type and the state of consolidation of the bed. Experimentally determined relationships between the critical surface erosion stress and the dry density of the bed of the form

$$\tau_{ce} = c\rho_d^a \tag{6.22}$$

have been presented (Mehta *et al.* 1989). Hwang and Mehta (1989) proposed the relationship

$$\tau_{ce} = a\left(\rho_b - \rho_l\right)^b + c \tag{6.23}$$

between the critical surface erosion stress and the bed bulk density with *a, b, c*, and ρ_l equal to 0.883, 0.2, 0.05, and 1.065, respectively for the stress in N/m^2 and the bulk density in gm/cm^3. Considering the relationship between dry and bulk density

$$\rho_d = \rho_s \frac{\left(\rho_b - \rho_w\right)}{\left(\rho_s - \rho_w\right)} \tag{6.24}$$

equations (6.22) and (6.23) are consistent. The EFDC1D model allows for a user defined constant critical stress for surface erosion or the use of (6.23). Alternate predictive expressions can be readily incorporated into the model.

Surface erosion rates ranging from 0.005 to 0.1 gm/m^2-s have been reported in the literature, and it is generally accepted that the surface erosion rate decreases with increasing bulk density. Based on experimental observations, Hwang and Mehta (1989) proposed the relationship

$$\log_{10}\left(\frac{dm_e}{dt}\right) = 0.23\exp\left(\frac{0.198}{\rho_b - 1.0023}\right) \tag{6.25}$$

for the erosion rate in mg/cm^2-hour and the bulk density in gm/cm^3. The EFDC1D model allows for a user defined constant surface erosion rate or predicts the rate using (6.25). Alternate predictive expressions can be readily incorporated into the model. The use of bulk density functions to predict bed strength and erosion rates in turn requires the prediction of time and depth in bed variations in bulk density which is related to the water and sediment density and the bed void ratio, ε, by

$$\rho_b = \left(\frac{\varepsilon}{1+\varepsilon}\right)\rho_w + \left(\frac{1}{1+\varepsilon}\right)\rho_s \tag{6.26}$$

Selection of the bulk density dependent formulations in the EFDC1D model requires implementation of a bed consolidation simulation to predict the bed void ratio as discussed in the following chapter.

7. Sediment Bed Geomechanical Processes

This chapter describes the representation of the sediment bed in the EFDC1D model. To make the information presented self-contained, the derivation of mass balance equations and comparison with formulations used in other models are also presented.

Consider a sediment bed represented by discrete layers of thickness B_k, which may be time varying. The conservation of sediment and water mass per unit horizontal area in layer k are given by:

$$\partial_t \left(\frac{\rho_s B_k}{1 + \varepsilon_k} \right) = J_{s:k-} - J_{s:k+} - \delta(k, k_b) J_{sb} \tag{7.1}$$

$$\partial_t \left(\frac{\rho_w \varepsilon_k B_k}{1 + \varepsilon_k} \right) = J_{w:k-} - J_{w:k+} - \delta(k, k_b) \frac{\rho_w}{\rho_s} \left(\varepsilon_k \max(J_{sb}, 0) + \varepsilon_b \min(J_{sb}, 0) \right) \tag{7.2}$$

where ε is the void ratio, ρ_s and ρ_w are the sediment and water density and J_s and J_w are the sediment and water mass fluxes with $k-$ and $k+$ defining the bottom and top boundaries, respectively, of layer k. The mass fluxes are defined as positive in the vertical direction and exclude fluxes associated with sediment deposition and erosion. The last term in equation (7.1) represents erosion and deposition of sediment at the top of the upper most bed layer, $k = k_b$, where

$$\delta(k, k_b) = \begin{cases} 1 : k = k_b \\ 0 : k \neq k_b \end{cases} \tag{7.3}$$

Consistent with this partitioning of flux,

$$J_{s:k+} = 0 : k \neq k_b \tag{7.4}$$

The last term in (7.2) represents the corresponding entrainment of bed pore water into the water column during sediment erosion and entrainment of water column water into the bed during deposition. The water flux, $J_{w:k+}$, at the top of the upper most layer, k_b, is not necessarily zero, since it can include ambient seepage and pore water expulsion due to bed consolidation.

Assuming sediment and water to be incompressible, (7.1) and (7.2) can be written as:

$$\partial_t \left(\frac{B_k}{1 + \varepsilon_k} \right) = \frac{1}{\rho_s} \left(J_{s:k-} - J_{s:k+} \right) - \delta(k, k_b) \frac{J_{sb}}{\rho_s} \tag{7.5}$$

$$\partial_t \left(\frac{\varepsilon_k B_k}{1 + \varepsilon_k} \right) = q_{w:k-} - q_{w:k+} - \delta(k, k_b) \left(\varepsilon_k \max\left(\frac{J_{sb}}{\rho_s}, 0 \right) + \varepsilon_b \min\left(\frac{J_{sb}}{\rho_s}, 0 \right) \right) \tag{7.6}$$

where the water specific discharges

$$J_{w:k-} = \rho_w q_{w:k-}$$
$$J_{w:k+} = \rho_w q_{w:k-}$$

(7.7)

have been introduced into (7.6). Four approaches for the solution of the mass conservation equations (7.5) and (7.6) have been previously utilized. The solution approaches, hereafter referred to as solution levels, increase in complexity and physical realism and will be briefly summarized below.

The first level or simplest approach assumes specified time-constant layer thicknesses and void ratios with the left sides of (7.5) and (7.6) being identically zero. Sediment mass flux at all layer interfaces are then identical to the net flux from the bed to the water column.

$$J_{s:k-} = J_{sb} : k = 1, k_b$$
$$J_{s:k+} = \begin{cases} 0 : k = k_b \\ J_{sb} : k \neq k_b \end{cases}$$

(7.8)

Bed representations at this level, as exemplified by the RECOVERY model (Boyer et al. 1994), typically omit the water mass conservation equations. However, it is noted that the water mass conservation is ill posed unless either q_{k-} the specific discharge at the bottom of the deepest layer or q_{kb+}, the specific discharge at the top of the water column adjacent layer, is specified. If q_{k-} is set to zero, q_{kb+} is then required to exactly cancel the entrainment terms is (7.6).

The second level of bed mass conservation representation assumes specified time invariant layer thicknesses. The mass conservation equations (7.5) and (7.6) become

$$B_k \partial_t \left(\frac{1}{1+\varepsilon_k} \right) = \frac{1}{\rho_s} \left(J_{s:k-} - J_{s:k+} \right) - \delta(k, k_b) \frac{J_{sb}}{\rho_s}$$

(7.9)

$$B_k \partial_t \left(\frac{\varepsilon_k}{1+\varepsilon_k} \right) = q_{w:k-} - q_{w:k+} - \delta(k, k_b) \left(\varepsilon_k \max\left(\frac{J_{sb}}{\rho_s}, 0 \right) + \varepsilon_b \min\left(\frac{J_{sb}}{\rho_s}, 0 \right) \right)$$

(7.10)

This system of 2 x k_b equations includes k_b unknown void ratios, k_b unknown internal sediment fluxes, and k_{b+1} unknown specific discharges and is under determined unless additional information is specified. The constant bed layer thickness option in the WASP5 model (Ambrose *et al.* 1993) uses specified burial velocities to define the following internal sediment fluxes:

$$J_{s:k-} = -w_{b:k-}S_k$$

$$J_{s:k+} = -w_{b:k+}S_{k+1}$$

$$w_{b:k+} = w_{b:k+1-}$$

(7.11)

$$S_k = \frac{\rho_s}{1+\varepsilon_k}$$

(7.12)

where w_b is the burial velocity and S is the sediment concentration (mass per unit total volume). Use of the burial velocity eliminates the indeterminacy in (7.9) and allows its solution for the void ratio. In the event that the sediment concentration in the upper most layer becomes negative, the layer is eliminated and the underlying layer becomes water column adjacent. The left side of the water mass conservation equations (7.10) is now known, and the equation is more appropriately written as

$$q_{w:k-} - q_{w:k+} = B_k \partial_t \left(\frac{\varepsilon_k}{1+\varepsilon_k} \right) + \delta(k,k_b)\left(\varepsilon_k \max\left(\frac{J_{sb}}{\rho_s},0 \right) + \varepsilon_b \min\left(\frac{J_{sb}}{\rho_s},0 \right) \right)$$

(7.13)

The determination of the specific discharges using (7.13) can be viewed as either under determined or physically inconsistent. As shown for the first level approach, the solution of (7.13) is ill posed unless either q_{k-}, the specific discharge at the bottom of the deepest layer or q_{kb+}, the specific discharge at the top of the upper most layer is independently specified. If q_{k-} is specified and the internal specific discharges are determined from (7.13), q_{kb+} is then required to partially cancel the entrainment terms in (7.13). As will be subsequently shown, the specific discharges can be dynamically determined using Darcy's law. However, the specific discharges determined using Darcy's law and the known void ratios are not guaranteed to satisfy (7.13); thus, the level two formulation is dynamically inconsistent with respect to water mass conservation in the sediment bed. The constant bed layer thickness option in WASP5 ignores this problem entirely by not considering the water mass balance and hence neglecting pore water advection of dissolved contaminants.

The third level of bed mass conservation representation assumes specified time invariant layer void ratios. The mass conservation equations (7.5) and (7.6) become

$$\left(\frac{1}{1+\varepsilon_k} \right) \partial_t B_k = \frac{1}{\rho_s}\left(J_{s:k-} - J_{s:k+} \right) - \delta(k,k_b)\frac{J_{sb}}{\rho_s}$$

(7.14)

$$\left(\frac{\varepsilon_k}{1+\varepsilon_k} \right) \partial_t B_k = q_{w:k-} - q_{w:k+} - \delta(k,k_b)\left(\varepsilon_k \max\left(\frac{J_{sb}}{\rho_s},0 \right) + \varepsilon_b \min\left(\frac{J_{sb}}{\rho_s},0 \right) \right)$$

(7.15)

This system of equations exhibits the same under determined nature as (7.9) and (7.10). Specification of internal sediment fluxes or burial velocities allows (7.14) to be solved for the layer thicknesses. Solution of (7.15) for the specific discharges then requires the specification of either q_{k-}, the specific discharge at the bottom of the deepest layer or q_{kb+},

the specific discharge at the top of the uppermost layer. The variable bed layer thickness option in the WASP5 model (Ambrose *et al.* 1993) exemplifies the third level of bed representation. Specifically, the thickness of the water column adjacent layer is allowed to vary in time, while the thicknesses of the underlying layers remain constant. A periodic time variation is specified for the bottom sediment flux in the uppermost layer

$$
\begin{aligned}
J_{s:kb-} &= 0 \quad : \quad t_o \le t \le t_o + (N-1)\Delta t \\
J_{s:kb-} &= \int_{t_o}^{t_o + N\Delta t} J_{sb}\, dt \quad : \quad t_o + (N-1)\Delta t \le t \le t_o + N\Delta t
\end{aligned}
\tag{7.16}
$$

where Δt is the standard water time-step and $N\Delta t$ is the sediment compaction time. This results in the thickness of the uppermost layer periodically returning to its initial value at time intervals of $N\Delta t$ unless the thickness becomes negative due to net resuspension. In that event, the underlying layer becomes the water column adjacent layer. The water mass conservation (7.15) for all but the uppermost layer becomes

$$
q_{k+} = q_{k-} = q_{1-} \quad : \quad k \ne k_b
\tag{7.17}
$$

which indicates that all internal specific discharges are equal to a specified specific discharge at the bottom of layer 1. Given the solution for the time variation of the water column adjacent thickness and bottom specific discharge, (7.15) can be solved for the specific discharge at the top of the layer. The constant porosity bed option in EFDC1D is also a level three approach. In EFDC1D, the internal sediment fluxes are set to zero and the change in thickness of the water column adjacent layer is determined directly using (7.14) while the underlying layers have time invariant thicknesses. As a result, the internal water specific discharges are set to zero and the water entrainment and expulsion in the water column adjacent layer are determined directly from (7.15). As a result, the internal water specific discharges are set to zero and the water entrainment and expulsion in the water column adjacent layer are determined directly from (7.15). The EFDC1D model is configured to have a user specified maximum number of sediment bed layers. At the start of a simulation, the number of layers containing sediment at a specific horizontal location is specified. Under continued deposition, a new water column layer is created when the thickness of the current layer exceeds a user specified value. If the current water column adjacent layer's index is equal to the maximum number of layers, the bottom two layers are combined and the remaining layers renumbered before addition of the new layer. Under continued resuspension, the layer underlying the current water column adjacent layer becomes the new adjacent layer when all sediment is resuspended from the current layer.

The fourth level of bed representation accounts for bed consolidation by allowing the layer void ratios and thicknesses to vary in time. The simplest and most elegant formulations at this level utilize a Lagrangian approach for sediment mass conservation. The Lagrangian approach requires that the sediment mass per unit horizontal area in all layers, except the upper most, be time invariant and without loss of generality, the

internal sediment fluxes can be set to zero. Consistent with these requirements (7.5) becomes

$$\partial_t \left(\frac{B_k}{1 + \varepsilon_k} \right) = -\delta(k, k_b) \frac{J_{sb}}{\rho_s} \tag{7.18}$$

Expanding the left side of the water conservation equation (7.6), and using (7.18) gives

$$\left(\frac{B_k}{1 + \varepsilon_k} \right) \partial_t \varepsilon_k = q_{w:k-} - q_{w:k+} + \delta(k, k_b)(\varepsilon_k - \varepsilon_b) \min \left(\frac{J_{sb}}{\rho_s}, 0 \right) \tag{7.19}$$

The Lagrangian approach for sediment mass conservation also requires that the number of bed layers vary in time. Under conditions of continued deposition, a new water column adjacent layer would be added when either the thickness, void ratio or mass per unit area of the current water column adjacent layer reaches a predefined value. Under conditions of continued resuspension, the bed layer immediately under the current water column adjacent layer would become the new water column adjacent layer when the entire sediment mass of the current layer has been resuspended.

At the fourth and most realistic level of bed representation, three approaches can be used to represent bed consolidation. Two of the approaches are semi-empirical with the first assuming that the void ratio of a layer decreases with time. A typical relationship that is used for the simple consolidation option in the EFDC model is

$$\varepsilon = \varepsilon_m + (\varepsilon_o - \varepsilon_m) \exp(-\alpha(t - t_o)) \tag{7.20}$$

where ε_o is the void ratio at the mean time of deposition, t_o, ε_m is the ultimate minimum void ratio corresponding to complete consolidation, and α is an empirical or experimental constant. Use of (7.20) in the EFDC1D model involves specifying the depositional void ratio, the ultimate void ratios and the rate constants. The ultimate void ratio can be specified as a function depth below the water column-bed interface. The actual calculation involves using the initial void ratios to determine the deposition time t_o, after which (7.20) is used to update the void ratios as the simulation progresses. After equation (7.20) is used to calculate the new time level void ratios, equation (7.18) provides the new layer thicknesses. The water conservation equation (7.19) can then be solved using

$$q_{w:k+} = q_{w:k-} - \left(\frac{B_k}{1 + \varepsilon_k} \right) \partial_t \varepsilon_k + \delta(k, k_b)(\varepsilon_k - \varepsilon_b) \min \left(\frac{J_{sb}}{\rho_s}, 0 \right) \tag{7.21}$$

to determine the water specific discharges, provided that the specific discharge q_{k-}, at the bottom of layer 1 is specified. When this option is specified in the EFDC1D model, the specific discharge at the bottom of the bottom sediment layer is set to zero. Layers are added and deleted in the manner previously described for EFDC1D's constant porosity option. The SED2D-WES model (Letter *et al.* 1998) utilizes a similar approach based on a specified time variation of bulk density

35

$$\rho_b = \frac{\rho_s + \varepsilon \rho_w}{1 + \varepsilon} = \rho_{bm} + (\rho_{bo} - \rho_{bm}) \exp(-\alpha(t - t_o)) \tag{7.22}$$

which in turn defines the variation in void ratio.

The second semi-empirical approach assumes that the vertical distribution of the bed bulk density or equivalently the void ratio at any time is given by a self-similar function of vertical position, bed thickness and fixed surface and bottom bulk densities or void ratios. Functionally this is equivalent to

$$\varepsilon = V(z, B_T, \varepsilon_{kb}, \varepsilon_1) \tag{7.23}$$

where V represents the function, z is a vertical coordinate measured upward from the bottom of the lowest layer, and B_T is the total thickness of the bed. This approach is used in the original HSCTM model (Hayter and Mehta 1983), the new HSCTM model (Hayter *et al.* 1999) and is an option in the CE-QUAL-ICM/TOXI model (Dortch *et al.* 1998). The determination of the new time level layer thickness and void ratios requires an iterative solution of equations (7.18) and (7.23). The solution is completed using (7.21) to determine the water specific discharges.

