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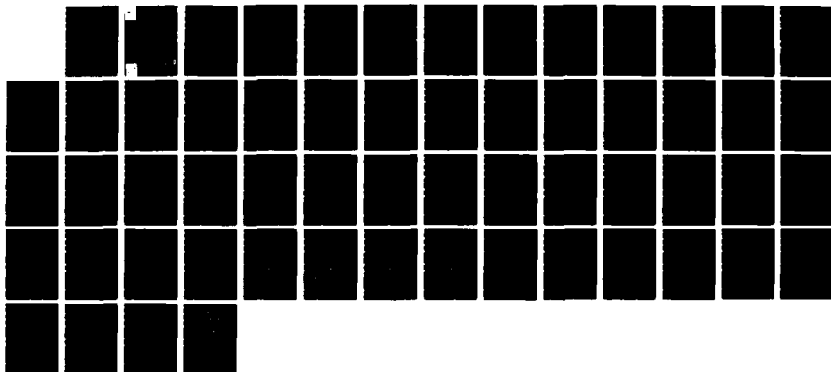
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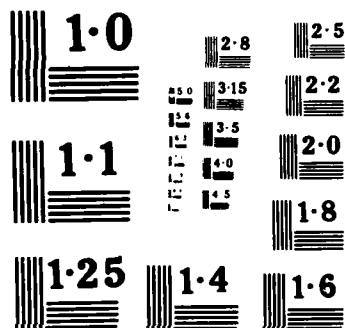
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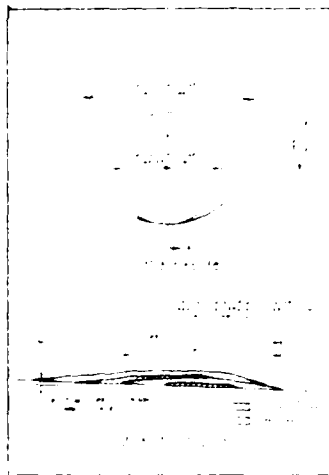






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TECHNICAL SUPPLEMENT TO DREDGED MATERIAL DISPOSAL STUDY US NAVY HOME PORT, EVERETT, WASHINGTON

by

Stephen A. Adamec, Jr., Billy H. Johnson
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A series of numerical model runs predicting the short-term fate of contaminated and uncontaminated dredged materials disposed in open water was performed. The conditions tested were intended to represent typical conditions for the disposal of material at the proposed US Navy Home Port site at Everett, Washington. Two types of disposal methods were tested: a bottom disposal of contaminated material and a capping operation with uncontaminated material using hydraulic dredging and pipe discharge. Long-term predictions of disposal mound configuration and capping thicknesses based on hand calculations were also made. Three current conditions and four dredged material clumping percentages were simulated for the bottom disposal of the contaminated material. Three discharge pipe configurations and four pipe discharges with varying density were simulated for the capping operation with uncontaminated material. (Continued)					
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19. ABSTRACT (Continued).

General conclusions from the modeling are as follows:

- a. For a single 4,000-cu-yd barge disposal of material, more than 98 percent of the disposed contaminated material will deposit within 1 hour for all tests at 265 ft of water depth. The disposed contaminated material will deposit within an area of 800 by 1,000 ft with a maximum thickness of approximately 0.60 ft.
- b. More than 90 percent (at a discharge rate of 30 cu yd of solids per minute for 47 min) of the disposed uncontaminated capping material from each sweep of the confined surface discharge will deposit within an hour. The swath of deposition will be less than 300 ft wide with a maximum thickness of approximately 0.09 ft. Bottom impact velocities will be less than 0.5 fps.
- c. More than 95 percent (at a discharge rate of 30 cu yd of solids per minute for 47 min) of the disposed capping material from the 50- and 150-ft stationary down-pipe capping operations will deposit within an hour. The area of deposition will have a radius of less than 100 ft with a maximum thickness of approximately 2.0 ft. Bottom impact velocities will be less than 1.1 fps.
- d. Based on sample computations of estimated volumes of material, the long-term disposal of 836,000 cu yd of material (97,000 contaminated and 739,000 uncontaminated) in the first dredging season and 2,469,000 cu yd (831,000 contaminated and 1,638,000 uncontaminated) in the second dredging season is estimated to generate a disposal mound with a final radius of approximately 2,400 ft, a side slope of approximately 1V on 30H, and a cap thickness of approximately 4 ft.

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PREFACE

The work described in this report was performed by the US Army Engineer Waterways Experiment Station (WES) for the US Army Engineer District, Seattle (NPS). Mr. Eric Nelson was NPS liaison during the study.

Personnel of the Hydraulics Laboratory (HL), WES, performed this study under the direction of Messrs. F. A. Herrmann, Jr., Chief, HL; R. A. Sager, Assistant Chief, HL; W. H. McAnally, Jr., Chief, Estuaries Division (ED); and R. A. Boland, Chief, Estuarine Simulation Branch (ESB). The project was conducted and this report prepared by Messrs. S. A. Adamec, Jr., ESB; B. H. Johnson, Math Modeling Group; A. M. Teeter, Estuarine Processes Branch; and M. J. Trawle, ED. Other WES personnel participating in the study were Messrs. G. E. Banks, Estuarine Engineering Branch; B. Brown, Jr., Chief, Design Criteria Branch, Hydraulic Analysis Division; J. V. Letter, Jr., Chief, ESB; and M. R. Palermo, Chief, Water Resources Engineering Group, Environmental Engineering Division, Environmental Laboratory. Mrs. Marsha C. Gay, Information Products Division, Information Technology Laboratory, edited this report.

The many valuable contributions of Mr. Nelson as NPS liaison and his technical assistance in preparing long-term projections of disposal mound configurations are gratefully acknowledged.

COL Dwayne G. Lee, CE, is the Commander and Director of WES.
Dr. Robert W. Whalin is the Technical Director.

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CONVERSION FACTORS, NON-SI TO SI (METRIC)
UNITS OF MEASUREMENT

Non-SI units of measurement used in this report can be converted to SI (metric) units as follows:

<u>Multiply</u>	<u>By</u>	<u>To Obtain</u>
cubic feet	0.02831685	cubic metres
cubic yards	0.7645549	cubic metres
degrees (angle)	0.01745329	radians
Fahrenheit degrees	5/9	Celsius degrees or Kelvins*
feet	0.3048	metres
miles (US nautical)	1.852	kilometres
square feet	0.09290304	square metres

* To obtain Celsius (C) temperature readings from Fahrenheit (F) readings, use the following formula: $C = (5/9)(F - 32)$. To obtain Kelvin (K) readings, use: $K = (5/9)(F - 32) + 273.15$.

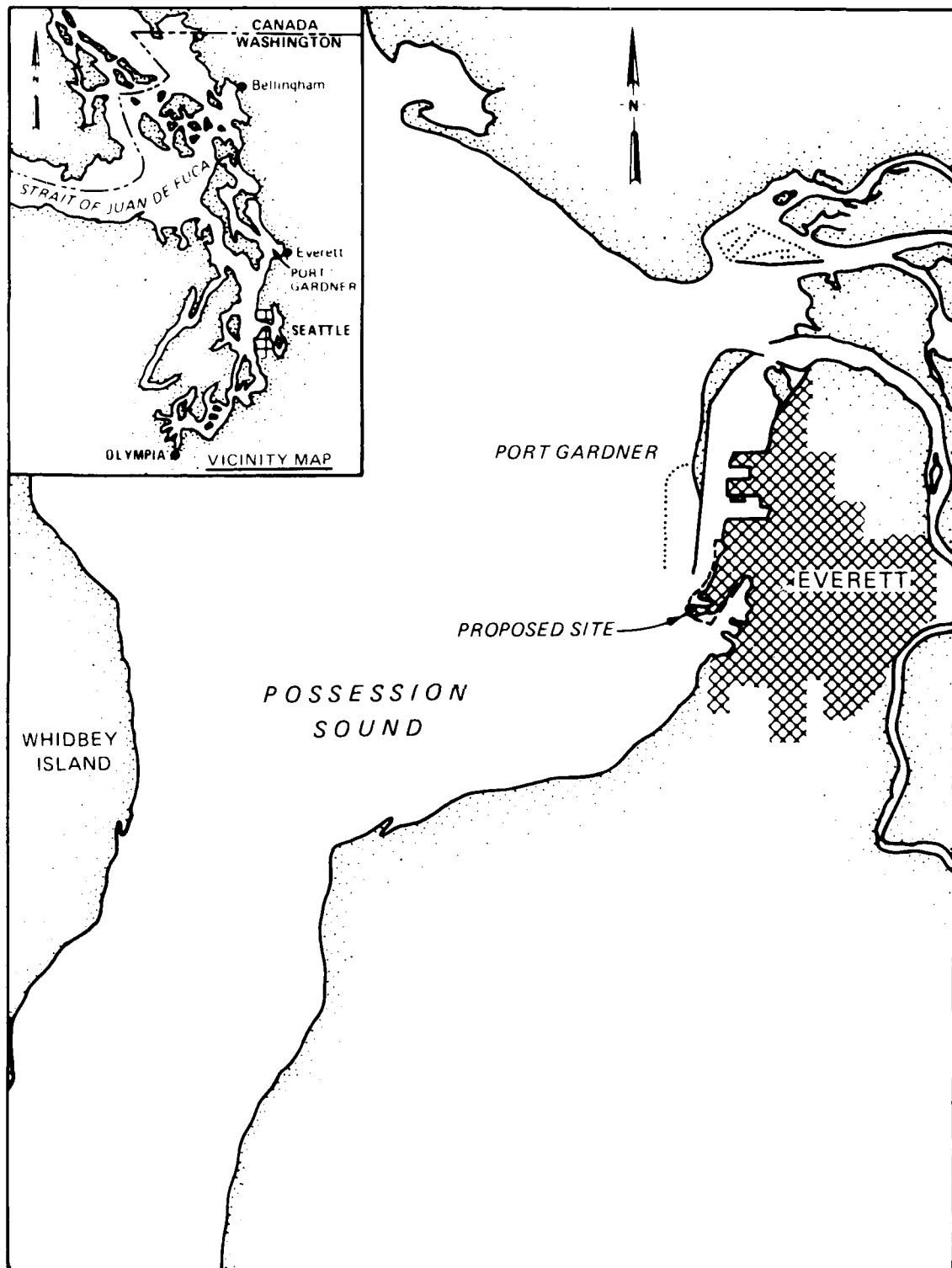


Figure 1. Location and vicinity map showing proposed home port site

TECHNICAL SUPPLEMENT TO DREDGED MATERIAL DISPOSAL STUDY

US NAVY HOME PORT, EVERETT, WASHINGTON

PART I: INTRODUCTION

Background

1. The US Navy has proposed to site a Carrier Battle Group (CVBG) Home Port at Puget Sound in the east waterway of Everett Harbor, Washington (Figure 1). Construction of the home port facility will involve dredging and disposal of 3.3 million cu yd* of contaminated and uncontaminated sediments from the east waterway. Approximately 928,000 cu yd of that total has been defined as contaminated by the Navy. The contaminated material would be removed using a mechanical dredge. Removal of the remaining approximately 2.4 million cu yd would be by hydraulic dredge. The Navy has selected the Deep Delta site in Port Gardner for contained aquatic disposal (CAD) as its preferred disposal alternative. The disposal site under consideration is located in water depths averaging approximately 265-400 ft (Figure 2). Navy-supplied current data indicate that currents range from 0.1 to 0.2 fps and generally run from southeast to northwest. A key factor in the feasibility of disposal at this site is the ability to adequately cap approximately 900,000 cu yd of contaminated material with approximately 2 million cu yd of uncontaminated material. This procedure will require accurate placement of contaminated and uncontaminated material within a defined boundary at the site without significant dispersal. In June 1984, the Navy contracted with the US Army Engineer District, Seattle, to provide technical assistance in developing the dredging and disposal plans. This report presents the results and interpretations of a numerical modeling study performed by the US Army Engineer Waterways Experiment Station (WES) for the Seattle District in support of the District's assistance to the Navy.

* A table of factors for converting non-SI units of measurement to SI (metric) units is found on page 3.

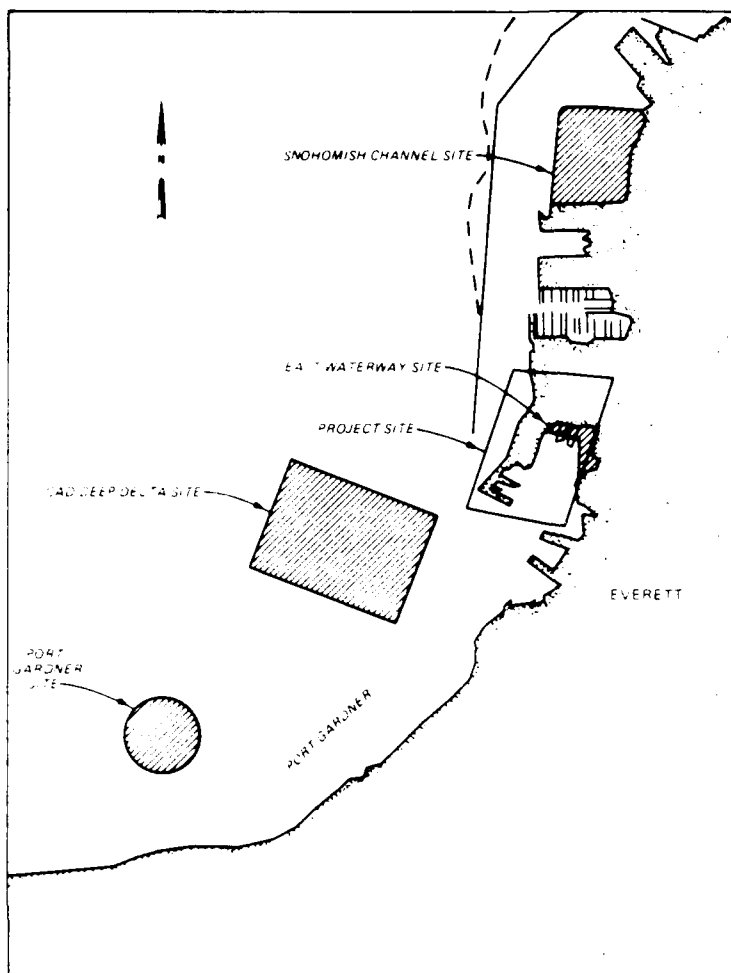


Figure 2. Location of known alternative disposal sites, as of April 1986

the numerical model DIFID (Disposal from Intermediate Dump). The model predicted the deposition pattern of disposed material for each of the conditions tested as well as suspended sediment concentrations in the lower water column. DIFID was then modified to simulate the proposed capping operations. The model predicted bottom impact velocities, deposition patterns, and suspended sediment concentrations throughout the water column over time. Long-term prediction of mound configuration was determined using side slopes observed at existing disposal sites along with assumptions concerning consolidation of the mound.

Objective

2. The objective of this investigation was to predict the short-term fate of both contaminated and uncontaminated material which may be dredged and disposed in the Everett Harbor/Port Gardner area. These results were combined with field experience from previous Corps dredging projects to predict the overall dimensions of the disposal area upon completion of the dredging operations.

