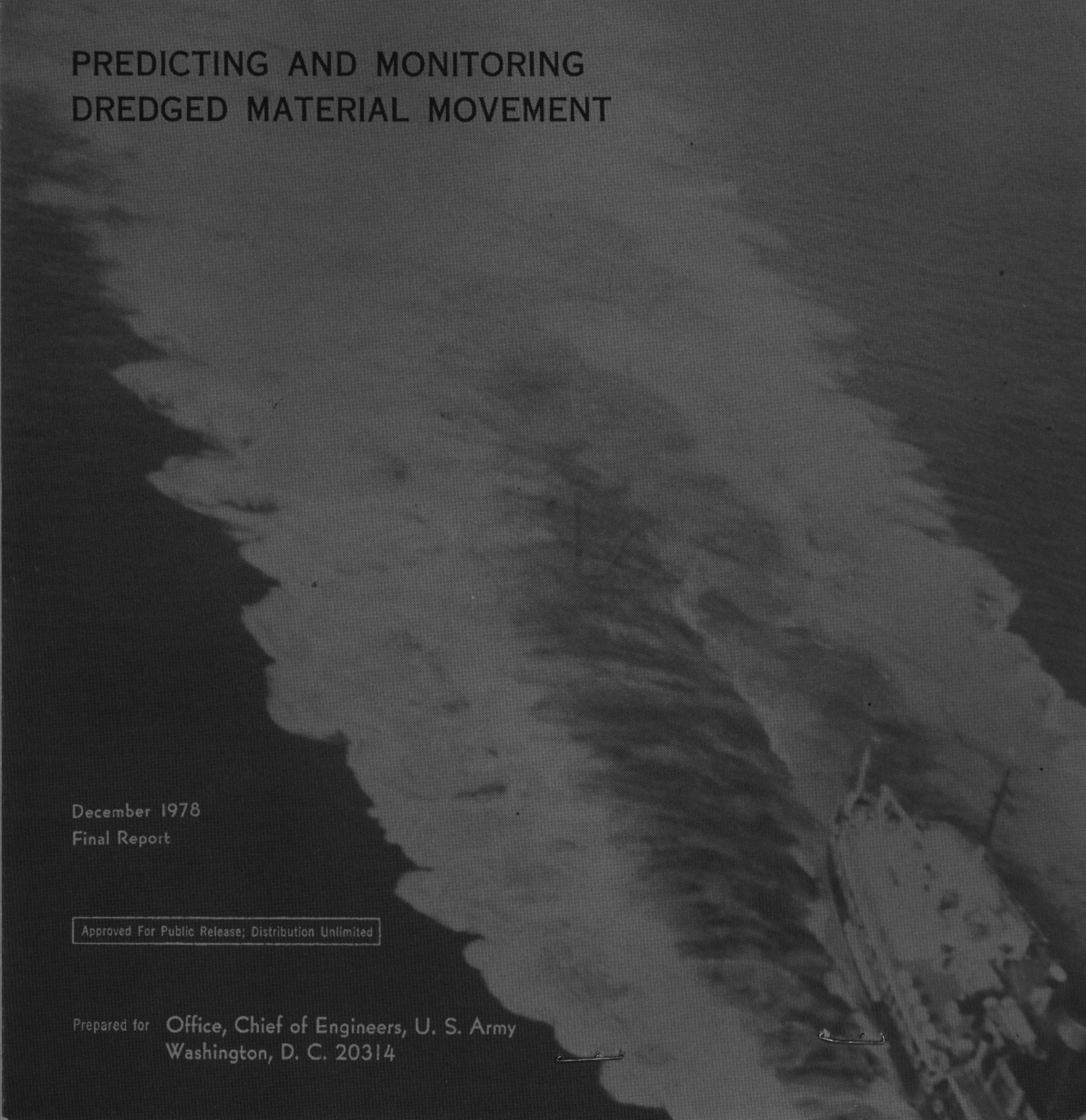
SYNTHESIS OF RESEARCH RESULTS

DREDGED MATERIAL RESEARCH PROGRAM

TECHNICAL REPORT DS-78-3

PREDICTING AND MONITORING DREDGED MATERIAL MOVEMENT



December 1978
Final Report

Prepared for Office, Chief of Engineers, U. S. Army
Washington, D. C. 20314

THE DMRP SYNTHESIS REPORT SERIES

Technical Report No.	Title
DS-78-1	Aquatic Dredged Material Disposal Impacts
DS-78-2	Processes Affecting the Fate of Dredged Material
★DS-78-3	Predicting and Monitoring Dredged Material Movement
DS-78-4	Water Quality Impacts of Aquatic Dredged Material Disposal (Laboratory Investigations)
DS-78-5	Effects of Dredging and Disposal on Aquatic Organisms
DS-78-6	Evaluation of Dredged Material Pollution Potential
DS-78-7	Confined Disposal Area Effluent and Leachate Control (Laboratory and Field Investigations)
DS-78-8	Disposal Alternatives for Contaminated Dredged Material as a Management Tool to Minimize Adverse Environmental Effects
DS-78-9	Assessment of Low-Ground-Pressure Equipment in Dredged Material Containment Area Operation and Maintenance
DS-78-10	Guidelines for Designing, Operating, and Managing Dredged Material Containment Areas
DS-78-11	Guidelines for Dewatering/Densifying Confined Dredged Material
DS-78-12	Guidelines for Dredged Material Disposal Area Reuse Management
DS-78-13	Prediction and Control of Dredged Material Dispersion Around Dredging and Open-Water Pipeline Disposal Operations
DS-78-14	Treatment of Contaminated Dredged Material
DS-78-15	Upland and Wetland Habitat Development with Dredged Material: Ecological Considerations
DS-78-16	Wetland Habitat Development with Dredged Material: Engineering and Plant Propagation
DS-78-17	Upland Habitat Development with Dredged Material: Engineering and Plant Propagation
DS-78-18	Development and Management of Avian Habitat on Dredged Material Islands
DS-78-19	An Introduction to Habitat Development on Dredged Material
DS-78-20	Productive Land Use of Dredged Material Containment Areas: Planning and Implementation Considerations
DS-78-21	Guidance for Land Improvement Using Dredged Material
DS-78-22	Executive Overview and Detailed Summary
DS-78-23	Publication Index and Retrieval System

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SECURITY CLASSIFICATION OF THIS PAGE (*When Data Entered*)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER Technical Report DS-78-3	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (*and Subtitle*) PREDICTING AND MONITORING DREDGED MATERIAL MOVEMENT		5. TYPE OF REPORT & PERIOD COVERED Final report
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(*s*) Barry W. Holliday, Billy H. Johnson, William A. Thomas		8. CONTRACT OR GRANT NUMBER(*s*)
9. PERFORMING ORGANIZATION NAME AND ADDRESS Environmental Laboratory and Hydraulics Laboratory U. S. Army Engineer Waterways Experiment Station P. O. Box 631, Vicksburg, Miss. 39180		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS DMRP Task 1B
11. CONTROLLING OFFICE NAME AND ADDRESS Office, Chief of Engineers, U. S. Army Washington, D. C. 20314		12. REPORT DATE December 1978
		13. NUMBER OF PAGES 44
14. MONITORING AGENCY NAME & ADDRESS(*if different from Controlling Office*)		15. SECURITY CLASS. (*of this report*) Unclassified
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (*of this Report*)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (*of the abstract entered in Block 20, if different from Report*)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (*Continue on reverse side if necessary and identify by block number*)

Dredged material
Dredged material disposal
Mathematical models
Predictions
Sediment transport
Waste disposal sites

20. ABSTRACT (*Continue on reverse side if necessary and identify by block number*)

A summary of the results from three work units (1B06, 1B07, and 1B09) of the Dredged Material Research Program, concerned with predicting and monitoring dredged material movement, is presented. Work Units 1B06 and 1B09 were concerned with the prediction of the short-term fate of dredged material discharged in open water. In particular, 1B06 was an evaluation and calibration of the Tetra Tech disposal models (developed under Work Unit 1B02 of the DMRP by Tetra Tech, Inc.) using field data collected at several disposal sites, including the

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Unclassified

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20. ABSTRACT (Continued).

Duwamish, New York Bight, and Lake Ontario sites. The collection of these field data was performed under Work Unit 1B09 by Yale University. Work Unit 1B07 involved an evaluation of two two-dimensional finite element models (developed under Work Unit 1B05 of the DMRP by the University of California at Davis) for the long-term prediction of sediment transport in estuaries.

Part II of the report discusses the modifications of the Tetra Tech models made by the U. S. Army Engineer Waterways Experiment Station and presents calibration results using field data from the Duwamish, New York Bight, and Lake Ontario disposal sites. In addition, a summary of observations from a field data collection program on the mechanics of the placement of dredged material at open-water disposal sites is presented. Major conclusions noted are:

a. The Tetra Tech models should only be used in a qualitative sense until knowledge of the required coefficients is improved.

b. Proper material characterization is extremely important in obtaining realistic predictions from the models.

c. Entrainment and drag coefficients in the descent and collapse phases appear to be the most sensitive coefficients in the models.

Part III of the report presents a discussion of the factors involved in the long-term transport of sediment in estuaries and how they are handled by finite element models. In addition, limitations of the models and their current status are discussed.

PREFACE

This report summarizes the results of Work Units 1B06, 1B07, and 1B09 of the Dredged Material Research Program (DMRP) concerned with predicting and monitoring dredged material movement. As noted, the above work units as well as this synthesis report were conducted under funding by the DMRP, sponsored by the Office, Chief of Engineers, and administered by the U. S. Army Engineer Waterways Experiment Station (WES), Vicksburg, Miss.

