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Proceedings of the 16th Dredging Seminar

J.B. Herbich, compiler
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PROCEEDINGS

OF THE

SIXTEENTH ANNUAL DREDGING SEMINAR

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NEW TOOLS FOR EVALUATING

HARBOR DEEPENING

by

David F. Bastian[1]

ABSTRACT

Benefit/cost analysis for deep-draft harbor and channel deepenings require extensive data gathering and repetitive calculations. Through the use of time sharing data bases and a computer model, study time can be minimized and analysis can be more uniform. The purpose of this paper is to describe the data bases and ship operating cost model for use in evaluating deep-draft channel improvements and alternatives.

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INTRODUCTION

Federal participation in the improvement of harbors and channels to meet the requirements of ocean-going and Great Lakes shipping dates back to the early 1800's. Justification for improvement is based upon economic analysis and environmental assessment. The Federal objective is to alleviate navigation problems while increasing economic efficiency and maintaining Federal environmental quality standards. The basic economic benefit derived from the deep-draft features of water resources projects is the reduction in costs required to transport commodities. Transportation savings may result from the use of larger vessels, more efficient use of vessels, reduction in transit time and lower cargo handling costs.

The Army Corps of Engineers has the responsiblity of developing and maintaining the nation's navigable waterways. Before any navigation improvement can be made, current planning guidance mandates that the beneficial contributions to the national economic development accounting system must be assessed[1]. The procedures are shown in figure 1. The present (without-project) condition serves as a benchmark against which all alternatives are compared. The planner must incorporate into the analysis the non-structural (i.e., lightering, tug assistance, topping-off, alternative modes, etc.) and structural (reflecting advancing technology) measures/changes likely to occur during the planning period.

PLANNING PROCESS

The planning process, as can be seen from figure 1, is rather extensive and requires a large data base. In the past such studies have required time consuming research to obtain shipping data in order to make projections and analyses. The Corps has recently subscribed to time sharing data bases and developed a ship operating cost model. These tools give the planner accurate and current data to make projections and input into an interactive program to develop unit costs at a fraction of the time previously required.

To see how this is possible a brief review the planning process for deep draft navigation projects is presented. The starting point is to determine the economic study area followed by identifying the types and volumes of commodities that move on the existing project or that may be attracted to the proposed improvement. Thus, a historical summary of types and trends of commodity tonnage should be displayed.

Analyzing commerce that flows into and out of the economic study area provides a basis for estimating the gross potential cargo tonnage. To do this requires obtaining origins, destinations and vessel itineraries. If benefits from economics of ship size are related to proposed deepening of the harbor, the analysis should concentrate on the specific commodities or types of shipments that will be affected.

Key components in the study of deep-draft harbor improvements are the size and characteristics of the vessels expected to use the project. Data on past trends in vessel size and fleet composition and on anticipated changes in fleet composition over the project life are needed. The planner must determine the composition of both the current and future fleet that would utilize the harbor both with and without the proposed improvement. Vessel size may vary according to trade route, length of haul, origin or destination, port depths, canal restrictions, volume of traffic and type of commodity.

Based upon the vessel mix, the before and after project vessel operating costs are determined. Concurrently the planner must estimate potential tonnages by commodity. These must also be compared with alternative movements including competitive harbors, lightering, topping-off, etc. Cost and commodity volumes have to be projected into the future.

Once the estimated tonnages that would move with and without the planned project have been projected and the cost via the proposed harbor versus each alternative have been estimated, the total navigation benefits have to be computed using the applicable discount rate. This involves determining the difference between current and future transportation cost for the movement by the existing project and the proposed improvement. Navigation project benefits are cost reductions sufficient to divert traffic from established distribution patterns and trade routes.

To accomplish all of the above tasks in assessing the economic merit of a navigation project the Corps planner has been faced with extensive data gathering requirements. Recently, however, the magnitude of this effort has been significantly reduced through data base time sharing subscriptions and an interactive computer model.

DATA BASES

Presently the Corps subscribes to four computer data bases referred to as libraries by the vendor, Maritime Data Network Ltd. (MARDATA). The data from these libraries are available on-line through the General Electric Timesharing Network via a local telephone number. This access provides the capability to interactively search and perform statistical analysis. The libraries are described below:

1. Ship Characteristics Library

Data for this library is furnished by Lloyd's Register of Shipping, Ltd., and consists of practically all commercial ships of the world over 1000 gross registered tons, (a total in excess of 29,000). The file contains over 65 items of description on these vessels from deadweight to self-unloading capabilities. A search may be conducted on any single or combination of parameters. For example, selection of ships may be made by specific parameters such as U.S. flag or by a range such as dead-weight between 20,000 and 40,000 tons. The system can easily identify ships having a particular parameter or set of parameters such as machinery type, age, flag and owner.

Listed in alphabetic order below are 10 of the 65 library search parameters useful to the planning process:

1. Breadth
2. Bunker/Capacity
3. Deadweight
4. Delivery Date
5. Draft
6. Flag
7. Fuel Consumption
8. Name
9. Ship Type
10. Speed

More than 2,000 validity checks are built into the programs that updates this file every 30 days[2].

2. Ships on Order Library

This data base consists of a list of all commercial ships which have been ordered and/or are under construction. The user has the ability of determining, among other things, the future fleet size of ships meeting certain requirements as this library is directly integrated with the one containing ship characteristics. Additional items include keel date, launch date, estimated delivery date and cancellation date.

Listed in alphabetic order below are 9 of the 36 library search parameters useful in the planning process:

1. Breadth
2. Cargo Type
3. Deadweight
4. Draft
5. Estimated Delivery Date
6. Flag
7. Name
8. Ship Type
9. Speed

The above two libraries are effective tools which allow the planner to look at trends in ship size against time. For example, one can look at the world fleet using draft and/or DWT vs. delivery date for a given ship type[3].

3. Ship Movement Library

The Ship Movement Library contains information on worldwide ship movements for the past two years covering over 20,000 ships and 5,000 ports. This includes tankers, dry bulk carriers and combination vessels equal to or greater than 10,000 DWT, and all other ships equal to or greater than 5,000 DWT. The library is based on data supplied by Lloyd's of London Press, as published in Lloyd's Voyage Record and Lloyd's Shipping Index, and is updated biweekly. Historic trading patterns for a given port or area can be analyzed to help project future trends. The user can review traffic to a given port, specific itineraries (including stops), as well as the voyage history of a single ship. This library is limited in that it does not provide either the actual arrival draft of a given ship or list the commodity and amount[4].

4. Charter Fixture Library

The Charter Fixture Library contains all reported fixtures, both tanker and dry cargo since the beginning of 1976. These fixtures (time and voyage) are collected from a number of sources in the U.S. and Europe and are updated daily. The library includes ship name, charterer, deadweight, cargo, load area, discharge area, rate, period, delivery and redelivery date. The charter rates are really a barometer of the economy and as such are not true indicators of cost. This library also allows the user to analyze traffic movements but only those which are chartered[5].

The above four data bases provide much of the necessary background data needed for economic analysis.

SHIP OPERATING COST MODEL

The required freight rate (the cost per short ton to move a commodity from one location to another) provides the basic unit for comparison of transportation alternatives and is also the specific unit for determining the cost/benefit associated with specific port improvement programs. The Corps of Engineers has supported development for an interactive computer model to calculate the transportation cost per ton associated with different size vessels and channel depths and different port turnaround times. The cost per ton differences associated with these factors can be developed, which when multiplied by the annual throughput at the particular port, will provide the potential savings associated with specific port improvement projects.

Transportation Cost Program

The tool that allows the planner to determine the transportation cost in order to evaluate the economic effects of a navigation project is a ship operating cost model entitled Transportation Cost Program[6]. This model allows the user to compute the cost per ton or required freight rate to move any given commodity as a function of ship type and size. The model allows the user to investigate various channel depth scenarios necessary to evaluate incremental savings when ships cannot use the channel fully loaded.

The development of required freight rates (transportation cost) requires collecting specific data on ship characteristics, voyage characteristics, voyage costs and ship operating costs. Four files grouped by vessel type and size have been created. Each of the files is expandable and provides input data to the Transportation Cost Program. Table 1 shows the parameters included in the files.

TABLE 1

Files for Transportation Cost Program

1. Ship Costs

A. Capital Investment

1) Ship Cost - new and second hand
2) Annual Finance Charges
3) Residual Value

B. Operating Costs

1) Wages
2) Subsistence
3) Stores & Supplier
4) Maintenance and Repair
5) Insurance
6) Other

C. Total Costs

1) Annual Cost (A&B above)
2) Time Charter Equivalent Rate

2. <u>Ship Characteristics</u>

A. Deadweight
B. Cubic Capacity
C. Length
D. Beam
E. Draft
F. TPI (tons per inch)
G. Horsepower
H. Speed
I. Fuel Consumption (at sea and in port)

3. Voyage Costs

A. Port Charges (per DWT or per container)

B. Fuel Prices

4. Voyage Characteristics

A. Distance (One-Way)

B. Port Days (load port and discharge port by ship type)

C. Draft Limit (load port and discharge port)

By selecting ship type, size and flag, (see tables 2 and 3) the ship operating costs and characteristics are inserted into the program. The user can display this information and, if desired, can alter any of the given parameters in the files. Once satisfied, one of the four general voyages presented in table 4 is selected. That file data is displayed and, unless modified, is also input into the program. The program now computes the voyage cost, duration and cargo per voyage.

TABLE 2

Files Established for Various Size and Types of Ships

	Dry Bulk		Tanker		General Cargo	
Flag	U.S.	Foreign	U.S.	Foreign	U.S.	Foreign
Deadweight						
11,000					X	X
14,000					X	X
15,000		X				
16,000					X	X
20,000					X	X
24,000					X	X
25,000	X	X	X	X		
30,000					X	X
35,000		X	X	X		
40,000		X	X	X		
45,000		X				
50,000		X	X	X		
60,000		X	X	X		
80,000	X	X	X	X		
90,000			X	X		
100,000		X				
120,000		X	X	X		
150,000		X	X	X		
175,000			X	X		

TABLE 3

Files Established for Various Sized Container Ships

20-ft Equivalent Units	Flag	
	U.S.	Foreign
600	X	X
1000	X	X
1200	X	X
1400	X	X
1600	X	X
2000	X	X
2400	X	X
2800		X

TABLE 4

General Voyages Established for Ship Types

Trade Type	One-Way Distances (nautical miles)			
	1500	2500	5000	10,000
Bulk Voyages	X	X	X	X
Tank Voyages	X	X	X	X
Container Voyages	X	X	X	X
General Cargo Voyages	X	X	X	X

The program must then be furnished an estimate of the anticipated operating days per year for the vessel in question. With this information the annual cargo laydown is computed. Finally, the program uses data from the ship cost files to calculate annual capital and operating costs and transportation cost per ton.

The following example demonstrates the ship operating cost model[7]. Because most Corps navigation studies will involve channel deepening, the case is one where the transportation cost is determined for different depth scenarios. For this exercise, the files shown as figures 2 and 3 for the dry bulker, "Bornheim" are created. Note on the ship file that the "Bornheim's" design draft is 35 feet but the limiting depth at the discharge port (voyage file) is 32 feet.

The transportation cost program is called forward and the file data is input by designating the proper ship, voyage, and operating cost file numbers (see figure 4). The program responds by first giving the ship's name (Bornheim) and then the voyage name (Port A/Port B). At this point, the option to modify or use different files is waived. The user responds to five querries after which the program provides voyage and cost information and on the last line it provides the cost per ton of $19.17. An optional voyage summary can also be printed out (figure 5).

Next, the impact of increasing the depth limitation from 32 to 33 feet on the cost per ton using the "Bornheim" is evaluated. This requires modifying line 27 of the voyage file. All other input data was left unchanged. This 1-foot channel depth limitation increase changed the cost per ton from $19.17 to $18.36 (see figure 6), or a transportation cost saving of $0.81.

The example demonstrates the ease by which the Transportation Cost Program can calculate the required freight rate for various ships and channels. The planner would have to repeat this procedure for various types and sizes of ships expected to benefit from the channel improvements. This would best be accomplished using the already established files for general voyages and ships previously referred to in tables 2-4. With the files established and updated as needed the model provides a fast, efficient and uniform analysis.

SUMMARY

Port improvements ultimately provide cost benefits in marine transportation in principally two ways, namely:

a. increasing the size of vessel that can call on the port

b. reducing port turnaround time

There are, of course, additional benefits to the port such as increase in throughput, but this will not impact the cost of transportation unless one or both of the benefits mentioned above are realized.

Federal participation in navigation improvements has to be economically justified. In the past, determining economic justification has been a laborious and time consuming effort. With the availability of computer data bases and an interactive model, the planner now has the tools which can significantly reduce the study time and allow for uniform analysis.

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2. Ship's Library, Maritime Data Network, Ltd.

3. Ships-On-Order, Maritime Data Network, Ltd.

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5. Charter Fixtures Library, Maritime Data Network, Ltd.

6. Economics & Planning System Instruction Book, Marine Management Systems, Inc., December 1980.

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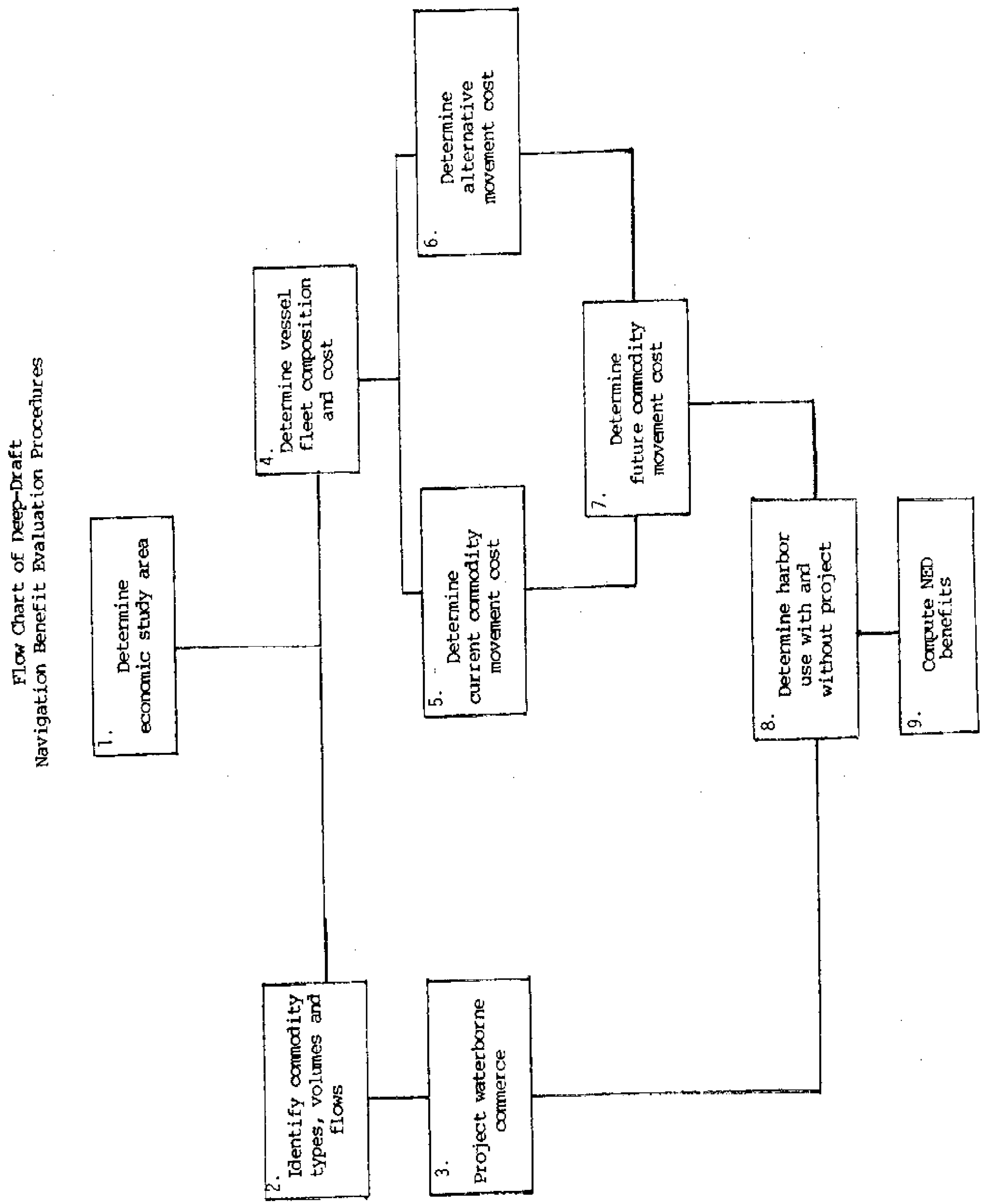


Figure 1
Source: Principles and Guidelines

Figure 2

Ship File For Bornheim

```
INPUT SHIP NO. ?11

REC # =  64
 1 SHIP NO        =          11.
 2 NAME:    BORNHEIM
 3 SHIP CODE      =  HVF
 4 SHIP TYPE      =  DRY BULK
 5 SUMMER DWT     =      42129.
 6 SERV SPEED LD=      14.50
 7 SERV SPEED BL=      14.50
 8 DRAFT (SUM)    =    35.25
 9 LIQUID CUBIC =    1982000.
10 GRAIN CUBIC    =  1982000.
11 HV FUEL SEA/D=      38.00
12 HVFUEL PORT/D=      4.00
13 DIESEL SEA/D =      0.
14 DIESEL PORT/D=      0.
15 SUEZ NRT       =          0.
16 PANAMA NRT     =          0.
17 WATER & STRS =          150.
18 SHIP COST $.   =  28560000.
19 TONS/INCH      =        135.
20 PANAMA DWT     =          0.
"1 WINTER DWT     =      40939.
22 TROPICAL DWT =        43319.
23 SUEZ DWT       =          0.
24 BUNKER CAP LT=            0.
```

Figure 3

Voyage File For Bornheim

```
INPUT VOY NO. ?11

REC NO.    18
 1 VOYAGE NUMBER      =              11.
 2 NAME: PORT A/PORT B
 3 DIST LOADED        =      4615.
 4 DIST BALLAST       =      4615.
 5 BKR DIST LD PORT   =      4615.
 6 BKR DIST INTR PORT=          0.
 7 FREEBD ZONE DIST   =         0.
 8 CANAL DISTANCE     =         0.
 9 CNL DYS <= 60K DWT=       0.
10 CANAL DAYS > 60000=       0.
11 PORT DAYS  LD      =      3.00
12 LOAD RATE 1000 T/D=       0.
13 PORT DAYS  DISCH   =      3.00
14 DISCH RATE  TH T/D=       0.
15 FUEL PRC BKR C $/L=     225.00
16 FUEL PRICE HVF $/L=     225.00
17 FUEL PRICE DD $/LT=     300.00
18 SUEZ RATE LD $/RT =       0.
19 SUEZ RATE BAL $/RT=       0.
20 PANAMA RTE LD $/RT=       0.
21 PANAMA RTE BAL     =      0.
22 PORT CHG  LD     $=          0.
23 PT CHG  LD    $/DWT=      0.250
24 PORT CHG  DISCH  $=       6600.
25 PT CHG  DCH   $/DWT=      0.800
26 DRAFT LIM LD PORT =      40.00
27 DRAFT LIM DSCHG PT=      32.00
28 DRAFT LIM CANAL    =      0.
29 LOADING PORT ZONE =
30 INTERMED PORT ZONE=
31 FREEBOARD ZONE     =
32 STOWAGE FACTOR     =     14.00
33 CARGO RESTRICTION =          0.
34 STAND. SCALE $/LT=      0.
35 WORLDSCALE FLAT    =      0.
36 DAYS IN CANAL BAL =       0.
37 SOURCE PRICE  $/LT=       0.
38 VOY DESCRIPT :

INPUT VOY NO. ?

USED      3.21 UNITS
```

Figure 4

Output From Transportation Cost Program
For 32-Foot Draft Limitation

```
TRNCST       09:02EST     02/27/83

 MARINE MANAGEMENT SYSTEMS - TRANSPORTATION COST PROG

SHIP NO. ?11

VOYAGE NO. ?11

OPER CST NO. ?1

SHIP    :  BORNHEIM
VOYAGE  :  PORT A/PORT B

MODS: 'SHIP','VOY',OR 'OPER'   ?


CHAR RTE  $/DWT/MOS= ?9.26

CHARTER TERM= ?15

ESCALATION COSTS : BASE $= ?


OPER DAYS/YR= ?350

CARGO TYPE: 1.LIQ 2.DRY BULK ?2

PORT CHG/VOY $ ?

 CARGO DWT    =   36524.
 DAYS / VOY   =    32.52
 VOY / YR     =    10.76
 ANNUAL LAYDN=  393057.


ANNUAL VOY COST =  3045613.
 VOY CST ESCAL %= ?

AVG ANNUAL ESC VOY COST=  3045613.
ANNUAL CHAR CST        =  4488989.
TOTAL COST $           =  7534603.
TRANS COST $/T =    19.17
```

Figure 5

Transportation Cost Program
Voyage Summary Display

```
MORE? ?SUM

VOYAGE SUMMARY
                  BAL.VOY LOAD PORT LOAD VOY DISCH PT    TOTAL
SEA DAYS             13.3       0.      13.3       0.     26.5
PORT DAYS             0.       3.0       0.       3.0      6.0
CANAL DAYS            0.        0.       0.        0.      0.
TOTAL DAYS           13.3      3.0      13.3      3.0     32.5

FUEL COST         113386.    2700.   113386.    2700.  232172.
PORT CHARGES           0.   10532.        0.   40303.   50835.
CANAL CHARGES          0.       0.        0.       0.       0.
TOTAL VOY COSTS   113386.   13232.   113386.   43003.  283007.

LOADING SUMMARY
 SUMMER DWT                                  42129.
 RESTRICTION DUE TO:
  DISCH PORT DRAFT
 LOADED DWT                                  37392.
 LESS WATER & STORES             150.
 LESS BUNKERS                    528.
 LESS RESERVE BUNKERS            190.          868.
 CARGO DWT                                   36524.

MORE? ?YES
```

Figure 6

Output From Transportation Cost Program
For 33-Foot Draft Limitation

```
MODS: 'SHIP','VOY',OR 'OPER'   ?VOY

MOD VOY LN NO:?27

DRAFT·LIM DIST PORT      32.00   NEW VALUE: ?33

MOD VOY LN NO:?


MODS: 'SHIP','VOY',OR 'OPER'   ?


CHAR RTE  $/DWT/MOS= ?9.26

CHARTER TERM= ?15

ESCALATION COSTS : BASE $= ?


PORT CHG/VOY $ ?

 CARGO DWT    =   38144.
 DAYS / VOY   =    32.52
 VOY / YR     =    10.76
 ANNUAL LAYDN= ·410491.


ANNUAL VOY COST =  3045613.
 VOY CST ESCAL %= ?

AVG ANNUAL ESC VOY COST=  3045613.
ANNUAL CHAR CST        =  4488989.
TOTAL COST $           =  7534603.
TRANS COST $/T =     18.36
```

FEASIBILITY OF USING HOPPER DREDGES

UNDER ARCTIC ENVIRONMENTS

by

K. Takekuma[1], T. Kawamoto[2], Y. Sakai[3], P. Noble[4]

ABSTRACT

With progress of Arctic exploration, artificial islands have been constructed as one of the most cost effective drilling platforms due to their high reliability, long working period under Arctic environments and relative ease of construction completed within only one or two open-water seasons by use of current dredging systems. With extension of Arctic exploration to deeper water, dredging systems are required to collect much more amount of soil for construction of an artificial island within their available working period. For this purpose, extension of dredging period into ice-infested water season is highly desired by support of icebreakers and commissioning ice-capable hopper dredges in service. This paper summarizes technical aspects of hopper dredges operating in ice-infested water under Arctic environments. Study on feasibility of Arctic hopper dredge is also described together with conceptional design of some candidates of ice-capable hopper dredge.

[1,2,3]Mitsubishi Heavy Industries, Ltd., 3-48 Bunkyo-Maachi, Nagasaki 850, Japan.
[4]ARCTEC Canada Ltd., No. 16, 6324-11th Street, S.E., Calgary, Alberta T2H 2L6 Canada.

1 INTRODUCTION

Exploration for hydrocarbon resources has been conducted in Arctic regions during the last decades with future demand for energy resources in view. Various types of drilling systems such as artificial islands, caisson retained islands, drill ships and converted tankers have been used in the exploration under condition of extremely low air temperature, large ice loads on structures and various severe environmental characteristics. To cope with the severe environments above, some alternatives of drilling systems, such structures as monopods, inverted monocones, single column mats, round drill barge etc. have been proposed and recently put into service (Fig.1). Evaluation of candidates of drilling systems above indicated that the artificial island system was most cost effective from view points of resistance to ice motion, economy, reliability and working period. Cost effectiveness of the artificial island system was due to the fact that most of the Arctic exploration had been conducted in shallow water area along the cost of the continent or Arctic islands where construction of an artificial island could be completed in only one or two open water seasons by use of dredges (Table.1).

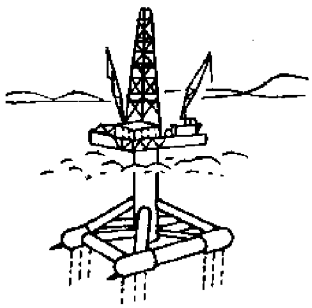
As exploration extends to deeper water, cost effectiveness of the artificial island system decreases in comparison with that of other candidates of drilling systems. This because larger amount of soil is required for construction of an artificial island, whereas the existing type of dredges can work only within a short Arctic summer season when waterways are cleared of young ice sheets (Fig.2). Thus, in order to expedite Arctic exploration with improvement of economics of the artificial island system, it is highly desirable

(1) to extend dredging period into ice infested water season by proper maintenance and support of powerful ice-breakers, and by commissioning in service some advanced ice-capable hopper dredges or

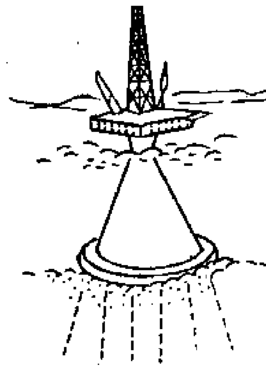
(2) to keep dredging period within the open water season by commissioning in service more number of dredge of existing type or more advanced and large sized hopper dredges for collecting a large amount of soil.

In this study, an attempt was made to investigate feasibility of some candidates of hopper dredge for Arctic use. Conceptional design of some types of ice-capable hopper dredge was made to assess the technical and economic aspects of ice-capable hopper dredging system operating in the Arctic regions.

This paper describes the present state of the study made in Mitsubishi Heavy Industries, Ltd. for development of Arctic hopper dredge through conceptional design, economics evaluation and so on.



Monopod Type



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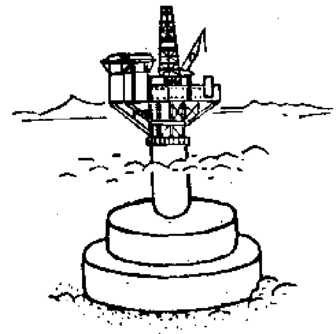

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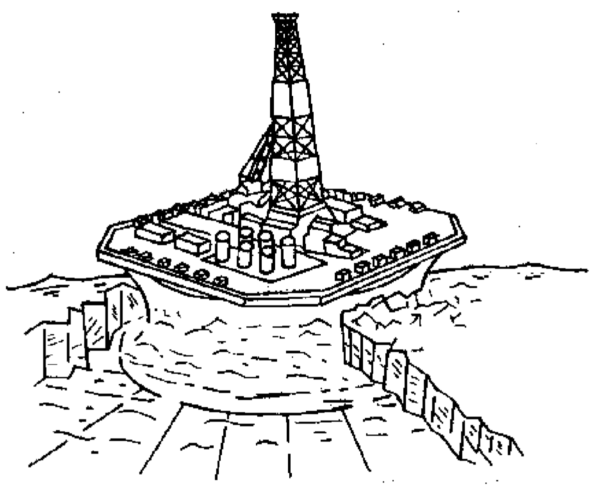
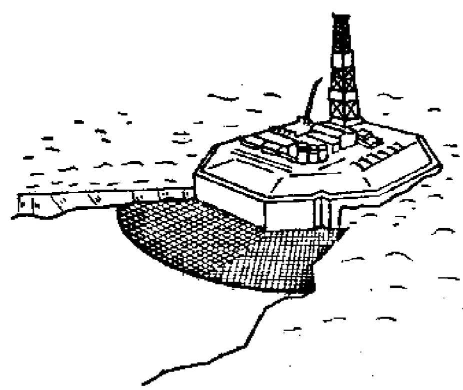


Round Drilling Barge



Artificial Island

Fig. 1 Typical Concept for Drilling System in Arctic Offshore

Table 1 Typical Artificial Island and Required Volume of Sand/Gravel

Location	Issungnuk	Tarsiut	Uviluk	Nerlork
Water depth	20m	22m	31m	45m
Dredged volume	5.0 Mm^3	2.0 Mm^3	2.4 Mm^3	4.5 Mm^2
Construction period	'79∿'80?	'80∿'82	'81∿'82	'82∿'83
Total dredging days	200	183	160	147+α

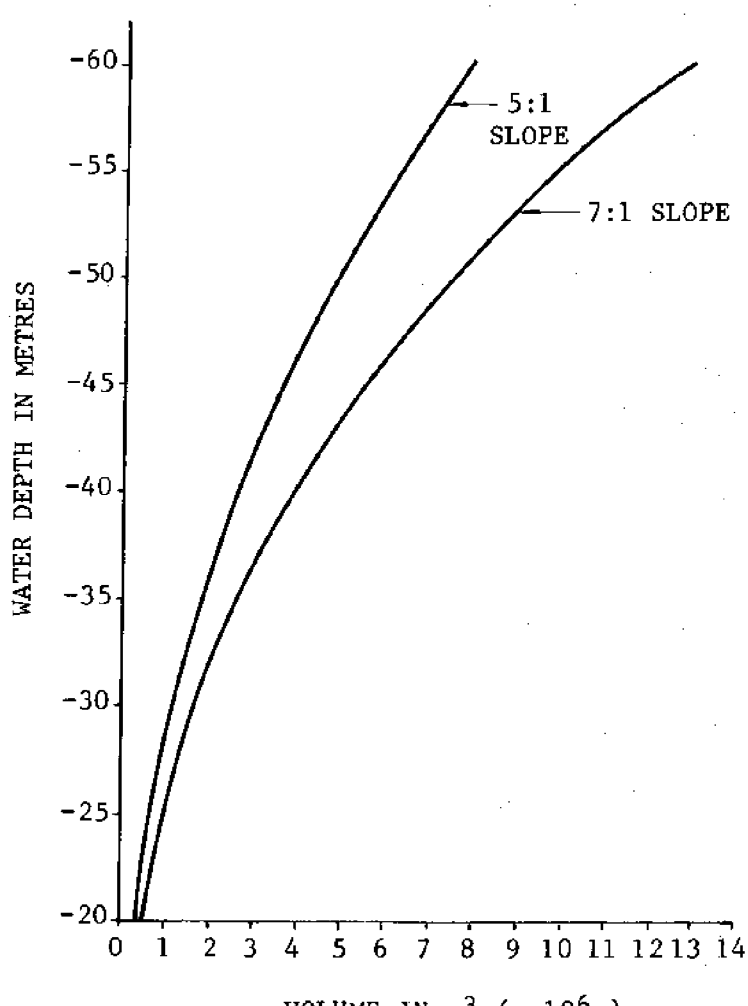


Fig. 2 Quantity of Berm Material vs. Water Depth
(From Ref.(1))

2 HOPPER DREDGES UNDER ARCTIC ENVIRONMENTS

The Arctic regions are characterized by severe environments through the whole year except for the short summer season. These include extremely low air temperature, darkness and waterways covered by thick ice fields, large ridges and rubble ice fields, and glacial ice fragments. Artificial islands have been constructed as one of the most cost effective platforms due to their high reliability, long working period under severe Arctic environments, and relative ease of construction completed within only one or two open-water seasons by use of current dredging systems.

As an example of construction method for Artificial island, the case of Tarsuit constructed by Canadian Marine Drilling Ltd. is shown below (Fig.3).

(1) Engineering and environmental studies
(2) To remove 3 m thick soft clay layer 130 m in diameter at the center of the island by the hopper dredge
(3) To dump the soil by the hopper dredge or dump barges until the soil was deposited outside the theoretical island boundary
(4) To discharge the soil dredged by the hopper dredge or the cutter dredge through the discharge barge to obtain 1:5 slope
(5) To distribute the gravel dredged by the hopper dredge evenly over the berm top up to one meter thick through the discharge barge.
(6) To screed the berm top by a special screeding beam to keep the tolerance of plus or minus 50 cm.

With extension of Arctic exploration to deeper water, dredging systems are required to collect much more amount of soil for construction of an artificial island within their available working period. Therefore in view of economics of such artificial island system in deeper water, it is essential

(1) to extend dredging period into ice-infested water season or
(2) to collect sufficient amount of soil within the open water season.

Of both measures mentioned above, the extension of dredging period (1) is considered to be a challenging theme in the Arctic exploration. There are various technical items to be investigated and economic aspects to be considered in the dredging under Arctic environments.

Dredging system for constructing an artificial island in the Arctic regions consists of the following components.

(1) Trailing suction hopper dredges
(2) Stationary suction dredges
(3) Dump Barge
(4) Discharge Barge
(5) Support ships
(6) Transportation system
(7) Terminal or base of operation

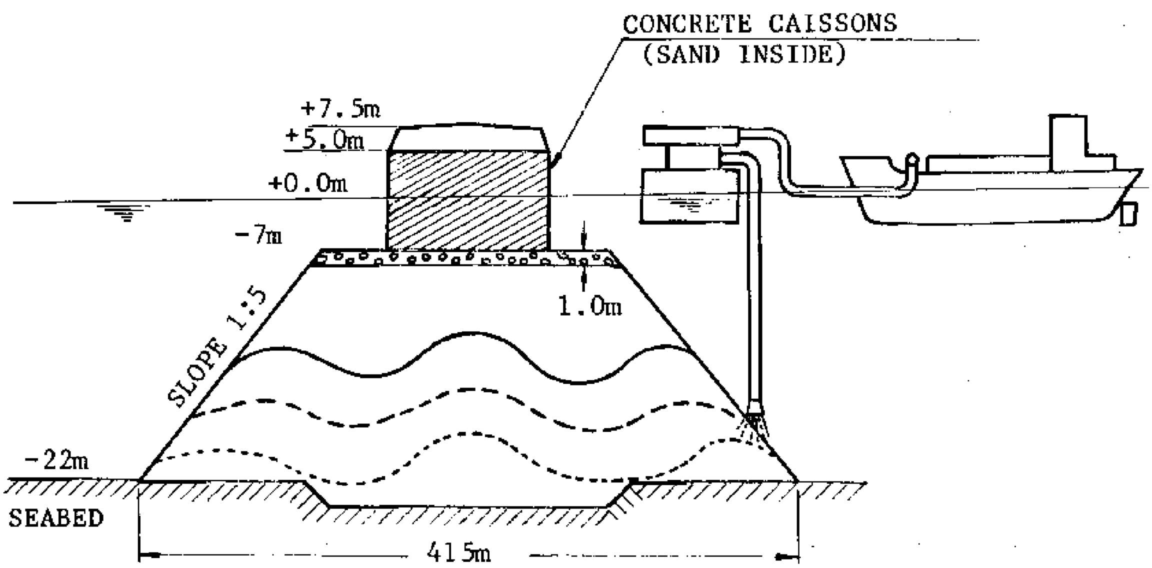


Fig. 3 Construction of Tarsiut Island
(From Ref.(2))

Among the components above, development of hopper dredge for Arctic use seems to be a new area to be explored, while on the other items, there are some accumulated experiences under Arctic environments. Thus, the present study is concentrated first to assess the technical problems ecountered in the design, construction and operation of ice-capable hopper suction dredges as follows (Fig.4).

(1) Ship form and performance.
(2) Structure and structural strength including high tensile steel for low temperature use.
(3) Propulsion system with high powered engine and effective load absorption system.
(4) Interaction between ice and drag arms.
(5) Heating system for dredging equipment and hopper.
(6) Deep water dredging.
(7) Operation pracitce, such as ice navigation, dredging or positioning in ice, support by icebreakers and so on.

Based on the results of the studies above, conceptional design of hopper dredges for Arctic use is made to clarify the details of problems to be investigated, together with evaluation of their feasibility under Arctic environments.

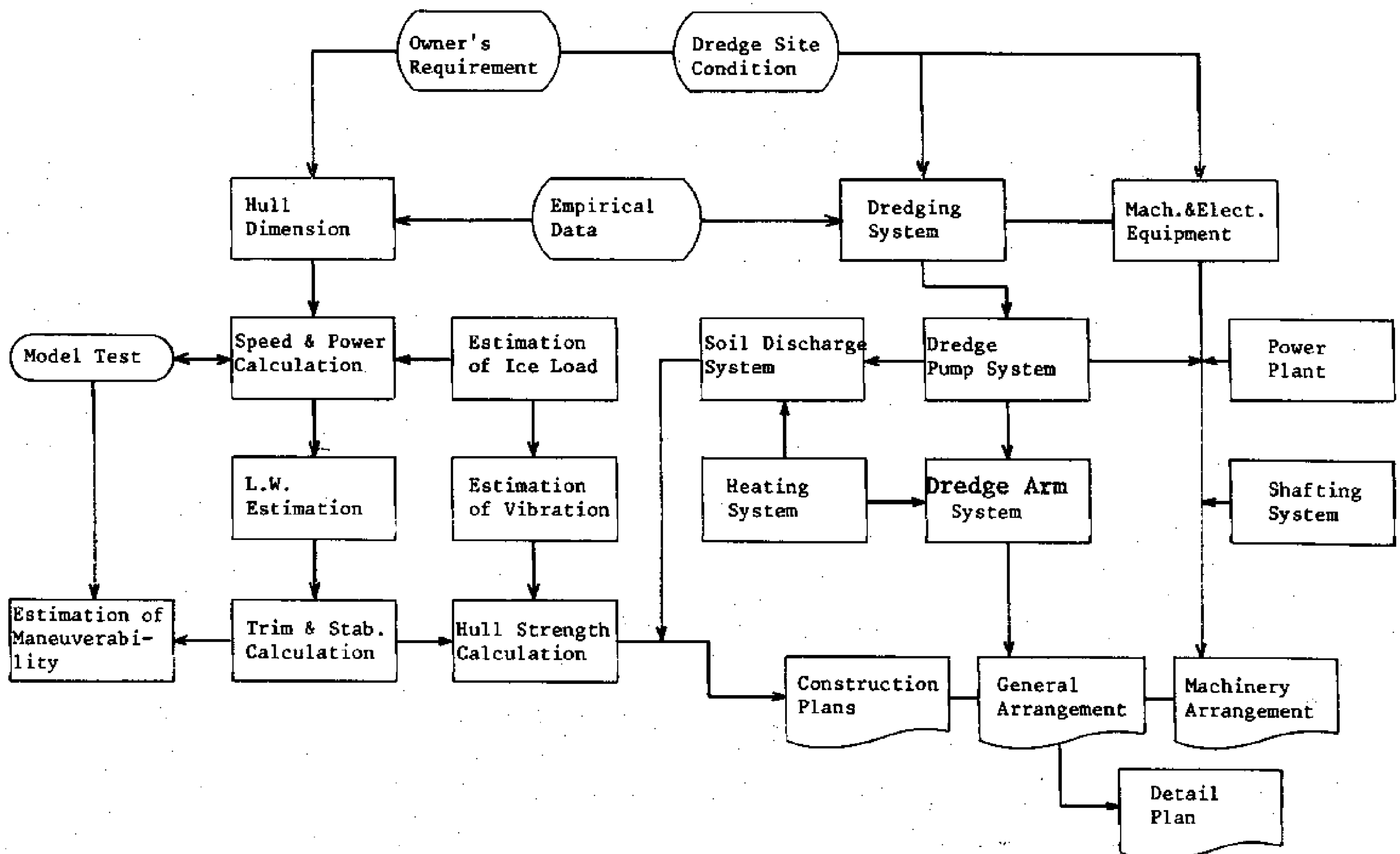


Fig. 4 Design Procedure for Arctic Hopper Dredge

3 TECHNICAL ASPECTS

As described in the previous section, a hopper dredges for construction of artificial island in deep water area in the Arctic is characterized by its capability in ice-infested water. In this chapter, considerations and investigations made on the individual aspects of hopper dredge for Arctic use are examined, proceeding with a sample design of this kind of hopper dredge (Fig.5). In the course of this work, model tests in ice were conducted on bow form and ice-dredging equipment, available reference materials were reviewed, and accumulated experiences on existing dredges were incorporated.

3-1 HULL FORM AND PROPULSIVE PERFORMANCE

Several design criteria for ice-going ship forms have been proposed through full scale experiences on icebreakers aiming at less ice resistance, less ice load on the hull and improved maneuverability in ice. In designing a hull form, care must be taken to decrease the amount of broken ice around the propellers in order to avoid troubles with propeller, shaft and propulsion systems and hull vibration. Further, it should be taken into consideration that drag arms extruding out of the hull surface is subject to impact or jam of ice floes. Since the behavior of ice floes around ship hull varies appreciably with bow form, three candidates of ice-breaking bows were designed and experimentally investigated in a saline ice tank. Namely, conventional icebreaking bow, spoon shaped bow and ice deflector bow were examined by resistance test in ice and observation of ice floes around ship hull.

As the results, it was found that with the spoon shaped bow, the ice floes made by icebreaking at the bow were pushed out under ice sheet at both sides of a ship model, while with the other candidates ice floes flowed afterward along the ship sides (Fig.6). Resistance in level ice was found to be the same order as that obtained by the existing formula of Kashetelian (Fig.7).

Thus, the spoon shaped bow can be concluded to be the most appropriate one from view point of behavior of ice floes around the ship hull.

3-2 STRUCTURE AND STRUCTURAL STRENGTH AND STEEL MATERIAL FOR LOW TEMPERATURE USE

Guidance for prediction of ice loads on ship hulls and structural design has been provided by rules and regulations based on full scale experience of icebreaker operation.