The third and most realistic approach is to dynamically simulate the consolidation of the bed. In the Lagrangian formulation, (7.18) is directly solved for the equivalent sediment thickness

$$\Delta_k = \frac{B_k}{1 + \varepsilon_k} \tag{7.24}$$

and the water conservation equation (7.19) is integrated to determine the void ratio.

$$\Delta_k \partial_t \varepsilon_k = q_{w:k-} - q_{w:k+} + \delta(k, k_b)(\varepsilon_k - \varepsilon_b) \min\left(\frac{J_{sb}}{\rho_s}, 0\right) \tag{7.25}$$

The specific discharges in (7.25) are determined using the Darcy equation

$$q = -\frac{K}{g\rho_w} \partial_z u \tag{7.26}$$

where K is the hydraulic conductivity and u is the excess pore pressure defined as the difference between the total pore pressure u_t, and the hydrostatic pressure u_h.

$$u = u_t - u_h \tag{7.27}$$

The total pore pressure is defined as the difference between the total stress σ and effective stress σ_e.

$$u_t = \sigma - \sigma_e \tag{7.28}$$

The total stress and hydrostatic pressure are given by

$$\sigma = p_b + g \int_z^{z_b} \left(\left(\frac{\varepsilon}{1+\varepsilon} \right) \rho_w + \left(\frac{1}{1+\varepsilon} \right) \rho_s \right) dz \tag{7.29}$$

$$u_h = p_b + g\rho_w (z_b - z) \tag{7.30}$$

where p_b is the water column pressure at the bed z_b. Solving for the excess pore pressure using (7.27) through (7.30) gives

$$u = g\rho_w \left(\frac{\rho_s}{\rho_w} - 1 \right) \int_z^{z_b} \left(\frac{1}{1+\varepsilon} \right) dz - \sigma_e \tag{7.31}$$

The specific discharge (7.26), can alternately be expressed in terms of the effective stress

$$q = \frac{K}{g\rho_w} \partial_z \sigma_e - \left(\frac{\rho_s}{\rho_w} - 1 \right) K \partial_z \left(\int_z^{z_b} \left(\frac{1}{1+\varepsilon} \right) dz \right) \tag{7.32}$$

or the void ratio

$$q = \frac{K}{g\rho_w} \left(\frac{d\sigma_e}{d\varepsilon} \right) \partial_z \varepsilon - \left(\frac{\rho_s}{\rho_w} - 1 \right) K \partial_z \left(\int_z^{z_b} \left(\frac{1}{1+\varepsilon} \right) dz \right) \tag{7.33}$$

where $d\varepsilon/d\sigma_c$ is a coefficient of compressibility.

For consistency with the Lagrangian representation of sediment mass conservation, a new vertical coordinate ζ, defined by

$$\frac{d\zeta}{dz} = \frac{1}{1+\varepsilon} \tag{7.34}$$

is introduced. The discrete form of (7.34) is

$$\zeta_{k+} - \zeta_{k-} = \frac{z_{k+} - z_{k-}}{1+\varepsilon_k} = \frac{B_k}{1+\varepsilon_k} = \Delta_k \tag{7.35}$$

where Δ_k is the equivalent sediment thickness previously defined by (7.24). Introducing (7.34) into (7.26), (7.32), and (7.33) gives

$$q = -\frac{K}{g\rho_w(1+\varepsilon)} \partial_z u \tag{7.36}$$

37

$$q = \frac{K}{g\rho_w(1+\varepsilon)}\partial_\zeta\sigma_e + \left(\frac{\rho_s}{\rho_w}-1\right)\frac{K}{(1+\varepsilon)} \tag{7.37}$$

$$q = \lambda\left(\frac{K}{1+\varepsilon}\right)\partial_\zeta\varepsilon + \left(\frac{\rho_s}{\rho_w}-1\right)\left(\frac{K}{1+\varepsilon}\right) \tag{7.38}$$

where

$$\lambda = \frac{1}{g\rho_w}\frac{d\sigma_e}{d\varepsilon} \tag{7.39}$$

is a compressibility length.

Three formulations for the solution the consolidation problem can be utilized. The void ratio-excess pore pressure formulation, used in the EFDC1D model, evaluates the specific discharges at the current time level n, using (7.36) and explicitly integrates (7.25)

$$\varepsilon_k^{n+1} = \varepsilon_k^n + \frac{\theta}{\Delta_k^n}\left(q_{w:k-} - q_{w:k+} + \delta(k,k_b)(\varepsilon_k - \varepsilon_b)\min\left(\frac{J_{sb}}{\rho_s},0\right)\right)^n \tag{7.40}$$

where θ is the time-step, to give the new time level void ratios. The layer thicknesses are then determined by explicit integration of (7.18).

$$\left(\frac{B}{1+\varepsilon}\right)_k^{n+1} = \left(\frac{B}{1+\varepsilon}\right)_k^n - \theta\delta(k,k_b)\frac{J_{sb}}{\rho_s} \tag{7.41}$$

$$\Delta_k^{n+1} = \Delta_k^n - \theta\delta(k,k_b)\frac{J_{sb}}{\rho_s}$$

Constitutive equations required for consolidation prediction generally express the effective stress and hydraulic conductivity as functions of the void ratio. Thus the new time level void ratio is used to determine new time level values of the effective stress and hydraulic conductivity. The new time level excess pore pressure is then given by

$$u = g\rho_w\left(\frac{\rho_s}{\rho_w}-1\right)(\zeta_b - \zeta) - \sigma_e \tag{7.42}$$

the transformed equivalent of (7.31). The primary advantage of the void ratio-excess pore pressure formulation is the simplicity of its boundary conditions

$$u = u_b : \zeta = \zeta_b \tag{7.43}$$

38

$$u = u_o : \zeta = 0$$

$$or$$

$$q = q_o : \zeta = 0$$

(7.44)

The water column-sediment bed interface boundary condition generally sets u_b to zero if the surface water flow is hydrostatic but can incorporate wave induced pore pressures. The bottom boundary conditions allows either the specification of pressure or specific discharge. The primary disadvantage of this formulation is the stability or positivity criterion imposed on the time-step

$$\theta \le \frac{\Delta_k^n \varepsilon_k^n}{\left(q_{w:k+} - q_{w:k-} + \delta(k,k_b)(\varepsilon_b - \varepsilon_k)\min\left(\frac{J_{sb}}{\rho_s},0\right)\right)^n}$$

(7.45)

$$\theta \le \frac{\Delta_k^n}{\delta(k,k_b)\max\left(\frac{J_{sb}}{\rho_s},0\right)}$$

(7.46)

In practice, these criteria are readily satisfied if the consolidation time-step is identical to the time-step of the hydrodynamic model. In the event that these criteria are not met using the hydrodynamic time-step, the bed consolidation is sub-cycled using an integer number of time sub-steps, satisfying (7.45) and (7.46), per each hydrodynamic time-step.

Alternately, the consolidation problem can be directly formulated in terms of the effective stress or void ratio. Combining (7.25) and (7.37) using (7.39) gives the effective stress formulation

$$\Delta_k \partial_t \varepsilon_k = \left(\lambda\left(\frac{K}{1+\varepsilon}\right)\partial_\zeta \varepsilon + \left(\frac{\rho_s}{\rho_w}-1\right)\left(\frac{K}{1+\varepsilon}\right)\right)_{k-}$$

$$-\left(\lambda\left(\frac{K}{1+\varepsilon}\right)\partial_\zeta \varepsilon + \left(\frac{\rho_s}{\rho_w}-1\right)\left(\frac{K}{1+\varepsilon}\right)\right)_{k+} + \delta(k,k_b)(\varepsilon_k - \varepsilon_b)\min\left(\frac{J_{sb}}{\rho_s},0\right)$$

(7.47)

The continuum equivalent is

$$\frac{1}{\lambda}\partial_t \sigma_{e:k} = -\partial_\zeta\left(\frac{K}{(1+\varepsilon)}\partial_\zeta \sigma_e + g(\rho_s - \rho_w)\frac{K}{(1+\varepsilon)}\right)$$

$$+ g\rho_w \delta(\zeta_b)(\varepsilon_k - \varepsilon_b)\min\left(\frac{J_{sb}}{\rho_s},0\right)$$

(7.48)

which is parabolic since λ is negative. Combining (7.25) and (7.38) using (7.39) gives the void ratio formulation

39

$$\Delta_k \partial_t \varepsilon_k = \left(\lambda \left(\frac{K}{1+\varepsilon} \right) \partial_\zeta \varepsilon + \left(\frac{\rho_s}{\rho_w} - 1 \right) \left(\frac{K}{1+\varepsilon} \right) \right)_{k-}$$

$$- \left(\lambda \left(\frac{K}{1+\varepsilon} \right) \partial_\zeta \varepsilon + \left(\frac{\rho_s}{\rho_w} - 1 \right) \left(\frac{K}{1+\varepsilon} \right) \right)_{k+} + \delta(k, k_b)(\varepsilon_k - \varepsilon_b) \min\left(\frac{J_{sb}}{\rho_s}, 0 \right) \qquad (7.49)$$

The continuum equivalent is

$$\partial_t \varepsilon_k = -\partial_\zeta \left(\lambda \left(\frac{K}{1+\varepsilon} \right) \partial_\zeta \varepsilon + \left(\frac{\rho_s}{\rho_w} - 1 \right) \left(\frac{K}{1+\varepsilon} \right) \right) + \delta(\zeta_b)(\varepsilon_k - \varepsilon_b) \min\left(\frac{J_{sb}}{\rho_s}, 0 \right) \qquad (7.50)$$

Equation (7.50) is the discrete form of the finite strain consolidation equation first derived by Gibson *et al.* (1967). Equation (7.50) was used by Cargill (1985) in the formulation of a model for dredge material consolidation and by Le Normant *et al.* (1998) to represent bed consolidation in a three-dimensional cohesive sediment transport model.

The classic linear consolidation equation (Middleton and Wilcock 1994) omits the second term associated with self weight in (7.50) and introduces a constant consolidation coefficient

$$C_c = -(1+\varepsilon) \frac{\partial \sigma_e}{\partial e} \frac{K}{g \rho_w} \qquad (7.51)$$

reducing (7.50) to

$$\partial_t \varepsilon = C_c \partial_{zz} \varepsilon \qquad (7.52)$$

Equation (7.52) has separable solutions of the form

$$\varepsilon = \phi_n(\zeta) \exp\left(-\lambda_n \frac{C_c}{B^2} t \right)$$

$$\partial_{\zeta\zeta} \phi_n + \lambda_n \phi_n = 0 \qquad (7.53)$$

$$\zeta = \frac{z}{B}$$

which provides some justification for empirical relationship (7.20).

The solution of the finite strain consolidation problem in any of its three forms requires constitutive relationships

$$\sigma_e = \sigma_e(\varepsilon) \qquad (7.54)$$

$$K = K(\varepsilon) \qquad (7.55)$$

Bear (1979) notes that curve fitting of experimental data typically results in relationships of the form

$$\varepsilon - \varepsilon_o = -a_v \left(\sigma_e - \sigma_{eo} \right) \tag{7.56}$$

$$\varepsilon - \varepsilon_o = -C_c \ln \left(\frac{\sigma_e}{\sigma_{eo}} \right) \tag{7.57}$$

for noncohesive and cohesive soils respectively, where a_v is the coefficient of compressibility and C_c is the compression index. Graphical presentation of experimental forms of (7.54) and (7.55) are presented in Cargill (1985) and Palermo *et al.* (1998) which are generally consistent with (7.57) and suggest

$$\varepsilon - \varepsilon_o \propto \ln \left(\frac{K}{K_o} \right) \tag{7.58}$$

as a candidate relationship between the void ratio and hydraulic conductivity for cohesive sediment beds. Similarly, a linear relationship

$$\varepsilon - \varepsilon_o \propto K - K_o \tag{7.59}$$

would likely suffice for noncohesive sediment beds.

8. Sorptive Contaminant Transport

The EFDC1D model currently includes the capability for simulating sorptive contaminants including, heavy metals and hydrophobic organic compounds. Complete documentation of this capability will be included in subsequent versions of this document.

9.   Model Configuration and Input Files

Configuration of the EFDC1D model requires the development of model input files describing the geometry of the channel network, initial conditions, boundary conditions, solution options and output options. An alphabetical listing of input files is given in Table 1. The second and third columns indicate the method by which the files are created for the standalone version (SA) and the HSPF embedded version (HS) of EFDC1D. User created files are denoted by "u", files automatically created by the model are denoted by "a", files created by the HSPF/EFDC1D interface are denoted by "i", and provided default data files are denoted by "d". Certain files can be user or interface created. Files having standard EFDC model formats are denoted under the file description column.

The recommended sequence for the construction of the input files for configuration of the model and set up for a simulation generally begins with the *cellnet.inp* file defining the channel network. Following the creation of the *cellnet.inp* file, the channel section properties file, *chansec.inp*, the master input file, *efdc1d.inp*, and inflow time series file, *qser.inp*, should be created. If active screen display is selected in the *efdc1d.inp*, the screen display control file *show.inp* should be properly set to the desired display location. Default, zero concentration, time series files for dye, *dser.inp*, salinity, *sser.inp*, temperature, *tser.inp*, cohesive sediment, *sdser.inp*, and noncohesive sediment, *snser.inp* are also required. To complete the configuration for hydrodynamic simulations, the *qctl.inp* file, defining flow control structures or rating curve properties, and the *pser.inp* file, defining water surface elevation open boundary conditions must be created as required for a specific application.   Temperature or thermal simulations requires atmospheric conditions from the *aser.inp* file and wind conditions from the *wser.inp* file. If it is desired to include direct rainfall and evaporation in the simulation, the *aser.inp* can be used even if thermal simulation is not selected. All of the EFDC1D input files conform to standard templates which the model is designed to read, however user data input into the templates is treated as free form across an input line. All of the input files are internally documented, and the sample input file sets distributed with the model can be used as starting templates for setting up a new simulation. The following subsections of this chapter provide additional details regarding the user created input files.

Table 1. Input files for the EFDC1D model.

File Name	SA	HS	Description
Aser.inp	u	u	File containing time series for atmospheric conditions including air temperature, relative humidity, rainfall, shortwave solar radiation and cloud cover. Standard EFDC format
Cell.inp	a	a	Horizontal cell type identifier for the computational domain Standard EFDC format
Cellllt.inp	a	a	Horizontal cell type identifier for saving mass transport to drive external water quality model Standard EFDC format
Cellnet.inp	u	u	File specifying the channel network, including certain boundary conditions
Chanjunij.inp	a	a	File defining junctions in the channel network Standard EFDC format
Chansec.inp	u	u	File defining channel cross-section properties as a function of depth or water surface elevation
Chansecij.inp	a	a	A reformated version of chansec.inp Standard EFDC format
Dser.inp	u	u	File containing time series for dye tracer concentration for use a boundary conditions or loadings Standard EFDC format

Table 1 (continued). Input files for the EFDC1D model.

File Name	SA	HS	Description
Dxdy.inp	a	a	File containing channel cell control volume information Standard EFDC format
Efdcdat.inp	d	d	A version of multidimensional efdc.inp file containing default data and solution options. Should be modified only by experienced EFDC users. Standard EFDC format
Efdc1d.inp	u	u	Master input file providing run time control, certain boundary conditions, and output control
Flow1d.inp	a	a	File contains initial flow and discharge data from the cellnet.inp file which has been reordered to the computational grid. This information is used for cold starts.
Flwctl.inp	a	a	File containing data on inflow and control structure locations
Lxly.inp	a	a	File containing geographic orientation information for channel cells Standard EFDC format
Map1d2ij.inp	a	a	File containing network to computational grid mapping data
Mappgns.inp	a	a	File containing additional network to computational grid mapping data Standard EFDC format

Table 1 (continued). Input files for the EFDC1D model.

File Name	SA	HS	Description
Pser.inp	u	u	File containing time series of water surface elevation for tidal open boundary conditions Standard EFDC format
Qctl.inp	u	u	File specifying properties of hydraulic control structures Standard EFDC format
Qser.inp	u	u/i	File containing time series for dye tracer concentration for use a boundary conditions or loadings Standard EFDC format
Restart.inp	a	a	File for restarting a simulation Standard EFDC format
Sdser.inp	u	u/i	File containing time series for cohesive sediment concentration for use a boundary conditions or loadings. Standard EFDC format
Show.inp	u	u	File controlling screen output during model execution. Standard EFDC format
Snser.inp	u	u/i	File containing time series for noncohesive sediment concentration for use a boundary conditions or loadings Standard EFDC format
Sser.inp	u	u	File containing time series for salinity concentration for use a boundary conditions or loadings. Standard EFDC format

Table 1 (continued). Input files for the EFDC1D model.