The report was prepared by Mr. Barry W. Holliday of the WES Environmental Laboratory (EL) and Dr. Billy H. Johnson and Mr. William A. Thomas of the WES Hydraulics Laboratory (HL) under the direct supervision of Mr. M. B. Boyd, Chief, Hydraulics Analysis Division, and Dr. Robert M. Engler, Environmental Impacts and Criteria Development Project Manager, and under the general supervision of Mr. Henry B. Simmons, Chief, HL, Dr. Roger T. Saucier, Special Assistant, EL, and Dr. John Harrison, Chief, EL.

This report is also being published as Engineer Manual 1110-2-5012.

The Director of WES during the preparation of this report was COL John L. Cannon, CE. Technical Director was Mr. F. R. Brown.

CONTENTS

CONVERSION FACTORS, U. S. CUSTOMARY TO METRIC (SI) UNITS OF MEASUREMENT

U. S. customary units of measurement used in this report can be converted to metric (SI) units as follows:

Multiply	By	To Obtain
cubic feet per second	0.02831685	cubic metres per second
cubic yards	0.7645549	cubic metres
degrees (angle)	0.01745329	radians
feet	0.3048	metres
feet per second	0.3048	metres per second

PREDICTING AND MONITORING DREDGED MATERIAL MOVEMENT

PART I: INTRODUCTION

1. Dredging and disposal operations occur in many different types of aquatic environments. One important aspect in determining the impact of these operations is determining where and how the dredged material is initially dispersed and/or deposited after discharge. This initial deposition may take place over a time frame ranging from minutes to hours. A second major consideration is the longer term sediment movement patterns (over a time frame of perhaps days or months) in or near dredged material disposal sites and/or navigable waterways. The Office, Chief of Engineers, Dredged Material Research Program (DMRP), administered by the U. S. Army Engineer Waterways Experiment Station (WES), Vicksburg, Miss., sponsored development of tools (mathematical models) to study these two aspects. The information gained in these studies can be used to help evaluate potential environmental impacts, guide field monitoring programs, aid in disposal site selection, and help address dredged material disposal criteria questions. This report summarizes the rationale for this work and describes the current status of these tools. The study forms part of DMRP Task 1B of the Environmental Impacts and Criteria Development Project.

2. Prediction of the short-term physical fate of dredged material discharge into an aquatic environment based on data and observations from other specific study sites is extremely risky because of the variability in factors that influences the fate of the material. As a result, a mathematical model of the physical processes affecting the fate of dredged material was considered necessary. The model needs to be flexible enough to allow for local environmental conditions, sediment characteristics, and initial discharge conditions of the different methods of disposal. As a first step toward meeting this objective, the DMRP initiated an effort (DMRP Work Unit No. 1B01) to assess the existing mathematical models applicable to the disposal of dredged material in terms of assumptions, limitations for practical use, and

degree of verification. Johnson[1] reported the existence of very little technology in this area. A model developed by Koh and Chang[2] was the most promising for predicting the short-term dispersion and settling of dredged material. However, the model was developed for use in an ocean environment and would not handle disposal operations in a dynamic environment such as an estuary. A contract was awarded to Tetra Tech, Inc., for major modifications to the Koh Chang model to expand its applicability. Two models, one for a continuous discharge and one for an instantaneous dump, resulted from this contract.[3] These models were not designed for use over timeframes within which erosion and resuspension play dominant roles and no attempt was made to incorporate these phenomena into the Tetra Tech models. A discussion of these models and their current state of development is presented in Part II.

3. In order to predict the fate of dredged material released at the water surface, it is necessary to determine the significance of the controlling physical processes affecting the deposition of this material on the bottom. Consequently, a field study was initiated with Yale University (Work Unit 1B09) to investigate the mechanics of the placement of dredged material disposed from barges as well as hopper dredges at five open-water disposal sites.[4] The objectives were to follow the path of the dredged material, determine how much material reaches the bottom and in what form, document how much sediment is dispersed into the water column, and measure how long the placement processes take to complete. The results of this work are being used to calibrate the Tetra Tech models and to evaluate their potential predictive capability. A brief summary of this work is included in Part II with the discussions of the Treta Tech models.

4. While the Tetra Tech models are aimed directly at answering questions concerning the dredged material disposal operation, the DMRP also sponsored development of sediment transport models for calculating the longer term movement of silts and clays. Potential uses of these models include predicting maintenance dredging quantities and the longer term (after initial impact on the bottom) fate of dredged material deposited in open-water disposal sites. The DMRP contracted with the

University of California, Davis (UCD), to consolidate appropriate portions of existing theory concerning cohesive sediments into a numerical model.[5] Along with a report, UCD furnished four computer codes: one for the two-dimensional analysis of sediment concentration in the horizontal plane, one for two-dimensional analysis of sediment concentration in the vertical plane, and two auxiliary codes to aid in using these sediment models. A discussion of these models and their current state of development is presented in Part III.

5. Both the Tetra Tech and UCD models are at the forefront of the state of the art in numerical simulation of sedimentological processes involving dredged material and have been subjected to very limited testing and evaluation. Although the models are conceptually sound, significant additional evaluation, modification, and field verification are needed to ensure their predictive capabilities and to provide rational guidance for their use. Initial work toward these objectives has been under way in the Hydraulics Laboratory at WES and results are summarized in Parts II and III.

PART II: PREDICTION OF SHORT-TERM FATE OF DREDGED MATERIAL DISCHARGED IN OPEN WATER

Model Development

6. The Koh-Chang model[6] was evaluated to determine its applicability for predicting the fate of dredged material discharged in various environments (DMRP Work Unit No. 1B03). The study concluded that it was necessary to modify the model to address the complexities of the estuarine environment. As a result, Brandsma and Divoky[3] developed two numerical models (the Tetra Tech models), one for an instantaneous bottom dump and one for a continuous discharge from either a fixed or moving source. In both models, the behavior of the material is assumed to be separated into three phases. Figure 1 illustrates these phases for the instantaneous dump model.

7. The Tetra Tech models use the convective descent and dynamic collapse phases of the Koh-Chang model, but use a different approach for handling the longer term turbulent diffusion phase. The new approach allows for the temporal and spatial viability of the ambient environment, spatial variation of depth, and lateral boundaries. The models allow for the specification of ambient velocities in one of three ways: (a) a constant depth, time invariant profile varying only in the vertical, (b) a two-dimensional, depth-averaged velocity field, or (c) two-layered, unsteady, nonuniform velocities. A detailed discussion of these models is in Brandsma and Divoky,[3] and revisions incorporated into the models during their evaluation and calibration at WES are described in Johnson and Holliday.[7]

Model Input Requirements

8. Input data required for the operation of the Tetra Tech models can be grouped into (a) a description of the ambient environment at the disposal site, (b) characterization of the dredged material, (c) description of the disposal operation, and (d) model coefficients. Each is discussed in the following paragraphs.

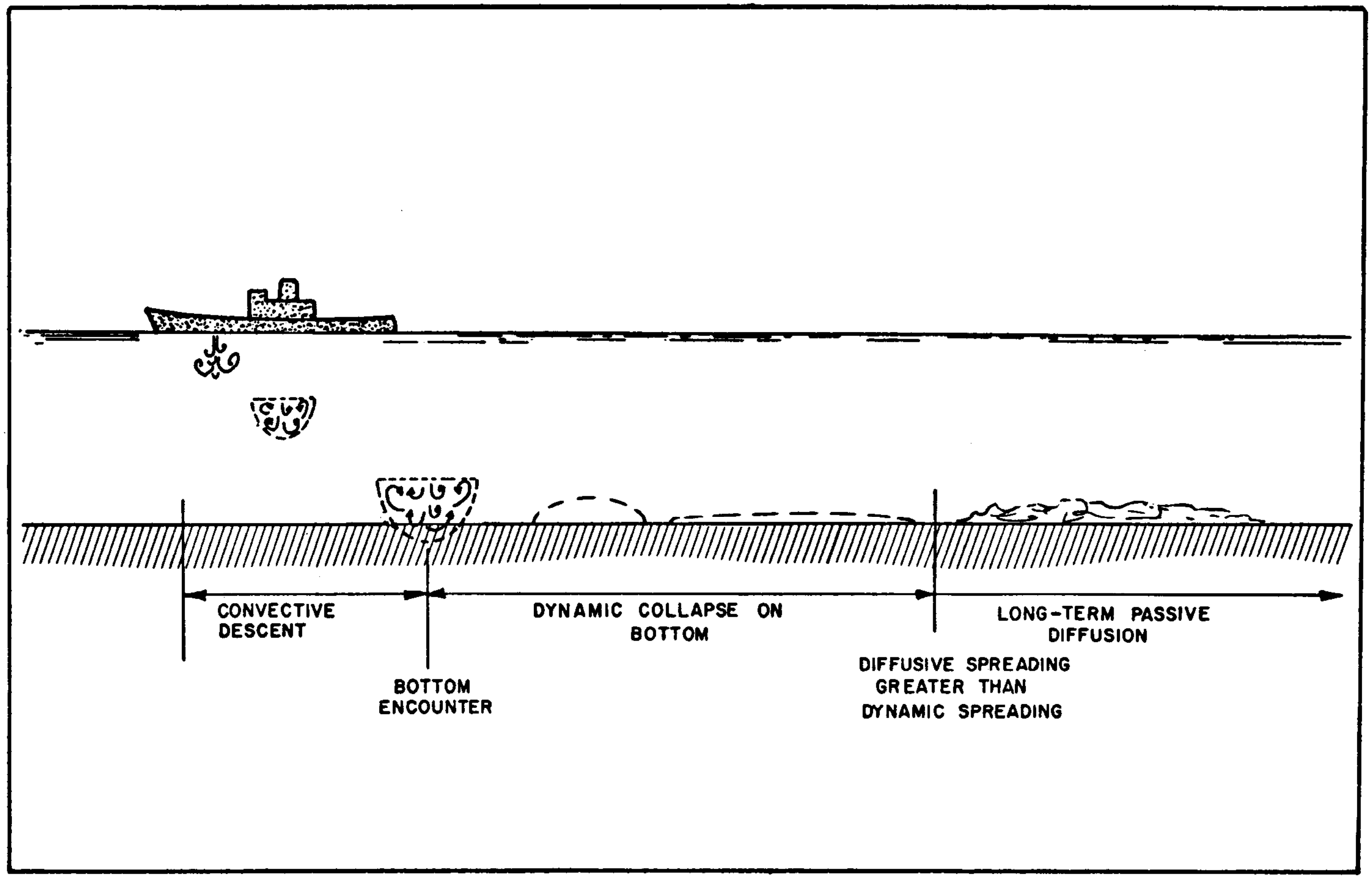

Figure 1. Phases in the instantaneous dump model (from Brandsma and Divoky[3])