Approach

3. The approach used was to simulate the open water barge bottom disposal of dredged material using

PART II: THE NUMERICAL MODEL, DIFID

Description

4. DIFID was developed by Brandsma and Divoky (1976) for WES under the Dredged Material Research Program. Much of the basis for the model was provided by earlier model development by Koh and Chang (1973) for the barged disposal of wastes in the ocean. That work was conducted under funding by the Environmental Protection Agency in Corvallis, Oregon. Modifications to the original model have been made by Johnson and Holliday (1978) and Johnson (in preparation).

5. In the simulation of a bottom barge disposal operation, the behavior of the disposed material is assumed to be separated into three phases: convective descent, during which the disposal cloud falls under the influence of gravity; dynamic collapse, occurring when the descending cloud impacts the bottom; and long-term passive transport-dispersion, commencing when the material transport and spreading are determined more by ambient currents and turbulence than by the dynamics of the disposal operation. Figure 3 illustrates these phases.

6. During convective descent, the disposed material cloud grows as a result of entrainment and may descend at a velocity exceeding 10 fps. The model assumes that none of the disposed material is lost to the water body during this phase. (This assumption is supported by dredged material disposal monitoring in the lower part of Grays Harbor in 1982, in which no increase in suspended sediment concentrations was observed within the water column at a station located 1,000 m from the disposal site.* The fact that no increase was detectable indicates that loss to the water column during descent was minimal.) Eventually, the material reaches either the bottom or a neutrally buoyant position in the water column. In 100 ft of water, the convective descent phase for typical maintenance material is completed in a few seconds after disposal. However, as computed by Trawle and Johnson (1986), in 800 ft of water, the convective descent is computed to last about 2 min. When the

* Personal Communication, March 1986, between Mr. Dave Schuldt, Seattle District, and Dr. James Phipps, Department of Geology-Oceanography, Grays Harbor College, Aberdeen, Wash.

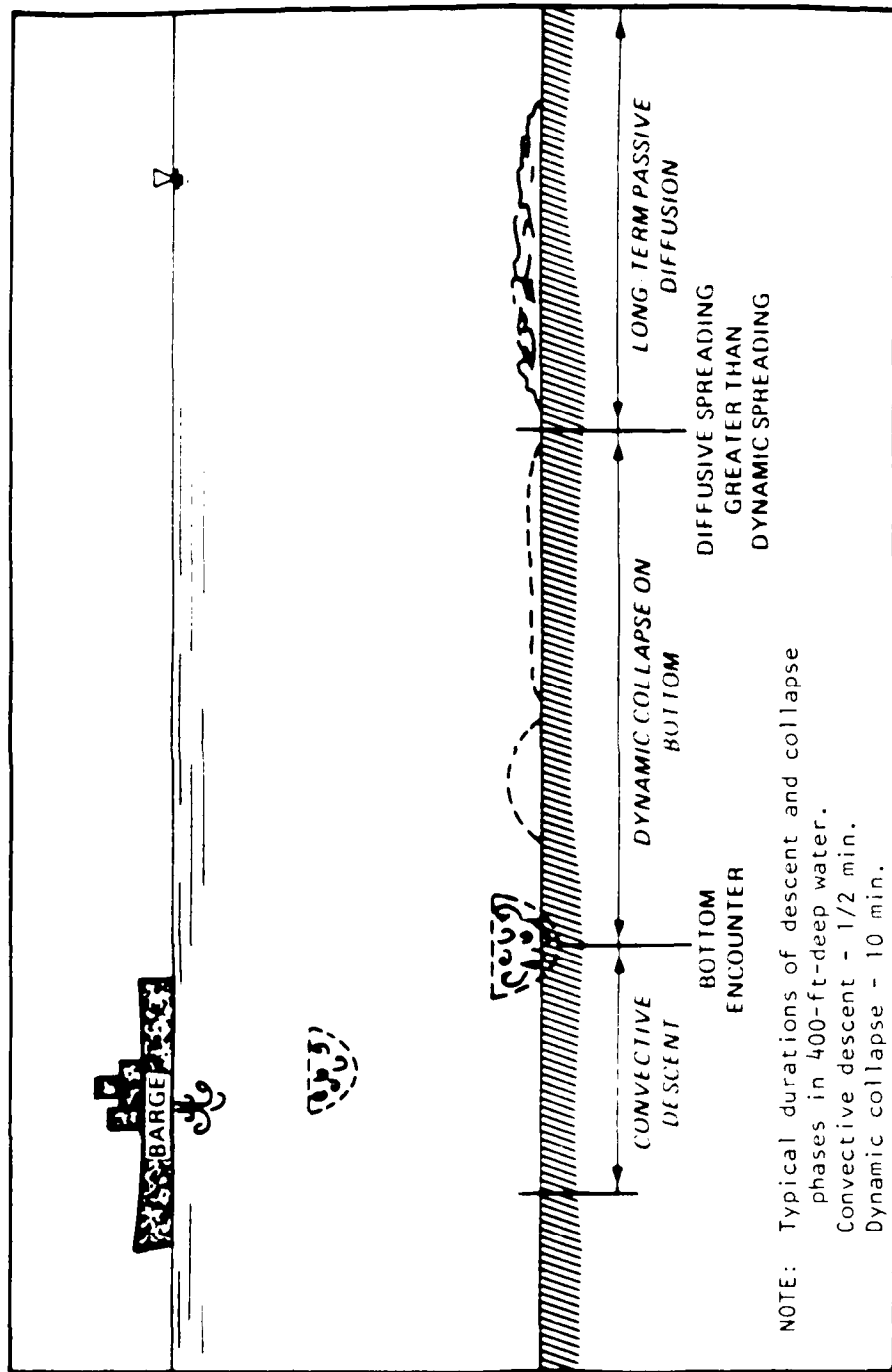


Figure 3. Illustration of idealized bottom encounter after instantaneous disposal of dredged material (from Brandsma and Divoky 1976)

vertical motion is arrested, a dynamic spreading or collapse in the horizontal direction occurs.

7. The basic shape assumed for the collapsing cloud in the water column is an oblate spheroid. When the cloud collapses on the bottom, it takes the shape of a general ellipsoid and can spread over several hundred feet. 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 phase begins. As particles leave the main body of material, they are stored in small clouds that are assumed to have a Gaussian distribution. The small clouds are then advected horizontally and diffused. During this phase, the clouds grow both horizontally and vertically.

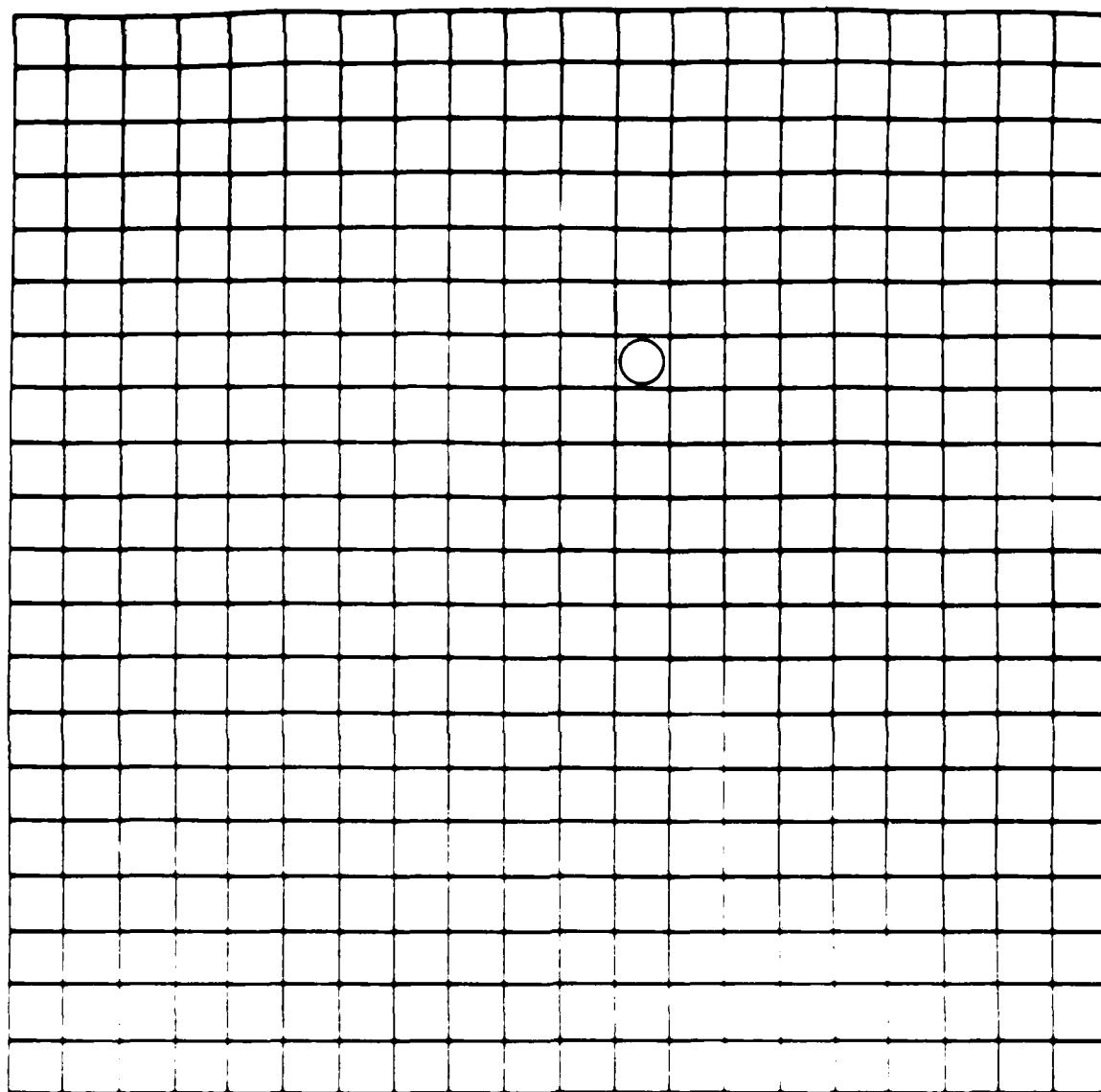
8. The model requires that the settling velocity for each solid fraction (e.g., sand, silt, and clay) be specified. In many cases, a significant portion of the material remains in "clumps." This situation is especially true for the Puget Sound area, where much of the dredging is done by clam-shell, and can be true in the case of hydraulically dredged material if consolidation takes place in the hopper during transit to the disposal site.

9. Throughout the simulation, settling of the suspended solids occurs, and the amount of solid material deposited on the bottom and a corresponding thickness are determined at each grid point of the model. The model assumes that no subsequent resuspension of material from the bottom occurs.

Required Input Data

10. The required input data to DIFID can be grouped into (a) a description of the ambient environment at the disposal site, (b) characterization of the dredged material, (c) data describing the disposal operation, and (d) model coefficients.

11. The first task is that of constructing a horizontal grid over the disposal site. The model grid used in this study is shown in Figure 4. The ambient conditions imposed on the grid model for these tests were represented by a constant density and, with the exception of run 7, a depth-averaged time-invariant current velocity. Current conditions for all runs are described in paragraph 27.



○ LOCATION OF DISPOSAL

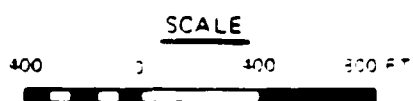


Figure 4. DIFID numerical grid

12. Although the model has the capability to handle dredged material composed of as many as 12 fractions, the dredged material for these tests was characterized by three solid fractions. For each solid fraction, its concentration by volume, density, fall velocity, void ratio, and an indicator as to whether or not the fraction is cohesive must be specified. In addition, the bulk density and aggregate void ratio of the material must be prescribed. The bulk density is the density of the slurry in the barge. The aggregate void ratio is actually a bulking factor used to convert the mass of deposited material to a thickness of deposition. The equation used by the model to convert solids volume deposited to thickness of deposition (Brandsma and Divoky 1976) is

$$TH = \frac{1 + AVR}{AREA} \times VOL \quad (1)$$

where

TH = average grid cell thickness, ft

AVR = aggregate voids ratio

AREA = grid cell area, sq ft

VOL = solids volume, cu ft

13. Disposal operations data required include the position of the barge on the horizontal grid, the volume of material disposed, and the loaded and unloaded draft of the disposal vessel.

14. There are 14 model coefficients in DIFID. These required coefficients include entrainment coefficients, drag coefficients, and turbulent dispersion coefficients. Default values that reflect the model developer's judgment are contained in the code. Computer experimentation such as that presented by Johnson and Holliday (1978) has shown that results appear to be fairly insensitive to many of the coefficients. The most important coefficients are drag coefficients in the convective descent and collapse phases, coefficients governing the entrainment of ambient water into the dredged material cloud, and diffusion coefficients. The values selected for the convective descent entrainment and drag coefficients in this study were based upon experimental work done by Bowers and Goldenblatt (1978) and a limited verification of DIFID using field data from the Elliott Bay/Duwamish disposal operation. This verification is discussed later.

Model Limitations

15. The following model limitations should be considered in the interpretation and use of model results: (a) limited knowledge of appropriate values for the various model coefficients, (b) imprecise specification of settling velocities for the disposed material, and (c) representation of real disposal operations in an idealized fashion. A detailed description of the theoretical aspects of DIFID is given by Brandsma and Divoky (1976).

Elliott Bay Application

16. During February 1976, personnel from Yale University (Bokuniewicz et al. 1978), under contract to WES, collected data during a series of barge disposal operations at the Duwamish disposal site in Elliott Bay near Seattle, Washington. The disposals, made from a 530-cu-yd barge, were of material possessing an average bulk density of 1.50 g/cc with the solid material being composed of 55 percent silt/clay and 45 percent sandy material. Although the data collected for comparison with computed results from the disposal model were very limited, it is believed that any verification of the model using field data from an area near the current disposal area lends credibility to model results for the subject area.

17. When the dredged material models are applied to real disposal operations, a basic problem is determining how to apply the models so that an actual operation can be represented by the idealized methods of disposal considered in the models. For example, there are no dredged material disposal operations in which all of the material leaves the disposal vessel instantaneously. However, for the case of a barge disposal such as that made at the Duwamish site in Elliott Bay, all of the material normally leaves fairly quickly. If the water depth is sufficiently large, such a disposal resembles a hemispherical cloud falling through the water column by the time the bottom is encountered and thus can be adequately modeled by the instantaneous disposal model.

