MODELING THE ULTIMATE TRANSPORT AND FATE OF DREDGE-INDUCED SUSPENDED SEDIMENT TRANSPORT AND DEPOSITION

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ABSTRACT

SSFATE (Suspended Sediment FATE) is a computer model originally developed jointly by the U.S. Army Corps of Engineers Engineer Research and Development Center and Applied Science Associates to estimate the water column suspended sediment concentrations and bottom deposition patterns resulting from dredging operations. The model requires specification of circulation in the area of interest, the type of dredging technology used, and the loss rate and vertical distribution of initial material release. Using a random walk procedure, the model tracks representative particle classes as they disperse in the water column and settle to the bottom. Model output includes water column suspended sediment concentrations and bottom deposition thicknesses.

The model originally tracked only the initial deposition of sediment on the bottom as the local shear stress dropped below the critical deposition threshold. If the velocity (and shear stress) subsequently increased, the sediments were not resuspended. To expand the capability of the model to include resuspension and thus transport of suspended sediment after initial deposition, a two step resuspension algorithm was implemented.

The expanded model was tested to prove the concept for a simple channel configuration and an actual coastal application. Comparisons between the original nonresuspension version and the updated resuspension version were made for both applications. The addition of the resuspension calculation tended to cause a larger areal bottom deposition pattern and increased the maximum concentration away from the dredging site. The model provides consistent and reasonable results but remains to be tested against actual field data. Future work will concentrate on locating suitable data sets to verify model performance.

Keywords: Dredging, modeling, suspended sediment, resuspension

INTRODUCTION

SSFATE (Suspended Sediment FATE) is a computer model originally developed jointly by the U.S. Army Corps of Engineers Engineer Research and Development Center and Applied Science Associates to estimate the water column suspended sediment concentrations and bottom deposition patterns resulting from dredging operations (Johnson et al., 2000). The model was developed to provide a consistent estimate of the transport and fate of the portion of dredged material lost during dredging. The model requires specification of circulation in the area of interest typically from hydrodynamic model output; the type of dredging technology used, and the loss rate and vertical distribution of initial material release. Using a random walk procedure, the model tracks representative particle classes as they disperse in the water column and settle to the bottom. Model output includes water column suspended sediment concentrations and bottom deposition thicknesses.

The model originally tracked only the initial deposition of sediment on the bottom as the local shear stress dropped below the critical deposition threshold. If the velocity (and shear stress) subsequently increased, perhaps due to larger currents during the maximum flood or ebb periods of the tide or larger waves and currents during storm events, the sediments were not resuspended. To expand the capability of the model to include resuspension and thus transport of suspended sediment after initial deposition additional algorithms were added to simulate this resuspension process. In the sections to follow a summary of the mathematical formulation of SSFATE is given and results of test cases presented as a proof of concept.

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SSFATE MODEL DESCRIPTION

SSFATE is a model that was jointly developed by ASA and the U.S. Army Corps of Engineers (USACE) Environmental Research and Development Center (ERDC) to simulate the sediment suspension and deposition from dredging operations. It has been documented in a series of USACE Dredging Operations and Environmental Research (DOER) Program technical notes (Johnson et al. 2000 and Swanson et al. 2000), at a previous World Dredging Conference (Anderson et al. 2001) and a series of Western Dredging Association Conferences (Swanson et al., 2004; Swanson and Isaji, 2006). A number of ASA technical reports have been prepared that demonstrates successful application to dredging. In addition SSFATE has been extended to include the simulation of cable and pipeline burial operations using water jet trenchers (Swanson et al., 2006).

SSFATE (Suspended Sediment FATE) computes suspended sediment distributions and deposition patterns resulting from dredging operations and contains the following features:

- Ambient currents can be imported from a variety of numerical hydrodynamic models.
- Computational model predicts the transport, dispersion, and settling of suspended sediment released to the water column during dredging using a random walk procedure.
- Model simulates suspended sediment source strength and vertical distribution from mechanical (e.g., clamshell) or hydraulic (e.g., cutterhead, hopper) dredges and water jet trenchers.
- Multiple sediment types or fractions can be simulated simultaneously.
- Model output consists of concentration contours in both horizontal and vertical planes, time series plots of suspended sediment concentrations, and the spatial distribution of sediment deposited on the sea floor.
- Sediment particle movement and concentration evolution can be animated over Geographic Information System (GIS) layers depicting sensitive environmental resources and areas.

Depending on the resolution of the numerical grid employed, SSFATE can make predictions close to the dredging operation; however, the processes modeled are not near field effects of bucket activities but far field (~25 m [80 ft]) effects in which the mean transport and turbulence associated with ambient currents dominate. A particle-based model predicts the transport and dispersion of the suspended material. Particle advection is based on the simple relationship that a particle moves linearly with a local velocity, obtained from the hydrodynamic model, for a specified model time step. Particle diffusion is assumed to follow a simple random walk process.

Sediment particles are divided into five size classes shown in Table 1. Each particle class behaves uniquely in the model.

Table 1. Sediment size classes.

Class	Type	Size Range (microns)
1	Clay	0-7
2	Fine silt	8-35
3	Coarse silt	36-74
4	Fine sand	75-130
5	Coarse sand	>130

SSFATE MODEL EQUATIONS

Sediment Transport

The basic equation determining the location of each particle at the next time step in the simulation is given below:

$$X^{n+1} = X^{n} + \Delta X \tag{1}$$

$$Y^{n+1} = Y^{n} + \Delta Y \tag{2}$$

$$Z^{n+1} = Z^{n} + \Delta Z \tag{3}$$

where

$$\Delta X = U\Delta T + L_x \tag{4}$$

$$\Delta Y = V\Delta T + L_y \tag{5}$$

$$\Delta Z = Ws_i\Delta T + L_z \tag{6}$$

where

X,Y, Z = location of particle in the x-, y- and vertical directions, respectively
U, V = mean ambient velocity in the x- and y-directions, respectively
ΔT = time step
Ws_i = settling velocity of particle class *i*
L_x, L_y, L_z = particle diffusion distances in x-, y- and vertical directions, respectively

Particle diffusion is assumed to follow a simple random walk process. A diffusion distance defined as the square root of the product of an input diffusion coefficient and the time step is decomposed into X and Y displacements via a random direction function. The Z diffusion distance is scaled by a random positive or negative direction. The equations for the horizontal and vertical diffusion displacements are written as:

$$L_x = \sqrt{D_h \Delta T} \;\; COS \;\; (2pR) \tag{7}$$

$$L_y = \sqrt{D_h \Delta T} \;\; SIN \;\; (2\pi R) \tag{8}$$

$$L_z = \sqrt{D_z \Delta T} \;\; (0.5 - R) \tag{9}$$

where

D_h, D_z = horizontal and vertical diffusion coefficients, respectively
R = random real number between 0 and 1

The particle model allows the user to predict the transport and fate of classes of settling particles, e.g., sands, silts, and clays. The fate of multi-component mixtures of suspended sediments is predicted by linear superposition. The particle-based approach is robust and independent of the grid system. Thus, the method is not subject to artificial diffusion near sharp concentration gradients and is easily interfaced with all types of sediment sources, i.e., different dredging technologies as well as jet trenchers and plows.

In addition to transport and dispersion, sediment particles also settle at some rate through the water column to the bottom. Settling of mixtures of particles, some of which may be cohesive in nature, is a complex but predictable process with the different size classes interacting, i.e., the settling of one particle type is not independent of the other types. In addition, the clay-sized particles, typically cohesive, undergo enhanced settling due to flocculation. These processes have been implemented in SSFATE and are based on previous USACE studies (Teeter, 1998).

At the end of each time step the concentration of each sediment class C_i as well as the total concentration C is computed on a concentration numerical grid. The size of all grid cells is the same relative to one another in time, with the total number of cells increasing as the suspended sediment plume moves away from the dredging source.