Disposal site data

9. The first task to be accomplished when applying the models is that of constructing a horizontal long-term grid over the disposal site. The number of grid points should be kept as small as possible but large enough to extend the grid beyond the area of interest at the level of spatial detail desired. Quite often one may wish to change the horizontal grid after a few preliminary runs. Water depths and the horizontal components of the ambient current must be input at each grid intersection point. The ambient density profile at the deepest point in the disposal site must also be input. This profile may vary with time but is assumed to be the same at each net point of the grid.

Characterization of dredged material

10. The dredged material can be classified into as many as 12 solid fractions, a fluid component, and a conservative chemical constituent if desired. For each solid fraction, its concentration by volume, density, fall velocity, voids ratio, and an indicator as to whether or not the fraction is cohesive must be input. Proper material characterization is extremely important. For example, field observations have shown that the majority of the solids settle to the bottom of the hoppers in the case of hopper dredged material with the resulting density of the upper portion of the hopper being almost that of the ambient water. This is discussed in more detail in paragraphs 31 and 41. If a conservative chemical constituent is to be traced, its initial concentration and a background concentration must be given. In addition, the bulk density and aggregate voids ratio of the dredged material must be given.

Disposal operations data

11. For the instantaneous dump model, information required includes the position of the barge on the horizontal grid, the radius of the initial hemispherical cloud, the depth below the water surface at which the material is released, and the initial velocity of the release. Normally, the initial cloud radius is computed from the known volume of material. However, one may wish to set the radius from geometrical considerations, e.g., the barge width. If this is the case, one must

adjust the bulk density to reflect the initial dilution, making sure the resulting cloud contains the exact amount of solid material contained within the barge. For the continuous discharge model, the following data are required: the initial position of the discharge (hopper dredge or pipeline terminus) on the horizontal grid, the vessel's course and speed if moving, the orientation and depth below the water surface of the discharge, the radius and flow rate of the initial discharge, and the total discharge time.

Model coefficients

12. The models contain suggested average values for 14 coefficients in the instantaneous dump model and 17 in the continuous discharge model, but the user may input other values if desired. Computer experimentation has shown that model results appear to be fairly insensitive to most of the coefficients. The entrainment and drag coefficients in the convective descent and collapse phases along with the bottom friction coefficient appear to be the most sensitive in the instantaneous dump model. The jet convection entrainment coefficient is important in the continuous discharge model, but additional experimentation for the case of jet bottom encounter is needed before a definitive statement can be made concerning coefficients connected with collapse on the bottom. In any calibration of the models, variation of the more sensitive coefficients is to be expected to achieve a satisfactory adjustment of the models.

Model Output

13. In both the instantaneous dump and the continuous discharge model, the discharged material is traced through 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 or jet either impacts the bottom or arrives at the level of neutral buoyance at which descent is retarded and horizontal spreading dominates; and long-term passive dispersion, commencing when the material transport and spreading is determined more by ambient

currents and turbulence than the dynamics of the disposal operation. Output from the models in both tabular and plotted form describes the movement of the material through each of the three phases.

Convective descent
and dynamic collapse

14. The time history of position in the water column, velocity, and size of the cloud or jet plume is provided at the end of both the convective descent and collapse phases. In addition, the volume of solids and the corresponding concentrations, as well as the density difference between the discharged material and the ambient, are provided. As a guide for determining dilution rates, the time history of the conservative chemical constituent concentrations is also furnished.

Passive dispersion

15. A basic assumption by which the three-dimensional aspects of the suspended sediment concentrations are represented on the two-dimensional horizontal grid is that the concentration profile in the vertical is a "top-hat" profile. As illustrated in Figure 2, such a

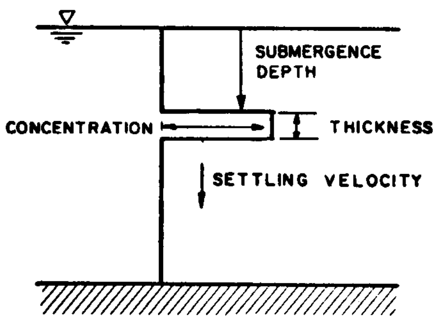

Figure 2. Typical concentration
profile at a grid point

profile is characterized by a thickness, top position, and an average concentration. Therefore, in the passive dispersion phase, at each net point of the horizontal grid, the concentration, position of the top, and the thickness of each suspended solids profile, as well as the conservative chemical constituent, are output at as many time steps as requested. In addition, at each net point the amount and thickness of deposited solids on the bottom are also provided as functions of time.

Evaluation and Calibration

16. As part of the contract, WES was provided the final report and card decks for both the instantaneous bottom dump and the continuous discharge models by Tetra Tech, Inc. Details of the theoretical aspects as well as listings of the computer codes can be found in Brandsma and Divoky.[3] Upon receiving the codes, an in-house effort (Work Units 1B06 and 1B07) was initiated to evaluate and calibrate the models through application to actual disposal operations.[7] A brief discussion of these efforts is presented.

Evaluation of instantaneous dump model

17. There is some question as to what constitutes an instantaneous dump. A barge dump in which all the material leaves the barge before any of the material strikes the bottom is probably as simple a definition as possible for the instantaneous dump. In the instantaneous dump model it is assumed that a single cloud maintains a hemispherical shape while falling through the water column. A basic assumption is that the cloud behaves as a dense liquid. The entrainment coefficient in the model for the entrainment of ambient fluid into the descending dense liquid cloud does not appear to be properly represented in the numerical simulations. Model output is quite sensitive to this coefficient and the entrainment coefficient is dependent upon the characteristics of the material being dumped (the higher the moisture content, the larger the value of the entrainment coefficient). Developmental research by JBF Scientific Corporation[8] is under way to better represent the entrainment of the ambient fluid, and the final results will be incorporated into the instantaneous dump model.

18. In the derivation of the force that drives the horizontal spreading during the collapse phase, it is assumed that the density at the center of the cloud is the same as the ambient density. The driving force is then computed assuming that the density gradient within the cloud differs from the ambient density gradient. This analysis seems reasonable for the case of collapse within the water column, i.e., a

level of neutral buoyancy has been encountered. However, if the cloud strikes the bottom, the above assumption is in error. In that case, the overall density difference of the cloud and ambient should be included in the derivation of the force presented in Koh and Chang[2] and Brandsma and Divoky.[3] The model has been modified to reflect this.[7]

19. Brandsma and Divoky indicated that an entrainment coefficient specified as input was utilized in determining the entrainment of ambient fluid during collapse on the bottom. However, the model actually employed a computed entrainment coefficient that appeared to be zero in practically all cases. The model has been modified by WES to use the input entrainment coefficient, which has resulted in a much better representation of the bottom collapse phase, based upon observations at disposal sites in Lake Ontario.

20. Initially, the model made one vertical diffusion computation over the complete long-term time step. This can create excessive diffusion. The program has been modified by WES so that vertical diffusion computations are now made in increments of one tenth of the long-term time step. An additional problem was observed with the manner in which vertical diffusion was handled. Vertical diffusion was considered to be dependent upon the Richardson number based upon only the ambient density gradient. However, the suspended solids density would seem to have a stabilizing effect that was not accounted for. Therefore, the program has been modified by WES to compute a Richardson number based upon a density gradient that accounts for the suspended solids density.

21. A basic input to the model is the settling or fall velocity of each solid type. In the original model there was no allowance for the cohesive nature of fine silts and clays. The model has since been modified by WES to compute the settling velocity of a cohesive sediment assuming the velocity to be a function of only the suspended sediment concentration. In the original model, the manner in which the ambient velocity was interpolated from the prescribed velocity profiles to provide the proper value for computing concentration fields was obviously in error. This problem has since been corrected by WES.

22. In initial experimentation with the model, mass conservation

problems were encountered in the long-term computations when applying the model to a variable depth disposal site. This problem has also since been corrected by WES.

23. In the original model, a conservative chemical constituent in the dredged material cloud could be traced through cloud collapse but the computation of a concentration field on the long-term grid taking into account a background concentration was not allowed. The model has since been modified by WES to handle these computations, which should increase its usefulness in addressing dredged material criteria questions.

24. In summary, as is usually the case with newly developed models, many problems were encountered in computer experimentation with the instantaneous bottom dump model. However, it is believed that these problems have been corrected and, purely from the standpoint of executing properly, the model can be used with confidence to yield qualitative information. Use of the model in real disposal operations is discussed in more detail in paragraphs 33-37.

Evaluation of the continuous discharge model

25. Some dredging vessels discharge material through openings at the bottom of the vessel while moving. A similar mode of discharge, although fixed and of a much longer duration, is a pipeline discharging in the water column. In either case, the discharge is continuous and the flow phenomenon near the discharge opening is that of a sinking momentum jet in a cross current. The continuous discharge model handles these types of disposal operations.