18. Upon release of the material during the Duwamish site disposal operation, a time of 25 sec was observed for the leading edge of the disposal cloud to strike the bottom at a depth of 197 ft. With the convective descent drag coefficient increased from its default value of 0.5 to 1.0, the model

computed a time of 23 sec. The speed of the front of the bottom surge at 160 ft from the point of the disposal was recorded to be 20 cm/sec. With an increase in the drag coefficient in the bottom collapse phase from 1.0 to 1.5 and a bottom friction coefficient of 0.06, the simulated rate of spreading of the cloud on the bottom was computed to be 22 cm/sec. During field monitoring, suspended solids data were recorded at 3 ft above the bottom at a point 300 ft downstream of the disposal point. At 600 sec after the disposal, the recorded suspended sediment concentration was 64 mg/l. The corresponding computed concentration from the disposal model at the same location and time was 75 mg/l. These results were obtained with the vertical diffusion coefficient for a well-mixed water column computed from

$$AKY\emptyset = 8.6 \times 10^{-3} \frac{UZ^2(H-Z)^2}{H^3} \quad (2)$$

where

$AKY\emptyset$ = vertical diffusion coefficient

U = ambient velocity, fps

Z = water depth at which the value of the coefficient is desired, ft

H = total water depth, ft

19. The ambient current near the bottom of the Duwamish site was 0.3 fps and the water depth averaged 197 ft. All coefficients other than those discussed in paragraph 18 retained their default values.

20. Proper material characterization is extremely important in obtaining realistic model predictions. The results discussed in paragraph 18 were obtained by assuming that of the clay/silt, 30 percent consisted of clumps, 65 percent flocculated as cohesive material, and the remaining 5 percent retained individual particle characteristics with a settling rate of 0.0025 fps. The use of consolidated clumps is consistent with the field observations of Bokuniewicz et al. (1978).

21. In summary, the disposal model does not precisely describe the detailed structure of the impact and subsequent bottom surge observed during the field studies. However, with proper material characterization and selection of values for the more sensitive model coefficients, the lateral spread and suspended sediment concentrations can be reasonably estimated by the disposal model.

PART III: TEST PROGRAM AND RESULTS

Contaminated Material Disposal

Test conditions

22. Grid size. The model grid used for all tests is shown in Figure 4, representing an area 4,000 by 4,000 ft. Each grid cell represented an area of 200 by 200 ft. The grid was oriented with its horizontal axis approximately parallel to the bottom depth contours.

23. Disposal size. The disposal size used in all simulations was 4,000 cu yd.

24. Duration of simulations. The duration of each test simulation was 3,600 sec (1 hr) after the barge disposal.

25. Disposal spot. The location of the disposal spot is shown in Figure 4.

26. Model coefficients. The model coefficients used in these runs were established from the original model development and from the Elliott Bay/Duwamish disposal site application.

27. Ambient currents. Depth-averaged current speeds of 0.1 and 0.5 fps were used. All runs were made with a uniform velocity over depth with the exception of a single barge bottom disposal simulation with a three-layer velocity profile provided by a Navy subcontractor.* The upper layer extended from the surface to a depth of 120 ft and was assigned a current velocity of 0.19 fps toward 125 deg. The lower layer extended from 170 to 265 ft and was assigned a velocity of 0.16 fps toward 286 deg. The velocities in the transition layer between 120 and 170 ft varied linearly between those in the upper and lower layers.

28. Material type. A sample of Everett Harbor material was obtained for analysis. The material tested consisted of 22 percent fine sand, 25 percent wood, and 53 percent clay/silt. Bulk density of the material was 1.25 gm/cc and the water content was 250 percent. After sieving to 0.074 mm to remove the coarse fraction and fibrous organic material, settling tests were run on the fine-grained fraction. A 10-cm-diam by 185-cm-high clear

* Personal Communication, 29 April 1986, John Downing, NORTEC, Inc., Redmond, Wash.

plastic tube was used. The samples were mixed with ocean water of 33.8-ppt salinity. Settling tests were performed at 70° F. Two initial concentrations were used for the tests, 320 and 835 mg/ℓ. The samples were mixed, allowed to stand overnight, then mixed vigorously by hand before the start of the settling tests. The settling tests used the pipette method, and samples were drawn at 0, 7.5, 15, 30, and then every 30 to 60 min during the tests. Because the sediment appeared visually to flocculate, the clay/silt fraction was modeled as being cohesive. Results from the fine-grained settling tests are given in terms of cumulative settling velocities in the following tabulation:

Percent Greater Than	Cumulative Settling Velocity, mm/sec, for Indicated Concentration, mg/ℓ	
	320	835
10	3.188E+00	5.602E+00
20	2.216E+00	4.965E+00
30	1.535E+00	4.393E+00
40	1.060E+00	3.880E+00
50	7.299E-01	3.419E+00
60	5.007E-01	3.007E+00
70	3.423E-01	2.639E+00
80	2.332E-01	2.311E+00
90	1.582E-01	2.019E+00

A random sampling of the wood chip fraction, which contained some attached sediment, was subjected to visual discrete settling determinations in ocean water. A frequency distribution of these results is shown in Figure 5. A fourth fraction, clumps, was modeled as a 30, 50, or 70 percent composite of wood, sand, and silt/clay. The percentage of sand, silt/clay, and wood in the clumps was the same as that of the overall fractions. A bulk void ratio of 4.5 was used.

29. Disposal methods. Two disposal methods were modeled, a barge bottom disposal at the surface and a disposal through a vertical pipe extending 250 ft below the surface.

30. The following basic assumptions were used in modeling the vertical pipe disposal operation:

- a. A 10-ft-diam pipe will extend 250 ft below the water surface.
- b. A total load of 4,000 cu yd of material will be dropped into the pipe at the rate of 10 cu yd/min.
- c. The ambient velocity near the bottom was specified to be either 0.1 or 0.5 fps.

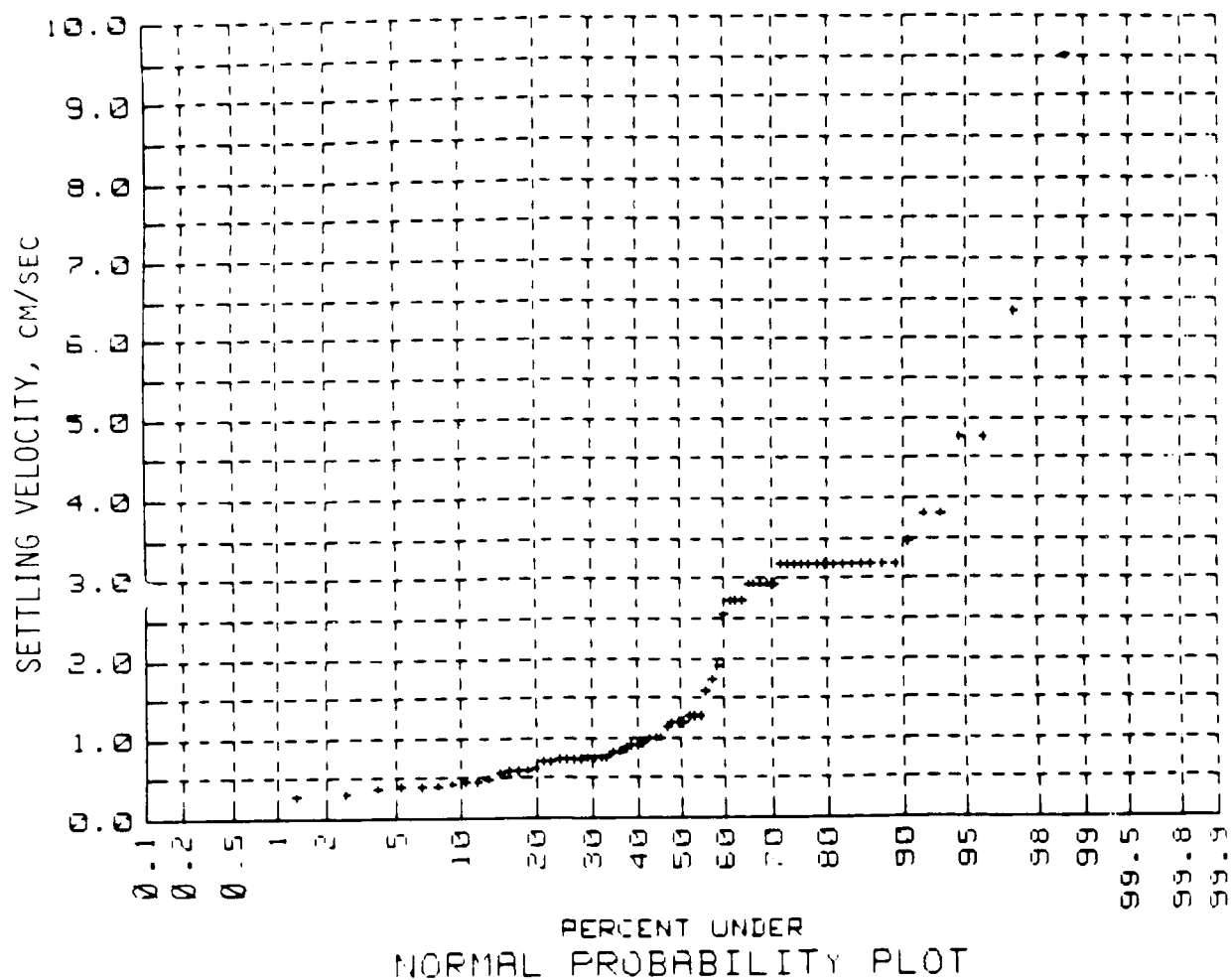


Figure 5. Settling velocities of wood chips

Test results

31. Barge bottom disposal. Results from the model tests are shown as deposition patterns in Plates 1-7. These deposition patterns demonstrate the predicted extent and thickness of material deposited from a single 4,000-cu-yd disposal operation for the portion of the disposed material which had deposited after 60 min. Suspended percentages after 30 and 60 min for each simulation are shown in Table 1. At the end of 30 min of simulation, the model predicted a higher percentage of suspended sand than of suspended silt/clay. This apparent anomaly is explained by the fact that the silt/clay fraction of the dredged material was specified to be cohesive, permitting the settling velocity for that fraction to vary as a function of concentration. During the first 30 min of simulation, the calculated settling velocity for the silt/clay fraction was greater than that of the sand fraction, allowing more silt/clay

to deposit. However, the computed settling velocity for silt/clay in the last 30 min of the simulation had decreased significantly, allowing a greater percentage of sand to deposit.

32. Vertical pipe disposal. The initial effort in numerically modeling the vertical pipe disposal operation involved an attempt to modify the semi-continuous model, DIFHD (Disposal from a Hopper Dredge), under the assumption that the operation should be treated as a continuous surface source with a "feeding" of material into the bottom collapse phase from material passing through the end of the pipe. This effort was discontinued after it was realized that such an approach would likely yield an unreasonably large lateral spread of material on the bottom. This large lateral spread would be caused by an extended bottom collapse phase that would last the full 400 min required to complete the disposal operation.

33. Since the disposal operation is actually a series of small instantaneous disposals, it was decided to employ the instantaneous disposal model, DIFID, with a superposition of results to yield the final deposition pattern on the bottom. This modeling was accomplished through a series of eight individual model runs. Results from each run were then used to represent 50 drops of 10 cu yd each with all 8 runs representing a single 4,000-cu-yd barge load.

34. At the end of the first run (50 drops), the material was deposited in a circular pattern with a radius of approximately 23 ft. At the end of this run it was assumed that the thickness of the bottom deposit, computed from

$$TH = \frac{1 + BVOIDS}{\pi R^2} \cdot V50 \quad (3)$$

where

BVOIDS = aggregate voids ratio

R = radius of the deposit

V50 = total volume of solids in 50 drops

would decrease to 75 percent of its value due to consolidation. At the end of the next 50 drops the thickness of the previous 50 drops would decrease another 25 percent. The first 7 runs of 50 drops each were consolidated twice in this manner with the last run being consolidated once.

35. Once the deposition pattern for the first 50 drops was established,

DIFID was rerun, but with a nonzero bottom slope determined by the thickness of deposit and the bottom spread. This calculation resulted in a greater spread of material on the bottom for the second run. Although the numerical model cannot simulate the actual flow of material down the sides of a bottom mound, this approach seems reasonable as an attempt to simulate the effect of the mound. This same procedure of consolidating the previous 50 drops, determining a bottom slope, and rerunning the model was carried out 8 times to represent a total of 400 drops (4,000 cu yd) of material through the pipe.

36. It should be noted that no entrainment was allowed in the convective descent phase since the radius of a 10-cu-yd hemispherical cloud is 5.05 ft, i.e., approximately the radius of the pipe. In reality, some entrainment would occur, resulting in an elongated shape for the cloud falling through the pipe. However, a basic assumption of the model is that the material falls as a hemispherical cloud in the convective descent phase. Modifications to change this assumption were beyond the scope of this study. With these limitations, the basic effect of the pipe was to translate the disposal from the surface to the end of the pipe with the cloud now possessing a descent velocity the same as that computed in open water.

37. Results from the vertical pipe disposal operation are presented in Table 2. As illustrated in Plate 8, the final deposition of material on the bottom is contained within a radius of approximately 50 ft from the end of the disposal pipe. The maximum thickness is computed to be approximately 10 ft under the pipe with a gradual tapering of the bottom thickness to about 3 ft at the outer boundary of the deposited mound.

38. These results hold for both velocity conditions, 0.1 and 0.5 fps. Since the material is subject to ambient current conditions for only 15 ft of descent to the bottom, displacement of the cloud during descent is insignificant. Once the bottom collapse phase begins, the ambient current does transport small clouds as they are formed. However, since settling takes place during each time-step in the model before the transport, material from these runs is always deposited on the bottom before it can be transported by the current. The only other way that the ambient current can influence model results is through its effect on the estimated rate of vertical diffusion, which can sometimes be the deciding factor in terminating the collapse phase. However, neither current condition was large enough to influence the collapse

termination in these runs. Therefore, the results presented hold for both current conditions tested.

Limitations

39. The following factors affect the required disposal area size but are not addressed by the model:

- a. The model treats each of three sediment fractions (sand, clay/silt, and wood chips) separately. Model results for the barge disposal indicate that the sand fraction had the longest settling time. In the actual disposal process, as the clay/silt particles flocculate and fall through the water column, with a settling velocity greater than that attached to the sand fraction, they will probably entrap and carry a significant portion of the fine sand to the bottom more rapidly than depicted by the model.
- b. The ability of the model to accurately portray the material fate decreases as the percent of material in suspension decreases and as the time into the run increases. At the point where the percent suspended becomes less than perhaps 2 percent and the time exceeds perhaps 3,600 sec, other uncertainties such as how much material dissociates from the cloud in the descent phase and the influence of turbulent diffusion in the vertical become important factors that are not clearly understood.
- c. If the contaminated material is associated primarily with clay/silt fraction, the area required for a CAD site may be dictated by the spread of this material rather than by that of the fine sand fraction, which has the lowest settling rate and tends to remain in near-bottom suspension for the longest period of time.
- d. In an actual disposal operation, the material leaving the barge may differ considerably from that being modeled. Factors such as the relative quantities of the various fractions (sand, clay/silt, wood chips) of material, water content, the percent of clumps, and time for the material to leave the barge, all significantly affect the spread of material on the bottom. Conditions assumed for the model represent a worst case (maximum dispersion) condition.

Capping Material Disposal

Test conditions

40. Hydraulic dredging. The proposed Navy dredging plan anticipates capping of contaminated sediments with underlying native material. Samples of this native material indicate that because the in situ water content is very low, the material may be too dense to be useable as a capping material. If a

clamshell dredge and bottom disposal barge are used, large clumps of the capping material would impact with the bottom at a high rate of speed, and could displace or resuspend the previously placed contaminated material. However, by hydraulically dredging the native material, a mixture suitable for use in capping can be obtained. Twelve model runs were made to simulate possible methods of depositing the capping material.