Sediment Settling Velocity

The settling velocity of each particle size class, except for coarse sand, is computed as

$$Ws_i = a\left(\frac{C}{\overline{C}_{ul}}\right)^{n_i} \tag{10}$$

$$a = \frac{1}{C}\sum_i a_i C_i \tag{11}$$

$$\overline{C}_{ul} = \frac{1}{C}\sum_i C_{ul_i} C_i \tag{12}$$

$$\overline{C}_{ll} = \frac{1}{C}\sum_i C_{ll_i} C_i \tag{13}$$

where
C_{uli} and C_{lli} are the nominal upper and lower concentration limits, respectively, for enhanced settling of grain class i,
a_i is a grain-size class average maximum floc settling velocity,
C is the total concentration for all grain size classes (except coarse sand).

If $C \gtrsim \overline{C}_{ul}$ then

$$Ws_i = a \tag{14}$$

whereas, if $C \lesssim \overline{C}_{ll}$ then

$$Ws_i = a\left(\frac{\overline{C}_{ll}}{\overline{C}_{ul}}\right)^{n_i} \tag{15}$$

Typical values of C_{uli} , C_{lli} , a_i, and n_i for four size classes are given in Table 2. The settling velocity for class size 5 (coarse sand) is assumed constant at 0.1 m/s.

Table 2. Typical values of coefficients.

Class	Size (microns)	C_{lli} (mg/L)	C_{uli} (mg/L)	a_i (m/s)	n_i
1	0-7(clay)	50	1000	0.0008	1.33
2	8-35(fine silt)	150	3000	0.0023	1.10
3	36-74(coarse silt)	250	5000	0.0038	0.9
4	75-130(fine sand)	400	8000	0.0106	0.8

Sediment Deposition:

Sediment mass is removed from the largest size class first. The deposition for the remaining size classes is then computed, starting with the second largest size class and working down to the smallest. This deposition flux is computed as follows:

If $0 \lesssim P_i \lesssim 0.05$, then

$$Flux_i = \frac{C_i Flux_{i+1}}{C_{i+1} + 1} \tag{16}$$

otherwise,

$$Flux_i = b_i\, C_i\, W_{si}\, P_i \tag{17}$$

where

P_i = deposition probability (described below) of i-th class
C_i = sediment concentration
Ws_i = calculated settling velocity
b_i = empirical parameter that includes all other factors influencing deposition other than shear.

Table 3 lists typical values for the coefficient b_i for the four smaller size classes.

Table 3. Typical values for b_i.

Class	b_i
1 (clay)	0.2
2 (fine silt)	0.4
3 (coarse silt)	0.6
4 (fine sand)	1.0

The deposition probability, P_i is calculated as follows,

P_1 , for size class 1 (clay);

$$P_1 = \left(1 - \frac{\tau}{\tau_{cd}}\right) \text{, if } \tau < \tau_{cd} \tag{18}$$

$$P_1 = 0 \text{ , if } \tau > \tau_{cd} \tag{19}$$

where τ_{cd} is the critical shear stress for deposition for the clay fraction. A typical value for τ_{cd} is 0.016 Pa. The bottom shear stress is based on the combined velocity due to waves and currents using the parametric approximation by Soulsby (1998). Both waves and currents are external to SSFATE. Wave information can be input from either observed time series (significant wave amplitude, period and direction) or from numerical wave models (such as SWAN). Current inputs are likely form hydrodynamic models. SSFATE can use various forms of current file including HYDROMAP output and COARD compliant NetCDF files.

P_i , for other size classes (2, 3 and 4);

$$P_i = 0 \text{ , if } \tau \geq \tau_{uli} \tag{20}$$

$$P_i = 1.0 \text{ , if } \tau \leq \tau_{lli} \tag{21}$$

where

τ_{uli} = the shear stress above which no deposition occurs for grain class *i*
τ_{lli} = the shear stress below which the deposition probability for grain class *i*

For values of τ between τ_{lli} and τ_{uli} , linear interpolation is used. Typical values for τ_{lli} and τ_{uli} are given in Table 4.

Table 4: Typical values for τ_{lli} and τ_{uli}

Class	τ_{lli} (Pa)	τ_{uli} (Pa)
2 (fine silt)	0.03	0.06
3 (coarse silt)	0.06	0.20
4 (fine sand)	0.20	0.90

SSFATE represents each sediment class by a set of Lagrangian particles. Their locations correspond to a cloud center of the Gaussian distribution of designated sediment. Several Lagrangian particle packets are released (simulating sediment loss during a dredging operation) per computational time step. Each packet consists of 25 particles that represent sediment types (clay, fine silt, coarse silt, fine sand, and coarse sand) and vertical distributions. For a 5-packet release over a 5-day simulation, for example, the total number of Lagrangian particles would be ~180,000 (25 x 5 packets per every time step (5 min) for 5 days). Lagrangian particles do not deposit as whole but by fractions based on the calculated flux described in the above formulations. Actual deposition can continue to occur indefinitely from the remaining particle mass for each class and deposit location. The distribution of deposited mass is mapped on the same Eulerian grid and the water column concentration.

Sediment Resuspension

Sediments that have been lost from the dredging process and redeposited on the bottom are fundamentally different from the undisturbed sediments upon which they fall. The new sediments are often very high in water content since no consolidation has yet taken place and are more easily resuspended than the undisturbed sediments. Since the purpose of SSFATE is to track only sediment lost from dredging operations and not the general sediment transport in the area, the algorithms must account for this difference. The selected resuspension algorithm therefore consists of a combination of two schemes,

> Scheme-1: The critical shear stress for resuspension is based on accumulated sediment deposition mass from the recent past (~ within one tidal period).
>
> Scheme-2: Existing physical properties of sediments determine the critical shear stress for resuspension. This is similar to the traditional formulation and the time history of deposition is not taken into account.

Dredging operations, particularly maintenance dredging near urban estuaries, excavate sediments with significantly high clay and silt content (>50%). Unlike natural erosion and deposition cycles in which sediment mass movements are gradual and cumulative, these deposited sediments may be significantly different in that large amounts of clay and silt portions can be suspended and then resettle in a short period. Resuspension of this portion (deposited mass within ~6 hours) is simulated by Scheme-1. For those sediments that are not subject to Scheme-1 (deposited but not resuspended within this period) they may be resuspended by Scheme-2. Sediments deposited during quiescent periods (small currents for longer than ~6 hours) will not ever be resuspended by Scheme-1, but may be resuspended by Scheme-2 when they encounter stronger currents and waves (storms) later on.

Potential resuspension is evaluated for both Scheme-1 and Scheme-2 at each computational time step. The scheme that yields higher suspension is used. Scheme-1 only evaluates those sediments deposited within 6 hrs independent of how they were suspended. Irrespective of which scheme is used, only sediments that originated from dredging operations are potentially resuspended, i.e. natural sediments are not suspended, although bottom sediment characteristics are combinations of dredged and underlying natural sediments. The main objective of Scheme-1 is to augment floc resuspension that Scheme-2 will miss.

Resuspension algorithm of Scheme-1:

This scheme is based on the work of Sanford and Maa (2001), and subsequently, Lin et al. (2003). Lin et al. applied Sanford and Maa's approach, which is empirical and based on the sea carousel experiments. It allows the critical shear stress for erosion to vary with the deposition and erosion history at the bed, and was used in a three-dimensional sediment transport model to simulate suspended sediment distributions in Baltimore Harbor, Maryland, USA. The results of the model compared favorably with the observational data. Particularly attractive aspects of this scheme are the analogy of the deposition history concept to dredging sediments and its simplicity of resuspension formulations;

$$E = M\left(\tau_b - \tau_c\right) \tag{22}$$

$$M = 0.027\left(m - 0.017\right)^{0.54} \tag{23}$$

$$\tau_c = 0.86\left(m - 0.017\right)^{0.5} \tag{24}$$

where

E is the resuspension rate (kg/m^2/s)
M is an empirical parameter (kg/m^2/s/Pa)
τ_b is the bed shear stress (Pa)
τ_c is the critical shear stress (Pa) for resuspension

M and τ_c are functions of the sediment mass m (kg/m^2) accumulated over last deposition and erosion cycle.

