DRP-1-02
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Dredging Research Technical Notes

Numerical Disposal Modeling

Purpose

This technical note presents the status of a personal computer (PC) version of numerical disposal models for predicting the short-term fate of dredged material placed in open water. ***This PC version is an update of an earlier release, and this technical note replaces the earlier Technical Note DRP-1-02, which should be discarded.***

Background

The original disposal models were developed under the Dredged Material Research Program. Two of the models were developed by Brandsma and Divoky (1976) to handle both instantaneous dumps and continuous discharges. The models were based on work by Koh and Chang (1973). A third model that utilized features of the two earlier models was constructed to handle a semicontinuous disposal operation from a hopper dredge.

These models are known as DIFID (**DI**sposal **F**rom an **I**nstantaneous **D**ump), DIFCD (**DI**sposal **F**rom a **C**ontinuous **D**ischarge), and DIFHD (**DI**sposal **F**rom a **H**opper **D**redge). Applications of the DIFID model include Trawle and Johnson (1986a,b) and Adamec and others (1987). A user's guide was provided by Johnson (1990). Features of these models have been incorporated into a PC-based model called STFATE (**S**hort-**T**erm **FATE**), which simulates the initial placement processes associated with a single disposal operation from either a split-hull barge or a hopper dredge. Previously, STFATE was referred to as SSTFATE (**S**ingle Operation **S**hort-**T**erm **FATE**).

Additional Information

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Need for Short-Term Fate Model

Regardless of the location or character of a disposal site, an integral part of the problem of assessing the environmental impact of open-water placement operations is the ability to determine the spatial and temporal distribution of the dredged material following its discharge into the water. The description of the fate of material discharged requires a model of considerable generality and complexity. The disposal site environment may include time-dependent currents that vary significantly in three dimensions, density stratification, and variable depths. The material itself may be a composite ranging from slow-settling extremely fine particles to fast-falling coarse particles and may include a soluble fraction. All of these and many other factors contribute to the complexity of modeling the physical fate of dredged material. In addition to providing water column concentrations of suspended sediment and the soluble fraction, initial deposition patterns are provided by the short-term fate model for input to long-term sediment transport models to address site capacity questions. Water column concentrations of the soluble fraction are used either to provide maximum concentrations outside designated disposal sites and mixing zones or to compute mixing zones and/or zones of initial dilution as required in Section 103 of the Marine Protection Research and Sanctuary Act and Section 401 and 404(b)(1) of the Clean Water Act regulating the water quality impacts from disposal in the waters of the United States.

Processes Modeled

The behavior of the placed material is assumed to be separated into three phases: convective descent, during which the dump cloud or discharge jet falls under the influence of gravity; dynamic collapse, occurring when the descending cloud impacts the bottom or reaches a neutrally buoyant position in the water column; and long-term passive diffusion, commencing when the material transport and spreading are determined more by ambient currents and turbulence than by the dynamics of the placement operation.

Whether disposal is from a split-hull barge or a hopper dredge, based upon visual observations from laboratory tests, the material descends through the water column as a jet that is usually composed of "globs" of material of varying characteristics. During the convective descent phase, the disposal jet grows as a result of entrainment. Depending upon the nature of the disposal material in the vessel, movement of the disposal vessel or ambient currents at the disposal site, and stratification of the water column, a small portion of the extremely fine fraction may be stripped from the jet and become trapped in the upper portion of the water column. In the latest PC model STFATE, this behavior is simulated by representing the disposal jet as a series of convecting clouds. Each cloud is characterized by its size, density, location, and the types and concentrations of solids contained within the cloud. As each convecting cloud descends through the water column, fine material may be stripped from the main cloud. This behavior is simulated through the concept of small Gaussian clouds. In 100 ft of water, the convective descent phase for typical material from maintenance dredging is completed in a few seconds after dumping.

Eventually, the material reaches either the bottom or a neutrally buoyant position in the water column. The vertical motion is arrested, and a dynamic spreading or collapse in the horizontal plane occurs. When the rate of horizontal spreading or vertical collapse in the dynamic collapse phase becomes less than an estimated rate of change due to turbulent diffusion, the collapse phase is terminated and the long-term transport diffusion begins. During collapse, laboratory experiments show that fine material tends to be lost to the water column above the collapsing cloud. As these particles are left behind the main body of material, they are stored in small clouds that are assumed to have a Gaussian distribution in the same manner as the material stripped during convective descent. The small clouds are then advected horizontally by the imposed current field. In addition, the clouds grow both horizontally and vertically as a result of turbulent diffusion. Since settling of the suspended solids occurs at each grid point if the bottom shear stress does not excess the critical shear stress for deposition, the amount of solid material deposited on the bottom and a corresponding thickness are determined. The model assumes that no subsequent erosion of material from the bottom occurs.

