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Transport of Dredge-Induced Suspended Sediments in Asan Bay
아산만에서의 준설에 의한 부유사 이동

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1. INTRODUCTION

The dredging of sediments in navigation channels, harbors, and port areas is common practice throughout the world. There are two main factors governing the suitability of a site for the disposal of dredged material: Firstly, short-term recycling of material back into the dredged area must be low enough for the disposal method to be cost effective; Secondly, the environmental impact must be within an acceptable level (Diserens and Delo, 1989). For economic reasons much of the dredged material from the dredging operations is disposed back into the marine environment. Also, portions of sediments inevitably escape into ambient water during dredging operations, thus potentially impairing water quality and surrounding habitat. This impact is particularly significant when the bottom sediments being removed are contaminated by toxic pollutants. Dredging operations, both routine maintenance and channel deepening projects, have received increasing scrutiny in recent years because of these potential environment impacts. Under this scrutiny, procedures are needed to reduce this impact from dredging to a minimum, and to estimate the impact with some precision (Kuo and Hayes, 1991).

To quantify the degree of short-term recycling it is necessary to know the fate of the disposed material. In the past this has been done using tracer studies to examine the appropriateness of specific sites. However tracer studies involve considerable organization that limits the number of positions that can be investigated. A mathematical model that could predict the fate of material disposed at any given time and position would enable more effective minimization of short-term recycling. Due to the rising political importance of environmental issues, the influence of the disposal of polluted waste and dredged material on the marine environment are being increasingly investigated. Sediments dredged from channels passing through industrial areas are usually high in pollutants, particularly heavy metals. The prediction of the movement of these sediments are also considerable beneficial when assessing the environmental implications of proposed disposal schemes.

In this study, we developed a numerical model for predicting the short-term dispersion of dredged material in tidal waters and applied the model for simulating the dispersal of muddy dredged material in Asan Bay, Korea (Fig.1).

2. MODEL DEVELOPMENT

Sources of suspended sediments resulting from a bucket dredge operation include the sediments pulled from the bottom with bucket impact; loss of material as the bucket is pulled through the water column; spillage as the bucket travels in the air to the holding barge; overflow during the barge loading; and also the cleansing of the bucket as it descends through the water column (Kuo and Hayes, 1991). Because of the cycle of the bucket operation, suspended sediments from a series of patches tend to spread and merge as they are advected to downstream. Beyond the initial mixing zone, the plume may be considered as the result of a continuous line source stretching from the channel bottom to the water surface as shown in Fig. 2 The dispersion and deposition of suspended solids depend mainly on advection by currents, the settling of the sediment and the diffusion due to

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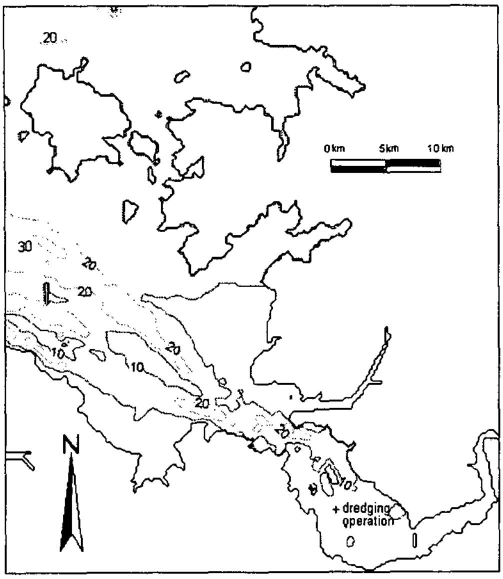


Fig. 1. Location Map of Dredging Site in Asan Bay

natural turbulence in the flow. The vertical velocity component of a suspended solid particle depends both on the characteristics of the ambient flow, turbulence conditions, and the sediment characteristics, such as size, shape and density of the particles and the tendency of the sediment to flocculate. The settling velocity reflects these properties. The turbidity plume assumes to be vertically well mixed. This assumption is a reasonable approximation for dredging in tidal rivers or estuaries where the tidal mixing is intense and the resuspended sediment particles are primarily fine-grained sediment such as clay and fine silt. In this model, the line plume is substituted with particles that have different settling velocities.