Resuspension algorithm of Scheme-2:

This traditional scheme is based on van Rijn (1989). The resuspension rate is defined as

$$E = b_i \rho C_{ai} Q_p \tag{25}$$

where

E is the resuspension rate (kg/m^2/s)
b_i is a correction factor
ρ is the sediment density (kg/m^3)
C_{ai} is reference concentration (non-dimensional) of i-th sediment at the reference height from the bed from van Rijn (1989)'s formulation
Q_p is the sediment pickup function

The reference concentration and pickup function are defined as

$$C_{ai} = 0.015 \frac{D_i}{a} \frac{T^{1.5}}{D_*^{0.3}} \tag{26}$$

$$Q_p = kU_* \tag{27}$$

with

$$T = \frac{\tau_b - \tau_{cr}}{\tau_{cr}} \tag{28}$$

$$\tau_{cr} = \theta_{cr} \rho (s-1) g D_i \tag{29}$$

$$\theta_{cr} = \frac{0.3}{1+1.2D_*} + 0.055\left[1 - e^{-0.02D_*}\right] \tag{30}$$

$$D_* = D_{50} \left(\frac{(s-1)g}{\nu^2} \right)^{1/3} \tag{31}$$

where

D_i is characteristic sediment size
D_* is non-dimensional sediment grain size
T is the transport parameter
a is the reference height (m, > bottom roughness)
τ_b is the effective bed shear stress (Pa) under combined waves and current
τ_{cr} is the Shields critical bed shear stress (Pa) for sediment suspension from Soulsby and Whitehouse (1997)
s is the specific density
g is the gravitational acceleration
ν is the kinematic viscosity of water

Resuspension fluxes based on the schemes above are evaluated at each Eulerian grid cell location where sediment deposition characteristics (accumulated mass, grain size, and history) are kept at every computational time step. When a resuspension flux is positive (a bottom stress exceeds either of the critical stresses), additional Lagrangian particle packets are released at the vertical height from the bed, z_i,

$$z_i = x\, Z_s \tag{32}$$

where

Z_s is the height of the sediment centroid based on the regression to Rouse profile (MacDonald et al 2006)
x is the time factor for the Rouse profile to develop full height.

These parameters are defined as

$$Z_s = 0.0398\; h\, 10^{-1.08 \tanh\left[1.2 \ln\left(\frac{Ws_i}{kU*}\right) - 0.4\right]} \tag{33}$$

$$x = 1.0 - \exp\left(-\sqrt{2 D_z \Delta t}\,\frac{2}{h}\right) \tag{34}$$

where

h = water depth
k = von Karman's constant
U_* = friction velocity
D_z = depth averaged vertical viscosity of water
Δt is the computational time step.

MODEL RESULTS

A series of model runs was performed as a proof of concept for the resuspension approach chosen. The model runs consisted of an application to a simple channel case with constant depth and bidirectional tidal currents and a more realistic case with actual bathymetry and complex tidal currents. This case was taken from an actual application of SSFATE to a proposed dredging operation in China. The purpose of these test cases was to examine the difference in results without resuspension and with the new resuspension algorithms.

Simple Channel Results

A simple test case of a channel 10 m deep with an oscillating tidal current of 33 cm/s is first presented to show the effects of resuspension. A sediment source of 7.6 kg/s was simulated for two days and then no additional sediment was released while the model ran for a additional three days. The sediment was equally divided among the five fractions (20% each). The sediment mass in the water column and on the bottom was tracked over that 5-day period and expressed as a percentage of total mass released. Figure 1 shows the time series from the model. The total mass in the system is seen to rise linearly for the first two days and then stay constant for the subsequent three days. The tidal velocity variation is shown as is the phasing of sedimentation to velocity. Most of the sediment released deposited quickly on the bottom as shown by the small amount of mass in the water column at any time (maximum of less than 7% at 1.5 to 2 days into the simulation. Towards the end of the simulation only 2.5% of the sediment released remained in the water column.

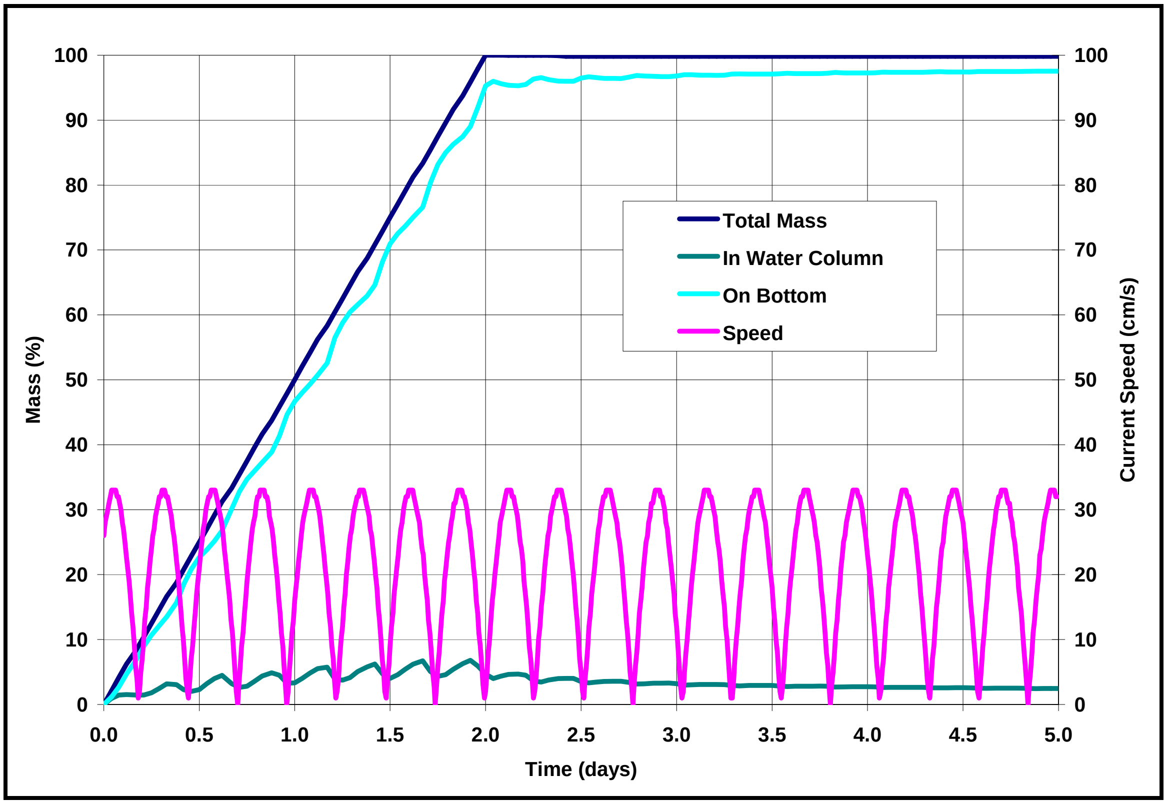

Figure 1. Time series of sediment mass balance for case of no resuspension in simple tidal channel. Mass input stops after two days. Small fraction of fine particles remains suspended in water column.

The model results when resuspension is included are shown in Figure 2. Here the effects of the oscillating tidal velocity are clearly seen. At times of slack water the sediment settles to the bottom with less than 3% remaining in the water column. At maximum currents the mass resuspended back into the water column reaches 12%. There is a clear pattern of resuspension and deposition in phase with the tidal velocities. The condition at slack water is very similar to the no resuspension case shown in Figure 1 as expected.