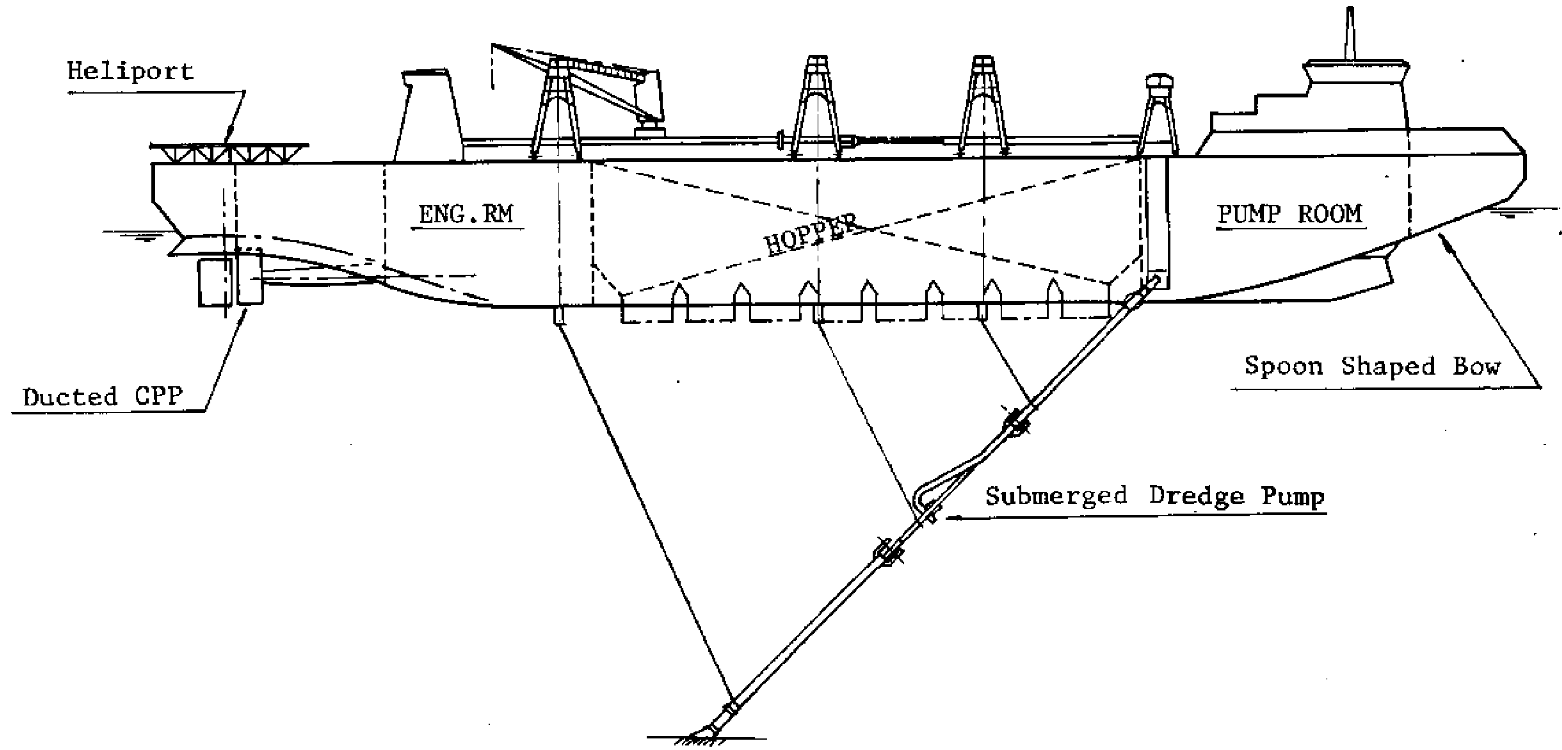
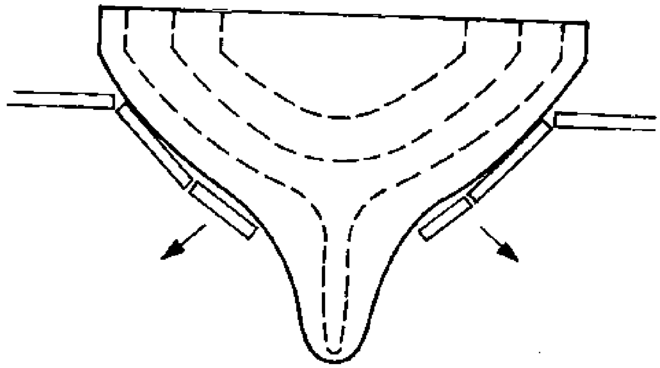
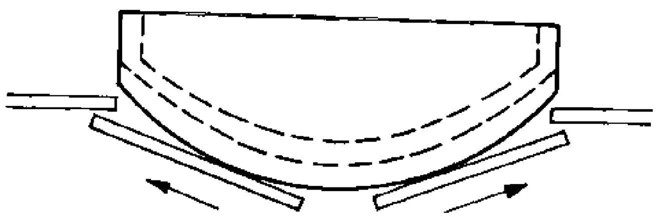


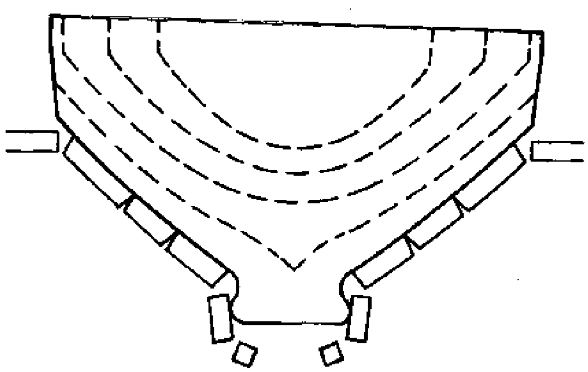
Fig. 5 Scheme of an Arctic Hopper Dredge



Conventional Icebreaking Bow



Spoon Shaped Bow



Ice Deflector Bow

Fig. 6 Comparison of Icebreaking Patterns

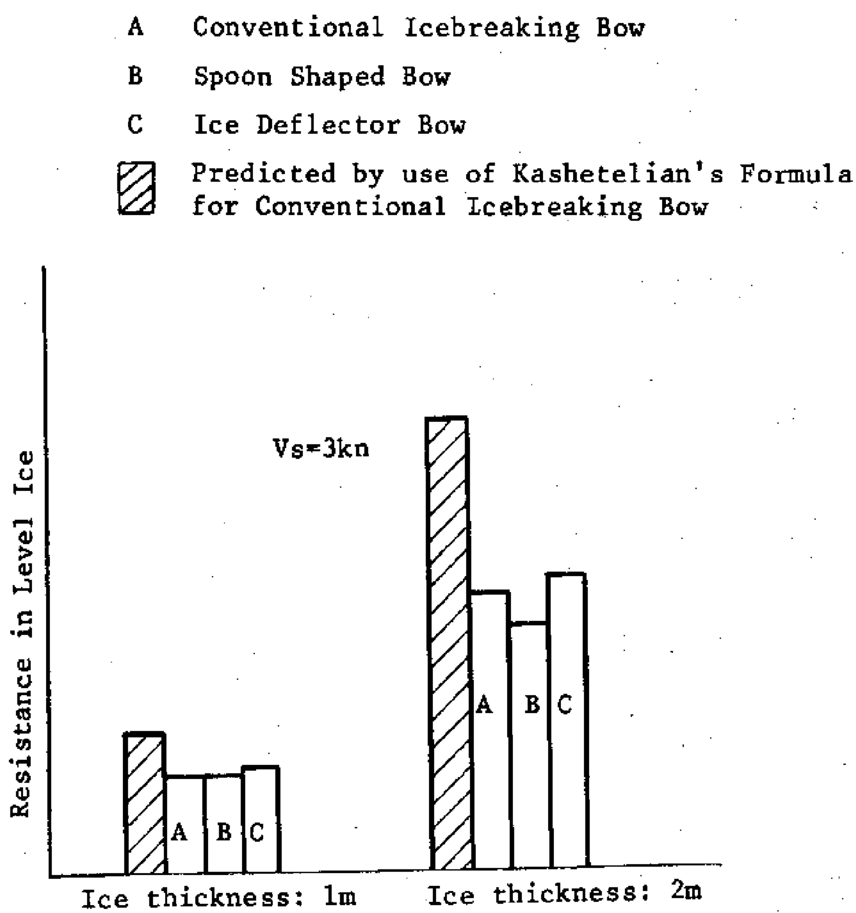


Fig. 7 Comparison of Ice Resistances

Accumulated experiences of design and construction of conventional types of icebreaker also assist design of hull structure, appendages etc. including countermeasure for severe ice-induced vibration. However, careful attention should be paid for longitudinal strength in icebreaking condition. Structural design criteria for large sized ice-capable hopper dredge should be developed on the basis of investigations to acquire a fundamental understanding of ship-ice interaction, structural strength, vibration etc. together with ice load estimation based on current full scale experience.

Steel material for low temperature use should be selected from view point of safety for brittle fracture. Especially, decrease of fracture toughness with increase of plate thickness is one of the most important items to be taken into account, because most part of shell plate exposed under extreme low air temperature is requested to be much thicker than that of conventional ships.

Characteristics of high tensile strength steel for low temperature use have been much improved in recent decades, by application of thermo-mechanical controlled rolling process in manufacturing steel. High tensile strength steel plate about 50 $\sim$ 60 mm in thickness has been applied to some marine structures operating in the Arctic regions.

3-3 PROPULSION SYSTEM WITH HIGH POWERED ENGINE AND EFFECTIVE LOAD ABSORPTION SYSTEM

Accurate prediction of full scale propulsion power is also a matter of primary importance in the design of ice-capable hopper dredge. There have been proposed some prediction formulas based on model tests in ice. Model ship correlation data having been examined on some existing icebreakers can be applied to hopper dredges with nearly the same size. However, for large sized hopper dredges, model-ship correlation data are very scarce to validate the extrapolation of propulsion power to full scale. Investigations should be conducted to establish full scale prediction practice on rational basis.

In ice navigation, severe vibration phenomena are frequently experienced together with significant variation of propeller thrust and torque caused by milling and hitting of large ice floes sucked into a propeller (Fig.8). For absorption of the large amplitude of variation of loads on a propeller, a diesel-or turbo-electric system has been used in the majority of icebreakers in operation. As an alternative, the variational load can be absorbed by pitch control if a controllable pitch propeller (Fig.9) is installed. This has been adopted on ships operating in the waterways seasonally covered by ice thinner than that in the Arctic, taking into account easy operation of propulsion plant. Recently controllable pitch propellers were installed on some ships operating in the Arctic regions. The experiences of these vessels have been of great technical interest to marine community.

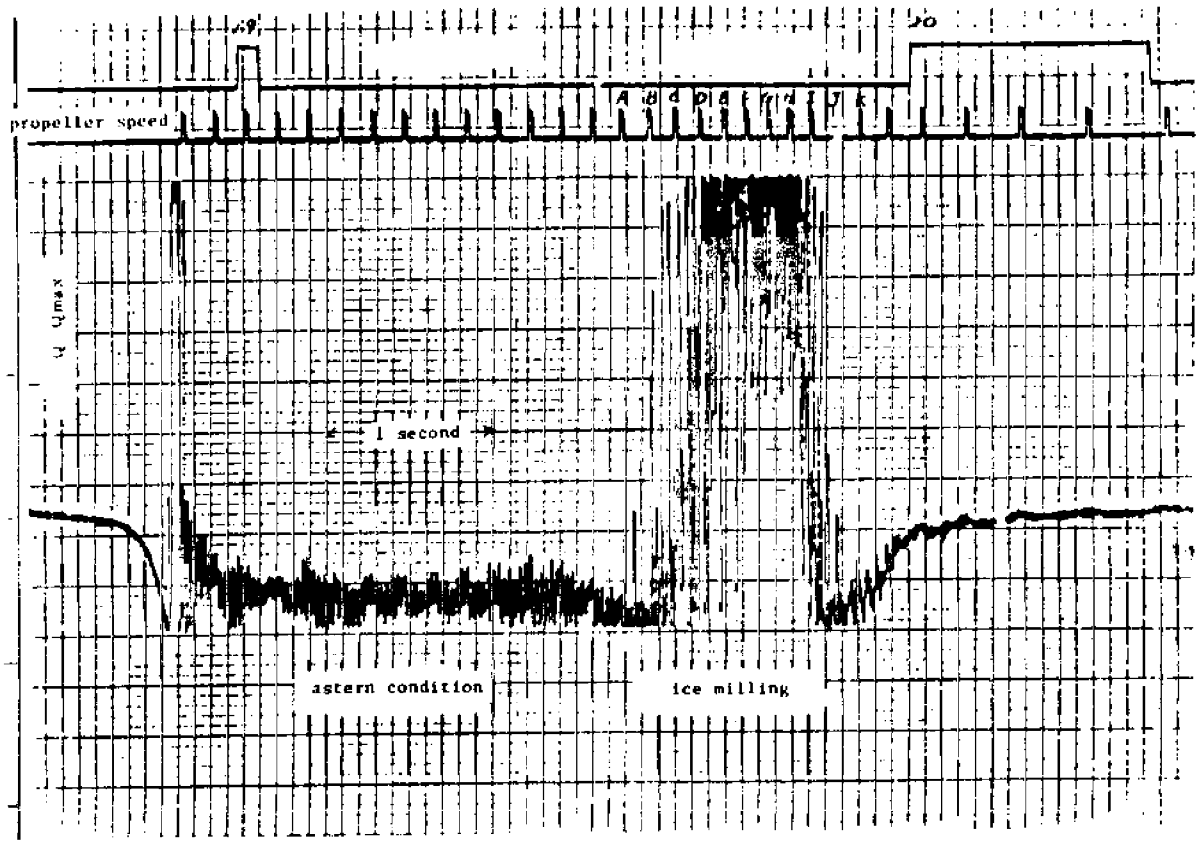


Fig. 8 An Example of Torque Variation due to Ice Milling

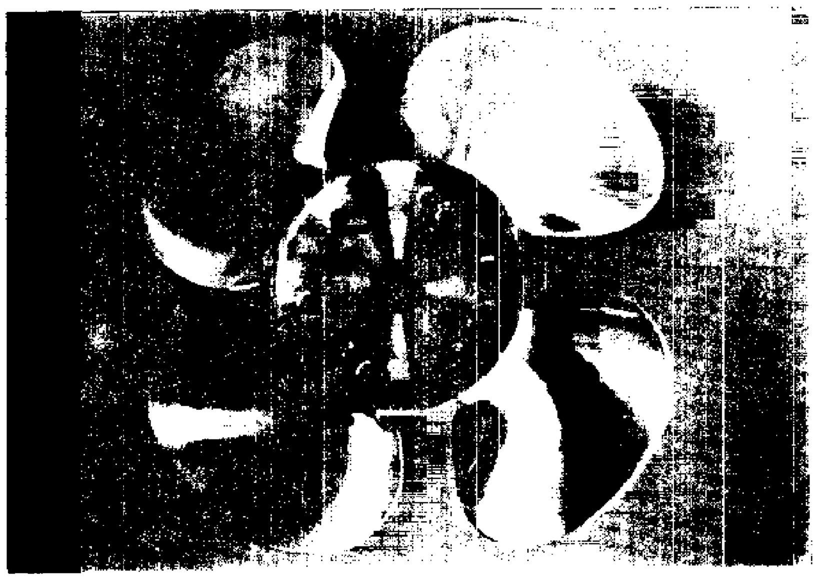


Fig. 9 Controllable Pitch Propeller for
Ice Capable Ship

Ducted propeller should be studied as an effective device for protection of propeller blades from ice impact together with improvement of propulsive performance.

Most of currently operating icebreakers are installed with propulsion system of about 12,000 ps per shaft or below, the maximum being 20,000 ps per shaft of USCG icebreaker POLAR STAR and POLAR SEA (Fig.10). For a large sized ice-going hopper dredge, 30,000 - 40,000 ps per shaft is estimated to be needed. Thus, the design of propulsion system is a challenging theme in the design of a large sized ice-capable hopper dredge for Arctic use.

3-4 INTERACTION BETWEEN ICE AND DREDGING EQUIPMENTS

A hopper dredge is installed with a drag arm system at both sides of ship, which includes dredge pipes, trunnions, intermediate joints, drag heads, and davits with suspension wires for the drag arm. Dredge pipes and suspension wires are generally subject to intermittent load due to impact or jam of ice floes flowing around them. To investigate into the ice impact load on dredge pipes and suspension wires, the model test was conducted in ice tank using the ship model with the spoon shaped bow (Fig.11).

In the investigation, amount of ice floes around dredge pipes, level of impact load and its frequency were examined together with effect of location of dredge pipes, advance speed, yawing angle, ice condition etc. The results are summarized as follows (Table.2 and Fig.12).

(1) Impact loads on dredge pipes decrease, when locating dredge pipe towards the stern. This is due to decrease in number of ice floes flowing around them.
(2) Amount of ice floes around a dredge pipe on the center line of ship's bottom is less than that on dredge pipes on ship's sides.
(3) Impact load on the dredge pipes increases with increase of advance speed and/or ice thickness.
(4) Yawing the model by 11 degrees does not produce a marked change in impact loads on the dredge pipes.
(5) Impact loads obtained in the broken ice floes with 90 percent coverage are of the same order as these in level ice.
(6) Suspension wires scarcely encounter ice floes, if appropriate ice protection device is applied in the area between water line level and ships bottom.
(7) Impact loads on dredge pipes can be minimized by proper choice of their positions.

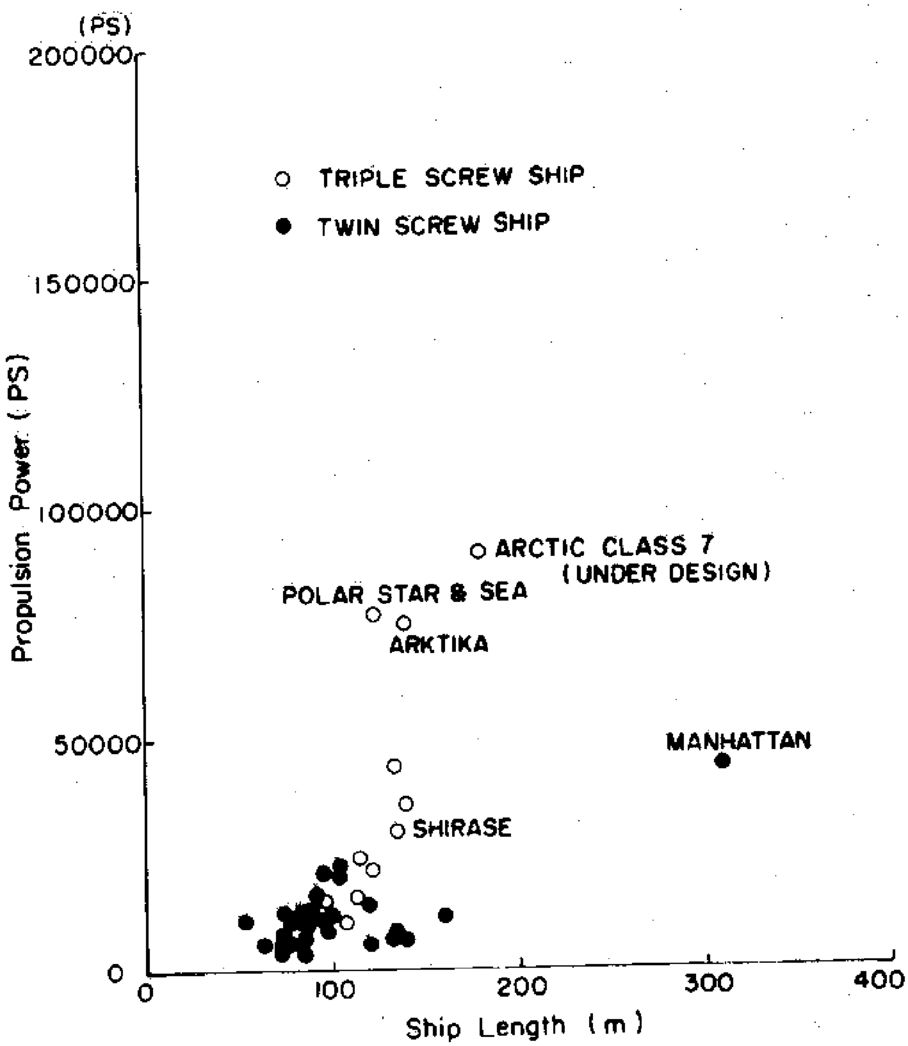


Fig. 10 Propulsion Power for Ice-Capable Ships

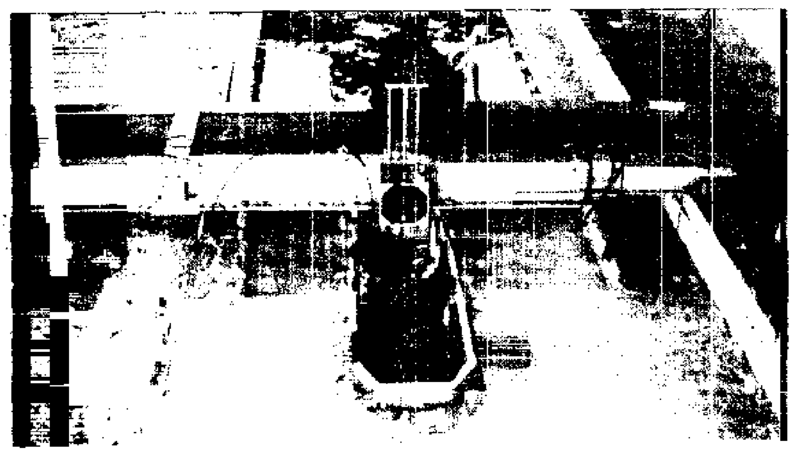
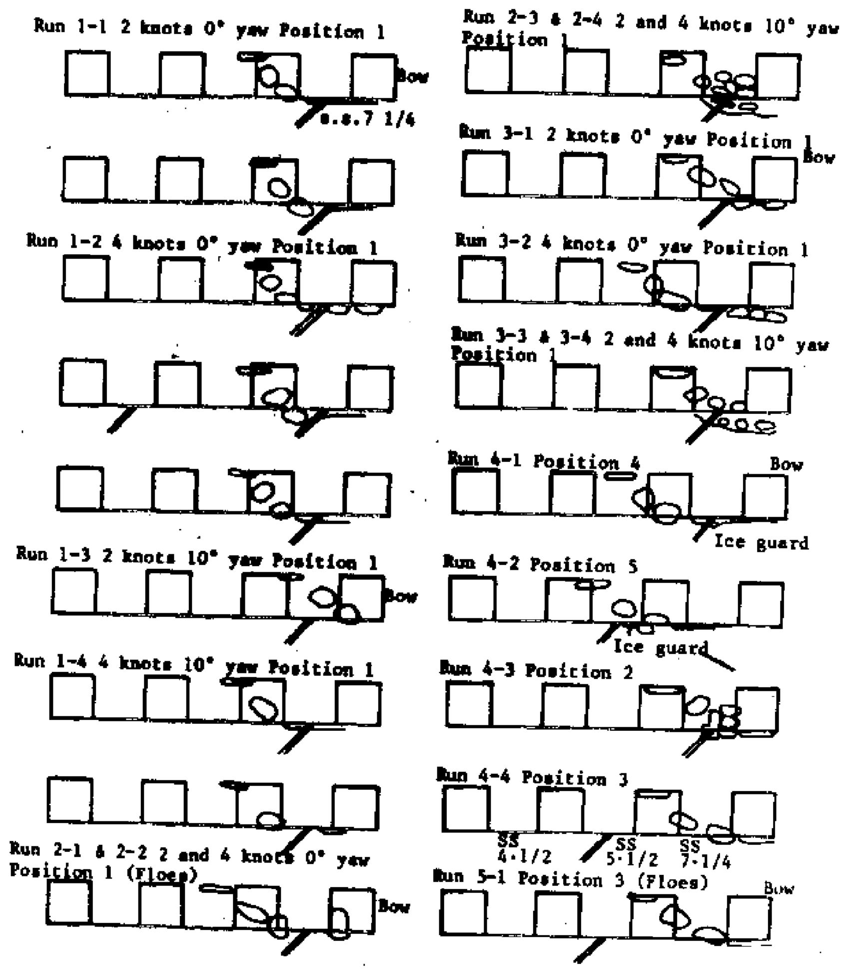


Fig. 11 Model Test in Ice on An Arctic Hopper Suction Dredge

Table 2 Model Scale Test Results

RUN	SPEED m/sec	YAW o	THICK mm	LEVEL/ FLOES	IND. kPa	RESIST-ANCE TOTAL (N)	PORT DRAG ARM			STBD. DRAG ARM		
							(1)N	(2)N	(3)Hz	(1)N	(2)N	(3)Hz
1-1	0.11	0	26	L	21.8	11.3	1.23	2.39	.26	1.43	2.96	.72
1-2	0.22	0	26	L	21.8	11.9	1.94	4.03	.56	2.41	3.89	.50
1-3	0.10	11.1S	26	L	18.3	60.4	1.21	2.07	.11	1.70	3.34	.26
1-4	0.21	11.1S	26	L	25.0	63.9	1.71	3.47	.35	1.57	2.73	.72
2-1	0.13	0	26	F	--	21.0	1.22	2.52	.22	2.31	3.90	.22
2-2	0.23	0	26	F	--	20.5	0.91	2.49	.40	1.28	2.72	.30
2-3	0.13	11.1S	26	F	--	13.4	0.68	1.00	.06	0.79	0.85	.54
2-4	0.23	11.1S	26	F	--	34.7	2.24	4.41	.46	1.05	1.34	.21
3-1	0.12	0	21	L	20.0	20.9	0.60	1.11	.51	0.62	1.03	.38
3-2	0.24	0	21	L	20.3	29.7	1.53	2.24	.23	1.66	2.97	.38
3-3	0.13	11.1P	21	L	12.9	33.1	0.18	1.80	.02	0.41	0.65	.07
3-4	0.24	11.1P	21	L	14.2	39.3	0.44	0.65	.30	0.75	1.01	.44
4-1	0.23	0	21	L	Faulty	39.3	--	--	--	--	--	--
4-2	0.23	0	21	L	19.9	28.8	--	--	--	--	--	--
4-3	0.22	0	21	L	22.3	39.8	3.84	7.59	.49	6.83	8.33	.52
4-4	0.22	0	21	L	18.4	23.7	0	0	0	0	0	0
5-1	0.23	0	21	F	--	24.5	0	0	0	0	0	0
6-1	0.23	0	38	L	NA	71.3	Both Dredge Arms Jammed					
6-2	0.23	0	38	L	30.7	86.4	3.06	5.65	.30	2.93	5.61	.21
6-3	0.22	0	38	L	32.6	82.1	6.52	1.40	.43	10.5	12.5	.46
6-4	0.24	0	38	L	32.8	59.5	--	--	--	--	--	--

NOTES: (1) Average Peak Load (2) Maximum Peak Load (3) Frequency (4) S: Starboard P: Port



Drag Arm Position
Position 1 = Trunnion for drag arm at Square Station 7 1/4
Position 2 = Same as position 1, but with ice guard in front of trunnion
Position 3 = Trunnion for drag arm at Square Station 5 1/2
Position 4 = Drag arm fitted on bottom at Square Station 7 1/4
Position 5 = " " " 5 1/2

Fig. 12 Behavior of Ice Piece around Drag Arm

3-5 HEATING SYSTEM FOR DREDGING EQUIPMENT AND HOPPER

Dredge works in the ice infested water season in the Arctic are conducted under extremely low air temperature. Major parts of dredging equipment, such as, sliding trunnion, joint parts, pivoting parts, davits and sheaves for suspension wires etc. suffer from deterioration of their performance due to icing, freezing and ice adhesion during operation. Thus, some effective heating system is required to maintain dredge works without troubles. Air temperature in hopper should also be kept at least higher than 0°C for discharging a large amount of soil without trouble due to freezing. For this, large amount of heating energy is required. Investigations are necessary for design of reliable and economical heating system, such as thermal oil, steam, exhaust gas etc.

3-6 DEEP WATER DREDGING

In order to dredge soil in the deep water, high powered electric motor driven pumps are often installed to the drag arm to operate it underwater for collecting soil. Reliable supply system of large electric current is needed for the underwater pump. Investigation on the underwater electric cables for Arctic use was made, taking into account the severe Arctic environments, reliability of waterproofing etc. As the result, reliable electric cable for Arctic use was developed as shown in Table.3 and Fig.13.

Drag arm for deep water dredging is much longer than that of the current hopper dredges for shallow water use. In the design of hopper dredge and dredging system, considerations should be made for handling long drag arm, such as, length of hopper dredge, special handling device etc.

3-7 OPERATION PRACTICE

Dredge work by hopper dredge consists of collecting, transporting and discharging soil, while cutter suction dredges have a simpler operation mode. In the open water season, operation practice of dredge work in the Arctic is almost the same as that in the southern areas, except that larger amount of soil is handled to complete construction within the short Arctic summer season. In ice-infested water, several operation modes can be considered to cope with various characteristics of ice.

Table 3 Heat Cycle Test Results for Newly Developed Electric Cable

Test Items	Before Test	Result at 11 atmosphere	Result at -50°C
Insulation Resistance (MΩ.Km) Conductor	15000	11000	7400 at -50°C in air 11000 at -50°C in cooled methanole 14000 at normal temp. 25°C
Earth Wire	10000	5600∿7400	4400 at -50°C in air
Corona Current	Not occurred at 18KV	Not occurred at 18KV Start to occured at 33KV	Not occurred at 18KV
Breakdown Voltage	110KV at termination	Flush-over at 60KV at termination	Directly after raising up to 145KV at termination
Transformation in Structure		Little Transformation of insulation	Nil

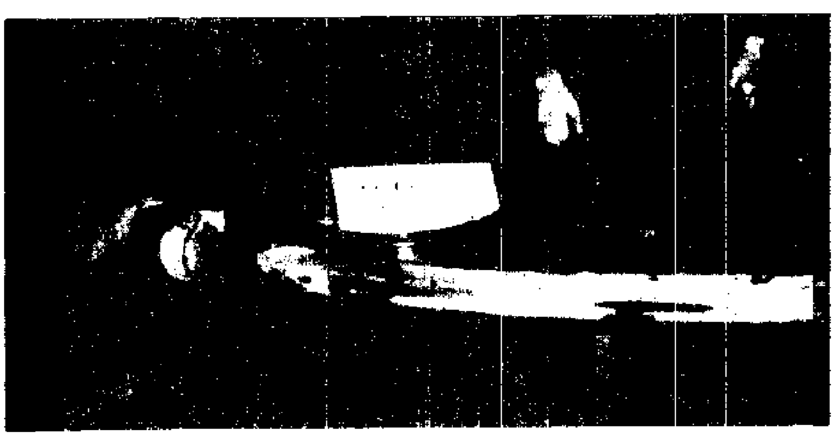


Fig. 13 Bending Test of Electric Cable

(1) Convoy system
Icebreakers support ice-strengthened hopper dredges by clearing waterways out of ice sheets for collecting, transporting and discharging soil, and also for maneuvering.
(2) Large ice-capable hopper dredger
Ice-capable hopper dredgers operate without any icebreaker support.

Capacity of hopper, dredge pumps, propulsion power etc. should be decided, taking into account the size of artificial island to be constructed, water depth, ice conditions, working period etc.

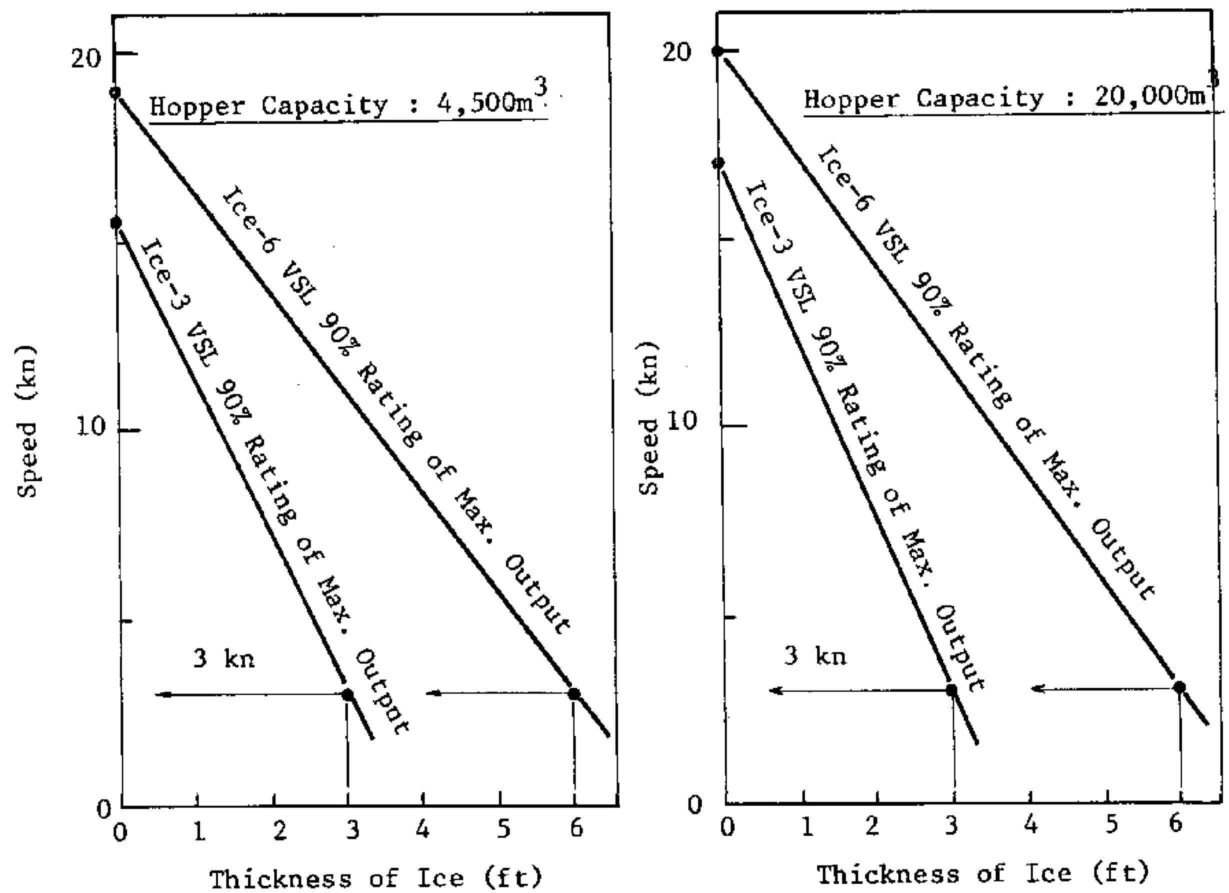
Details of operation practice in the ice infested water should be established on the basis of accumulated experiences of current icebreaker and investigation into operation of drag arms, positioning, discharging etc. under Arctic environments. Some simulation studies are essential to find the most effective dredge system to establish an appropriate operation practice for Arctic use.

4 FEASIBILITY OF ARCTIC HOPPER DREDGE

Feasibility of Arctic hopper dredge in its economic aspect should be examined, taking into account the technical background described in the previous section. Conceptional design of some candidates of dredge was made to evaluate their economy, compared with that of the existing type of dredge. In the design, some conditions and assumptions were applied as follows.

A	Speed in open water	Speed at 90% Maximum output of Main Propulsion Engine
B	Speed in ice	Speed obtained by use of data illustrated in Fig. 14
C	Dredging speed	3 knots
D	Navigation (transporting soil) is made in level ice sheet, while dredging is made in broken ice with 90 percent in coverage after breaking level ice sheet. Ref (Fig.15)	
E	Water depth at the dredging site	30 m
F	Dredging quantity per one cycle	Hopper capacity x 0.6
G	Dredging time (hopper filling time)	1 hour
H	Hopper discharge time average time for damping and pumping out	1 hour
I	Distance between construction site and dredging site	Case-1; 10 s.miles Case-2; 30 s.miles Case-3; 60 s.miles
J	Working hours	20 h/day
K	Working days	20 day/month
L	Seasonal variation of ice condition and corresponding working period	Ref. Fig.16, Fig.17 and Fig.18
M	Resistance in level ice and broken channel floes is predicted by use of Kashetelian's and Rublin's formula respectively.	
N	Troubles of dredge systems due to Arctic environments can be avoided by adopting spoon shaped bow, proper location of dredge pipes, heating system etc.	
O	Propulsion system with output of 20,000ps per shaft is available and that with output of 30,000ps -40,000ps per shaft will be available in the near future.	
P	Two controllable pitch propellers coupled with diesel engines are adopted together with a system of device for effective absorption of variational load on the propellers.	
Q	No support of icebreaker.	
R	Other Assumptions	

Deprociation	:	To be done in 10 years
Interest	:	10% per year
Crew's Expense	:	2 Million Dollars per year
Fuel Expense	:	350 Dollars per unit volume (m^3)
Other Expense	:	0.1 x Price of the Dredge
Price of the Dredge	:	Estimated from the present market price



Progress speed in ice is assumed to be inversely proportional to thickness of ice.

Fig. 14 Progress Speed in Ice

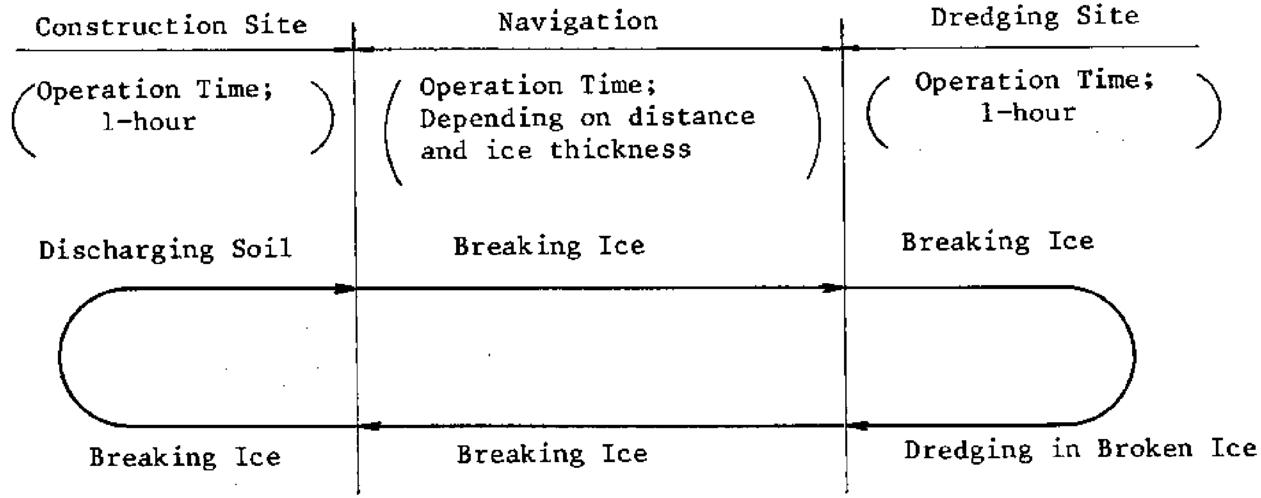


Fig. 15 Assumed Dredging Cycle in Ice

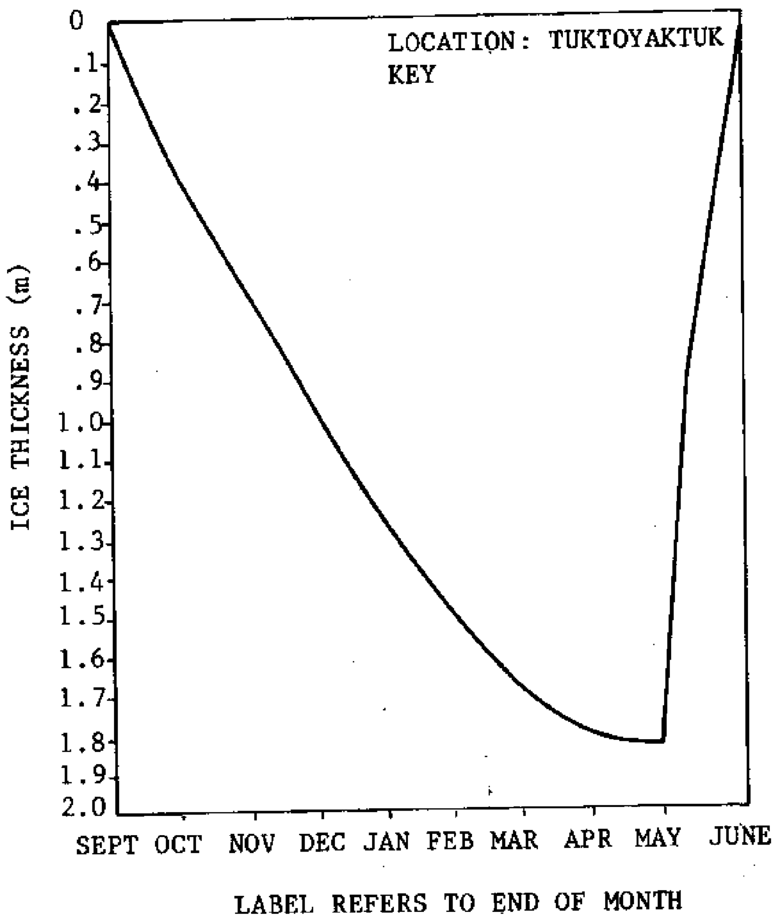
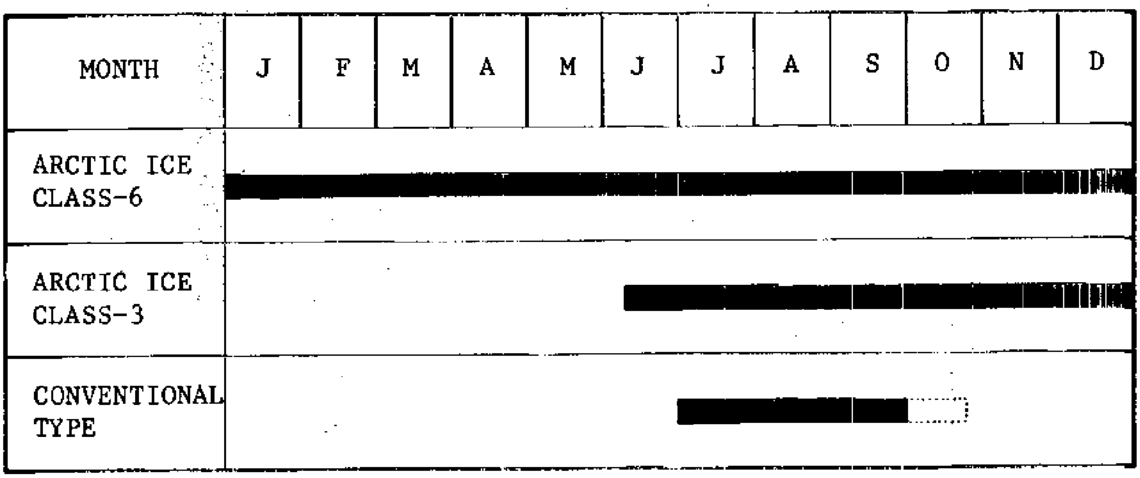


Fig. 16 Seasonal Variation of Ice Thickness

Fig. 17 ASPPR Division of Arctic Zone



Note: Working period of conventional type dredge is assumed as 3 months based on the experience of actual dredge.

Fig. 18 Working Period by ASPPR
(Zone 12 shown in Fig. 17)

Some candidates of hopper suction dredge were designed varying ice-capability and hopper capacity.

Operation cost per unit volume was predicted on the basis of the assumptions above, our accumulated experiences on the existing dredges, and data for cost estimation (Table.4).

Results are illustrated in Fig.19, 20 and 21. It is found that.

(1) dredging cost decreases with increase of hopper capacity.

(2) dredging cost of ice capable hopper dredges is a little lower than that of conventional hopper dredges.

(3) there seems to be nearly optimum hopper capacity or ice capability for Arctic hopper dredge corresponding to the distance between the construction and dredging sites, such as 4,500 m^3 hopper dredge with ice class 3 being nearly optimum for distance 30 and 60 s.mile, and 20,000 m^3 hopper dredge with ice class 6 being nearly optimum for distance 60.

On the basis of the results above economical evaluation of hopper dredge for Arctic use are made for the conditions of required amount of soil and distance between construction and dredging sites being 5,000,000 m^3 and 60 s.miles respectively. (Table-5). It was found that initial investment for large ice-capable hopper dredge is much lower than dredging system composed of small sized conventional type hopper dredges. As the results, a large ice capable hopper dredge may be concluded to be feasible and the economical dredging system for construction of Artificial island in the Arctic.

However, this examination was made on the basis of simplified assumptions. Various factors particular to Arctic environments, operation modes, investment for development of technology, characteristics of each project, various alternatives of the system etc. have to be taken into consideration for more acculate evaluation of economics of Arctic dredge system.