The σ -coordinate transformed transport equation for a conservative tracer C can be written as

$$\frac{\partial HC}{\partial t}+\frac{\partial UHC}{\partial x}+\frac{\partial VHC}{\partial y}+\frac{\partial \Omega C}{\partial \sigma} = \frac{\partial}{\partial x}\left(E_H H\frac{\partial C}{\partial x}\right)+\frac{\partial}{\partial y}\left(E_H H\frac{\partial C}{\partial y}\right)+\frac{\partial}{\partial \sigma}\left(\frac{E_V}{H}\frac{\partial C}{\partial \sigma}\right) \tag{1}$$

where $H\ (=h+\eta)$ is the total water depth, h is the water depth, η is the water surface elevation, U, V, Ω are the velocity components in the principal directions of x, y, σ −coordinates. Here, σ is defined by $(z-\eta)/H$ with z denoting positively upward from a fixed reference datum. E_H and E_V are the eddy diffusion coefficients in the horizontal and vertical directions, respectively. Writing the right hand side of Eq. (1) as a pure second derivative, the σ coordinate transformed transport equation becomes

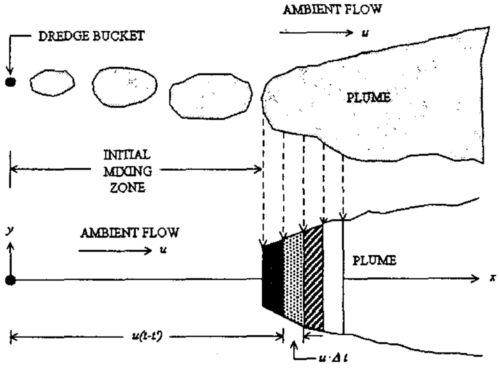


Fig. 2. Hypothetical Dredge-induced Plume (Adapted from Kuo and Hayes, 1991)

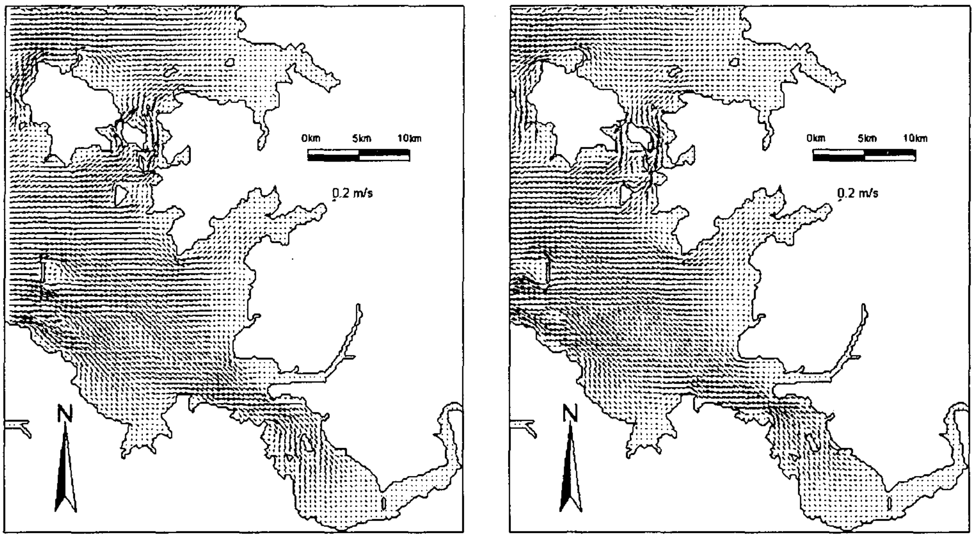
$$\frac{\partial HC}{\partial t}+\frac{\partial}{\partial x}\left[\left\{U+\frac{1}{H}\frac{\partial E_H H}{\partial x}\right\}HC\right] +\frac{\partial}{\partial y}\left[\left\{V+\frac{1}{H}\frac{\partial E_H H}{\partial y}\right\}HC\right] +\frac{\partial}{\partial \sigma}\left[\left\{\frac{\Omega}{H}+\frac{1}{H}\frac{\partial}{\partial \sigma}\left(\frac{E_V}{H}\right)\right\}HC\right] =\frac{\partial^2}{\partial x^2}(E_H HC)+\frac{\partial^2}{\partial y^2}(E_H HC)+\frac{\partial^2}{\partial \sigma^2}\left(\frac{E_V}{H^2}HC\right) \tag{2}$$