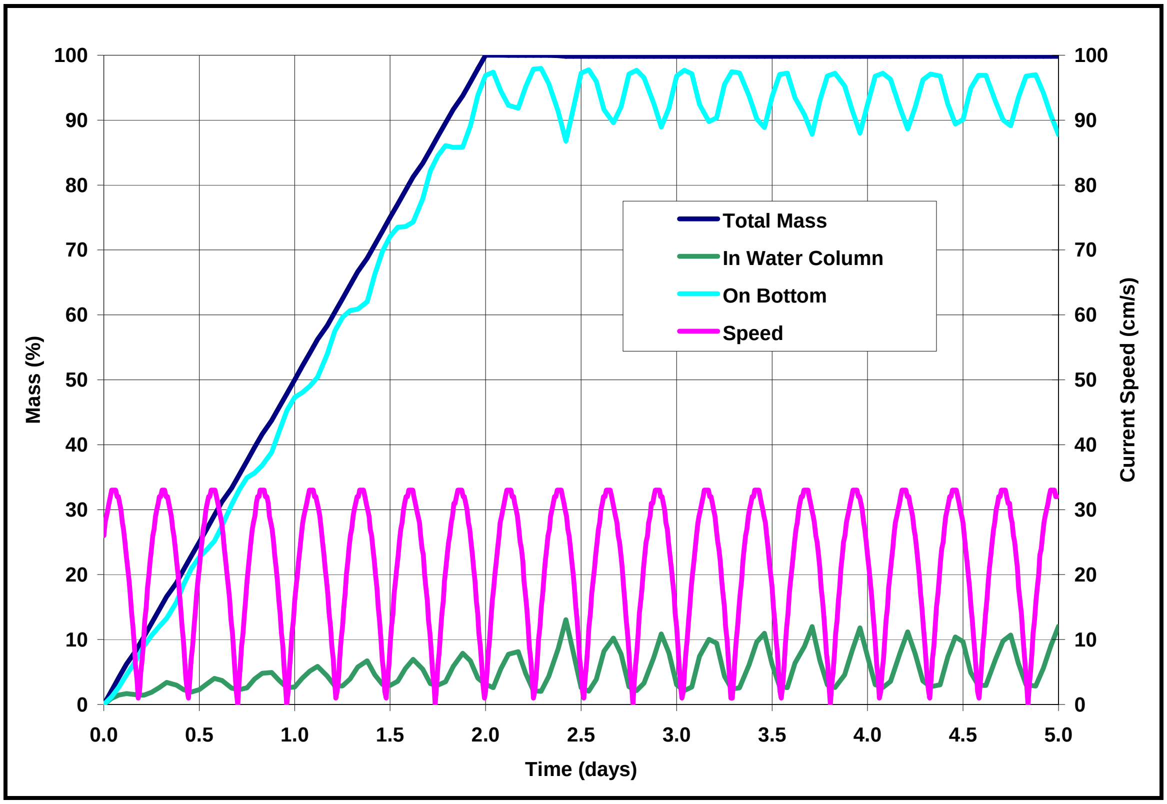

Figure 2. Time series of sediment mass balance for case of resuspension in simple tidal channel. Mass input stops after two days. Small fraction of fine particles remains suspended in water column.

To assess the changes in bottom deposition patterns between the two conditions Figures 3 and 4 show the plan views of cumulative deposition after five days. The release point is shown circle with a cross at the center of the pattern. The pattern is shown as a series of contours of bottom concentration expressed as g/m^2. Highest deposition occurs at the release site consistent with the heavier fractions quickly settling out of the water column. The pattern shows some variability due to the random walk diffusion used in moving the sediment particles through the water column. Figure 3 shows a very elongated pattern that reaches approximately 4.5 km from the release point. This is consistent with the theoretical excursion distance of 5.2 km. The width of the pattern is approximately 0.75 to 1 km.

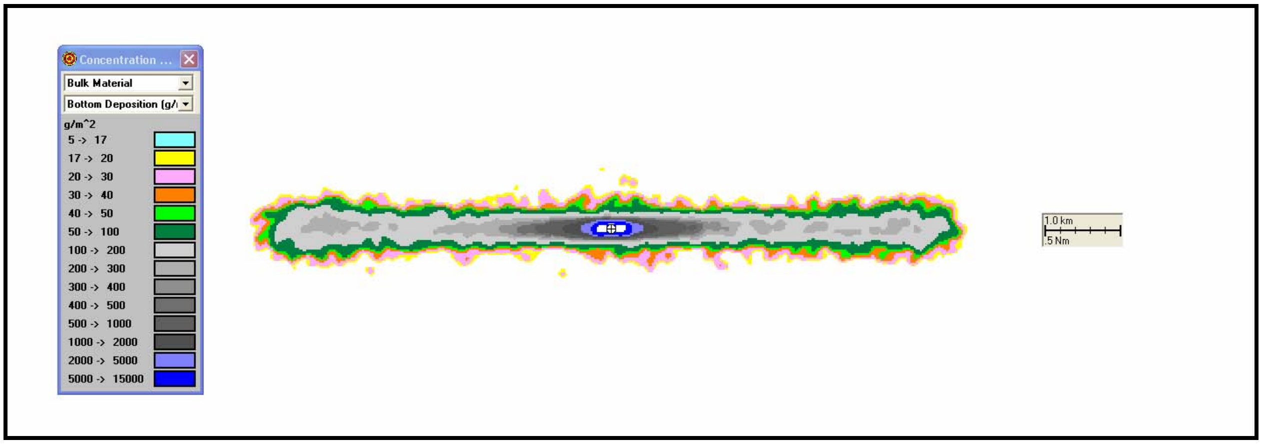

Figure 3. Cumulative bottom deposition pattern in plan view for case of no resuspension in simple tidal model.

Figure 4 shows snapshots of deposition patterns during the tidal cycle. This figure shows how each size fraction responds to the tidal velocity induced shear stress. The top panel shows deposition at slack water after a left-running tide. Here the material has deposited on the bottom since the currents are very small. The length of the pattern from the release point to its left most edge is 6.5 km and the width is approximately 2.2 km. There is a center section that consists of the larger size fractions that is constant throughout the tide cycle. The center panel shows the bottom deposition remaining during the maximum current condition. Only the larger size fractions remain on the bottom. The total length of this pattern is approximately 5 km and the width is 0.9 km. The lower panel shows deposition at slack water after a right-running tide. These results are almost the mirror image of the top panel. The slight differences are due to both the random walk diffusion and that the panels were created from results output on the hour over the 12.42 hr tidal cycle and therefore not exactly at slack and maximum current conditions.