Table-4 Particulars and dredging cost for each type of hopper dredge (1/2)

HOPPER CAPACITY (m^3)		2,000	4,500	4,500	4,500	7,000
TYPE OF VESSEL		CONV.	CONV.	ICE-3	ICE-6	CONV.
DEPRECIATION		10 YEARS				
INTEREST/YEAR		10%				
FEES FOR CREW/YEAR (M.$)		2.0				
GENERAL CHARGE INCLD. MAINTENANCE, SPARE		10% OF INITIAL INVESTMENT				
WORKING HRS/DAY		20				
WORKING DAYS/MONTH		20				
UNIT PRICE OF FUEL OIL		350 ($\$/M^3$)				
DUMPING/PUMPING HRS		1.0				
DREDGING HRS		1.0				
INITIAL INVESTMENT (M.$)		10.0	19.0	32.0	42.0	28.0
APPROX. SIZE						
L, PP (m)		76.0	96.0	112.0	118.0	120.0
B, MLD (m)		15.4	18.4	19.4	19.8	22.6
D, MLD (m)		6.7	9.0	10.2	12.2	10.0
d, MLD (m)		5.5	7.3	8.0	9.1	7.5
PROPULSION ENG. (TOTAL-PS)		3,000	7,000	13,600	48,000	9,600
DREDGING PUMP (m^3/H)		3,600x2	8,100x2	8,100x2	8,100x2	12,600x2
FULL LOAD SPEED AT 90%, RATING		12.0	15.0	15.5	19.0	14.5
DISTANCE	ANNUALLY DREDGED SOIL & OPERATION COST PER UNIT VOLUME					
10-s.m.	SOIL ($1000m^3$)	403	990	1,860	3,250	1,520
	COST ($\$/m^3$)	11.7	7.3	6.3	6.6	6.3
30-s.m.	SOIL ($1000m^3$)	214	557	984	1,740	848
	COST ($\$/m^3$)	22.1	13.0	12.1	13.1	11.4
60-s.m.	SOIL ($1000m^3$)	126	336	580	1,040	510
	COST ($\$/m^3$)	37.7	21.6	20.8	22.7	19.1

Table-4 Particulars and dredging cost for each type of hopper dredge (2/2)

HOPPER CAPACITY (m^3)		20,000	20,000	20,000	30,000
TYPE OF VESSEL		CONV.	ICE-3	ICE-6	CONV.
DEPRECIATION		WITHIN 10 YEARS			
INTEREST/YEAR		10%			
FEES FOR CREW (M.$)		2.0			
GENERAL CHARGE INCLD. MAINTENANCE, SPARE		10% OF INITIAL INVESTMENT			
WORKING HRS/DAY		20			
WORKING DAYS/MONTH		20			
UNIT PRICE OF FUEL OIL		350 ($\$/M^3$)			
DUMPING/PUMPING HRS		1.0			
DREDGING HRS		1.0			
INITIAL INVESTMENT (M.$)		75.0	125.0	166.0	112.0
APPROX. SIZE					
L, PP (m)		162.0	178.0	182.0	190.0
B, MLD (m)		31.0	31.0	33.0	36.0
D, MLD (m)		15.4	17.8	20.0	18.0
d, MLD (m)		11.0	12.5	14.0	13.0
PROPULSION ENG. (TOTAL-PS)		20,000	26,000	86,000	26,000
DREDGING PUMP (m^3/H)		36,000x2	36,000x2	36,000x2	54,000x2
FULL LOAD SPEED AT 90%, RATING		15.0	17.0	30.0	15.2
DISTANCE	ANNUALLY DREDGED SOIL & OPERATION COST PER UNIT VOLUME				
10-s.m.	SOIL (1000m^3)	4,400	8,560	14,700	6,630
	COST ($\$/m^3$)	5.0	4.3	4.1	4.8
30-s.m.	SOIL (1000m^3)	2,480	4,630	7,970	3,740
	COST ($\$/m^3$)	9.0	8.0	7.8	8.5
60-s.m.	SOIL (1000m^3)	1,490	2,720	4,780	2,260
	COST ($\$/m^3$)	14.9	13.5	13.3	14.1

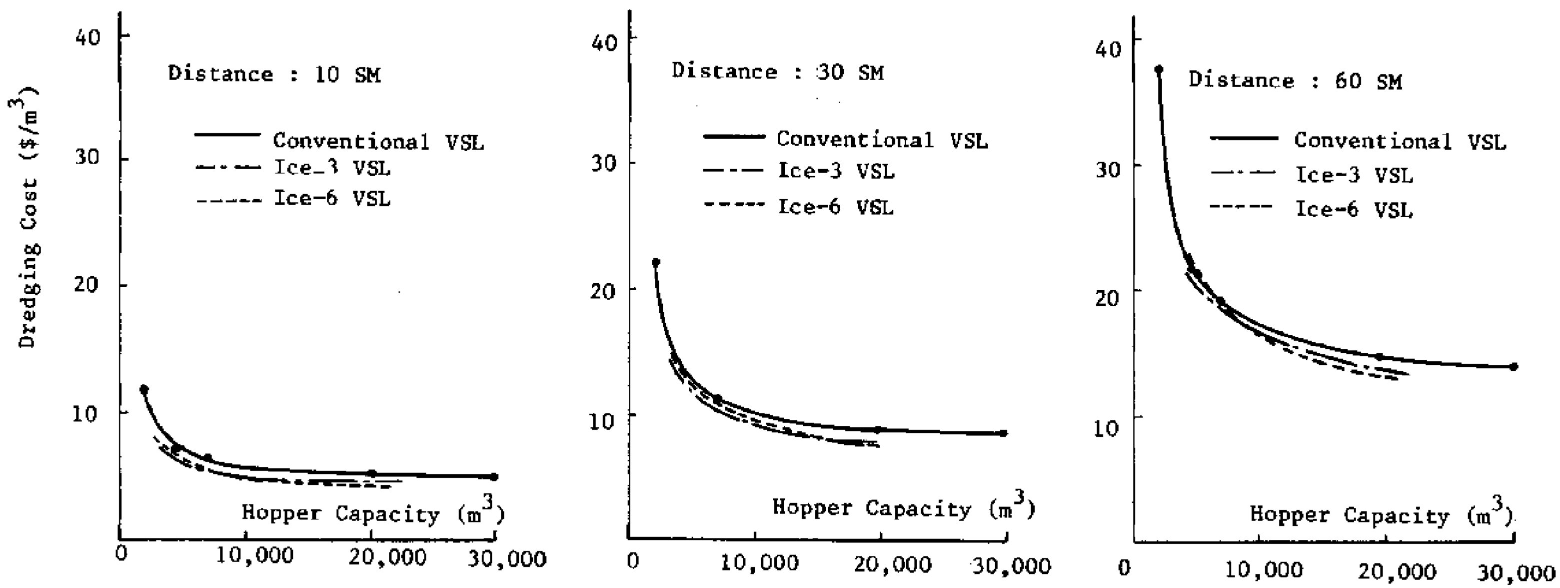


Fig. 19 Dredging Cost v.s. Hopper Capacity

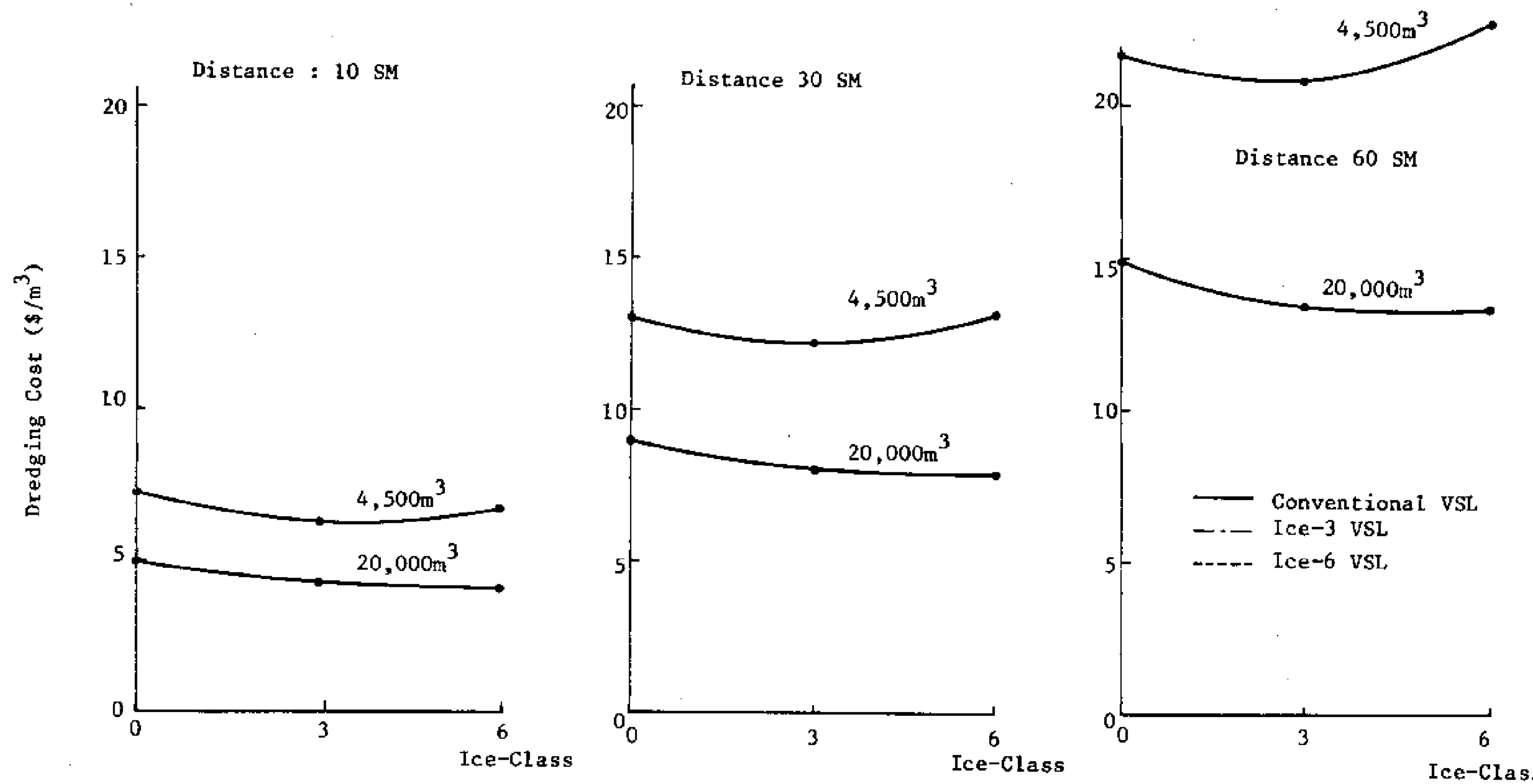


Fig. 20 Dredging Cost v.s. Ice Capability

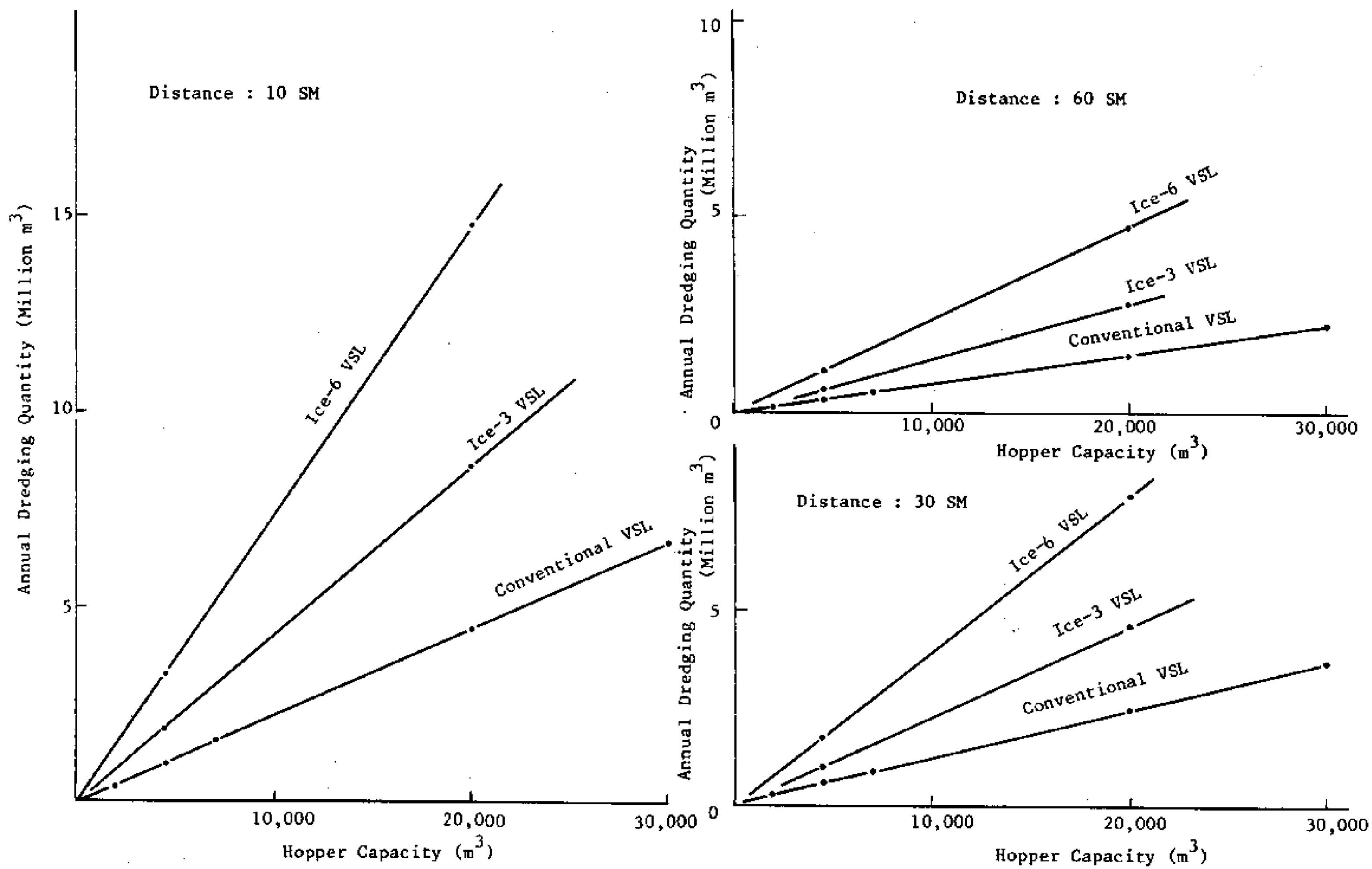


Fig. 21 Annual Dredging Quantity v.s. Hopper Capacity & Ice Capability

Table-5 Economic Aspect of Arctic Hopper Dredge

Type of Hopper Dredge	Hopper Capacity	Required No. of Dredges	Initial Investiment	Dredging Cost	Total Dredging Cost
Conventional Type	7,000 m^3	10	290 M$	19 $/$m^3$	9500 M$
	13,200 m^3	5	255 M$	16 $/$m^3$	8000 M$
	22,400 m^3	3	252 M$	14.5 $/$m^3$	7250 M$
Arctic Ice Class 3	7,500 m^3	5	250 M$	18 $/$m^3$	9000 M$
	12,200 m^3	3	234 M$	15.6 $/$m^3$	7800 M$
	18,000 m^3	2	226 M$	14 $/$m^3$	7000 M$
Arctic Ice Class 6	7,000 m^3	3	180 M$	19 $/$m^3$	9500 M$
	10,500 m^3	2	180 M$	16.2 $/$m^3$	8100 M$
	21,000 m^3	1	174 M$	13.2 $/$m^3$	6600 M$

Assumption (1) Required dredging quantity per year: 5 Mm^3

(2) Distance between dredging and construction site: 60 sea miles

(Remark) 7000 m^3 Hopper Dredge (conventional type) is the max. size working in the Arctic Region at the present time.

5 CONCLUDING REMARKS

As exploration in the Arctic extends to deeper water, larger amount of soil is required for construction of an artificial island. Since the existing types of dredge can work only within the open water season in the short Arctic summer, it is desired to extend dredging period into ice-infested water season by proper maintenance and support of powerful icebreakers, and by commissioning in service some advanced ice-capable hopper dredges. In this paper, present state of technical aspects of hopper dredge was examined on the basis of experimental investigation, engineering studies, economic evaluation, available materials and our accoumulated experiences on existing dredge systems. Conceptional design of some candidates of hopper dredger showed that some type of hopper dredges are feasible under Arctic environments. However, results are still inconclusive. Further investigations are necessary to design the reliable and economical hopper dredging system for Arctic use.

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Mr. E. Kitami	General Manager of Ocean Engineering Center, Hiroshima Shipyard MHI

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Professional Affiliations:	° Member of the Royal Institute of Naval Architects Member of the American Society of Naval Engineers Member of the Society of Naval Architects and Marine Engineers (Founding Chairman, Arctic Section of S.N.A.M.E.)
Publications:	° Numerous papers and articles published, Arctic offshore engineering and icebreaker technology.

TECHNIQUES TO REDUCE THE SEDIMENT RESUSPENSION CAUSED BY DREDGING

by
Captain Gene L. Raymond[1]

INTRODUCTION

Background

During the last 100 years, the sediments of the Nation's waterways have increasingly become repositories for a variety of contaminants. This contamination is a result of river commerce, industrial activities, widespread use of pesticides in agriculture, and intentional or inadvertent dumping of pollutants. Regardless of the source of pollution, today's dredging activities frequently must be conducted within this contaminated environment. However dredging equipment and practices in the United States evolved in an era when the major emphasis was to achieve the greatest possible economic returns through maximizing production, with only secondary consideration given to environmental impacts. As a result, conventional dredges are not specifically designed for operation in highly contaminated sediments. Therefore, some modification of either existing equipment or operating methods may be necessary when dredging highly contaminated sediments.

Sediments become contaminated because of the affinity of contaminants, particularly chlorinated hydrocarbon pesticides and PCBs, for the clay-sized particles and natural organic solids found in most river sediments. When sediments are disturbed, such as during dredging operations, contaminants may be transferred to the water column either through resuspension of the sediment solids, dispersal of interstitial water, or desorption from the resuspended solids. Investigations by Fulk, Gruber, and Wullsheleger (1975) showed that, for sediment concentrations of less than 100 g/ℓ, the amount of pesticides and PCBs that are dissolved or desorbed into the water column from the resuspended sediment is negligible. They determined that basically all contaminants transferred to the water column were due to the resuspension of solids. Conversely, they reported that the reduction of suspended solids concentrations due to settling resulted in a decrease in contaminant concentrations. The spread of contaminants during dredging operations then is linked to the resuspension of sediments, particularly clay-sized and organic particles.

In addition to the concern of conducting dredging operations in contaminated sediments, Federal, state, and local environmental regulatory agencies have set standards for the resuspension of sediments

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in general. The resuspension of sediments is usually referred to in the regulations as turbidity, which is an optical term describing the cloudy appearance of water. Regulatory standards for turbidity are usually motivated by a concern for the suspected effects of suspended material on aquatic plants or animals.

Purpose and Scope

The Waterways Experiment Station (WES) has initiated studies to determine the relative effectiveness of various methods of dredging contaminated sediments. These studies are being conducted as part of the Improvement of Operation and Maintenance Techniques (IOMT) Research Program. The specific environmental concerns addressed include resuspension of contaminated sediments and the possibility of contaminant release during the dredging operation. Although specific dredging operations involving contaminated sediments have been monitored by various Corps offices and governmental regulatory agencies, data are not available on a national basis to allow the prediction of the impact of the operation of a specific dredge in a given situation.

This question of dredging in contaminated sediments is being addressed in three ways: the assembly and evaluation of available domestic and foreign information concerning sediment resuspension and contaminant release, the development of appropriate laboratory tests to predict contaminant release from resuspended sediments, and the use of field studies to monitor performance and compare dredges operating under various conditions. The purpose of this paper is to present findings from this research effort. It will discuss the sediment resuspension characteristics of various dredges, provide a comparison between dredge types with respect to sediment resuspension and water column effects, and present methods for limiting the sediments resuspended by various dredges. This report is based on an extensive review of foreign and domestic information on sediment resuspensions due to dredging and on the results of field studies conducted under the IOMT program.

SEDIMENT RESUSPENSION FROM DREDGING

Nature of Suspended Sediment

Investigations by Wechsler and Cogley (1977) found that the material resuspended during dredging consists primarily of silt, clay, and organics. This resuspended material is generally referred to as turbidity. While turbidity, which describes an optical property of water, can give an indication of the extent of sediment resuspension, it cannot be used to quantitatively describe the amount of resuspended sediments. Turbidity cannot be consistently correlated with weight concentration of suspended matter because the optically important factors of size, shape, and refractive index of the particulate materials bear little relationship to the concentration and specific gravity of the suspended matter. Turbidity cannot be used to tell which grain sizes contribute most to the resuspension problem. Therefore, whenever possible comparison of dredge resuspension will be made in terms of suspended solids as determined by gravimeteric analysis.

Wechsler and Cogley (1977) reported that the coarse-grained fractions (>74μ) settle rapidly under normal conditions of water turbulence and thus do not contribute significantly to the turbid appearance of water. Silt comprises the nonclay mineral fraction of sediment and has a grain size of 2-74μ. Although silt particles, with settling rates as low as 1 cm/hr, may contribute to turbidity, in most cases the clay fraction and the organic matter are mainly responsible for the turbid appearance of water in the vicinity of dredging operations.

Extensive reviews of the literature concerning sediment resuspension caused by dredging were conducted by Barnard in 1978 and more recently by Herbich and Brahme (in press). They found that most conventional dredges create low-solids-concentration plumes of silt- and clay-sized particles or small flocs that settle through the water column at very slow rates. Although the solids concentration in the water column in the vicinity of the dredging operation usually does not exceed several hundred milligrams per liter (mg/ℓ), the particles continue to settle until the solids concentration near the bottom can exceed 10 grams per liter (g/ℓ). Barnard (1978) referred to this level of solids concentration (0 to 10 g/ℓ) as turbidity (Figure 1). Higher concentrations take on the properties of fluid mud. Barnard noted that the nature, degree, and extent of sediment resuspension are controlled by many factors, including characteristics of the sediment, hydrologic regime, and hydrodynamic forces.

Characteristics of Various Dredges

In addition to the characteristics of sediments that contribute to resuspension, different types of dredges generate different levels of resuspended sediment. Both the type of equipment and the operating techniques used with the equipment are important. This section will discuss some of the commonly used dredges and their potential for causing sediment resuspension during operations.

Cutterhead dredges. The cutterhead dredge is basically a hydraulic suction pipe combined with a cutter to loosen material that is too consolidated to be removed by suction alone (Figure 2). This combination of mechanical and hydraulic systems makes the cutterhead one of the most versatile and widely used dredging systems; however, its use also increases the potential for sediment resuspension. While a properly designed cutter will cut and guide the bottom material toward the suction efficiently, the cutting action and the turbulence associated with the rotation of the cutter resuspend a portion of the bottom material. The level of sediment resuspension is directly related to the type and quantity of material cut but not picked up by the suction. The ability of the dredge's suction to pick up bottom material determines the amount of cut material that remains on the bottom or is resuspended.

While little experimental work on cutterhead resuspension has been done, there have been several field studies that attempted to identify

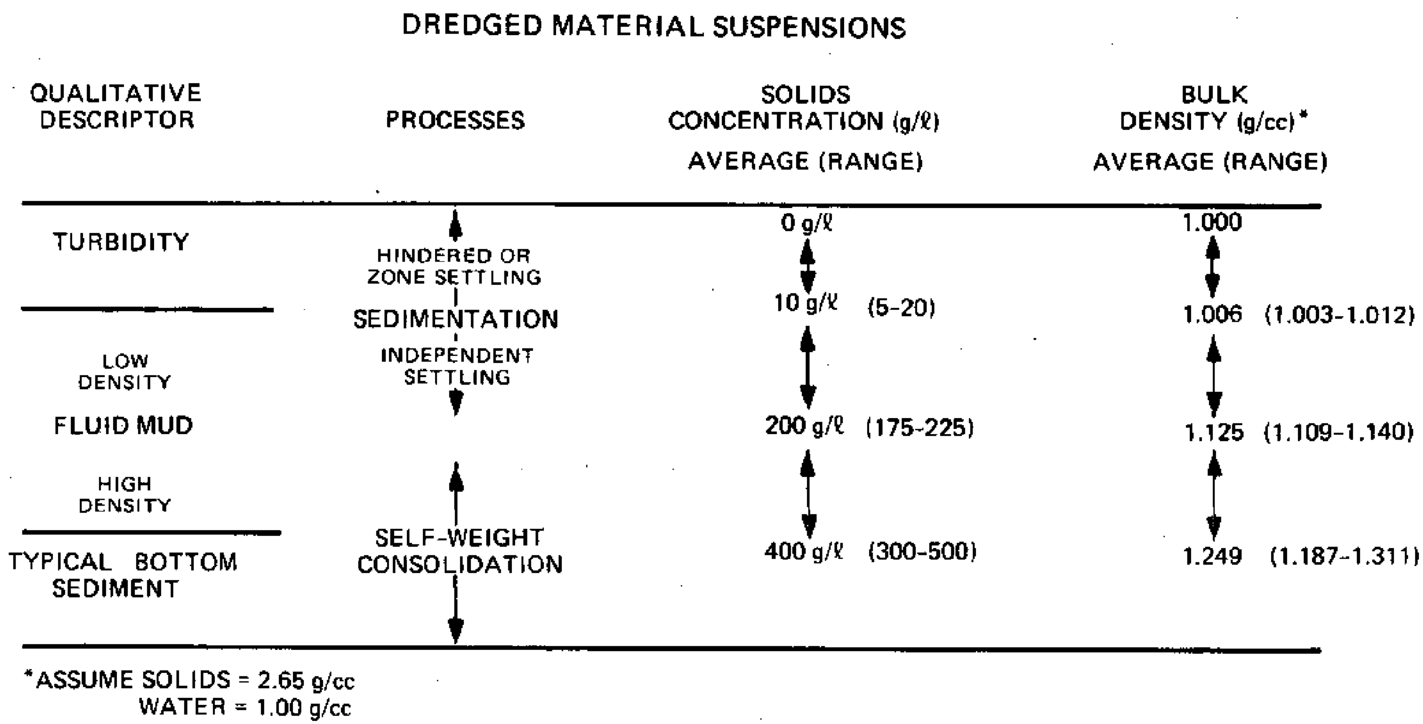

Figure 1. Characteristics of suspended solids in the water column in the vicinity of dredging operations (Barnard, 1978).

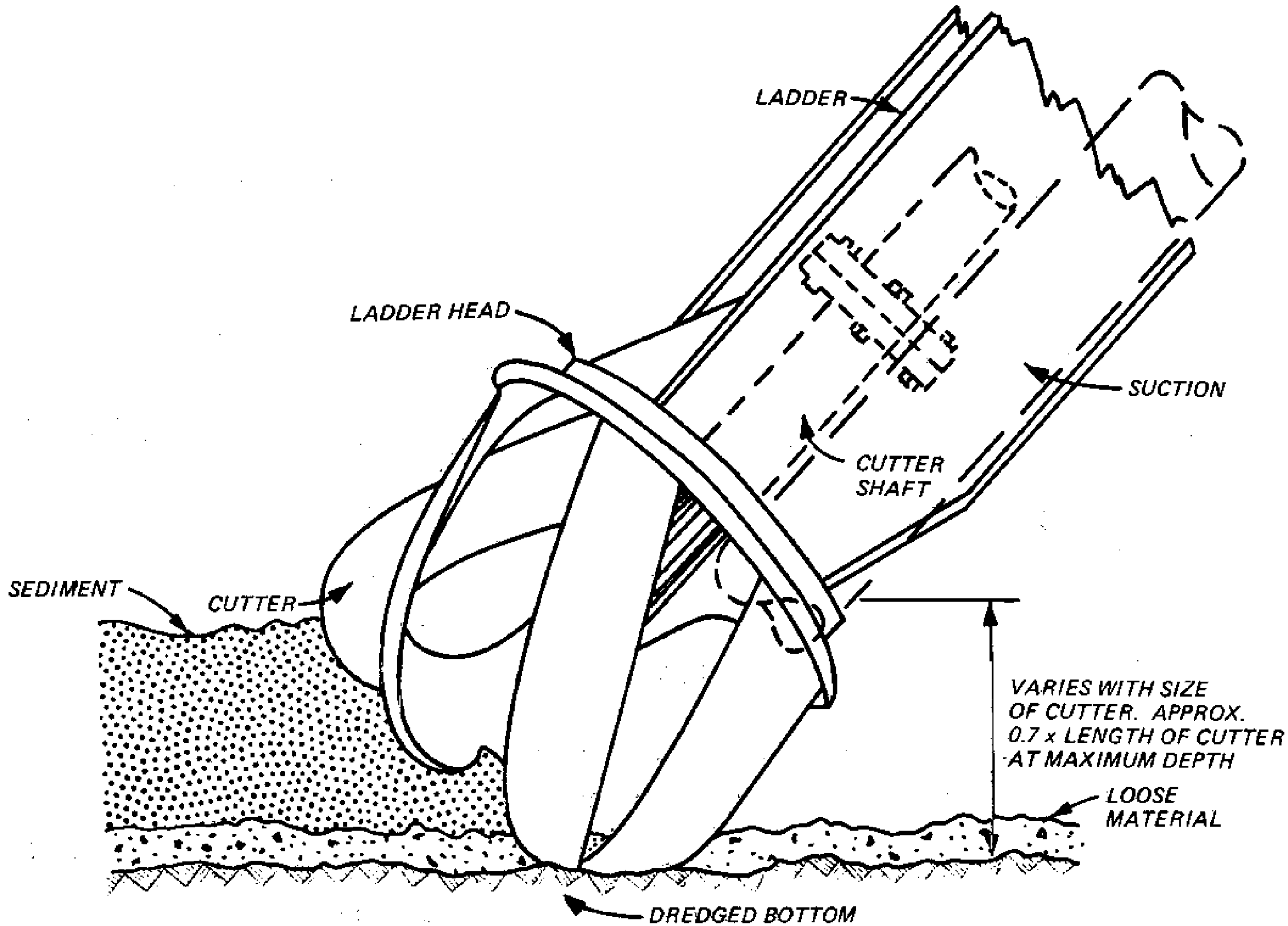

Figure 2. Cross-sectional view of typical cutterhead suction dredgehead.

the extent of cutterhead resuspension. Barnard (1978), reporting on the field investigations of Huston and Huston (1976) and Yagi, et al. (1975), stated that, based on the limited field data collected under low-current speed conditions, elevated levels of suspended material appear to be localized in the immediate vicinity of the cutter as the dredge swings back and forth across the dredging site. Within 10 ft of the cutter, suspended solids concentrations are highly variable, but may be as high as a few tens of grams per liter; these concentrations decrease exponentially with depth from the cutter to the water surface. Near-bottom suspended solids concentrations may be elevated to levels of a few hundred milligrams per liter at distances of 1000 ft from the cutter.

Recent field tests and literature reviews by WES have found cutterhead resuspension to actually be substantially less than discussed by Barnard. Sediment resuspension in the vicinity of the cutter has seldom been found to exceed 1000 mg/ℓ. Figure 3 is a schematic representation of average suspended sediment values observed during an 18 inch cutterhead operation in the James River (Raymond, in preparation). These values are a four day average, and represent the actual suspended sediment levels, as determined by gravimeteric analysis, less the background suspended sediment levels for the appropriate depth and current speed. Therefore, a value of zero means there is no increase above background, not that the level of suspended sediment is zero. This figure highlights several characteristics of cutterhead dredges. First, as pointed out by Barnard (1978) and Herbich and Brahme (in press), and suggested by intuition, depth has an important correlation to suspended sediment level. Secondly, even though the plume of resuspended material has its source at the bottom, some material appears to move upward surprisingly fast. This upward movement is probably connected to action of the cutter. Finally, the effect of the different average ambient current speeds can be seen. The ebbs higher current speed appears to propel the resuspended sediments higher in the water column, thus making the overall average suspended sediment values higher for the ebb than the flood. The average suspended sediment values of the flood and ebb respectively for the upper water column (20 ft level and above) are 11 mg/ℓ and 37.5 mg/ℓ. This difference is significant at the 95% confidence level. Apparently the effects of dredging in higher current speeds will be magnified over that of lower current speeds. This is surprising since the data just presented were "normalized" for background suspended sediment level and as such should not show a difference between ebb and flood. This difference suggests that some other current effect exists. It appears that for current speeds in the 2 fps range the sediment is sufficiently hindered to prevent the "normal" settling that might occur at the lower current levels. This effect cannot be confirmed in the lower water column however.

Hopper dredges. Hopper dredges are used mainly for maintenance dredging in harbor areas and shipping channels where traffic and operating conditions rule out the use of stationary dredges. As the dredge

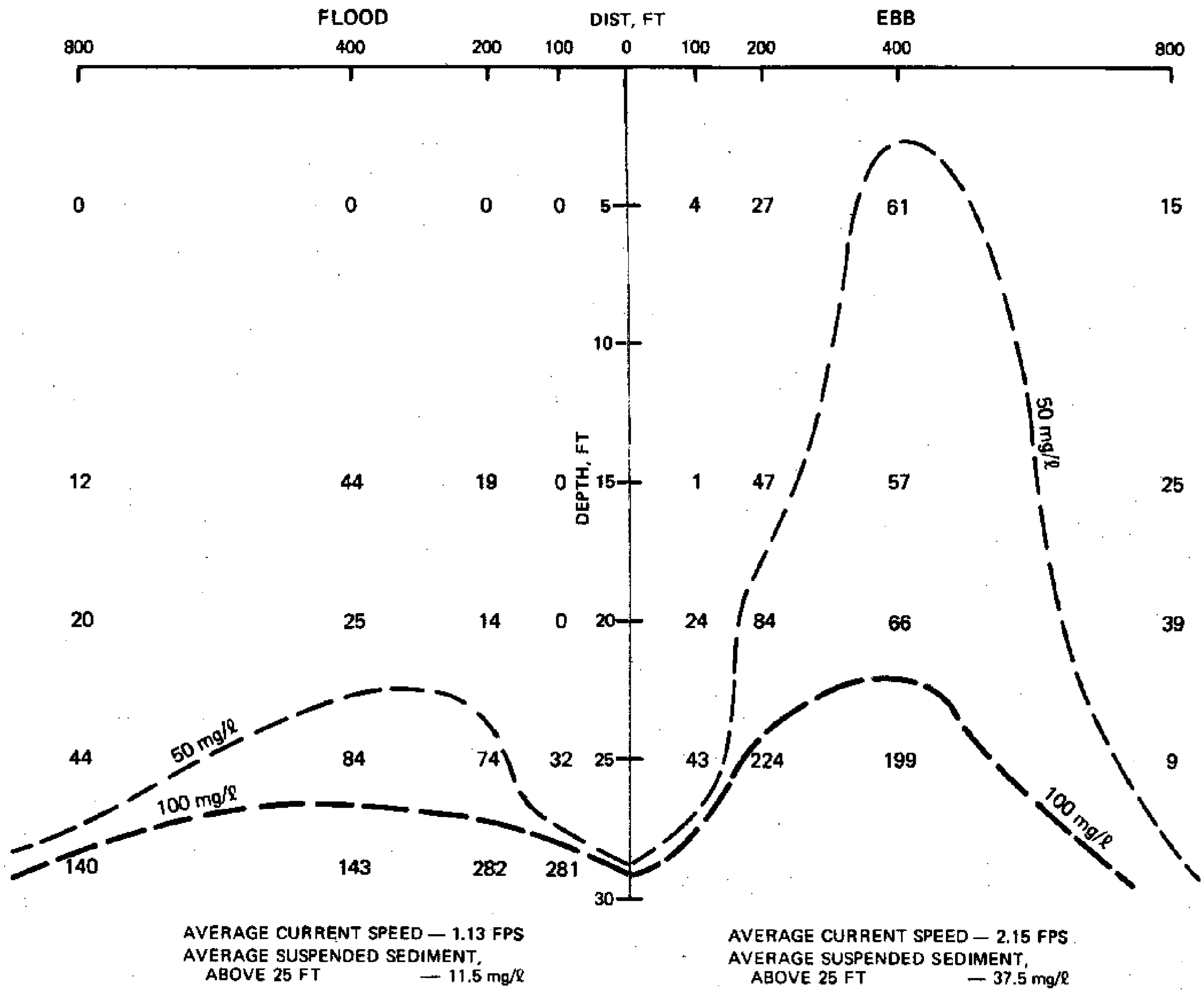

Figure 3. Schematic representation of average suspended sediment value for indicated depths and distances, James River Cutterhead Test (Raymond, in preparation).

moves forward, the bottom sediment is hydraulically lifted from the channel bottom with a draghead, transported up the dragarm (i.e., trailing suction pipe), and temporarily stored in hopper bins in the ship's hull. Most modern hopper dredges have one or two dragarms mounted on the side of the dredge and have storage capacities ranging from several hundred to over 12000 cu yd. During the filling operation, pumping of the dredged material slurry into the hoppers is often continued after the hoppers have been filled in order to maximize the amount of high-density material in the hopper. The low-density turbid water at the surface of the filled hoppers then overflows and is usually discharged through ports located near the waterline of the dredge. Resuspension of fine-grained sediment during hopper dredge operations is caused by the dragheads as they are pulled through the sediment, turbulence generated by the vessel and its prop wash, and overflow of turbid water during hopper filling operations.

Field data confirm that the suspended solids levels generated by a hopper dredge operation are primarily caused by hopper overflow in the near-surface water and draghead resuspension in near-bottom water. In the immediate vicinity of the dredge, a well-defined upper plume is generated by the overflow process and a near-bottom plume by draghead resuspension; 900 to 1200 ft behind the dredge, the two plumes merge into a single plume (Figure 4). As the distance from the dredge increases, the suspended solids concentration in the plume generally decreases, and the plume becomes increasingly limited to the near-bottom waters. Suspended solids concentrations may be as high as several tens of grams per liter near the discharge port and as high as a few grams per liter near the draghead. Suspended sediment levels in the near-surface plume appear to decrease exponentially with increasing distance from the dredge due to settling and dispersion, and the levels quickly reach concentrations of less than 1 g/ℓ. However, plume concentrations may exceed background levels even at distances in excess of 3600 ft (Barnard 1978).

Bucket dredges. The bucket dredge consists of various types of buckets operated from a crane or derrick mounted on a barge or on land. It is used extensively for removing relatively small volumes of material, particularly around docks and piers or within restricted areas. The sediment removed is at nearly in-situ density; however, the production rates are quite low compared to that for a cutterhead dredge, especially in consolidated material. The dredging depth is practically unlimited, but the production rate drops with increases in depth. The bucket dredge usually leaves an irregular, cratered bottom. The resuspension of sediments during bucket dredging is caused primarily by the impact, penetration, and withdrawal of the bucket from the bottom sediments. Secondary causes are loss of material from the bucket as it is pulled through the water, spillage of turbid water from the top and through the jaws of the bucket as it breaks the surface, and inadvertent spillage while dumping.

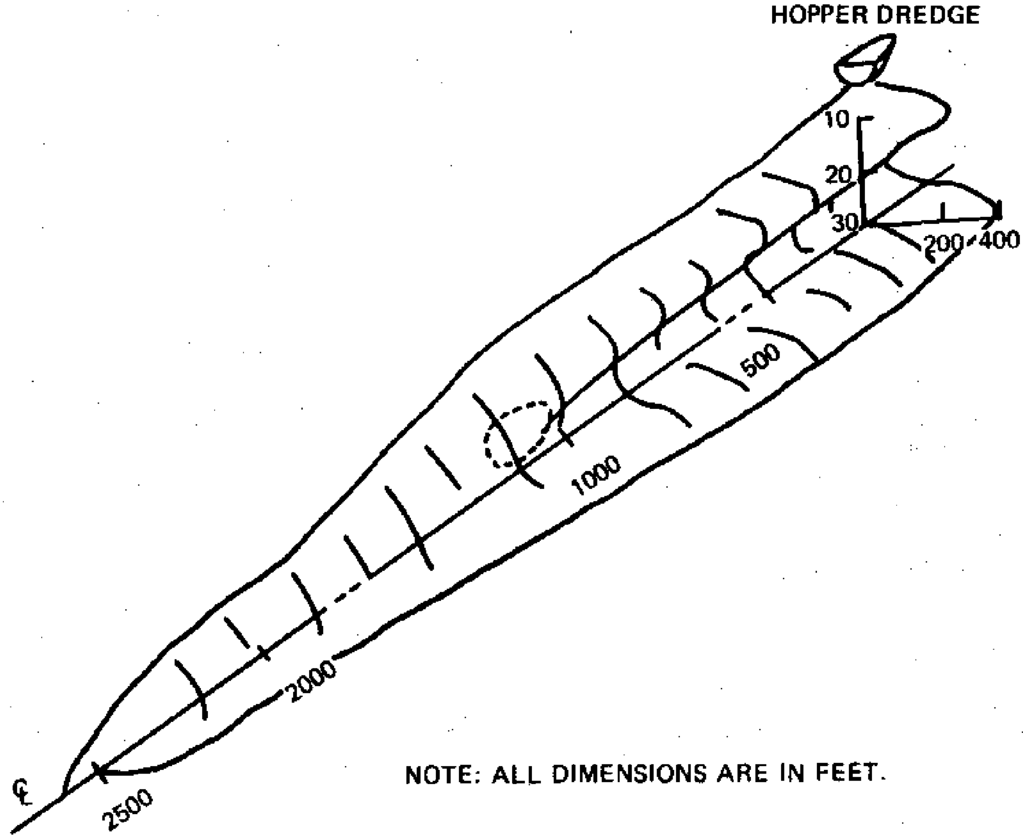

Figure 4. Postulated double plume resulting from hopper dredge operations.

Limited field measurements of sediment resuspension caused by bucket dredges showed that the plume downstream of a typical clamshell operation may extend approximately 1000 ft at the surface and 1500 ft near the bottom. It was also observed that the maximum suspended sediment concentration in the immediate vicinity of the dredging operation was less than 500 mg/ℓ and decreased rapidly with distance from the operation due to settling and mixing effects (Barnard, 1978). Field studies concluded by WES in the St. Johns River around a 13 cubic yard clamshell bucket operation show the effect of the clamshell bucket on the water column (Raymond, in press). Figure 5 shows the sample location and radials used to collect the sediment resuspension data. Figure 6 is a schematic representation of the data collected along radials one and two. The suspended sediment values were determined by gravimeteric analysis and have had the background values deducted. The current speeds were low, with no difference between radials. Radial three is not shown since it represents a more shallow, backwater type area. Here again we see that the greater sediment resuspension is at the bottom. However, elevated levels of suspended sediment reach almost to the surface, as shown by the 50 mg/ℓ line, even under low current conditions.

Dustpan dredges. The dustpan dredge is a hydraulic suction dredge that uses a widely flared dredgehead along which water jets are mounted. The jets loosen and agitate the sediments, which are then captured in the dustpan head as the dredge moves forward. This type of dredge works best in free-flowing granular material and is not suited for use in fine-grained clay sediments. During 1982, an experiment was conducted using a modified dustpan head (without water jets) to dredge the fine-grained sediments of the James River. It was hoped that the dustpan head, using suction only, could excavate thin layers of contaminated clay sediment with less resuspension than a cutterhead. However, the dustpan head experienced repeated clogging and produced at least as much resuspension as a cutterhead operating in the same material (Raymond in preparation).

Dredge Comparison

When planning a dredging operation, the project engineer may be faced with the problem of selecting the best dredge based on the cost and availability of different dredges, the operating conditions at the project site, the material to be dredged, the job specifications, and various environmental considerations. Since each dredging/disposal project is site specific, a dredge that might be ideal in one situation may not be suitable for another. The production rate of a given dredge relative to the levels of turbidity that may be generated, the duration of the project, and the background levels of suspended sediment and contamination should all be considered when evaluating the potential impact of different sizes and types of dredges. The effect of current speed has already been shown.

It is important to remember that a sophisticated and expensive dredging system will not necessarily eliminate all sediment

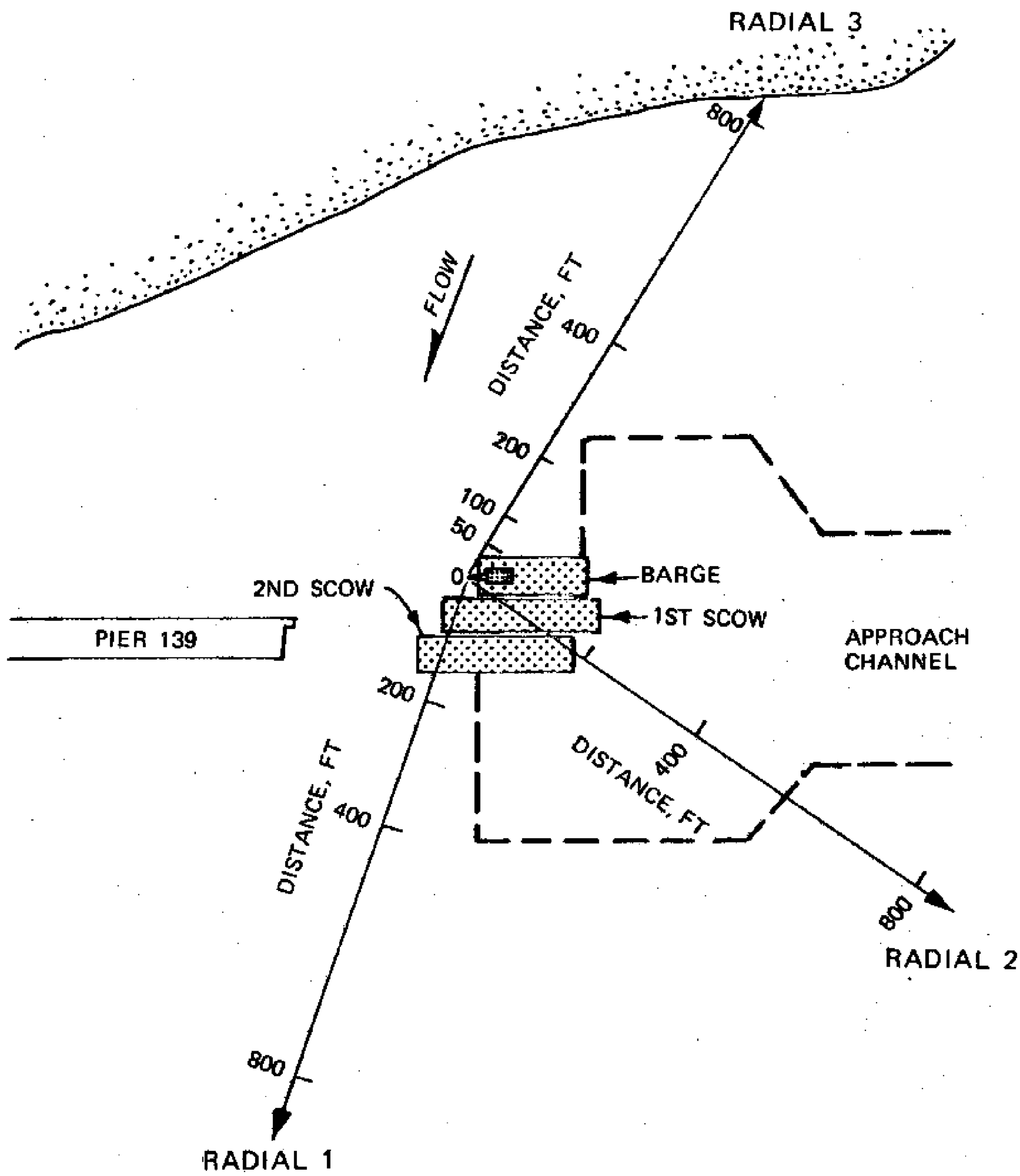

Figure 5. Location of radials and sample points along the radials used for the Jacksonville clamshell comparison test (Raymond, in press).

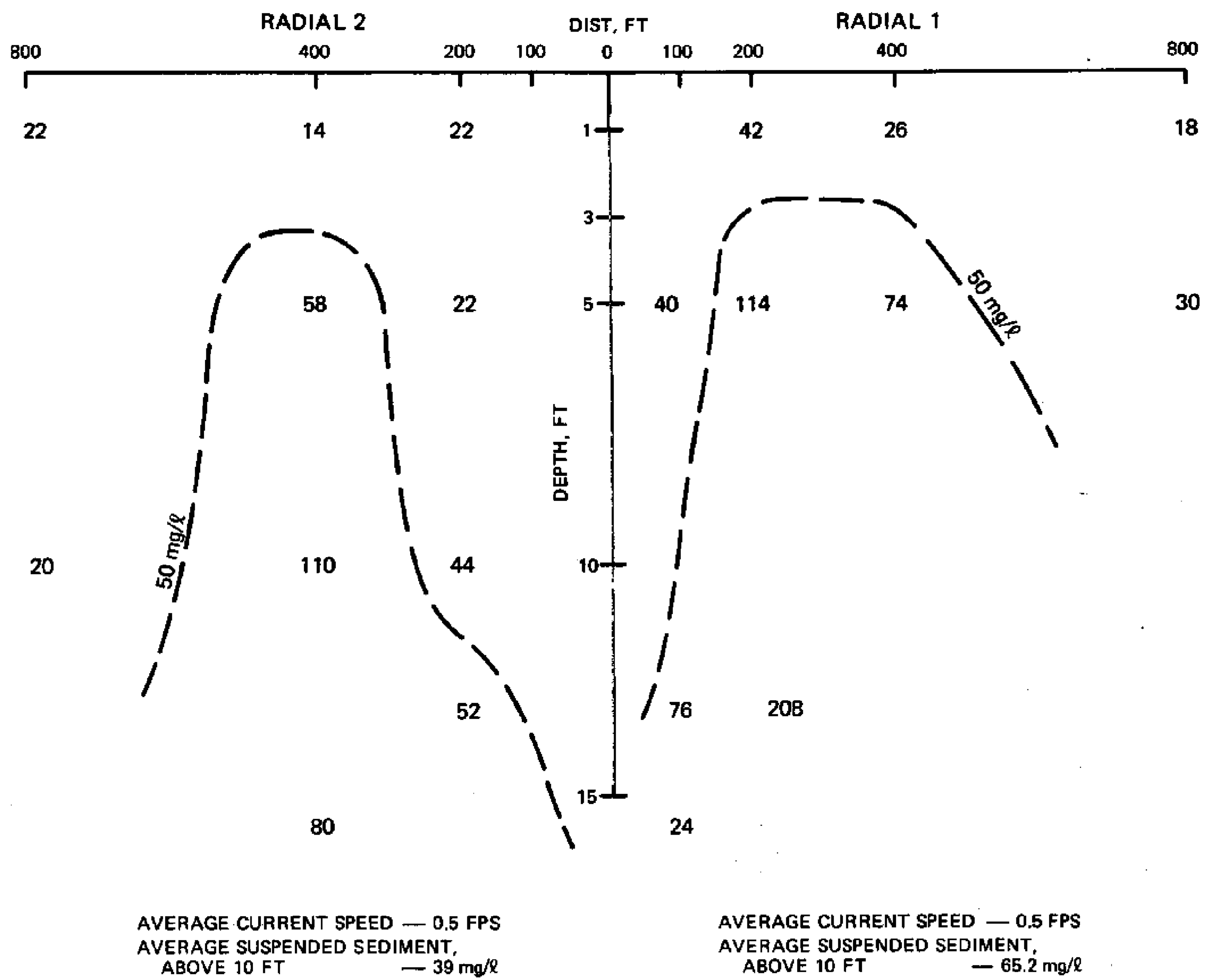

Figure 6. Schematic representation of average suspended sediment levels for indicated distance and depths, Jacksonville clamshell comparison (Raymond, in press).

resuspension. In addition, it is imperative to concurrently consider the compatibility of all the phases of the dredging operation (excavation, transportation, treatment, and disposal) as a total integrated system and not as separate components. The relative impact of each operation must be objectively evaluated relative to its cost and overall benefits.

