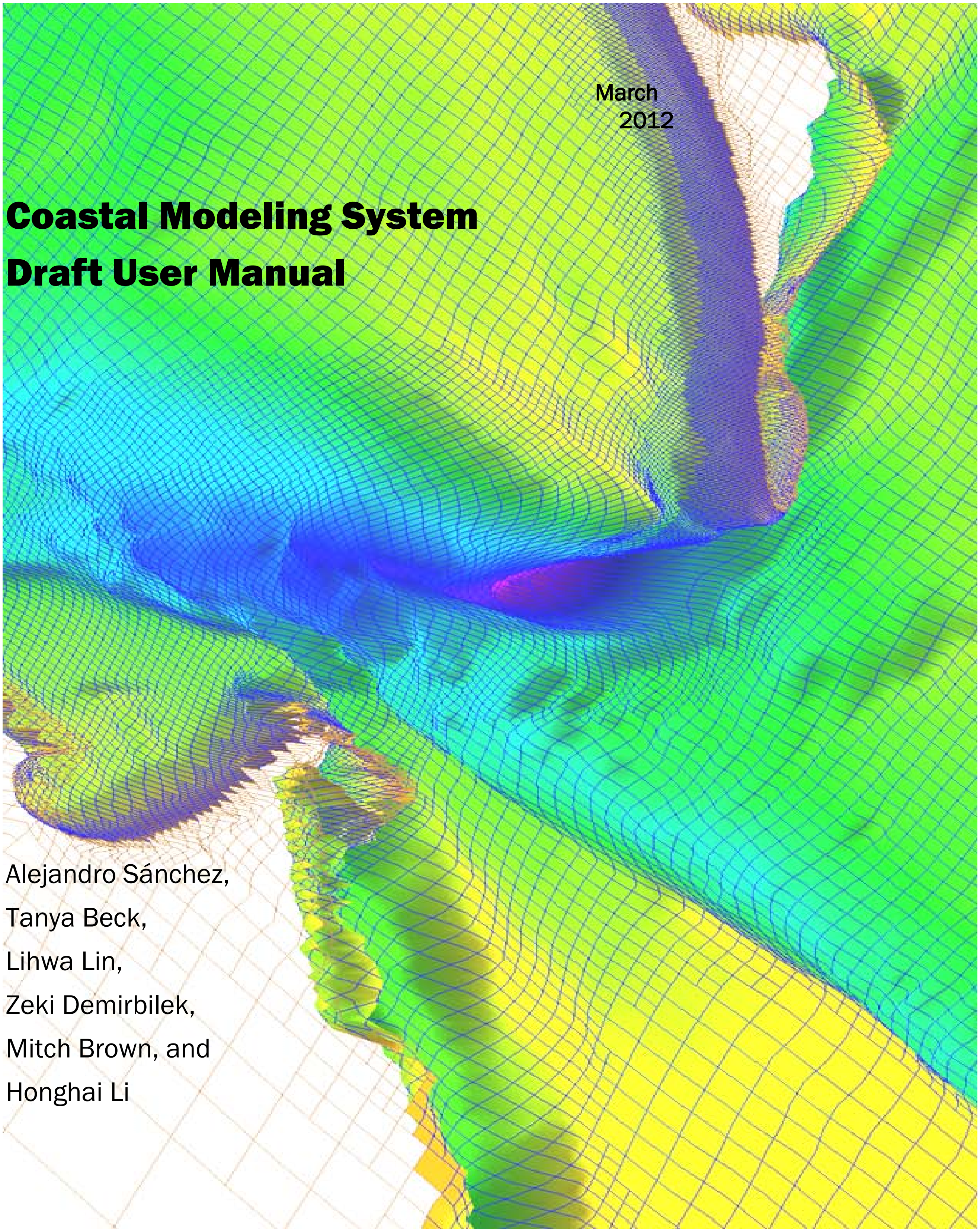

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Coastal Modeling System
Draft User Manual

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Unit Conversion Factors

Multiply	By	To Obtain
cubic yards	0.7645549	cubic meters
degrees (angle)	0.01745329	radians
feet	0.3048	meters
knots	0.5144444	meters per second
miles (nautical)	1,852	meters
miles (U.S. statute)	1,609.347	meters
miles per hour	0.44704	meters per second
pounds (force)	4.448222	newtons
pounds (force) per foot	14.59390	newtons per meter
pounds (force) per square foot	47.88026	pascals
square feet	0.09290304	square meters
square miles	2.589998 E+06	square meters
tons (force)	8,896.443	newtons
tons (force) per square foot	95.76052	kilopascals
yards	0.9144	meters

1 Introduction

The hills surrounding ancient kingdoms still remain, But waves beating on ruined walls silently roll away
- Liu Yuxi (772-842)

The Coastal Modeling System (CMS) is an integrated numerical modeling system for simulating nearshore waves, currents, water levels, sediment transport, and morphology change (Militello et al. 2004; Buttolph et al. 2006; Lin et al. 2008; Reed et al. 2011). The system was developed and continues to be supported by the Coastal Inlets Research Program (CIRP), a research and development program of the U.S. Army Corps of Engineers (USACE) that is funded by the Operation and Maintenance Navigation Business Line of the USACE. CMS is designed for coastal inlets and navigation applications including channel performance and sediment exchange between inlets and adjacent beaches. Modeling provides planners and engineers essential information for reducing costs of USACE Operation and Maintenance activities. CIRP is developing, testing, improving and transferring the CMS to Corps Districts and industry and assisting users in engineering studies. The overall framework of the CMS and its components are presented in Figure 1.

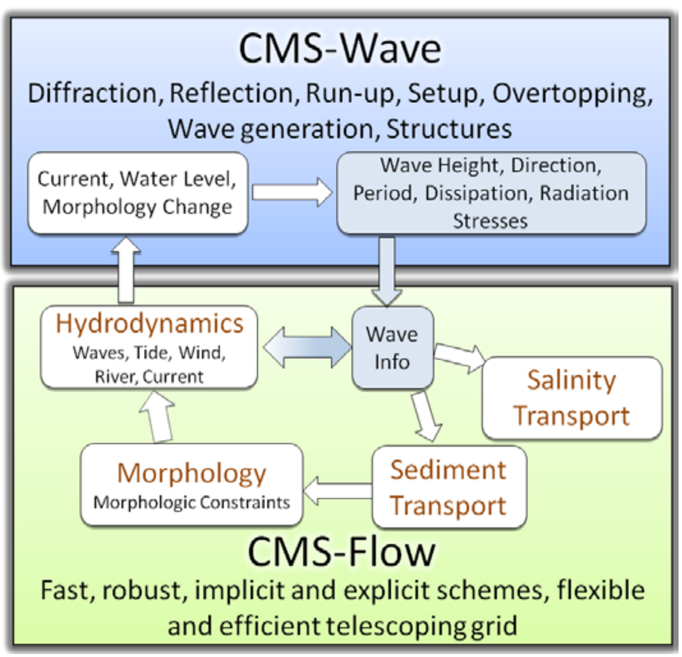


Figure 1. CMS framework and its components.

The CMS includes a flow model which calculates hydrodynamics and sediment transport (CMS-Flow) and a wave model (CMS-Wave), all coupled together within the Surface-water Modeling System (SMS). CMS-Flow is a two-dimensional (2-D) depth-averaged nearshore circulation model. CMS-

Flow calculates currents and water levels including physical processes such as advection, turbulent mixing, combined wave-current bottom friction; wind, wave, river, and tidal forcing forcing; Coriolis force; and the influence of coastal structures (Buttolph et al. 2006a; Wu et al. 2011). The implicit solver uses the SIMPLEC algorithm (Van Doormal and Raithby 1984) on a non-staggered grid to handle the coupling of water level and velocity. Primary variables u-, v-velocity, and water level are stored on the same set of grid points, and fluxes at cell faces are determined using a Rhie and Chow (1983) type momentum interpolation method (Wu et al. 2011). The explicit solver uses a staggered grid with velocities at the cell faces and the water levels and water depths at the cell centers (Buttolph et al. 2006a). CMS-Flow also calculates salinity and sediment transport and morphology change as discussed in a companion report.

CMS-Wave is a spectral wave transformation model and solves the wave-action balance equation using a forward marching Finite Difference Method (Mase et al.2005; Lin et al. 2008). CMS-Wave includes physical processes such as wave shoaling, refraction, diffraction, reflection, wave-current interaction, wave breaking, wind wave generation, white capping of waves, and the influence of coastal structures. The CMS takes advantage of the SMS interface (Zundel 2006) versions 8.2 through 11.1 for grid generation, model setup, plotting and post-processing of modeling results. The SMS also provides a link between the CMS and the Lagragian Particle Tracking Model (PTM) (MacDonald et al. 2006).

Typical applications of CMS-Flow include analyses of past and future navigation channel performance; wave, current, and wave-current interaction in channels and in the vicinity of navigation structures; and sediment management transport issues around coastal inlets and adjacent beaches. Some examples of CMS-Flow applications are: Batten and Kraus (2006), Buttolph et al. (2006b), Zarillo and Brehin (2007), Li et al. (2009), Li et al. (2011), Beck and Kraus (2010), Byrnes et al. (2010), Rosati et al. (2011), Reed and Lin (2011), and Wang and Beck (2011). Several verification and validation tests are presented in Lin et al (2011) for waves, in Sánchez et al. (2011) for hydrodynamics, and Sánchez et al. (2011a,b) for sediment transport and morphology change.

Both CMS-Flow and CMS-Wave rely on the SMS for grid generation, model setup and viewing results. Chapter 4 describes the user interface and contains step-by-step instructions on using the interface as well as preparing input files, and analyzing and viewing results. In addition, several Matlab and Fortran utilities are described in the Appendices.

The User Manual is organized as follows. Chapter 2 presents the theoretical background; Chapter 3 presents the numerical methods, Chapter 4 is the User Guide, Chapter 5 is the summary, and Chapter 6 contains the references.

2 Theoretical Background

"But I surmise instead that Nature first made things its own way and then endowed man with the ability to understand, even if hardly, some of its secrets."
- Galileo Galilei

Hydrodynamics

Continuity and Momentum

Assuming depth-uniform currents in the presence of oscillatory waves, the general depth- and phase-averaged continuity and momentum equations may be written as (Phillips 1977, Svendsen 2006)

$$\frac{\partial h}{\partial t} + \frac{\partial (hU_j)}{\partial x_j} = S^m \quad (1)$$

$$\frac{\partial (hU_i)}{\partial t} + \frac{\partial (hU_i U_j)}{\partial x_j} - \varepsilon_{ij} f_c h U_j = -gh\frac{\partial \eta}{\partial x_i} - \frac{h}{\rho}\frac{\partial p_{atm}}{\partial x_i} + \frac{\partial}{\partial x_j}\left(\nu_t h \frac{\partial U_i}{\partial x_j}\right) + \frac{\tau_i^w + \tau_i^s - \tau_i^b}{\rho} \quad (2)$$

where

t = Time [s]

f_c = Coriolis parameter [1/s]

h = time-averaged total water depth $h = \zeta + \eta$ [m]

η = mean water surface elevation with respect to reference datum [m]

ζ = Water depth (positive downwards) with respect to vertical reference datum [m]

S^m = source term due to precipitation, evaporation and structures (e.g. culverts) [m/s]

U_i = depth-averaged Lagrangian current velocity defined as $U_i = U_i^E + U_i^S$ [m/s]

U_i^E = time- and depth-averaged current velocity vector (i.e. Eulerian velocity) [m/s]

U_i^S = depth-averaged Stokes velocity [m/s]

g = gravitational constant (9.806 m/s^2)

p_{atm} = atmospheric pressure [Pa]

ρ = water density (~1025 kg/m^3)

ν_t = turbulent eddy viscosity [m^2/s]

τ_i^s = wind surface stress vector [Pa]

τ_i^w = wave stress vector [Pa]

τ_i^b = combined wave-current mean bed shear stress vector [Pa]

Figure 2 shows the vertical conventions used for mean water surface elevation and bed elevations. The arrows indicate the positive direction for each variable. Note that the total water depth is always positive.

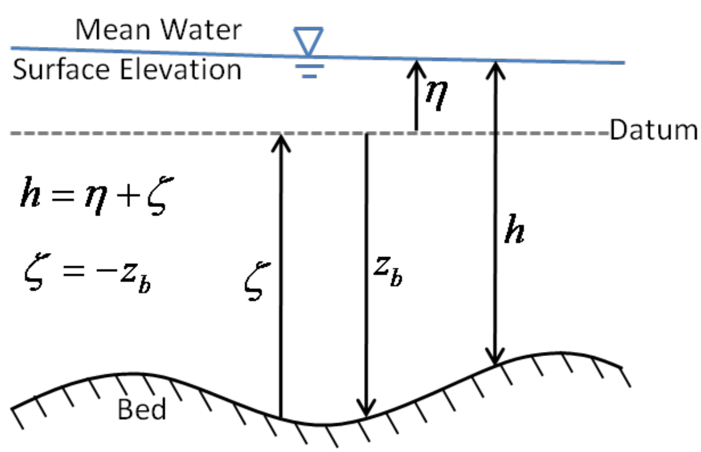


Figure 2. Vertical conventions used for mean water surface elevation and bed elevations.

Here the Boussinesq approximation has been made for approximating the Reynolds stresses.

Stokes Velocity

In the presence of waves, the oscillatory wave motion produces a net mass transport known as Stokes drift. The depth-averaged Stokes velocity is approximated by (Phillips 1977)

$$U_i^S = \frac{E_w w_i}{\rho h c} \tag{3}$$

where

c = wave speed [m/s]

E_w = wave energy $=1/16 \rho g H_s^2$ [N/m]

H_s = significant wave height [m]

w_i = wave unit vector $=(\cos\theta, \sin\theta)$ [-]

Wave-averaged wave-current bottom friction

The mean (short-wave averaged) bed shear stress τ_i^b is calculated as

$$\tau_i^b = m_b \lambda_{wc} \rho c_b U_E U_i^E \tag{4}$$

where

c_b = bed friction coefficient [-]

m_b = bed slope friction coefficient [-]

λ_{wc} = nonlinear bottom friction enhancement factor ($\lambda_{wc} \geq 1$) [-]

U_E = Eulerian current magnitude $= \sqrt{U_i^E U_i^E}$ [m/s]

The bottom roughness is specified with either a Manning's roughness coefficient, roughness height (Nikuradse bed roughness), or bed friction coefficient. It is important to note that the roughness value is held constant throughout the simulation and is not changed according to bed composition and bed forms. It is also independent of the bed roughness calculation used for various sediment transport formula, since different formulas use different methods for computing the bed shear stresses.

The bed friction coefficient, c_b , is related to the Manning's roughness coefficient n by

$$c_b = gn^2 h^{-1/3} \tag{5}$$

Similarly, the bed friction is related to the roughness length z_0 by

$$c_b = \left(\frac{\kappa}{\ln(z_0 / h) + 1} \right)^2 \tag{6}$$

where $\kappa = 0.4$. The roughness length is related to the Nikuradse roughness (roughness height in SMS) by $z_0 = k_s / 30$.

The nonlinear bottom friction enhancement factor is calculated using one of the following formulations:

1. Quadratic formula (QUAD)
2. Soulsby (1995) two coefficient data fit (DATA2)
3. Soulsby (1995) thirteen coefficient data fit (DATA13)
4. Fredsoe (1984) wave-current boundary layer model (F84)
5. Huynh-Thanh and Temperville (1991) wave-current boundary layer model (HT91)

In the case of the quadratic formula,

$$\lambda_{wc} = \frac{\sqrt{U_E^2 + c_w u_w^2}}{U_E^2} \tag{7}$$

where the DATA2, DATA13, F84, and HT91 formulations are calculated using general parameterization of Soulsby (1995),

$$\lambda_{wc} = 1 + bX^P \left(1 - X\right)^q \tag{8}$$

where $X = \tau_c / (\tau_c + \tau_w)$, and b, P and q are coefficients that depend on the formulation selected. τ_c and τ_w are the current- and wave-related bed shear stress magnitudes.

The bed slope friction coefficient is calculated as

$$m_b = \sqrt{1 + \left(\frac{\partial z_b}{\partial x}\right)^2 + \left(\frac{\partial z_b}{\partial y}\right)^2} \tag{9}$$

where z_b is the bed elevation.

Wave Stresses

The wave stresses are calculated as (Phillips 1977, Svendsen 2006)

$$\tau_i^w = -\frac{\partial}{\partial x_j}\left(S_{ij}^w + S_{ij}^r - \rho h U_i^S U_j^S\right) \tag{10}$$

where

S_{ij}^w = wave radiation stress tensor [N/m]

S_{ij}^r = surface roller stresses [N/m]

The last term is of fourth order with respect to the wave steepness and is therefore usually small but is still included here for completeness. S_{ij} is calculated using linear wave theory

$$S_{ij}^w = \iint E_w(f,\theta)\left[n_g w_i w_j + \delta_{ij}\left(n_g - \frac{1}{2}\right)\right] df\, d\theta \tag{11}$$

where

f = the wave frequency, [1/s]

θ = the wave direction, and

$$n_g = \frac{c_g}{c} = \frac{1}{2}\left(1 + \frac{2kh}{\sinh 2kh}\right) \quad (12)$$

The roller stresses are calculated as

$$S_{ij}^r = 2E_r w_i w_j \quad (13)$$

where E_r is the surface roller energy.

Wind Surface Stress

The wind surface stress is calculated as

$$\tau_i^s = \rho_a c_D |W| W_i \quad (14)$$

where

ρ_a = air density at sea level [kg/m³]

c_D = wind drag coefficient [-]

W_i = 10-m wind speed [m/s]

W = 10-m wind velocity magnitude $= \sqrt{W_i W_i}$ [m/s]

The wind speed is calculated using either an Eulerian or Lagrangian reference frame as

$$W_i = W_i^E - \gamma_w U_i \quad (15)$$

where W_i^E is the 10-m atmospheric wind speed relative to the solid earth (Eulerian wind speed)in [m/s], and γ_w is equal to 0 for the Eulerian reference frame or 1 for the Lagrangian reference frame. Using the Lagrangian reference frame or relative wind speed is more accurate and realistic for field applications (Bye 1985; Pacanowski 1987; Dawe and Thompson 2006), but the option to use the Eulerian wind speed is provided for idealized cases. The drag coefficient is calculated using the formula of Hsu (1988) and modified for high wind speeds based on field data by Powell et al. (2003) (see Figure 3).

$$c_D = \begin{cases} \left(\dfrac{\kappa}{14.56 - 2\ln W} \right)^2 & \text{for } W \le 30\,\text{m/s} \\ 10^{-3}\max(3.86 - 0.04W, 1.5) & \text{for } W > 30\,\text{m/s} \end{cases} \tag{16}$$

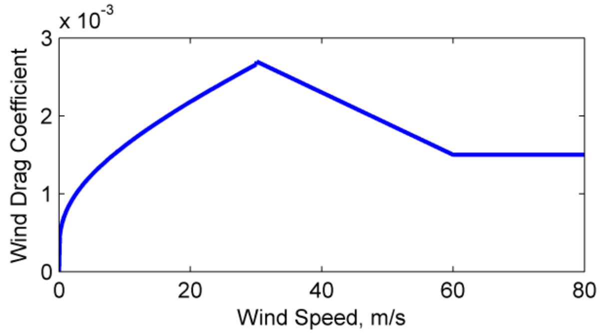


Figure 3. Modified Hsu (1988) wind drag coefficient.

Powell et al. (2003) speculate that that the reason for the decrease in drag coefficient is due to increasing foam coverage leading to the formation of a “slip” surface at the air-sea interface.

Wind measurements taken at heights other than 10 m, are converted using the 1/7 rule (SPM 1984)

$$W_i = W_i^z \left(\frac{10}{z} \right)^{1/7} \tag{17}$$

where z is the elevation above the sea surface of the wind measurement.

Eddy Viscosity

The term eddy viscosity comes from the fact that small-scale vortices or eddies on the order of the grid cell size are not resolved and only the large scale flow is simulated. The eddy viscosity is intended to simulate the dissipation of energy at smaller scales than the model can simulate. In nearshore environments, large mixing or turbulence occurs due to waves, wind, bottom shear, and strong horizontal gradients; and therefore the eddy viscosity is an important aspect which has a large influence on the calculated flow field and sediment transport. In CMS-Flow, total eddy viscosity ν_t is calculated as the sum of a base value ν_0, the current-related eddy viscosity ν_c and the wave-related eddy viscosity ν_w ,

$$\nu_t = \nu_0 + \nu_c + \nu_w \tag{18}$$

The base value for the eddy viscosity is approximately equal to the kinematic eddy viscosity can be changed using the advanced cards.

Current-Related Eddy Viscosity Component

There are four options for the current-related eddy viscosity: Falconer, Parabolic, Subgrid, and Mixing-Length. The default turbulence model is the subgrid model, but may be changed in the advanced cards section of the cmcards file.

Falconer Equation

The Falconer (1980) equation is the method is the default method used in the previous version of CMS, known as M2D. The first is the Falconer (1980) equation given by

$$\nu_c = 0.575 c_b U h \tag{19}$$

where c_b is the bottom friction coefficient, U is the depth-averaged current velocity magnitude, and h is the total water depth.

Parabolic Model

The second option is the parabolic model given by

$$\nu_c = c_1 u_* h \tag{20}$$

where c_1 is approximately equal to $\kappa/6$.

Subgrid Model

The third option for calculating ν_c is the subgrid turbulence model given by

$$\nu_c = c_1 u_* h + c_2 \Delta \left| S \right| \tag{21}$$

where c_1 and c_2 are empirical coefficients related the turbulence produced by the bed and horizontal velocity gradients, and Δ is the average grid area. The parameter c_1 is approximately equal to 0.0667 (default) but may vary from 0.01-0.2. The variable c_2 is equal to approximately the Smagorinsky coefficient and may vary from 0.1 to 0.3 (default is 0.2). $|S|$ is equal to

$$|S| = \sqrt{2S_{ij}S_{ij}} \text{ , with } S_{ij} = \frac{1}{2}\left(\frac{\partial U_i}{\partial x_j} + \frac{\partial U_j}{\partial x_i} \right) \tag{22}$$

The subgrid turbulence model parameters may be changed in the advanced cards.

Mixing Length Model

The Mixing Length Model implemented in CMS includes a component due to the vertical shear and is given by

$$\nu_c = \sqrt{\left(c_1 u_{*c} h\right)^2 + \left(l_h^2 |S|\right)^2} \tag{23}$$

where the mixing length l_h is determined by $l_h = \kappa \min(c_2 h, y)$, with y being the distance to the nearest wall and c_2 is an empirical coefficient between 0.3-1.2. The above equation takes into account the effects of bed shear and horizontal velocity gradients respectively through the first and second terms on its right-hand side. It has been found that the modified mixing length model is better than the depth-averaged parabolic eddy viscosity model that accounts for only the bed shear effect.

Wave-Related Eddy Viscosity

The wave component of the eddy viscosity is separated into two components

$$\nu_w = c_3 u_w H_s + c_4 h \left(\frac{D_{br}}{\rho} \right)^{1/3} \tag{24}$$

where c3 and c4 are empirical coefficients, H_s is the significant wave height and u_w is the peak bottom orbital velocity based on the significant wave height. The first term on the R.H.S. of Equation (24) represents the component due to bottom friction and the second term represents the component due to wave breaking. The coefficient c3 is approximately equal to 0.1 and may vary from 0.05 to 0.2. The coefficient c4 is approximately equal to 0.08 and may vary from 0.04 to 0.15.

Boundary Conditions

Rigid Wall Boundary Condition

A wall function is used to simulate the extra flow drag produced by the presence of banks or shores. The resulting wall shear stress is modeled as

$$\tau_{wall} = -\lambda_w U_{\parallel} \tag{25}$$

where $\lambda_w = \rho u_*^w \kappa / \ln(E y_p^+)$ with $y_p^+ = u_*^w y_p / \nu$. Here E is a wall roughness parameter, y_P^+ is the distance from the wall to point p and u_*^w is the wall shear stress defined as $u_*^w = \sqrt{\tau_{wall} / \rho}$. The wall roughness is calculated using the formula of Cebeci and Bradshaw (1977),

$$E = \exp\left(\kappa\left[B_0 - \Delta B\right]\right) \tag{26}$$

where B_0 is a constant equal to 5.2 and ΔB is equal to

$$\Delta B = \begin{cases} 0 & k_s^+ < 2.25 \\ \left(B_0 - 8.5 + \frac{1}{\kappa}\ln k_s^+\right)\sin\left(0.4258\left[\ln k_s^+ - 0.811\right]\right) & 2.25 \le k_s^+ < 90 \\ B_0 - 8.5 + \frac{1}{\kappa}\ln k_s^+ & k_s^+ \ge 90 \end{cases} \tag{27}$$

where k_s^+ is the wall Reynolds number given by $k_s^+ = u_*^w k_s / \nu$.

Flux Boundary Condition

The flux boundary is typically applied to the upstream end of a river or stream. In CMS, a conveyance approach is used to distribute the total flux across the boundary. In this approach, the flow discharge, q_B at each boundary cell B is calculated across a boundary according to

$$q_B = \frac{Q_b}{\sum (h_B^{1+r} / n_B)\Delta l} \frac{h_B^{1+r}}{n_B} \tag{28}$$

where Q_b is total flow discharge, n is the Manning's coefficient, r is an empirical constant equal to approximately 2/3 and Δl is the cell width in the transverse direction.

Water Level Boundary Condition

Water level time series, both constant and spatially variable, are applied at ghost cells. This treatment is common practice in many finite volume models. It is not strictly clamped and allows for some relaxation of the boundary which improves stability and convergence. When applying a Water Level BC to the nearshore, the wave-induced setup is not included and can lead to local flow reversals and boundary problems. This problem is avoided by adjusting the local water to account for the cross-shore wind and wave setup similar that described in Reed and Militello (2005).

Tidal/Harmonic Boundary Condition

Tidal water level predictions are based on the official United States National Oceanographic and Atmospheric Administration (http://tidesonline.nos.noaa.gov) and National Ocean Service (http://co-ops.nos.noaa.gov) prediction formula

$$\eta(t) = \sum f_i A_i \cos\left(\omega_i t + V_i^0 + u_i - \kappa_i\right) \tag{29}$$

where A_i is the constituent *mean* amplitude, f_i is a node factor which is time varying correction to the mean amplitude, $V_i^0 + u_i$ is the time varying constituent *equilibrium* phase, and κ_i is the constituent phase lag or epoch. The speed of the constituent ω_i is given in degrees per mean solar hour and t is a serial time in hours from midnight starting the year of predictions. The equilibrium phase has a uniform component V_i^0 and an relatively smaller periodic component. The zero-superscript of V_i^0 indicates that it refers to the constituent phase at zero time. The table (Table 1) below shows a list of the tidal constituents currently supported in CMS.

Table 1. Tidal Constituents names and speeds in solar hours implemented in CMS.

Constituent	Speed	Constituent	Speed	Constituent	Speed	Constituent	Speed
SA*	0.041067	SSA*	0.082137	MM*	0.54438	MSF*	1.0159
MF*	1.098	2Q1*	12.8543	Q1*	13.3987	RHO1*	13.4715
O1*	13.943	M1*	14.4967	P1*	14.9589	S1*	15.0
K1*	15.0411	J1*	15.5854	OO1*	16.1391	2N2*	27.8954
MU2*	27.9682	N2*	28.4397	NU2*	28.5126	M2	28.9841
LDA2*	29.4556	L2*	29.5285	T2*	29.9589	S2	30
R2*	30.0411	K2	30.0821	2SM2*	31.0159	2MK3*	42.9271
M3*	43.4762	MK3*	44.0252	MN4*	57.4238	M4	57.9682
MS4*	58.9841	S4*	60.0	M6	86.9523	S6*	90.0
M8*	115.9364						

* Only available through advanced cards for CMS >v4.0

If a harmonic boundary condition is applied, then the node factors and equilibrium arguments are set to zero.

Similary to the water level boundary condition, the local water level at the boundary is adjusted to account for the wind and wave setup in order to avoid local flow reversals or instabilities (Reed and Militello 2005).

Cross-shore Boundary Condition

In the implicit flow solver a similar wave-adjusted BC is applied by solving the 1-D cross-shore momentum equation including wave and wind forcing (Wu et al. 2011a, 2011b). Along a cross-shore boundary, it is assumed that a well-developed longshore current exists. Thus, the alongshore (x-direction) momentum equation can be reduced to

$$\frac{\partial}{\partial y}\left(\nu_t h \frac{\partial U}{\partial y}\right) = \frac{1}{\rho}\left(\tau_{Sx} + \tau_{wx} - \tau_{bx}\right) \qquad (30)$$

where τ_{Sx}, τ_{wx}, and τ_{bx} are the wave, wind, and bottom stresses the long-shore direction respectively. The equation above is solved iteratively for the longshore current velocity. The cross-shore (y) component of the velocity may be copied from internal nodes.

The water level due to waves and winds at the cross-shore boundary can be determined by assuming a zero alongshore gradient of water level, the y (cross-shore) momentum equation reduces to

$$\rho g h \frac{\partial \eta}{\partial y} = \tau_{Sy} + \tau_{wy} \tag{31}$$

where τ_{Sy} and τ_{wy} are the wave and wind stresses in the cross-shore direction. Note that the bed stress equal to zero because the depth-averaged cross-shore current velocity is assumed to be zero.

Salinity Transport

Transport Equation

The CMS calculates the salinity field based on the following 2D salinity conservation equation

$$\frac{\partial\left(hC_{sal}\right)}{\partial t}+\frac{\partial\left(hU_jC_{sal}\right)}{\partial x_j}=\frac{\partial}{\partial x_j}\left[\nu_{sal}h\frac{\partial C_{sal}}{\partial x_j}\right]+S_{sal} \qquad (32)$$

where C_{sal} is depth-averaged salinity; h is total water depth, U is the depth-averaged current velocity, ν_{sal} is the horizontal mixing coefficient, and S_{sal} is source term due to precipitation, evaporation and structures (e.g. culverts). Equation (32) represents the horizontal fluxes of salt in water bodies and is balanced by exchanges of salt via diffusive fluxes. Major processes contributing to the salinity are freshwater inflows from rivers, vertical fluxes of freshwater by precipitation and evaporation at the water surface, and groundwater fluxes, which can be specified as the surface and bottom boundary conditions in the equation.

Boundary Conditions

The boundary condition (BC) for the salinity transport equation is dependent on the flow direction. At cell faces between wet and dry cells, a zero-flux BC is applied. The cell face velocity U_f is zero between wet and dry cells which eliminates the advection transport. In addition, the salinity horizontal mixing coefficient at the cell face $\overline{\nu}_{sal,f}$ is set to zero which eliminates the diffusive flux. If the flow is directed inward of the modeling domain, then a user specified salinity concentration is specified (Direchlet BC) series is specified. If the flow is directed outwards, then a zero-gradient BC is applied (Neumann BC).

Sediment Transport

Equilibrium Total Load Transport Model

The equilibrium total load transport model, also referred to as the Exner model, assumes that both the bed and suspended loads are always in equilibrium providing a simple sediment mass balance equation

$$\frac{1-p'_m}{f_{morph}}\frac{\partial z_b}{\partial t}+\frac{\partial q_{t*,j}}{\partial x_j}=\frac{\partial}{\partial x_j}\left(D_S\left|q_{t*,j}\right|\frac{\partial z_b}{\partial x_j}\right) \tag{33}$$

where

t = time [s]

x_j =Cartesian coordinate in the j^{th} direction [m]

q_{t*} = Equilibrium total sediment transport rate [m^2/s]

z_b = Bed elevation with respect to the vertical datum [m]

p'_m = bed porosity [-]

D_s = the bed-slope coefficient [-]

f_{morph} = morphologic acceleration factor [-]

The first term represents the bed change, the second term represents the spatial gradients in the sediment transport, and the last term represents the effect of the bed slope and to improve the model stability. Because of its simplicity, the Exner model is one of the most common sediment transport models. However, because of the assumptions of equilibrium transport the model can sometimes result in numerical instabilities. In CMS, the Exner model is only available as a single-size sediment transport model with an explicit time marching scheme.

Equilibrium Bed Load and Nonequilibrium Suspended Sediment Transport

Suspended Sediment Transport Equation

An improvement on the equilibrium total load transport model is to assume that the suspended load is not in equilibrium. This requires the solution of a transport equation for the suspended sediment concentration, while the bed load is comobined with the bed change equation. The suspended sediment transport equation is given by

$$\frac{\partial(hC)}{\partial t}+\frac{\partial(U_j hC)}{\partial x_j}=\frac{\partial}{\partial x_j}\left[\nu_s h\frac{\partial C}{\partial x_j}\right]+E_b-D_b \tag{34}$$

where

t = time [s]

h =total water depth [m]

x_j =Cartesian coordinate in the j^{th} direction [m]

U_j = depth-averaged current velocity [m/s]

C = depth-averaged suspended sediment concentration [m^3/m^3]

ν_s = horizontal sediment mixing coefficient described in the Horizontal Sediment Mixing Coefficient section.

Erosion Rate

The erosion flux is determined as

$$E_b=\omega_s c_{a*} \tag{35}$$

where ω_s is the sediment fall velocity, and c_{a*} is the equilibrium sediment concentration at the reference height a. In CMS, there are two options for estimating c_{a*}. These are the van Rijn (1984b) and Lund-CIRP (Camenen and Larson 2007) described in the Equilibrium Transport and Nearbed Concentration Formula section.

Deposition Rate

The deposition rate is approximated as

$$D_b = \omega_s c_a \tag{36}$$

where ω_s is the sediment fall velocity, and c_a is the actual sediment concentration at the reference height a. The sediment concentration c_a is a function of the vertical mixing profile. The CMS has two options for estimating c_a. The first assumes an exponential profile, and second integrates the steady-state vertical transport equation for suspended sediment using an empirical distribution for the mixing coefficient. For additional details the reader is referred to Buttolph et al. (2006).

Bed change Equation

The bed continuity equation is given by

$$\frac{1-p'_m}{f_{morph}}\frac{\partial z_b}{\partial t}+\frac{\partial q_{b*,j}}{\partial x_j}=\frac{\partial}{\partial x_j}\left(D_S\left|q_{t*}\right|\frac{\partial z_b}{\partial x_j}\right)-D_b-E_b \tag{37}$$

where

z_b = Bed elevation with respect to the vertical datum [m]

p'_m = bed porosity [-]

q_{b*} = Equilibrium bed-load sediment transport rate [m^2/s]

D_s = the bed-slope coefficient [-]

f_{morph} = morphologic acceleration factor [-]

It is noted that the the above model is only available as a single size sediment transport model with an explicit time marching scheme.

Nonequilibrium Total-Load Transport Model

Total-load Transport Equation

The single-sized sediment transport model described in Sánchez and Wu (2011a,b) is extended to multiple-sized sediments. In this model, the sediment transport is separated into current- and wave-related transports. The transport due to currents includes the stirring effect of waves; and the wave-related transport includes the transport due to asymmetric oscillatory wave motion and also steady contributions by Stokes drift, surface roller, and undertow. The current-related bed and suspended transports are combined into a single total-load transport equation, thus reducing the computational costs and simplifying the bed change computation. The 2DH transport equation for the current-related total load is

$$\frac{\partial}{\partial t}\left(\frac{hC_{tk}}{\beta_{tk}}\right)+\frac{\partial(U_j hC_{tk})}{\partial x_j}=\frac{\partial}{\partial x_j}\left[\nu_s h\frac{\partial(r_{sk}C_{tk})}{\partial x_j}\right]+\alpha_t\omega_{sk}\left(C_{t*k}-C_{tk}\right) \quad (38)$$

for $j=1,2;\ k=1,2,...,N$, where N is the number of sediment size classes

t = time [s]

h =total water depth [m]

x_j =Cartesian coordinate in the j^{th} direction [m]

U_j = depth-averaged current velocity [m/s]

C_{tk} = depth-averaged total-load sediment concentration for size class k defined as $C_{tk}=q_{tk}/(Uh)$ in which q_{tk} is the total-load transport [m^3/m^3]

C_{tk*} = depth-averaged total-load sediment concentration for size class k and described in the Equilibrium Concentration and Transport Rates section [m^3/m^3]

β_{tk} = the total-load correction factor described in the Total-Load Correction Factor section [-]

r_{sk} = fraction of suspended load in total load for size class *k* (equal to 1 for fine-grained sediments) and is described in Fraction of Suspended Sediments section.

ν_s = horizontal sediment mixing coefficient described in the Horizontal Sediment Mixing Coefficient section.

α_t = total-load adaptation coefficient described in the Adaptation Coefficient section.

ω_{sk} = sediment fall velocity.

The above equation may be applied to single-sized sediment transport, by using a single sediment size class. The bed composition however is allowed to vary even for single-size sediment transport. For

Fraction of Suspended Sediments

In order to solve the system of equations for sediment transport implicitly the fraction of suspended sediments must be determined explicitly. This is done by assuming

$$r_{sk} = \frac{q_{sk}}{q_{tk}} \simeq \frac{q_{sk*}}{q_{tk*}} \qquad (39)$$

where q_{sk} and q_{tk} is the actual fractional suspended- and total-load transport rates and q_{sk*} and q_{tk*} are the equilibrium fractional suspended- and total-load transport rates.

Adaptation Coefficient

The total load adaptation coefficient α_t is an important parameter in the setting up the sediment transport model. There are many variations of this parameter in literature. CMS uses an adaptation coefficient α_t which is related to the total load adaptation length T_t and time by

$$L_t = \frac{Uh}{\alpha_t \omega_s} = UT_t \qquad (40)$$

where ω_s is the sediment fall velocity, U is the depth-averaged current velocity, and h is the total water depth. The adaptation length (time) is a characteristic distance (length) for sediment to adjust from non-equilibrium to equilibrium transport. Because the total load is a combination of the bed and suspended loads, its adaptation length may be calculated as $L_t = r_s L_s + (1-r_s)L_b$ or $L_t = \max(L_s, L_b)$, where L_s and L_b are the suspended- and bed-load adaptation lengths. L_s is defined as

$$L_s = \frac{Uh}{\alpha\omega_s} = UT_s \tag{41}$$

in which α and T_s are the adaptation coefficient lengths for suspended load. There are several expressions in the literature for calculating α, either empirical or based on analytical solutions to the pure vertical convection-diffusion equation of suspended sediment. One example of an empirical formula is that proposed by Lin (1984)

$$\alpha = 3.25 + 0.55\ln\left(\frac{\omega_s}{\kappa u_*}\right) \tag{42}$$

where u_* is the bed shear stress, and κ is the von Karman constant. Armanini and di Silvio (1986) proposed a analytical equation

$$\frac{1}{\alpha} = \frac{\delta}{h} + \left(1 - \frac{\delta}{h}\right)\exp\left[-1.5\left(\frac{\delta}{h}\right)^{-1/6}\frac{\omega_s}{u_*}\right] \tag{43}$$

where δ is the thickness of the bottom layer defined by $\delta = 33z_0$ and z_0 is the zero-velocity distance from the bed. Gallapatti (1983) proposed the following equation to determine the suspended load adaptation time

$$T_s = \frac{h}{u_*}\exp\left[\begin{array}{l}(1.57 - 20.12u_r)\omega_*^3 + \left(326.832u_r^{2.2047} - 0.2\right)\omega_*^2 \\ + \left(0.1385\ln u_r - 6.4061\right)\omega_* + \left(0.5467u_r - 2.1963\right)\end{array}\right] \tag{44}$$

where u_{*c} is the current related bottom shear velocity, $u_r = u_* / U$, and $\omega_* = \omega_s / u_*$.

The bed-load adaptation length L_b is generally related to the dimension of bed forms such as sand dunes. Large bed forms are generally proportional to the water depth and therefore the bed load adaptation length can be estimated as $L_b = a_b h$ in which a_b is an empirical coefficient on the order of 5-10. Fang (2003) found that an L_b of approximately two or three times the grid resolutions works well for field applications. However, although there is some guidance on ways to estimate L_b, its determination is still empirical and in the developmental stage. For a detailed discussion of the adaptation length see Wu (2007). In general, it is recommended that the adaptation length be calibrated with field data in order to have the best and most reliable results.

Total-Load Correction Factor

The correction factor β_{tk} accounts for the vertical distribution of the suspended, and velocity profiles as well as the fact that bed load travels a slower velocity than the depth-averaged current (see Figure 4). By definition β_{tk} is the ratio of the total-load depth-averaged and flow velocities.

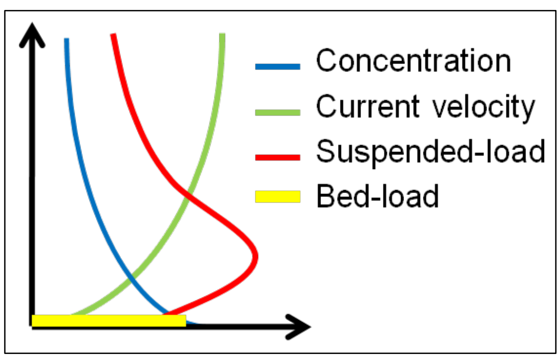


Figure 4. Schematic of sediment and current vertical profiles.

In a combined bed load and suspended load model, the correction factor is given by

$$\beta_{tk} = \frac{1}{r_{sk} / \beta_{sk} + (1 - r_{sk}) U / u_{bk}} \tag{45}$$

where u_{bk} is the bed load velocity and β_{tk} is the suspended load correction factor and is defined as the ratio of the depth-averaged sediment and flow velocities. Because most of the sediment is transported near the bed, both the total and suspended load correction factors are usually less than 1 and typically in the range of 0.3 and 0.7, respectively. By assuming logarithmic current velocity and exponential suspended sediment concentration profiles, an explicit expression for the suspended load correction factor β_{sk} may be obtained as

$$\beta_s = \frac{\int_a^h ucdz}{U\int_a^h cdz} = \frac{\mathrm{E}_1(\phi A) - \mathrm{E}_1(\phi) + \ln(A/Z)\,\mathrm{e}^{-\phi A} - \ln(1/Z)\,\mathrm{e}^{-\phi}}{\mathrm{e}^{-\phi A}\left[\ln(1/Z) - 1\right]\left[1 - \mathrm{e}^{-\phi(1-A)}\right]} \tag{46}$$

where $\phi = \omega_s h/\varepsilon$, $A = a/h$, $Z = z_0/h$, ε is the vertical mixing coefficient, a is a reference height for the suspended load, and E_1 is the exponential integral. The equation can be further simplified by assuming that the reference height is proportional to the roughness height (e.g. $a = 30z_0$), so that $\beta_s(Z,\phi)$. Figure 5 shows a comparison of the suspended load correction factor based on the logarithmic velocity, and Exponential and Rouse suspended sediment profiles.

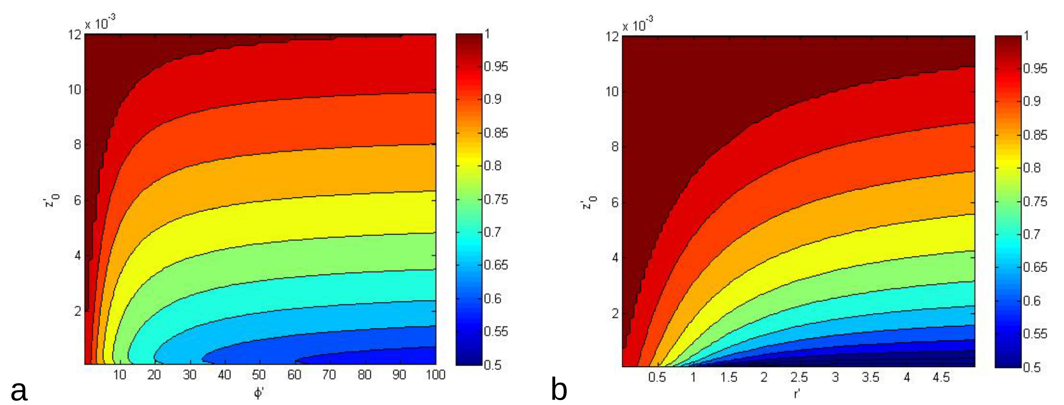


Figure 5. Suspend load correction factors based on the logarithmic velocity profile and exponential (a) and Rouse (b) suspended sediment profile.

The bed load velocity u_b is calculated using the van Rijn (1984a) formula with re-calibrated coefficients from Wu *et al.* (2006)

$$u_b = 1.64\left[\left(\frac{U_*^{'}}{U_{*cr}}\right)^2 - 1\right]^{0.5}\sqrt{(s-1)gd_{50}} \tag{47}$$

where s is the specific gravity, g is the gravitational constant, d_{50} is a characteristic median grain size diameter, $U_*^{'}$ is the effective bed shear velocity related to grain roughness and U_{*cr} is the critical bed shear velocity for sediment motion as given by the shields diagram.

Bed change Equation

The fractional bed change is calculated as

$$\frac{1-p_m'}{f_{morph}}\left(\frac{\partial z_b}{\partial t}\right)_k = \alpha_t \omega_{sk}\left(C_{tk} - C_{tk*}\right) + \frac{\partial}{\partial x_j}\left(D_s \left|q_{bk}\right| \frac{\partial z_b}{\partial x_j}\right) \tag{48}$$

where

z_b = the bed elevation with respect to the vertical datum [m]

p_m' = the bed porosity [-]

D_s = the bed-slope coefficient [-]

$q_{bk} = hUC_{tk}(1-r_{sk})$ is the bed load [m^2/s]

f_{morph} = morphologic acceleration factor [-]

The total bed change is calculated as the sum of Equation (41) for all size classes

$$\frac{\partial z_b}{\partial t} = \sum_k \left(\frac{\partial z_b}{\partial t}\right)_k \tag{49}$$

The purpose of the morphologic acceleration factor f_{morph} is to speed-up the bed change so that the simulation time t_{sim} represents approximately the change that would occur in $t_{morph} = f_{morph} t_{sim}$. The factor should be used with caution and only for idealized cases or time periods which are periodic (mainly tidal). If time varying winds or waves are important in driving sediment transport, then the parameter is not recommended.

Bed sorting and layering

The bed material above the erodible depth, is divided in multiple layers, and the sorting of sediments is calculating using the mixing layer concept (Hirano 1971; Karim and Kennedy 1982; and Wu 1991). The mixing layer is top most layer of the bed. Figure 6 is a schematic of the multi-layer bed-sorting model.

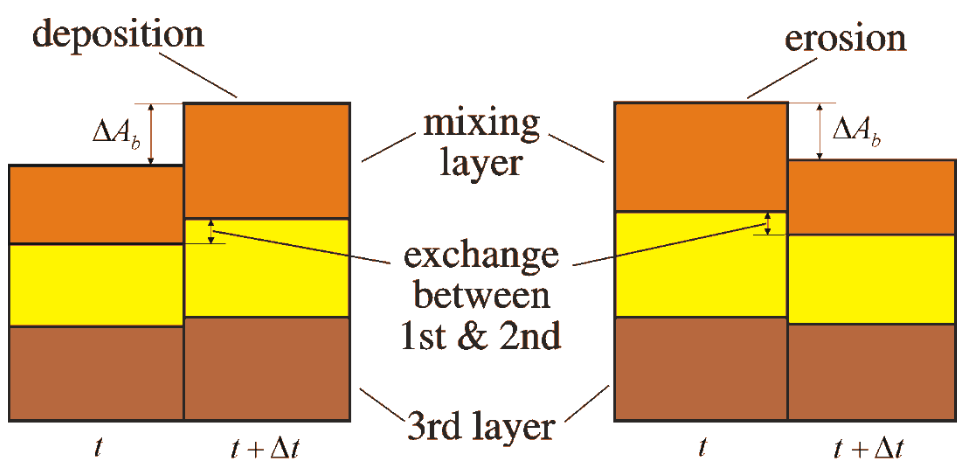


Figure 6. Schematic of the multi-layer bed sorting model.

The temporal variation of the bed-material gradation in the mixing layer is calculated as

$$\frac{\partial(\delta_1 p_{1k})}{\partial t} = \left(\frac{\partial z_b}{\partial t}\right)_k + p_{bk}^* \left(\frac{\partial \delta_1}{\partial t} - \frac{\partial z_b}{\partial t}\right) \tag{50}$$

where δ_1 is the thickness of the first layer, which is commonly referred to as the mixing or active layer. p_{bk}^* is equal to p_{1k} for $\partial z_b / \partial t - \partial \delta_1 / \partial t \geq 0$, and equal to the fraction of the second sediment layer for $\partial z_b / \partial t - \partial \delta_1 / \partial t < 0$. The bed-material sorting in the second layer is calculated as

$$\frac{\partial(\delta_2 p_{2k})}{\partial t} = -p_{1k}^* \left(\frac{\partial \delta_1}{\partial t} - \frac{\partial z_b}{\partial t}\right) \tag{51}$$

where δ_2 is the thickness of the second layer, and p_{2k} is the fraction of the k^{th} sediment size in the second layer. The last two equations assume no material exchange between the sediment layers below the second layer.

The sediment transport, bed change, and bed gradation are solved simultaneously (coupled), but are decoupled from the flow calculation at the time step level. To illustrate the bed layering process, Figure 7 shows an example of the temporal evolution of 7 bed layers during erosional and depositional regimes. Details on the mixing layer thickness calculation and the bed layering algorithm are left for a subsequent publication.

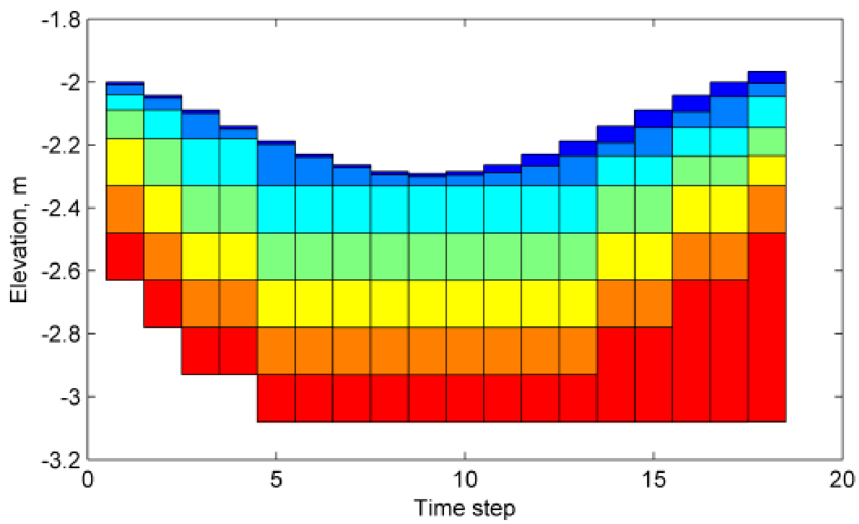


Figure 7. Schematic showing an example bed layer evolution. Colors indicate layer number.

Mixing Layer Thickness

The mixing layer thickness is calculated as

$$\delta_1 = \max(0.5\Delta, 2d_{50}, \delta_{1,\min}, \Delta z_b + \delta_{1,\min}) \tag{52}$$

where Δ is the dune height, and $\delta_{1,\min}$ is a user-specified minimum layer thickness. The third argument above is important for strong deposition. For cell with a hard bottom, the mixing layer is calculated

$$\delta_{1,hb} = \min(\delta_1, z_b - z_{hb}) \tag{53}$$

Equilibrium Concentration and Transport Rates

In order to close the system of equations given by the transport formula, bed change, and bed sorting equation, the fractional equilibrium depth-averaged total-load concentration C_{tk*} needs to be estimated from empirical formula. For convenience the C_{tk*} is written in general form as

$$C_{tk*} = p_{1k} C_{tk}^{*} \tag{54}$$

where p_{1k} is the fraction of the sediment size k in the first (top) bed layer and C_{tk}^{*} can be potential equilibrium total-load concentration. The potential concentration C_{tk}^{*} can be interpreted as the concentration for a uniform bed of size d_k. The above equation is essential to the coupling of the transport, bed change, and bed sorting equations. The depth averaged equilibrium concentration is calculated

$$C_{tk*} = \frac{q_{tk*}}{Uh} \tag{55}$$

where q_{tk*} is the total load transport estimated from empirical formula. The total load transport is the sum of the $q_{tk*} = q_{sk*} + q_{bk*}$.

Equilibrium Transport and Nearbed Concentration Formula

Lund-CIRP Bed-load Transport Formula

Camenen and Larson (2005, 2007, and 2008) developed a general sediment transport formula for bed and suspended load under combined waves and currents. These are referred to as the Lund-CIRP transport formulas. The general transport formulas can be used for both symmetric and asymmetric waves but for simplicity the waves are assumed to be symmetric in CMS. The current-related bed load transport with wave stirring is given by

$$\frac{q_{b*}}{\sqrt{(s-1)gd_{50}^{3}}} = f_b \rho_s 12 \sqrt{\Theta_c}\, \Theta_{cw,m} \exp\left(-4.5 \frac{\Theta_{cr}}{\Theta_{cw}} \right) \tag{56}$$

where

q_{b*} = Equilibrium bed load transport [kg/m/s]

d_{50} = median grain size [m]

s = sediment specific gravity or relative density [-]

g = gravitational constant = 9.81 m/s^2

ρ_s = sediment density (~2650 kg/m^3)

Θ_c = Shields parameters due to currents [-]

$\Theta_{cw,m}$ = mean Shields parameters due to waves and currents [-]

Θ_{cw} = maximum Shields parameters due to waves and currents [-]

Θ_{cr} = critical Shields parameter [-]

f_b = Bed-load scaling factor (default 1.0)

The current related shear stress is calculated as

$$\tau_c = \rho c_b U^2 \tag{57}$$

where ρ is the water density, c_b is the bed friction coefficient, and U is the (Eulerian) current velocity magnitude. The drag coefficient is calculated as

$$c_b = \left[\frac{\kappa}{\ln(h/z_0) - 1} \right]^2 \tag{58}$$

where κ is the von Karman constant (0.4), h is the total water depth, and z_0 is the roughness length calculated as $z_0 = k_s/30$ where k_s is the total bed Nikuradse roughness. The total bed roughness is assumed to be a linear sum of the grain-related roughness $k_{s,d}$, form-drag (ripple) roughness $k_{s,r}$, and sediment-related roughness $k_{s,s}$. Bed forms are also separated into current and wave-related bed forms. The current- and wave-related total roughness is then

$$k_{s,i} = k_{sg} + k_{sr,i} + k_{ss,i} \tag{59}$$

where the subscript i indicates either the current (c) or wave (w) related component. The grain-related roughness is estimated as $k_{sg} = 2d_{50}$.

The ripple roughness is calculated as (Soulsby 1997)

$$k_{sr,i} = 7.5H_{r,i}^2 / L_{r,i} \, , \tag{60}$$

where $H_{r,i}$ and $L_{r,i}$ are the either the current- or wave-related ripple height and length respectively. The current-related ripple height and length are calculated as

$$H_{r,c} = L_{r,c} / 7 \tag{61}$$

$$L_{r,c} = 1000d_{50} \tag{62}$$

The wave-related ripple height and length are calculated using the expressions proposed by van Rijn (1984b, 1989)

$$H_{r,w} = \begin{cases} 0.22A_w & \text{for } \psi_w < 10 \\ 2.8\times10^{-13}(250-\psi_w)^5 A_w & \text{for } 10 \le \psi_w < 250 \\ 0 & \text{for } 250 \le \psi_w \end{cases} \tag{63}$$

$$L_{r,w} = \begin{cases} 1.25A_w & \text{for } \psi_w < 10 \\ 1.4\times10^{-6}(250-\psi_w)^{2.5} A_w & \text{for } 10 \le \psi_w < 250 \\ 0 & \text{for } 250 \le \psi_w \end{cases} \tag{64}$$

where A_w is the semi-orbital excursion and ψ_w is the wave mobility parameter. The semi-orbital excursion is defined as

$$A_w = \frac{u_w T_P}{2\pi} \tag{65}$$

in which u_w is the maximum bottom orbital velocity, and T_P is the peak wave period. The wave mobility parameter ψ_w is defined as

$$\psi_w = \frac{u_w^2}{(s-1)gd_{50}} \tag{66}$$

The maximum wave bottom shear stress is given by (Johnson 1966)

$$\tau_w = \frac{1}{2}\rho f_w u_w^2 \tag{67}$$

where f_w is the wave friction factor calculated using the expression of Swart (1976)

$$f_w = \begin{cases} \exp\left(5.21r^{-0.19} - 6.0\right) & \text{for } r > 1.57 \\ 0.3 & \text{for } r \le 1.57 \end{cases} \tag{68}$$

where r is the relative roughness defined as $r = A_w / k_{sg}$.

The current- and wave-related sediment roughness is estimated as

$$k_{ss,i} = 5d_{50}\Theta_i \tag{69}$$

The above equation has to be solved simultaneously with the expressions for the bottom shear stress, because the roughness depends on the stress. The exact solution is approximated using explicit polynomial fits in order to avoid time-consuming iterations in calculating the bed shear stress.

The critical shields parameter is estimated using the formula proposed by Soulsby and Whitehouse (1997)

$$\Theta_{cr} = \frac{0.3}{1+1.2d_*} + 0.055\left[1-\exp\left(-0.02d_*\right)\right] \tag{70}$$

where d_* is the dimensionless grain size

$$d_* = d_{50}\left[\frac{(s-1)g}{\nu}\right] \tag{71}$$

Lund-CIRP Suspended-load Transport Formula

The current-related suspended load transport with wave stirring is given by

$$\frac{q_{s*}}{\sqrt{(s-1)gd_{50}^3}} = f_s \rho_s c_R U \frac{\varepsilon}{\omega_s}\left[1-\exp\left(-\frac{\omega_s h}{\varepsilon}\right)\right] \quad (72)$$

where

q_{s*} = Suspended load transport [kg/m/s]

U = Depth-averaged current velocity [m/s]

h = Time-averaged total water depth [m]

ω_s = Sediment fall velocity [m/s]

ε = Vertical sediment diffusivity [m^2/s]

c_R = Reference bed concentration [kg/m^3]

f_s = Suspended-load scaling factor (default 1.0) [-]

The sediment fall velocity is calculated using the formula by Soulsby (1997)

$$\omega_s = \frac{\nu}{d}\left[\left(10.36^2 + 1.049 d_*^3\right)^{1/2} - 10.36\right] \quad (73)$$

where d is the grain size. The vertical sediment diffusivity is calculated as

$$\varepsilon = h\left(\frac{D_e}{\rho}\right)^{1/3} \quad (74)$$

where D_e is the total effective dissipation given by

$$D_e = k_b^3 D_b + k_c^3 D_c + k_w^3 D_w \quad (75)$$

in which k_b, k_c, and k_w are coefficients, D_b is the wave breaking dissipation, and D_c and D_w are the bottom friction dissipation due to currents and waves respectively. The dissipations from bottom friction due to current D_c and from bottom friction due to waves D_w are expressed as

$$D_{c|w} = \tau_{c|w} u_{*,c|w} \tag{76}$$

where $u_{*c|w}$ is either the current or wave bottom shear velocity and is either the current or wave related shear stress. The wave breaking dissipation is obtained directly from the wave model. The coefficient k_b =0.017, and the k_c, and k_w are a function of the Schmidt number

$$k_{c|w} = \frac{\kappa}{6} \sigma_{c|w} \tag{77}$$

where $\sigma_{c|w}$ is either the current or wave-related Schmidt number calculated from the following relationships

$$\sigma_c = \begin{cases} 0.7 + 3.6 \sin^{2.5}\left(\dfrac{\pi}{2} \dfrac{\omega_s}{u_{*c}}\right) & \text{for } \dfrac{\omega_s}{u_{*c}} \le 1 \\ 1 + 3.3 \sin^{2.5}\left(\dfrac{\pi}{2} \dfrac{u_{*c}}{\omega_s}\right) & \text{for } \dfrac{\omega_s}{u_{*c}} > 1 \end{cases} \tag{78}$$

$$\sigma_w = \begin{cases} 0.09 + 1.4 \sin^{2.5}\left(\dfrac{\pi}{2} \dfrac{\omega_s}{u_{*w}}\right) & \text{for } \dfrac{\omega_s}{u_{*w}} \le 1 \\ 1 + 0.49 \sin^{2.5}\left(\dfrac{\pi}{2} \dfrac{u_{*w}}{\omega_s}\right) & \text{for } \dfrac{\omega_s}{u_{*w}} > 1 \end{cases} \tag{79}$$

In the case of coexisting waves and currents, the combined wave-current Schmidt number is estimated as

$$\sigma_{cw} = X_v^5 \sigma_c + \left(1 - X_v^5\right) \sigma_w \tag{80}$$

Lund-CIRP Nearbed Sediment Concentration Formula

The reference bed concentration is calculated from

$$c_R = A_{cR}\Theta_{cw,m}\exp\left(-4.5\frac{\Theta_{cr}}{\Theta_{cw}}\right) \tag{81}$$

where the coefficient A_{cR} is given by

$$A_{cR} = 0.0035\exp\left(-0.3d_*\right) \tag{82}$$

and ν is the kinematic viscosity of water.

Modification for multiple-sized sediment transport

For multiple-sized (nonuniform) sediments, the fractional equilibrium sediment transport rates are calculated as

$$\frac{q_{bk*}}{\sqrt{(s-1)gd_k^3}} = f_b\xi_k p_{bk}\rho_s 12\sqrt{\Theta_c}\Theta_{cw,m}\exp\left(-4.5\frac{\Theta_{crk}}{\Theta_{cw}}\right) \tag{83}$$

$$\frac{q_{sk*}}{\sqrt{(s-1)gd_k^3}} = f_s\xi_k p_{bk}\rho_s c_{Rk}U\frac{\varepsilon}{\omega_{sk}}\left[1-\exp\left(-\frac{\omega_{sk}h}{\varepsilon}\right)\right] \tag{84}$$

where the subscript k indicates variables which are calculated based only on the sediment size class k. ξ_k is the hiding and exposure coefficient described in Hiding and Exposure.

Van Rijn Reference Concentration Formula

The first is the van Rijn (1984b) formula

$$c_{a*} = 0.015\frac{d_{50}}{ad_*^{0.3}}\left(\frac{\tau_{b,\max}}{\tau_{cr}}-1\right)^{1.5} \tag{85}$$

where $\tau_{b,\max}$ is the combined wave-current maximum bed shear stress calculated as (Soulsby 1997)

$$\tau_{b,\max} = \sqrt{\left(\tau_b+\tau_w\cos\varphi\right)^2+\left(\tau_w\sin\varphi\right)^2} \tag{86}$$

where τ_b is the mean shear stress by waves and current over a wave cycle, τ_w is the mean wave bed shear stress, and φ is the angle between the waves and the current.

The reference height is estimated as

$$a = \max(0.5H_r, 0.01h) \tag{87}$$

where H_r is the ripple height and h is the total water depth.

Van Rijn Bed- and Supended-load Transport Formula

The van Rijn (1984a,b) transport equations for bedload and suspended load are used with the recalibrated coefficients of van Rijn (2007a,b) and given by

$$q_{b*} = f_b 0.015 \rho_s U h \left(\frac{U_e - U_{cr}}{\sqrt{(s-1)gd_{50}}} \right)^{1.5} \left(\frac{d_{50}}{h} \right)^{1.2} \tag{88}$$

$$q_s^* = f_s 0.012 \rho_s U d_{50} \left(\frac{U_e - U_{cr}}{\sqrt{(s-1)gd_{50}}} \right)^{2.4} d_*^{-0.6} \tag{89}$$

where

q_{b*} = Equilibrium bed-load transport [kg/m/s]

q_{s*} = Equilibrium suspended-load transport [kg/m/s]

d_{50} = median grain size [m]

s = sediment specific gravity or relative density [-]

g = gravitational constant = 9.81 m/s^2

ρ_s = sediment density (~2650 kg/m^3)

U = depth-averaged current velocity [m/s]

U_{cr} = the critical depth-averaged velocity for initiation of motion

U_e = the effective depth averaged velocity

f_s = Suspended-load scaling factor (default 1.0)

f_b = Bed-load scaling factor (default 1.0)

The effective depth-averaged velocity is calculated as $U_e = U + 0.4u_w$. The critical velocity is estimated as $U_{cr} = \beta U_{crc} + (1-\beta)U_{crw}$ where β is a blending factor and U_{crc} and u_{crw} are the critical velocities for currents and waves respectively. As in van Rijn (2007), the critical velocity for currents is

$$U_{cr} = \begin{cases} 0.19(d_{50})^{0.1}\log_{10}\left(\dfrac{4h}{d_{90}}\right), & \text{for } 0.1 \le d_{50} \le 0.5\,\text{mm} \\ 8.5(d_{50})^{0.6}\log_{10}\left(\dfrac{4h}{d_{90}}\right), & \text{for } 0.5 \le d_{50} \le 2.0\,\text{mm} \end{cases} \quad (90)$$

where d_{50} and d_{90} are the sediment grain size in meters of 50th (median) and 90th percentiles. The critical velocity for waves is based on Komar and Miller (1975),

$$U_{crw} = \begin{cases} 0.24\left[(s-1)g\right]^{0.66}(d_{50})^{0.33}T_p^{0.33}, & \text{for } 0.1 \le d_{50} \le 0.5\,\text{mm} \\ 0.95\left[(s-1)g\right]^{0.57}(d_{50})^{0.43}T_p^{0.14}, & \text{for } 0.5 \le d_{50} \le 2.0\,\text{mm} \end{cases} \quad (91)$$

where T_p is the peak wave period. According to van Rijn (2007), the bed load transport formula predicts transport rates with a factor of 2 for velocities higher than 0.6 m/s, but underpredicts transports by a factor of 2-3 for velocities close to initiation of motion.

Modification for multiple-sized sediment transport

The van Rijn formula was original proposed for well sorted sediments. The sediment availability is included by multiplication with the fraction of the sediment size class in the upper bed layer. The hiding and exposure is considered by in a correction factor which multiplies by the critical velocity.

When applied to multiple-sized sediments, the fractional equilibrium transport rate is calculated as

$$q_{bk*} = f_b p_{bk} 0.015 \rho_s U h \left(\frac{U_e - \xi_k U_{crk}}{\sqrt{(s-1) g d_k}} \right)^{1.5} \left(\frac{d_k}{h} \right)^{1.2} \quad (92)$$

$$q_{sk*} = f_s p_{bk} 0.012 \rho_s U d_k \left(\frac{U_e - \xi_k U_{crk}}{\sqrt{(s-1) g d_k}} \right)^{2.4} d_{*k}^{-0.6} \quad (93)$$

where p_{bk} is the fractional bed composition, ξ_k is the hiding and exposure coefficient. The subscript k indicates values which are calculated based on the k^{th} sediment size class.

Soulsby-van Rijn Total-load Transport Formula

Soulsby (1997) proposed the following equation for the total load sediment transport rate under action of combined currents and waves,

$$q_{t*} = \rho_s A_s U \left[\left(U^2 + 0.018 \frac{u_{rms}^2}{C_d} \right)^{0.5} - U_{cr} \right]^{2.4} \quad (94)$$

where

q_{t*} = Equilibrium total-load transport [kg/m/s]

ρ_s = sediment density (~2650 kg/m^3)

A_s = an empirical coefficient = $A_{sb} + A_{ss}$

U = depth-averaged current velocity [m/s]

u_{rms} = peak bottom wave orbital velocity based on the root-mean-squared wave height [m/s]

C_d = drag coefficient due to currents alone, and the coefficient [-]

U_{cr} = critical depth-averaged velocity for initiation of motion [m/s]

The coefficients A_{sb} and A_{ss} are related to the bed and suspended transport loads respectively and are given by

$$A_{sb} = f_b \frac{0.005h(d_{50}/h)^{1.2}}{\left[(s-1)gd_{50}\right]^{1.2}}, \quad A_{ss} = f_s \frac{0.012 d_{50} d_*^{-0.6}}{\left[(s-1)gd_{50}\right]^{1.2}} \tag{95}$$

Note that the bed and suspended load scaling factors are applied to the coefficients A_{sb} and A_{ss}.

The current drag coefficient is calculated as,

$$C_d = \left[\frac{\kappa}{\ln(h/z_0)-1}\right]^2 \tag{96}$$

with a constant bed roughness length z_0 set to 0.006 m.

Modification for multiple-sized sediment transport

The Soulsby-van Rijn formula is modified for multiple-sized sediments similarly to the van Rijn formula in the previous section.

$$q_{tk*} = p_{bk} A_{sk} U \left[\left(U^2 + 0.018\frac{U_{rms}^2}{C_d}\right)^{0.5} - \xi_k U_{crk}\right]^{2.4} \tag{97}$$

where the subscript k indicates that the value is calculated based only on the size class k and not the median grain size.

Watanabe Total-load Transport formula

The equilibrium total load sediment transport rate of Watanabe (1987) q_{t*}, is given by

$$q_{t*} = A_{Wat} U \left(\frac{\tau_{b,\max} - \tau_{cr}}{\rho g}\right) \tag{98}$$

where

q_{t*} = Equilibrium total-load transport [kg/m/s]

$\tau_{b,\max}$ = combined wave-current maximum shear stress [Pa]

ρ = water density (~1025 kg/m^3)

g = gravitational constant = 9.81 m/s^2

τ_{cr} = critical shear stress of incipient motion in [Pa]

A_{Wat} = an empirical coefficient typically ranging from 0.1 to 2.

The critical shear stress is determined from the Shields diagram. The maximum bed shear stress $\tau_{b,max}$ is calculated as (Soulsby 1997)

$$\tau_{b,\max} = \sqrt{\left(\tau_b + \tau_w \cos\varphi\right)^2 + \left(\tau_w \sin\varphi\right)^2} \quad (99)$$

where τ_b is the mean shear stress by waves and current over a wave cycle, τ_w is the mean wave bed shear stress, and φ is the angle between the waves and the current.

The mean wave bed shear stress is calculated as

$$\tau_w = \frac{1}{2}\rho f_w u_w^2 \quad (100)$$

where f_w is a wave friction factor, and u_w is the peak bottom wave orbital velocity calculated based on linear wave theory. The wave friction factor is calculated with the expression by Nielson (1992)

$$f_w = \exp\left(5.5 r^{-0.2} - 6.3\right) \quad (101)$$

where r is the relative roughness defined as $r = A_w / k_{sg}$ .Here, A_w is the semi-orbital excursion defined as $A_w = u_w T / \left(2\pi\right)$.

Hiding and Exposure

In the case of the van Rijn, Soulsby and Watanabe transport formula, the hiding and exposure mechanism is considered by correcting the critical velocity. In the case of the Lund-CIRP transport formula, an alternate approach is needed due to the way the Shields number and grain size are included in the calculation. When using the Lund-CIRP formulas the hiding and exposure correction function is directly multiplied by the transport formula. To methods are used for calculating ξ_k depends whether the sediment transport model is run with a single sediment size or multiple sediment sizes.

Single-sized sediment transport

In many cases on the coast the bed material is dominated by a single sediment size with patches of other sediment sizes or materials (e.g. shell hash), which do not contribute significantly to morphology change at specific regions, but do modify the sediment transport through hiding and exposure. For example, it is common for the bed material to have a bimodal distribution with a second peak corresponding to local patches of coarser material consisting mostly of shell fragments. The shell material is difficult to model numerically because it is usually poorly sorted and its hydraulic properties are still largely unknown. Sediment transport models commonly estimate excessive erosion in these areas because of ignoring the hiding effect of the coarser shell material (e.g. Cayocca 2001).

In the case of single-sized sediment transport, the correction function is calculated following Parker et al. (1982) and others,

$$\xi_k = \left(\frac{d_{50}}{d_k} \right)^m \tag{102}$$

where d_{50} is the bed-material median grain size and m is an empirical coefficient between 0.5-1.0. The aforementioned sediment transport capacity equations are implemented by using the transport grain size d_k rather than the bed-material d_{50}. A single, constant transport size d_k is used, while the bed-material d_{50} varies spatially. The spatial distribution of d_{50} can be obtained from measurement data, and for simplicity is assumed constant during the simulation time. It is noted that the best hiding and exposure function may depend on the chosen transport equations and sediment characteristics. However, this method provides a simple conceptual mechanism for considering an important process in the proposed single-sized sediment transport model.

Multiple-sized sediment transport

The hiding and exposure of the each sediment size class is considered by modifying the critical shields parameter Θ_{ck} for each sediment size class based on (Wu et al. 2000)

$$\xi_k = \left(\frac{P_{ek}}{P_{hk}} \right)^{-m} \quad (103)$$

where m is an empirical coefficient between and varies for each transport formula. P_{ek} and P_{hk} are the total hidden and exposed probabilities and are calculated as

$$P_{hk} = \sum_{j=1}^{N} p_{1j} \frac{d_j}{d_k + d_j}, \qquad P_{ek} = \sum_{j=1}^{N} p_{1j} \frac{d_k}{d_k + d_j} \quad (104a, b)$$

Horizontal Sediment Mixing Coefficient

The horizontal sediment mixing coefficient represents the combined effectts of diffusion and dispersion due to nonuniform vertical profiles. In CMS it is assumed to be proportional to the turbulent eddy viscosity as

$$\upsilon_s = \upsilon_t / \sigma_s \quad (105)$$

where σ_s is the Schmidt number. There are many formulas to estimate the Schmidt number. However, for simplicity it is assumed to be constant in CMS and by default is equal to 1.0 but may be modified by the user.

Boundary Conditions

At the interface between wet and dry cells the transport rate is set to zero. The inflow boundary condition requires given concentration at the boundary. Since for most coastal applications, the actual concentration is not available, the model implements the equilibrium concentration capacity (Dirichlet BC). The model also requires the size distribution of the inflow transport. For stability reasons, it is assumed that the inflow size distribution is equal to the initial size distribution of the bed at the boundary. Inflow sediment transport rates are specified either as a total sediment transport $Q_{sed,tot}$ in kg/s or as a fractional sediment transport rate $Q_{sed,k}$ for each sediment size class, also in kg/s. If only the total sediment transport rate is specified, the fractional sediment transport rate is calculated as $Q_{sed,k} = p_{bk} Q_{sed,tot}$ where p_{bk} is bed material fraction at the boundary. The fractional total sediment transport $q_{tk,B}$ at boundary cell *B* in kg/m/s is then calculated along the cell string according to

$$q_{tk,B} = \frac{q^*_{tk,B}}{\sum \Delta l_f q^*_{tk,N}} Q_{sed,k} \quad (106)$$

where $q^*_{tk,B}$ is the potential sediment transport rate at boundary cell *B*, and Δl_f is the inflow cell face width. If the flow is directly outwards of the flow domain, a zero-gradient BC is used for the outflow (Neumann BC).

Surface Roller

As a wave transitions from nonbreaking to fully breaking, part of the energy is converted into momentum which goes into the aerated region of water known as the surface roller. Under the assumption that the surface roller moves in the mean wave direction, the evolution and dissipation of the surface roller energy is calculated by an energy balance equation (Stive and De Vriend 1994, Ruessink et al. 2001)

$$\frac{\partial (S_{sr} c_j)}{\partial x_j} = -D_{sr} + f_e D_{br} \tag{107}$$

where $S_{sr} = 2E_{sr}$, E_{sr} is the roller energy density, $c_j = cw_j$, c is the roller propagation speed, $w_j = (\cos\theta_m, \sin\theta_m)$ is the wave unit vector, θ_m is the mean wave direction, D_{sr} is the roller dissipation, and D_{br} is the wave breaking dissipation. The roller speed is calculated using the longwave approximation $c = \sqrt{gh}$ where h is the total water depth. The roller dissipation is approximated as

$$D_{sr} = \frac{g S_{sr} \beta_D}{c} \tag{108}$$

where β_D is a roller dissipation coefficient approximately equal to 0.05-0.1. The units of the roller dissipation are N/m/s. The roller contribution to the wave radiation stresses, R_{ij}, is given by

$$R_{ij} = S_{sr} w_i w_j \tag{109}$$

Wave Propogation

CMS-Wave is a phase-averaged model for propagation of directional irregular waves over complicated bathymetry and nearshore where wave refraction, diffraction, reflection, shoaling, and breaking simultaneously act at inlets. Wave diffraction terms are included in the governing equations following the method of Mase et al. (2005). Four different depth-limiting wave breaking formulas can be selected as options including the interaction with a current. The wave-current interaction is calculated based on the dispersion relationship including wave blocking by an opposing current (Larson and Kraus 2002). Wave generation and whitecapping dissipation are based on the parameterization source term and calibration using field data (Lin and Lin 2004a and b, 2006a). Bottom friction loss is estimated from the classical drag law formula (Collins 1972).

Wave-action Balance Equation with Diffraction

The fundamental theoretical basis of the CMS-Wave is the wave-action balance equation. This equation represents two-dimensional variation of wave energy in space, and takes into account the effect of an ambient horizontal current on wave behavior. This equation may be written as (Mase 2001)

$$\frac{\partial (C_x N)}{\partial x} + \frac{\partial (C_y N)}{\partial y} + \frac{\partial (C_\theta N)}{\partial \theta} = \frac{\kappa}{2\sigma}\left[\left(CC_g \cos^2\theta N_y\right)_y - \frac{CC_g}{2}\cos^2\theta N_{yy}\right] - \varepsilon_b N - S$$

(110)

where

$$N = \frac{E(\sigma,\theta)}{\sigma} \qquad (111)$$

is the wave-action density to be solved and is a function of frequency σ and direction θ. $E(\sigma,\theta)$ is two-dimensional (2-D) spectral wave density representing the wave energy per unit water-surface area per frequency and direction interval. In the presence of an ambient current, the wave-action density is conserved, whereas the spectral wave density is not (Bretherton and Garrett 1968; Whitham 1974). Both wave diffraction and energy dissipation are included in the governing equation.

The numerical solution scheme for solving Equations 110 and 111 is described elsewhere (Mase 2001; Mase et al. 2005). The variables C and C_g are wave celerity and group velocity, respectively; x and y are the horizontal coordinates; C_x, C_y, and C_θ are the characteristic velocity with respect to x, y, and, θ respectively; N_y and N_{yy} denote the first and second derivatives of N with respect to y, respectively; κ is an empirical parameter representing the intensity of diffraction effect; ε_b is the parameterization of wave breaking energy dissipation; S denotes additional source S_{in} and sink S_{ds} (e.g., wind forcing, bottom friction loss, etc.) and nonlinear wave-wave interaction term S_{nl}.

Wave Diffraction

The first term on the right side of Equation (110) is the wave diffraction term formulated from a parabolic approximation wave theory (Mase 2001). In applications, the diffraction intensity parameter κ (≥ 0) needs to be calibrated and optimized for structures. The model omits the diffraction effect for κ = 0 and calculates diffraction for κ > 0. Large κ (> 15) should be avoided as it can cause artificial wave energy losses. In practice, values of κ between 0 (no diffraction) and 4 (strong diffraction) have been determined in comparison to measurements. A default value of κ = 2.5 was used by (Mase 2001; Mase et al. 2005) to simulate wave diffraction for both narrow and wide gaps between breakwaters. In CMS-Wave, the default value of κ is 4 corresponding to strong diffraction. This default κ is recommended for wave diffraction at a semi-inifinite long breakwater or at a narrow gap, with the opening equal or less than one wavelength. For a relatively wider gap, with an opening greater than one wavelength, κ = 3 is recommended. The exact value of κ in an application is dependent on the structure geometry and adjacent bathymetry, and it may need to be verified with measurements.

Wave-current Interaction

The characteristic velocties C_x, C_y, and C_θ in Equation (110) are expressed as:

$$C_x = C_g \cos\theta + U \tag{112}$$

$$C_y = C_g \sin\theta + V \tag{113}$$

$$C_\theta = \frac{\sigma}{\sinh 2kh}\left(\sin\theta \frac{\partial h}{\partial x} - \cos\theta \frac{\partial h}{\partial y}\right) + \cos\theta \sin\theta \frac{\partial U}{\partial x} - \cos^2\theta \frac{\partial U}{\partial y} + \sin^2\theta \frac{\partial V}{\partial x} - \sin\theta\cos\theta \frac{\partial V}{\partial y} \tag{114}$$

where U and V are the depth-averaged horizontal current velocity components along the x and y axes, k is wave number, and h is water depth. The dispersion relationships between the relative angular frequency σ, the absolute angular frequency ω, the wave number vector $\vec{k}$, and the current velocity vector $\left|\vec{U}\right| = \sqrt{U^2 + V^2}$ are (Jonsson 1990)

$$\sigma = \omega - \vec{k} \cdot \vec{U} \tag{115}$$

and

$$\sigma^2 = gk \tanh(kh) \tag{116}$$

where $\vec{k} \cdot \vec{U}$ is the Doppler-shifting term, and g is the gravitational acceleration. The main difference between the wave transformation models with and without ambient currents lies in the solution of the intrinsic frequency. In treatment of the dispersion relation with the Doppler shift, there is no solution corresponding to wave blocking, if intrinsic group velocity C_g is weaker than an opposing current (Smith et al. 1998; Larson and Kraus 2002):

$$C_g = \frac{d\sigma}{dk} < \vec{U} \cdot \vec{k} / k \tag{117}$$

Under the wave blocking condition, waves cannot propagate into a strong opposing current. The wave energy is most likely to dissipate through breaking with a small portion of energy either reflected or transformed to lower frequency components in the wave blocking condition. In CMS-Wave, the wave-action corresponding to the wave blocking is set to zero for the corresponding frequency and direction bin.

Wave Reflection

The wave energy reflected at a beach or upon the surface of a structure is calculated under assumptions that the incident and reflected wave angles are equal and that the reflected energy is a given fraction of the incident wave energy. The reflected wave action N_r is assumed linearly proportional to the incident wave action N_i :

$$N_r = K_r^2 N_i \tag{118}$$

where K_r is a reflection coefficient (0 for no reflection and 1 for full reflection) defined as the ratio of reflected to incident wave height (Dean and Dalrymple 1984).

CMS-Wave calculates the wave energy reflection at a sidewall or a lateral solid boundary within the wave transformation routine. It can also calculate wave reflection off the beach or detached breakwater using a backward marching calculation routine (Mase et al. 2005). Users should be aware that, while the computer run time with the forward reflection can be efficient, the time is almost double for the backward reflection routine.

Wave Breaking Formulas

The simulation of depth-limited wave breaking is essential in nearshore wave models. A simple wave breaking criterion that is commonly used as a first approximation in shallow water, especially in the surf zone, is a linear function of the ratio of wave height to depth. For random waves, the criterion is (Smith et al. 1999)

$$\frac{H_b}{h} \leq 0.64 \tag{119}$$

where H_b denotes the significant breaking wave height. CMS applies a more comprehensive criterion on the limiting steepness by Miche (1951) for random waves as

$$H_b \leq \frac{0.64}{k_p} \tanh(k_p h) \tag{120}$$

where k_p is the wave number corresponding to the spectral peak. In the shallow water condition ($k_p h$ small), Equation (120) reduces asymptotically to Equation (10). Iwagaki et al. (1980) verified that Miche's breaker criterion could replicate laboratory measurements over a sloping beach with a current present provided that the wavelength was calculated with the current included in the dispersion equation.

In CMS-Wave, the depth-limited spectral energy dissipation can be selected from four different formulas: (a) Extended Goda formulation (Sakai et al. 1989), (b) Extended Miche (Battjes 1972), (c) Battjes and Janssen (1978), and (d) Chawla and Kirby (2002). These formulas, considered more accurate for wave breaking on a current, can be divided into two generic categories (Zheng et al. 2008). The first class of formulations attempt to simulate the energy dissipation due to wave breaking by truncating the tail of the Rayleigh distribution of wave height on the basis of some breaker criterion. The Extended Goda and Extended Miche formulas belong to this class. The second category of wave breaking formulas uses a bore model analogy (Battjes and Janssen 1978) to estimate the total energy dissipation. The Battjes and Janssen formula and Chawla and Kirby formula are in this class. The spectral energy dissipation is calculated based on one of these four wave breaking formulas, while the computed wave height is further limited by Equations (119) and (120).

Wind Forcing and Whitecapping Dissipation

The evolution of waves in the large-scale, open coast is more affected by wind-ocean-wave interactions than the nearshore wave-current-bottom processes. The result is a nonlinear wave field that is balanced between wind forcing, whitecapping, and wave growth. The surface wind can feed energy into the existing waves and also generate new waves. On the other hand, the energy can dissipate through whitecapping from turbulence-wave interactions and air-wave-water interactions. In CMS-Wave, these wind forcing and whitecapping processes are modeled as separate sink and source terms.

Wind input function

The wind-input source S_{in} is formulated as functions of the ratio of wave celerity C to wind speed W, the ratio of wave group velocity to wind speed, the difference of wind speed and wave celerity, and the difference between wind direction θ_{wind} and wave direction θ (Lin and Lin 2006a):

$$S_{in} = \frac{a_1 \sigma}{g} F_1(|\overrightarrow{W} - \vec{C}_g|) F_2\left(\frac{C_g}{W}\right) E^*_{\mathrm{PM}}(\sigma)\Phi(\theta) + \frac{a_2 \sigma^2}{g} \left(F_1(|\overrightarrow{W} - \vec{C}_g|) F_2\left(\frac{C_g}{W}\right) F_3\left(\frac{C_g}{W}\right) \right) N$$

(121)

where

$$F_1(\vec{W} - \vec{C}_g) = \begin{cases} W\cos(\theta_{\text{wind}} - \theta) - C_g, & \text{if} \quad C_g < W \\ 0, & \text{if} \quad C_g \geq W \end{cases} \tag{122}$$

$$F_2\left(\frac{C_g}{W}\right) = \begin{cases} \left(\frac{C_g}{W}\right)^{1.15}, & \text{if} \quad C_g < W \\ 1, & \text{if} \quad C_g \geq W \end{cases} \tag{123}$$

$$F_3\left(\frac{C_g}{W}\right) = \begin{cases} \log_{10}\left[\left(\frac{C_g}{W}\right)^{-1}\right], & \text{if} \quad C_g < W \\ 0, & \text{if} \quad C_g \geq W \end{cases} \tag{124}$$

and

$$E^*_{\text{PM}}(\sigma) = \frac{g^2}{\sigma^5}\exp\left(-0.74\frac{\sigma_0^4}{\sigma^4}\right) \tag{125}$$

$E^*_{\text{PM}}(\sigma)$ is the functional form of the Pierson-Moskowitz (PM) spectrum, $\sigma_o = g/W$ is the Phillips constant, and

$$\Phi(\theta) = \frac{8}{3\pi}\cos^4\left(\theta - \theta_{\text{wind}}\right), \quad \text{for} \quad |\theta - \theta_{\text{wind}}| \leq \frac{\pi}{2} \tag{126}$$

is a normalized directional spreading. The function F_1 presents the wind stress effect, F_2 designates Phillips' mechanisms (Phillips 1957) and F_3 accounts the wave age effect. For swell or long waves, the wave group velocity C_g is generally large and $F_3 < 1$. If $C_g \geq W$, then $F_3 = 0$. For short waves, the phase velocity is generally small and $F_3 > 1$.

Whitecapping dissipation function

The wave energy dissipation (sink) S_{ds} (Lin and Lin 2006a) for whitecapping including current and turbulent viscous effect is

$$S_{ds} = -\sigma_{ds}(a_e k)^{1.5}\frac{\sigma^2}{g}F_4(\vec{W}, \vec{U}, \vec{C}_g)F_5(kh)N(\sigma, \theta) \tag{127}$$

with

$$F_4(\vec{W}, \vec{U}, \vec{C}_g) = \frac{v + W}{|\vec{W} + \vec{U} + \vec{C}_g|} \tag{128}$$

and

$$F_5(kh) = \frac{1}{\tanh kh} \tag{129}$$

where c_{ds} is a proportionality coefficient, and υ is for the turbulent viscous dissipation. The wave amplitude $a_e = \sqrt{E(\sigma, \theta)\, d\sigma\, d\theta}$ is calculated at each grid cell. To avoid numerical instability and considering the physical constraint of energy loss for the dissipation, the function F_4 is set to equal to 1 if the computed value is greater than 1.

Wave Generation with Arbitrary Wind Direction

In the case of wind forcing only and with no (zero) wave energy input at the sea boundary, CMS-Wave can assimilate the full-plane wave generation. The model will execute an internal grid rotation based on the given wind direction to calculate the wave field and map the result back to the original grid. This feature is convenient for the local wave generation by wind in a lake, bay, or estuary, neglecting swell from the ocean.

Spatially Varied Spectral Wave Input

This input will also be used later for the child grid case, where spatially varied wave spectra are assigned to a few user-specified nodes along or near the seaward boundary of the child grid. To apply the spatially varied spectra as wave input without a parent grid, user has to prepare the wave input file with the format as described in the child grid run.

A FORTRAN program **merge-eng-to-nst.exe** (available download from http://cirp.usace.army.mil/wiki/Utilities#Wave_Transformation) is provided to combine all wave spectra files (*.eng) from individual locations into a single wave input file in the format for spatially varied spectral input to CMS-Wave. Figure 8. Child grid domain and two wave input locations Pt1 and Pt2. shows the map of two locations that each location has a wave input files available, 2009-ndbc.eng at Pt 1 (coordinates are 192,602 m and 151,037

m) and 2009-sp154.eng at Pt 2 (coordinates are 192,315 m and 149,579 m) – recall that 2009-ndbc.eng and 2009-sp154.eng were originally generated for the parent grid. Figure 9 shows the running of the **merge-eng-to-nst.exe** in DOS to combine two wave input files into one single wave input file (spatially varied spectral wave input to the child grid). Because 2009-ndbc.eng and 2009-sp154.eng were generated respect to the shore-normal direction at 167 deg and the local child grid orientation is 165 deg, a -2 deg direction adjustment is needed for running the code **merge-eng-to-nst.exe** here.

It is required that all individual wave input files to cover the same period and timestamps (users must edit the files to fill the missing data). In the example, wave spectra at time stamps 09122000, 0912003, and 0912006 are missing in 2009-ndbc.eng, and wave spectra at timestamps 09120400 and 09121000 are missing in 2009-sp154.eng. Two revised files, 2009-ndbc-edit.eng and 2009-sp154-edit.eng (cover the time period from 09120103 to 09123121 in 3-hr interval) are actually used in **merge-eng-to-nst.exe** to generate c2009.nst.

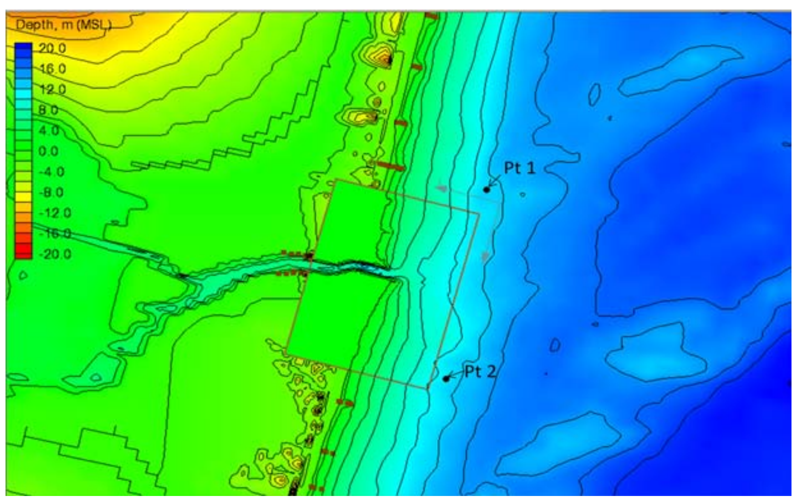


Figure 8. Child grid domain and two wave input locations Pt1 and Pt2.

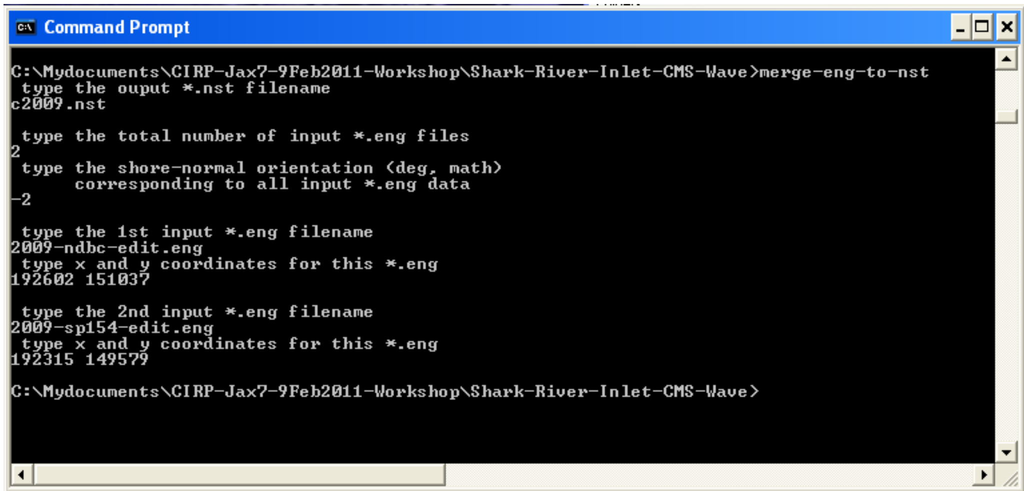


Figure 9. Example of running merge-eng-to-nst.exe in DOS.