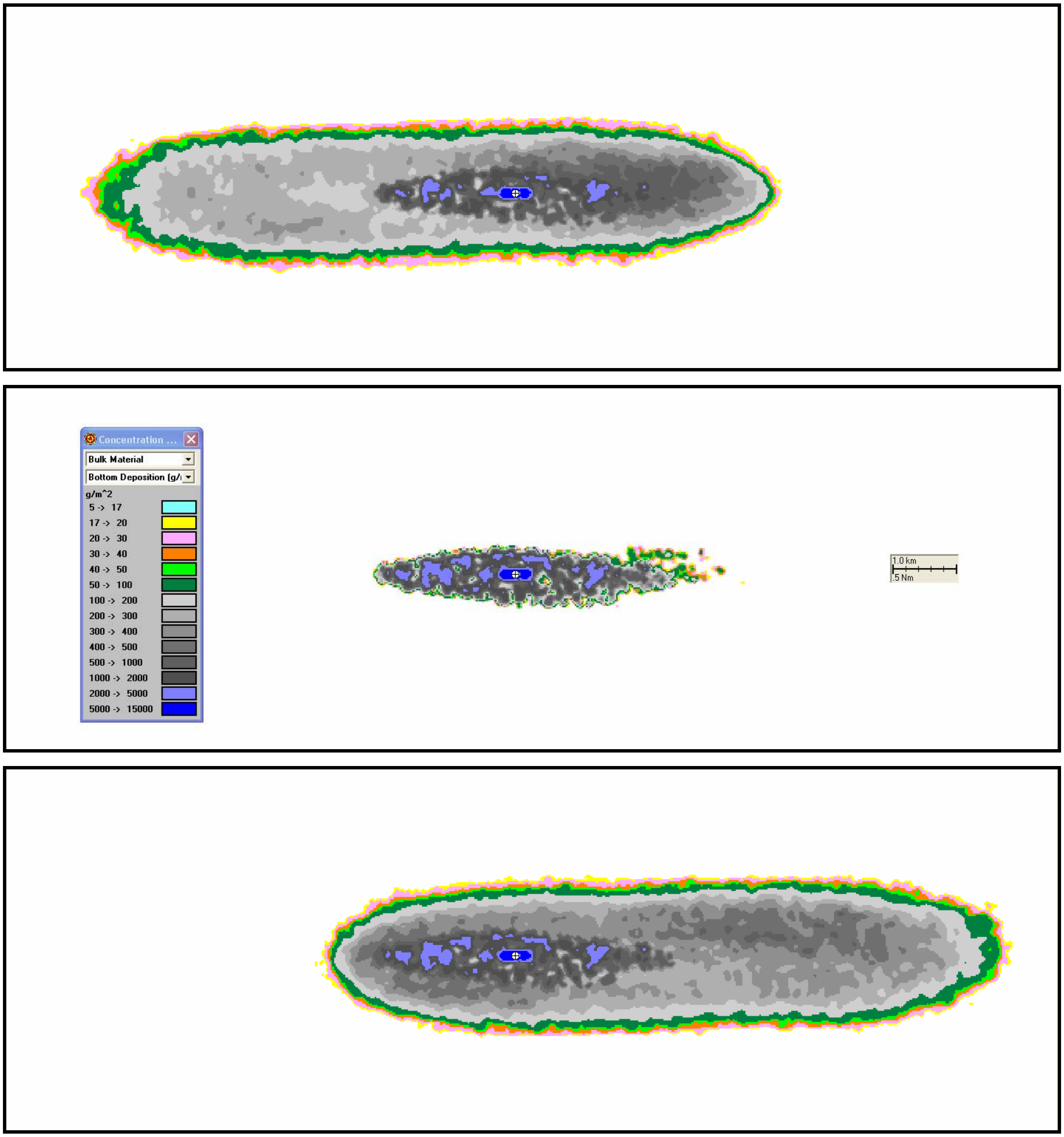

Figure 4. Cumulative bottom deposition pattern in plan view for case of resuspension in simple tidal model. Top panel shows deposition at slack water after left running tide. Mid panel shows deposition at maximum current. Bottom panel shows deposition at slack water after right running tide.

Application to Real Conditions

To further test the model with respect to the inclusion of resuspension SSFATE was reapplied to a project previously completed. This project involved the dredging of a channel in a coastal area averaging approximately 10 m deep. Bathymetry for the area is shown in Figure 5. It is gently sloping, increasing in depth from east to west, away from the shore, shown in gray. The hydrodynamic model used was HYDROMAP (Isaji et al., 2001) an auto nesting, telescopic grid model. The grid cell size in the area of interest is 310 m with a doubling of the cell size shown in the bottom right portion of the figure. The location of the dredging is shown as cross embedded in a circle near the center of the figure.

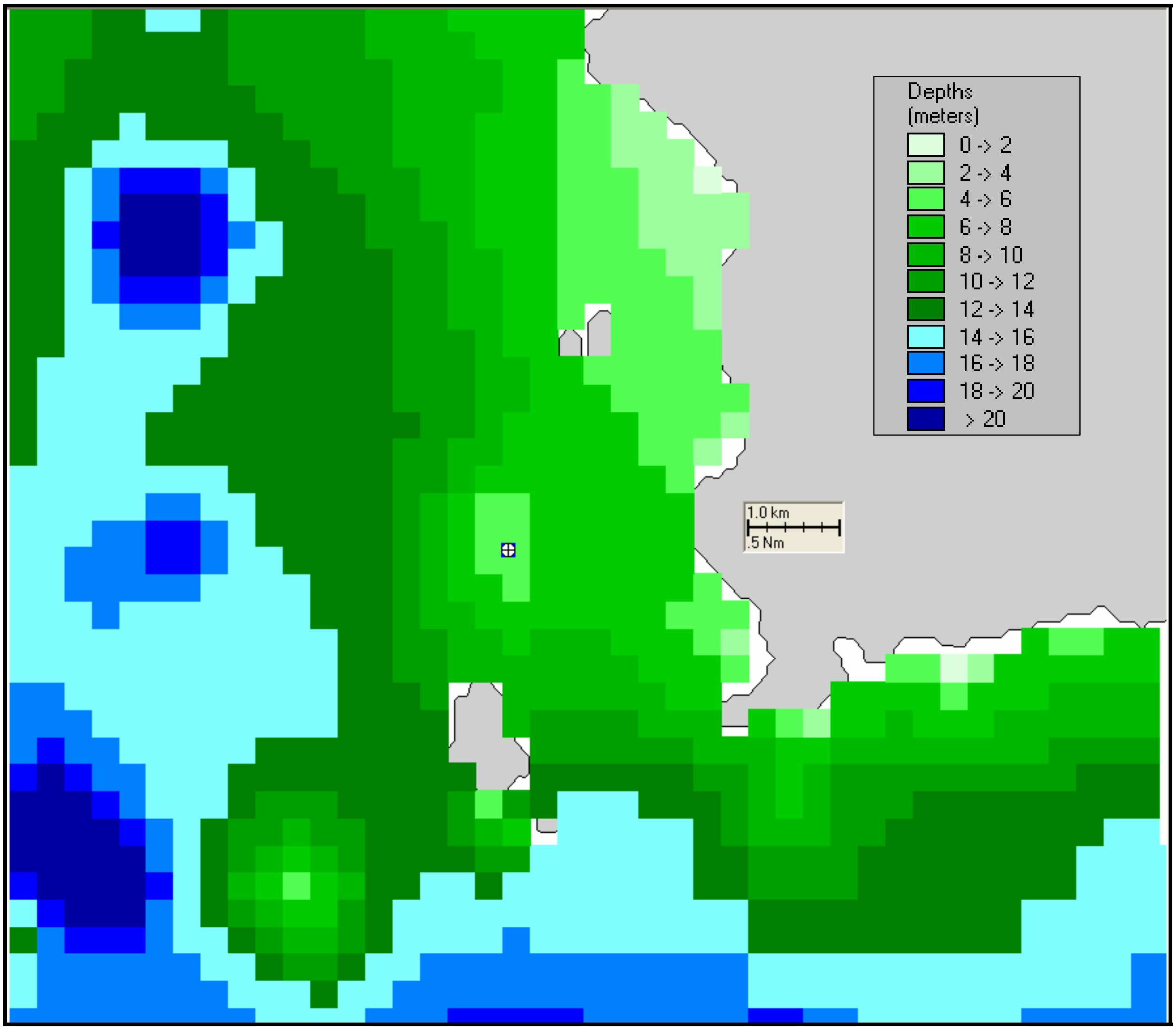

Figure 5. Bathymetry of example location.

The area is primarily driven by the semidiurnal (M2) tide. Figure 6 shows the maximum ebb (left panel) and maximum flood (right panel). The vectors are scaled by speed as shown in the embedded window with orientation in the direction of the current. Ebb tide is primarily south along the coast and then east at the bottom of the figure and flood tide is generally the reverse. The strait between the southwest corner of the main land mass and an offshore island to the west shows highest currents in the region. North of the dredging site the currents are essentially north and south. South of the dredging site the currents are generally north northwest and south southeast.