The results of field studies may provide some insight into dredge selection when limiting sediment resuspension is an important factor. Barnard (1978), quoting Wakeman, Sustar and Dickson (1975), states "the cutterhead dredge seems to have the least effect on water quality during the dredging operation. This is followed by the hopper dredge without overflow. The clamshell dredge and hopper dredge during overflow periods both can produce elevated levels of suspended solids in the water column." Herbich and Brahme (in press), discussing Japanese comparisons of the sediment resuspension potential of different dredges operating in clay, found that the trailing suction dredge (without overflow) and the cutterhead dredge had a similar resuspension potential, while the clamshell dredge was determined to produce about two and a half times as much resuspension. Field test conducted by Raymond (in press) also support this ranking. The following tabulation of Raymond's test results summarizes the effects of a clamshell bucket dredge and a cutterhead dredge operating in similar fine-grained sediments. These data were normalized with respect to their background levels of suspended

Resuspended Sediment, mg/ℓ

Dredge Type	Upper Water Column	Near Bottom
Cutterhead	34.6	133.5
Clamshell	105.9	134.3

sediment and represent the average of all samples taken within 800 ft of the dredge along similar radials. The table shows that while the effect of the cutterhead and the clamshell are similar at near-bottom levels (1 to 5 ft from the bottom), the cutterhead's effect is much less than the clamshell's in the upper water column. This can also be seen by comparing the two dredges 50 mg/ℓ lines shown in Figures 3 and 6. Figure 7 is the average of the suspended sediment values shown in Figures 3 and 6, with the clamshell bucket values shown in parenthesis. We see that the cutterhead exceed 50 mg/ℓ only near the bottom, and its effect is barely detectable above 5 feet. The clamshell bucket effects can be seen up to the surface. Thus, the clamshell effects a greater portion of the water column to a greater extent than does the cutterhead.

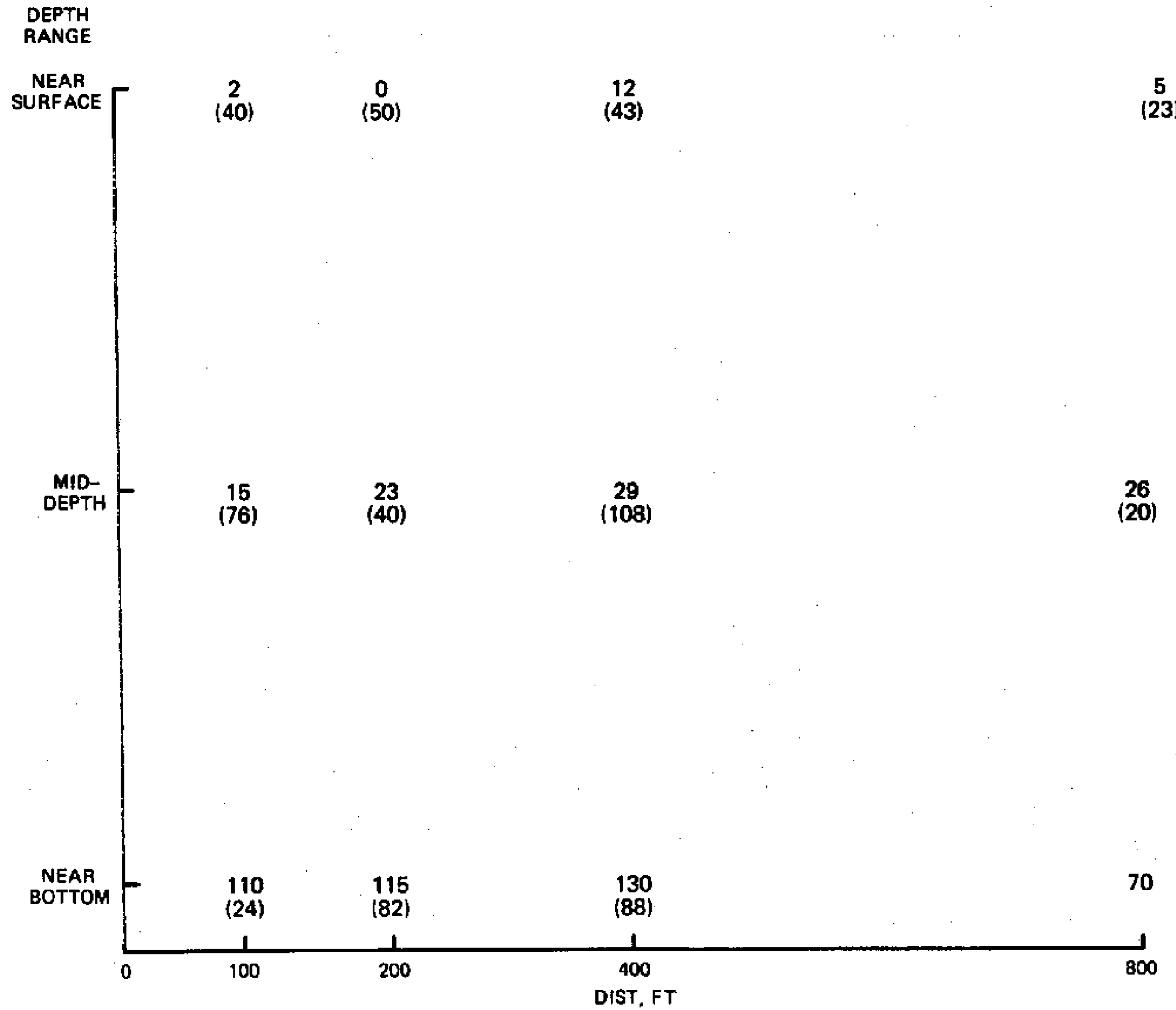

Figure 7. Comparison of average suspended sediment values for a cutterhead operation and a clamshell operation. Values without parenthesis are for the cutterhead, values within parenthesis are for the clamshell.

LIMITING SEDIMENT RESUSPENSION

Cutterhead Operations

As pointed out by Barnard (1978) and Huston and Huston (1976), the sediment resuspended by cutterhead excavation is dependent on the operating techniques used. Indeed the cutterhead may be the most sensitive of any dredge type to changes in operating techniques. Barnard (1978) stated that the sediment resuspended by the cutter of a cutterhead dredge apparently increases exponentially as thickness of cut, rate of swing, and cutter rotation rate increase. Although suspended solids levels around the cutter also increase with increasing rates of production, it is possible to maximize the production rate of the dredge without resuspending excessive amounts of bottom sediment. Herbich and Brahme (in press) reporting on Japanese studies also identify the cutter's revolutions per minute, swing speed, and thickness of cut as important factors in determining the level of sediment resuspension.

Although many researchers have commented on the importance of these operating factors, few have tried to quantify them. Yagi et. al. (1975) and Shiba and Koba (in press) felt that increasing the depth of cut would also increase the sediment resuspension. However, efficiency experiments (i.e., energy required to produce a given output) conducted by Slotta, Joanknecht, and Emrich (1977) showed that the greatest production and efficiency came from deeper, rather than shallow cuts (a 45^{o} ladder depression versus a 20^{o} ladder depression for the same depth). Yagi et al. (1975), Shiba and Koba (in press), and Kaneko, Watari, and Aritomi (in press) all found that the greater the swing speed, the greater the sediment resuspension. They found this particularly to be true of swing speeds above 0.5 fps. Slotta, Joanknecht, and Emrich (1977) found the most efficient swing speed to be 0.3 fps. Finally all of the above authors found cutter revolutions per minute (cutter speed) to be a factor; however, only Shiba and Koba, based on their testing, stated that this was the major factor. None of the authors attempted to quantify a minimum cutter speed; however, Slotta, Joanknecht, and Emrich did find that a cutter speed of 75 revolutions per minute was the most efficient. Finally, both Yagi et al. (1975) and Kaneko, Watari, and Aritomi (in press) reported that by using the suction without rotating the cutter, resuspension could be reduced by about one-half.

Operational controls. Based on the impact of the factors described above, Huston and Huston (1976) recommend the following operational controls to reduce levels of sediment resuspension. These controls will reduce the amount of material disturbed by the cutterhead but not entrained by the suction:

a. Large sets and very thick cuts should be avoided, since they tend to bury the cutterhead and may cause high levels of resuspension if the suction cannot pick up all of the dislodged material.

b. The leverman should swing the dredge so that the cutterhead will cover as much of the bottom as possible. This minimizes the formation of windrows or ridges of partially disturbed material between the cuts; these windrows tend to slough into the cuts and the material in the windrows may be susceptible to resuspension by ambient currents and turbulence caused by the cutterhead. Windrow formation can be eliminated by swinging the dredge in close concentric arcs over the dredging area. This may involve either modifying the basic stepping methods used to advance the dredge or using a Wagger or spud carriage system.

c. Side slopes of channels are usually dredged by making a vertical box cut; the material on the upper half of the cut then sloughs to the specified slope. The specified slope should be cut by making a series of smaller boxes. This method, called "stepping" the slope, will not eliminate all sloughing, but will help to reduce it.

d. On some dredging projects, it may be more economical to roughly cut and remove most of the material, leaving a relatively thin layer for final cleanup after the project has been roughed out. However, this remaining material may be subject to resuspension by ambient currents or prop wash from passing ship traffic.

e. When layer cutting is used, the dredge will remove a single layer of material over a large portion of the channel; the dredge is then set back to dredge another layer. This continues down to the required depth of the project. Since loose material is often left on the bottom after each layer is dredged, this technique should only be used where resuspension of the remaining material will not create sediment resuspension problems.

Equipment design considerations. Design of the cutterhead greatly influences the dredge's production and sediment resuspension during the dredging process. The dredge's suction (Figure 2), which picks up the material that has been cut by the cutter, can be partially responsible for sediment resuspension around the cutter if the energy provided to the suction by the dredge pump is not great enough to cause the suction to pick up all of the material disturbed by the cutter. Water-jet booster systems or ladder-mounted submerged pumps installed on cutterhead dredges have been found to enhance the dredge's pickup capability, increase slurry density and potential production rate, and decrease the generation of suspended solids (Barnard 1978).

The shape of the cutterhead also affects the sediment resuspended, particularly if no over-depth is allowed. The cutterheads shown in Figure 8 have the same length and base width. They are also depressed to the same angle and are buried to the same depth. However, with the conical shaped head (right hand drawing), the suction is brought closer

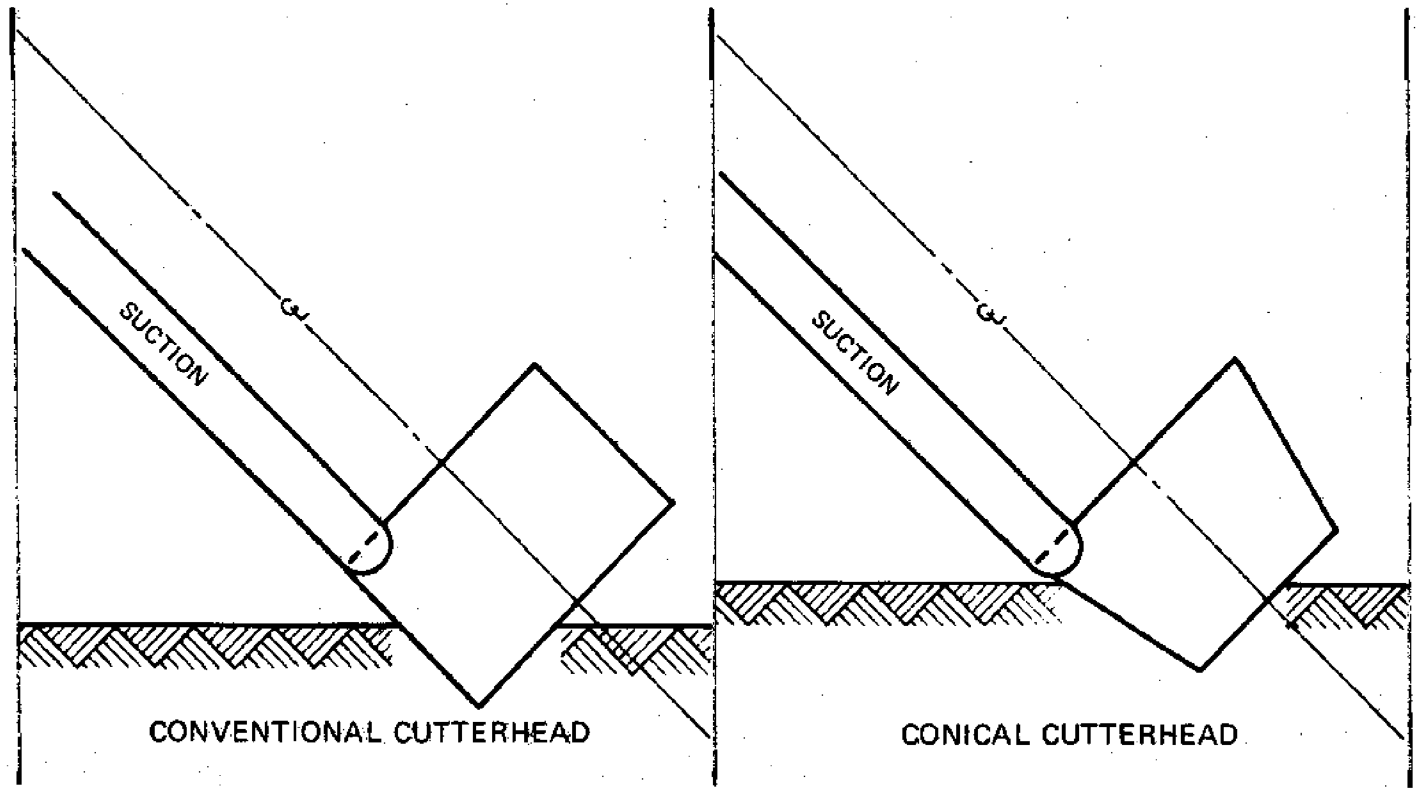

Figure 8. Effect of cutterhead shape on suction height above the bottom (Turner).

to the material and the chance of entrainment is improved. This shape difference would be particularly important if the head was not completely buried.*

The angle α in Figure 9 is called the rake angle. If the rake angle is too large, it will cause a gouging action that will sling soft fine-grained material outward. If the rake angle is too small, heeling (the striking of the bottom with the heel of the tooth) will occur and increase resuspension. For fine-grained maintenance-type material, a small rake angle of from 20 to 25 deg would be best. This would allow a shallow entry that would lift the bottom sediment and guide it toward the suction.*

Hopper Dredge Operation

Of the two hopper-dredge sources of sediment resuspensions mentioned earlier, the draghead and pumping pass overflow, the overflow of material from the hopper produced by far the most sediment resuspension. This source of near surface resuspension can be addressed in several ways. The first is to assess the type material being dredged and its environmental impact. If the material being dredged is clean sand, the percentage of solids in the overflow will be small and economic loading may be achieved by pumping past overflow. When contaminated sediments are to be dredged and adverse environmental effects have been identified, pumping past overflow is not recommended. In such cases, other types of dredges may be more suitable for removing the contaminated sediments from the channel prism. In the case of fine-grained materials, the settling properties of silt and clay sediments may be such that only a minimal load increase would be achieved by pumping past overflow (HQDA 1983).

Another approach has been suggested by the Japanese. They have developed a relatively simple submerged discharge system for hopper dredge overflow, called an anti-turbidity overflow system (ATOS) (Herbich and Bramhe in press). The overflow collection system in the dredge was streamlined to minimize incorporation of air bubbles, and the overflow discharge ports were moved from the sides to the bottom of the dredge's hull (Figure 10). With this arrangement, the discharge descends rapidly to the bottom with a minimum amount of dispersion within the water column. The system can be incorporated in existing dredges through modifications of their overflow systems. This system has been successfully incorporated in three Japanese trailing-hopper dredges with capacities ranging from 2500 to 5000 cu yd. Tests carried out on the dredge KAIRYU MARU indicated considerable reduction in sediment resuspension at the surface and 3 ft below the surface both beside

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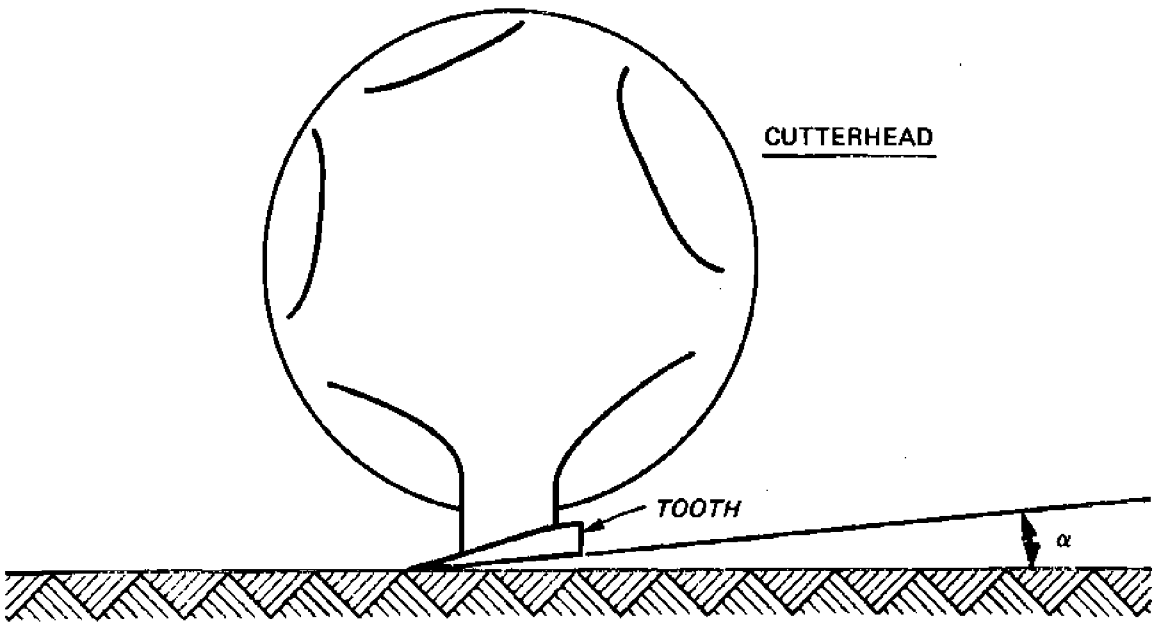
* Personal communication from Thomas M. Turner, Turner Consulting Inc., Sarasota, FL., March 1983. Mr. Turner also provided sketch for Figure 8. See also WES Environmental Laboratory files (WESEE) Memorandum for Record, 15 April 1983, Subject: Equipment Aspects of Dredging Contaminated Sediments.



RAKE ANGLE α

Figure 9. Schematic front view of a cutterhead showing the cutter tooth rake angle.

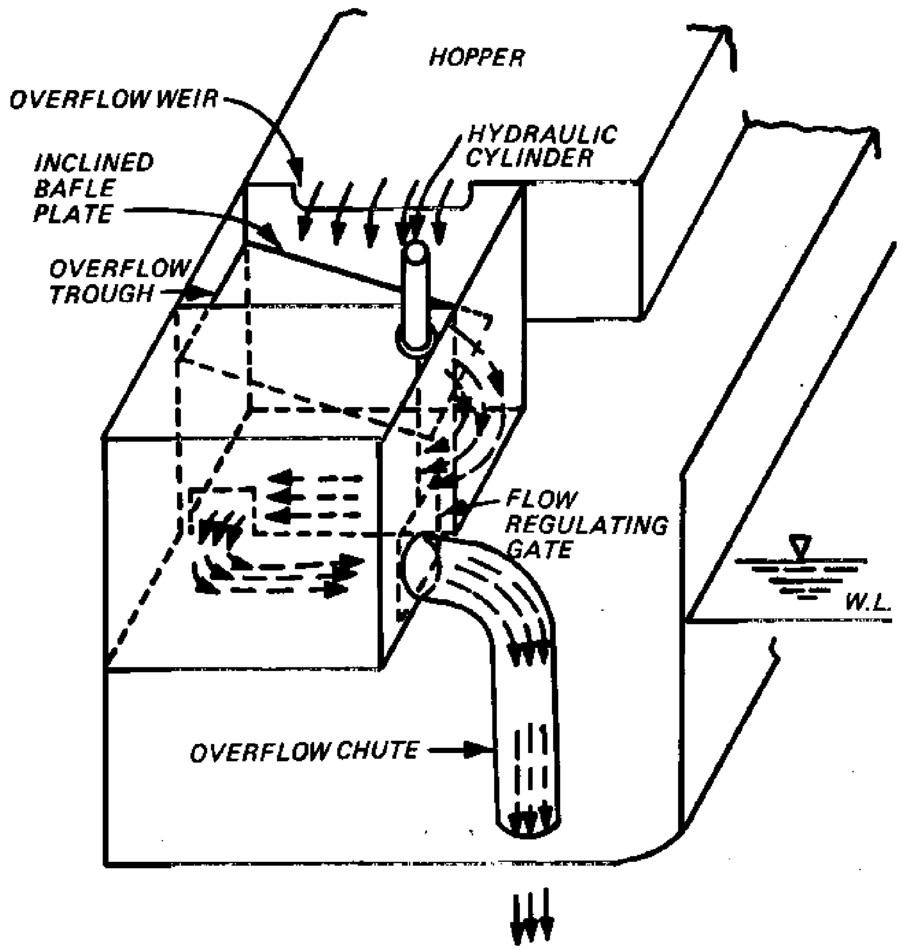


Figure 10. Schematic drawing of a hopper dredge bin equiped with the Japanese designed Anti-Turbidity Overflow System (ATOS).

the ship and 100 ft behind the ship. The data comparing the sediment resuspended by a conventional overflow system and by the ATOS are shown in the following tabulation.

	Average Concentration of Suspended Solids, mg/ℓ			
	Conventional System		ATOS	
Sampling Location	Surface	3' below Surface	Surface	3' below Surface
Beside ship	627	272	6.0	8.0
100 ft aft of ship	119	110	6.5	8.9

It should be pointed out, however, that the ATOS system is intended only to reduce near-surface resuspension, not overall resuspension. The ATOS device has the effect of forcing the solids plume down to a lower level. This in itself can have the effect of inducing more rapid settlement of the resuspended solids.

Clamshell Bucket Dredge

Although Japanese experimenters have reported some reduction in sediment resuspension with the variation of hoist speed and depth of cut, their greatest reduction in resuspension with clamshell dredging came from the use of a so-called "watertight" or enclosed clamshell bucket. The Port and Harbor Institute of Japan developed a watertight bucket in which the top is enclosed so that the dredged material is contained within the bucket. A direct comparison of a 1-cu m standard open clamshell bucket with a watertight clamshell bucket indicates that watertight buckets generate 30 to 70 percent less resuspension in the water column than the open buckets (Barnard 1978).

WES conducted a field test to compare the effectiveness of enclosed clamshell buckets. The resuspension produced by an enclosed 13-cu yd bucket was compared to a 12-cu yd standard open bucket during dredging of the St. Johns River near Jacksonville, Florida. The results of this test are given in the following table. The sampling locations and radials used in this test were shown in Figure 5. Figure 11 shows the average suspended sediment levels at increasing depths along each radial. This test reveals a marked reduction (greater than 50 percent) in sediment resuspension in the upper water column with the enclosed bucket (Raymond in press). Some drawbacks were also revealed however. The enclosed bucket produced increased resuspension near the bottom, probably due to a shock wave of water that precedes the watertight bucket due to the enclosed top. Also both the earlier Japanese and the Jacksonville buckets had rubber gaskets along the cutting edge of the bucket to seal it. This limited the use of the bucket to soft material and trash-free areas. Current design concepts include the use of interlocking tongue-and-gloove edge to overcome the sealing problems.

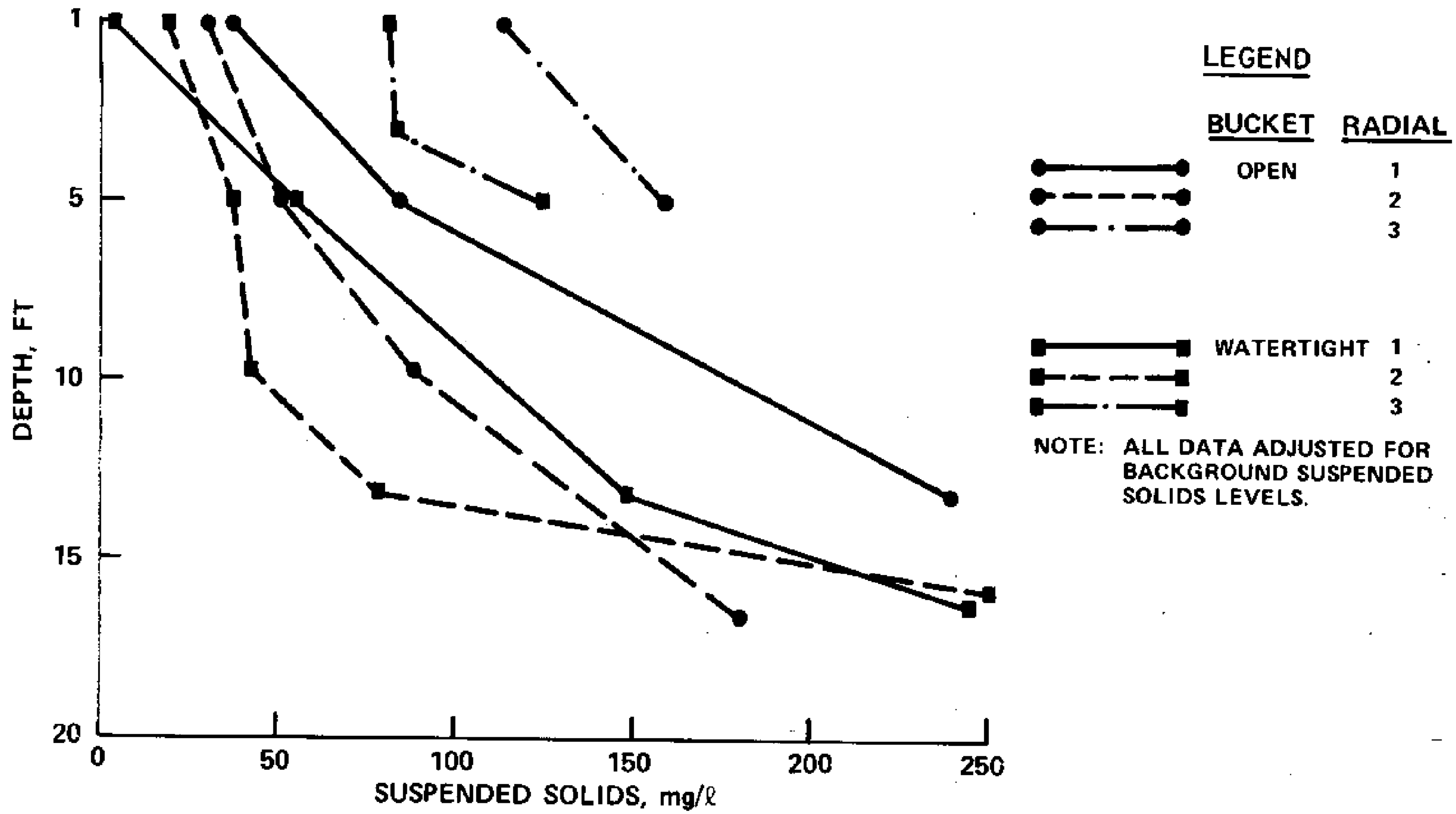


Figure 11. Average suspended sediment levels along sampling radials during clamshell dredging for Jacksonville comparison tests. Data were adjusted for background conditions (Raymond, in press).

Results of Comparison of Enclosed and Open Clamshell Bucket

Type of Clamshell Bucket	Sampling Radial	Average Suspended Sediment Levels, mg/ℓ*	
		Upper Water Column	Near Bottom**
Enclosed	1	27	123.25
	2	35.6	61.0
	3	80.6	133.3
Open	1	233	146.6
	2	300	122.0
	3	N/A	N/A

* Average of all samples taken along the radial, adjusted for background suspended sediment level.

** Measurements made within 5 ft of bottom.

Operationally, clamshell bucket resuspension can be lessened by ensuring the operator does not "drop" the bucket into the sediment but allows it to settle under its own weight, and by avoiding "sweeping." Sweeping is where the bucket is swung across the width of the cut to smooth the bottom and level off the high points. Sweeping occurs at the end of the cut prior to advancing to a new cut. Sweeping does help to level the irregular bottom that results from clamshell dredging, however it contributes significantly to sediment resuspension.

Special-Purpose Dredges

Special-purpose dredging systems have been developed during the last few years in the United States and overseas to pump dredged material slurry with a high solids content and/or to minimize the resuspension of sediments. Most of these systems are not intended for use on typical maintenance operations; however, they may provide alternative methods for unusual dredging projects such as in chemical hot spots. The special-purpose dredges that appear to have the most potential in limiting resuspension are shown in the following tabulation, which was taken from Herbich and Brahme (in press). A description of each dredge follows the tabulation.

Name of Dredge	Suspended Sediment Level
Pneuma Pump	48 mg/ℓ 3 ft above bottom
	4 mg/ℓ 23 ft above bottom (16 ft in front of pump)
Clean-Up System	1.1 to 7.0 mg/ℓ 10 ft above suction
	1.7 to 3.5 mg/ℓ at surface
Oozer Pump	6 mg/ℓ (background level) 10 ft from head
Refresher System	4 to 23 mg/ℓ at 10 ft from head

Pneuma pump. The Pneuma system was the first dredging system to use compressed air instead of centrifugal motion to pump slurry through a pipeline. It has been used extensively in Europe and Japan. According to the literature published by the manufacturer, this system can pump slurry at a relatively high solids content with little generation of turbidity. The operation principle is illustrated in Figure 12. During the dredging process, the pump is submerged and sediment and water are forced into one of the empty cylinders through an inlet valve. After the cylinder is filled, compressed air is supplied to the cylinder, forcing the water out through an outlet valve. When the cylinder is almost empty, air is released to the atmosphere, thus producing atmospheric pressure in the cylinder. A pressure difference occurs between the inside and outside of the cylinder, creating a suction that forces the sediment into the cylinder. When the cylinder is filled with sediment, compressed air is again pumped into the cylinder to expel the sediment from the cylinder. The capacity of a large plant (type 1500/200) is 2600 cu yd/hr. The system has been used in water depths of 150 ft; however, 500 ft depths are theoretically possible.

Field tests on a Pneuma model 600/100 were conducted by WES (Richardson et al. 1982). The results of turbidity monitoring, although not definitive, seemed to support the manufacturer's claim that the Pneuma pump generates a low level of turbidity when operated in loosely consolidated fine-grained sediments. It was also found that the Pneuma pump was able to dredge at almost in-situ density in a loosely compacted silty clay typical of many estuarine sediments. The Pneuma pump, however, was not able to dredge sand at in-situ density.

Clean-Up system. To avoid resuspension of sediment, Toa Harbor Works of Japan developed a unique Clean-Up System for dredging highly contaminated sediment (Sato 1976). The Clean-Up head consists of an auger that collects sediment as the dredge swings back and forth, and a shield that guides the sediment towards the suction of a submerged centrifugal pump (Figure 13). To minimize sediment resuspension, the auger is covered and a movable wing covers the sediment as it is being

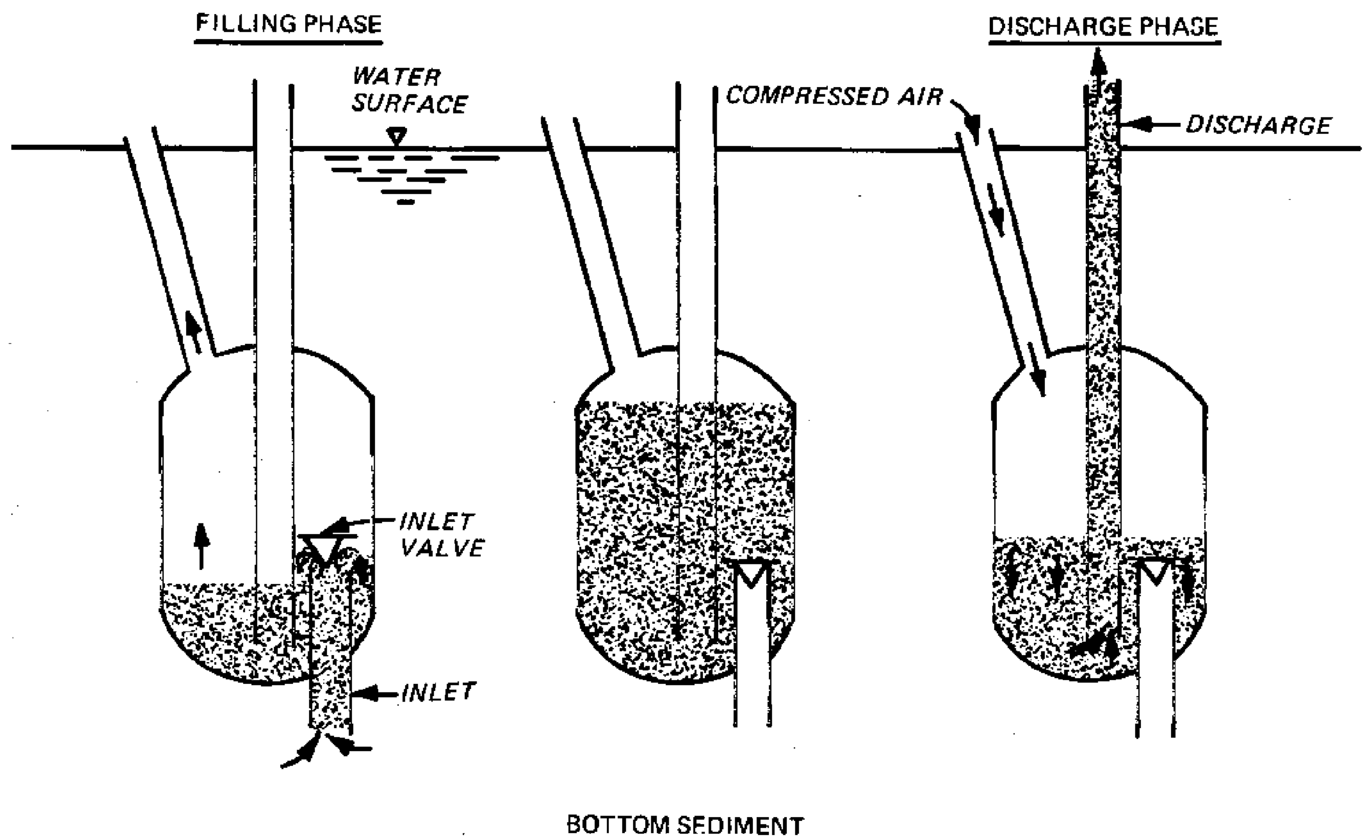


Figure 12. Operating cycle of Pneuma Pump.

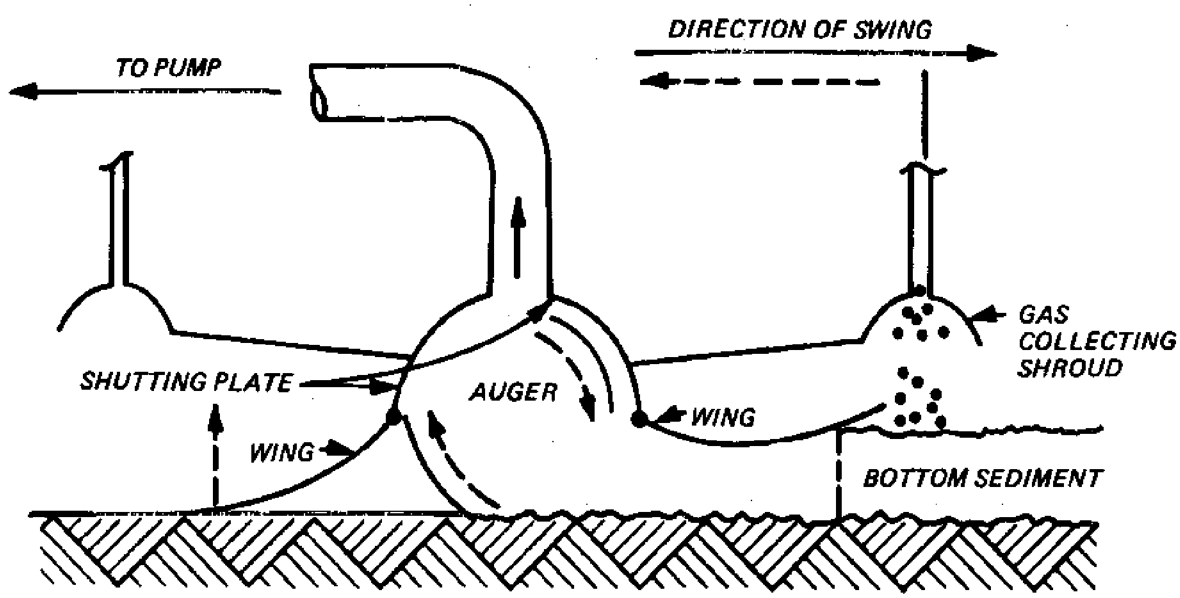


Figure 13. Schematic of Japanese "Clean-up dredge system.

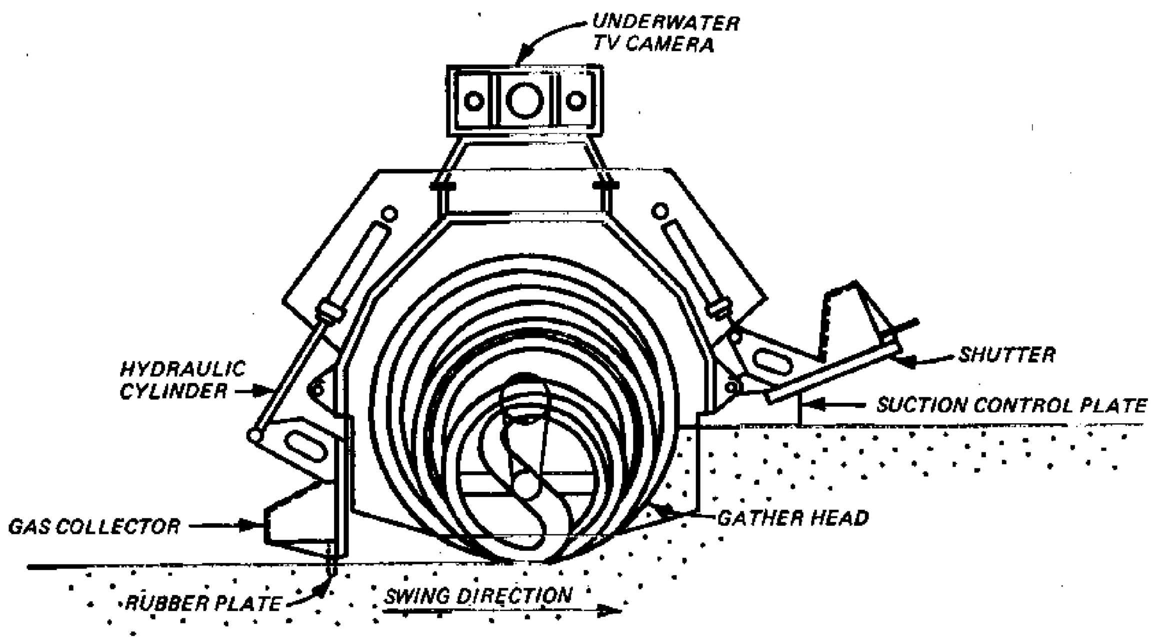
collected by the auger. Sonar devices indicate the elevation of the bottom. An underwater television camera is used to show the material being resuspended during a dredging operation. Suspended sediment concentrations around the Clean-up System ranged from 1.7 to 3.3 mg/ℓ at the surface to 1.1 to 7.0 mg/ℓ at 10 ft above the suction equipment, relative to the background near-surface levels of less than 4.0 mg/ℓ (Herbich and Brahme in press).

Oozer pump. The Oozer Pump was developed by Toyo Construction Company, Japan. The pump operates in a manner similar to the Pneuma Pump system; however, there are two cylinders (instead of three) and a vacuum is applied during the cylinder-filling stage to achieve more rapid filling of the cylinders. The pump is usually mounted on a dredge ladder and is equipped with special suction and cutter heads depending on the type of material being dredged. The conditions around the dredging system, such as the thickness of the sediment being dredged, the bottom elevation after dredging, and the amount of resuspension, are monitored by high-frequency acoustic sensors and an underwater television camera. A large Oozer Pump has a dredging capacity ranging from 400 to 650 cu yd/hr. During one dredging operation, suspended solids levels within 10 ft of the dredging head were all within background concentrations of less than 6 mg/ℓ (Herbich and Brahme in press).

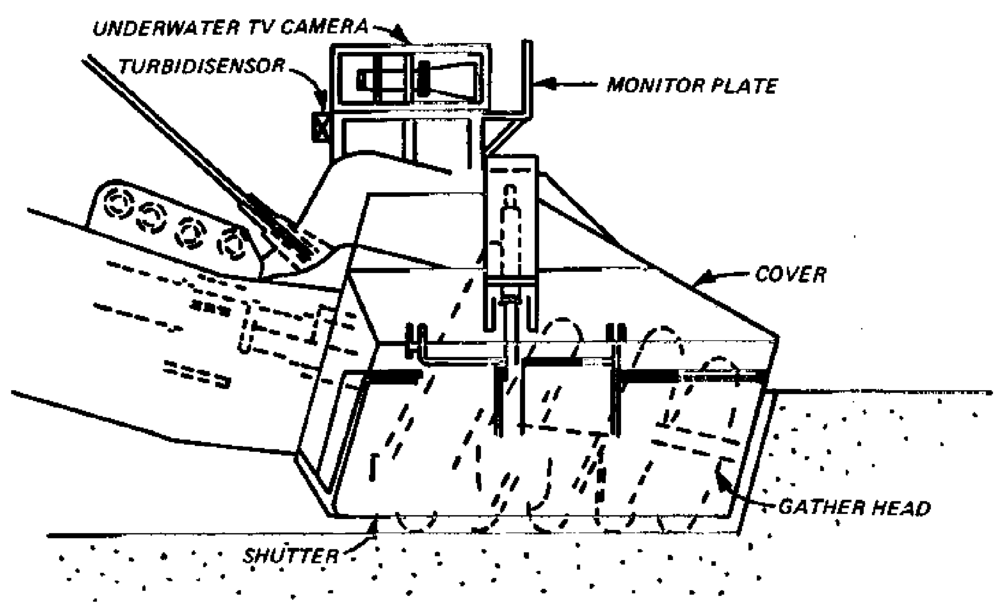
Refresher system. Another system designed recently by the Japanese is the Refresher System. This system is an effort to modify the cutterhead hydraulic dredge. The Refresher uses a helical shaped gather head to feed the sediments into the suction, with a cover over the head to reduce resuspension (see Figure 14). The Refresher also uses an articulated dredge ladder to keep the head level to the bottom over a wide range of dredging depths. During several tests in similar material, the Refresher system produced suspended sediment levels of from 4 to 23 mg/ℓ within 10 ft of the dredge head as compared to 200 mg/ℓ with a conventional cutterhead dredge. Production for the cutterhead (26-in. discharge) was 800 cu yd/hr while production with the Refresher System (17-in. discharge) was 350 cu yd/hr. The researchers felt that the Refresher system produced one-fiftieth of the total resuspension produced by the operation of a cutterhead dredge (Kaneko, Watari, and Aritomi in press).

SUMMARY

Dredging can cause the resuspension of contaminated sediments from the bottom into the water column. The sediments most likely to remain resuspended during a dredging operation, fine-grained clay-sized and organic particles, are the ones that show the greatest affinity for chemical contaminants of various types. Dredging operations conducted in coarser sediments should experience little difficulty with resuspension or contamination.



a. FRONT VIEW



b. SIDE VIEW

Figure 14. Front and side view of Japanese "Refresher" dredge system (Kaneki, Watari and Aritoni, in press).

Different dredge types produce different amounts of suspended sediment in different parts of the water column. The cutterhead produces most of its resuspension near the bottom, as does the hopper dredge without overflow. The bucket dredge and hopper dredge with overflow however produces suspended sediments throughout the water column. Sediments resuspended in the upper water column are particularly serious since a greater potential for suspended sediment dispersal exists in the upper water column.

Sediment resuspension caused by many dredges can be lessened by changing operating techniques or by modifying the equipment. Many researchers suggest that controlling cutter revolutions per minute, swing speed, and depth of cut of a cutterhead dredge can reduce sediment resuspension. In fact, any operating technique that improves the production of the cutterhead dredge will probably reduce resuspension. Hopper and bucket dredges will probably require some equipment modification to achieve a meaningful reduction in sediment resuspension.

Finally, a wide variety of special-purpose dredges are available that appear to substantially reduce the resuspension of sediment. However, most of these dredges have low production rates, and more research is needed to evaluate their areas of application and their limitations.

The problem of limiting the environmental impact of dredging contaminated sediments through reducing resuspension of sediments will continue to be addressed by WES under the IOMT program. Many of the currently unresolved questions discussed in this paper will be addressed by future research efforts.

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DREDGING CURVES FOR HUMBOLDT HARBOR AND BAY, CALIFORNIA

by
Jimmie W. Humphries[1]

ABSTRACT

Unit costs, based on 1975 prices for dredging and transporting materials various distances via pipeline or hopper dredge ships, are shown in Figure 3. Cost curves are for a sixteen-inch pipeline and are related to estimated power requirements for booster pumps. Curves do not include mobilization costs or replacement costs for Government-owned hopper dredge ships. Some views and experience with public perceptions in planning public works are given.