During the transport-diffusion phase, advection of the small Gaussian clouds over variable bathymetry and through a spatially varying velocity field is allowed. Options for the velocity field include a vertically averaged flow field as well as a vertical profile reflecting highly stratified flow conditions. Output of water column concentrations at a particular depth is obtained by superposition of the individual clouds. Solid boundaries as well as the surface are treated as reflection boundaries.

Limitations of Existing Model

STFATE requires that the dredged material be broken into various solid fractions with a settling velocity specified for each fraction. In many cases, a significant portion of the material falls as "clumps." This is especially true if the dredging is done by clamshell and can be true in the case of hydraulically dredged material if consolidation takes place in the hopper during transit to the disposal site or if consolidated clays are dredged. The specification of a clump fraction is rather subjective. Therefore, the inability to characterize the placed material accurately in some placement operations prevents a quantitative interpretation of model results in those operations.

As noted, a settling velocity must be prescribed for each solid fraction. A basic assumption is that unless the fraction is specified as being cohesive, in which case the settling velocity is computed as a function of concentration, the settling is considered to occur at a constant rate.

Computations are referenced to a horizontal grid containing either a constant or variable water depth field. Collapse on the bottom is assumed to occur at a single depth, although an average bottom slope at the impact point can be specified as input data. Even though the effect of a bottom slope has been incorporated, a basic limitation still exists in that the bottom can slope in only one direction over the collapsed region; that is, bottom collapse on a "mound" where the collapsing cloud runs down the sides is not treated. For controlled disposal operations in which material is disposed into bottom depressions, collapse of the bottom cloud in a rectangular hole is assumed.

A major limitation of STFATE is the basic assumption that if solid particles are deposited on the bottom, they remain there. Therefore, the model should be applied only over time frames in which erosion of the newly deposited material is insignificant.

Status of Development of STFATE

The primary objective of Dredging Research Program (DRP) work unit "Numerical Simulation Techniques for Evaluation of Short-Term Fate and Stability of Dredged Material Placed in Open Waters" is to provide an easy-to-use, accurate, and well-verified PC-based model of dredged material disposal operations.

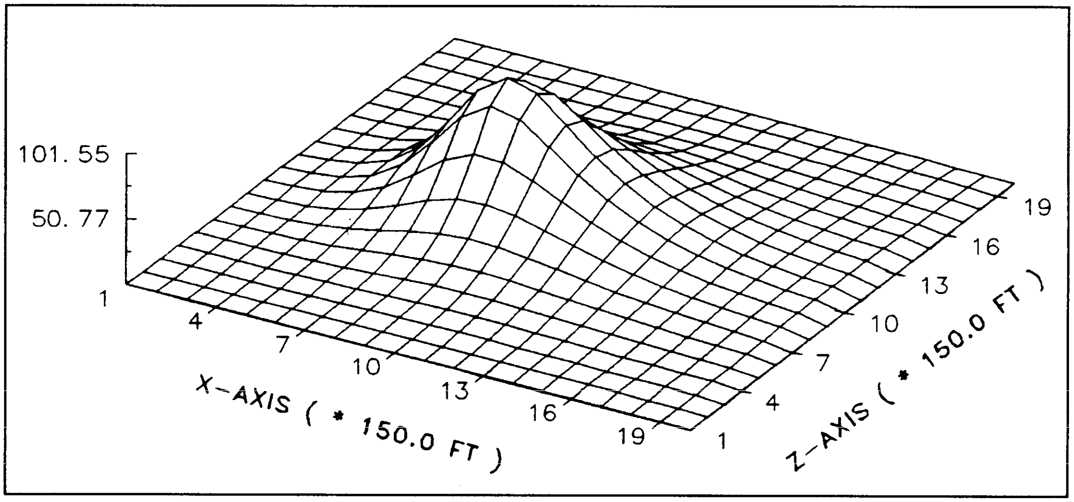
The previous DRP menu-driven PC model has been merged with a version of the model that resided within the ADDAMS (**A**utomated **D**redging and **D**isposal **A**lternatives **M**anagement **S**ystem). This merger should eliminate the confusion resulting from the existence of two separate models. The combined model has enhanced file management capabilities and a user-friendly graphical display of model results that can be applied to either a general disposal operation or to regulatory evaluations in which water quality considerations are addressed. In these applications, if a disposal site is not designated, the mixing zone required to meet a water quality standard is computed.