26. The drag force on the descending jet in the original model was assumed to always act perpendicular to the jet axis. If material was discharged in the vertical from a stationary vessel in essentially a quiescent ambient, little bending of the jet occurred and thus essentially no drag force was computed to oppose the downward motion. From model applications in Lake Ontario, the computed time required for a nearly vertical jet to hit the bottom was significantly less than observed times for bottom encountered. To enable the model to compute more realistic convective descent travel times, if the angle between

the jet center line and the vertical is less than 10 deg,* an additional drag force (with an associated drag coefficient, ADDRAG) in the vertical similar to the force acting on the descending hemispherical cloud in the instantaneous dump model has been added by WES. There are other problems associated with a stationary, vertical discharge in a quiescent ambient. For example, for essentially a vertical discharge that remains vertical, the model does not allow for the radial outward flow of material from the point of contact that is known to occur along the bottom. This is not a very realistic representation.

27. As in the instantaneous dump model, the force driving the collapse of the plume is based upon assuming that the plume density at the plume center is equal to the ambient density. As previously noted, if a neutrally buoyant position in the water column is reached, this assumption is correct; however, if the plume strikes the bottom, the density difference is not zero. A new expression for the force driving collapse on the bottom that accounts for the difference between the plume density and the ambient density has been programmed into the model.

28. All of the modifications connected with long-term computations as discussed in the instantaneous dump model have also been made in the continuous discharge model since this phase is the same in both models.

29. In summary, many problems have been encountered in computer experimentation of the continuous discharge model. However, it is believed these problems, with the exception of the vertical jet case, have been corrected and, purely from the standpoint of executing properly, the model can be used with confidence to yield qualitative information. Use of the model in a real hopper dredge disposal operation is discussed in more detail in paragraphs 40 and 41. No attempt to apply the model to a continuous pipeline operation has been made. Shubel at the State University of New York at Stony Brook, under contract with the DMRP,[9] has developed a simple passive model for the estimation of

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* A table of factors for converting U. S. customary units of measurement to metric (SI) units can be found on page 4.

concentrations and areal extent of suspended sediment plumes resulting from pipeline disposal operations. The basic limitations of Shubel's model are:

- a. The concentrations are vertically averaged.
- b. The disposal site is assumed to be of constant depth.
- c. The discharge rate is assumed constant and only one solid component is considered.
- d. The effect of lateral boundaries is not included.
- e. Ambient velocity is constant in space and time.

Output that can be obtained from the series of graphs presented by Shubel includes the center-line concentration at any distance from the source as well as the variance of the lateral distribution of the concentration from which the width of the plume can be obtained. A more extensive discussion of Shubel's work and the status of the usability of the above model for estimating suspended sediment plumes from pipeline disposal operations can be found in the synthesis report "Prediction and Control of Dredged Material Dispersion Around Open-Water Pipeline Disposal Operations" by Barnard.[10] A discussion of the results of a field study (by Nichols, Thompson, and Faas[11]) of the physical nature and dispersal of fluid mud from pipeline disposal operations in Mobile Bay and the James River also can be found in the above synthesis report.

Model calibration for an instantaneous dump operation

30. When attempting to apply the dredged material models, a basic problem is that of determining how an actual operation can be represented by the conditions idealized in the models. For example, there are no dredged material disposal situations in which all the material leaves the disposal vessel instantaneously. However, for the case of a barge dump, all of the material leaves fairly quickly, e.g., 15 to 20 sec. If the water is sufficiently deep, such a dump does resemble a hemispherical cloud falling through the water column by the time the bottom is encountered and thus can be adequately modeled by the instantaneous dump model. If the volume of the dump is of such magnitude and/or the water is so shallow that collapse occurs on the bottom before all the material

leaves the disposal vessel, the instantaneous model will not yield an accurate description of the disposal process.

31. Proper material characterization is extremely important in obtaining realistic predictions from the models, particularly when collapse of the disposal cloud in the water column is a real possibility. In some dumps, it has been observed that even the cohesive solids settle to the bottom of the vessel before disposal, with the resulting bottom material possessing a lower water content and corresponding higher bulk density. It is believed that a large portion of the material then falls from the collapsing cloud as clumps with fall velocities of perhaps 1.0 to 2.0 ft/sec. This is, of course, quite different from a characterization of the material where various solid types are assumed to settle at essentially particle fall velocities.

32. There are 14 coefficients in the instantaneous dump model. The model contains default values, i.e., an average value over a range of disposal and ambient conditions for some coefficients but perhaps only the model developer's best estimate for others. However, the user has the option of prescribing these coefficients as input if better estimates are available. Earlier computer experimentation with the Koh-Chang model concluded that model output was most sensitive to three coefficients: namely, the entrainment and drag coefficients in the convective descent phase and a drag coefficient in the collapse phase. Later experimentation with the modified Tetra Tech model indicated that the bottom friction coefficient and the collapse entrainment coefficient are also important. Therefore, when attempting to calibrate the model using data collected at a disposal site, these coefficients provide a good starting point in the variation of coefficients to match computed results with recorded data.

33. Duwamish disposal site. During February 1976, the DMRP collected data during and after several dumps over a 2-week period at the Duwamish disposal site in Elliott Bay near Seattle, Washington. All dumps were made from a 530-cu-yd barge; thus, the instantaneous dump model with an initial radius of 19.0 ft for the hemispherical cloud with a bulk density of 1.60 g/cc was selected to best represent the disposal

operation. A depth-averaged velocity field over the approximately 200-ft-deep disposal site was constructed, making sure to satisfy mass conservation of the flow field. A detailed description of the input data can be found in Johnson and Holliday.[7]

34. Upon release of the material during the field tests, it was observed that a time of 25 to 30 sec normally was required for the cloud to strike the bottom. With the convective descent drag coefficient increased from its suggested value of 0.5 to 1.0, the model computed a time of 24 sec with a final radius of 59 ft at bottom encounter. The speed of the front of the surge in the field at 160 ft from the point of dump was estimated to be 20 cm/sec. With an increase in the drag coefficient in the collapse phase from 1.0 to 1.75, the model computed a corresponding speed of 19 cm/sec. During the field tests, suspended solids data were recorded at 3 ft from the bottom at only one point, which was 300 ft downstream of the dump point. At 600 sec after the dump, the recorded suspended sediment concentration was 64 mg/ℓ. After 1000 sec, the computed concentration of the suspended material was 42 mg/ℓ, extending 8 ft up from the bottom. The times could not be compared due to a restriction on the long-term time step in the model, the restriction being that the long-term time step must be greater than the time required for the collapse phase to terminate. Based upon recorded data, it took 1800 sec for the suspended sediment concentration at the point above to decrease from 94 to 35 mg/ℓ, i.e., a rate of decrease of 0.0328 mg/ℓ/sec. From the model computations, 1000 sec was required to reduce the suspended sediment concentration at the same point from 42 to 11 mg/ℓ, i.e., a rate of decrease of 0.0310 mg/ℓ/sec.

35. New York Bight site. As a second application of the instantaneous dump model, data collected during a scow dump in the New York Bight were used. The solids of the 3000-m^3 dump were assumed to be composed of 30 percent cohesive "clumps" with a fall velocity of 2.0 ft/sec and 70 percent silty clay with a fall velocity of 0.01 ft/sec. The water depth was 85 ft and the bulk density of the material was 1.60 g/cc. There were two prototype data points in the bottom surge available for comparison with computed results. Based upon transmissometer data, the

front of the surge arrived at about 300 ft from the dump 70 sec after initiation of the dump, whereas, after about 250 sec, a current meter recorded the arrival of the surge at approximately 800 ft from the dump. From the transmissometer data, the suspended sediment concentration at 3 ft from the bottom was 7.5 g/ℓ after 138 sec, 1.5 g/ℓ after 558 sec, and was down close to background levels after approximately 1000 sec.

36. Various combinations of the more sensitive coefficients were tried in the attempted calibration of the model. In all runs, the drag coefficient in the convective descent phase was increased to 1.0. As noted, the most sensitive coefficients in the bottom collapse are a drag coefficient, CDRAG; an entrainment coefficient, α_c ; and the bottom friction coefficient, FRICTN. The default values of these coefficients are 1.0, 0.001, and 0.01, respectively. However, Koh and Chang[2] indicate that very little is known about these coefficients and thus no great significance should be attached to these default values. In addition, it should be realized that the bottom collapse entrainment coefficient has gained added significance due to the modification previously discussed.

37. It became obvious early in the computer experimentation that, as in the Duwamish simulation, CDRAG had to be increased in order to match the arrival time of the surge front 300 ft from the dump. However, unlike the Duwamish simulation, in addition to matching an early surge arrival time, the spread after 250 sec in the New York Bight simulation also had to be considered. Values of CDRAG = 5.0 , $\alpha_c = 0.04$, and FRICTN = 0.075 resulted in a computed spread of 350 ft after 70 sec and 685 ft after 250 sec. The computed cloud thickness after 250 sec was approximately 3 ft which, based upon similar surge observations at a hopper dredge disposal operation in Lake Ontario, probably comes close to approximating the proper surge volume. These hopper dredge disposal observations are discussed in more detail in the next section. After 450 sec, the computed average suspended sediment concentration over the cloud was 6.2 g/ℓ and had fallen to essentially zero after 900 sec. It should be remembered that the recorded concentrations of 7.5 g/ℓ after 138 sec and essentially background after 1000 sec were point values rather than averages over the collapsing cloud.