41. Disposal methods. Three capping methods were simulated: a moving surface pipe discharge, a pipe discharge into a stationary 50-ft downpipe, and a pipe discharge into a stationary 150-ft downpipe. The diameter of both downpipes was 10 ft. All capping runs were made using a modified version of DIFID where a capping operation is represented by a series of discrete clouds. Each cloud settles through the water column at the average descent velocity as determined from a normal application of DIFID to a single small cloud. As the series of individual clouds settle, they are transported by the ambient current and grow as a result of entrainment. The radius of the cloud is determined from

$$R = R_o + \alpha_m D \quad (4)$$

where

R_o = initial radius, ft

α_m = entrainment coefficient

D = distance from release point, ft

For the material used in these runs, a value of $\alpha_m = 0.3$ was selected from results presented by Krishnappan (1975).

42. Grid size. The model grid used for all tests represented an area of 2,000 by 2,000 ft. Each grid cell represented an area of 100 by 100 ft.

43. Duration of simulation. The duration of each simulation was 3,600 sec (1 hr) after initiation of the capping operation.

44. Discharge rate. Pipe discharge rates of 20, 30, 40, and 50 cu yd/min were simulated for each of the three disposal methods. Bulk densities for the material discharged at these rates were 1.25, 1.1833, 1.1167, and 1.05 g/cc, respectively.

45. Disposal spot. The disposal operation for the confined surface discharge consisted of a 1,400-ft "sweep" down the center of the grid, top to bottom. This sweep was intended to simulate a capping operation with a moving

surface pipe discharge. The pipe moved across the water surface at 0.5 fps, traversing a 1,400-ft path in approximately 2,800 sec. The effective discharge radius after the slurry hit the scatter plate at the end of the discharge pipe was assumed to be 20 ft.

46. The 50- and 150-ft downpipes were stationary and were located at the center of the numerical grid. The radius of each discrete cloud was taken as the pipe radius with the insertion location of each cloud being the end of the pipe.

47. Model coefficients. The model coefficients used in these runs were the same as those used in the contaminated material disposal runs. These coefficients were established in the original model development and during the Elliot Bay/Duwamish disposal site application.

48. Ambient currents. A depth-averaged current of 0.1 fps with an assumed direction from southeast to northwest was simulated.

49. Material type. The uncontaminated capping material consisted of 30 percent fine sand and 70 percent silt/clay. This material was modeled as a single cohesive fraction with no clumps. The capping modifications made in DIFID allow for only one material fraction.

Test results

50. Confined surface discharge. Results from the model tests for a single pass are shown as deposition patterns in Plates 9-12. These deposition patterns demonstrate that for a confined surface discharge, the majority of deposition occurred within a 300-ft-wide swath along the line of movement of the discharge pipe. Maximum cap thickness for a single pass of the surface discharge pipe was approximately 0.09 ft at the 30-cu-yd/min discharge. A 1-ft-thick cap would be generated within approximately 11 passes, or 8.6 hr. Suspended percentages after 60 min for each simulation are shown in the following tabulation:

<u>Capping Method</u>	<u>Suspended Sediment Percentages for Indicated Discharge, cu yd/min</u>			
	<u>20</u>	<u>30</u>	<u>40</u>	<u>50</u>
Contained surface	11.1	9.4	15.5	22.0
50-ft downpipe	2.7	4.2	10.9	26.2
150-ft downpipe	0.5	0.4	1.6	9.3

The test conditions for each model run are presented in Table 3. Bottom impact velocities of the disposal material are shown in the following tabulation:

<u>Capping Method</u>	Bottom Impact Velocities, fps, for Indicated Discharge, cu yd/min			
	<u>20</u>	<u>30</u>	<u>40</u>	<u>50</u>
Contained surface	0.46	0.47	0.41	0.24
50-ft downpipe	0.63	0.64	0.57	0.32
150-ft downpipe	1.09	1.09	0.94	0.54

51. After approximately 1 hr, 10.4 percent of material remained in suspension. The vast majority of this material was distributed over the lower 60-65 ft of the water column and was spread horizontally over an area of about 175 by 500 ft. The maximum concentration at 255 ft was 442 mg/l and at 175 ft was 0.7 mg/l.

52. Stationary downpipe discharge. Results from the model tests after 1 hr are shown as deposition patterns in Plates 13-20. For the 50-ft downpipe runs, a maximum cap thickness of 1.8 ft was generated within a radius of less than 100 ft from the center of the downpipe. For the 150-ft downpipe runs, the maximum cap thickness was 2.0 ft. These results indicate that a 1-ft cap would be generated after approximately 30 min. Suspended percentages after 60 min for each simulation are listed in paragraph 50. Bottom impact velocities of the disposed material as determined from a normal application of DIFID to a single small cloud are also shown in paragraph 50.

53. After approximately 1 hr, only 5.1 percent of the material discharged into the 50-ft pipe remained in suspension. Most of this material was distributed over the lower 40-45 ft of the water column within a radius of about 65 ft surrounding the location of the pipe. The maximum concentration at 255 ft was 832 mg/l. An essentially zero concentration was computed at 175 ft below the surface. Only 0.8 percent of the material remained in suspension from the discharge of material into the 150-ft pipe. This material was distributed over the lower 30-35 ft of the water column within a radius of about 40 ft surrounding the location of the pipe. The maximum concentration at 255 ft was computed to be 260 mg/l with essentially a zero concentration at 175 ft below the surface. The decrease in maximum concentration at 255 ft compared to that computed for the 50-ft pipe disposal was primarily because much less material remained in suspension.

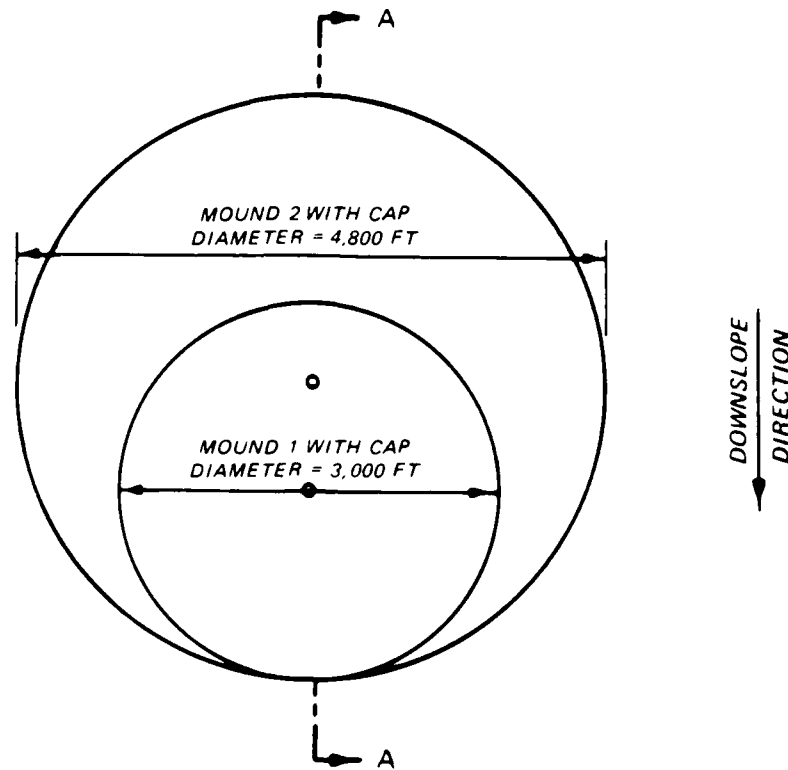
Extension to multiple disposals

54. The disposal model predicts the area of deposition for the disposal of one barge of dredged material. It does not simulate the effects of mounding or settlement, and cannot be used to predict the size and shape of the

disposal area after a large amount of material has been deposited. An estimate of the final configuration of the disposal mound was made based on previous field measurements of mound slopes by the US Army Engineer Division, New England, at other disposal sites (Bokuniewicz, Cerrato, and Hirshburg, in preparation). Since the proposed dredging plan extends over two dredging seasons, the sequence of dredging operations was taken into consideration. This sequence includes initial placement of a relatively small amount of contaminated material and immediate capping with native material. After approximately 9 months, a much larger amount of contaminated material would be disposed at the same site and immediately capped with a large quantity of native material.

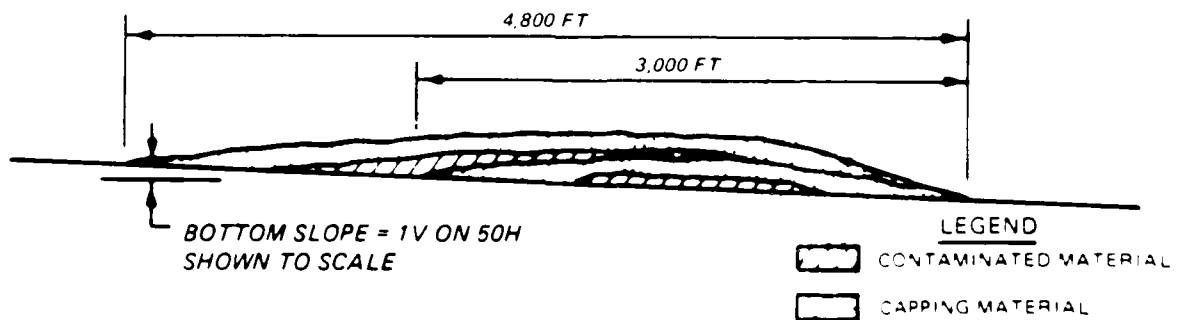
55. Because the exact amounts to be dredged in each sequence were not known as this report was being prepared, an example scenario is presented in which representative quantities are used for each portion of the dredge/disposal sequence. Figure 6 shows the predicted disposal mound configuration. Basic assumptions are as follows:

- a. In situ initial dredging of contaminated material of 100,000 cu yd (bulk density 1.25 g/cc = 15 percent solids).
- b. In situ initial dredging of native material of 500,000 cu yd (bulk density 1.88 g/cc = 50 percent solids).
- c. In situ final dredging of contaminated material of 800,000 cu yd.
- d. In situ final dredging of native material of 1,500,000 cu yd.
- e. Average bottom slope = 1:50 to the south.
- f. Mound assumes a truncated cone shape with maximum side slopes of 1V on 100H, relative to bottom slope (i.e., 1:30 on down-slope side).
- g. Initial void ratio of 4.5 for both contaminated and native material after placement in the disposal mound.
- h. Clamshelled contaminated material with surface disposal from barges.
- i. Hydraulically dredged capping material with uniform surface disposal using scatter plate.
- j. Invariant disposal location for contaminated material disposal (point disposal using taut-line buoy).
- k. Top of truncated cone will be approximately equal in radius to the area of deposition of the contaminated material.
- l. Ultimate consolidation of 50 percent for both contaminated and native material in mound after disposal.



CONCEPTUAL PLAN VIEW

NOTE VERTICAL SCALE FOR MOUND LAYERING
GREATLY EXAGGERATED LAYERING SHOWN
FOLLOWING CONSOLIDATION.



CONCEPTUAL CROSS SECTION A-A

Figure 6. Final disposal mound configuration

56. Calculations for long-term mounding are as follows:

- a. For initial disposal: 100,000 cu yd contaminated material with bulk density 1.25 g/cc (15 percent solids).

$$VOL = (15 \text{ percent})(100,000 \text{ cu yd}) = 15,000 \text{ cu yd} = 4 \times 10^5 \text{ cu ft} \quad (5)$$

- (1) To determine the volume occupied by the disposed material on the bottom:

$$\begin{aligned} V_b &= (1 + \text{voids ratio})(VOL) = (1 + 4.5)(4 \times 10^5 \text{ cu ft}) \\ &= 2.3 \times 10^6 \text{ cu ft} \end{aligned} \quad (6)$$

- (2) To determine the dimensions of a truncated cone having a volume equal to V_b , use the mound volume V_m :

$$V_m = \frac{\pi R^2 H}{3} - \frac{\pi r^2 h}{3} = V_b \quad (7)$$

where

R = radius of cone base = 100H

H = height of cone without truncation

r = 500 ft (radius of mound top from model runs)

$h = \frac{1}{100} r = 5 \text{ ft}$ (top portion of cone that is missing)

- (3) Using equation 7 for V_m and substituting the values above yield:

$$\frac{\pi (100H)^2 H}{3} - \frac{\pi (500)^2 (5)}{3} = 2.3 \times 10^6 \text{ cu ft} \quad (8)$$

Therefore,

$$H^3 = 344 \text{ cu ft} \quad (9)$$

and thus

$$H = 7.0 \text{ ft} \quad (10)$$

This result then yields

$$R = 100H = 700 \text{ ft} \quad (11)$$

$$H_m = H - h = 2.0 \text{ ft} \quad (12)$$

Therefore, the height of the disposal mound H_m is 2.0 ft.

- b. For initial capping: 500,000 cu yd uncontaminated material with bulk density 1.88 g/cc (50 percent solids)

$$\text{VOL} = (50 \text{ percent})(500,000 \text{ cu yd}) = 250,000 \text{ cu yd} = 6.75 \times 10^6 \text{ cu ft} \quad (13)$$

- (1) To determine V_b :

$$\begin{aligned} V_b &= (1 + \text{voids ratio})(\text{VOL}) \\ &= (1 + 4.5)(6.75 \times 10^6) = 3.7 \times 10^7 \text{ cu ft} \end{aligned} \quad (14)$$

plus volume of previously disposed contaminated material
 $= 4.06 \times 10^7 \text{ cu ft}$

- (2) Using previous procedure, $H^3 = 4.00 \times 10^3 \text{ cu ft}$,
 $H = 16.0 \text{ ft}$, $R = 1,600 \text{ ft}$

$$\begin{aligned} H_m &= H - 5 \text{ ft} \\ &= 16 \text{ ft} - 5 \text{ ft} \\ &= 11 \text{ ft} \end{aligned} \quad (15)$$

- c. For 9 months settlement, assume, based on field experience, 50 percent consolidation. Cap thickness after 9 months is calculated as $(0.50)(11 \text{ ft}) = 5.5 \text{ ft} \approx 6 \text{ ft}$ with a volume of $2.3 \times 10^7 \text{ cu ft}$

Mound height calculations for the final disposal of 800,000 cu yd of contaminated material (bulk density 1.25 g/cc, 15 percent solids), and 1,500,000 cu yd of uncontaminated capping material (bulk density 1.88 g/cc, 50 percent solids) are carried out in a similar manner. Results of these calculations, adjusted for 1:50 bottom slope, are shown in Figure 6.

57. Assuming 50 percent of consolidation for newly disposed material, new mound thickness is now approximately 12 ft, with a cap thickness of approximately 4 ft.