Bottom friction loss

The bottom friction loss S_{ds} is calculated by a drag law model (Collins 1972)

$$S_{ds} = -c_f \frac{\sigma^2}{g} \frac{\langle u_b \rangle}{\sinh^2 kh} N \tag{130}$$

with

$$\langle u_b \rangle = \frac{1}{2} \sqrt{\frac{g}{h} E_{total}} \tag{131}$$

where $\langle u_b \rangle$ presents the ensemble mean of horizontal wave orbital velocity at the sea bed, E_{total} is the total energy density at a grid cell, and c_f is the Darcy-Weisbach type friction coefficient. The relationship between c_f and the Darcy-Weisbach friction factor f_{DW} is $c_f = f_{DW}/8$.

Typical values of c_f for sandy bottom range from 0.004 to 0.007 based on the JONSWAP experiment and North Sea measurements (Hasselmann et al. 1973; Bouws and Komen 1983). Values of c_f applied for coral reefs range from 0.05 to 0.40 (Hardy 1993; Hearn 1999; Lowe et al. 2005). c_f = 0.005 is the default value in CMS-Wave.

If the Manning friction coefficient n is used instead of the Darcy-Weisbach type coefficient, the relationship between the two drag coefficients is (in the SI system)

$$c_f = \frac{gn^2}{h^{1/3}} \tag{132}$$

Estimates of Manning coefficient n are available in most fluid mechanics reference books (e.g., 0.01 to 0.05 for smooth to rocky/weedy channels).

Wave Runup

Wave runup is the maximum shoreward wave swash on the beach face for engineering structures such as jetties and breakwaters by wave breaking at the shore. Wave runup is significant for beach erosion as well as wave overtopping of seawalls and jetties. The total wave runup consists of two components: (a) rise of the mean water level by wave breaking at the shore known as the wave setup, and (b) swash of incident waves. In CMS-Wave, the wave setup is computed based on the horizontal momentum equations, neglecting current, surface wind drag and bottom stresses.

$$\frac{\partial \eta}{\partial x} = -\frac{1}{\rho g h}\left(\frac{\partial S_{xx}}{\partial x} + \frac{\partial S_{xy}}{\partial y}\right) \tag{133}$$

$$\frac{\partial \eta}{\partial y} = -\frac{1}{\rho g h}\left(\frac{\partial S_{xy}}{\partial x} + \frac{\partial S_{yy}}{\partial y}\right) \tag{134}$$

where ρ is the water density, S_{xx}, $S_{xy,}$ and S_{xy} are radiation components from the excess momentum flux due to waves. By using the linear wave theory (Dean and Dalrymple 1984), S_{xx}, $S_{xy,}$ and S_{xy} can be expressed as

$$S_{xx} = E(\sigma,\theta)\int\left[n_k(\cos^2\theta + 1) - \frac{1}{2}\right]d\theta \tag{135}$$

$$S_{xx} = E(\sigma,\theta)\int\left[n_k(\sin^2\theta + 1) - \frac{1}{2}\right]d\theta \tag{136}$$

$$S_{yy} = \frac{E}{2} n_k \sin 2\theta \tag{137}$$

where $n_k = \frac{1}{2} + \frac{kh}{\sinh 2kh}$. Equations (133) and (134) also calculate the water level depression from the still-water level due to waves known as wave setdown outside the breaker zone. Equation (133) mainly controls wave setup and setdown calculations, whereas Equation (134) predominantly acts to smooth the water level alongshore.

The swash oscillation of incident natural waves on the beach face is a random process. The most landward swash excursion corresponds to the maximum wave runup. In the engineering application, a 2% exceedence of all vertical levels, denoted as $R_{2\%}$, from the swash is usually estimated for the wave runup (Komar 1998). This quantity is approximately equal to the local wave setup on the beach or at structures such as seawalls and jetties, or the total wave runup is estimated as

$$R_{2\%} = 2\,|\eta| \tag{138}$$

In CMS-Wave, $R_{2\%}$ is calculated at the land-water interface and averaged with the local depth to determine if the water can flood the proceeding dry cell. If the wave runup level is higher than the adjacent land cell elevation, CMS-Wave can flood the dry cells and simulate wave overtopping and overwash at them. The feature is useful in coupling CMS-Wave to CMS-Flow (Demirbilek and Rosati 2011; Lin et al. 2011b) for calculating beach erosion or breaching. Calculated quantities of $\partial S_{xx}/\partial_x$, $\partial S_{xy}/\partial x$, $\partial S_{xy}/\partial y$, and $\partial S_{yy}/\partial y$ are saved as input to CMS-Flow. CMS-Wave reports the calculated fields of wave setup and maximum water level defined as

$$\text{Maximum water level} = \text{Max}\,(R_{2\%},\ \eta + H_s/2) \tag{139}$$

where $H_s = 4\sqrt{E_{total}}$ is referred as the significant wave height.

Use the SMS11.1 interface (Figure 8 and Figure 9) to choose any wave processes to be included in a CMS-Wave simulation. For example, user can select the corresponding options in the SMS to include wave run-up, infragravity wave, nonlinear wave-wave interaction, multiple processors, muddy bed, spatial wind field input, and also the binary (xmdf) output option. These wave processes can be included or excluded by user to be considered in simulations. However, user is reminded that additional files are required for the muddy bed and spatial wind field input options.

In applications with a muddy bed in parts or all of modeling domain, user must prepare a mud.dat or *.mud input file in the same format as the *.dep file. This file provides values of the spatial maximum kinematic viscosity for the entire grid. The default value of the kinematic viscosity for mud is zero, and recommended maximum is 0.04 m^2/sec.

In applications requiring a spatial wind field input, user should provide a wind.dat or *.wind file in the same format as the *.cur file. This file contains the x- and y-component wind speed data that correspond to the incident wave conditions specified by user in the *.eng file.

Wave Transmission and Overtopping at Structures

CMS-Wave applies a simple analytical formula to compute the wave transmission coefficient K_t of a rigidly moored rectangular breakwater of width B_c and draft D_c (Macagno 1953)

$$K_t = \left[1 + \left(\frac{kB_c \sinh kh}{2\cosh k(h - D_c)}\right)^2\right]^{-\frac{1}{2}} \tag{140}$$

Wave transmission over a structure or breakwater is mainly caused by the fall of the overtopping water mass. Therefore, the ratio of the structure crest elevation to the incident wave height is the prime parameter governing the wave transmission. CMS-Wave calculates the rate of overtopping of a vertical breakwater based on the simple expression (Goda 1985) as

$$K_t = 0.3\ (1.5 - \frac{h_c}{H_i}), \quad \text{for} \quad 0 \le \frac{h_c}{H_i} \le 1.25 \tag{141}$$

where h_c is the crest elevation of the breakwater above the still-water level, and H_i is the incident wave height. Equation (32) is modified for a composite breakwater, protected by a mound of armor units at its front, as

$$K_t = 0.3\ (1.1 - \frac{h_c}{H_i}), \quad \text{for} \quad 0 \le \frac{h_c}{H_i} \le 0.75 \tag{142}$$

For rubble-mound breakwaters, the calculation of wave transmission is more complicated because the overtopping rate also depends on the specific design of the breakwater (e. g., toe apron protection, front slope, armor unit shape and size, thickness of armor layers). In practice, Equation (33) still can be applied using a finer spatial resolution with the proper bathymetry and adequate bottom friction coefficients to represent the breakwater.

For permeable rubble-mound breakwaters, the transmission is calculated from D'Angremond et al. (1996) formula:

$$K_t = 0.64 \left(\frac{B\xi}{H_i}\right)^{-0.31} \left[1 - \exp\left(-\frac{\xi}{2}\right)\right] - 0.4 \frac{h_c}{H_i}, \quad \text{for} \quad B < 10 \ H_i \qquad (143)$$

where B is the crest width, and ξ is the Iribarren parameter defined as the fore-slope of the breakwater divided by the square-root of deepwater incident wave steepness. In practice, Equations (142) to (143) are applicable to both monochromatic and random waves.

Permeable Structure

To model a permeable structure in CMS-Wave, it is necessary for user to select and specify which CMS-Wave grid cells cover the permeable structure. This is done in the SMS11.1 interface by using the menu CMS-Wave *Assign Cell Attributes* and selecting *Permeable Breakwater* (see Figure 8). In SMS11 or earlier versions which does not have the permeable structure cell feature, users will need to modify the *.struct file manually to specify the permeable structure cells. Each feature cell in the CMS-Wave grid is described by four parameters: istruc, jstruc, kstruc, and cstruc in a line format in the *.struct file. See CMS-Wave Technical Report CHL-TR-08-13 for details. These four parameters and values that user can assign to them are listed below:

- istruc = i-th column in the grid

- jstruc = j-th row in the grid

- kstruc = feature cell id denoting the types of structure

  = 1 (for adding an alternative feature or structure immersed or exposed, without modifying the input depths)

  = 2 (for calculation of wave runup and overwash on beach face or structure and adjacent land)

= 3 (for calculation of transmitted waves for a floating breakwater)

= 4 (for a vertical wall breakwater)

= 5 (for a composite or rubble-mound breakwater)

= 6 (for a highly permeable structure like the pier or bridge)

=7 (for a low-permeable structure, like the rubble-mound breakwater)

- cstruc =feature structure characteristic dimension (could be the depth or elevation or draft of structure as defined below)

  = feature structure depth (for kstruc = 1; model assumes a land cell if not provided)

  = beach or structure elevation above mean water level (for kstruc = 2; model uses the input depth if not provided; no effect for cstruc < 0)

  = floating breakwater draft (for kstruc =3; model skips calculations if not provided or cstruc < 0.05 m)

  = breakwater or structure elevation (for kstruc = 4 or 5; model uses the input depth if not provided; immersed if cstruc < 0)

  = the permeable portion (for cstruc >0, but used for the section below the mean water depth of a high-crest structure for kstruc = 6 or 7)

Variable-rectangular-cell Grid

CMS-Wave can run on a grid with variable rectangular cells. This feature is suited to large-domain applications in which wider spacing cells can be specified in the offshore where wave property variation is small and away from the area of interest to save computational time. A limit on the shore-normal to shore-parallel spacing ratio in a cell is not required as long as the calculated shoreward waves are found to be numerically stable.

Non-linear Wave-wave Interaction

The non-linear wave-wave interaction is a conserved energy transfer from higher to lower frequencies. The mechanism can produce transverse waves and energy diffusion in the frequency and direction domains. The effect is more pronounced in the intermediate to shallow water depth. Directional spreading of the wave spectrum tends to increase as the wavelength decreases.

The exact computation of the nonlinear energy transfer involves six-dimensional integrations. This is computationally too taxing in practical engineering nearshore wave transformation models. Mase et al. (2005) have shown that calculated wave fields differ with and without nonlinear energy transfer. CMS-Wave applied a theoretically based formula proposed by Jenkins and Phillips (2001) to calculate the nonlinear wave-wave interaction.

In finite water depth, the nonlinear wave-wave interaction function can be expressed as (Lin et al. 2011a)

$$S_{nl} = a\frac{\partial F}{\partial \sigma} + b\frac{\partial^2 F}{\partial \theta^2} \tag{144}$$

where $a = \frac{1}{2n^2}[1+(2n-1)^2 \cosh 2kh]-1$ is a function of kh, $b = \frac{a}{n\sigma}$, and

$$F = k^3\sigma^5 \frac{n^4}{(2\pi)^2 g}\left[(\frac{\sigma_m}{\sigma})^4 E\right]^3 \tag{145}$$

Wave Dissipation over Muddy Bed

The calculation the wave dissipation over muddy bed in CMS-Wave is based on the assumption that the turbulent eddy viscosity is several orders of magnitude greater than the kinematic viscosity of sea water. By neglecting the kinematic viscous effect, the wave dissipation over a muddy bed can be expressed as (Lamb 1932)

$$S_{dp} = -4\nu_t k^2 E \tag{146}$$

where the turbulent eddy viscosity ν_t is equal to a maximum viscosity $\nu_{t,\max}$ representing the wave breaking condition times the ratio of wave height over depth.

3 Numerical Methods

All models are wrong.
Some are useful.
- George Box

Overview

CMS-Flow has both implicit and explicit solution schemes. The explicit solver is designed for dynamic problems with extensive wetting and drying which require small computational time steps, while the implicit solver is intended for simulating tidal and wave-induced circulation at tidal inlets, navigation channels, and adjacent beaches. A detailed description of the theoretical and numerical formulation of the explicit solver can be found in Buttolph et al. (2006) and is not repeated here. The sections below refer to the implicit solver.

CMS-Flow Computational Grid

CMS-Flow implicit uses a generic Cartesian grid which can be regular, nonuniform, or locally refined by splitting cells into two or four (only splitting into four supported by the interface at moment). Only three requirements are imposed on the input grid:

1. Cells must have a rectangular shape. Irregularly shaped cells are not allowed.

2. Cells may have a total of four to six neighboring cells (faces).

3. Only two cells are allowed in the same neighboring direction (i.e. North, South, East, West).

Mesh refinement can be done by either locally decreasing the grid spacing (nonuniform Cartesian grid) as shown on the left panel of Figure 10 or by subdividing or splitting a cell into multiple cells as shown on the right panel of Figure 10. The refined mesh can be further refined in multiple levels, if needed. This refined mesh is referred to here as telescoping in order to avoid the use of misleading terms such as quadtree or refined.

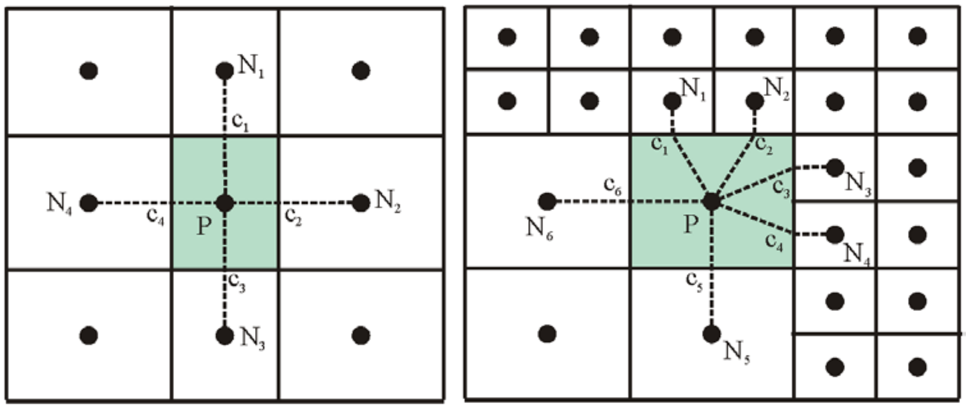


Figure 10. Examples of a Cartesian grids allowed in CMS. Regular Cartesian (left) and stretched telescoping Grid (right)

An important aspect of incompressible flow models is the location of primary variables: velocity and pressure (water level). On a staggered grid, the pressure is located at the center of cells and the *u*- and *v*-velocities are on the faces of cells (Harlow and Welsh, 1965; Patankar, 1980). On the non-staggered grid, all the primary variables are located at the center of cells. The staggered grid can more conveniently eliminate the checkerboard oscillations than the non-staggered grid, but the non-staggered grid results in a simpler computer code and can minimize the number of coefficients that must be computed and stored because many of the terms in each of the equations are essentially identical. In particular, the staggered grid is more complicated in handling the interface between coarse and fine cells where five- or six-face control volumes are used. Therefore, the non-staggered (collocated) grid approach is adopted here, with the Rhie and Chow's momentum interpolation technique used to eliminate the checkerboard oscillations. Figure 10 the location of primary variables and the 5- and 7-point stencils (computational molecule) used in the calculations.

The data structure for the grid mesh can be managed in several ways: block-structured, hierarchical tree, and unstructured. The block-structured approach divides the domain into multiple blocks, each of which is treated as structured. A special treatment is applied between blocks to ensure mass and momentum balance. The tree data structure is memory intensive, requiring parent-child relationships and a tree traverse to determine the mesh connectivity. In the unstructured approach, all cells are numbered in a one-dimensional sequence, and tables are used to determine the connectivity of neighboring cells. Among the three approaches, the unstructured approach is simpler and thus is used in this study.

Computational cells are numbered in an unstructured manner via a 1-D index array. Inactive cells (permanently dry) are not included in the 1-D index array to save memory and computational time. All active computational nodes are numbered sequentially. For convenience in handling boundary conditions, each boundary cell has a neighboring ghost or dummy cell outside of the computational domain. Each dummy cell corresponds to a boundary face of the boundary cell. The ghost cells are stored in the end of the 1-D index array.

General Transport Equation

In order to avoid redundant and repetitive derivations of discretized equations. The discretization is outlined and described below for a general transport. Since all of the governing equations are some form of a transport equation, the same discritization may be applied to all of the equations. The general transport equation is given by

$$\underbrace{\frac{\partial(h\phi)}{\partial t}}_{\text{Temporal Term}} + \underbrace{\frac{\partial(hU_j\phi)}{\partial x_j}}_{\text{Advection Term}} = \underbrace{\frac{\partial}{\partial x_j}\left(\Gamma h\frac{\partial\phi}{\partial x_j}\right)}_{\text{Diffusion Term}} + \underbrace{S_\phi}_{\text{Source Term}} \quad (147)$$

where ϕ is a general scalar, t is time, h is the total water depth, U_j is the depth averaged current velocity, Γ is the diffusion coefficient for ϕ, and S_ϕ includes all remaining terms. Note that in the case of the continuity and momentum equations ϕ is equal to 1 and U_i respectively.

Spatial Discretization

The CMS uses a control-volume technique in which the governing equations are integrated over each control volume to obtain an algebraic equation that can be solved numerically

$$\int_A \frac{\partial(h\phi)}{\partial t}\mathrm{d}A + \oint_L h\left[\left(\hat{n}_i U_i\right)\phi - \Gamma\left(\hat{n}_i\nabla_i\phi\right)\right]\mathrm{d}L = \int_A S_\phi \mathrm{d}A \quad (148)$$

$$\frac{\partial(h_P\phi_P)}{\partial t}\Delta A_P + \sum_f \Delta l_f \bar{h}_f\left[U_f\phi_f - \bar{\Gamma}_f\left(\nabla_\perp\phi\right)_f\right] = S_\phi \Delta A_P \quad (149)$$

where $\hat{n}_i = (\hat{n}_1, \hat{n}_2)$ is the outward unit vector normal to cell face *f*, $U_f = (n_i U_i)_f$ is the outward cell face velocity, ϕ_f is the advective value of ϕ on cell face *f*, $\overline{h}_f$ is the linearly interpolated total water at the cell face *f*, and $(\nabla_\perp \phi)_f = (\hat{n}_i \nabla_i \phi)_f$ is the outward normal gradient of ϕ at cell face *f*. The overbar indicates a cell face linear interpolation operator described in a subsequent section. The cell face velocity U_f is calculated using a momentum interpolation method similar to that of Rhie and Chow (1983) and described in a subsequent section.

Temporal Discretization

Integration of the transport equation in time leads to

$$\int \frac{\partial (h\phi)}{\partial t} dt = \int \mathrm{F} \; dt \tag{150}$$

where F includes all remaining terms. For stability and efficiency a fully implicit time stepping scheme is used

$$\frac{(1+0.5\theta)h^{n+1}\phi^{n+1} - (1+\theta)h^n\phi^n + 0.5\theta h^{n-1}\phi^{n-1}}{\Delta t} = \mathrm{F}^{n+1} \tag{151}$$

where θ is a weighting factor between 0 and 1. When θ = 0, the scheme is equal to the first order backward Euler scheme, and when θ = 1, the scheme is equal to the second order Adams-Bashforth scheme (reference-Ferziger and Peric 1997). The superscripts indicate the time step level where n+1 is the current time step.

Cell-face interpolation operator

The general formula for estimating the cell-face value of $\overline{\phi}_f$ is given by

$$\overline{\phi}_f = f_\perp \phi_N + (1 - f_\perp)\phi_P + f_\perp \left(r_\parallel \nabla_\parallel \phi \right)_N + (1 - f_\perp)\left(r_\parallel \nabla_\parallel \phi \right)_P \tag{152}$$

where $f_\perp = \Delta x_{\perp,P} / \left(\Delta x_{\perp,P} + \Delta x_{\perp,N} \right) = \left(x_{\perp,f} - x_{\perp,P} \right) / \left(x_{\perp,N} - x_{\perp,P} \right)$ is a linear interpolation factor, $\nabla_\parallel$ is the gradient operator in the direction parallel to face *f*, and $r_\parallel$ is the distance from the cell center to the ghost point O parallel to the cell face *f* (see Figure 11).

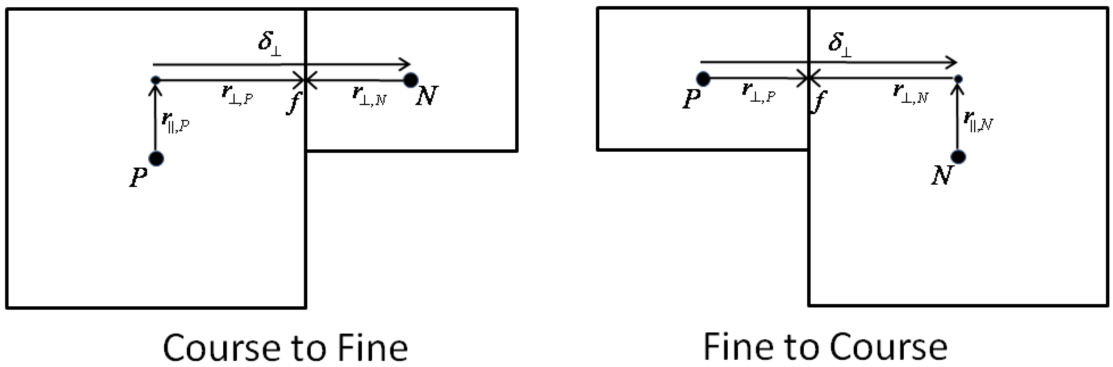


Figure 11. Schematic showing two types of refinement cells.

Note that for neighboring cells without any refinement $r_{\|}$ is equal to zero and thus the above equation is consistent with non-refined cell faces.

Finally, the linear interpolation factor is defined as

$$f_\perp = \frac{x_{\perp,f} - x_{\perp,P}}{x_{\perp,N} - x_{\perp,P}} = \frac{\Delta x_{\perp,P}}{\Delta x_{\perp,P} + \Delta x_{\perp,N}} \tag{153}$$

where $x_{\perp,f}$ is the coordinate of *f* perpendicular to the face.

Advection Schemes

Hybrid Scheme

The hybrid scheme is a composed of both the first order upwind scheme and the second order central difference scheme. When the first order upwind scheme is selected, quantities at the cell faces are approximated as the upwind cell center values

$$\phi_f = \begin{cases} (\phi_D + \phi_C)/2 & \text{for } |P_f| < 2 \\ \phi_C & \text{for } |P_f| > 2 \end{cases} \tag{154}$$

where the subscripts D and C indicate the downstream and first upstream nodes and $P_f = U_f |\delta_\perp| / \bar{\Gamma}_f$ is the Peclet number at the cell face in which $|\delta_\perp| = |x_{\perp,N} - x_{\perp,P}|$.

Exponential Scheme

The exponential scheme interpolates the face value using an exact solution to the 1-D steady state advection-diffusion equation

$$\frac{\phi_f - \phi_0}{\phi_L - \phi_0} = \frac{\exp\left(P_f x_f / |\delta_\perp|\right) - 1}{\exp\left(P_f\right) - 1} \tag{155}$$

where $\phi_0 = \phi|_{x=0}$, $\phi_L = \phi|_{x=L}$. The exponential scheme has automatic up-winding and is stable but is only first order.

Hybrid Linear/Parabolic Scheme

The Hybrid Linear/Parabolic Approximation scheme of Zhu (1991) may be written as

$$\phi_f = \begin{cases} \phi_C + \left(\phi_D - \phi_C\right)\hat{\phi}_C & \text{for } 0 \le \hat{\phi}_C \le 1 \\ \phi_C & \text{otherwise} \end{cases} \tag{156}$$

where the subscripts D, C and U indicates the downstream and first and second upstream cells. The normalized variable $\hat{\phi}_C$ is determined based on the formulation of Jasak et al. (1999)

$$\hat{\phi}_C = \frac{\phi_C - \phi_U}{\phi_D - \phi_U} = 1 - \frac{\phi_D - \phi_C}{2\left(\nabla_\perp \phi\right)_C \delta_{\perp,C}} \tag{157}$$

where $\delta_{\perp,C} = x_{\perp,D} - x_{\perp,C}$. The HLPA scheme is second order.

Cell-face gradient operator

A linearly exact, second-order approximation for the normal gradient at cell face *f* is calculated using the auxiliary node concept of Ferziger and Peric (1997)

$$(\nabla_\perp \phi)_f = \frac{\phi_N - \phi_P + \left(r_\parallel \nabla_\parallel \phi\right)_N - \left(r_\parallel \nabla_\parallel \phi\right)_P}{|\delta_\perp|} \tag{158}$$

where the subscripts P and N refer to two neighboring cells, $|\delta_{\perp}| = |x_{\perp,N} - x_{\perp,P}|$ is the distance between cells P and N, normal to the cell face (see Figure 11), and $\nabla_{\parallel}$ is the gradient operator in the direction parallel to face *f*. Ham et al. (2002) compared the auxiliary node formulation to the fully unstructured discretization viscous flux discretization proposed by Zwart et al. (1998) for the viscous terms and cand found that the auxiliary node formulation is significantly more stable.

Cell-centered gradient operator

The cell-centered gradient operator is calculated using the Green-Gauss theorem as

$$\int_A \nabla_i \phi \mathrm{d}A = \sum_f \hat{n}_{\perp} \Delta l_f \bar{\phi}_f \tag{159}$$

The above expression is second order, and conservative for regular and non-uniform grids.

Source/sink term

The source/sink term is

$$\int_A S\mathrm{d}A = \left(S^C + S^P \phi\right) \Delta A_P \tag{160}$$

where ΔA_P is the cell area, and $S = S^C + S^P \phi$ is approximated as the cell average source/sink term.

Assembly

Assembly refers to the process of combining all terms to create a linear algebraic equation for each cell. The discretization proceeds as follows. First the above terms are combined. The continuity equation is multiplied by ϕ_p^{n+1} and is subtracted from the transport equation. After combining all terms, the resulting discretized equation for cell P may be written as

$$a_P \phi_P^{n+1} = \sum_N a_N \phi_N^{n+1} + b_\phi \tag{161}$$

where the subscript N refers to the neighboring cell sharing cell face, a_P and a_N are linear coefficients for ϕ_P^{n+1} and ϕ_N^{n+1}. The last term b_ϕ contains all remaining terms. A similar equation is written for each cell on the grid creating a system of algebraic equations. The matrix solvers used in CMS are described briefly in Appendix C

Implicit Relaxation

The under-relaxation of equations, known as implicit relaxation, is used to stabilize the convergence of the outer nonlinear iteration loop by introducing a relaxation parameter in the discretized equations as (Patankar 1980)

$$\frac{a_P}{\alpha_\phi}\phi_P^{n+1} = \sum_N a_N \phi_N^{n+1} + b_\phi + \frac{1-\alpha_\phi}{\alpha_\phi} a_P \phi_P^m \tag{162}$$

where α_ϕ is an under-relaxation parameter, ϕ^m is the value of ϕ from the previous iteration. The under-relaxation has the effect of making the coefficient matrix more diagonally dominant.

Iterative Solvers

The selection of the iterative solution solver is a key issue concerning the overall performance of the model. The CMS has several numerical solvers available: GMRES, BiCGStab, and Gauss-Seidel. The default solver is a variant of the GMRES (Generalized Minimum Residual) method (Saad, 1993) to solve the algebraic equations. The original GMRES method (Saad and Schultz, 1986) uses the Arnoldi process to reduce the coefficient matrix to the Hessenburg form and minimizes at every step the norm of the residual vector over a Krylov subspace. The variant of the GMRES method recommended by Saad (1993) allows changes in the preconditioning at every iteration step. An ILUT (Incomplete LU Factorization; Saad, 1994) is used as the preconditioner to speed up the convergence. The GMRES solver is applicable to symmetric and non-symmetric matrices and leads to the smallest residual for a fixed number of iterations. However, the memory requirements and computational costs become increasingly expensive for large systems.

The BiCGStab (BiConjugate Gradient Stabilized) is also a Krylove subspace solver and is applicable to symmetric and non-symmetrix matrices (Saad 1996). BiCGStab also uses ILUT as a preconditioner Saad (1994). The BiCGStab and can be viewed as a combination of the standard Biconjugate Gradient solver where every step is followed by a restarted GMRES step. One advantage of the BiCGStab solver is that the memory requirements remain the same for each iteration and are less compared to the GMRES (for GMRES restart numbers larger than 4). For large problems BiCGStab scales better than the GMRES.

The simplest of the solvers, is the point-implict Gauss-Seidel solverwhich can be applied in CMS with or without Succesive-Over-Relaxation to speed up convergence (Patankar 1980). Unlike the GMRES and BiCGStab, the Gauss-Seidel is highly parallelized. Even though the Gauss-Seidel requires more iterations to converge, the overall efficiency can be much higher than the GMRES and BiCGStab, but because each iteration is so inexpensive and the parallelization. However, the GMRES and BiCGStab are more robust and perform better for stiff problems.

Convergence and Time Stepping

During the iterative solution process, the error is monitored and used to decide when the solution has converged, diverged, or stalled at an error below a certain tolerance limit. There are many ways of monitoring the solution error. An estimate of the error in solving the general algebraic equation is given by

$$r_P = \frac{1}{a_P}\left(\sum_N a_N \phi_N^{n+1} - a_P \phi_P^{n+1} + b_\phi\right) \tag{163}$$

Many statistics can be estimated from the normalized errors. For example, the l^2-norm is given by

$$\left\|r\right\|_2 = \sqrt{\sum_{cells\,P} r_P^2} \tag{164}$$

However, since this value depends on the problem size, the final statistic (residual) used for estimating the model convergence is obtained by diving the normalizing by the problem size as

$$R^m = \frac{\left\|r\right\|_2}{\sqrt{N_c}} \tag{165}$$

Here R^m is referred to as the normalized residual error and the superscript refers to the iteration number. R^m is calculated for each variable being solved, at every iteration of the solution process. Each equation has default maximum tolerances for determining if the solution has converged, diverged, or stalled. Table 2 lists the default tolerances for determining if the model has converged. The maximum number of iterations is imposed equal to M. A minimum of 5 iterations is required for the hydrodynamic equations and a minimum of M/2 for the sediment transport equations. Table 2 shows the default criteria for determining whether the iterative solution procedure has converged, diverged, or needs the time step reduced.

Table 2. Default criteria for determining whether the iterative solution procedure has converged, diverged, or needs the time step reduced.

Variable	Converged	Diverged	Reduce Time Step
Current velocity, m/s	*If* R^m>1x10^{-7} *or* $\|R^m-R^{m-2}\|$<1x10^{-7}	*If* R^M>1.0x10^{-2} or $\|U_i\|$>10	*If* R^M>1.0x10^{-3}
Pressure-correction, m^2/s^2	*If* R^m>1x10^{-8} *or* $\|R^m-R^{m-2}\|$<1x10^{-8}	*If* R^M>1.0x10^{-3} or $\|p\|$>50	*If* R^M>1.0x10^{-4}
Total-load concentration, kg/m^3	*If* R^m>1x10^{-8} *or* $\|R^m-R^{m-2}\|$<1x10^{-8}	*If* R^M>1.0x10^{-3} or C_{tk}<0	None
Salinity, ppt	*If* R^m>1x10^{-6}	*If* S<0	None

It is noted that for the implicit model, the time steps for the hydrodynamics, sediment and salinity transport are the same. This is done in order to avoid mass conservation problems and for simplicity. If any of the time step reduction criteria are met, the time step is reduced by half and a minimum number of 3 time steps are calculated at the reduced time step and then the time step is increased if the last time step converged properly. The maximum time step allowed is equal to the initial time step.

Ramp Period

For most coastal applications, the model is is initialized from a "Cold Start", which the water level and current velocities are set to zero. The ramp period is used to allow the model to slowly transition from the initial condition without "shocking" the system. In CMS, the ramp function is defined as

$$f_{Ramp} = \frac{1}{2} - \frac{1}{2}\cos\left[\pi \min\left(t / t_{Ramp}, 1\right)\right] \tag{166}$$

where t is the simulation time, and t_{Ramp} is the ramp duration. The ramp function provides a smooth function for transitioning from the initial conditionis plotted in the figure (Figure 12) below.

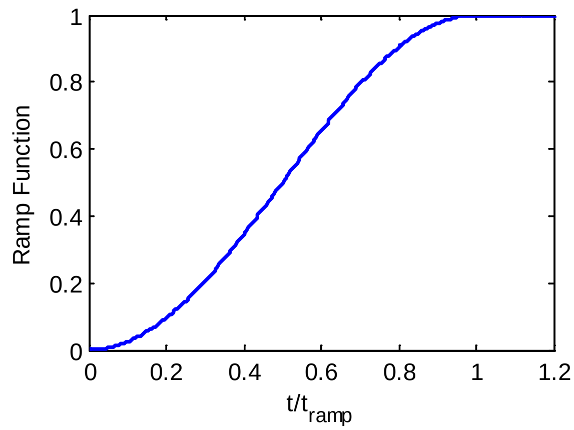


Figure 12. Ramp function used in CMS.

The ramp function is applied to the mode forcing including the wave forcing τ_i^w, surface wind τ_i^s, sediment concentration capacity C_{tk*}, and the significant wave height H_s by directly multiplying them by the ramp function at each time step. Since boundary conditions in CMS are specified without consideration of this transition or rampup period, boundary conditions are alos slowly transitioning from the initial condition.

Hydrodynamics

Solution Procedure

The governing equations are solved in a segregated manner in which each governing equation is solved separated with the latest values from the other equations until a converged solution is obtained. The coupling between the velocity (momentum eq.) and water level (continuity eq.) is achieved using the SIMPLEC algorithm (van Doormal and Raithby 1984). The main difficulty in solving the momentum equations is that the water level is not known a priori and must be calculated as part of the solution. Given am initial or estimated water level η^*, the corresponding velocity is therefore given by

$$\frac{\partial(hU_i^*)}{\partial t}+\frac{\partial(hU_j^*U_i^*)}{\partial x_j}=\frac{\partial}{\partial x_j}\left(\nu_t h\frac{\partial U_i^*}{\partial x_j}\right)-gh\frac{\partial \eta^*}{\partial x_i}+S_i \quad (167)$$

where S_i includes all remaining terms. Next, velocity U' and water level η' corrections are defined such that both the momentum and continuity equations are satisfied.

$$U^{n+1}=U^*+U' \qquad \eta^{n+1}=\eta^*+\eta' \quad (168)$$

Subtracting the guessed velocity equation from the momentum equation leads to velocity correction equation

$$\frac{\partial(hU_i')}{\partial t}+\frac{\partial(hU_j'\,U_i'\,)}{\partial x_j}=\frac{\partial}{\partial x_j}\left(\nu_t h\frac{\partial U_i'}{\partial x_j}\right)-gh\frac{\partial \eta'}{\partial x_i} \quad (169)$$

or written in descritized form

$$a_P U_{i,P}'=\sum a_N U_{i,N}'-gh\nabla_i\eta_P'\Delta A_P \quad (170)$$

In the SIMPLEC algorithm, the velocity correction is assumed to vary smoothly so that $\sum a_N U_{i,N}'$ may be approximated as $U_{i,P}'\sum a_N$, which leads to the velocity correction equation

$$U_i'=-G\nabla_i\eta' \quad (171)$$

where $G=\dfrac{gh\Delta A_P}{a_P-\sum a_N}$.

Using $h^{n+1}-h^n\simeq\eta^*+\eta'-\eta^n$ and substituting $U_i^{n+1}=U_i^*+U_i'$ in the continuity equation, gives the water level correction equation

$$\frac{\eta^*+\eta'-\eta^n}{\Delta t}=\frac{\partial}{\partial x_j}\left(hG\frac{\partial \eta'}{\partial x_j}\right)-\frac{\partial\left(hU_j^*\right)}{\partial x_j} \quad (172)$$

Note that at convergence $p'=0$ = 0 and the above equation reduces to the continuity equation. Once the pressure correction equation solved, the water level is corrected as $\eta^{n+1}=\eta^*+\eta'$. The cell face velocities are also corrected as $U_f^{n+1} = U_f^* + U_f'$ in which the velocity correction is given by $U_f' = -G_f \left(\nabla_\perp p'\right)_f$.

Summary of SIMPLEC Algorithm

1. Guess the water level and pressure field p^*
2. Solve the momentum equations to obtain U_i^*
3. Use the Rhie and Chow's momentum to determine the velocities and fluxes at cell faces
4. Solver the pressure equation to obtain p'
5. Correct velocities and water levels
6. Treat the corrected water pressure, as a new guess, and repeat the procedure from step 2 until convergence.

Cell-face Velocity

The Rhie and Chow (1983) type method is used to estimate the inter-cell current velocities as

$$U_f^* = \overline{\left(H_\perp^*\right)}_f - \overline{\left(\frac{\Delta A_P}{a_P}\right)}_f (h\nabla_\perp p^*)_f \quad (173)$$

where $H_\perp^* = U_\perp^* + \frac{\Delta A_P}{a_P} h\nabla_\perp p^*$. It is noted that this approach is slightly different from Lai (2010) and others and was found to be significantly more stable.

Wetting and Drying

In the numerical simulation of the surface water flows with sloped beaches, sand bars and islands, the water edges change with time, with part of the nodes being possibly wet or dry. In the present model, a threshold flow depth (a small value such as 0.02 m in field cases) is used to judge drying and wetting. If the flow depth at the cell center is larger than the threshold value, this node is considered to be wet, and if the flow depth is lower than the threshold value, this node is dry. For the implicit solver all the wet and dry cells are included in the matrix solver. Dry cells are assigned a zero velocity. Cell faces are classified as either *open* if the two cells neighboring cells are wet or *closed* otherwise (i.e. cell faces are not classified as wet or dry).

Sediment Transport

Transport Equations

The sediment transport equations are descritized using the methods described in the General Transport Equation section and are not repeated here.

Mixing Layer

The mixing or active layer thickness calculation is slightly modified to avoid excessively small layers and for cases of strong deposition as

$$\delta_1 = \max(\Delta / 2, 2d_{50}, \delta_{m,\min}, \Delta\zeta + \delta_{m,\min}) \quad (174)$$

where Δ is the bed form height, and $\delta_{m,\min}$ is a user specified the minimum mixing layer thickness.

Bed Sorting

The bed material sorting is discretized from

$$\delta_1^{n+1} p_{1k}^{n+1} = \Delta z_{bk} + \delta_1^n p_{1k}^n + \Delta z_2 p_k^{*n} \quad (175)$$

where $\Delta z_2 = \delta_1^{n+1} - \delta_1^n - \Delta z_1$, is the top elevation change of the second bed layer, and $p_k^{*n} = p_{1k}^n$ for $\Delta z_2 \geq 0$ and $p_k^{*n} = p_{2k}^n$ for $\Delta z_2 < 0$. The bed material gradation in the second layer is calculated from

$$\delta_2^{n+1} p_{2k}^{n+1} = \delta_2^n p_{2k}^n - \Delta z_2 p_k^{*n} \quad (176)$$

Bed Layering

In order to avoid sediment layers from becoming extremely thin or thick, a layer merging and splitting algorithm is implemented between layers 2 and 3. Here, the subscript s corresponds to the second layer. To illustrate the bed layering process, Figure 13 shows an example of the temporal evolution of 7 bed layers during erosional and depositional regimes.

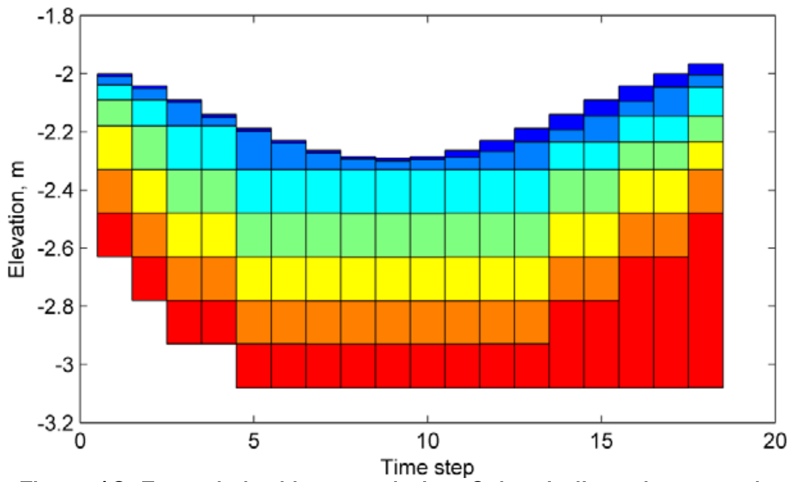


Figure 13. Example bed layer evolution. Colors indicate layer number.

Avalanching

When the slope of a non-cohesive bed ϕ_b is larger than the angle of repose ϕ_R, the bed material will slide (avalanche) to form a new slope approximately equal to the angle of repose. The process of avalanching is simulated by enforcing $|\phi_b| \le \phi_R$, while maintaining mass continuity between adjacent cells. The following equation for bed change due to avalanching is obtained by combining the equation of angle of repose and the continuity equation between two adjacent cells:

$$\Delta z_{b,p}^{a} = -\alpha_a \sum_N \frac{\Delta A_N |\delta_N|}{\Delta A_P + \Delta A_N} \left(\tan\phi_b - \operatorname{sgn}\phi_b \tan\phi_R \right) \mathrm{H}\left(|\phi_b| - \phi_R \right) \quad (177)$$

where δ_N is the cell center distance between cells P and N, ΔA is the cell area, α_a is an under-relaxation factor (approximately 0.25-0.5), and $\mathrm{H}(X)$ is the Heaviside step function representing the activation of avalanching and equal to 1 for $X \ge 0$ and 0 for $X < 0$. The sign function $\operatorname{sgn} X$ is equal to 1 for $X \ge 0$ and -1 for $X < 0$ and accounts for the fact that the bed slope may have a negative or positive sign. The equation above is applied by sweeping through all computational cells to calculate Δz_b^a and then modifying the bathymetry as $z_b^{m+1} = z_b^m + \Delta z_b^a$. Because avalanching between two cells may induce new avalanching at neighboring cells, the above sweeping process is repeated until no avalanching occurs. The under-relaxation coefficient α_a is used to stabilize the avalanching process and avoid overshooting since the equation is derived considering only two adjacent cells but is summed over all (avalanching) neighboring cells. The equation above may be applied to any grid geometry type (i.e. triangles, rectangles, etc.), and also in situations where neighboring cells are joined at corners without sharing a cell face.

Hard bottom

The transport and bed equations assume a loose bottom in which the bed material is available for entrainment. Sometimes one may encounter hard bottoms where bed materials are nonerodible, such as bare rocks, carbonate reefs, and concrete structures. The hard-bottom cells are treated simply by modifying the equilibrium concentration as $C'_{t*} = \min(C_{t*}, C_t)$ in both the transport and bed-change equations. The bed-slope term in the bed equation is also modified, so that only deposition occurs at hard-bottom cells.

Semi-Coupling Procedure

In a semi-coupled sediment transport model, the sediment calculations are decoupled from the hydrodynamics but the sediment transport, bed change and bed material sorting equations are coupled at the time step level and thus solved simultaneously. Here a modified form of the iteration procedure of Wu (2004) is implemented. The equations are obtained by substituting $C_{t*k}^{n+1} = p_{1k}^{n+1} C_{tk}^{*n+1}$ into the bed change and sorting equations and then substituting the sorting equation into the bed change equation.

The solution procedure of sediment transport is as follows:

1. Calculate boundary layer variables and bed form roughness
2. Estimate the sediment transport capacity C_{tk}^{*n+1}
3. Make initial estimate of bed composition as $p_{bk}^{n+1} = p_{bk}^{n}$
4. Calculate the fractional concentration capacity $C_{t*k}^{n+1} = p_{bk}^{n+1} C_{t*k}^{n+1}$
5. Solve transport equations for each sediment size class.
6. Estimate the mixing layer thickness.
7. Calculate the total and fractional bed changes.
8. Estimate the bed sorting in the mixing layer.
9. Update the bed elevation.
10. Go back to step 3 and iterate until convergence
11. Calculate the bed gradation in the bed layers below the mixing layer
12. Calculate avalanching
13. Correct the sediment concentration for depth change $C_{tk}^{n+1} = \left(h - \Delta z_b\right) C_{tk}^{n+1} / h$

Surface Roller

The surface roller equation is solved on the CMS-Wave grid using finite differences. The source terms are calculated at the cell centers. The advective or transport term is solved using either a first order or second order upwind finite difference scheme. The first order scheme is given by

$$\left.\frac{\partial(S_{sr}c_j)}{\partial x_j}\right|_i = \begin{cases} \dfrac{\left(S_{sr}c_j\right)_i - \left(S_{sr}c_j\right)_{i-1}}{\delta x_{j,i-1}}, & \text{for } c_{j,i} > 0 \\ \dfrac{\left(S_{sr}c_j\right)_{i+1} - \left(S_{sr}c_j\right)_i}{\delta x_{j,i}}, & \text{for } c_{j,i} < 0 \end{cases} \quad (178)$$

where i indicates the position along either the rows or columns, and $\delta x_{j,i}$ is the cell-center distance between adjacent cells in the j^{th} direction and position i.

The second-order upwind scheme is given by

$$\left.\frac{\partial(S_{sr}c_j)}{\partial x_j}\right|_i = \begin{cases} \dfrac{3\left(S_{sr}c_j\right)_i - 4\left(S_{sr}c_j\right)_{i-1} + \left(S_{sr}c_j\right)_{i-2}}{\delta x_{j,i} + \delta x_{j,i-1}}, & \text{for } c_{j,i} > 0 \\ \dfrac{-3\left(S_{sr}c_j\right)_i + 4\left(S_{sr}c_j\right)_{i+1} - \left(S_{sr}c_j\right)_{i+2}}{\delta x_{j,i} + \delta x_{j,i+1}}, & \text{for } c_{j,i} < 0 \end{cases} \quad (179)$$

The steady-state solution is found by setting the initial roller energy and time stepping until the steady-state solution is reached. For simplicity, an explicit Euler scheme is used as follows

$$\left(S_{sr}\right)^{n+1} = \left(S_{sr}\right)^n + \Delta t_{sr}\left(-D_r + f_e D_{br} - \frac{\partial(S_{sr}c_j)}{\partial x_j}\right)^n \quad (180)$$

where Δt_{sr} is the surface roller time step and is determined as $\Delta t_{sr} = 0.5\max\left(\Delta x_j / c\right)$, where Δx_j is the cell size in the j^{th} direction . At The steady-state solution is usually reached after about 40-80 time steps and takes about 1-2 seconds to run on a desk-top PC.

Coupling with Waves

CMS-Flow and CMS-Wave can be run separately or coupled together using a process called steering (Figure 14). The variables passed from CMS-Wave to CMS-Flow are the significant wave height, peak wave period, wave direction, wave breaking dissipation, and radiation stress gradients. CMS-Wave uses the updated bathymetry (if sediment transport is on), water levels, and currents from CMS-Flow. The time interval at which CMS-Wave is run is called the steering interval. Currently in CMS the steering interval is constant and the input spectra in CMS-Wave must be at constant intervals without any gaps.

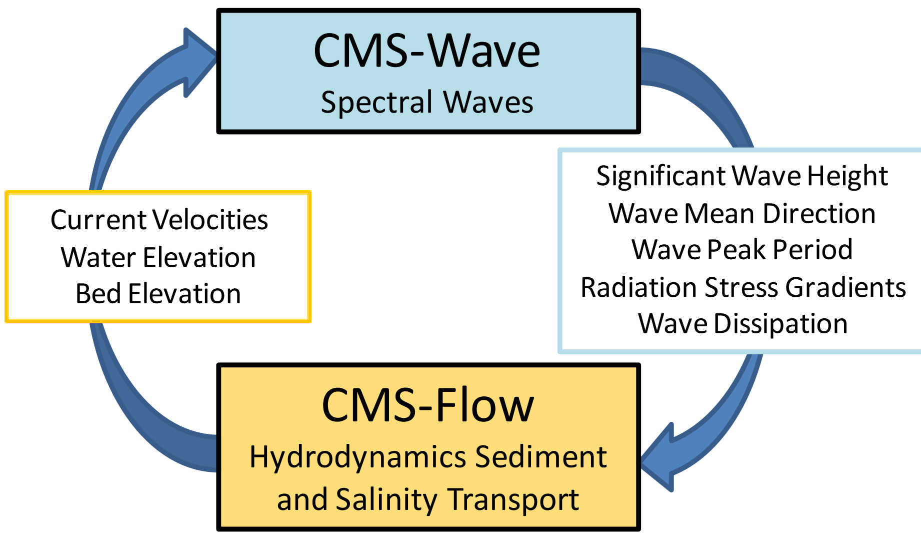


Figure 14. CMS coupling process between CMS-Flow and CMS-Wave.

In CMS versions less than 4.0, the steering process is controlled in the SMS interface using communication files because the CMS-Wave and CMS-Flo models where separate executables. In CMS v4.0 and above, both CMS-Flow and CMS-Wave are contained within a single executable (inline) and the steering process is controlled by an interval steering module. The advantages of the inline steering are that the model runs faster because there is no need to use communication files or reinitialize the models (memory allocation, variable initialization, etc.), makes the improvement and maintenance of the steering module easier for the developers, and also makes the code more portable to other operating systems. The inline steering process is as follows:

1. CMS-Wave model is run the first two time steps and the wave information is passed to CMS-Flow (Figure 15). If specified, the surface roller model is run on the wave grid and the roller contributions to the radiation stresses are added to the wave radiation stresses.
2. The wave height, period, dissipation, radiation stress gradients, and wave unit vectors are interpolated spatially from the wave grid to the flow grid.
3. CMS-Flow is run until the next steering interval and wave variables are linearly interpolated in time during the steering interval. At each flow time step, variables such as wave length and bottom orbital velocities are updated for wave-current interaction.
4. Water levels, current velocities and bed elevations are estimated for the next wave time step and are interpolated from the flow grid to the wave grid.
5. CMS-Wave is run again for the next time step.
6. Step 2-7 are repeated until the end of the simulation.

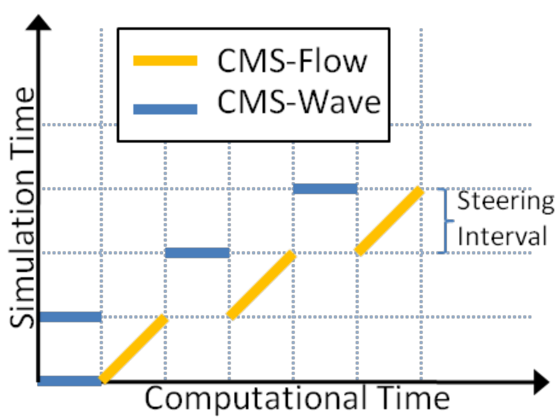


Figure 15. Schematic of steering process.

Spatial Interpolation and Extrapolation

CMS allows the user to use the same or different grids for CMS-Flow and CMS-Wave. If the same grid is used, then no spatial interpolation s are carried out. If different grids are used, then spatial interpolation are needed for passing information from one model grid to another. The interpolation of wave variables from the CMS-Wave grid to the CMS-Flow grid is done using a combination of bilinear and linear triangular interpolation methods. Bilinear interpolation is applied to at non-jointed cells were 4 neighboring points can be identified and triangular interpolation at jointed cells. If the extents of the CMS-Wave and CMS-Flow grids are different (e.g. the CMS-Flow grid is smaller), the extrapolation of variables is needed in order to avoid boundary problems with the models. Different extrapolation methods are applied to different variables based on experience of what methods work best.

Water levels

Water levels are extrapolated out using a nearest neighbor interpolation over the whole domain, but not across land (dry) boundaries. This approach is more physically accurate than extrapolating only to a certain distance since water levels are mostly controlled by tides along the coast and the spatial variation is usually much smaller than the tidal range.

Current Velocities

Current velocities are extrapolated out only to a certain distance called the extrapolation distance. A nearest neighbor interpolation is applied to cells within that distance and multiplied by a cosine function to produce a smooth transition from the boundary to a value of zero:

$$\left(U_{i,P}\right)^{n+1}_{\text{wave grid}} = \frac{1}{2}\left\{1+\cos\left[\pi \min\left(\left|\vec{r}_N\right| / r_x, 1\right)\right]\right\}\left(U_{i,N}\right)^{n}_{\text{flow grid}} \qquad (181)$$

where $U_{i,P}$ is the current velocity at the extrapolated cell, $U_{i,N}$ is the current velocity at the nearest neighbor, and $\left|\vec{r}_N\right|$ is the distance vector from cell P to N, and r_x is an extrapolation distance.

Bed elevations

Extrapolating bed elevations from a boundary can lead to sharp changes in bathymetry in the wave model and lead to instability problems in both the wave and flow models. A better approach is to extrapolate the bed change

$$\left(z_{b,P}\right)_{\text{wave grid}}^{n+1} = \left(z_{b,P}\right)_{\text{wave grid}}^{n} + \frac{1}{2}\left\{1+\cos\left[\pi \min\left(\left|\vec{r}_N\right|/r_x,1\right)\right]\right\}\left(\Delta z_{b,N}\right)_{\text{flow grid}}^{n} \quad (182)$$

where $z_{b,P}$ is the bed elevation the extrapolated cell, $z_{b,N}$ is the bed elevation at the nearest neighbor, and $\left|\vec{r}_N\right|$ is the distance vector from cell P to N, and r_x is in this case the flow grid extrapolation distance.

Significant Wave height

The significant wave is extrapolated in the same way as the current velocities out to a certain distance called the extrapolation distance. A nearest neighbor interpolation is applied to cells within that distance and multiplied by a cosine function to produce a smooth transition from the boundary to a value of zero:

$$\left(H_{s,P}\right)_{\text{flow grid}}^{n+1} = \frac{1}{2}\left\{1+\cos\left[\pi \min\left(\left|\vec{r}_N\right|/r_x,1\right)\right]\right\}\left(H_{s,N}\right)_{\text{wave grid}}^{n} \quad (183)$$

where $H_{s,P}$ is the significant wave height velocity at the extrapolated cell, $H_{s,N}$ is the current velocity at the nearest neighbor, and $\left|\vec{r}_N\right|$ is the distance vector from cell P to N, and r_x is in this case the flow grid extrapolation distance.

Wave Period

The wave period is extrapolated out in a similar way as the water levels using a nearest neighbor interpolation over the whole domain, but not across land (dry) boundaries. This approach is more physically accurate than extrapolating to a finite distance will produce zero wave periods over the ocean domain which is not physically meaningful.

Wave Direction

The wave direction is first converted to wave unit vectors and these are interpolated in space. Wave unit vectors are also extrapolated out over the whole domain except across land (dry) boundaries without consideration of an extrapolation distance. This approach leads to more physically accurate results.

Temporal Interpolation and Extrapolation

Because CMS-Wave requires the water surface elevation at times that are ahead of the hydrodynamics, the water surface elevation and currents. If the steering is relatively small (<30 min), then the values from the previous time step may be used without significant error.

$$U_i^{n+1} = U_i^n \quad \eta^{n+1} = \eta^n \quad z_b^{n+1} = z_b^n \tag{184}$$

where n is the steering time step (CMS-Wave time step). However, in many coastal engineering projects it is desirable and common to use relatively large steering intervals of 2-3 hours. Over large steering intervals, the change in water depth has the largest influence on the nearshore wave heights. Therefore, when using large steering intervals, it is desirable to make a better prediction of water levels than using the previous time step. In cases where the relative surface gradients at any time are much smaller than the mean tidal elevation, a better approximation of water level may be obtained by decomposing the water level into

$$\eta^{n+1} = \overline{\eta}^{n+1} + \eta'^{n+1} \tag{185}$$

where $\overline{\eta}$ is the mean water level, and η' is a variation around the mean due to due to tidal, wave, and wind generated surface gradients. $\overline{\eta}$ can be estimated from water level boundary conditions and is generally much larger, so η' may be neglected. The surface gradient term may be approximated as

$$\eta'^{n+1} \approx \eta'^{n} = \eta^n - \overline{\eta}^n \tag{186}$$

For most coastal inlet applications, the above expression is a much better representation of the water surface elevation and used as the default in CMS.

4 User Guide

"... and though nature begins with the cause and ends with the experience, we must follow the opposite course, namely begin with experience and by means of it investigate the cause."
- Leonardo Da Vinci

Overview

Buttolph et al. (2006) described the graphical interface for CMS in the SMS Version 9.0 (Zundel 2006). A summary of key features of the interface is provided in this chapter to familiarize users with the CMS-Flow interface. The interface is designed to facilitate the model setup and create input files and as well as view output. The interface described here is for SMS Version 11.0.

Limitations and Recommendations

CMS is designed to model hydrodynamics and sediment transport in coastal waters. The model is depth-averaged is does not calculate the vertical profile of current velocities and suspended sediments (although assumed profiles are used for some corrections). Caution is needed when using very small cell sizes compared to the flow depth, since the assumptions of the Shallow Water Equations may be violated. A 3D model may be needed in these situations. The influence of the sub-grid scale turbulence can be particularly relevant in these situations. The implicit hydrodynamic model is capable of handling subcritical, transcritical and supercritical flow regimes but may require a very small time for transcritical and supercritical flows making the computation making the model inefficient. For flows with a high Froude number, it is recommended to use the explicit flow model. Flow through structures is handled using empirical equations.

Sediments are simulated as a passive scalar (no interaction with water) and assumed to be noncohesive, and have constant density and porosity. The hydrodynamic model has capability of including the mass transport due to waves (Stokes velocities) referred to as the undertow. This produces a net offshore current velocity in the surf zone which is consistent with field measurements. The offshore sediment transport caused by the undertow is counter acted by an onshore sediment transport due wave asymmetry, and skewness. Currently, the formulations for onshore sediment transport are still under development. Therefore, when the Stokes velocities are activated in CMS-Flow, the sediment transport is still calculated using the Lagrangian current velocities and no cross-shore sediment transport is included.

It is recommended to always turn on the Surface Roller Model. This model is very fast and represents an insignificant increase in computational costs. The results however, have been shown to significantly improved when simulating nearshore currents and water levels (Sánchez et al. 2011).

The CMS is designed to run on a desktop PC for grids with less than 500,000. The recommended maximum grid size depends on the simulation duration, time step, wave coupling, and sediment transport. But in general it is recommended to keep the total number of active cells less than 150,000 for short term simulations (weeks to months), less than 80,000 for mid-term (months-years), and less than 30,000 for long-term simulations (multiple-years). The grid resolution is therefore a compromise between accuracy and computational costs. For nearshore circulation, it is recommended to have at least 10 computational cells in the in the surf zone in the cross-shore direction. For channels a minimum of three cells is recommended perpendicular to the channel axis. For inlets it is recommended to have at least ten cells across the entrance. However, these are just rules of thumb and it is recommended to test the grid convergence by comparing results from different grids with different resolutions.

Introduction to the Modeling Process

The steps of a numerical modeling study may vary, but a general flow chart is presented in Figure 16. A description of each stage is provided in the sections below.

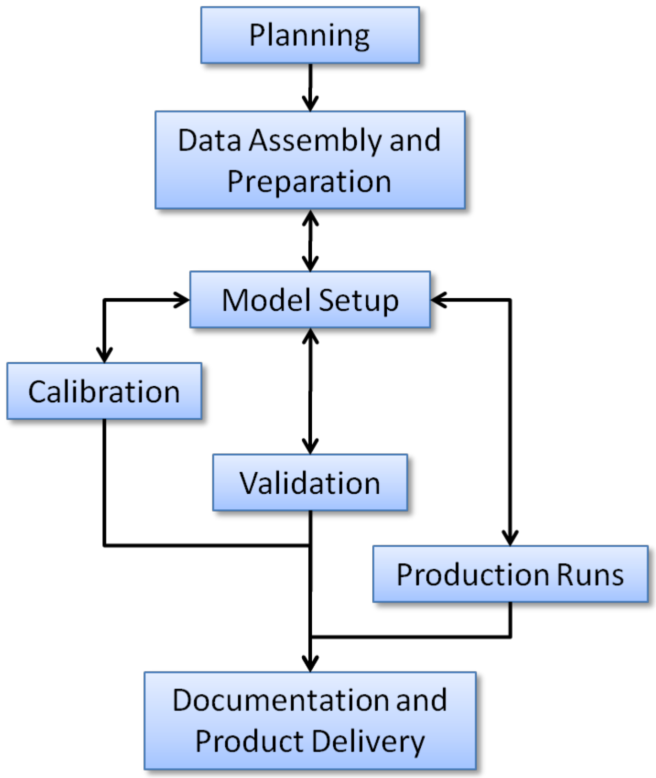


Figure 16. General steps or stages in a modeling study.

Planning Stage

If the modelers and key personnel involved are not familiar with the study area, then a site visit should be made. At that time, the study sponsors can point out concerns and various features of interest, such as conditions of jetties and shoreline, general hydrodynamics, and type of sediment. Those with local knowledge can be interviewed to learn about the presence of sand shoals and current conditions. At this point, a meeting of the modeling team and project delivery team is beneficial to review modeling objectives and essential features governing the waves, circulation, and sediment transport at the site. Several bathymetry grids may need to be developed to represent a past condition, existing condition, and the engineering alternatives under consideration. At this stage it is also important to conduct a literature review and define the scope of modeling work, timelines, milestones, budgets, and group responsibilities.

Data Assembly and Preparation

The first step to start a CMS modeling project is to gather and assemble data. The important data can include geometry, bathymetry, shoreline position, location and configuration of coastal structures, oceanographic and atmospheric data, and sediment characteristics in the study domain. If existing, the datasets from previous modeling studies at the project site should be reviewed and mined for useful information. In addition, historic and recent aerial photographs, preferably vertical photographs that can be rectified, should be assembled, from which locations of structures and shorelines can be obtainedReliable shoreline and bathymetry data with geo-referenced images can assist to design and build a model grid system. It is essential to correctly process bathymetric data and set a domain volume for a model grid. Volume errors related to shoreline and bathymetry data could affect the tidal prism estimate and flow calculations in the model, especially near inlet entrance, navigation channel, and coastal embayment.

All the assembled data would provide sufficient information to describe the physical processes occurring in the study area and lay a solid foundation for configuring and calibrating/validating the CMS later. Based on the data coverage, a model simulation period will be selected.

Model Setup

The model setup here refers to the process of grid generation, selections of model parameters, and specifications of model forcing. It may need to be done multiple times during a project for the purposes of (1) tests, (2) calibration, (3) validation, and (4) production or project alternatives. Because all those simulations may be set up for different time periods, the model will require corresponding forcing, boundary conditions, and possibly bathymetry and bottom characteristics.

Initial test runs may be conducted to guide the user in determining proper model setup for different cases such as grid resolution, domain extent, boundary condition types, and time steps. Test runs can also be conducted in the calibration, validation, and production stages of the study, which are a good modeling practice for improving the quality of the model results and detecting errors early. For a new modeling project it may be helpful to start simple with basic options and fewer processes and slowly increase the complexity until the desired level is achieved. This way, the problems with the setup can be identified more easily.

Calibration

Model should be calibrated by comparing calculated results against measurements. The model output time intervals shall be consistent with data sampling frequency to avoid bias in model-data comparisons. For time series comparisons, the grid depth at the model output location should be similar to the data sampling station. Flow conditions can be misrepresented if the model and the data station have different depth and location. Through the calibration process, a set of model parameters, and model geometry and bathymetry may require adjustments.

Validation

A calibrated model is run for model validation through model-data comparisons for a different period. A validation process proves that the model can be applied to the study area and to provide reasonable results.

Production

The production runs can be conducted after the model calibration and validation. Those runs should include sensitivity tests - various experiments with different model parameters and different model forcing, and alternative conditions – modifications and additions of coastal structures and adjustments of model configuration.

Documentation and Product Delivery

As the final step of a CMS modeling project, extensive analysis of model output will be conducted and the study findings will be properly documented. This stage also includes the archive of the model I/O information, technology transfer, and product delivery.

Horizontal Coordinate System and Conventions

CMS uses a local coordinate system in which all vector values are positive along the I and J axis (Figure 17). All output vector arrays are specified in the local coordinate system. Any input that is specified on the local grid must be specified in the local coordinate system (e.g. initial condition for currents, interpolated wave forcing, etc). If input vector arrays are specified on a different grid, such as a spatially variable wind field or waves on a CMS-Wave grid, then the vectors are assumed to follow the coordinate system of their native grid. The grid is always created in SMS with the origin is by default always at the lower left hand corner of the grid.

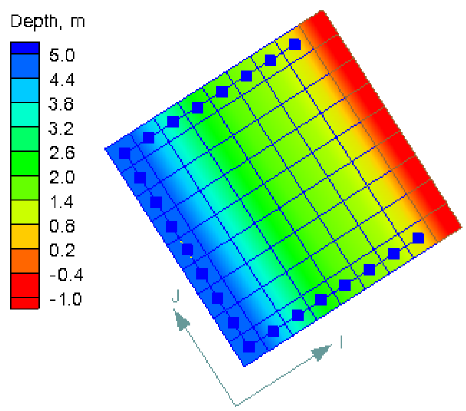


Figure 17. CMS-Flow local coordinate system

In the SMS, the term “projection” refers to a horizontal map projection such as “State Plane” or “Geographic”. Within the software, a global projection can be associated with a project. Individual datasets may also have their own projections, which if properly associated with their original reference, can be displayed without the global projection reference. Previous versions of the SMS software referred to projections as “coordinate systems” and reprojection as “coordinate conversion”.

The projection for the project can be specified from the *Edit | Projection* pull-down menu command. Changing the projection does not alter the coordinates of the project data. To change the projection of the individual project data, the dataset must be reprojected to the common reference system. The CMS models operate in a Cartesian coordinate system such as State Plane or UTM and units must always be specified in meters.

Vertical Coordinate System and Conventions

In CMS, water depths in CMS are positive and land elevations are negative. The vertical reference Datum in CMS is a local datum. Therefore, any vertical datum can be used by the user. However, it is important to note that the default initial water surface elevation is set to zero with respect to the local datum. In addition tidal

In choosing the vertical datum for CMS it is important to understand the differences between tidal and geodetic datums. It is common to use both types of datums. However, the most appropriate datum type depends on the project application. Tidal datums are a standard elevation defined by a tidal statistic such as the arithmetic mean of mean high water and mean low water over a tidal epoch known as the Mean Tide Level or MTL. Therefore, tidal datums vary spatially and in time. This is an important difference with respect to Geodetic datums such NAVD88 which are fixed reference elevations determined by geodetic leveling. Tidal datums should not be used for projects where the tidal datums vary spatially. It is common for bays to have tidal setup or super elevation of the mean water level caused by wind, fresh water inflow, and bottom friction. This will cause a difference in the MTL in the bay with respect to the ocean as illustrated in Figure 18.

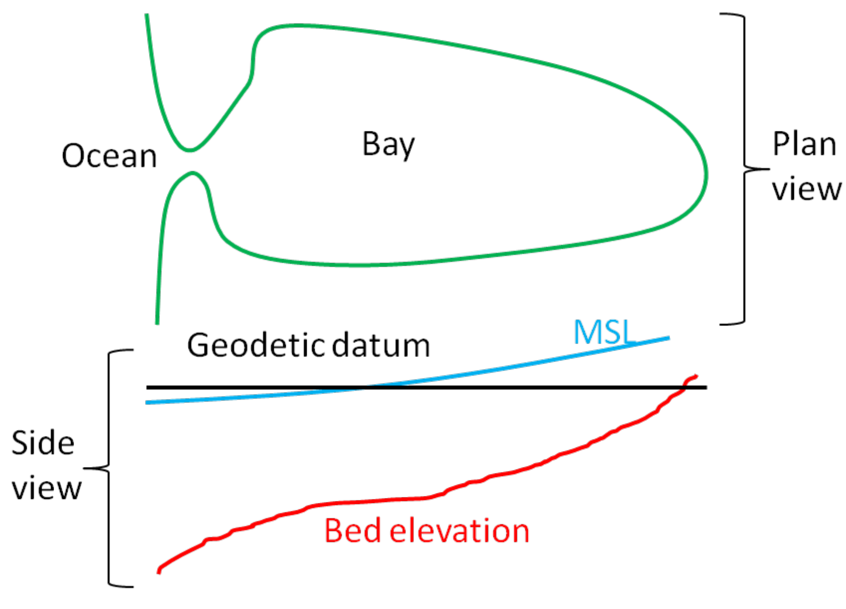


Figure 18. Schematic of showing the difference between MSL (tidal) and geodetic datums.

Important Notes:

- If the project site is a small section of coastline with a small harbor or structures, then it is generally ok to use a tidal datum.
- If the project site includes an estuary, it is recommended to use a geodetic datum.
- When using a geodetic datum in combination with tidal constituent forcing, it is recommended to offset the entire bathymetry so that the geodetic datum matches the offshore MSL. The reason for this is that tidal constituent boundary assumes that the reference datum is MSL.
- When using a geodetic datum in combination with water level time series, it is important to make sure the time series has the same geodetic datum as the bathymetry. In addition, an initial water level may be specified which is close to MSL (see the Hot Start section for details).

Setting the Projection in SMS

1. Choose *Edit* | *Projection* from the pull down menu. The resulting dialog is shown in Figure 19.
2. Click "Set Projection" and choose Projection - State Plane Coordinate System, Zone - New Jersey, Planar Units – Meters, Datum NAD83.

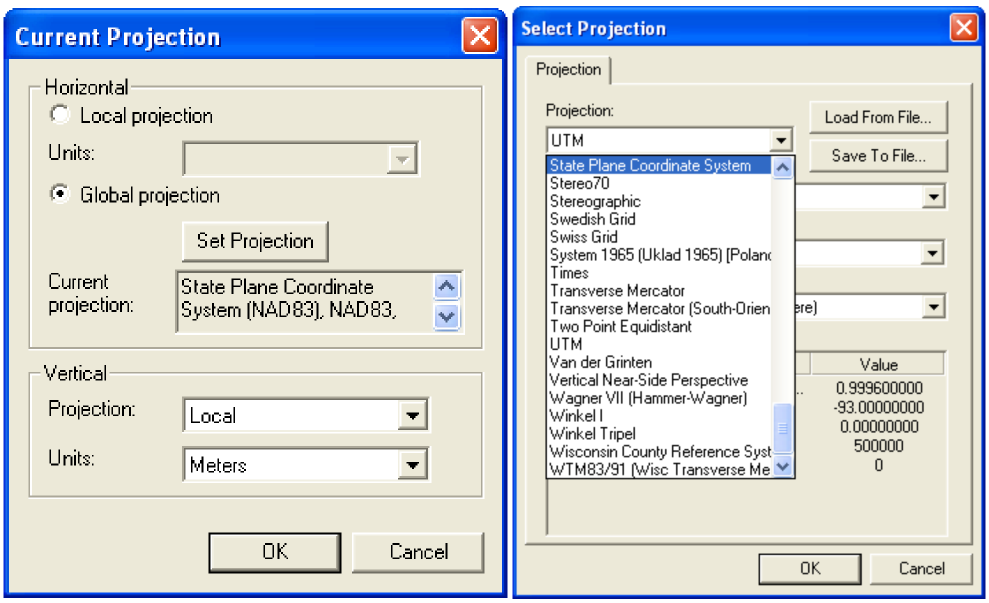
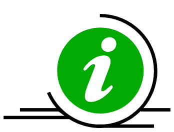


Figure 19. Current Projection dialog box.



Important Notes:

- The units of the horizontal coordinate system should always be set to meters. By default, in SMS the horizontal units are set to feet. It is recommended to change the units to meters and save this setting by clicking on the menu *File* | *Save Settings*. This will save the horizontal projection and will be set every time SMS opens.

Preparing Bathymetry

This guided example is for the user to work with real bathymetric and topographic datasets, many of which were provided by the U.S. Army Corps of Engineers, New York District (NAN). The most common culprit in a poorly calibrated hydrodynamic model is the resolution and accuracy of the model grid bathymetry. This exercise will teach the proper procedure to align and confirm the accuracy of the horizontal and vertical position of your bathymetric and topographic files.

The CMS setup for Shark River Inlet provides a succinct example for illustrating a number of methods and SMS tools that can be applied to most inlet-modeling projects. Shark River Inlet has a semi-annually maintained navigation channel with multiple surveys, and has experienced some engineering modifications to its structures that can be analyzed in the CMS. Structures in the area include a jettied inlet (and a jetty spur), and a developed bay shoreline of seawalls and riprap), and densely spaced groins, some of which on the south (up-drift) side have been notched.

The original datasets for creating the Shark River Inlet grid are provided in sub-folders described throughout this document. Bathymetry can come from various sources and often is given in various horizontal and vertical projections. Before bathymetry datasets can be used to build a CMS grid, they must all reside in the same horizontal plane and have the same horizontal and vertical datum reference and units. This section explains how to convert all loaded data over to a common reference system that is appropriate for estuarine and coastal modeling.

The following files, located in the “Bathymetry” folder will be used for this tutorial on working with bathymetry:

- Channel_Survey_NJ-DEP_0609_ft_MLW.xyz
- Coastal_Relief_Model_ll_m_msl.xyz
- 3364_0409_ft_MLW.xyz
- LIDAR_ft_NAVD.xyz
- Field_Team_Measurements_0809_m_NAVD.xyz
- 0.75m_Contour.xyz

The final merged bathymetry file can be loaded for application in the next hands-on section.

Open XYZ Files

1. Open  the “Bathymetry” folder and observe the various data files. Select the six files with your mouse and drag them into the SMS graphical window. SMS will attempt to open each file in the format as defined by their extension (such as .xyz or .pts for columnar data), and if it does not exist it will prompt the user to use the import wizard or select the format.
2. During the import process, there are two screens that appear for each dataset (Figure 20). Simply hit *Next* or *Finish* through each. Note that there is a default horizontal distance tolerance that is assigned to delete points located within that distance.

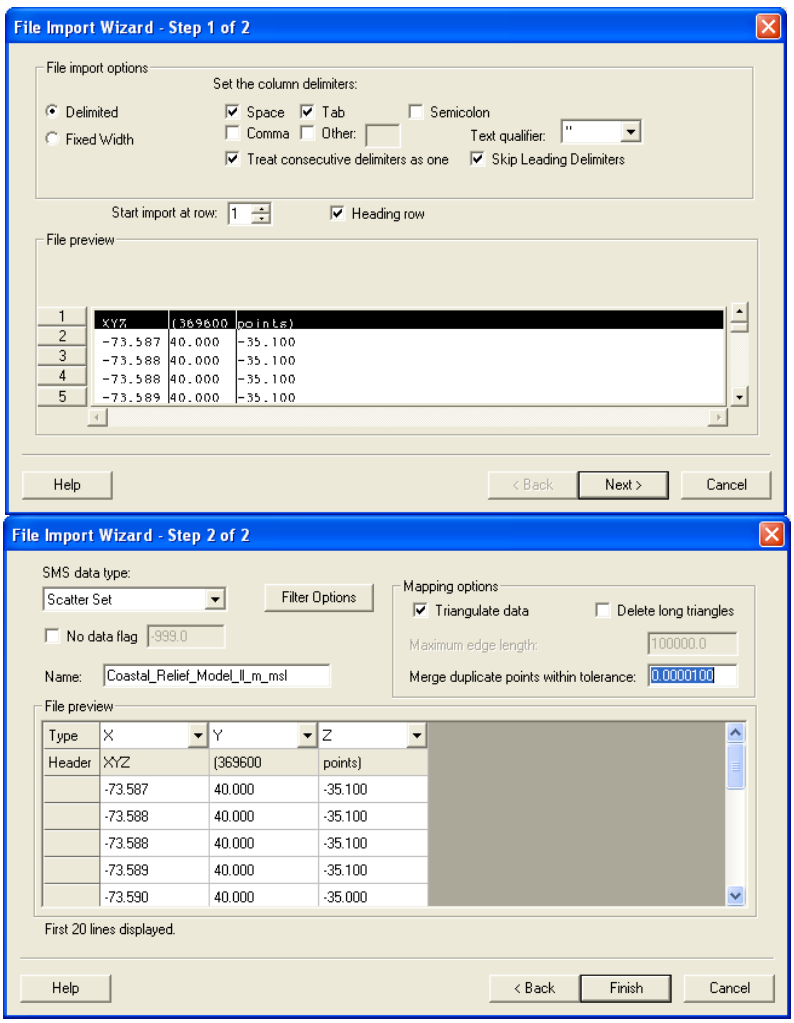


Figure 20. File Import Wizard.

3. When loading certain very dense datasets (e.g. multibeam surveys) or datasets that are relative to degrees (Latitude and Longitude), there may be a message that appears stating that a certain number of points have been removed due to the tolerance factor (Figure 21). Take care to set this tolerance appropriately so as not to delete too much of the original dataset.

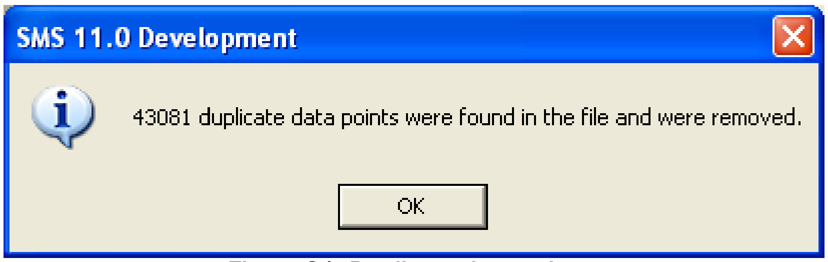


Figure 21. Duplicate data points.

For convenience, the file names have been altered to give a description of a) the data contained, and b) the projection and units associated with the data. For example, the file "Channel Survey NJ-DEP 0609_ft_MLW.xyz" contains channel survey data obtained in June 2009 and the values are in feet relative to mean lower water (MLW). Because the 6 datasets loaded are not all in the same frame of reference (projection), the graphical interface screen will zoom to an area that contains all three, shown in Figure 22.

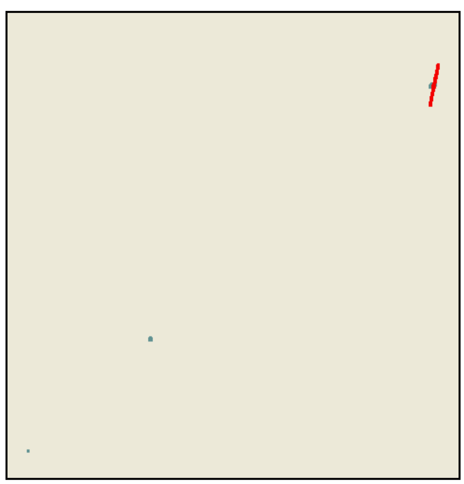


Figure 22. After loading 6 datasets.

Saving Your Progress

Working with bathymetry files can be a lengthy process. This tutorial loads only six surveys, but some projects may have many more. To be on the safe side and to keep from having to duplicate effort because of a SMS bug, computer glitch, or user mistake, it is a wise idea to save your project frequently during this stage.

There are few different ways to save your progress. One of the most useful in the early stages of grid development in the SMS is to save the entire project. This saves everything that is listed in the data tree under a project name. Images are handled differently due to their possible size and only a link to these files is stored.

1. Under the *File* pull-down menu, choose the “Save New Project” option (shown in Figure 23).
2. Choose the directory where you wish to save the project and enter “Workshop” as the filename.
3. Just choose the present directory as the location.
4. The filename that you choose should be brief but descriptive in a manner that you are able to understand. Note that all datasets loaded in the data tree will have this filename as a prefix. This means that the entire filename for each dataset can be long.
5. For this example, “Workshop” is the project filename. Figure 24 shows the list of files after the project has been saved so far. Notice that the original files still exist.

The next time you start SMS, you can simply load the file “Workshop.sms” to load all associated files with this project. Also, after a project has been saved or loaded, the *File* menu changes to “Save Project” and simply re-saves all the data under the previously saved filename.

Periodically through the following sections, it is good to save the project, so as to save your progress.

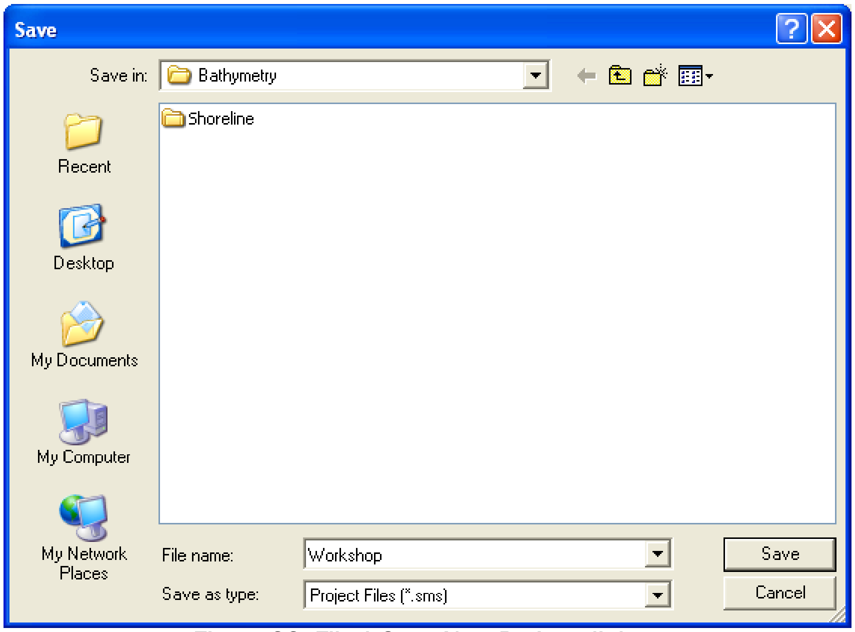


Figure 23. File | Save New Project dialog.

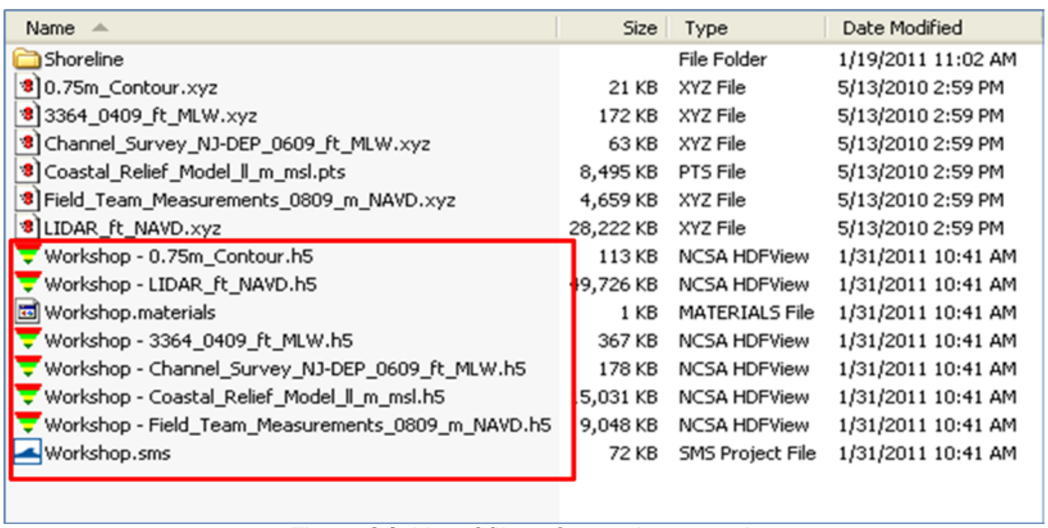


Figure 24. List of files after project saved.

Reproject Datasets

Since we have previously set the Project projection, we can now reproject each dataset individually.

1. Right-click on each dataset within the data tree, and select Reproject.
2. A dialog box will come up for the reprojection (Figure 25).
3. The left side is reserved for the projection in which each individual dataset (survey) resides. Each dataset will be converted FROM this projection.
4. The right side is for the projection that you want to work in. By selecting “Specify”, you are indicating that this dataset will be reprojected. The dataset will be converted TO this projection.
5. At the bottom of both sides is an area for vertical reprojection. Make sure that the values are the same on both the Object and Project side of the dialog are both Local, Meters, despite their original datum and unit. The Vertical Datum and unit will be converted next using a different tool.
6. Set the left side to the projection that the datasets are in. Table 3 is shown below with projection information for all six datasets.
7. Repeat this process for each of the six datasets.
8. When finished, all datasets will be in a common horizontal projection and the graphics screen should look similar to Figure 26. The datasets are still separate, and all but the active datasets (black points) are displayed as grey points.
9. SAVE

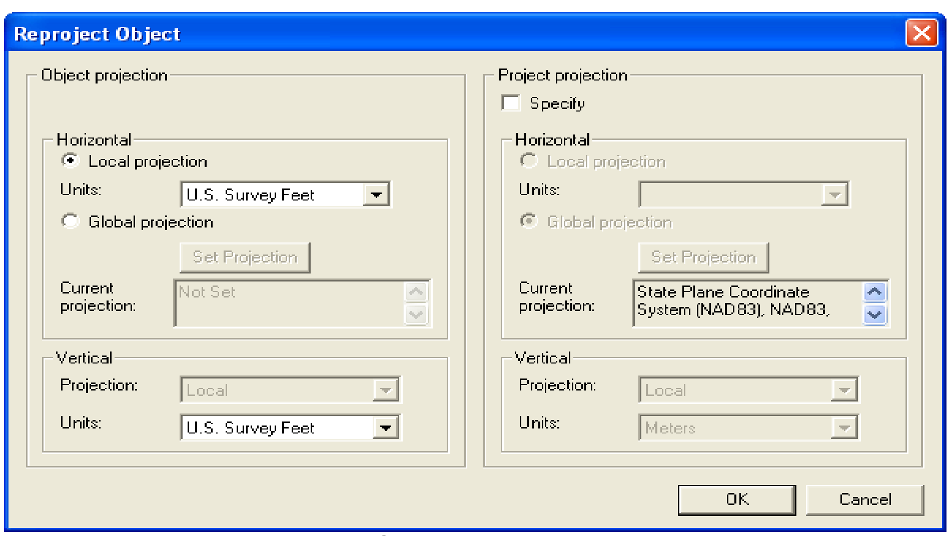


Figure 25. Reprojection Dialog.

Table 3. Survey list with Horizontal Projection Information.

Filename	Horizontal Projection information
Channel_Survey_NJ-DEP_0609_ft_MLW.xyz	State Plane, New Jersey, U.S. Feet, NAD83
Coastal_Relief_Model_ll_m_msl	Geographic (Lat/Long), Arc Degrees, NAD83
3364_0409_ft_MLW.xyz	State Plane, New Jersey, U.S. Feet, NAD83
LIDAR_ft_NAVD	State Plane, New Jersey, U.S. Feet, NAD83
Field_Team_Measurements_0809_m_NAVD.xyz	State Plane, New Jersey, Meters, NAD83 (Reprojection not needed)
0.75m_Contour	State Plane, New Jersey, Meters, NAD83 (Reprojection not needed)

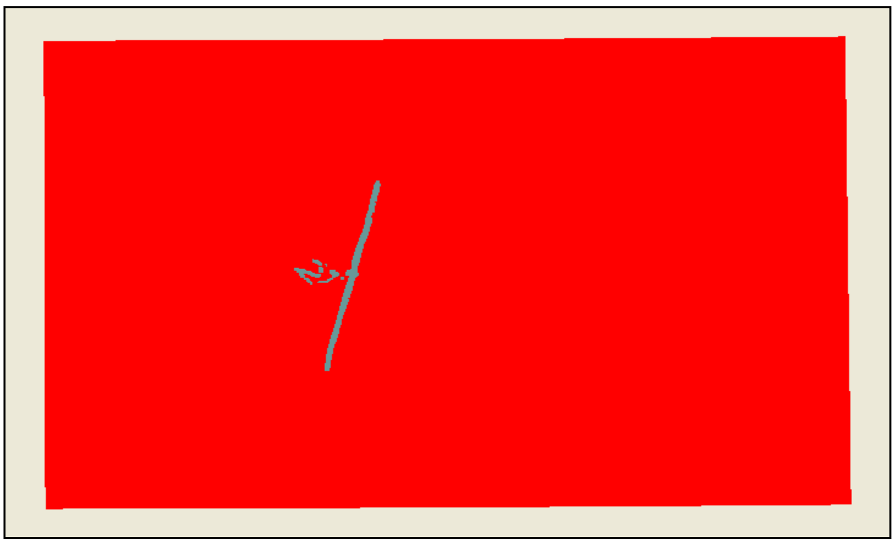


Figure 26. Graphics screen after reprojection of 6 overlain, individual surveys.

Vertical Units and Datums in the CMS

In preparing the vertical reference for the survey datasets, one must consider the various datum references and the sign and units of the data values. The files that are obtained from various sources are generally in positive elevations rather than positive depths, which is opposite from what is required in CMS. This information for each survey should accompany the data by means of a metadata file. Each of the six datasets have vertical references that are positive elevations.

An easy way to convert from elevations to depths is to use the *Data | Transform* tool (from the SMS pull-down menu) for each survey dataset in the data tree.

1. On the dialog, shown in Figure 27, select "Depths ←→ Elevations" and enter a water surface elevation (WSE) value of zero.
2. When OK is clicked, the signs of all values in that z-dataset will be reversed.
3. Repeat for all 6 survey datasets.
4. SAVE to overwrite the new z-dataset values.

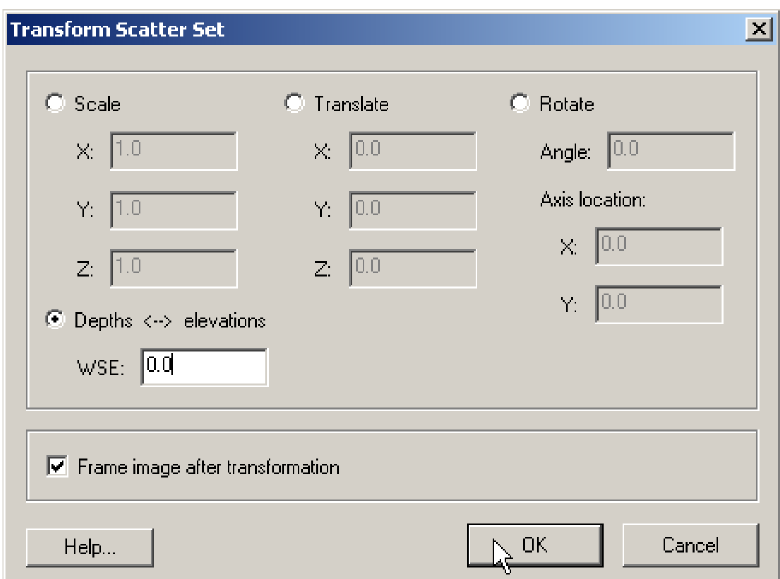


Figure 27. Transform dialog box.

Vertical Datums: Local and Regional

There are two types of vertical datums. Some use local references (e.g. mean low water, mean sea level, or mean higher high water) and others use national or regional references such as NAVD88. The National Oceanic and Atmospheric Administration (NOAA) website maintains a list of many US locations and offers a National Geodetic Datum benchmark sheet that explains the relationship between the available datums for a given location. Not all references are available at each location. A sample benchmark sheet for Long Branch Fishing Pier, NJ, NOAA station 8531991, is shown in Figure 28. These datum relationships are needed to convert from one to another. For example, for NOAA station 8531991, the value for mean lower low water (MLLW) is 19.00 ft and the value for mean sea level (MSL) is 21.44 ft. To convert from MLLW to MSL, the user must subtract desired vertical datum from the individual datum. So, to convert MLLW to MSL, the following expression must be evaluated: MSL – MLLW = 21.44 – 19.00 = +2.44 ft. This is generally easy to figure out for local datums.

Additionally, there may be additional benchmark information from where the survey was obtained that gives relationships for datums in the area. If one is provided, use this information over what is given by NOAA. It is often beneficial to draw a graphical representation of the relationships of the various benchmarks. One such diagram is shown in Figure 29 and shows both NOAA and the Corps of Engineers (COE) benchmarks for this region.