Then the σ transformed transport equation becomes the Fokker-Planck equation, and the positions of particles can be described by the non-linear Langevin equation using random numbers with zero mean and unity standard deviation (Zhang, 1995). In the staggered grid of the hydrodynamic model, the U, V, Ω velocity components are defined at cell interfaces in the x, y, σ directions. The velocity components of the particles are obtained by linear interpolation using the eight nearest available values. Both land and free surface boundaries are treated as non-flux boundaries where particles crossing the boundaries are reflected. Resuspension of particles from the bottom is ignored, thus the movement of particles is stopped at the bottom boundaries. Open sea boundaries are treated as flushing boundaries where a zero-concentration boundary condition is specified. Thus, particles crossing an open sea boundary are taken out of the domain. This approach assumes that open boundaries have been chosen far enough away from the sources to minimize the possible contribution from returning pollutants (Kim *et al.*, 2001).

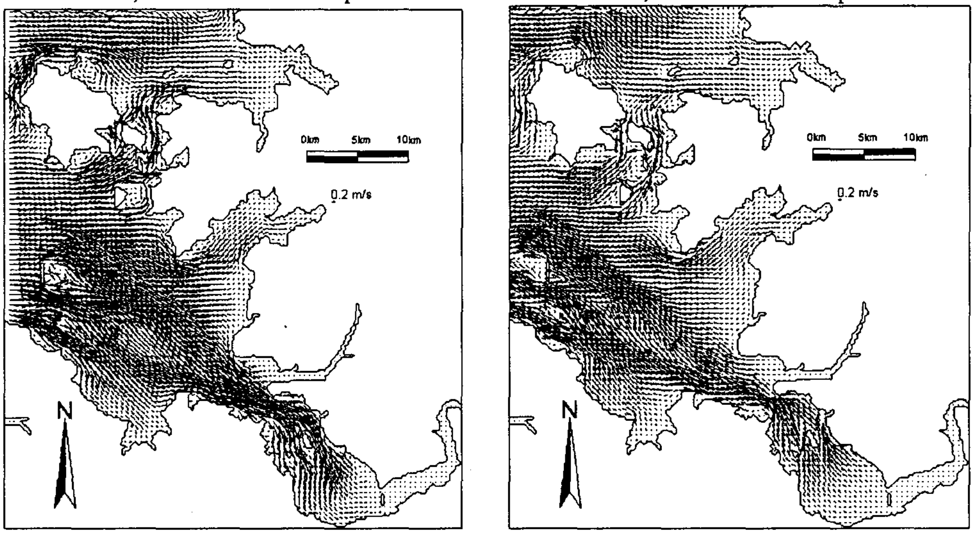
3. MODEL APPLICATION

3.1 Velocity Fields

To simulate strong tidal currents in Asan Bay, tidal calculation has been performed using a two-dimensional, depth-integrated nonlinear hydrodynamic model with a horizontal resolution of 250m. At land boundaries, the component of