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DREDGING CURVES FOR HUMBOLDT HARBOR AND BAY, CALIFORNIA

Improvement of navigation channels in Humboldt Harbor was authorized by the River and Harbor Act of 1968. Funds for initiation of Advanced Engineering and Design were provided the U. S. Army Corps of Engineers' San Francisco District in fiscal year 1973. The survey report (House Document No. 330, 90th Congress) recommended disposing of material to be dredged from the channels at two sites: one in vicinity of the municipal airport on the North Spit and on Indian Island at the "Y" between the Samoa and Eureka Channels. See Figures 1 and 2 appending text.

In forwarding the report to the Secretary of the Army, the Chief of Engineers recommended that the North Spit disposal area be enlarged to accommodate all of the material to be dredged from the project in order to avoid possible adverse environmental effects and controversy resulting from use of the Indian Island site for disposal of dredged material. As noted by the Director of the Bureau of the Budget, higher costs associated with the change in plans posed a potential problem in showing economic justification for deepening and widening the channels. Therefore, a large number of potential disposal sites were investigated and evaluated in preparation of the General Design Memorandum and its companion Environmental Statement.

Tests on the material to be dredged indicated it was suitable for use as fill for a number of potentially beneficial purposes, such as construction of new shipping terminals, development of industrial sites, beach replenishment and a proposed freeway embankment along the east side of the bay. Evaluation of these alternatives required preparation of detailed cost estimates for dredging and pumping all or some portion of dredged material various distances to a large combiniation of potential disposal sites.

Figure 3 was developed from a skeleton of basic cost estimates for dredging and pumping from relatively short distances (less than 2,500 feet) and for longer pump distances requiring use of booster pumps. Unit costs from these estimates (with mobilization and demobilization costs subtracted out) were plotted and supplemented by some hydraulic and energy computations by the author. Development of these curves allowed us to make comparative cost evaluations of what seemed to be an endless list of proposals for disposal of dredged materials: seventeen different sites factored by their capacity! The author's calculations for head loss in a 16 inch diameter pipeline were straight forward, but the variation in flow rates with different lengths of pipeline and steps of added horsepower for pumping dredge slurry at reasonable rates required a number of trial solutions and some experienced judgement to arrive at an estimated average production rate of 560 cubic yards per hour of in place material. Of course the size of the dredge (pump horsepower) determines the maximum dredging rates that might be achieved, but if that figure is set, then the diameter of the pipe is a most significant variable in limiting production and slurry transport rates.

A 1,200 horsepower suction dredge and booster pumping plant with up to 6,000 H.P. for pumping slurry as much as 35,000 feet through a 16 inch pipeline was used to estimate about eighteen months would be required to remove an estimated 2.3 million cubic yards of material from the channels. Of course a larger plant and pipeline could accomplish the job quicker, but from an engineering economics point of view, a larger plant requires a larger capital investment, is more expensive per hour to operate and usually has higher mobilization and demobilization costs. Nevertheless, the pipeline dredging portion of the project was actually completed in about six months by a contractor using a bigger dredge and 24 inch pipeline. That is one reason the author considers it inadvisable to include mobilization and demobilization costs in dredging curves.

The Humboldt Bay Project also included use of Government owned hopper dredge ships to make some improvements in the harbor Entrance Channel, where rough sea conditions made pipeline dredging impractical. Carefully kept maintenance records of operating costs and production of these vessels were used to estimate and plot unit costs shown on Figure 3; and to compare costs for disposing of dredged material off shore and at more distant deep ocean disposal sites. The analysis did not include the cost of replacement of these vessels, but a comparison of unit operating costs shows hopper dredging to be very efficient with unit costs less than half those for a much smaller and less powerful suction dredge. Mobiliation and demobilization of hopper dredges for part of the project improvements was not a significant item of project cost because these vessels were deployed on a regular basis to Humboldt Bay for maintenance of existing project channels.

The unit costs shown on Figure 3 are based on 1975 prices for dredging operations in northern California. However, they have since been used with cost indexing factors for making preliminary estimates and comparison of costs for transporting dredged materials various distances at other sites and study locations. Mobilization and demobilization costs were added to fit the location and situation.

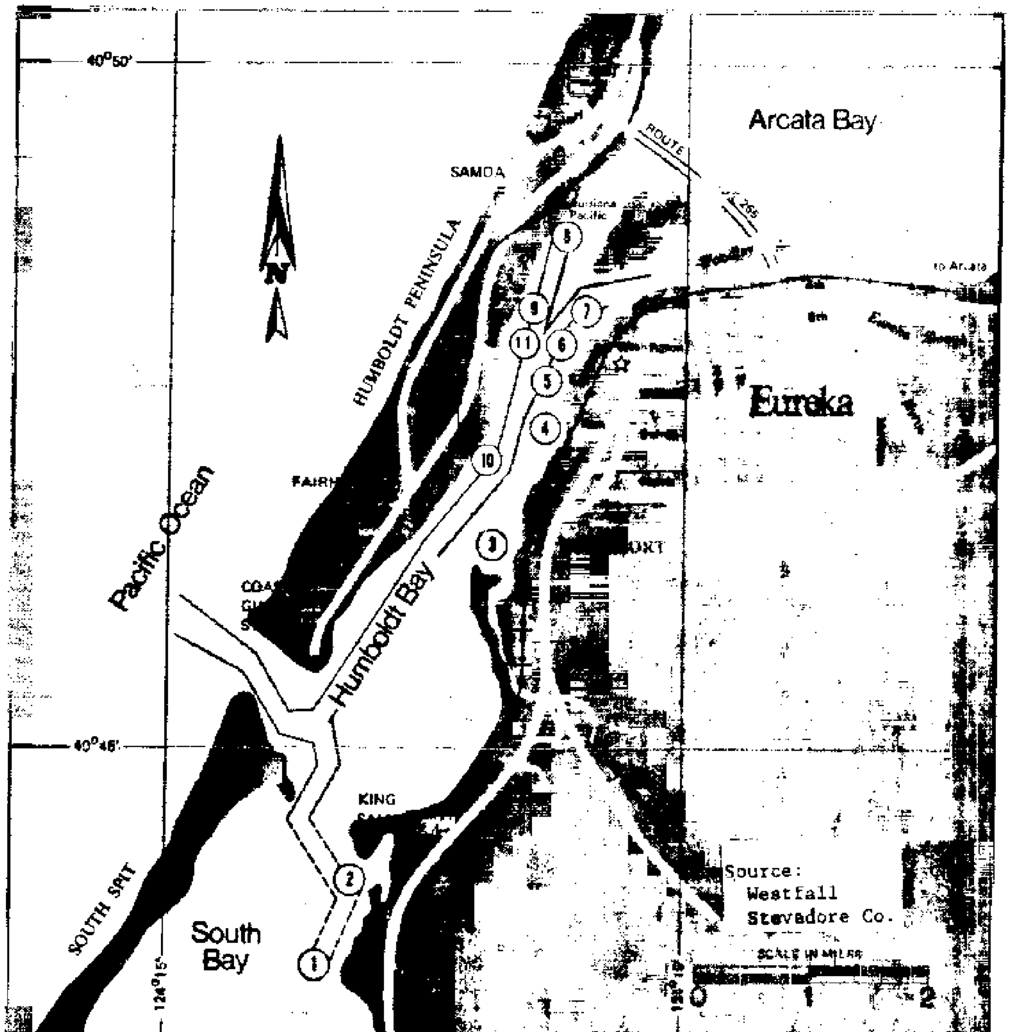
The change in plans for disposal of dredged materials mentioned earlier in this discussion occurred after drafts of the GDM and ES were circulated and final editions were being prepared for submittal to higher authority. A rare beach plant, Erysimum menzieii, was discovered to be growing on the recommended disposal sites on the North Spit. This was a disappointing setback to our schedule for construction. Resolution of the problem required close coordination with local citizens and State agencies, who insisted that size of the disposal site be significantly reduced to preserve the most productive area of native growth. This required re-evaluation of several alternative disposal sites considered in the draft reports, but eliminated in "final" additions in favor of the Project Document site on the North Spit.

An "Ad Hoc" committee of local citizens and agency representatives was formed to review project plans and suggest revisions that might allow developments critical to the local economy with minimum adverse effects on the environment. The committee recommended the Corps re-evaluate a land disposal site on private property and a beach disposal site. The additional studies required about nine months. Quantative evaluation of possible adverse effects from the beach disposal alternative was particularly difficult, due to the complex nature of off shore currents and shoaling patterns and a lack of quantative knowledge on how disposal might affect crab migrations and other biological resources. Also, there was serious concern as to how disposal on the beach might impact wastewater outfalls from a paper mill.

An Addendum to the ES was prepared to discuss, in detail, two alternative disposal sites previously discarded in the Final ES. Beach disposal site was recommended in lieu of the most southerly land site 13C on the North Spit, which was eliminated to preserve best populations of the rare plant. Use of the beach for disposal of dredge material included some conditions as to season of use and type of material that could be disposed on the beach was limited to sand. This required some additional sampling at the dredging sites in the Samoa Channel and Turning Basin.

A large pile of dredged material was deposited on the beach, but was nearly totally obliterated over one winter's storm season on this high energy beach. And reference to curves on Figure 3 indicates citizens' choice in weighing the facts and risks of disposing of about 1,000,000 cubic yards of dredged materials on the beach saved an estimated 1,200,000 KWH of energy and perhaps asmuch as $1,000,000 in dredging and pumping costs. The modified plan also afforded very significant savings in diking costs that would have otherwise been spent to contain this material at the land disposal site on the North Spit. Diking and certain other project costs were an obligation of the local sponsor: Humboldt Bay Harbor Recreation and Conservation District.

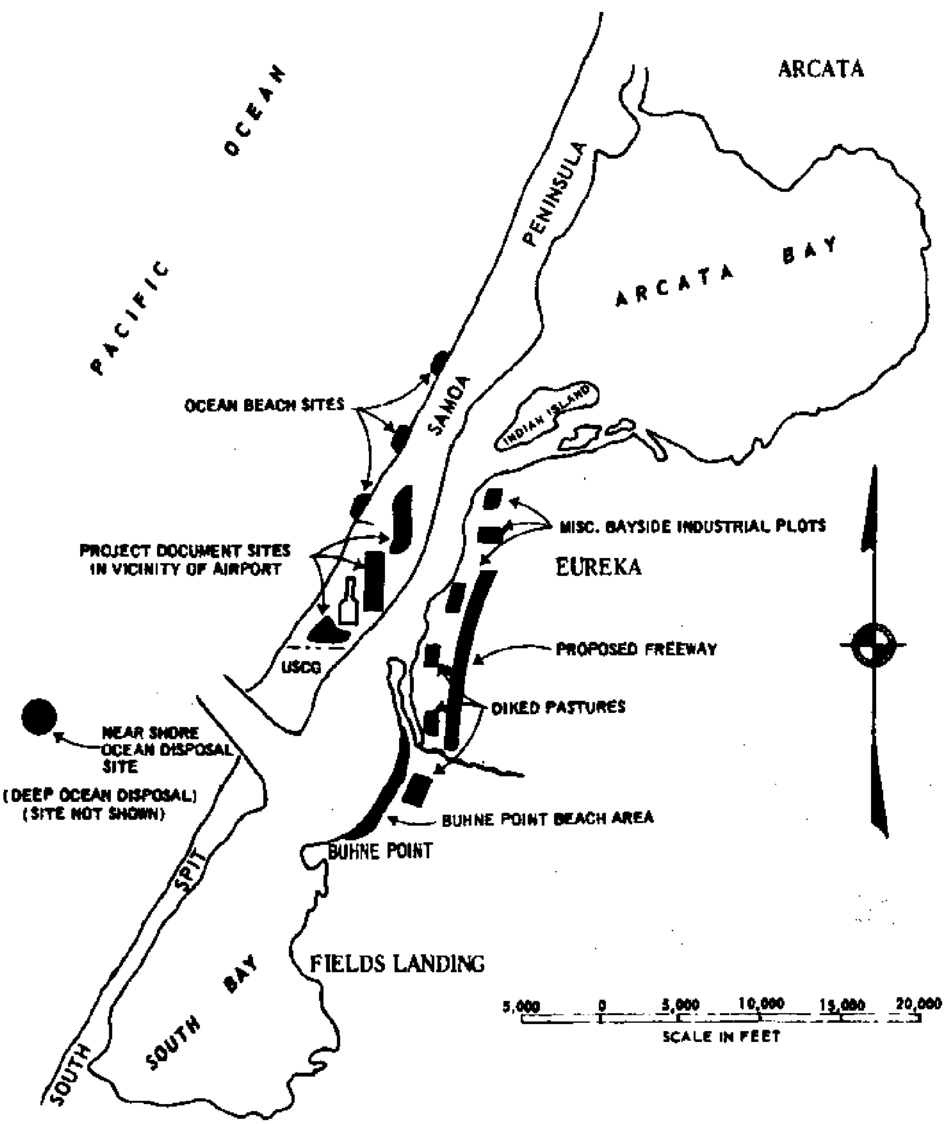
In conclusion, I would like to relate some personal opinions concerning the planning process: Open lines of communication and public relations are at least as important as careful engineering and economic analyses in weighing diverse public interests and needs. Planners cannot afford to ignore any concern, no mater how trite it may seem. On the otherhand, no particular proposal should be dropped prematurely when the winds of public concern may make such a proposal seem politically inexpedient. For example, dredging and side casting is probably the least expensive means of dredging large quantities of material, but such practice is currently considered a no-no in environmentally sensitive harbors and bays. Actually this form of disposal would allow some valuable shellfish resources a better chance of survival than plans for disposing of dredged materials on dry land or in deep ocean. Finally, I would like to say I have often been impressed by the reservoir of engineering and scientific expertise that can be found in many local communities when the "fish bowl" approach to planning public projects is practiced.



Major Terminals in Humboldt Bay

(1) PACIFIC DOCK–KRAMER SALES
(2) OLSON TERMINALS
(3) STANDARD OIL COMPANY
(4) EUREKA FOREST PRODUCTS
(5) UNION OIL COMPANY
(6) HUMBOLDT DOCK "A"
(7) HUMBOLDT DOCK "B"
(8) LOUISIANA PACIFIC REDWOOD DOCK
(9) LOUISIANA PACIFIC CHIP BERTH
(10) CROWN SIMPSON DOCK
(11) NORTH COAST EXPORT CO.

FIGURE 1



HUMBOLDT HARBOR AND BAY
ALTERNATIVE DISPOSAL
SITES CONSIDERED

FIGURE 2

ESTIMATED DREDGING AND TRANSPORT COSTS

HUMBOLDT HARBOR AND BAY, CALIFORNIA

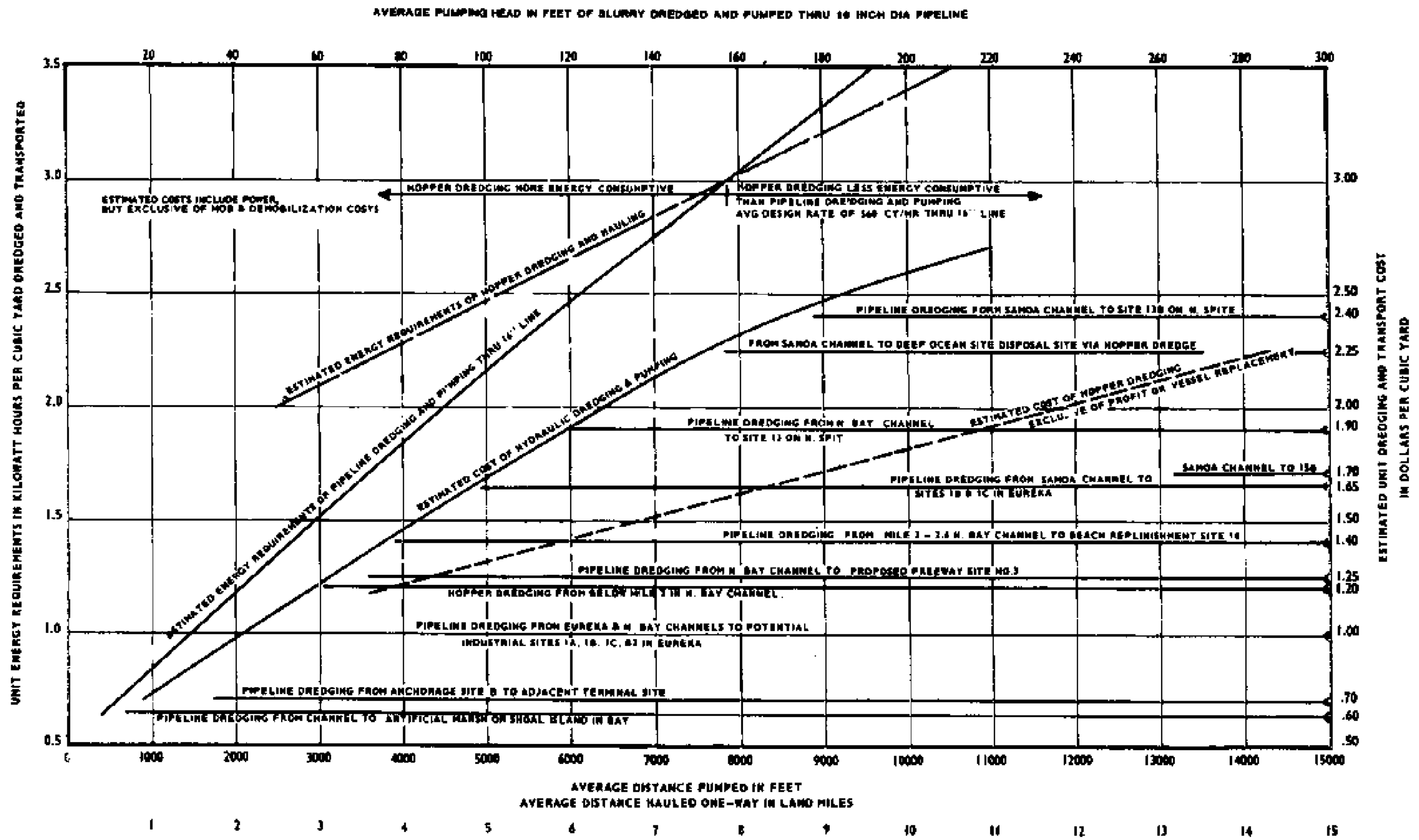


FIGURE 3

BRIEF PERSONAL HISTORY

Jim Humphries

Education:	University of Oklahoma, 1960
Experience:	Initial employments in engineering with mining, civil engineering and construction firms in Colorado: AMAX, R.F. Harrison and Tecon Constructors on Blue Mesa Dam.
	In 1963 began civil service career with Tulsa District, Corps of Engineers. Transferred to San Francisco in 1966 with the Planning Branch until February 1982.
	Presently reside in Sacramento, California.

PROTECTION OF CANAL BANKS, CABLES AND PIPELINES

by
Alan D. Crowhurst[1]

ABSTRACT

This paper describes the principles of construction and uses of one form of construction, wire enclosed rip-rap or gabions, for a range of applications above and below normal water levels.

Comparisons are made between the use of conventional rip-rap and gabions in various structures such as river and canal bank and bed linings. Underwater pipeline protection is discussed with specific references to design criteria, methods of placement and the development of flexible mastic asphalt grouted mattresses for estuarial and offshore works. A list of reports and publications is included.

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INTRODUCTION

Of the many materials used to protect the banks of canals, rivers or streams and to armour their beds following the construction of pipeline crossings, rip-rap is by far the most commonly used. However this method of protection has a number of disadvantages, not least the fact that in order to achieve the required minimum cover over the design area considerable additional tonnages have to be dumped. The loose stone may also migrate into dredged channels or sink into the bed of the channel.

Although the use of concrete in the form of either proprietary systems of the well known articulated concrete mattresses used by the Corps of Engineers is quite common and produces very good results, there are nevertheless many instances where the qualities inherent in rip-rap protection such as free drainage meet site requirements most closely.

In order to control the quantities used, wire mesh may be employed to contain the rip-rap. Although many types of mesh have been used over the years, hexagonal woven mesh with a double twist has been specifically developed in its modern derivation in which it is pre-fabricated into rectangular boxes or mattresses.

Since smaller sized rock may be used as fill than would be required for rip-rap, each gabion or mattress contains at least two or three layers thus producing a denser lining with smaller interstices through which bed material would pass. Grading of the rock is to very closely defined limits readily achievable in quarries where there is difficulty in producing the larger sizes of rip-rap.

Since the rock is contained within the mesh it is not able to migrate into dredged channels nor, if used to cover pipelines buried on the river bed, does it form underwater obstructions provided the gabions have been placed accurately in the first instance.

CANAL BANK PROTECTION

Since very few navigable waterways in the United States are in the form of canals with low blockage ratios but, typically, are natural waterways dredged to allow passage of barge trains, erosion effects due to navigation are limited in most locations.

Nevertheless, problems can arise due to the passage of barges and, in the lower reaches, ocean going vessels travelling fairly fast. In some parts of Europe attempts are made to limit velocities. For example, in the narrow canals of England speed restrictions as low as 4 mph are applied but, of course, enforcement is another matter especially as many navigators are not professionals but recreational users.

Away from narrow waterways erosion of canal banks arises predominantly from natural causes and many millions of dollars are spend annually on the placement of rip-rap and on a range of other solutions from the articulated concrete mattresses favored by the Corps down to thin plastic sheets in the less serious situations.

Rip-rap can be contained within wire mesh in the form of gabions or mattresses and can give superior performance in many applications. Smaller rock may be used, 4 to 8 inches for gabions and 3 to 6 inches for the mattresses, but the finished protection performs as well as rip-rap of up to 24 inches thickness provided the gabions are properly filled and wired together.

The usual method of construction is for a series of baskets to be assembled and then securely wired together before filling, which should follow in sequence.

Filling may be by machine or by hand, with the rock being placed in one foot lifts. At these heights horizontal wires are inserted in order to maintain a regular shape and, incidentally, to control rock quantities. The rock used can be sedimentary or igneous provided it is hard and, above all, durable. There is little point in using rock that will degrade in a few freeze-thaw cycles or abrade under flow conditions.

Protection may be in the form of walls or revetments. In the former case gabions are used to form a conventional gravity retaining wall which, as it is free draining, can be designed ignoring hydrostatic pressures unless soil conditions indicate a risk of 'clogging'.

Where there is a risk of scour or where soils are poor, it is customary to use a mattress or twelve or eighteen inch deep gabion as an apron or platform extending out into the stream at least one and a half times the projected scour depth.

In rivers, however, with a gravel bed load this is replaced by a foundation carried down into the river bed below the anticipated scour depth.

Canals and channels are often lined with mattresses, which are a thinner version of the gabion having a greater length and width, typically 12 ft. by 6 ft. by nine inches. These may be placed in the dry or, if necessary, can be laid underwater using special pontoons which in some cases have been developed to enable 100 square metres to be lined in one operation.

Although canals are generally considered to have flows with velocities less than a few feet per second, those serving hydro-power stations and similar industrial applications may well require velocities of much greater magnitude.

Considerable research has therefore been carried out recently at Fort Collins (1) to establish design criteria for high velocity flows.

CANAL BED PROTECTION

Protection to the beds of navigable canals and waterways is generally necessary only when pipes and cables have been taken across the channel or where localized scour occurs near a bridge or other structure.

Gabions and mattresses have been used to give protection in such cases and a number of methods of construction have been devised to place them in position.

Although filling in position is possible it is very expensive and therefore pre-filling is almost always employed. Lifting frames have been designed to enable units to be located in position by crane. Pontoons have also been developed to permit placing of linings as a continuous operation.

It is necessary to take simple precautions to ensure that the gabions remain rectangular and can thus be placed close together on the bed but this is sound practice whether the work is above or below water.

Advantages of using gabions and mattresses for underwater protection include accuracy of placement, control of rock volumes used, the stability of the finished lining and, not least, the fact that the rock is contained and does not migrate downstream.

PIPES AND CABLES

Protection is required where pipes or cables pass through the banks and also when they are laid below the natural bed if it is unstable or if future dredging is envisaged.

Bank protection can be by walls or revetments following the methods mentioned in preceding paragraphs. Bed protection also follows these general procedures, with adaptions if not built in the dry.

It may, however, be necessary to ensure that an underlayer be provided to insulate the pipe from direct contact with the mattress and such a feature is included in a specialized form of mattress manufactured with a sand mastic asphalt grout.

This has been more fully described in a paper by the author presented to the Eighteenth Coastal Engineering Conference of the ASCE in November 1982.

This form of construction has developed from the use of linings in situations where the river or canal banks are themselves permeable. Gabions are, as previously stated, free draining and as such are highly suitable for the construction of bunds into which fill is placed hydraulically.

However, there is often a need for a structural lining which is itself impermeable. The use of a sand mastic asphalt grout provides a lining which combines the strength and weight of the gabion mattress with the density and impermeability of the mastic while, most important, retaining flexibility.

The mastic asphalt so used is typically 70% by weight of sand, 15% filler and 15% bitumen. It is poured hot at temperatures at which it flows readily into all the interstices.

Such linings have been used in a number of canals overseas including Suez (2) and numerous others (3). Mastic asphalt has been described in publications by Visser, by the Asphalt Institute and many more (4).

OFFSHORE PIPELINES & CABLES

Although pre-filled gabions and mattresses have been used very successfully in rivers, canals and estuaries it is also useful to have similar protective methods with slightly different qualities for offshore works.

The strength and flexibility of the wire enclosed rip-rap mattress is still necessary, of course, but additional weight is required when the units are to be laid in depths of several thousand feet.

Sand mastic asphalt grout is therefore employed to fully grout the mattresses and also to provide an insulating layer under the mattress itself.

The mix design used permits flexibility at the jobsite, which has been as deep as 600 metres, while remaining manageable on the surface where ambient temperatures as high as 100°F may be experienced.

Such mattresses have been placed accurately in position by remote control vessels in deep water on top of pipelines of 30 to 36 inch diameter. They have also been used in the tidal zone. Simplified forms would, no doubt, be suitable for estuarial use and for crossings of major waterways here.

MATERIALS

The gabions and mattresses referred to in the preceding paragraphs are manufactured in a range of sizes from as small as 6ft.x3ft.x1ft. up to 12ft. x3ft.x3ft.

Mattresses are typically 6 ft. wide and either 9 ft. or 12 feet long. Thicknesses are from 6 inches to 18 inches but the 9 inch thickness is generally used in the United States.

Metric sizes are also made but in view of the lack of progress in metrication there is little demand in domestic projects.

Larger sizes are made from time to time, the largest being units 100 ft. x 6ft. x1'6" supplied to the Old River Project of the Corps. These were, however, found to be a little awkward to handle and 45 feet long units were used for much of the work.

The gabions are fabricated from a double twist mesh, with openings approximately 3" x 4", using heavily galvanized mild steel wire. For use in salt or brackish water a PVC coating is recommended and this should also be used if pollution is present.

The mattresses have a slightly smaller mesh opening and thinner wire but the galvanizing or, more properly, zinc coating is to the same standard. PVC coatings are also commonly used.

Each unit is divided into cells by diaphragms thus effectively reducing movement of rock within the gabions. Assembly is straightforward since lids, sides and ends are already wired together. Of course, proper care is necessary in wiring together adjacent edges.

To maintain the units in rectangular form during filling internal tie wires are recommended at suitable heights.

Reference has already been made to the quality of the rock fill which must be durable. The recommended ranges of sizes are those which would permit maximum use of machines to fill the gabions. Larger rock is permissible in certain cases but requires much more care in placing to avoid excessive voids.

Where wave action is a consideration larger stone should never be used to fill the face of the structure since one advantage of gabions is the dissipation of wave energy in the interstices between the rocks.

Unskilled labor can be used to fill the gabions provided competent supervision is available. As with any other material, proper design procedures must be followed if satisfactory structures are to be the result.

CONCLUSIONS

As a method of construction for canal banks and for pipeline protection the use of wire enclosed rip-rap has a number of attractive qualities, not least the strict control that can be exercised on lines and levels and the avoidance of migratory materials in dredged channels.

The attractive natural appearance of gabion structures, which can become covered with vegetation without affecting the integrity of the system, is another asset in areas where close attention is paid to the environment.

This paper has not entered into detailed design considerations since each project is considered on its merits and standard gabion designs are, perhaps, best avoided since each stretch of a river has its own special characteristics as any pilot will agree.

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DREDGING IN THE PANAMA CANAL

by
Julio R. Rodriguez[1]

I. INTRODUCTION

The Panama Canal is a 50 mile artificially made channel, completed in 1914. It is a locks canal joining the Atlantic and Pacific Oceans. Through a set of three locks, ships are raised up to an average of 85 feet above sea level to Gatun Lake level, one of the largest artificial lakes in the world.

Starting at the Atlantic end, by the Cristobal Breakwater, there is a dredged channel, 500 feet wide, 42 feet deep, that goes from sea to Gatun Locks, where a three-stage double chamber raises the ships from sea level to an elevation of 85 feet above sea level.

From Gatun Locks to Gamboa there are 23 miles through Gatun Lake. The channel in the lake, which is fresh water, is 500, 800, and 1000 feet wide. The minimum depth is 45 feet below the mean lake level. At the south end of the lake is the entrance to the Gaillard Cut, which was dug in dry, mainly on rock, and is the narrowest part of the Canal. The Gaillard Cut is eight miles long, and reaches to the next set of locks, named Pedro Miguel Locks. The width of the Canal in the Cut is 500 feet, widened in 1970. The depth in the Cut, as in the lake, is 45 feet below mean lake level.

At the south end of the Gaillard Cut is Pedro Miguel Locks, where a single stage double chamber lowers the ships from Gatun Lake, 31 feet average, to the Miraflores Lake, also fresh water.

In Miraflores Lake, the channel is 500 feet wide, and 45 feet below mean lake level. At the south end of the lake is the next set of locks, named Miraflores Locks, consisting of a two-stage double chamber that lowers the ships to the Pacific Ocean level at the south end of the Canal. Due to the variation of the tides of 22 feet maximum, ships are lowered up to 65 or up to 43 feet, depending on the tide status.

From Miraflores Locks to sea, there is a seven mile dredged channel, 500 feet wide, with a depth of 42.4 feet minimum below the mean low tides in the Pacific Ocean. The total length of the channel is 51.6 miles.

As all channels, the Panama Canal requires constant maintenance dredging. This dredging is due to several reasons, mainly sedimentation brought by tides and coastal currents, rivers flowing to the Canal, and bank erosion. In addition to the periodic maintenance dredging, a considerable amount of channel improvements are performed with the purpose of increasing the Canal capacity and to improve safety of the users of the Canal. Another source of dredging in the Canal is shoal removal, especially during the low water

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periods in the dry season. One of the most critical dredging requirements in the Canal is slide removal, as past experience indicates; great efforts have been made through the years on slide removals. Other type dredging is occasionally performed as required, such as dredging channels to landing areas, or to remove ships which have been grounded.

Due to the great emphasis put on dredging, the Panama Canal Dredging Division consists of some 600 employees, of which approximately 300 are constantly dedicated to dredging activities.

II. DREDGING REQUIREMENTS IN THE PANAMA CANAL

Several types of dredging are required in the Panama Canal in order to maintain it navigable, to perform improvements and to keep it free from obstructions to traffic. Different types of equipment and techniques are utilized according to these requirements, type of material, traffic restrictions and disposal area limitations. All this dredging is performed in-house with Panama Canal Commission equipment and personnel.

A. Maintenance Dredging: Most maintenance is performed by suction dredging. The material removed is mainly silt and mud. The maintenance dredging is performed periodically, depending on the areas, and the yearly siltation rates. Maintenance dredging is considered the most important type of dredging, since it is a requirement in order to keep the minimum depth for transiting vessels all year round with minimum restrictions to draft.

1. Equipment: On maintenance dredging, the 28" cutter-suction Dredge MINDI is utilized. The MINDI is a three-pump dredge, with a ladder pump and two transport pumps. Its total power is 10,000 h.p. The MINDI, built by Ellicot Machine Corporation in 1943, was originally steam powered, and converted to diesel power in 1980. She can dig to a depth of 65 feet and can produce 1500 cu. yd. of material per hour in good digging conditions. Material is pumped to the disposal site through a combination of floating and shore line of up to 12,000 ft. Floating pipe is 28" steel on steel pontoon floats with mobile pulley ball joints. Shore line is connected with cone ends and clips. Presently, a spud carriage is being procured for the MINDI, together with swing winches, cutter motor and controls, as the final phase of the modernization of the MINDI. This new equipment will increase its production. (Picture #1)

2. Disposal sites: When performing maintenance suction dredging, the material is disposed of at several dumps along the banks of the Canal. A considerable amount of maintenance is performed on these dumps. Most of the maintenance is performed

during the three-month dry season since the weather is more favorable for dike restoration, dewatering and spillway maintenance. Considerable amount of ditching is performed for dewatering, by means of explosives. Explosives have been used for several years with excellent results, saving time and money, and reducing maintenance costs. Good sanitation control is carried out by constant inspection and monitoring and the use of chemical products in the dump areas, reducing to a minimum the growth of mosquitoes and other plagues.

B. Channel Improvements: A great deal of dredging effort is put on channel improvements with the purpose of increasing the Canal capacity and to improve the safety of transiting ships. These improvements are deepening and widening.

1. Equipment: Due to the nature of the material dredged on deepening and widening projects, special equipment which can handle this material is utilized. Through the entire Canal there is a diverse mixture of igneous, sedimentary and metamorphic rock, with 17 different rock formations, complicated by faulting, jointing, and fissuring. Blast fracturing before dredging is necessary on most channel improvement projects.

a) Dipper Dredge RIALTO M. CHRISTENSEN: Built in Japan in 1977 by the Hakodate Dock Company, the CHRISTENSEN is the largest diesel electric dipper dredge in the world. With a 15 cu. yd. capacity, the CHRISTENSEN can dig to 60 feet, making a force of 280,000 lbs. to dredge hard material previously fractured by blasting. The CHRISTENSEN is the most efficient piece of equipment for the type of material to be removed on deepening and widening projects. (Picture #2)

b) Dipper Dredge CASCADAS: Also a dipper dredge, the CASCADAS is a back-up dredge. It has always been the policy of the Panama Canal to have a back-up dredge in order to maintain a slide removal capability. The CASCADAS is a steam dredge built by Bucyrus and is in the Canal since 1915, being still in operation. Its maximum digging depth is 58 feet, and it operates when the CHRISTENSEN is on maintenance. (Picture #3)

c) Dump Scow Fleet: An important equipment in dipper dredging operations is the dump barge. Until August of this year the dump scow fleet consisted of ten 1000 cu. yd. dump scows, bottom dump, pneumatically operated, some built by the U.S. Steel Export Company and the remainder built in-house by Canal forces. The average age of this fleet is 43 years. In August of this year, two of these barges were replaced by modern and larger barges built by Twin City Shipyard. The new barges, diesel-electric-hydraulic, are 1300 cu. yd. capacity, split hull, and are ruggedly built in order to withstand the severe use imposed by the dipper dredging operation. The new scows can be operated from the engine room, from the deck, or by radio control from a distance of up to one-quarter mile. More of these barges will be procured in coming years.

d) Drillboat THOR: Channel improvements in the Panama Canal would not be possible without an effective rock fracturing process. This is the task of the Drillboat THOR. Built by Bethlehem Steel Corporation in 1942, the THOR is responsible for all subaqueous drilling and blasting. With four sliding towers, four powered spuds and deck winches, the THOR is one of the largest drillbarges in the world. Powered by three 1400 cfm compressors, the THOR, when spudded down, is a stable working platform in rough water and the turbulence of passing ships. Its towers can drill four simultaneous holes 71 feet below the water surface on a single pass. Water gel explosives are loaded utilizing the Kelly Bar Method, to a powder factor of 1 to 1.5 pounds per cubic yard. Blasting operations are carefully coordinated with Canal traffic. Once the holes are drilled and loaded, the THOR remains on location until the blast is completed, the area is surveyed and checked for shoals. If a shoal is found, arrangements are made to remove it as soon as possible, depending on the location. In September of 1982, the THOR made the cover of "World Construction" magazine, featuring an article titled, "Drilling and Blasting in the Panama Canal." (Picture #4)

e) Land Drilling Equipment: Land drilling required for channel widening is performed by truck and skid-mounted drill rigs, but mainly by a track-mounted Drillmaster, which is the most powerful and rugged rig for rotary or downhole drilling in soft or hard rock. This quarter million dollar piece of equipment paid for itself in one single project: The Gamboa Reach Widening Project. (Picture #6)

2. Most Recent Channel Improvements: Several improvements of great magnitude have been performed during the past few years, with the purpose of increasing the Canal capacity and improving the safety in the Canal. Among these improvements are:

a) Gaillard Cut Widening: In 1977, the largest improvement in the Panama Canal was completed: The Gaillard Cut Widening, during which 47 million cu. yd. of material were removed. The eight mile long stretch was widened from 300 ft. to 500 ft.

b) San Pablo/Tavernilla Reach Widening: This curve was widened in 1975. One-half million cu. yd. of material were removed. This improvement improved safety since several groundings had occurred in this curve.

c) Gamboa Reach Widening: This 2.7 mile reach was widened from 500 to 650 ft. and the project was completed in 1979. Three and one-half million cubic yards of material were removed in this project. During the Gamboa Reach Widening the largest blast in the history of the Canal was performed: 137,000 lbs. of explosives in a single blast.

d) Mamei Curve Widening: This project was completed in 1982. This curve was also widened for safety purposes. Two and seven-tenths million cubic yards of material were removed in this project which involved the two dipper dredges, the cutter-suction dredge, the clamshell dredge and the Drillboat THOR.

C. Slide Removal: Slides have been a major source of dredging requirements since the opening of the Canal in 1914. Many millions of cubic yards of material have been excavated as a result of slides since then. Due to this, it has been the policy of the Panama Canal Commission to maintain one dipper dredge as a back-up for slide removal. Prior to the arrival of the CHRISTENSEN in the Canal, the CASCADAS was the working dredge and another dipper dredge was the back-up. Now the CHRISTENSEN is the working dredge and the CASCADAS is the back-up dredge. Depending on the magnitude of the slide, several pieces of equipment have been utilized for the removal, including a clamshell dredge. Table 1 shows the major slides since the Canal opening.

D. Shoal Removal: Another dredging requirement in the Canal is the removal of shoals. The reasons for these shoals may be the results of blasts, propeller action or rock falls from the banks.

1. Equipment: Shoal removal is performed by the 7-1/2 yard Clamshell Dredge GOLIATH. The GOLIATH is a 100-ton floating crane built by Bay Shipbuilding Corporation in 1970. Like most of the Canal work, shoal removal and clamshell dredging is closely coordinated with Canal traffic. Due to this requirement, most shoal removals are performed during the non-traffic hours at night, especially when working in the Gaillard Cut. (Picture #6)

E. Other Dredging Requirements: Other types of dredging requirements include the maintenance of access channels to docks and landings, the digging of channels for special purposes, such as removal of vessels which may occasionally go aground. For these dredging requirements different pieces of equipment are utilized depending on the magnitude of the project, type of material, location, disposal site location, etc.

III. CHANNEL DEEPENING PROJECT

A. Background: The Panama Canal Commission is presently undertaking a major dredging project known as Channel Deepening Project. The purpose of this project is to provide additional usable water for the operation of the Canal. Water is essential for the operation of the Canal. On every lockage, 52,000,000 gallons of water are lost from Gatun Lake into the sea. In addition, if water in excess of the needs to maintain maximum ships' draft is available from Gatun Lake it may be utilized for power generation at Gatun Hydroelectric Plant, and water from Madden Lake is used for power generation at Madden Hydroelectric Plant. The water reservoirs for Canal operations are Madden and Gatun Lakes (Picture #7). Madden operates at a maximum elevation of 252 ft. above sea level and feeds water into Gatun Lake at 85 ft. above sea level. During the high water periods (rainy season) these lakes are at their maximum elevations, Gatun at 87+ ft. and Madden at 252+ ft. (Picture #8) and there is plenty of water to generate electric power and for Canal operation. During the low water period (dry season) these lakes are at their minimum levels, as low as 81 ft. in Gatun and 194 feet in Madden during 1983, and water becomes very critical. (Picture #9)

For many years various studies have recognized the need and have proposed methods for providing additional lockage water for ship transits. There are three major methods for gaining the additional water. They are:

a. Additional impoundments.
b. Sea water pumping.
c. Canal Deepening.

The more recent studies, including the 1970-72 Operational Water Board, the 1969 Kearney Report and various in-house studies have recommended that first priority be given to deepening the Canal as the best means of providing additional lockage water at least cost. Following deepening, priorities should be established and detailed studies should be made on reservoirs to impound fresh water.

Because of the many environmental and ecological problems, sea water pumping was relegated to a lower priority. However, since there is a limit to the amount of fresh water available, marine biological studies were recommended and begun on the effects of sea water introduction into Gatun Lake. Because of lack of funding these studies were suspended at the end of FY 1974.

B. The Channel Deepening Concept: The maximum draft in the Canal is 39.5 ft. This draft can be maintained to a certain level. When the lake level drops below 84.5 ft., the draft is reduced accordingly (Figure 1). By deepening the Canal three feet, from PLD 40 to PLD 37, there is an extra three feet that the lake level can be reduced before starting to reduce the draft. That is, the lake can reach a height of 81.5 feet during dry season, not affecting the draft and consequently Canal revenues. The PLD concept is shown on Figure 3.

The average area of Gatun Lake is 160 square miles. By being able to reduce its level three feet, a volume of:

$$3 \times 160\ (5280)^2 \times 7.48 = 1 \times 10^{11} \text{ gal.}$$

This is equivalent to eleven lockages/day of additional water. The additional water obtained by deepening the channel three feet is shown on Figure 2.

C. The Canal Deepening Test Program: The proposed deepening brought out questions relating to ship safety while deepening in the narrow confines of Gaillard Cut. It also brought out other problems such as bank stability, feasibility of using available dredging equipment and various technical and operational procedures.

Dredging Division initiated channel deepening from PLD 40 to PLD 37 on January 13, 1975, when the Drillboat THOR began drilling and blasting in Gaillard Cut. This was the first stage of deepening to a guaranteed navigable bottom of PLD 34. In March-April 1975, the concept of channel deepening to PLD 37 was altered, because the then current hydrographic charts indicated that by deepening in one foot increments the benefits of channel deepening could be accelerated to provide an extra foot of water each year for the succeeding three years.

Subsequently, it was found that one foot incremental deepening was impractical. In addition, the Marine Bureau found it necessary to place constraints on dredging operations that limited the hours in which operations on and near the centerline could be performed. Briefly, the constraints included working on or near the channel centerline only during nighttime hours and the operational requirement of having extra tugs available to assist ships in passing working equipment. These constraints and the requirement to blast only during daylight hours were imposed to insure ship safety as well as safety to the dredging equipment. These constraints, plus difficulties encountered in identifying and digging the scattered areas to achieve a navigable bottom of PLD 39 combined with the higher priority for widening Gamboa Reach resulted in a decision to terminate the one-foot incremental deepening operation. Also, dredging capability and procedures and their operational impact on transiting ships had to be clearly defined.

A demonstration of typical deepening operations was needed to prove that deepening could be done without significantly interfering with ships' transits. Therefore, in coordination with the Marine Bureau, a test program was initiated in October 1976 to determine the operational feasibility of drilling, blasting, and dredging on the channel centerline under present day traffic and ship mix constraints. The test was also established to evaluate conditions which affect ships passing dredging equipment working in a straight reach and on a curve. Of these two conditions, passing equipment working on a curve was considered the most critical and therefore the worst curve was selected for the test program.

Along with determining operating procedures to assure ship safety, it was decided to conduct tests to determine the best means by which the overall deepening project could be most economically and efficiently accomplished. In addition to marine safety, the two primary factors considered in undertaking the overall deepening test program were the time required to complete the total project and the total cost of the project.

2. <u>Objectives</u>:

The objectives of the test deepening program were as follows:

a. Evaluate ship traffic safety in passing dredging equipment working on or near the channel centerline.

b. Determine if drilling, blasting and dredging could be accomplished under present day and anticipated ship traffic constraints.

c. Evaluate current practices regarding drilling, blasting and dredging and recommend changes to improve current practices if warranted.

(1) Determine if blasting could be accomplished under existing blasting constraints which were imposed due to concern for slope stability.

(2) Determine if changes are needed to improve existing blasting procedures.

(3) Determine the optimum drilling and blasting pattern.

(4) Determine shoaling and bulking from blasts.

(5) Investigate the use of alternate equipment.

d. Determine how much of the existing deep areas (areas below PLD 34) within a required drill pattern were practical to eliminate from drilling.

e. Determine whether it was practical and economical to dig to PLD 37 on the first pass and then to PLD 34 on a subsequent pass.

The Canal Deepening Test Program was a practical test, made under actual working conditions. It was started in November 1976 and concluded in October 1977. During the test program, Gatun Lake level varied from a low of 81.45 feet PLD to a high of 85.71 feet, PLD.

The study also determined:

a. The best pattern to be used.
b. Fragmentation of material.
c. Shoaling and bulking due.
d. Delays to be used in different cuts.
e. Powder factors.

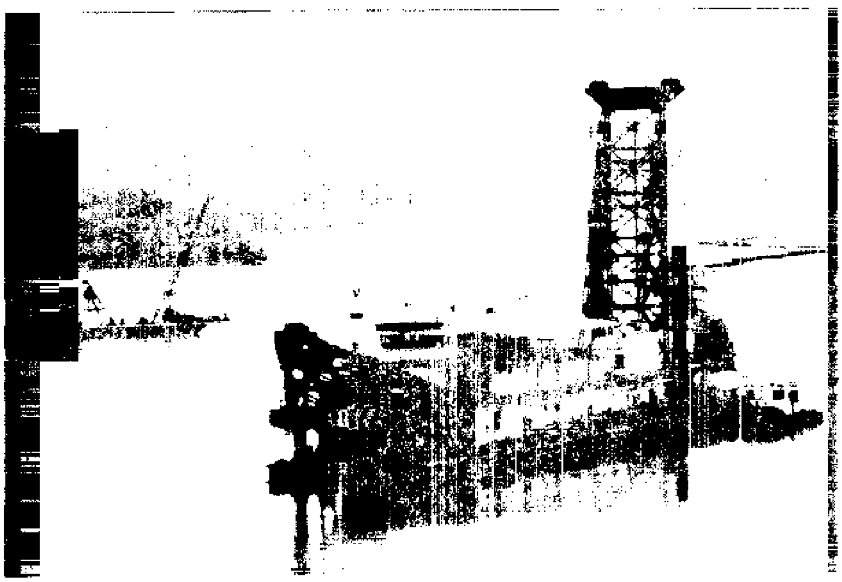
The Channel Deepening is presently underway and is expected to be completed by May of 1985.