Influence of water depth

58. One final run of DIFID for the disposal of contaminated material in 400 ft of water was made to assess the impact of water depth on the spread of material on the bottom. This is listed as run 22 in Table 3 and results are presented in Plate 21. Comparing these results with depositional results from run 1 on Plate 1 shows that increasing the water depth from 265 ft to 400 ft results in an increased spread of the material on the bottom with a subsequent reduction in the maximum thickness of the material deposited. For the 265-ft depth, the diameter of the cloud at the end of bottom collapse was approximately 850 ft; whereas, for the 400-ft depth, the diameter was about 1,000 ft. After 1 hour, approximately 2.3 percent of the solids remained in suspension at the 400-ft depth while about 1.2 percent was in suspension at the 265-ft depth.

PART IV: CONCLUSIONS

59. The following general conclusions are drawn from the modeling:

- a. More than 98 percent of the disposed contaminated material will deposit within 1 hr for all conditions tested. The disposed contaminated material will deposit within an area of 800 by 1,000 ft with a maximum thickness of approximately 0.60 ft for a single 4,000-cu-yd barge of material. If a 250-ft-long by 10-ft-diam downpipe is used, the area of deposition is approximately 50 ft in radius with a maximum thickness of approximately 10 ft.
- b. More than 90 percent (at a discharge rate of 30 cu yd/min for 47 min) of the disposed capping material from each sweep of the confined surface discharge will deposit within an hour. The swath of deposition will be less than 300 ft wide with a maximum thickness of approximately 0.09 ft. Bottom impact velocities will be less than 0.5 fps.
- c. More than 95 percent (at a discharge rate of 30 cu yd/min for 47 min) of the disposed capping material from the 50- and 150-ft stationary downpipe capping operations will deposit within an hour. The area of deposition will have a radius of less than 100 ft with a maximum thickness of approximately 2.0 ft. Bottom impact velocities will be less than 1.1 fps.
- d. Long-term disposal of 600,000 cu yd of material (100,000 contaminated and 500,000 capping) in the first dredging season and 2,300,000 cu yd (800,000 contaminated and 1,500,000 capping) in the second dredging season will generate a disposal mound with a final radius of approximately 3,500 ft long and 2,400 ft wide, with a side slope of approximately 1V on 30H and a cap thickness of approximately 4 ft.

Limitations of the numerical model DIFID and the various assumptions that have been made in modeling the various disposal operations have been discussed. These should be taken into account when the works and practices that may depend upon the results of this study are planned.

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Table 1
Suspended Sediment Percentages for Bottom Disposal

Run No.	Current Speed fps	Clump Factor %	Suspended Fractions			
			Sand %	Silt/Clay %	Wood %	Composite %
<u>After 30 Min</u>						
1	0.1	0	3.4	2.2	0	1.9
2	0.5	0	12.7	3.5	0	4.6
3	0.1	30	3.3	2.3	0	1.9
4	0.5	30	10.7	3.6	0	4.3
5	0.1	50	3.2	2.4	0	2.0
6	0.1	70	2.8	2.6	0	2.0
7	stratified (0.2 maximum)	0	3.4	2.2	0	1.9
22	0.1	0	6.5	4.1	0	3.6
<u>After 60 Min</u>						
1	0.1	0	0.7	2.0	0	1.2
2	0.5	0	3.6	2.0	0	1.9
3	0.1	30	0.8	2.1	0	1.3
4	0.5	30	3.1	2.1	0	1.8
5	0.1	50	0.8	2.2	0	1.3
6	0.1	70	0.8	2.3	0	1.3
7	stratified (0.2 maximum)	0	0.6	2.1	0	1.2
22	0.1	0	1.1	3.9	0	2.3

Table 2
Deposition Amounts for Vertical Pipe Disposal

After No. of Disposals	Thickness, ft, at Indicated Radius from Pipe, ft				
	23	36	43	49	52
50	6.70	--	--	--	--
100	7.77	2.74	--	--	--
150	7.33	3.98	1.92	--	--
200	7.64	4.29	2.92	1.48	--
250	8.10	4.75	3.38	2.42	1.31
300	8.71	5.36	3.99	3.03	2.29
350	9.37	6.02	4.65	3.69	2.95
400	10.02	6.67	5.30	4.34	3.03

Table 3
Test Conditions for All Model Runs

Run No.	Material Type*	Water Content/ Bulk Density**	Dredging Method	Percent Clumps	Production Rate, cu yd/min	Disposal Method†	Current Speed fps	Water Depth ft	Results on Plate No.
1	C	250/1.25	Clamshell	0	--	Barge	0.1	265	1
2	C			0	--		0.5		2
3	C			30	--		0.1		3
4	C			30	--		0.5		4
5	C			50	--		0.5		5
6	C			70	--		0.5		6
7	C			0	--		stratified		7
8	C			0	--	250' DP	0.1		8
9	C			0	--	250' DP	0.5		8
10	U	50/1.88	Hydraulic	--	20	SC	0.1		9
11	U			--	20	SC	0.1		10
12	U			--	40	SC	0.1		11
13	U			--	50	SC	0.1		12
14	U			--	20	50' DP	0.1		13
15	U			--	30	50' DP	0.1		14
16	U			--	40	50' DP	0.1		15
17	U			--	50	50' DP	0.1		16
18	U			--	20	150' DP	0.1		17
19	U			--	30	150' DP	0.1		18
20	U			--	40	150' DP	0.1		19
21	U			--	50	150' DP	0.1		20
22	C	250/1.25	Clamshell	0	--	Barge	0.1	400	21

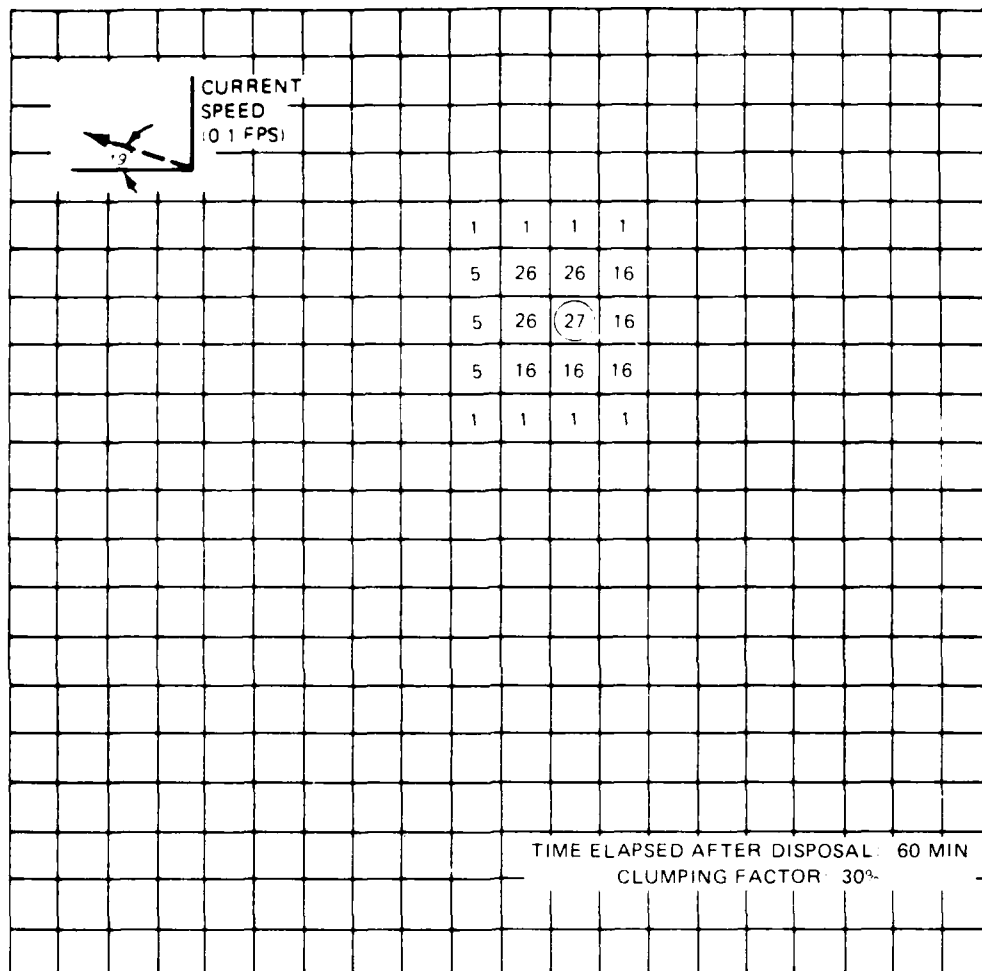
* C = Contaminated material: 25% wood chips, 22% sand, 53% clay/silt.

U = Uncontaminated material: 30% sand, 70% clay/silt.

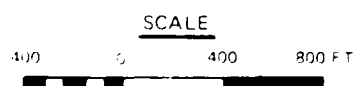
** In situ percent water content and bulk density.

† SC = Surface-contained hydraulic discharge.

DP = Downpipe discharge.

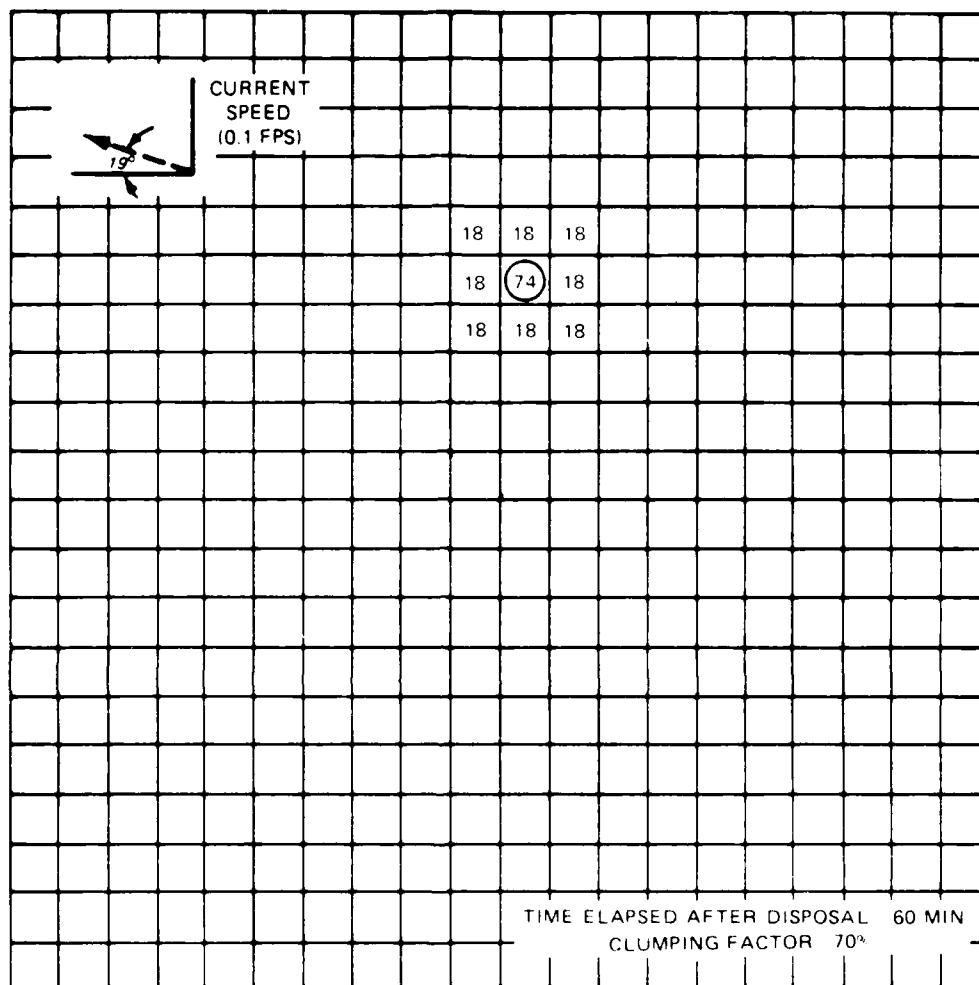


○ LOCATION OF DISPOSAL

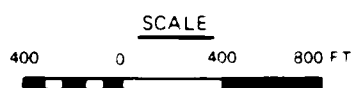


NOTE: DEPOSITIONS GIVEN IN HUNDREDTHS
OF A FOOT.