Model calibration for a
continuous discharge operation

38. As previously noted, a major question when attempting to apply these disposal models is how best to model the particular disposal operation with the idealized disposal methods simulated by the models. For example, the continuous discharge model allows for only one discharge opening, whereas, most hopper dredges have eight doors, all of which discharge continuously for a discrete period of time but not necessarily concurrently. Of course, for the case of a pipeline discharge, there is no problem with representing the disposal operation, although other problems such as very shallow water depths may exist.

39. The purpose of the discussion below is to demonstrate the manner in which hopper dredged disposal operations might be modeled as well as to present calibration results. Although the applications are for actual disposal operations in the New York Bight and Lake Ontario, the data from the New York Bight site were not sufficient for model calibration.

40. New York Bight disposal site. The disposal in the New York Bight was accomplished by a hopper dredge moving at over 4 ft/sec. The dredge contained four pairs of doors, with disposal occurring by opening first a pair of forward doors and then a pair of aft doors until the complete load was discharged. Normally, the discharge from one pair of doors was essentially complete by the time the next pair opened. The continuous discharge model was used to simulate this disposal operation by making the assumption that the operation could be represented as a continuous discharge through a circular opening with an area equivalent to a pair of doors. Although no field data collected at the site were considered suitable for comparison with model predictions, the approach did appear to provide a reasonably qualitative description of the short-term fate of disposed material. However, a note of caution must be raised concerning the concept of representing the outflow from several openings by a single discharge since the hydrodynamic similarity may be significantly altered. Thus, combining several openings of a hopper dredge into a single opening is not recommended.

41. Lake Ontario disposal site. The disposal operation in Lake Ontario at Rochester, N. Y., was accomplished from a stationary hopper dredge discharging simultaneously from eight doors. As previously discussed, the continuous discharge model applied to a stationary, vertical discharge does not behave well at bottom encounter. Based upon observations by Yale University, the eight individual jets grew fairly quickly and at some point in the water column had grown enough to mix together. From this point, the material falling through the water column resembled the type of disposal operation that could be simulated with the instantaneous dump model. However, the discharge continued for about 45 sec, whereas, the bottom was encountered within 15 to 20 sec. Thus, although the dump model will yield the radial outflow pattern on the bottom, some mechanism for accounting for the material still being discharged must be developed. This was accomplished as follows. From field observations, it was estimated that the majority of the solids settled to the bottom of the hoppers with the resulting material in the lower one third of the hoppers having a bulk density of 1.50 g/cc and the material in the upper two thirds having an average bulk density of about 1.17 g/cc. The continuous discharge model was first run assuming a release density of 1.50 g/cc. Results from this run were then used to initiate the instantaneous dump model, taking into account the case of all eight doors being opened. The continuous model was then rerun assuming a release density of 1.17 g/cc to arrive at a resulting flow rate near the bottom. The instantaneous dump model was then modified to accept this flow rate as entrained fluid into the collapsing cloud on the bottom for as long as the discharge continued. It is believed this approach yields the most realistic representation possible with the current structure of the models.

42. A major question that must be answered in the calibration phase is that of which of the computed results should be compared with recorded field values. For example, comparing computed and recorded times to bottom encounter certainly seems justified, whereas, attempting a direct comparison of cloud thickness at some point on the bottom does not. The most important data to be gained from the models are time to

bottom encounter, spread of material through the water column, and lateral extent and total volume of the bottom surge versus time. Therefore, these were the quantities compared in the calibration phase.

43. Two dump sites in Lake Ontario were monitored by Yale University with the major difference between the two being the water depth, 58 ft at one and 87 ft at the other. Results from the 58-ft site were used for calibration purposes due to more detailed data having been collected there.

44. With a drag coefficient of ADDRAG = 1.50 for the additional vertical drag force previously discussed and a convective descent jet entrainment coefficient of $\alpha_1 = 0.20$, the front of the descending jet reached 42 ft below the surface in 10 sec, which was essentially the time recorded by Yale. After initiating the instantaneous dump model, the total computed elapsed time until bottom encounter was 17 sec, whereas, Yale recorded 18 sec.

45. Comparisons between computed and recorded bottom surge arrival times and volumes for different combinations of CDRAG, α_c, and FRICTN are presented in Figures 3 and 4. As indicated, ADDRAG, α_1, and α_0 were fixed at values of 1.50, 0.20, and 0.65, respectively. As can be seen from the slots increasing α_0 from its default value of 0.235 to 0.65 had little effect at the 58-ft site due to the instantaneous dump model being initiated very close to the bottom. However, the larger value was needed at the deeper 87-ft site and thus was also incorporated here. Values of CDRAG = 5.0, $\alpha_c = 0.04$, and FRICTN = 0.10 appear to be the best combination to make computed values approximate both measured surge spread and surge volume, simultaneously.

46. The models were then applied to the disposal operation at the 87-ft site with the same values for the coefficients as determined for the 58-ft site. Figure 5 illustrates the comparison between computed and recorded positions of the surge front versus time. No recorded surge volumes were available for comparison. However, the computed final thickness of the collapsed cloud at the 87-ft site increased by 40 percent over that at the 58-ft site. Yale observed a similar increase of surge thickness with water depth.