TABLE 1

MAJOR SLIDES IN GAILLARD CUT

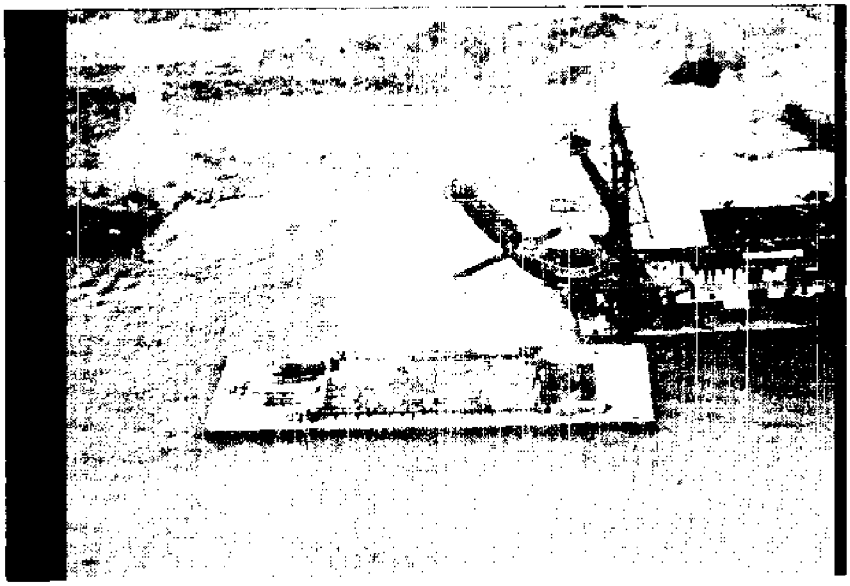
SINCE CANAL OPENING

LOCATION		Period of Activity		TOTAL CU. YD.
		From F.Y.	To F.Y.	
CUCARACHA SLIDE	(EAST)	1914	1934	9,344,350
CULEBRA SLIDE	(EAST)	1914	1960	21,070,600
CULEBRA SLIDE	(WEST)	1914	1957	14,975,750
LA PITA SLIDE	(EAST)	1915	1958	151,300
LA PITA SLIDE	(WEST)	1915	1933	47,450
WHITE HOUSE SLIDE	(EAST)	1916	1959	97,700
WHITE HOUSE SLIDE	(WEST)	1916	1933	121,500
EMPIRE SLIDE	(EAST)	1916	1938	278,550
LIRIO SLIDE	(EAST)	1916	1937	245,150
LIRIO SLIDE	(WEST)	1917	1961	2,614,800
CASCADAS SLIDE	(EAST)	1917	1943	62,450
POWDER HOUSE SLIDE	(EAST)	1917	1938	468,000
PARAISO SLIDE	(EAST)	1917	1933	9,200
BUENA VISTA SLIDE	(WEST)	1918	1937	8,500
HAUT OBISPO SLIDE	(EAST)	1918	1933	12,200
DIVISION OFFICE SLIDE	(WEST)	1918	1932	23,600
CONTRACTOR'S HILL SLIDE	(WEST)	1918	1919	39,500
CONTRACTOR'S HILL SLIDE	(NORTH)	1918	1943	167,600
BUENA VISTA SLIDE	(EAST)	1919	1923	29,650
BARGE REPAIR SLIDE	(EAST)	1922	1946	762,100
CUCARACHA SIGNAL STA. SLIDE	(WEST)	1923	1941	247,900
SOUTH CUCARACHA SLIDE	(EAST)	1924	1939	193,250
CARTAGENA SLIDE	(WEST)	1924	1937	315,950
CUCARACHA VILLAGE SLIDE	(EAST)	1925	1931	110,800
CULEBRA SLIDE EXTENSION	(EAST)	1933	1940	1,483,450
MIRAFLORES SLIDE (COCOLI HILL)		1950	SAME	46,100
WHITE HOUSE SLIDE EXTENSION	(WEST)	1955	SAME	62,850
CUCARACHA SIGNAL STA. SLIDE	(SOUTH)	1955	SAME	18,400
BAS OBISPO SLIDE	(EAST)	1959	1966	26,500
CARTAGENITA SLIDE	(WEST)	1965	SAME	54,200
CASCADAS SLIDE	(EAST)	1973	SAME	114,500
CULEBRA SLIDE	(EAST)	1974	SAME	397,300

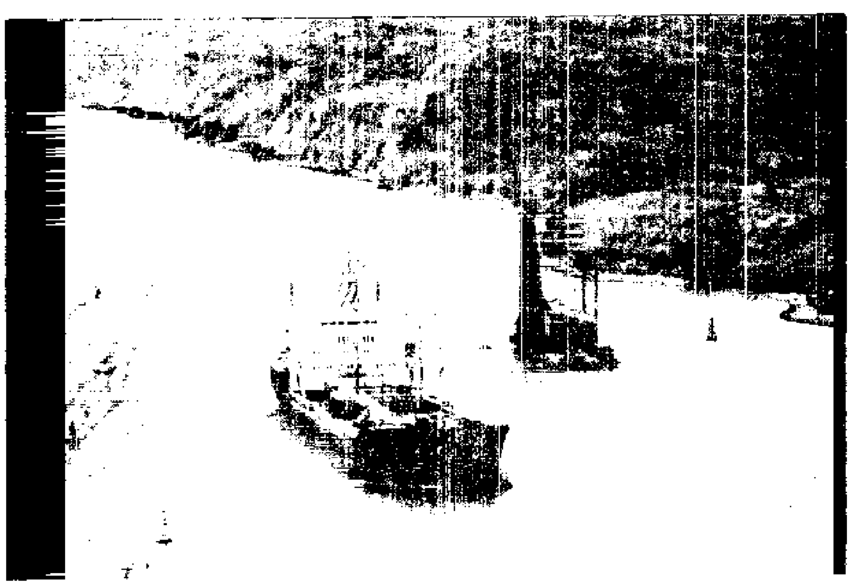


PICTURE #1 CUTTER SUCTION DREDGE MINDI

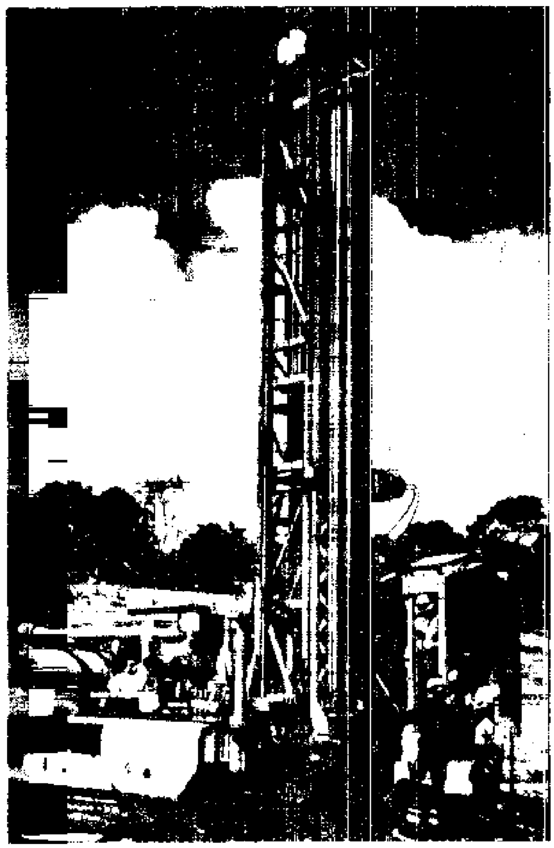
PICTURE #2 DIPPER DREDGE RIALTO M. CHRISTENSEN



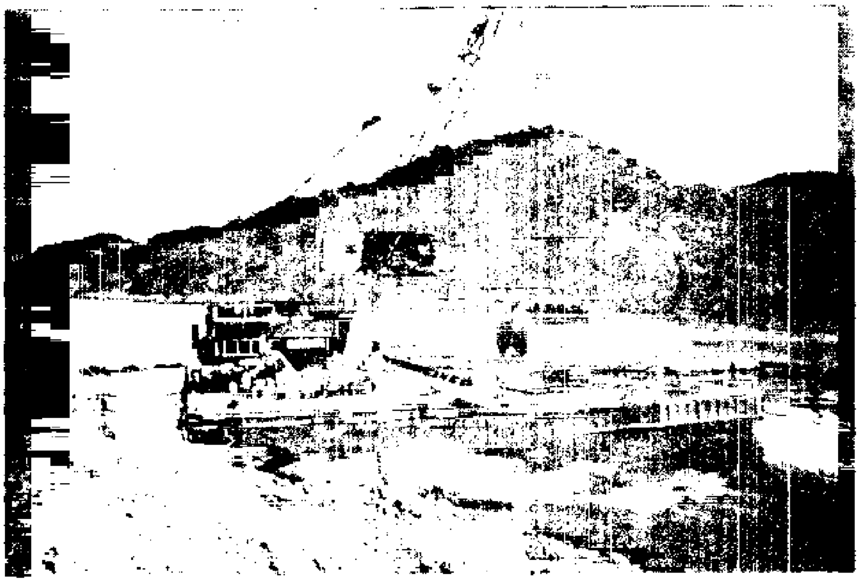
PICTURE #3 DIPPER DREDGE CASCADAS



PICTURE #4 DRILLBOAT THOR

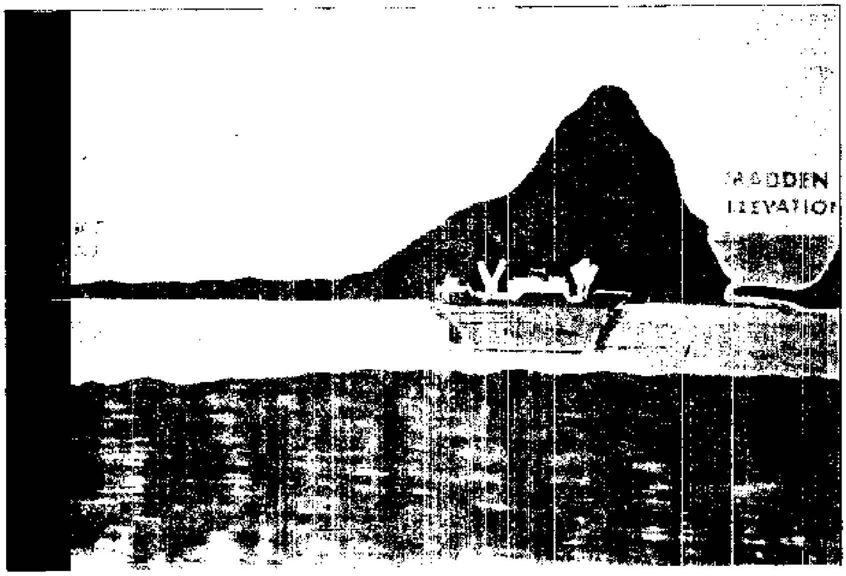


PICTURE #5 DRILLMASTER

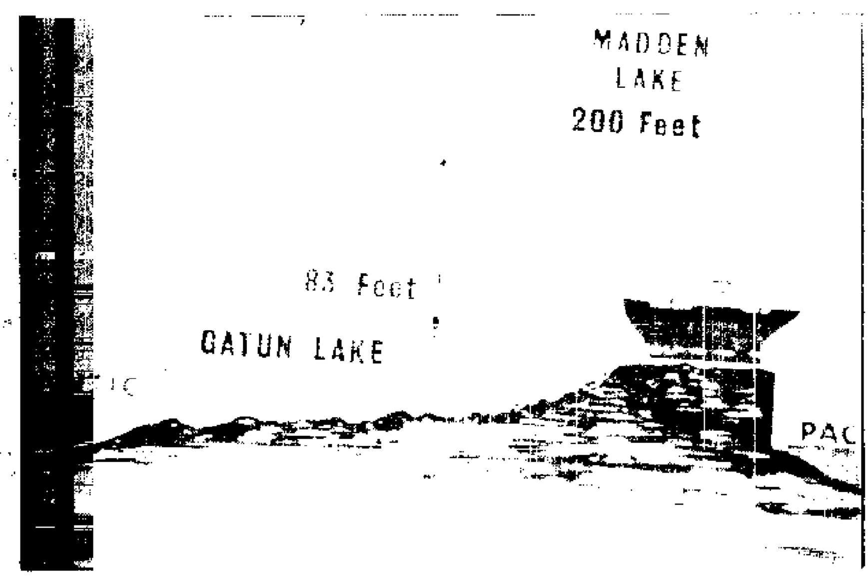


PICTURE #6 CLAMSHELL DREDGE GOLIATH

PICTURE #7 MADDEN AND GATUN LAKES



PICTURE #8 MADDEN AND GATUN LAKES AT HIGH WATER



PICTURE #9 MADDEN AND GATUN LAKES AT LOW WATER

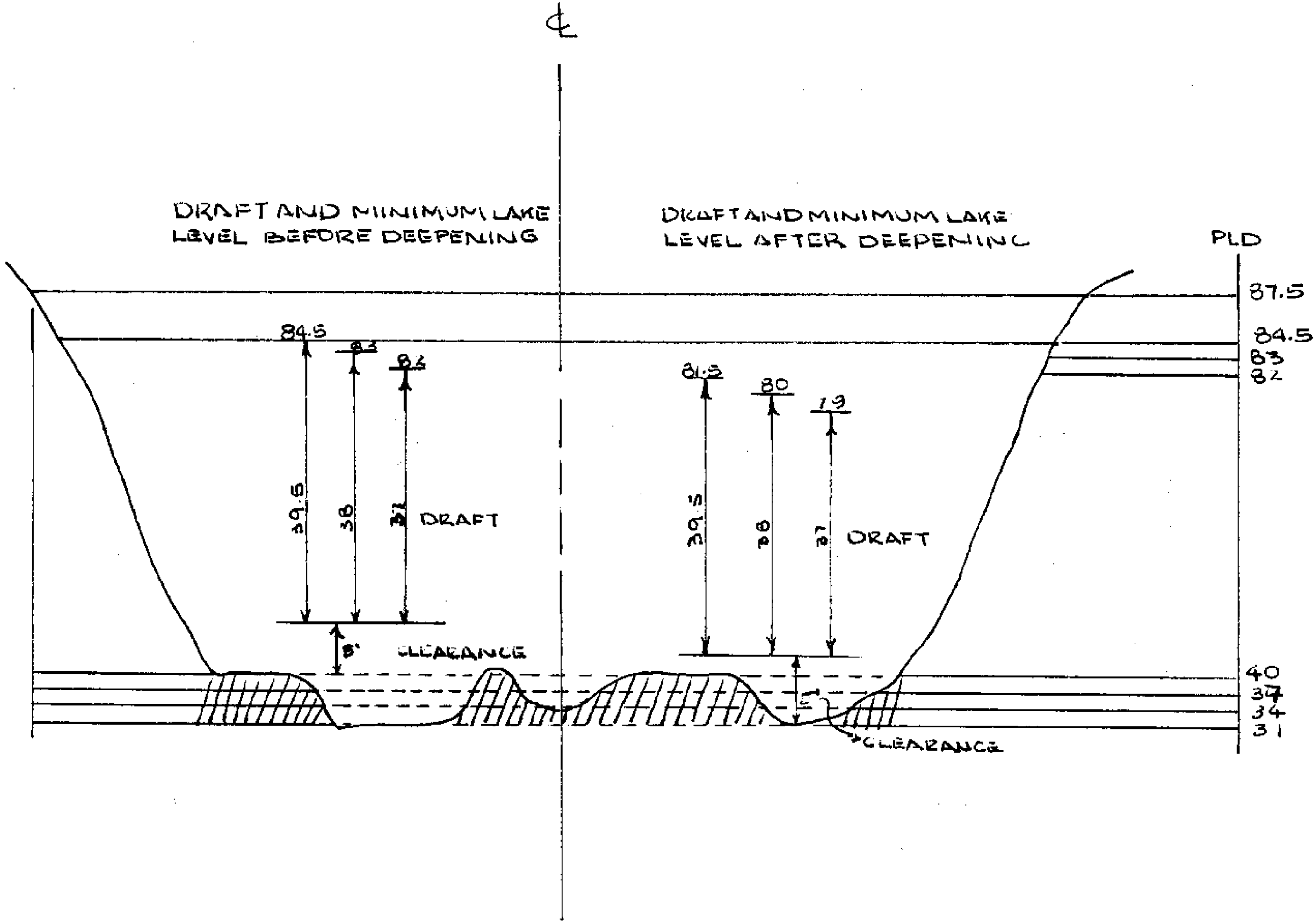


Figure 1. Drafts and Lake Levels Before and After Deepening

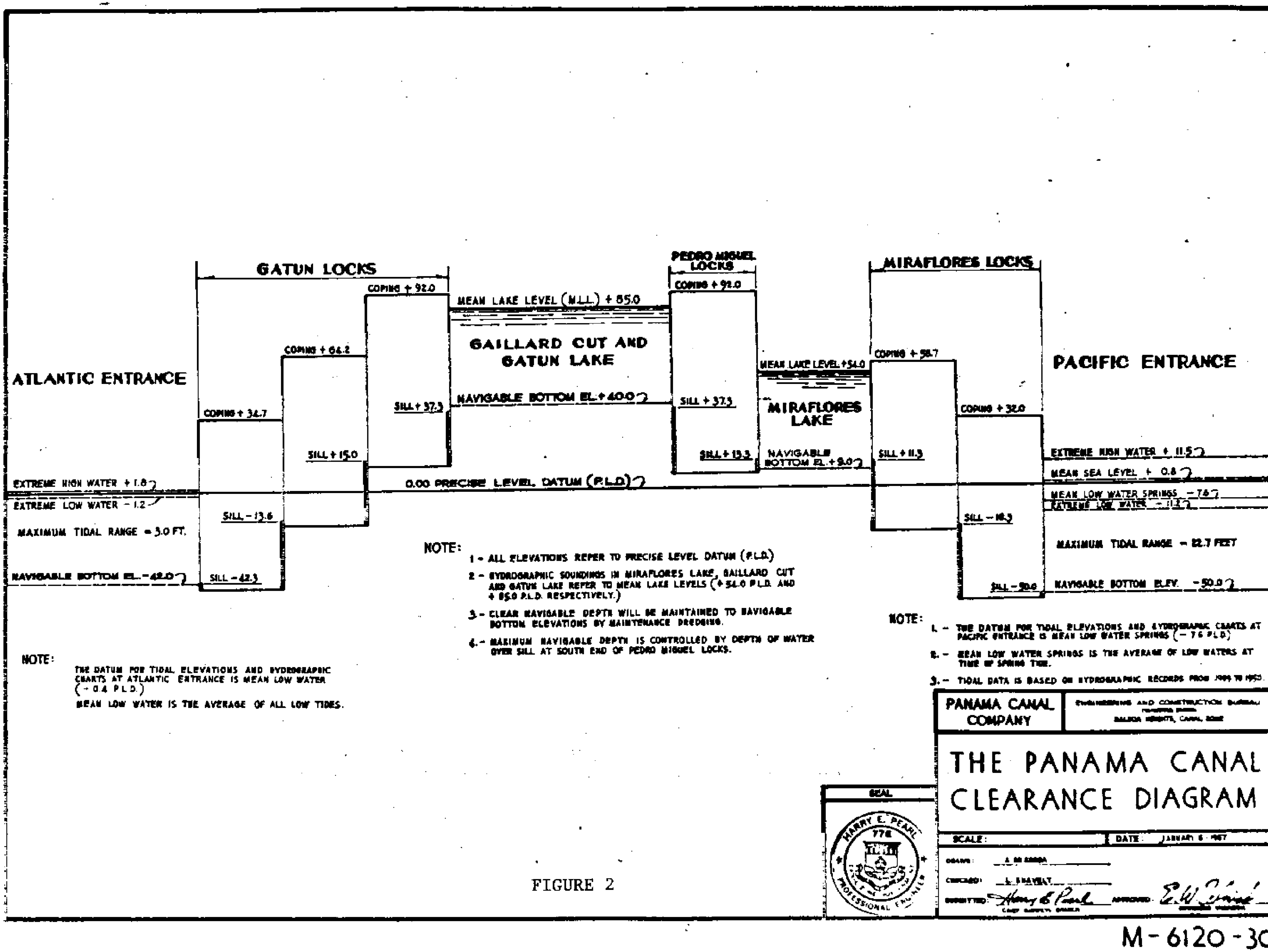

GATUN LOCKS
COPING + 34.7
COPING + 64.2
COPING + 92.0
SILL + 15.0
SILL + 37.3
SILL - 13.6
SILL - 42.3
ATLANTIC ENTRANCE
EXTREME HIGH WATER + 1.8
EXTREME LOW WATER - 1.2
MAXIMUM TIDAL RANGE = 3.0 FT.
NAVIGABLE BOTTOM EL. -42.0
MEAN LAKE LEVEL (M.L.L.) + 85.0
GAILLARD CUT AND GATUN LAKE
NAVIGABLE BOTTOM EL. + 40.0
0.00 PRECISE LEVEL DATUM (P.L.D.)
PEDRO MIGUEL LOCKS
COPING + 92.0
SILL + 37.3
SILL + 13.3
MEAN LAKE LEVEL + 54.0
MIRAFLORES LAKE
NAVIGABLE BOTTOM EL. + 9.0
MIRAFLORES LOCKS
COPING + 58.7
COPING + 32.0
SILL + 11.3
SILL - 18.3
SILL - 50.0
PACIFIC ENTRANCE
EXTREME HIGH WATER + 11.5
MEAN SEA LEVEL + 0.8
MEAN LOW WATER SPRINGS - 7.6
EXTREME LOW WATER - 11.3
MAXIMUM TIDAL RANGE - 22.7 FEET
NAVIGABLE BOTTOM ELEV. - 50.0
NOTE:
1 - ALL ELEVATIONS REFER TO PRECISE LEVEL DATUM (P.L.D.)
2 - HYDROGRAPHIC SOUNDINGS IN MIRAFLORES LAKE, GAILLARD CUT AND GATUN LAKE REFER TO MEAN LAKE LEVELS (+ 54.0 P.L.D. AND + 85.0 P.L.D. RESPECTIVELY.)
3 - CLEAR NAVIGABLE DEPTH WILL BE MAINTAINED TO NAVIGABLE BOTTOM ELEVATIONS BY MAINTENANCE DREDGING.
4 - MAXIMUM NAVIGABLE DEPTH IS CONTROLLED BY DEPTH OF WATER OVER SILL AT SOUTH END OF PEDRO MIGUEL LOCKS.
NOTE:
THE DATUM FOR TIDAL ELEVATIONS AND HYDROGRAPHIC CHARTS AT ATLANTIC ENTRANCE IS MEAN LOW WATER (- 0.4 P.L.D.)
MEAN LOW WATER IS THE AVERAGE OF ALL LOW TIDES.
NOTE:
1. - THE DATUM FOR TIDAL ELEVATIONS AND HYDROGRAPHIC CHARTS AT PACIFIC ENTRANCE IS MEAN LOW WATER SPRINGS (- 7.6 P.L.D.)
2. - MEAN LOW WATER SPRINGS IS THE AVERAGE OF LOW WATERS AT TIME OF SPRING TIDE.
3. - TIDAL DATA IS BASED ON HYDROGRAPHIC RECORDS FROM 1909 TO 1953.
PANAMA CANAL COMPANY
THE PANAMA CANAL CLEARANCE DIAGRAM
SEAL
SCALE:
DATE:
M-6120-30

FIGURE 2

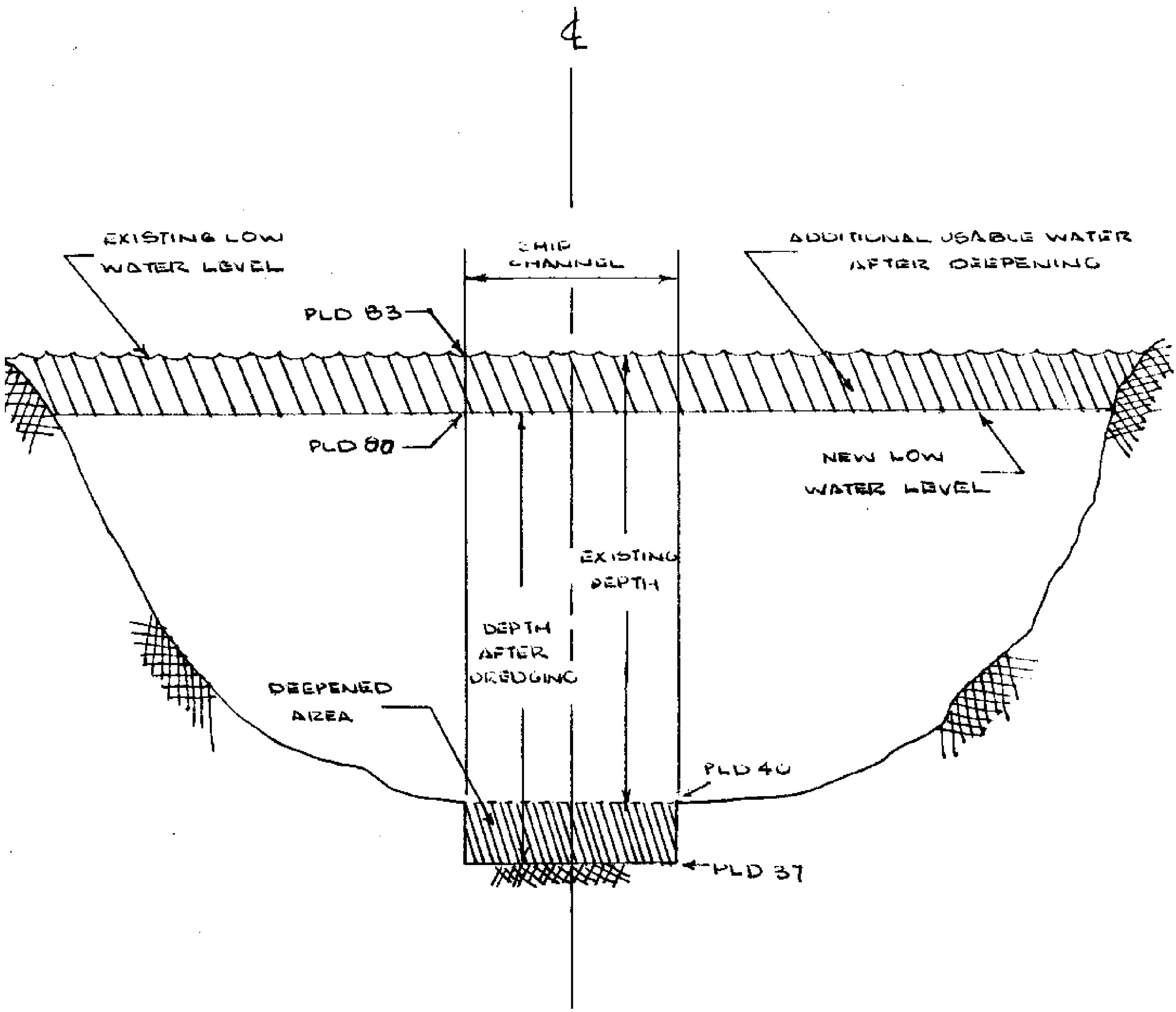


Figure 3. Water Available Before and After Dredging to PLD 37

BRIEF PERSONAL HISTORY

Julio R. Rodriguez

Education:	B.S., Electromechanical Engineering, University of Panama, 1969. Post graduate studies in Dredging at the University of Zulia, Venezuela.
Experience:	From 1969 to present am employed by Panama Canal Commission. Present position: Chief, Operations Branch of the Dredging Division, Panama Canal Commission.
Registrations:	Registered Professional Engineer, Texas. Registered Professional Engineer, Republic of Panama
Professional Affiliations:	Member of the National Society of Professional Engineers Past President of the Panama Canal Chapter and presently, National Director.

MANAGEMENT OF LAKES THROUGH SEDIMENT REMOVAL

by

Spencer A. Peterson [1]

When properly conducted, sediment removal is an effective lake management technique. This paper describes: 1) the purpose of sediment removal, 2) environmental concerns, 3) depth of sediment removal, 4) sediment removal techniques, 5) suitable lake conditions, 6) exemplary case histories, and 7) costs.

PURPOSES OF SEDIMENT REMOVAL

When recreational activities are impaired due to shoaling, the only practical means of restoring lake use is to deepen it through sediment removal. The intended lake use, availability of dredge material disposal area, and available funds must be considered in the design of a lake deepening project. The reasons for deepening and the means of measuring the success of such projects is the most straightforward of the sediment removal objectives. The efficiency of modern dredging equipment being what it is, it is little wonder that in 1970 Pierce indicated all lake dredging projects undertaken for the purpose of deepening were successful.

Shallow eutrophic lakes frequently are susceptible to periodic influx of nutrients from the sediment. These inputs of phosphorus and nitrogen occur most often during peak recreation periods. They usually result in algal blooms and are thus an annoyance to users.

Welch _et al_. (1979) estimated phosphorus inputs to Long Lake, Washington were 200-400 kg yr^{-1} or about 25-50% of the external loading. Shagawa Lake, Minnesota experiences summer internal phosphorus pulses of approximately 2000-3000 kg during June, July, and August. This represents about 66% of the total annual phosphorus loading. Sediment recycled phosphorus in Shagawa Lake has been sufficient to produce large summer algal blooms, thus reducing its predicted rate of recovery following advanced wastewater treatment at the City of Ely (Larsen _et al_., 1981).

The above indicates phosphorus loading from sediment constitutes a significant portion of total phosphorus loading in some lakes. Therefore, sediment removal might be expected to reduce the rate of internal nutrient recycling, thus improving water quality for recreational purposes.

Toxic substances are becoming a common concern among industrialized nations. Insufficient treatment and disposal practices of the past have materialized into today's problems. Large scale surveys and improved

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analytical techniques are demonstrating that toxicants are more common to freshwater sediments than previously suspected (Horn and Hetling, 1978; Matsubara, 1979; Bremer, 1979). Many of the toxicants recycle from the sediment to the overlying water column where they may be bioaccumulated by aquatic organisms. Perhaps the most infamous incident of this type was the mercury pollution of Minimata Bay, Japan in 1956 (Fujiki and Tajima, 1973). More recent incidents in the United States have involved kepone contamination of the James River, Virginia (Mackenthun et al., 1979) and PCB contamination of Waukegan Harbor, on the Great Lakes (Bremer et al., 1979).

Removal is the most obvious solution to the problem of contaminated sediments. However, removal frequently is complicated by secondary pollution of the overlying water column due to sediment agitation during the removal process. Cutterhead hydraulic dredges can remove large volumes of sediment, but unfortunately they can also resuspend large volumes of fine sediment (Suda, 1979; Barnard, 1978). Resuspension of sediment while dredging toxic substances must be minimized to prevent potential environmental damage. Therefore, proper selection of equipment becomes important to the success of toxic sediment removal.

Rooted aquatic plants may interfere with fishing, boating, and swimming activities. An overabundance of these plants may also be aesthetically displeasing. Beyond this a large biomass of plant material may produce adverse oxygen conditions due to respiration in the littoral zone during hours of darkness. In addition, there is an increasing literature on the effects of macrophytes on internal nutrient cycling. Their role in this process, with its effect on algal dynamics, may be an important reason for attempting to control macrophytes by removing them from a lake. Wetzel (1975) indicates that most of the organic matter found in small lakes may be derived from their littoral zone. A number of other researchers have documented that various species of freshwater aquatic plants extract nutrients chiefly from the sediment and translocate them to the surrounding water (Schults and Malueg, 1971; Twilley et al., 1977; Carignan and Kalff, 1980).

Barko and Smart (1979) estimated that in-lake mobilization of phosphorus by *Myriophyllum* in Lake Wingra, Wisconsin, might amount to approximately 60% of the annual external phosphorus loading. Welch et al. (1979) indicated that much of the "sediment" phosphorus loading in Long Lake, Washington was probably due to rapid plant die-off and decay. Current information indicates that any long range lake restoration project concerned with in-lake nutrient controls will need to focus on both macrophytes and sediment (Carignan and Kalff, 1980; Barko, 1980).

ENVIRONMENTAL CONCERNS

There are a number of potential environmental problems associated with sediment removal. The problems generally can be classified according to in-lake and disposal area types. In-lake problems commonly center around the resuspension of sediment during its removal by dredge. One of the most common problems is the liberation of nutrients. Phosphorus is of particular concern due to its high concentration in interstitial waters of eutrophic lakes. Dredge agitation and wind action tend to move dredge-disturbed nutrient-laden sediment into the euphotic zone of the lake, creating the potential for algal blooms. Dunst (1980) found increased algal production in Lilly Lake, Wisconsin, when hydraulic dredging began. It was short-lived, however, and never posed a nuisance level problem. It appears that nutrient enrichment due to dredging can be real, but that in most cases the short-term impacts relative to the long-term benefits will be negligible.

Toxic substances in sediments may be a major concern. Although small lake, sediment removal projects for the purpose of removing toxic substances have been relatively uncommon, there is a growing concern (Matsubara, 1979; Sakakibara and Hayashi, 1979; Bremer, 1979; Spencer Engineering, 1981). The major problem associated with toxicants and resuspended sediment centers around fine particles. Murakami and Takeishi (1977) have shown that up to 99.7 percent of the polychlorinated biphenyls (PCB) associated with sediment is attached to particles less than 74 µm in diameter. This could become a problem in freshwater dredging projects where particle settling times are significantly greater than for marine waters. Therefore, special precautions including dredge types and/or disposal and treatment techniques should be considered (Matsubara, 1979).

A relatively common concern with lake dredging projects is the destruction of the benthic community. If the lake basin is dredged completely, two to three years may be required to reestablish the benthic fauna (Carline and Brynildson, 1977). However, if portions of the bottom are left undredged the reestablishment may be almost immediate (Andersson _et al._, 1975; Collett _et al._, 1981) or within one to two years (Crumpton and Wilbur, 1974). In any case, the effect on benthic communities appears to be short-lived relative to the longer term benefits derived. The same appears to be true for game fish populations (Carline and Brynildson, 1977; Spitler, 1973).

The major non-lake impact of sediment removal concerns the dredged material disposal area. Locating a disposal site for urban projects is a major problem. Section 404 of Public Law 92-500 prohibits the filling of any wetland area exceeding 4.0 ha (10 acres) without a Federal permit. Thus, low lying areas which in the past were commonly filled are more difficult to obtain permits for if they are available at all. The flooding of wooded areas with dredge disposal material should be discouraged. Flooding kills trees providing unsitely evidence of an improper disposal plan.

A frequently used disposal method in recent years employs diking in upland areas. A not uncommon problem with these sites is dike failure and associated destruction of adjacent areas (Calhoun, 1979). Groundwater contamination may become a problem with upland disposal if sand or gravel underlies the disposal area. Water wells in these areas could become contaminated, potentially adding liability to the sediment removal project.

Another problem not uncommon to lake dredging is underdesign of disposal area capacity. Unfortunately, these failings usually become apparent only after the project is fully operational. The problem may be associated with the slow settling rate of suspended sediment in freshwater (Wechler and Cogley, 1977). As disposal areas begin to fill, their ponding depth is reduced and so is their efficiency to retain suspended solids. This may result in failure to meet discharge permit requirements. If that happens there are but two choices: shut-down until seepage and evaporation allow additional filling, or treat the discharge water. Either alternative means additional expense to the project. Disposal area designs must be formulated for end of project efficiency, not average discharge requirements over the entire project. Palermo *et al*. (1978) have summarized important technical information that will assist with the proper design, construction, and maintenance of dredged material disposal areas. Barnard and Hand (1978) describe when and how to treat disposal area discharges if standards cannot be met. Other reports by Brannon (1978), Chen *et al*. (1978), Gambrell *et al*. (1978) and Lunz *et al*. (1978) provide valuable information that will help minimize environmental problems at disposal sites.

SEDIMENT REMOVAL DEPTH

When restoring a lake for sailing, power boating, and associated activities, the deepening requirements are relatively straightforward. However, when deepening to control internal nutrient cycling and macrophyte growth, the criteria are less clearly defined.

Lake Trummen, Sweden, is perhaps the most thoroughly documented case history of sediment removal to control internal nutrient cycling. Sediment removal depth in Lake Trummen was determined by mapping both the horizontal and vertical distribution of nutrients in the sediment. Digerfeldt (1971), as referenced by Bjork (1972), determined that approximately 40 cm of fine surface sediment accumulated from 1940 to 1965. Aerobic and anaerobic release rates of $PO_4^{=}$-P and NH_4^{+}-N from this surface layer were markedly greater than for the underlying sediment. Based on these differences a plan was developed to remove the upper 40 cm of sediment.

Another approach to determining sediment removal depth has been proposed by Stefan and Hanson (1979). Their approach is similar to that developed by Stauffer and Lee (1973) which described thermocline erosion by wind in northern temperate lakes. Stefan and Hanson (1979), have used their model to predict the depth to which a lake must be dredged to maintain stable summer stratification.

The Stefan and Hanson (1979) model assumes stable summer stratification is necessary to prevent enriched hypolimnetic waters from mixing into the epilimnion. Based on that assumption they calculated that Hall Lake, Minnesota, would require dredging to a maximum depth of 8.0 m. Dredging volume to obtain the 8.0 m depth would be enormous given the lake's current 2.25 km^2 surface area and 2.1 m mean depth.

There is no apparent chemical/physical distinction between shallow and deep sediments in Hall Lake. Phosphorus concentration is relatively uniform from the sediment surface to a depth of 8.5 m. However, it is possible that the phosphorus release rates from deeper sediment could be less than those of surface sediments. If that were the case for Hall Lake, surface sediment skimming might produce nearly the same result as deep dredging and at a considerable saving. Therefore, it seems advisable to conduct nutrient release rate experiments prior to adopting a lake temperature modeling approach to determine dredging depth for nutrient control.

Dredging will remove rooted macrophytes from the littoral zone of lakes, but there have been few detailed studies to determine depths necessary to prevent plant regrowth. Factors influencing the areas in which rooted macrophytes grow include temperature, sediment texture, sediment nutrient content, and light level.

Using information developed by Belonger (1969) and Modlin (1970), the Wisconsin Department of Natural Resources developed a guide to prescribe dredging depths necessary to control the regrowth of macrophytes. The guide was developed by regressing the maximum depth of plant growth in several Wisconsin lakes against their average summer water clarity (light level via Secchi disk). The relationship is described by the equation:

$$Y = 0.83 + 1.22X$$

where,

Y = maximum depth of plant growth (meters)
X = average summer water clarity (meters)

According to Dunst (1980) the above relationship is used as a rough guide to develop dredging plans for macrophyte control. Dunst indicated, however, that dredging depths need not always exceed the predicted Y-value to achieve control. He indicated further that slight deepening frequently changes plant speciation to less objectionable forms.

Hutchinson (1975) while describing the work of Maristo (1941) stated "The maximum depth at which autotrophic plants can grow, irrespective of their nature, clearly does depend on the transparency of the water." The reliability of this relationship could be determined simply by regressing maximum depth of summer plant growth for several individual lakes against average summer Secchi disk transparency and determining the correlation coefficient.

SEDIMENT REMOVAL TECHNIQUES

There are two basic types of lake sediment removal practices. The first is the land based technique which employs buckets, or clamshells operated by mechanical dragline from the shore. A variation of the same technique is lake drawdown or dewatering followed by bulldozer excavation in the lake basin.

One advantage of bucket or clamshell dragline operations is their ability to remove hard sediment at *in situ* density. A second advantage is their mobility from one location to another since most are truck transportable track-mounted units. Beyond these two factors most aspects of dragline use for lake sediment removal are negative. One of the greatest limitations of the dragline is its short reach, commonly no more than 20 to 40 m. A second disadvantage is the rough, uneven bottom configuration normally created in hard sediment by dragline buckets. The sediment production rate for draglines is relatively low because of their bucket swing, drop, close, retrieve, lift, and dump operation cycle. Dragline operations commonly create very turbid water conditions.

Some of the problems mentioned above can be overcome by using silt curtains. The silt curtain consists of a continuous polyethylene sheet (skirt) buoyed at the surface and weighted at the bottom so it hangs perpendicular to the water surface. It may be used to isolate a length of shoreline where draglines are being operated or to encircle an open water dredging operation (Figure 1). The purpose of the silt curtain is to isolate turbidity conditions within the immediate dredging area, thus protecting adjacent clean water areas. Silt curtains, while effective in controlling surface turbidity, are open at the bottom and will permit the escape of turbid water near the sediment water interface.

Another means of minimizing turbidity from grab or bucket type dredging operations is to use a covered, watertight unit (Figure 2). These watertight buckets are manufactured in sizes ranging from 2 to 20 m^3. The manufacturer claims turbidity reductions from 30 to 70 percent compared to open buckets of comparable size. Dredged material production using watertight buckets is cleaner than conventional buckets, but still relatively inefficient compared to hydraulic dredges.

Lake drawdown or dewatering, a preliminary step to bulldozer excavation, usually is restricted to artificial lakes having outlet control structures. Water level in these reservoirs can be lowered easily exposing a large portion of the basin. After proper drying, sediment is scraped from the basin with earthmoving equipment. Apparent drying of lake sediments can be deceiving. Although they become crusted and cracked at the surface, they frequently are fluid and soft underneath. Pierce (1970) pointed out that the drawdown and bulldozer technique may be accomplished most effectively in cold climates, during the fall or winter when the sediment is frozen. An added incentive for this is that total expenses may be reduced by employing equipment operators during the off season. Fall and winter treatment would also minimize recreational use impairment.

The limitations of dragline operations and the problems of dewatering natural lakes leads to the second basic approach to sediment removal, the use of floating equipment. The simplest type of floating equipment is a clamshell or bucket dredge mounted on a barge. This type of dredge is used most frequently in removing "hard-pan" material and is not employed commonly in small lake dredging. This configuration has

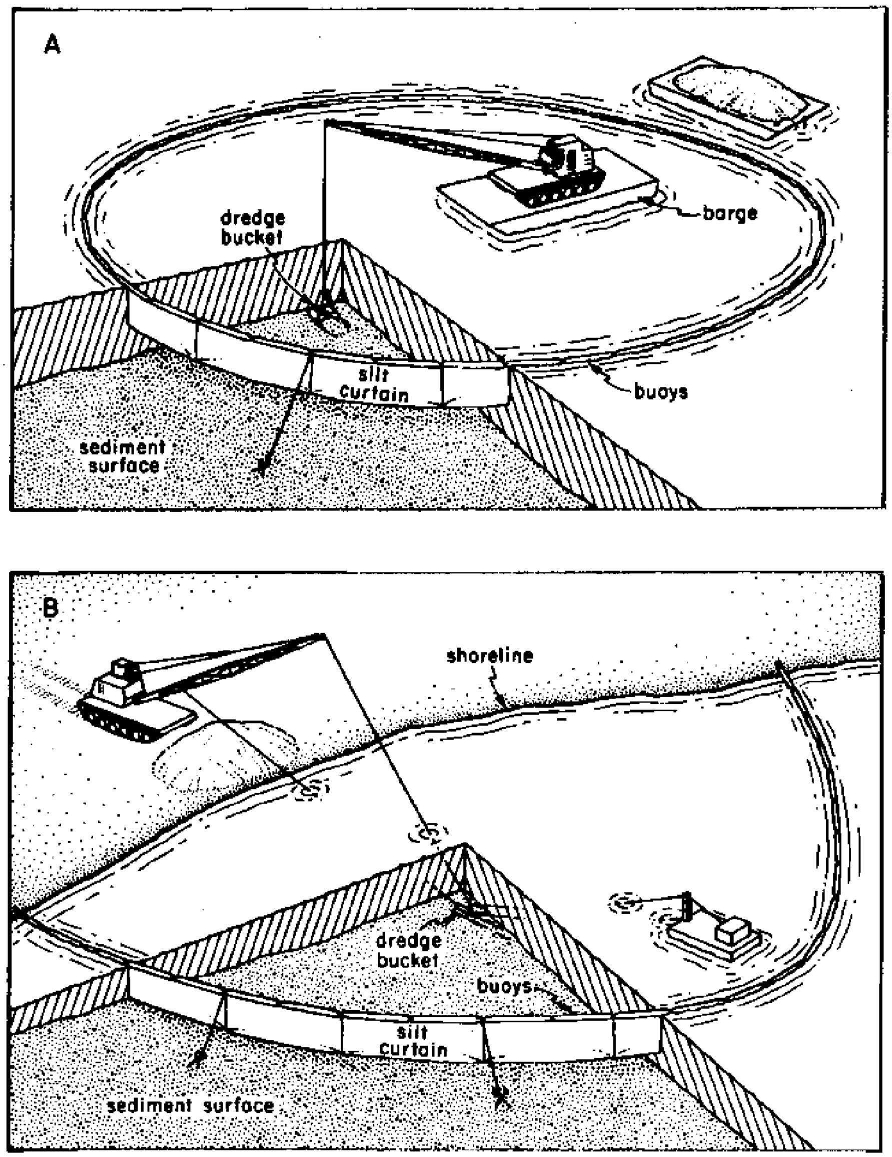

Figure 1. A) Silt curtain encirclement of an open water clamshell operation.

B) Shoreline isolation of a bucket dragline operating using a silt curtain.