File Name	SA	HS	Description
Tmser1d.inp	a	a	File contains time series output save locations referenced to computational grid
Tser.inp	u	u/i	File containing time series for temperature for use a boundary conditions or loadings Standard EFDC format
Txser.inp	u	u/i	File containing time series for sorptive toxic contaminant concentration for use a boundary conditions or loadings Standard EFDC format
Wser.inp	u	u	File containing time series wind speed and direction Standard EFDC format

9.1 Unit Conventions Used in EFDC1D

The EFDC1D model uses an arbitrary time convection. Simulation start time is specified by TBEGIN in data block 5 of the *efdc1d.inp* file. This starting time can be viewed as the elapsed time in days, hours, etc. from the 0.0 time origin. The time origin is arbitrary, but is usually taken as midnight January 1 of a user defined reference year. The reference year is not input as data into any of the input files, but a good practice is noting the reference year in comment areas of all input files involving temporal data. The reference time year should also be noted in the simulation title in data block 1 of *efdc1d.inp*. For example if the reference year were 1999, midnight March 1, 1999 would be 90.0 days. Likewise, midnight March 1, 2000 would be 456.0 days, noting that 2000 is a leap year. All files having time data include time adjustment factors and unit conversions. The convention used is

$$\text{Model Internal Time} = \text{TCxxx} * (\text{Input Time} + \text{TAxxx})$$

where the internal time is always seconds, and Taxxx and TCxxx are adjustment and conversion factors. TCxxx converts from various input time units to seconds, (TCxxx = 86400, for input time units of days). TAxxx must always have the same units as input time data.

The internal unit system in EFDC1D is meters-kilograms-seconds, with the exception of concentration variables. Unit conversion factors are included for flow, elevation, and concentration in all appropriate input files allowing, for example, a flow time series to be input in CFS and converted to CMS. Salinity and temperature variables must the PSU (practical salinity units) and Celsius since the internal equation of state requires these units. The dye concentration state variable can have arbitrary input units, which are carried through to output. Suspended sediment concentrations must be in mg/liter, (which is equivalent to gm/m^3) which is the conventional unit and is required for sediment concentration influences in the equation of state. For the sediment bed, the internal model variable is sediment mass per unit area, in gm/m^2, for each sediment bed layer. For correct coupling with water column sediment processes, settling velocities and resuspension rates must the specified in m/s and gm/m^2-sec, respectively. Toxic contaminant concentrations can be in mg/liter or μg/liter at the user's discretion. For toxic contaminant simulation, the equilibrium partition coefficients must be input in liter/mg, the inverse of the sediment concentration units, as opposed to the traditional unit of liter/Kg.

9.2 Aser.inp Input File

The atmospheric conditions file, *aser.inp*, specifies information for necessary for temperature simulation including atmospheric pressure, air temperature, wet bulb air temperature or relative humidity, rainfall rate, evaporation rate, water surface incident solar short wave radiation, and fractional cloud cover. If wet bulb temperature is specified instead of relative humidity, the relative humidity is internally calculated. Input

relative humidity must be a decimal fraction rather than percent. The evaporation rate can be either specified or internally calculated if the temperature simulation option is active. When temperature simulation is not active, rainfall and evaporation rates from the *aser.inp* file are still used as source and sink terms in the continuity equation. Input solar short wave radiation should be converted using the SOLRCVT conversion factor to watts/m^2, as appropriated. An example of the *aser.inp* file is shown in Figure 3, and can be used as a template for file construction.

9.3   Cellnet.inp Input File

The *cellnet.inp* file specifies the connectivity and individual cell properties of the channel network. If also defines the location of control structures or rating curve boundaries and volumetric inflows and associated concentrations. Control table identifier and time series identifier for flow and concentration are also defined. It is noted that the use of a zero concentration time series identifier with a nonzero flow identifier results in zero concentrations being associated with that inflow.

Figure 4 shows an example channel network having the following properties:

Channel segment 5 (cells 32-36) flows freely into cell 28 of channel segment 4 (cells 22-31)

Channel segment 4 (cells 22-31) flows freely into cell 17 of channel segment 3 (cells 15-21)

Channel segment 3 (cells 15-21) flows by control structure into cell 6 of channel segment 1 (cells 1-6)

Channel segment 2 (cells 7-14) flows freely into cell 4 of channel segment 1 (cells 1-6)

Channel segment 1 (cells 1-6) flows out of the domain by control rating curve, discharge or water surface elevation time series, or tidal open boundary condition (obc). The cell table above uses tidal obc.

| or -- denotes a cell having volume, cross-section area, surface width, etc, determined by water surface elevation

+ denotes flow face where discharge is defined

F is free flowing connection

C is connection by control structure or rating curve

O is tidal open boundary

The *cellnet.inp* file for this network is shown in Figure 5. The main feature notation requiring mastery in construction of the *cellnet.inp* file is the concept of segment order. The main stem channel segment is defined as order 1. There can be only one main stem segment. Channel segments flowing into the main stem or 1st order segment are defined as 2nd order segments. Channel segments flowing into the 2nd order segments are defined as 3rd order segments and so on. Stream segments defined in this ordering fashion cannot have internal control structures. Thus a continuing reach of a stream channel above a control structure must be defined as a new segment and be considered as a tributary of the stream segment below the control structure. Data columns in the *cellnet.inp* file are internally explained in the file header lines.

```
C  aser.inp file, in free format across line, repeats naser=1 times
C
C  ATMOSPHERIC FORCING FILE, USE WITH 7 APRIL 97 AND LATER VERSIONS OF EFDC
C
C  MASER     =NUMBER OF TIME DATA POINTS
C  TCASER    =DATA TIME UNIT CONVERSION TO SECONDS
C  TAASER    =ADDITIVE ADJUSTMENT OF TIME VALUES SAME UNITS AS INPUT TIMES
C  IRELH     =0 VALUE TWET COLUMN VALUE IS TWET, =1 VALUE IS RELATIVE HUMIDITY
C  RAINCVT   =CONVERTS RAIN TO UNITS OF M/SEC
C  EVAPCVT   =CVRT EVAP TO M/SEC, IF EVAPCVT<0 EVAP IS INTERNALLY COMPUTED
C  SOLRCVT   =CONVERTS SOLAR SW RADIATION TO JOULES/SQ METER
C  CLDCVT    =MULTIPLIER FOR ADJUSTING CLOUD COVER
C  IASWRAD   =O DIST SW SOL RAD OVER WATER COL AND BED, =1 ALL TO SURF LAYER
C  REVC      =1000*EVAP TRANSFER  COEF, REVC<0 USE WIND SPD DEPD DRAG COEF
C  RCHC      =1000*CONV  HEAT TRAN COEF, REVC<0 USE WIND SPD DEPD DRAG COEF
C  SWRATNF   =FAST SCALE SOLAR SW RADIATION ATTENUATION COEFFCIENT 1./METERS
C  SWRATNS   =SLOW SCALE SOLAR SW RADIATION ATTENUATION COEFFCIENT 1./METERS
C  FSWRATF   =FRACTION OF SOLSR SW RADIATION ATTENUATED FAST  0<FSWRATF<1
C  DABEDT    =DEPTH OR THICKNESS OF ACTIVE BED TEMPERATURE LAYER, METERS
C  TBEDIT    =INITIAL BED TEMPERATURE
C  HTBED1    =CONV  HT COEFFCIENT BETWEEN BED AND BOTTOM WATER LAYER  NO DIM
C  HTBED2    =HEAT TRANS COEFFCIENT BETWEEN BED AND BOTTOM WATER LAYER  M/SEC
C  PATM      =ATM PRESS MILLIBAR
C  TDRY/TEQ  =DRY ATM TEMP ISOPT(2)=1 OR EQUIL TEMP ISOPT(2)=2
C  TWET/RELH =WET BULB ATM TEMP IRELH=0, RELATIVE HUMIDITY IRELH=1
C  RAIN      =RAIN FALL RATE LENGTH/TIME
C  EVAP      =EVAPORATION RATE IS EVAPCVT>0.
C  SOLSWR    =SOLAR SHORT WAVE RAD AT WATER SURFACE  ENERGY FLUX/UNIT AREA
C  CLOUD     =FRATIONAL CLOUD COVER
C
C   MASER    TCASER   TAASER   IRELH    RAINCVT   EVAPCVT   SOLRCVT    CLDCVT
C
C  IASWRAD REVC RCHC SWRATNF   SWRATNS FSWRATF DABEDT TBEDIT HTBED1 HTBED2
C
C  TASER(M)  PATM(M)  TDRY(M) TWET(M) RAIN(M)  EVAP(M)   SOLSWR(M)  CLOUD(M)
C                     /TEQ    /RELH                      /HTCOEF
    3447      86400.   0.      1        1.0       -1.       0.95       1.00
    0       1.5   1.5     2.5     0.      1.        1.      14.0   0.001      0.
    0.0354   1005.47   11.72    0.74  0.000E+00    0.00    0.00     0.95
  120.0354   1005.47   11.72    0.74  0.000E+00    0.00    0.00     0.95
  120.0771   1004.46   11.72    0.77  0.000E+00    0.00    0.00     0.95
  120.1188   1003.44   12.22    0.75  0.000E+00    0.00    0.00     0.95
```

Figure 3.   Example of the aser.inp file.

```
                                                +
                                                | 36
                                                +
                                                | 35
                        +                       +
               21 |                             | 34
                        +           seg 5       +
               20 |                 order 4     | 33
                        +                       +
               19 |                             | 32
                        +                       +
     seg 3     18 |                             +
    order 2         +                            F
               17 |   F   +--+--+--+--+--+--+--+--+--+
                        +     22 23 24 25 26 27 28 29 30 31
               16 |
                        +                seg 4
               15 |                     order 3
                        +

                    C

                        +
                6 |
                        +
                5 |
                        +
     seg 1       4 |   F   +--+--+--+--+--+--+--+
    order 1         +         7  8  9 10 11 12 13 14
                3 |
                        +                seg 2
                2 |                     order 2
                        +
                1 |
                        +

                    O
```
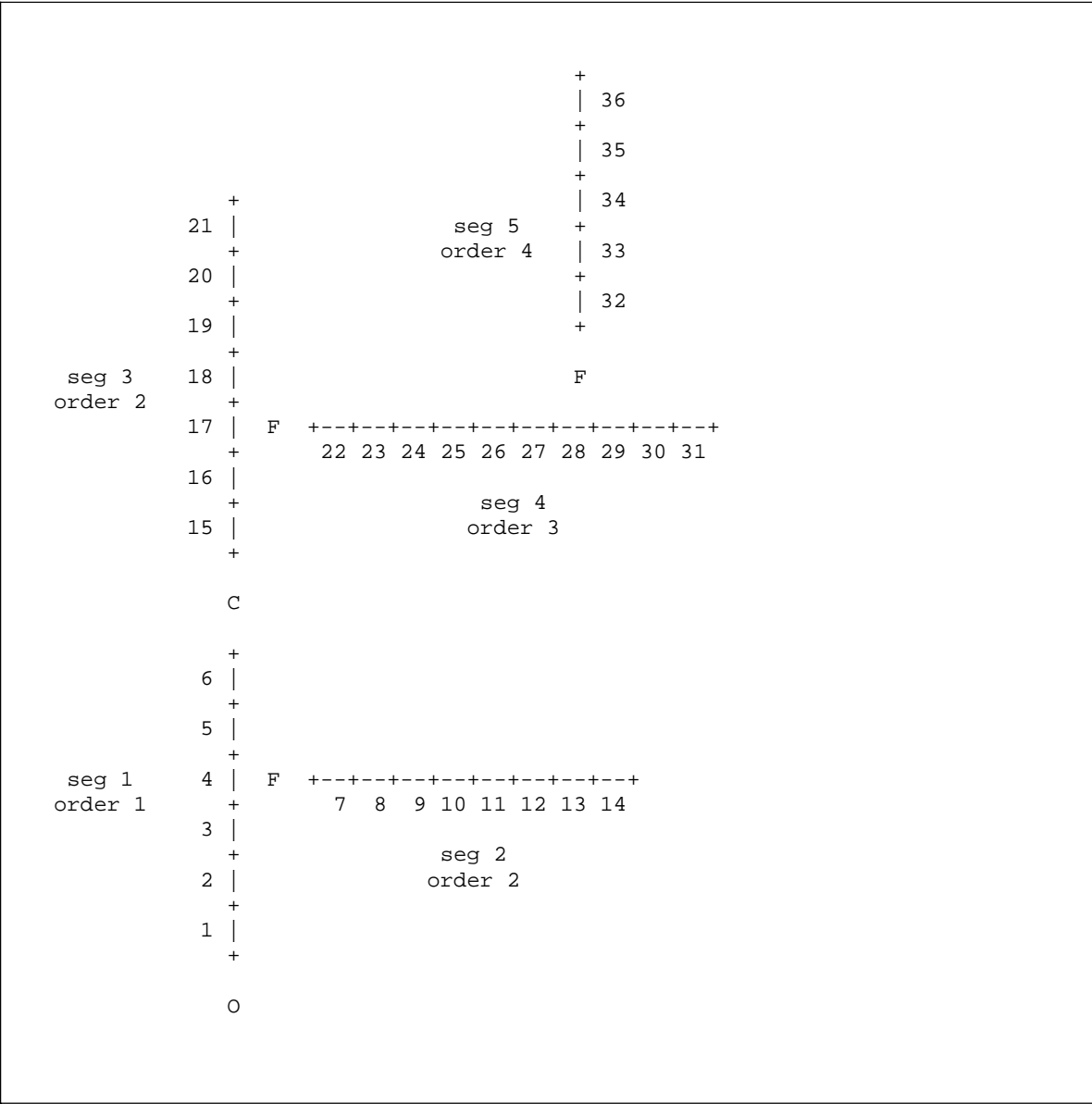
Figure 4.   Example of a cell network.

```
c----------------------------------------------------------------------
c file cellnet.inp - cell network file
c----------------------------------------------------------------------
c channel network data 1
c
c   nsegs  - number of stream segments
c   nords  - highest order segment
c   ncells - total number of cells
c   ncells - total number of cells
c   ncells - total number of cells
c
c nsegs   nords   ncells   nctl   nqts   ncts   nobc
    5       4       36       0      0      0      0
c----------------------------------------------------------------------
c channel network data 2
c
c   iseg  - stream segment id number (main stem must be 1)
c   isord - order of this segment (main stem is 1)
c   isgdn - number of segment downstream from this segment
c   iscdn - cell number of most downstream cell in this segment
c   iscup - cell number of most upstream cell in this segment
c
c iseg    isord   isgdn    iscdn   iscup
   1        1       0        1       6
   2        2       1        7      14
   3        2       1       15      21
   4        3       3       22      31
   5        4       4       32      36
```

Figure 5.   Example of the cellnet.inp file.

```
c----------------------------------------------------------------------
c cell data
c
c  icell - cell id number
c  iseg  - segment id number
c  itype - cell type id number
c          1 interior
c          2 downstream end of channel segment with free flowing
W            connection to downstream segment
c          3 downstream end of channel segment with control
W            structure or rating curve connection to downstream segment
c          4 downstream end of channel segment with time series outflow
c          5 downstream end of channel segment with tidal open
W            boundary condition
c          6 head of channel segment
c  iupc  - number of upstream cell (use zero at head of channel segment)
c  idnc  - number of downstream cell (use zero at end of channel segment)
c  ifru  - number of upstream cell interacting by free flowing
W          connection (use zero for null)
c  ifrd  - number of downstream cell interacting by free flowing
W          connection (use zero for null)
c  iqcu  - number of upstream cell interacting by control structure
W          or rating curve (use zero for null)
c  iqcd  - number of downstream cell interacting by control structure
W          or rating curve (use zero for null)
c  nqctu - id number of control table or rating curve for upstream to
W           downstream flow (use zero for null)
c  nqctd - id number of control table or rating curve for downstream
W           upstream flow (use zero for null)
c  nqts  - id number of time series inflow or withdrawal (use zero for null)
c  ncts  - id number of concentration inflow time series (use zero for null)
c  nobs  - id number of tidal open boundary condition (use zero for null)
c  nsec  - id number of cross-section property table for this cell
c  rlen  - length of cell
c  xcrd  - x coordinate of cell center (any consistent system,
W          used only for graphics)
c  ycrd  - y coordinate of cell center (any consistent system,
W          used only for graphics)
c  angc  - cell orientation angle (bearing from downstream cell
W          boundary to upstream boundary)
c  qint  - initial discharge across downstream cell face
c  hint  - initial depth in cell
c  bint  - initial thalweg bed elevation of cell
c  idum  - dummy data can follow in columns after the last column
```