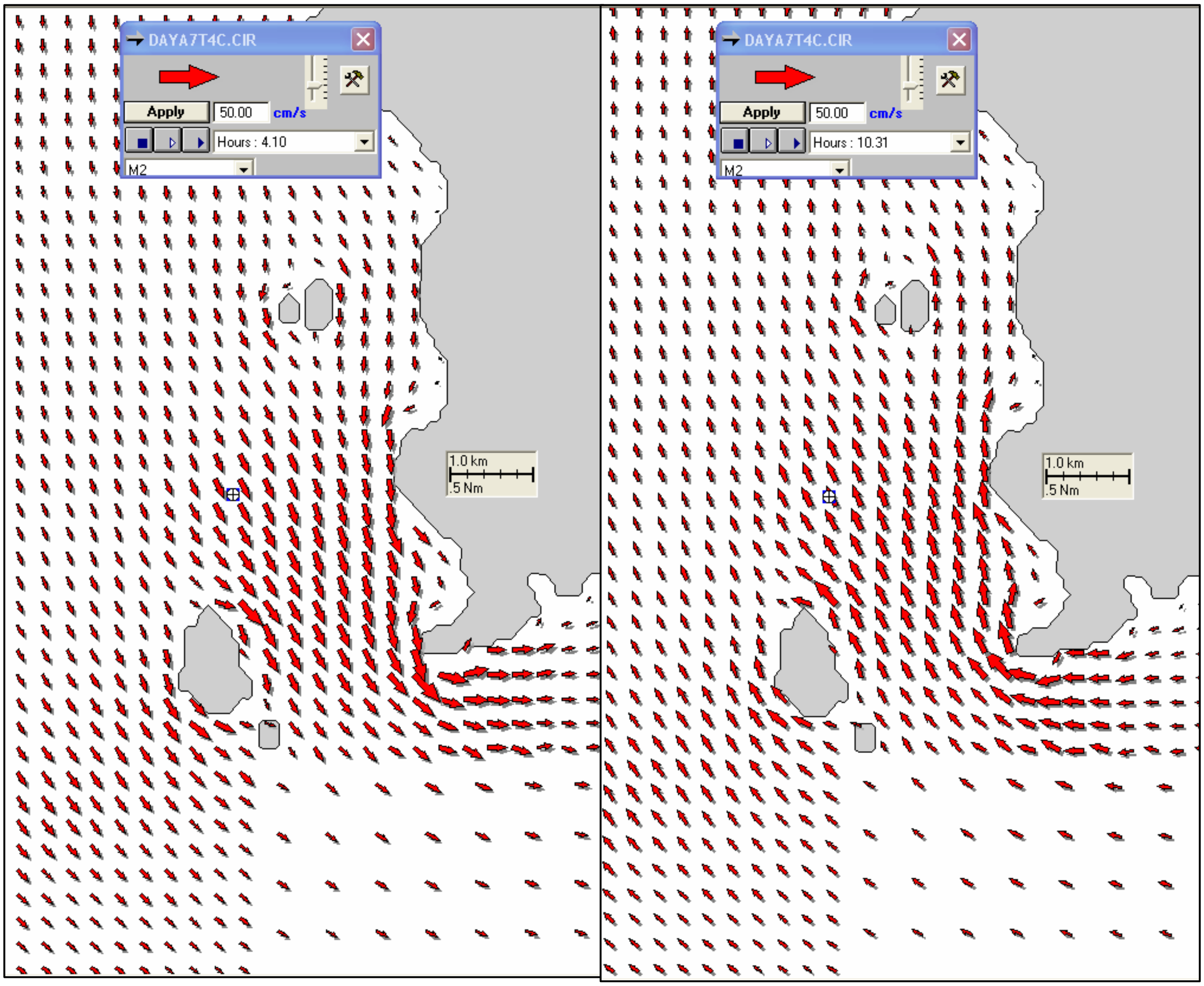

Figure 5. Ebb (left panel) and flood (right panel) tidal currents for example site.

A sediment source of 7.6 kg/s was simulated for two days and then no additional sediment was released while the model ran for a additional three days. As before, the sediment was equally divided among the five fractions (20% each). The sediment mass in the water column and on the bottom was tracked over that 5-day period and expressed as a percentage of total mass released. Figure 6 shows the time series from the model without resuspension. The total mass in the system is seen to rise linearly for the first two days and then stay constant for the subsequent three days. The tidal velocity variation is shown the phasing of sedimentation to velocity. The velocity is never at a slack water condition (zero velocity) since the tidal currents are rotary and not purely rectilinear. Most of the sediment released deposited quickly on the bottom as shown by the small amount of mass in the water column at any time (maximum of 9.5% at 1.85 days into the simulation. At the end of the simulation only 2.6% of the sediment released remained in the water column. There is a slight negative slope to the water column mass and a slight positive slope to the mass deposited on the bottom indicating a slow deposition of the smaller fractions.

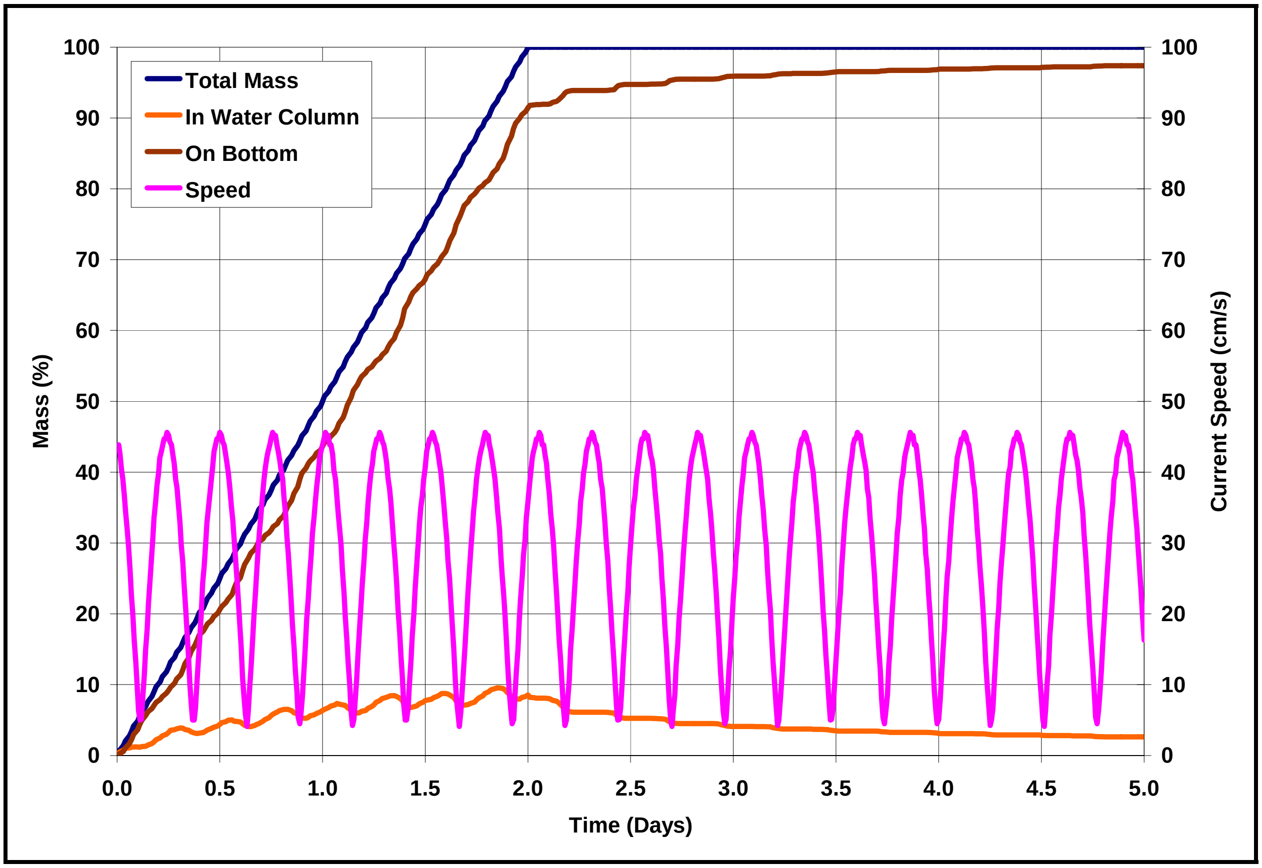

Figure 6. Time series of sediment mass balance for case of no resuspension in an actual coastal location. Mass input stops after two days. Small fraction of fine particles remains suspended in water column.