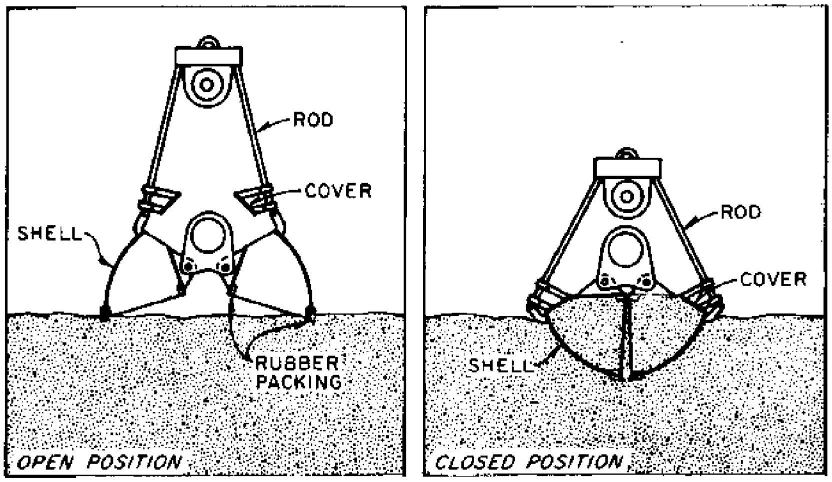

Figure 2. Open and closed positions of the watertight bucket redrawn from Barnard (1978).

the same shortcomings as its land based counterpart in terms of production efficiency and turbidity. Floating clamshell operations are frequently encircled by silt curtains to minimize turbidity. Although their operating cycles are somewhat inefficient relative to hydraulic dredges, they can be very effective where underwater logs, stumps, or boulders might be encountered. These conditions frequently are found in reservoirs.

Hydraulic dredges include hopper, dustpan, and cutterhead systems. Hopper dredges typically are large ocean-going vessels used for maintaining stream channels and harbor areas on large lakes. They are impractical for small lake use.

Dustpan dredges employ wide vacuum cleaner like heads with a series of high velocity water jets to loosen the sediment. Suction heads of a dustpan dredge are typically oriented upstream so that material broken up by the water jets flows into the pickup head in a fashion similar to the sweeping of debris into a dustpan. From there it is taken up by suction from the pump and discharged through a pipeline to a disposal area. Dustpan dredges usually are large non-portable apparatuses and thus not readily employed in lake restoration. However, Pierce (1970) indicated the dredge used at Greene Lake, Washington, in 1961-62 was a unique variation of a dustpan dredge. The apparatus described by Pierce was an extremely simple, but apparently efficient, one which removed 9.17×10^3 m^3 of sediment from the lake. The positive experience at Greene Lake indicates that dustpan or modified dustpan dredging practices may warrant further examination for freshwater lakes.

Inland lake sediment removal is most commonly accomplished with a cutterhead hydraulic pipeline dredge. This type of equipment has become the workhorse of the dredging industry and has become relatively common to inland lake dredging projects with the advent of small portable equipment. The primary components of any cutterhead dredge system include: 1) the hull, 2) the cutter head, 3) the ladder, 4) the pump, 5) the power unit, and 6) the dredged material distribution pipe (Figure 3A).

Sediment loosened by the cutter moves to the pickup head by suction from the pump. The sediment slurry, typically 10 to 20 percent solids, is discharged to a remote disposal area by pipeline. Diameter of the discharge pipe describes the nomenclature of cutterhead dredges. Figure 3B shows how the cutterhead is swung from side to side by pulling alternately on the port and starboard swing wires. Forward movement of the dredge is accomplished by alternately raising and lowering spuds at the stern.

Portable dredges for lake use are essentially miniatures of the large cutterhead dredges that have been used in coastal construction and harbor maintenance work for years. Consequently, they are probably not as efficient as they might be, if modified specifically to handle lake sediment which is highly viscous and commonly contains 40 to 60 percent organic materials.

Modern hydraulic dredged can move large quantities of sediment. One reason for this is that they are not confined to near-shore operations. Another reason is their continuous operating cycle. High production rates are not without their negative aspects. Most hydraulic dredge slurry contains 10-20% solids. Stated another way, 80-90% of the slurry volume is water. If the residence time of the disposal area is inadequate to precipitate the solids, discharge permits may be violated. In this event, it becomes necessary to either shut down temporarily or to treat the discharge water. In either case the large water volumes produced by hydraulic dredges might become an added expense. The large pumping capacity of these dredges adds the possibility of an unplanned lake drawdown unless overflow water is returned to the lake.

The amount of sediment supplied to the suction head is controlled by cutter rotation rate, thickness of the cut, and the swing rate (Barnard, 1978). Improper combination of any of these might cause the generation of excessive turbidity. Therefore, not only the configuration of the dredge equipment itself, but the skill of the dredge operator is important to minimizing turbidity.

Portable cutterhead dredges, as mentioned previously, are essentially miniatures of large coastal waterways dredges. The cutterheads of coastal dredges were designed for cutting sand, clay, and silt sediment. They were not intended for use in fine, flocculant organic sediments encountered in lake dredging. Therefore, simple downsizing of the coastal dredge has not been entirely satisfactory for lake dredging projects. Consequently, soft lake sediments have been a challenge to

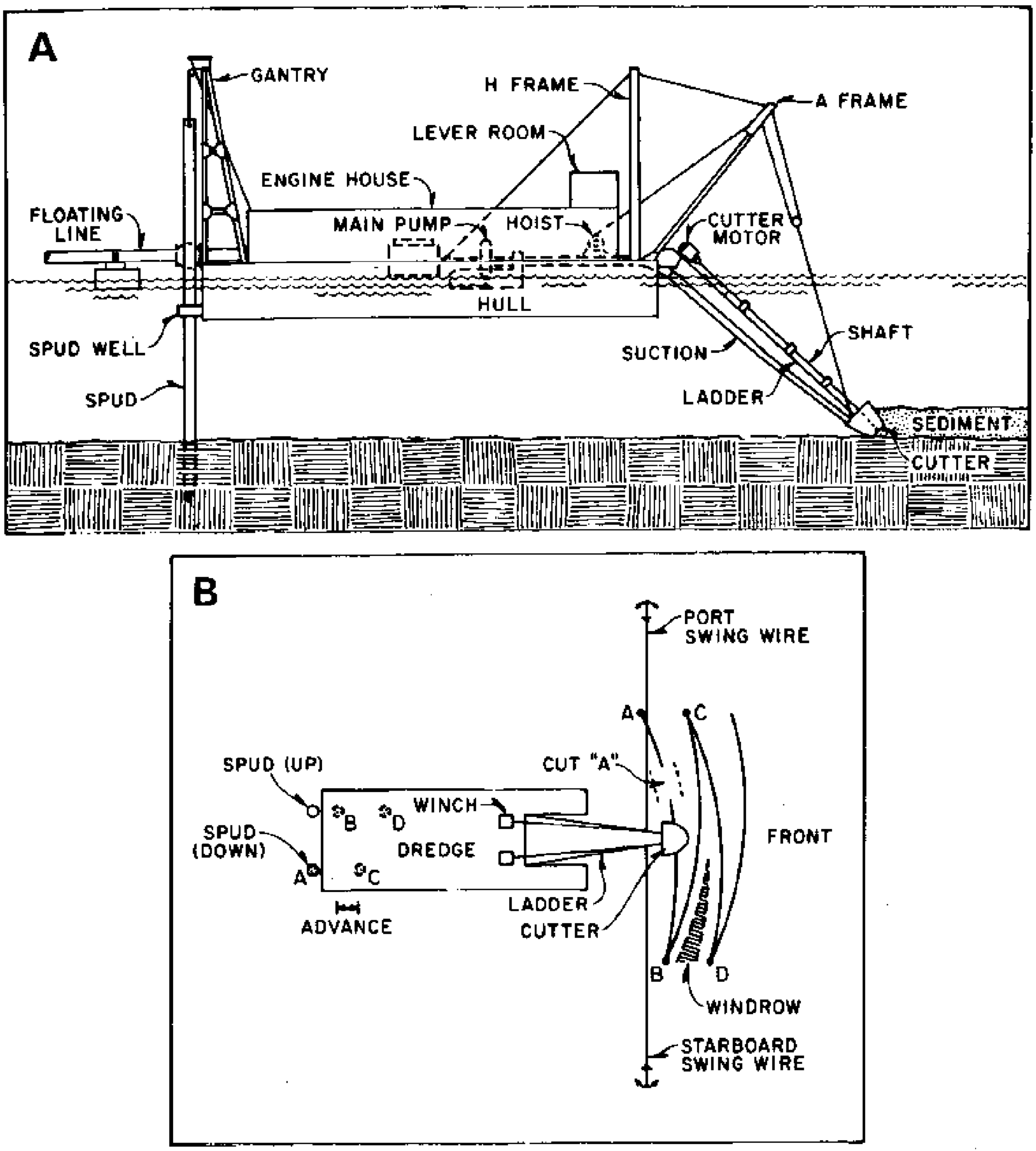

Figure 3A. Configuration of a typical cutterhead dredge. B. Spud stabbing method for forward movement and resultant pattern of cut (modified after Barnard, 1978).

the dredging industry. These fine sediments are easily disturbed and resuspended to the overlying waters by dredging activity. Attempts to deal with this problem has brought several innovations. Among them is the cutterhead design used by Mud Cat®. Mud Cat dredge intakes resemble those of dustpan dredges, but instead of water jets, they use a horizontal auger to dislodge and move sediment to the center of the (2.4 m wide) dredge head where it is sucked up the intake.

Figure 4 demonstrates the high mobility of the small Mud Cat dredges. Note also the mud shield which can be raised or lowered over the auger head to minimize resuspension of sediments. Nawrocki (1974) reported turbidity plumes due to dredging with a Mud Cat machine were confined to an area no more than 6 m distant from the dredge; however, operating conditions were not clearly defined. Suspended solids in the increased turbidity area ranged from 39 to 1260 mg liter^{-1}. Those near the bottom were approximately 1000 mg liter^{-1}. More turbidity is created by forward motion of the dredge than by backwad motion. This appears to be associated with raising the mud shield while moving forward and lowering it when moving backward. Mallory and Nawrocki (1974) indicated the Mud Cat dredge should be capable of producing 30 to 40 percent solids.

The Mud Cat guidance system is well suited to work on small water bodies. The dredge operates on a cable anchored at both shorelines. This permits uniform dredging of the bottom with few missed strips. Mud Cat dredges have been used successfully at Collins Park and several other small lakes in New York State. The portability, guidance system, reduced turbidity, and increased solids content of these dredges appears to make them ideally suited to small lake restoration projects.

There are a few other dredging systems which, although not commonly used on lake dredging projects, deserve mention because of their unique capabilities. Each of these systems was developed specifically for soft, viscous sediment similar to that found in lakes. The machines were originally created on a large scale for harbor maintenance, however, it appears feasible to downsize them for lake dredging, which has been done in some cases (Matsubara, 1979; Spencer Engineering, 1981).

The pneuma dredging system is unique among dredging systems. It was developed in Italy and employs air driven pumps. The system commonly consists of three cylindrical pump bodies, a pickup head, a compressor, and air lines to the pump bodies. This system operates on the principle that sediment and water, under hydrostatic pressure, will be forced into the pump body which is maintained at atmospheric pressure. Therefore, the filling efficiency increases with increased depth (increased hydrostatic pressure). At depths less than 10m, however, hydrostatic pressure is insufficient to operate the system effectively. The Japanese Oozer® dredge system (a modified pneuma system) has overcome the problem of operating at shallow depths by creating partial vacuum in the pump bodies during the filling phase. Partial vacuum in the pump bodies also permits more rapid filling at

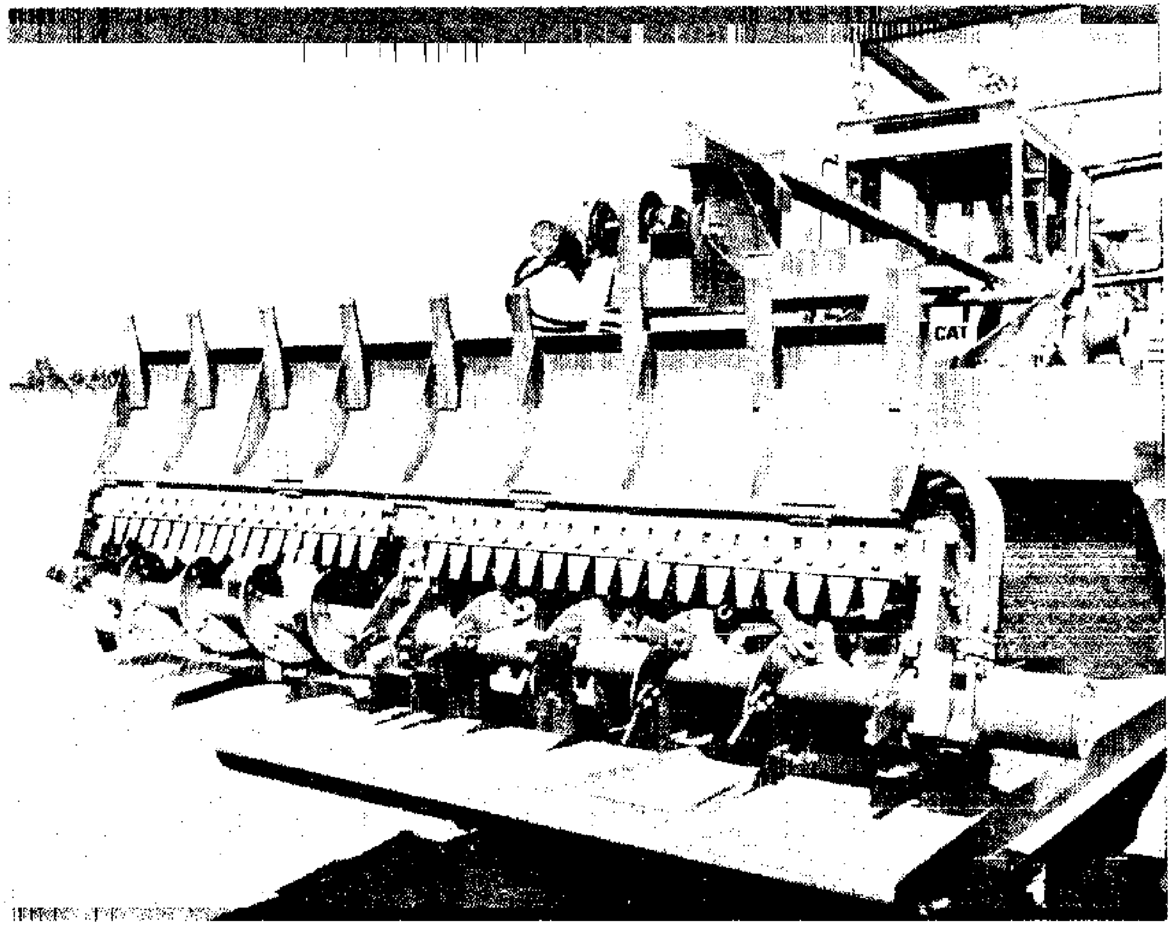

Figure 4. The mud cat dredge features a unique auger-type cutterhead. Size of the dredge makes it extremely portable (with permission of National Car Rental).

greater depths. Figure 5 is a schematic diagram of the Oozer dredge system. The use of vacuum and air pressure to respectively fill and empty the pump body and drive sediment through the discharge pipe, permits the removal of soft sediment at in situ density. This means the solid content of these dredge slurrys may run as high as 70 percent (Koba et al., 1975).

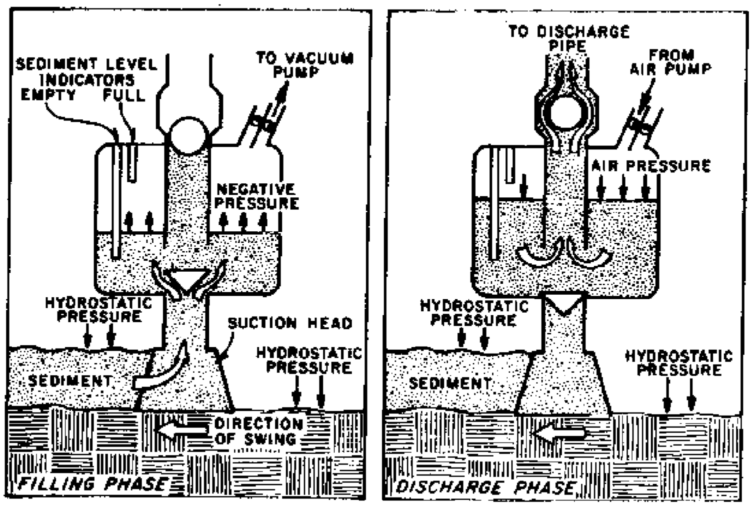

Figure 5. Schematic of oozer dredge system.

High solid content of the dredge material has several advantages, among them is that production rate is relatively high (500 to 2,000 m^3 hr^{-1}), sediment removal at in situ density minimizes its resuspension, and far less water volume must be contained at the disposal area.

Another dredge specialized for soft sediment removal is the cleanup system developed by TOA Harbor Works Company of Tokyo, Japan. This system employs a special suction head consisting of an auger, movable plates to direct sediment flow, a floating wing device to contain sediment as it is fed to the auger, and a large gas collection shroud (Figure 6). Methane and hydrogen sulfide gases, frequently liberated from organic sediment during dredging, are collected by the shroud thus preventing foul odors.

The structural configuration of the Oozer and Cleanup dredges are similar to a conventional cutterhead dredge (Figure 3a). Likewise their cutpaths are created by swinging the cutter from port to starboard and vice-versa. The major differences are in the pickup head configuration, the cutter (auger) apparatus, and the pumps. As with most hydraulic cutterhead dredges, the Cleanup System has a large centrifugal pump mounted within the hull. However, in addition it has an auxillary submerged centrifugal pump at the end of the ladder near the pickup head. The combination of pickup head configuration and pump equipment, as with the Oozer System, permits the removal of soft sediment at in situ density (20 to 70 percent solids in the slurry according to Sato, 1978).

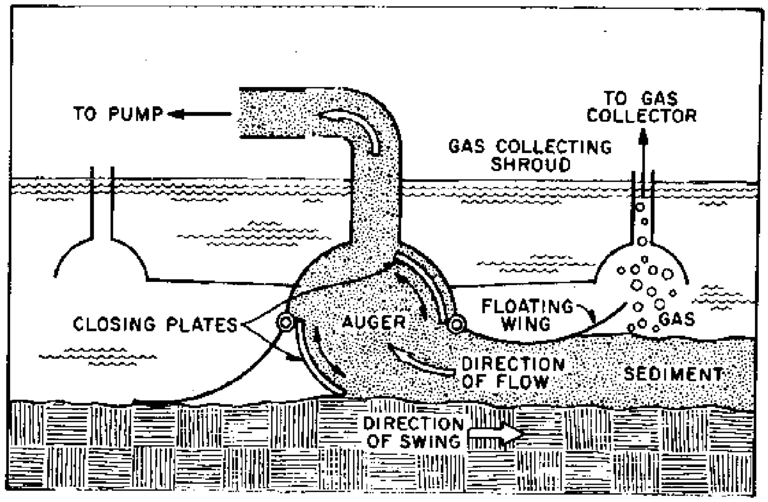

Figure 6. Suction-head of cleanup dredge system.

Both systems were compared with conventional cutterhead equipment to determine their relative ability to minimize secondary pollution from sediment resuspension (Suda, 1979). Suspended solids concentrations 1.5 m above the sediment water interface, and directly over the two special dredge heads averaged 6 to 8 mg liter^{-1}. Under similar conditions the suspended solids concentrations around a conventional cutterhead averaged 40 to 80 mg liter^{-1} at the same depth.

Although the above two specialized dredge systems were developed by the Japanese to remove highly contaminated sediments from large harbors, they demonstrate that extremely soft sediment can be removed efficiently with minimal resuspension if properly designed equipment is employed. A miniature Oozer system has been used successfully to remove polluted sediment from Lake Kasumigaura, Japan (Matsubara, 1979). Also, a Pneuma Pump dredge system was employed recently at Gibraltar Lake, California where mercury contaminated sediment was removed. The major problem encountered with the Pneyma system at Gibralter Lake was poor pump body construction. The entire pump bodies had to be disassembled and re-welded. Also, the rubber in the valving system proved to be a weak point (Spencer Engineering, 1981). After much reworking, the dredge system averaged 500-600 µ3 hr^{-1} production at an average suspended solids concentration of 40-50 percent.

LAKE CONDITIONS SUITED TO DREDGING

When a lake has sedimented sufficiently to be unusable for boating, swimming, and fishing activities, virtually nothing short of dredging will restore these uses. However, the high cost of dredging (Peterson,

1979) dictates that the feasibility of this treatment be examined closely in comparison to the intended use of the lake and alternative treatment methods.

Size of the lake might seem important to determining dredging feasibility. However, size appears not to be a constraint. Peterson's (1979) examination of 64 lake dredging projects found that size ranged from less than 2 ha to over 1,050 ha and that volume of removed sediment ranged from a few hundred m^3 to over 7 million m^3. The mobility of modern hydraulic dredges and their pipeline disposal systems indicate that there are few technological limitations to dredging large inland lakes.

The one aspect of large inland lake dredging that might become limiting is the requirement for a commensurately large disposal area. A dicotomy arises from the fact that restoration is most frequently sought for lakes in densely populated areas where sediment disposal space is most scarce. It is also true, however, that the greatest user benefits will be derived from projects in densely populated areas (JACA, 1980). Therefore, it is important that disposal alternatives be explored for these situations.

Various productive uses of dredged material have been examined by Lunz et al. (1978), Walsh and Malkasian (1978), and Spaine et al. (1978). A practical solution was employed at Nutting Lake, Massachusetts, where approximately 153 x 10^3 m^3 of sediment was sold as a soil conditioner at a price of \$1.40 m^{-3}. This reduced the total dredging cost by \$215,000 and the per unit dredging cost to about \$1.00 m^{-3} (Worth, 1981). The selling and removal of dredged material does not negate the need for a "disposal area," but it may reduce the size requirement of what actually becomes a sediment handling area. A 7 ha, two-basin handling area with a total holding capacity of approximately 98 x 10^3 m^3 was used at Nutting Lake. This area provided sufficient capacity for a season's dredging. Before the next dredging season (summer), the material was removed, sold, and the initial disposal capacity was available once more. In this way, the disposal area need not be permanently dedicated to a fill. The point is that any lake, to be suitable for dredging must be in reasonable proximity to a disposal area, but lack of an area adequate to accommodate <u>all</u> of the dredged material need not hamper a project from going forward.

Sediment removal projects should have reasonable assurance of longevity in order to be cost effective. Therefore, an estimate of sedimentation rates should assist in determining the feasibility of dredging. Although dredging is expensive on a per unit basis of dredged material, when costs are amortized over the life expectancy of the project they may look much more reasonable. Sedimentation rates will help establish this "reasonableness." If all other conditions are similar, lakes with large surface areas, relative to their watershed areas, will probably have lower sedimentation rates than small lakes with large watersheds. Thus, the large lake/small watershed scenario will probably benefit more from dredging than will the small lake/large watershed one.

All of the above factors address physical features, i.e., depth, size, disposal, and watershed area, and sedimentation rate, but what of the chemical aspects of sediment and their influence on lake biota? Current information demonstrates that lakes with highly enriched surface sediments relative to underlying sediment might benefit from shallow dredging (Andersson et al., 1975; Bengtsson et al., 1975). Lake Trummen, Sweden showed marked changes in water chemistry and biota when 40 cm of rich surface sediment was removed (Bjork, 1978). Similar changes were observed in Steinmetz Lake, New York when 25 cm of organic sediment was removed and replaced by the same amount of clean sand (Snow et al., 1980). In both cases, extensive sediment surveys before dredging revealed that surface sediment was disproportinately rich in phosphorus and nitrogen relative to the deeper sediment. Sediment profiles can be developed with the assistance of a Livington piston corer. It will be important to note sediment color and texture differences with depth and to chemically characterize (phosphorus and nitrogen) the surface (0 to approximately 2 in) sediment relative to deeper sediment if nutrient control is the intent (Peterson, 1981). Beyond this it will be quite useful to know the sediment particle size, settling rate, volume, etc. in order to design a disposal area and select the proper dredge. A report by Palermo et al. (1978) provides good guidance for disposal area design and Pierce (1970) offers assistance in selecting lake dredging equipment.

Several variables may determine the suitability of a lake to dredging. However, the lakes most suitable would generally be shallow, have low sedimentation rates, organically rich sediments, long hydraulic residence times, and the potential for extensive use following dredging.

CASE HISTORIES

Dunst et al. (1974) identified 33 United States dredging projects in their "Survey of Lake Rehabilitation Techniques and Experiences." Seven years later Peterson (1981) listed 64 planned, active, or completed projects in this country. No doubt both the 1974 and 1981 listings were incomplete since many small lake dredging projects are completed, but never reported in the open literature. If records are available from these projects they seldom extend beyond the completion date. Therefore, few well documented long-term evaluations are available. The two case histories that follow represent sediment skimming and deep sediment removal techniques. They are both considered to be successful at this time and have ample documentation to demonstrate that success.

It should not be construed from the following presentations that all dredging projects to control internal nutrient recycling are successful. On the contrary, there have been numerous failures. However, almost all failures or marginally successful projects can be traced to inaccurate predredging assessment of the problem and to inadequate amounts of sediment removal (Brashier et al., 1973; Churchill et al., 1975; George et al., 1981). The need for accurate assessment of the problem cannot be overemphasized.

The most thoroughly documented long-term evaluation of lake dredging took place at Lake Trummen, Sweden. The lake has a history of receiving domestic and milling wastes since 1936. Sewage discharge to the lake stopped in 1959 after the flax-dressing plant closed and wastewater from the surrounding area was connected with a municipal treatment system. Despite the wastewater diversion, no apparent recovery of the lake followed. A limnological investigation of the lake in 1968 revealed that the upper 1 meter of sediment was extremely nutrient rich relative to that underlying it.

One meter of surface sediment was dredged from the main lake basin in 1970 and 1971. This removal increased the mean depth of the lake from 1.1 to 1.75 m and the maximum depth from 2.1 to 2.5 m. The total volume of the sediment removed was about 30 x 10^5 m^3. By any standard the lake was still extremely shallow and could have remained eutrophic except that the sediment skimming treatment reduced the phosphate phosphorus content in the surface sediment layer sediment from 2.4 to 0.1 mg $liter^{-1}$ (Sjön Trummen i Växjo, 1977).

The dredged material was partially disposed in shallow diked-off bays. The remainder went to upland diked ponds where return flow was treated with aluminum sulfate to reduce the total phosphorus concentration from about 1 mg $liter^{-1}$ to 30 μg $liter^{-1}$. Dried dredge material was sold as top soil dressing for about $2 (U.S.) m^{-3}.

Bengtsson _et al_. (1975) indicated that the role of the sediment in recycling nutrients was reduced substantially following dredging. The data in Figure 7 demonstrate an approximate 90 percent reduction of total phosphorus in the surface water of Lake Trummen after dredging (from 600 μg $liter^{-1}$ to a range of 70-100 μg $liter^{-1}$).

The significant nutrient reduction in the lake resulted in equally significant biological changes. The Shannon diversity index for phytoplankton rose from 1.6 in 1968 to 3.0 in 1973 (Cronberg _et al_., 1975). Secchi disc transparency went from 23 to 75 cm during the same period. The blue-green algal biomass was reduced dramatically and the nuisance species _Oscillatoria agardii_ disappeared completely. Phytoplankton productivity went from a level of 370 g C m^{-2} in 1968-69 to about 225 g C m^{-2} in 1972-73.

The affect of dredging on the benthic community of Lake Trummen was negligible. A year after dredging tubificid oligocheates and chironomids were more numerous than before dredging, but the total number of benthic organisms changed little (Andersson _et al_., 1975). Rapid recolonization was attributed to the mobility and constant swarming of chironomids.

Surface sediment skimming at Lake Trummen was successful in rolling back the effects of eutrophication. The results have remained relatively constant for nine years, which attests to the thorough pretreatment evaluation and the rational plan for restoration. These

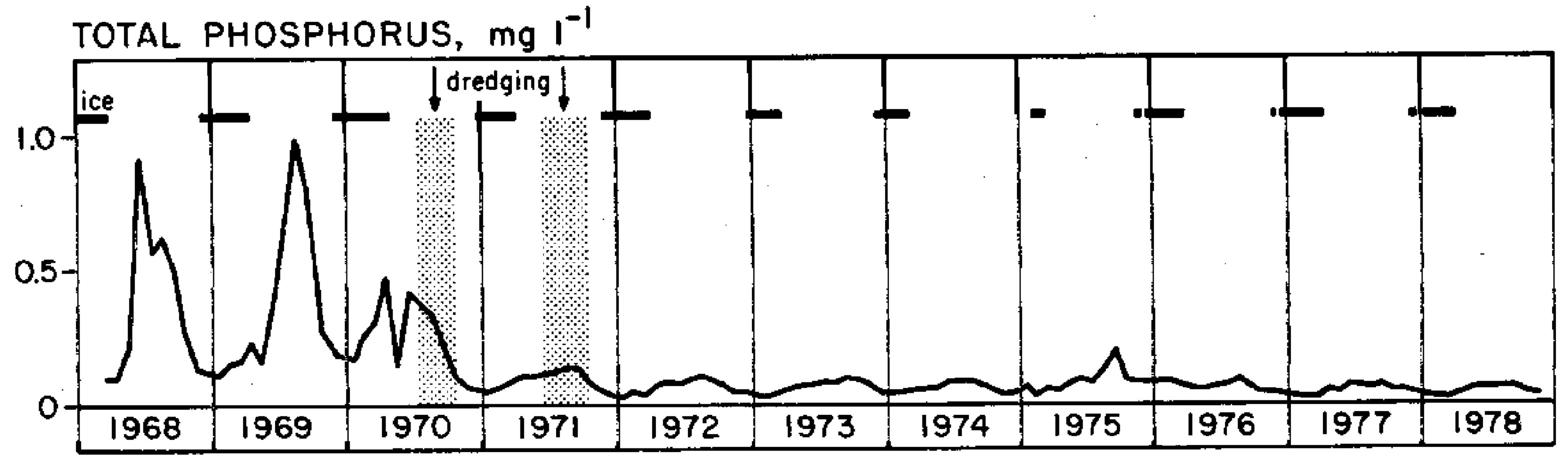

Figure 7. Total phosphorus concentraration in Lake Trummen, Sweden before and after dredging (courtesy of Gunnar Andersson, Department of Limnology, University of Lund, Lund, Sweden).

results are highly encouraging, because if surface sediment dredging is successful in a shallow lake like Trummen, it should also be successful in deeper ones with similarly enriched surface sediment.

Lilly Lake is a 37 ha closed basin lake in southeastern Wisconsin. Its agricultural watershed is only 155 ha. In 1977, shoaling had advanced to the point that the lake had a maximum depth of 1.8 m and a mean depth of only 1.4 m. The basin contained more than 10 m of partially decomposed plant materials. The Wisconsin Department of Natural Resources (1969) reported that chemical eradication and restocking of centrarchid and northern pike failed due to severe winter kill problems. The rate of basin infilling by sedimentation had reached 0.5 cm yr^{-1} (Dunst, 1981).

Restoration of Lilly Lake for fish management purposes was recommended by the Wisconsin DNR (1969). The plan called for deepening at least 10 percent of the basin to a depth of 6m. This required removing 665 x 10^3 m^3 of sediment.

Dredging began in July 1978 and continued until freeze-up in November. It began again in May 1979 and was completed in September. The dredged material was pumped approximately 3 km and disposed of in an abandoned gravel pit. Although the groundwater table rose temporarily due to this disposal, monitoring wells revealed no adverse impact on groundwater quality. Figures 8, 9, 10, and 11 show in-lake changes for selected variables before, during, and after dredging. Prior to dredging in 1977 the total inorganic nitrogen (TIN) concentrations were barely detectable. Although total phosphorus (TP) increased to more than 40 µg $liter^{-1}$ during July, August, and September it was not due to excessive phytoplankton concentrations as evidenced in Figure 10. The water quality *per se* of Lilly Lake was not exceptionally poor prior to dredging. However, water volume was reduced significantly due to the presence of macrophytes and partially decomposed macrophytes in the sediment.

Adverse, although not severe, short-term changes occurred during the active dredging period. TIN increased rapidly (Figure 8) when dredging began in July 1978, due mostly to the liberation of ammonium-nitrogen from the sediment (Dunst, 1981). It remained in excess of 3.5 mg $liter^{-1}$ during most of the 1978-1979 ice-cover period then declined steadily throughout the spring and summer.

TP concentrations behaved in a fashion similar to TIN, except there were minor peaks in TP during the summer of 1978. TP remained relatively high during the fall and winter of 1978-1979.

Phytoplankton responded in a predictable manner to the increased nutrient concentrations (Figure 10). The July-September average gross primary productivitity increased from 185 mg C m^{-3} day^{-1} in 1976 and 140 mg C m^{-3} day^{-1} in 1977 to over 1,000 mg C m^{-3} day^{-1} in 1978 (Dunst,

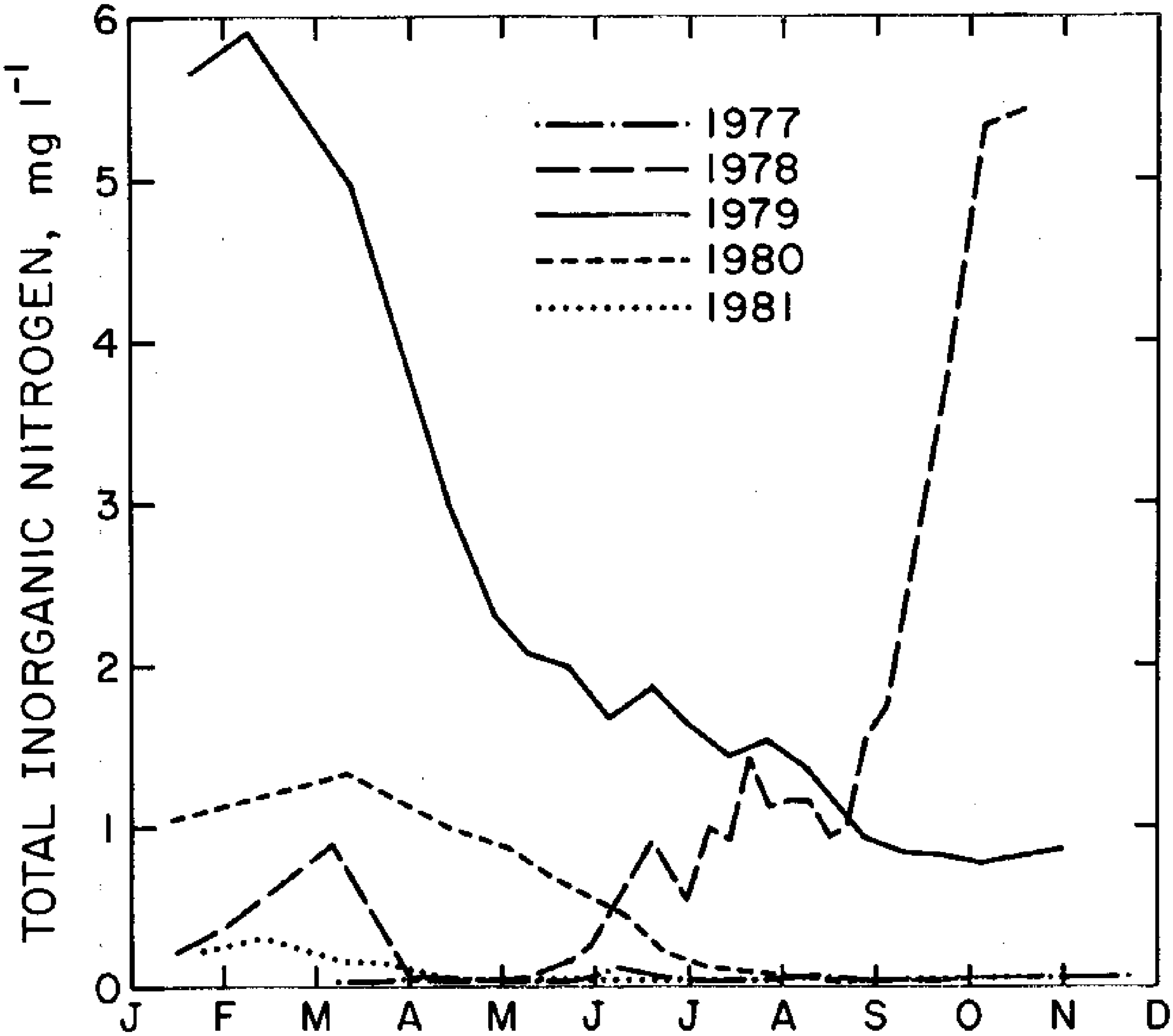

Figure 8. Total inorganic nitrogen in Lilly Lake, Wisconsin (data courtesy of Russell Dunst, Wisconsin DNR, Madison).

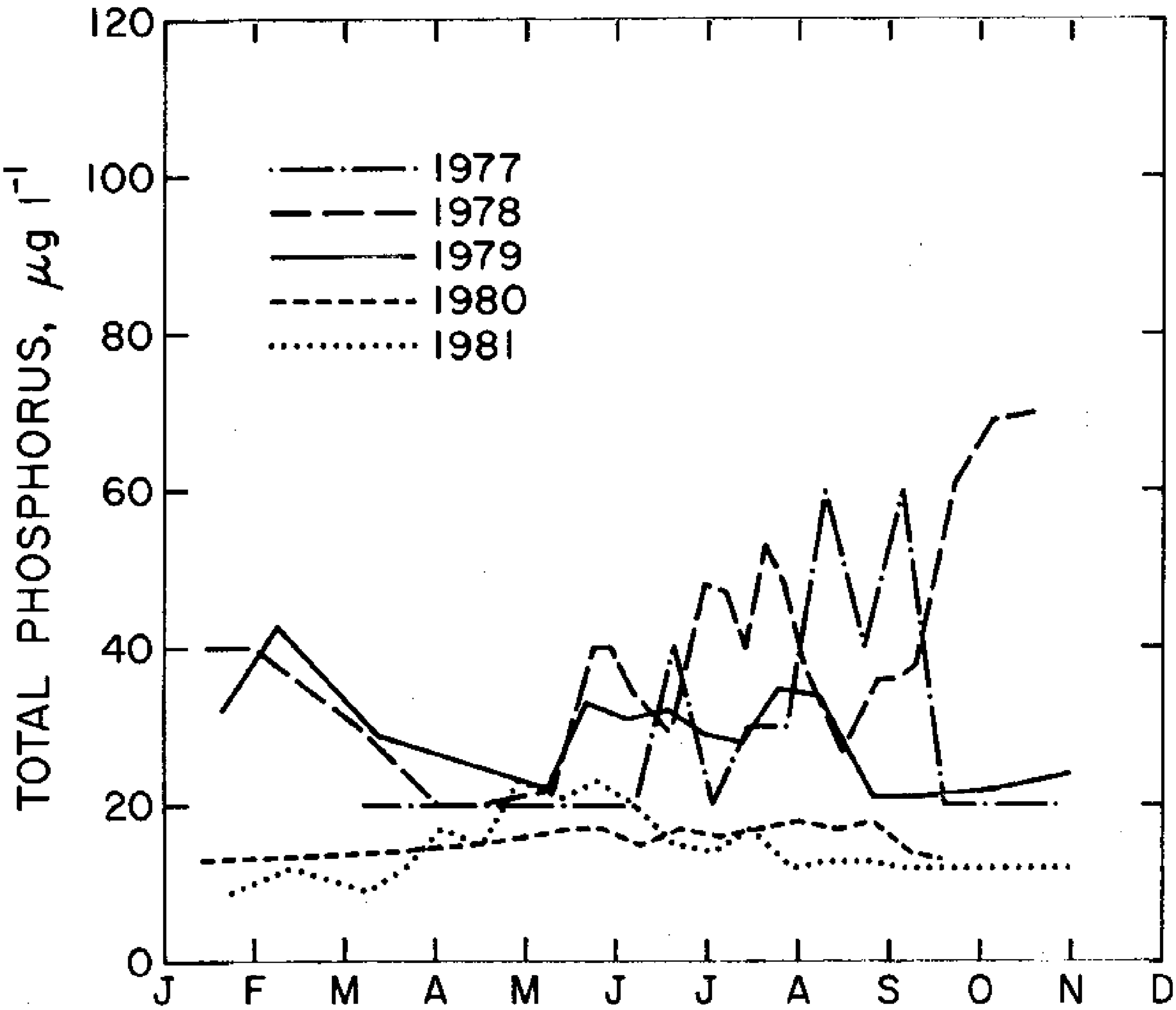

Figure 9. Total phosphorus in Lilly Lake, Wisconsin (data courtesy of Russell Dunst, Wisconsin DNR, Madison).

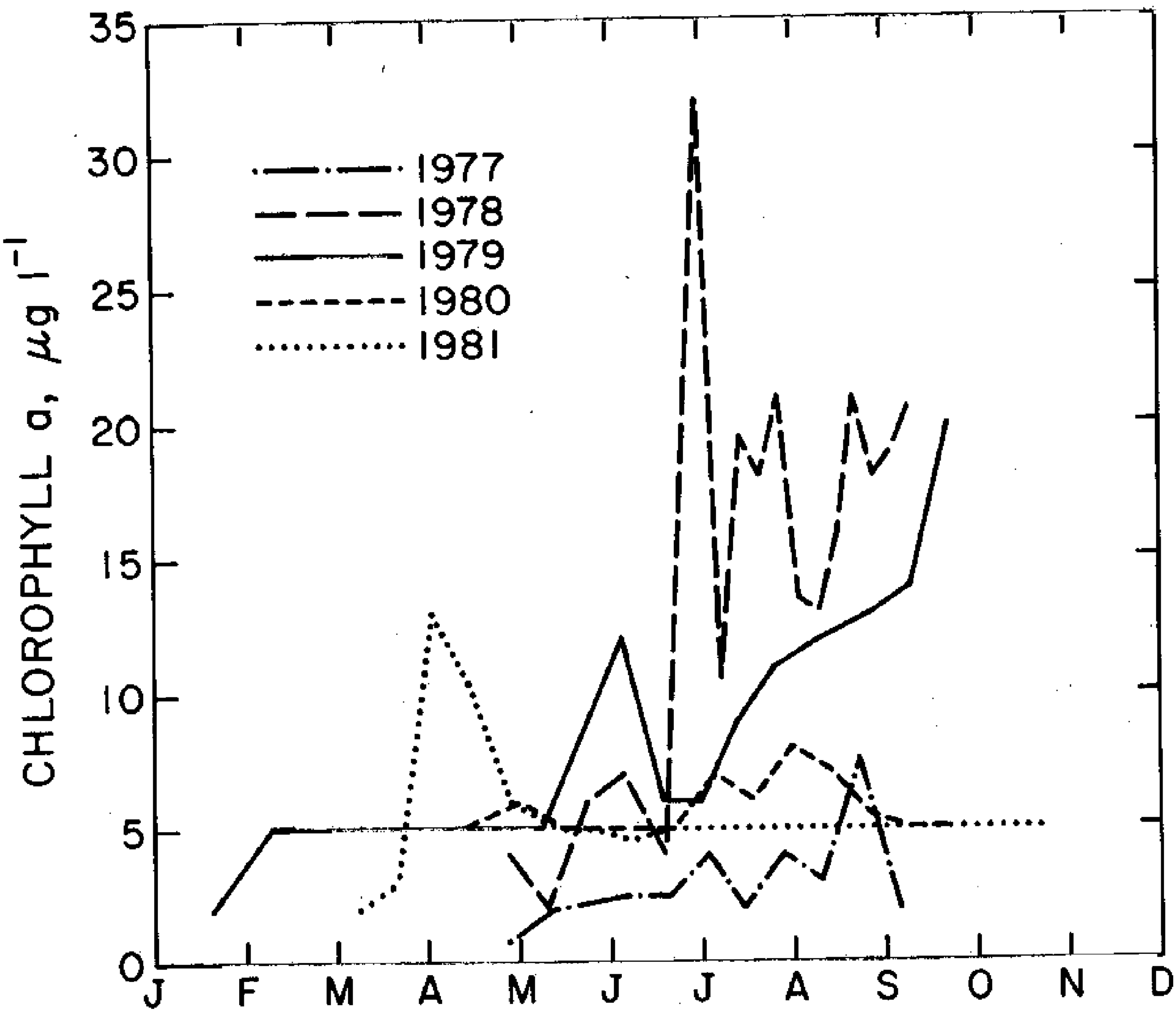

Figure 10. Chlorophyll a in Lilly Lake, Wisconsin (data courtesy of Russell Dunst, Wisconsin DNR, Madison).

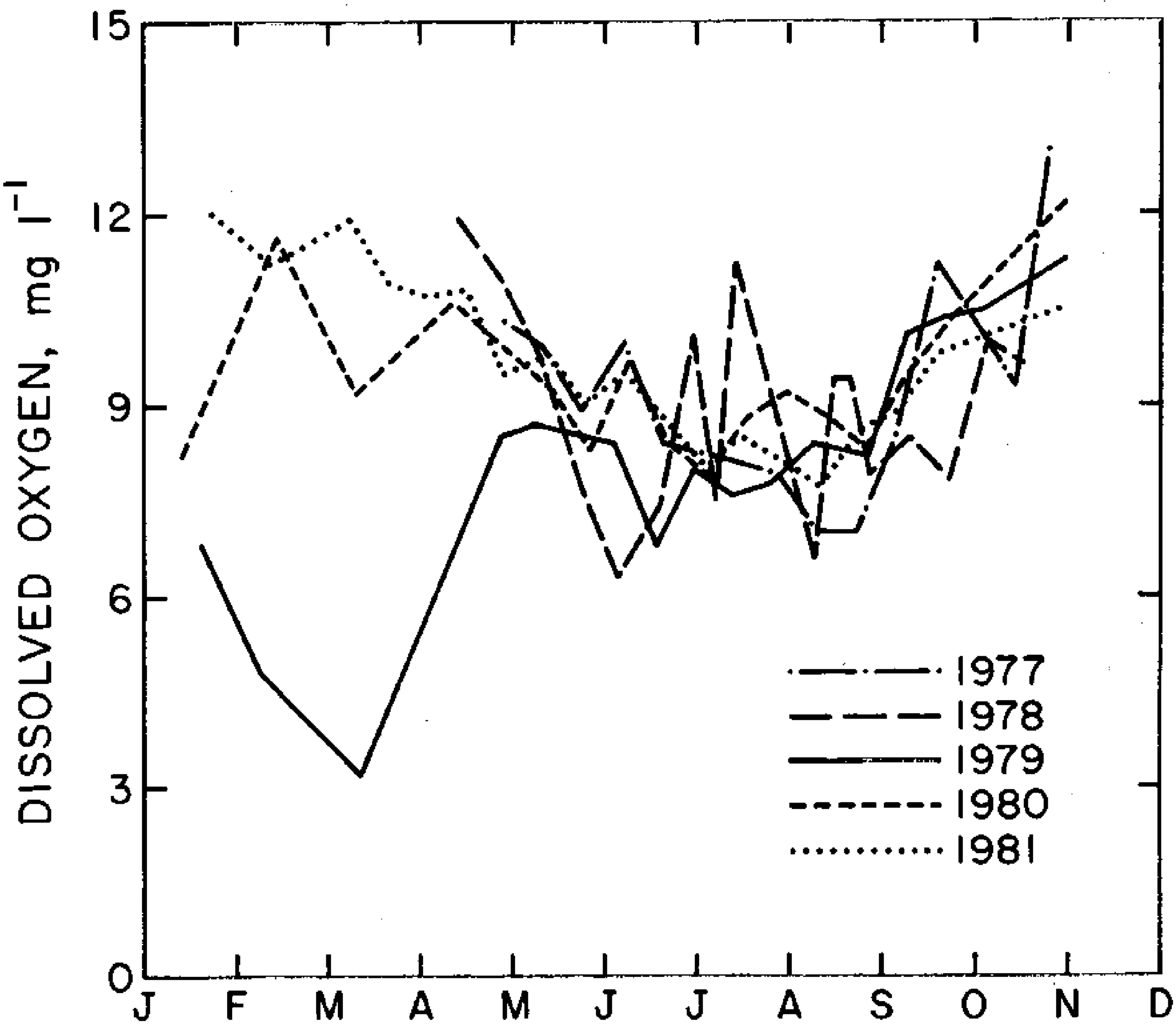

Figure 11. Dissolved oxygen in Lilly Lake, Wisconsin (data courtesy of Russell Dunst, Wisconsin DNR, Madison).