a) flood current in neap tide b) ebb current in neap tide



c) flood current in spring tide d) ebb current in spring tide

Fig. 3. Calculated Velocity Fields

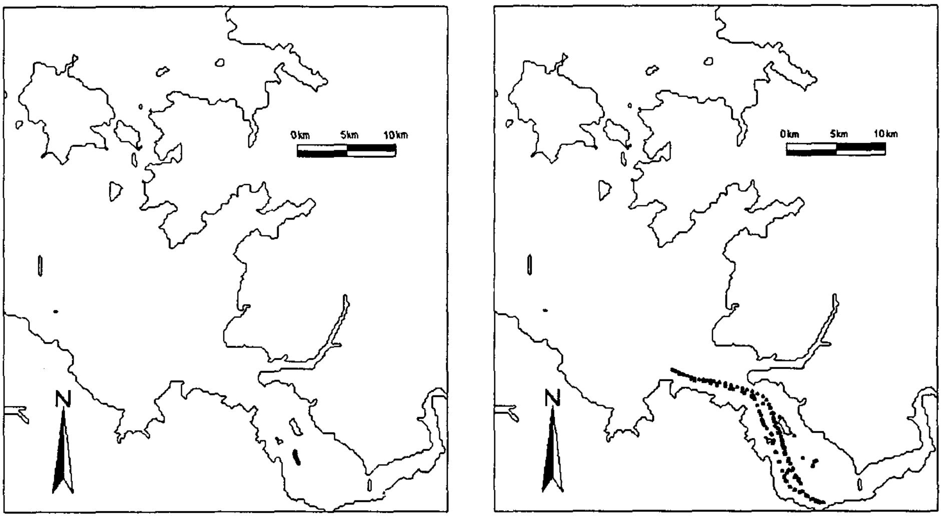
current normal to the boundary is set to zero. Along the open boundaries of the model, elevations derived by the M_2 and S_2 tides are specified. Horizontal diffusion terms are calculated using the Smagorinsky eddy diffusivity concept. The model has been run over 15 days starting from a state of rest to cover neap and spring conditions. The open boundary values of the M_2 and S_2 tides are interpolated from Lee et al (2001). Details on the distribution of tidal elevation and currents in Asan Bay are given in Lee et al (2001). The bottom topography of the region was prepared on the basis of a preliminary version of digital bottom bathymetry of adjacent seas of Korea. Previous calculations (Lee et al, 2001) showed the semi-major axises and directions for the M_2 currents in the region are reasonably well simulated, though the semi-major axises for the S_2 currents are generally overestimated. The computed velocity fields for flood and ebb tides are shown in Fig. 3. The strong current at dredging site during the spring tide is about 1m/s.

3.2 Concentration Fields

In the particle tracking simulation, the number of particles introduced at each time step is 100. The horizontal diffusion coefficients are given as 10 m^2/s (Kang et al., 1993), and the vertical diffusion coefficients are given as 10^{-5} m^2/s (Dimou, 1992). In this study, model simulations have been performed for 15 days with transport time interval of 1800. Typical values for the settling velocity of a particle used in the modeling of the far field transport are given in Table 1. The projected streaklines of particles for cases having different fall velocities are depicted in Fig. 4. In these simulations, single values of the settling velocity are used for each case in order to delineate the effect of the settling velocity. As shown in Fig. 4, the projected line gets longer as the settling velocity gets smaller. This indicates that particles settle down very fast without being advected widely when the settling velocity is high. Fig. 5 shows the spatial distribution of suspended sediment after 15 days' simulations period with the multi-component mixtures of 5 different sediment size classes in Table 1. This figure reveals that higher concentration occurs in the vicinity of the dredging site, and the concentrations become lower far from the dredging site because of particle deposition.