The input data required to run the model are grouped into the following six menu categories: site description, ambient velocity field, model operational parameters, dredged material description, disposal description, and coefficients. Since the PC version features full-screen editing of input data for each category with descriptors and typical value ranges, development of the input data file is a simple process.

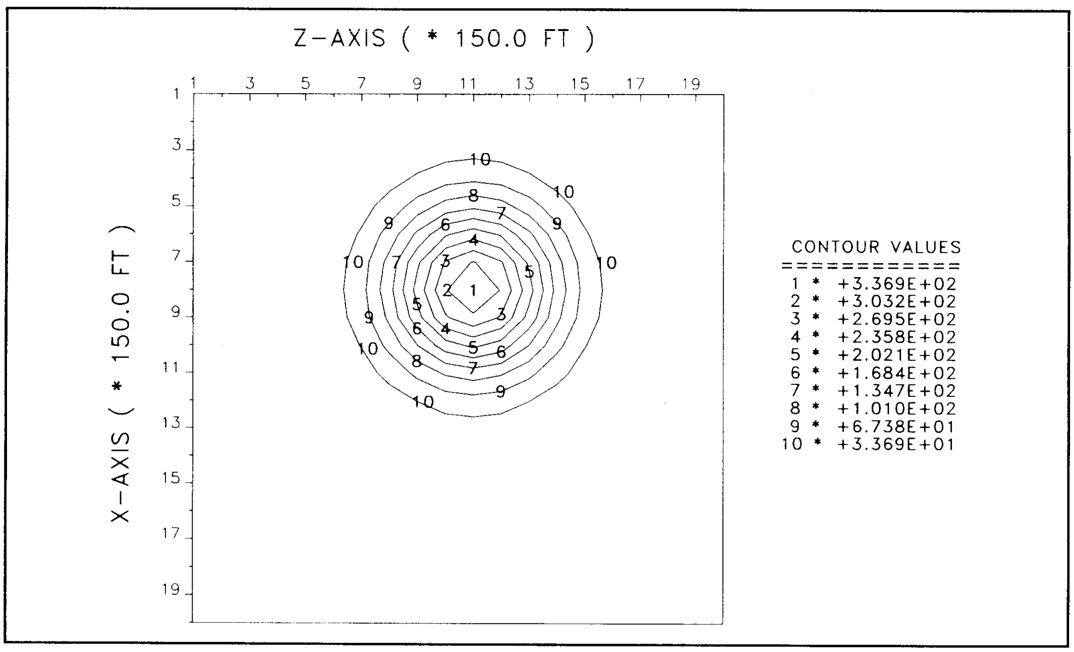
Graphical displays of model results include the following options:

- Contour plots and three-dimensional surface displays showing both thickness and volume of deposited material on the bottom (both total and by grain-size fraction).
- Contour plots of suspended sediment concentration and dissolved constituent in a horizontal slice at a specified depth in the water column at a specified time.
- Plots of maximum concentration of suspended sediment (both total and by grain-size fraction) and dissolved constituent as a function of time, both within and outside mixing zones.

Example displays are presented below.



Total volume (cu ft/grid square) of new material



Concentration above background of sand (mg/L) at 999.0 ft, 300.0 sec after dump

Technical advances in this updated version are primarily related to the regulatory application options. If a disposal site is designated, the maximum concentration of the soluble fraction is compared to a specified criterion to determine if water quality criteria have been violated. If a disposal site is not designated, mixing zones are computed at each time step along with a final mixing zone that encompasses all of the area within which limiting permissible concentrations were exceeded at some time during the simulation. Other advances are the ability to simulate stripping of material during both the convective descent and the dynamic collapse phases and the allowance of a spatially variable velocity field.

Conclusions

An easy-to-use PC-based numerical disposal model, operating within the ADDAMS and referred to as STFATE, is now available for field use. STFATE also is available as a separate program. The PC version features menu-driven input data entry with typical values of variables displayed and an enhanced graphical display of model results and file management. Users should be aware of the limitations of the existing model. As these limitations are removed and the PC model is improved, this technical note will be updated.

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