DEPOSITION PATTERN
CONTAMINATED MATERIAL
RUN 3

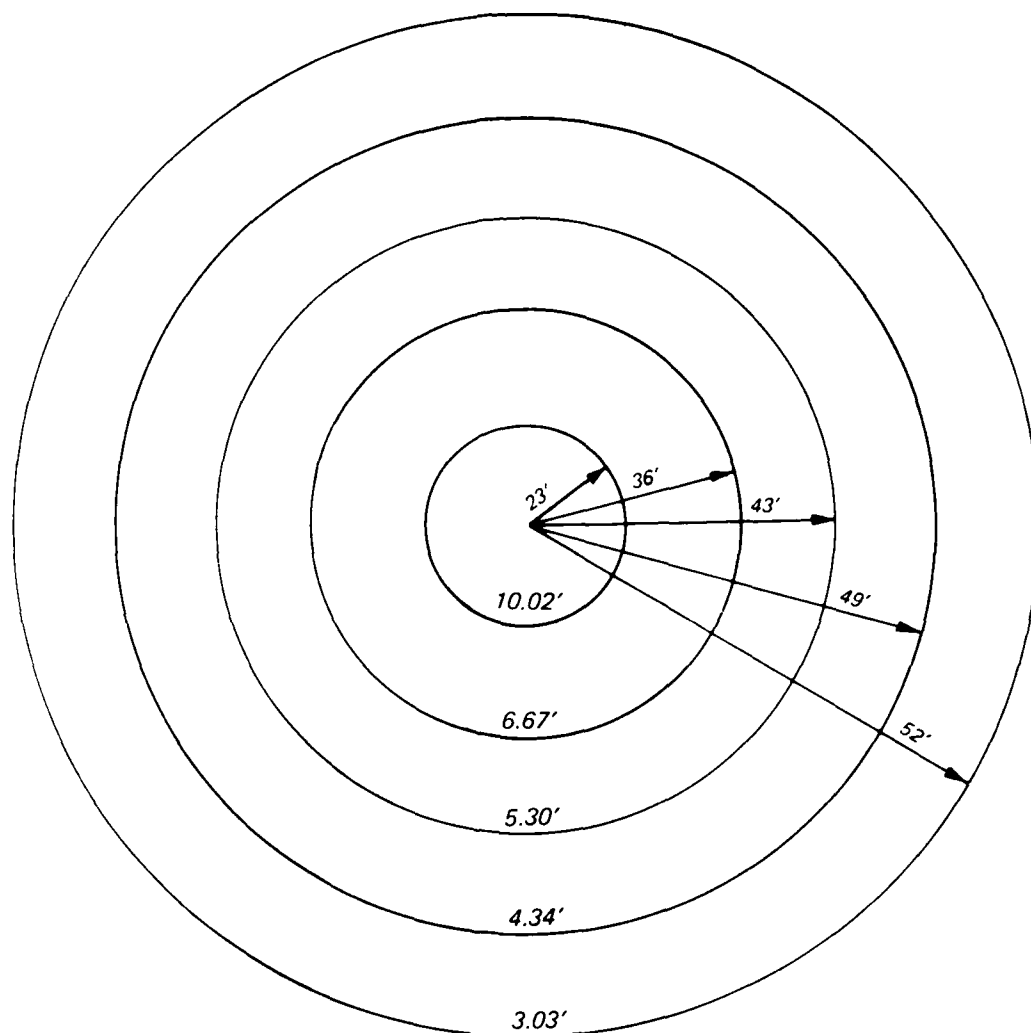


○ LOCATION OF DISPOSAL

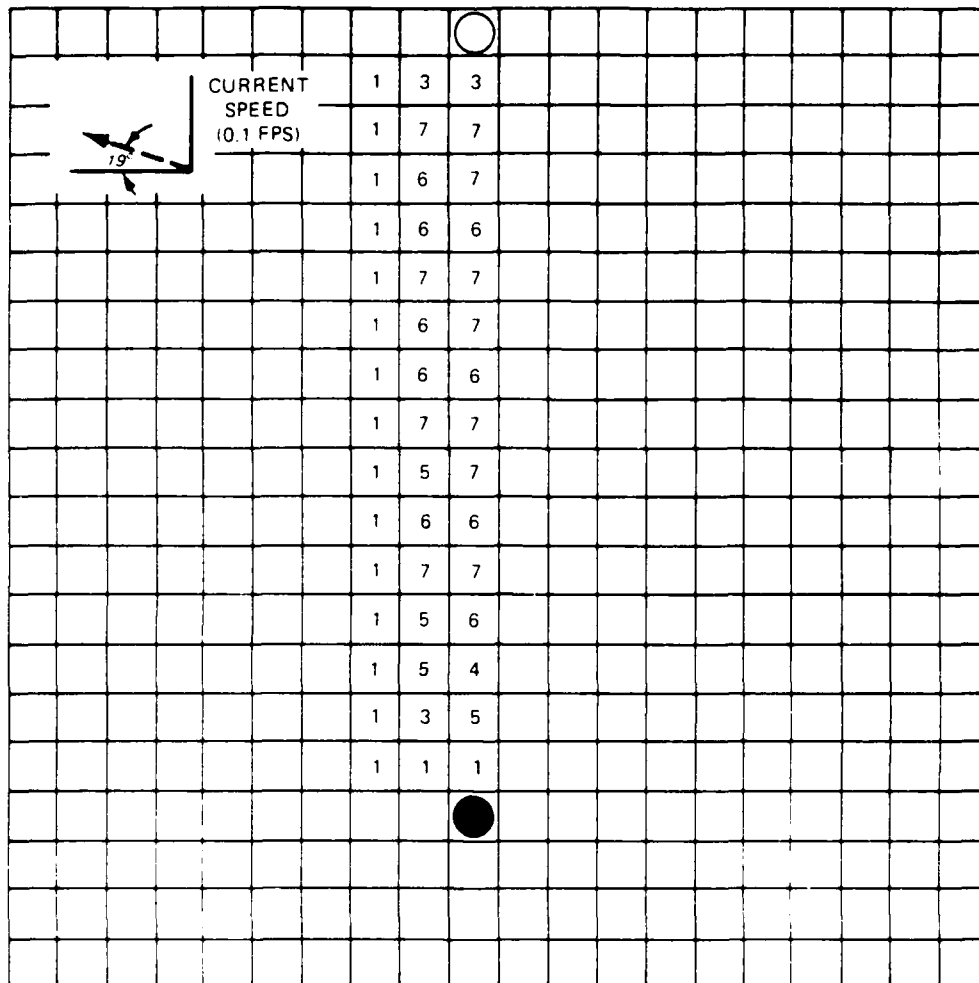


NOTE DEPOSITIONS GIVEN IN HUNDREDTHS
OF A FOOT.

DEPOSITION PATTERN
CONTAMINATED MATERIAL
RUN 6



DISTRIBUTION OF CONTAMINATED
MATERIAL FROM 250-FT PIPE



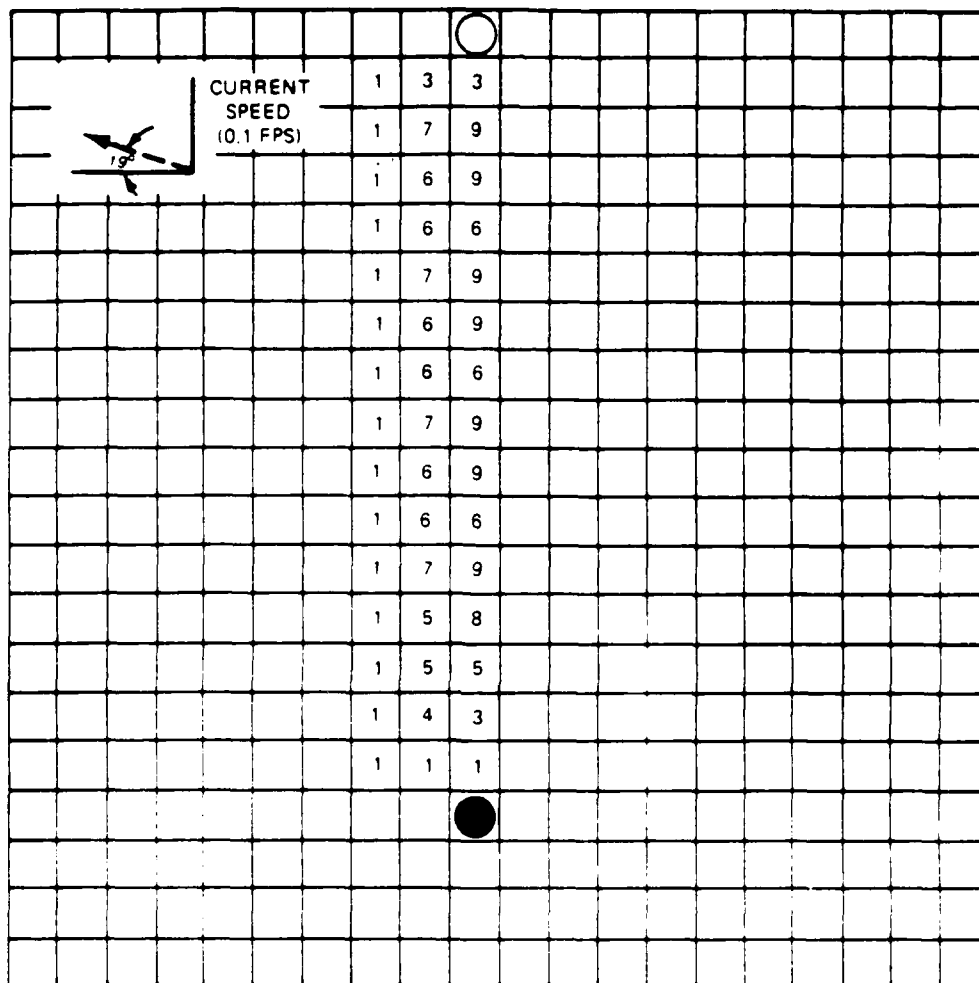
○ START OF DISPOSAL

● END OF DISPOSAL
SCALE



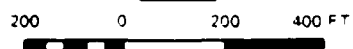
NOTE: DEPOSITIONS GIVEN IN HUNDREDTHS
OF A FOOT.

DEPOSITION PATTERN
CONFINED SURFACE
DISCHARGE = 20 CU YD MIN



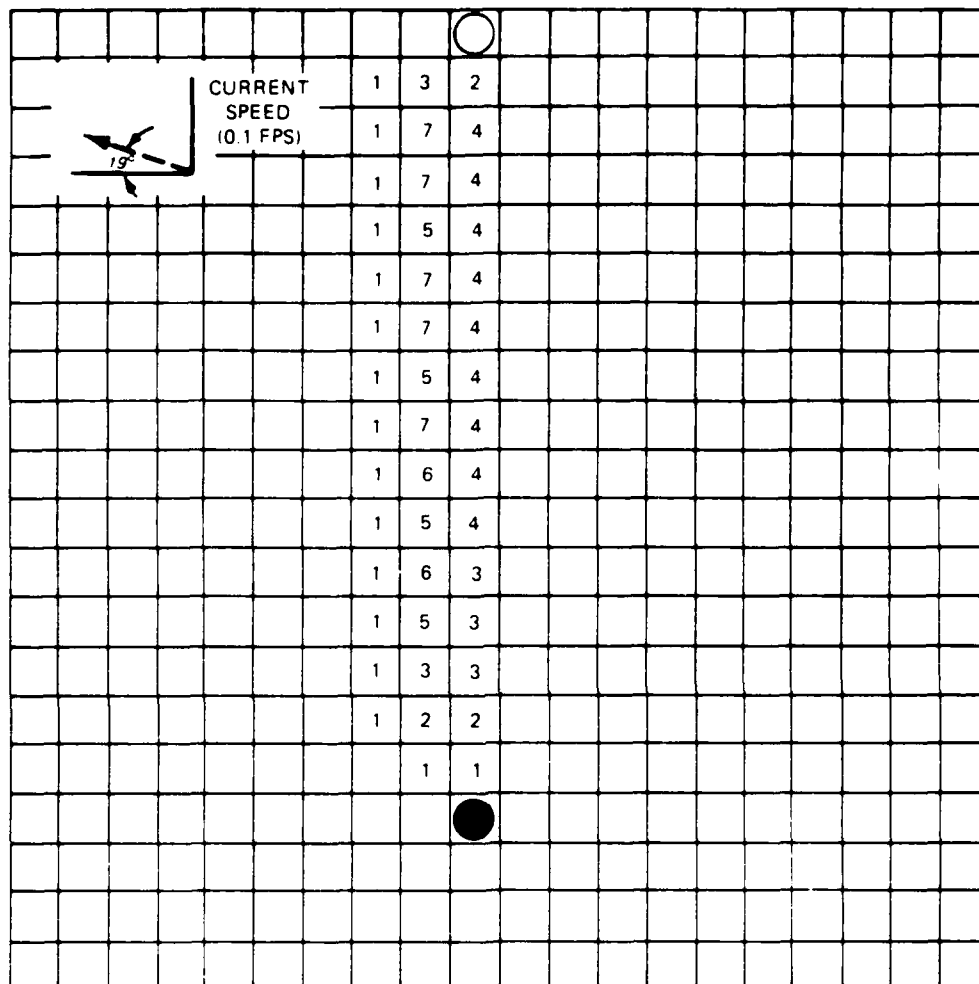
○ START OF DISPOSAL

● END OF DISPOSAL
SCALE



NOTE DEPOSITIONS GIVEN IN HUNDREDTHS
OF A FOOT.

DEPOSITION PATTERN
CONFINED SURFACE
DISCHARGE = 30 CU YD/MIN



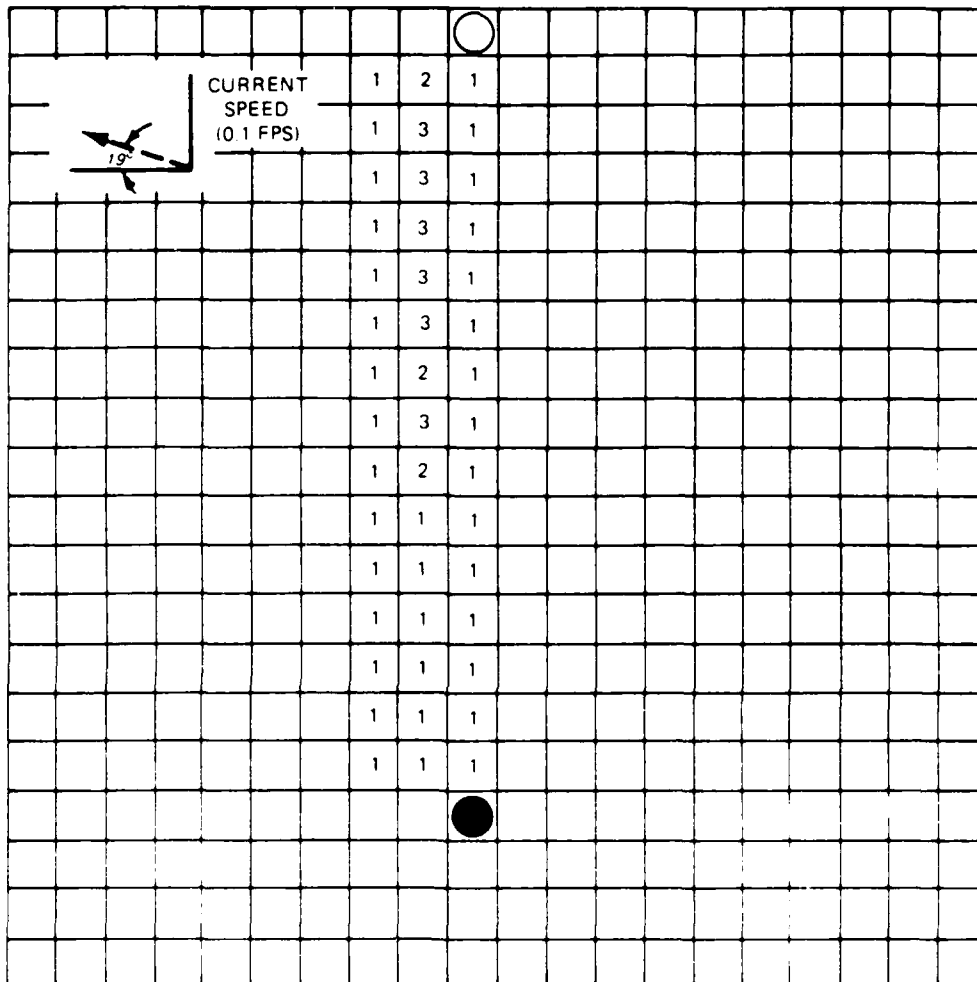
○ START OF DISPOSAL

● END OF DISPOSAL
SCALE

200 0 200 400 FT

NOTE DEPOSITIONS GIVEN IN HUNDREDTHS
OF A FOOT.