Figure 5 (continued). Example of the cellnet.inp file.

```
c
c icell iseg itype  iupc  idnc  ifru  ifrd  iqcu  iqcd  nqctu  nqctd
   1    1    5     2     0     0     0     0     0     0      0
   2    1    1     3     1     0     0     0     0     0      0
   3    1    1     4     2     0     0     0     0     0      0
   4    1    1     5     3     7     0     0     0     0      0
   5    1    1     6     4     0     0     0     0     0      0
   6    1    6     0     5     0     0    15     0     1      0
   7    2    2     8     0     0     4     0     0     0      0
   8    2    1     9     7     0     0     0     0     0      0
   9    2    1    10     8     0     0     0     0     0      0
  10    2    1    11     9     0     0     0     0     0      0
  11    2    1    12    10     0     0     0     0     0      0
  12    2    1    13    11     0     0     0     0     0      0
  13    2    1    14    12     0     0     0     0     0      0
  14    2    6     0    13     0     9     0     0     0      0
  15    3    3    16     0     0     0     0     6     0      2
  16    3    1    17    15     0     0     0     0     0      0
  17    3    1    18    16    22     0     0     0     0      0
  18    3    1    19    17     0     0     0     0     0      0
  19    3    1    20    18     0     0     0     0     0      0
  20    3    1    21    19     0     0     0     0     0      0
  21    3    6     0    20     0     0     0     0     0      0
  22    4    2    23     0     0    17     0     0     0      0
  23    4    1    24    22     0     0     0     0     0      0
  24    4    1    25     0     0     0     0     0     0      0
  25    4    1    26    24     0     0     0     0     0      0
  26    4    1    27    25     0     0     0     0     0      0
  27    4    1    28    26     0     0     0     0     0      0
  28    4    1    29    27    32     0     0     0     0      0
  29    4    1    30    25     0     0     0     0     0      0
  30    4    1    31    26     0     0     0     0     0      0
  31    4    6     0    30     0     0     0     0     0      0
  32    5    2    33     0     0    28     0     0     0      0
  33    5    1    34    31     0     0     0     0     0      0
  34    5    1    35    32     0     0     0     0     0      0
  35    5    1    36    33     0     0     0     0     0      0
  36    5    6     0    34     0     0     0     0     0      0
```

Figure 5 (continued). Example of the cellnet.inp file.

```
nqts   ncts   nobc   nsec   rlen   xcrd   ycrd   angc qint   hint   bint !icell
 1      1      1      1      L      X      Y      A    Q      H      B    !  1
 1      1      0      2      L      X      Y      A    Q      H      B    !  2
 1      1      0      3      L      X      Y      A    Q      H      B    !  3
 1      1      0      4      L      X      Y      A    Q      H      B    !  4
 1      1      0      5      L      X      Y      A    Q      H      B    !  5
 1      1      0      6      L      X      Y      A    Q      H      B    !  6
 2      2      0      7      L      X      Y      A    Q      H      B    !  7
 2      2      0      8      L      X      Y      A    Q      H      B    !  8
 2      2      0      9      L      X      Y      A    Q      H      B    !  9
 2      2      0     10      L      X      Y      A    Q      H      B    ! 10
 2      2      0     11      L      X      Y      A    Q      H      B    ! 11
 2      2      0     12      L      X      Y      A    Q      H      B    ! 12
 2      2      0     13      L      X      Y      A    Q      H      B    ! 13
 6      6      0     14      L      X      Y      A    Q      H      B    ! 14
 3      3      0     15      L      X      Y      A    Q      H      B    ! 15
 3      3      0     16      L      X      Y      A    Q      H      B    ! 16
 3      3      0     17      L      X      Y      A    Q      H      B    ! 17
 3      3      0     18      L      X      Y      A    Q      H      B    ! 18
 3      3      0     19      L      X      Y      A    Q      H      B    ! 19
 3      3      0     20      L      X      Y      A    Q      H      B    ! 20
 6      6      0     21      L      X      Y      A    Q      H      B    ! 21
 4      4      0     22      L      X      Y      A    Q      H      B    ! 22
 4      4      0     23      L      X      Y      A    Q      H      B    ! 23
 4      4      0     24      L      X      Y      A    Q      H      B    ! 24
 4      4      0     25      L      X      Y      A    Q      H      B    ! 25
 4      4      0     26      L      X      Y      A    Q      H      B    ! 26
 4      4      0     27      L      X      Y      A    Q      H      B    ! 27
 4      4      0     28      L      X      Y      A    Q      H      B    ! 28
 4      4      0     29      L      X      Y      A    Q      H      B    ! 29
 4      4      0     30      L      X      Y      A    Q      H      B    ! 30
 8      8      0     31      L      X      Y      A    Q      H      B    ! 31
 5      5      0     32      L      X      Y      A    Q      H      B    ! 32
 5      5      0     33      L      X      Y      A    Q      H      B    ! 33
 5      5      0     34      L      X      Y      A    Q      H      B    ! 34
 5      5      0     35      L      X      Y      A    Q      H      B    ! 35
 9      9      0     36      L      X      Y      A    Q      H      B    ! 36
```

Figure 5 (continued).   Example of the cellnet.inp file. Note that the above lines actually appear inline with those of the previous page in the actual input file.

9.4 Chansec.inp Input File

The *chansec.inp* file is used to specify channel cross-sectional area, wetted perimeter, and surface width as a function of water depth (ISECDAT = 1) or water surface elevation (ISECDAT = 0). If the table is defined for depth, the bottom elevation of the lowest point in the cross-section must be specified. A separate table must be entered for each cell. Properties are presumed to be defined at the center of the cell, corresponding to the continuity control volume. A unity conversion factor is included for each section. A safe practice is to extend the property table well beyond the raw data range, since a simulation will stop if model computed water surface elevation or depth falls outside of the table range. Figure 6 shows an example of the *chansec.inp* file that can be used as a template for file construction.

9.5 Dser.inp, Sser.inp, and Tser.inp Input Files

Figure 7 shows an example of the dye concentration file *dser.inp*. The salinity and temperature time series files follow identical formats. The example file in Figure 7 can be used as a template for file construction. All time series for a given concentration variable are loaded sequentially into this file. Each time series has either one or two header lines. If ISTYP is equal to 1, a single concentration is entered and a second header lines of weights are used. If ISTPY is equal to zero, the number of concentration columns must equal to number of layers. For EFDC1D, the number of layers is by default equal to one. Both adjustment and conversion factors can be specified for time and concentration units.

```
C  chansec.inp file, in free format across line, repeats lc-2 times
C
C  EFDC 1-D CHANNEL CROSS-SECTION DATA FILE
C
C  NSEC    = section ID number
C  ISECDAT = 0 for elevation table, 1 for depth table
C  NXYSDAT = number of elevation (or depth) vs area and wetted perimeter
C            data points for section
C  BELVB   = channel bot elev corresponding to depth of zero (isecdat=1)
C  RMULADJ = multiplicative unit conversion, multiplies BELVB,EHXYS,WPER
C            AREA is converted by RMULADJ**2
C  EHXYS   = elevation or depth relative to BELVB
C  AREA    = corresponding cross-sectional area
C  WPER    = corresponding wetted perimeter
C  SURF    = corresponding surface width
C
C   NSEC  ISECDAT   NXYSDAT   BELVB    RMULADJ
C
C  EHXYS(I,J,NXY) AREA(I,J,NXY) WPER(I,J,NXY) SURF(I,J,NXY)
C
        1    1    4    253.68        1.00  notes =     75    76     2
     0.00      0.00      0.00      0.00
     0.47     13.83     35.55     35.43
     0.95     32.58     41.64     41.35
     1.42     52.90     44.17     43.67
        2    1    5    255.18        1.00  notes =     74    75     2
     0.00      0.00      0.00      0.00
     0.47     21.73     47.22     47.01
     0.95     44.50     49.50     49.07
     1.42     68.25     51.77     51.13
     1.90     92.98     54.04     53.19
```

Figure 6.   Example of the chansec.inp file with first two property tables.

57

```
C  dser.inp file, dye, in free format across line
C  repeats ncser(3) times, test case
C
C  ISTYP  MCSER(NS,3)  TCCSER(NS,3)  TACSER(NS,3)  RMULADJ(NS,3)  ADDADJ(NS,3)
C
C  if istyp.eq.1 then read depth weights and single value of CSER
C
C  (WKQ(K),K=1,KC)
C
C  TCSER(M,NS,3)   CSER(M,NS,3)  !(mcser(ns,3) pairs for ns=3,ncser(3) series)
C
C  else read a value of dser for each layer
C
C  TCSER(M,NS,3)    (CSER(M,K,NS,3),K=1,KC) !(mcser(ns,3) pairs)
C
  1   7   86400.0   0.0  1.0  0.0     !01 tracer test
   1.0    1.0   1.0    1.0   1.0    1.0   1.0   1.0   1.0    1.0
 -1000.      0.0
     0.      0.0
   121.99   0.0
   122.01   1.0
   122.99   1.0
   123.01   0.0
  1000.      0.0
  0   7   86400.0   0.0  1.0  0.0     !02 tracer test
 -1000.      0.0
     0.      0.0
   121.99   0.0
   122.01   1.0
   122.99   1.0
   123.01   0.0
  1000.      0.0
```

Figure 7.   Example of the dser.inp, sser.inp, and tser.inp files. File shown with two
            concentration time series.

9.6   Efdc1d.inp Input File

An example of the master input file, *efdc1d.inp* is shown in Figure 8, and can be used as a template for file construction. The file is organized into 34 data blocks. The definitions of all variables in each data block are included in the block headers. The user cannot insert any extract lines in the block headers, but can make notes and comments beyond the end of the header and data lines. The remainder of this section highlights some important features of selected data blocks.

Data block 2 controls restart and diagnostic options. For ISRESTI = 0 the model cold starts using initial depths and flows from the cell.net files. The ISLOG option controls the generation of a log file containing diagnostic information. The ISNEGH switch, when activated, causes a model simulation to stop when a negative depth is computed, since the one-dimensional solution procedure does not allow drying and wetting. If a negative depth is encountered, information on its location will be printed in the *efdc.log* output file, and the user should verified the channel section properties for that cell as well as consider using a smaller time-step for the time integration. Data block 3 contains additional solution options. The water surface elevation solution tolerance should be a very small number below machine precision. If the solution does not achieve this precision after ITERM iterations, the simulation will stop. The actual number of iterations is recorded in the *efdc.log* file, and should be between 10 and 100. If the maximum number of iterations is exceeded, the time-step should be reduced before lowering the value of RSQM by a few orders of magnitude. For serious start up problems, such as negative depth or NaN (not a number) output, the ISDSOLV option can be activated. However, familiarity with the numerical solution scheme and subroutine CALPUV1D is necessary to interpret the diagnostic output files. Potential problems with control structures, such as control structure out of bounds messages, and inflows can be investigated using the ISDIQ option. Use of this option requires familiarity with subroutine CALQVS. Data block 4 is used to activate transport of various concentration variables. It is recommended that the solution options ISADAC and ISFCT remain 1. For thermal transport, ISTOPT on the temperature line should be set to 1. Reading and writing concentration variables from and to the *restart.inp* file is controlled by ISCI and ISCO.

Temporal run time control is specified in data block 5. The beginning time and its unit conversion to seconds is specified by TEBEGIN and TCON. The duration of the simulation is defined as

   Simulation Duration = NTC * TREF

The example in Figure 8 sets a 152-day simulation time, since 152 time cycles, each having a duration of 1 day (86400 seconds) is specified. The model time set is specified by

   Time Step = TREF/NTSPTC

where NTSPTC is the number of time-steps per reference time cycle. For the example, the time-step is 86400/1440 = 60 seconds. The value of NTSPTC should be chosen to result in even whole number time-step sizes to avoid round off errors in time accumulation in the model code. The EFDC1D model employs explicit momentum and mass advection which limits the time-step by the Courant criteria

$$\theta \le \alpha \left| \frac{A\Delta}{Q} \right| = \alpha \left| \frac{\Delta}{u} \right| \qquad (9.1)$$

where θ is the time-step, and A, Δ, Q, and u are the cross-sectional area, flow direction length, discharge, and cross-sectional average velocity in a cell, respectively, and α is a safety factor less than unity. Experience has shown that the safety factor should be less than 0.5, with 0.25 being a reasonable value for rapidly varying flow. Note that the time-step is constrained by the minimum value of the right side of (9.1) over all cells. The most common manifestation of instability due to using too large a time-step is the occurrence of negative depths, divide by zeros, or NaN outputs. Generally when a negative depth is detected in particular cell, the *show.inp* file should be set to display that cell, with the user observing the velocity at which the instability occurs and then resetting the time-step accordingly using (9.1).

Data block 6 allows adjustment or over riding of the Manning roughness values specified in the *cellnet.inp* file. The convention is

Actual Roughness = ZBRADJ + ZBRCVT * (cellnet.inp Roughness)

Data block 7 specifies the use of various forcing files. The MTIDE variable defines the number of tidal constituents to be specified in data block 8 if a tidal harmonic boundary condition is used or an in place least squares harmonic analysis of water surface elevations in selected cells is specified in data blocks 32 and 33. If MTIDE is set to 0, no data are read from data block 8. If a tidal open boundary is to be specified by a water surface elevation time series or the combination of a water surface elevation time series and tidal harmonics, NPSER should be set to one. NPFOR should be set to 1 if harmonic forcings are used. If harmonics are used, the mean sea level water surface elevation should be specified by *pser.inp* if a zero mean sea level is not used. The parameters NASER and NWSER specify the number of atmospheric and wind time series, which should be either 0 or 1. Specifying 0 eliminates the requirement for the *aser.inp* and *wser.inp* files and sets all variables normally entered in these files to zero. Both *aser.inp* and *wser.inp* files are required for thermal simulation. Data block 8 specifies harmonic water surface elevations amplitudes and phases for NPFOR equal to 1 and MTIDE greater than zero. Harmonic constituent amplitudes should be in meters and phases should be in seconds relative to the zero time origin of the reference year.

Data block 10 specifies the number of toxic state variables, and the number of classes of cohesive and noncohesive sediment. The distribution executable is limited to one toxic, one cohesive sediment class and two noncohesive sediment classes. The model can be extended to more variables by modifying the *efdc.par* file following instructions in that file and recompiling the code to create a new executable. The remaining number of time

series for each concentration variable is not active. Instead, if a time series for inflows or open boundaries is specified in the *cellnet.inp* file, each active concentration variable must have a corresponding time series with the total number of time series for each concentration variable specified in *cellnet.inp*.

Data blocks 11 through 18 define sediment transport process options, consistent with descriptions provided in Chapters 6, 7 and 8 of this document. Model users are also referred to subroutine SSEDTOX of the model for details of the computational implementation of sediment transport and sorptive contaminant fate and transport.

Data block 22 provides additional information for constituent transport. The parameter BSC controls density or buoyancy coupling of salinity, temperature and suspended sediment. The parameter TEMO is an initial temperature and also the constant equilibrium temperature if the simple equilibrium temperature option, ISTOPT(2) = 1, is used. In this case, HEQT is the bulk heat transfer coefficient. If a tidal open boundary is specified at the downstream end of segment 1 in the *cellnet.inp* file, NOBC should be set to 1 and inflowing concentrations should be specified in data blocks 24 through 27. It is noted that these specified values are used if no concentration time series is specified for the open boundary cell in the *cellnet.inp* file. If a concentration time series is specified, the values specified in data blocks 24 through 27 are additive with the time series values. Note that surface values in data blocks 26 and 27 should be set to the corresponding bottom values in data blocks 24 and 25. Only the first parameter in data block 23, NTSCRS needs to be specified when NOBC is set to 1. This parameter specifies the transition period as NTSCRS time-steps from the last outflow concentration to the specified inflow concentration. A value of 0 immediately changes the concentration to the inflow concentration at the start of incoming tidal flow.