May 5 2010 14:45 **ELEVATIONS ON STATION DATUM**
National Ocean Service (NOAA)

Station: 8531991 **T.M.:** 75 W
Name: LONG BRANCH,FISHING PIER, NJ **Units:** Feet
Status: Accepted **Epoch:** 1983-2001

Datum	Value	Description
MHHW	23.93	Mean Higher-High Water
MHW	23.59	Mean High Water
DTL	21.46	Mean Diurnal Tide Level
MTL	21.39	Mean Tide Level
MSL	21.44	Mean Sea Level
MLW	19.19	Mean Low Water
MLLW	19.00	Mean Lower-Low Water
GT	4.93	Great Diurnal Range
MN	4.40	Mean Range of Tide
DHQ	0.34	Mean Diurnal High Water Inequality
DLQ	0.19	Mean Diurnal Low Water Inequality
HWI	12.26	Greenwich High Water Interval (in Hours)
LWI	6.04	Greenwich Low Water Interval (in Hours)
NAVD	21.68	North American Vertical Datum
Maximum	27.13	Highest Water Level on Station Datum
Max Date	19870102	Date Of Highest Water Level
Max Time	09:12	Time Of Highest Water Level
Minimum	14.40	Lowest Water Level on Station Datum
Min Date	19780110	Date Of Lowest Water Level
Min Time	21:00	Time Of Lowest Water Level

To refer Water Level Heights to a Tidal Datum, apply the desired Datum Value.

Click HERE for further station information including New Epoch products.

To refer Water Level Heights to either
NGVD (National Geodetic Vertical Datum of 1929) or
NAVD (North American Vertical Datum of 1988), apply the values located at:
National Geodetic Survey

Figure 28. NOAA Benchmark sheet for Long Branch Fishing Pier, NJ.

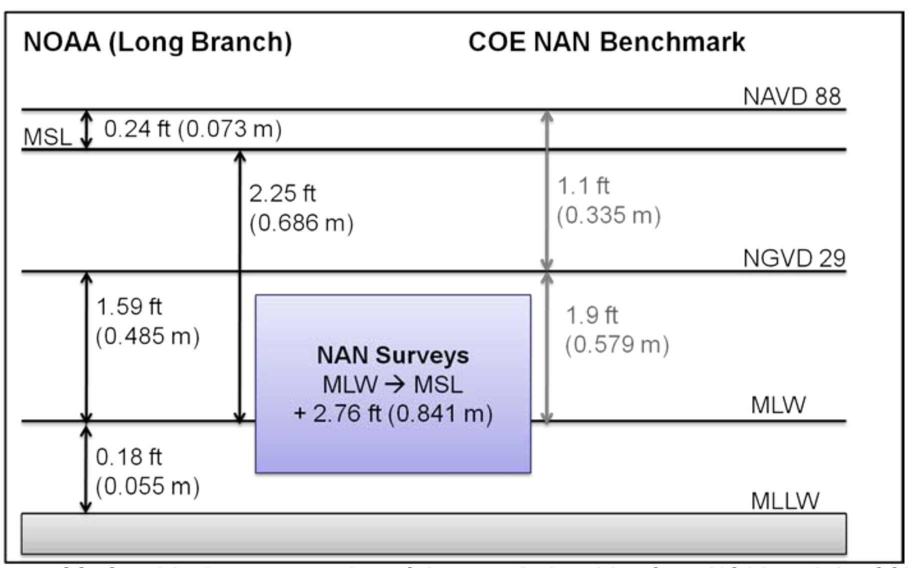


Figure 29. Graphical representation of datum relationships from NOAA and the COE.

Be aware that regional or national datums in some locations may be higher than MSL and in other locations be lower than MSL. All datasets must have both units and datums converted for modeling with the CMS. MSL in meters is the suggested vertical datum for bathymetry and forcing files in smaller estuaries or bays that do not experience variable tidal ranges or relative sea level rise rates. For Shark River Inlet, it is appropriate to use the local MSL datum. For larger reaches, such as the San Francisco Bay or the Chesapeake Bay, a common datum such as NAVD88 is most appropriate where multiple local datums may be applied to the local bathymetric/topographic datasets.

The following process is used to convert from one datum and unit (feet to meters) to another.

1. Select the "Channel_Survey..." dataset from the data tree.
2. Obtain necessary information about the data.
3. From Table 4, the datum for this file is MLW in feet.
4. From Table 4, the information can be derived to get the conversion from MLW to MSL.
5. In the COE Benchmark (right side), the distance from MWL to NAVD88 is 3.0 ft. No information is available for MSL.
6. From the NOAA Benchmark (left side), the distance from MSL to NAVD88 is 0.24 ft.
7. A combination of these two is used (3.0 ft – 0.24 ft) to get the total distance from MLW to MSL which is 2.76 ft.
8. The final column in Table 4 has been updated to reflect the conversion values for each survey.
9. Make sure you get the conversion value for the appropriate units (feet or meters) to change the datum reference. The next section covers changing the units from feet to meters, where necessary.
10. Choose Data | Dataset Toolbox from the SMS pull-down menu, shown in Figure 30.
11. Select "Data Calculator" and note the item assignment for the Z-dataset. It may be different on your computer than in this figure. In the figure, the item is assigned "d1". Select the Z dataset and choose "Add to expression".
12. For the expression in the "Calculator" blank, add the conversion information so that the expression reads "d1 + 2.76".

13. Give a new dataset name (bottom of middle pane) such as “MSL, ft” and click the “Compute” button. Do not hit Enter because we want to stay in this dialog for the next step.

Table 4. Survey list with Vertical Datum information.

Filename	**Vertical Datum, Units**	**Conversion to MSL (feet and meters)**
Channel_Survey_NJ-DEP_0609_ft_MLW.xyz	MLW, ft	2.76 ft
Coastal_Relief_Model_ll_m_msl	MSL, m (not accurate for nearshore)	--------
3364_0409_ft_MLW.xyz	MLW, ft	2.76 ft
LIDAR_ft_NAVD	NAVD88, ft	-0.24 ft
Field_Team_Measurements_0809_m_NAVD.xyz	NAVD88, m	-0.073 m
0.75m_Contour	MSL, m	--------

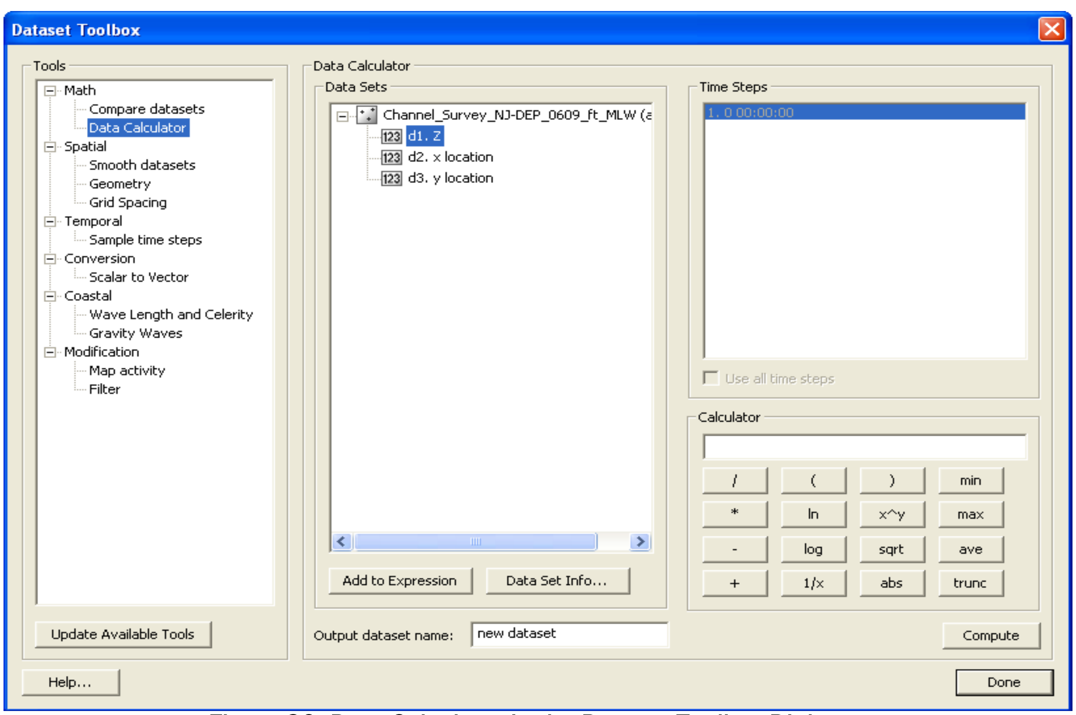


Figure 30. Data Calculator in the Dataset Toolbox Dialog.

14. From the dataset toolbox, you now see that there is a new entry listed and its assigned number is “d4”.
15. Now we want to convert this new dataset from feet to meters.
16. Select the new dataset and then hit “Add to Expression”.
17. Enter the conversion from feet to meters in the calculator expression blank, “d4 * 0.3048”.
18. Enter a new name for the converted units, such as “MSL, m” and hit “Compute”.

Repeat this process where appropriate for datasets loaded into SMS. The datasets “0.75m Contour” and “Coastal_Relief_Model_ll_m_msl” need no datum or unit conversion, since those datasets are already in MSL, m.

SAVE your progress before continuing.

Merging Multiple Surveys

When generating a CMS-Flow grid, a single, unified bathymetry set is needed to provide depth values for each cell. This tutorial has demonstrated how to bring in several surveys and perform horizontal reprojections and datum corrections. The next step is to merge all surveys together into this one full dataset.

Merging all scattersets will integrate all points. Overlapping areas of scattersets should either be deleted, or use a separate method of merging (by prioritizing using triangles). Figure 31 shows the SMS dialog for merging scattersets.

1. From the pull-down menu, select Scatter | Merge Sets.
2. Select each dataset by clicking the Merge check box next to each dataset or by choosing the “Select All” button.
3. For each dataset, manually select the appropriate dataset value to use for the merge (MSL, m). (The check box may need to be checked on/off manually to be able to select the ‘MSL, m’ dataset.)
4. Choose a name for the merged scatter set. The default is “Merged”.
5. Choose “Merge all scatter points” and click OK.

A thorough check of bathymetry is necessary, and will likely result in adding more data or deleting sections of unnecessary data to improve the final results of the merged file. For example, where the fine resolution beach data meets the coarse offshore data there may be an offset in the vertical position of those points. In this case, either the datums were not properly set, or the offshore dataset may potentially be off in precision due to its original averaging of this complex area. The finer resolution beach bathymetry is preferred, and the user may manually delete sections of the offshore dataset prior to merging so that the unified bathymetry will have a smooth transition between the datasets.

In the Grid Generation Section, we will be loading a different set of files where all of the conversions and merging has already been completed.

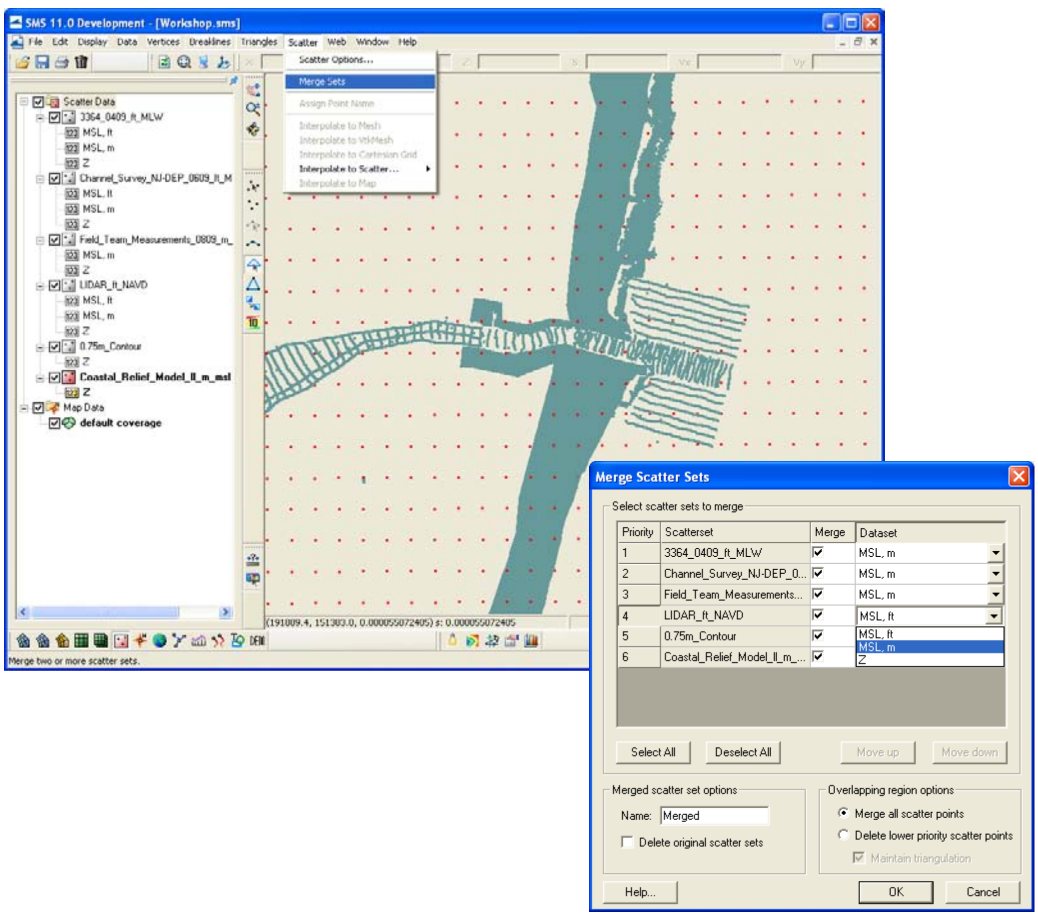


Figure 31. Merge scatter points dialog.

Once the merge has been checked and verified, and you are satisfied with the results, you can delete the old datasets from the SMS data tree since they are no longer needed. Removing from the data tree will not erase the actual file, it is only deleted from memory and when the next Save of the project is made, these datasets will no longer be brought back into the datatree. SAVE your project.

Additionally, the final merged bathymetry can be enhanced to produce optimal Triangular Integrated Network (TIN) visualized scatterset bathymetry or grided bathymetry through post-processesing tools. One such tool is the breakline, which forces the triangulation between two points to be fixed on the interpolated value from point to point. That is, triangulation over largely-spaced points will not be affected by a nearby region of multiple points; or, a channel with transect bathymetry can be longitudinally defined through breaklines as seen in Figure 32.

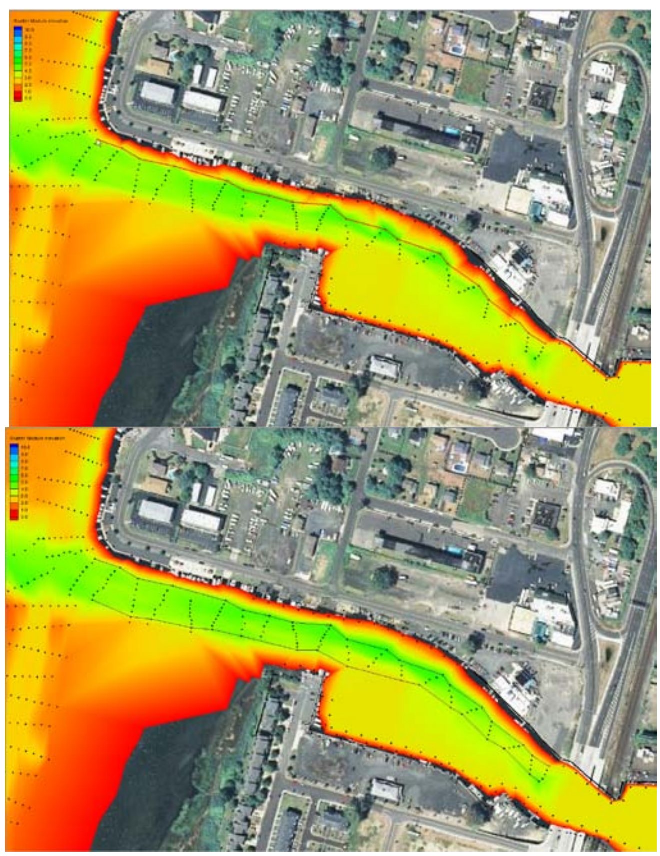


Figure 32. Before (top) and after (bottom) breaklines are forced longitudinally along a channel.

Important Notes:

- A good merged bathymetric dataset is often the result of spending 50% of the time it takes to get the model up and running just on checking and cleaning up the bathymetry alone. If a significant amount of time is spent paying attention to detail, there will be less instability problems in the hydrodynamic model which are difficult to trace back to the source.
- Always double check that you have calculated your datum corrections very carefully by analyzing and comparing to nearby datasets.
- When merging bathymetry, try both methods to combine the datasets and evaluate for depth consistency and dataset coverage.
- Save often, and occasionally save new versions of your merge-testing in new folders. If you delete too much of one dataset, its useful to have the older, datum converted and unaltered datasets.

Computational Grids

Cartesian Grid Module

The Cartesian Grid Module contains tools for creating and editing Cartesian grids. SMS supports regular and nonuniform Cartesian grids as well as regular and stretched telescoping grids (see Figure 33).

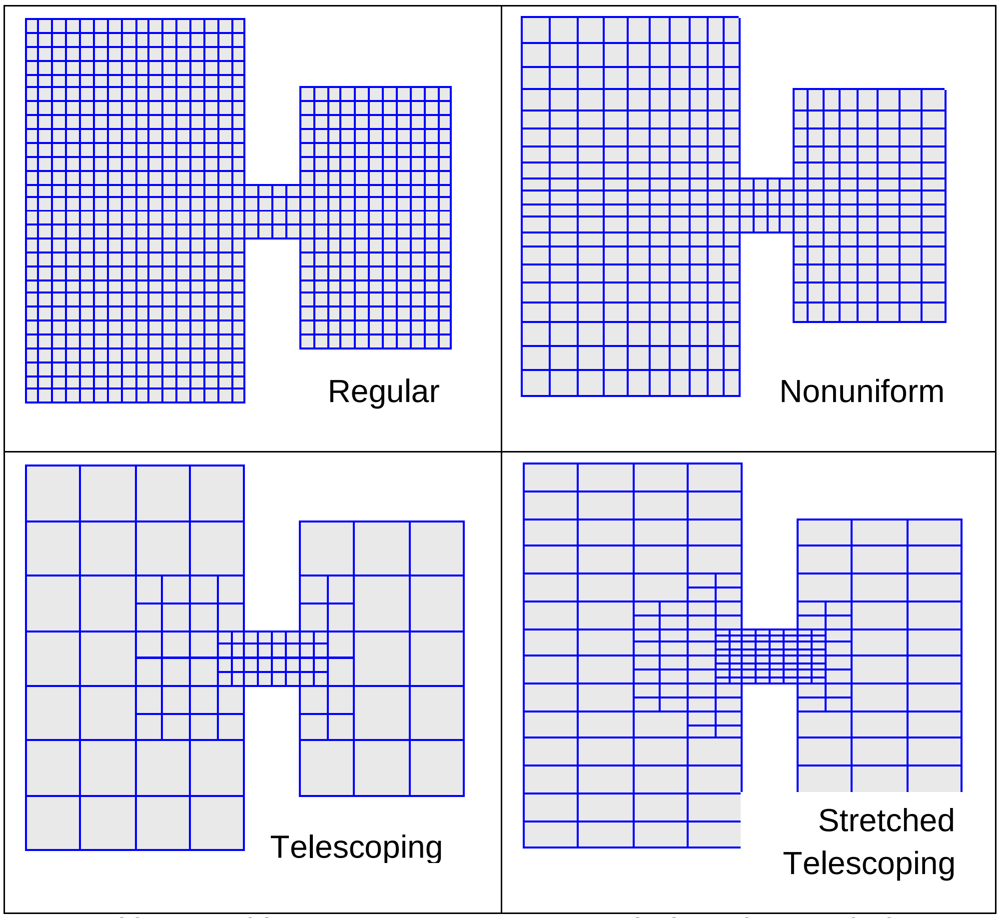


Figure 33. Types of Cartesian grids supported by the SMS interface and CMS-Flow.

Regular Cartesian grids are the easiest to generate making them useful for feasibility type studies, simple field cases, or test runs for more complicated field cases. Nonuniform Cartesian grids allow local refinement by gradually varying the grid spacing. These grids are offer more flexibility than regular Cartesian grids for a relatively low additional cost in generation. Nonuniform Cartesian grids are available for both CMS-Flow and CMS-Wave. For large complex modeling domains, Telescoping grids offer the most flexibility by providing local refine through the the subdivision or splitting of cells into four. In many cases, the hydrodynamics can be alighned with one of the Cartesian coordinates. For these cases, the number of grid cells can be reduced by using a stretched Telescoping grid. Currently in SMS, the stretched Telescoping grids can only have a constant aspect ratio between the grid resolution in the *x* and *y* directions.

Create 2D Grid Frame

The 2D Cartesian Grid Frame (purple box) creation tool allows the user to visually specify the location and orientation of the grid in space. To create a grid frame, simple click three times to the desired length and width dimensions. SMS will complete the rectangle.

Select 2D Grid Frame

A 2D Cartesian Grid Frame can be modified with this selection tool. Once the frame is generated, the edges can be modified, the grid can be rotated (by selecting a small circle usually found in the lower left part of the grid), and the grid can be selected (middle black square) for manipulating location or opening the Grid Properties dialog box.

An existing grid can be read in from a CMS-M2D simulation file, or created through the Map Module. To enter the Cartesian Grid Module from another module, select *Cartesian Grid Data* from the Data Tree. With a grid in memory, the following tools are available to edit the grid:

Select Cell

The *Select Cell* tool is used to select a grid cell. A single cell is selected by clicking on it. A second cell can be added to the selection list by holding the SHIFT key while selecting it. Multiple cells can be selected at once by dragging a box around them. A selected cell can be de-selected by holding the SHIFT key as it is clicked. When a single cell is selected, its *Z* coordinate is shown in the Edit Window. The *Z* coordinate can be changed by typing a new value in the edit field, which updates the depth function. If multiple cells are selected, the *Z* coordinate field in the Edit Window shows the average depth of all selected cells. If this value is changed, the new value will be assigned to all selected cells. With one cell selected, the Edit Window shows the cells *i,j* location. With multiple cells selected, the Edit Window shows the number of selected cells.

Select Row/ Select Column

The *Select Row* and *Select Column* tools are used to select cell rows and columns, respectively. Multiple rows and columns are selected in the same manner as selecting multiple individual cells: holding the SHIFT key, etc.

Insert Column/ Insert Row

When the *Insert Column* or *Insert Row* tools are active, clicking within a cell splits the row/column containing the selected cell, creating a new row or column in the grid. The Z-values of all split cells are the same as the original cells' values.

Drag Column/ Drag Row Boundary

The position of the edge of rows or columns in a grid can be changed with the *Drag Column* or *Drag Row* tools. These tools make one column/row narrower while making its neighbor wider. These tools allow for manual specification of the resolution in specific portions of the grid. Note that depth values are not adjusted, so significant dragging of boundaries should be avoided or depths should be re-interpolated after the boundaries are modified.

Create Cell String

The *Create Cell String* tool allows the modeler to group a string of cells together for the purpose of assigning boundary conditions. Cell strings are created automatically around water boundaries when a grid is generated. The user may create others as desired or delete and replace the automatically generated cell strings. When the *Create Cell String* tool is active, the modeler selects each cell to be added to the string. By holding down the SHIFT key, all boundary cells between the previously selected cell and the selected cell are added to the cell string.

Select Cell String

To specify a boundary condition, the modeler must create a cell string along the desired boundary cells, and then select the cell string while the *Select Cell String* tool is active. Specification of a boundary condition for the selected cell string is conducted through the *Assign BC* dialog, which is accessed through the CMS-M2D pull-down menu.

CMS-Flow Grid Files and Cards

When a CMS-Flow grid is saved, SMS writes a *CMS-Flow Grid File* named "*_grid.h5". If the grid is non-telescoping, this file contains the *x* and *y* coordinates as well as the water depths. If a telescoping grid is saved, then the SMS saves multiple-grids in the *CMS-Flow XMDF Grid File* which correspond to different levels of resolution of the telescoping grid. This information is only used by SMS. The information used in CMS when saving a telescoping grid is saved in the CMS-Flow Telescoping Grid File with the extension "*.tel". The *Telescoping Grid File* contains the cell coordinates, resolution, connectivity and water depths. A description of *XMDF Grid File* and the *Telescoping Grid File* along with Matlab scripts for reading these files are provided in Appendix B.

Table 5 provides a descryption of the CMS-Flow cards used to specify the grid information in CMS.

Table 5. CMS-Flow cards related to the grid specification and options.

Card	Arguments	Default/Format	Description
GRID_FILE	character character	"[case name]_grid.h5"	File name (including path if not the same as the executable) of the CMS-Flow XMDF Grid File. For a description of the file see XMDF CMS-Flow Grid File (*_grid.h5).
TELESCOPING	character	"[case name].tel"	File name (including path if not the same as the executable) of the CMS-Flow Telescoping Grid File ASCII Telescoping Grid File (*.tel).
GRID_ANGLE	real	none	Specifies the grid angle measured counter-clockwise from the the East direction to thegrid *i*-axis (*x*-axis).
GRID_ORIGIN_X	real	none	Specifies the *x*-coordinate of the grid origin.
GRID_ORIGIN_Y	real	none	Specifies the *y*-coordinate of the grid origin.
BATHYMETRY_DATASET	character character	"[case name]_grid.h5" "[case name]/Datasets/Depth"	Specifies the file name and path of the bathymetry dataset. Depths are specified as positive values.

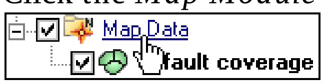
Important Notes:

- The grid angle specified in the Card File and the Telescoping Grid File use different convensions (unfortunately). The angle in the Card file is measured counter-clockwise from the East direction to the grid *x*-axis, while the angle in the *Telescoping Grid File* is measured clock-wise also from the East direction to the grid *x*-axis.
- By default the *XMDF Grid File* also contains the bathymetry and other spatial datasets including the the bottom friction, hard bottom, D50, etc. However, these datasets can be specified in separate files.
- If a telescoping grid is used, the bathymetry is included by default in both the *XMDF Grid File* and the *Telescoping Grid File*. However, the depths in the in Telescoping Grid have -999 values for inactive cells. These cells are internally removed from the computational grid. Therefore, when using telescoping grids, only the depth values in the *Telescoping Grid File* are used by CMS.

Creating a CMS-Flow Nonuniform Cartesian Grid

Two grid options, constant and refined cell spacing, will run at more optimal speeds than a large project area such as a West Coast inlet or river mouth. Nevertheless, the refined option provides for more optimal CMS runtimes. The main inlet channel is the primary area of focus for capturing the correct current velocity with finer resolution, and should have 8-12 cells across it, limiting the cell size down to at least 10 m in the entrance channel. The two main back channels splitting off of the entrance, the north and south channel, also have large velocities (the north channel actually has the strongest current) and should be represented by at least several cells in width (minimum of 5 m in the narrow north channel).

Setting Refine Points.

1. Click the *Map Module* button, or Map Data


2. Right-click on *default coverage*, and under *Type*, *Models*, select *CMS-Flow*,
3. Click the *Feature Point* button to generate Refine Points, and place points in area of refinement, focusing on the end of the jetty tips and down the entrance channel (setting maybe 2 to 4 points) and with varying resolution with larger base cell sizes for the area near the back bay since that area does not need as fine of resolution for flooding and drying,
4. Click the *Feature Point Selection* button and select the generated point or points, Rt-click and click on *Node Attributes* (Figure 34), and set the base cell size for the area of the grid where the points are located.
5. The undo function does not yet exist in SMS, so be sure to save the project periodically (*Save Project*).

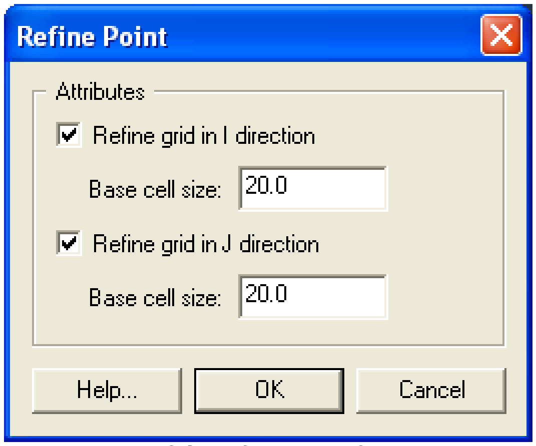
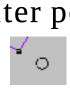


Figure 34. Refine Point Options.

Next, the grid boundary is set square to the general orientation of the coastline, with the computational direction, I & J (or IJ triad), set according to the model type. For the CMS-Flow coverage (which was selected in step 2), the point of origin will be automatically placed in the lower left corner of the grid after the grid has been created. This is default for CMS-Flow. This means that for most Atlantic coast (east facing) projects the IJ triad will be located over land on the lower left corner. Do not change the direction of the IJ, because this is specific to CMS-Flow.

Generating the Cartesian Grid.

1. Click the Create 2-D Grid Frame button 
2. Draw two legs of the rectangular boundary for the model domain by clicking the lower-right ocean boundary corner point, then the upper ocean boundary corner, and then the upper landward boundary corner to close the box.
3. Use the Select 2-D Grid Frame button  to select the center point of the purple outlined grid domain, adjust the edges by dragging the center point of each edge, and change the orientation by selecting the  at the corner of the grid (Note that the IJ triad should be in the lower left corner),
4. Right-click the highlighted center button and click Properties to further modify the dimensions of the grid boundary (Figure 35),

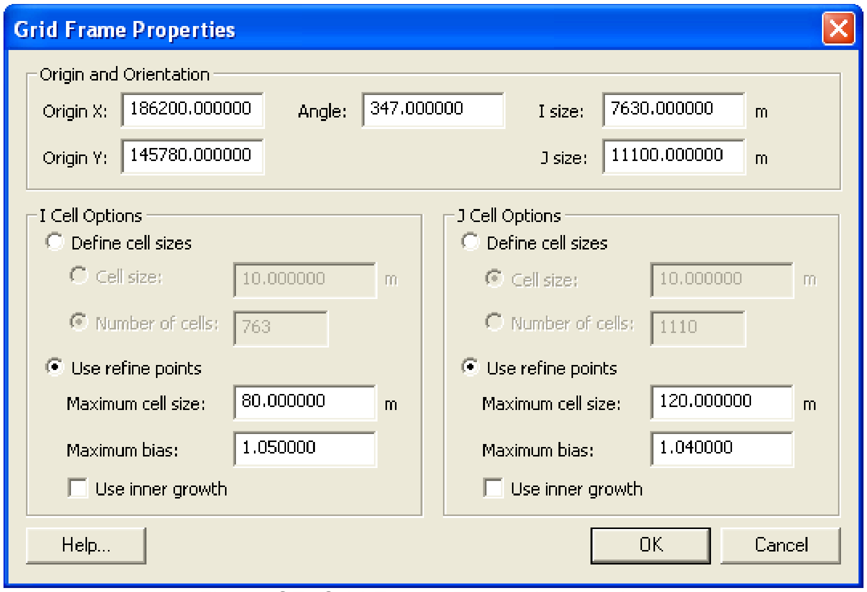


Figure 35. Grid Frame Properties window.

5. Correct the angle orientation if it is far from 347° (the general orientation of the coastline is 13 deg from North), and set the I and J Cell Options to *Use Refine Points* and choose a maximum cell size and bias (cell sizes increase in distance away from refine points), click *OK*,
6. Click *Feature Objects*, *Map*→*2D Grid*, and check that all the grid properties are set properly, *Use inner growth* is turned off, the *Interpolated Depth* (Figure 36) from the merged file is selected, and define an elevation cutoff where cells will be non-computational land cells (i.e., these cells will always be dry and act as a wall) (Figure 37), click *OK*.

Generating the first refined grid typically takes some trial and error testing to see how the grid looks. Be sure to modify the refine points to address areas of concern, particularly the number of cells across the entrance, north, and south channels, and groin cell width toward the lateral boundaries. Note that both the I and J directions do not need to be specified for each refine point, if refining only one direction is required.

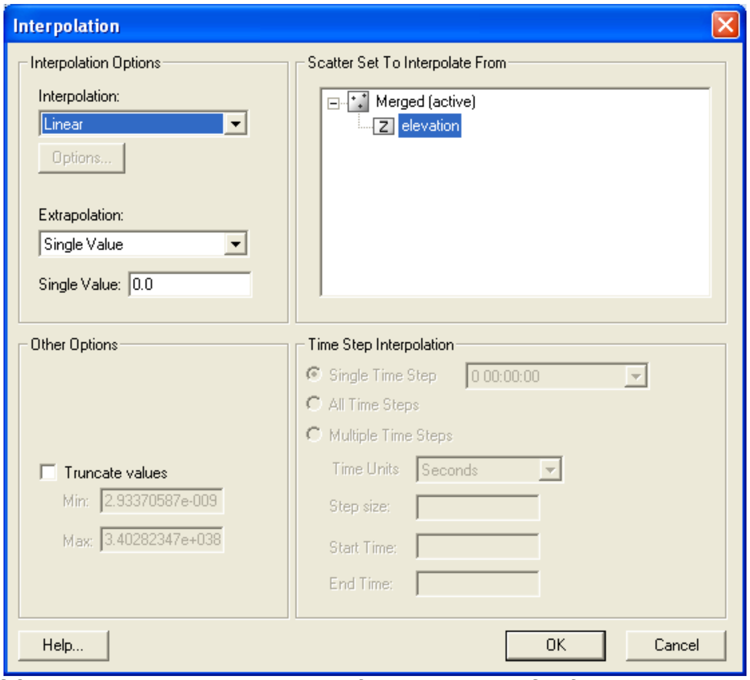


Figure 36. Depth Interpolation options for the Map –> 2D function. Make sure to choose the Depth scalar dataset.

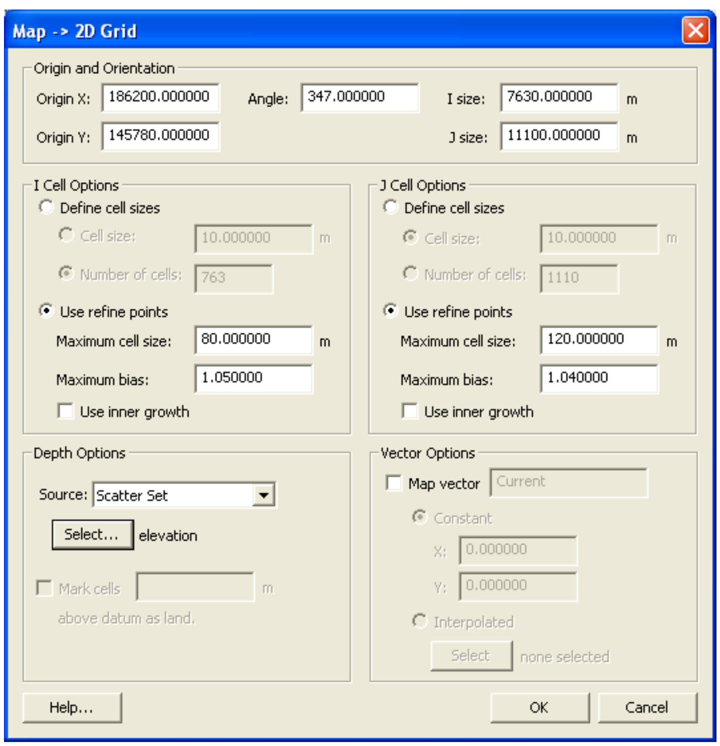


Figure 37. Map -> 2D Grid options.

After the grid is generated, two pop ups warn of overlapping cellstrings and land-locked ocean cells. These land-locked ocean cells that are not to be in the computation should be changed to inactive land cells. Also, the bay should be bound by land cells, and so any open 'ocean' cells in the bay that lie on the grid boundary should similarly be changed to land cells.

To account for beach or berm cells to be wetted along the shoreline (cells with elevations higher than the land cell cutoff set in the grid generation section), sections of the beach should be changed to *Active Ocean* cells. This is difficult for Shark River because of the dense spacing of the groins as well as the fact that many of them are notched. Much of this information was retained in the LIDAR and subsequent generation of the bathymetric set provided for this example.

Address Warnings: Fix Land-Locked Cells and Cellstring Warnings for the CMS-Flow Grid.

7. For changing land-locked ocean cells to land cells, click the *Select Grid Cell* button  if not already highlighted, and change the Z number to -1.0 (Figure 38), or manually select cells by dragging the mouse over the target ocean cells and change the Z.
8. Right-click on the cells, select *Cell Attributes* (Figure 39), and change the cell type from *Active Ocean* to *Inactive Land* cells, click *OK*,

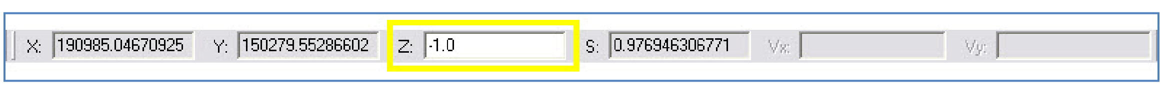


Figure 38. Toolbar at top of SMS window containing the X,Y,Z, and S (scalar quantity) of the selected cell or an average Z of multiple selected cells.

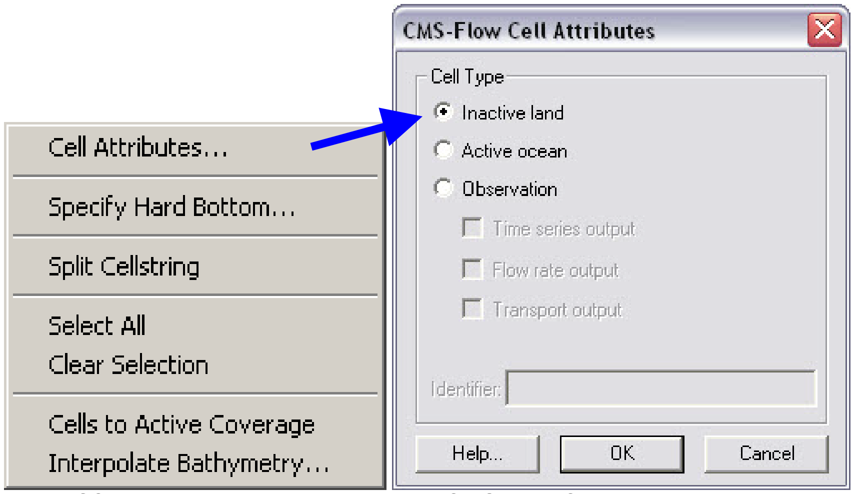
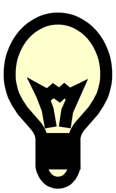


Figure 39. Right-click drop down menu; CMS-Flow Cell Attributes (cell type).

9. The same process can be done for ocean cells that need to be changed to land cells along the bay edges (an aerial image will be useful for determining the proper widths of the channels); a simple way to check the entire land boundary is to use a directional selection method: hold down *ctrl* and click and drag the mouse along the outer edges of the landward side of the domain to highlight large sections.



Tips:

10. To grab multiple areas, hold down shift while selecting new cells, and all will stay highlighted.
11. To change large sections of nearshore/beach cells that are land cells, select them with a polygon by clicking *Edit, Select with Poly* (clicking *Crtl + Shift* also initiates selecting by a polygon), and click a polygon covering a few cells across the ocean/land interface along a section of beach from groin to groin, and change to *Active Ocean* cells.
12. Change all required stretches of beach to ocean, and check that the landward grid boundaries have all inactive cells.
13. Select the *Select Cellstring*  button and drag over the bay side of the grid to highlight the cellstrings generated there, and click delete (Figure 40),
14. Click *Edit, Select All* (*Ctrl+A*), and check to see if only the one ocean cellstring remains, delete all others.

As always, be sure to save the project to save the grid files, which are otherwise stored temporarily. Note that all files currently opened in the SMS will be saved over and may be recreated in the folder (with a 2 behind it).

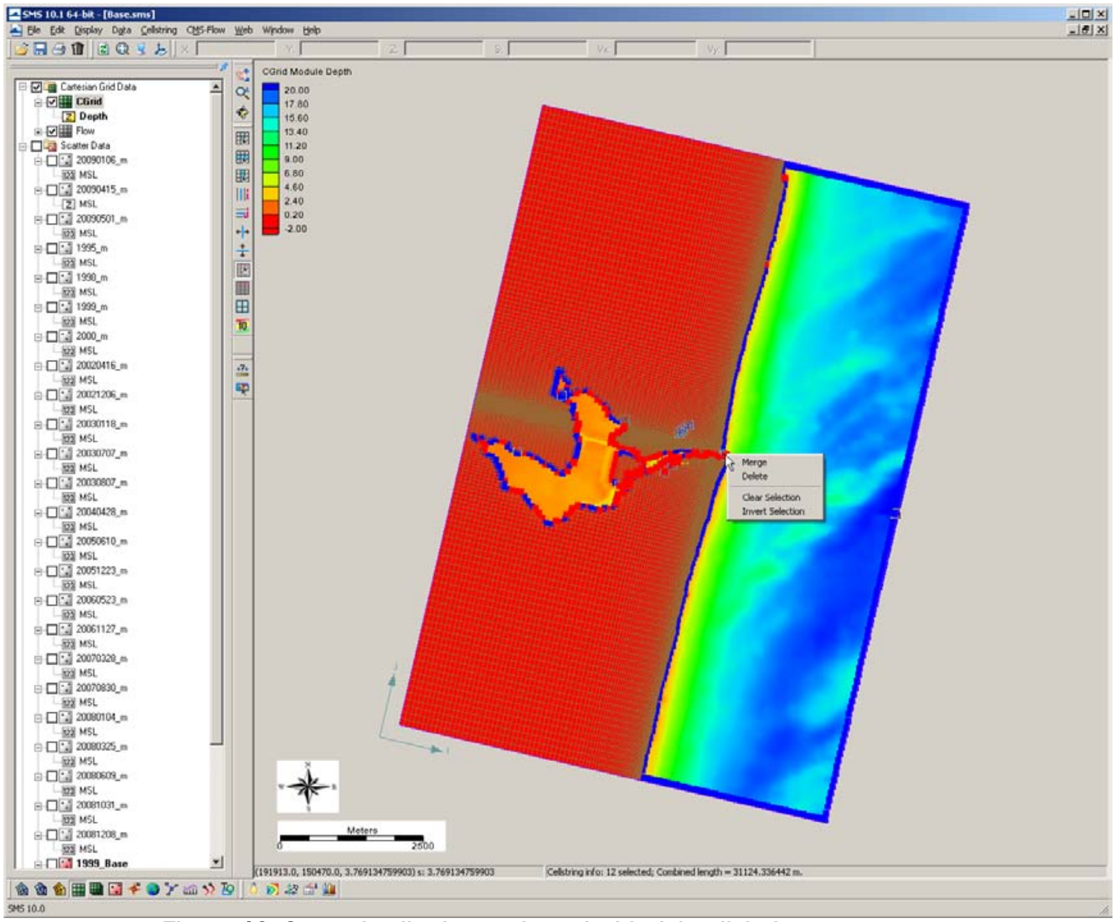


Figure 40. Several cellstrings selected with right-click drop menu.

Creating a CMS-Flow Telescoping Grid

The telescoping grid capability was introduced in SMS 11.0 for CMS-Flow Inline (Implicit) V4.0. Also referred to as a quadtree grid, the telescoping grid offers local grid refinement with low effort and very clear visualized boundaries of refinement. In a telescoping grid, local refinement is achieved by subdividing a rectangular cell into four cells. The grid can be arranged as block-structured or rectilinear block-structured. This improved user-defined refinement allows for small scale accuracy of one or more areas of interest or a region with limited spatial extent in a very large, regional domain. Having more expansive domains allows the user to include more coastal environmental forcing that play a role in the hydrodynamics and morphodynamics of an area. As an example, a multi-inlet system can now include several inlets that serve one bay, but only truly refine one particular inlet of interest.

In the case of Shark River Inlet, a telescoping grid is used because of its flexibility in having very small computational cells for the narrow inlet throat that quickly coarsen in refinement to large cells, which allow for extending the lateral domain to capture more of the littoral zone that is dominated by structures. Because of the refinement within the inlet and the structured beaches, the computational efficiency is improved without reducing accuracy at these key coastal features.

The main inlet channel at Shark River is the primary area of focus for calculating the correct current velocity, and should have 8-12 cells across it. The general rule of thumb for any major channel carrying flow is for it to have at least 10 cells across to better define the horizontal (2D) processes. CMS-Flow Inline (Implicit) requires a passageway, river entrance, or channel to have a minimum width of 3 cells. The two main back channels splitting off of the entrance, the north and south channels, each carry half of the tidal prism and therefore also have large velocities. The north channel actually has the strongest current because it is narrower, yet is the closest route to the north portion of the bay. Both these channels should be represented by at least five cells in width.

Set Project & Bathymetry Projection.

1. Choose *Edit*, *Projection* from the pull down menu. The resulting dialog is shown in Figure 41.

2. Click "Set Projection" and choose Projection - State Plane Coordinate System, Zone - New Jersey, Planar Units – Meters, Datum NAD83.

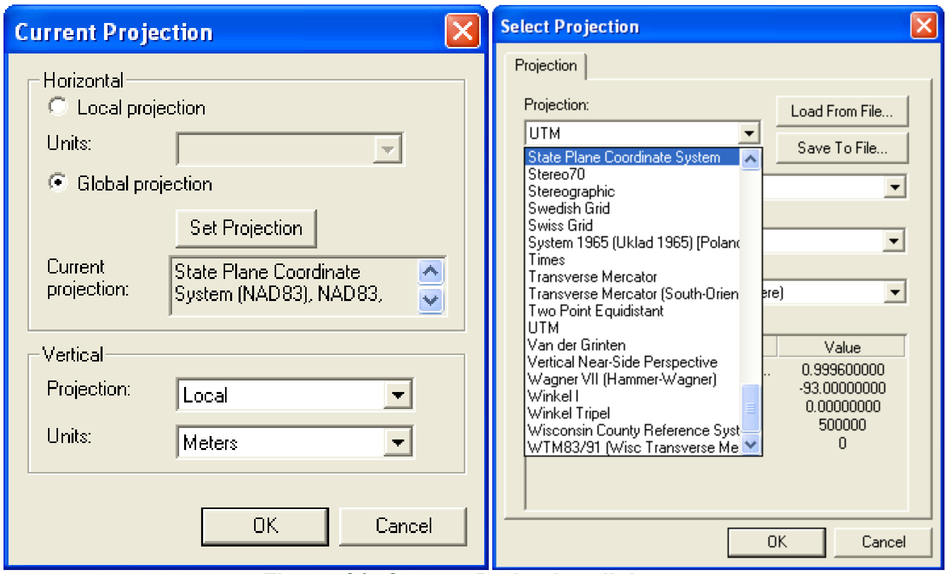
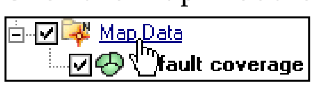
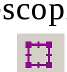
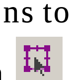
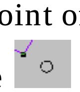


Figure 41. Current Projection dialogs.

To create a new CMS-Flow Grid, you must first bring your final bathymetric dataset (merged) into the metric projection you will be working in.

Define Map Module Coverage & Create a Grid Frame.

3. Click the Map Module button , or Map Data, 

. Right-click on default coverage, and under Type, Models, select CMS-Flow. Now there is the option to create either a refined, rectilinear grid or a telescoping grid.
4. Click the Create 2-D Grid Frame button, , draw two legs of the rectangular boundary for the model domain by clicking the lower ocean boundary corner point, then the lower landward boundary corner, and then the upper landward boundary corner to close the box.
5. If modifications to the grid are desired, use the Select 2-D Grid Frame button  to select the center point of the purple outlined grid domain, adjust the edges by dragging the center point of each edge, and change the orientation by selecting the circle  at the corner of the grid.

6. Right-click the highlighted center button and click Properties to further modify the dimensions of the grid boundary (Figure 42).

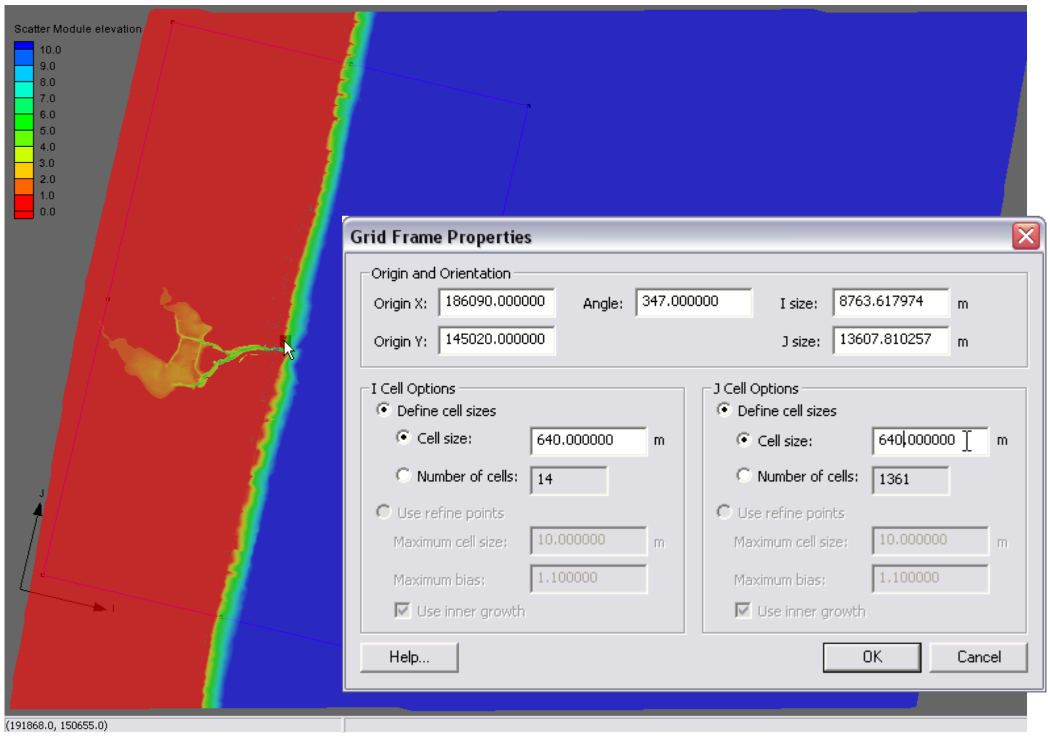


Figure 42. Grid Frame Properties dialog with settings for telescoping grid generation.

Define Refinements through Polygons.

A telescoping grid is developed by using polygons to specify the local resolution to areas. Ideally, a Polyline is used or drawn to delineate the non-computational (land) area first, and then subsequent polygons that require finer resolution are added. This section describes one methodology used to refine the channel inlet and littoral zone. Resolution can be added anywhere the user thinks there will be high flow or significant morphologic change.

First, create an arc that delineates the non-computational land (anything higher than the tidal range or potential storm surge reach), and close this off along the landward or backside of the domain. Be sure to extend this polygon beyond the extent (purple line) of the future grid (Figure 43).

How to Close an Arc: If the arc does not snap to close the polygon, confirm this by zooming close to the connection. The feature point, , at the end of the arc can be dragged to the line, and preferably overlain on another node or feature point. Select Feature Object, Clean, and check Snap Nodes and Vertices, select OK, and click on the two feature points to complete the connection. Now if you try to drag the feature point it should drag the arcs from both lines because they are connected.

Vertices can be added manually, , between the feature points, and the arcs can be moved as the user specifies.

Bring in the “SRI_LandOnly.map” file to skip this step.

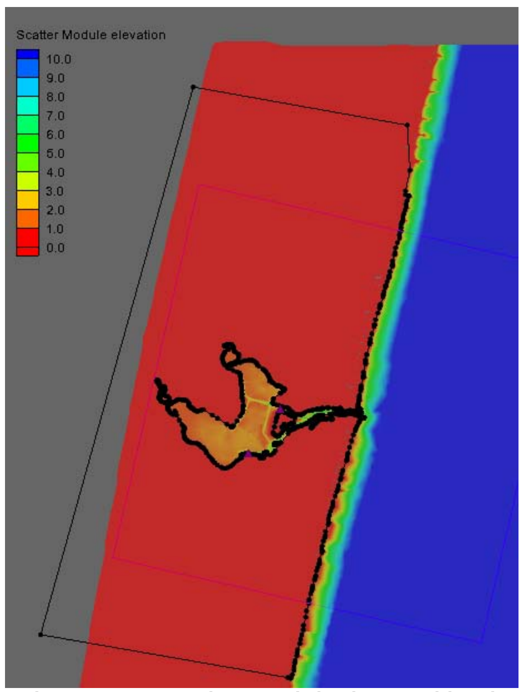


Figure 43. Land polygon generated around the bay and landward of the beach.

Build Polygons.

A rule of thumb for designing the polygons is to make sure that the area being refined will be at least 3-4 cells wide. When generating the arcs, keep the resolution size in mind when deciding how far apart to make each polygon.

Create small refinement polygons around the areas of interest. Based on experience or previous simulations, place more resolution in areas with complex hydrodynamics. Next, add feature arcs that cover the nearshore zone (Figure 44, left). Because the resolution is decreasing seaward, i.e. the cell sizes will become larger with polygons further offshore, the distance between arcs should be increasing seaward to accommodate 3-4 cells in the transition.

It is important that all arcs create closed areas that can be used to later generate polygons.

When drawing the polygons around the inlet, be sure that each polygon expands much further offshore to accommodate the needed resolution to reproduce the ebb jet (Figure 44, right). Some arcs will need to close in the nearshore if they are much finer than the rest of your littoral zone.

In Figure 45, the bay has been divided up to keep the finer resolution in the north and south channels, increasing in size (decreasing in resolution) towards the middle of the open bay.

Finer resolution is necessary along most estuary shorelines to properly model the wetting and drying due to the tidal range. This is done for Shark River Estuary for example, but is not necessary for much of the shoreline because it is structured (with seawalls).

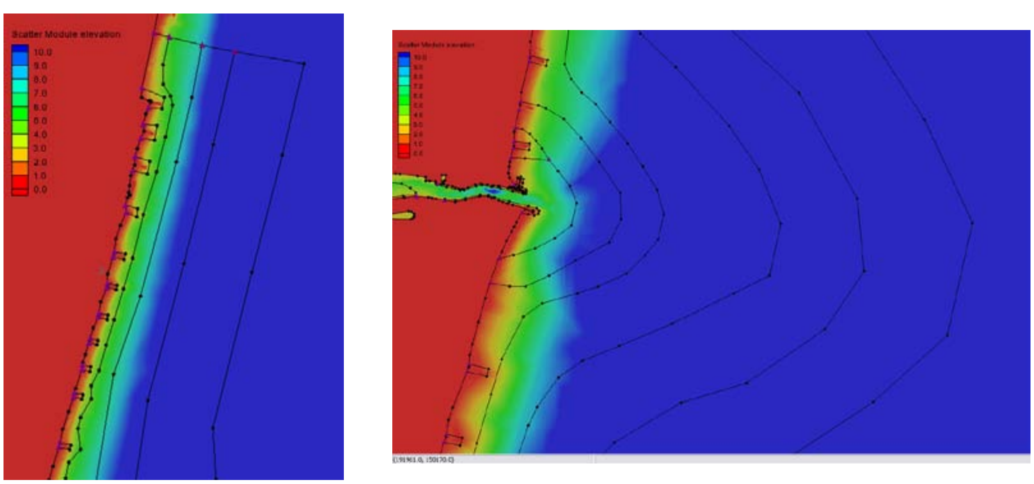


Figure 44. Left: resolution added to the nearshore with the finest resolution around the groins, with increasing distance moving seaward, from arc to arc. Right: continuation of the polygons around the inlet region that expand further offshore to accommodate the needed resolution to reproduce the ebb jet.

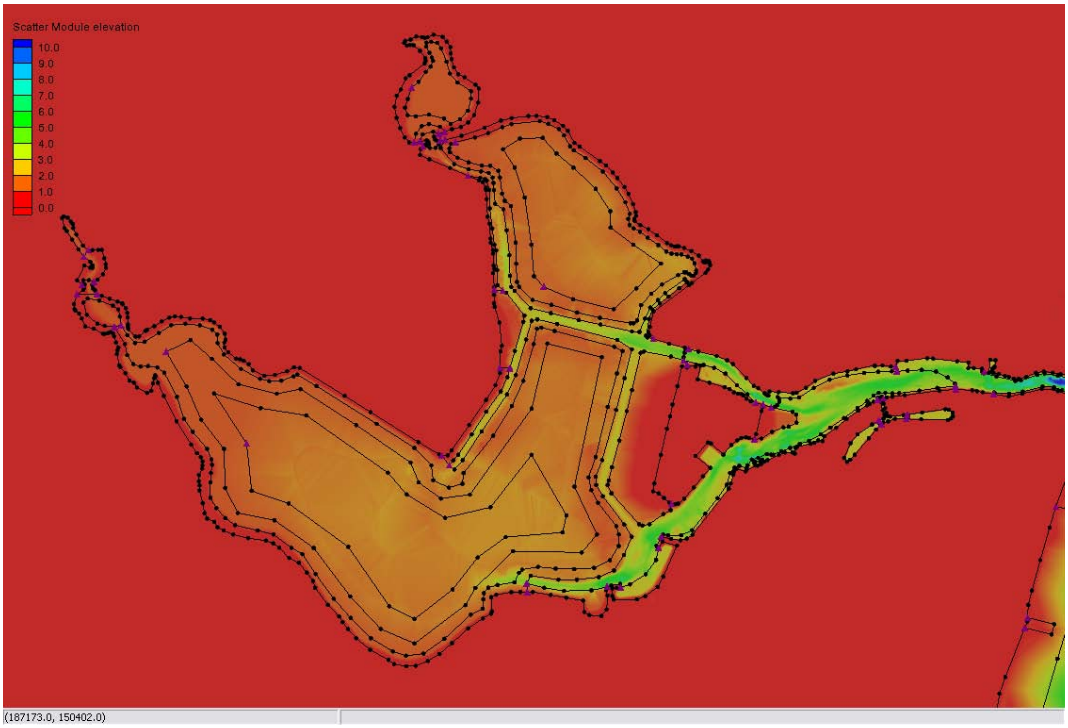


Figure 45. Telescoping polygons within the bay. Note the decreasing resolution in the bay means wider polygons.

Once the arcs have been created, the enclosed areas are converted to polygons. These polygons can then be selected and their attributes changed to create the desired telescoped cell size. It's suggested to start with the smallest resolution and work outward. This approach will facilitate finding any issues or constraints with how many polygons you have made in the bay, inlet, and nearshore.

Convert Feature Arcs to Feature Polygons by selecting Feature Objects, Build Polygons (Figure 46). If a polygon isn't created for one of your arcs, it is likely that the arc doesn't completely close (see above section on 'How to Close and Arc').

Assign resolution values to all ocean polygons, and designate appropriate polygons as land by double clicking the polygon, or, click on the select feature polygon tool, .

Right-click on a polygon to assign resolution, select Attributes, and specify the telescoping grid cell size desired for the polygon. Repeat for all polygons in the domain.

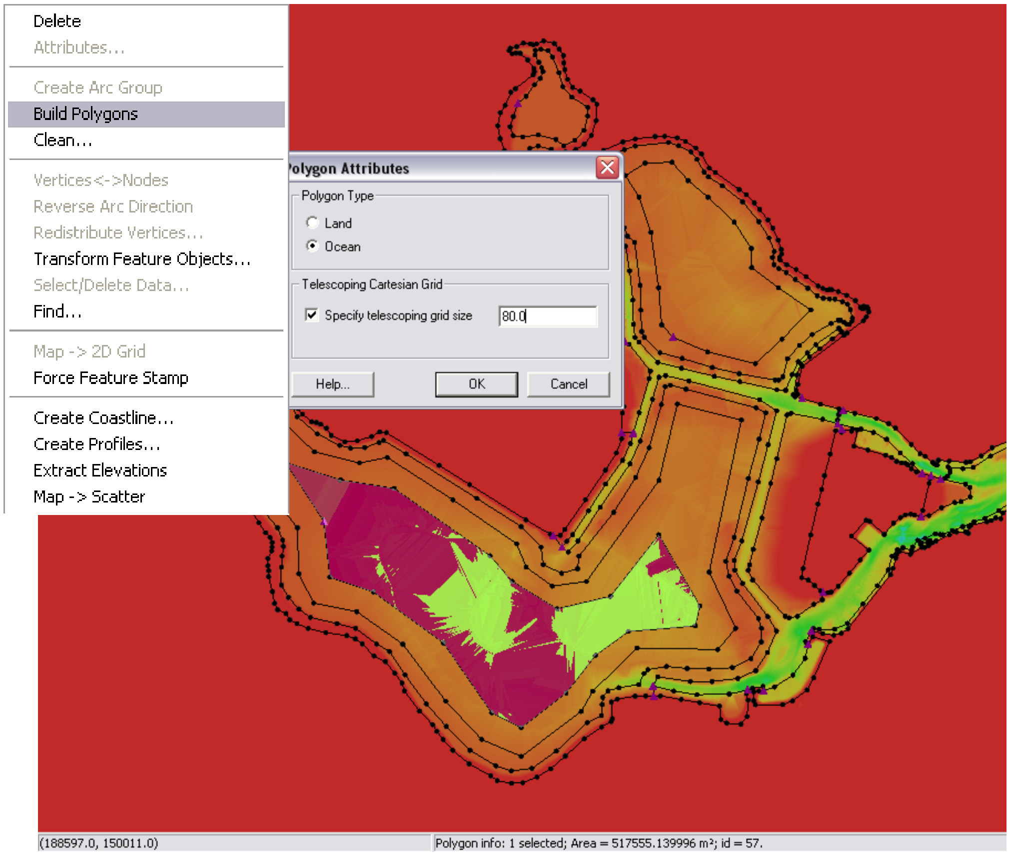


Figure 46. Note the decreasing resolution in the bay means wider polygons.

Generating the Telescoping Grid.

Generate Telescoping grid by right-clicking on Default Coverage, selecting Convert, Map>2D Grid, then defining I and J cell options for the telescoping grid (Figure 47)

Select the elevation from the merged bathymetry. There is no need to "mark cells above datum as land" because the polygons have already delineated the land areas.

Generating the final telescoping grid typically takes some trial and error, testing to see how the grid looks, and refining the polygons. Be sure to modify the polygons to address areas of concern, particularly the number of cells across the entrance, north, and south channels, and groin cell width toward the lateral boundaries.

Figure 48 illustrates the grid with the bathymetry contours turned on, and a zoomed in look at the highly resolved bathymetry around the inlet. Note that there are at least 10 cells across the inlet entrance channel. Figure 49 illustrates what the final grid looks like with the Cartesian cells outlined in blue (ocean) and brown (land).

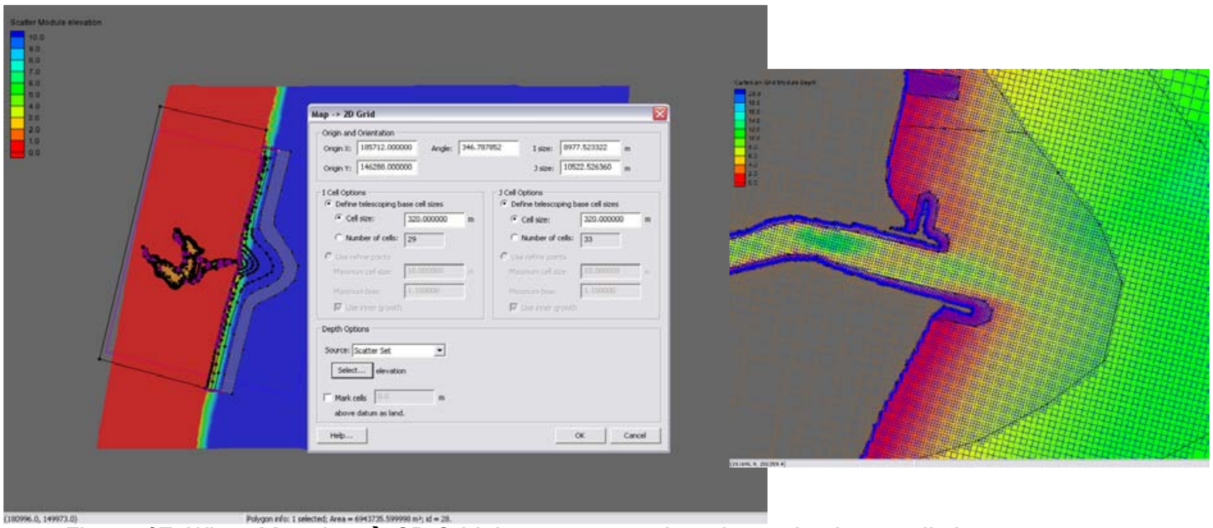


Figure 47. When Mapping → 2D Grid, be sure to set the telescoping base cell size to the maximum cell size the grid will automatically generate for non specified reaches.

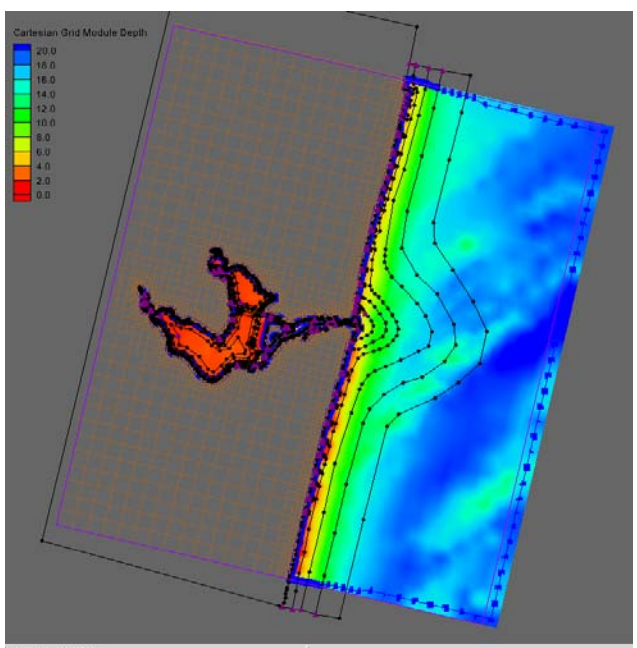


Figure 48. Grid showing bathymetry with arcs overlain. The blue-square line around the offshore boundary serves as the boundary condition “cellstring”. A close zoom to the inlet illustrates the fine resolution around the structures and across the inlet entrance channel.

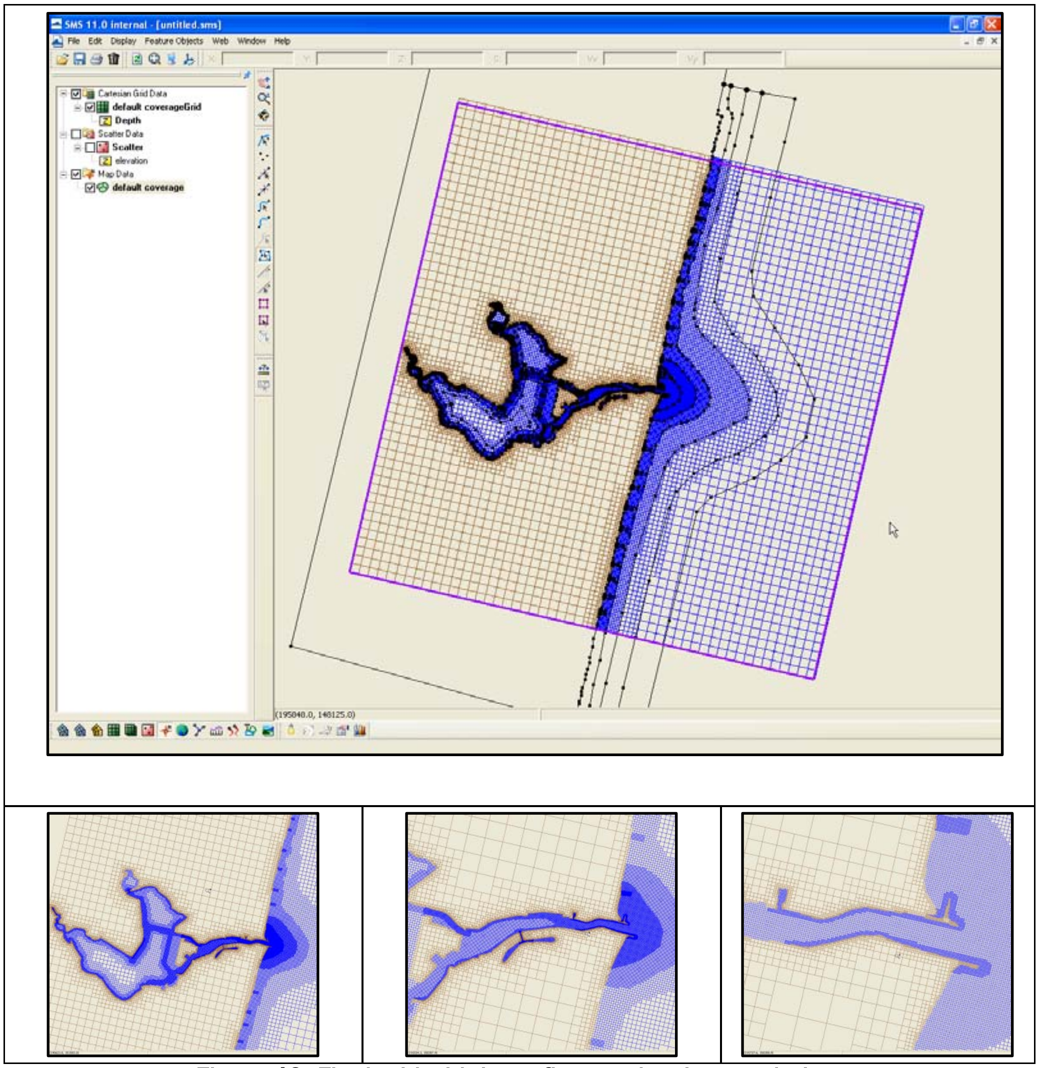


Figure 49. Final grid with inset figures showing resolution.

Important Note:

- After flawed bathymetry, grid resolution is the next most common issue related to hydrodynamic stability and accuracy. Without prior knowledge of the special hydrodynamics, the model has to be run before more inferences can be made about grid resolution. Trial and error is a part of this process and very necessary.

CMS-Wave Grid Generation

Now that all modifications to the CMS-Flow grid alternatives have been finalized, the wave grid can be generated from the Flow grid. CMS-Wave grids are typically generated from scatter datasets, but can be a mirror image of the flow grid if the boundary condition (BC) locations are close enough to force both the tide and waves from the same BC area. In the near future, CMS will have the option to be run fully inline, where only one grid will contain all of the information needed to run both CMS-Wave and CMS-Flow.

The CMS-Wave IJ triad should be adjusted where the I-direction is pointing in the dominant wave direction, or more specifically from the open ocean. This means that it will be 180 deg off as compared to the CMS-Flow grid. Therefore, after the CMS-Flow grid is generated, the model domain should be set to include all major reaches of the bay, extending laterally a couple kilometers from the inlet and extending seaward well beyond the anticipated reach of the ebb jet. A good rule of thumb for setting the ocean boundary for inlet modeling is to place the boundary three or four times the length of the ebb jet (leaving provision for extreme discharges, such as during storm surge). The given bathymetry ends at approximately four times the length of the ebb jet at Shark River.

Transforming the CMS-Flow grid to a CMS-Wave Grid.

7. Open one of the generated grids rt-click the Grid in the SMS list, and click on *Duplicate*, select the copied grid (copy) to activate it, and go to *Data*, *Switch Current Model* (Figure 50).

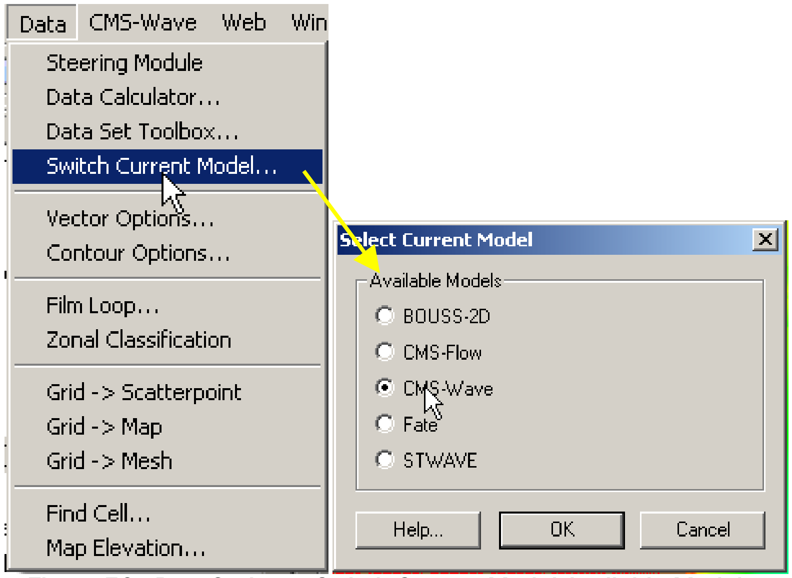


Figure 50. *Data* Options, *Switch Current Model*: Available Models.

8. Change the Model from CMS-Flow to CMS-Wave, click OK, and rename the grid by rt-clicking on the copy name and clicking Rename,
9. Set the jetty and groin cells to rubble-mound type structures by selecting the cells (Figure 51), and rt-click, Cell Attributes.., and select a Rubble-mound from the Structure Type, click OK.
10. File, Save As, Wave.sim (selecting the Save As Type as a .sim for simulation) in the folder with the CMS-Flow grid.

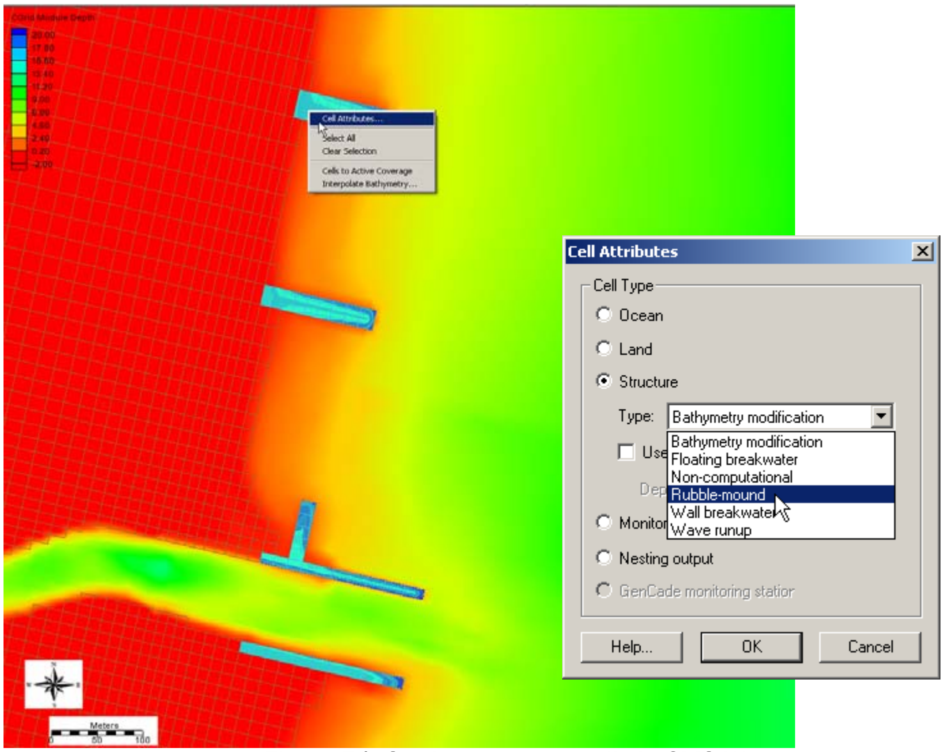


Figure 51. Setting structure cells in CMS-Wave.

CMS-Flow Model Setup

All of the CMS-Flow model parameters, settings, and output options are controlled from the *CMS-Flow Model Control Window* (see Figure below). The window also has a section for Advanced Cards in which features and options can be entered which have not been incorporated into the SMS interface yet or more advanced model features more experienced users.

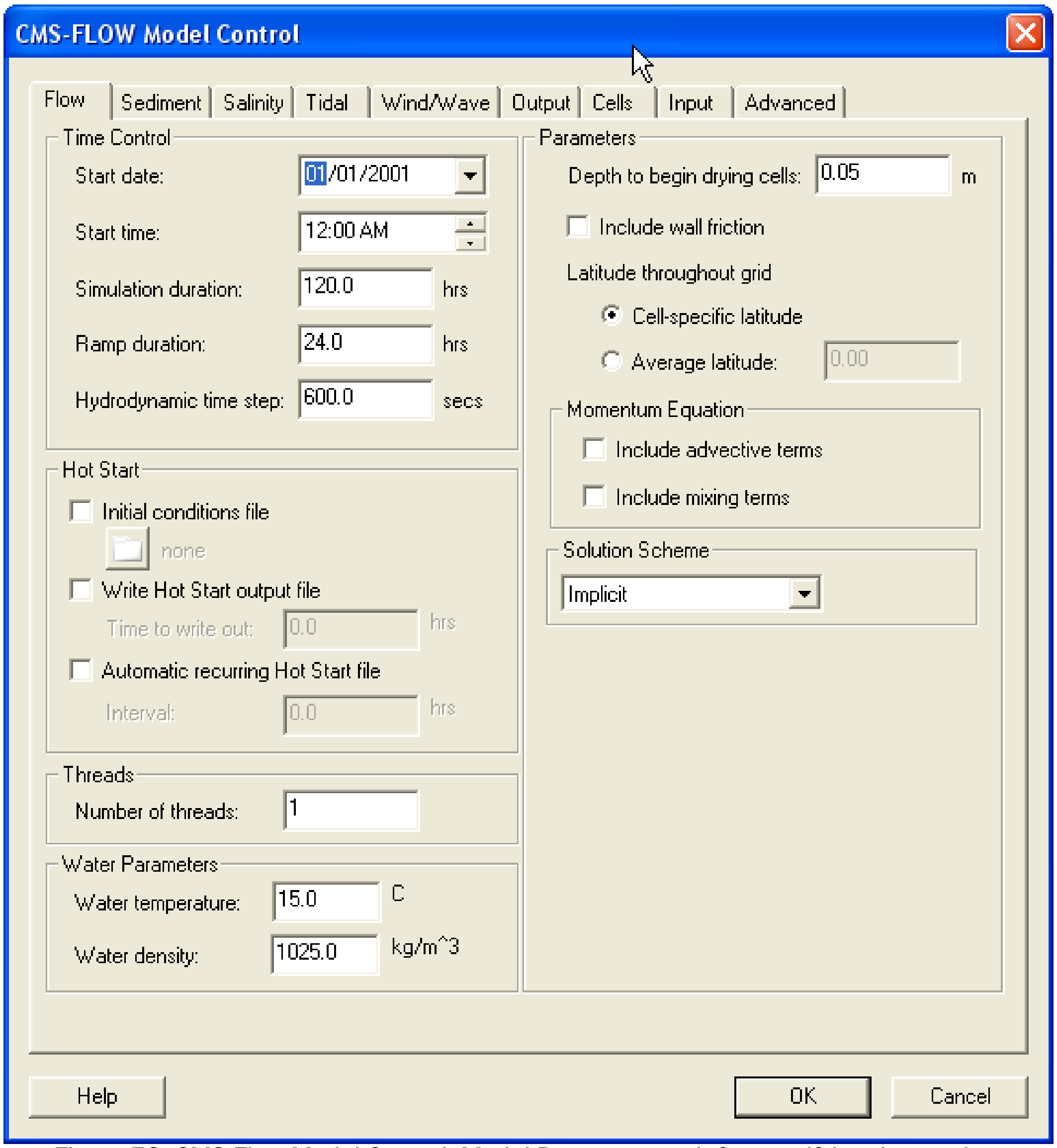


Figure 52. CMS-Flow Model Control: Model Parameters tab for specifying time series output of CMS-Flow calculated datasets.

Flow Options and Parameters

1. Click on *CMS-Flow*, *Model Control*, and set each tab as the following figures (Figure 52 through Figure 54).
2. For *Time Control*, change the *Simulation duration* to 744.0 hours, *Ramp* to 24 hours, and *Hydrodynamic time step* to 1.0 (must be tested by running CMS-Flow only).
3. For *Transport Parameters*, change the *Transport rate* to 1.0 and the *Morphologic time* step to 10 seconds, check *Use non-equilibrium transport* and set the parameters as those in Figure 52.

A description of the CMS-Flow cards specified in the Model Control window are described in Table 6.

Table 6. CMS-Flow Cards associated with the Flow Tab.

Card	Arguments	Default	Range	Description
STARTING_JDATE	integer	none	none	Sets the the simulation starting time in as Julian date in yyddd, where yy is the two digit year and ddd is the three digit day.
STARTING_JDATE_HOUR	integer	none	none	Sets the the simulation starting time hours.
DURATION_RUN	real	none	none	Sets the duration of the simulation in hours.
DURATION_RAMP	real	0.05	>=0.0	Specifies the length of the ramp period. For details on the ramp period see the Ramp Period section.
HYDRO_TIMESTEP	real	none	none	Sets the time step for the hydrodynamics.
NUM_THREADS	integer	1	>=1	Specifies the number of threads for parallel processing on multi-core machines.
WATER_TEMPERATURE	real	none	none	Water temperature in °C. The water temperature is used in the calculation of the water kinematic viscosity.
WATER_DENSITY	real	1025	none	Specifies the water density in kg/m^3. The water density is assumed to be constant for the simulation.
DRYING_DEPTH	real	0.05	>=0.0	Specifies the critical depth in m for wetting and drying. For details on the wetting and drying see the Wetting and Drying section.
USE_WALL_FRICTION_TERMS	character	ON	ON OFF	Turns on or off the wall friction. For details on the wall friction calculation see the Rigid Wall Boundary Condition section.
CELL_LATITUDES	character character	none	none	Specifies the XMDF fileand path for the cell latitudes. If specified and average latitude is calculated for the grid and used to estimate the Coriolis parameter. By default the cell latitudes

				are stored in the XMDF Model Parameters File. For additional details on this file see XMDF CMS-Flow Model Parameters File (*_mp.h5).
AVERAGE_LATITUDE	real	0.0	-90° to 90°	Specifies the average latitude in degrees for the grid. The average latitude is used to estimate the Coriolis parameter.
USE_ADVECTION_TERMS	charater	ON	ON OFF	Turns on or off the advection terms. This card applies to hydrodynamics, sediment transport and salinity transport.
USE_MIXING_TERMS	character	ON	ON OFF	Turns on or off the mixing or diffusion terms. This card applies to hydrodynamics, sediment transport and salinity transport.
SOLUTION_SCHEME	character	IMPLICIT	IMPLICIT EXPLICIT	Sets the temporal solution scheme for all governing equation sin CMS-Flow.

Important Note:

- A description fo the *Hot Start* section of the *Flow* tab, see the Hot Start section.

Bottom Friction

Bottom Friction Dataset

In SMS versions 10.1 and earlier, the bottom roughness is specified using the Manning's *n* coefficient in the *Cells* tab of the *CMS-Flow Model Control* window. In SMS 11.0, the option is provided to use a roughness height, or bottom friction coefficient in addition to the Manning's coefficient. In SMS 11.0 the bottom roughness is specified in the *Bottom Friction Dataset* section of within the *Input* tab of the *CMS-Flow Model Control* window (see Figure 53). The *Bottom Friction Dataset* is specified at every computational (ocean) cell and is required for each model simulation.

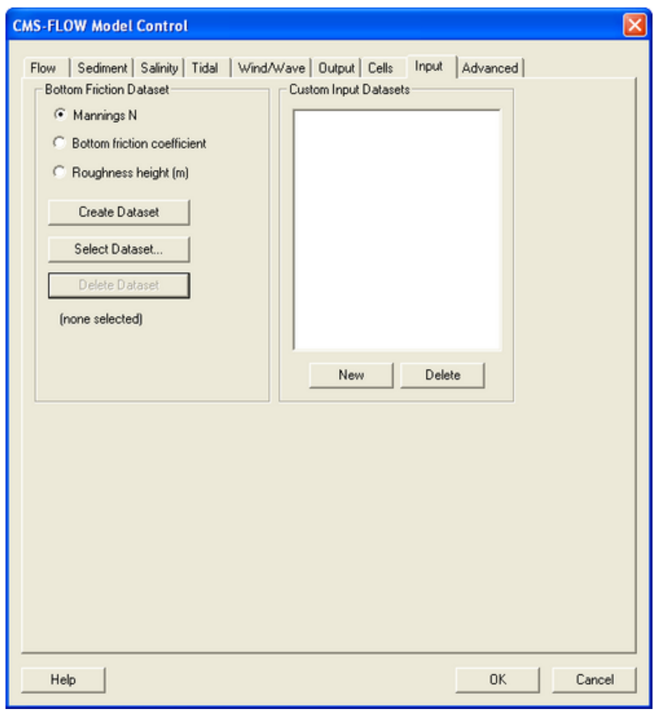


Figure 53. Specification of the *Bottom Friction Dataset* via the *Input* tab of the *CMS-Flow Model Control* window in SMS 11.0

Creating the bottom friction dataset

In SMS 11.0 each time a new CMS-Flow simulation is created a bottom friction (roughness) dataset needs to be created using the *Create Dataset* button (see Figure 54). The bottom friction parameter (related to Manning *n*) is spatially varying (cell-specific) over the grid domain. The default value upon grid creation is 0.025. At times a user may desire to represent locations where added friction is needed due to structures, vegetation, or increased turbulence due to rapid changes in current speed.

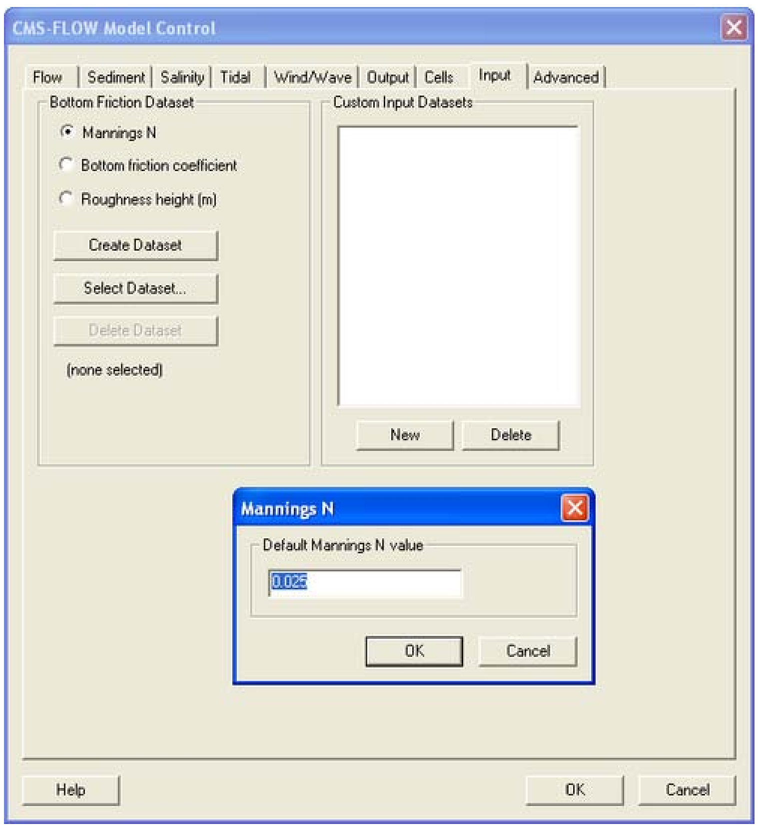


Figure 54. Initialization of the *Manning's N Dataset* in SMS 11.0

Once the *Bottom Friction Dataset* is created and the *CMS-Flow Model Control* window closed, a new auxiliary dataset will appear in the *SMS Project Explorer* (see Figure 55).

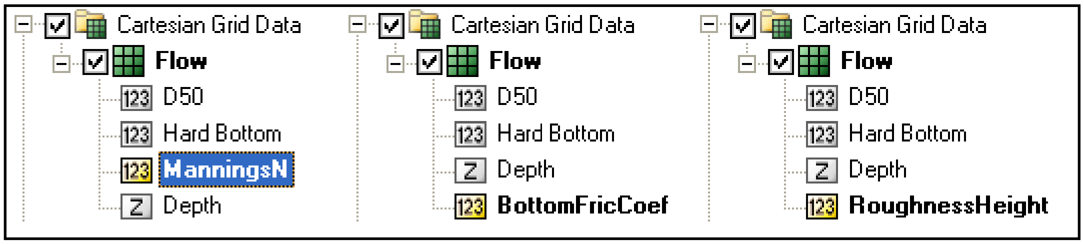


Figure 55. Three SMS Project Explorer showing the Manning's *n*, Bottom Friction Coefficient and Roughness Height datasets.

A description of the CMS-Flow cards related to the bottom friction datasets are shown in Table 7.

Table 7. SMS Cards related to the bottom friction datasets

Card	Arguments	Range	Description
USE_WALL_FRICTION	character	ON OFF	Turns on or off wall friction
MANNING_N_DATASET	character character	none	Grid file name and dataset path for the input Manning's n dataset
BOTTOM_FRICTION_COEF_DATASET	character character	none	Grid file name and dataset path for the input bottom friction coefficient dataset
ROUGHNESS_HEIGHT_DATASET	character character	none	Grid file name and dataset path for the input roughness height dataset

Spatially Constant Bottom Friction

Additional advanced cards (in Table 8) are available for setting the bottom friction to a constant for the whole grid. These cards are useful for running sensitivity analysis for a wide range of values in cases which can be approximated with a single constant bottom friction value.

Table 8. Advanced Cards to set bottom friction dataset to a constant value

Card	Arguments	Default	Range	Description
MANNING_N_CONSTANT	real	none	>=0.0	Specifies a constant input *Manning's n* coefficient. Over-rides any previous bottom friction cards.
BOTTOM_FRICTION_COEF_CONSTANT	real	none	>=0.0	Specifies a constant input *Bottom Friction Coefficient*. Over-rides any previous bottom friction cards.
ROUGHNESS_HEIGHT_CONSTANT	real	none	>=0.0	Specifies a constant *Roughness Height* in m. Over-rides any previous bottom friction cards.

Wave-enhanced Bottom Friction

In the presence of waves, the mean (short-wave averaged) bottom shear stress which is used in the momentum equations is enhanced. There are 5 different options in CMS for estimating the wave-enhanced bottom friction. The default is a simple quadratic formula but can be changes using the *Advanced Card* described inTable 9.

Table 9. Advanced Card used for specifying the wave-current mean stress formulation

Card	Arguments	Default	Options	Description
WAVE-CURRENT_MEAN_STRESS WAVE_CURRENT_MEAN_STRESS	character	QUAD	QUAD DATA2 DATA13 F85 HT95	Defines the model used for calculating the mean bottom shear stress used in hydro
WAVE_BOTTOM_FRICTION_COEFFICIENT	real	0.5	0.3-0.7	Wave bottom friction coefficient used for quadratic combined wave-current mean bed shear stress calculation.

Bed Slope Friction Factor

The bed slope friction factor accounts for the increased surface area over sloping beds as compared to the horizontal area. This feature may be turned *On* or *Off* through the Advanced Card described inTable 10.

Table 10. Advanced Card used for activating the bed slope friction factor

Card	Arguments	Default	Options	Description
BED_SLOPE_FRICTION_FACTOR	character	OFF	ON OFF	Specifies whether to include the bed slope friction factor or not in the calculation of the bed friction

Wall Friction

The wall friction enhances the flow drag perpendicular to any dry boundary. The wall friction may be turned *On* or *Off* in the *Flow* tab of the *CMS-Flow Model Control* window (seeFigure 56). The default in SMS is for the wall friction to be *ON*. Table 11 shows the CMS card used activating the wall friction.