DEPOSITION PATTERN
CONFINED SURFACE
DISCHARGE = 40 CU YD/MIN



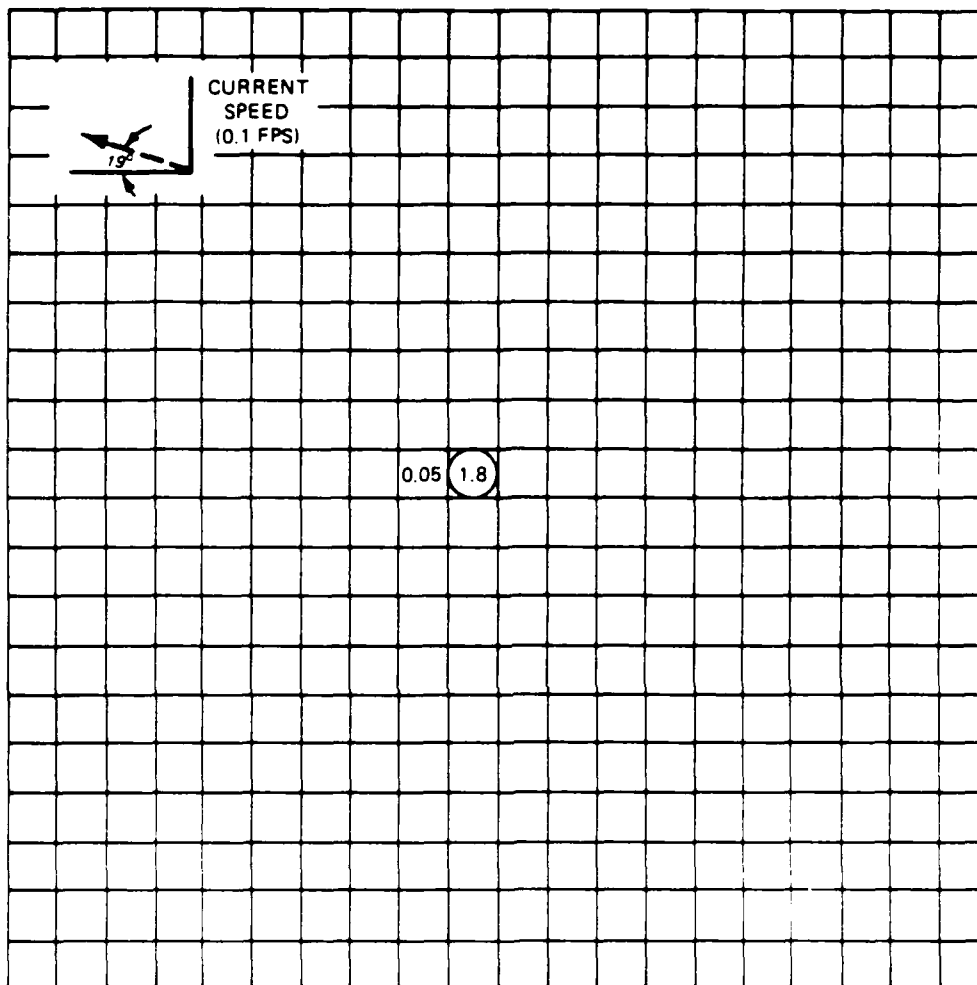
○ START OF DISPOSAL

● END OF DISPOSAL
SCALE

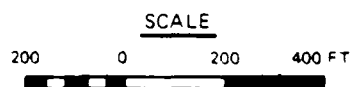
200 0 200 400 FT

NOTE DEPOSITIONS GIVEN IN HUNDREDTHS
OF A FOOT.

DEPOSITION PATTERN
CONFINED SURFACE
DISCHARGE - 50 CU YD MIN

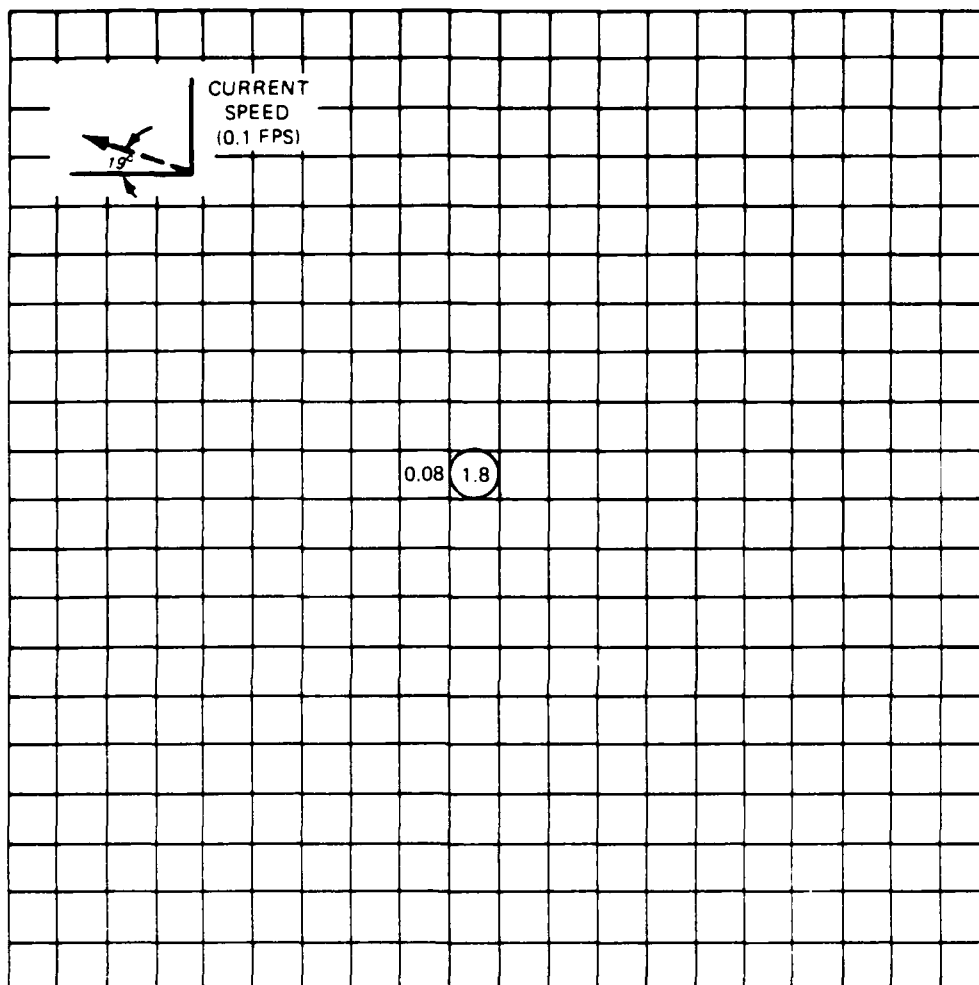


○ LOCATION OF DISPOSAL

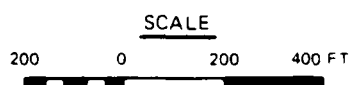


NOTE DEPOSITION GIVEN IN FEET.

DEPOSITION PATTERN
50-FT PIPE
DISCHARGE = 20 CU YD MIN

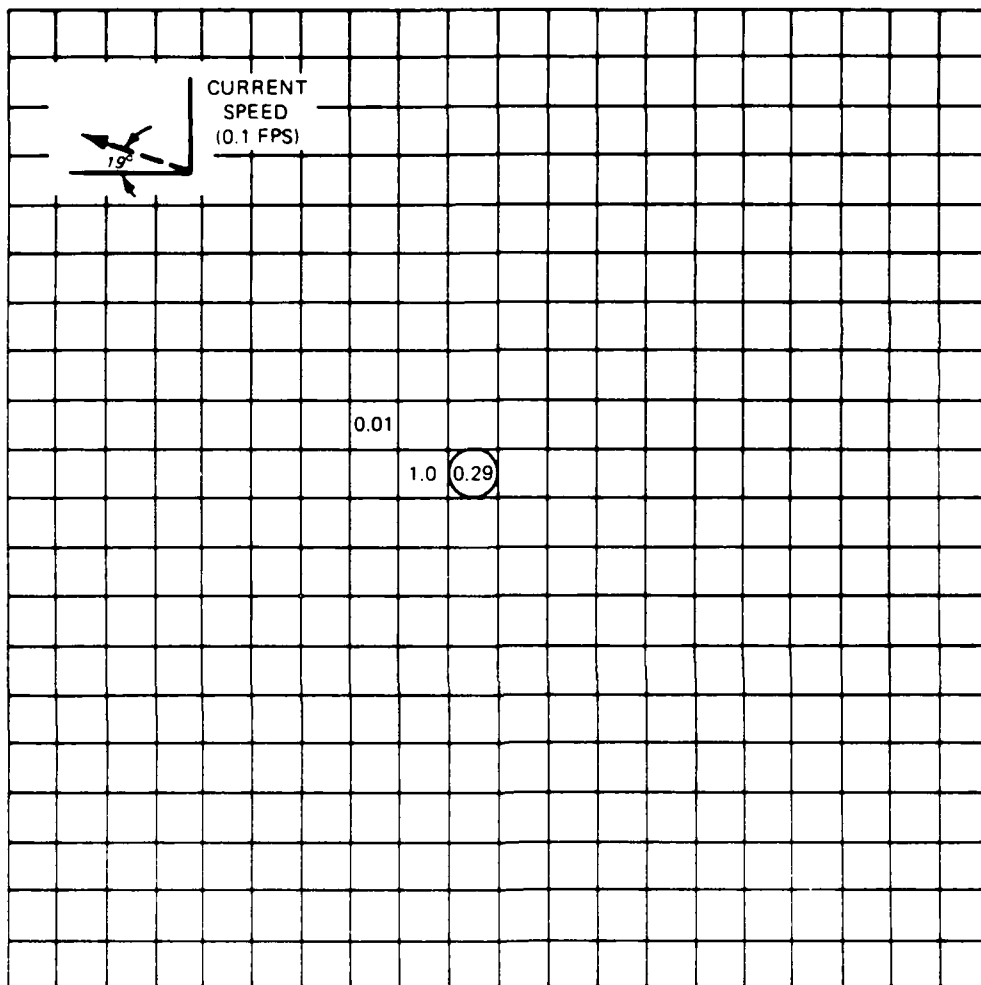


○ LOCATION OF DISPOSAL

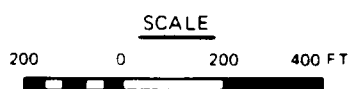


NOTE: DEPOSITION GIVEN IN FEET.

DEPOSITION PATTERN
50-FT PIPE
DISCHARGE = 30 CU YD/MIN

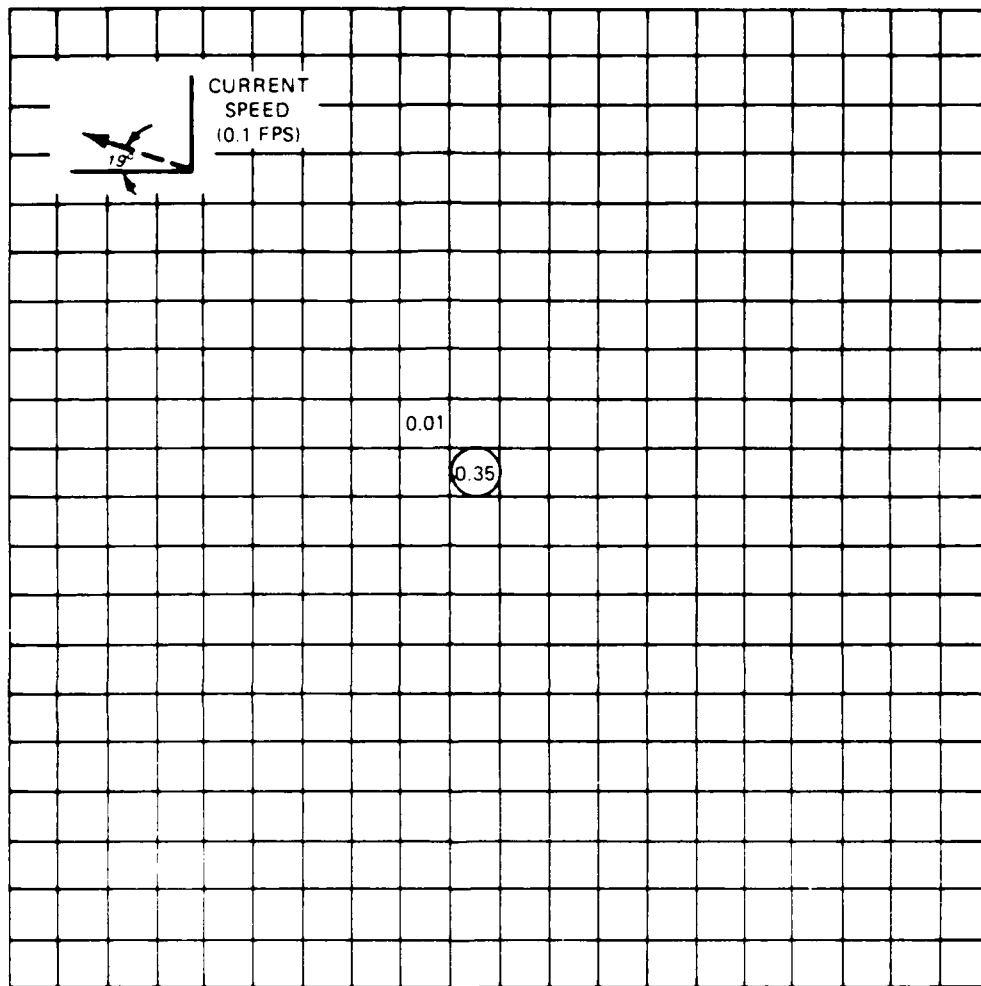


○ LOCATION OF DISPOSAL

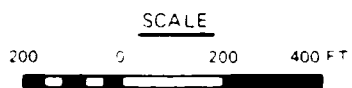


NOTE DEPOSITION GIVEN IN FEET.

DEPOSITION PATTERN
50-FT PIPE
DISCHARGE = 40 CU YD/MIN

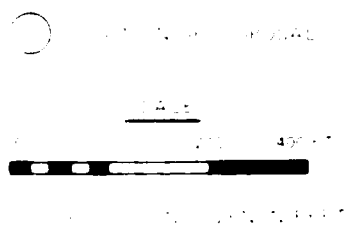
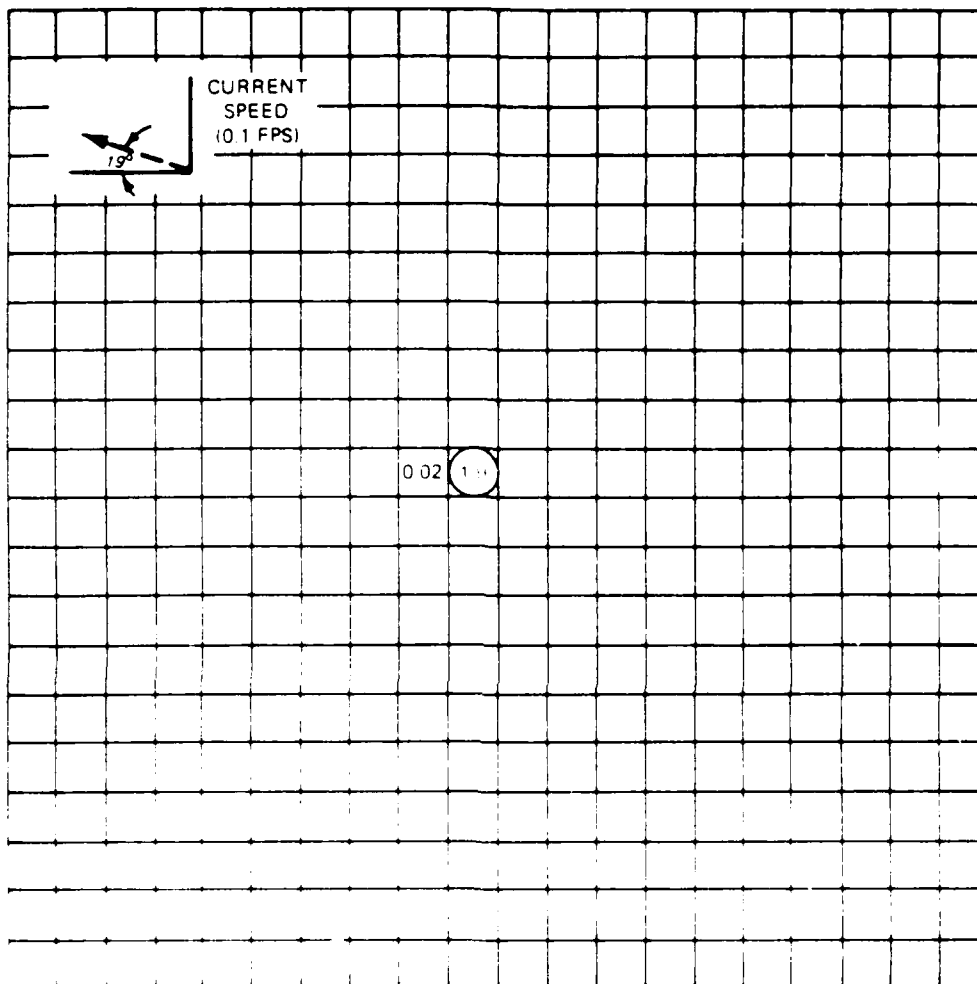