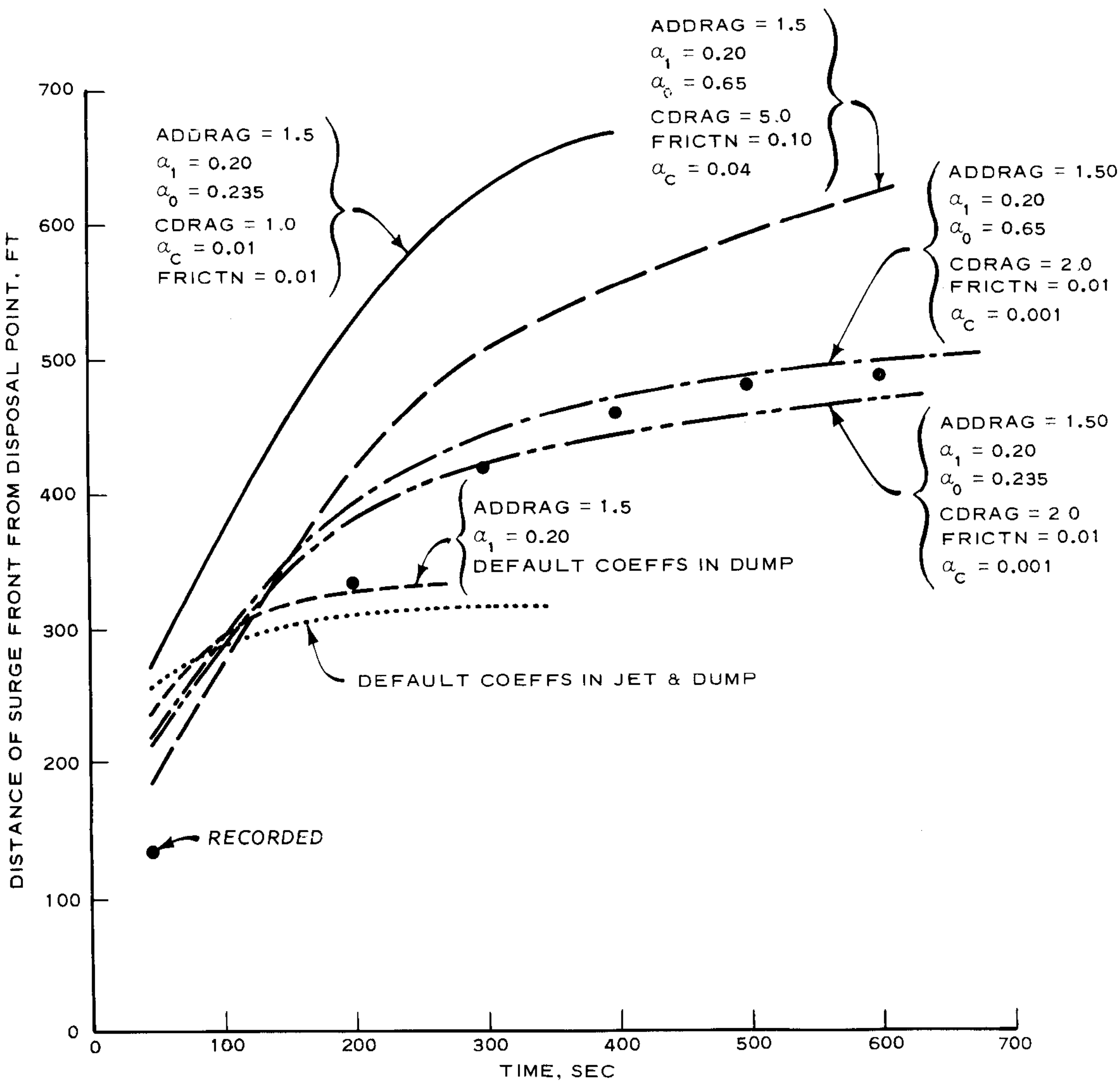

Figure 3. Surge spread versus time after disposal at the Lake Ontario 58-ft site

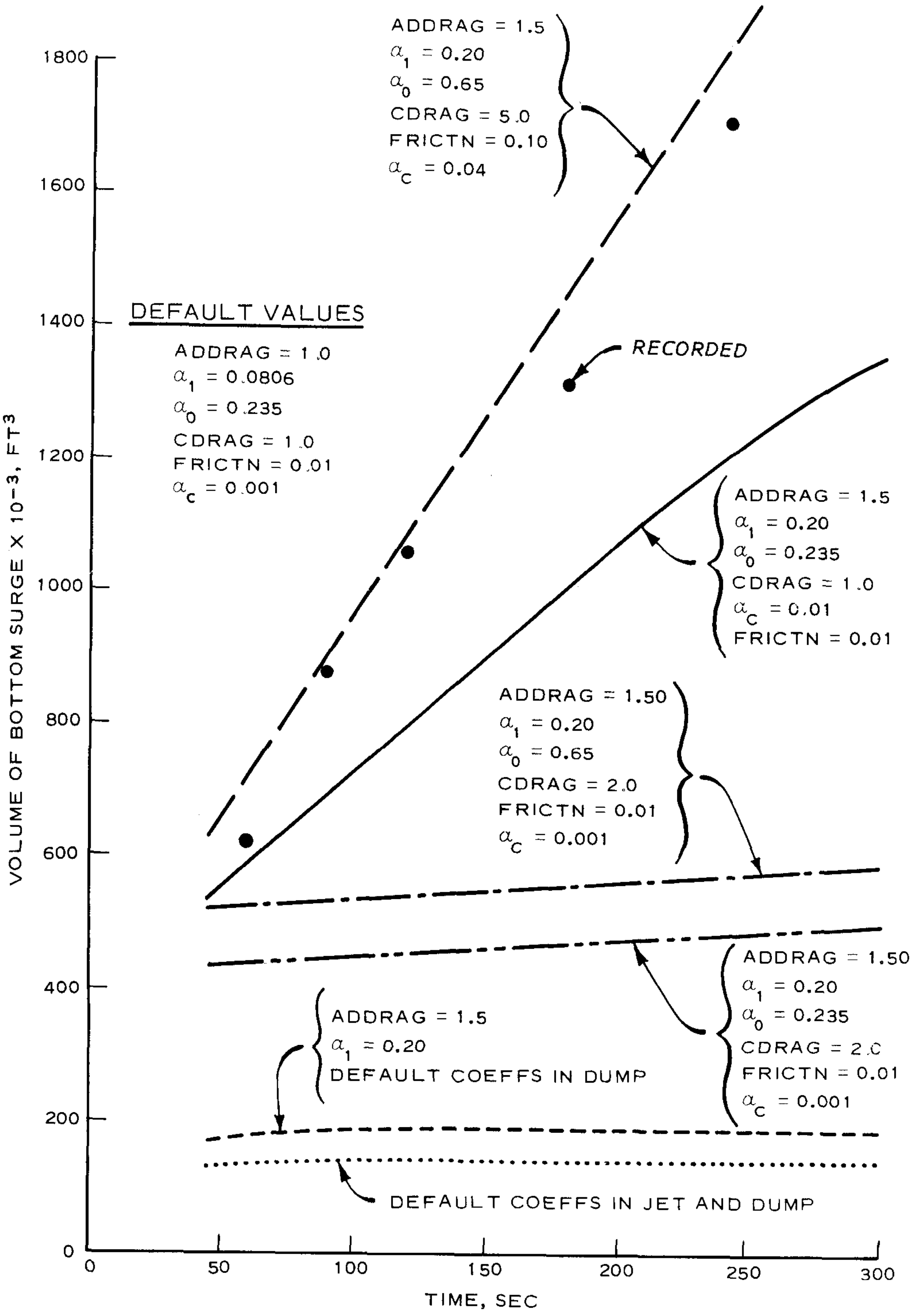

Figure 4. Surge volume versus time after disposal at the Lake Ontario 58-ft site

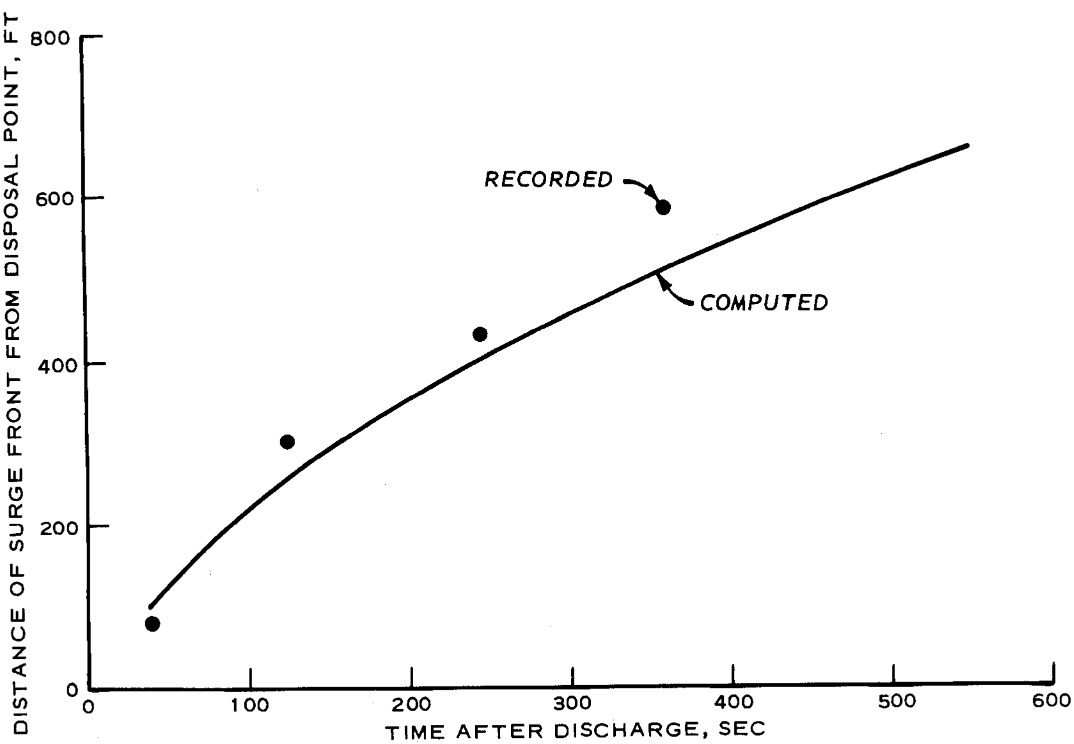

Figure 5. Lateral extent of bottom surge versus time at 87-ft site

47. Although the above results, as well as those for the barge and scow disposal simulations in the Duwamish Waterway and New York Bight, respectively, do not constitute a detailed calibration of the models, they do indicate that proper use of the models will provide reasonable qualitative information. An improved knowledge of the dependence of the more sensitive coefficients on characteristics of the disposed material and the disposal site, plus perhaps the method of disposal, must be obtained through additional comparison of model results with field data before any quantitative significance should be attached to information obtained from the models. However, it should be noted that results from the scow dump in the New York Bight and the hopper dredge disposal in Lake Ontario are encouraging. Even though the methods of disposal were vastly different and site characteristics were not the same, approximately the same values of the bottom collapse coefficients provided reasonable matching of computed results with the limited field data (Table 1). Therefore, when applying the models to operations similar to those discussed, coefficients should be selected

Table 1

Summary of Calibration Results

Location of Operation	Mode of Disposal and Volume	Water Depth	Material Description	Convective Descent Coefficients Varied			Bottom Collapse Coefficients Varied		
				Coeff	Default	Final	Coeff	Default	Final
Duwamish Waterway	Instantaneous barged dump of 530 cu yd	≈200 ft	14% Sand 17% Clay Bulk density = 1.50 g/cc	CD	0.50	1.0	CDRAG	1.0	1.75
New York Bight	Instantaneous scow dump of 3900 cu yd	85 ft	11% "clumps" 26% silt-clay Bulk density = 1.60 g/cc	CD	0.50	1.0	CDRAG α_c FRICTN	1.0 0.001 0.01	5.0 0.04 0.075
				Jet Convection Coeff's					
Lake Ontario	Continuous discharge from stationary hopper dredge for 45 sec at 365 cfs modeled by using both models	Two disposal operations at 58 and 87 ft, respectively	Bulk density ranged from 1.07 g/cc at the top of the hoppers to 1.70 near the bottom	α_1 ADDRAG	0.0806 "New Coeff" (1.0)	0.20 1.50	CDRAG α_c FRICTN	1.0 0.001 0.01	5.0 0.04 0.10
				Instantaneous Descent Coeff's					
				α_0	0.235	0.650			

Note:
CD - Convective descent drag coefficient in instantaneous dump model
CDRAG - Bottom collapse drag coefficient in instantaneous dump model
α_c - Bottom collapse entrainment coefficient in instantaneous dump model
FRICTN - Bottom collapse bottom friction coefficient in instaneous dump model
α_1 - Jet convection entrainment coefficient
ADDRAG - Drag coefficient associated with the additional drag force inserted into the continuous discharge model for the case of a vertical discharge
α_0 - Convective descent entrainment coefficient in instantaneous dump model.

close to those determined here to yield the best results at the New York Bight and Lake Ontario sites.

Field Obserations During Disposal

48. The data presented in Bokuniewicz et al.[4] indicate that dredged material is deposited from hopper dredges and scows or barges by the same three steps. Upon release, the dredged material descends through the water as a well-defined jet of high density fluid, which may contain blocks of solid material. Ambient water is entrained during descent. After falling through the water, bottom impact occurs. Some material is deposited during impact and some enters the horizontally spreading bottom surge formed by the impact. This surge moves out radially from the impact point until the driving forces are sufficiently reduced to allow deposition to occur.

Variables affecting the placement of dredged material

49. There are two groups of variables that influence the placement of dredged material: those determined by the dredging and disposal methods chosen and those characterizing the disposal site. The dredging/disposal method variables include:

a. Quantity of material released. The same general behavior will occur during disposal irrespective of the total quantity in the disposal vessel; however, the thickness of the surge, the travel time of the surge, and the lateral extent of the bottom surge may be greater for larger quantities.

b. Insertion speed. Insertion speeds are dependent on the design of the hoppers and doors and on the physical properties of the dredged material.

c. Dredged material properties. The cohesion and water content of the material to be released influence insertion speed and the form assumed by the sediment during descent. Characterization of the physical properties of dredged material is critical to fully understand the processes during disposal and to model these processes.

d. Speed of the discharge vessel. Moderate speeds will not affect the entrainment rate but may laterally move the impact point. Observations of moving dumps from hopper dredges reveal potential effects from the propeller action.