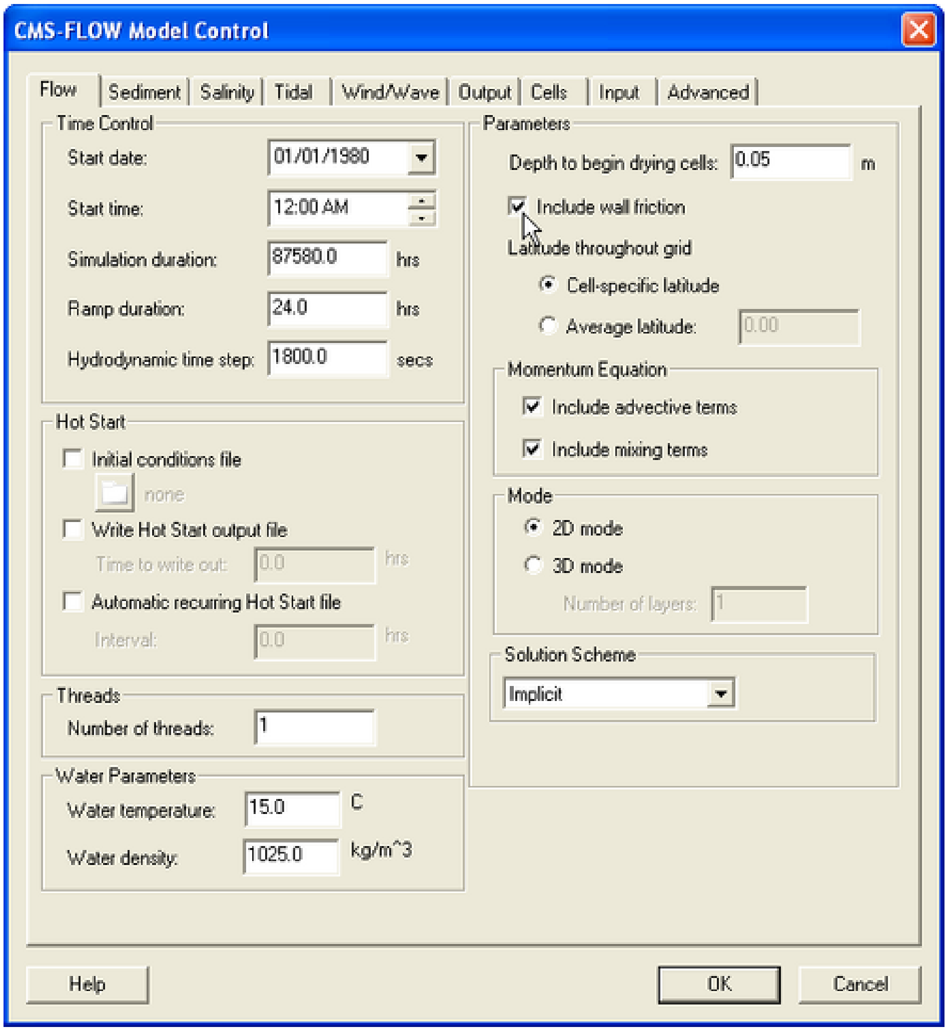


Figure 56. Wall friction specification in the SMS 11.0 *CMS-Flow Model Control* window.

Table 11. SMS Cards related to the bottom friction datasets

Card	Arguments	Default	Options	Description
USE_WALL_FRICTION	character			Turns on or off wall friction

Eddy Viscosity

Due to the large amount of turbulence in the surf zone, the nearshore eddy viscosity and resulting mixing terms can be quite large making the flow sensitive to the eddy viscosity formulation implemented. Turbulent mixing is calculated in CMS using the eddy viscosity concept. For a detailed description of the eddy viscosity models in CMS see section Eddy Viscosity. In SMS 11.0 all of the eddy viscosity options and parameters are entere via Advanced Cards and only the option is given to turn *On* or *Off* the mixing terms (Figure 57).

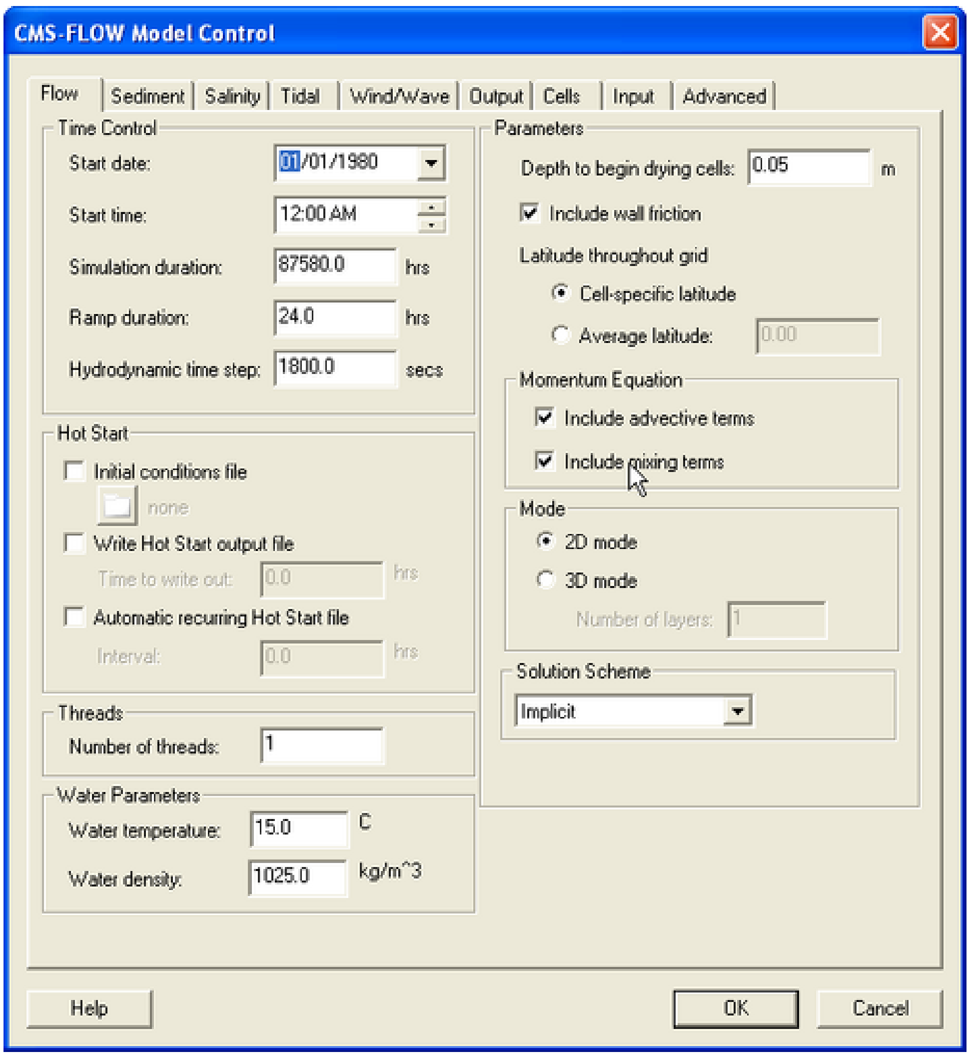


Figure 57. Toggle for turning *On* and *Off* the mixing terms in the SMS 11.0 interface.

A description of the CMS-Flow Cards related to eddy viscosity is shown, below, in Table 12.

Table 12. CMS card used to set turbulence model and eddy viscosity terms

Card	Arguments	Default	Options/ Typical Range	Description
USE_MIXING_TERMS	character	ON	ON OFF	Turns On and Off the mixing terms in the momentum and transport equations.
TURBULENCE_MODEL	character	SUBGRID	SUBGRID FALCONER PARABOLIC MIXING-LENGTH	Specifies the turbulence model used. For details on the different turbulence models see section Eddy Viscosity.
EDDY_VISCOSITY_CONSTANT	real	1.0E-6	>=0.0	Constant contribution or base value of eddy viscosity
EDDY_VISCOSITY_BOTTOM	real	0.0667	0.02-0.1	Coefficient related to the contribution to eddy viscosity from the bottom shear
EDDY_VISCOSITY_HORIZONTAL	real	0.4	0.1-0.2	Coefficient related to the contribution to eddy viscosity from horizontal velocity gradients
EDDY_VISCOSITY_WAVE	real	0.5	0.2-1.0	Coefficient related to the wave bottom friction contribution to eddy viscosity
EDDY_VISCOSITY_BREAKING	real	0.05	0.05-0.1	Coefficient related to the wave breaking contribution to eddy viscosity

Important Notes:

1. The eddy viscosity can be calibrated by looking at several features of the flow. Increasing the eddy viscosity

   a. Increases the width of the longshore current.
   b. Increases the spread of the ebb and flood tidal jet currents.
   c. Decreases the offshore extent of the ebb jet current.
   d. Smoothes out small gyres and recirculation zones.

2. The eddy viscosity affects the sediment mixing since the sediment mixing coefficient is calculated as the eddy viscosity divided by the Schmidt number.

Editing Spatial Datasets

Spatial datasets including the bottom roughness may be edited manually by selecting and modifying cells, using the *Data Calculator*, or by interpolating from a scatter set. Figure 58 shows an example where the Manning's *n* coefficient was increased for Shark River Inlet to account for the presence of vertical piles. To manually edit a spatial dataset

1. Click on the *Select Cell* tool in the Cartesian Grid module toolbar.
2. Select a single or multiple cells by either:
   a. Clicking on a single cell.
   b. Use a selection box by single-left-clicking and holding to drag a selection box over a group of cells.
   c. Use a selection polygon by clicking on the menu *Edit* and selecting the submenu *Select with Poly* to select a group of cells with a polygon (see Figure below).

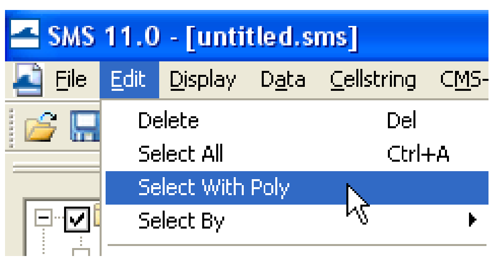


Figure 58. Selecting cells with a polygon in SMS.

   d. Select scells by their value by clicking on the menu *Edit* and selecting the submenu *Select By* and then clicking the *Data Set value…* option (Figure 59).

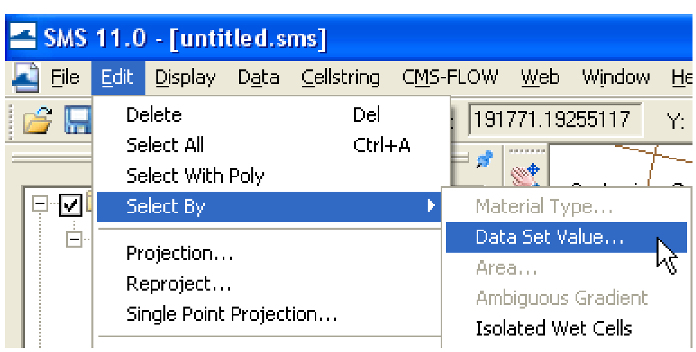


Figure 59. Selecting cells with a polygon in SMS.

Figure 60 shows an example of a spatial dataset (Manning's n in this case) which has manually been modified.

Figure 60. Manning's *n* contours after modifying the areas under all three bridges.

Interpolating a Scatter Set to the Whole Grid

1. Select the scatter set
2. Click on the menu Scatter | Interpolate to Cartesian Grid (see Figure 61)
3. In the Interpolation window, enter an extrapolation value, a name for the dataset and click OK (see Figure 62).

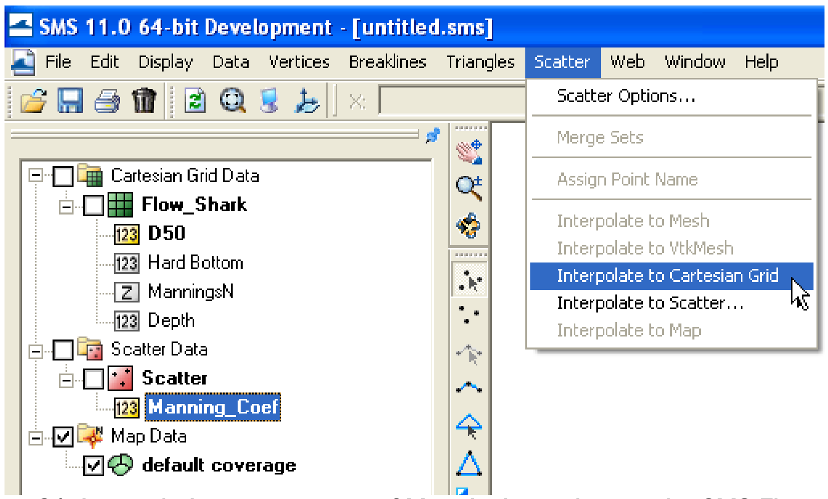


Figure 61. Interpolating a scatter set of Manning's *n* values to the CMS-Flow grid.

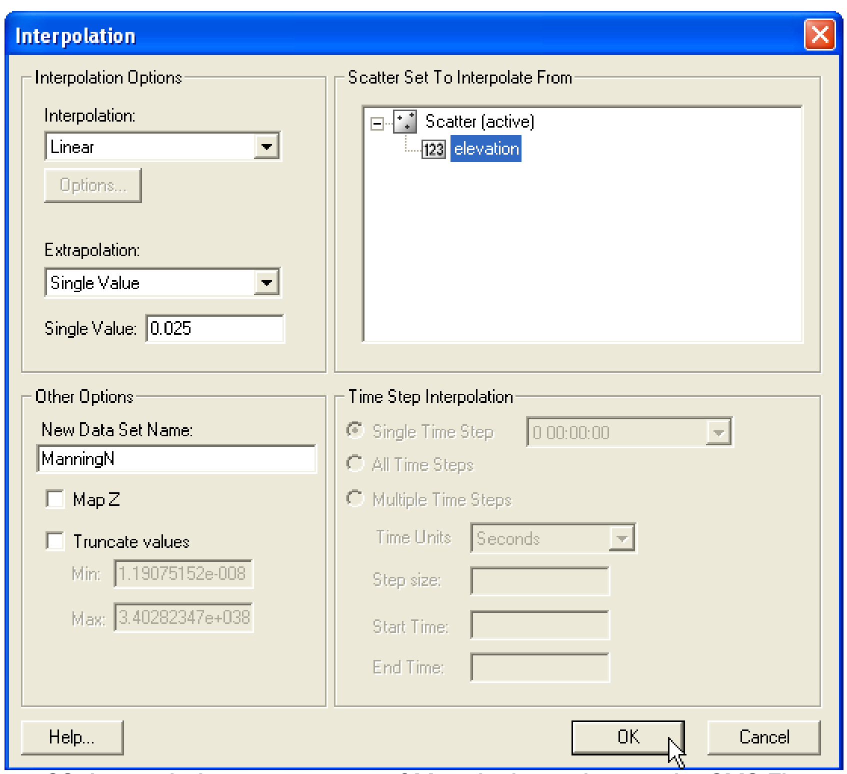


Figure 62. Interpolating a scatter set of Manning's *n* values to the CMS-Flow grid.

The dataset will be interpolated to the whole grid and grid cells outside of the scatter triangulation will be set to the extrapolation value.

Interpolating a Scatter Set to a Portion of Grid

In some cases, it is desirable to only interpolate a bottom roughness scatter set to a portion of the grid. However, it is only possible to interpolate portions of the grid from scatters for the *Elevation* dataset. The *Elevation* dataset is the dataset with a  to the left. Therefore, it is necessary to *Map* the bottom friction dataset as the *Elevation* dataset, interpolate the scatter set and then re-map the actual grid elevation (usually named *Depth*) dataset as the *Elevation* dataset. To interpolate a bottom roughness dataset to a portion of a grid.

1. Click on the menu *Data* | *Map Elevation* (Figure 63). The bottom friction dataset will appear with the symbol .

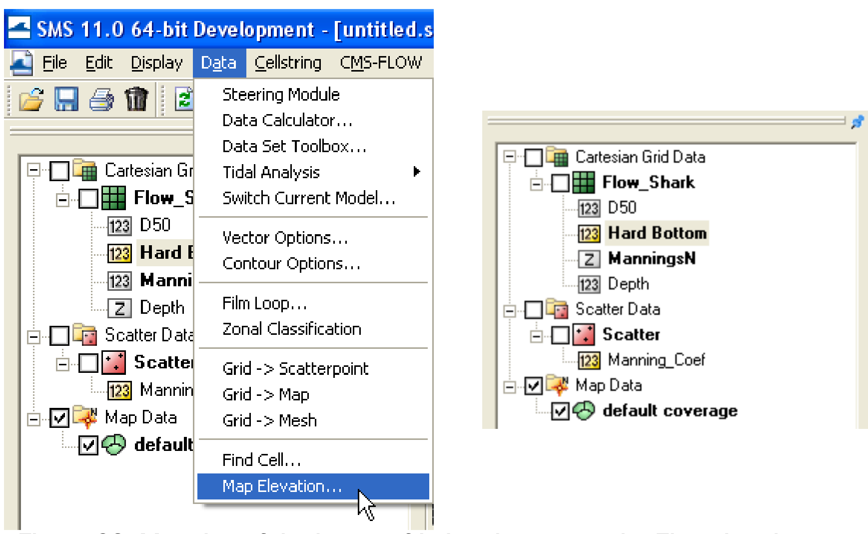


Figure 63. Mapping of the bottom friction dataset as the Elevation dataset.

2. Select the portion of the grid from which you want to interpolate the bottom friction dataset. This can be done by clicking and holding the left mouse button or by holding the Control key and single clicking so select the polygon and double clicking on the last polygon point (shown in Figure 64).

3. Once the correct cells are selected, right-click on the selected cells and select *Interpolate Bathymetry*.

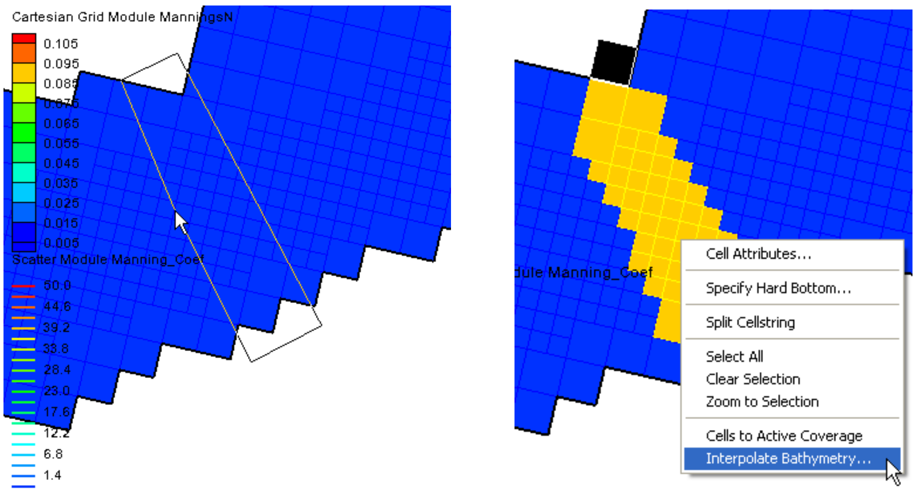


Figure 64. Mapping of a dataset (bottom friction in this case) as the Elevation dataset.

1. In the interpolation window, select and appropriate extrapolation value and click *OK* (see Figure 65).

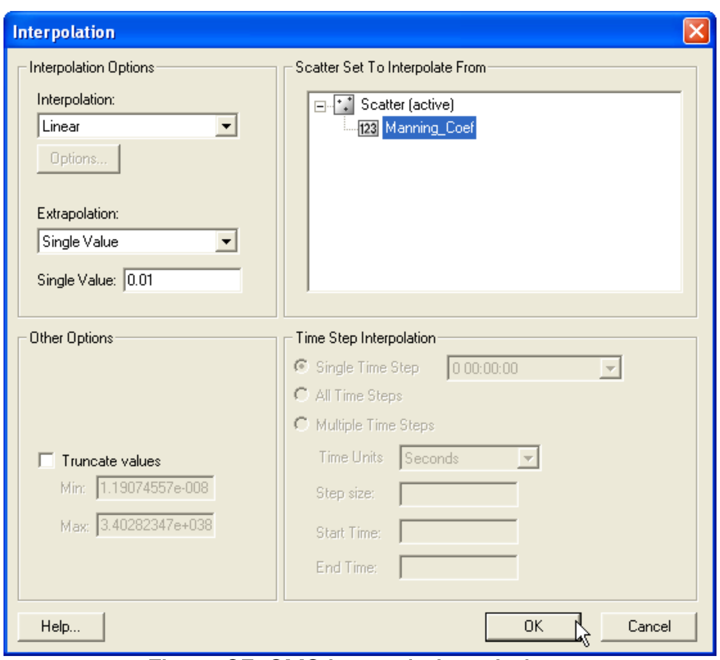


Figure 65. SMS Interpolation window.

Figure 66 shows an example of how the final bottom friction dataset looks like once a portion of the dataset has been interpolated from a scatter set.

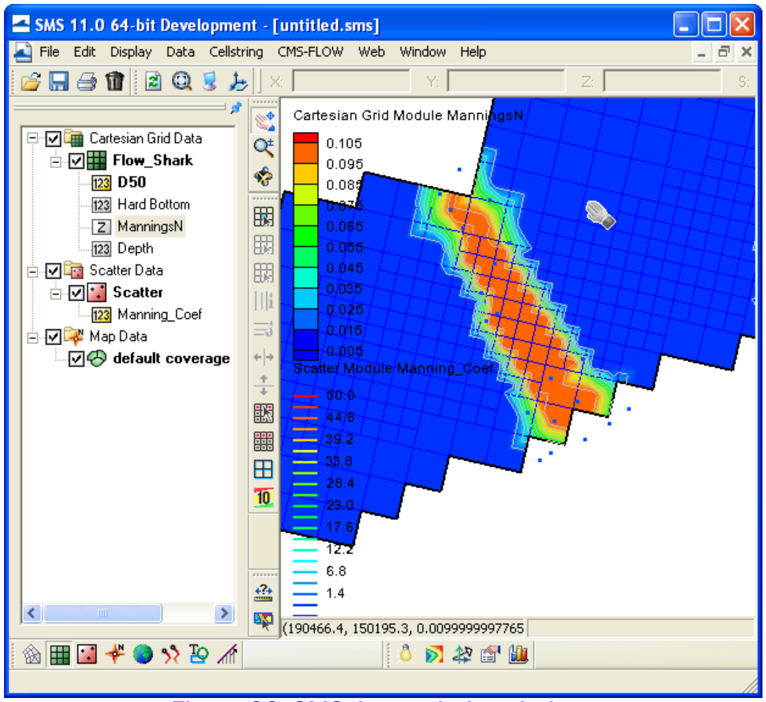


Figure 66. SMS *Interpolation* window.

2. Re-map the *Depth* dataset as the Elevation dataset by clicking on Data | Map Elevation and selecting the Depth dataset (Figure 67).

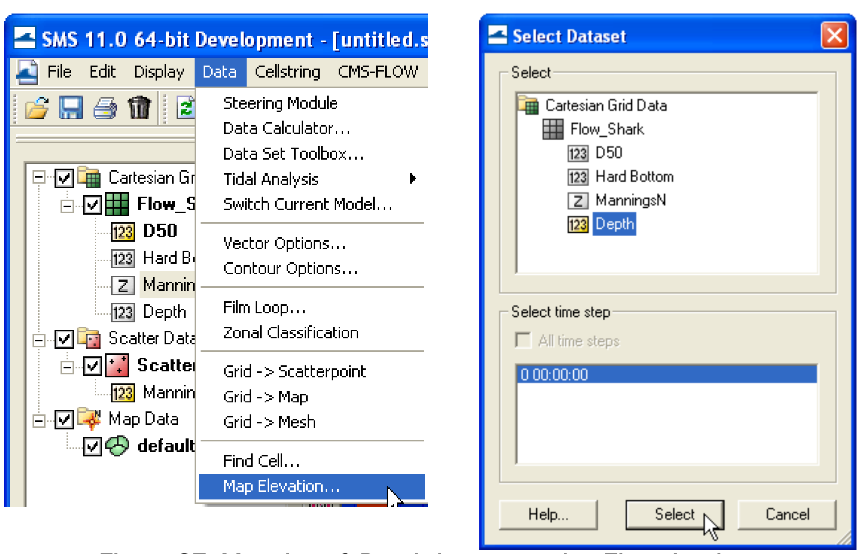


Figure 67. Mapping of *Depth* dataset as the *Elevation* dataset.

Exporting a CMS-Flow Dataset

Exporting a spatially variable dataset such as bottom roughness (friction) datasets is useful for creating different project alternatives, scripting multiple runs, or for switching from different datasets for use as model input. Figure 68 illustrates how to export a dataset into an XMDF file. Multiple datasets can be exported into the same file. To export a dataset:

1. Select the CMS-Flow dataset(s) in the *SMS Project Explorer*.
2. Right-click and select the *Export* option. A window called *Export Data Set* will open
3. Under *File Type* select *XMDF File.*
4. *Under Time Steps*, select *All time Steps*, even if the dataset only has one time step.
5. Under *Filename* click on the folder icon and enter the location and filename for the dataset(s).

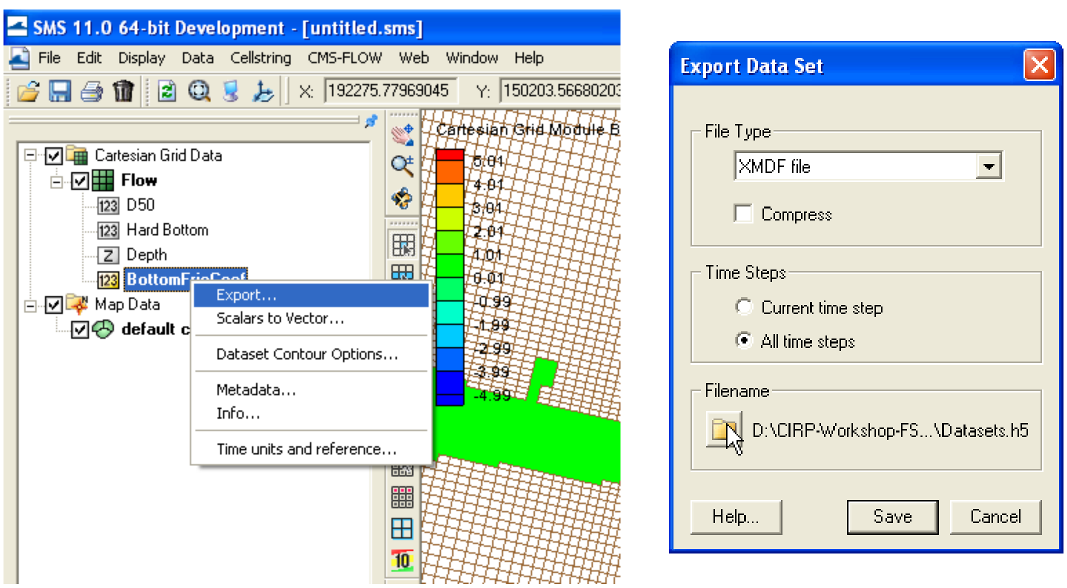


Figure 68. Manning's *n* contours after modifying the areas under all three bridges.

CMS-Flow Wind and Atmospheric Pressure Forcing

Spatially Constant Wind

Spatially constant wind is specified in the Wind/Wave tab of the CMS-Flow Model Control window (see Figure 69).

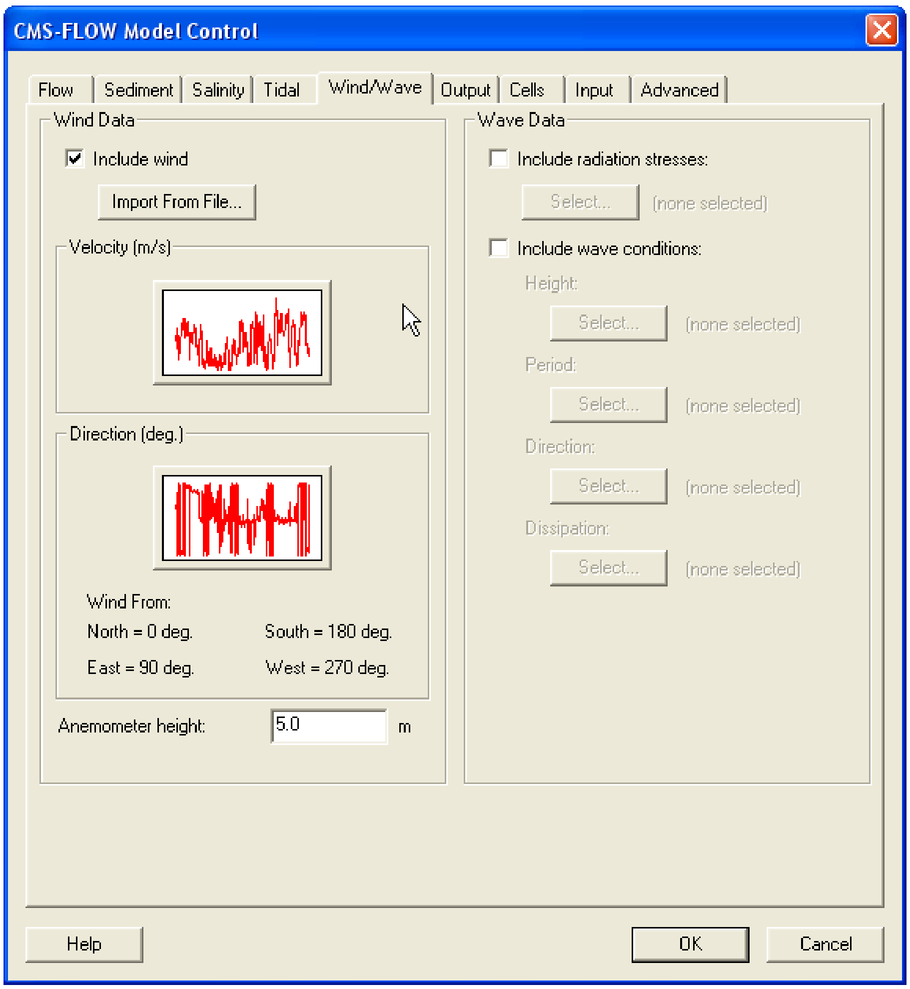


Figure 69. CMS-Flow Wind/Wave tab in the CMS-Flow Model Control window.

Table 13. CMS cards used for spatially constant wind forcing.

Card	Arguments	Default	Options	Description
USE_MIXING_TERMS	character	ON	ON OFF	Turns On and Off the mixing terms in the momentum and transport equations.

Spatially Variable Wind and Atmospheric Pressure

CMS-Flow V4.0 and higher have the option to use spatially variable wind and atmospheric pressure forcing. Currently, this feature is specified in the advanced card section. A description of the cards related to winds and atmospheric pressure are described, below, in Table 14.

Table 14. CMS-Flow cards related to winds and atmospheric pressure

Card	Arguments	Type
WIND_OUT_TIMES_LIST	Id number of output times list	integer
WIND_DRAG_COEFFICIENT	kappa in Hsu (1988) (default 0.4)	real
WIND_INPUT_CURVE	Name of model parameter file followed wind curve path	character
ANEMOMETER_HEIGHT	Height of wind speeds	meter
OCEANWEATHER_WIND_FILE	Name of Oceanweather, Inc. wind file (*.win)	character
OCEANWEATHER_PRES_FILE	Name of Oceanweather, Inc. pressure file (*.pre)	character
OCEANWEATHER_XY_FILE	Name of Oceanweather, Inc. coordinate file (*.xy)	character
WIND_PRESSURE_SINGLE_FILE	Name of fleet wind and pressure file	character
WIND_PRESSURE_GRID_PARAM	Nwlat,Nwlon,wLatMax,wLonMin,wLatInc,wLonInc	integer and real
WIND_PRESSURE_TIME_INCREMENT	wTimeInc	real

Important Notes:

1. Interpolation File: When using spatially variable winds CMS V4.0 will output a file named *Intpcoef_wndfl.bin*. This file contains the coefficients used to interpolate the winds and atmospheric pressure to the CMS-Flow grid. If the same flow and wind grids are run, the model will automatically detect the interpolation file and read in the coefficients instead of calculating them. If the either grid is changed in size, the model will automatically detect this and recalculate the coefficients. However, if the grids are changed but stay the same size, the model will not be able to detect that they have changed. Therefore, whenever any changes are made to the flow or wind grids, it is best to delete the prior interpolation file.

2. Ramp Period: During the ramp period, the ramp is applied to both the wind shear stresses and spatial variations of the atmospheric pressure.

Single ASCII Wind File

This file format is equivalent to the ADCIRC fort.22 format with NWS=6. The winds and atmospheric pressure are specified on a rectangular grid at constant temporal intervals. The wind grid is assumed to be in the same horizontal coordinate system as the CMS grid. The wind data is spatially interpolated using an inverse distance method and temporally interpolated using linear interpolation. The grid is assumed to vary from North to South and West to East so that north-west corner is the grid origin. The spatial extents of the wind/pressure grid must be consistent with the flow grid. The wind file is written from West to East starting at the North-West Corner. The file is read in in free format. An example of section of a single ASCII Wind File is shown below.

```
7.5835 1.2324 0.00
7.5835 1.2324 0.00
7.5835 1.2324 0.00
...
```

An example FORTRAN code used to read the file is shown below:

```
!For each wind snap shot
do i=1,nwindi
  do j=1,nwindj
    read(wunit,*,end=444,err=222)
wndspdx(i,j),wndspdy(i,j),atmpres(i,j)
  enddo
enddo
```

Example CMS Card File Section

```
WIND_PRESSURE_SINGLE_FILE         "wind.dat"
WIND_PRESSURE_GRID_PARAM          201 201 50000.0 -50000.0 500.0 500.0
WIND_PRESSURE_TIME_INCREMENT      360000.0    !seconds
```

Important Notes:

- The wind is assumed to start at the start of the CMS simulation.
- The wind grid is assumed to be in the same horizontal coordinate system as the CMS grid.
- The wind velocities must be in m/s and the atmospheric pressure in Pa.

Oceanweather Wind File

The file format for the Oceanweather wind file (*.win) is best described with an example:

```
Oceanweather WIN/PRE Format                            2008090912     2008091406
iLat= 118iLong= 201DX=0.0150DY=0.0150SWLat=28.50000SWLon=-96.0000DT=200809091200
-4.8891    -4.8873    -4.8855    -4.8838    -4.8821    -4.8805    -4.8789    -4.8774
-4.8759    -4.8744    -4.8730    -4.8717    -4.8704    -4.8692    -4.8680    -4.8669
...
-2.1530    -2.1382    -2.1233    -2.1085    -2.0937    -2.0788    -2.0637    -2.0486
-2.0335    -2.0184    -2.0035    -1.9887    -1.9741    -1.9598    -1.9458    -1.9322
-1.9190    -1.9062    -1.8938    -1.8820    -1.8707    -1.8600
iLat= 118iLong= 201DX=0.0150DY=0.0150SWLat=28.50000SWLon=-96.0000DT=200809091215
-4.9107    -4.9090    -4.9074    -4.9058    -4.9043    -4.9028    -4.9014    -4.9001
-4.8988    -4.8975    -4.8963    -4.8952    -4.8942    -4.8932    -4.8923    -4.8914
-4.8906    -4.8898    -4.8889    -4.8881    -4.8873    -4.8866    -4.8860    -4.8854
...
```

The last two arguments of the header are the starting and end times in yyyymmddhh. The wind data are preceded by a header line with the grid information. iLat and iLong are latitude North and longitude West. DX and DY are the grid spacing in units of degrees. SWLat and SWLon are the coordinates of the south-west grid point. DT is the actual time in yyyymmddhhMM. First the wind velocities in the x-direction are read then the velocities in the y-direction. The wind speeds are written in m/s.

An excerpt of the FORTRAN code used to read the file is shown below:

```fortran
open(nunit,file=windfile,status='old')
read(nunit,*)   !skip  header
11 format(t6,i4,t16,i4)
read(nunit,11) nwindi,  nwindj
backspace(nunit)
 !...
13  format(68x,I4,4(I2))
read(nunit,13,end=333,err=333)  iyear,imonth,iday,ihour,imin
!...
12  format(8f10.0)
read(nunit,12,end=333,err=333)
((wndspdx(i,j),j=1,nwindj),i=1,nwindi)
read(nunit,12,end=333,err=333)
((wndspdy(i,j),j=1,nwindj),i=1,nwindi)
!...
333 close(nunit)
```

Oceanweather Pressure File

The file format for the Oceanweather pressure file (*.pre) is best described with an example:

```
   Oceanweather WIN/PRE Format                            2008090912
2008091406
  iLat= 118iLong= 201DX=0.0150DY=0.0150SWLat=28.50000SWLon=-96.0000DT=200809091200
  1012.8565 1012.8564 1012.8563 1012.8563 1012.8563 1012.8563 1012.8563 1012.8564
  1012.8583 1012.8587 1012.8591 1012.8596 1012.8600 1012.8605 1012.8610 1012.8616
  ...
  1014.2051 1014.2062 1014.2073 1014.2084 1014.2096 1014.2107 1014.2119 1014.2130
  1014.2141 1014.2152 1014.2164 1014.2175 1014.2186 1014.2197
  iLat= 118iLong= 201DX=0.0150DY=0.0150SWLat=28.50000SWLon=-96.0000DT=200809091215
  1012.9089 1012.9089 1012.9089 1012.9089 1012.9090 1012.9091 1012.9092 1012.9094
  1012.9095 1012.9098 1012.9100 1012.9103 1012.9106 1012.9109 1012.9113 1012.9117
  ...
```

The last two arguments of the header are the starting and end times in yyyymmddhh. The atmospheric pressure data (in units of mbar) is preceded by a header line with the grid information. iLat and iLong are latitude North and longitude West. DX and DY are the grid spacing in units of degrees. SWLat and SWLon are the coordinates of the south-west grid point. DT is the actual time in yyyymmddhhMM.

Oceanweather Coordinate File

The file format for the Oceanweather coordinate file (*.xy) should contain the coordinates of the Oceanweather grid in the same coordinate system as the CMS-Flow grid. The order of the points should be from the south-west corner along each row. A small fortran program provided here converts the Oceanweather grid information to an *.xy file. This can also be downloaded from the CIRP website:
http://cirp.usace.army.mil/CIRPwiki/images/8/82/WINDLOC.rar

```
903301.20526 77626.22617
904769.21902 77663.98766
906237.22790 77701.93744
907705.23188 77740.07550
909173.23093 77778.40184
910641.22504 77816.91646
...
```

Important Notes:

- The first column is the horizontal coordinate, and the second is the vertical coordinate.

Wind Reference Frames

Winds are specified in an Eulerian reference frame with respect to the solid earth. When the wind in the same direction of the currents the wind shear stress is lowered (Figure 70, left). When the wind and currents are in opposing directions, the wind shear stress is increased.

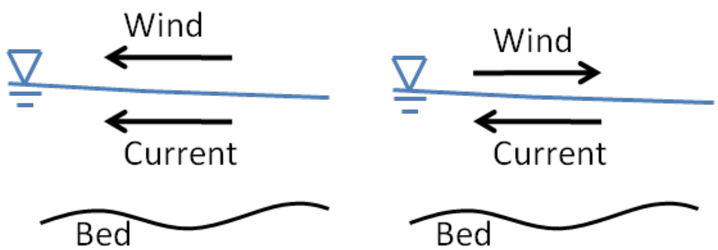


Figure 70. Schematic of wind and currents in same direction (left) and in opposing directions (right).

Table 15. CMS-Flow card for specifying the reference frame.

Card	Arguments	Default	Options	Description
WIND_REFERENCE_FRAME	character	EULERIAN	EULERIAN LAGRANGIAN	Sets the reference frame for wind forcing

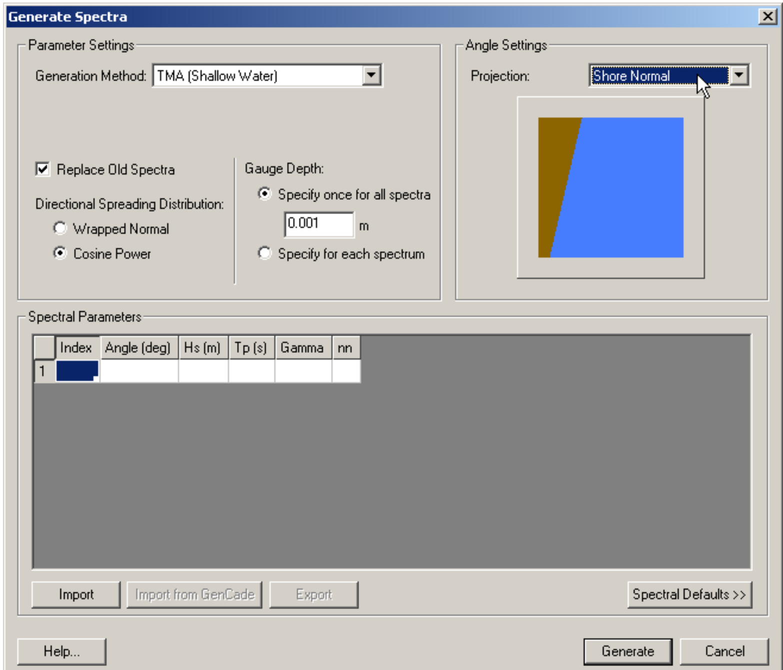
Additional Wind and Atmospheric Cards

CMS-Wave Model Parameters

Spectral waves or wave parameters can be generated for the wave grid forcing, or wind direction and speeds can provide the necessary information for wind- wave generation. Full (directional) spectra can be imported into the SMS for the CMS-Wave, as well as simplified wave parameters (angle, wave height, and period, etc). The spectral energy file format is given in Appendix A, as well as guidelines for using automated programs to generate these files from NOAA/NDBC raw buoy data.

Adding Wave Parameter Generated Spectra to CMS-Wave

1. Click on *CMS-Wave, Spectral Energy*, and select *Create Grid* (wave spectra can be imported),
2. Click *OK* for the default spectral properties, and then click *Generate Spectra* to bring up the window to input wave parameters (Figure 71),
3. Open the Excel spreadsheet *44025buoy_199902.xls* and select the wave parameters (1 month, Feb 1999), copy and paste this into the *Generate Spectra – Spectral Parameters* section (Figure 71), click *Generate, OK.*
4. Go to CMS-Wave, Model Control, and turn on *Allow wetting and drying* and *Bed friction* (Figure 72),
5. Users can also specify constant or varied forward and backward reflection coefficients in *Settings*.
6. Water level and wind information are optional source as specified under *Wave Source* in addition to the spectral input data.
7. *File, Save As*, Wave.sim (selecting the *Save As Type* as a .sim for simulation) in the folder with the CMS-Flow grid.


Generate Spectra
Parameter Settings
Generation Method: TMA (Shallow Water)
Replace Old Spectra
Directional Spreading Distribution:
Wrapped Normal
Cosine Power
Gauge Depth:
Specify once for all spectra
0.001 m
Specify for each spectrum
Angle Settings
Projection: Shore Normal
Spectral Parameters
Index
Angle (deg)
Hs (m)
Tp (s)
Gamma
nn
1
Import
Import from GenCade
Export
Spectral Defaults >>
Help...
Generate
Cancel

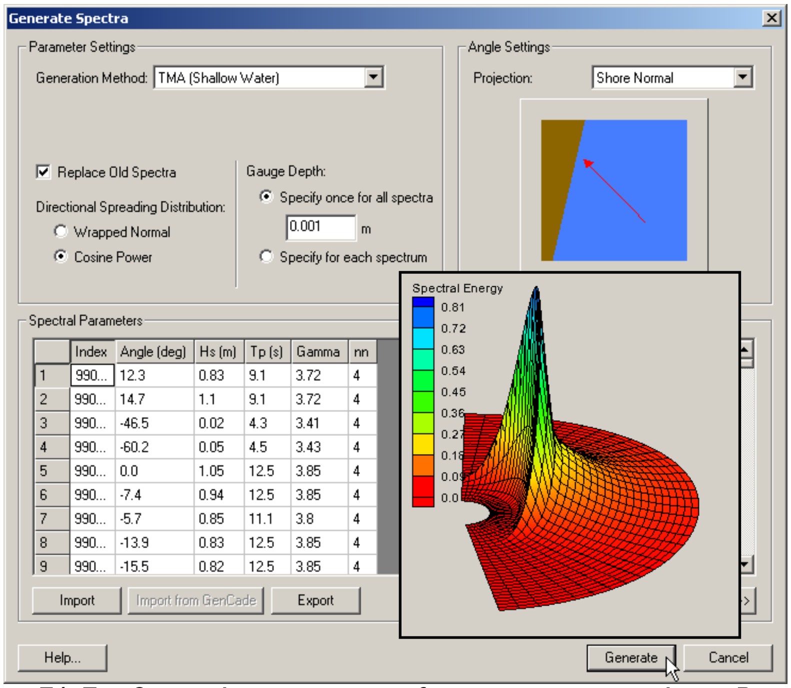


Figure 71. Top Generating wave spectra from wave parameter input; Bottom: Generated wave parameters with a snapshot of spectral output.

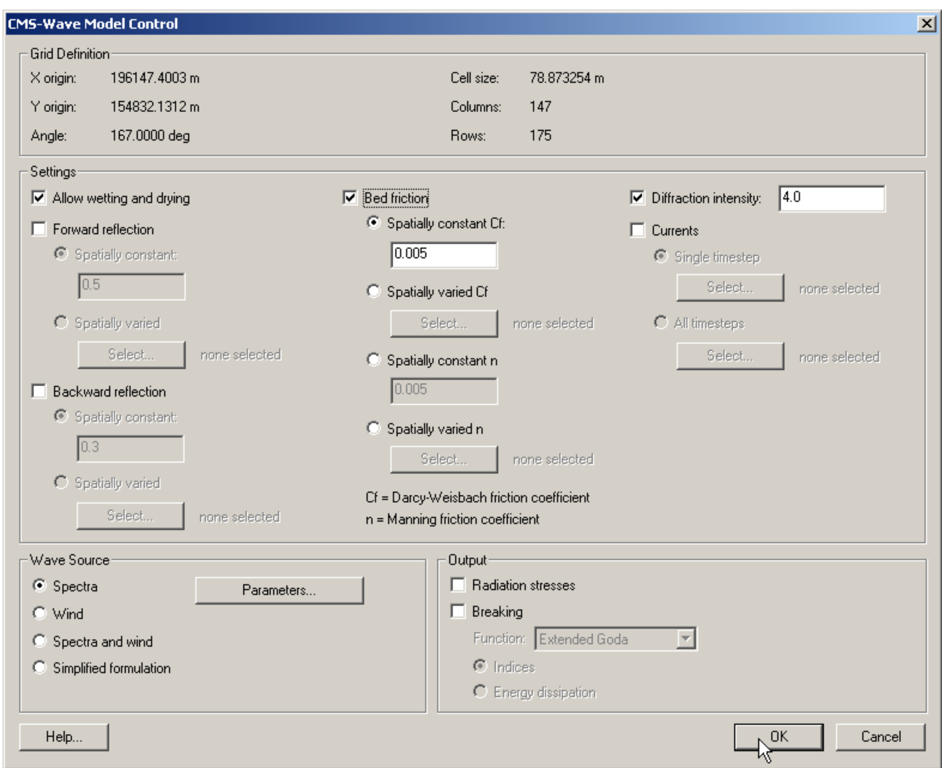


Figure 72. CMS-Wave model control options

Preprocessing CMS-Flow Input Time Series

Typically, time series of water levels, winds, river fluxes, salinity, and other types are specified as boundary conditions and it is extremely important that this data be prepared properly for use in the model. Although measured data is often regarded as the “truth”, no instrument is free of errors, failures, or immune to human misuse and mistakes. In numerical models “If junk goes in, junk goes out”. Time series analysis is a topic much to large to be covered in this manual, and only key points are described. For an in-depth review of time series analysis the reader is referred to Emery and Thompson (1998)

The general steps for preprocessing time series for CMS are:

1. Data Assembly and Conversion
2. Quality Control (QC)
3. Interpolation
4. Filtering

Data assembly and Conversion

This step includes the download, format conversion (e.g. binary to ASCII), and conversion of units, reference frames, datums, etc. Often time series must be compiled from several raw data files.

Quality Control

Before any manipulation of the data is made, a QC must be performed to remove inaccurate or unreliable data. The definition of inaccurate data depends on the measurement type and its use in a model. Bad data should be removed from the time series before continuing and manipulating the data any further.

Interpolation

Gaps or “holes in data are very common in geophysical measurements. In some cases the model input may require that it be spaced at regular intervals. Therefore, any gaps in the data must be interpolated. Also, if any spectral calculations or filtering are to be calculated. It is more convenient to have the data at uniformly spaced intervals.

Important Note:

- CMS input time series can have irregular intervals.
- It is important that the input time series cover the extent of the simulation to avoid extrapolation issues.
- CMS uses a quadratic interpolation for input boundary condition forcing.

Filtering

Measured data often noise or physical processes at frequencies other than the frequencies that want to be used as a mode input. Filtering is the process of removing the signals at any frequencies other than the desired frequencies.

Tip:

1. A Matlab Guided User Interface (GUI) for preprocessing model time series is provided on the CIRP wiki (http://cirp.usace.army.mil/wiki/Utilities#Time_Series_Analysis) called *filter1d.m*. A hands-on tutorial on how to use this utility is provided in Appendix G.

Important Notes:

- The wave grid for most inlet and coastal cases will be not much longer alongshore than the flow model. If the wave model does not extend far enough, there are model parameters to smoothly interpolate the wave data to some distance alongshore in the flow model.
- Because the grid boundary is often the location of a wave buoy, the cross-shore domain tends to extend further.
- In some cases the best IJ location for the half-plane model may not be apparent, especially for open coasts. Often the degree of energy in the open ocean is dominantly from one direction or the other, and the i-direction should be aligned to that direction.

CMS-Flow Boundary Conditions

Boundary conditions for CMS-Flow are assigned along cellstrings. Cellstrings are a collection of cells used to identify the spatial extent of a boundary condition type. When a CMS-Flow grid is generated, cellstrings are automatically generated along all of the boundaries. The user has the option to use any of these cellstrings or to create new cellstrings. Once cellstrings have been created, each a boundary cellstring needs to assign a boundary type.

Creating and Deleting Cell Strings in SMS

Cell strings can either be manually created by clicking on the cells or by using the SMS interface to automatically detect and assign the cell strings.

Manually create a cellstring.

1. Select the *Create cellstring* tool .
2. Single-click on the first cell of the cellstring.
3. If necessary, single click on subsequent cells in the cellstring (around corners).
4. Double-click on the last cellstring to finish.

Figure 73 below shows several examples of good and bad cellstrings.

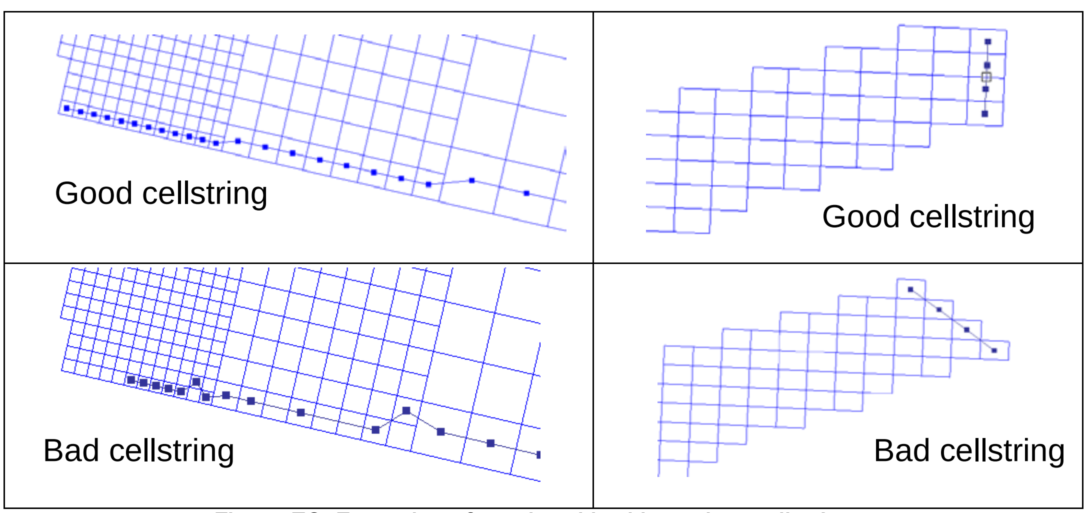


Figure 73. Examples of good and bad boundary cellstrings.

Automatically generate cellstring.

1. Click on *Cellstring* | *Generate Cellstrings* and select one of the options (Figure 74):

   - Along Open Boundaries
   - Along Land Boundaries
   - Along Open and Land Boundaries

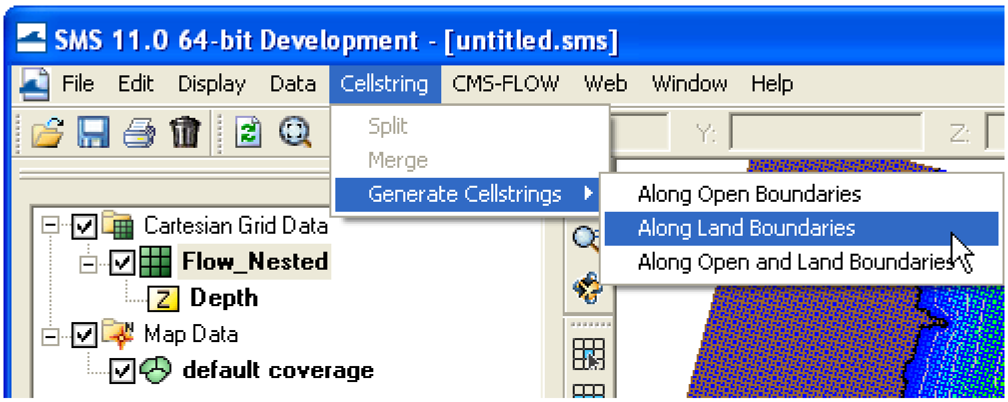


Figure 74. Automated Cellstring generation in SMS 11.0

Important Notes:

- Cellstrings must be specified at boundaries. Internal boundaries are not allowed.
- Cellstrings must be at least three cells wide.
- Cellstrings must be specified at ALL open boundaries. Leaving any open boundaries without an assigned boundary will close that boundary and apply a wall boundary condition.
- Land boundary conditions are not necessary at close boundaries (cells next to inactive cells). The CMS will automatically detect these land boundaries.
- The orientation of cellstrings is important. Some inflow and all outflow boundary conditions assume a zero-gradient in the normal direction. If this assumption is not valid, the boundary may produce instability problems. It is recommended that the boundaries be placed in a orientation such that the spatial gradients normal to the cellstring or minimal.

- Even though cell strings display along the cell centers, the actual boundary conditions are assigned at the cell faces.

Delete a cellstring.

1. Click on the *Select a Cellstring* button 
2. Right-click the cellstring boundary and select *Delete* (Figure 75).

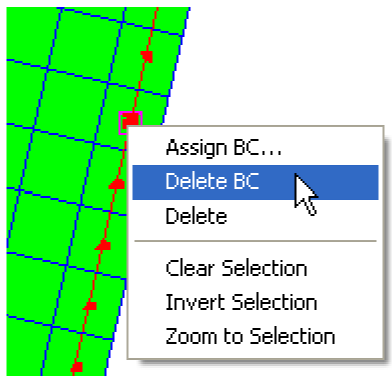


Figure 75. Deleting a cellstring in SMS.

Tips:

- The SMS interface has the option to turn on or off the display of unselected cell strings. To change this option click on *Display* | *Display Options* or the *Display Options Icon* , and under the *Cartesian Grid* options, select the check box for *Cellstrings*, and the appropriate boundary condition types.

Selecting Cellstring

Once a boundary cellstring is created, the cell needs to be selected before assigning a boundary condition. If a cellstring is not selected, no boundary conditions can be assigned even if there is only one cellstring for the grid. There are basically two ways of selecting a cellstring in SMS. To assign this type of BC in SMS:

1. Enable the cellstring selection tool by left-clicking on the *Select a Cellstring* button  in the *Cartesian Module Toolbar*.
2. Select a cellstring by either
   a. Right-clicking on a cellstring handle and select *Assign BC* (see left panel in the Figure below).
   b. Left-click and hold the button while dragging the mouse creating a selection box over the cellstring (see right panel of Figure 76).

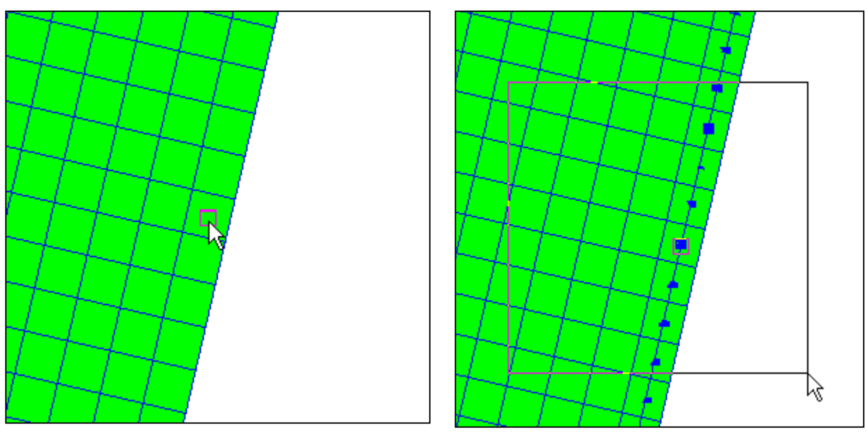


Figure 76. Selecting a celstring by either clicking on the cellstring handle (left) or dragging a selection box of the cellstring (right).

Opening the CMS-Flow Boundary Conditions Window

Once a cellstring is selected, the boundary condition can be assigned in the *CMS-Flow Boundary Conditions Window*.

1. Select a cellstring (see Selecting Cellstring section)
2. Assign the Boundary Condition by either:
   a. Right-clicking on a cellstring handle and selecting the *Assign BC* option (see Figure 77).

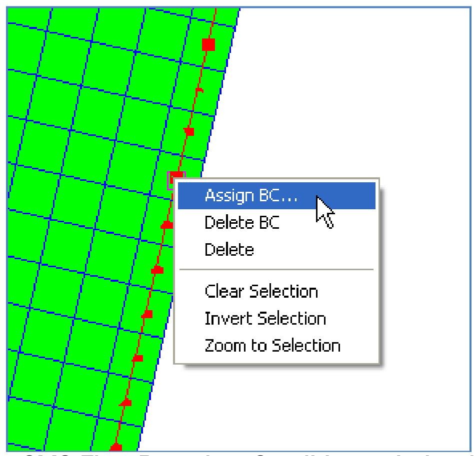


Figure 77. Opening the CMS-Flow Boundary Conditions window by left clicking.

   b. Click on the *CMS-Flow* menu, and select *Assign BC* (Figure 78).

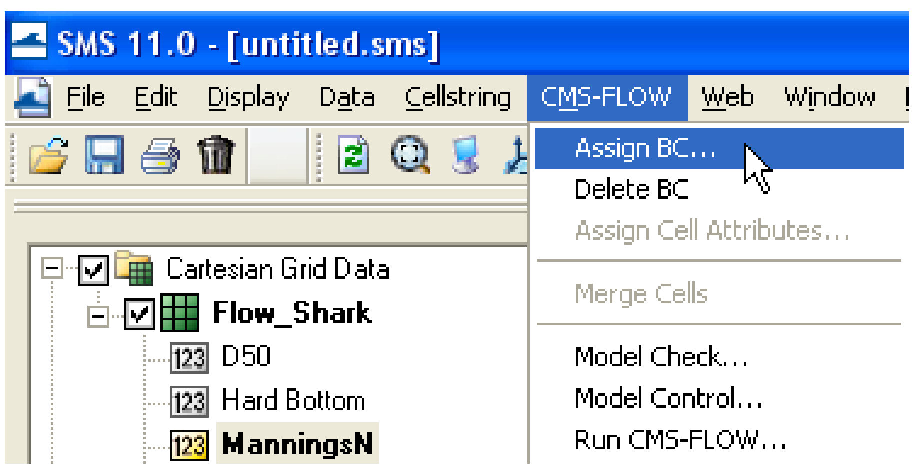


Figure 78. Opening the CMS-Flow Boundary Conditions Window through the CMS-Flow menu.

An example view of the how the *CMS-Flow Boundary Conditions Window* is shown in the Figure (Figure 79) below. The sections below describe in detail each type of boundary condition and the information required.

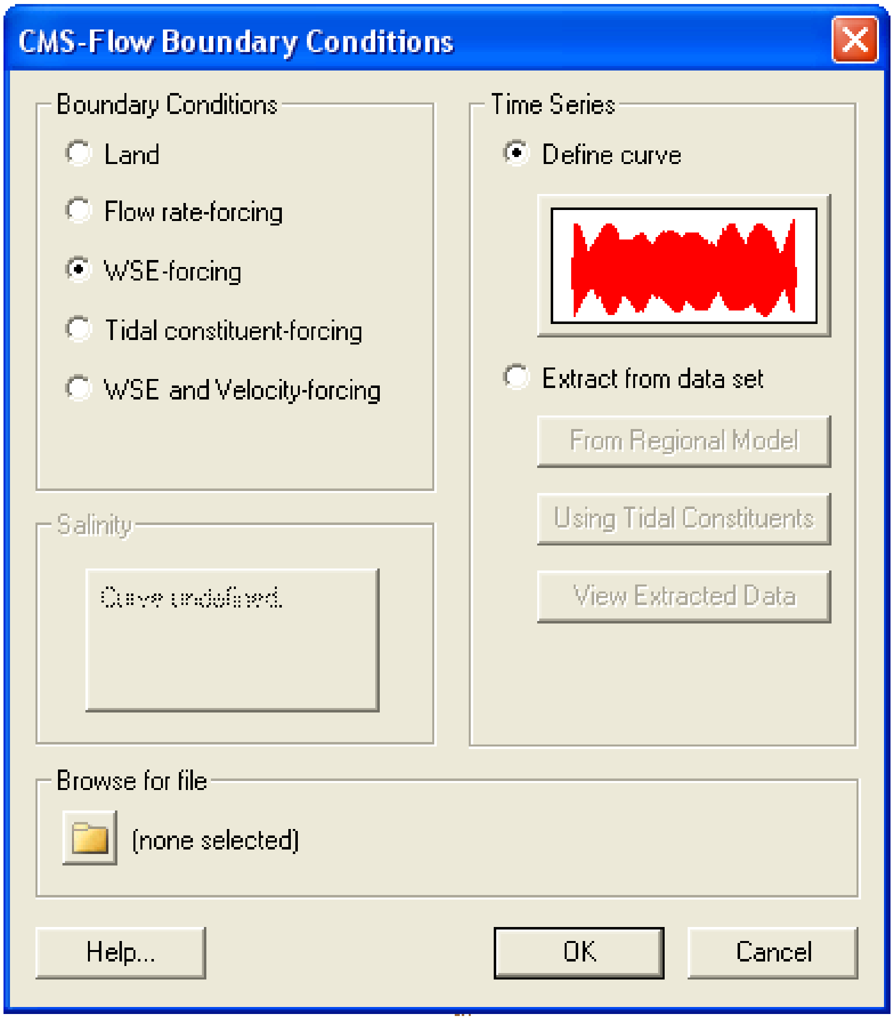


Figure 79. CMS-Flow Boundary Conditions Window.

Assigning Boundary Conditions

CMS-Flow has five types of boundary conditions which are listed and discussed below. The figure below shows the CMS-Flow Boundary Conditions window in SMS. All CMS-Flow boundary conditions are forced at the edges of the domain by use of cellstrings defined with the Surfacewater Modeling System (SMS). Cellstrings can either be created manually or using the SMS tool called *Generate Along Boundary* which is found under the *Cellstring* menu.

Flux Boundary Condition.

The flow rate boundary condition specifies a time series of water fluxes in units of m^3/s per cell. To assign a flux BC in SMS:

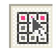
1. If not already created by SMS, create the cellstring at the flux boundary (see section Creating and Deleting Cell Strings in SMS for details).
2. Select the cellstring (see section Selecting Cellstring for details) and open the *CMS-Flow Boundary Conditions Window* (see section Opening the CMS-Flow Boundary Conditions Window for details).

Important Notes:

- Total flow rate specified is divided between the total number of cells in the cellstring with each assigned a portion of the total flux as function of the local water depth and bottom friction.
- This boundary type may only be specified along cellstrings which are straight.
- Positive fluxes are directed inward and negative fluxes are directed outward.

Single Water Level Time Series Curve.

This is the option called *Define Curve* in SMS. In this BC, a single time series of water levels is specified and is applied at all of the cells along a boundary cell string. The time series curve may be specified by either importing an SMS *.xys file, copying tabular data into SMS, or manually entered the time series information in SMS. To assign this type of BC in SMS:

1. Click on the *Select a Cellstring* button 
2. Right-click the boundary cellstring
3. Select *Assign BC* (Figure 80).
4. Select the *WSE-forcing* boundary condition, and click curve undefined (Figure 81) under *Define Curve*.

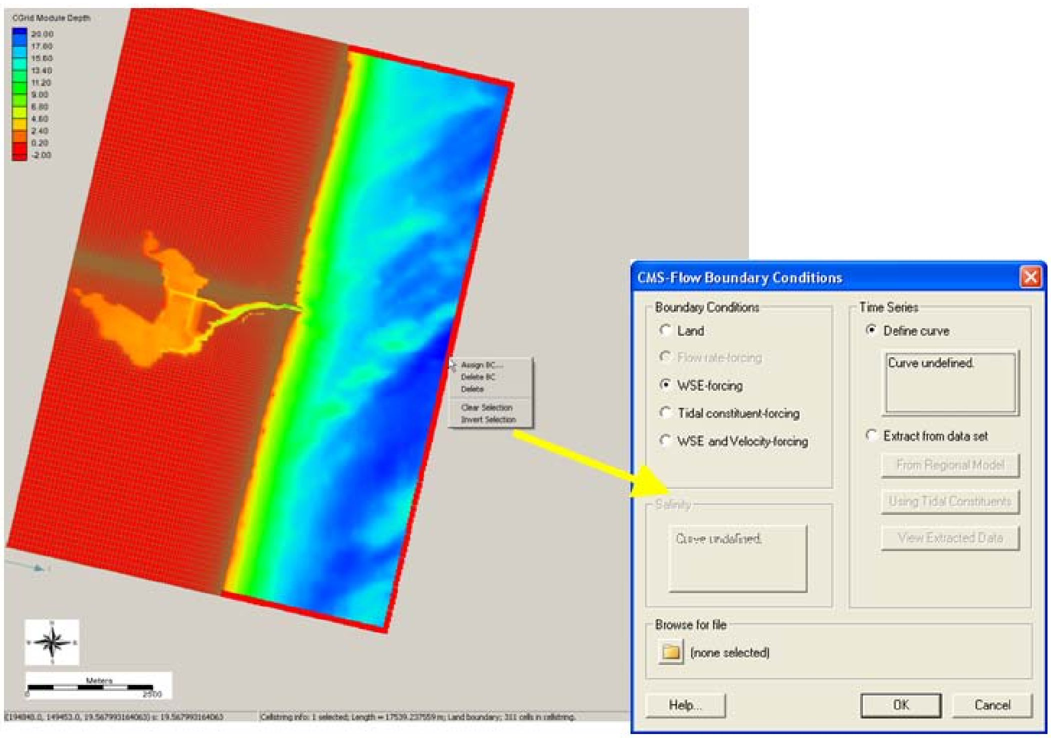


Figure 80. Selecting the cellstring along the ocean boundary, and clicking on Assign BC.

5. Copy-paste a time series into the *XY Series Editor* (Figure 81),
6. Click on the *Export* button to save the water level time series to an SMS xys file (time series file).
7. Save the *SMS project File* (*.sms) or *CMS-Flow Simulation File* (*.cmcards).

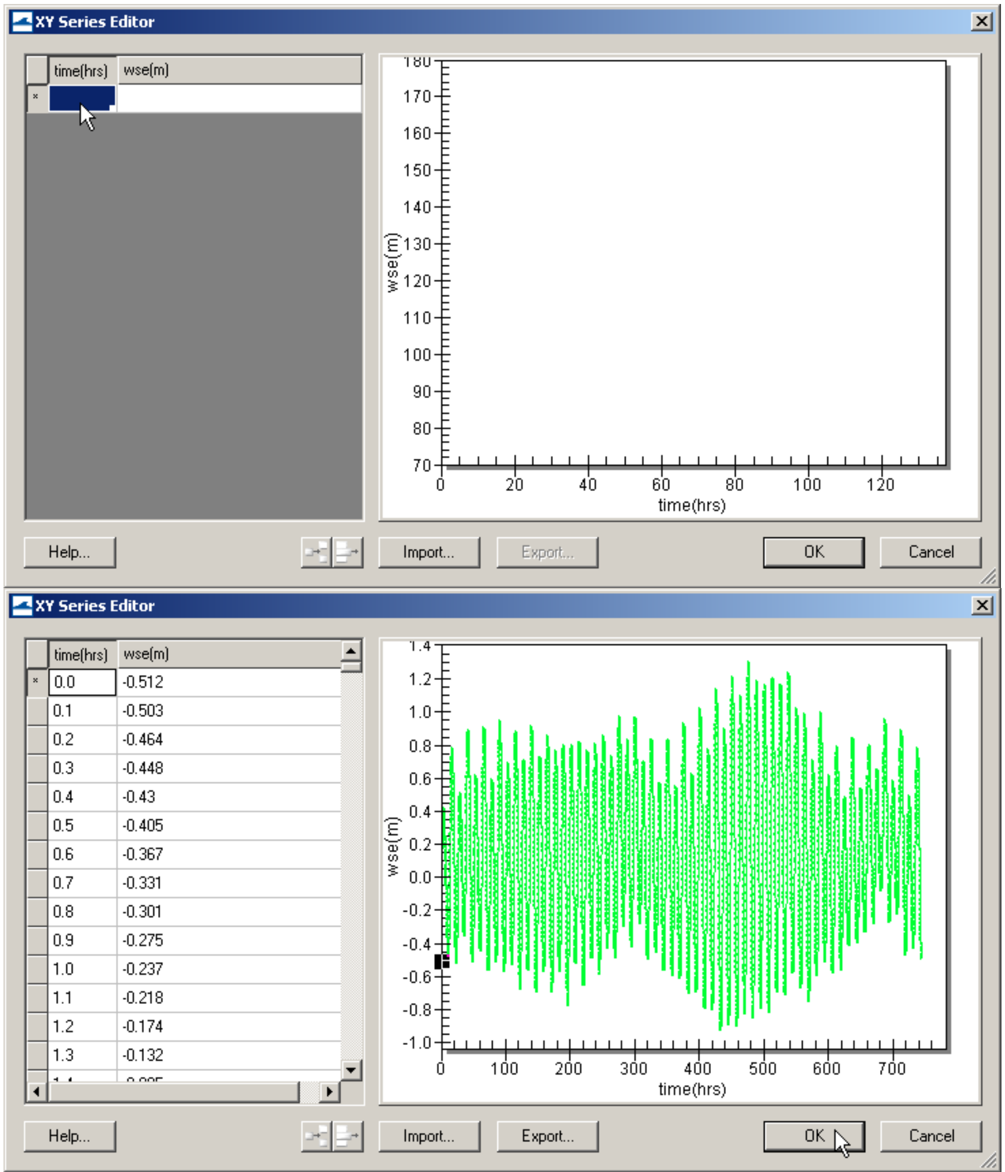


Figure 81. Top: is the blank *XY Series Editor*; Bottom: after the data is pasted in.

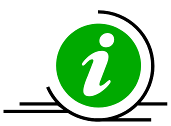
Tips:

- When specifying the time series forcing in SMS manually or by copying from an spreadsheet, it is recommended to save the time series forcing in SMS XY Series Files (*.xys). These files serve as a record of the model forcing, serve as a backup in case the Model Parameters File becomes corrupt, and can easily be reloaded in SMS for different model setups.

Extracted Water Levels.

This BC type is named *Extract from data set* in SMS 11.0. For this BC, water level time series are extracted for each cell along a cellstring. The water levels can be extracted from either:

1. A larger domain solution (ie. Larger CMS-Flow or ADCIRC grid solution files)
2. A tidal database. SMS reads and extracts tidal constituent information from either an ADCIRC (http://www.unc.edu/ims/ccats/tides/tides.htm) or LeProvost (http://sms.aquaveo.com/leprovost.zip) tidal database and constructs water level time series at each boundary cell.



Important Note:

- Due to their size, the tidal databases do come installed with SMS, and must be downloaded separately. Before using the tidal databases in SMS for the first time it is necessary to follow the steps below.

Setting up the Tidal Database Extraction Feature in SMS.

1. Download the tidal database. The ADCIRC database can be downloaded from http://www.unc.edu/ims/ccats/tides/tides.htm and LeProvost from http://sms.aquaveo.com/leprovost.zip.
2. Unzip the files and save them to the SMS directory (preferably).
3. Set the path to the tidal database by opening SMS and clicking on the *Edit* menu and selecting *Preferences…* (see Figure 82).
4. Enter the correct location (path) of the tidal database.

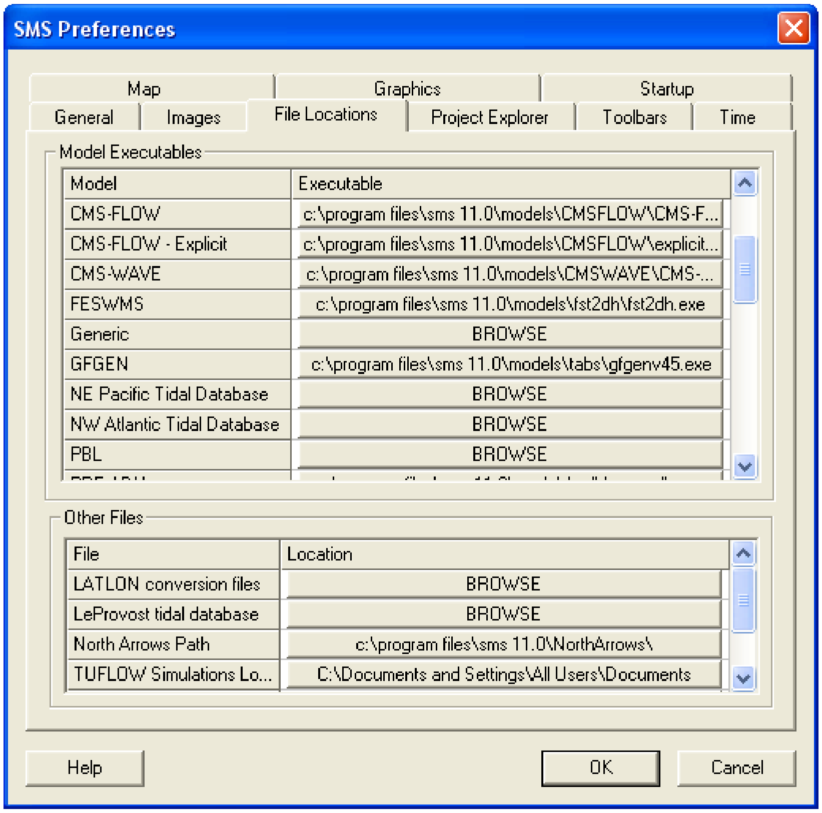


Figure 82. Setting the tidal database executable location in the SMS Preferences window.

Tidal/Harmonic Boundary Condition.

CMS and SMS 11.0 support to 37 tidal constituents. The names and speeds are provided in Table 16.

Table 16. Tidal Constituents names and speeds in solar hours implemented in CMS.

Constituent	Speed	Constituent	Speed	Constituent	Speed	Constituent	Speed
SA*	0.041067	SSA*	0.082137	MM*	0.54438	MSF*	1.0159
MF*	1.098	2Q1*	12.8543	Q1*	13.3987	RHO1*	13.4715
O1*	13.943	M1*	14.4967	P1*	14.9589	S1*	15.0
K1*	15.0411	J1*	15.5854	OO1*	16.1391	2N2*	27.8954
MU2*	27.9682	N2*	28.4397	NU2*	28.5126	M2	28.9841
LDA2*	29.4556	L2*	29.5285	T2*	29.9589	S2	30
R2*	30.0411	K2	30.0821	2SM2*	31.0159	2MK3*	42.9271

M3*	43.4762	MK3*	44.0252	MN4*	57.4238	M4	57.9682
MS4*	58.9841	S4*	60.0	M6	86.9523	S6*	90.0
M8*	115.9364						

* Only available through advanced cards for CMS >v4.0

Salinity Transport

Salinity refers to the salt content of water. Its value runs typically from 0 for fresh water to 31-35 ppt (parts per thousand) for ocean water. In water bodies with poor mixing and limited water exchange, or experiencing high evaporation, salinity can be higher and lead to formation of brine. Table 17, taken from the Wikipedia, presents typical values and nomenclature for describing degree of saline water:

Table 17. Water salinity classification.

Fresh water	Brackish water	Saline water	Brine
< 0.05 %	0.05 – 3 %	3 – 5 %	> 5 %
< 0.5 ppt	0.5 – 30 ppt	30 – 50 ppt	> 50 ppt

In coastal zones and estuaries, both temporal and spatial variations in salinity are controlled by changes in circulation, waves, tides, precipitation, evaporation, and freshwater inflows. These changes in salinity can have major effects on water density and water stratification, changing circulation patterns. Dynamic behavior of suspended sediment can be controlled by the salinity-driven flow and mixing. Any sustained changes to salinity can directly change the aggregation and consolidation of cohesive sediment as well (Nicholson and O'Connor 1986). Salinity can also alter the water chemistry that is closely related to marine organisms. Distribution and abundance of marine life will change water turbidity and define water quality in coastal and estuarine systems. Modifications of coastal inlets, such as channel deepening and widening and rehabilitation or extension of jetties may alter the salinity distribution within the estuary.

Example Application in SMS Interface

Matagorda Bay is the largest estuarine bay on the coast of Texas and is connected to the Gulf of Mexico and the Gulf Intracoastal Waterway (GIWW) through Matagorda Ship Channel (MSC), a federally-maintained inlet, and Pass Cavallo, a natural inlet just downdrift from the MSC (Figure 83).

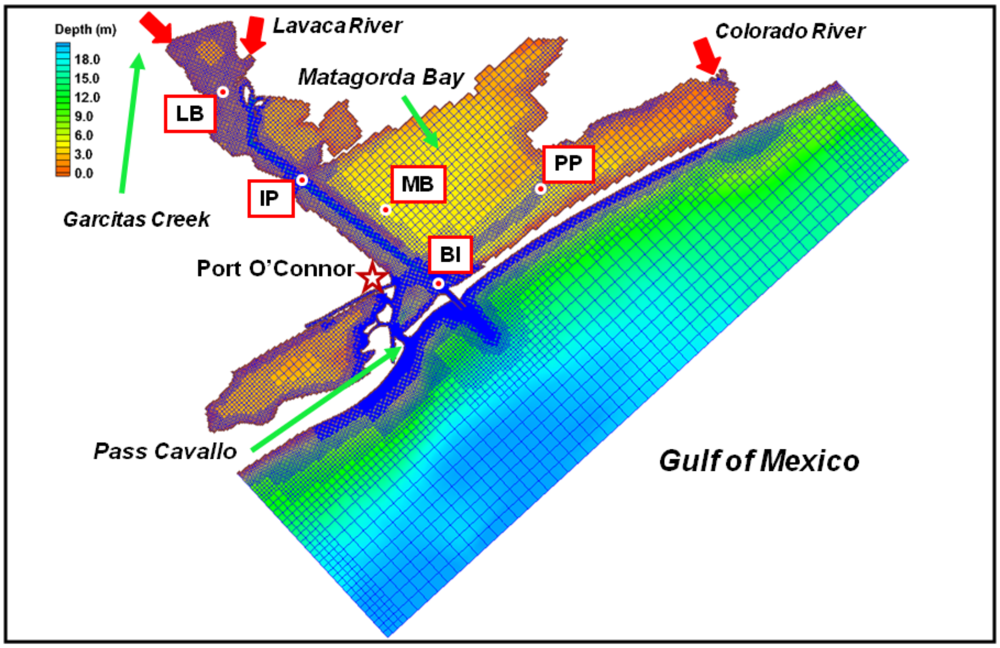


Figure 83. CMS domain, quadtree grid, and bathymetry of Matagorda Bay, TX. Red dots are the survey stations and red arrows indicate freshwater inflow locations.

In application of the CMS to Matagorda Bay, a telescoping grid was developed to discretize the bay and the offshore. The computational domain extends approximately 80 km alongshore and 20 km offshore, and the seaward boundary of the domain reaches to the 25 m isobath. Figure 1 shows the quadtree grid with 70,000 ocean cells, bathymetric features of Matagorda Bay, and the adjoining nearshore area. The CMS grid permits fine resolution in areas of high interest such as jetties and channels. The implicit solver of the CMS, with a large time step of 15 minutes, was employed for the simulation.

Freshwater discharges into the bay come from a number of streams along the coast. The Colorado and the Lavaca Rivers provide most of the inflows. However, “the freshwater discharge is typically less than 10 percent of the daily tidal exchange” in the bay (Kraus et al. 2006) (Figure 83). The bay entrance is protected by dual jetties from ocean waves. Momentum transfer, diffusive process and spatial distributions of salinity in the system are mostly controlled by wind, tide, and freshwater inflows.

CMS-Flow is driven by time-dependent water surface elevation at the offshore open boundary, wind forcing over the air-sea interface, and freshwater inflows from rivers and tributaries. Time varying salinity values at BI are also specified along the open boundaries with the water surface elevation and the river boundaries with the freshwater inflows (Figure 83). The initial salinity field is specified to the entire CMS domain as well.

1. **CMS-Flow setup:** The CMS hydrodynamic input files for Matagorda Bay are required and prepared by the SMS shown in Figure 84.

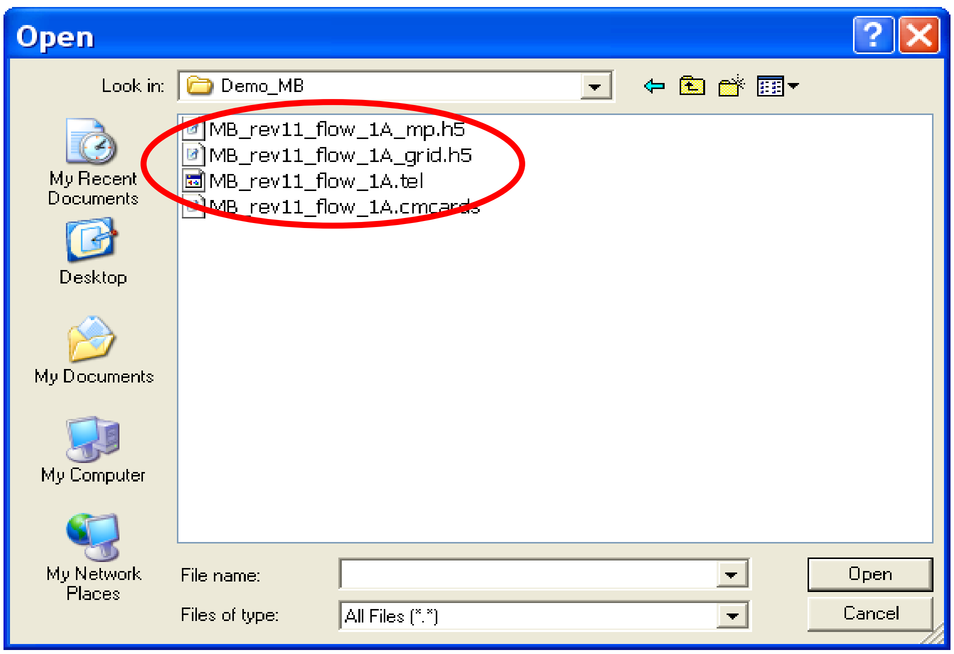


Figure 84. Files for the CMS-Flow salinity simulation.

After opening "MB_rev11_flow_1A.cmcards" in the SMS, choose CMS-Flow | Model Control, click on Salinity, and select Calculate salinity (Figure 85). A default time step equal to the hydrodynamic time step has been specified. In this case, 900 sec is used for the salinity calculation.

2. **Salinity initial condition:** Because of the large spatial variability of salinity in a coastal system, it usually requires long spin-up periods for a salinity simulation to reach to the present salinity distribution, which could range from a few days to weeks. To shorten the spin-up time, an accurate initial condition for the salinity field should be specified. There are two options to assign the initial salinity condition in CMS-Flow:

i) **A global initial salinity:** Specify a constant initial value for the entire model domain. The salinity value can be specified by checking the *Global concentration (ppt)* under the *Initial condition* (Figure 85). If this option is applied, it is best to define an average representative salinity for the entire domain.

ii) **Spatially varying initial salinity:** Generate a spatially varying initial salinity field by choosing the *Spatially varied* toggle under the *Initial condition* (Figure 85). Clicking the *Create Dataset* and assigning a value under the *Default concentration (ppt)* in the pop-up window will generate a new dataset with a constant initial salinity value. Clicking *OK* to close this window and then clicking *OK*, to close the *CMS-FLOW Model Control* window, will cause the dataset, *Salinity Initial Concentration*, to appear in the CMS-Flow data tree, as shown in Figure 86a. Highlight the dataset to specify different salinity values in the CMS domain in the same way to modify other datasets such as *D50* or *Hard Bottom*.

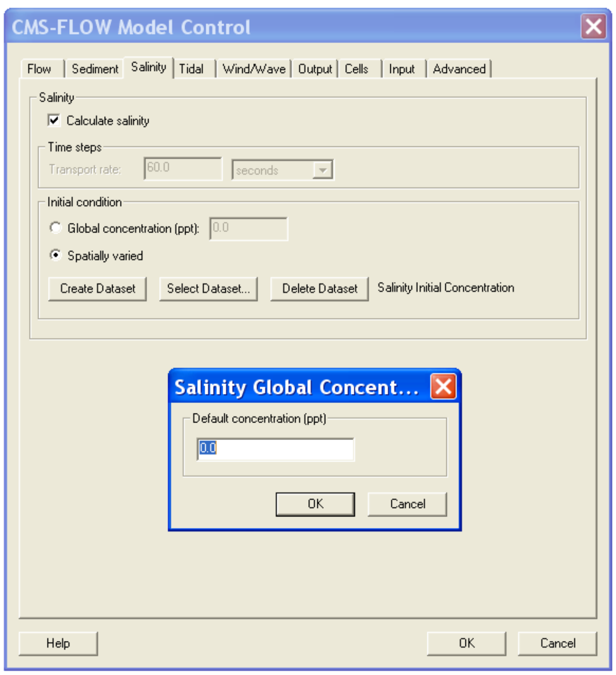
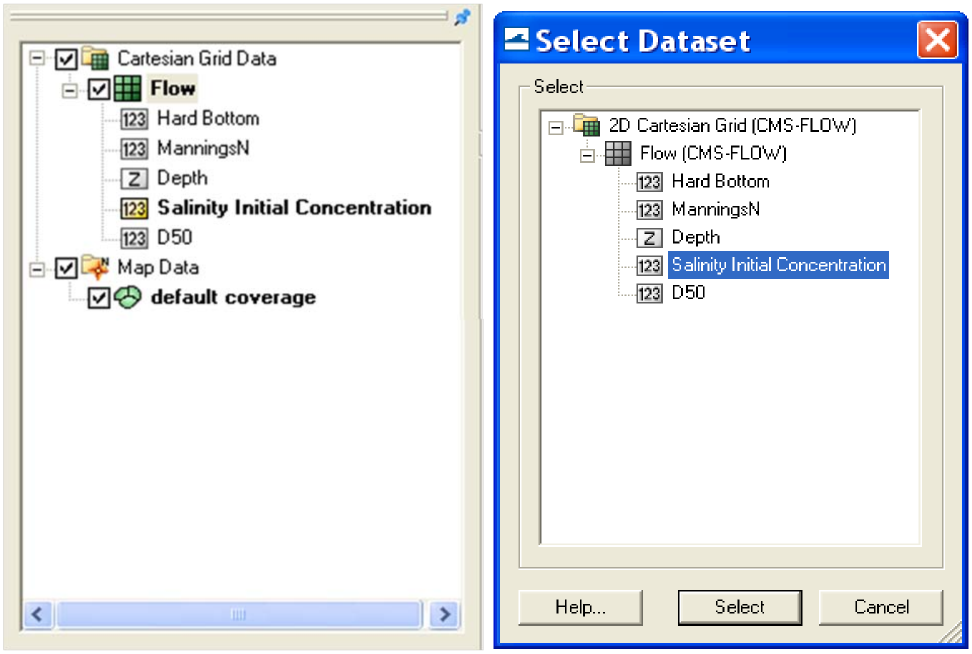


Figure 85. Setting up the salinity calculation and specifying spatially varied initial salinity.



(a) (b)

Figure 86. CMS-Flow data tree.

The dataset for a spatially varying initial salinity can also be generated by using the *Data Calculator* tool in the *Data* menu (Demirbilek et al. 2007). For an existing dataset, click the *Select Dataset* under the *Spatially varied* toggle and then select the dataset for the initial salinity that already exists (Figure 86b).

Based on the historical survey data, initial salinity is assigned in the dataset, *Salinity Initial Concentration*, for the Matagorda Bay system. The salinity varies from 21.0 ppt near the mouth of the Lavaca River to 33.0 ppt at the offshore open boundary (Figure 87).

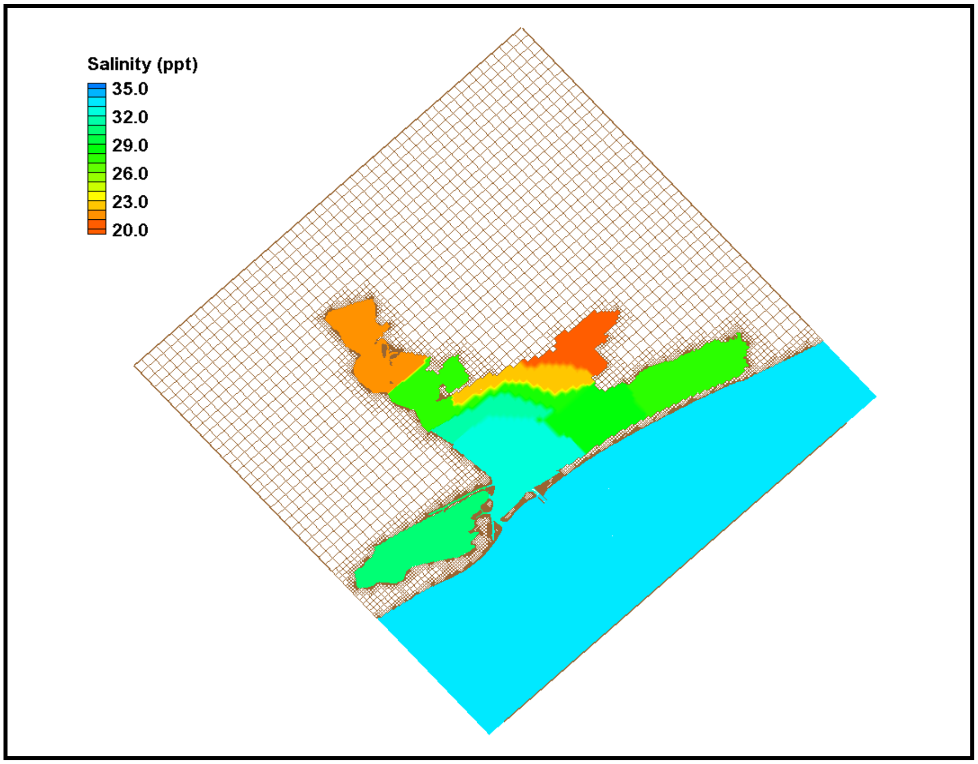
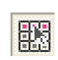


Figure 87. Initial salinity distribution.

3. **Salinity boundary conditions:** To calculate salinity transport, salinity values at CMS-Flow boundaries need to be specified. Salinity may be specified at two boundary types in the CMS: water surface elevation (WSE) boundary (*WSE-forcing* boundary) (Figure 88a) and freshwater inflow boundary (*Flow rate-forcing* boundary) (Figure 88b).

   i) **WSE-forcing boundary:** Using the *Select Cellstring*  tool and clicking/ highlighting, the cellstring of water surface elevation boundary can be specified as shown in Figure 88a. Selecting *CMS-Flow* | *Assign BC* will open the *CMS-Flow Boundary Conditions* window (Figure 89). A time series of salinity can be assigned along the *WSE-Forcing* boundary by clicking the *Curve undefined* under *Salinity* on the left hand side of the dialog.

   The time series is specified either by clicking the *Import* button to read a salinity boundary input file in xys format (Figure 90) (Aquaveo 2010), or by entering time and salinity values manually in two separate data columns, or by importing salinity data from an opened *Excel* file by using *Copy/Paste*.