Data block 28 controls writing to the primary output file, dump1d.out, of the EFDC1D model. To activate output to this file, ISDUMP should be set to 3. The write frequency is specified as the number of time-steps by NSDUMP, while the beginning and ending times are specified by TSDUMP and TEDMP, which must be in days relative to the reference year time origin. The last five parameters are not currently used. Data blocks 29 through 31 allow output of model results using formats originally developed for the multi-dimensional EFDC model. Users familiar with EFDC may elect to use these options. Data blocks 32 and 33 control in place least squares harmonic analysis of selected state variables. This option is useful in analyzing model predictions in tidal systems by users who are familiar with harmonic descriptions of tidal varying quantities and least squares harmonic analysis. Data block 33 activates time series output at locations specified in the *cellnet.inp* file. Starting and stopping time-step numbers and the write frequency, in number of time-steps are specified by NBTMSR, NSTMSR, and NWTMSR, respectively. Output file names follow the following conventions

dyetsNN.out - dye
q3dtsNN.out - net volume flow into cell
saltsNN.out - salinity
sedtsNN.out - cohesive sediment
seltsNN.out - water surface elevation and depth
sndtsNN.out - noncohesive sediment

temtsNN.out - temperature
        toxtsNN.out - toxics concentration
        uvetsNN.out - velocity
        uvttsNN.out - discharge

where NN denotes the output time series identifier assigned to particular cells in the *cellnet.inp* file.

```
*************************************************************************
*                                                                       *
*    WELCOME TO THE ENVIRONMENTAL FLUID DYNAMICS COMPUTER CODE SERIES    *
*    DEVELOPED BY JOHN M. HAMRICK.                                       *
*                                                                       *
*    THIS IS THE MASTER INPUT FILE efdc1d.inp, AND SHOULD BE USED WITH THE  *
*    10 JANUARY 2001 OR LATER VERSION OF efdc1d.f                        *
*                                                                       *
*    THIS FILE IS SELF DOCUMENTED WITH DEFINITIONS AND GUIDANCE FOR EACH *
*    INPUT VARIABLE CONTAINED IN ITS CARD IMAGE SECTION. REFER TO USERS MAN  *
*    AVAILABLE FROM DEVELOPER AT ham@visi.net FOR ADDTIONAL DOCUMENTATION    *
*                                                                       *
*************************************************************************
C1   TITLE FOR RUN                                                       |
C                                                                        |
     TITLE OR IDENTIFIER FOR THIS INPUT FILE AND RUN                     |
C                                                                        |
C1  (LIMIT TO 80 CHARACTERS LENGTH)                                      |
     'brandywine creek, christina river basin'
-------------------------------------------------------------------------
C2  RESTART, GENERAL CONTROL AND DIAGNOSTIC SWITCHES                     |
C                                                                        |
     ISRESTI: 1 FOR READING INITIAL CONDITIONS FROM FILE   restart.inp   |
              -1 AS ABOVE BUT ADJUST FOR CHANGING BOTTOM ELEVATION       |
               2 INTIALIZES A KC LAYER RUN FROM A KC/2 LAYER RUN FOR KC.GE.4 |
              10 FOR READING IC'S FROM restart.inp WRITTEN BEFORE 8 SEPT 92  |
     ISRESTO:-1 FOR WRITING RESTART FILE restart.out AT END OF RUN       |
               N INTEGER.GE.0 FOR WRITING restart.out EVERY N REF TIME PERIODS|
     ISLOG:   1 FOR WRITING LOG FILE efdc.log                            |
               2 FOR WRITING LOG FILE efdc.log WITH OVER WRITE           |
                 EVERY REFERENCE TIME    PERIOD                          |
     ISNEGH:  1 FOR SEARCHING FOR NEGATIVE DEPTHS AND WRITING TO SCREEN  |
               2 FOR STOPPING SIMULATION WHEN NEGATIVE DEPTH OCCURS      |
     ISH0W:   1 TO SHOW PUV&S ON SCREEN, SEE INSTRUCTIONS FOR FILE show.inp  |
C                                                                        |
C2  ISRESTI ISRESTO  ISLOG  ISNEGH   ISHOW                               |
     0        1        2       2        1
```

Figure 8.   Example of the efdc.inp file.

```
--------------------------------------------------------------------------
C3   SOLUTION OPTION PARAMETERS AND SWITCHES                                |
C                                                                          |
       RSQM:   TRAGET SQUARE RESIDUAL OF ITERATIVE SOLUTION SCHEME         |
      ITERM:   MAXIMUN NUMBER OF ITERARTIONS                               |
    ISDSOLV: 1 TO WRITE DIAGNOSTICS FILES FOR EXTERNAL MODE SOLVER         |
      ISDIQ: 1 TO WRITE FLOW AND CONTROL DIAGNOSTIC FILE, diaq.out         |
     ISSSMMT: 0 WRITES MEAN MASS TRANSPORT TO restran.out AFTER EACH       |
               AVERAGING PERIOD  (FOR RESEARCH PURPOSES)                   |
           2 DOES NOT WRITE                                                |
      ISHDMF: 1 TO ACTIVE HORIZONTAL MOMENTUM AND MASS DIFFUSION           |
C                                                                          |
C3   RSQM  ITERM ISDSOLV ISDIQ ISSSMMT  ISHDMF                             |
     1.E-20  300  0       0      2         0                               |
--------------------------------------------------------------------------
C4   DISSOLVED AND SUSPENDED CONSTITUENT TRANSPORT SWITCHES                |
C4   SAL=1,TEM=2,DYE=3,TOX=5, (cohesive sediment) SED=6,                   |
C4   (noncohesive sediment) SND=7                                          |
C                                                                          |
     ISTRAN:  1 OR GREATER TO ACTIVATE TRANSPORT                           |
     ISTOPT:   NONZERO FOR TRANSPORT OPTIONS, SEE USERS MANUAL             |
     ISCDCA:  0 FOR STANDARD DONOR CELL UPWIND DIFFERENCE ADVECTION        |
              1 FOR CENTRAL DIFFERENCE ADVECTION FOR THREE TIME LEVEL STEPS |
              2 FOR EXPERIMENTAL UPWIND DIFFERENCE ADVECTION (FOR RESEARCH) |
     ISADAC:  1 TO ACTIVATE ANTI-NUMERICAL DIFFUSION CORRECTION TO         |
              STANDARD DONOR CELL SCHEME                                   |
     ISFCT:   1 TO ADD FLUX LIMITING TO ANTI-NUMERICAL DIFFUSION CORRECTION |
     ISPLIT:  1 TO OPERATOR SPLIT HORIZONTAL AND VERTICAL ADVECTION        |
              (FOR RESEARCH PURPOSES)                                      |
     ISADAH:  1 TO ACTIVATE ANTI-NUM DIFFUSION CORRECTION TO HORIZONTAL    |
              SPLIT ADVECTION STANDARD DONOR CELL SCHEME (FOR RESEARCH)    |
     ISADAV:  1 TO ACTIVATE ANTI-NUM DIFFUSION CORRECTION TO VERTICAL      |
              SPLIT ADVECTION STANDARD DONOR CELL SCHEME (FOR RESEARCH)    |
     ISCI:    1 TO READ CONCENTRATION FROM FILE restart.inp               |
     ISCO:    1 TO WRITE CONCENTRATION TO FILE restart.out                |
C                                                                          |
C4   ISTRAN ISTOPT ISCDCA ISADAC ISFCT ISPLIT ISADAH ISADAV ISCI ISCO     |
      0      0      0      1      1     0      0      0      0    0   !sal 1
      0      0      0      1      1     0      0      0      0    0   !tem 2
      0      0      0      1      1     0      0      0      0    0   !dye 3
      0      0      0      1      1     0      0      0      0    0   !tox 5
      1      0      0      1      1     0      0      0      0    0   !sed 6
      1      0      0      1      1     0      0      0      0    0   !snd 7
```

Figure 8 (continued).   Example of the efdc.inp file.

```
--------------------------------------------------------------------------
C5   TIME-RELATED INTEGER PARAMETERS                                      |
C                                                                        |
      NTC:     NUMBER OF REFERENCE TIME PERIODS IN RUN                   |
      NTSPTC:  NUMBER OF TIME-STEPS PER REFERENCE TIME PERIOD            |
      NTCMMT:  NUMBER OF NUMBER OF REF TIME TO AVERAGE OVER TO OBTAIN    |
               RESIDUAL OR MEAN MASS TRANSPORT VARIABLES                 |
      TCON:    CONVERSION MULTIPLIER TO CHANGE TBEGIN TO SECONDS         |
      TBEGIN:  TIME ORIGIN OF RUN                                        |
      TREF:    REFERENCE TIME PERIOD IN SEC (i.e. 44714.16s or 86400s)   |
|                                                                        |
C                                                                        |
C5   NTC  NTSPTC  NTSMMT   TCON      TBEGIN     TREF                      |
     152  1440     720     86400.    121.0      86400.
--------------------------------------------------------------------------
C6   GRID, ROUGHNESS AND DEPTH PARAMETERS                                |
C                                                                        |
      ZBRADJ:   LOG BDRY LAYER CONST OR VARIABLE ROUGH HEIGHT ADJ IN METERS |
      ZBRCVRT:  LOG BDRY LAYER VARIABLE ROUGHNESS HEIGHT CONVERT TO METERS  |
C      0.0     1.00
C6    ZBRADJ ZBRCVT
       0.0    1.00
--------------------------------------------------------------------------
C7   TIDAL & ATMOSPHERIC FORCING                                         |
C                                                                        |
      MTIDE:  NUMBER OF PERIOD (TIDAL) FORCING CONSTITUENTS              |
      NPSER:  NUMBER OF TIME SERIES FORCINGS                            |
      NPFOR:  NUMBER OF HARMONIC FORCINGS                               |
      NWSER:  NUMBER OF WIND TIME SERIES (0 SETS WIND TO ZERO)          |
      NASER:  NUMBER OF ATMOSPHERIC CONDITION TIME SERIES (0 SETS ALL  ZERO) |
C                                                                        |
C7   MTIDE   NPSER NPFOR   NWSER   NASER
      0       0     0       1       1
--------------------------------------------------------------------------
C8   PERIODIC FORCING (TIDAL) CONSTITUENT SYMBOLS AND PERIODS            |
C                                                                        |
      SYMBOL:  FORCING SYMBOL (CHARACTER VARIABLE) FOR TIDES, THE NOS SYMBOL |
      PERIOD:  FORCING PERIOD IN SECONDS                                |
C                                                                        |
C8   SYMBOL    PERIOD                                                    |
```

Figure 8 (continued).   Example of the efdc.inp file.

```
----------------------------------------------------------------------
C9   PERIODIC FORCING (TIDAL) SURF ELEV OR PRESSURE BOUNDARY COND. FORCINGS   |
C                                                                             |
     NPFOR:        FORCING NUMBER                                             |
     SYMBOL:       FORCING SYMBOL (FOR REFERENCE HERE ONLY)                   |
     AMPLITUDE:    AMPLITUDE IN M (PRESSURE DIVIDED BY RHO*G)                 |
     PHASE:        FORCING PHASE RELATIVE TO TBEGIN IN SECONDS                |
C                                                                             |
C9  NPFOR    SYMBOL     AMPLITUDE      PHASE                                  |
----------------------------------------------------------------------
C10  SPECIFY NUM OF SEDIMENT AMD TOXICS AND NUM OF CONCENTRATION TIME SERIES  |
C                                                                             |
     NTOX:    NUMBER OF TOXIC CONTAMINANTS (DEFAULT = 1)                      |
     NSED:    NUMBER OF COHESIVE SEDIMENT SIZE CLASSES (DEFAULT = 1)          |
     NSND:    NUMBER OF NON-COHESIVE SEDIMENT SIZE CLASSES (DEFAULT = 1)      |
     NSSER:   NUMBER OF SALINITY TIME SERIES                                  |
     NTSER:   NUMBER OF TEMPERATURE TIME SERIES                               |
     NDSER:   NUMBER OF DYE CONCENTRATION TIME SERIES                         |
     NTXSER:  NUMBER OF TOXIC CONTAMINANT CONCENTRATION TIME SERIES           |
              EACH TIME SERIES MUST HAVE DATA FOR NTOX TOXICICANTS            |
     NSDSER:  NUMBER OF COHESIVE SEDIMENT CONCENTRATION TIME SERIES           |
              EACH TIME SERIES MUST HAVE DATA FOR NSED COHESIVE SEDIMENTS     |
     NSNSER:  NUMBER OF NONCOHESIVE SEDIMENT CONCENTRATION TIME SERIES        |
              EACH TIME SERIES MUST HAVE DATA FOR NSND NONCOHESIVE SEDIMENTS  |
C                                                                             |
C10   NTOX NSED  NSND  NSSER NTSER NDSER NTXSER NSDSER NSNSER                 |
       1    1     2     0     0     0     0      0      0                      |
```

Figure 8 (continued).   Example of the efdc.inp file.

```
 ------------------------------------------------------------------------
C11 SEDIMENT INITIALIZATION AND WATER COLUMN/BED REPRESENTATION OPTIONS   |
C   DATA REQUIRED EVEN IF ISTRAN(6) AND ISTRAN(7) ARE 0                   |
C                                                                        |
    ISEDINT: 0 FOR CONSTANT INITIAL CONDITIONS                           |
             1 FOR SPATIALLY VARIABLE WATER COLUMN INITIAL CONDITIONS    |
               FROM sedw.inp AND sndw.inp                                |
             2 FOR SPATIALLY VARIABLE BED INITIAL CONDITIONS             |
               FROM sedb.inp AND sndb.inp                                |
             3 FOR SPATIALLY VARIABLE WATER COL AND BED INITIAL CONDITIONS|
   ISEDBINT: 0 FOR SPATIALLY VARYING BED INITIAL CONDITIONS IN MASS/AREA |
             1 FOR SPATIALLY VARYING BED INITIAL CONDITIONS IN MASS FRACTION|
               OF TOTAL SEDIMENT MASS (REQUIRES BED LAYER THICKNESS      |
               FILE bedlay.inp)                                          |
     ISEDWC: 0 COHESIVE SED WC/BED EXCHANGE BASED ON BOTTOM LAYER CONDITIONS|
             1 COHESIVE SED WC/BED EXCHANGE BASED ON WAVE/CURRENT/SEDIMENT|
               BOUNDARY LAYERS EMBEDDED IN BOTTOM LAYER                  |
      ISMUD: 1 INCLUDE COHESIVE FLUID MUD VISCOUS EFFECTS USING EFDC     |
               FUNCTION CSEDVIS(SEDT)                                    |
     ISNDWC: 0 NONCOH SED WC/BED EXCHANGE BASED ON BOTTOM LAYER CONDITIONS|
             1 NONCOH SED WC/BED EXCHANGE BASED ON WAVE/CURRENT/SEDIMENT |
               BOUNDARY LAYERS EMBEDDED IN BOTTOM LAYER                  |
     ISEDVW: 0 FOR CONSTANT OR SIMPLE CONCENTRATION DEPENDENT            |
               COHESIVE SEDIMENT SETTLING VELOCITY                      |
            >1 CONCENTRATION AND/OR SHEAR/TURBULENCE DEPENDENT COHESIVE  |
               SEDIMENT SETTLING VELOCITY. VALUE INDICATES OPTION TO BE USED|
               IN EFDC FUNCTION CSEDSET(SED,SHEAR,ISEDVWC)               |
             1 HUANG AND METHA - LAKE OKEECHOBEE                         |
             2 SHRESTA AND ORLOB - FOR KRONES SAN FRANCISCO BAY DATA     |
             3 ZIEGLER AND NESBIT  - FRESH WATER                        |
     ISNDVW: 0 USE CONSTANT SPECIFIED NONCHOESIVE SED SETTLING VELOCITIES|
               OR CALCULATE FOR CLASS DIAMETER IS SPECIFIED VALUE IS NEG |
            >1 FOLLOW OPTION 0 PROCEDURE BUT APPLY HINDERED SETTLING     |
               CORRECTION. VALUE INDICATES OPTION TO BE USED WITH EFDC   |
               FUNCTION CSNDSET(SND,SDEN,ISNDVW) VALUE OF ISNDVW INDICATES|
               EXPONENTIAL IN CORRECT (1-SDEN(NS)*SND(NS)**ISNDVW        |
        KB:    MAXIMUM NUMBER OF BED LAYERS (EXCLUDING ACTIVE LAYER)     |
     ISEDAL: 1 TO ACTIVATE STATIONARY COHESIVE MUD ACTIVE LAYER         |
     ISNDAL: 1 TO ACTIVATE NONCOHESIVE ARMORING LAYER ACTIVE LAYER      |
C                                                                        |
C11 ISEDINT ISEDBINT ISEDWC ISMUD ISNDWC ISEDVW ISNDVW  KB ISEDAL ISNDAL |
      0        0        0      0      0      0      0     1    0      1   |
```