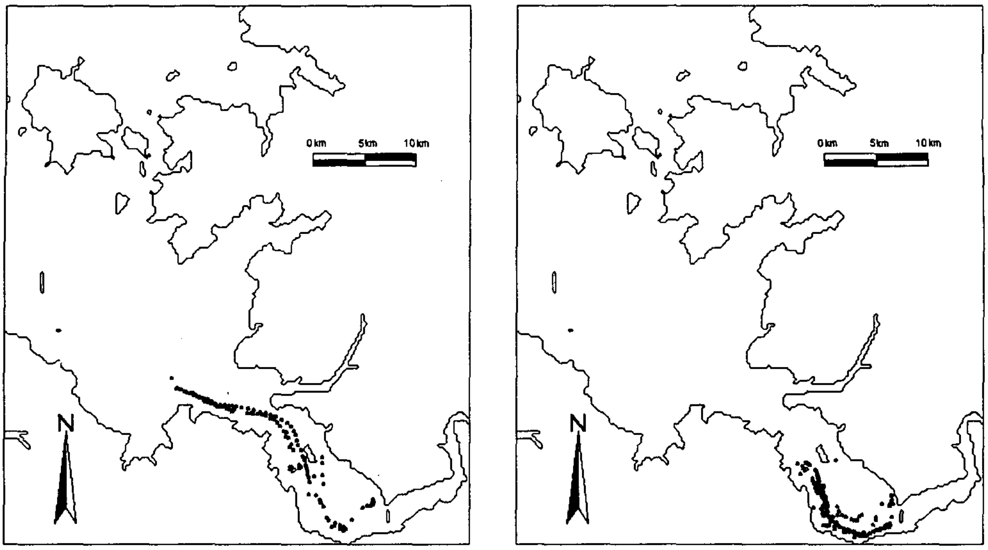
Table 1. Settling Velocity

Sediment Size Class	Particle Size (μm)	Settling Velocity (mm/s)	Percentage (%)
Chunks	N/A	N/A	5
Sand	>62	320	25
Coarse Silt	16~62	6.28	30
Fine Silt	3,3~16	0,394	20
Clay	<3.3	0,0134	20



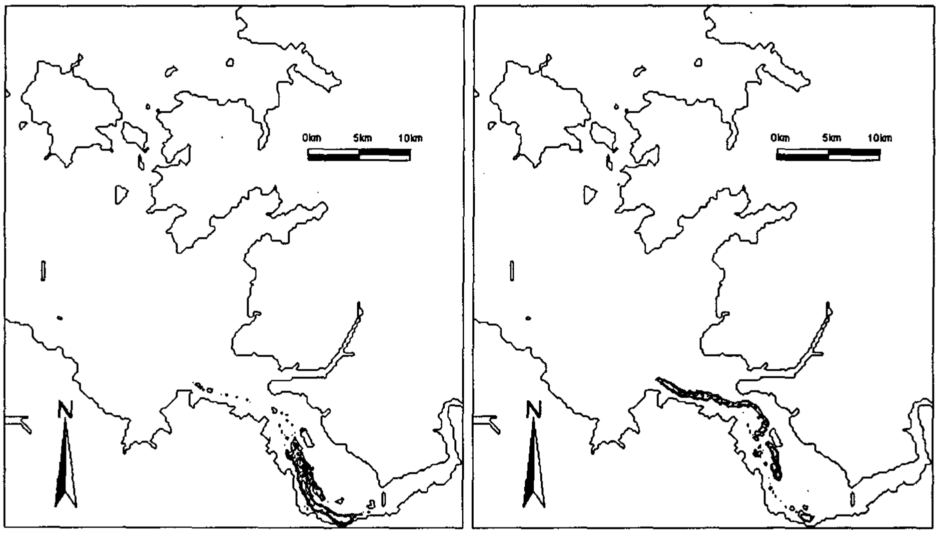
a) coarse silt

b) fine silt



c) clay; low tide d) clay; high tide

Fig. 4. Streaklines of Suspended Sediment Plumes



a) low tide b) high tide

Fig. 5. Spatial Extent of Suspended Sediment Plumes and Suspended Sediment Concentration After 15 Days of the Dredging Operation.

4. CONCLUSIOIN

A three-dimensional particle-tracking model has been developed to predict far-field transport of suspended sediment loads resulting from dredging operation. The model was used for the case study of waterway-dredging operation in Asan Bay, where semi-diurnal tides are dominated and the maximum tidal currents are about 1 m/s. Total suspended sediment concentrations and the spatial extent of suspended sediment plumes resulting from the dredging operation were estimated by the model simulations. The streaklines of continuously released particles show that the fine-grained sediments were transported up to ~20km downstream distance due to the strong tidal currents while the coarse sediments were deposited immediately in the dredging area. The projected streaklines become longer as the settling velocities become smaller. Higher concentration occurred in the vicinity of the dredging site, and concentrations become lower away from the dredging site.

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