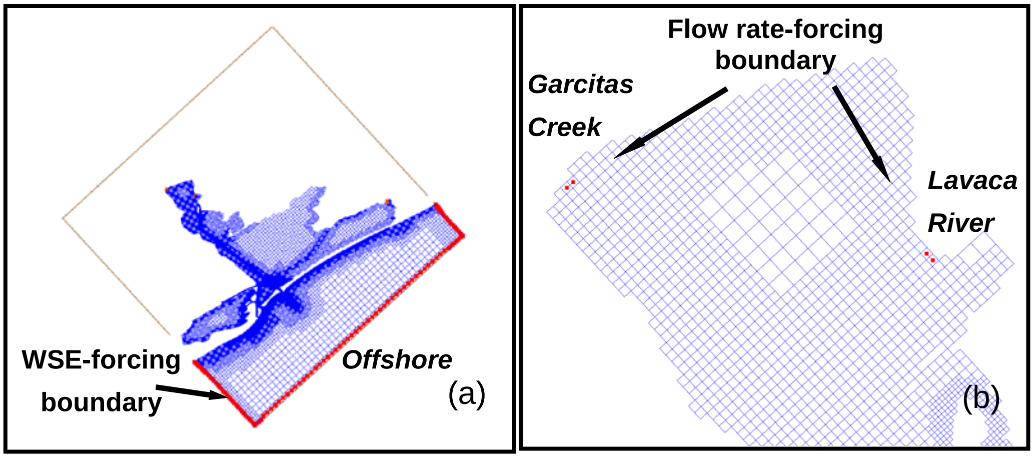


Figure 88. Salinity boundary types in the CMS.

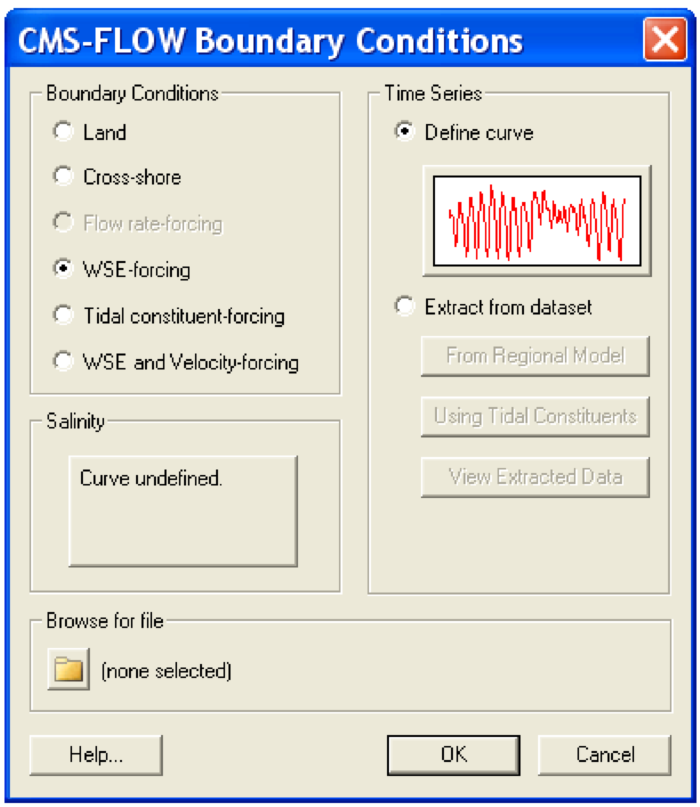


Figure 89. Salinity specifications along the *WSE-forcing* boundary.

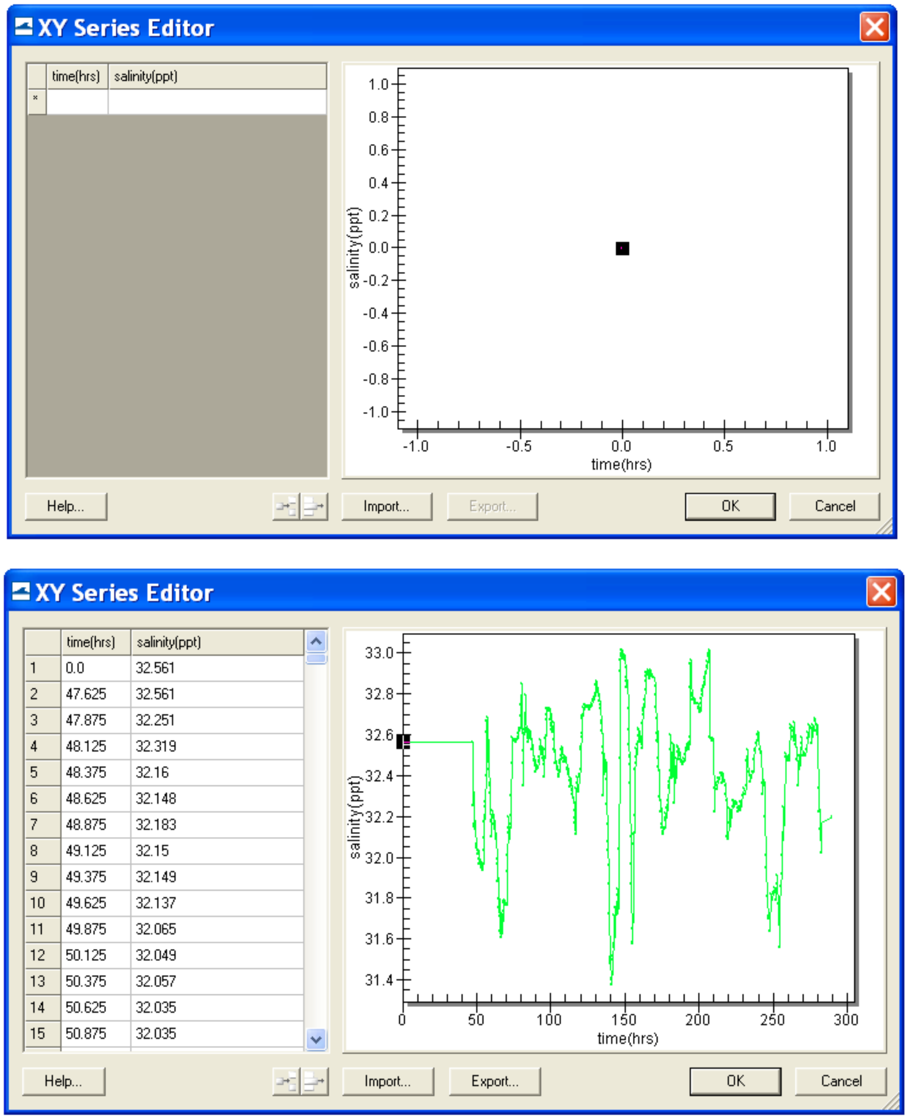


Figure 90. Salinity boundary input from a xys file.

The salinity and water surface elevation measurements at Pass Cavallo and the NOAA Corpus Christi Gage were assigned to the offshore boundary. The 12-day time series of salinity data (November-December 2005) is shown for the *WSE-forcing* boundary in Figure 8. Salinity at this location varies between 31.5 and 33.0 ppt and shows apparent influence of the ocean during the period.

ii) ***Flow rate-forcing*** **boundary:** Following the same steps as specifying *WSE-forcing* boundary, salinity values at freshwater inflow boundaries can be assigned together with flow specifications.

> The Colorado River, the Lavaca River, and the Garcitas Creek are fresh water sources that flow into Matagorda Bay and flow measurements are available at three USGS gages. A zero salinity value is assigned at the *Flow rate-forcing* boundaries.

The CMS' capability in conducting the depth-averaged salinity calculation in Matagorda Bay was demonstrated. The CMS simulations represent the salinity transport in Matagorda Bay to a level useful for comparison between engineering alternatives, and to understand the temporal variation and spatial distribution of salinity and the interaction between tides, freshwater inflows and meteorological conditions in the bay.

Sediment Transport

The sediment transport controls are located in the *Transport* section of the *CMS-Flow Model Control* window as shown in Figure 91. The sediment transport is activated by going to the *Transport* section of the *CMS-Flow Model Control* and checking the box labeles *Calculate sediment transport*. The CMS card used to turn on or off the sediment transport is described in Table 18.

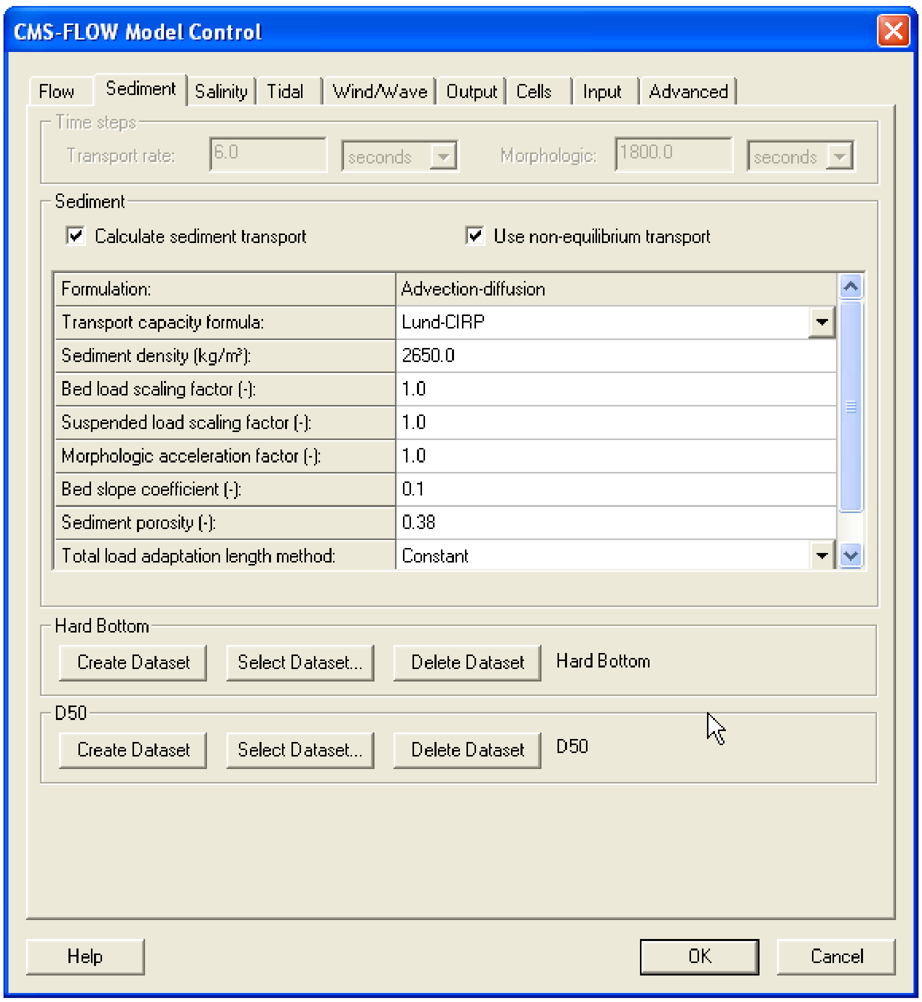


Figure 91. SMS 11.0 interfaces for sediment transport.

Table 18. CMS card used to turn *On* or *Off* the sediment transport

Card	Arguments	Default	Range	Description
CALC_SEDIMENT_TRANSPORT	character	OFF	ON OFF	Turns on or off the sediment transport calculation.

Sediment Transport and Morphologic Time steps

The sediment transport and morphologic time steps are the time steps at which the transport and bed change equations are calculated. For the explicit model, these time steps can be several times that of the hydrodynamic model. Table 19 gives a description, default value, and range for the sediment transport and morphologic time steps.

Table 19. CMS card used to set the sediment transport and morphologic time steps.

Card	Arguments	Default	Range	Description
SED_TRAN_CALC_INTERVAL	real		greater or equal to hydro time step for explicit scheme, or equal hydro time step for implicit scheme	Time step used for transport equation. See note 2 below.
MORPH_UPDATE_INTERVAL	real		greater or equal to hydro time step for explicit scheme, or equal hydro time step for implicit scheme	Time step used for updating bed elevation. See note 2 below.

Important Notes:

- For the explicit solver, the sediment transport and morphologic time steps should always be equal or a multiple of the hydrodynamic time step.
- For the implicit solver, the sediment transport and morphologic time steps are always set to the hydrodynamic time and the user is not allowed to change them.

Sediment Characteristics

The sediment characteristics are set in the "Sediment" tab of the "CMS-Flow Model Control" window. The sediment characteristics are the porosity, density, shape, and fall velocity. Table 20 gives a description, default value, and range for the sediment characteristics.

Table 20. CMS-Flow card used for setting the Schmidt number.

Card	Arguments	Range	Default	Description
SEDIMENT_POROSITY	real	0-1	0.4	Sets the sediment porosity
SEDIMENT_DENSITY	real	none	2650	Sets the sediment density in kg/m^3
SEDIMENT_FALL_VELOCITY	real	4.0e-4 - 0.4	none	Sets the sediment fall velocity to a constant in m/s
SEDIMENT_FALL_VELOCITIES	integer real real ...	none	none	Sets the sediment fall velocity to a constant in m/s for multiple grain size classes. The first number is the number of size classes and is followed by the fall velocities for each size class in ascending order.
SEDIMENT_FALL_VEL_FORM	character	SOULSBY-WHITEHOUSE WU-WANG	SOULSBY-WHITEHOUSE	Sets the sediment fall velocity formula.
SEDIMENT_COREY_SHAPE_FACTOR	real	none	0.7	Sets the Corey shape factor which is used in the Wu-Wang sediment fall velocity formula.

Important Notes:

- It is NOT recommended to use the sediment fall velocity, porosity, density or shape factor as calibration parameters. These parameters should be estimated using field or literature data.
- The sediment porosity and density are assumed constant for the whole domain and all grain size classes. For most coastal applications these assumptions are reasonable but need to be taken into consideration.

Transport model

There are currently three sediment transport models available in CMS: (1) Equilibrium total load, (2) Equilibrium bed load plus advection-diffusion for suspended load, and (3) Non-equilibrium total load. The first two models are selected by unchecking the checkbox which says "Use non-equilibrium transport" and selecting either "Total load" for the first model, or "Advection-diffusion" for the second next to input item named "Formulation". The third model is selected by checking the box "Use non-equilibrium transport". Table 21 gives a description, default value, and range for the sediment transport models.

Table 21. CMS card used to specify the sediment transport model.

Card	Arguments	Default	Range	Description
SED_TRAN_FORMULATION	character	NET	WATANABE LUND_CIRP A-D NET	Selects the sediment transport model. See note 1 below.
SED_TRAN_CALC_INTERVAL	real		greater or equal to hydro time step for explicit scheme, or equal hydro time step for implicit scheme	Time step used for transport equation. See note 2 below.
MORPH_UPDATE_INTERVAL	real		greater or equal to hydro time step for explicit scheme, or equal hydro time step for implicit scheme	Time step used for updating bed elevation. See note 2 below.

Important Notes:

- When selecting the equilibrium total load model, the SED_TRAN_FORMULATION card is set to either WATANABE or LUND_CIRP depending on the transport formula chosen. When selecting the equilibrium A-D model, the transport formula is specified through the concentration profile formula (described below).
- All three sediment transport models are available with the explicit solver, while only the NET is available witht implicit solver.

A description of each sediment transport model is described in the sections below.

Equilibrium Total load

In this model, both the bed load and suspended load are assumed to be in equilibrium. The bed change is solved using a simple mass balance equation known as the Exner equation.

Equilibrium Bed load plus Advection-Diffusion Suspended Load

Calculations of suspended load and bed load are conducted separately. The bed load is assumed to be in equilibrium and is included in the bed change equation while the suspended load is solved through the solution of an advection-diffusion equation. Actually the advection diffusion equation is a non-equilibrium formulation, but because the bed load is assumed to be in equilibrium, this model is referred to the "Equilibrium A-D" model.

Nonequilibrium Total Load

In this approach, neither the bed nor suspended loads are assumed to be in equilibrium. The suspended- and bed-load transport equations are combined into a single equation and thus there is one less empirical parameter to estimate (adaptation length).

Important Note:

- Only the Nonequilibrium Total Load model is available in CMS versions 4.0 and greater at the moment. Plans are under way to include the Equilibrium Bed plus Advection-Diffusion Suspended Load model as an option, but the Equilibrium Total Load model will likely be discontinued.

Sediment Transport Formula

The nearbed sediment concentation or concentration capacity are calculated with one of the following transport formula:

- Lund-CIRP (2006)
- Van Rijn (1998)
- Watanabe (1987)
- Soulsby-van Rijn (1997) (>=V4.0)

Table 22 gives a description, default value, and range for the sediment transport formulae.

Table 22. CMS-Flow cards used to specify the sediment transport formula and related parameters and options.

Card	Arguments	Default	Range	Description
NET_TRANSPORT_CAPACITY	character	LUND-CIRP	LUND-CIRP VAN_RIJN SOULSBY WATANABE	Selects the transport formula. Note that SOULSBY is only available in v>=4.0
TRANSPORT_FORMULA	character	LUND-CIRP	LUND-CIRP VAN_RIJN SOULSBY WATANABE	Selects the transport formula. Note that SOULSBY is only available in v>=4.0.
SED_TRANS_FORMULATION	character	LUND-CIRP	LUND-CIRP A-D WATANABE NET	Selects the transport formula for the equilibrium total load model. Does not specify the transport formula for the equilibrium A-D and non-equilibrium total load models.

CONCENTRATION_PROFILE	character	LUND-CIRP	LUND-CIRP EXPONENTIAL ROUSE VAN_RIJN	Selects the concentration profile to be used either in the equilibrium A-D or total load nonequilibrium models.
A_COEFFICIENT_WATANABE	real	0.1	0.05-0.5	Empirical coefficient which goes into the Watanabe transport formula.

Important Notes:

- Different transport formula may produce very different results in morphology change.
- The Lund-CIRP does well in predicting the surf zone sediment transport but tends to overestimate the transport rates near the wetting and drying limit and in deep water (>10 m).
- The van Rijn transport formula tends to underestimate the transport for conditions near the critical shear stress of motion. The formula also tends to underestimate the transport close to the shoreline.
- The Watanabe formula tends to underestimate the transport in deep water (>10 m).

Recommendations:

- For every sediment transport project, it is recommended to test several sediment transport formula to observe the sensitivity of the results to the sediment transport formula. The sediment transport formula is perhaps the most important parameter of any sediment transport model and the largest source error.

Scaling Factors

Transport Scaling Factors

The bed- and suspended-load transport scaling factors multiply directly by the transport capacity or near-bed sediment concentration calculated from the transport formula. These factors should be used to calibrate sediment transport rates and due to the large uncertainty in the transport formula, it is generally acceptable to use scaling factors in the range of 0.5-2.0. Table

23 gives a description, default value, and range for the bed- and suspended-load scaling factors.

Table 23. CMS card used to specify the bed- and suspended-load scaling factors.

Card	Arguments	Default	Range	Description
BED_LOAD_SCALE_FACTOR	real	1.0	0.5-2.0	Calibration factor for bed load transport capacity formula
SUSP_LOAD_SCALE_FACTOR	real	1.0	0.5-2.0	Calibration factor for suspended load transport capacity formula

Morphologic Acceleration Factor

The morphologic scaling factor is directly multiplied by the calculated bed change at every time step and is intended as a means of speeding up the computational time. It is only recommended for periodic boundary conditions or conditions that do not change rapidly over time. Table 24 gives a description, default value, and range for the morphologi acceleration factor.

Table 24. CMS card used to specify the morphologi acceleration factor.

Card	Arguments	Default	Range	Description
MORPH_ACCEL_FACTOR	real	1.0	1-100	Morphologic acceleracion factor. Directly multiplies by calculated bed change.

Important Note:

- The morphologic scaling factor is NOT a calibration parameter. It should only be used in cases with periodic forcing and boundary conditions and even then it should be used with caution. It is NOT recommended to use larger values than 20-30.

Schmidt Number

The sediment mixing coefficient is calculated as the eddy viscosity divided by the Schmidt number. For simplicity the Schmidt number is assumed to be constant and the default value is 1.0. Table 25 gives a description, default value, and range for the Schmidt number.

Table 25. CMS card used to turn On or Off the mixing terms in the momentum and transport equations

Card	Arguments	Default	Range	Description
SCHMIDT_NUMBER	real	1.0	none	Controls the sediment mixing strength

Important Note:

- The Schmidt number should NOT be used as a calibration number and should only be changed in sensitivity analysis or model testing.

Adaptation Coefficient

The adaptation coefficient is an important parameter to consider in setting up the CMS sediment transport model. The sensitivity of results to the adaptation coefficient depends on the spatial and temporal scales of the problem. For example, if a high resolution grid is used to model short-term dynamics of a nearshore disposal site or a small inlet, then the adaptation coefficient is likely to be important. However, if a relatively coarse grid is used to study sediment pathways in a large estuary entrance, then the adaptation coefficient will not be important.

Total Load

There are four methods for calculating the total load adaptation coefficient in CMS:

1. CONSTANT_LENGTH: A temporally and spatially total load adaptation length is used for the whole domain. The total load adaptation coefficient is calculated as

$$\alpha_t = Uh / (L_t \omega_s) \quad (187)$$

   where ω_s is the sediment fall velocity of the transport grain size, for single size sediment transport, or the median grain size, in the case of multiple-sized sediment transport.

2. CONSTANT_TIME: A temporally and spatially constant total-load adaptation time is used for the whole domain. The total load adaptation coefficient is calculated as

$$\alpha_t = h/(T_t \omega_s) \tag{188}$$

where ω_s is the sediment fall velocity of the transport grain size for single size sediment transport, or the median grain size, in the case of multiple-sized sediment transport.

3. WGHT_AVG_BED_SUSP_LENGTH: A temporally and spatially constant total-load adaptation time is used for

$$L_t = r_s L_s + (1 - r_s) L_b \tag{189}$$

where L_s is the suspended load adaptation length, L_b is the bed load adaptation length, and r_s is the fraction of suspended load of the total load. The methods for determining L_b and L_s are described in subsequent sections.

4. MAX_BED_SUSP_LENGTH: A temporally and spatially constant total-load adaptation time is used for

$$L_t = \max(L_s, L_b) \tag{190}$$

where L_s is the suspended load adaptation length and L_b is the bed load adaptation length. The methods for determining L_b and L_s are described in subsequent sections.

The CMS cards related to the total load adaptation coefficient are described in the Table 26 below.

Table 26. CMS card used to specify the total-load adaptation coefficient.

Card	Arguments	Default	Options/Range	Description
ADAPTATION_METHOD_TOTAL	character	CONSTANT_LENGTH	CONSTANT_LENGTH CONSTANT_TIME WGHT_AVG_BED_SUSP_LENGTH MAX_BED_SUSP_LENGTH	Sets the method for calculating the total load adaptation coefficient.
ADAPTATION_LENGTH_TOTAL	real	10.0	≥0	Total load adaptation length in meters.
ADAPTATION_TIME_TOTAL	real	2.0	≥0	Total load adaptation time in seconds.

Important Note:

- If the total-load adaptation length is set to -1.0, then the maximum of the bed- and suspended-load adaptation lengths is used. This is the input format used by SMS.

Recommendations:

1. When first setting up a sediment transport model, it is recommended to use a spatially constant total load adaptation length for simplicity.

2. If the user is not sure of the sensitivity of the results to the adaptation length for the specific project, then it is recommended to test different total load adaptation lengths; for example 5, 10, and 50 meters. This will provide an insight into the sensitivity of the results to the adaptation length. In many cases, the results are not found to be sensitive and the default value of 10 m can be used. If the results are found to be more tests are necessary in determining to optimal method and parameters for calculating the adaptation length.

3. WGHT_AVG_BED_SUSP_LENGTH is the most physically accurate method for determining the total load adaptation length. However, it can lead to relatively small adaptation lengths which cause instabilities, especially for large computational time steps. If this occurs then it is recommended to use MAX_BED_SUSP_LENGTH.

Bed Load

The CMS cards related to the bed load adaptation coefficient are described in the Table 27 below.

Table 27. CMS card used to specify the bed-load adaptation coefficient.

Card	Arguments	Default	Range/Options	Description
ADAPTATION_METHOD_BED	character	1.0	CONSTANT_LENGTH CONSTANT_TIME DEPTH_DEPENDANT	Calibration factor for bed load transport capacity formula
ADAPTATION_LENGTH_BED	real	10.0	none	Calibration factor for suspended load transport capacity formula
ADAPTATION_TIME_BED	real	1.0	0.5-2.0	Calibration factor for suspended load transport capacity formula
ADAPTATION_DEPTH_FACTOR_BED	real	10.0	none	

Important Note:

- If the total-load adaptation length is set to a negative number, then the value is interpreted as being the bed-load adaptation length depth factor. The bed-load adaptation length is therefore calculated as the depth times the positive depth factor.

Recommendations:

- Based on experience, it is recommended to use a constant bed load length from one to three times the grid resolution.

Suspended Load

The suspended-load adaptation parameters only need to be specified if the total-load adaption coefficient is set as a function of the suspended-load adaptation length (see Total Load section). There are several options in CMS for specifying the sThe CMS cards related to the suspended-load adaptation coefficient are described in the Table 28 below.

Table 28. CMS card used to specify the suspened-load adaptation coefficient.

Card	Arguments	Default	Range/Options	Description
ADAPTATION_METHOD_SUSPENDED	character	1.0	CONSTANT_LENGTH CONSTANT_TIME CONSTANT_ALPHA ARMANINI_DISILVIO LIN GALLAPPATTI	Calibration factor for bed load transport capacity formula For additional details on each method see the Adaptation Coefficient section.
ADAPTATION_COEFF_SUSPENDED	integer	1	1,2	Specifies the suspended-load adaptation method. See note below.
ADAPTATION_COEFFICIENT_SUSPENDED	real	2.0	0.5-2.0	Calibration factor for suspended load transport capacity formula
ADAPTATION_LENGTH_SUSPENDED	real	1.0	0.5-2.0	Calibration factor for suspended load transport capacity formula
ADAPTATION_TIME_SUSPENDED	real	1.0	0.5-2.0	Calibration factor for suspended load transport capacity formula

Important Notes:

- By default, SMS writes the CMS-Flow card ADAPTATION_COEFF_SUSPENDED. However, this card is out-dated and can be confused with the card ADAPTATION_COEFFICIENT_SUSPENDED (see table above). Instead, it is recommended for the user to use the ADAPTATION_METHOD_SUSPENDED to specify the method for the suspended-load adaptation coefficient.

Hard Bottom

Hard Bottom is a morphologic constraint that provides the capability to simulate mixed bottom types within a single simulation. This cell-specific feature limits the erodibility of the constrained cells down to a specified depth below the water surface. During sediment transport calculations, exposed hard bottom cells may become covered through deposition. By default, CMS-Flow cells are fully-erodible cells with no specified hard bottom depth (inactive cells; denoted by the CMS-Flow null value of -999.0). Hard bottom only needs to be specified only for computational (ocean) cells.

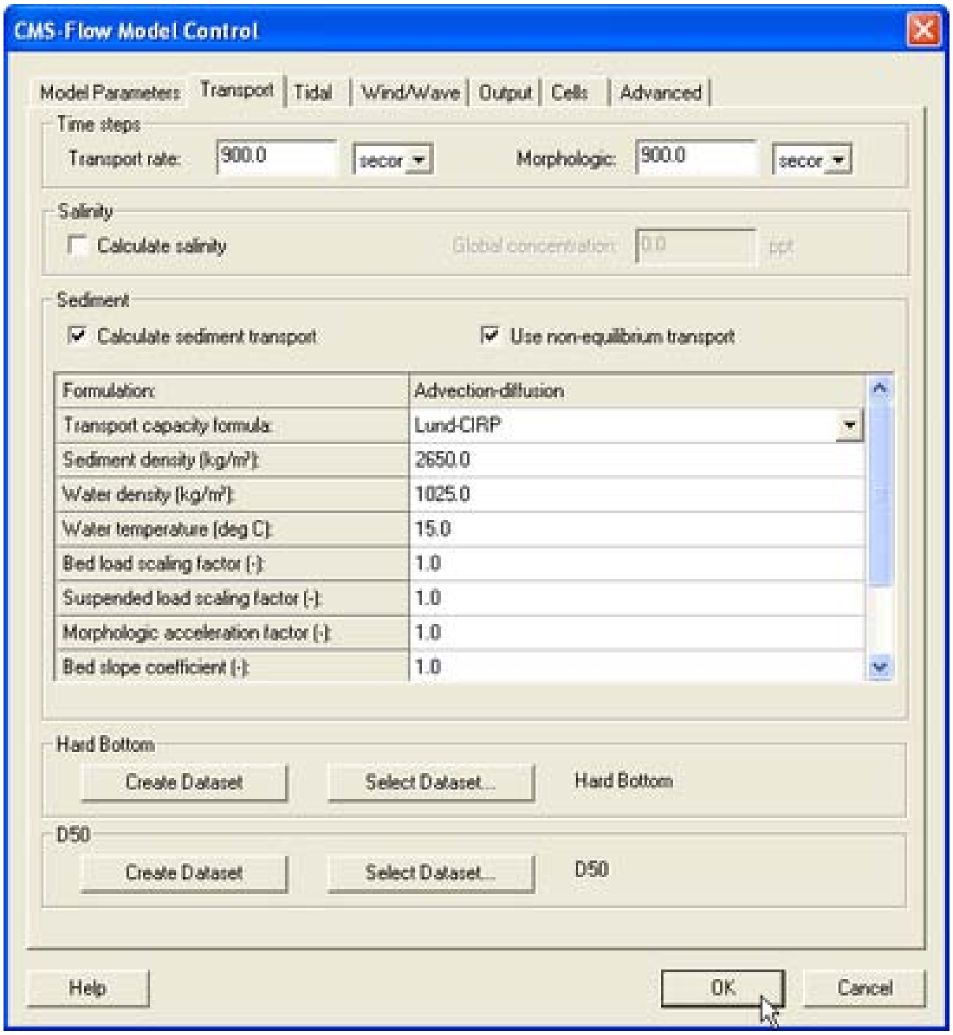


Figure 92. CMS-Flow Model Control window showing the location where the hard bottom dataset is specified.

Within the *CMS-Flow Model Control* window, the hard bottom dataset can be created from the *Sediment* tab. If the dataset does not exist, it can be created using the *Create Dataset* button. If a dataset exists (created using the Data Calculator) which represents the intended hard bottom specifications, the *Select Dataset* button can be used to select such dataset and copy the values to the hard bottom dataset.

When specified, cell hard bottom depths will appear in the Project Explorer as a scalar dataset beneath the CMS-Flow grid. This dataset can not be deleted, though it can be edited like any other dataset. A CMS-Flow simulation must contain the hard bottom dataset (even if it is not specified) so SMS will create a defaulted (inactive cells) dataset if it does not already exist when saving the simulation. The hard bottom dataset can created, edited, viewed and verified using the following SMS interface features.

Figure 93. SMS Project Explorer showing Hard bottom dataset

Hard Bottom Specification

Although the hard bottom dataset can be edited (when its the active dataset) by selecting a cell (or group of cells) and changing the scalar (S) value in the Edit Window, an user-friendly window exists which provides specification options. With the *Select Grid Cell* tool active, make a selection, right click to bring up the tool menu and choose the *Specify Hard Bottom...* option. This will open the CMS-Flow Hard Bottom Specification window.

The following options are provided in the Hard Bottom Specification window:

- **Use bathymetric cell depth** - Sets the cell hard bottom depth to be the cell geometry value thereby creating an exposed non-erodible condition. If multiple cells were selected, then each cell will use its respective bathymetric depth.
- **Specified distance below bathymetric cell depth** - Sets the cell hard bottom depth to be the cell geometry value plus the specified distance thereby creating a sediment-covered non-erodible condition. The distance is limited to positive values to ensure the hard bottom depth is greater than the geometry value. The cell can provide sediment for transportation, however, the amount of erosion is limited. If multiple cells were selected, then each cell will use its respective bathymetric depth.
- **Specified depth** - Sets the cell hard bottom depth to the specified depth thereby creating a sediment-covered non-erodible condition similar to specified distance. The depth is limited to greater than the geometry value. If multiple cells were selected, then the depth is limited to greater than the largest geometry value and all cells will have the same value.

- **Unspecified** - Resets to an inactive hard bottom condition. The cell hard bottom depth is set to the CMS-Flow null value. If multiple cells were selected, then all cells will be reset.

If no cells are selected when opening the Hard Bottom Specification window, then all computational (ocean) cells will be used. If a selection of only non-computational cells, then specification cannot occur. If a selection contains computational and non-computational cells, then the specification will only apply to the computational cells.

If multiple computational cells with differing specifications are selected, the window will not display a selected specification type and the *OK* button will be disabled. This is to protect the previous specifications from being overwritten by mistake. The *OK* button will be enabled when an option is selected. The minimum hard bottom depth of the multiple computational cells selected will be displayed in the *Depth* edit field and the minimum hard bottom depth minus the maximum geometry depth of the multiple computational cells selected will be displayed in the *Distance* edit field.

Display Options

The hard bottom dataset (when its the active dataset) will only display the cells with hard bottom specified if the *Ocean cell* display option is turned on. Inactive hard bottom cells are not displayed.

CMS-Flow includes hard bottom symbols to differentiate specifications. On the *Cartesian Grid* page of the Display Options window (when CMS-Flow is the active model), the *Hard bottom symbols* check box controls the display of symbols that will appear in hard bottom cells (even if the hard bottom dataset is not active). If this is turned on, then the user must be aware of the individual symbol settings accessed by clicking on the *Options...* button. The *Options...* button displays the CMS-Flow Hard Bottom Symbols window.

Hard bottom symbols can be selected for three hard bottom specification types:

- **Non-erodible** - Displayed in exposed hard bottom cells (cell hard bottom depth is equal to cell bathymetric depth).
- **Erodible to specified depth** - Displayed in sediment-covered hard bottom cells (cell hard bottom depth is greater than cell bathymetric depth).

- **Invalid specification -** Displayed in hard bottom cells where the hard bottom depth is less than cell bathymetric depth (the geometry is below the erosion limit).

If the *Hard bottom symbols* check box is turned off, no symbols will be displayed and the individual settings cannot be accessed, however, the individual settings will not be changed.

Bed slope Term

The bedslope term accounts for the effect of gravity on sloped beds. The larger the bed slope coefficient, the more sediment tends to move down-slope, thus smoothing the solution. The CMS-Flow used to specify the slope coefficient is described in Table 29 below. The bedslope coefficient is set in the *Sediment* tab of the *CMS-Flow Model Control* window in SMS 11.0.

Table 29. CMS card used to *turn On or Off the* mixing terms in the momentum and transport equations

Card	Arguments	Default	Range	Description
SLOPE_COEFFICIENT	real	1.0	0-5	Bed slope coefficient which controls enters a diffusion term which moves sediment down slope

Avalanching

Avalanching is the process of sediment sliding when the critical angle of repose is reached. In CMS, avalanching is simulated using a mass conservative relaxation method which limits the bed slope to the critical angle of repose. For most coastal applications, the critical angle of repose is never reached, so it is not needed. The CMS-Flow cards used for specifying avalanching, and its options, are described in Table 30 below.

Table 30. CMS-Flow cards related to avalanching.

Card	Arguments	Range	Default	Description
USE_AVALANCHING	character	ON OFF	ON	Turns On or Off the avalanching.
RESPOSE_ANGLE	real	none	32°	Specifies the angle of repose in degrees.
AVALANCHE_MAX_ITERATIONS	integer	none	200	Specifies the maximum number of iterations used in the implicit solution scheme. For the explicit solution scheme, the avalanching is calculated every transport time step for one iteration.

Ramp Period

The option is available to not calculate the morphology change during the ramp period. The best practice is the start the model simulation so that the time when the ramp period ends corresponds to the time of the measured bathymetry. This avoids the initial bed erosion (although slight) of the bed. This also facilitates calculating simulation statistics such as transport rates and residual currents.

Table 31. CMS-Flow card used to turn On or Off bed updating during the ramp period.

Card	Arguments	Range	Default	Description
CALC_MORPH_DURING_RAMP	character	ON OFF	ON	Turns On or Off the morphology change calculation during the ramp period

Total Load Correction Factor

The total load correction factor accounts for the nonuniform vertical profile of sediment concentration and current velocity and produces temporal lag in between the flow and sediment transport. The factor is used in the nonequilibrium total load sediment transport formula.

Table 32. CMS-Flow cards related to the total load correction factor.

Card	Arguments	Default	Range	Description
TOTAL_LOAD_CORR_FACTOR_CONSTANT	real	0.3-1.0	none	Sets the total load correction factor to a constant.
CONCENTRATION_PROFILE	character	LUND-CIRP VAN_RIJN EXPONENTIAL ROUSE	none	Sets the concentration profile to be used either in the pickup and deposition functions or the total load correction factor calculation.

Single-sized Sediment Transport

Hiding and Exposure Correction

This cell-specific parameter allows for the single-sized sediment transport model to make a hiding and exposure correction factor.

Table 33. CMS card used for specifying the single-sized sediment transport hiding and exposure correction.

Card	Arguments	Default	Range	Description
TRANSPORT_GRAIN_SIZE	real	none	none	Transport grain size in mm. The transport grain size is the sediment size which is eroded, transported, and deposited. When this card is specified the D50 dataset is used to make a

				hiding and exposure correction to the critical shear stress.
HIDING_EXPOSURE_COEFFICIENT	real	0.7	0.6-1.0	Hiding and exposure coefficient.
SEDIMENT_STANDARD_DEVIATION	real	1.5	<=1.0	Specified the geometric standard deviation
D50_DATASET	character character	none	None	File and path in which the varying D50 information is stored.
CONSTANT_GRAIN_SIZE	Real	None	None	Defines single size grain and forces CMS to neglect D50 dataset.

Important Notes

1. If the no transport grain size is specified, then the transport grain size is calculated as the mean D50 of the whole domain.
2. If the card CONSTANT_GRAIN_SIZE is used, then the D50 dataset will be ignored.
3. The geometric standard deviation MUST be larger or equal to 1.0.

Boundary and Initial Conditions

In the case of the Equilibrium Total Load sediment transport model, all boundaries are set to the equilibrium transport rate. For the Equilibrium Bed Load plus Advection Diffusion model, the suspended load is specified as the equilibrium concentration at inflow cells and a zero gradient at outflow cells. For the Total load nonequilibrium sediment transport model, the sediment concentration is set to the equilibrium concentration at inflow cells and a zero gradient boundary condition is applied at outflow cells.

In the case an initial conditions file is NOT specified both the hydrodynamics and sediment concentrations are initialized as zero. If an initial conditions file is specified, than the initial sediment concentrations are read in. If an initial conditions file is specified but without the sediment concentration, than the initial sediment concentration is set to the equilibrium concentration.

Table 34. CMS Flow cards related to the boundary conditions.

Card	Arguments	Default	Range	Description
NET_LOADING_FACTOR	real	1.0	0.5-2.0	Used to specify under- or overloading at sediment inflow boundaries. Only for NET.
SEDIMENT_INFLOW_LOADING_FACTOR	real	1.0	0.5-2.0	Used to specify under- or over-

				loading at sediment inflow boundaries.
CALC_MORPH_DURING_RAMP	character	ON	ON OFF	Determines whether to calculate the morphology change during the ramp period

Multiple-sized Sediment Transport

The CMS multiple-sized sediment transport model is calculated using the multifraction approach, in which the total sediment transport is equal to the sum of the transports of discrete sediment sizes classes.

The input information for multiple-sized sediment transport can be divided into the following groups:

1. Grain size classes
2. Fractional bed composition
3. Bed layer thickness
4. Mixing layer
5. Hiding and Exposure

Further details on each type of information are provided in the sections below.

Grain Size Specification

In the multiple-sized sediment transport model, the continuous grain sizes are divided into discrete bins or size classes. Each size class has a character diameter, and lower and upper limits. Because sediment sizes classes are transport from one cell to another the size classes must be constant over the whole domain. In CMS there are two options for specifying the grain size information:

1. Characteristic diameters
2. Size class limits

The characteristic diameters d_k are calculated using the geometric mean of the lower $d_{l,k}$ and upper $d_{u,k}$ bin limits

$$d_k = \sqrt{d_{lk} d_{uk}} \tag{191}$$

The bin width is given by

$$\Delta d_k = d_{uk} - d_{lk} \quad (192)$$

Table 35 below describes the CMS-Flow cards related to the grain size class information.

Table 35. CMS-Flow cards related to the grain size classes

Card	Arguments	Example	Description
SEDIMENT_SIZE_CLASS_NUMBER	integer	3	Specifies the number of grain size classes.
MULTIPLE_GRAIN_SIZES	integer [real, real,..., real]	3 0.1 0.2 0.3	Specifies the number of grain sizes followed by the grain sizes for each size class in mm.
SEDIMENT_SIZE_CLASS_DIAMETERS	integer [real, real,..., real]	3 0.1 0.2 0.3	Specifies the number of grain sizes followed by the grain sizes for each size class in mm. Same as MULTIPLE_GRAIN_SIZES.
SEDIMENT_SIZE_CLASS_LIMITS	integer [real, real,..., real]	4 0.07 0.15 0.26 0.34	Specifies the size classes limits. The first entry is the number of size class limits which is one greater than the number of size classes.

Important Notes:

- It is only necessary to specify either the size class characteristic diameters or limits. The other will be calculated internally by the model.

Recommendations:

- Because each grain size requires the iterative solution of a separate transport formula, it is recommended to not use more 8-9 sediment size classes. For most cases, 3-5 sediment size classes is sufficient.
- A good and simple way of estimating the grain size classed based only on the size limits of the distribution is by distributing the diameters logarithmically so that

$$d_k = \exp\left[\ln d_1 + \ln(d_N / d_1)\frac{k-1}{N-1} \right] \quad (193)$$

Fractional Bed Composition

Since the sediment size classes are constant for the whole domain, the bed composition is specified as the fractional amount of each size class per cell and per bed layer. In CMS V4.0 there are 5 options for specifying the fractional bed composition:

1. Two-dimensional horizontal (2DH) D50 dataset plus spatially constant geometric standard deviation (option D50_SIGMA).
2. 2DH D16, D50, and D84 datasets (option D16_D50_D84)
3. 2DH D35, D50, and D90 datasets (option D35_D50_D90)
4. 2DH Percentiles datasets.
5. Spatially (horizontally and vertically) constant size class fractions (option SIZE_CLASS_FRACTIONS)
6. Fraction of each sediment size class for each cell and bed layer (option FRACTIONS_DATASET)

A description of the CMS-flow card used to select each bed material composition option is described in Table 36 below.

Table 36. CMS-Flow card used to specify the option for specifying the bed material composition.

Card	Arguments	Default	Options	Description
BED_COMPOSITION_INPUT	character	none	D50_SIGMA D16_D50_D84 D35_D50_D90 PERCENTILES SIZE_CLASS_FRACTIONS FRACTIONS_DATASET	Selects the method for specifying the bed material composition.

Further details on each option are provided in the sections below.

D50 Dataset and Standard Deviation

This is the simplest and easiest way to specify the bed composition for multiple-sized sediment transport in CMS because it only requires the D50 dataset which is already in the SMS interface and one extra parameter, the geometric standard deviation.

- **Assumptions:**
  1. The initial sediment sorting is constant for the whole domain
  2. The initial bed composition may vary spatially according to the D50 dataset but is constant with depth
  3. The initial grain size distribution can be approximated by a log-normal distribution

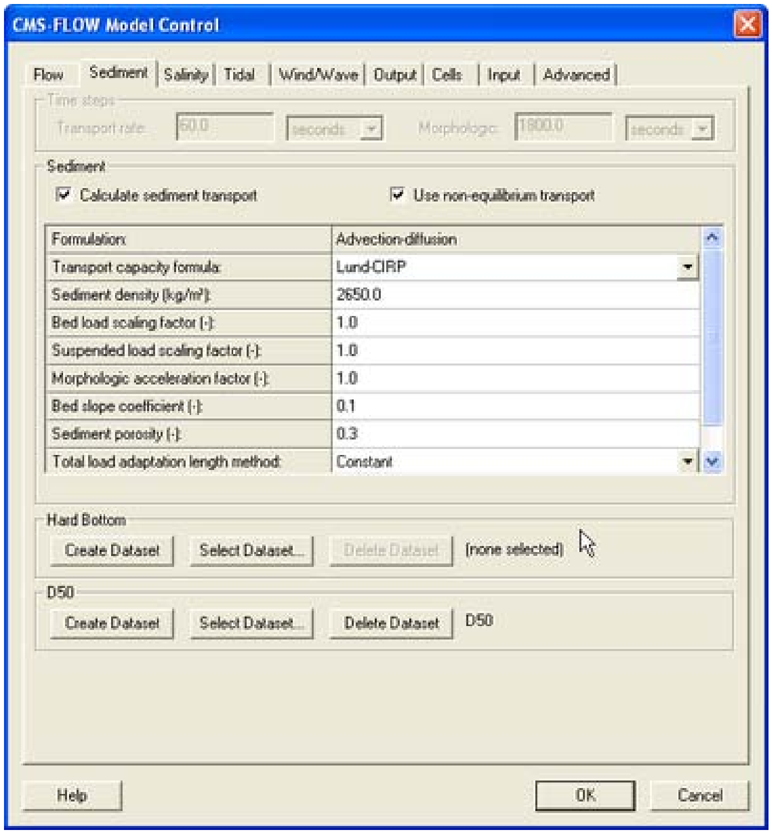


Figure 94 *Sediment* tab of the *CMS-Flow Model Control* window (SMS 11.0)

The geometric standard deviation σg can be defined using the method of moments

$$\sigma_g = \exp\sqrt{\sum p_k \left(\ln d_k - \ln d_g\right)^2} \qquad (194)$$

where p_k is the fraction, d_k is the size class diameters in mm, d_g is the geometric mean in mm given by

$$d_g = \exp\left(\sum p_k \ln d_k\right) \qquad (195)$$

An alternate approach to the above equation for obtaining geometric standard deviation is by using the graphical measures (cumulative percentile values) (Folk and Ward, 1957)

$$\sigma_g \approx \sigma_G = \exp\left(\frac{\ln d_{16} - \ln d_{84}}{4} + \frac{\ln d_5 - \ln d_{95}}{6.6}\right) \approx \left(\frac{d_{84}}{d_{16}}\right)^{1/2} \quad (196)$$

where σ_G is a graphical measure of the geometric standard deviation. The size class fractions p_k are calculated using log-normal sediment size distribution

$$p_k = \frac{\Delta d_k}{d_k \ln \sigma_g \sqrt{2\pi}} \exp\left[-\frac{1}{2}\left(\frac{\ln d_k - \ln d_{50}}{\ln \sigma_g}\right)^2\right] \quad (197)$$

Table 37. Sorting classification based on the geometric standard deviation (Folk and Ward, 1957)

Geometric Standard Deviation	Sorting Classification
<1.27	Very well sorted
1.27-1.41	Well sorted
1.41-1.62	Moderately well sorted
1.62-2.00	Moderately sorted
2.00-4.00	Poorly sorted
4.00-16.00	Very poorly sorted
>16.00	Extremely poorly sorted

A description of the CMS-Flow cards related to the D50_SIGMA option for specifying the bed material composition is provided in Table 38 below.

Table 38. CMS-Flow cards related to the D50 dataset and standard deviation

Card	Arguments	Default/Format	Description
D50_DATASET	character character | character	[file name] [dataset path and name]	Specifies the D50 dataset file followed by the path and name. If the file name is not specified than it is assumed to be the grid file (*_grid.h5).
SEDIMENT_STANDARD_DEVIATION	real	1.5	Specifies the geometric sediment standard deviation for all cells and layers in mm.

D16, D50, and D84 Datasets

The second approach for specifying the initial bed composition is using 2DH D16, D50, and D84 datasets. Because only the D50 dataset can be specified through the SMS interface, it is necessary to specify the additional datasets either through the *Custom Input Datasets* are by manually creating the datasets using the *Data Calculator* and exporting them to XMDF file(s).

- **Assumptions:**
  1. The initial bed composition may vary spatially according to the D16, D50, and D84 datasets but is constant with depth
  2. The initial grain size distribution can be approximated by a log-normal distribution

The bed sorting is estimated as

$$\sigma_g \approx \left(\frac{d_{84}}{d_{16}} \right)^{1/2} \tag{198}$$

The fractional bed composition is calculated using a log-normal distribution according to the above equations. The table below describes the CMS-Flow cards used for specifying the bed material composition using the D16, D50, and D84 datasets.

Table 39. CMS-Flow cards related to the D16_D50_D84

Card	Arguments	Default/Format	Description
D16_DATASET	character character	[file name] [dataset path and name]	Specifies the D16 dataset path and file name.
D50_DATASET	character character | character	[dataset path and name] | [file name] [dataset path and name]	Specifies the D50 dataset path and file name. If the file is not specified than it is assumed to be the model grid file (*_grid.h5).
D84_DATASET	character character	[file name] [dataset path and name]	Specifies the D84dataset path and file name.
CUSTOM_DATASET	character character	[file name] [dataset path and name]	Specifies a custom dataset path and file name. The custom dataset can be used for any additional user defined dataset. The name of the dataset must be equal to the variable name. For example the D16 dataset must be named D16 and cannot be myD16.

Custom Datasets

The first approach of specifying the D16 and D84 datasets is by using the *Custom Input Datasets* section under the *Input* tab of the *CMS-Flow Model Control* window. The advantage of using this approach is that the user can edit the datasets once they are created without having to map each dataset as the *Elevation* dataset. It also avoids having to specify the dataset files and names manually in the *.cmcards file. The steps for creating and specifying the D16 and D84 datasets are outlined below:

1. Open *CMS-Flow Model Control* window and go to the *Input* tab.
2. To create the D16 dataset, click on the *New* buttom and a window will appear titled *New Editable Dataset*.
3. Name the dataset D16 for the D16 dataset or D84 for the D84 dataset. The names must be correct for CMS to be able to interpret the dataset.
4. Set the initial values by either specifying a spatially constant value or selecting a current dataset.
5. Click *OK* in the *New Editable Dataset* window
6. Repeat steps 2 through 5 for the D84 dataset.
7. Click *OK* in the *CMS-Flow Model Control* window
8. Save the CMS-Flow project

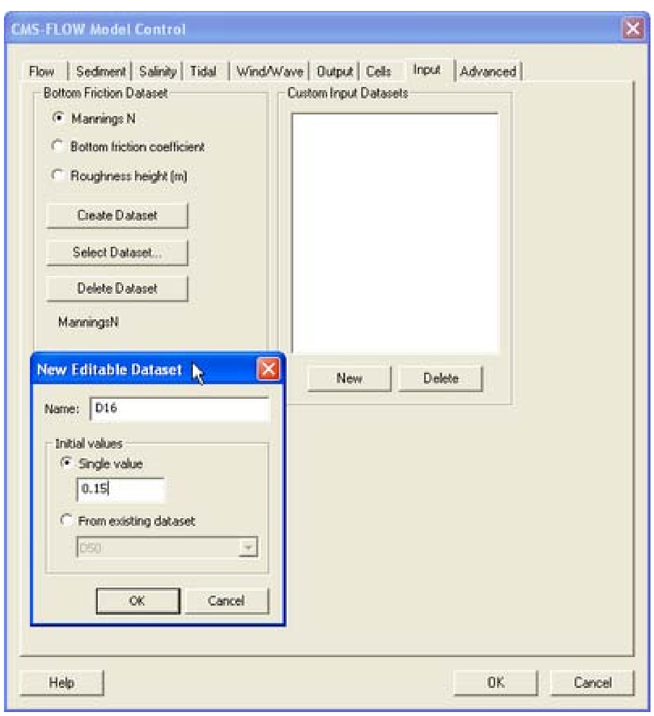


Figure 95. SMS project explorer showing Custom Datasets for D16 and D84.

3. Once the datasets are created the SMS project explorer will show a folder with the D16 and D84 datasets.

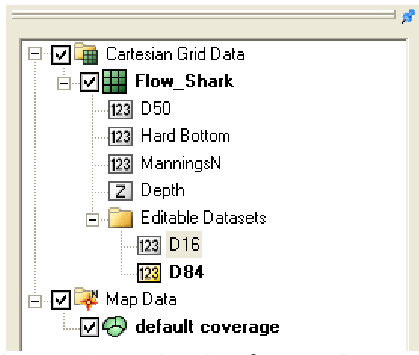


Figure 96. SMS project explorer showing Custom Datasets for D16 and D84.

4. After saving the CMS-Flow project the project folder will show a new dataset called *Flow_Shark_input_datasets.h5*.

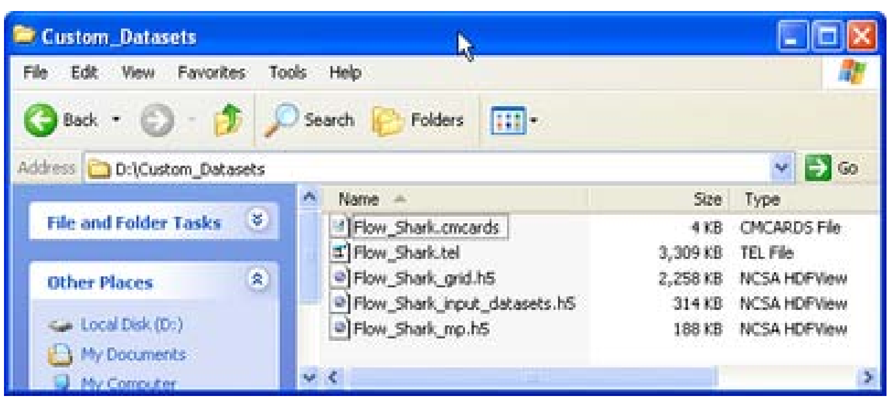


Figure 97. SMS project explorer showing Custom Datasets *for D16 and D84.*

5. *The data s*tructure of the *Flow_Shark_input_datasets.h5* file is shown in Figure 98 below.

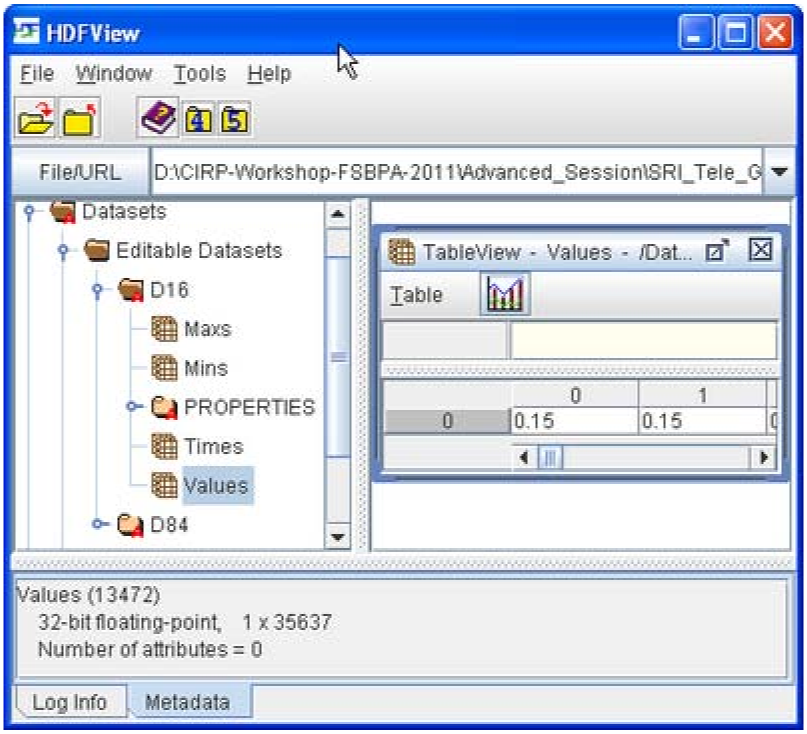


Figure 98. Structure of the *Custom Input Datasets* file shown in HDFView.

Exported Datasets

An alternate approach for specifying datasets is by exporting them into XMDF files and then specifying the file names and paths in the *Advanced* cards section of the *.cmcards file. The advantage of this approach is that is allows more flexibility in specifying project alternatives and also works for SMS versions 10.1 and earlier. To export the D16 and D84 datasets

1. Create and initialize the D16 and D84 datasets
   1. Click on the menu *Data* | *Data Calculator*

   2. Enter a constant value under the *Calculator* section and make sure the *Output dataset name* is either D16 or D84.

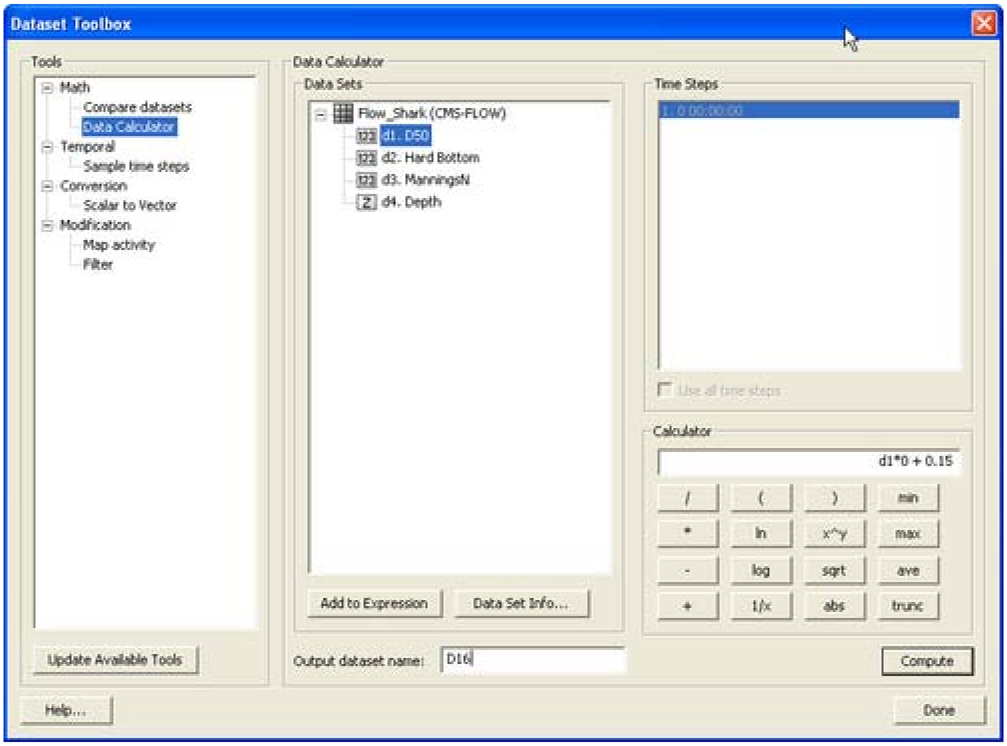


Figure 99. SMS project explorer showing Custom Datasets for D16 and D84.

If necessary, edit the D16 and D84 datasets. As shown in Figure 100 below, it is not possible to edit the D16 and D84 datasets once they are created. A workaround for this is to set either dataset as the *Elevation* dataset, which then allows you to edit the dataset.

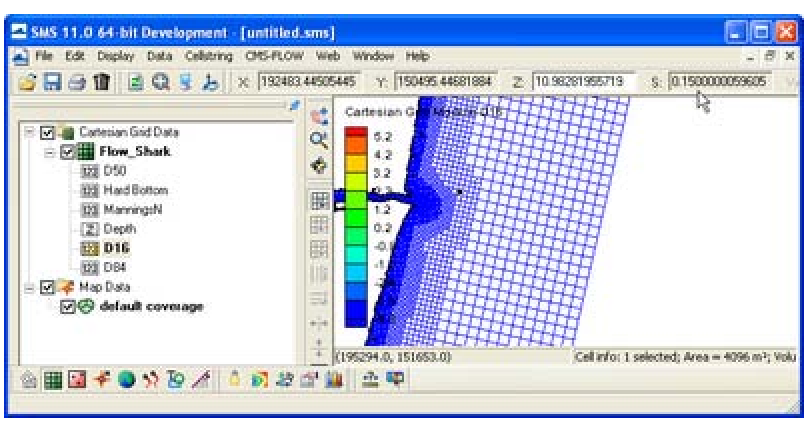


Figure 100. It is not possible to edit user defined datasets unless they are the Depth, D50, ManningN, Hardbottom, or a Custom Dataset.

2. Set the D16 dataset as the *Elevation* dataset:
    - Click on *Data* | *Map elevation*.

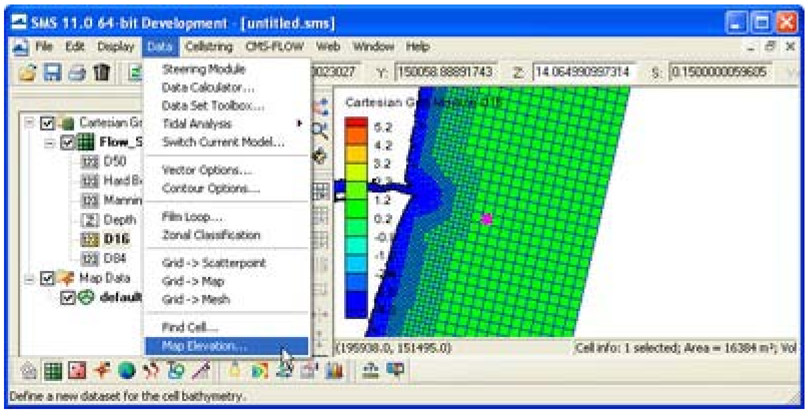


Figure 101. Mapping of D16 dataset as the *Elevation* dataset.

3. A window titled *Select Dataset* will appear. Select the D16 dataset and click *Select*.

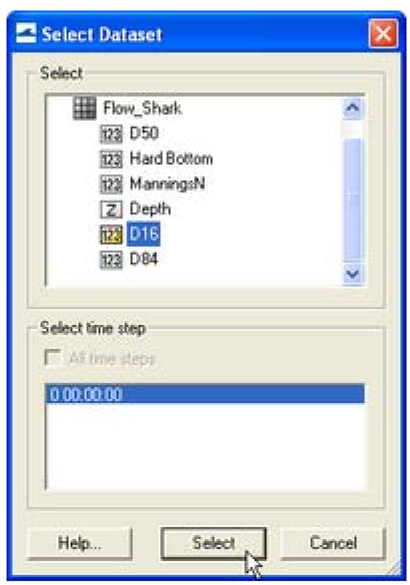


Figure 102. *Elevation* dataset selection.

4. The D16 dataset will show with a large *Z* on the left indicating that it is mapped as the *Elevation* dataset.

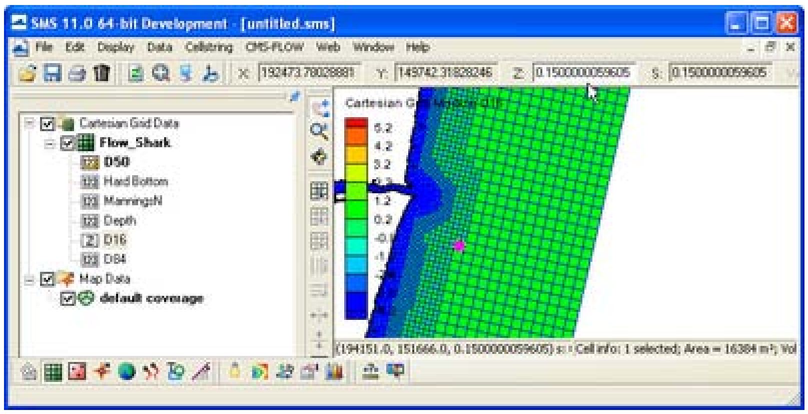


Figure 103. SMS window showing D16 dataset mapped as the *Elevation* dataset.

5. Once you are finished editing the dataset, make sure to remap the appropriate dataset as the *Elevation* dataset (usually called *Depth* dataset).
6. Export the D16 and D84 datasets to XMDF file(s). The datasets can be exported to the same or separate file. The important thing is that the correct file name is specified in the Advanced Cards.

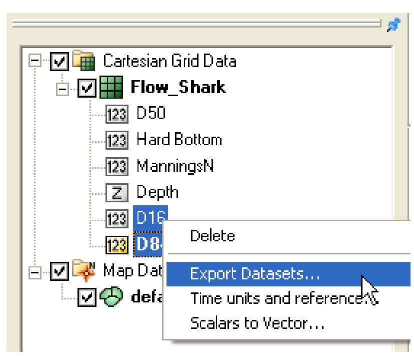


Figure 104. Exporting the D16 and D84 datasets.

D35, D50, and D90 Datasets

This method is very similar to the previous method. The only difference is that the D35 and D90 datasets are used to estimate the bed sorting instead of the more commonly used D16 and D84 datasets. The reason for including this method is that the D35 and D90 datasets are also required for running the Paticle Tracking Model so it reduces the number of datasets that need to be prepared by the user in cases where both models are being run.

- **Assumptions:**
  1. The initial bed composition may vary spatially according to the D35, D50, and D90 datasets but is constant with depth
  2. The initial grain size distribution can be approximated by a log-normal distribution

The geometric standard deviation is estimated as

$$\sigma_g \approx \left(\frac{d_{90}}{d_{35}} \right)^{0.61} \tag{199}$$

The fractional bed composition is then calculated with log-normal distribution. Table 40 below describes the CMS-Flow cards used for specifying the bed material composition using D35, D50, and D90 datasets.

Table 40. CMS-Flow cards related to the D35_D50_D90 option for specifying the bed material composition

Card	Arguments	Default/Format	Description
D35_DATASET	character character	[file name] [dataset path and name]	Specifies the D35 dataset path and file name.
D50_DATASET	character character | character	[dataset path and name] | [file name] [dataset path and name]	Specifies the D50 dataset path and file name. If the file is not specified than it is assumed to be the model grid file (*_grid.h5).
D90_DATASET	character character	[file name] [dataset path and name]	Specifies the D84dataset path and file name.
CUSTOM_DATASET	character character	[file name] [dataset path and name]	Specifies a custom dataset path and file name. The custom dataset can be used for any additional user defined dataset. The name of the dataset must be equal to the variable name. For example the D35 dataset must be named D35 and cannot be myD35.

Size Class Fractions

For this case, the fractional bed compositions are specified for each size class for all cells and all bed layers. The fractional bed compositions must sum to 1.0. This option is useful for simulating cases where the bed composition is well known and is constant both in the horizontal and vertical directions.

- **Assumption:**
  The initial bed composition is constant at every cell and layer for whole domain

Table 41. CMS-Flow cards related to the SIZE_CLASS_FRACTIONS option for specifying the bed material composition

Card	Arguments	Example	Description
SEDIMENT_SIZE_CLASS_FRACTIONS	integer [real, real,..., real]	3 0.2 0.5 0.3	Specifies the fractional composition for each size class and for all cells and bed layers. The first entry is the number of grain size classes.

Bed Layer Thickness

The initial bed layer thickness needs to be specified by the user. There are three methods for specifying the initial bed layer thickness:

1. CONSTANT – User specified constant for all cells and bed layers.
2. LAYER – User specified bed layer thickness for each bed layer and is applied to all cells on the grid.
3. LAYER_DATASET – User specified dataset for each cell and bed layer (3D dataset).

The CMS-Flow cards related to the bed layer specification are described in Table 42 below.

Table 42. CMS-Flow cards related to the general parameters

Card	Arguments	Default Format	Range	Description
BED_LAYER_THICKNESS_INPUT	character	none	CONSTANT LAYER_THICKNESS LAYER_DATASET	Sets the method for specifying the sediment bed layer thickness.
BED_LAYER_THICKNESS_DATASET	character character	none	[file] [path]	Specifies the bed layer thickness file and dataset path.
BED_LAYERS_MAX_NUMBER	integer	8	>= Input bed layers	Sets the maximum number of bed layers. M

BED_LAYERS_CONSTANT_THICKNESS	real	none	> minimum layer thickness.	Sets the initial bed layer thickness to a constant in meters for all cells and bed layers.
BED_LAYERS_THICKNESS	integer [real, real,..., real]	[N_lay] [thickness 1] ... [thickness N_lay]	none	Sets the thickness for each layer in meters for all cells.
BED_LAYER_MIN_THICKNESS	real	0.01	none	Sets the minimum layer thickness. Applicable to all bed layers including the mixing layer (layer 1).
BED_LAYER_MAX_THICKNESS	real	0.5	none	Sets the MAXIMUM-layer thickness. Applicable to all bed layers including the mixing layer (layer 1).

Important Note:

- If the initial bed layer thickness is not specified than it will be set to zero.

Mixing Layer

The mixing layer is the first layer from the surface which is allowed to exchange (or mix) sediments with the sediment transport. The mixing layer thickness is calculated based on the median grain size and bed form size. The option is also available to set the mixing layer to a constant. The CMS-Flow cards used for setting the mixing layer thickness to a constant is described in Table 43 below.

Table 43. CMS-Flow used for setting a constant mixing layer thickness.

Card	Arguments	Default	Range	Description
MIXING_LAYER_CONSTANT_THICKNESS	REAL	none	greater than minimum thickness	Sets the mixing layer thickness to a constant in meters.

Imporant Notes:

1. Using a larger mixing layer will slow down the temporal change in bed material composition and enhance model stability.
2. Erosional cases tend to have smaller mixing layer thicknesses and depositional cases tend to have larger mixing layer thicknesses.

3. The mixing layer thickness should NOT be used as a calibration parameter.

Hiding and Exposure

The hiding and exposure is an important parameter for multiple-sized sediment transport. Currently, there are no well established coastal sediment transport formulas for nouniform sediments. The most common approach is to adapt single-size transport formulas by applying correction factors. The most common of these factors is the hiding and exposure correction. The implementation of this factor varies depending on the transport formula and usually involves a coefficient (exponent) which needs to be calibrated. Because all of the transport formulas used in CMS were originally developed for uniform sediments, there is still a large uncertainty in the value of the hiding and exposure coefficient. It is expected that the hiding and exposure coefficient will be different for different transport formula especially since the implementation of the hiding and exposure correction may be different for different formula.

Table 44. CMS-Flow card used for setting the hiding and exposure coefficient.

Card	Arguments	Default	Range	Description
HIDING_EXPOSURE_COEFFICIENT	real	1.0	0.4-1.0	Sets the hiding and exposure coefficient.

CMS-Flow Numerical Methods

The most overlooked advantage of owning a computer is that if they foul up there is no law against whacking them around a little.
- Joe Martin

Temporal Solution Scheme

This refers to the temporal discritization of the hydrodynamic, sediment and salinity transport equations. There are two options in CMS: Implicit and Explicit. The implicit scheme uses a time step on the order of 5-15 minutes and is designed for tidal flow, and mid-term morphology change. The explicit scheme uses a time step on the order of 0.5-1.0 seconds and is appropriate for cases that vary quickly in time such as flooding or barrier island breaching.

Table 45. CMS-Flow cards related to the surface roller

Card	Arguments	Default	Range	Description
SOLUTION_SCHEME	character	EXPLICIT	EXPLICIT IMPLICIT	Determines the solution scheme used in CMS-Flow.
IMPLICIT_WEIGHTING_FACTOR	real	0.0	>=0.0, <=1.0	Weighting factor in implicit temporal scheme. 0 – First order, 1- second order. For more details on the temporal solution scheme see the Temporal Discretization section.

Imporant Note:

- The second order solution scheme requires three time step levels. Therefore, for the first time step, the model uses the first order two-level temporal scheme.

Matrix Solver Options

The four different solvers implemented in the implicit solution scheme are the Gauss-Seidel, Gauss-Seidel with Successive-Over-Relaxation, BICGSTAB, and GMRES. The same solver is applied to flow, sediment and salinity. The default solver is the GMRES. The solver may be changed using the advanced card in Table 46 below.

Table 46. CMS-Flow cards related to the matrix solver.

Card	Arguments	Default	Range	Description
MATRIX_SOLVER	character	GMRES	GAUSS-SEIDEL GAUSS-SEIDEL-SOR BICGSTAB GMRES	Selects the matrix solver for flow, sediment and salinity.
HYDRO_MAX_ITERATIONS	integer	Function of grid size	>0	Sets the maximum number of iterations for the flow (hydro) solver (outer loop).
PRESSURE_ITERATIONS	integer	Depends on Solver	>0	Sets the number of solver iterations for the pressure equation (inner loop).
VELOCITY_ITERATIONS	integer	Depends on Solver	>0	Sets the number of solver iterations for the velocity or momentum equations (inner loop).
SEDIMENT_MAX_ITERATIONS	integer	20	>1	Maximum number of iterations (outer loop) for the sediment transport
SALINITY_MAX_ITERATIONS	integer	20	>1	Maximum number of iterations (outer loop) for the salinity transport

Advection Schemes

As in the case of the implicit solution scheme, the same advection scheme is applied for the flow, sediment and salinity transport equations. There are three choices for advection schemes with upwinding in the implicit model: hybrid, exponential and HLPA. The hybrid scheme is fast but is the most diffusive. The exponential scheme is based on the 1D analytical solution to an advection-diffusion equation and produces very stable results. The HLPA is very stable and non-diffusive, but requires slightly more computational time. For most applications, the exponential scheme is recommended and is set as the default. The advection scheme may be change using the advanced card

Table 47. CMS-Flow cards related to numerical methods

Card	Arguments	Default	Range	Description
ADVECTION_SCHEME	character	POWERLAW	NONE HYBRID POWERLAW EXPONENTIAL HLPA GAMMA CUBISTA ALVSMART HOAB	Sets the advection scheme for flow, sediment and salinity.

Wetting and Drying

In CMS, a minimum depth is required for cells to be considered. A cell is classified as wet if the total water depth is larger than this depth. Cell faces are either classified as either open if the two cells neighboring cells are wet or otherwise closed (i.e. cell faces are not classified as wet or dry) , in order to improve stability.

Table 48. CMS-Flow cards related to wetting and drying.

Card	Arguments	Default	Options	Description
DRYING_DEPTH	real	0.05	none	Sets the minimum depth for wet cells.
WATER_PONDING	character	OFF	ON OFF	Turns *On* or *Off* water ponding. If water ponding is *Off*, isolated bodies of water will become dry.
ONE_CELL_WIDE_CHANNELS	character	ON	ON OFF	Limits wetting and drying to areas with at least 3 cells wide. When turned off, the model stability is improved.

Parallelization with OpenMP

Both Intel and AMD processors now are shipping chips with multiple cores/processors (henceforth referred to as "processors") available. CMS-Flow is now configured to make use of these extra processes that are available on newer machines.

Table 49. CMS-Flow cards related to numerical methods.

Card	Arguments	Default	Description
NUM_THREADS	integer	1	Determines the number of threads used for parallel processing.
OPENMP_THREADS	integer	1	Determines the number of threads used for parallel processing.

Hot Start

The term "hot start" refers to starting a simulation with an initial condition other zero (cold start). Hot starts are used for specifying initial conditions or restarting simulations at intermediate times. The hot start controls are set in the *Flow* tab of the *CMS-Flow Model Control* window.

Hot Start File

The CMS hot start feature CMS lets the user restart simulations that have been stopped due to electric outages, hardware malfunctions, or model crashes. In the case of a model crash the user, may restart the model using larger solver iterations and/or time steps to stabilize the simulation. The user has the option to specify a hot start output time or an interval for out-putting a recurring hot start file. Every time the hot start file is written, it overwrites the previous information. The CMS Hot Start file saves infor-mation on the water elevation (pressure), and current velocities. If the se-diment transport is active, the water depth and sediment concentrations are also saved for each size class. The CMS hot start file is a binary XMDF file, has the name Hot_Start.h5 and is saved in the directory of the CMS-Flow files. Figure 105 shows the structure of the hot start file. After saving a CMS Hot Start file, it is a good idea to rename the file with a different name before using it as an initial conditions file. This way, the file will not be overwritten in future simulations.

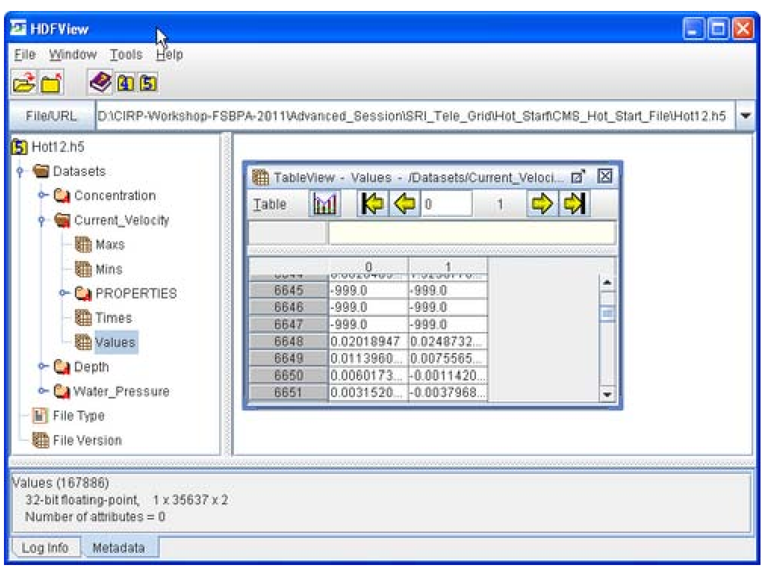


Figure 105. HDFView showing the structure of the CMS Hot Start File.

Table 50. CMS-Flow cards used to specify the hot start output file.

Card	Arguments	Default	Range	Description
HOT_START_OUTPUT_FILE	character	none	none	Julian hour.
HOT_START_TIME	real	none	none	Sets the hot start output time.
AUTO_HOT_START_INTERVAL	real	none	none	Sets the recurring hot start output time.

Initial Conditions File

There are several situations where it is convenient to specify a user defined initial condition (hot start) file. For example, if the user forgets to setup the model output a hot start file or when running idealized cases with known initial conditions. A hot start file can easily be created and exported by the user from the SMS interface. The model requires at water levels, current velocities, concentrations, and water depths. Any datasets that are missing from the initial file are assigned a default value which depends on the dataset. If the water level or current velocities are not specified, they are set to zero. If the depth is not specified, then it is set to the input grid depth. If the sediment concentrations are not specified, then they are set to the equilibrium concentrations. It is important to note that the names and paths of the initial condition datasets are important.

Table 51. Path and name for initial condition file variables.

Variable	Path and Name
Water surface elevation	Datasets\Water_Elevation
Current velocity	Datasets\Current_Velocity
Sediment concentrations	Datasets\Concentration
Salinity concentrations	Datasets\Salinity

The steps for creating a user defined hot start or initial condition file from a CMS-Flow solution file are outlined below.

1. Import CMS-Flow grid and solution file.
2. Sample a time step of the solution datasets for use in the initial condition
    1. Click on *Data* | *Data Calculator*
        1. Under the *Tools* section, select *Sample time steps*.
        2. Under the *Datasets* section, click on the *Water Elevation*
3. Export the initial condition datasets to an XMDF file

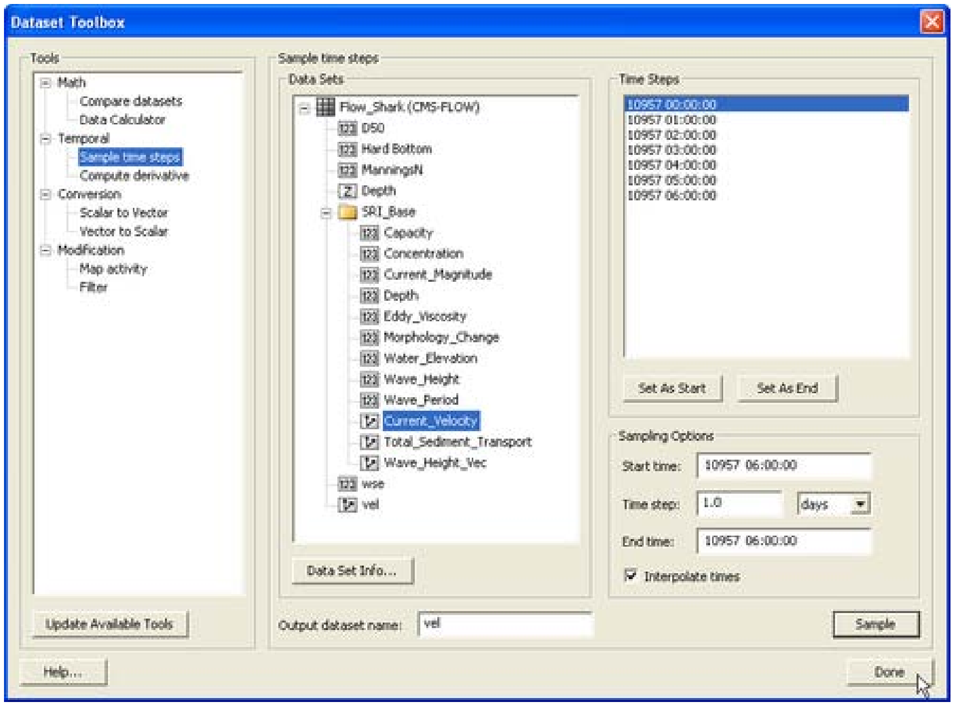


Figure 106. Dataset Toolbox showing a time step sample of the water elevation and current velocity datasets for use in a hot start (initial condition) file.

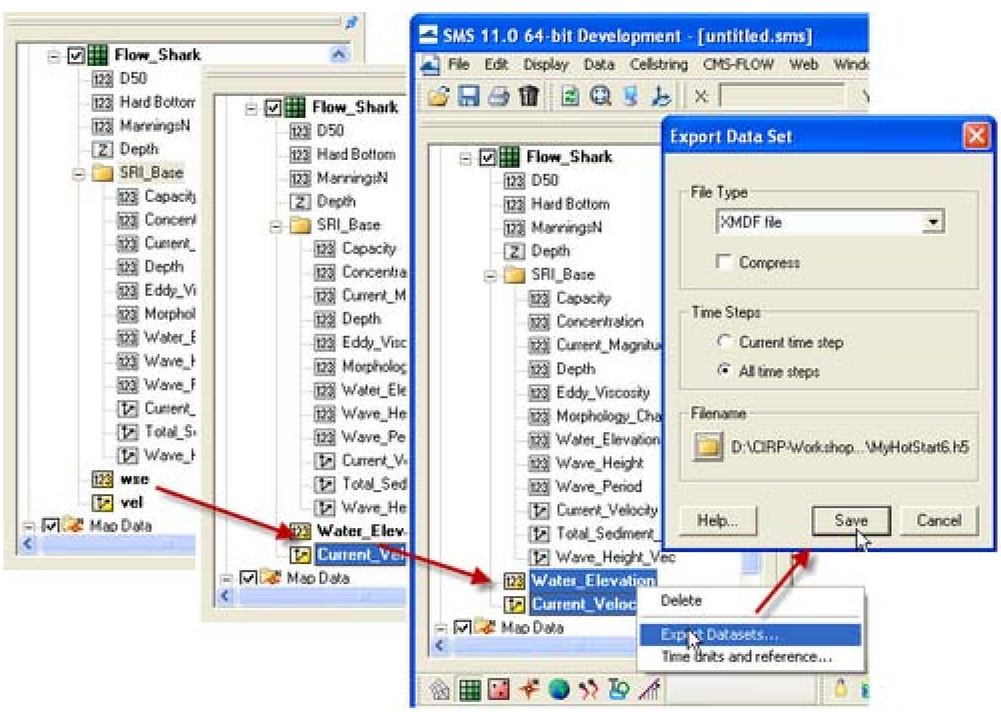


Figure 107. Dataset Toolbox showing a time step sample of the water elevation and current velocity datasets for use in a hot start (initial condition) file.

Table 52. CMS-Flow card for specifying the initial condition file.

Card	Arguments	Default	Range	Description
INITIAL_STARTUP_FILE	character	none	none	Julian data in YYDDD with YY being last two digits of the year, and DDD the Julian day of the year.

CMS-Flow Output

Global Output

Global output refers to the variables that are output on every active cell on the grid. The global output options are specified in *Output* tab of the *CMS-Flow Model Control* window. More information on the global output variables, groups and CMS-Flow cards is provided in the sections below.

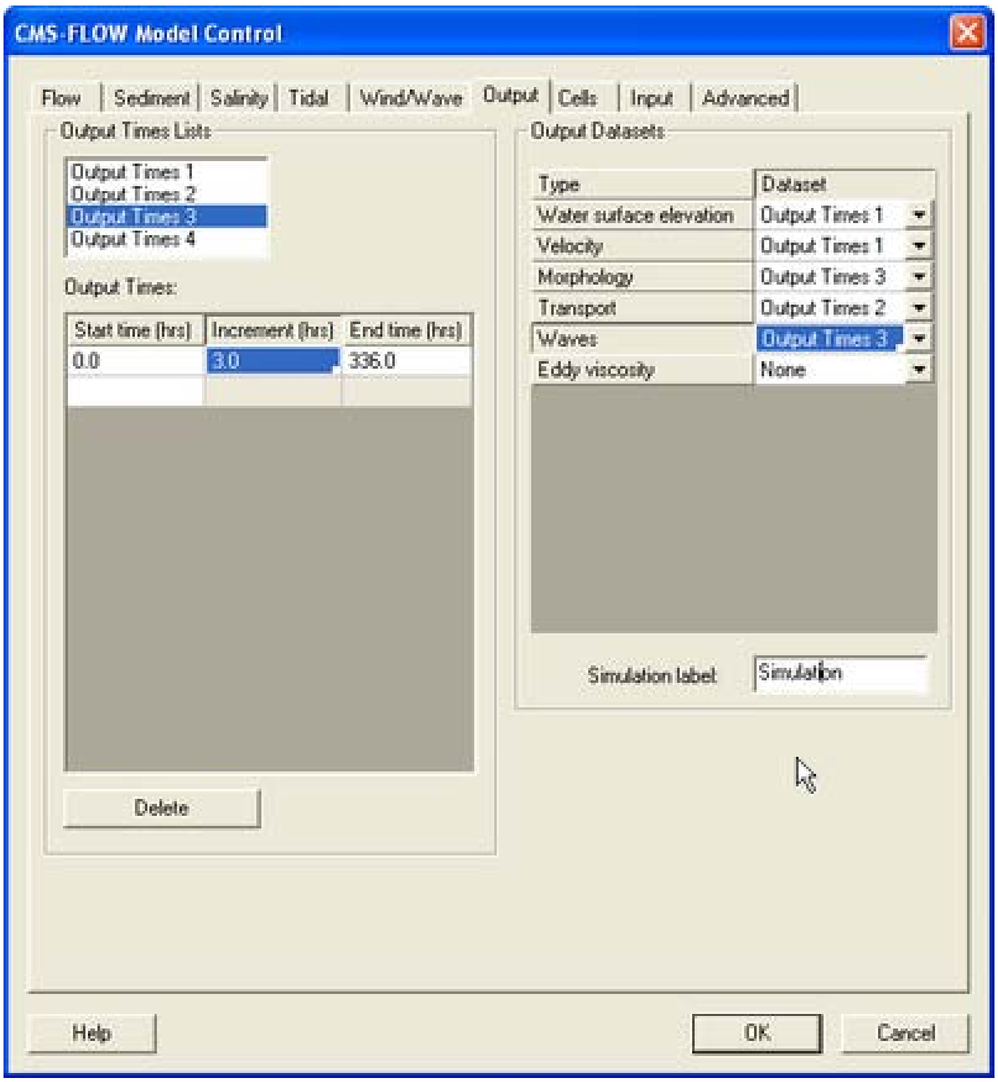


Figure 108. *Output* tab in SMS 11.0

Global Output Datasets

Global output datasets are divided into groups and each group is assigned an output times, and file. A description of the various output datasets and the associated groups is provided in Table 53.

Table 53. CMS-Flow cards related to the output datasets.

Output Dataset	Group	Description	Units
Current_Velocity	Velocity	Depth-averaged and cell-centered current velocity vector dataset and with respect to local grid coordinates	m/s
Current_Magnitude	Velocity	Depth-averaged and cell-centered current velocity magnitude dataset	m/s
Water_Elevation	Water surface elevaation	Cell-centered water surface elevation	m
Eddy_Viscosity	Eddy viscosity	Cell-centered horizontal eddy viscosity	m^2/s
Concentration	Transport	epth-averaged and cell-centered sediment concentration	kg/m^3
Capacity	Transport	Depth-averaged and cell-centered sediment concentration capacity	kg/m^3
Total_Sediment_Transport	Transport	Depth-averaged and cell-centered total-load sediment transport	kg/m/s
Salinity	Transport	Depth-averaged and cell-centered sediment concentration capacity	kg/m^3
Depth	Morphology	Cell-centered still water depth	m
Morphology_Change	Morphology	Cell-centered morphology (bed) change. Positive is accretion and negative is erosion	m
Wave_Height	Waves	Cell-centered significant wave height	m
Wave_Height_Vec	Waves	Cell-centered significant wave height vector	m
Wave_Period	Waves	Cell-centered peak wave period	s

Output Time Series and Lists

The times at which each group is output is determined by the selecting one of four user defined output time series or lists. In SMS versions 10.1 and earlier, the output time series were used. However, because the output time series can become very large for long-term simulations, the time series have been replaced by lists in which the output times are specifying a list of starting, ending and increments. This option is more compact and also makes it easier to manually change the output options in the cmcards file.

Table 54. CMS-Flow cards used for specifying the time series and lists.

Card	Aguments/Format	Default value	Description
TIME_SERIES_1	[length of list 1] [output times for list 1]	0	Output time series for list 1 in hours.
TIME_SERIES_2	[length of list 2] [output times for list 2]	0	Output time series for list 2 in hours.
TIME_SERIES_3	[length of list 3] [output times for list 3]	0	Output time series for list 3 in hours.
TIME_SERIES_4	[length of list 4] [output times for list 4]	0	Output time series for list 4 in hours.
TIME_LIST_1	[number of sublists] [sublist 1: start, end, increment] [sublist 2: start, end, increment]…	0	Sublist(s) for output time series 1. For each sublist, the arguments are starting time, end time and increment in hours.
TIME_LIST_2	[number of sublist] [sublist 1: start, end, increment] [sublist 2: start, end, increment]…	0	Sublist(s) for output time series 2. For each sublist, the arguments are starting time, end time and increment in hours.
TIME_LIST_3	[number of sublist] [sublist 1: start, end, increment] [sublist 2: start, end, increment]…	0	Sublist(s) for output time series 3. For each sublist, the arguments are starting time, end time and increment in hours.
TIME_LIST_4	[number of sublist] [sublist 1: start, end, increment] [sublist 2: start, end, increment]…	0	Sublist(s) for output time series 4. For each sublist, the arguments are starting time, end time and increment in hours..
WSE_OUT_TIMES_LIST	integer	0	Output time series id for water surface elevation in m.
VEL_OUT_TIMES_LIST	integer	0	Output time series id for current velocity and magnitude in m/sec.
MORPH_OUT_TIMES_LIST	integer	0	Output time series id for evolving bed and bed change in m.
TRANS_OUT_TIMES_LIST	integer	0	Output time series id for sediment concentration, capacity and salinity concentration in kg/m^3 and sediment transport rates in m^2/sec.
WAVE_OUT_TIMES_LIST	integer	0	Output time series id for wave height in m, wave period in sec, and wave height vector in m.
EDDY_VISCOSITY_OUT_TIMES_LIST	integer	0	Output time series id for horizontal eddy viscosity in m^2/sec.

Output Group File Specification

For large grids or long simulations, outputting all of the variables to a single XMDF solution file can lead to a file that is unmanageable. To help reduce to the size of the output files each variable group listed in Table 54 can be output into separate files. The table below lists and describes the CMS-Flow cards used to specify the output file names for each variable group.

Table 55. Variable group output file name specification.

Card	Arguments	Default	Description
WSE_OUT_FILE	character	none	Specifies the XMDF output file name for the water level group
VEL_OUT_FILE	character	none	Specifies the XMDF output file name for the current velocity group
EDDY_VISCOSITY_OUT_FILE	character	none	Specifies the XMDF output file name for the eddy vicosity group
VISC_OUT_FILE	character	none	Specifies the XMDF output file name for the eddy vicosity group (same as card above)
TRANS_OUT_FILE	character	none	Specifies the XMDF output file name for the transport group
MORPH_OUT_FILE	character	none	Specifies the XMDF output file name for the morphology change group
WIND_OUT_FILE	character	none	Specifies the XMDF output file name for the wind group

Advanced Global Output

In addition to the variables specified in the SMS interface, CMS has the option to output advanced mode output including the bed shear stress, bed composition, wind speed, etc.

Table 56. Advanced output datasets.