Figure 8 (continued).   Example of the efdc.inp file.

```
--------------------------------------------------------------------------
C12 BED MECHANICAL PROPERTIES PARAMETER SET 1                             |
C   DATA REQUIRED EVEN IF ISTRAN(6) AND ISTRAN(7) ARE 0                    |
C                                                                         |
        IBMECH: 0 TIME INVARIANT CONSTANT BED MECHANICAL PROPERITES       |
                1 SIMPLE CONSOLIDATION CALCULATION WITH CONSTANT COEFFICIENTS |
                2 SIMPLE CONSOLIDATION WITH VARIABLE COEFFICIENTS DETERMINED |
                  EFDC FUNCTIONS CSEDCON1,2,3(IBMECH)                      |
                3 COMPLEX CONSOLIDATION WITH VARIABLE COEFFICIENTS DETERMINED |
                  EFDC FUNCTIONS CSEDCON1,2,3(IBMECH). IBMECH > 0 SETS THE |
                  C38 PARAMETER ISEDBINT=1 AND REQUIRES INITIAL CONDITIONS |
                  FILES bedlay.inp, bedbdn.inp and bedddn.in              |
        IMORPH: 0 CONSTANT BED MORPHOLOGY (IBMECH=0, ONLY)                |
                1 ACTIVE BED MORPHOLOGY: NO WATER ENTRAIN/EXPULSION EFFECTS |
                2 ACTIVE BED MORPHOLOGY: WITH WATER ENTRAIN/EXPULSION EFFECTS |
       HBEDMAX:   TOP BED LAYER THICKNESS (M) AT WHICH NEW LAYER IS ADDED OR IF |
                  KBT(I,J)=KB, NEW LAYER ADDED AND LOWEST TWO LAYERS COMBINED |
       BEDPORC:   CONSTANT BED POROSITY (IBMECH=0, OR NSED=0)              |
                  ALSO USED AS POROSITY OF DEPOSITIN NONCOHESIVE SEDIMENT  |
       SEDMDMX:   MAXIMUM FLUID MUD COHESIVE SEDIMENT CONCENTRATION (mg/l) |
       SEDMDMN:   MINIMUM FLUID MUD COHESIVE SEDIMENT CONCENTRATION (mg/l) |
       SEDVDRD:   VOID RATIO OF DEPOSITING COHESIVE SEDIMENT              |
       SEDVDRM:   MINIMUM COHESIVE SEDIMENT BED VOID RATIO (IBMECH > 0)    |
       SEDVDRT:   BED CONSOLODATION RATED CONSTANT (1/SEC) (IBMECH = 1,2)  |
C                                                                         |
C12 IBMECH IMORPH  HBEDMAX  BEDPORC SEDMDMX SEDMDMN SEDVDRD SEDVDRM SEDVRDT |
      0      0       2.0       0.5    1.1E5   4000.    20.      4.    1.E-5 |
--------------------------------------------------------------------------
C13 BED MECHANICAL PROPERTIES PARAMETER SET 2                             |
C   DATA REQUIRED EVEN IF ISTRAN(6) AND ISTRAN(7) ARE 0                    |
C                                                                         |
     BMECH1:   BED MECHANICS FUNCTION COEFFICIENT                         |
     BMECH2:   BED MECHANICS FUNCTION COEFFICIENT                         |
     BMECH3:   BED MECHANICS FUNCTION COEFFICIENT                         |
     BMECH4:   BED MECHANICS FUNCTION COEFFICIENT                         |
     BMECH5:   BED MECHANICS FUNCTION COEFFICIENT                         |
     BMECH6:   BED MECHANICS FUNCTION COEFFICIENT                         |
C                                                                         |
C13  BMECH1 BMECH2 BMECH3 BMECH4 BMECH5 BMECH6                            |
     0.0     0.     0.     0.     0.     0.                               |
```

Figure 8 (continued).   Example of the efdc.inp file.

```
--------------------------------------------------------------------------------
C14 COHESIVE SEDIMENT PARAMETER SET 1 REPEAT DATA LINE NSED TIMES              |
C   DATA REQUIRED EVEN IF ISTRAN(6) AND ISTRAN(7) ARE 0                        |
C                                                                             |
      SEDO:    CONSTANT INITIAL COHESIVE SEDIMENT CONC IN WATER COLUMN        |
                 (mg/liter=gm/m**3)                                          |
      SEDBO:   CONSTANT INITIAL COHESIVE SEDIMENT IN BED PER UNIT AREA        |
                 (gm/sq meter)  IE 1CM THICKNESS BED WITH SSG=2.5 AND         |
                 N=.6,.5 GIVES SEDBO 1.E4, 1.25E4                            |
      SDEN:    SEDIMENT SPEC VOLUME (IE 1/2.25E6 m**3/gm)                     |
      SSG:     SEDIMENT SPECIFIC GRAVITY                                     |
      WSEDO:   CONSTANT OR REFERENCE SEDIMENT SETTLING VELOCITY              |
                 IN FORMULA WSED=WSEDO*( (SED/SEDSN)**SEXP )                 |
      SEDSN:   NORMALIZING SEDIMENT CONC (COHESIVE SED TRANSPORT) (gm/m**3)  |
      SEXP:    EXPONENTIAL (COHESIVE SED TRANSPORT)                          |
      TAUD:    BOUNDARY STRESS BELOW WHICH DEPOSITION TAKES PLACE ACCORDING  |
                 TO (TAUD-TAU)/TAUD                                          |
   ISEDSCOR: 1 TO CORRECT BOTTOM LAYER CONCENTRATION TO NEAR BED CONC        |
C                                                                             |
C14  SEDO   SEDBO    SDEN    SSG    WSEDO   SEDSN    SEXP    TAUD    ISEDSCOR  |
     0.0    1.0E5   0.4E-6   2.5    1.0E-4   1.0     0.     2.0E-4     0       |
--------------------------------------------------------------------------------
C15 COHESIVE SEDIMENT PARAMETER SET 2 REPEAT DATA LINE NSED TIMES              |
C   DATA REQUIRED EVEN IT ISTRAN(6) AND ISTRAN(7) ARE 0                        |
C                                                                             |
      IWRSP: 0 USE RESUSPENSION RATE AND CRITICAL STRESS BASED ON PARAMETERS  |
                ON THIS DATA LINE                                            |
            >1 USE BED PROPERTIES DEPENDEDNT RESUSPENSION RATE AND CRITICAL  |
                STRESS GIVEN BY EFDC FUNCTIONS CSEDRESS,CSEDTAUS,CSEDTAUB    |
                FUNCTION ARGUMENSTS ARE (BDENBED,IWRSP)                      |
             1 HWANG AND METHA - LAKE OKEECHOBEE                             |
      WRSPO:   REF SURFACE EROSION  RATE IN FORMULA                          |
                WRSP=WRSP0*( ((TAU-TAUR)/TAUN)**TEX ) (gm/m**2-sec)          |
      TAUR:    BOUNDARY STRESS ABOVE WHICH SURFACE EROSION OCCURS (m/s)**2   |
      TAUN:    NORMALIZING STRESS (EQUAL TO TAUR FOR COHESIVE SED TRANS)     |
      TEXP:    EXPONENTIAL (COH SED)                                         |
C     0    0.005   4.E-4    4.E-4     1.                                      |
C15  IWRSP  WRSPO   TAUR     TAUN     TEXP                                    |
     0    0.005   4.E-4    4.E-4     1.                                       |
```

Figure 8 (continued).   Example of the efdc.inp file.

```
--------------------------------------------------------------------------
C16 NONCOHESIVE SEDIMENT PARAMETER SET 1 REPEAT DATA LINE NSND TIMES     |
C   DATA REQUIRED EVEN IT ISTRAN(6) AND ISTRAN(7) ARE 0                   |
C                                                                        |
       SNDO:    CONSTANT INITIAL NONCOHESIVE SEDIMENT CONC IN WATER COLUMN |
                 (mg/liter=gm/m**3)                                      |
       SNDBO:   CONSTANT INITIAL NONCOHESIVE SEDIMENT IN BED PER UNIT AREA |
                 (gm/sq meter)  IE 1CM THICKNESS BED WITH SSG=2.5 AND     |
                 N=.6,.5 GIVES SNDBO 1.E4, 1.25E4                         |
       SDEN:    SEDIMENT SPEC VOLUME (IE 1/2.65E6 m**3/gm)                |
       SSG:     SEDIMENT SPECIFIC GRAVITY                                |
       SNDDIA:  REPRESENTATIVE DIAMETER OF SEDIMENT CLASS                |
       WSNDO:   CONSTANT OR REFERENCE SEDIMENT SETTLING VELOCITY         |
                 IF WSNDO < 0, SETTLING VELOCITY INTERNALLY COMPUTED     |
       SNDN:    MAX MASS/TOT VOLUME IN BED (NONCOHESIVE SED TRANS) (gm/m**3) |
       SEXP:    DIMENSIONLESS RESUSPENSION PARAMETER GAMMA ZERO          |
       TAUD:    DUNE BREAK POINT STRESS  (m/s)**2                        |
    ISNDSCOR: 1 TO CORRECT BOTTOM LAYER CONCENTRATION TO NEAR BED CONC   |
C               3.77E-5  2.65                                            |
C16 SNDO  SNDBO   SDEN    SSG   SNDDIA  WSNDO  SNDN   SEXP    TAUD   ISNDSCOR |
    0.0   1.E5  3.77E-5  2.65  8.0E-5  -1.00  1.E6   1.E-3  7.E-5    0      |
    0.0   1.E5  3.77E-5  2.65  3.0E-4  -1.00  1.E6   1.E-3  7.E-5    0      |
--------------------------------------------------------------------------
C17 NONCOHESIVE SEDIMENT PARAMETER SET 2 REPEAT DATA LINE NSND TIMES     |
C   DATA REQUIRED EVEN IT ISTRAN(6) AND ISTRAN(7) ARE 0                   |
C                                                                        |
       ISNDEQ: >1 CALCULATE ABOVE BED REFERENCE NONCHOHESIVE SEDIMENT    |
                  EQUILIBRIUM CONCENTRATION USING EFDC FUNCTION          |
                  CSNDEQC(SNDDIA,SSG,WS,TAUR,TAUB,SIGPHI,SNDDMX,IOTP)    |
                  WHICH IMPLEMENT FORMULATIONS OF                        |
                1 GRACIA AND PARKER                                      |
                2 SMITH AND MCLEAN                                       |
                3 VAN RIJN                                               |
       ISBDLD:  0 BED LOAD PHI FUNCTION IS CONSTANT, SBDLDP              |
                1 VAN RIJN PHI FUNCTION                                  |
                2 OHTER PHI FUNCTION                                     |
                3 OHTER PHI FUNCTION                                     |
       ISBDLD:  0 BED LOAD PHI FUNCTION IS CONSTANT                      |
       TAUR:    CRITICAL SHIELDS STRESS IN (m/s)**2   (ISNDEQ=2)         |
                NOTE: IF TAUR < 0, THEN TAUR, TAUN, AND TEXP ARE INTERNALLY |
                      COMPUTED USING VAN RIJN'S FORMULAS                 |
       TAUN:    EQUAL TO TAUR FOR NONCHOESIVE SED TRANS  (ISNDEQ=2)      |
       TEXP:    CRITICAL SHIELDS PARAMETER  (ISNDEQ=2)                   |
C                                                                        |
C17  ISNDEQ  ISBDLD   TAUR     TAUN     TEXP                             |
        3       0    -1.E+6   -1.E+6   -0.2                              |
        3       0    -1.E+6   -1.E+6   -0.2                              |
```

Figure 8 (continued).   Example of the efdc.inp file.

```
--------------------------------------------------------------------------
C18 NONCOHESIVE SEDIMENT PARAMETER SET 3 (BED LOAD FORMULA PARAMETERS)    |
C    DATA REQUIRED EVEN IT ISTRAN(6) AND ISTRAN(7) ARE 0                   |
C                                                                          |
     SBDLDA:    ALPHA EXPONENTIAL FOR BED LOAD FORMULA                     |
     SBDLDB:    BETA EXPONENTIAL FOR BED LOAD FORMULA                      |
     SBDLDG:    GAMMA CONSTANT FOR BED LOAD FORMULA                        |
     SBDLDP:    CONSTANT PHI FOR BED LOAD FORMULA                          |
C                                                                          |
C18  SBDLDA   SBDLDB   SBDLDG   SBDLDP                                     |
       2.1     0.       0.       0.
--------------------------------------------------------------------------
C19 TOXIC CONTAMINANT INITIAL CONDITIONS AND PARAMETERS                    |
C   USER MAY CHANGE UNITS OF WATER AND SED PHASE TOX CONCENTRATION         |
C   AND PARTIATION COEFFICIENT ON C44 - C46 BUT CONSISTENT UNITS MUST      |
C   MUST BE USED FOR MEANINGFUL RESULTS                                    |
C   DATA REQUIRED EVEN IT ISTRAN(5) IS 0                                   |
C                                                                          |
      NTOXN:   TOXIC CONTAMINANT NUMBER ID (1 LINE OF DATA BY DEFAULT)     |
     ITXINT:   0 FOR SPATIALLY CONSTANT WATER COL AND BED INITIAL CONDITIONS |
               1 FOR SPATIALLY VARIABLE WATER COLUMN INITIAL CONDITIONS    |
               2 FOR SPATIALLY VARIABLE BED INITIAL CONDITIONS             |
               3 FOR SPATIALLY VARIABLE WATER COL AND BED INITIAL CONDITION |
    ITXBDUT:   SET TO 0 FOR CONST INITIAL BED GIVEN BY TOTAL TOX (ugm/litr) |
               SET TO 1 FOR CONST INITIAL BED GIVEN BY                     |
                 SORBED MASS TOX/MASS SED(mg/kg)                           |
    TOXINTW:   INIT WATER COLUNM TOT TOXIC VARIABLE CONCENTRATION (ugm/litr) |
    TOXINTB:   INIT SED BED TOXIC CONC SEE ITXBDUT                         |
     RKTOXW:   FIRST ORDER WATER COL DECAY RATE FOR TOX VARIABLE IN 1/SEC  |
     TKTOXW:   REF TEMP FOR 1ST ORDER WATER COL DECAY DEG C                |
     RKTOXB:   FIRST ORDER SED BED DECAY RATE FOR TOX VARIABLE IN 1/SEC    |
     TKTOXB:   REF TEMP FOR 1ST ORDER SED BED DECAY DEG C                  |
C                        ck blw kevin uses 6.0                             |
C19 NTOXN ITXINT ITXBDUT TOXINTW TOXINTB RKTOXW TKTOXW RKTOXB TRTOXB COMMENTS |
      1      0      0       1.      1.      0.     0.     0.     0.   DUMMY
```

Figure 8 (continued).   Example of the efdc.inp file.

```
--------------------------------------------------------------------------
C20 ADDITIONAL TOXIC CONTAMINANT PARAMETERS                               |
C    DATA REQUIRED EVEN IT ISTRAN(5) IS 0                                  |
C                                                                         |
       NTOXN:   TOXIC CONTAMINANT NUMBER ID (1 LINE OF DATA BY DEFAULT)    |
      VOLTOX:   WATER SURFACE VOLITIALIZATION RATE MULTIPLIER (0. OR 1.)   |
      RMOLTX:   MOLECULAR WEIGHT FOR DETERMINING VOLATILIZATION RATE       |
      RKTOXP:   REFERENCE PHOTOLOYSIS DECAY RATE 1/SEC                     |
      SKTOXP:   REFERENCE SOLAR RADIATION FOR PHOTOLOYSIS (WATTS/M**2)     |
      DIFTOX:   DIFFUSION COEFF FOR TOXICANT IN SED BED PORE WATER (M**2/S)|
C                                                                         |
C20  NTOXN VOLTOX RMOLTX RKTOXP SKTOXP DIFTOX   COMMENTS                   |
       1    0.     0.     0.      0.    1.E-9    DUMMY
--------------------------------------------------------------------------
C21 TOXIC CONTAMINANT SEDIMENT INTERACTION PARAMETERS                      |
C    2 LINES OF DATA REQUIRED EVEN IT ISTRAN(5) IS 0                       |
C                                                                         |
     NTOXC: TOXIC CONTAMINANT NUMBER ID.  NSEDC+NSEDN LINES OF DATA        |
            FOR EACH TOXIC CONTAMINANT (DEFAULT = 2)                       |
  NSEDN/NSNDN: FIRST NSED LINES COHESIVE, NEXT NSND LINES NON-COHESIVE.    |
            REPEATED FOR EACH CONTAMINANT                                  |
   ITXPARW: EQUAL 1 FOR SOLIDS DEPENDENT PARTITIONING (WC) GIVEN BY        |
            TOXPAR=PARO*(CSED**CONPAR)                                     |
   TOXPARW: WATER COLUMN PARO (ITXPARW=1) OR EQUIL TOX CON PART COEFF BETWEEN|
            EACH TOXIC IN WATER AND ASSOCIATED SEDIMENT PHASES (liters/mg) |
   CONPARW: EXPONENT IN  TOXPAR=PARO*(CSED**CONPARW) IF ITXPARW=1          |
   ITXPARB: EQUAL 1 FOR SOLIDS DEPENDENT PARTITIONING (BED)                |
   TOXPARB: SEDIMENT BED PARO (ITXPARB=1) OR EQUIL TOX CON PART COEFF BETWEEN|
            EACH TOXIC IN WATER AND ASSOCIATED SEDIMENT PHASES (liters/mg) |
   CONPARB: EXPONENT IN  TOXPAR=PARO*(CSED**CONPARB) IF ITXPARB=1          |
C            1         0.8770  -0.943          0.025                       |
C21 NTOXN NSEDN ITXPARW TOXPARW CONPARW ITXPARB TOXPARB CONPARB  COMMENTS  |
      1     1      0      1.      0.      0       1.      0.      FOR NSED=1
      1     2      0      1.      0.      0       1.      0.      FOR NSND=1
      1     2      0      1.      0.      0       1.      0.      FOR NSND=2
```