○ LOCATION OF DISPOSAL

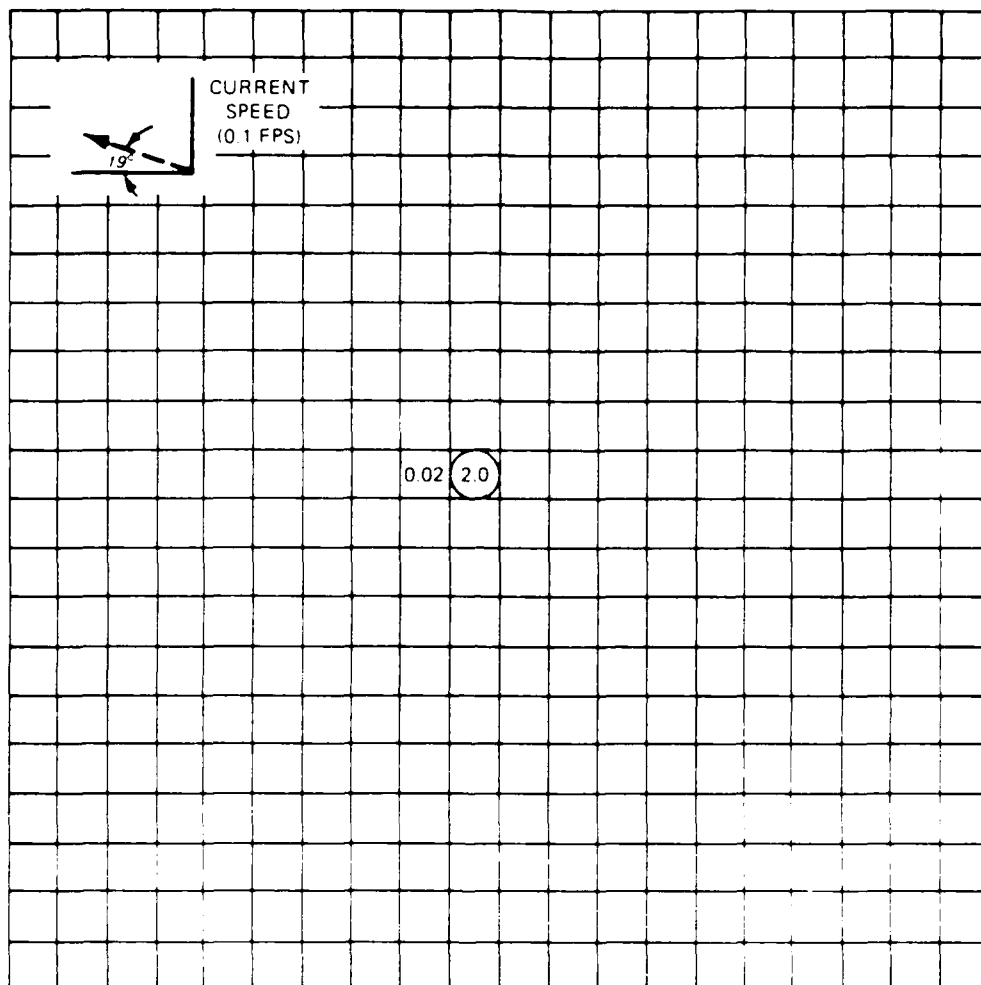


NOTE: DEPOSITION GIVEN IN FEET.

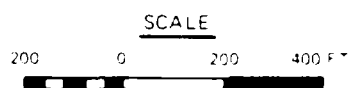
DEPOSITION PATTERN
50 FT PIPE
DISCHARGE - 50 CU YD MIN



DEPOSITION PATTERN
150 FT PIPE
DISCHARGE 20 CU YD MIN

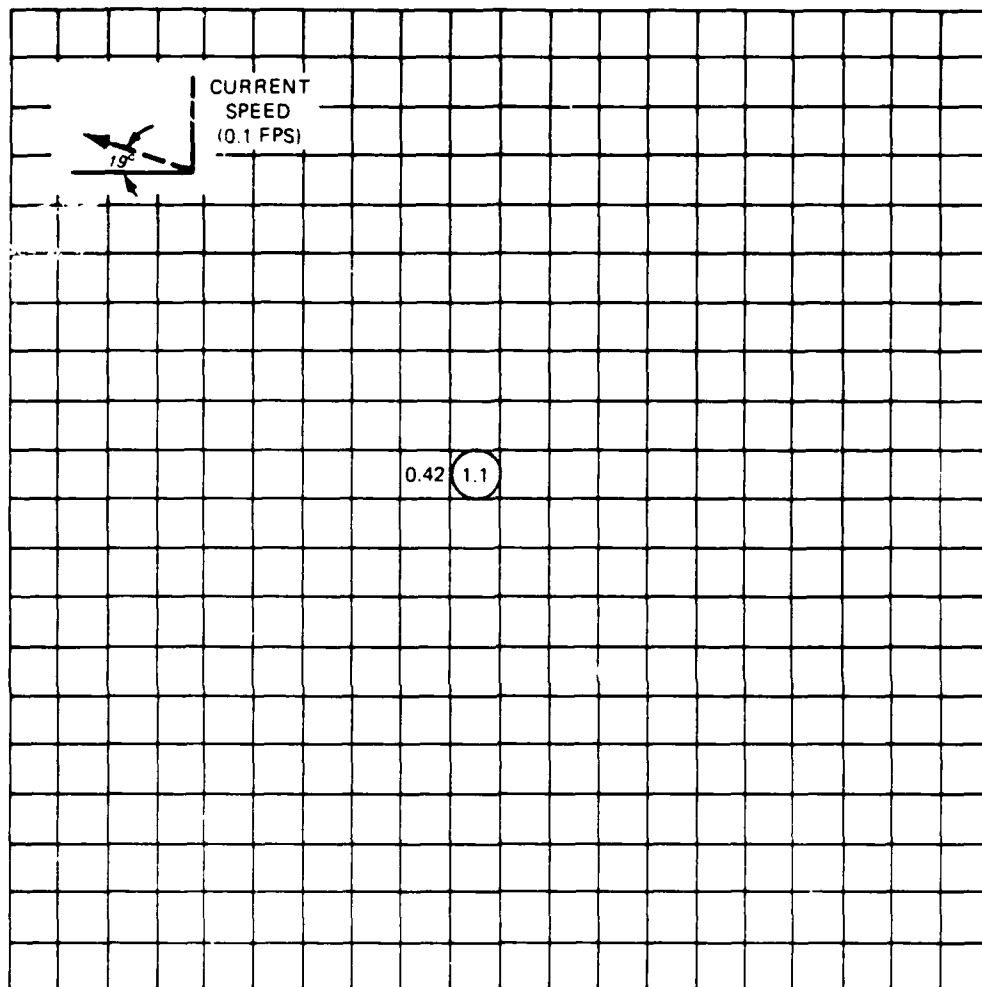


○ LOCATION OF DISPOSAL

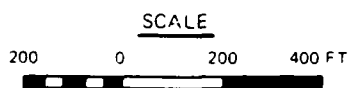


NOTE - DEPOSITION GIVEN IN FEET.

DEPOSITION PATTERN
150 FT PIPE
DISCHARGE - 30 CU YD MIN

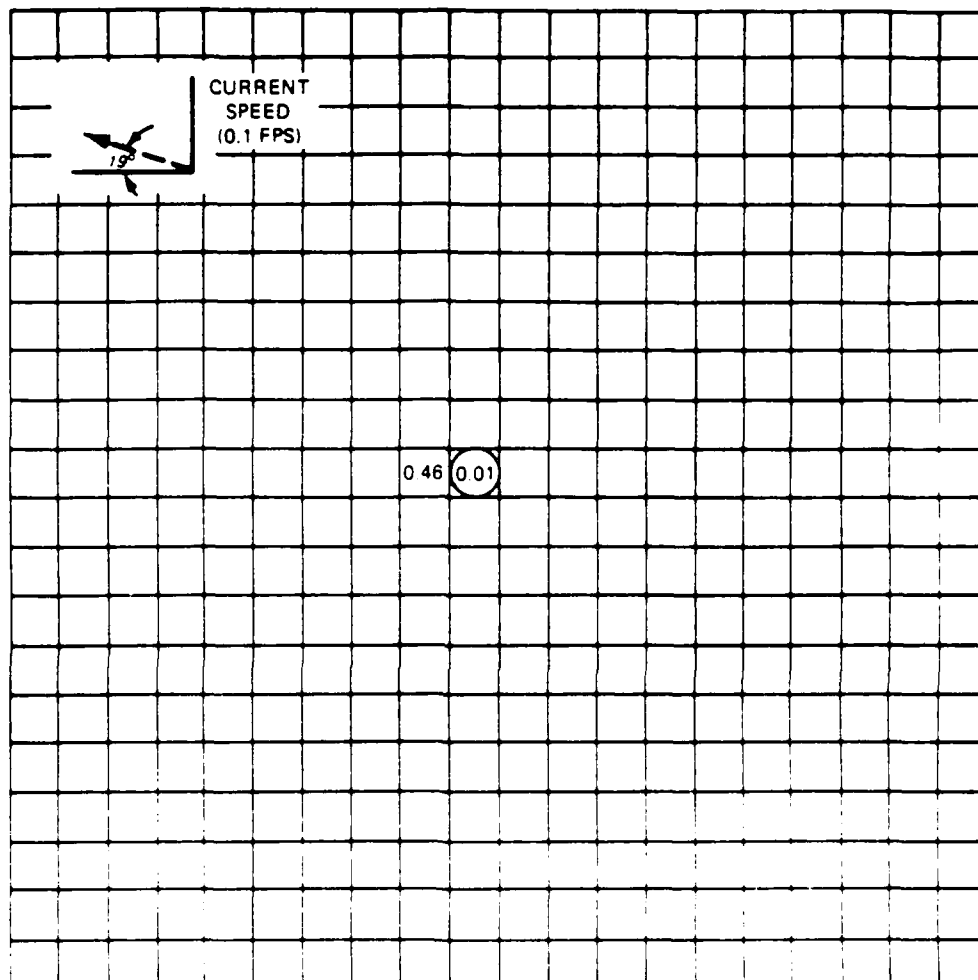


○ LOCATION OF DISPOSAL

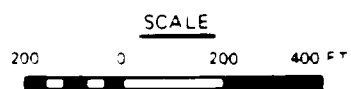


NOTE: DEPOSITION GIVEN IN FEET.

DEPOSITION PATTERN
150-FT PIPE
DISCHARGE = 40 CU YD/MIN

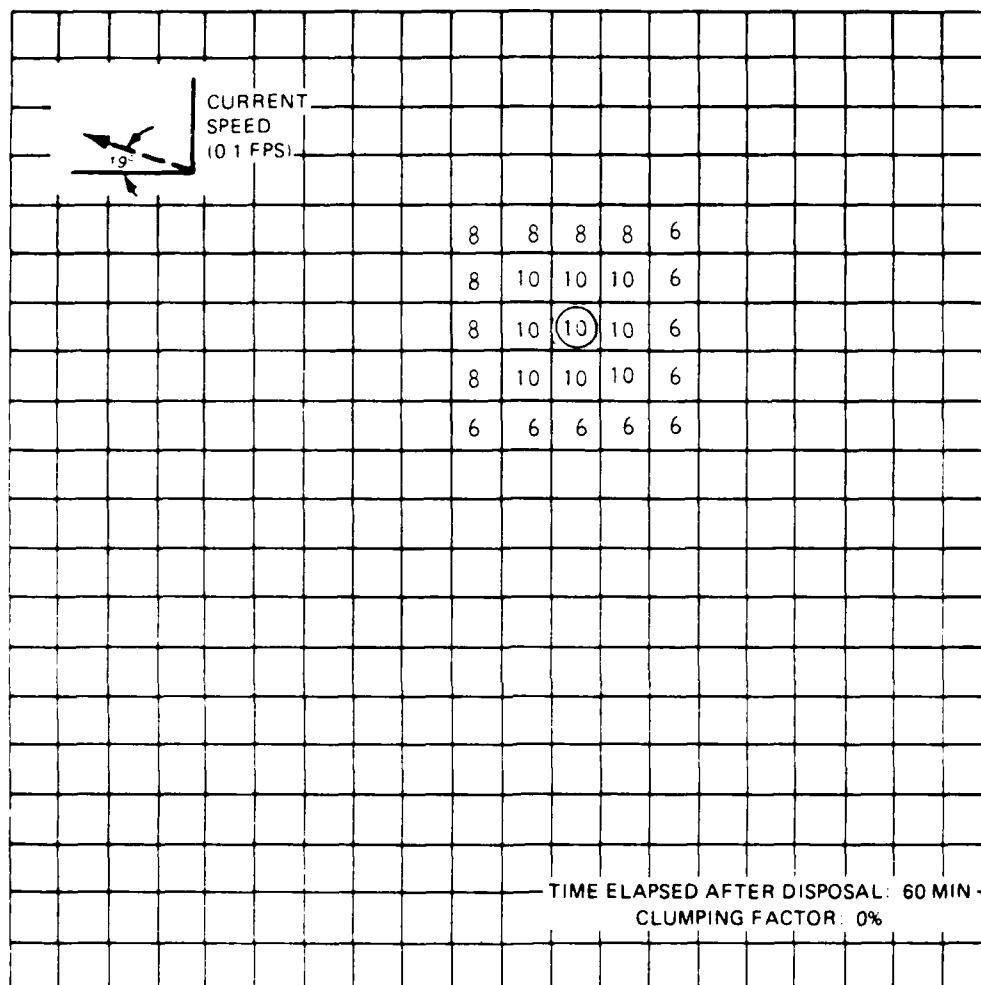


○ LOCATION OF DISPOSAL

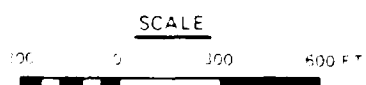


NOTE DEPOSITION GIVEN IN FEET

DEPOSITION PATTERN
150 FT PIPE
DISCHARGE 50 CU YD MIN



○ LOCATION OF DISPOSAL



NOTE: DEPOSITION GIVEN IN HUNDREDTHS OF A FOOT

DEPOSITION PATTERN
BARGE DISPOSAL IN
400 FT OF WATER

END

FEB.

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DTic