The disposal site characteristics include:

- a. Depth. Entrainment will be greater with increasing depth, but there will not be an increase in the impact speed nor the bottom surge spreading rate. The thickness will be greater because of the larger quantity of fluid entering the surge.
- b. Current in the receiving water. Entrainment of the ambient water will cause the descending dredged material to acquire the lateral velocity of the receiving water and the impact point will be displaced. The bottom surge velocity will not be influenced by the current.
- c. Density gradient in the water column. Substantial density gradients or a highly stratified situation in sufficiently deep water can result in arrest of the descent phase and collapse in the water column. In coastal waters or lakes, this density gradient may act as a barrier limiting the vertical diffusion of the bottom surge after impact.
- d. Bottom hardness. If the bottom is soft, it can act to absorb some of the energy during impact and reduce the potential deformation of cohesive masses of dredged material.
- e. Critical erosion velocity of the bottom. The more susceptible the bottom is to erosion, the greater the amount of sediment mixed with the bottom surge in the impact area.
- f. Bottom slope. If the bottom is not horizontal, there may be an additional force to act upon the bottom surge.
- g. Bottom roughness. The greater the roughness of the bottom, the greater the rate of spreading of the surge may be reduced by friction and energy dissipation.

50. The above-mentioned process variables have complex interactive effects that cannot be readily delineated without elaborate testing and evaluation. However, recognizing the impact of these variables on the mechanism of dredged material placement allows one to adequately predict the potential distribution of dredged material within a disposal site. The actual data from each field site investigated will be used to calibrate and verify short-term dispersion models for use as predictive tools.

PART III: PREDICTION OF SEDIMENT TRANSPORT IN ESTUARIES

51. In response to an urgent need, the DMRP contracted with the University of California, Davis, for the initial development of an estuarial sediment transport model. This work is reported by Ariathurai, MacArthur, and Krone.[5] Two two-dimensional models, one for the horizontal plane and one for the vertical plane, were developed to provide a means for describing cohesive particle concentrations throughout the water body as they change with time and to describe rates of deposition or bed erosion. These models, Sediment II-H and Sediment II-V, are currently under evaluation by WES Hydraulics Laboratory personnel. This part of the report discusses a basic conceptual model for sediment processes in estuaries, a preliminary evaluation of the state of development of the sediment transport models, and the potential applicability of the models to estuarine problems.

The Conceptual Model for Scour and Deposition in Estuaries

52. The objective in calculating scour and deposition is to establish the equilibrium elevation of the bed of the estuary and to establish the rate of return to equilibrium when that bed is modified as by dredging or material placement. The rate of return to the equilibrium merely reflects deposition or scour and, consequently, may relate to the quantity of material that must be dredged.

53. The approach utilizes a sediment budget analysis to calculate net deposition or scour. The basic principle is: when the sediment in motion exceeds the transport potential of the flow, deposition occurs. When transport potential of the flow exceeds the sediment load, material is entrained from the bed. Transport potential changes when velocity changes, and velocity depends on energy from tides, freshwater inflows, storm surges, wind, waves, and density currents. The net deposition or scour is calculated by aggregating the effects of all these energy forces.

54. Periods of high freshwater inflow and storm surge periods

create the drastic changes in bed geometry of the estuary, and the impact of successive events is as variable as the size and pattern of the successive storms. Tidal action is more uniform and tends to return the estuary to an equilibrium state. The estuary will respond to these energy and sediment sources as if they were independent populations, and their combined impact can be evaluated by studying each separately and by using the expected value approach to combine results. The most attractive method for analyzing the impact of each energy source is numerical modeling.

55. Numerical modeling of scour and deposition begins with a digital description of the geometry. This subdivides the estuary into cells for computation purposes. Cell sizes vary as required to model problems areas, and their alignment is curved to follow boundaries or channels. The initial bed elevation is prescribed for each cell from sounding charts, and, thereafter, computations change the bed elevation in response to the inflowing sediment load and interaction between hydraulic forces and the estuary bed.

56. Water velocity vectors and water depths, depicting hydraulic forces, are input data. They are available from field measurements, hydraulic model (physical or numerical) data, or calculations. Hourly values are satisfactory and a few days will usually cover tide or storm surge periods. Data are provided at eight points around the boundary of each cell. Freshwater flood periods require the same hydraulic data as tidal flow or storm surge periods. Rather than a few days, however, the significant period for high freshwater inflows will extend through the flood season. In addition, several different flood seasons will be required to develop an expected value of project performance.

57. The concentration of suspended sediment in the estuary is produced by the interaction between hydraulic forces and the bed of the estuary and by water bringing sediment into the estuary from land or sea sources. Wind-blown sediment may be a significant contribution during some events. Prototype surveys will establish the concentration of suspended sediment throughout the estuary at the start of a study period; thereafter, the numerical model will combine sediment from all

sources, using the prescribed hydraulic data, to determine the concentration of sediment in motion and the rate at which material is exchanged with the bed.

58. The sediment reservoir on the bed of the estuary is a layered system. The top layers can have the density and shear strength of a fluid mud, and both density and shear strength increase with depth. Both particle erosion and mass erosion of the entire layer are functions of shear stress. When shear stress in the flow exceeds the critical shear stress for mass erosion, that layer fails over the entire cell and immediately becomes a sediment source for possible entrainment. The actual amount entrained is controlled by hydraulic forces, the existing suspended sediment material, and settling velocity of the sediment.

59. The most important properties of the sediment particles are size and density. Particles having a grain size greater than 0.0625 mm are called sand (American Geophysical Union Classification scale) and movement depends only on mechanical forces. Particles smaller than 0.004 mm are called clay, and movement (or behavior) depends strongly on electrochemical forces. Information on salt concentration in the water is required to analyze such behavior. Particles between these two limits are called silt, and behavior depends upon the amount of clay present.

60. The direction and distance that a suspended particle will travel are calculated from hydraulic data and settling velocity of the particle. Settling velocity for sand and silt can be determined analytically. Clay particles flocculate to form aggregates, and their settling velocity depends on the effective size of the aggregate. Counteracting this aggregation process are hydraulic forces (shear and turbulence) that break up the flocs. Consequently, the settling velocity for clay will be estimated from field data and calibrated during early phases of a study.

61. Interaction between the bed sediment and the water force is a function of the bed shear stress. The uppermost bed layer that can withstand the hydraulic shear stress becomes the bed surface for that

point in time. Aging causes the critical shear of a layer to increase, especially when additional layers of material are deposited to add overburden.

62. Energy due to waves and boat traffic is not included in the models discussed herein. The analysis of mixtures of sand, silt, and clay also will require additional research. Littoral transport is an input data item rather than a calculated result.

63. The sediment budget analysis will automatically determine the location and amount of scour or deposition. In addition, the concentration of suspended sediment will be calculated at all times. A table of bed elevations or suspended sediment concentrations may be obtained at any time during the computation period.

64. Since this methodology relates hydraulic forces to the resistance of bed material and amount of sediment inflow, it works equally as well for determining the fate of sediments placed in open-water disposal areas as it does for deposition in dredged areas. Furthermore, a variety of current patterns can be imposed and the resulting movement of suspended and bed material can be calculated using this approach. Although local scour (i.e., within grid cells) is not calculated, bed changes resulting from dikes or other training structures can be determined once the impact of the structures on velocity vectors has been determined.

Calibration and verification

65. These numerical models require sufficient field data to calibrate coefficients and verify model performance. Bottom elevations surveyed at two points in time and a history of dredging that shows locations, quantities, and gradation of dredged material are desirable in addition to the necessary input data on flow hydraulics, sediment properties, and water-sediment inflows. During calibration, the size of cells, the location of cells, and the shape of the computation grid are adjusted; effective diffusion coefficients are estimated; and settling velocity of particles and flocs are fine tuned until an observed condition in the prototype is reconstituted in the model.

Performance criteria
for computational models

66. In the general case, flow in estuaries is three-dimensional. Therefore, a three-dimensional mathematical model is required to calculate hydraulic parameters. Likewise, a three-dimensional sediment model is required to analyze scour and deposition. The state of the art has not yet advanced to that level of sophistication in numerical modeling; therefore, the sediment models will solve two-dimensional problems. One code is for the horizontal plane and will be applied when estuaries are well mixed (that is, little or no vertical salinity gradient). The other is for the vertical plane and will be applied when estuaries are not well mixed (definite vertical salinity gradient) in the vertical, but can be represented by a breadth-averaged model. Some estuaries will not fit either of these categories; however, many will and this criterion is a reasonable first step toward a more generally applicable methodology. Hydraulic parameters will be input data to these sediment codes.

67. The computation grid will be developed to model local depths and velocities in channels while averaging over large areas in shallow water. The models will generate these grids of cells automatically while allowing final locations of cells to be shifted by the engineer.

68. Computations are designed for transient hydraulic conditions and will analyze several days of continuous flow records. Not only must all estuary space be analyzed each time step, but also boundary points where sediment enters the estuary (locations where sediment boundary conditions are prescribed) must change between ebb and flood tides.

69. Initial applications of sediment transport modeling will focus on estuaries where sediment is represented by a single grain size and deposits form layers. The density and shear stress will be uniform in a layer but will vary from one layer to the next. Erosion of the bed will be by mass failure of the entire layer in a cell rather than by particle erosion. A continuous accounting of the bed surface elevation will show the results of hydraulic forces acting on the bed;

however, the computations will not tag particles or trace the path of particles from a specific location.