Figure 8 (continued).   Example of the efdc.inp file.

```
--------------------------------------------------------------------------
C22  BUOYANCY, TEMPERATURE, DYE DATA AND CONCENTRATION BC DATA             |
C                                                                          |
     BSC:    BUOYANCY INFLUENCE COEFFICIENT 0 TO 1, BSC=1. FOR REAL PHYSICS |
     TEMO:   REFERENCE, INITIAL, EQUILIBRUM AND/OR ISOTHERMAL TEMP IN DEG C |
     HEQT:   EQUILIBRUM TEMPERTURE TRANSFER COEFFICIENT M/SEC              |
     RKDYE:  FIRST ORDER DECAY RATE FOR DYE VARIABLE IN 1/SEC             |
     NCOBC:  1 TO ACTIVATE CONCENTRATION BC ON TIDAL OPEN BOUNDARIES      |
C                                                                          |
C22   BSC  TEMO  HEQT   RKDYE  NCOBC                                       |
      1.0  20.0  1.E-6  0.      0                                          |
--------------------------------------------------------------------------
C23  LOCATION OF CONC BC'S ON TIDAL OPEN BOUNDARY                          |
C                                                                          |
       NTSCRS:  NUMBER OF TIME-STEPS TO RECOVER SPECIFIED VALUES ON CHANGE  |
                TO INFLOW FROM OUTFLOW                                     |
       NSSERS:  BOUNDARY CELL SALINITY TIME SERIES ID NUMBER              |
       NTSERS:  BOUNDARY CELL TEMPERATURE TIME SERIES ID NUMBER           |
       NDSERS:  BOUNDARY CELL DYE CONC TIME SERIES ID NUMBER              |
       NTXSERS: BOUNDARY CELL TOXIC CONTAMINANT CONC TIME SERIES ID NUM.  |
       NSDSERS: BOUNDARY CELL COHESIVE SED CONC TIME SERIES ID NUMBER     |
       NSNSERS: BOUNDARY CELL NONCOHESIVE SED CONC TIME SERIES ID NUMBER  |
C                                                                          |
C23 NTSCRS NSSERS NTSERS NDSERS NTXSERS NSDSERS NSNSERS                    |
--------------------------------------------------------------------------
C24 TIME CONSTANT BOTTOM CONC ON OPEN BOUNDARY                             |
C                                                                          |
     SAL:  ULTIMATE INFLOWING BOTTOM LAYER SALINITY                       |
     TEM:  ULTIMATE INFLOWING BOTTOM LAYER TEMPERATURE                    |
     DYE:  ULTIMATE INFLOWING BOTTOM LAYER DYE CONCENTRATION              |
     TOX:  NTOX ULTIMATE INFLOWING BOTTOM LAYER TOXIC CONTAMINANT         |
           CONCENTRATIONS NTOX VALUES TOX(N), N=1,NTOX                    |
C                                                                          |
C24 SAL   TEM   DYE    TOX1-TOXN                                          |
--------------------------------------------------------------------------
C25 TIME CONSTANT BOTTOM CONC ON OPEN BOUNDARY                             |
C                                                                          |
     SED:  NSED ULTIMATE INFLOWING BOTTOM LAYER COHESIVE SEDIMENT         |
           CONCENTRAIONS  FIRST NSED VALUES SED(N), N=1,NSND              |
     SND:  NSND ULTIMATE INFLOWING BOTTOM LAYER NONCOHESIVE SEDIMENT      |
           CONCENTRATIONS LAST NSND VALUES SND(N), N=1,NSND               |
C                                                                          |
C25 SED1  SND1  SND2                                                      |
```

Figure 8 (continued).   Example of the efdc.inp file.

```
--------------------------------------------------------------------------
C26 TIME CONSTANT SURFACE CONC ON OPEN BOUNDARY                           |
C                                                                        |
      SAL:  ULTIMATE INFLOWING SURFAC LAYER SALINITY                     |
      TEM:  ULTIMATE INFLOWING SURFAC LAYER TEMPERATURE                  |
      DYE:  ULTIMATE INFLOWING SURFAC LAYER DYE CONCENTRATION            |
      TOX:  NTOX ULTIMATE INFLOWING SURFAC LAYER TOXIC CONTAMINANT       |
            CONCENTRATIONS NTOX VALUES TOX(N), N=1,NTOX                  |
C                                                                        |
C26 SAL    TEM    DYE    TOX1-TOXN                                        |
--------------------------------------------------------------------------
C27 TIME CONSTANT SURFACE CONC ON OPEN BOUNDARY                           |
C                                                                        |
      SED:  NSED ULTIMATE INFLOWING SURFAC LAYER COHESIVE SEDIMENT       |
            CONCENTRAIONS  FIRST NSED VALUES SED(N), N=1,NSND            |
      SND:  NSND ULTIMATE INFLOWING SURFAC LAYER NONCOHESIVE SEDIMENT    |
            CONCENTRATIONS LAST NSND VALUES SND(N), N=1,NSND             |
C                                                                        |
C27 SED1   SND1   SND2                                                    |
--------------------------------------------------------------------------
C28 CONTROLS FOR WRITING ASCII OR BINARY DUMP FILES                       |
C                                                                        |
    ISDUMP: GREATER THAN 0 TO ACTIVATE                                   |
            1 SCALED ASCII INTERGER (0<VAL<65535)                        |
            2 SCALED 16BIT BINARY INTEGER (0<VAL<65535) OR (-32768<VAL<32767) |
            3 UNSCALED ASCII FLOATING POINT                              |
            4 UNSCALED BINARY FLOATING POINT                             |
    ISADMP: GREATER THAN 0 TO APPEND EXISTING DUMP FILES                 |
    NSDUMP: NUMBER OF TIME-STEPS BETWEEN DUMPS                           |
    TSDUMP: STARTING TIME FOR DUMPS (NO DUMPS BEFORE THIS TIME)          |
    TEDUMP: ENDING TIME FOR DUMPS (NO DUMPS AFTER THIS TIME)             |
    ISDMPP: GREATER THAN 0 FOR WATER SURFACE ELEVATION DUMP              |
    ISDMPU: GREATER THAN 0 FOR HORIZONTAL VELOCITY DUMP                  |
    ISDMPW: GREATER THAN 0 FOR VERTICAL VELOCITY DUMP                    |
    ISDMPT: GREATER THAN 0 FOR TRANSPORTED VARIABLE DUMPS                |
   IADJDMP: 0 FOR SCALED BINARY INTEGERS (0<VAL<65535)                   |
            -32768 FOR SCALED BINARY INTEGERS (-32768<VAL<32767)         |
C                                                                        |
C28 ISDUMP ISADMP NSDUMP TSDUMP TEDUMP ISDMPP ISDMPU ISDMPW ISDMPT IADJDMP |
    3      0      2880   0.     731.   0      0      0      1     -32768
```

Figure 8 (continued).   Example of the efdc.inp file.

```
----------------------------------------------------------------------
C29 CONTROLS FOR HORIZONTAL PLANE SCALAR FIELD CONTOURING             |
C                                                                     |
     ISSPH:  1 TO WRITE FILE FOR SCALAR FIELD CONTOURING IN HORIZONTAL PLANE |
     NPSPH:   NUMBER OF WRITES PER REFERENCE TIME PERIOD              |
     ISRSPH: 1 TO WRITE FILE FOR RESIDUAL SALINITY PLOTTING IN        |
             HORIZONTAL                                               |
     ISPHXY: 0 DOES NOT WRITE I,J,X,Y IN ***cnh.out and r***cnh.out FILES |
             1 WRITES I,J ONLY IN ***cnh.out and r***cnh.out FILES    |
             2 WRITES I,J,X,Y  IN ***cnh.out and r***cnh.out FILES    |
     DATA LINE REPEATS 7 TIMES FOR SAL,TEM,DYE,SFL,TOX,SED,SND        |
C                                                                     |
C29 ISSPH    NPSPH    ISRSPH    ISPHXY                                |
    0         1        0         1       !SAL
    0         1        0         1       !TEM
    0         1        0         1       !DYE
    0         1        0         1       !SFL
    0         1        0         1       !TOX
    0         1        0         1       !SED
    0         1        0         1       !SND
----------------------------------------------------------------------
C30 CONTROLS FOR HORIZONTAL SURFACE ELEVATION OR PRESSURE CONTOURING  |
C                                                                     |
     ISPPH:  1 TO WRITE FILE FOR SURFACE ELEVATION OR PRESSURE CONTOURING |
             IN HORIZONTAL PLANE                                      |
     NPPPH:   NUMBER OF WRITES PER REFERENCE TIME PERIOD              |
     ISRPPH: 1 TO WRITE FILE FOR RESIDUAL SURFACE ELEVATION  CONTOURNG IN |
             HORIZONTAL PLANE                                         |
C                                                                     |
C30 ISPPH    NPPPH    ISRPPH                                          |
    1         1         0                                             |
----------------------------------------------------------------------
C31 CONTROLS FOR HORIZONTAL PLANE VELOCITY VECTOR PLOTTING            |
C                                                                     |
     ISVPH:  1 TO WRITE FILE FOR VELOCITY PLOTTING IN HORIZONTAL PLANE |
     NPVPH:   NUMBER OF WRITES PER REFERENCE TIME PERIOD              |
     ISRVPH: 1 TO WRITE FILE FOR RESIDUAL VELOCITY PLOTTIN IN         |
             HORIZONTAL PLANE                                         |
C                                                                     |
C31 ISVPH    NPVPH    ISRVPH                                          |
    0         1        0                                              |
```

Figure 8 (continued).   Example of the efdc.inp file.

```
--------------------------------------------------------------------------
C32 INPLACE HARMONIC ANALYSIS PARAMETERS                                 |
C                                                                        |
     ISLSHA:  1 FOR IN PLACE LEAST SQUARES HARMONIC ANALYSIS             |
     MLLSHA:  NUMBER OF LOCATIONS FOR LSHA                               |
     NTCLSHA: LENGTH OF LSHA IN INTEGER NUMBER OF REFERENCE TIME PERIODS |
     ISLSTR:  1 FOR TREND REMOVAL                                        |
     ISHTA :  1 FOR SINGLE TREF PERIOD SURFACE ELEV ANALYSIS             |
C                   90                                                   |
C32 ISLSHA  MLLSHA   NTCLSHA  ISLSTR  ISHTA                              |
    0        0        29        0       0                                |
--------------------------------------------------------------------------
C33 HARMONIC ANALYSIS LOCATIONS AND SWITCHES                             |
C                                                                        |
     LLLSHA:    CELL INDEX                                               |
     LSHAP:  1 FOR ANALYSIS OF SURFACE ELEVATION                        |
     LSHAB:  1 FOR ANALYSIS OF SALINITY                                 |
     LSHAUE: 1 FOR ANALYSIS OF EXTERNAL MODE HORIZONTAL VELOCITY        |
     LSHAU:  1 FOR ANALYSIS OF HORIZONTAL VELOCITY IN EVERY LAYER       |
     CLSL:      LOCATION AS A CHARACTER VARIALBLE                        |
C                                                                        |
C33 LLLSHA   LSHAP  LSHAB  LSHAUE LSHAU  CLSL                            |
--------------------------------------------------------------------------
C34 CONTROLS FOR WRITING TO TIME SERIES FILES                           |
C                                                                        |
     ISTMSR:  1 OR 2 TO WRITE TIME SERIES OF SURF ELEV, VELOCITY, NET    |
              INTERNAL AND EXTERNAL MODE VOLUME SOURCE-SINKS, AND        |
              CONCENTRATION VARIABLES,  2 APPENDS EXISTING TIME SERIES FILES |
     NBTMSR:  TIME-STEP TO BEGIN WRITING TO TIME SERIES FILES            |
     NSTMSR:  TIME-STEP TO STOP WRITING TO TIME SERIES FILES             |
     NWTSER:  WRITE INTERVAL FOR WRITING TO TIME SERIES FILES            |
     TCTMSR:  UNIT CONVERSION FOR TIME SERIES TIME.  FOR SECONDS, MINUTES, |
              HOURS,DAYS USE 1.0, 60.0, 3600.0, 86400.0 RESPECTIVELY     |
C                                                                        |
C34 ISTMSR   NBTMSR   NSTMSR   NWTMSR   TCTMSR                           |
    1        1        2000000  180      86400.                           |
--------------------------------------------------------------------------
```

Figure 8 (continued).   Example of the efdc.inp file.

9.7   Pser.inp Input File

The water surface elevation open boundary condition file, *pser.inp*, is shown in Figure 9. The file in this figure can be used as a template for file construction.

9.8   Qctl.inp Input File

The input file *qctl.inp* specifies data to implement flow between pairs of cells controlled by hydraulic structures or rating curves. The flow is unidirectional between an upstream and downstream cell. Bi-directional flow is implemented by a control structure for each direction. An example of the file, which can contain data sequences for an arbitrary number of structures is shown in Figure 10, which can also be used as a template for file construction. The header line contains a number of adjustment and multiplier factors for the upstream and downstream water surface elevations and the flow value. The data table has a head difference in the first column and one or more flow data columns. The flows in the flow data column can be adjusted both by addition and multiplication. For example, if the flow in the flow data column represents flow per unit width over a spillway in CFS, RMULADJ would include both the width of the spillway and the unit conversion from CFS to the required units of CMS. When the flow is calculated in the EFDC1D model in subroutine CALQVS, the value of the head difference is calculated by:

$$hdifctl = hctlum \otimes (selu + hctlua) - hctldm \otimes (seld + hctlda) \tag{9.2}$$

where *selu* and *seld* are the water surface elevations upstream and downstream of the control structure. For example, a rating curve or flow over a spillway has only upstream control and *hctldm* would be set to zero. For a culvert, both *hctlum* and *hctldm* would be set to one or a unit conversion factor if required. For a rating curve in terms of the flow depth, the *hctlua* adjustment would be set to the negative of the channel bottom elevation. Likewise for a spillway rating curve based on the upstream head above the spillway crest, *hctlua* would be set to the negative of the spillway crest elevation.

```
C  pser.inp file, in free format across line, repeats npser times
C
C  MPSER(NS)    TCPSER(NS)   TAPSER(NS)   RMULADJ(NS)     ADDADJ(NS)
C
C  TPSER(M,NS)     PSER(M,NS)    !(mpser(ns) pairs for ns=1,npser series)
C
  5040          86400.        0.           1.0              0.0
  59.042   0.157
  60.042   0.157
  60.083   0.163
  60.125   0.161
  60.167   0.165
  60.208   0.169
```

Figure 9.   Example of the pser.inp file.

```
C  qctl.inp file, repeats nqctl times, for Christina River
C
C  ISTYP MQCTL  HCTLUA HCTLUM  HCTLDA HCTLDM  RMULADJ ADDADJ  ACQCTL
C                  hctlua is negative of dam crest elevation in meters
C  if istyp.eq.1 then read depth weights and single value of QCTL
C
C  (WKQ(K),K=1,KC)
C
C  HDIFCTL(M,NS)    QCTL(M,1,NS)    !(mqctl(ns) pairs for ns=1,nqser series)
C
C  else read a value of qser for each layer
C
C  HDIFCTL(M,NS)     (QCTL(M,K,NS),K=1,KC) !(mqctl(ns) pairs)
C
  0   7  -3.5  1.0   0.0  0.0 25.0   0.00  0.0  ! 1  Brandywine Park Dam
   0.0000    0.0000
   0.0800    0.0386
   0.1600    0.1091
   0.2400    0.2005
   0.3200    0.3086
   0.4000    0.4313
  12.0000   70.8712
  0   5  -50.6  1.0    0.0  0.0  16.0  0.00  0.0  ! 2 Brandywine-E.Br. (Lenape)
   0.0000    0.0000
   0.0800    0.0386
   0.1600    0.1091
   0.2400    0.2005
   0.3200    0.3086
```

Figure 10. Example of the qctl.inp file with two control tables.

9.9   Qser.inp Input File

The *qser.inp* file, shown in Figure 11, is used to specify time varying inflow and withdrawals.   Its structure is similar to other EFDC1D time series input files. Withdrawals from a model cell are specified by a negative flow multiplier or negative values in the flow column.

9.10   Sdser.inp and Snser.inp Input File

The *sdser.inp* and *snser.inp* files are used to specify inflow and open boundary cohesive and noncohesive sediment concentrations.   Since the EFDC1D model can simulate multiple classes of each sediment group, their time series files can be slightly different than those for other concentration variables. Figure 12 shows an example of the *sdser.inp* for a single class of cohesive sediment. The file is identical in form to the *dser.inp* file. Figure 13 shows an example of the *snser.inp* for two classes of noncohesive sediment. Note that the sediment concentration adjustment factors for the second sediment class are included on a second header line before the time series data.

9.11   Show.inp Input File

The *show.inp* file, shown in Figure 14 is used to control screen display during run time. Use of this option is set in data block 2. The *show.inp* file is reread after NSHOWR time-steps, allowing the user to edit the file and change options between subsequent reads. When active, time, water surface elevation, velocity, concentration variables, and vertical diffusivity (for 3D applications only) in computational grid cell ISHOWC, JSHOWC, are displayed numerically on the screen. A map relating the computational I,J locations to the cellnet.inp defined cell indices is generated by the model and output in file map1d2ij.out, at the start of a simulation. Options defined by NSTYPE include:

1 - strip chart (not recommended)
2 - time-step rather than time, concentration variable shown is salinity
3 - time in days and salinity
4 - time in days and temperature
5 - time in days and total cohesive and total noncohesive sediment

The total cohesive and noncohesive concentrations displayed for option 5 represent the sum of all classes of each sediment type. The parameter ISHPRT defines the frequency of screen output in number of time-steps.