The model results for the actual coastal location when resuspension is included are shown in Figure 7. Here the effects of the oscillating tidal velocity are clearly seen. At times of low current speed the resuspended sediment settles to the bottom. At relatively high currents a portion of the mass on the bottom is resuspended back into the water column. There is a clear pattern of resuspension and deposition in phase with the tidal velocities. As with the no resuspension case there is a slight negative slope to the water column mass and a slight positive slope to the mass deposited on the bottom indicating a slow deposition of the smaller fractions. However the maximum mass on the bottom does not exceed 90% although the minimum mass slowly increases to about 80% at the end of the 5-day simulation.

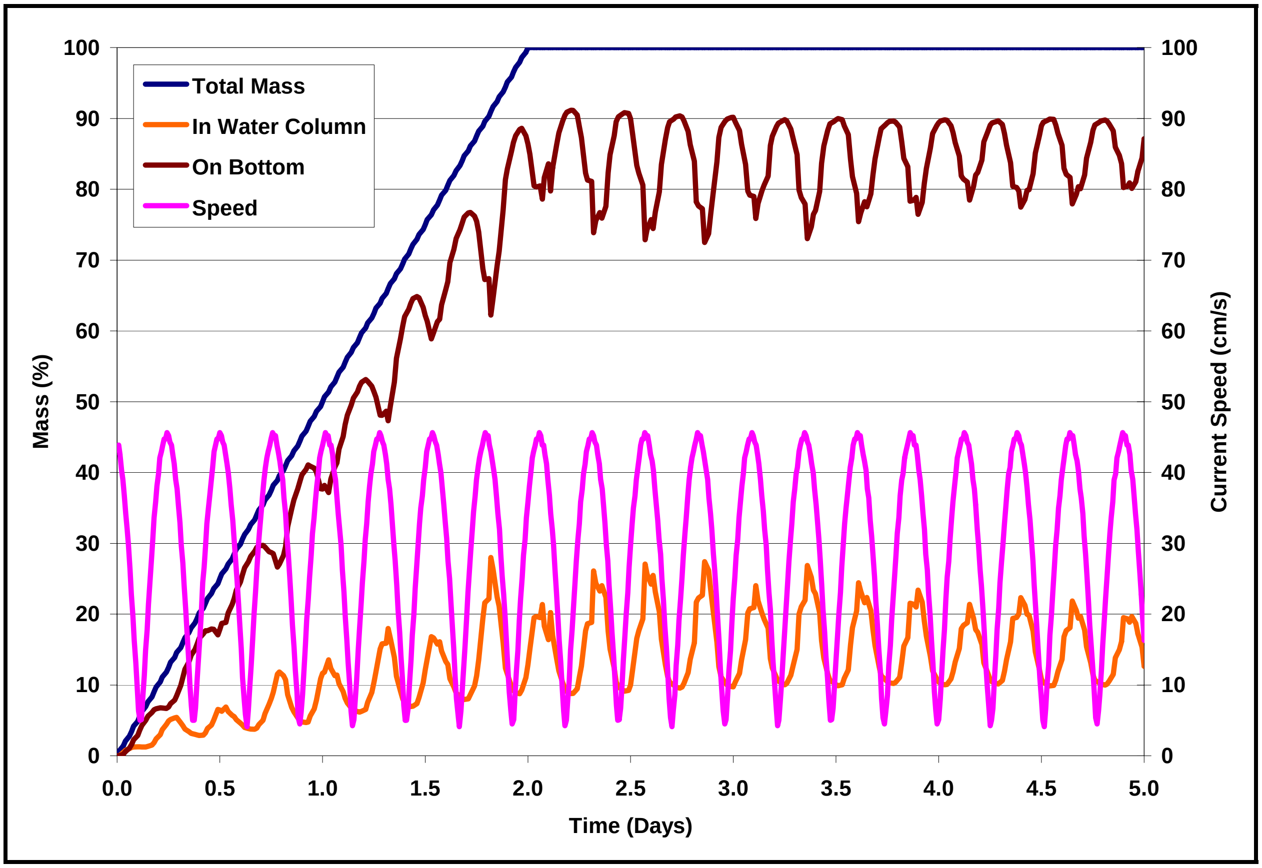

Figure 7. Time series of sediment mass balance for case of resuspension in an actual coastal location. Mass input stops after two days. Small fraction of fine particles remains suspended in water column.

The differences in bottom deposition patterns without and with resuspension are shown in Figure 8 after five days. The release point is shown circle with a cross at the center of the pattern. The pattern is shown as a series of contours of bottom concentration expressed as g/m^2. Both cases show an elongated pattern that follows the directions of the currents, particularly the eastward turning currents 3 km southeast of the release site. Both cases show high deposition near the release site that is due to the larger size particles settling quickly. The width of the deposition patter is significantly wider for the resuspension case compared to the non resuspension case and is due to the continual reworking of the freshly deposited fine fractions. The extent of the pattern is larger by about 1 km to the southeast for the resuspension case compared to the nonresuspension case. The larger deposition pattern is consistent with the simple channel case.