Card	Arguments	Default	Description
WIND_OUT_TIMES_LIST	integer	0	Output time series id for wind velocity and magnitude in m/s.
STRESS_OUT_TIMES_LIST	integer	0	Output time series id for mean bed shear stress in Pa.
WAVE_OUTPUT_DETAILS	ON OFF	OFF	Outputs additional wave variables including wave direction, radiation stresses, breaking dissipation and roller energy.

XMDF File Compression

The standard CMS-Flow output is written to an XMDF file with the name <Case Name>_sol.h5. The binary file may be written in compressed format using the card described in Table 57.

Table 57. CMS-Flow card for compressing the XMDF output file

Card	Arguments	Default	Description
XMDF_COMPRESSION	ON OFF	OFF	Compresses the XMDF file

Observation Cells (Save Points)

Time series at selected *Obervation* cells is set in the *Cells* tab of the *CMS-Flow Model Control* window. A description of CMS-Flow cards used for specifying *Observational* cells are described below.

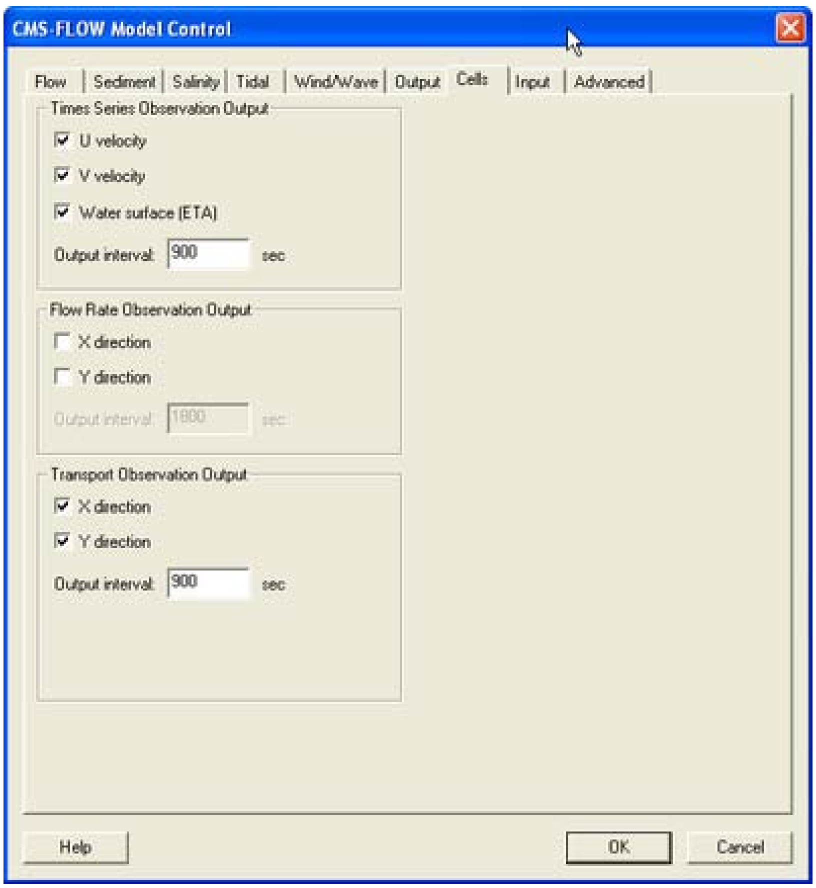


Figure 109. *Cells* tab in SMS 11.0

Table 58. CMS-Flow card for compressing the XMDF output file

Card	Arguments	Description
TIME_SERIES_INCREMENT	real	Sets the output time increment for the *Time series Observation* points.
ELEV_OBS_CELLS_BEGIN	none	Marks the beginning of a *Times series Observation* point list.

ELEV_OBS_CELLS_END	none	Marks the end of a *Times series Observation* point list.
FLOW_RATE_INCREMENT	real	Sets the output time increment for the *Flow rate Observation* points.
FLOW_OBS_CELLS_BEGIN	none	Marks the beginning of a *Flow rate Observation* point list.
FLOW_OBS_CELLS_END	none	Marks the end of a *Flow rate Observation* point list.
Q_TRANS_INCREMENT	real	Sets the output time increment for the *Flow rate Observation* points.
Q_TRANS_OBS_CELLS_BEGIN	none	Marks the beginning of a *Transport Observation* point list.
Q_TRANS_OBS_CELLS_BEGIN	none	Marks the end of a *Transport Observation* point list.

Simulation Statistics

CMS V4.0 has the option to calculate statistics over the whole model domain for a user-specified time period. This option is accessed using the advanced cardss. The starting time, end time, and time interval should be specified in hours with respect to the model start time. The time interval should be larger or equal to the hydrodynamic time step. When activated the global statistics will be output in the same solution file within a subfolder named *stats*.

This option outputs the statistics for hydrodynamics, sediment and salinity transport. If only the statistics for one group

- **Hydrodynamic statistics:**
  1. Maximum current velocity
  2. Maximum water level
  3. Residual currents (vectors and magnitude)
  4. Hydroperiod
  5. Maximum spatial gradient for water levels
  6. Maximum spatial gradient for current magnitude

- **Sediment Transport and Morphology Change:**
  1. Maximum total load transport rate, kg/m/s
  2. Net total load sediment transport rates, kg/m/s
  3. Gross total load sediment transport rates, kg/m/s
  4. Maximum spatial gradient of bathymetry

- **Salinity Statistics:**
  1. Mean Salinity

Table 59. CMS-Flow cards related to output statistics

Card	Arguments	Description	Default
GLOBAL_STATISTICS	[t0] [tn] [dt]	Calculates global statistics if specified	none
FLOW_STATISTICS	[t0] [tn] [dt]	Calculates flow statistics if specified	none
SEDIMENT_STATISTICS	[t0] [tn] [dt]	Calculates sediment statistics if specified	none
SALINITY_STATISTICS	[t0] [tn] [dt]	Calculates salinity statistics if specified	none

ASCII Output Files

In addition to the XMDF output file, CMS-Flow provides the output two types of ASCII output files:

1. Tecplot snap shot (*.dat), and history files (*.his)
2. SMS Super ASCII files (*.sup, *.xy, *.dat)

The CMS-Flow cards used for outputting these two types of files are described in Table 60.

Table 60. CMS-Flow cards used to output Tecplot and SMS Super ASCII files.

Card	Arguments	Default	Description
GLOBAL_TECPLOT_FILES	ON OFF	OFF	Outputs Tecplot ASCII files
GLOBAL_SUPER_FILES	ON OFF	OFF	Outputs Super ASCII files

Advanced CMS-Wave Features

The most recent CMS-Wave code developed is Version 3-2. Several new capabilities and advanced features in this version include:

- Full-plane
- Automatic wave run-up calculation
- Infra-gravity wave
- Nonlinear wave-wave interaction
- Muddy bottom
- Binary file output
- Selection of multiple processors
- Permeable structure
- Spatially varied wind input
- Spatially varied spectral input
- Grid nesting
- Wave surging (roller) in surf zone

Full-plane

In this mode, CMS-Wave performs two half-plane runs in the same grid. The first run is in the half-plane with the principle wave direction toward the shore. The second run is in the seaward half-plane. Upon the completion of the second run, two half-plane results are combined to one full-plane solution. Because the run time for the full-plane is approximately twice of the regular half-plane, users shall consider the full-plane mode only if the full-plane features like wave generation and propagation in a bay or around an island. An example is to run the Shark River wave case, 2009.sim, in the full plane (modify 2009.std).

Wave Run-up, Infra-gravity Wave, Nonlinear Wave-Wave Interaction, Muddy Bed, Spatial Wind Input

- To include (trigger) either of wave run-up, infra-gravity wave, nonlinear wave-wave interaction, binary (xmdf) output, multiple processors, muddy bed, and spatial wind field input is just a one-click step in the SMS11.1 interface (Fig 6.1). Additional files are required for the muddy bed and spatial wind field input.

- If the muddy bed calculation is required, users shall prepare a mud.dat file or *.mud (in the same format as *.dep) to list the spatial maximum kinematic viscosity for the entire grid (recommended maximum kinematic viscosity for mud is 0.04 m^2/sec)

- If the spatial wind field input is required, users shall prepare a wind.dat file or *.wind (in the same format as *.cur) to provide the x- and y-component wind speed data corresponding to the incident wave conditions in the model grid.

Permeable Structure

Users will need to select and specify permeable structure cells through SMS11.1 CMS-Wave *Assign Cell Attributes* and select *Permeable Break-water* (see Figure 110). In SMS11 or lower version which does not have the permeable structure cell feature, users will need to modify the *.struct to manually assign the permeable structure cells of interest. Recall that each feature cell is described by four parameters, istruc, jstruc, kstruc, and cstruc in a line format in *.struct (CMS-Wave Technical Report CHL-TR-08-13).

- istruc = i-th column in the grid
- jstruc = j-th row in the grid
- kstruc = feature cell identity
  - = 1, for adding alternative feature or structure (immersed or exposed) without modifying the input depth
  - = 2, for calculation of wave runup and overwash on beach face or structure, and adjacent land
  - = 3, for calculation of transmitted waves of a floating break-water
  - = 4, for vertical wall breakwater
  - = 5, for composite or rubble-mound breakwater
  - = 6, for a highly permeable structure like the pier or bridge
  - =7, for a low-permeable structure, like the rubble-mound breakwater
- cstruc =feature structure characteristic length
  - = feature structure depth, for kstruc = 1 (assume a land cell if not provided)
  - = beach/structure elevation above mean water level, for kstruc = 2 (use the input depth if not provided; no effect for cstruc < 0)
  - = floating breakwater draft, for kstruc =3 (skip if not pro-vided or cstruc < 0.05 m)
  - = breakwater/structure elevation, for kstruc = 4 or 5 (use the input depth if not provided; immersed if cstruc < 0)
  - = the permeable portion (>0, the section below the mean wa-ter depth) of a high-crest structure for kstruc = 6 or 7

In the Figure 2 example, users can modify 2009.struct to assign South Jetty 6 seaward end breakwater cells as permeable ones. The top 10 lines of the modified 2009.struct is shown below (the number 191 in the first row is the total structure cells in *.struct)

- 191
- 76 110 7 1.5
- 77 110 7 1.5
- 78 110 7 1.5
- 79 110 7 1.5
- 76 111 7 1.5
- 77 111 7 1.5
- 91 10 5
- 92 10 5
- 93 10 5

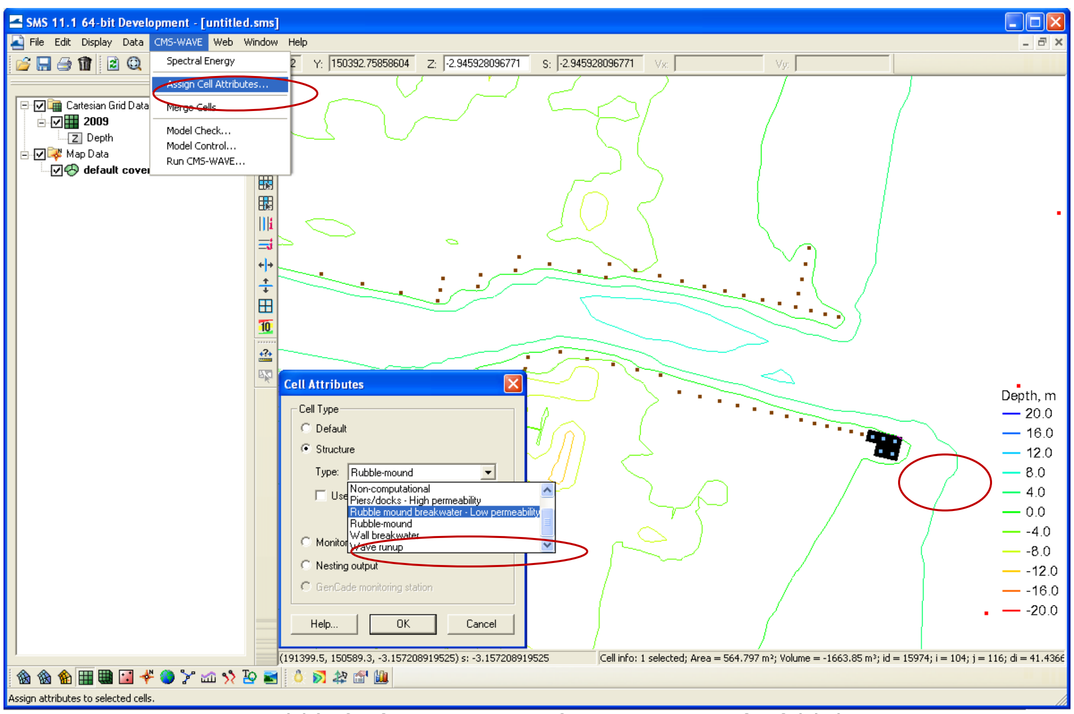


Figure 110. CMS-Wave *Assign Cell Attributes* in SMS11.1.

Grid Nesting

Grid Nesting – Users can use the CMS-Wave *Assign Cell Attributes* and *Nesting Output* (Figure 110) to specify the wave information output cells for saving spectrum data file (to serve as wave input to a child grid run). Figure 111 shows 6 nesting output locations (blue triangle) using the Shark River 2009.sim case. The nesting output file is *.nst (in the case of running CMS steering, an additional file nst.dat is automatically generated that merge all individual cycle *.nst files).

Figure 112 shows a child grid domain (c2009.sim) within the parent grid (the child grid was generated based on scatter points converted from the parent grid). The child grid wave input file (2009.nst, as generated from the parent grid) shall be assigned in the child *.std. This can be done by manually editing the child *.std or using the SMS *CMS-Wave* and *Nest Grid* menu (Figure 113).

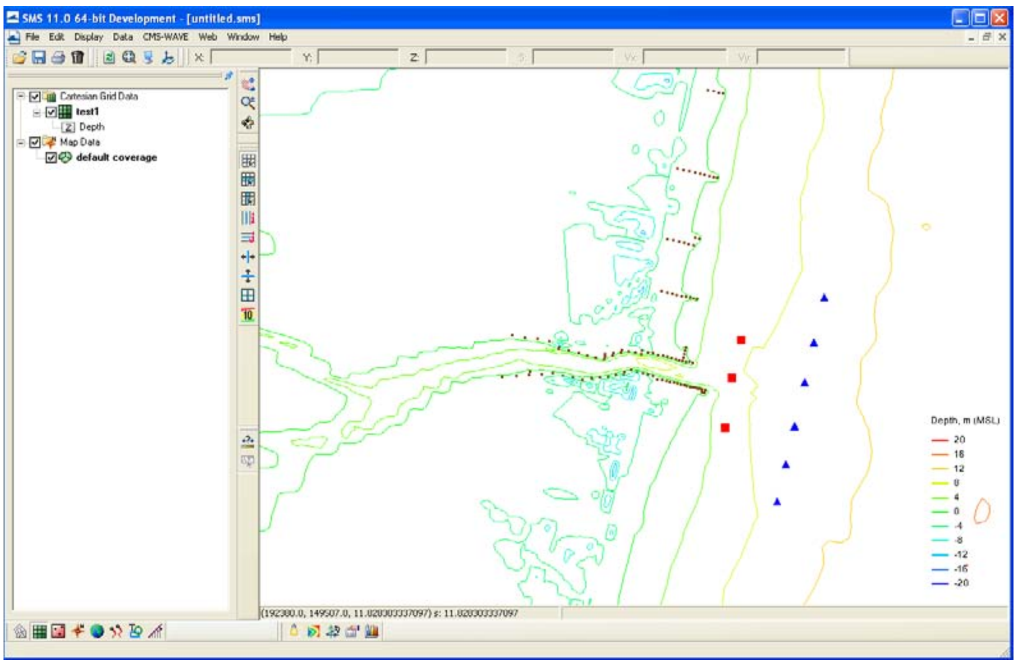


Figure 111. Nesting output 6 locations (blue triangle) and monitoring output 3 stations (red square).

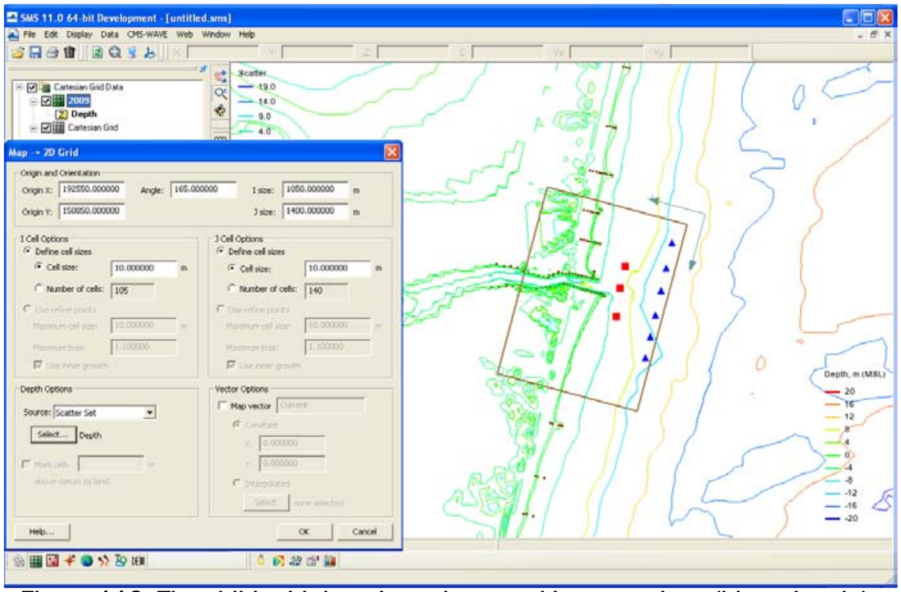


Figure 112. The child grid domain and spectral input stations (blue triangle).

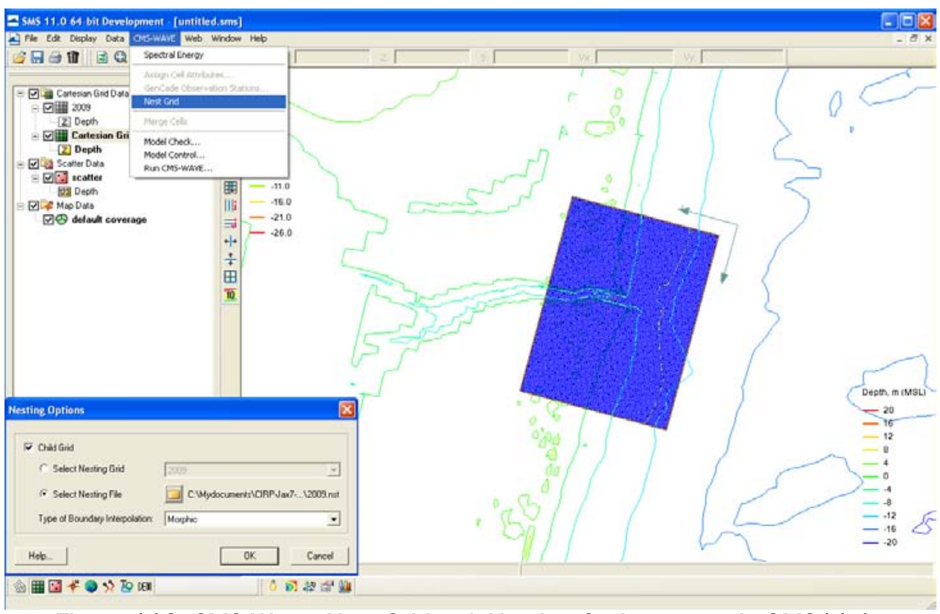


Figure 113. CMS-Wave *Nest Grid* and *Nesting Options* menu in SMS11.1.

The child wave input file format is almost identical to the parent *.eng. The only difference is that the child wave input has additional 3 parameters (the local x and y coordinates, and local significant wave height at the spectral wave input location) in the individual spectral header along with the regular 5 parameters (spectral id, wind speed, wind direction, spectral peak frequency, water level adjustment) in the parent *.eng. The top 10 lines of 2009.nst are shown below (notice the 8th line is a spectral header for the 1st individual wave input spectrum):

```
  30      35      6   167.00
 0.04    0.05   0.06   0.07    0.08
 0.09    0.10   0.11   0.12    0.13
 0.14    0.15   0.16   0.17    0.18
 0.19    0.20   0.21   0.22    0.23
 0.24    0.25   0.26   0.27    0.28
 0.29    0.30   0.31   0.32    0.33
9120103     9.80  -221.0  0.1200  0.00    192440.33    150712.28  0.563
 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00
0.00 0.00 0.00 0.00
 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00
0.00 0.00 0.00 0.00
```

To run the child grid in the steering mode, the spectral wave input file needs to be renamed to a default "nest.dat" (overwrite the wave input filename in the child *.std). It is noted that this "nest.dat" is only required for the child steering run. The parent grid run must be conducted and completed first to start a child grid run irrespective of whether CMS-Wave is or is not coupled with CMS-Flow (see more information in ERDC/CHL CHETN-IV-76).

Spatially Varied Spectral Wave Input

- Spatially varied spectral input – This is simply the case as in a child grid that spatially varied wave spectra are permitted to assign at user specified locations along or near the seaward boundary of the child grid. To apply spatially varied spectra for wave input without a parent grid, users will need to prepare the wave input file with the format as described in the child grid run.

  A FORTRAN program **merge-eng-to-nst.exe** is provided to combine all wave spectra files (*.eng) from individual locations into a single wave input file in the format for spatially varied spectral input to CMS-Wave. Figure 114 shows the map of two locations that each location has a wave input files available, 2009-ndbc.eng at Pt 1 (coordinates are 192,602 m and 151,037 m) and 2009-sp154.eng at

Pt 2 (coordinates are 192,315 m and 149,579 m) – recall that 2009-ndbc.eng and 2009-sp154.eng were originally generated for the parent grid. Figure 115 shows running **merge-eng-to-nst.exe** in DOS to combine two wave input files into one single wave input file (spatially varied spectral wave input to the child grid). Because 2009-ndbc.eng and 2009-sp154.eng were generated respect to the shore-normal direction at 167 deg and the local child grid orientation is 165 deg, a -2 deg direction adjustment is needed in running **merge-eng-to-nst.exe** here.

It is required that all individual wave input files must cover the same period and timestamps (users must edit the files to fill the missing data). In the example, wave spectra at time stamps 09122000, 0912003, and 0912006 are missing in 2009-ndbc.eng, and wave spectra at timestamps 09120400 and 09121000 are missing in 2009-sp154.eng. Two revised files, 2009-ndbc-edit.eng and 2009-sp154-edit.eng (cover the time period from 09120103 to 09123121 in 3-hr interval) are actually used in **merge-eng-to-nst.exe** to generate c2009.nst.

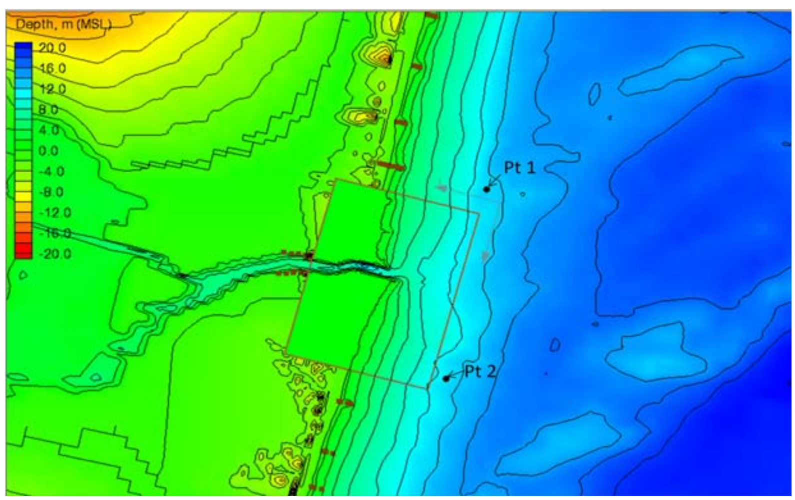


Figure 114. Child grid domain and two wave input locations Pt1 and Pt2.

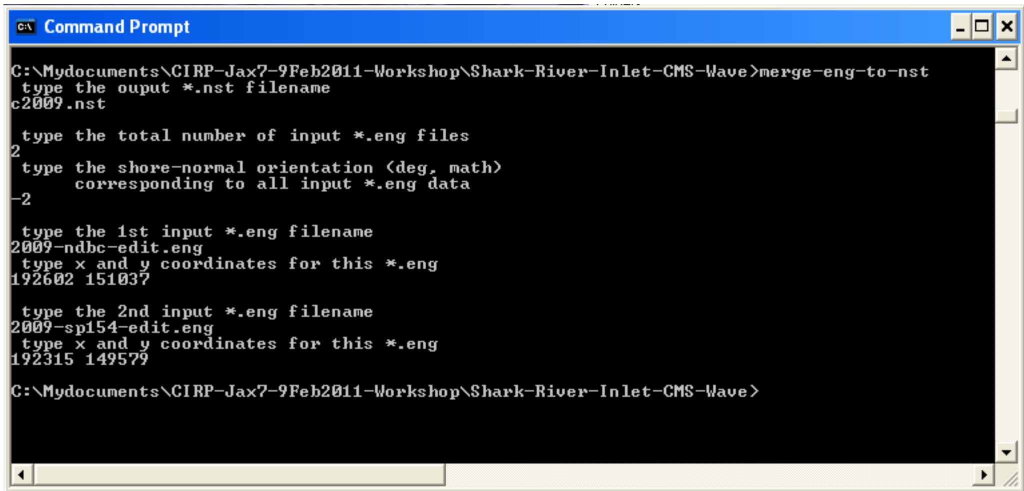


Figure 115. Example of running merge-eng-to-nst.exe in DOS.

Coupling with Waves

Steering refers to the coupling process between CMS-Flow and CMS-Wave. In CMS-Flow versions v3.75 and older (explicit CMS-Flow), the steering was done by the SMS interface. The new inline CMS contains both CMS-Flow and CMS-Wave and performs the coupling process internally. In either, the steering process is similar. First the wave model is run twice at time zero to the first steering interval. The wave information is then interpolated on to the flow grid and the flow model is run from time zero to the first steering interval. The flow information is then interpolated on the wave grid and the wave model is run for the second steering interval and the process is repeated until the simulation is complete.

Before running steering, it is a good idea to test the CMS-Flow and CMS-Wave separately to make sure there are no problems with their grids, or input parameters. Once the CMS-Flow and CMS-Wave models have been setup properly and loaded in SMS, the steering can be initiated.

Important Notes:

1. For both the SMS steering and inline steering, the CMS-Wave input spectra need to be spaced at regular time intervals and begin at the same time as the CMS-Flow model.
2. The way variables are interpolated and extrapolated both in space and time are slightly different between the SMS steering and inline steering versions of CMS.
3. Currently, the inline version of CMS only contains the implicit CMS-Flow solution scheme. Therefore, if the user decides to switch from explicit to implicit solvers, the user must also change the CMS-Flow executable under the SMS preferences.

CMS-Flow Versions 3.75 and Older

In CMS-Flow versions 3.75 and older, the steering process is done by the SMS interface. The interface does all of the variable interpolation and passing of variables from one model to another using communication files. The advantage of this approach is that it keeps the CMS-Flow and CMS-Wave codes separate and makes them easier to maintain and update.

- Make sure both the CMS-Flow and CMS-Wave grids are loaded in SMS.

- Check the CMS-Flow and CMS-Wave file names under the SMS Preferences menu (see Figure 116).

  1. Click on *Edit* | *Preferences*.
  2. Under the *File Locations* tab, in the section called *Model Executables* check the file names for CMS-Flow and CMS-Wave and make sure they are consistent with the latest releases (http://cirp.usace.army.mil/products/index.html CIRP Products).

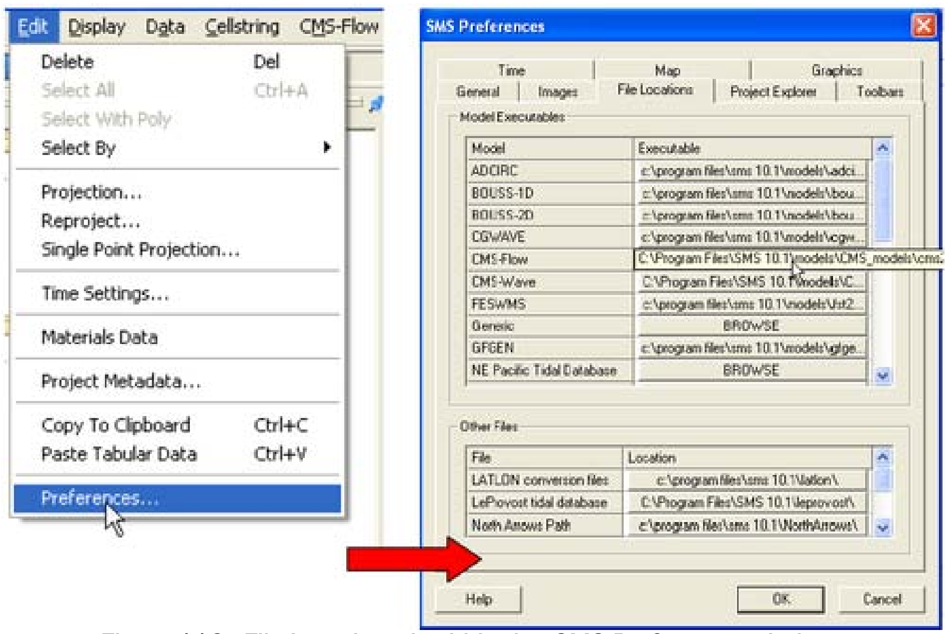


Figure 116. *File Location* tab within the *SMS Preferences* window.

- Start Steering Module to run the CMS

  1. Open the SMS Steering Wizard by clicking on the menu *Data* | *Steering Module*.
  2. Click on *CMS-Flow* <-> *CMS-Wave*, click next,
  3. Enter the steering interval next the *Time* section.
  4. Check the variables which should be passed from one model to the other.
  5. Click *Start*.
  6. A window will appear that says *Are you sure you want CMS-Wave to run every* <*x*> *hours*. Make sure the steering interval is correct and click *Yes* to start the steering module or click *No* to exit.

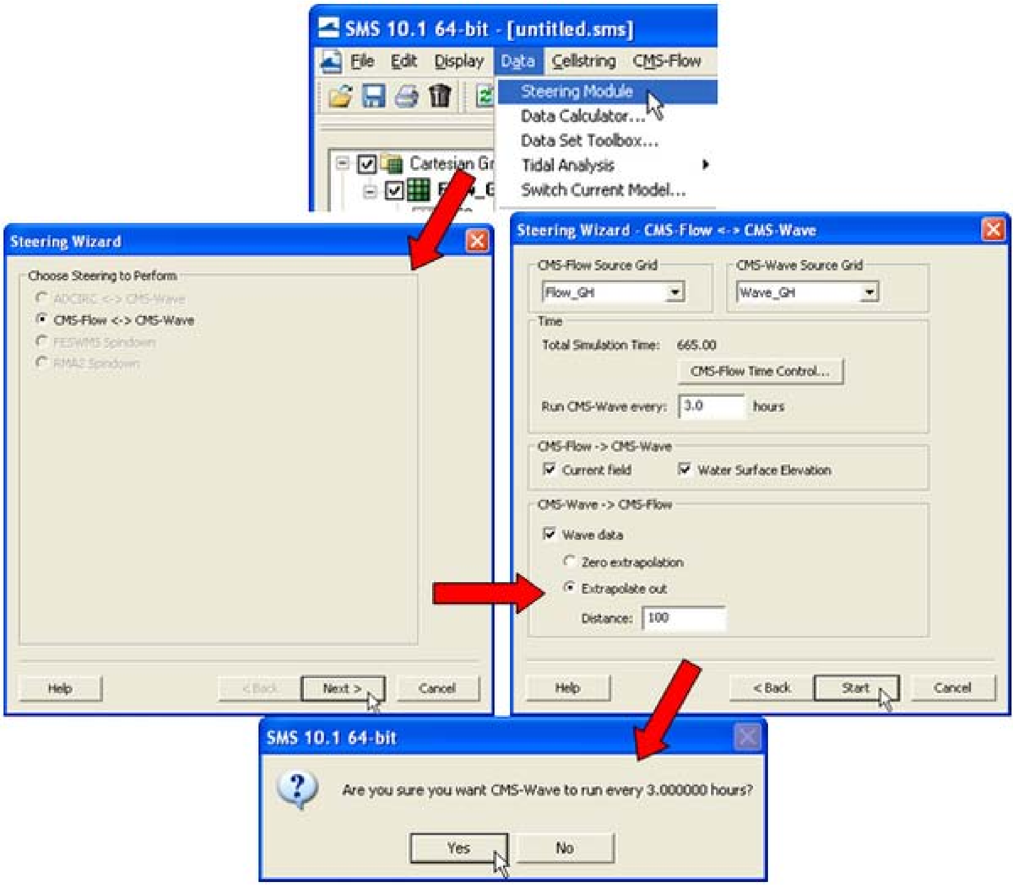


Figure 117. SMS Steering Module for CMS v3.75 and older.

CMS-Flow Versions 4.0 and Newer

CMS Versions 4.0 and newer the steering process is done internally by the CMS. This means that that both CMS-Flow and CMS-Wave are contained within a single code or executable. Even though CMS-Flow and CMS-Wave use different grids, the two models are in a single code which facilitates the model coupling and speeds up the computation by avoiding communication files, variable allocation and model initialization at every steering interval. The inline CMS can be launched from the SMS Steering Wizard or as a command line with arguments specifying the input files and steering options. The table below describes the CMS-Flow cards used for the steering process in the inline CMS.

Table 61. CMS-Flow cards related to steering

Card	Arguments	Default	Range	Description
CMS-WAVE_SIM_FILE	character	none	none	File name including path for the CMS-Wave sim file.
WAVE_SIM_FILE	character	none	none	Same as CMS-WAVE_SIM_FILE.
STEERING_INTERVAL	real	none	none	Sets the recurring hot start output time.
WAVE_WATER_LEVEL	character	TIDAL_PLUS_VARIATION	LAST TIDAL TIDAL_PLUS_VARIATION	Determines the method used to calculate the water levels passed to the wave model.
FLOW_EXTRAPOLATION_DISTANCE	real	Calculated based on grid geometry	none	Determines the extrapolation distance used for flow variables on the wave grid.
WAVE_EXTRAPOLATION_DISTANCE	real	Calculated based on grid geometry	none	Determines the extrapolation distance used for wave variables on the flow grid.

Interpolation Files

When running the inline CMS with flow and waves, the CMS steering module write out two files named:

- Intpcoef_flwav.bin
- Intpcoef_wavfl.bin

These files contain the interpolation information between the CMS-Flow and CMS-Wave grids. Because calculating the interpolation infomration can take several minutes, saving this information in files allows the model to quickly read this information and avoid their computation for subsequent runs when using the same CMS-Flow and CMS-Wave grids. When the model is restarted it will automatically detect these files and read them if the grids are the same size. If changes have been made to the grids but the grid size is the same, the steering module will not be able to detect the changes and the interpolation information will be incorrect. Therefore, it is recommended to delete the interpolation files every time a change is made the either the CMS-Flow or CMS-wave grid. In the future, this problem will be avoided by writing a counter to the CMS-Flow and CMS-Wave files every time a change is made to them from the interface.

Running the CMS

Recommended Folder Structure

Any folder structure may be used. However, for purposes of organization and ease of use, it is recommended that a folder structure similar to that proposed here be used. For large modeling projects with many alternatives and simulations, a more complex folder structure may be warranted, but should be based on that below.

While the CMS accepts file names and paths with spaces, other software may have issues with spaces. Therefore, it is recommended that spaces are not used in the simulation path and filename without prior testing.

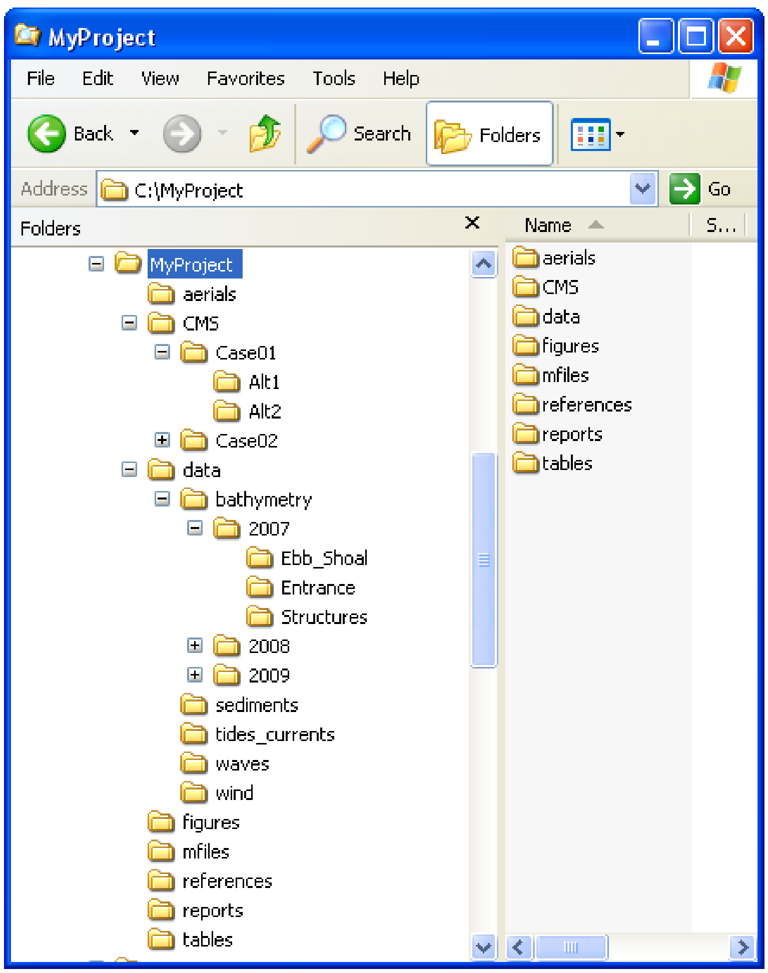


Figure 118. Recommended folder structure for CMS projects.

File Names and Conventions

Model Input and Output Files can be generally classified as:

1. Control Files
2. Data Input Files
   a. Geometry
   b. Initial condition
   c. Boundary conditions
3. Data Output Files
4. Diagnostic Files

Control (Card) File

Control files are used for specifying input parameters, options, and boundary conditions, initial conditions and forcing. In CMS-Flow the Control File is the *.cmcards (card) file. The ASCII file uses a simple card format to specify model input in free format. Data Input Files depend on the specific model setup, and may include but are not limited to spatially variable

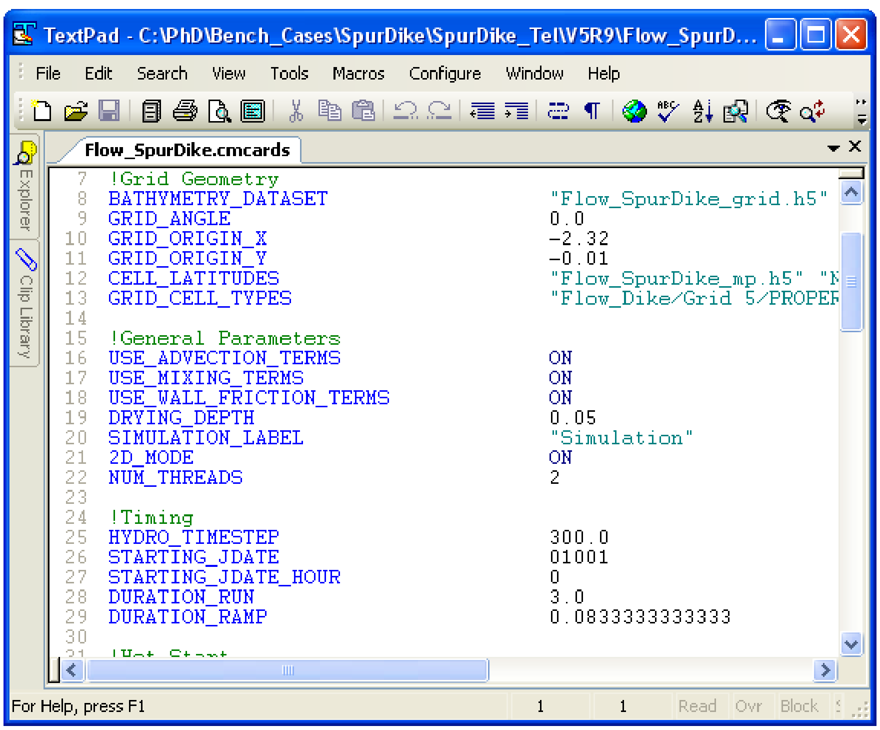


Figure 119. CMS-Flow Control (card) File viewed in TextPad.

Table 62. Input Files for CMS-Flow

File	Description
Card File	File name including path for the CMS-Wave sim file.
XMDF Grid File	Same as CMS-WAVE_SIM_FILE.
XMDF Model Parameters File	Sets the recurring hot start output time.
Telescoping Grid File	Determines the method used to calculate the water levels passed to the wave model.
User-defined datasets	Determines the extrapolation distance used for flow variables on the wave grid.

SMS Steering Module

The inline CMS can be launched from the SMS 11.0 Steering Module in a similar way to previous versions of CMS. The steps for launching the inline CMS (versions 4.0 and higher) are outlined below.

- Make sure both the CMS-Flow and CMS-Wave grids are loaded in SMS.
- Check the CMS executable file name under the SMS preferences menu (see Figure 120).
    1. Click on *Edit | Preferences*.
    2. Under the *File Locations* tab, in the section called *Model Executables* check the file names for CMS-Flow and CMS-Wave and make sure they are consistent with the latest releases (http://cirp.usace.army.mil/products/index.html CIRP Products).

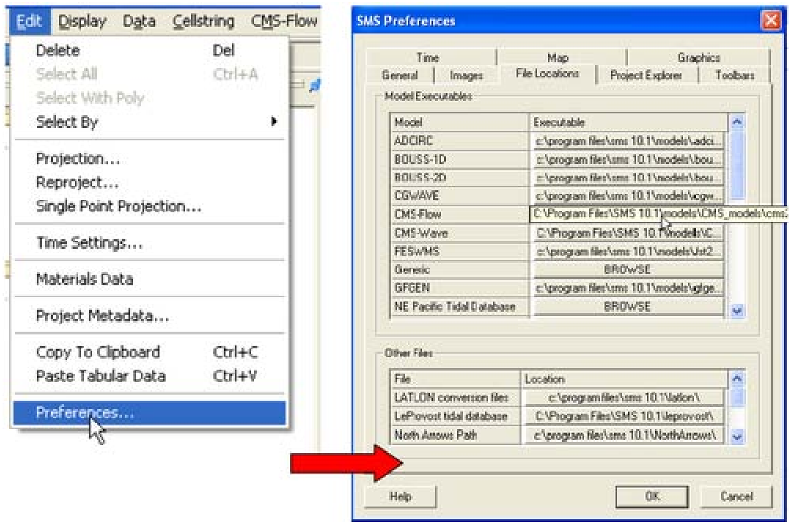


Figure 120. Changing the CMS-Flow model executable.

- Set the steering information in the Advanced Cards
    1. Click on *CMS-Flow | Model Control...*
    2. Enter the steering interval and CMS-Wave *.sim file using the cards described in the table above. Note that the full path to the *.sim file must be provided within quotation marks.

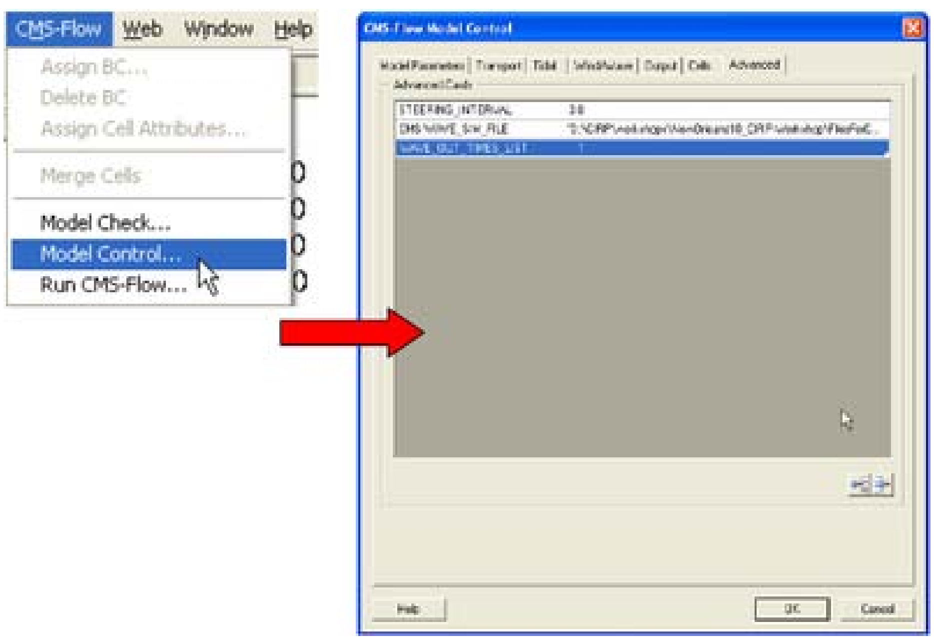


Figure 121. Setting the CMS steering information.

- Start Steering Module
    1. Click on *Data | Steering Module*.
    2. In the *SMS Steering Wizard* select the *CMS INLINE* option and click on the *Next>* button.

3. Enter the *Steering Interval* under the *Time* section and and click on the *Start* button.

Notes:

1. When Running the inline CMS from SMS, it is not necessary to specify the CMS-Wave Sim File or Steering Interval in the advanced cards section.
2. Steering options besides the CMS-Wave Sim File and Steering Interval such as the extrapolation distances need to be specified in the Advanced Cards

SMS CMS-Flow Menu

The second option for launching CMS versions 4.0 and newer is by entering the steering information in the cmcards file and simply running from the SMS CMS-Flow menu. The steps are outlined below.

- Make sure both the CMS-Flow and CMS-Wave grids are loaded in SMS.

- Check the CMS executable file name under the SMS preferences menu.
    1. Click on *Edit* | *Preferences*.
    2. Under the *File Locations* tab, in the section called *Model Executables* check the file names for CMS-Flow and CMS-Wave and make sure they are consistent with the latest releases (http://cirp.usace.army.mil/products/index.html CIRP Products).

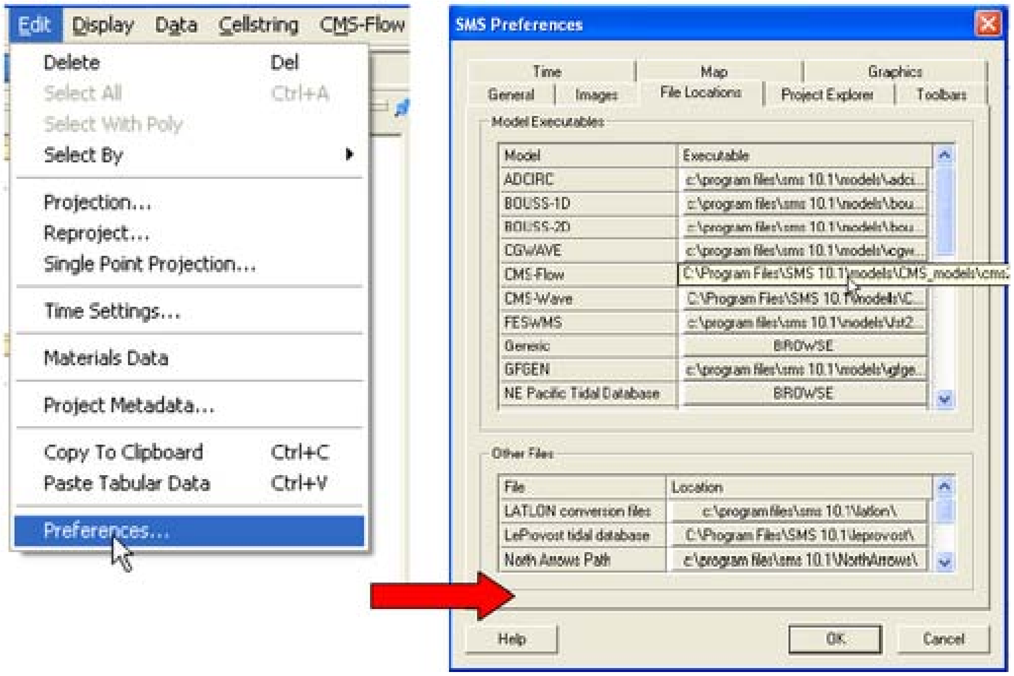


Figure 122. Changing the CMS-Flow model executable.

- Start CMS from the CMS-FLOW Menu
    1. Click on *CMS-FLOW | Run*
    2. In the *SMS Steering Wizard* select the *CMS INLINE* option and click on the *Next>* button.
    3. Enter the *Steering Interval* under the *Time* section and and click on the *Start* button.

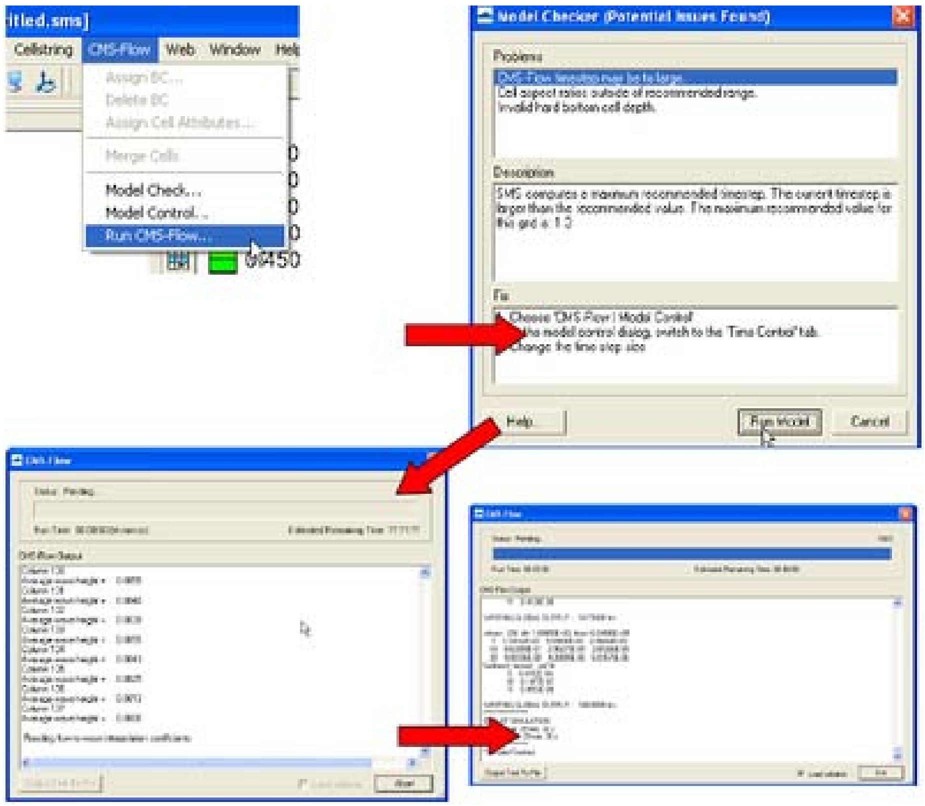


Figure 123. Example of launching the CMS from the CMS-Flow menu.

Standalone Program

Standalone refers to the fact that the CMS executable is not part of a larger software package nor does it require a network connection, and support or services of the operating system or other software. If the CMS were run from the SMS it would not be considered a standalone program.

Because the inline CMS does all of the steering internally, it is a standalone program and there is really no need for CMS to be launched from SMS. Running CMS outside of SMS is useful because it allows the user to launch CMS from script files and also to pause the model for checking model results during the model simulation without causing access errors. When running several models, pausing the some of them will free up some of the computer to do other tasks such as plotting and checking model results. Running CMS outside of the SMS, also avoids the extra memory and work requirements from the interface.

There are three mean approaches for running CMS as a standalone program

1. From a command prompt
2. Double-click on the CMS executable or shortcut to the executable.
3. Drag-and-drop the CMS input files on the CMS executable or shortcut to the executable.

Important Notes:

1. For advanced users, it is recommended to put a copy of the CMS executable in the project directory and running the CMS from a command prompt. This keeps a record of the executable used for the project, facilitates making and transferring script files for running multiple project alternatives and keeps the window open after the model has completed or even crashed.
2. To pause the simulation, press the "Pause/Break" button on your keyboard.
3. To stop the model simulation, press and hold the "Ctrl" key and press the "C" key.

Command Prompt

The first step is to open a command prompt. There are two ways of doing this:

The first method for opening a command prompt is

1. Click on Windows *Start* | Accessories | Command Prompt

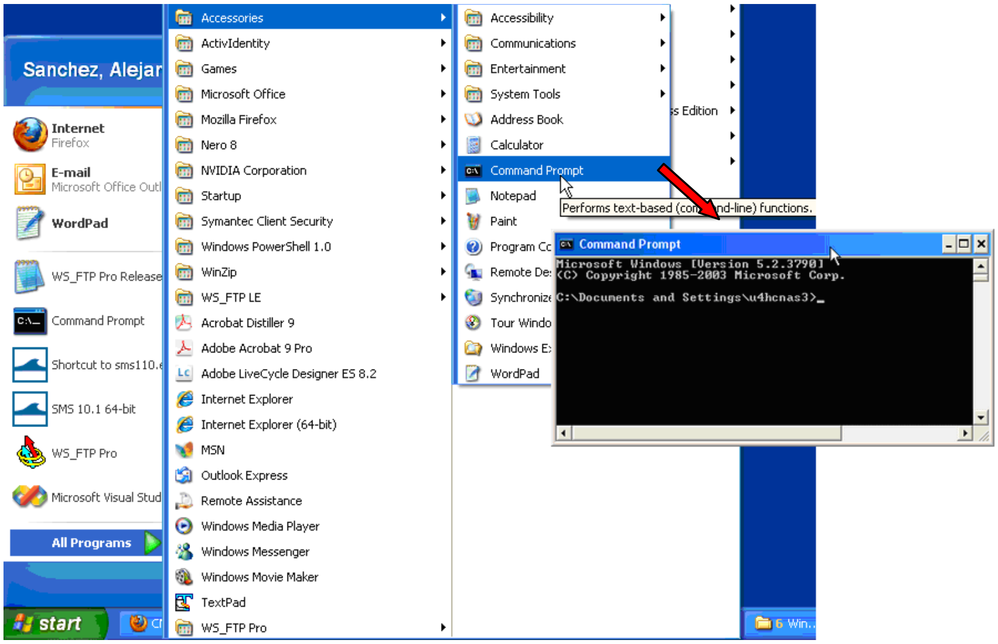


Figure 124. Example of launching the inline CMS-Flow steering run.

The second method for opening a command prompt

1. Click on Windows *Start* menu then the *Run…* utility
2. In the *Run* window, enter the command *cmd* and click *OK*

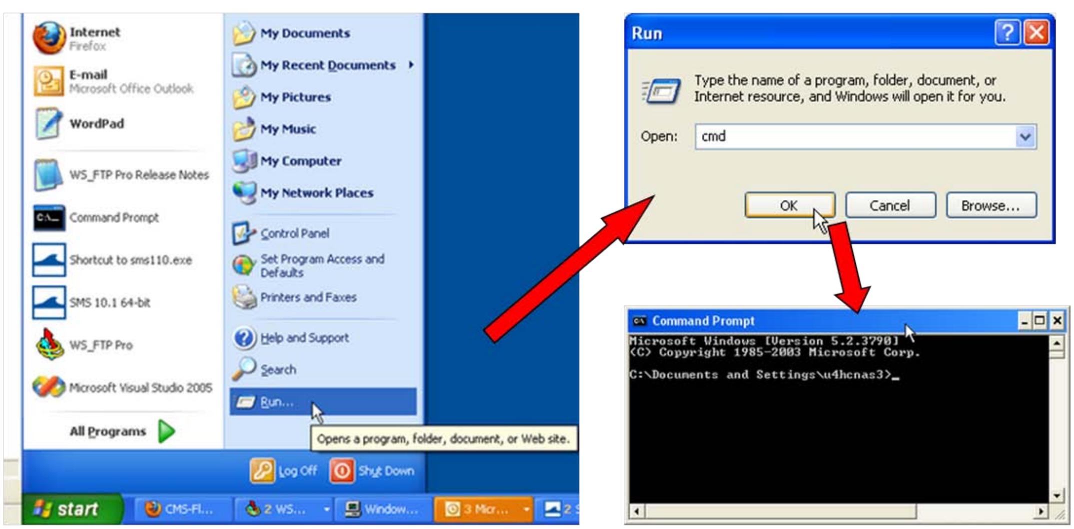


Figure 125. Example of launching the inline CMS-Flow steering run.

Important Note:

- It is recommended to put a shortcut to the Command Prompt on the desktop to more easily open the Command Prompt.

Once the command prompt is open the CMS can be launched using one of the following syntax

>> [cms2d_*exe] [.sim or .cmcards file] [.sim or .cmcards file] [steering interval] [wave water level option]

where the steering interval is in hours and the wave water level option is either

1. Wave water levels are estimate as the last water levels from the flow model (i.e. WAVE_WATER_LEVEL option equal to LAST)
2. Wave water levels are estimated as the mean tidal water level at the wave time step (i.e. WAVE_WATER_LEVEL option EQUAL TO TIDAL).
3. Wave water levels are estimated as the mean tidal water level at the wave time step plus the water surface variations estimated from the last flow time step (i.e. WAVE_WATER_LEVEL option EQUAL TO TIDAL_PLUS_VARIATION).

Important Notes:

1. The sim and cmcards files must contain the full or relative path with respect to the executable if different from the executable.
2. If no input arguments are specified, than the user will be prompted to manually enter the name of the CMS-Flow and CMS-Wave files and steering information.
3. If the cmcards file is specified the CMS will check for the steering cards. If the sim file is found, than it will run in steering.
4. If no steering interval is specified in the cmcards file or the command line, than a default value of 3.0 hours will be used.
5. If no wave water level option is specified in the cmcards file or the command line, than a default method equal to three.
6. It is possible to create a short-cut to the model executable and simply drag-and-drop the cmcards file and or sim file with the steering options specified in the cmcards file.

Below are some examples

>> cms2d_v4b43-x32.exe
>> cms2d_v4b43-x32.exe Flow.cmcards
>> cms2d_v4b43-x32.exe Flow.cmcards Wave.sim
>> cms2d_v4b43-x32.exe Wave.sim Flow.cmcards
>> cms2d_v4b43-x32.exe Flow.cmcards Wave.sim 1.0
>> cms2d_v4b43-x32.exe Wave.sim Flow.cmcards 3.0 1

Drag-and-Drop

To launch CMS as a standalone application using the drag-and-drop method:

1. Select all of the CMS input files by holding the "Ctrl" key and single-clicking on each input file.
2. Drag all of the input files on the CMS executable or shortcut to the executable by holding the left mouse button.
3. Drop the the files by letting go of the left mouse buttom.

- **Note:** If running steering, make sure all of the steering options are in the cmcards file when using the method.

Double Click

This is one of the easiest ways of running the CMS but also one of the most time consuming because it requires the user to type the name and path (if different from executable) for all of the input files and if necessary the steering options.

- To run the CMS by using the Double-Clik method:
    1. Double-click on the executable
    2. Follow the instructions on the screen.

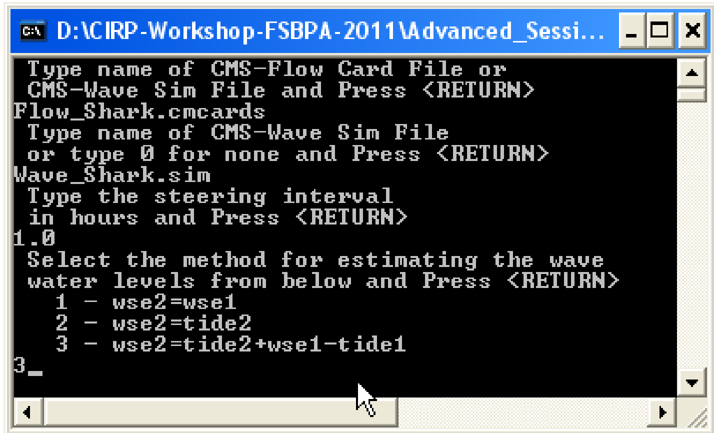


Figure 126. Example of launching the inline CMS by double-clicking on the executable.

- **Note:** If CMS input files are not in the same folder as the executable, the file names must include the full or relative path with respect to the executable

Windows NT/2000/XP/7 Priority Levels

In Windows NT/2000/XP/7 it is possible to assign a process a different priority level using the Task Manager. This is useful for running CMS in the "background" without slowing down the computer. Windows NT offers three different priority levels while Windows 2000/XP/7 offers five. The priority level can be set when launching the executable from a Commnd Prompt or batch file or changed after the model is started from the Task Manager. To set the priority level from the Command Prompt use one of the following switches /low, /belownormal, and /abovenormal.

When initiating CMS simulations from a batch file, precede each of the lines in the above example with "start "CMS" /wait /low" as shown below. This initiates a separate Console Window for each simulation on a low priority. You can also see which simulation is active by viewing the primary Console Window. The /wait option is necessary to force the next simulation not to start until the current one is complete. It is not recommended to use /high priority since this may cause the machine to freeze up. To change the priority level of simulation manually, open Task Manager (see your System Administrator if you're not sure how to do this), click on the Processes Tab and find the CMS executable process you wish to change, right click on the process, choose Set Priority, then set the priority.

Viewing and Post-Processing Results

Calibration of hydrodynamic and morphologic datasets requires use of post-processed data in order to compare to measurements and make incremental changes. This section gives guidance on how to process or extract data from model results, and examples of measured data to compare results with. Of course, the post-processed data can be exported and comparisons can be made in another program, but there are some options within SMS that can help with repetitive testing and comparisons.

Water Levels & Currents

The first stage in calibration of a numerical hydrodynamic model is to accurately represent measured tides (or water levels) and currents. The number of calibration measurement sites required for sufficient model calibration increases with larger domains and increased complexity in processes.

Of the three main data sources required for good hydrodynamic calibration (geomorphic, forcing, and field data), inaccurate knowledge of, or mistakes in conversion between datums is the most common underlying factor in poor model calibration. Model calibration cannot be achieved without proper representation of datums. Some examples of field data typically used for calibration of hydrodynamics include fixed water level gauges, fixed acoustic Doppler velocimeters (ADV) and acoustic Doppler current profilers (ADCP), and roaming or boat-mounted ADCPs. Both fixed and roaming data can be assessed over a time series, where boat-mounted data are collected at specified locations over time intervals. However, roaming data that were collected continuously must be assessed as a function of location in three-dimensional space.

For hydrodynamic data, the most common forms of measurements are recorded either temporally at a station, temporally at a fixed spatial extent, or spatially at relatively singular times. For example, a tide gage is stationary, but a horizontal accostic Doppler current meter (H-ADCP) may collect temporal measurements at multiple points. Of course, the multiple locations are depth-averaged, as would be an upward-looking ADCP, in order to compare to the 2D CMS. Similarly, a field campaign of depth-averaged current measurements collected at transects are all contemporaneous (within reason), but there are multiple time periods to compare.

With good forcing data and accurate corresponding datums, the final check before hydrodynamic calibration can be achieved is the accuracy and detail of the geomorphic parameters such as bathymetry, sediment characterization, and structure definition. The most important of these is bathymetry, which can have several issues which are typically associated with quality control, density, interpolation, and final grid resolution and domain size. A good example of this is a poorly resolved small channel in the far reaches of a bay, such as that in the northern portion of the Shark River estuary (Figure 127). Although lower velocities may be passing through this channel, and there may be little interest in morphology change here, it may be integral to providing the conduit of tidal prism to a shallow bay platform.

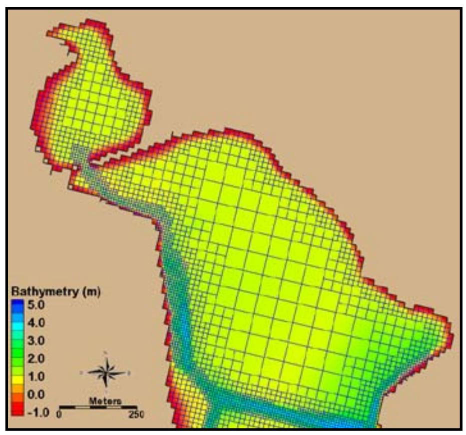


Figure 127. Northern portion of the Shark River estuary.

Figure 128 shows the closest locations of water-level gauges to Shark River Inlet. Sandy Hook and Atlantic City, NJ, are two ocean pier-mounted gauges approximately 30 and 100 miles away from Shark River Inlet, respectively. Both NOAA gauges were evaluated against the Belmar tide gauge using the tidal constituents of one year, and Sandy Hook was found to have the closest amplitudes and phases. Measured tides from Sandy Hook were used to force the offshore boundary condition. The calibration period that the model was evaluated on was for the 13-hour tidal cycle over which field measurements were collected on 20 August 2009.

Figure 128. Location of NOAA (red) and USGS (blue) water level gauges.

Diplay Options

The results of the CMS calculated hydrodynamics can be viewed and compared to measured results in a number of ways. Scalar results are typically in planar view and are illustrated by color representing magnitude, and arrow lengths representing magnitude and direction. Color setting can be manipulated in the overall Display Options, or individually for each dataset.

1. Open a solution file for the hydrodynamic output and right click on the *WSE* dataset, select *Display Options*.
2. In the *Contours* tab, adjust the color settings and the value range to that in Figure 129.

Figure 130 illustrates the new color scheme for displaying the water surface elevation.

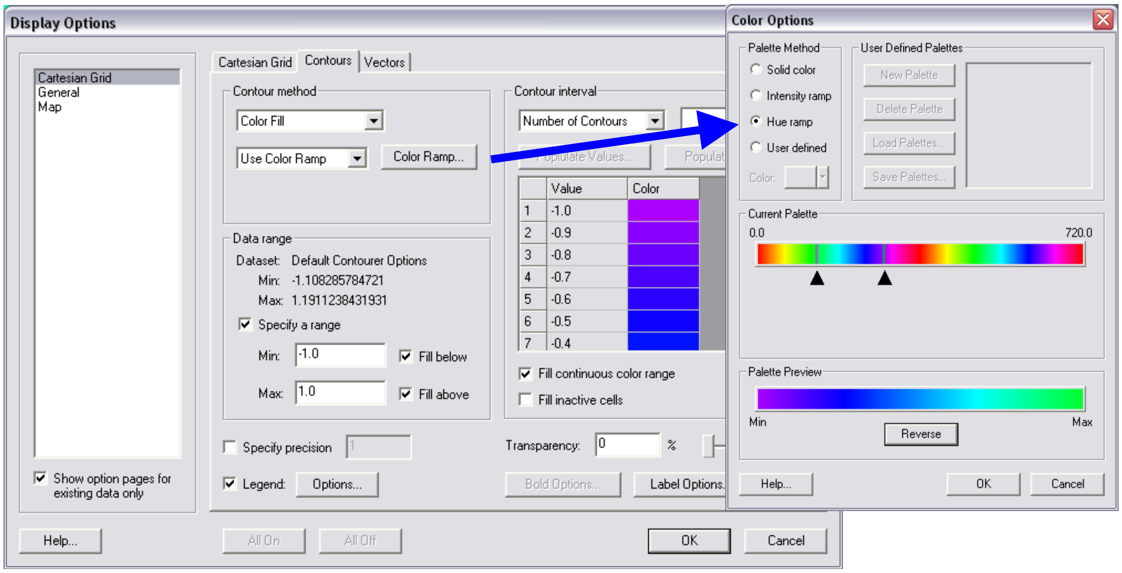


Figure 129. Contour tab settings for color display and value range. Note the blue colors were selected for the visible range.

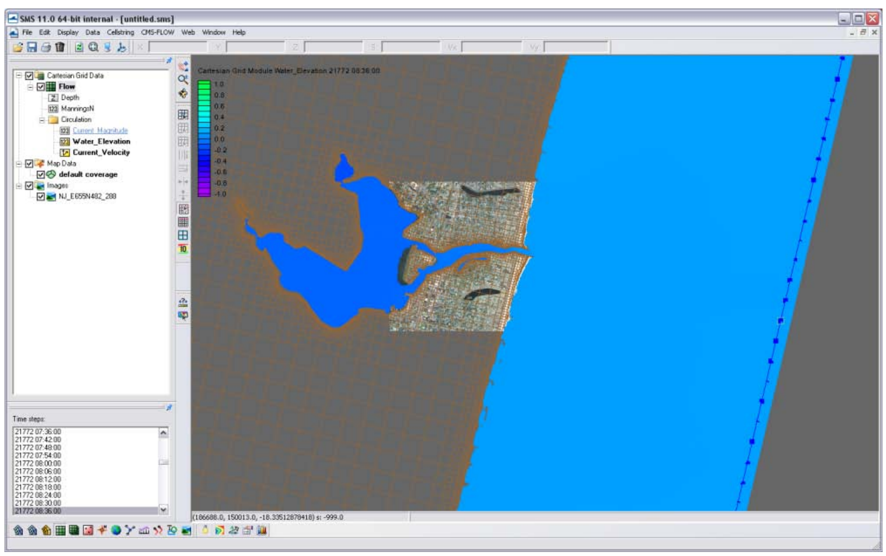


Figure 130. Water surface elevation color contours modified.

Currents are automatically given in vector format as the solution files are generated. These can be converted into Vx and Vy components, or into magnitude and direction. If the modeled results are compared to simple magnitude measurements, then the magnitude dataset is appropriate. If the modeled results will be compared to measurements collected in easting and westing, care should be taken to compare the correct derivative of the vector format. Because the vectors are based on the Cartesian grid's orientation, be sure to convert with respect to the axis difference.

1. Right click on the current vector dataset and select *Vector to Scalar*. Select Vx and Vy, and this gives the x and y components of the current velocity.
2. Next, convert the vector to *Magnitude and Direction*. The color component of the magnitude can be selected along with the vector of the current velocity.
3. Open the *Display Options*, and go to the *Vector* tab. Change the vectors to the below settings (Figure 131) to view the vectors over a prescribed gridding. (Note that individual vectors at each cell is difficult to visualize for the whole domain and often only useful when zoomed in very close.)

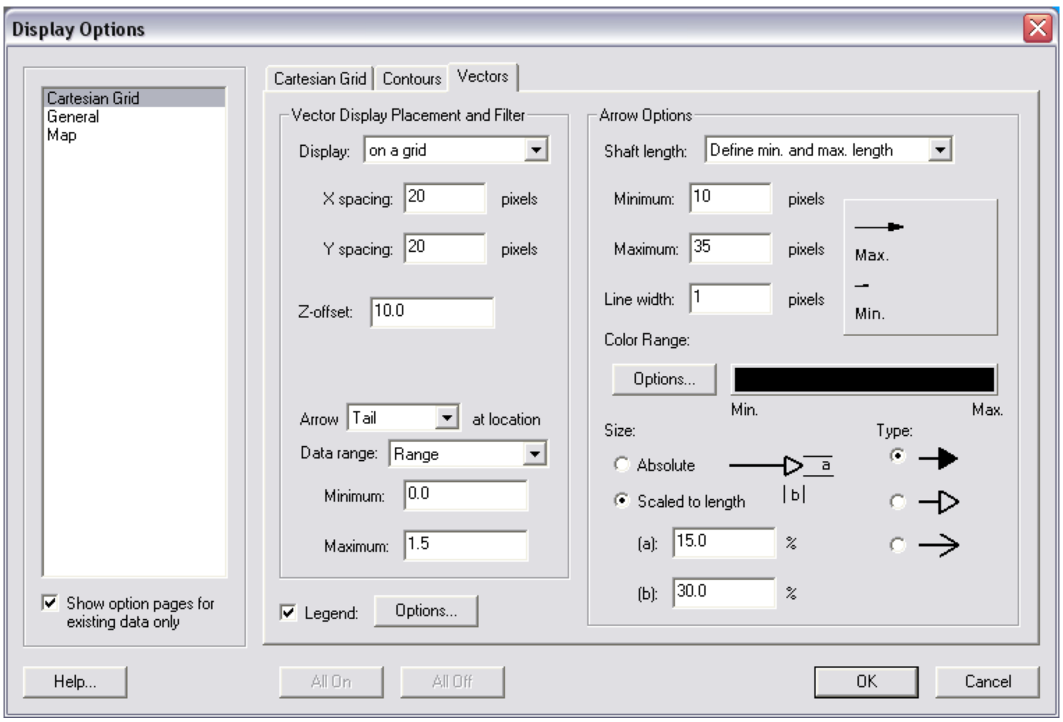


Figure 131. Vector Display options set for a gridded display across the domain.

Figure 132 shows an example of displaying current magnitudes with color contours and the current direction with vectors.

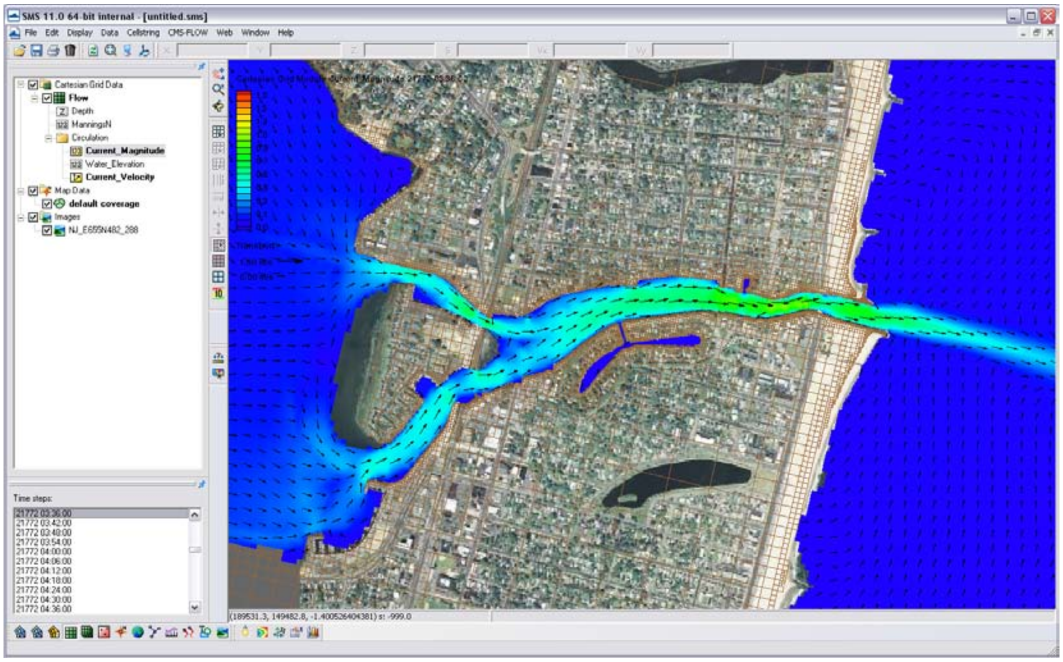


Figure 132. Vectors and color contours set for displaying current magnitude (color) and direction (vectors). Note that the vectors are slightly scaled on this setting to reflect magnitude.

Importing water level measurements into SMS for comparison

To compare the measured data within SMS, the measurements must be brought into the program and into a comparable format. SMS will import a variety of ASCII, columnar data that can be categorized and labeled in a scatter dataset (scatterset).As a simple example of comparing tidal data to calculated tides, the USGS Belmar tide data is given in the folder Hydro\Water Level Calibration in the Tide_Comparison_AUG09_Workshop.xls file. This is the only tide measurement for Shark River Estuary to compare the bay tidal harmonics. To import this data, it must be brought in as observational data within the *Observation Map Module*.

1. In the Cartesian Module, go to *Display*, *Plot Wizard*, and select *Time Series Plot*. Select scalar, and the WSE as the dataset. (Note it takes some time to populate a plot in SMS.)

2. Change the map module *Default Coverage* type to *Observation*, and add a *Feature Point*  to the approximate location of the tide gauge shown in Figure 128.

3. Right click on this feature point (**Error! Reference source not found.**), and select attributes.

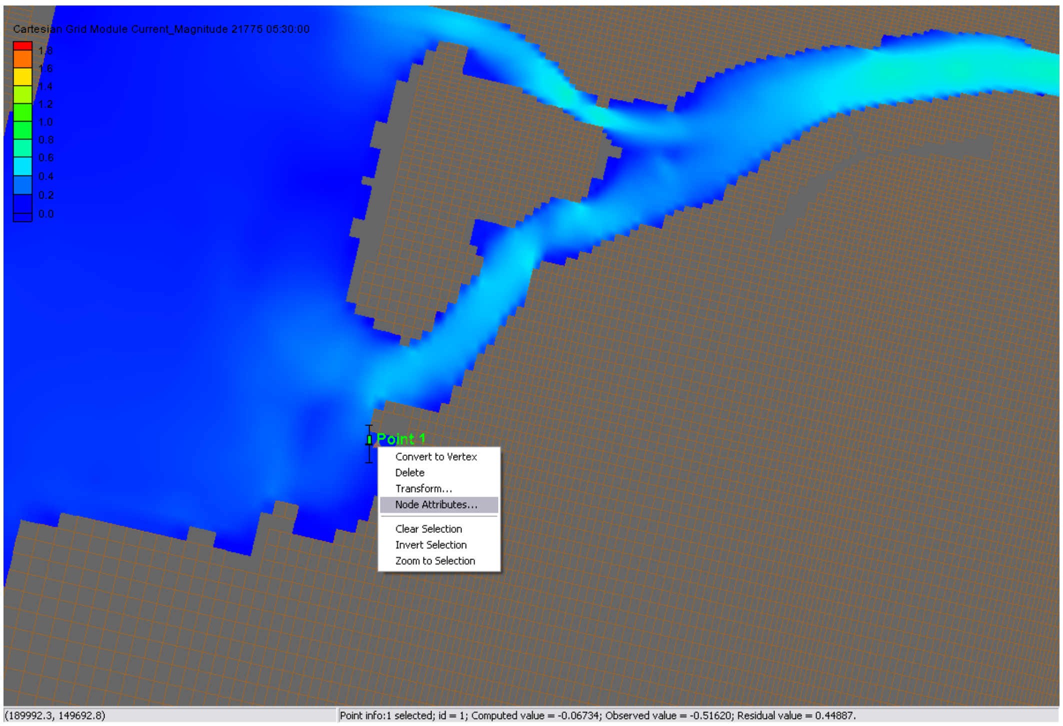


Figure 133. Observation point placed at the location of the Belmar tide station.

4. In the *Attributes*, check the Trans box in measurements, and select 2D Cartesian under Module, and the Water_Elevation dataset (Figure 134). If your Observe Point is checked, an Options box should appear under the Time Series column. Select this and import the Belmar_Tide.xys file.

Time series of the measured water levels can be manually pasted here. A file of measured water levels is provided and available for *Import*: Belmar Tide Input.tsd.

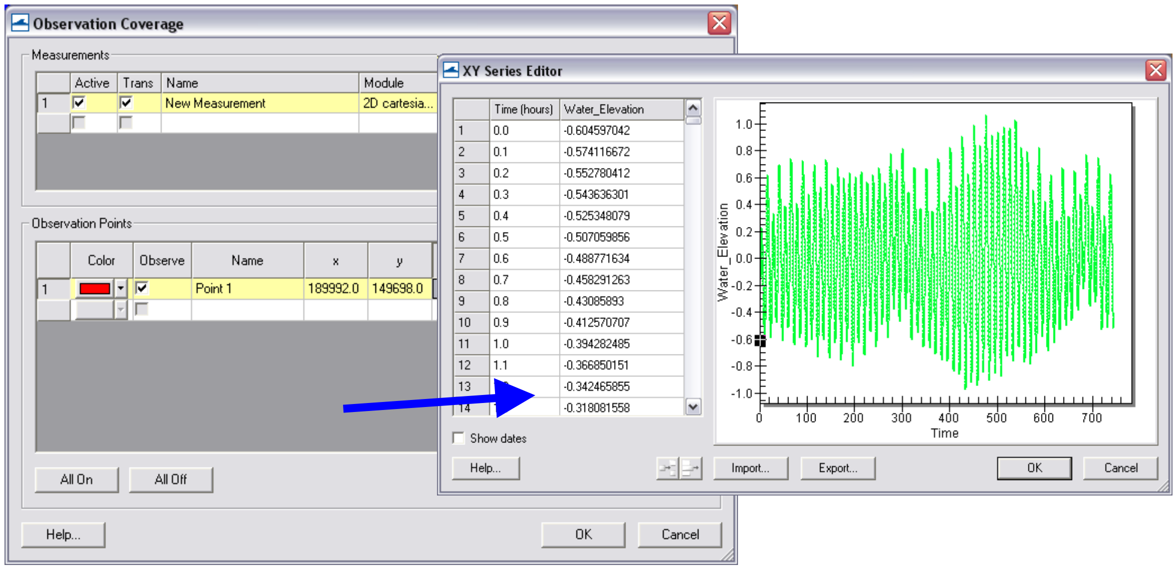


Figure 134. Input of time series water surface elevation data into an observation point.

Water level data plotting from Feature Points

Time plots can be compared within SMS through their software plotting package. To create a plot:

1. Select *Display|Plot Wizard|Time* Series and select *Next*. The *Function* is *Scalar*, and the *Water Elevation* scalar dataset should be selected with the full time period (Figure 135).

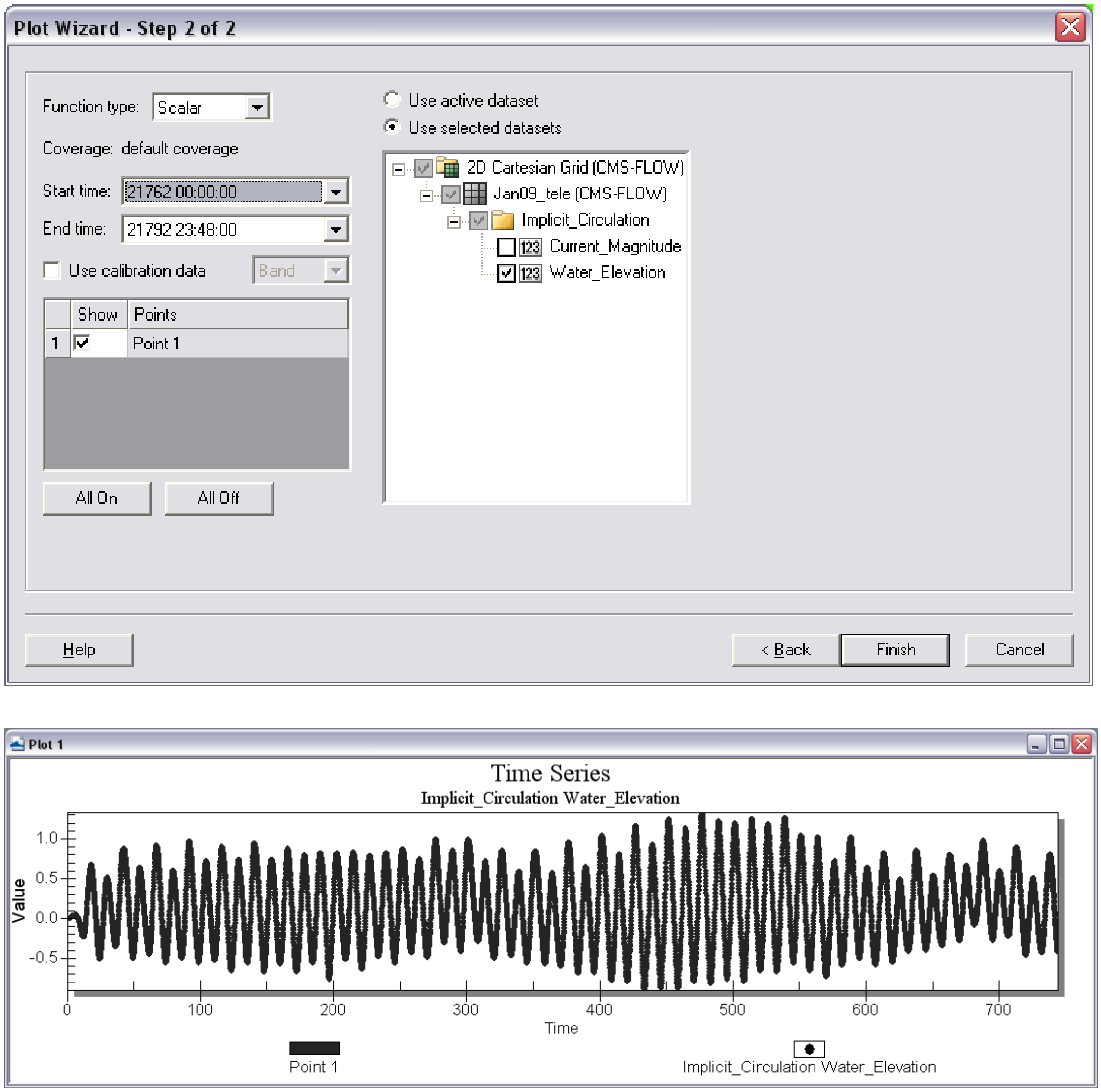


Figure 135. Plot Wizard for time series data (top); Time Series plot of Water Elevation (bottom).

2. The plots can be updated by right-clicking the graph window and selecting *Plot Data*. Also, the time frame can be modified.

3. Changing the location of the Feature Point by dragging the point will also automatically update any graph open within SMS. Note that moving Feature Points that are extracting large datasets may take a considerable amount of time to reload.

Extensive statistical analysis of time series water levels is not available in SMS. However, it is convenient to extract this information from SMS which can be used in other software or Microsoft Excel.

4. To extract the raw data for use in other software right-click on the graph window and select *Export*. In the *Exporting Time Series* window, select *Export|Text/Data, Export Destination|File* (and specify a location), and select *Export*. Change the *Export Style* to *Table* and *Row vs. Column* to *Points/Subsets* (Figure 136). Export.

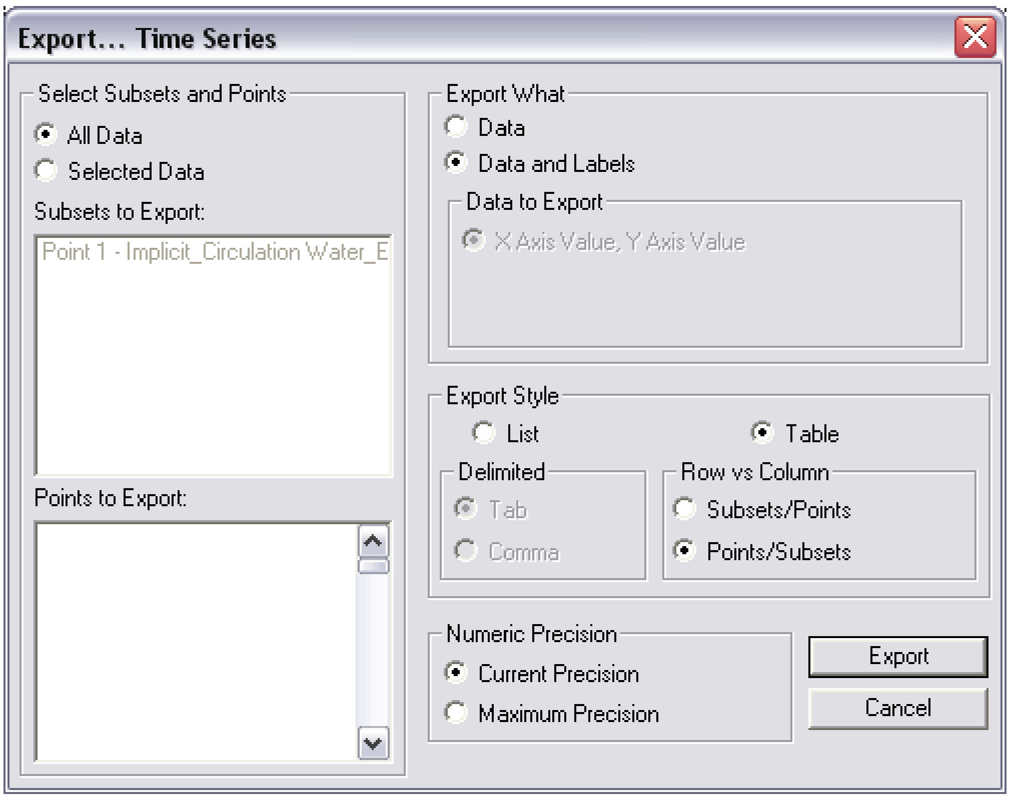


Figure 136. Export Wizard for plotted data.

5. To view the raw data (and another way to extract) right-click on the graph window and select *View Values*. The data are presented in a table that can be highlighted and copied to another program.

Other options for the display plot can be found on the XMS Wiki (http://www.xmswiki.com/xms/SMS:2D_Plots).

CMS-calculated water level variation is compared with water levels from the Belmar gauge (location shown in Figure 128) and given in Figure 137. Because the Sandy Hook gauge is located 30 km north of Shark River, the calculations have a slight phase advance in comparison to the measurements because the tidal wave propagates from north to south on this coast. The ocean gauge typically leads the bay gauge by 20-30 min.

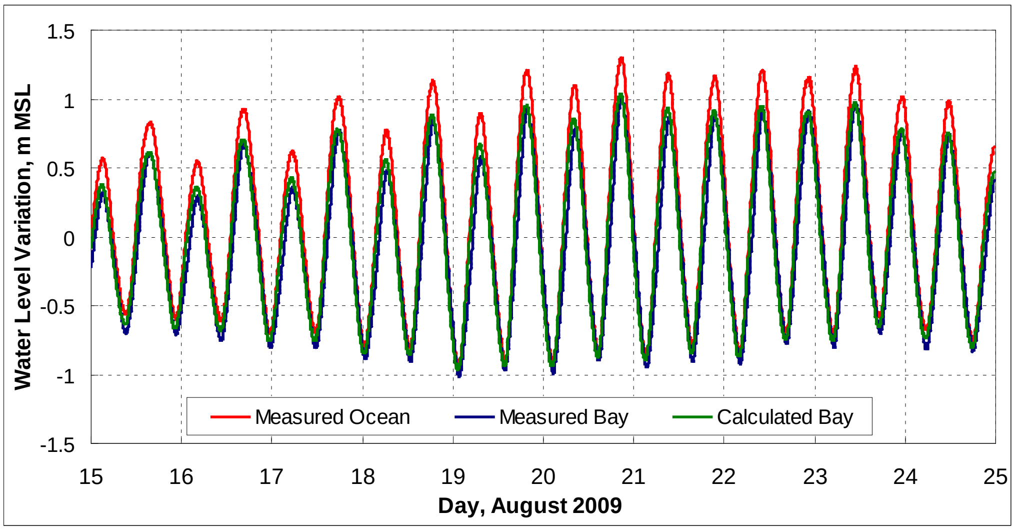


Figure 137. Observed time series of water level at Sandy Hook and Belmar ("Bay") and calculated water level at Belmar.

If time series data for the model were not set to the same interval as the measured data, there are filtering options within the data calculator.Reducing output (water level) from the solution:

1. To create a 30 minute dataset of water levels from the original 6 minute output, go to *Data*, *Data Calculator*, and under the *Tools* section, select *Temporal*, *Sample Time Steps* (Figure 138).

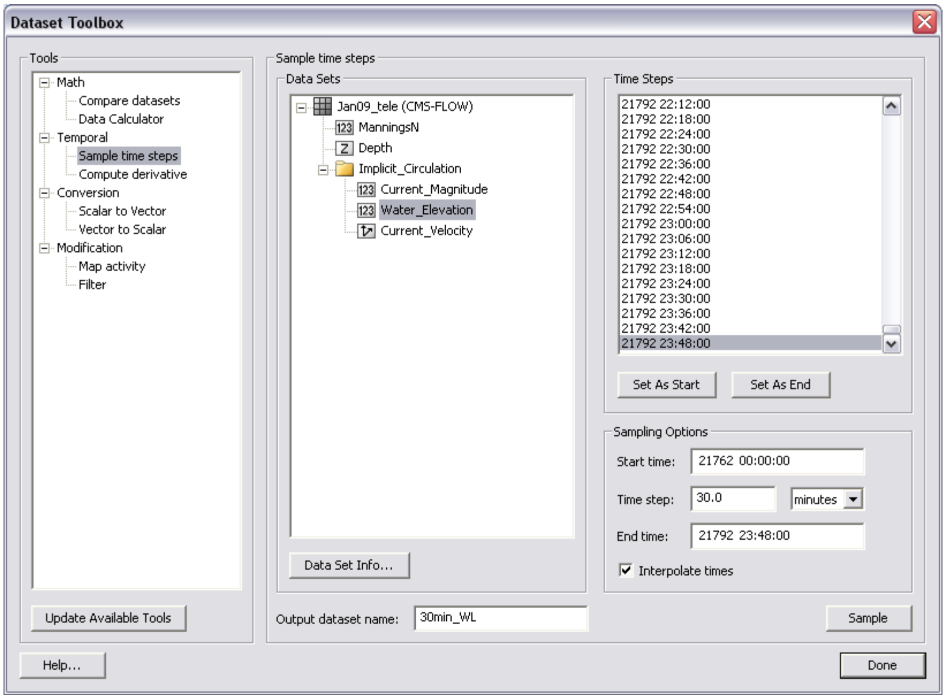


Figure 138. Sampling time steps of the Water_Elevation scalar dataset in the Dataset Toolbox.