70. Both tabular and graphical output are provided by the model. The graphical output will produce contours from calculated values of scour and deposition. The location for output may be selected in time and in space.

Model design

71. The convective-diffusion equations are used to approximate the suspended sediment movement processes. Interaction with the bed is established through applying the logarithmic velocity profile over the lowest 15 percent of the water depth. The resulting shear stress is appropriate for plane beds.

72. By solving the equations with finite element theory, the variable size and complex alignment of computation cells can be achieved. A technique for generating the grid requires inputing only the boundary outline of the estuary, and the interior cells are positioned and linked together automatically. Cells may also be positioned by the engineer, or any of the automatically generated cells may be shifted if required.

Current Status of Models

73. Both numerical experiments and an independent analysis of the basic mathematical equations have been made in the models by Ariathurai, MacArthur, and Krone.[5] The following points have been raised concerning the basic equations in the two-dimensional vertical computer code:

a. Only small variations in the water surface (compared to water depth) are permitted in a transient system.

b. The equation formulations assume the sides of the estuary are vertical and parallel.

c. The use of Galerkin's criteria for weighted residuals[12] in the finite element model results in implied boundary conditions that overstate the problem (i.e., more equations than unknowns).

The significance of these points is being evaluated by numerical experiments. Meanwhile, vertical model applications should be selected to avoid large changes in water surface elevation relative to depth and large changes in widths along the estuary. The objective of the numerical experiments is to develop guidelines for using the computer codes and to identify needed enhancements. Shape and size of cells, effective diffusion coefficients, fall velocity, and computation time interval are input parameters requiring evaluation.

74. The original grid generator has been combined with both sediment transport models so the shape and size of cells can be quickly changed. Computations can be halted after processing the grid or they can be allowed to proceed into the scour and deposition phase.

75. Although not required theoretically, the grid should be organized in a systematic fashion. Computation lines should approximate streamlines and their orthogonals and the computation grid should have the greatest density of cells in areas of sharp concentration gradients and a lower density of cells elsewhere. Gradual transitions are recommended. Length to width ratios from 0.05 to 150 have been successfully used.

76. Effective diffusion coefficients and fall velocities have been changed from average cell values to point values around the cells. Constant values are usually used in the horizontal plane. However, reconstitution of analytical concentration profiles for coarse silt required that diffusion coefficients vary in the vertical. A simple analytical expression was developed for the equilibrium case, and its results aid in establishing vertical diffusion coefficients for any problem analysis. The horizontal diffusion coefficients vary with computation interval, but calibration to prototype conditions offers the only clue to their value.

Potential Areas of Application

77. The model methodology is designed to predict both short- and long-term sediment movement in estuaries. It will be useful for

estimating maintenance dredging requirements on new projects or on projects where the size of the channel is to be modified.

78. The fate of material placed in open-water disposal areas can be evaluated by the model. In areas where an estuary is well mixed, both direction and rate of movement of this material can be calculated. In those areas that are not well mixed, the rate of movement of sediment material can be calculated if the flow direction is prescribed. Therefore, the suitability of a proposed disposal area may be evaluated, in terms of the fate of material placed there.

79. The impact of changing either the rate or the duration of freshwater inflows can also be evaluated by the model. Either of these could change the location and rate of development of deposition zones. Likewise, the impact of changes in either the rate or character of the inflowing sediment load can be evaluated. The quantity and frequency of maintenance dredging can be used to measure that impact.

80. The WES Hydraulics Laboratory plans to use these models in performing a hybrid physical model/mathematical model analysis in connection with studies in the Columbia Estuary. This application will include the mobility of material placed in open-water disposal areas as well as deposition in back channels, the impact of dikes on sediment movement, and sediment movement at the inlet.

81. Another potential problem area for application is the Atchafalaya Bay which is undergoing rapid changes in bed elevation making it necessary to predict future conditions to aid in estimating maintenance dredging for navigation as well as the resulting impact on flood stages upstream. The value of the methodology discussed in this report will be to separate the impact of man's activities required for navigation and flood control from the natural processes that are presently remolding that bay. This application differs substantially from the Columbia in both the characteristics of sediment material (clay as opposed to sand) and the fact that the bed cannot be considered fixed in elevation.

82. The Columbia and Atchafalaya applications will undoubtedly

require major enhancements to the existing codes. Furthermore, insights gained from these trial applications will permit additional capability to be incorporated into the programs.

PART IV: SUMMARY

Prediction of Short-Term Fate of Dredged Material Discharged in Open Water

83. Insight gained from the ongoing evaluation and calibration study of the Tetra Tech models can be summarized as follows:

- a. The instantaneous dump model represents a barge dump (in which all material has left the barge before the bottom encounter) quite well in a qualitative sense. Results from the Duwamish and New York Bight calibration efforts support this.
- b. The continuous discharge model should be used to represent disposal from hopper dredges. If the hopper dredge is moving, one should look at the operating scheme in order to determine the best approach to take, keeping in mind that combining too many individual hopper gate openings into a single opening may alter the hydrodynamic similarity. If the hopper dredge is stationary, one should not attempt to apply the continuous discharge model alone since it does not provide a realistic representation of a vertical jet bottom encounter. The approach used in the Lake Ontario calibration effort should be considered.
- c. Proper material characterization is extremely important in obtaining realistic predictions from the models, particularly when collapse in the water column is a real possibility. One should attempt to classify not only solid particle fractions such as coarse sandy material but also that fraction of the material that falls as "clumps."
- d. Entrainment and drag coefficients in the descent and collapse phases appear to be the most sensitive coefficients in the models. When attempting to calibrate the models against field data collected at a disposal site, these coefficients provide a good starting point in the variation of coeffients required for model adjustment. For disposal operations similar to those discussed, the values of the coefficients should be selected close to those determined to yield the best matching of computed and recorded results as the New York Bight and Lake Ontario sites.
- e. No quantitative significance should be attached to predictive computations from either model until knowledge of the required coefficients is improved.

84. Major modifications made to the Tetra Tech models other than correcting the computer codes include:

- a. Allowing for the computation of a conservative chemical constituent through the passive dispersion phase taking into account a background concentration.
- b. Computing settling velocities for cohesive fractions beginning with the collapse phase and extending through the passive dispersion phase.
- c. Removal of the excessive dilution experienced in transferring small clouds to the long-term transport grid and also in the vertical diffusion computations.
- d. Inclusion of an additional driving force in the bottom collapse phase.

85. Although these models still have not undergone sufficient calibration and subsequent verification to warrant confidence in a quantitative sense, the limited calibration discussed herein and the in-depth evaluation the models have received do justify confidence in a qualitative sense, especially if the material is properly characterized and the models are judiciously applied to adequately represent a real disposal operation.

86. From the evaluation and testing program, including the data collected from the field studies, the following conclusions can be made concerning the short-term models at this time:

- a. The models can realistically simulate what happens in the water column during the release. The limiting factor determining which model or models to apply is the relationship between the time required for the leading edge of the descending cloud to impact the bottom and the time required to empty the hopper dredge or barge.
- b. These models cannot describe accurately the detailed structure of the impact and subsequent bottom surge as observed and discussed in Bokuniewicz et al.[4] However, with proper selection of coefficients, the lateral spreading and the rate of change in the total volume of the radially expanding surge can be estimated.
- c. After the collapse phase, the dispersion of the extremely fine material is represented qualitatively by the model.
- d. An accurate description of the concentrations within the surge and long-term phase is dependent on an adequate

characterization of the sediment composing the dredged material.

Prediction Of Sediment Transport in Estuaries

87. This study has discussed a basic conceptual model for sediment processes in estuaries, a preliminary evaluation of the state of development of the sediment transport models, and the potential applicability of the models to estuarine problems.

88. The objective of predicting sediment transport in estuaries is to establish the equilibrium elevation of the bed of the estuary and to establish the rate of return to that equilibrium when that bed elevation is modified. The conceptual model for estuarine processes includes energy sources, sediment sources, flow hydraulics, and the interaction between the fluid and sediment material. The equilibrium elevation of the bed may be estimated by aggregating the effects of individual energy and sediment sources.

89. The computational models reported by Ariathurai, MacArthur, and Krone[5] address the mechanical interaction between the fluid and cohesive sediment material. A horizontal model is available for application where flow is well mixed in the vertical. A breadth-averaged vertical model is available for application where the velocity profile in the vertical does not obey the analytical velocity distribution laws. Flow hydraulic parameters (x-velocity and y-velocity or z-velocity plus depth) must be given as input data. Consequently, energy sources must be identified, analyzed, and translated into flow hydraulic parameters by a technique that is external to the sediment models such as prototype data, physical model results, or numerical model results. The sediment models compute suspended concentration of clay and changes to the bed surface elevation due to deposition and mass erosion. The response of the clay material to electro-chemical forces must be developed by methods not included in these computational models.

90. Calibration parameters for the sediment models are grid cell size, particle fall velocity, and diffusion coefficients. An automatic

grid generator is incorporated to facilitate changing the grid cell size. Particle fall velocity may be estimated from field data. Diffusion coefficients must be adjusted until the model stimulates the behavior of the prototype during some event when both the bed elevation and the suspended sediment concentration were measured.

91. When calculating hydraulic parameters with breadth-averaged (vertical) models, only that portion of the flow field having the average velocity should be included. Some calibration is required to arrive at the proper width since unit discharge may vary from point to point along the estuary.

92. Calculation of estuarine sedimentation is in its infancy and any computational models, including those referenced in this report, must be coupled with a great deal of insight into the behavior of the specific estuary. Nevertheless, these models represent the state of the art and can certainly aid those who are studying estuarine problems.

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Holliday, Barry W
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TA7.W34 no.DS-78-3