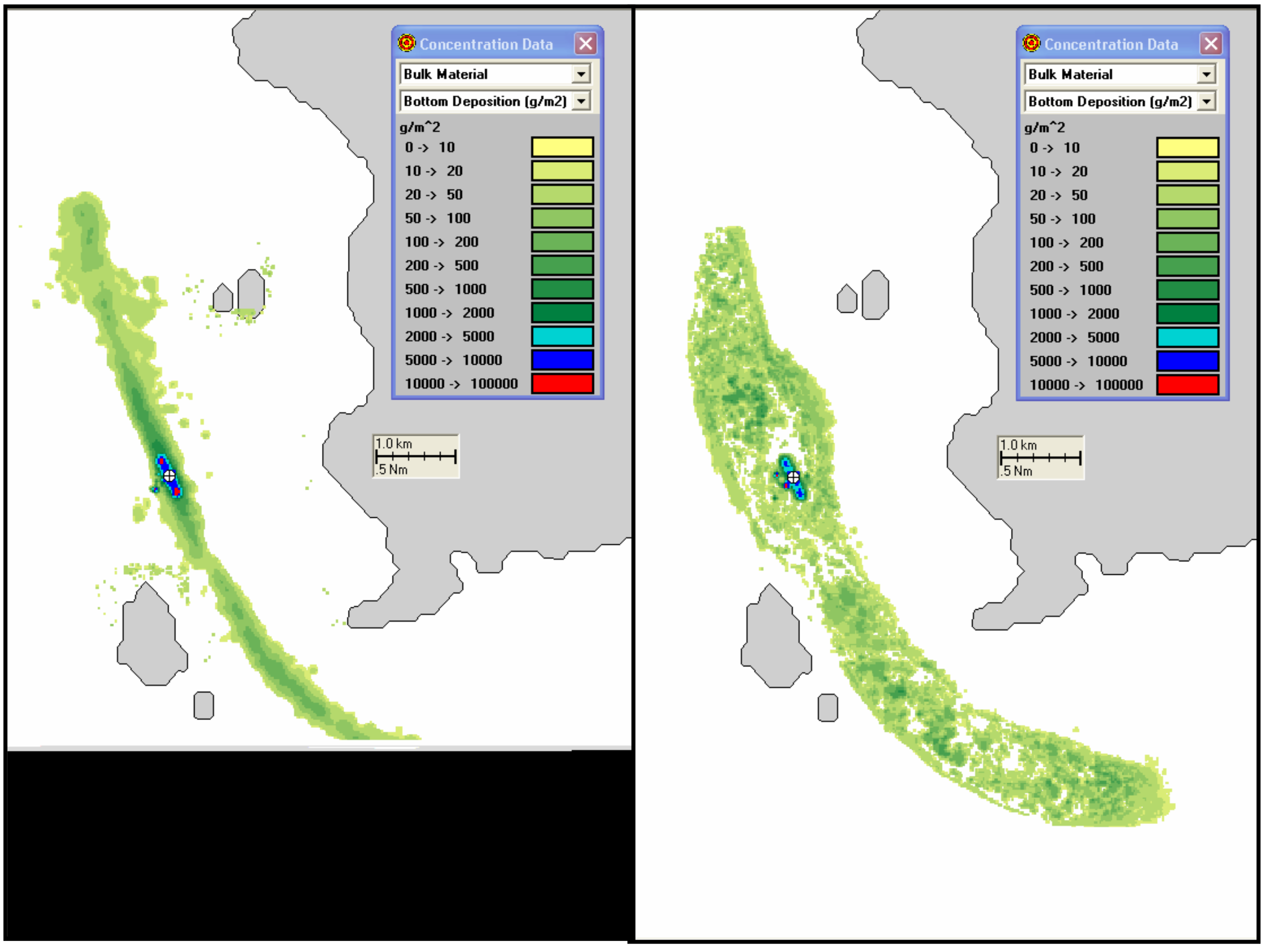

Figure 8. Plan view of cumulative bottom deposition for case of no resuspension (left panel) and resuspension (right panel) for an actual coastal application.

The final comparison between the cases is the maximum water column concentration shown in Figure 9. Maximum concentration is calculated by checking the concentration in each layer in the vertical at a grid cell for the entire 5-day simulation period. The nonresuspension case (on the left) shows the higher concentrations emanating from the release point and ultimately settling out. The resuspension case (on the right) dramatically shows the effects of increased suspended sediment concentrations both along the main axis of flow (north northwest to south southeast) as well as normal to that axis. The highest concentration is found in the lower water column where the resuspended sediment is typically found.

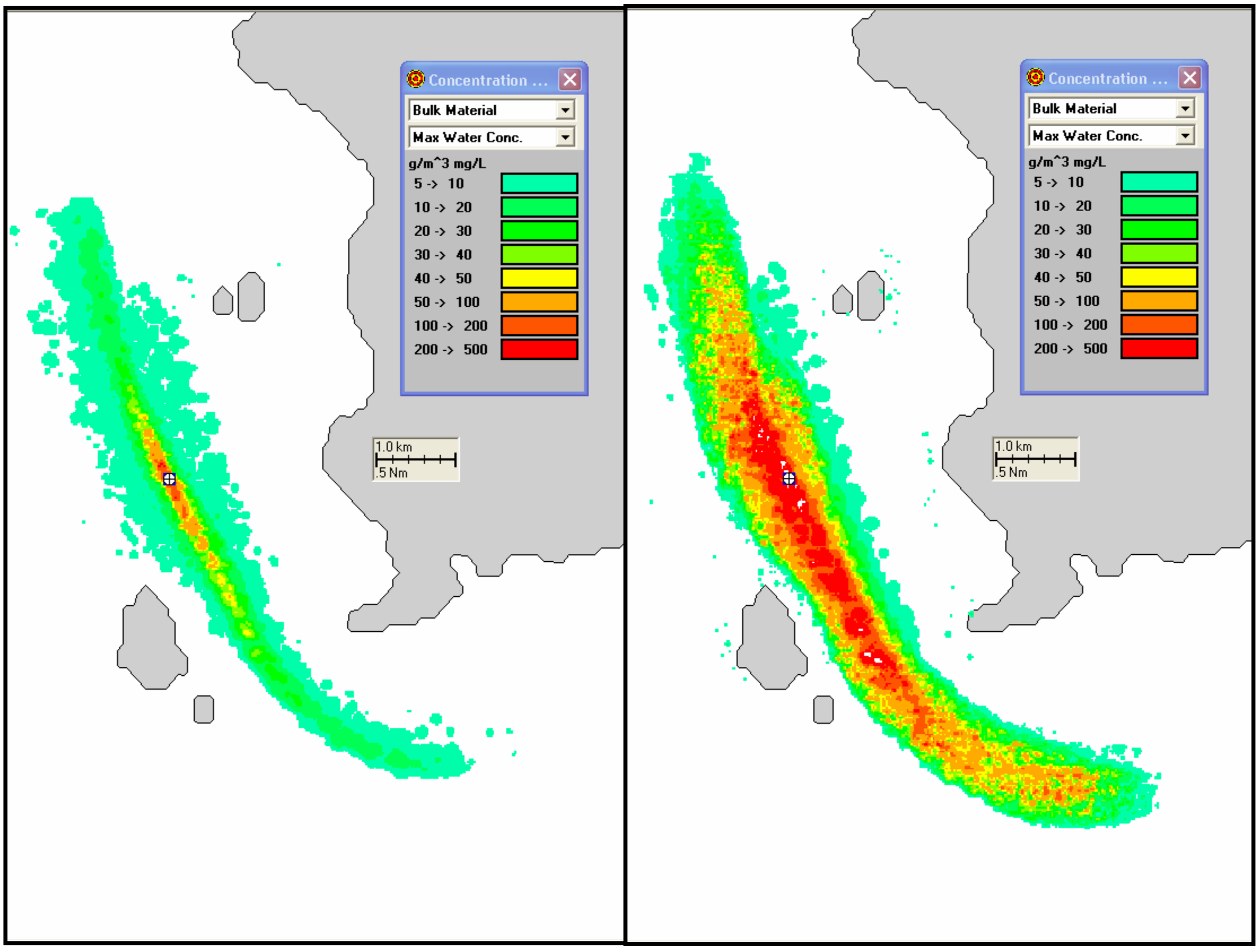

Figure 9. Plan view of maximum water column concentration for case of no resuspension (left panel) and resuspension (right panel) for an actual coastal application.

CONCLUSIONS

SSFATE (Suspended Sediment FATE) is a computer model originally developed jointly by the U.S. Army Corps of Engineers Engineer Research and Development Center and Applied Science Associates to estimate the water column suspended sediment concentrations and bottom deposition patterns resulting from dredging operations. Using a random walk procedure, the model tracks representative particle classes as they disperse in the water column and settle to the bottom. Model output includes water column suspended sediment concentrations and bottom deposition thicknesses. The model originally tracked only the initial deposition of sediment on the bottom as the local shear stress dropped below the critical deposition threshold. If the velocity (and shear stress) subsequently increased, the sediments were not resuspended. To expand the capability of the model to include resuspension and thus transport of suspended sediment after initial deposition, a two step resuspension algorithm was implemented.

Sediments that have been lost from the dredging process and redeposited on the bottom are fundamentally different from the undisturbed sediments upon which they fall. The new sediments are often very high in water content since no consolidation has yet taken place and are more easily resuspended than the undisturbed sediments. Since the purpose of SSFATE is to track only sediment lost from dredging operations a two scheme approach was selected,

Scheme-1: The critical shear stress for resuspension is based on accumulated sediment deposition mass from the recent past (~ within one tidal period).
Scheme-2: Existing physical properties of sediments determine the critical shear stress for resuspension. This is similar to the traditional formulation and the time history of deposition is not taken into account.

The expanded SSFATE model was tested to prove the concept for a simple channel configuration and an actual coastal application. Comparisons between the original nonresuspension version and the updated resuspension version were made for both applications. The addition of the resuspension calculation tended to cause a larger areal bottom deposition pattern and increased the maximum concentration away from the dredging site. The model provides consistent and reasonable results but remains to be tested against actual field data. Future work will concentrate on locating suitable data sets to verify model performance.

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