9.12   Txser.inp Input File

Figure 15 shows an example of the toxic contaminant time series file for two contaminants. The convention used follows that for multiple sediment classes.

78

9.13   Wser.inp Input File

An example of the wind speed and direction time series file, wser.inp is shown in Figure 16. The file includes time adjustment and unit conversion factors and a speed conversion factor for wind speed. When ISWDINT equal to zero or one, direction is bearing (angle CW from north) to which the wind is going (0) or coming from (1). For ISWDINT equal to 3, the second and third data columns represent the east and north vector components of the wind velocity.

```
c QSER.INP for Brandywine Creek, Christina River Basin
c flow in cfs; harmonic mean flow for nonpoint sources
c
c  ISTYP MQSER(NS) TCQSER(NS) TAQSER(NS) RMULADJ(NS) ADDADJ(NS) ICHGQS
c
c  if istyp.eq.1 then read depth weights and single value of QSER
c
c  (WKQ(K),K=1,KC)
c  TQSER(M,NS)    QSER(M,1,NS)    !(mqser(ns) pairs for ns=1,nqser series)
c
c  else read a value of qser for each layer
c
c  TQSER(M,NS)     (QSER(M,K,NS),K=1,KC) !(mqser(ns) pairs)
c
     0   7  86400.00       0.00   0.02832   0.00000     0  ns =     1
 -10000.0000      2.6306
    121.5000      2.6306
    122.5000      2.4074
    123.5000      2.6689
    124.5000      3.3037
    125.5000      3.4919
  10000.0000      0.9863
     0   7  86400.00       0.00   0.02832   0.00000     0  ns =     2
 -10000.0000      4.3250
    121.5000      4.3250
    122.5000      3.9562
    123.5000      4.3863
    124.5000      5.4313
    125.5000      5.7381
    126.5000      4.3250
```

Figure 11. Example of qser.inp file with two flow time series.

```
C  sdser.inp file - cohesive sediment
C  repeats nsdser times, test case
C
C  ISTYP  MCSER(NS,1)  TCCSER(NS,1)  TACSER(NS,1)  RMULADJ(NS,1)  ADDADJ(NS,1)
C
C  if istyp.eq.1 then read depth weights and single value of CSER
C
C  (WKQ(K),K=1,KC)
C
C  TCSER(M,NS,1)   CSER(M,NS,1)  !(mcser(ns,1) pairs for ns=1,ncser(1) series)
C
C  else read a value of dser for each layer
C
C  TCSER(M,NS,1)    (CSER(M,K,NS,1),K=1,KC) !(mcser(ns,1) pairs)
C
    0    4     86400.0   0.     1.    0.
  -100.0        1.
   100.0        1.
  1000.0        1.
 10000.0        1.
    0    4     86400.0   0.     1.    0.
  -100.0        1.
   100.0        1.
  1000.0        1.
 10000.0        1.
```

Figure 12.   Example of the sdser.inp file with two time series for a single cohesive
              sediment class.

```
C  snser.inp file - noncohesive sediment - 2 size classes
C  repeats nsnser times, test case
C
C  ISTYP  MCSER(NS,1)  TCCSER(NS,1)  TACSER(NS,1)  RMULADJ(NS,1)  ADDADJ(NS,1)
C
C  if istyp.eq.1 then read depth weights and single value of CSER
C
C  (WKQ(K),K=1,KC)
C
C  TCSER(M,NS,1)   CSER(M,NS,1)  !(mcser(ns,1) pairs for ns=1,ncser(1) series)
C
C  else read a value of dser for each layer
C
C  TCSER(M,NS,1)    (CSER(M,K,NS,1),K=1,KC) !(mcser(ns,1) pairs)
C
     0     4      86400.0   0.     1.    0.
                                   1.    0.    ! adjustment factors for 1st class
   -100.0        1.                           !silt (very fine sand)
                 1.                           !sand (fine to coarse sand)
    100.0        1.
                 1.
   1000.0        1.
                 1.
  10000.0        1.
                 1.
     0     4      86400.0   0.     1.    0.
                                   1.    0.    ! adjustment factors for 2nd class
   -100.0        2.                           !silt (very fine sand)
                 2.                           !sand (fine to coarse sand)
    100.0        2.
                 2.
   1000.0        2.
                 2.
  10000.0        2.
                 2.
```

Figure 13. Example of the snser.inp file with two time series for two classes of
noncohesive sediments.

```
C  show.inp file, in free format across line
C
C  NSTYPE     NSHOWR     ISHOWC    JSHOWC    ISHPRT
C
C  ZSSMIN     ZSSMAX     SSALMAX
C
    3          360         2         3         1
  -500.        500.       35.
```

Figure 14. Example of the show.inp file.

```
C  txser.inp file – sorptive toxic contaminant time series file
C  repeats ntxser times, test case
C
C  ISTYP  MCSER(NS,1)  TCCSER(NS,1)  TACSER(NS,1)  RMULADJ(NS,1)  ADDADJ(NS,1)
C
C  if istyp.eq.1 then read depth weights and single value of CSER
C
C  (WKQ(K),K=1,KC)
C
C  TCSER(M,NS,1)   CSER(M,NS,1)  !(mcser(ns,1) pairs for ns=1,ncser(1) series)
C
C  else read a value of dser for each layer
C
C  TCSER(M,NS,1)    (CSER(M,K,NS,1),K=1,KC)  !(mcser(ns,1) pairs)
C
    0    4     86400.0    0.     1.    0.
                                  1.    0.    ! adjustment factors for 2nd toxic
  -100.0        1.                           !toxic 1 concentration
                1.                           !toxic 2 concentration
   100.0        1.
                1.
  1000.0        1.
                1.
 10000.0        1.
                1.
    0    4     86400.0    0.     1.    0.
                                  1.    0.    ! adjustment factors for 2nd toxic
  -100.0        1.                           !toxic 1 concentration
                1.                           !toxic 2 concentration
   100.0        1.
                1.
  1000.0        1.
                1.
 10000.0        1.
                1.
```

Figure 15. Example of the txser.inp file for two time series and two toxic contaminants.

```
C  wser.inp file, in free format across line, repeats nw=1,nwser times
C
C  WIND FORCING FILE, USE WITH 7 APRIL 97 AND LATER VERSIONS OF EFDC
C
C  MASER(NW)      =NUMBER OF TIME DATA POINTS
C  TCASER(NW)     =DATA TIME UNIT CONVERSION TO SECONDS
C  TAASER(NW)     =ADDITIVE ADJUSTMENT OF TIME VALUES SAME UNITS AS INPUT TIMES
C  WINDSCT(NW)    =WIND SPEED CONVERSION TO M/SEC
C  ISWDINT(NW)    =DIRECTION CONVENTION
C                 0 DIRECTION TO
C                 1 DIRECTION FROM
C                 2 WINDS IS EAST VELOCITY, WINDD IS NORTH VELOCITY
C
C  MASER  TCASER   TAASER  WINDSCT  ISWDINT
C
C  TASER(M) WINDS(M) WINDD(M)
C
    3447   86400.    0.       1.         0
    0.0354      4.16     310.00
  120.0354      4.16     310.00
  120.0771      4.16     330.00
  120.1188      4.68     330.00
```

Figure 16. Example of the wser.inp file.

10. Model Output Files and Post-processing

The primary model output files are the dump1d.out file and the cell time series files. Controls for writing the dump1d.out files are found in data block 28 of the efdc1d.inp file. Controls for writing the cell time series files are in the cellnet.inp file and data block 34 of the efdc1d.inp files. At each write to the dump1d.out file a time header line

       127.0000 TIME IN DAYS

is written followed by a variable definition line which in sequence defines the corresponding values written in ASCII test format. Definition of the variable header is as follows:

      L1D - Cell index number from cellnet.inp
      L - EFDC1D single count computational index
      I - EFDC1D I double count computational index
      J - EFDC1D J double count computational index
      X - cell center east coordinate from cellnet.inp
      Y - cell center north coordinate from cellnet.inp
      BEL - cell bottom elevation
      DEP - cell depth relative to lowest point in cross-section
      AREA - cell cross-section area
      WPER - cell wetted perimeter
      BSRF - cell water surface width normal to flow direction
      VEL - velocity (negative indicates downstream direction)
      Q - discharge (negative indicates downstream direction)
      SAL - cell salinity
      TEM - cell temperature
      SED - concentration of cohesive sediment (1st class if
          multiple classes)
      SND1 - concentration of 1st class of noncohesive sediment
      SND2 - concentration of 2nd class of noncohesive sediment
      SEDB - bed mass per unit area of 1st class of cohesive sediment
      SNDB1 - bed mass per unit area of 1st class of noncohesive
          sediment
      SNDB2 - bed mass per unit area of 2nd class of noncohesive
          sediment
      TAUBED - bed shear stress

The current output of only the first cohesive sediment class and the first two noncohesive sediment classes was designed for consistency with HSPF embedded applications of EFDC1D which have these class number limitations. The output format can be changed by modification of subroutine DUMP1D.

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Appendix A: Compilation Considerations

Compilation of the EFDC1D model requires the FORTRAN source code *efdc1d.f* and two include files, *efdc.cmn* and *efdc.par*. The *efdc.cmn* file is a global common block file identical to that used for the multi-dimensional EFDC model. The efdc.par file contains parameter statements defining the dimensions of global and local arrays. All parameters in *efdc.par* are defined within the file. The primary reason for recompilation of EFDC1D would be to enlarge array storage to accommodate a greater number of cells or more/longer time series files, more inflow locations and more control structure locations and/or control tables.

The number of cells and the domain size are specified by LCM, ICM, and JCM. The allowed number of active cells is actually LCM-2, since the internal data structure utilizes 2 dummy cells. The parameters ICM and JCM define the dimensions of a computational space. For EFDC1D, guidelines for setting these two parameters are:

ICM = (number of cells in the longest even order segment) + 6

JCM = (sum of number of cells in all odd order segments) + (number of odd order segments) + 4

The junctions parameters, NJUNX and NJUNY, should be greater than the number of segments plus two. Other parameters that might need to be changed include:

NCSERM = maximum number of concentration time series for any variable

NDCSER = maximum length of any concentration time series

NQSIJM = maximum number of inflow and flow withdrawal locations

NQSERM = maximum number of flow time series

NDQSER = maximum length of longest flow time series

NQCTLM = maximum number of flow control locations

NQCTTM = maximum number of flow control tables

NDQCLT= maximum length of longest control table

NDQCLT2 = NDQCLT

NDASER = maximum length of the atmospheric time series

NDWSER = maximum length of the wind time series

NPSERM = maximum length of the water surface elevation time series

NSCM = maximum number of cohesive sediment classes

NSNM = maximum number of noncohesive sediment classes

NSTM = NSCM + NSTM

NTXM = maximum number of sorptive toxic contaminants

NSTVM = 5 + NSCM + NSTM + NTXM

The EFDC1D model source code and include files conform to standard FORTRAN 77. The limited number of non-standard extensions in the code are supported by compilers from major PC compiler vendors including Absoft, Compaq, and Lahey. The code has been verified as compiling clean under FORTRAN 90/95 using the Wintel and Macintosh versions of Absoft's Pro FORTRAN compilers after changing the file descriptor 'ACCESS=APPEND' to 'POSITION=APPEND' throughout the source. For compilers distinguishing between upper and lower case letters, a fold to upper case option (-N109 for the Absoft compilers) should be used. The multidimensional EFDC model source code is compatible with SUN Unix FORTRAN, and EFDC1D should also be compatible although it has not been tested.

Appendix B: Sample Applications

Two sample application file sets are currently distributed with EFDC1D. The first file set is for the Los Angles River, shown in Figure B1. The cell network is relatively simple, being composed of the main stem of the river and seven-second order tributaries. Due to large bed elevation differences between the main stem and the tributaries, where the tributaries join the main stem, all of the tributaries are connected to the main stem by flow control structures representing free over falls.

The second file set is for Brandywine Creek in the Christina River Basin of Delaware and Pennsylvania, shown in Figure B2. The main stem, segment 1, corresponds to the lower portion of the creek extending upstream to a dam just below the confluence of the East and West Branches. Segment 2, corresponding to the East Branch, connects to segment 1 by a control structure. The lower portion of the West branch, segment 3, joins the East Branch segment 2, by a free flowing connection. Segment 3 extends upstream along the West Branch to a dam just below the confluence with Buck Run. Segment 4 is along the West Branch to a dam just beyond the confluence with Buck Run. Buck Run, segment 5, joins segment 4 by a free flowing connection. Segments 6, 7 and 8 represent the remaining portion of West Branch and are separated by dams.
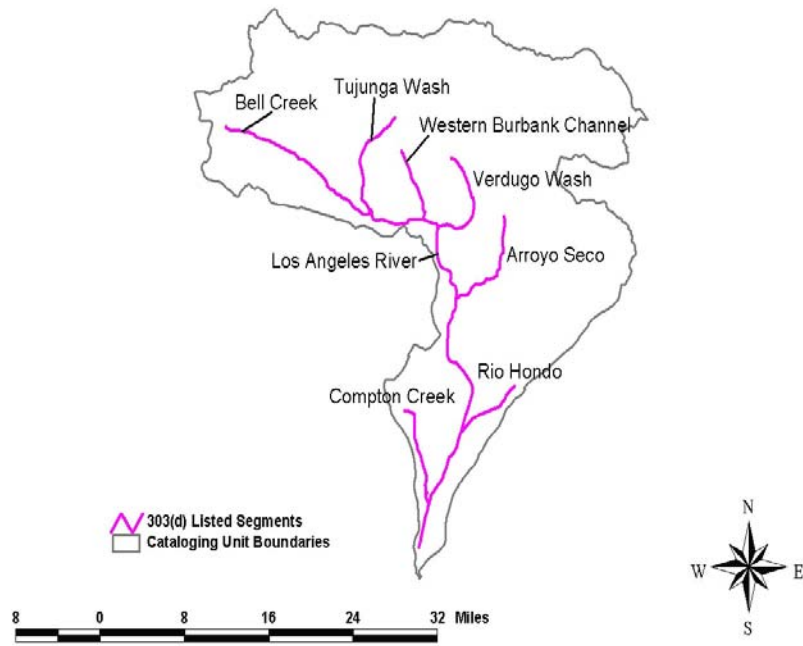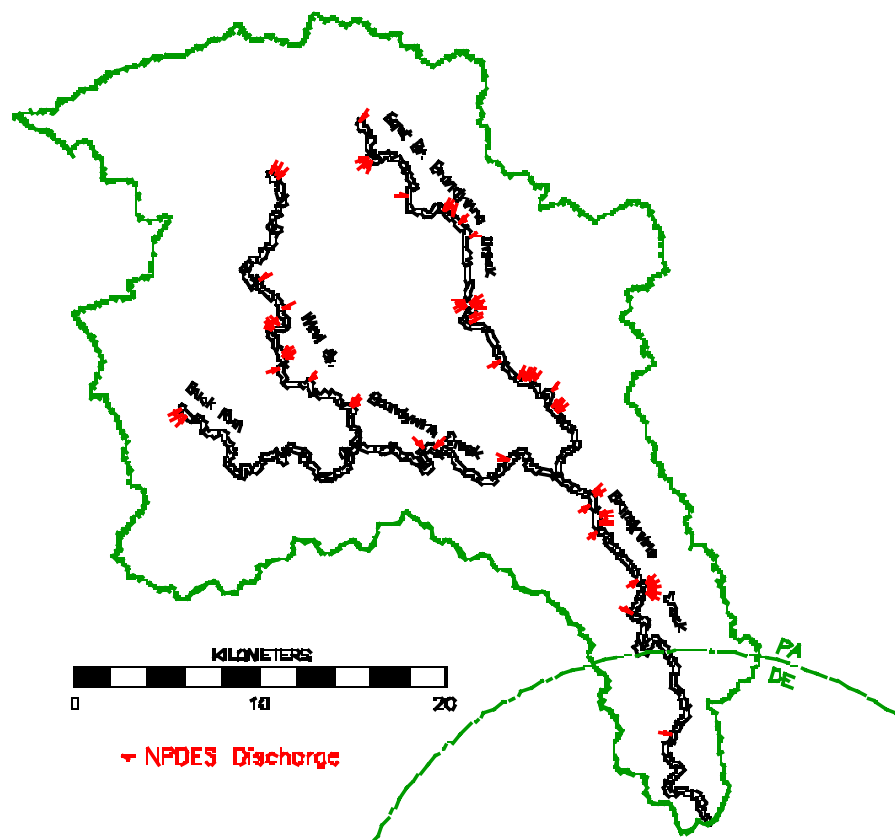
Figure B1. Los Angles River and Tributaries.

Figure B2. Brandywine Creek and Tributaries