2. Select the *water level* dataset under the solution datatree, and create an *Output dataset name* at the bottom.

3. Set the Start time to the beginning of the series and the end time to the end by selecting the time under *Time Steps* and selecting the associated button below. Change the time step to 30 minutes (or 0.5 hours), select *Sample*.

Depth-average down-looking ADCP current data were measured at three transects, or 2-D profiles along transects, in Shark River Inlet during the calibration time period in August, 2009. This data was processed with off-the-shelf software, where velocity was binned into depth measurements throughout the water column, and converted into a .GIS file. To display preprocessed measured velocities, they must be converted into an XYZ format with additional data (velocity and direction, or Vx and Vy) in additional columns. SMS will recognize both the XYZ data, and assign extra scalar or vector datasets to the imported files.

Importing GIS-type files from D-ADCP current measurements output into SMS:

1. Open the provided file in the section folder SRI082009_DAV_1300.GIS, and select *Use Import Wizard* (An excel version of the text file is also provided in the folder). Select *space/tab* deliminated if not already checked and click *Next*, and select the X, Y, Z, Vector X and Vector Y columns (Figure 139). Be sure that the Header of the Vector X & Y columns is the same. Change the headers so they are the same (Vector), otherwise this incurs an error when importing in SMS.

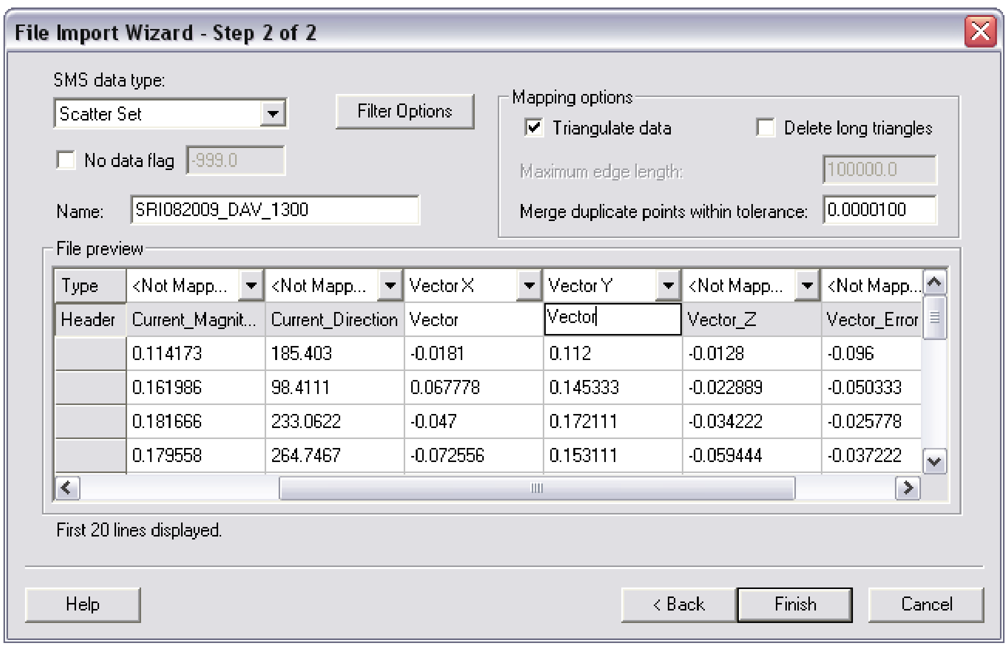


Figure 139. Sampling time steps of the Water_Elevation scalar dataset in the Dataset Toolbox.

All of the files were imported into SMS similarly as the time series data in the above section and are provided for you. All the data imported included X,Y,Z, Vx, Vy, Mag, and Dir for all three transects at a particular measurement time period. The files (under Hydro\Water Level Calibration\Measured D-ave velocity GIS\SMS) have been converted into scatter datasets for quick import in SMS for viewing.

2. Import (drag and drop) one or two of the .h5 files (e.g. *SHARK820_HOURLY - SRI082009_DAV_1100.h5*). In

Display Options, under *Scatter*, select velocity vectors and adjust the vector settings tab (Figure 140).

3. For a general estimate of comparison of the magnitude, convert one of the measurement files' vectors to magnitude and direction (right click, *vector to scalars*). This can be compared to the calculated magnitude for a rough estimate.
4. The scalar value of the measured data is in centimeters. Create a new dataset in meters using the data calculator (Figure 141).

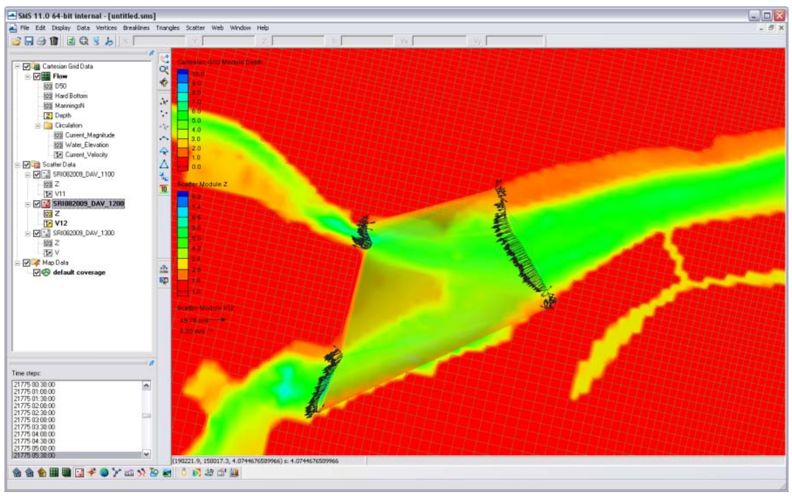


Figure 140. Example of the vector display along the measured transects. Note the vectors are scaled to the magnitude, and these scales can be manipulated in the Scatterset Vector tab.

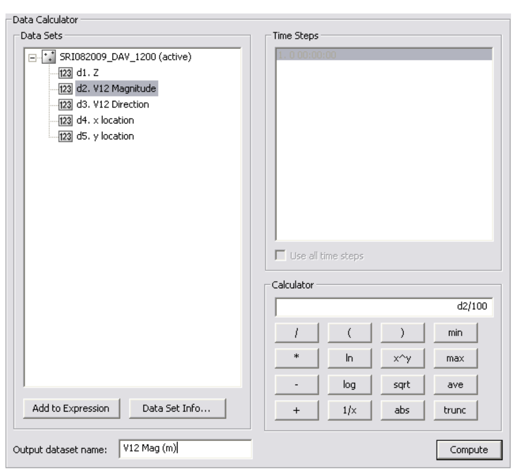


Figure 141. Data calculator used to convert the vector magnitude from centimeters to meters for comparison to the calculated velocity magnitude.

4. To display the scatter points with colors representing the flow, go to the *Scatter* Tab under the *Display Options*, and select the *Use Color Contour Scheme* under *Points*. Make the points a size 10 and they will be visible and the color differences noticeable as in Figure 142.

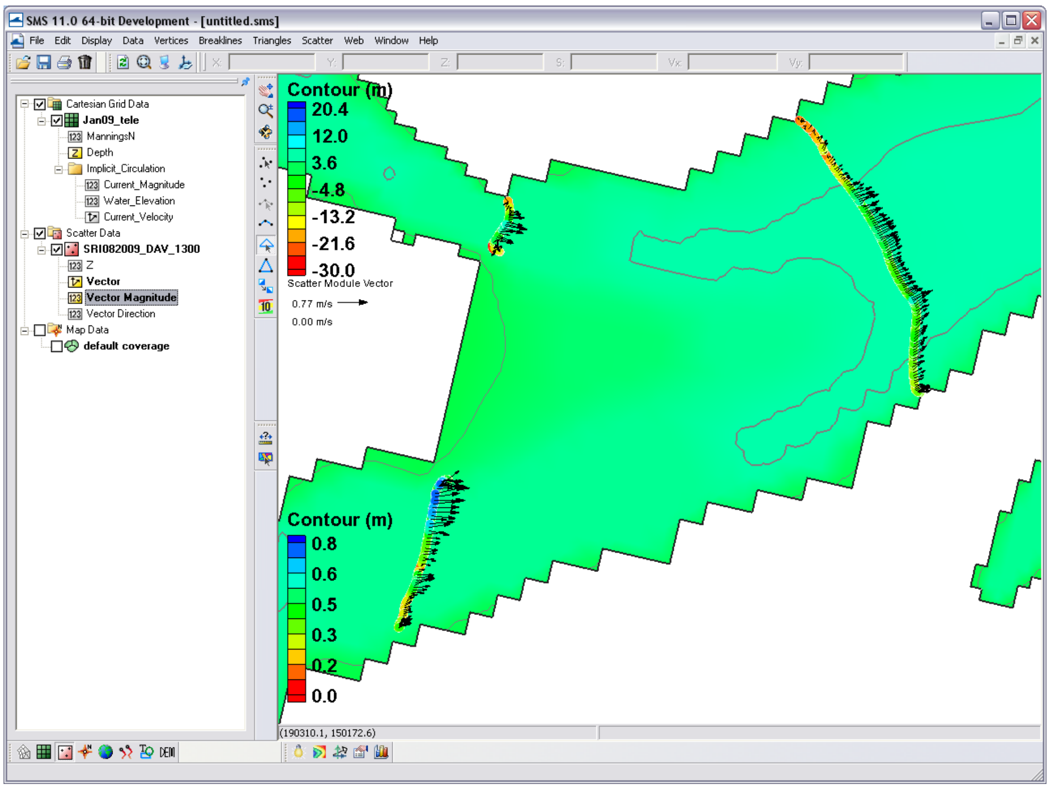


Figure 142. Color options turned on for scatter points.

To compare the measured current velocity data to calculated, the data must be in SMS in this format, where xyz data overlay the proper region and the units of the measurements are the sameBoth datasets can be viewed and extracted within the SMS through the use of observation arcs. The arcs must be set along the transect line and have enough points to illicit one value per cell, but not too many where there will be duplicate calculated values. The imported measured datasets are much denser than the cell coverage. . Below describes how to plot a transect, or observation arc, through the measured points that will display both measured point data and calculated data across a distance.

Displaying measured and calculated currents in SMS.

1. Following the above section, the current velocity file is displayed similar to Figure 143. Draw three observation arcs over each of the three transects. Directional arrows will display, and the direction of the arc should reflect ebbing or flooding. If the arrows face the flooding direction, flood currents will be positive, and ebb currents will be negative.
2. Redistribute the vertices on the arcs (they should not have any yet) to a value similar to the number of cells across each transect. E.g. Transect 1 (main channel) should have 25-30 vertices.

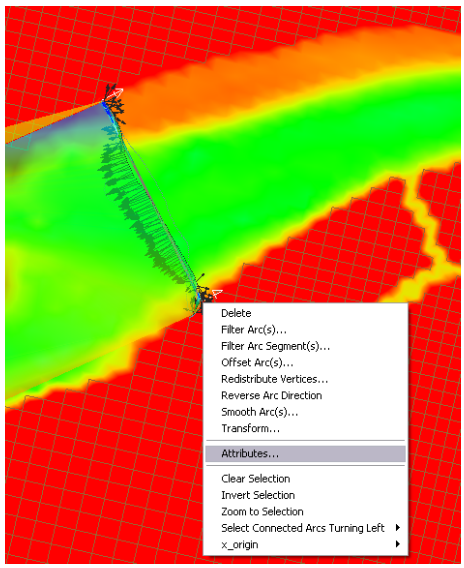


Figure 143. Example of a feature arc with arrows in the ebb direction. Redistribute Vertices, Reverse Arc, and other options are available in the drop down menu.

3. To plot, select *Plot Wizard* from *Display*, and select an *Observation Profile*. In Step 2, select one of the arcs (uncheck others), and under *Extra Profile* select *Model Intersections*. Figure 144 illustrates everything selected for plotting the measured and calculated data for the specific time of the transect measurement.

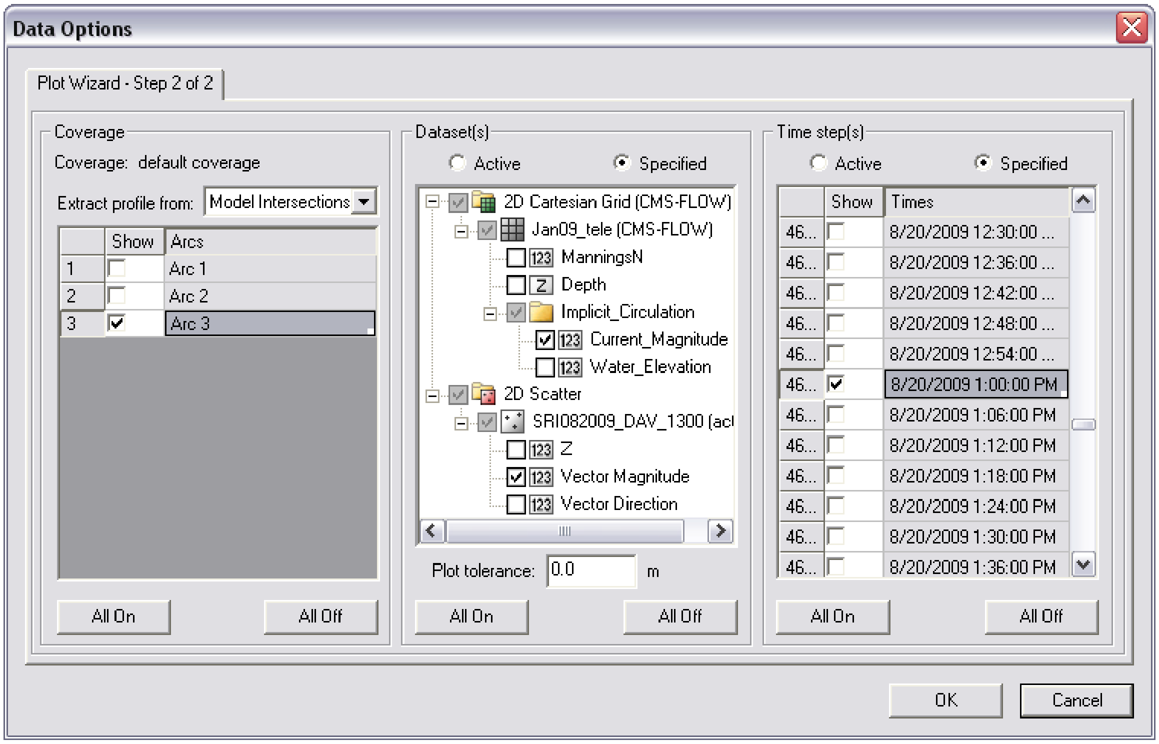


Figure 144. Plot Wizard data options for displaying measured and calculated data from an observation arc.

4. Specify the datasets to be plotted, the *Current_Magnitude* under the grid and the *Vector Magnitude* under the scatter-set data. Select the date and time the transect was measured, which was 20 August 2009 at 1PM GMT.

5. The resultant plot is shown in Figure 145, where the closest points from the measured data were plotted as distance across the arc, and model grid cell centers are where numbers are extracted for the calculated data. Data can be extracted from the plot similarly to the ways defined in the water level extraction section at the beginning of this section.

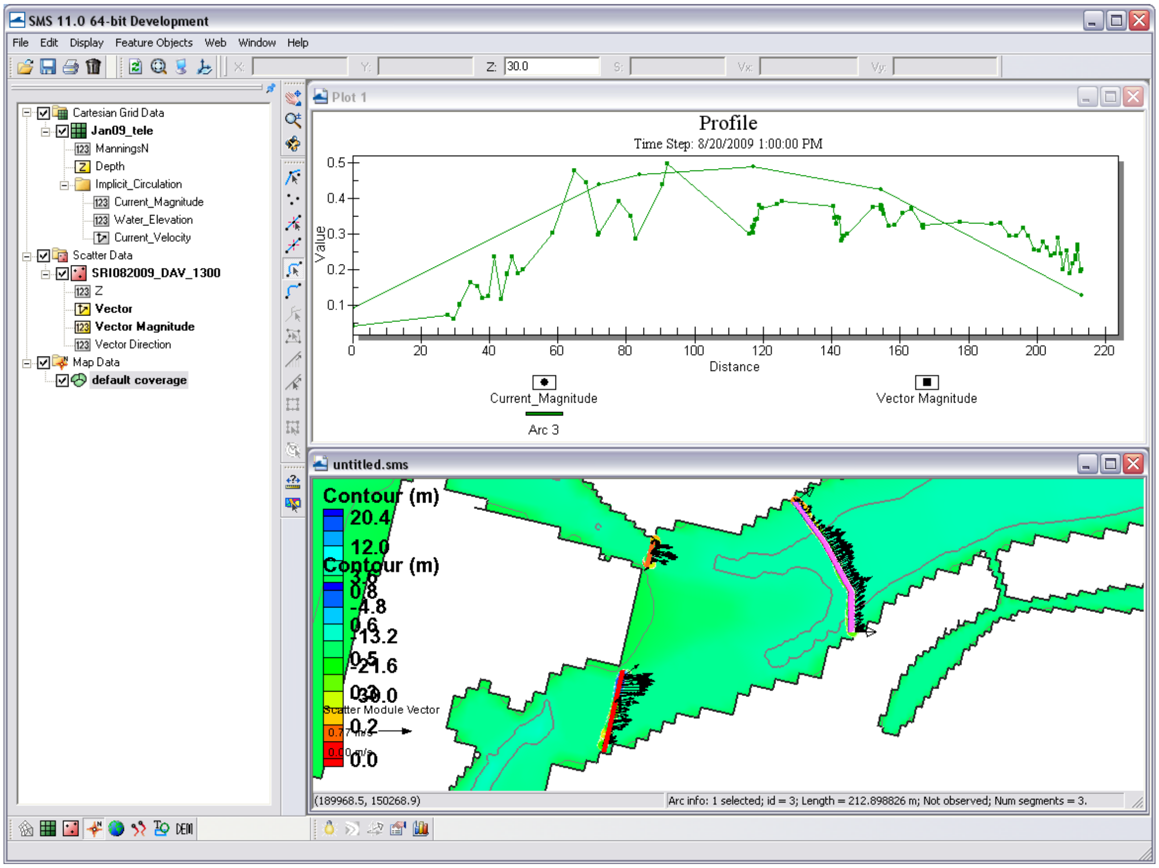


Figure 145. Plotted measured and calculated data from the larger observation arc to the East. Note that the positive direction reflects the observation arcs direction.

Sediment Transport

Sediment transport rates can be used to calculate sediment statistics, sediment pathways, fluxes across arcs, and balances over polygonal areas. Several sediment transport statistics can be calculated during the simulation and output at any time. These statistics include the net and gross total sediment transport rates. For additional details see the Simulation Statistics section.

Calculating Sediment Transpor Roses at Observation (Save) Points

Sediment transport roses are plots in which transport is integrated over directional bins and plotted over a map of the site in order to observe the amount and direction of sediment transport at a specific point. A general picture of the sediment transport pathways can be obtained by plotting several sediment transport roses in the areas of interest. Below is a step-by-step example for Shark River inlet on how to plot sediment transport roses:

Setup Observational Cells

1. Click on the Select Cells tool.
2. Select a cell and left-click
3. Select Cell-attributes... (see Figure below).

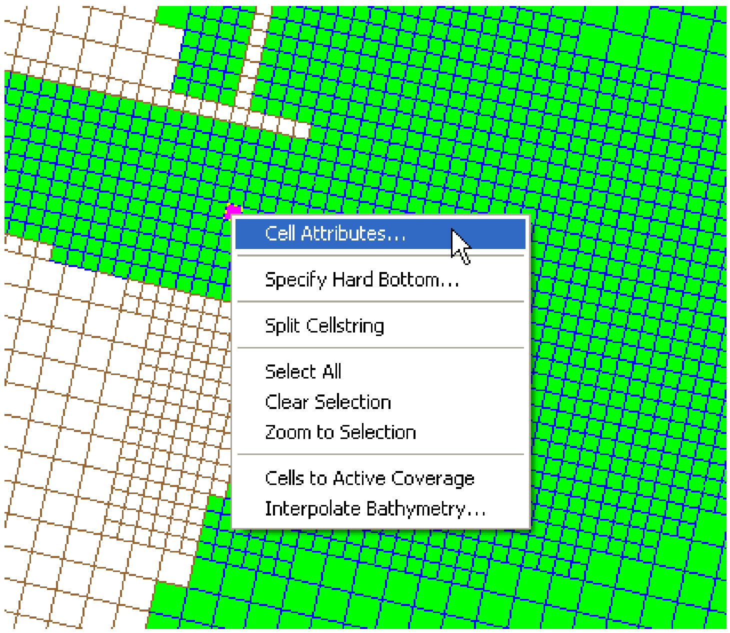


Figure 146. Opening the CMS-Flow Cell Attributes window.

4. The *CMS-Flow Cell Attributes* window will appear (see Figure below).
5. Check the box next to *Transport output*, so that the model will output the sediment transport rates.
6. Save the project

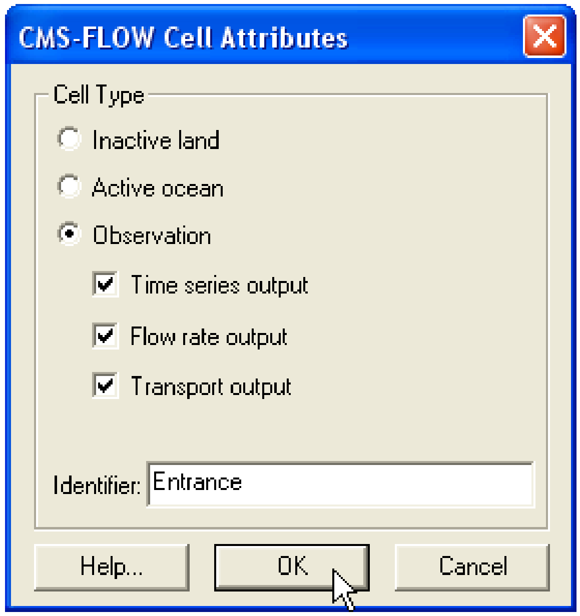


Figure 147. CMS-Flow Cell Attributes window.

The CMS-Flow Control (Card) File will contain a section for the observational cells that will look like this:

```
!Observation Cells
TIME_SERIES_INCREMENT               900.0
FLOW_RATE_INCREMENT                 900.0
Q_TRANS_RATE_INCREMENT              900.0
ELEV_OBS_CELLS_BEGIN
     22943 "North Beach"
     28784 "Bay"
     30926 "Bridge"
     33484 "Throat"
     34145 "Entrance"
ELEV_OBS_CELLS_END
FLOW_OBS_CELLS_BEGIN
     22943 "North Beach"
     28784 "Bay"
     30926 "Bridge"
     33484 "Throat"
     34145 "Entrance"
FLOW_OBS_CELLS_END
Q_TRANS_OBS_CELLS_BEGIN
     22943 "North Beach"
     28784 "Bay"
     30926 "Bridge"
     33484 "Throat"
     34145 "Entrance"
Q_TRANS_OBS_CELLS_END
```

Run the model

Once the model has completed. The project foler will contain two files with the extension *_qtx.txt, and *_qty.txt. These files contain the total sediment transport rates in the x andy directions in units of kg/m/s.

Plot the sediment transport roses in Matlab

Exporting a Georeferenced image in SMS

If the grid is telescoping, it may be difficult to plot the grid in Matlab. There are ways of plotting a telescoping grid in Matlab, but for the purposes of visualization, the easiest approach is to export a georeferenced image from SMS and plot the image in Matlab. This is done by

1. Click on *File* | *Save as…* (see Figure below)

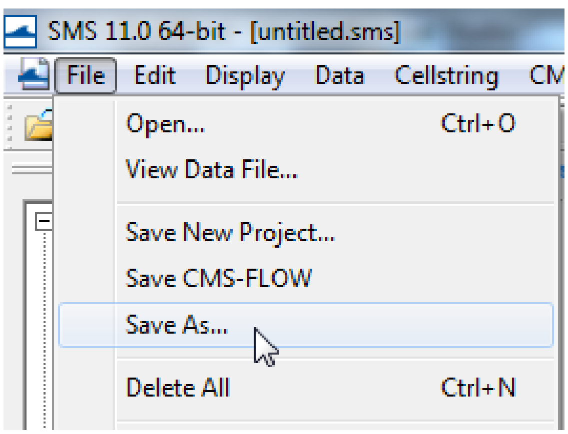


Figure 148. Opening the SMS Save As window.

2. Next to *Save as type*, select *JPEG Image File*.
3. Navigate to the correct directory
4. Enter a file name
5. Click *Save* (see figure below).

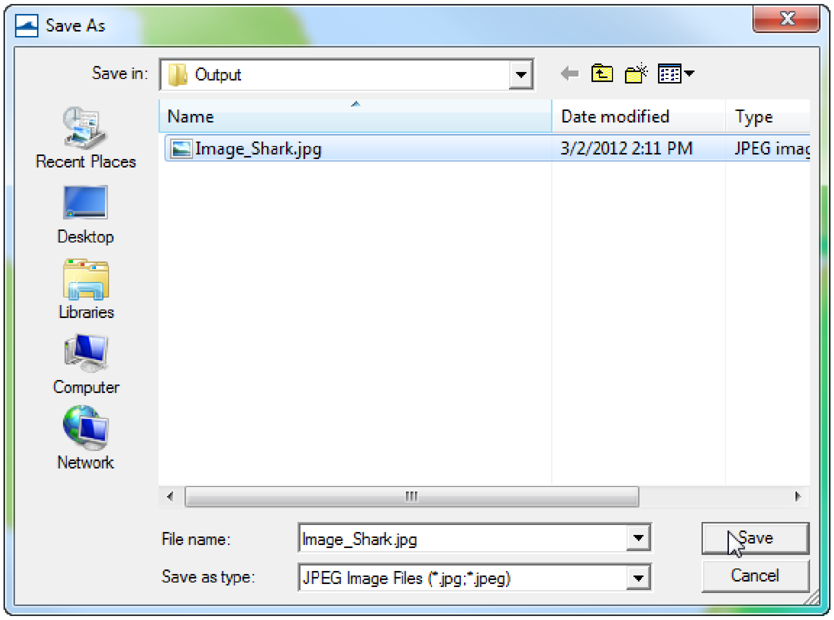


Figure 149. SMS Save As window.

An image file will be saved along with a projection and world file. The projection file contains the horizontal projection information and the world file contains the coordinates of the image origin, the rotation angles (zero for SMS), and pixcel size. The image file can easily be loaded and plotted in SMS.

Editing and running the Matlab script

The matlab script below is just an example to show the basic steps in plotting the sediment transport roses in Matlab. For each application, the file names, directories, station id's, and settings will need to be modified.

```
%Plots Sediment Transport Roses
clear all
%1. Obtain Observation Point coordinates
id = [22943 28784 30926 33484 34145]; Station id's
tel = read_cmstel('..\Hands-on\Flow_Shark.tel');
xsta = tel.x(id); ysta = tel.y(id);
cosang = cos(tel.angle*pi/180);
sinang = sin(tel.angle*pi/180);
%2. Read transport vectors
qtx = load('..\Hands-on\Flow_Shark_qtx.txt');
qty = load('..\Hands-on\Flow_Shark_qty.txt');
%3. Read and plot background image
A = imread('..\Hands-on\Image_Shark2.jpg');
wld = load('..\Hands-on\Image_Shark2.wld');
xi = wld(5) + (0:size(A,2)-1)*wld(1); %SMS images are NOT rotated
```

```
yi = wld(6) + (0:size(A,1)-1)*wld(4);
imagesc(xi,yi,A)
set(gca,'ydir','normal','Nextplot','add')
%4. Plot roses, Rotate transports from local grid angle to world
for k=1:size(qtx,2)-1
    qte = qtx(:,k+1)*cosang - qty(:,k+1)*sinang; %East
    qtn = qtx(:,k+1)*sinang + qty(:,k+1)*cosang; %North
    [sumx,sumy] = sumdirbin(qte,qtn);
    x = ones(length(sumx),1)*xsta(k);
    y = ones(length(sumx),1)*ysta(k);
    h = vecplot(x,y,sumx,sumy,'marker','^',...
        'lengthscale',10,'linewidth',2,...
        'MarkerFaceColor','k','MarkerSize',3);
end
axis([1.9018    1.9257    1.4979    1.5132]*1e5)
xlabel('X, State Plane, m'), ylabel('Y, State Plane, m')
return
```

The subroutine `sumdirbin` sums the transport rates over directional bins. Note that to integrate over time the values should also be multiplied by the output interval. However, because the vectors are only for plotting purposes, this step is not necessary here. The matlab script for summing the transports in directional bins is provided below

```
function [binx,biny] = sumdirbin(u,v,binsize)
% [binx,biny] = sumdirbin(u,v,varargin)
% Sums the vector u,v in directional bins
% written by Alex Sanchez, USACE
if nargin<3
    binsize = 22.5; %deg, default bin size
end
u = u(:); v = v(:);
mag = sqrt(u.^2+v.^2);
binlim = (-binsize/2:binsize:360-binsize/2)'; %limits
bincen = (0:binsize:360-binsize)';            %centers
ndir = length(binlim);
angle = atan2(v,u)*180/pi;
angle = mod(angle,360)+0.00001;
angle(angle==0) = 0.00001;
binmag = zeros(ndir-1,1);
for k=1:ndir-1
    ind = (angle>binlim(k) & angle<=binlim(k+1));
    binmag(k) = sum(mag(ind));
end
binx = binmag.*cos(bincen.*pi/180);
biny = binmag.*sin(bincen.*pi/180);
return
```

The resulting Matlab plot is shown in the figure below.

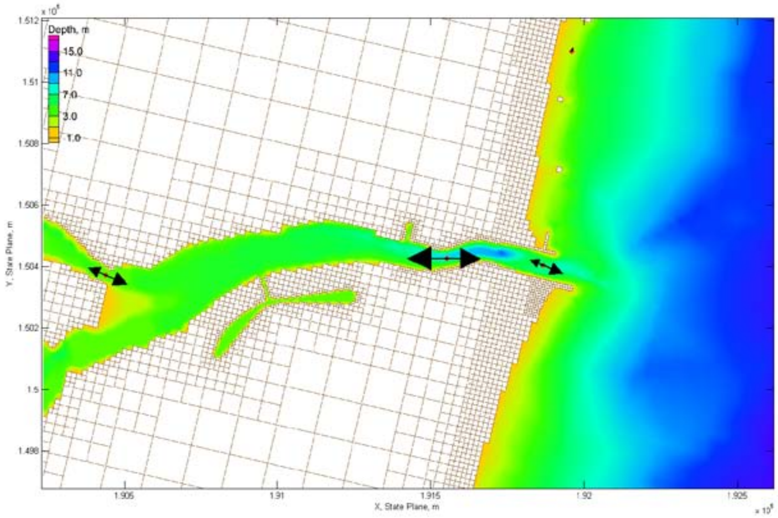


Figure 150. Total-load Sediment transport rates for Shark River Inlet.

Calculating Sediment Fluxes across Observational Arcs

In the CMS, sediment transport can be calculated across lines or polygons defined by feature arcs and polygons in a post-processing procedure. The total-load sediment transport rates calculated from CMS-Flow are integrated across user-defined boundaries. The sediment transport statistics are calculated from the integrated sediment transport rate. The calculated statistics are the net, gross, positive and negative total-load sediment transport rates and are output in units of either cy/ft or m3/m.

Calculating summed sediment fluxes over cross-sectional arcs can provide .channel infilling rates, nearshore sediment transport rates, a sediment budget through a channel, and boundary fluxes.

1. Load the *Jan09Tel.cmcards* into SMS - the solution file should l*oad in automatic*ally
2. Right-click on the default coverage and select *Type* | *Generic* | *Observation* to set up the map module for drawing an observational arc (Figure 151)

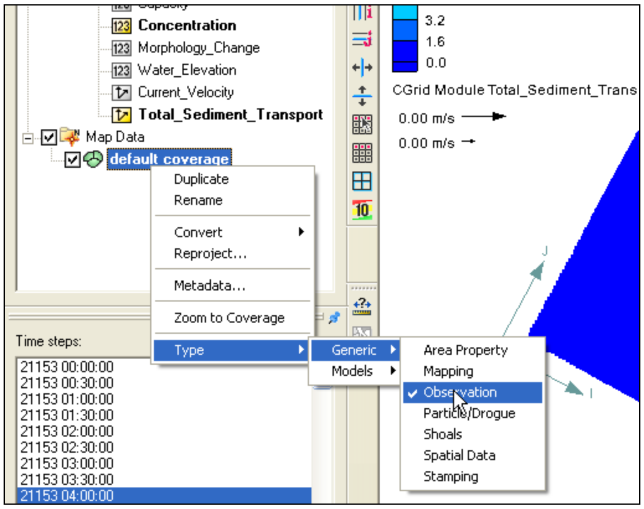


Figure 151. Changing a *Map coverage* type to *Observation.*

3. Zoom to the location selected for calculating sediment transport (Example of a cross-shore location shown in Figure 152) and draw the arc using on the *Create Feature Arc* tool .

4. Selecting the *Select Feature Point*  tool will allow modification of the end points of the arc; or the arc can be deleted by selecting with the *Select Feature Arc*  tool.

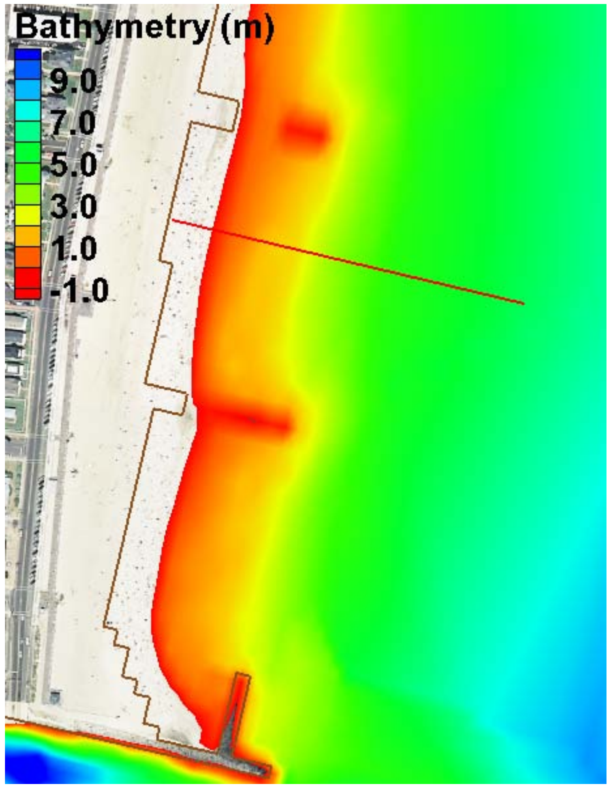


Figure 152. Example of a *Feature Arc* for calculating sediment transport.

Click on the starting and ending points on the grid that define the transect for calculating sediment transport. An example of a *Feature Arc* for calculating longshore sediment transport at Shark River Inlet is shown in Figure 153In the case of longshore transport, the offshore end should extend beyond the breaker zone and closure depth to capture all, mainly, wave-induced longshore sediment transport. Be sure that the observational arc end points do not touch inactive land cells as this may cause interpolation problems in SMS.

3. The positive direction of the sediment transport is defined by the *Feature Arcs* direction. To view the arc direction, click on the *Select Feature Arc* tool  and right-click on the *Feature Arc* once. The arrows displayed at the beginning and end of the transect indicate the direction of the arc which defines the positive for all fluxes or vectors calculated across it.

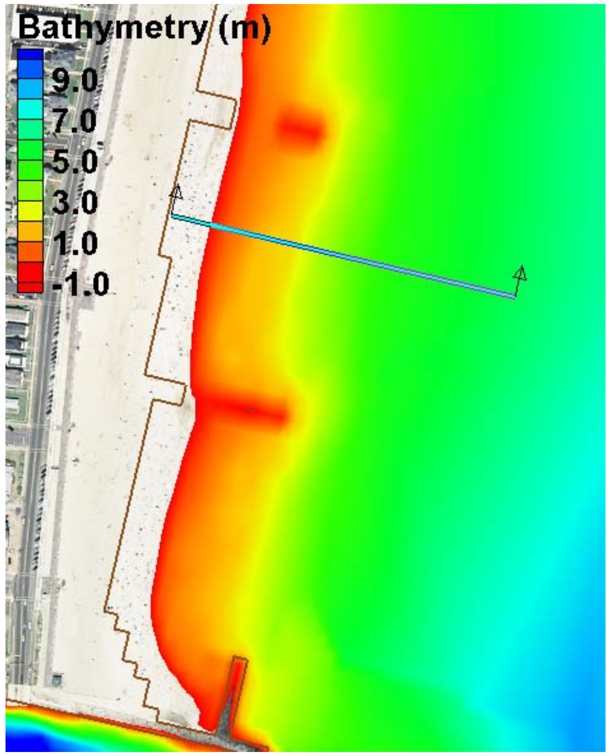


Figure 153. Highlighted Feature Arc with the positive direction shown by the arrows.

4. If necessary, the arc direction may be changed by clicking on the Select Feature Arc tool, and selecting the feature arc by right-clicking it once and selecting the option: Reverse Arc Direction. The same applies for feature polygons.

The sediment transport calculation across a feature arc requires a dataset of the same size and time series length with the constant value of 1. Steps 6-8 describe how to create a new dataset, of any scalar value, within the Cartesian Grid Module.

5. To create this dataset, select the Cartesian Grid Module, Click on *Data*, *Data Calculator*
6. In the *Data Calculator* (Figure 154), select the *water elevation* dataset (1), click on the *Use all time steps* checkbox (2), change the name of the *output dataset* to *ones* (3), double-click on the *water elevation* dataset (4) so that it appears in the *Calculator* window.
7. In the *Calculator*, multiply the dataset by zero and then add one (5), select *Compute* (6). The calculation might take a few minutes if the dataset is large. Once the calculation is completed, select *Done* (7), and the output dataset will appear under the Datasets window.

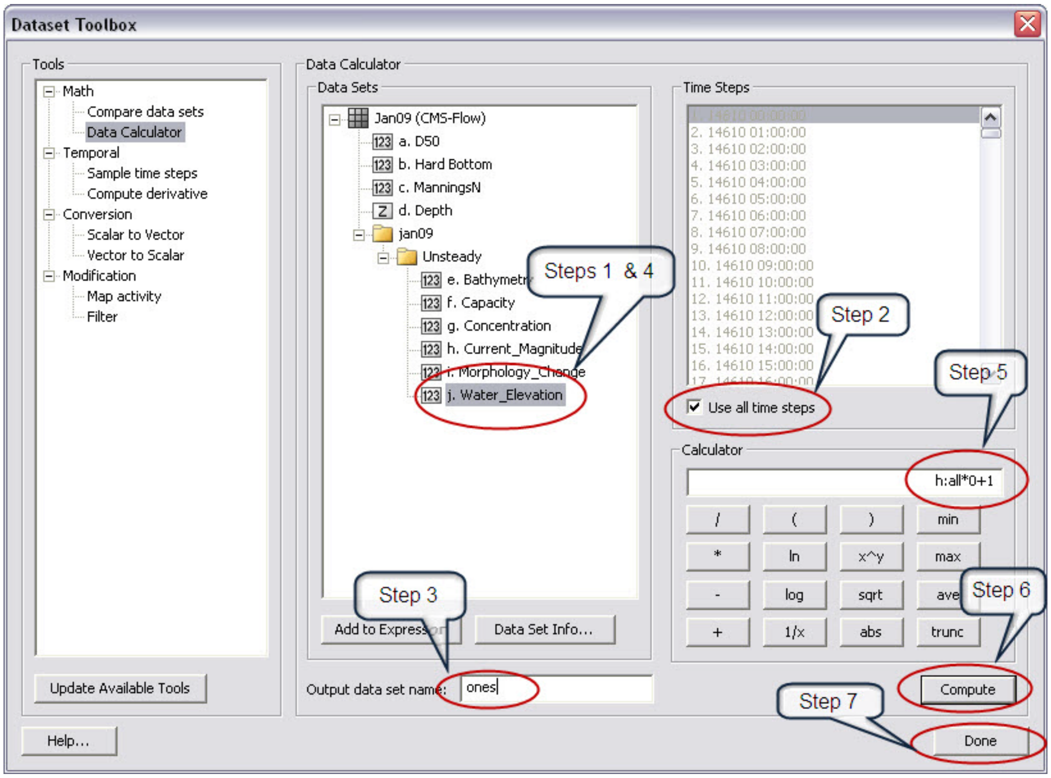


Figure 154. Steps to create a time series dataset of "ones" within the Cartesian grid module.

To obtain the sediment transport statistics, the sediment transport is first integrated spatially to compute a time series of sediment transport across the *Feature* Arc. This procedure is done in the SMS *Plot Wizard*. The sediment transport vector field is interpolated to the points where the arc intercepts cell faces and is then integrated across the *Feature Arc*. Follow each step outlined below:

8. Open the *Plot Wizard*, select *Time series* as the Plot Type and then *Next*. In the *Plot Wizard – Step 2 of 2* window, select *Flux* as the *function type*.

9. Check the feature arc checkbox (Figure 155), select the *ones* dataset for the scalar dataset, and *sediment transport* as the vector dataset, adjust to the correct start and end times, and select *Finish*. (Note that the computation might take a few minutes to tens of minutes, depending on the size of the dataset. This is because SMS must split the vector information, which is computationally slow.)

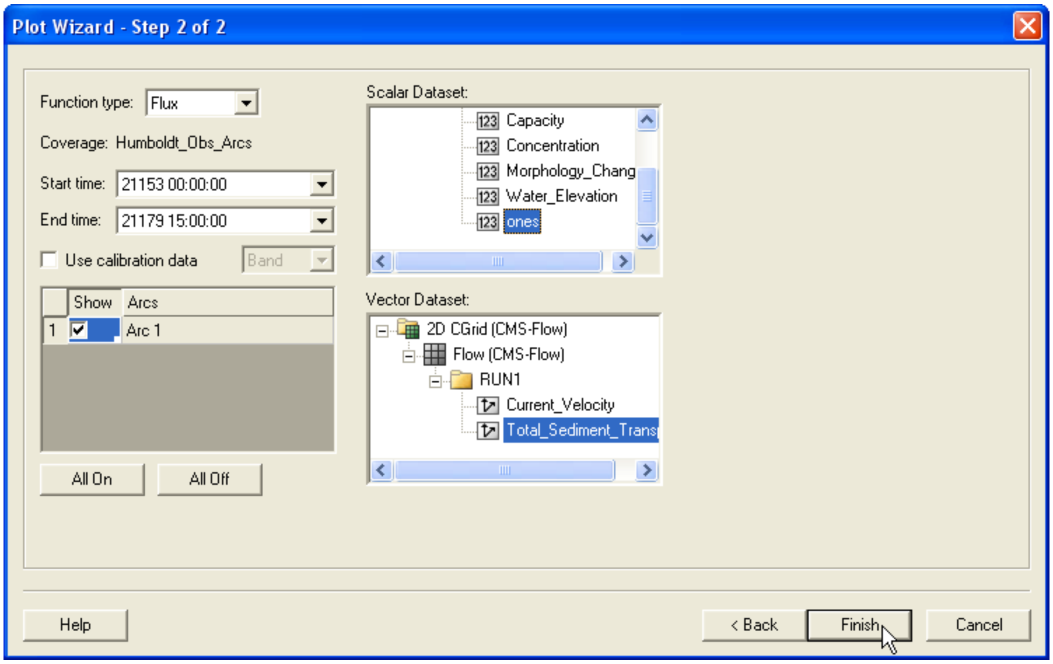


Figure 155. Selecting the correct *Start* and *End Times*, *Feature Arcs*, and *Scalar* and *Vector Datasets* in Step 2 of 2 of the *Plot Wizard.*

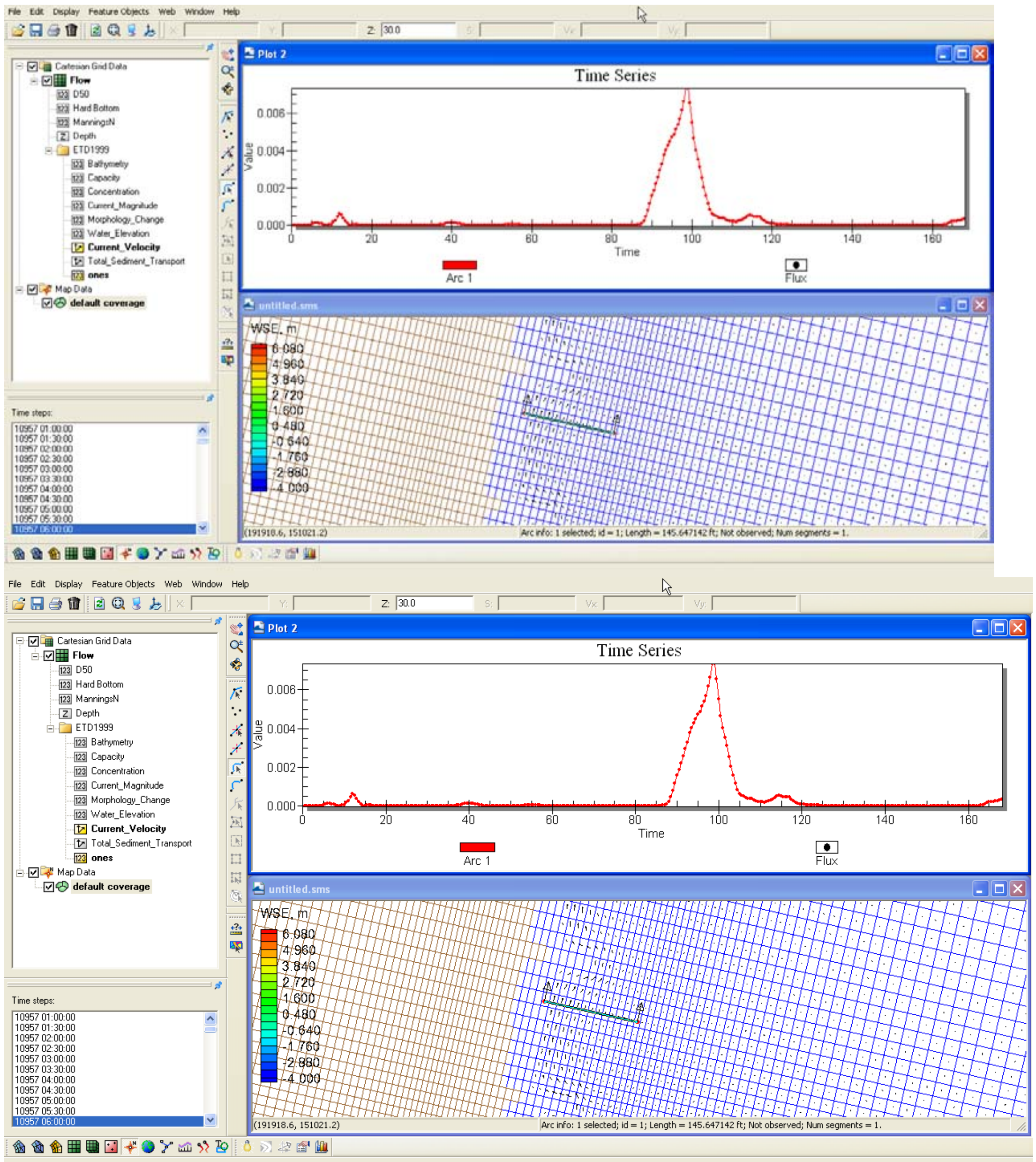


Figure 156. Example time series of integrated sediment transport across a Feature Arc.

Once the time series dataset is created in the form of the graph, the data must be exported for calculations in other software as SMS does not yet have the capability to do so. There are several programs that can process and calculate the sediment transport statistics. One, developed by CIRP, is a simple Fortran executable, though other programs such as Excel can do the same calculations.

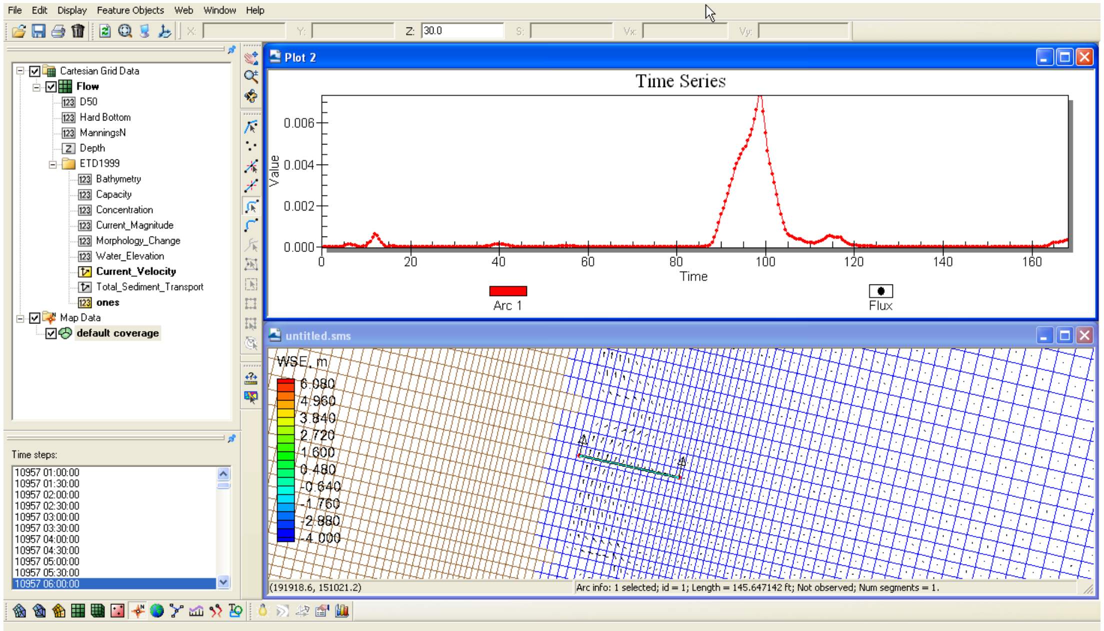


Figure 156. Example time series of integrated sediment transport across a Feature Arc.

The Fortran executable calculates the transport statistics based on the exported time series of integrated (along arc) transport rates obtained in the previous section. The program can be run from a command prompt, a script file or by simply double clicking on the executable and providing the name of the input file. The following explains how to create the input file.

1. From the generated graph, export the text data by rt-clicking on the time series plot and selecting *View value*

2. From the *View Values* window, select the data from the table (Figure 157) and copy-paste it to a text editor such as Wordpad. (Note the number of rows in the dataset by looking at the id number of the last row in the *View Values* window.)

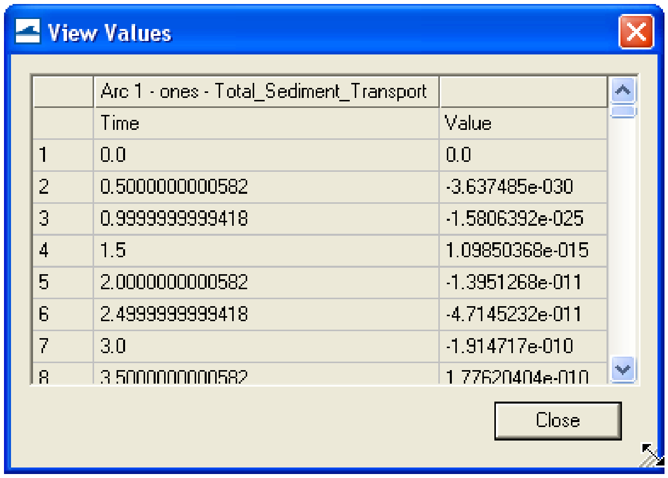


Figure 157. Example of a View Values window in SMS.

3. Save the file with the extension *.*txt* (Figure 158). The data may also be saved as an *.xys file (SMS xy series file), where the file needs a header (as shown in Figure 158). Make the second entry a file id, the third entry the number of time steps, and the last entry a name for the time series.

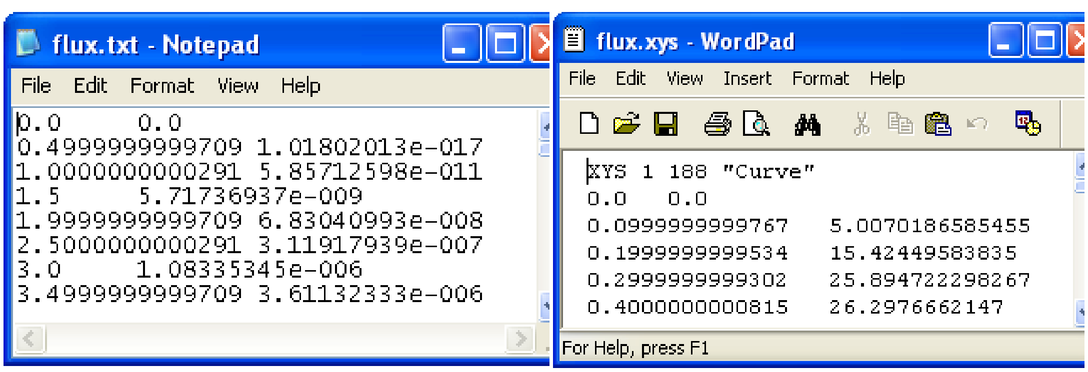
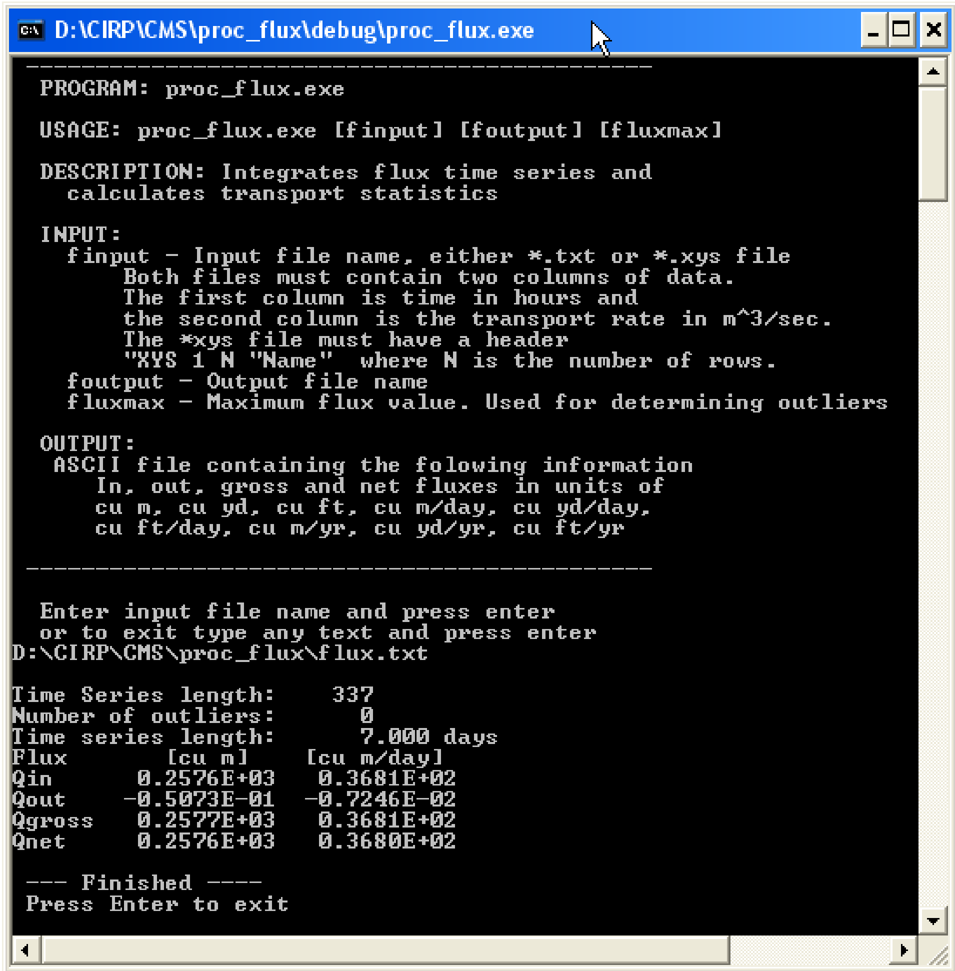


Figure 158. Examples of *.txt (left) or *.xys (right) files with extracted sediment transport time series.

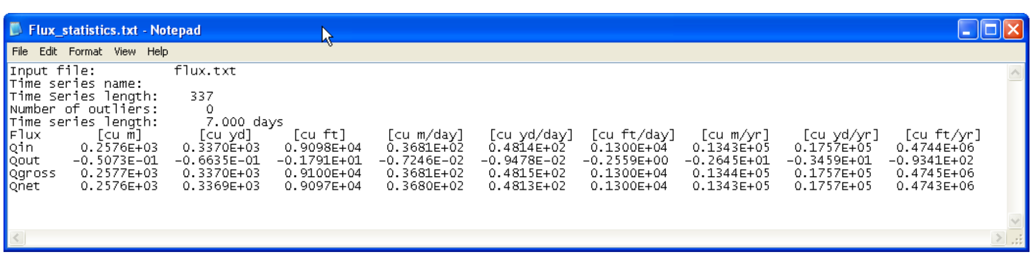
4. Double click on the executable named *proc_flux.exe* (Figure 159). The executable does not need to be in the same folder as the input file. If the file is not in the same directory, the path should be specified before the file name. If the path contains spaces quotation marks should be used.



```
D:\CIRP\CMS\proc_flux\debug\proc_flux.exe
 ---------------------------------------------
  PROGRAM: proc_flux.exe

  USAGE: proc_flux.exe [finput] [foutput] [fluxmax]

  DESCRIPTION: Integrates flux time series and
    calculates transport statistics

  INPUT:
    finput - Input file name, either *.txt or *.xys file
        Both files must contain two columns of data.
        The first column is time in hours and
        the second column is the transport rate in m^3/sec.
        The *xys file must have a header
        "XYS 1 N "Name"  where N is the number of rows.
    foutput - Output file name
    fluxmax - Maximum flux value. Used for determining outliers

  OUTPUT:
   ASCII file containing the folowing information
      In, out, gross and net fluxes in units of
      cu m, cu yd, cu ft, cu m/day, cu yd/day,
      cu ft/day, cu m/yr, cu yd/yr, cu ft/yr

 ---------------------------------------------

  Enter input file name and press enter
   or to exit type any text and press enter
D:\CIRP\CMS\proc_flux\flux.txt

Time Series length:     337
Number of outliers:       0
Time series length:       7.000 days
Flux          [cu m]     [cu m/day]
Qin       0.2576E+03   0.3681E+02
Qout     -0.5073E-01  -0.7246E-02
Qgross    0.2577E+03   0.3681E+02
Qnet      0.2576E+03   0.3680E+02

 --- Finished ----
 Press Enter to exit
```

Figure 159. Example calculation of sediment transport statistics using the proc_flux.exe from a command prompt. Note the input file name contains the directory location of the text file.

5. Press enter when the executable is finished. If no output file is specified, the default output file name is Flux_statistics.txt. An example of the output file is shown in the figure below.



```
Flux_statistics.txt - Notepad
File  Edit  Format  View  Help
Input file:          flux.txt
Time series name:
Time Series length:    337
Number of outliers:      0
Time series length:      7.000 days
Flux         [cu m]      [cu yd]      [cu ft]     [cu m/day]   [cu yd/day]  [cu ft/day]   [cu m/yr]    [cu yd/yr]   [cu ft/yr]
Qin       0.2576E+03   0.3370E+03   0.9098E+04   0.3681E+02   0.4814E+02   0.1300E+04   0.1343E+05   0.1757E+05   0.4744E+06
Qout     -0.5073E-01  -0.6635E-01  -0.1791E+01  -0.7246E-02  -0.9478E-02  -0.2559E+00  -0.2645E+01  -0.3459E+01  -0.9341E+02
Qgross    0.2577E+03   0.3370E+03   0.9100E+04   0.3681E+02   0.4815E+02   0.1300E+04   0.1344E+05   0.1757E+05   0.4745E+06
Qnet      0.2576E+03   0.3369E+03   0.9097E+04   0.3680E+02   0.4813E+02   0.1300E+04   0.1343E+05   0.1757E+05   0.4743E+06
```

Figure 160. Example output file of proc_flux.exe with sediment transport statistics.

Eliciting sediment transport fluxes from the CMS can contribute toward a check of sediment transport. It is important to note that the sediment transport extracted across an arbitrary arc is not entirely representative of the transport in the greater area. Because the user specifies the arc manually, there is uncertainty involved in capturing the true boundaries of transport processes over the region, and should only be used to determine relative fluxes through areas. Below is an example of calculating the sediment fluxes through the inlet ebb shoal at Shark River Inlet.

Arc box around the inlet shoals to capture sediment balance.

1. As instructed in the above section describing calculating sediment fluxes across arcs, here sediment flux transects were chosen along assumed boundaries of the inlet's shoal.

2. Create arcs using the *Create Feature Arc* tool , similarly to Figure 152, by making each quantifiable transect (arc) individually, and by starting the next arc on the end *Feature Point* of the last arc. This ensures that the arcs close the loop.

3. After the loop of arcs is closed, go to *Feature Objects*, and *Build Polygons* should be visible to select. If *Build Polygons* is grayed out, then the arc lines were not closed. To fix this, zoom in on the connecting Feature Points to determine which are offset. Move the points closer, highlight them, and select *Feature Objects, Clean*, and check *Snap Nodes and Vertices*.

4. Sediment transport fluxes can be obtained by following Steps 1 through 11 of the above section (after creating the "ones" time series dataset) for each individual arc.

Morphology

The results of the CMS calculated morphology change can be visualized several ways, from three dimensional or planar view of the bathymetry, planar view of the volumetric erosion and accretion, and with 1-D cross-sections of the time series. All vector and scalar information can be extracted from points and arcs (and polygons) in SMS. This section will cover the methodology used to post process time series morphology change data.

To plot channel infilling in SMS in a graphical format, the results in the solution file need to be changed from depths (the depth below the datum in which CMS calculates) to elevations. SMS can plot multiple cross-sections, or arcs, against each other, or through time.

Channel Infilling by cross-sections

1. Load *Jan09tel.cmcards* (and solution file, if it does not load automatically).

2. Rt-click on the *Time Series* window on the left and select "Time Settings", and change the time reference from *Relative* to *Absolute*.

3. In the Cartesian Grid Module, click *Data*, *Data Calculator*, and the Data Calculator should be selected in the Tools section as shown in Figure 161.

4. Select the *Bathymetry* scalar (123) dataset; under *Time Steps* check the *Use all time steps* on, and double-click the *Bathymetry* (highlighted in Figure 161).

5. The line under Calculator will display "e:all", add the multiplication symbol (*) and negative 1 (-1) as shown in Figure 161.

6. Change the *Output data set name* as shown in Figure 161 so as to distinguish this dataset from the original *Bathymetry* output, click *Compute*, and after the scalar set appears in the SMS window (Figure 162), click *Done*. (Note: values for the contours may need to be adjusted to view elevation range.)

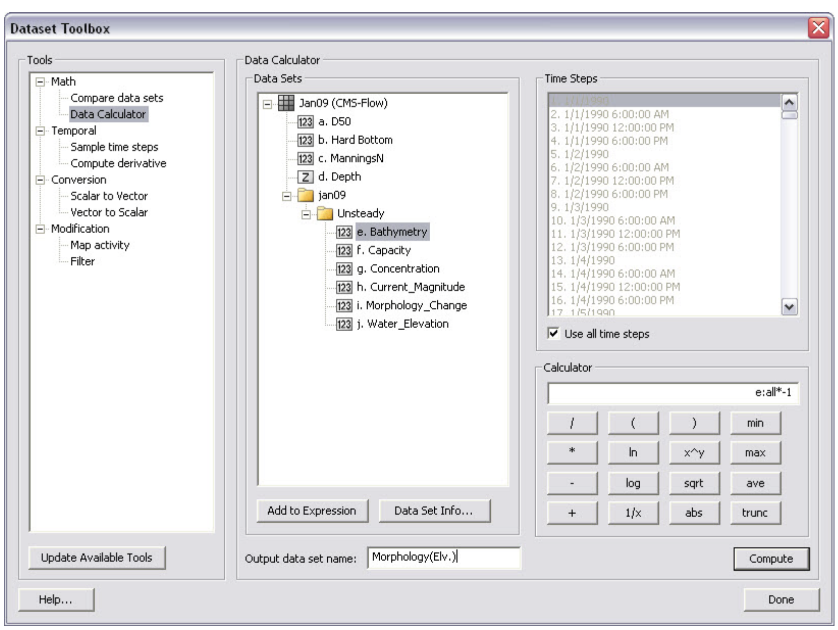


Figure 161. Data Calculator Options in the Dataset Toolbox.

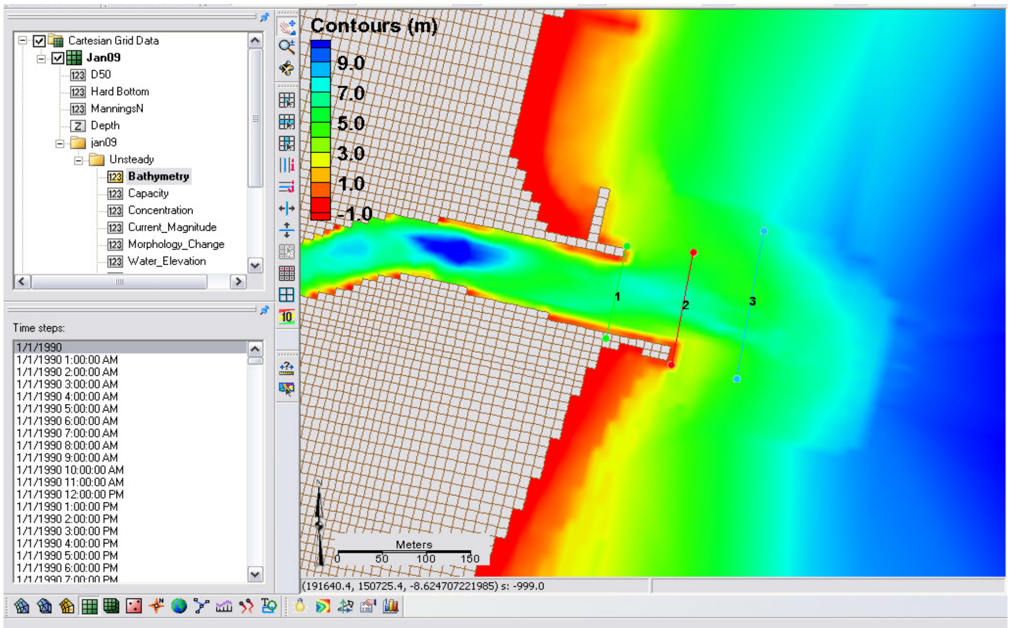
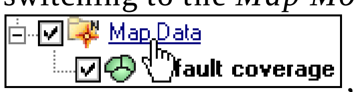


Figure 162. Display of calculated bathymetry now converted to elevations. Note the legend has been modified to display the new contours.

7. Create feature arcs for extracting the time series data by switching to the *Map Module* button , or Map Data 

, rt-click on *default coverage*, and select *Type, Generic, Observation*

8. Click the *Create a Feature Arc* button  to generate the arcs from which cross sections will be extracted, and click on one side of the channel and double-click on the other side to close the arc

9. Click the *Select a Feature Arc*  button and select the generated arc (Note that there is a direction associated with the arc, which determines the sideview of the cross section)

10. Rt-click an arc and click on *Attributes*, and set the color and name(s) of each arc which are listed together in the *Observation Coverage* options (**Error! Reference source not found.**), click *OK*

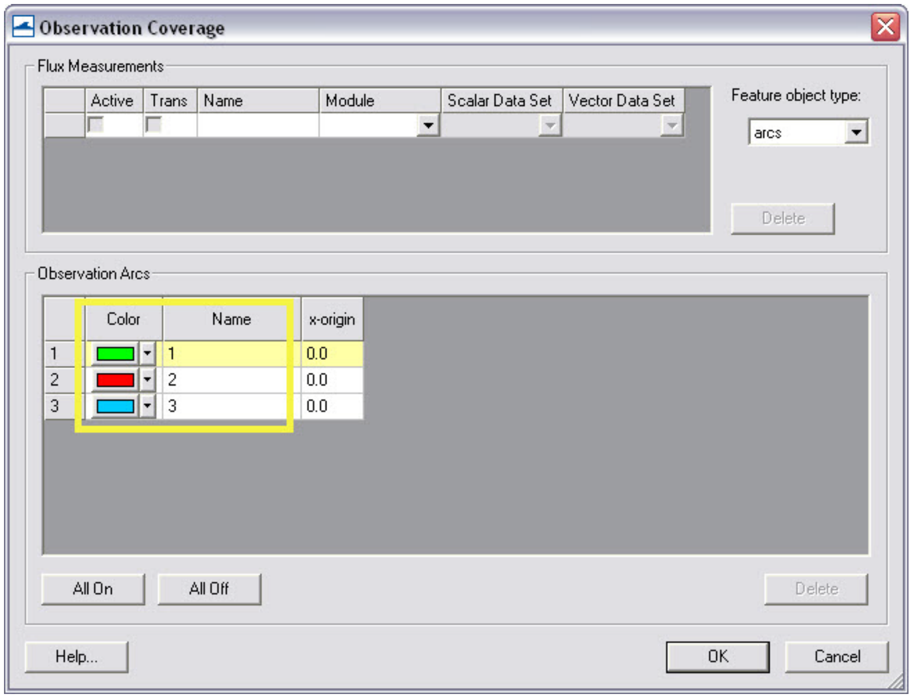


Figure 163. Observation Coverage attributes

11. To plot the profiles in SMS, Select *Display*, *Plot Wizard*, and *Observation Profile*, and select *Next*.

12. Following Figure 164, under *Coverage* check one arc (though multiple can be plotted), under *Data set* select *Specified data set(s)* and select the generated *Morphology* (Elev.) set only, and under *Time step* select *Specified time step(s)* and check on several times spaced apart by at least several days to months, click *Finish*.

13. Rt-click on the plot (Figure 165) and select *view values*.., and a table will appear with all the plotted distance and elevations given in the graph, (Note this ascii table can be copied and pasted into excel).

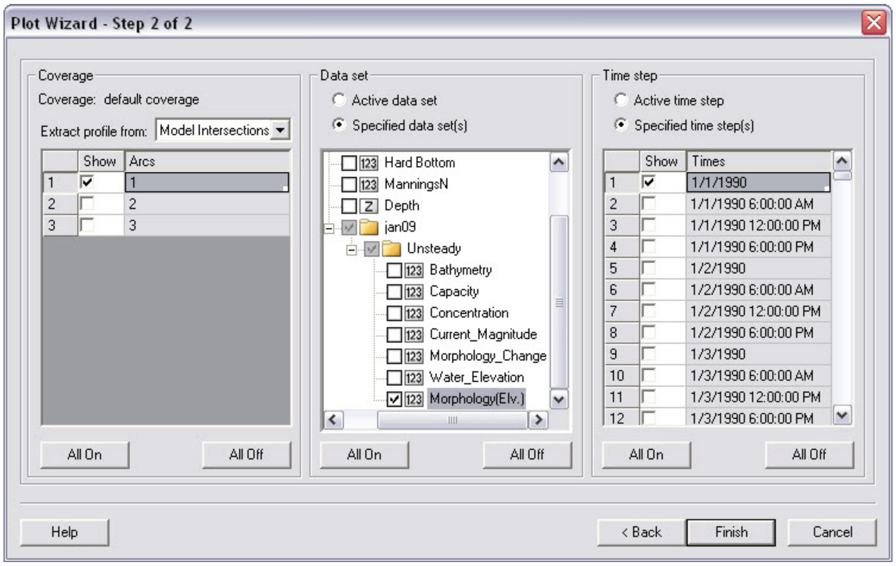


Figure 164. *Plot Wizard* Step 2.

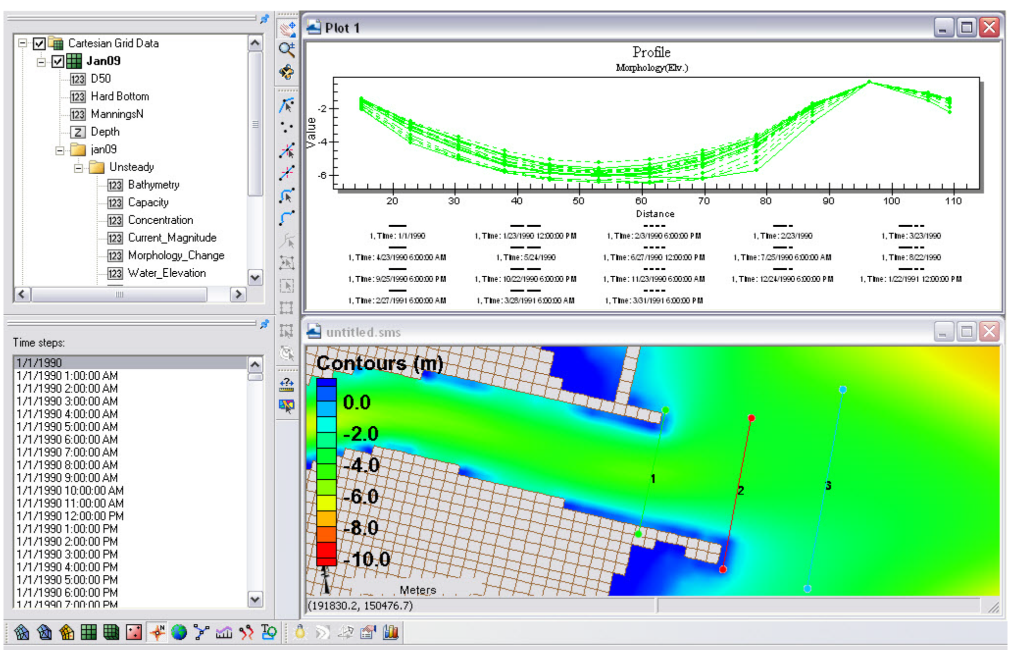


Figure 165. Plotted cross-section.

14. To export the data in different formats, rt-click on the plot, and select *Export/Print* for several options to export the graph or data from the graph (Figure 166)

15. To add more profiles or time-series, rt-click on the plot, and select *Plot data..* to bring up the original options from Figure 164.

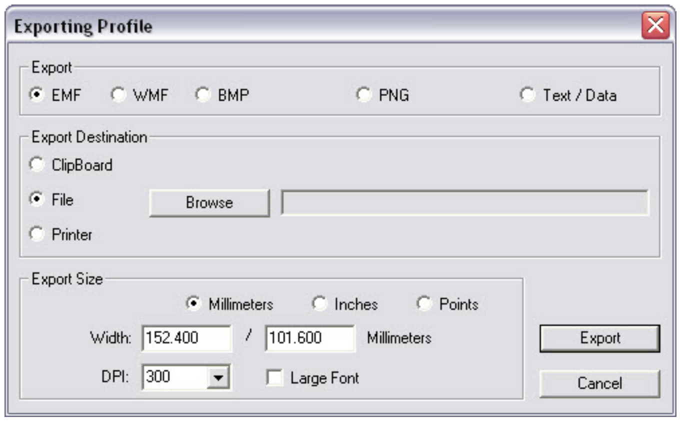


Figure 166. Data Export Options.

Analysis of cross-sectional area and sediment volume changes are the most common approaches to quantifying morphologic change. Another method of quantifying change in a spatial framework is through comparison of the planform aerial change. This method is useful in delineating active zones of transport, typically based off of the depth of closure, and can define the upper and lower limits of transport. These results can be used to interpret bypassing areas or zones, however, determining the bypassing pathways should not be based off of this analysis alone.

Planform area changes

1. To filter the morphology dataset for the time periods of interest, i.e. every month, open the *Data Calculator* and select *Sample time steps* under the *Temporal* section (Figure 167).

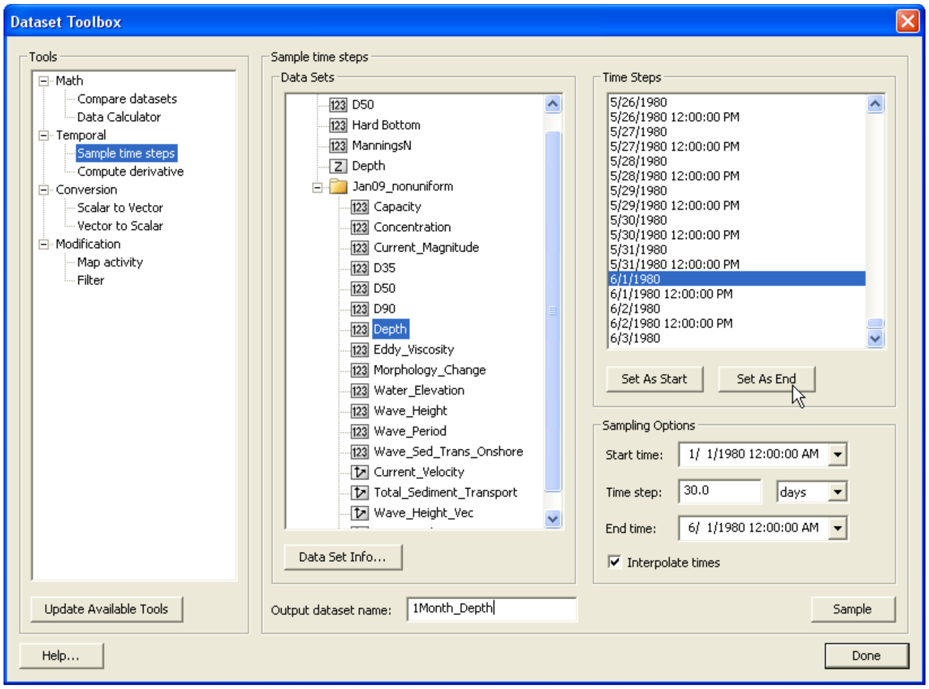


Figure 167. Sampling time steps from a solution dataset.

2. Select *Depth* under *Data Sets*, change the *Output dataset name*, and set the *start time* and *end time* to Jan 1 and Jun 1, respectively, with an interval of 30 days. Select *Sample*. This should produce a *Depth* timestep approximately every month.

3. In order to map an elevation, the grid must be converted to a scatterset.

   - Rather than take the time required to convert the entire solution during this workshop, we have provided this file in the folder (File: *1Month_Depth*). (To convert the grid solution file to a scatterset, select *Data|Map to Scatter*, and SMS will convert all of your time series datasets to the scatter module (Figure 168). This can take anywhere from minutes to hours, depending on the size of the file and speed of the processor. Open the provided scatterset.

   - Or, delete the Jan09_nonuniform solution datatree so that the main CMS-Flow datasets and the *1Month_Depth* dataset are the only datasets left. Then select *Data|Grid-> Scatter*, and SMS will convert only those datasets.

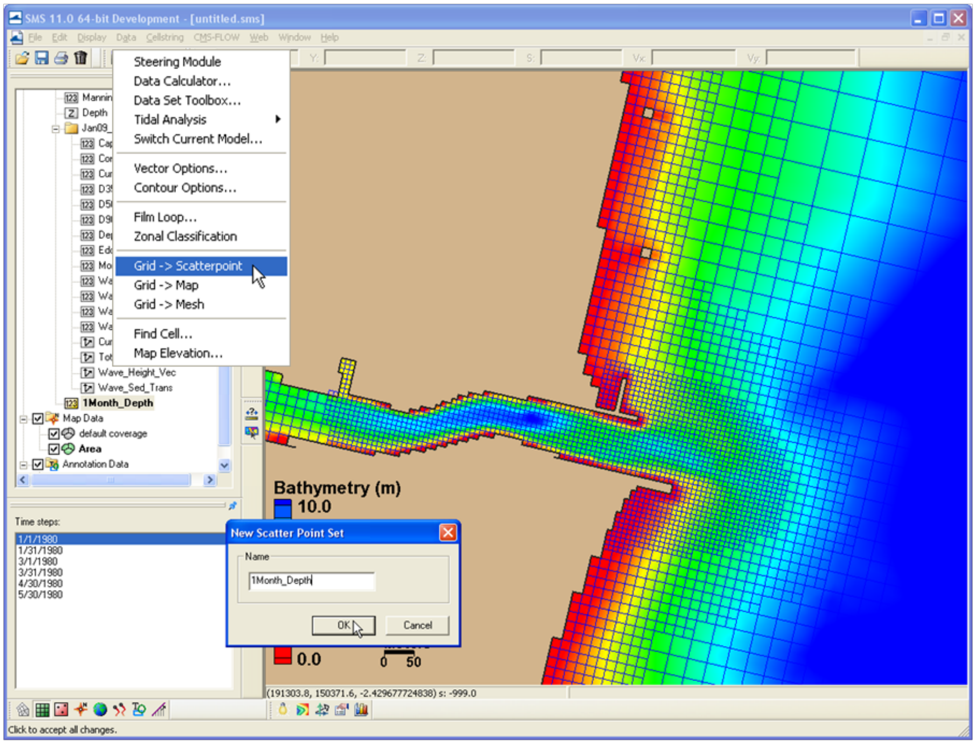


Figure 168. Converting a solution dataset to a scatter dataset.

4. Create a new map coverage (by right clicking *Map Data* in the data tree and selecting *New Coverage*) for mapping out specified contours over the time series depth scatterset.

5. Select the *1Month_Depth* Scatterset (*Scatter Module* should be on) and the first time stamp (1 Jan), and go to *Data|Scatter Contour* -> *Feature*. Choose an elevation to map (6.0 m), a spacing of the points in the resultant arc, and select the Map Coverage ('*Area*' in Figure 169) that the arcs are created in.

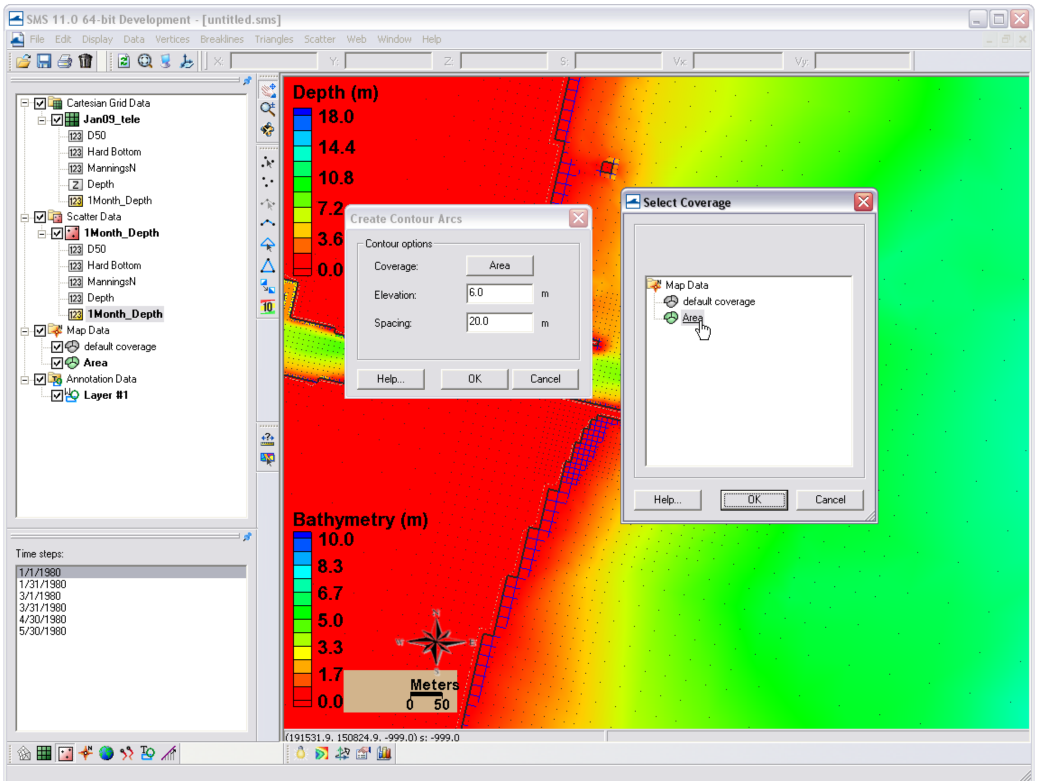


Figure 169. Mapping a scatterset contour to the map module.

6. Create another new Map Coverage, select the final time-stamp (30 May), and go to *Data|Scatter Contour -> Feature* and select the same elevation (6.0 m) and point spacing. Switch between the two coverages to view the location of each contour (Figure 170). Note that the arcs hold a z-elevation (displayed in Z in the bar above) and are partially visible under the color-filled scatter data.

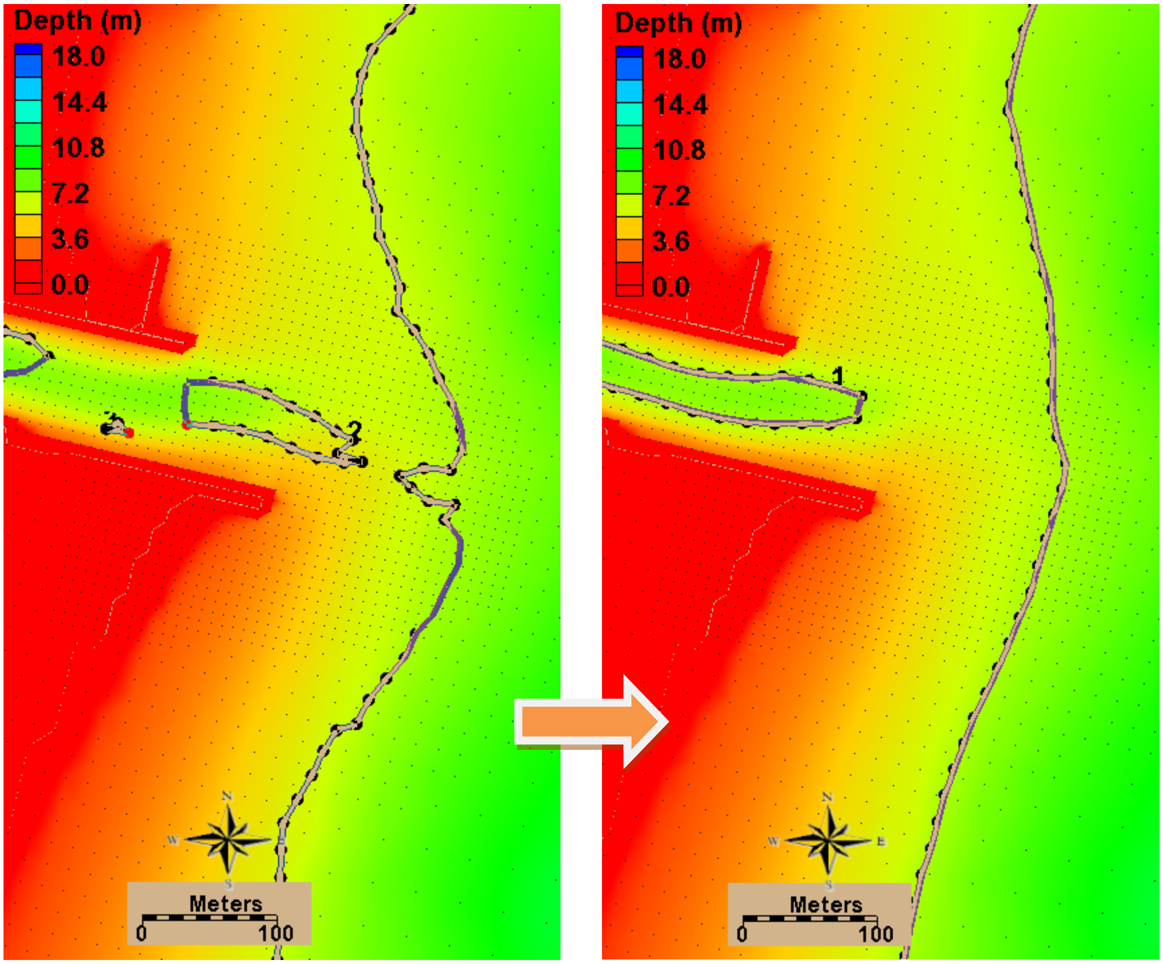


Figure 170. Mapped coverage of the 6-m contour at Months 1 and 6 (left and right, respectively).

7. To calculate planform area, each contour in both maps must be closed off with arcs to create a polygon. Create a polygon in the closed arcs by selecting *Feature Objects|Build Polygons*. An example is shown in Figure 171. Note that the area of the selected polygon is given at the bottom of the screen in the units the solution file is given in, which is always metric for the CMS.

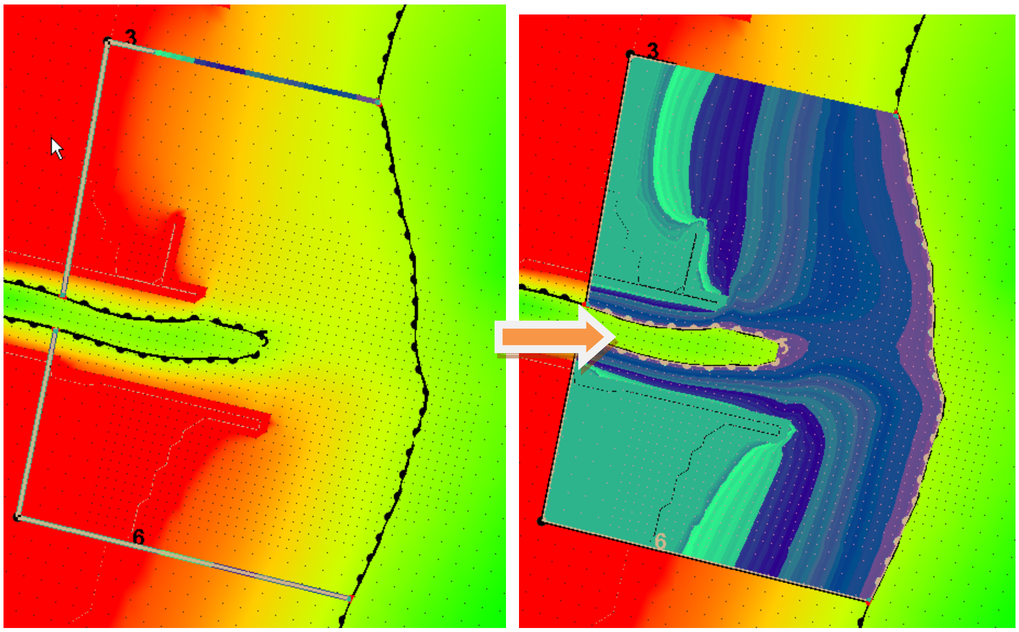


Figure 171. Left: Two arcs drawn to connect the 6m contour back to a common point to close off the polygon. Right: Highlighted polygon after created.

Creating polygons between time series allows for calculation of planform area change at a morphologic spatial scale through time. The difference shown in the arcs in Figure 8.4.10 is substantial, and can be quantified with the use of arcs and polygons. It is important to be careful with delineating the morphologic form of interest. If the full area is being calculated for a feature (an ebb shoal), be sure to be discrete in the size of these aerial calculations because they may skew the final calculation of the morphologic feature of interest.

Similarly, volume change can be elicited from polygons created with Feature Arcs. The next section describes how to calculate volume change over an arc.

Calculating volume change from polygons.

1. Create a polygon similarly to the above exercise that created arcs to complete a polygon in the planform area calculations. Choose an area around the ebb shoal, or within the channel, and draw a single arc connecting around the feature. Be sure to close the end of the polygon by letting the mouse automatically hover over the final point (the pointer will relocate when placed near another feature point).

2. Create a polygon in the closed arcs by selecting *Feature Objects|Build Polygons*. An example is shown in Figure 171.

3. To select the cells within the polygon, next, with the polygon selected, go to *Feature Objects|Select/Delete Data*, and select *select*, *Cartisian Grid Cells*, and *Inside Polygon* (Figure 172).

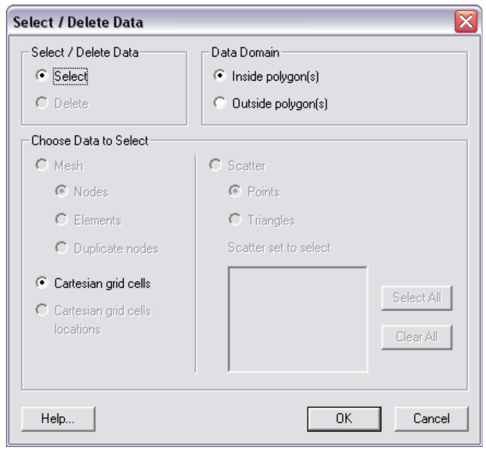


Figure 172. Options for selecting and deleting data from Mesh, Cartesian Grids, and Scattersets using polygons.

Note, again, that the volume of the selected polygon is given at the bottom of the screen in the units the solution file is given in, which is always metric (m^3) for the CMS. The volume given in the lower right corner of the window (Figure 173) are a positive, negative, and total volume representative of the integrated positive, negative, and combined volumes from each cell. Therefore, the numbers represent the volume based off of the dataset's datum.

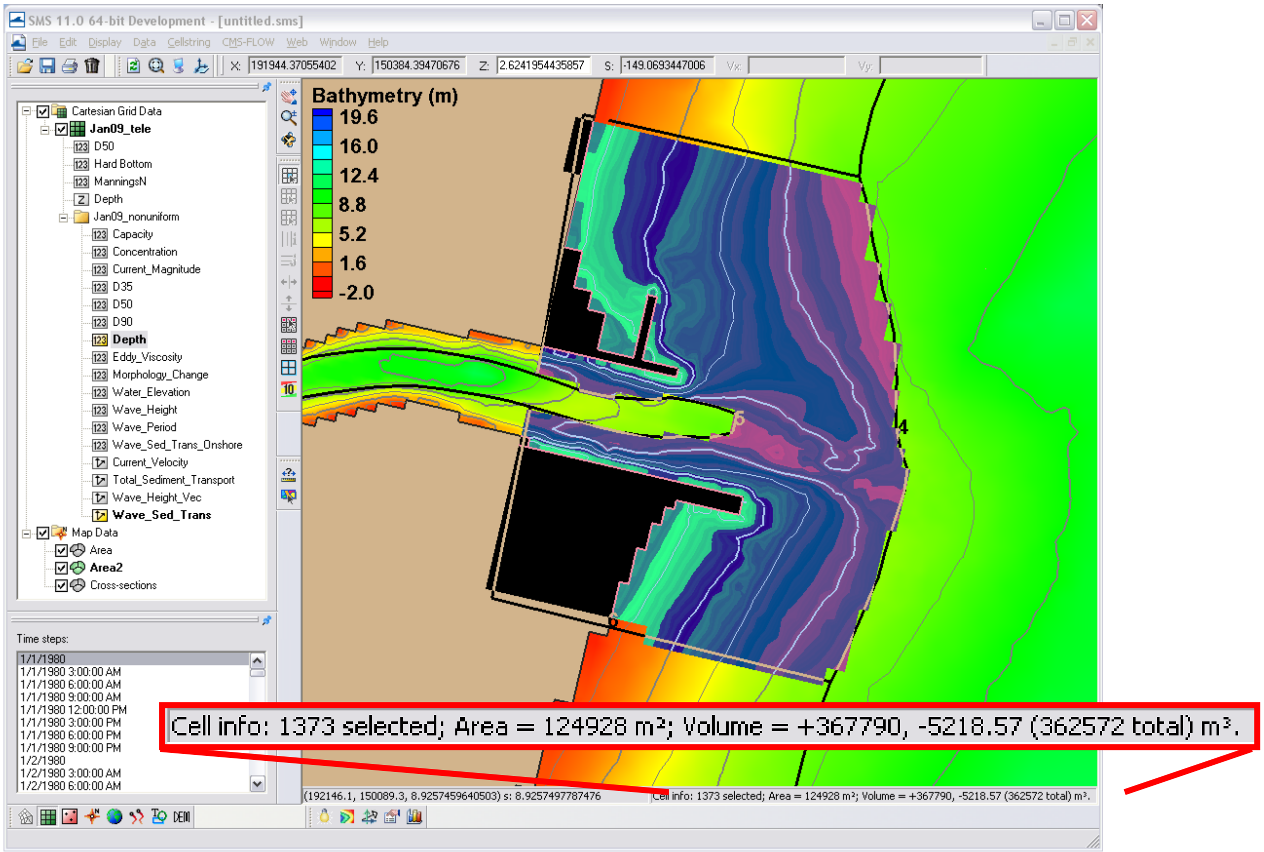


Figure 173. Selected cells from a polygon. Volume information given in lower, right corner of screen.

If depths are selected in the solution datatree as the measurement for volume calculation (one of the direct outputs in the CMS solution file), volume is positive and represents the space that the water occupies. To get the volume of a morphologic feature, a base level to calculate above must be chosen. Navigation depths or depth of closures are often used as a base level for a quick estimation of volume. The area of the cells is also included in basic cell info at the bottom of the screen, as illustrated in Figure 173. Multiplying this area by the base level (with respect to the model datum) will produce a base volume of which the calculated volumes can be subtracted from.

Waves

This section describes three FORTRAN codes, **concatwav.exe**, **pkcmswave.exe**, and **pkcmswave1.exe** to assist in handling the CMS-Wave output information. Three MATLAB codes, fig1sets.m, fig2sets.m, and fig4sets.m, are provided to plot and compare calculated wave parameters and/or measured data (NDBC or CDIP buoys).

An example is provided as a simple CMS-Flow explicit steering run of the Shark River application (run 2009.sim and 2009.cmcards for a total of 12-hr simulation with 3-hr steering interval – a10-min run time with 3-processors assigned to CMS-Flow).

Concatwav.exe - this FORTRAN code merges all individual cycle *.wav files from a CMS-Flow explicit and CMS-Wave steering (coupling) run into one single *.wav. Running **concatwav.exe** requires enter a text file that lists all or more individual *.wav files in sequential order (one-column format) – a sample text file concat.dat is provided that has included the first 200 cycle *.wav filenames. Users can avoid this code if a std.dat file (a modified copy of standard *.std to overwrite all individual *.std files generated in the steering process) is prepared with the 7th control parameter IWET set to -2 before running the steering. IWET = -2 will output a total.wav file include all individual cycle *.wav. In the present time, users should manually prepare the std.dat and set IWET = -2 for this option. In the SMS11 Beta and future SMS release, users can simply set IWET = -2 in the standard *.std (the std.dat is no longer required).

1. Under the DOS window, run **concatwav.exe** in the folder with all steering cycle *.wav files.
2. Following the screen request, type the name of a text file that lists all or more individual *.wav files in sequential order, or simply type the sample file ‘concat.dat’ that includes the first 200 cycle *.wav filenames. By using ‘concat.dat’, the output total.wav will include up to a maximum of 200 cycle *.wav. See Figure 174 to merge all 5 cycles *.wav into one total.wav file.

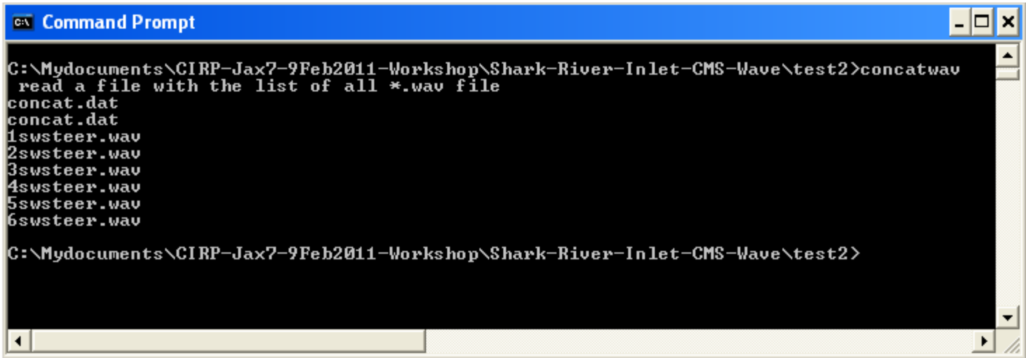


Figure 174. Run concatwav.exe.

Pkcmswave.exe – this code will extract the calculated wave height, period and direction information from *.wav for a single cell in the model grid. The output file is 'oneline.dat' that lists the extracted wave information (in sequential order) using the Wave Information Studies (WIS) short format (11-column format: id, year, month, date, hour, sig wave height, peak period, mean period, mean wave direction, wind speed, wind direction) – show all direction in the meteorological convention.

1. In the DOS window, run **pkcmswave.exe.**
2. Responding to the on-screen input, type the CMS-Wave wave output *.wav filename.
3. Type the year (last two digits of a calendar year), e.g. type '11' for 2011.
4. Type the local shoreline orientation (the CMS-Wave grid y axis) in clockwise polar coordinates (deg, positive from North covering the sea, e.g., 180 deg for St Mary's Entrance, FL/GA, or 360 deg - the wave grid orientation angle in *.sim).
5. Type a single cell i and j indices (two integer numbers) saving wave parameter information.
6. Type the starting timestamp (default value is 0) and ending timestamp (default is 99999999) for saving output files. See Figure 175 to run **pkcmswave.exe** to extract wave information at Cell (69, 92) from total.wav.

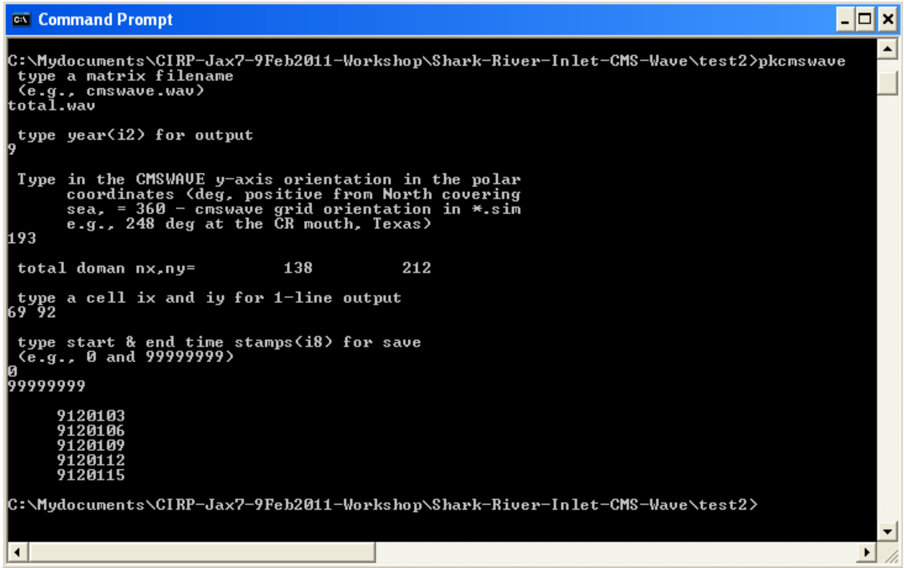


Figure 175. Run pkcmswave.exe.

Pkcmswave1.exe – this code will extract the calculated wave height, period and direction information from the monitoring station output file selhts.out (exists only if the monitoring station data is specified in the *.std) for a single station. The output file is 'oneline.dat' that lists the extracted wave information in the WIS short format. The selhts.out file has a 15-column format as described in Table 63.

Table 63. Description of selhts.out column format.

Column	**Description**
1	spectrum label (or timestamp)
2	*i* index in Cartesian (i,j) or ij index in Quad-tree mesh
3	*j* index in Cartesian (i,j) or 0 (dummy) in telescoping grid
4	significant wave height (m)
5	spectral peak wave period (sec)
6	mean wave direction (deg, local coordinate system)
7	swell height (m)
8	swell wave period (sec)
9	swell direction (deg)
10	local-generated wave height (m)
11	local-generated wave period (sec)
12	local-generated wave direction (deg)
13	wave breaking index (non-zero for breaking)

14	max water elevation mark (m), include wave run-up if calculated
15	flow discharge rate (m^2/sec) at structure cells if calculated

Note: Specify IWET = -1 or -3 to save swell and local sea data in selhts.out. (Swell is shown in Columns 7 to 9, and local sea in Columns 10 to 12).

1. In the DOS window, run **pkcmswave1.exe.**
2. Responding to the on-screen input, type the CMS-Wave monitoring station output filename (e.g., selhts.out)
3. Type the year (last two digits of a calendar year) for the data, e.g. type '11' for 2011
4. Type the local shoreline orientation (the CMS-Wave grid y axis) in clockwise polar coordinates (deg, positive from North covering the sea, e.g., 180 deg for St Mary's Entrance, FL/GA, or 360 deg - the wave grid orientation angle in *.sim)
5. Type a single cell i and j indices (need to be a monitoring station cell given in *.std)
6. Type the starting timestamp (default value is 0) and ending timestamp (default is 99999999) for saving output files. See Figure 176 to run pkcmswave1 to extract wave information for Cell (69, 92) from selhts.out.

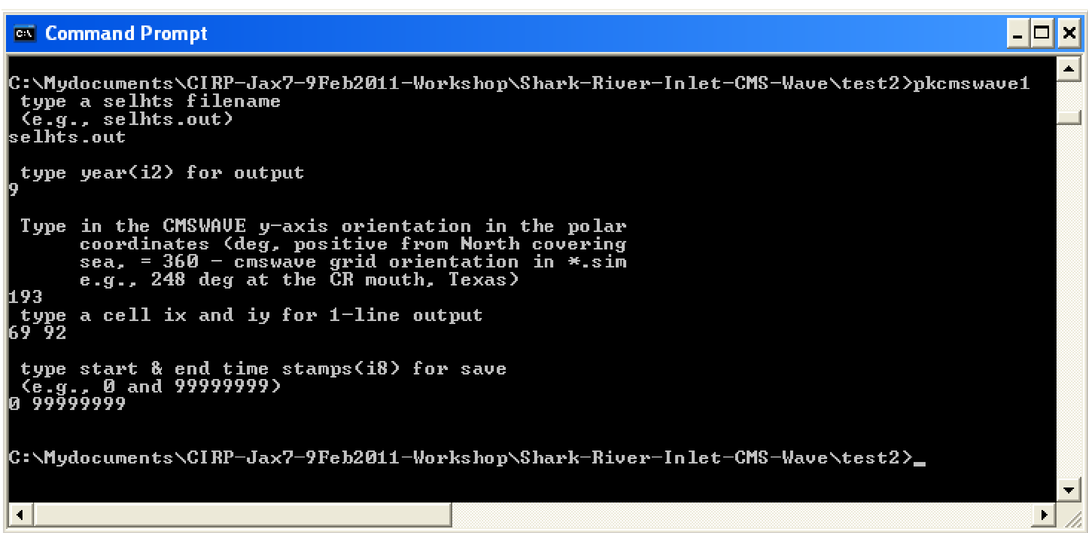


Figure 176. Run pkcmswave1.exe.

Fig1set.m (or **fig1set.exe**)– this MATLAB code reads a WIS short format file and plots the time series of wind and wave parameter data.

1. In the MATLAB console, go to the folder with the fig1set.m code, type ‘fig1set’ and press *Enter* to run (or in the DOS folder, run **fig1set.exe**).
2. Responding to the on-screen input window, browse and open (read) the WIS sort format file of interest (e.g., 4602509d.dat).
3. Enter 1 for plots shown in the Metric system (m, m/sec) or 2 in English system (ft, knot).
4. Type the year (last two digits of a calendar year) for the data, e.g. 11 for 2011.
5. Type starting month id number in the plot (e.g. 1) for January, 2 for February, etc..
6. Type ending month id in the plot (e.g. 3) for 13 for January of the following year, or enter 0 to input starting and ending dates in the same month.
7. Type starting and ending days to display the data plot or type “0 0” and *Enter* to skip this option.
8. Type the title (text) for the plot or simply press *Enter* to skip this option, to complete the run – see Figure 177 to run **fig1set.m** or **fig1set.exe** to plot NDBC Buoy 44025 data (2009-ndbc.out) for December 2009.

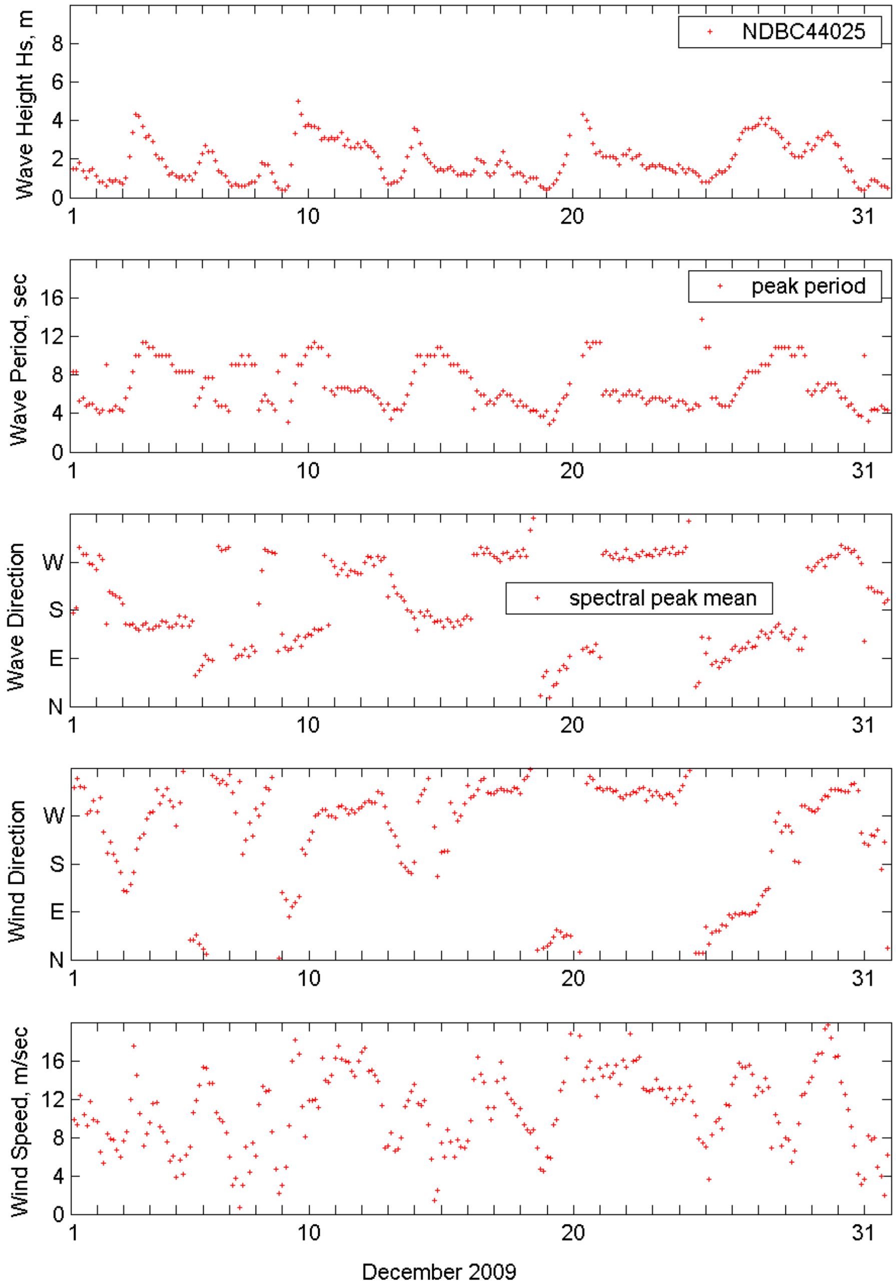


Figure 177. Run fig1set.m.

Fig2sets.m in MATLAB (or **fig2sets.exe** in the DOS command window). This code is similar to fig1set.m except it is capable of reading and plotting the time series of wind wave data from two or three WIS short format files. Run **fig2sets.m** following similar steps as run **fig1set.m.** See Figure 178 to plot NDBC 44025 and CDIP 154 (2009-sp154.out) for December 2009.

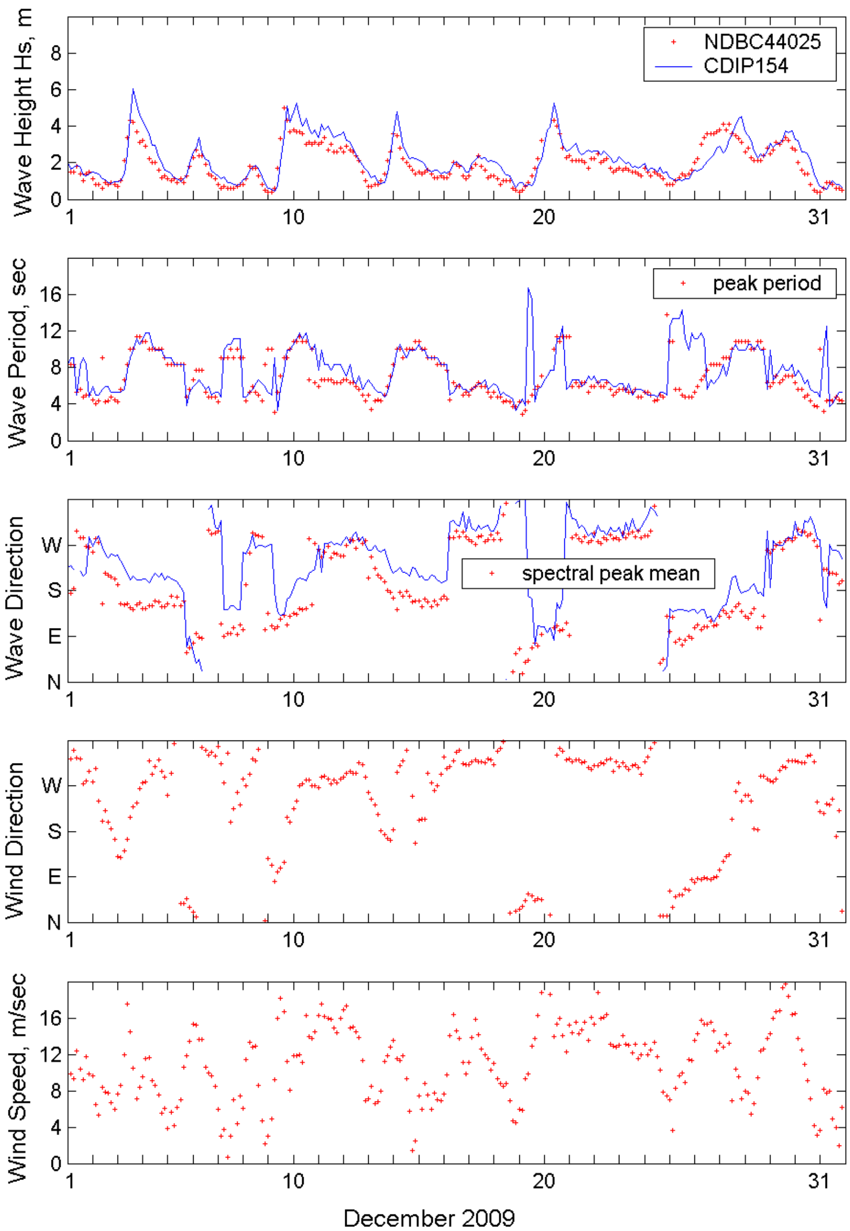


Figure 178. Run fig2sets.m.

Fig4sets.m (or **fig4sets.exe** in DOS). This code is similar to **fig1set.m** and **fig2sets.m** except it is capable of reading and plotting the time series of wind wave data from three or four WIS short format files. Run **fig4sets.m** following similar steps similar as run **fig1set.m** or **fig2sets.m.** See Figure 179 to plot NDBC 44025, CDIP 154, and these two sets of data transformed to the CMS-Wave grid offshore boundary (2009-ndbc.dat and 2009-sp154.dat).

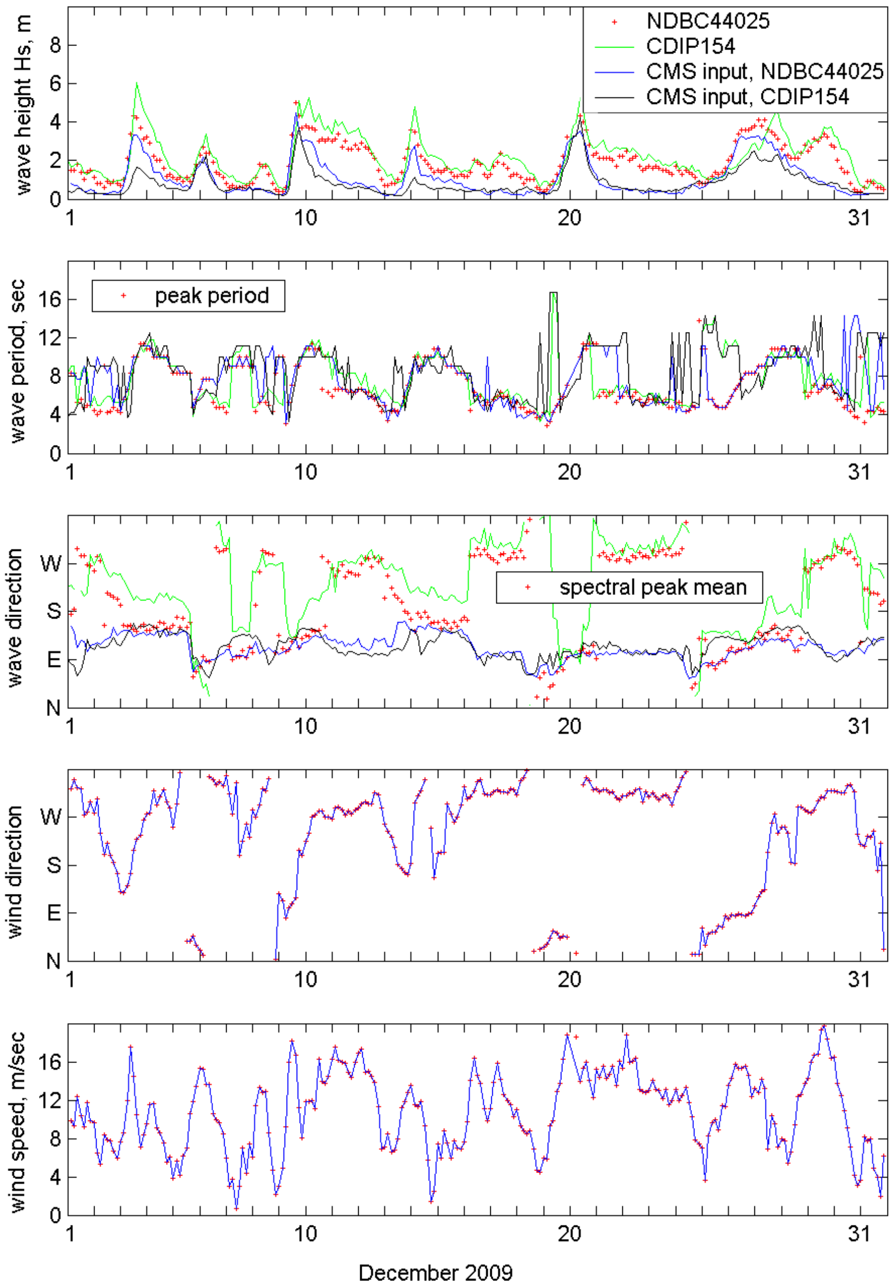


Figure 179. Run fig4sets.m.

Calibration and Validation

> *"...that a much too great generality often obscures more than it enlightens and leads to calculations so intricate that it becomes extremely difficult to deduce from them consequences even for the simplest of cases...."*
> *- Leonhard Euler*

Often, the default user-defined parameters assigned to each cell are not the best representation of the environment. This holds particularly true for areas with substrate bottom different than typical estuarine and littoral sands whether they are marsh, hardbottom, or a rubble pile. The defualt frictional value (Mannings n, 0.025) must be adjusted to better represent the hydrodynamics in these areas. An example in Shark River Estuary might be the very shallow, north and south upriver reaches that are dominiantly marsh platforms. These areas flood and dry within the tidal range, but with a higher friction than an open sand substrate, and therefore the frictional factor must be adjusted appropriately.

Additionally, flow in channels that are influenced by structures, such as bridge pilings, piers, or walls, must also include some modification to the frictional factor. For a seawall or shear wall, this is represented when the cell is designated a "land cell"; however, if your structure is much smaller than cell size an alternative option would be to increase the friction factor to imitate the frictional forces of that structure. This was done in an earlier section describing the bridge pilings located at three bridges crossing the main channels are Shark River Inlet.

Checklist

Below is a checklist for common issues that should be addressed during the initial calibration process.

1. Check the Bathymetry. The most common mistake in bathymetry is improper conversion to the common vertical datum. This will results in jagged triangulation within the grid, or a large increase or decrease that resembles a morphologic features suchas a shoal, but is in fact just poor datum control. Sometimes the horizontal datum may be off by a small margin. For example, many Federal Agencies still collect spatial data in NAD27 instead of the NAD83, and from a large scale these can easily be confused.

2. Grid dimensions. Does the grid cover the reaches it needs to support proper tidal prism, littoral range, and cover enough area to provide room to calculate large wave and hydrodynamic gradients?
3. Timing. Setting up the proper dates and times in the model control is crucial in calibration. Common mistakes include missing the measured time period in the forcing or the model period, not coordinating all forcings, and improperly interpreting the SMS output date and time intervals. Also, beware the differences between local time and Global Time (GMT/UTC).

Statistics

Statistics can be calculated on the equidistant measured and calculated profiles. There are many statistical approaches to compare the measured and calculated data for hydrodynamics. Of those approaches listed below in Appendix F, Correlation Coefficient, and RMAE are commonly used for interpreting goodness of fit for hydrodynamic measurements. The Brier Skill Score and Correlation Coefficient methods are often used in evaluating bathymetry change over transects or morphologic differences such as volumetric change for morphologic features.

5 Summary

The Coastal Modeling System (CMS) User Manual serves as a reference guide to the applied theory, numerical methodology, and the application of the modeling system. The CMS is an integrated wave, current, sediment transport and morphology change model available in the Surface-water Modeling System (SMS). The first chapter on theoretical background summarizes the governing hydrodynamic and sediment transport theory and empirical equations. The Numerical Methods chapter describes the numerical solvers and schemes used in the implicit CMS-Flow. Chapter 4, the User Guide, gives step by step guidance on how to setup and run the CMS and how to analyze the modeling results as part of the calibration process.

The CMS was developed under the Coastal Inlets Research Program (CIRP), an Operations & Maintenance Navigation research program at the Coastal and Hydraulics Laboratory, Engineer Research and Development Center, U.S. Army Corps of Engineers. Information presented herein was prepared for use in SMS 11.0 and higher, although many features may exist in earlier versions of SMS. The latest guidance, documentations and downloads are available at: http://cirp.usace.army.mil/ and from the CIRP wiki: http://cirp.usace.army.mil/wiki/Main_Page.

6 List of Symbols

Variable	Meaning	Units
f_c	Coriolis parameter	1/s
h	Time -averaged total water depth $h=\zeta+\eta$	m
η	Time-averaged water surface elevation above the still water line	m
ζ	Still water depth	m
S^m	Source term due to precipitation, evaporation and sub-grid structures	m/s
U_i	Depth-averaged Lagrangian current velocity defined as $U_i = U_i^E + U_i^S$	m/a
U_i^E	Time- and depth-averaged current velocity vector (i.e. Eulerian velocity)	m/s
U_i^S	Depth-averaged Stokes velocity	m/s
g	Gravitational constant (9.806 m/s^2)	m/s^2
p_{atm}	Atmospheric pressure	Pa
ρ	Water density (~1025 kg/m^3)	kg/m^3
ν_t	Turbulent eddy viscosity	m^2/s
τ_i^s	Wind surface stress vector	N/m^2
τ_i^w	Wave stress vector	N/m^2
τ_i^b	Combined wave-current mean bed shear stress vector	N/m^2
C_s	Depth-average salinity concentration	ppt
u_w	Peak bottom orbital velocity based on the significant wave height and linear wave theory	m/s
u_{rms}	Peak bottom wave orbital velocity based on the root-mean-squared wave height	m/s
ρ_a	Air density at sea level	kg/m^3
c_D	Wind drag coefficient	-
W_i	10-m wind speed vector	m/s
W	10-m wind velocity magnitude $=\sqrt{W_i W_i}$	m/s
q_{b*}	Equilibrium bed load transport	m^2/s

q_{s*}	Equilibrium suspended load transport	m²/s
q_{t*}	Equilibrium total load transport	m²/s
d_{50}	median grain size	m
s	sediment specific gravity or relative density	-
Θ_c	Shields parameters due to currents	-
$\Theta_{cw,m}$	Mean Shields parameters due to waves and currents	-
Θ_{cw}	Maximum Shields parameters due to waves and currents	-
Θ_{cr}	Critical Shields parameter.	-
d_*	Dimensionless grain size based on the median grain size	-
d_{*k}	Dimensionless grain size based on the k^{th} size class	-

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8 Appendix A: Description of Input Files

CMS-Flow

Telescoping Grid File (*.tel)

The telescoping Grid File is saved in SMS 11.0 when saving a telescoping grid. The format of the file is similar to the M2D grid file (*.m2g). The first line contains a header which says "CMS-Telescoping". The second line contains four elements corresponding to the (1) grid orientation *theta*, (2) grid origin in the x-direction x_0, (3) grid origin in the y-direction y_0, and (4) total number of cells N (including inactive cells). Lines 3 through N+3 contain the following column data:

Table A1. Description of column data in the CMS-Flow Telescoping Grid File.

Column	Symbol	Variable
1	*i*	Sequential index
2	*x*	Cell-centered x-coordinate of cell *i* in m
3	*y*	Cell-centered y-coordinate of cell *i* in m
4	Δx	Grid size in x-direction of cell *i* in m
5	Δy	Grid size in *y*-direction of cell *i* in m
6	*iN1*	Index of first neighboring cell to the North direction
7	*iN2*	Index of second neighboring cell to the North direction
8	*iE1*	Index of first neighboring cell to the East direction
9	*iE2*	Index of second neighboring cell to the East direction
10	*iS1*	Index of first neighboring cell to the South direction
11	*iS2*	Index of second neighboring cell to the South direction
12	*iW1*	Index of first neighboring cell to the West direction
13	*iW2*	Index of second neighboring cell to the West direction
14	*Depth*	Still water depth in m. Positive values indicate wet cells and dry cells indicate dry cells.

Important Notes:

- Directions of neighboring cells are relative to the local grid axis (i.e. positive in x = East, negative in x = West, positive in y = North, and negative in y = South).
- Indexes equal to 0 indicate the absence of a neighboring cell.
- If a cell is assigned as an inactive cell, -999
- Because the file is ASCII, the file size can be relatively large and difficult to view in WordPad or Notepad. To view the telescoping grid file, it is recommended to use a more advanced text editor such as UltraEdit or Textpad.

An example of the first 6 lines of a CMS-Flow telescoping grid file is provided below.

```
CMS-Telescoping

0  -2.32  -0.01  13522
1  0.085 0.235  0.17 0.094  17 0 2 0 169 168 0 0 0.188531
2  0.255 0.235  0.17 0.094  18 0 3 0 171 170 1 0 0.188543
3  0.425 0.235  0.17 0.094  19 0 4 0 173 172 2 0 -999
4  0.595 0.235  0.17 0.094  20 0 5 0 175 174 3 0 0.188566
```

A simple Matlab script is provided below to read the *.tel file.

```
function out = read_cmstel(telfile)
% out = read_cmstel(telfile)
% Reads a CMS telescoping grid file
% and output all variables to a structure array
% written by Alex Sanchez, USACE
fid = fopen(telfile,'r');
fgets(fid); %Skip header line
data=fscanf(fid,'%f %f %f %d',4);
out.ncells = data(4);
out.x0 = data(2); out.y0 = data(3); out.angle = data(1);
data=fscanf(fid,'%d %f %f %f %f %d %d %d %d %d %d %d %d %f',...
    [14,out.ncells])';
fclose(fid);
out.id = data(:,1); out.x = data(:,2); out.y = data(:,3);
out.dx = data(:,4); out.dy = data(:,5);
out.iloc = data(:,6:13);
out.depth = data(:,14);
return
```

XMDF CMS-Flow Grid File (*_grid.h5)

The SMS interface can save a scatter set in a binary format called the eXtensible Model Data Format (XMDF). The XMDF format (Butler et al. 2007) stores data in a much smaller file and decreases the time to load large data files, such as SHOALS or LIDAR surveys. Operation in XMDF format rather than ASCII format greatly reduces time of input and output operations.

XMDF CMS-Flow Model Parameters File (*_mp.h5)

TBC

CMS-Wave

CMS-Wave Spectral File (*.eng)

TBC

CMS-Wave Model Parameters File (*.std)

Users can use SMS11 or higher versions, or simply edit the existing model control file *.std, to specify/select these advanced features.

The *.std has a maximum of 24 parameters - the first 15 parameters are more the basic ones as described in the CMS-Wave Technical Report (CHL-TR-08-13) while the remaining 9 parameters are relatively new for advanced CMS-Wave features.

Number	Variable	Argument Type	Options/Range	Description
1	iprp	integer	**0 - waves and wind input in *.eng 1 - waves only, neglect wind input in *.eng -1 - fast mode 2 - forced grid internal rotation 3 - without lateral energy flux**	Wave propagation mode.
2	icur	integer	**0 - no current input 1 - with current input *.cur 2 -with *.cur, use only the 1st set current data**	Current interaction.
3	ibk	integer	**0 - no wave breaking output**	Wave breaking output option.

			1 - output breaking indices **2 - output energy dissipation rate**	
4	irs	integer	**0 - no wave radiation stress calculation or output** **1 - calculate and output radiation stresses** **2 - calculate and output radiation stresses plus setup/max-water-level**	Radiation stress and runup options.
5	kout	integer	**>= 0**	Number of special wave output location, output spectrum in *.obs and parameters in selhts.out.
6	ibnd	integer	**0 - no input a parent spectrum *.nst** **1 - read *.nst, averaging input spectrum** **2 - read *.nst, spatially variable spectrum input**	Nesting option.
7	iwet	integer	**0 - allow wet/dry, default** **1 - without wet/dry** **-1 allow wet/dry, output swell and local sea files** **-2 - output combined steering wav files** **-3 - output swell, local sea, and combined wav files**	Wetting and drying options.
8	ibf	integer	**0 - no bottom friction calc** **1 - constant Darcy-Weisbach coef, c_f** **2 -read variable c_f file, *.fric** **3 - constant Mannings n** **4 - read variable Mannings n file, *.fric**	Bottom friction option.
9	iark	integer	**0 - without forward reflection** **1 - with forward reflection**	Forward reflection option.
10	iarkr	integer	**0 - without backward reflection, 1 - with backward reflection**	Backward reflection option.
11	akap	real	**0.0<=akap<=4.0**	Diffraction intensity coefficient.

12	bf	real	**>=0**	constant bottom friction coef c_f or n (typical value is 0.005 for c_f and 0.025 for Man-nings n).
13	ark	real	**0.0<=ark<=1.0**	Constant forward reflection coef, global specifica-tion (0 for zero reflection, 1 for full reflection).
14	arkr	real	**0.0<=arkr<=1.0**	Constant back-ward reflection coef, global speci-fication (0 for zero reflection, 1 for full reflection).
15	iwvbk	integer	**0 - Goda-extended 1 - Miche-extended 2 - Battjes and Janssen 3 - Chawla and Kirby)**	Option for the primary wave breaking formula.
16	nonln	integer	**0 - none, default 1 - nonlinear wave-wave inte-raction**	Nonlinear wave-wave interaction.
17	igrav	integer	**0 - none, default 1 - infra-gravity wave enter inlets**	Infragravity waves option.
18	irunup	integer	**0 - none, default 1 - automatic, runup relative to absolute datum 2 - automatic, runup relative to updated MWL**	Runup option.
19	imud	integer	**0 - none default 1 - Mud dissipa-tion on**	Mud dissipation option. The kine-matic viscosity is specified in mud.dat in units of m^2/sec.
20	iwnd	integer	**0 - none, default 1 - Spatially varia-ble wind on**	Spatially variable wind field option. The winds are specified in wind.dat in units of m/s and in the reference frame of the CMS-Wave grid.
21	isolv	integer	**0 - GSR solver, default 1 - ADI**	Matrix solver for CMS-Wave.

22	ixmdf	integer	**0 - output ascii, default 1 - output xmdf 2 - input & output xmdf**	XMDF input and output options.
23	iproc	integer	**>=0**	Number of threads for parallel computing. Optimum number is approximately equal to the total row number divided by 300. Only for isolv = 0.
24	iview	integer	**0 - half-plane, default 1 - full-plane**	Half-plane/full-plane option. Users can provide additional input wave spectrum file wave.spc (same format as the *.eng) along the opposite side boundary an imaginary origin for wave.spc at the opposite corner; users can rotate the CMS-Wave grid by 180 deg in SMS to generate this wave.spc.

9 Appendix B: Description of Output Files

XMDF Solution Files (Binary Format)

By default, CMS global solution output files are written in a binary format called XMDF which is based on the HDF5 format which was developed to allow for portability between Windows and non-windows platforms. At present, the SMS reads and writes XMDF files. Additional binary formats are under review to be implemented in CMS for compatibility with other numerical models.

To make post-processing a little easier, CMS developers have written a Matlab code, shown below, that reads in the CMS XMDF solution file.

```
function varargout = read_cmsh5sol(filename,varargin)
% sol = read_cmsh5out(filename,...'dataset1','dataset2',...)
%
%DESCRIPTION:
% Reads a CMS solution file and creates
% a structure variable containing the solution
% datasets values and times
%
%INPUT:
% filename - input file name including full path
% varargin - dataset names
%
%OUTPUT:
% sol - structure variable containing dataset values and times
% varargout - variable length datasets corresponding to varargin
%
%USAGE:
% filename = 'test_sol.h5';
% sol = read_cmsh5sol(filename);
% wse = read_cmsh5sol(filename,'Water_Elevation');
% [wse,uv] = read_cmsh5sol(filename,'Water_Elevation',...
%            Current_Velocity');
%
% written by Alex Sanchez, USACE-ERDC-CHL
info = hdf5info(filename);
s = info.GroupHierarchy.Groups.Groups;
sol = struct();
for i=1:length(s);
    field = s(i).Name;
    ind = findstr(field,'/');
    field = field(ind(end)+1:end);
    if nargin>1 %select only few datasets
        for k=1:nargin-1
            if strcmpi(field,varargin{k})
                varargout{k}.Times = ...
                    double(hdf5read(s(i).Datasets(3)));
                varargout{k}.Values = ...
```

```
                    double(hdf5read(s(i).Datasets(4)));
                continue
            end
        end
    else %write all datasets
        field = regexprep(field,'(', '_');
        field = regexprep(field,')', '');
        field = regexprep(field,' ', '');
        try
            sol = setfield(sol,field,'Times',...
                double(hdf5read(s(i).Datasets(3))));
            sol = setfield(sol,field,'Values',...
                double(hdf5read(s(i).Datasets(4))));
        catch
            try
                for j=1:length(s(i).Groups)
                    field = s(i).Groups(j).Name;
                    ind = findstr(field,'/');
                    field = field(ind(end)+1:end);
                    field = regexprep(field,'(', '_');
                    field = regexprep(field,')', '');
                    field = regexprep(field,' ', '');
                    val = double(hdf5read( ...
                        s(i).Groups(j).Datasets(3)));
                    sol = setfield(sol,field,'Times',val);
                    val = double(hdf5read( ...
                        s(i).Groups(j).Datasets(4)));
                    sol = setfield(sol,field,'Values',val);
                end
            catch
                warning(['Unable to read ',field])
            end
        end
    end
end
if nargin>1 && nargout==1
    for k=1:nargin-1
        sol.(varargin{k}) = varargout{k};
    end
elseif nargin==1
    simlabel = info.GroupHierarchy.Groups.Name(2:end);
    sol.Simulation_Label = simlabel;
    varargout{1} = sol;
end
return
```

SMS Super Files (ASCII Format)

Another option in CMS is to write out solutions in an ASCII format. CMS developers decided to use a format previously implemented in the SMS for writing large ASCII datasets. This format requires three files to be present for each solution dataset: a super file, a scatter point file, and the scatter data file.

1. The super file simply contains a link to the scatter point file which stores the XY coordinates of each solution point. This file has a ".sup" file extension.

2. The scatter point file contains the name associated with this output file, the total number of solution points and a list of the XY coordinates of each solution point. This file has a ".xy" file extension.

3. The scatter data file typically contains information such as the name associated with this output file (same as the name given in 2. Above), reference time, time units, and then scalar or vector records for each output interval as specified in the parameter file. This file has a ".dat" file extension.

To activate ASCII output for solutions, the user must define the "`GLOBAL_SUPER_FILES  ON`" card in the CMS parameter file.

Time Series (Observation Point) Files

As an alternative to frequent output intervals in the global solutions, which are often quite large after completion, CMS has the option to output information for individual locations inside the domain into ASCII files. These are referred to as observation points. Because information is stored for a very small selection of points, users can define this output to be at much smaller time intervals without resulting in very large files.

Individual scalar files are written for each type of information that is to be written. Presently, these types are: current velocity U and V components, water surface elevation, flow rates in X and Y direction, sediment transport rates in X and Y direction, suspended load sediment concentration, salinity concentration, and bed composition. Each file may contain output for one or more cells as defined in the SMS observation cell selection procedure. A flagged value of '-999.0000' is given for any computational cell that is considered dry at each output time. A partial example of the file format is shown below:

```
% time(hrs)    22883    60601    62753
     0.0000    0.0000 -999.0000    0.0000
     0.5000    0.0078 -999.0000    0.0077
     1.0000    0.0500 -999.0000    0.0495
…
  2062.5000    1.1605    1.1216    1.1614
  2063.0000    1.3580    1.3414    1.3580
  2063.5000    1.4783    1.4835    1.4788
  2064.0000    1.5100    1.5406    1.5174
```

In each file, there is a header row which gives a description of the contents of the following rows. In the example above, the first column contains "time in hours", followed by three columns giving the cell numbers as saved by the SMS interface. There will be one row per output time.

10 Appendix C: Examples of Multiple-sized sediment transport

Multiple-sized Sediment Transport

Example 1

The first example used 6 sediment size classes. The size classes are specified with MULTIPLE_GRAIN_SIZES card. The bed composition is specified using the D50_SIGMA method, which requires a geometric standard which is set to 1.3 using the card SEDIMENT_STANDARD_DEVIATION. The initial bed layer thickness is set to a constant of 0.5 m.

```
SEDIMENT_MAX_ITERATIONS              30
SEDIMENT_STATISTICS                 120.0  720.0
BED_COMPOSITION_INPUT               D50_SIGMA
MULTIPLE_GRAIN_SIZES               6 0.1 0.126 0.16 0.2 0.25 0.31
SEDIMENT_STANDARD_DEVIATION         1.3
BED_LAYER_CONSTANT_THICKNESS        0.5
MIXING_LAYER_CONSTANT_THICKNESS     0.1
MIXING_LAYER_MIN_THICKNESS          0.05
HIDING_EXPOSURE_COEFFICIENT         0.6
SEDMIX_OUT_TIMES_LIST               2
BED_OUT_TIMES_LIST                   2
CALC_MORPH_DURING_RAMP              OFF
```

Example 2

The second example consists of 5 sediment size classes. Note that a alternate card for specifying the sediment size class diameters is used compared to Example 1. The bed material composition is specified with D16, D50, and D84 datasets in separate files.

```
SEDIMENT_MAX_ITER                   30
BED_COMPOSITION_INPUT               D16_D50_D84
D16_DATASET                         "Alt1_D16.h5" "Datasets/D16"
D84_DATASET                         "Alt1_D84.h5" "Datasets/D84"
SEDIMENT_SIZE_CLASS_DIAMETERS       5 0.08 0.12 0.17 0.28 0.45
BED_LAYER_CONSTANT_THICKNESS        0.5
MIXING_LAYER_CONSTANT_THICKNESS     0.02
```

11 Appendix D: Matlab Scripting

Scipting refers to the automation of running multiple CMS runs with different parameters, without manually having to create and edit each alternative. The scripting process can include the following steps:

1. Setting up alternatives
2. Creating batch file
3. Plotting and analyzing results

Scripting can be done using a variety of software programs. The examples shown here were written in Matlab because it is widely used, easy to read and convenient for plotting and analyzing results.

Setting Up Alternatives

In this example, 4 cases or alternatives (Figure 5.11.1) are set up using the Matlab script below. The script copies the base setup files into subfolders and then modifies specific CMS-Flow cards in the *.cmcards file. The settings for each case are setup using a structure variable with field names corresponding to each CMS-Flow card (e.g. TIME_SERIES_INCREMENT). Separating each case into its own subfolder keeps the input and output separate and also allows for the different cases to be run at the same time.

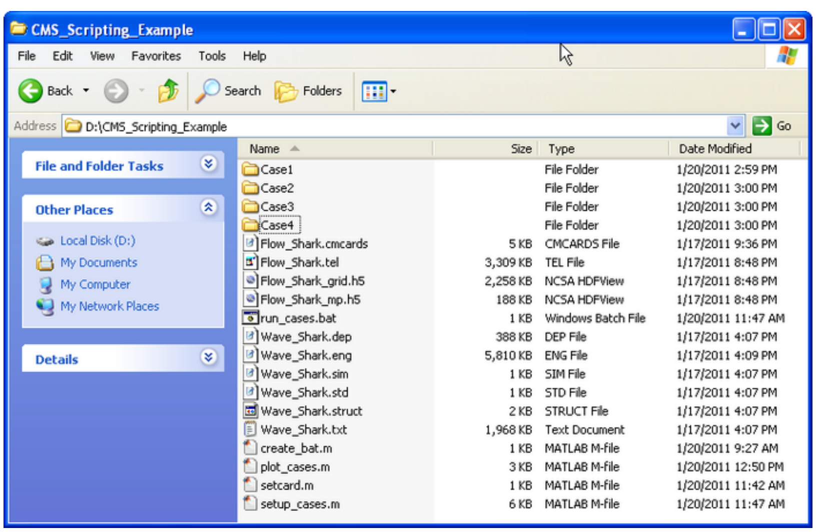

Figure D- 1. Example of scripting showing the files used.

```
% Matlab Script: setup_cases.m
clear all
flow = 'Flow_Shark';
wave = 'Wave_Shark';
ncases = 4; %Number of cases or alternatives
r(1).MANNINGS_N_DATASET = '"Manning_Alt1.h5"
"Flow_Shark/Datasets/ManningsN"';
r(1).WAVE_CURRENT_MEAN_STRESS = 'W09';
r(1).TIME_SERIES_INCREMENT = 1800;
r(2).MANNINGS_N_DATASET = '"Manning_Alt1.h5"
"Flow_Shark/Datasets/ManningsN"';
r(2).WAVE_CURRENT_MEAN_STRESS = 'DATA2';
r(2).TIME_SERIES_INCREMENT = 900;
r(3).MANNINGS_N_DATASET = '"Manning_Alt2.h5"
"Flow_Shark/Datasets/ManningsN"';
r(3).WAVE_CURRENT_MEAN_STRESS = 'W09';
r(3).TIME_SERIES_INCREMENT = 900;
r(4).MANNINGS_N_DATASET = '"Manning_Alt2.h5"
"Flow_Shark/Datasets/ManningsN"';
r(4).WAVE_CURRENT_MEAN_STRESS = 'DATA2';
r(4).TIME_SERIES_INCREMENT = 600;
for i=1:ncases
  d = ['Case',int2str(i)];
  if ~exist(d,'dir')
    mkdir(d)
  end
  copyfile([wave,'.*'],d)
  copyfile([flow,'.*'],d)
  copyfile([flow,'_mp.h5'],d);
  copyfile([flow,'_grid.h5'],d)
  cards = fieldnames(r(i));
  file = ['.\',d,'\Flow_Shark.cmcards'];
  fork=1:length(cards)
    setcard(file,cards{k},r(i).(cards{k}));
  end
end
return
```

The script above requires the subroutine below.

```
function setcard(cmcardsfile,card,value)
% setcard(file,card,value)
% Overwrites or appends a CMS-Flow card
% in the *.cmcards file
copyfile(cmcardsfile,'temp')
fid=fopen('temp','r');
fid2=fopen(cmcardsfile,'w');
nc=length(card);
ok = false(1);
if ~ischar(value)
  value = num2str(value);
end
while 1
  tline = fgets(fid);
  if ~ischar(tline), break, end
  if strncmp(card,tline,nc)
    fprintf(fid2,'%s       %s %s' ,card,value,tline(end));
    ok = true(1);
```

```
    continue
  end
  nline = length(tline);
  if(~ok && strcmp(tline(1:min(nline,14)),'END_PARAMETERS'))
    fprintf(fid2,'%s       %s %s',card,value,tline(end));
    fprintf(fid2,'%s' ,tline);
    break
  end
  fprintf(fid2,'%s' ,tline);
end
fclose(fid);
fclose(fid2);
delete('temp')
return
```

Creating a Batch File

Although it is possible to launch CMS from Matlab a batch file is preferable to use a batch file because it allows running all of the cases without opening Matlab.

```
% Matlab Script: create_bat.m
cmsexe = 'cms2d_v4b42_x64p.exe'; %CMS-Flow executable
batfile = 'run_cases.bat'; %Output batch file
fid = fopen(batfile,'w');
for i=1:ncases
  cmcards = ['.\Case',int2str(i),'\',flow,'.cmcards']; %CMS-Flow cmcards
file
  fprintf(fid,'START %s %s %s',cmsexe,cmcards,char(10));
end
fclose(fid);
return
```

The following text shows what the resulting batch file (*.bat) looks like

```
START cms2d_v4b42_x64p.exe .\Case1\Flow_Shark.cmcards
START cms2d_v4b42_x64p.exe .\Case2\Flow_Shark.cmcards
START cms2d_v4b42_x64p.exe .\Case3\Flow_Shark.cmcards
START cms2d_v4b42_x64p.exe .\Case4\Flow_Shark.cmcards
```

To run the batch file, simply double click on the file and each case will launch separately in its own MS-DOS window.

Plotting

The following example reads the Observation Point time series output file (*_eta.txt) and plots the 3rd column corresponding to the second observation point.

```
% Matlab Script: plot_cases.m
close all
eta = cell(ncases,1);
for  i=1:ncases
  etafile = ['.\Case' ,int2str(i),'\',flow,'_eta.txt' ]; %Water elevation
  eta{i} = load(etafile);
end
figure
hold on
for i=1:ncases
  h = plot(eta{i}(:,1),eta{i}(:,3),'-');  %3 is the index is the observa-
tion point index
end
ylabel('Water elevation, m')
xlabel('Elapsed Time, hr')
return
```

12 Appendix E: Determining the sediment size Classes

In order to determine the appropriate grain sizes for a simulation it is useful to be able to determine ahead of time the size class fractions using a log-normal distribution for different median grain sizes and sorting. The Matlab example below determines the grain size distribution given the smallest and largest grain sizes, number of sediment sizes, median grain size and geometric standard deviation. The figure shows the computed grain size distribution.

```
clear all; close all
%--- Start Input ---
d1 = 0.234;  %mm, smallest grain size
dn = 2;      %mm, largest grain size
nsed = 5;    %number of grain sizes
d50 = 0.4;   %mm, median grain size
sg = 1.5;   %mm, geometric standard deviation
%--- End Input ---
%Characteristic diameters
d = exp(log(d1) + log(dn/d1)*((1:nsed)-1.0)/(nsed-1));
%Limits or bounds
dlim = zeros(1,nsed+1);
dlim(2:nsed)=sqrt(d(2:nsed).*d(1:nsed-1));
dlim(1)=d(1)*d(1)/dlim(2);
dlim(nsed+1)=d(nsed)*d(nsed)/dlim(nsed);
%Fractions
p = diff(dlim).*lognpdf(d,log(d50),log(sg));
p = p/sum(p);
%Plotting
figure
hold on
for k=1:nsed
  fill([dlim(k) dlim(k+1) dlim(k+1) dlim(k)],...
    [0 0 p(k) p(k)]*100,0.5*[1,1,1])
end
ylabel('Fraction, %')
xlabel('Grain size, mm')
set(gca,'box','On','TickDir','out',...
  'XMinorTick','OFF','YMinorTick','OFF')
[d',p']
return
```

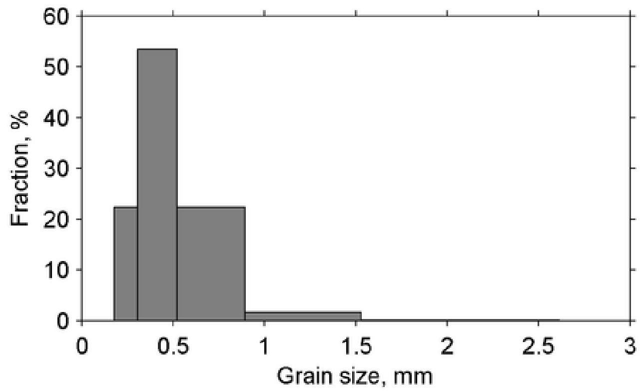

Figure E- 1. Computed grain size distribution from the Matlab script above.

13 Appendix F: Goodness of Fit Statistics

Brier Skill Score

The Brier Skill Score (BSS) is defined as

$$\mathrm{BSS} = 1 - \frac{\left\langle (x_m - x_c)^2 \right\rangle}{\left\langle (x_m - x_0)^2 \right\rangle} \tag{A1}$$

where the angled brackets indicate averaging, subscripts m, c, and 0 indicate measured, calculated, and initial values, respectively. The BSS ranges between negative infinity and one. A BSS value of 1 indicates a perfect agreement between measured and calculated values. Scores equal to or less than 0 indicates that the mean observed value is as or more accurate than the calculated values. The following quantifications are used for describing the BSS values: 0.8<BSS<1.0 = excellent, 0.6<BSS<0.8 = good, 0.3<BSS<0.6 = reasonable, 0<BSS<0.3 = poor, BSS<0 = bad.

Room Mean Squared Error

The Root Mean Squared Error (RMSE) is defined as

$$\mathrm{RMSE} = \sqrt{\left\langle (x_c - x_m)^2 \right\rangle} \tag{A2}$$

The RMSE has the same units as the measured data. Lower values of RMSE indicate a better match between measured and computed values.

The Normalized Root Mean Squared Error (NRMSE) is

$$\mathrm{NRMSE} = \frac{\mathrm{RMSE}}{\mathrm{range}(x_m)} \tag{A3}$$

Normalized Root Mean Squared Error

The NRMSE is often expressed in units of percent. The measured data range $\mathrm{range}(x_m)$ can be estimated as $\max(x_m) - \min(x_m)$. Lower values of NRMSE indicate a better agreement between measured and computed values.

Mean Absolute Error

The Mean Absolute Error (MAE) is defined as

$$\text{MAE} = \left\langle \left| x_c - x_m \right| \right\rangle \quad \text{(A4)}$$

Normalized Mean Absolute Error

Similarly, the Normalized Mean Absolute Error (NMAE) is given by

$$\text{NMAE} = \frac{\text{MAE}}{\text{range}(x_m)} \quad \text{(A5)}$$

The NMAE is often expressed in units of percent. Smaller values of NMAE indicate a better agreement between measured and calculated values.

Correlation Coefficient

Correlation is a measure of the strength and direction of a linear relationship between two variables. The correlation coefficient *R* is defined as

$$R = \frac{\left\langle x_m x_c \right\rangle - \left\langle x_m \right\rangle \left\langle x_c \right\rangle}{\sqrt{\left\langle x_m^2 \right\rangle - \left\langle x_m \right\rangle^2} \sqrt{\left\langle x_c^2 \right\rangle - \left\langle x_c \right\rangle^2}} \quad \text{(A5)}$$

A correlation of 1 indicates a perfect one-to-one linear relationship and -1 indicates a negative relationship. The square of the correlation coefficient describes how much of the variance between two variables is described by a linear fit. The interpretation of the correlation coefficient depends on the context and purposes. For the present work, the following qualifications are used: $0.7<R^2<1$ = strong, $0.4<R^2<0.7$ = medium, $0.2<R^2<0.4$ = small, and $R^2<0.2$ = none.

Bias

The Bias is defined as

$$\text{Bias} = \left\langle x_c - x_m \right\rangle \quad \text{(A6)}$$

Positive values indicate overprediction and negative values indicate underprediction.

14 Appendix G: Providing Sea Buoy Data to CMS-Wave

Directional spectral data collected by NDBC or CDIP buoys can be processed as alternative source for wave input to CMS-Wave. Two examples are given below using CDIP 154 and NDBC 44025 standard spectral files for December 2009.

- NDBC buoy data – run **ndbc-spectra.exe** (FORTRAN) to read the NDBC standard directional wave file and generate the CMS-Wave input spectral *.eng.

1. Download the NDBC standard monthly directional wave spectral file from http://www.nodc.noaa.gov/BUOY/buoy.html (e.g., 44025_200912) - see Figs 2.3.1 to 2.3.4 for accessing NDBC spectral data from the Web.

2. In the DOS window, run **ndbc-spectra.exe**
3. Responding to the on-screen input, type the NDBC spectral filename
4. Type the starting timestamp (default value is 0) for saving output files
5. Type ending timestamp (default is 99999999) for saving output files
6. Type the time interval (hr) for saving output data
7. Type 2 to save the CMS-Wave *.eng and *.txt files
8. Type the CMS-Wave input spectrum filename (*.eng)
9. Type the local shoreline orientation (the CMS-Wave grid y axis) in clockwise polar coordinates (deg, positive from North covering the sea, e.g., 180 deg for St Mary's Entrance, FL/GA, or 360 deg - the wave grid orientation angle in *.sim)
10. Type the NDBC buoy location water depth (m) and then the CMS-Wave seaward boundary mean water depth (m), e.g. Buoy 44025 has a nominal depth of 36.3 m relative to Mean Sea Level
11. Type 1 to include wind or 0 to skip the wind input information
12. Type 1 or 2 or 3 for different choice of calculated frequency bins to complete the run – see Fig 2.3.5 for running **ndbc-spectra.exe** in DOS.

The output files include *.txt, *.eng, *.out (time series of wave parameters at the buoy), and *.dat (time series of shoreward wave parameters at the CMS-Wave offshore boundary).

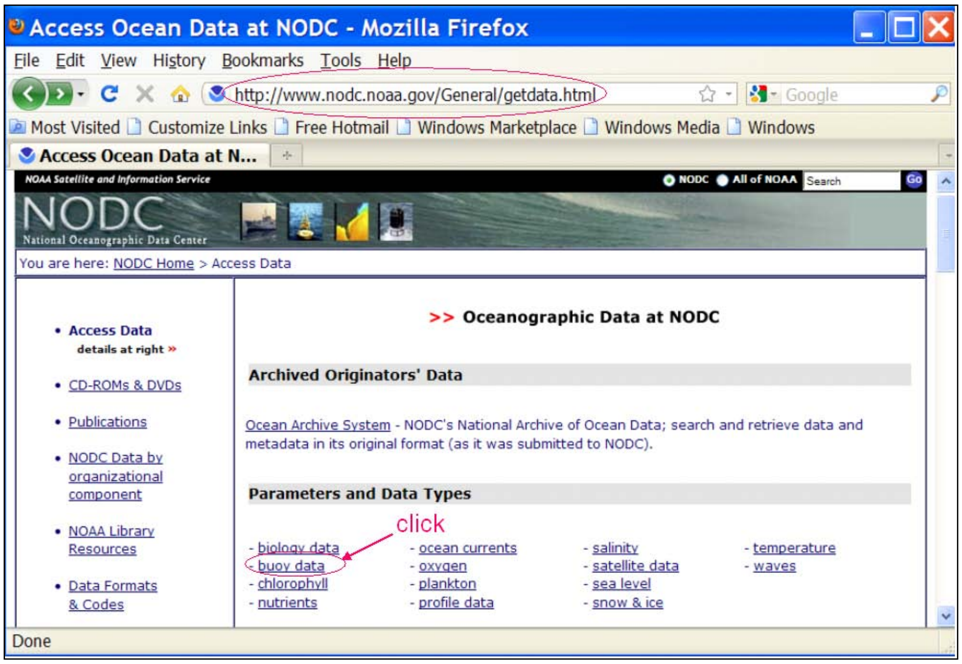

Figure G- 1. NODC buoy data access website.

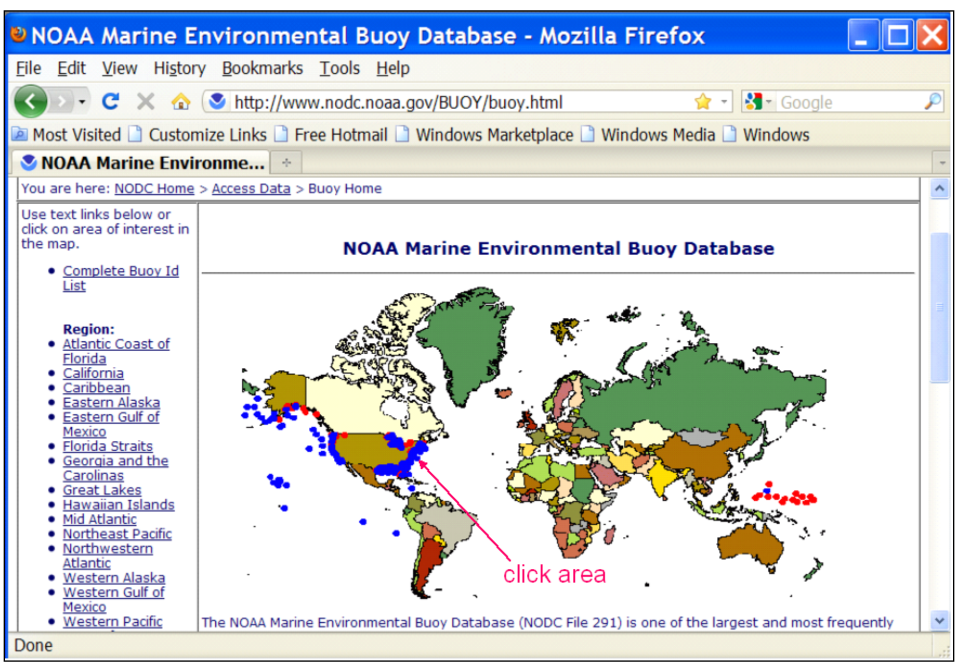

Figure G- 2. NODC buoy data access world map.

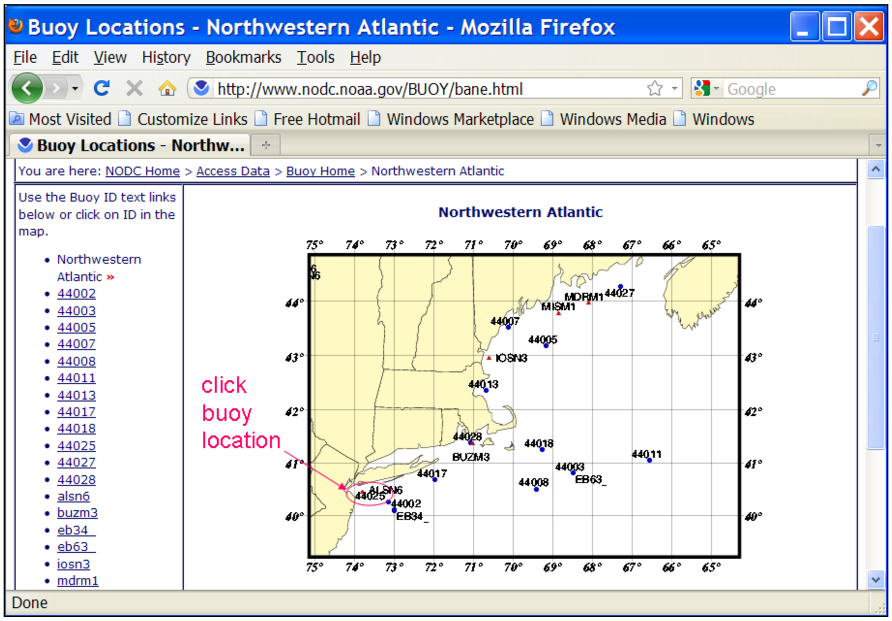

Figure G- 3. NODC buoy data access regional map.

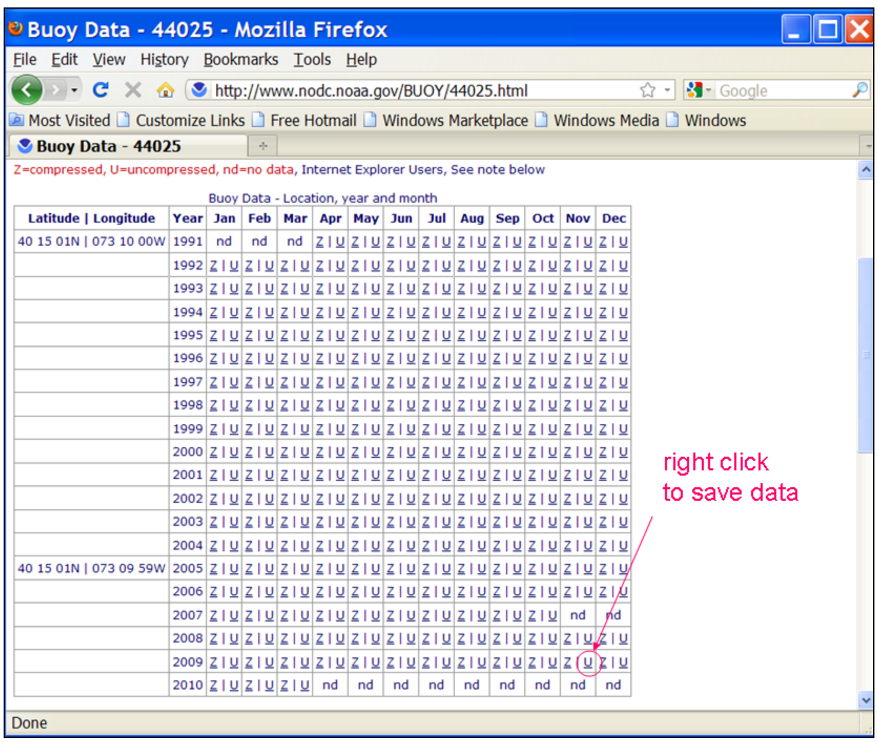

Figure G- 4. NDBC buoy spectral data download web page.

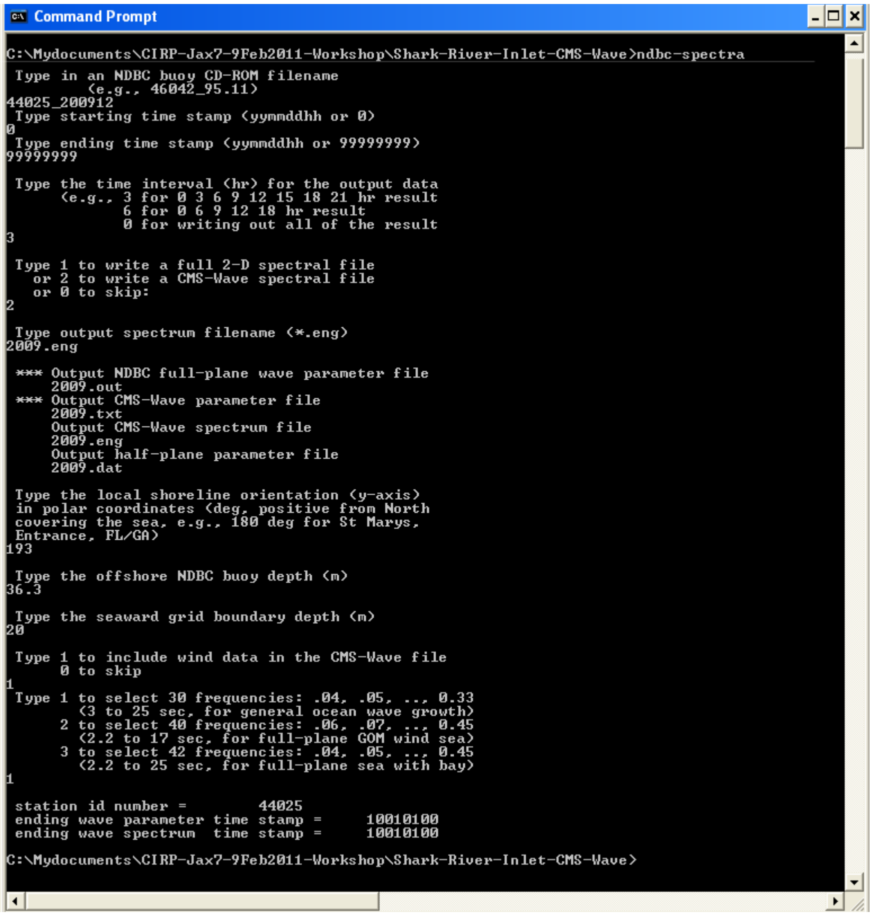

Figure G- 5. Run ndbc-spectra.exe in DOS

- CDIP buoy data - run **cdip-spectra.exe** (also FORTRAN code) to read the CDIP standard directional wave file and generate the CMS-Wave input *.eng file. Download the CDIP wave file from http://cdip.ucsd.edu/?nav=historic&sub=data (e.g., sp154-200912) – see Figure G- 6 to Figure G- 8.

Run **cdip-spectra.exe** in the DOS window similar to **ndbc-spectra.exe** – see Figure G- 9. Because CDIP spectral file already contains the buoy location depth information, **cdip-spectra.exe** will not prompt for this depth input. For processing either NDBC or CDIP data, users shall check and manually fill any data gaps in *.eng and *.txt files (using the first available spectral data from the neighboring time interval).

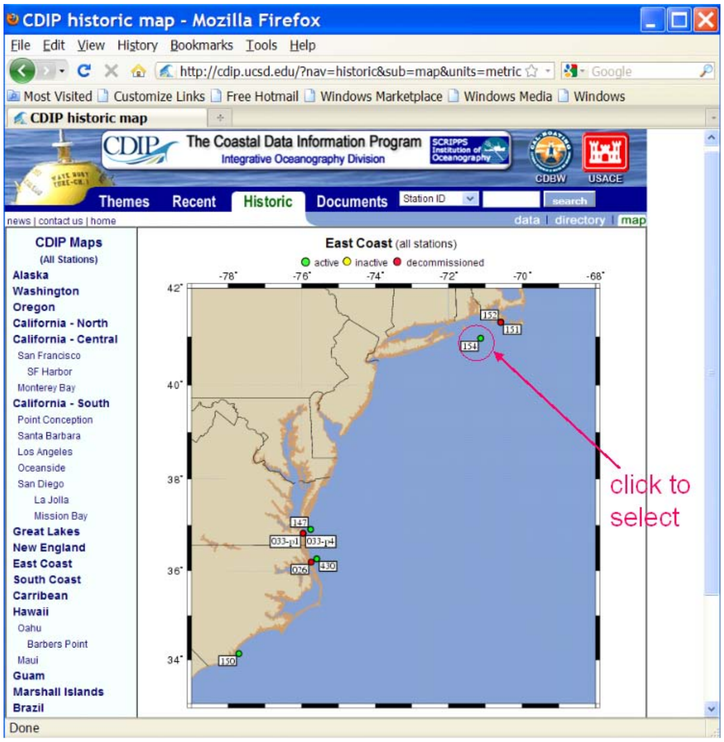

Figure G- 6. CDIP buoy data access web page.

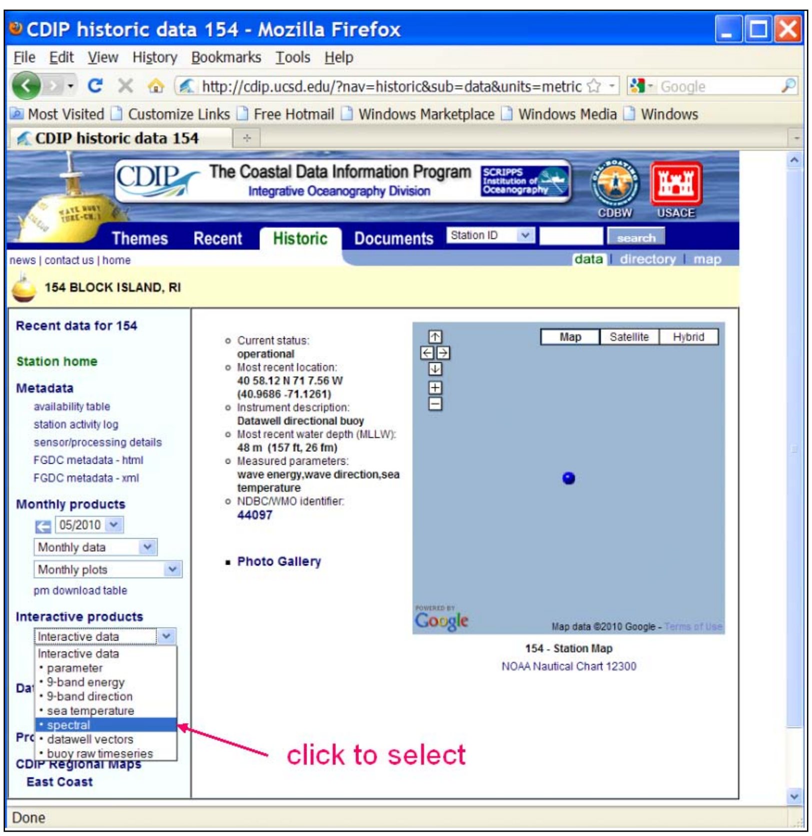

Figure G- 7. CDIP buoy data access web page.

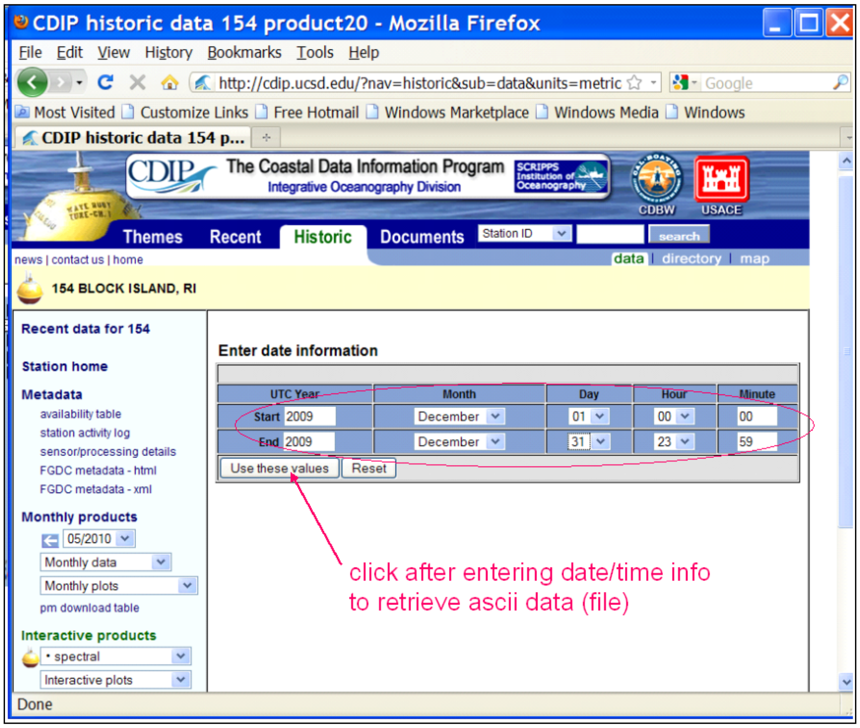

Figure G- 8. CDIP buoy spectral data download web page.

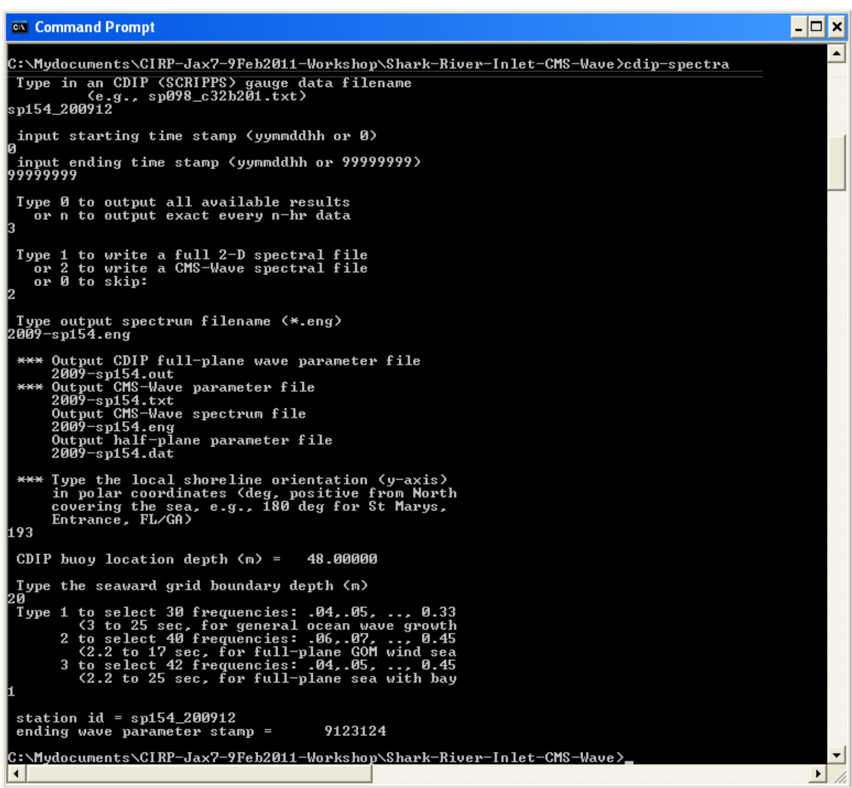

Figure G- 9. Run cdip-spectra.exe in DOS.

15 Appendix H: Glossary

A

Abrasion: The mechanical wearing away by rock material transported by wind or water

Active Layer: The first top layer of sediment in which sediments are subject to exchange with those moving with the flow (entrainment or deposition).

Accretion: The accumulation of (beach) sediment, deposited by natural fluid flow processes.

Advection: (1) Changes in a sea water property (salinity, temperature, oxygen content, etc.) that take place in the presence of currents. Also, changes in atmospheric properties in the earth's atmosphere. (2) The process by which solutes are transported by the motion of flowing groundwater.

Aggradation: The geologic process by which various parts of the surface of the earth are raised in elevation or built up by the deposition of material transported by water or wind.

Amplitude: Half of the peak-to-trough range (or height) of a wave.

Angle of Repose: Angle between the horizontal and the maximum slope that a soil assumes through natural processes.

Armoring: The formation of a resistant layer of relatively large particles resulting from removal of finer particles by erosion.

B

Bathymetry: The measurement of depths of water in oceans, seas and lakes; also the information derived from such measurements.

Bay: A recess or inlet in the shore of a sea or lake between two capes or headlands, not as large as a gulf but larger than a cove.

Bed: The bottom of a watercourse, or any body of water.

Bed load: Sediment transport mode in which individual particles either roll or slide along the bed as a shallow, mobile layer a few particles in height above the bed.

Bed form: Any deviation from a flat bed that is readily detectable by eye and higher than the largest sediment size present in the parent bed material; generated on the bed of an alluvial channel by the flow.

Breaker Index: Maximum ratio of wave height to water depth in the surf zone, typically 0.78 for spilling waves, ranging from about 0.6 to 1.5.

Bypasssing Sand: Hydraulic or mechanical movement of sand from the accreting updrift side to the eroding downdrift side of an inlet or harbor entrance. The hydraulic movement may include natural as well as movement caused by man.

C

Channel: (1) A natural or artificial waterway of perceptible extent which either periodically or continuously contains moving water, or which forms a connecting link between two bodies of water. (2) The part of a body of water deep enough to be used for navigation through an area otherwise too shallow for navigation. (3) The deepest portion of a stream, bay, or strait through which the main volume of current of water flows. (4) An open conduit for water either naturally or artificially created, but does not include artificially created irrigation, return flow or stockwatering channels.

Chart Datum: The plane or level to which soundings, tidal levels or water depths are referenced, usually low water datum. See also Datum.

Conveyance: A measure of the flow carrying capacity of a channel section. Flow is directly proportional to conveyance for steady flow. From Manning’s equation, the proportionality factor is the square root of the energy slope.

Coordinate System: A set of rules for specifying how coordinates are to be assigned to points.

Coriolis Force: Force or Pseudo-force due to the Earth's rotationwhich causes moving bodies to be deflected to the right in the Northern Hemisphere and to the left in the Southern Hemisphere. The force is proportional to the speed and latitude of the moving object. It is zero at the equator and maximum at the poles.

Cross-shore: Perpendicular to the shoreline.

D

Datum: A datum is a point, line or surface used as a reference as in surveying, mapping, geology or numerical modeling.

Depth: Vertical distance from still-water level (or datum as specified) to the bottom.

E

Ebb: Period when tide level is falling; often taken to mean the ebb current which occurs during this period.

Elevation: The distance of a point above a specified surface of constant potential; the distance is measured along the direction of gravity between the point and the surface.

Equilibrium Argument: The theoretical phase of the equilibrium tide. It is usually represented by the expression (V + u), in which V is a uniformly changing angular quantity involving multiples of the hour angle of the mean Sun, the mean longitudes of the Moon and Sun, and the mean longitude of lunar or solar perigee; and u is a slowly changing angle depending upon the longitude of the Moon's node. When pertaining to an initial instant of time, such as the beginning of a series of observations, it is expressed by (V0 + u).

Equilibrium Tide: Hypothetical tide due to the tide-producing forces under the equilibrium theory. Also known as gravitational tide.

F

Fetch length: (1) The horizontal distance (in the direction of the wind) over which a wind generates waves or creates wind setup. (2) The horizontal distance along open water over which the wind blows and generates waves.

G

Gradation: (ASTM D 653) The proportions by mass of a soil or fragmented rock distributed in specified particle-size ranges.

Graded Bed: An arrangement of particle sizes within a single bed, with coarse grains at the bottom of the bed and progressively finer grains toward the top of the bed.

Greenwich Mean Time or **GMT**: Mean solar time at the meridian of Greenwich, England. It has been used as a basis for standard time throughout the world. Also called Zulu time. (See also Coordinated Universal Time or UTC).

Grid: Network of points covering the space or time-space domain of a numerical model. The points may be regularly or irregularly spaced.

H

Harmonic Analysis: The mathematical process by which the observed tide or tidal current at any place is separated into basic harmonic constituents.

Hydrodynamic: Relates to the specific scientific principles that deal with the motion of fluids and the forces acting on solid bodies immersed in fluids, and in motion relative to them.

I

Infragravity wave: Long waves with periods of 30 seconds to several minutes.

Initial Conditions: The values of water levels, velocities, concentrations, etc., that are specified everywhere in the grid or mesh at the beginning of a model run. For iterative solutions, the initial conditions represent the first estimate of the variables the model is trying to compute.

Interpolation: Estimation of an intermediate value of one variable (dependent) as a function of a second variable (independent) when values of the dependent variable corresponding to several discrete values of the independent variable are known.

J

Jetty: (1) On open seacoasts, a structure extending into a body of water, and designed to prevent shoaling of a channel by littoral materials, and to direct and confine the stream or tidal flow. Jetties are built at the mouth of a river or tidal inlet to help deepen and stabilize a channel. (2) A shore-perpendicular structure built to stabilize an inlet and prevent the inlet channel from filling with sediment.

K

Kinematic Viscosity: The dynamic viscosity divided by the fluid density.

L

Longshore: Parallel to and near the shoreline; Alongshore.

LHW: Lower High Water.

LLW: Lower Low water

M

MHHW: Mean Higher High Water. The average of the higher high water height of each tidal day observed over the National Tidal Datum Epoch.

MHW: Mean High Water. The average of all the high water heights observed over the National Tidal Datum Epoch.

MSL: Mean Sea Level. The arithmetic mean of hourly heights observed over the National Tidal Datum Epoch.

MLW: Mean Low Water. The average of all the low water heights observed over the National Tidal Datum Epoch.

MLLW: Mean Lower Low Water. The average of the lower low water height of each tidal day observed over the National Tidal Datum Epoch

N

National Geodetic Vertical Datum: The vertical-control datum used by the National Geodetic Survey since 1980. This definition is considered to be misleading because it implies the adoption of an NGVD as adjusted in 1980. Accordingly, this expression should be disregarded. Consultation with the National Geodetic Survey (N/CG172, NOAA/NOS) resulted in the confirmation that NGVD of 1929 still applies. (See also National Geodetic Vertical Datum of 1929.)

Nodal Factor: A factor depending upon the longitude of the Moon's node which, when applied to the mean coefficient of a tidal constituent, will adapt the same to a particular year for which predictions are to be made.

O

Overdepth: (1) (EM 1110-2-1003) Additional depth below the required section (or template) specified in a dredging contract. This additional depth is permitted (but not required) because of inaccuracies in the dredging process. (2) The distance between the theoretical maintenance depth and the actual dredging depth. (3) The amount of extra dredging depth that is allowed and paid for, if dredged, in excess of prescribed contract depth

P

Particle Size: A linear dimension, usually designated as "diameter," used to characterize the size of a particle. The dimension may be determined by any of several different techniques, including sedimentation sieving, micrometric measurement, or direct measurement.

Phi Grade Scale: A logarithmic transformation of the Wentworth grade scale for size classifications of sediment grains based on the negative logarithm to the base 2 of the particle diameter: = -log2d.

Porosity: Percentage of the total volume of a soil sample not occupied by solid particles but by air and water, n = Vv/VT × 100. (ASTM D 653) the ratio, usually expressed as a percentage, of (1) the volume of voids of a given soil or rock mass, to (2) the total volume of the soil or rock mass.

Progradation: The building forward or outward toward the sea of a shoreline or coastline (as with a beach, delta, or fan) by nearshore deposition of river-borne sediments or by continuous accumulation of beach material thrown up by waves or moved by longshore drifting.

Q

Quality Assurance or **QA**: The total integrated program for assuring the reliability of data. A system for integrating the quality planning, quality control, quality assessment, and quality improvement efforts to meet user requirements and defined standards of quality with a stated level of confidence.

Quality Control or **QA**: The overall system of technical activities for obtaining prescribed standards of performance in the monitoring and measurement process to meet user requirements.

R

Rectification: The process of producing, from a tilted or oblique photograph, a photograph from which displacement caused by tilt has been removed.

Reconnaissance Survey: (EM 1110-2-1003) A general minimum-effort survey performed to determine the general project or channel conditions. The surveys may be controlled or uncontrolled. The survey may serve as a before dredging survey.

Reflection of Water Waves: The process by which the energy of the wave is returned seaward.

Refraction of Water Waves: (1) The process by which the direction of a wave moving in shallow water at an angle to the contours is changed. The part of the wave advancing in shallower water moves more slowly than that part still advancing in deeper water, causing the wave crest to bend toward alignment with the underwater contours. (2) The bending of wave crests by currents.

S

Salinity: Number of grams of salt per thousand grams of sea water, usually expressed in parts per thousand (symbol: ‰).

Scatter Plot: A two-dimensional plot showing the joint distribution of two variables within a data sample.

Sediment Transport Formula: A formula or algorithm for calculating sediment transport rate given the hydraulics and bed material characteristics at a point or cross section.

Sediment Transport Paths: The routes along which net sediment movement occurs.

T

Tidal Datum: A tidal datum is a standard elevation defined by a certain phase of the tide. Tidal datums are used as references to measure local water levels.

U

Universal Time: Generally equivalent to Greenwich mean time, GMT. (See also Coordinated Universal-Time, UTC.)

Universal Transverse Mercator or **UTM:** A worldwide metric military coordinate system rarely used for civil works applications (EM 1110-2-1003).

V

Validation: In computer modeling and simulation, validation is the process of determining the degree or accuracy to which a model or simulation is an accurate representation of a real world process from the perspective of the intended uses of the model or simulation.

Verification: In computer modeling and simulation, verification is the process of determining the accuracy of which the governing equations of a specific model or simulation are being solved.

W

Wash Load: Part of the suspended load with particle sizes smaller than found in the bed; it is in near-permanent suspension and transported without deposition; the amount of wash load transported through a reach does not depend on the transport capacity of the flow; the load is expressed in mass or volume per unit of time.

Water Surface Elevation: A measure of the free water surface with respect to a given datum. Also - Water Elevation.

Weir Jetty: An updrift jetty with a low section or weir over which littoral drift moves into a predredged deposition basin which is then dredged periodically.

Winnow: Natural removal of sediments through suspension and erosion of fine particles by water flow.

X

Y

Z