1981). Dissolved oxygen concentrations remained near saturation during most of the Lilly Lake project period. Except for the winter of 1978-1979 there were no signs of depressed values (Figure 11).

All of the above variables returned to near or below predredging levels when dredging ended in September 1979. The 1980 and 1981 TP concentrations were significantly lower than they were prior to or during dredging. Chlorophyll a concentrations were slightly higher in 1980 and 1981 than in the predredging year of 1977. Most importantly, the water storage capacity of the lake was increased 128 percent (Dunst, 1981) and the overall objective of increasing the recreational quality of Lilly Lake was realized. The two-summer inconvenience of dredging has resulted in what lake users hope will be a long-term benefit.

COSTS

The relevance of sediment removal cost comparisons is questionable because a large number of variables affect the cost figures. These include the type of equipment used, the project size (volume of material to be removed), availability of disposal area, the density of the material being removed, the distance to the disposal area, the ultimate use of the removed material, and a number of other factors. Data for 64 lake sediment removal projects in the United States indicated a cost range from \$0.24 m^{-3} to \$14.00 m^{-3} (Peterson, 1982). Given the above variability, an average cost figure is meaningless; however, hydraulic dredging costs ranging from \$1.25 m^{-3} to \$1.75 m^{-3} are relatively common and probably can be considered "reasonable." If toxic substance contaminated sediment is encountered and special dredges and/or treatment methods are required (Matsubara, 1979; Koba et al., 1975; Barnard and Hand, 1978), dredging costs may exceed \$25.00 m^{-3}. In general, the per unit volume cost of sediment removal will be inversely related to the total volume of material removed. Any time dredged material is of sufficient quality for use as potting or top soil dressing as was done at Lake Trummen, Sweden (Sjön Trummen i Växjö, 1977) and Nutting Lake, Massachusetts (Worth, 1981) the overall project costs might be reduced significantly.

SUMMARY

The reasons for dredging lakes are to deepen, limit nutrient recycling, reduce macrophytes, and to remove toxic substances. Case histories of lake dredging projects to date reveal that while some adverse impacts to the lake do occur during dredging, most are of short duration and the end result warrants the short term impacts.

There is little doubt that dredging can be a successful lake restoration technique if the project is properly designed and implemented. Successful examples of both surface sediment skimming and deep (6 to 8 m) dredging can be cited. Emphasis should be placed on proper pre-treatment evaluation and execution of thorough implementation plans.

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WHAT MAKES IT WORK?

by

Robert J. Hopman[1]

I. INTRODUCTION

This paper discusses what is needed to place a new, highly technical, extremely sophisticated hopper dredge, such as the Corps of Engineers minimum fleet hopper dredge ESSAYONS in operation. Public Law 95-269 is the vehicle by which the minimum fleet concept was developed. The designated minimum fleet will ultimately consist of four hopper and six non-hopper dredges, including NPD's two new hopper dredges - YAQUINA and ESSAYONS - located on the West Coast. This paper, in part, will describe some of the principal features of the ESSAYONS. Following this will be a description of some of the normal difficulties associated with the startup of a spanking new state-of-the-art dredge. Then, for comparative purposes, I will briefly examine the misconception that a new dredge will cost less in terms of operating costs and finally, I will describe several future items in store to make the ESSAYONS an even more productive and efficient component of the minimum fleet.

II. BACKGROUND

Public Law 95-269

Public Law 95-269 enacted on 26 April 1978, is the legislation that directed the Corps of Engineers to undertake a study, to be submitted to the United States Congress. The purpose of the study was to determine the size and makeup of the minimum federally-owned fleet of dredges capable of responding to the emergency and national defense needs of our country. This law stated that as the industry demonstrated a capability to perform the dredging work, currently performed by the existing federally-owned fleet, at reasonable prices and in a timely manner, the government-owned fleet of dredges shall be reduced by the orderly retirement of plant until the minimum fleet level prescribed by Congress is reached. The legislation also stated that the minimum fleet of the Corps of Engineers shall be maintained to technologically modern and efficient standards and be kept in a fully operational status.

Minimum Fleet

The study, required by PL 95-269, to determine a minimum number of federally-owned dredging vessels was submitted to the Office of the Secretary of Army in April 1982. The study, as prepared by the Corps recommended a minimum fleet of eight hopper and nine non-hopper dredges, was reviewed and fully considered in developing the final position by the Secretary on the size and configuration of the minimum fleet of government dredges. Since the submission of the final report, the Corps has developed a concept which provides a civil reserve fleet which

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could augment the Corps' minimum dredge fleet. This concept would provide for the guaranteed response of private sector dredges to augment the minimum federally-owned dredge fleet during responses to national defense or emergency situations. This concept was tested during a worldwide defense mobilization exercise and will be fully implemented later this year.

In addition, the Industry has developed a fleet of more than ten hopper dredges and for the most part they have been underutilized. Consequently, it has become apparent that a fewer number of government dredges would suffice, without accepting inordinate risks, for defense-related requirements and federal emergencies.

Accordingly, it was decided that a minimum dredge fleet sufficient to provide a dredge nucleus to meet national defense and emergency requirements would be four hopper dredges and six non-hopper dredges. The configuration of the minimum fleet would consist of two dredges being assigned to the West Coast. These dredges are the YAQUINA and ESSAYONS. Briefly, some of the primary factors considered in locating these two dredges on the West Coast are:

- o Geographical distribution of navigation projects in the United States and the overseas deployment areas related to national defense.
- o Project dimensions and operational conditions as related to the size and type of hopper dredge needed.
- o The frequency of the dredging cycle and level of maintenance required at each of the projects.
- o Haul distances, dredging depths, type of materials, restrictions on overflow dredging, etc.; all peculiar to West Coast operations.

ESSAYONS

The ESSAYONS, a medium class hopper dredge, is the newest hopper dredge in the Corps of Engineers fleet. It was built by Bath Iron Works of Maine under a subcontract from Sun Ship, INC., of Pennsylvania and was delivered to the West Coast this past summer. ESSAYONS - French for the Corps' Motto "LET US TRY"- will cost more than $75 million after all the construction haggling, negotiations, and associated expenses have been settled. You may be astounded by what appears to be an enormous price tag but the vessel came equipped with the latest technology available to the dredging industry and is well worth the $75 million in terms of national defense capabilities not found in private industry dredges.

The dredge has an overall length of 350 feet and a molded breadth of 68 feet with a maximum hopper volume of 6,000 cubic yards. Carrying materials with a specific gravity of 2.0 while loading to a 27-ft draft and with a burnout of 90% of consumables the ship should have the capability of loading 5,440 cubic yards.

Other Main Features of this Dredge are:

- PROPULSION POWER. Port and starboard engines drive controllable pitch (CP) propellers through reduction gears. Each General Motors, Model EMD 20-E5 engine develops 3,600 bhp @ 900 rpm.

- DREDGE PUMP POWER. Port and starboard engines drive A.C. generators which power (through transformers) A.C. motors that drive dragarm-mounted pumps, or power (through rectifiers) inboard D.C. dredge pump motors. Each generator is rated at 2,450 KW with each engine delivering 3,600 bhp.

- DREDGE PUMPS. There are four dredge pumps. For normal dredging port and starboard dragarm-mounted submerged pumps are provided. This allows deep dredging to be accomplished without danger of cavitation. Each pump is driven by a squirrel-cage induction motor specially designed for submersible operations. Motor rating is 1,450 hp for each pump.

- DREDGING DEPTH. The dragarms are of such a length to permit a normal maximum dredging depth of 80 feet with the ship at light service draft and with an arm angle of 45 degrees. Dragarm extensions will allow dredging to a depth of 94 feet.

- BOW THRUSTER. The dredge is equipped with a 600 hp A.C. motor-driven CP propeller bow thruster. Power for the motor is obtained through a common bus so that the starting of such a large motor will not create electrical disturbance on lighting and other loads.

- SPEED. Estimated speed through hull model testing was between 13.25 and 13.5 knots for loaded drafts. Actual measured speed is 13.7 knots under ideal conditions.

- DREDGING PERFORMANCE. Actual performance is much better than originally estimated. It was calculated that it would take 69.5 minutes to accumulate 5,000 cubic yards of sand in the hoppers. Measured performance indicates it takes under one half the estimated time to accumulate a like quantity of material.

- OTHER FEATURES. There are other features of the ESSAYONS that certainly make it called, and accurately so, the most practicable and versatile and yet most sophistacated state-of-the-art dredging craft afloat. Some of these principal features are:

    - Double Bottom Construction
    - Bridge Wing Propulsion Control Stations
    - Crusising Range of 7,500 Nautical Miles
    - Dry and Refrigerated Stores Capacity for 24 Hours per Day Dredging Operations for 30 Days
    - A Shipboard Helicopter Facility
    - Recreation/Entertainment Facilities
    - Forty Ton Deck Crane
    - Swell Compensation Capability, 12 Foot Stroke
    - Variable Pump Speed Capability for Direct Pumpout Operations

- Single Dragarm Dredging Capability
- Computerized variable Level Hopper Overflow System
- Direct Pumpout Capability
- Modern Electronic Positioning Equipment and Doppler Speed Log
- Nuclear Density Meters
- Production Meters
- Automatic Light Mixture Overboard (ALMO) System
- Yardage (Load) Meter
- Dredging Data Logger
- Automatic Dragtending
- Centralized Dredging Control System
- Long Range Navigation Equipment
- Collision Avoidance Radar
- Constant Tension Mooring Winches
- Monohull Design
- Unattended Engine Room Capability Through Automation
- Maximum Computerization and Instrumentation to Permit Accomplishment of any Global Mission

III. SHAKEDOWN OF THE NEW DREDGE

A successful transition from the "start up bugs" associated with a new state-of-the-art dredge to a fully responsive, productive and efficient role has not occurred without some difficulty. The following description of a number of the operating and mechanical difficulties on the ESSAYONS will verify this fact. However, it is not intended to cast a belittling portrayal on craftsmanship or any construction shortfalls stemming from real or imagined deficiencies on the vessel, but is the framework for describing what it has taken to keep the dredge effectively functioning.

The ESSAYONS is equipped with two sliding trunnion assemblies. Their justification is not questioned because of the many advantages over the fixed type. For example, several known advantages are that:

- o They increase the efficiency of the pumps because they allow suction elbows to be lowered with reference to the water surface.
- o They result in reduction of propulsion resistance thus allowing increased speed and/or fuel savings.
- o They allow the dredge to be berthed without danger or damage to or from a projecting dragarm.
- o They allow the crew to safely examine and repair parts of the dragarm while stowed on deck.

These are just some of the advantages which, without doubt, enforce the necessity of the sliding trunnions working properly in order to maximize dredge production and efficiency.

Soon after starting its mission on the West Coast, the ESSAYONS developed sliding trunnion problems. Galling as much as 1/4 inch deep developed in the trunnion carriage guide tracks. This was a serious condition because the tracks are an integral part of the ship's hull. It was first thought that the trunnion greasing system had failed. It was subsequently discovered that the metering orifices were too small. They were enlarged and, in addition, a heavier extreme pressure grease was used. These changes had little or no effect on the problem.

The solution to this major problem of galling was more than a simple engineering undertaking. Plans and specifications and technical manuals were not available so a systematic technical solution could not be derived as one would want. Because of not really knowing exactly what was causing the problem, we were unable to develop a repair concept that a shipyard facility could translate into a "FIX". Therefore, it was left to our own forces. First task was to grind the tracks so that the scored metal was smoothed out. Next, was to try to understand what was causing the problem, essentially through trial and error methods. The heavy weight of the carriage assembly exerted a horizontal force of some 40 tons against the hull castings. This tremendous weight turned out to be the cause of the galling and had to be lessened to prevent further troubles. It was thought by some Engineers, that a textbook solution would be to lessen the pressure by changing the pickpoint from the sliding piece to a position more outboard and in line with the dragarm. However, this challenge would require a great deal of time for design considerations and the services of a shipyard which were not available at the time because of an ongoing strike in the region. Therefore, we decided to modify the sliding carriage piece to accommodate larger bearing pads and experiment with different pad materials. Essentially, applying a basic understanding of frictional forces involving similar materials, we doubled the pad area and surfaced the new pads with a phenolic material which is an impregnated fabric with a bonding epoxy. This stopped the galling and burnished the guide tracks, but the pads wore out quickly. We then switched to replaceable bronze pads which have worked very well. Pads last on the order of 6 weeks. It was also determined that the guide rails are not parallel and therefore the ultimate solution to the trunnion problems can not be finalized until the dredge is drydocked.

I do not intend to give a detailed account of each problem on the ESSAYONS but will only briefly summarize a number of the major problems that we have been confronted with since receipt of the dredge. The purpose in describing them is the critical issue of this paper - - to point out to both the knowledgeable and the unsuspecting, that it takes a lot of tender loving care to keep a new dredge on line, and fortunately the Portland District of the Corps of Engineers has that capability by having, in my opinion, the best highly dedicated repair group in the country. The group of some 30 engineers, technicians, welders, laborers and the like in conjunction with ship personnel, have been able to keep the ship operating the majority of the shakedown time.

- We experienced significant problems with the dragarm winch motors. Each of the six motors, three for each dragarm assembly, had to be fully waterproofed. They developed leaks during the vessel's trip to the West Coast. In addition, reduction gears and motor couplings failed and had to be either repaired or replaced because we discovered alignment was off in some cases more than 3/4 inch. This took nearly one week to correct.

- Next work order consisted of increasing clearances between hopper door rods and their respective guide bearings. The hopper door rod is the shaft connecting the operating gear activation cylinger above the hopper to the dump door in the bottom of each hopper. A guide bearing located in the recesses of the hopper is used to minimize horizontal movement of the rod. Sand and gravel were binding the rods which necessitated the crew to literally increase the bearing sleeve diameter by approximately one inch to ease the vertical sliding motion with no appreciable sacrifice to resistance to eccentiric forces.

- The crew spent several days installing additional bracing onto the jetting pipes that are used to facilitate the dumping process. Pipes extending both horizonally and vertically in the hoppers yielded or sagged as much as 24 inches due to the loading action of heavy West Coast sands.

- The sliding valves that automatically regulate flow direction during ALMO operation continuously plugged with dredged material. This is due to the fact that because of space restriction, the valves have been installed horizontally rather than vertically as designed. Internal open/close sensors within the slide valves became inoperable. These sensors had to be refabricated and installed as external sensors. In addition, two of the valves were tilted approximately 45 degrees in an upward direction to help reduce sand plugging. Also, flushing piping was added and rerouted to further reduce the sand plugging. This operation resulted in five days of down time for the dredge.

- Leaks continuously developed in the many miles of hydraulic lines throughout the ship. We found it necessary to be always on the alert for such leaks because they not only hinder normal operations but the unrestrained hydraulic fluids can become a safety hazard. Correction consisted of eliminating the strain on the tubings by realignment wherever possible. Bracings were installed in other cases. Tightening of couplings and adding new "O" rings at number of leak locations occurred as often as four times per connection. Other times, the stainless steel tubing was replaced by high pressure rubber hose. Several weeks delay in dredge operations resulted from this continuous and widespread situation.

There were many other corrections made by our repair group such as repairing the constant tension winches which required about one week. Describing them would further amplify my point but, again, as already mentioned, the intention is to make you aware that it does take an extremely conscientious and experienced shore repair team and an appropriately outfitted boatyard to keep an automatic dredge effectively functioning during its initial working stages. That's what makes it work. All in all, our repair group has spent nearly 10,000 hours of actual work on the

ESSAYONS to keep it operative since its delivery to the West Coast.

IV. A MISCONCEPTION

As I mentioned before, the Corps of Engineers minimum fleet dredge, the ESSAYONS, is a state-of-the-art dredge especially with respect to the automated dredging system. This has not only significantly reduced the number of people working aboard the dredge but has changed the mix of licensed versus non-licensed personnel and has altered the way we maintain the dredge. The important thing for the dredging manager to realize is that his operating cost (including payroll, vessel maintenance, etc.) may not go down in proportion to reduced number of people on board and in fact, may increase slightly, although this, on the surface may seem alarming. When one compares the productivity of a new state-of-the-art dredge to an older dredge, however, the increased productivity more than makes up for increased operating costs. The most significant factor to the dredging manager, cost per unit volume of material dredged, goes down. We need only to compare the BIDDLE to the ESSAYONS to see clearly what is meant. Before she was retired the BIDDLE was manned by a crew of 82. The ESSAYONS is presently crewed with only 56 personnel and we expect that number to go down slightly. Therefore, we have reduced the total crew by more than 30%. It is very clear that in reducing the crew, we have eliminated for the most part, the lower paid positions such as the number of deck hands and non-licensed engine room personnel.

While total cost for number of people on the payroll has gone down, the average cost per person has gone up. However, where we have found our most significant change has been in the area of vessel maintenance. On the BIDDLE the day to day routine maintenance and minor repairs were the responsibility of the crew. The crew was able to care for such important items as pump changes, welding, painting, general housekeeping, etc. This type of work was cared for primarily by those same people that have been eliminated on the ESSAYONS. For this reason, when these minor repairs or routine maintenance items require attention, either the vessel must come to the dock or we must send a shore-based repair crew to the vessel. This, of course, has significantly increased their cost.

Another aspect of the ESSAYONS which we find is changing our maintenance attitude, is the sophistication of the automated feature of the dredge. Maintenance, upkeep and repair of this equipment require much more formal training than did maintenance of former dredges. Electronic engineers, technicians and computer experts are replacing mechanics and electricians and naturally at a greater cost in salaries. Because of the sophistication of the equipment on board, we have found it necessary to define maintenance items appropriate for the crew and maintenance items which should only be handled by the shore-based personnel and assigned the work accordingly. By so doing, we have accomplished two very important goals. We have defined the level of training required by the crew and ship personnel and have set definite areas of responsibilities for each group.

Although the final figures are not in yet, because the vessel is not yet fully operational, we expect that our operational costs may increase relative to the BIDDLE. However, our experience to date shows that the ESSAYON's ability to out dig her predecessor will significantly reduce that final bottom line $/cubic yard.

V. WHAT'S IN STORE FOR THE DREDGE?

Two weeks ago I was on a Delta Airlines flight to Atlanta from Jacksonville, Florida. After touchdown in Atlanta the pilot informed the passengers that the landing of the L-1011 Tristar Aircraft, in which we all had just landed, had been completely handled by an onboard Advanced Automatic Navigation System because of foggy conditions in the local area. The pilot went on to inform us that in this instance his chief duty was to sit back and make sure the guidance system functioned properly.

Shouldn't this be a goal to reach on the ESSAYONS? I definitely think so. We are not there yet but certainly are approaching it. We currently have a fully automatic dredging system that only requires pushing three buttons during an entire dredging cycle. We have electronic positioning equipment that allows the vessel to pinpoint designated areas needing dredging. Automation has also provided unattended engine room capability. What else is there?

In my opinion, automation, in light of what I have just described above, has advanced to such a degree that further automation most probably will proceed only grudgingly in shorter leaps. This is not to say that more sophisticated automation will not occur because it will, if for no other reason than because of the inherent nature and life span of current technology. Still, there are a number of ways at to improve overall operations of the ESSAYONS. For example, components of rapid wear - and there are many on a dredge due to abrasion, vibration and climatic conditions - could be constructed of inexpensive, non-repairable material. Throwaway elements would be modularized and standardized for rapid replacement. Ultimately less downtime on the dredge for scheduled and non-scheduled repairs would result which equates to money savings.

Another item would be a computerized production indicator to insure maximum production of the dredge at all times. This would entail such instantaneous additional inputs as exact density of bottom materials, water temperature and its conductivity value, knowledge of pump wear and efficiency and its relationship to motor efficiency, and knowledge of anticipative machinery output most likely from statistical measures. The list of inputs could go on and on. They, at best, may offer only slight improvements in dredge production but when we consider that the dredge costs over $40,000 a day to operate, any impending improvement most likely is worth the effort of study.

Finally, testing and evaluating various dredge components must continue in order to assess relative performance. In one example, this is exactly what Portland District is doing in its evaluation of several dragheads for the purpose of improving production while working in light silty bottom materials. Performance evaluation of at least three draghead configurations developed by the district personnel and the purchase of a new draghead developed by a Dutch company for dealing with silt, is currently being conducted. We expect to improve performance in fine materials by more than 20 percent.

As can be clearly seen from these several examples, the dedicated engineer with only the slightest amount of imagination can devise means to improve dredge production and efficiency at a relatively minor expense.

VI. SUMMARY

This paper began by pointing out that P.L. 95-296 was the critical piece of legislation that enabled the Corps of Engineers to determine what it needed as a minimum fleet capable of responding to emergency and national defense needs of our country. Four hopper dredges and six non-hopper dredges is the configuration. Two of the four hopper dredges - YAQUINA and ESSAYONS - are stationed on the West Coast.

Further on, I discussed the fact that making the ESSAYONS an effective and productive tool required a top notch, experienced repair group and a suitable repair facility. This often leads many to believe the new dredge is one of the finest testaments to modern day technology. New dredges may often cost comparatively more to operate than the older hopper dredges because payroll and some maintenance costs may be higher. The extra costs are however, offset by increased productivity.

Finally, I described several particulars that, in my opinion, are in store for the future that will make today's sophisticated hopper dredge even more productive.

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DEEP DRAFT PORT USER CHARGES, AND WHAT IT MEANS TO OCEAN SHIPPING

by
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ABSTRACT

Because of the hiatus in harbor improvement authorizations, it is unlikely that the U. S. will get any significant improvements until we agree on where the money is coming from. Based on the practices elsewhere in the world for cost sharing and cost recovery of harbor improvements, user charges have produced no visible impact on trade patterns, and the implication is that channel user charges are unlikely to be the end of the U. S. port system as we know it. The debate over user charges has obscured the economic realities and the ratemaking strategies that make the present multitude of port charges work, but it's reasonably safe to predict that there will be U. S. channel user charges, although the legislation is unlikely to be as good as it might have been. The result will not be permanent disruption of trade or the port system, but the benefits to the Nation, its ports and ocean shipping, will be mixed. For the dredging industry, there clearly will be benefits if the U. S. can break through the 40 to 45 foot plateau of its ports.

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DEEP DRAFT PORT USER CHARGES, AND
WHAT IT MEANS TO OCEAN SHIPPING

Franz Postuma was the port director in charge of reconstructing Rotterdam after World War II, and one of his favorite sayings was "Since we don't know where the money is coming from, we must start work at once"! His logic was compelling, but unfortunately there haven't been any U. S. harbor improvement projects authorized by Congress since 1976, and no significant ones since 1970. Now that we've had a lot of time to think about it, it's unlikely that the U. S. will get any significant harbor improvements until we do know where the money is coming from. Call it the "Postuma syndrome".

More accurately, the situation in the United States is not that we don't know where the money is coming from, it's that we haven't agreed on where it's coming from. It's probably safe to say that a majority of the U. S. port community recognizes that user charges will be at least one of the funding sources for new work and for maintenance; a minority thinks the funding should continue to be tax-supported, from the Federal General Fund. Based on budget realities and tradition, the concensus probably will be some combination of the two. Based on the practices elsewhere in the world, cost sharing, cost recovery, and user chargers owe more to political accident than economic theory.

Worldwide, cost sharing of channel improvements and maintenance between the central government and local interests varies from 100% national government (Belgium and most of the Americas and Africa) to 100% local (Denmark, Ireland, United Kingdom and Australia). Other countries share costs based on stature of the ports (France, Italy, Japan), channel location inside a port or offshore (Germany), or channel depth (The Netherlands). Typically but not always, when there is local cost sharing, there are channel user charges -- harbor dues, or in the case of the U. K., conservancy fees. On the other hand, some nations have harbor dues (Norway and Greece, with Sweden having "light dues" for navigation aids). In brief, there is no overall pattern to user charges, nor any visible correlation with trade patterns.

The ultimate example of user charges is the United Kingdom, where there is full cost recovery through both light dues and conservancy fees. Nationwide light dues apply in addition to any local navigation aid charges, with the uniform fee at all U. K. ports applied to a specified number of voyages per year, similar to the U. S. Customs Tonnage Tax. For domestic and foreign voyages, the fees are 24¢ (U. S.) and 48¢ per vessel Net Registered Ton (NRT), respectively. Conservancy fees are port specific and range from nothing at Southampton and other British Transport Docks Board ports, Liverpool, Felixstowe and some other ports where dredging costs may be recovered in other port charges, to up to $2.23 per vessel Gross Registered Ton (GRT) for a vessel call at Forth Ports Authority ports. Other examples are as follows:

Port Authorities	Conservancy Fee per GRT	Application
Clyde Ports (Glasgow)	domestic - 34.5¢	entering only
	foreign - $1.305	entering only
London (includes Tilbury)	tankers - 6.6¢ to 15¢	in and out
	other - 6.6¢ to 10¢	in and out
Medway Ports (Sheerness. etc)	large vessels - 20¢	in and out
	medium vessels - 15¢	in and out
	small vessels - 12.5¢	in and out
	domestic vessels - 4¢	in and out
Sunderland (Tyne and Wear)	foreign tankers - 53¢	entering only
	foreign other - 63.5¢	entering only
	shortsea tanker - 26.4¢	entering only
	shortsea other - 30.3¢	entering only

Source: Lloyd's Ports of the World, 1983 - 1981 editions. English Pound converted to U. S. dollars at $1.50.

Although the level of charges at English ports reflects in part a deliberate policy to promote economic rationalization, there is little evidence that it has shrunk the U. K. port system. In fact, there is something akin to a building boom underway in export grain facilities, including one at the Forth Ports Authority's Port of Leith.

The implication is that channel user charges are unlikely to be the end of the U. S. port system as we know it. With most occupants of our waterfronts attempting to recover their costs, the U. S. already has a multitude of port user charges. One reason for the resistance to channel user charges is that they'll be "one more mouth to feed". The real question is what are the legitimate concerns of the ports and their users, and what is the best way to minimize the pain of transition.

A time worn expression is that "the shipper pays", and correctly most impact analyses assume that channel user charges will be passed on as freight charges are, from the immediate to, hopefully the ultimate beneficiaries. On the other hand, nobody ever said the shippers pay willingly, and there's a lot of jostling on U. S. waterfronts in the attempt to recover costs. The last occupant to raise charges has a lot harder time than the first, and typically the carriers and labor intensive services have been most successful in this competition. The perception by local port authorities is that they have the least leverage and maximum competition, between ports as well as within ports, because they are expected to maximize port traffic and jobs as economic development agencies.

In the competitive U. S. port system, perception is, effectively, reality, and in part this explains why there are distinctly different levels of charges for authorities' terminal facilities on the four seacoasts. The highest are almost ten times the lowest, even though facility construction costs are quite similar nationwide. Combined with the fact that there are significant differences in the costs of maintaining or improving the channels at different ports, competition explains the mixed emotions and mixed signals of the local authorities that are the prospective collectors of channel user fees.

Unfortunately, there has been no comprehensive study of the impact of port user charges, nor general agreement on the best methodology for such a study. The Department of Commerce funded one of the most ambitious studies, but it addressed only impacts of a uniform nationwide O&M fee, and it has not been released yet. However, as an input-output modeling effort that assumes no stickiness in the pass-through of user charges, its results are fairly predictable. The multiplier effect that has been so convenient for ports in estimating the economic impact of a ton of cargo, also means the model will show changes in supply and demand, traffic and employment, that far exceed the actual user fees collected. On the other hand, with a model's rigid coefficients and provided the user charges are flowed back into the economy as a reduction in taxes, the likely result is a "wash". In brief, the model might be useful in showing the effects of users instead of taxpayers paying, but it has severe limitations in identifying actual impacts or how to minimize them.

As a result, the participants in the user charge debate are free to infer as much or as little impact as is convenient. Morever, the parochial interests of the participants focus their efforts on getting the best deal for their port, their carrier, or their constituent's shipments, and Congress never hears about their fundamental economics or their ratemaking strategies and rate interaction.

Worldwide, most waterfront enterprises attempt to recover their costs through either cargo charges such as wharfage, or vessel charges such as dockage, or some combination of the two. By careful use of a combination of the two, as most U. S. port authorities do, costs can alternately be loaded on shippers or carriers according to perceived least resistance. If either of the charges can be equated to units of cargo, they are typically flowed through to shippers, but carefully crafted vessel charges, particularly if they are low, will be absorbed into vessel voyage costs, and only ultimately reflected in the general level of freight rates.

The implications for user charge legislation are that charges under 25¢ per cargo ton are insignificant, since the variation in port costs for tugs and pilots not reflected in charter rates is within that range. In fact, cargo handling cost differences of several dollars per ton are not reflected in liner rates, but they're a different case. Charges below 25¢ per ton are probably below anybody's threshold of pain, but there is no point in making them disappear into vessel charges if the charge is uniform. By definition the same charge at all ports will not change their competitive positions. Similarly, a proposed value-related "uniform" charge in effect "gives away the store" on commodities below the threshold, but will likely raise others above the level of pain.

In trying to invent a uniform maintenance fee that is acceptable to all parties, over the past three years we appear to have missed the importance of providing room for port specific fees that can be blended into vessel voyage costs and shared by a range of ports, or related to the ability of shippers to pay. Although annual maintenance for the whole U. S. port system averages about 25¢ per ton of seagoing cargo, the recovery of new work costs under proposals such as assessing only ships drawing over 45 feet, could produce charges that exceed English conservancy fees. On the other hand, any legislation that increases the local cost shares over the present -- almost 10% of maintenance, about 20% of improvements, on average -- without local user fees, ignores the realities of port economics, however modest the increase.

User fee impacts on carriers and shippers pale in comparison with the problems of local interests funding more improvements with present revenues. The carriers have some flexibility in minimizing impacts, international more so than domestic, but project sponsors are captives of their location. Because of geography, there is a poor correlation between channel costs and port commerce. However, because channel costs are less variable than commerce, there is a better correlation between the size of the port and ability to pay. Finally, because the carrying capacity of ships goes up exponentially with draft, there is an even better correlation with channel depth. However, none of this relates to funding ability, which depends on the credit of the sponsor. Since most local authorities depend on revenue bonds, their credit is based on existing traffic. Typically they have a multitude of customers, many with poor credit, and probably none with credit willing to use it to guarantee a bond issue. In effect, more local funding without local user fees would be limited to a few ports with state sponsors. Most of the others still would not know "where the money is coming from".

In general, the official position of the Reagan Administration recognizes these realities. As stated by Assistant Secretary of the Army for Civil Works William R. Gianelli, it includes:

First, an increased non-Federal share of costs through user charges, to promote more efficient use of available Federal funds and to flow costs through to the beneficiaries more efficiently through a time-tested concept.

Second, systemwide and uniform cost recovery of O&M, to minimize the disruption of the existing system by introduction of user charges, preferably with some device to "cap" excessive cross-subsidy of high cost ports by low cost ports.

Third, port specific cost recovery of improvements, with optional local funding including local user charges.

It's Congress' prerogative to negotiate user charge legislation, and as Mark Twain said, "It's better not to know how sausages and laws are made". At this point it would be reckless to predict what form the ultimate legislation will take, or when. But it's reasonably safe to predict that there will be channel user charges, that the legislation may not be as good as it might have been, but it won't produce permanent disruption of trade or the port system.

The implications of all this for the Nation are that there may be more rational investment decisions made, but certainly a better identification of priorities. The present processes effectively identify the best solution for port improvements. What they don't do is consistently and continuously provide decisionmakers with a way to timely actions.

For the port authorities, the charge may be a mixed blessing, but at least it will provide some predictability in revenues and a guide for long-range and systematic development. With a visible planning horizon, permitting and associated processes can be addressed in a timely manner.

For the U. S. dredging industry, the benefits of timely, predicable port improvements are clear cut. Although the dollar value of port maintenance work continued to grow until the last few years, the port system has in effect plateaued at the 40 to 45 foot depth range for some time. Currently the Corps maintains no ports deeper than 45 feet, although some sea bar channels are deeper, and 28 Corps projects serve 35 ports in the 40 to 45 foot range. Corps studies somewhere in progress plus authorized work, could add 22 more ports to the 40-45 foot category, and deepen a number already at those depths.

Significantly, the 35 U. S. ports now 40 to 45 feet deep handle about 50% of all U. S. waterborne commerce, and about 12% of the world's waterborne international trade. The economies of scale are compelling in ocean shipping, and the sizes of ships will grow whether or not the U. S. is prepared for them. Because of size economies, large ships partially loaded still have cost advantages over smaller ships fully loaded. This explains why "Panamax" size bulkers have grown over the years from 50,000 to 80,000 deadweight. The canal draft limitation is still 39.5 feet freshwater (and less in dry seasons), but vessel owners have decided it's economic to pay for extra capacity to have an advantage on a voyage without draft limitations.

Vessel draft statistics show a startling number of trips lightloaded, not all of which are due to the present shipping slump. With the compelling economies of size, there will be an almost unlimited future supply of ships unable to use present U. S. channels fully loaded. The cargo demand vs. ship supply balance is far more important to the financial results of those ships than user charges, but the charges may be the key to the U. S. improving its ability to compete in world markets.

One reason for the 40 to 45 foot plateau in U. S. channel depths is the competitive U. S. port system; no port director wants to lose business to a deeper port, and we couldn't afford to go the next round of deepening. It may well be that channel user charges are a concept whose time has come.

STRATEGIC PLANNING IN NAVIGATION

by
Arlene L. Dietz[1]

ABSTRACT: Dependent is the key descriptor for the U.S. navigation system. Its use is dependent on national and international political and economic events and its capability to serve is dependent on the physical integrity and capacities of its features and its collective economic efficiencies. Navigation investment decisions are conducted in the national arena in the absence of adequate information on the program's contribution to the national goals. It is proposed that national goal-centered strategic navigation planning be incorporated as a essential part of the national decision making process. This planning involves four steps: goal identification; use forecasting; capability analysis; and strategy development. Its implementation would involve establishment of a program which annually monitors the system and subsystem use, the determinants of that use, and provides an analysis of system performance as measured by delays, downtime, accidents and other selected indicators. This annual assessment would then relate its findings to performance expectations and to the scheduled investment program. Periodically, as part of this system planning, it will be necessary to reassess the system's capability against a new set of emerging scenario forecasts and provide the decision makers with options for strategy modifications. Strategic planning from a national perspective is not a substitute for project planning but a necessary complement. It offers the combination of systematic network level monitoring and analysis which is necessary for the national goal-oriented decision making.

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INTRODUCTION

> "In transportation, the effects of unforeseen circumstances--blizzards, price hikes, embargoes, strikes--are usually complicated by the presense of system effects: events occurring in one location which then produce a ripple effect, provoking derivitive events elsewhere in the system. Because networks by nature involve dependencies between their components, any problem set in a network structure is susceptible to this cascading of consequences and its solution often requires an overall network perspective."[1] Professor Tom Magnanti, MIT's Sloan School of Management.

Professor Magnanti concisely captures the conditions supporting a modified approach for authorization, appropriation and planning for federal navigation investment. The unforeseen circumstances operating on this navigation network of complex interrelationships impact on both the supply and demand sides. The operative variables which the planner must use include the predictable, for which risks can be calculated, and the unpredictable. Both require integration into today's decision making.

The Chief of Engineers at the first International Inland Waterways Conference and Trade Show held in August 1983, enunciated his conviction that "... we have to look at them [navigation projects] as part of the whole, part of the series, a body of interrelated investments." The Chief closed on the point that we need streamlined ways of reaching the investment decisions and executing those decisions, he said we need to "... depart from our time-honored, long-standing ways of moving things through the authorization and appropriation committees to Congress." He considered it "... quite feasible to legislate certain authorities for the Secretary of the Army within the framework of that legislation, and within the framework of the guidelines set up by the National Waterways Study (NWS), to move ahead much more promptly with prelegislated authorities subject to limitations and controls..."[2]

This paper outlines a system-wide approach to strategic investment planning for navigation and the basic monitoring necessary to make it function. It does not provide solutions to the institutional dilemma referenced by General Bratton, nor does it address site specific design, planning, or operations and maintenance procedures, but instead focuses on the approach and methods applicable to overall network investment planning and programming under uncertainty. It describes a highly aggregate evaluation approach. The interrelated network of ports and channels is assessed against the alternative sets of transport demand derived from conditions and/or events which would substantially impact on the demand for that network. A series of strategies, managerial and engineering responses to the potential problems, can then be arrayed and the consequences of each evaluated. Consequences, such as the loss of international trade or increased resource costs, of failing to implement actions needed under one or more unpredictable, but plausible sets of future conditions can then be displayed for decision makers--the Chief of Engineers, the Secretary of the Army, the Congress, a board of users, or any of a combination of the participants in national level decision making. The analysis would outline the "cascading consequences" of optional strategies against an array of plausible future scenarios on the functioning of the entire network and on the national goals. The decisions from these results would be focused on broad, goal-oriented strategies appropriate for the national board room. The decision options would have screened out the confusion embodied in the project level of detail found on the engineer's drawing board. The national strategic planning concept is intended to to focus the investment decision makers on national board room decision criteria and away from the drawing board details.

STRATEGIC PLANNING - GOALS, SYSTEM USE, CAPABILITY, STRATEGIES

Modular describes the form of anlaysis used to arrive at national level strategies for navigation investment. The first step is to array the national goals which navigation supports. This is based on review of historical data. Second, the existing and future use of the system and its major parts for commercial navigation and defense support is thoroughly researched. This involves preparation of future flows of commerce as determined from sets of assumptions including external events (e.g. oil embargos and wars). Third, the existing system's capability is evaluated against the futures and the consequences of inadequate or surplus capability displayed. Finally, optional investment strategies with varying degrees of risk and costs are developed and evaluated in terms of national goal achievement.

GOALS

A decision maker must assess his options against a mix of goals. For the nation's navigation network the National Waterways Study (NWS) identified a myriad of contributions of the waterways to specific locales and regions, to the nation, and to the international sector. The contributions of the navigable waterways ranged from the provision of the local water supply through the maintenance of navigation pools, to insurance of low-cost domestic transportation for Illinois' soybean exports. But the national focus of the NWS, also true for subsequent national network decision making, required that only the major, widespread national goals which were supported by the navigation system be specified and planned against. Moving 2 billion tons of traffic annually, the waterway's contribution to the total economy and national economic development is dramatic. Since more than half of this traffic involves energy commodities and 20 percent of the domestic energy commodities move by water, there is a major role for the system in achieving energy self-sufficiency. The United States has over one-third of the world's coal reserves and is in a key position to support the free world's energy self-sufficiency as well as its own through its exports of steam coal. The role of the the nation's ports in national defense is critical for mobilization, resupply and for naval operations. During a prolonged conflict the inland, coastal and intracoastal waterways and the Great Lakes play key support roles for the nation's defense industry by moving great quantities of ore, petroleum and chemicals. NWS concluded that there were four national goals against which its frameworks should be prepared:

a. National economic development - The waterways are the major arteries for bulk commodity movements supporting the U.S. industrial complex.
b. Enhance energy self-sufficiency - Increased domestic use of coal and increased coal exports will contribute to free-world energy self-sufficiency.

c. Expansion of agricultural exports - Over $40 billion is brought into the U.S. economy through agricultural exports annually helping to support the U.S. balance of payments. Half of these agricultural commodities move on the inland waterways to export ports.
d. National Defense - Available ports for mobilization, resupply and service to the U.S. navy is necessary for defense. Adequate capability of the inland and intracoastal waterways and Great Lakes to move strategic commodities is essential for national security.

SYSTEM USE

The assessment of system use, that is the existing and future commercial transportation use and the defense related use of the channels and ports, involves first selecting those commodities and the key flow patterns which contribute most significantly to the four national goals. The waterborne commodity movements by major grouping which NWS identified as significantly influencing the four goals are: export coal flows, export destined agricultural commodity flow, and domestic and foreign trade movements of coal, petroleum, chemicals, iron and steel and ore. Finally, ports identified as major deployment and resupply ports and those serving naval operations should be introduced in a network use model.

Geographic analytical units

Geographically, use assessments have to be prepared for each major subdivision of the navigation network as well as the whole. Inland waterways generally interconnect therefore flow anlaysis for the larger system should be conducted, as should detailed analysis for major regional subdivisions for every major commodity group.

A coastal port may not be part of the interrelated network of inland, intracoastal and coastal channels. In fact, a port may be geographically removed from any interrelated domestic waterborne flow patterns. A coastal port's connection is often to the international trade network and the non-water domestic transportation network. To accommodate an analytical link-up of the broad inland geographical subdivisions and the unique independent characteristics of coastal ports an aggregation of ports by region and their respective inflows and outflows by region is necessary to satisfy the need for uniformity. This accommodation results in very generalized forecasts for the coastal aggregations. Project level use information at this point should be reviewed in terms of these national and regional use forecasts.

One major national goal which ports, as discrete nodes, support is national defense, specifically mobilization and resupply functions and as harbors for naval fleets and support operations. The analysis of defense use when aggregated into coastal regions, as done in NWS, loses the detail necessary to clearly display and justify a defense need and programs to support these needs. There is no good option available for ports other than considering each ones defense support role in the context of all substitutable port facilities, regionally and nationally.

Commodity Groupings

Forecasting at the national and regional levels dictates fairly large commodity groupings. The first step in grouping is to segregate those commodities which will have a major influence on the achievement of goals if they are not efficiently transported. Then the individual commodities need to be organized into groups to limit the number of forecasts. This does not obviate detailed analysis of the determinants of demand for the individual commodities in each group however. For example, in NWS the growth coefficients for export metallurgical coal were negliable whereas those for export steam coal were very large. Both coal types had to be separately assessed in order to develop a joint growth rate.

Design of Forecasts

Forecasts of waterborne commodity flows rely heavily on forecasts of future economic conditions. Once these basic economic-driven forecasts were derived in the NWS they became input into a second phase of forecasting, the scenario forecasts. This NWS two-phased forecasting is the methodology proposed.

For phase 1, national-scope macroeconomic models provide input for the industry models which in turn provide the national growth rates expected for key commodities. To arrive at regional growth rates the national levels of industry growth need to be modified to reflect regionalized production and consumption characteristics. The resulting regionalized growth rates by commodity are then applied to the region's base traffic flow. Finally, recent industrial developments or plans for plant and raw material location with the associated transportaton logistics are then used to adjust the expected regional forecasts. The end result is a set of waterborne forecasts by region, each generated from the same national assumptions regarding the nation's economy.

Phase 2, the scenario forecasting, sets this national level forecasting approach apart from all others. Historically the waterway specific traffic forecasts were based primarily on the macroeconomic assumptions. NWS used this output, however, as input into a second step in the forecasting process. This added step was used to assess the "unpredictable" but plausible events, over which little control can be exerted but which would significantly alter growth rates nationally, regionally or both for one or more of the major commodities. For example, in NWS assumptions regarding the world demand for coal exports varied greatly with no certainty attached to any one prediction, consequently three assumptions were tested: historical, historical as modified by recent events and a third which adopted the assumption that major shifts from oil and the desire for energy security would substantially increase the demand for U.S. coal. One other assumption involved more stringent environmental regulations. This affected the siting of power plants and the sourcing of fuels based upon their sulfur and BTU contents. The outcome of this assumption was model shifts, changes in the direction of flows, and altered levels of use on certain waterways.

The key scenario assumptions in NWS across the seven forecasts are summarized in Table 1. The forecasted tonnage for the year 2003 (defense excluded since it differed only in year 1990) by major commodity groups and

Table I

THE NATIONAL WATERWAYS STUDY PRINCIPAL ASSUMPTIONS FOR NWS SCENARIOS[1]

Principal Assumptions	Baseline	High Use	Low Use	Bad Energy	Defense	High Coal Exports
1. Macroeconomic	Trendlong	Trendlong	Larger Government	Bad Energy	Wartime Economy[2]	Trendlong
2. Corn Yields by 2003 (Bushels per Acre)	121	121	110	121	121	121
3. West Coast Share of Farm Products Exports (Percent)	14	14	14[3]	14	Overall Decline During Conflict	14
4. Phosphate Exports	Decrease After 1985	Constant After 1985	Decrease After 1985	Decrease After 1985	Constant After 1985	Constant After 1985
5. Steel Imports (Percent of Total Consumption)	Decrease After 1990 from 17 to 15	Decrease After 1990 from 17 to 15	Increase to 26 by 2003	Decrease After 1990 from 17 to 15	Decline Sharply During Conflict	Decrease After 1990 from 17 to 15
6. Crude Oil Prices (Average Annual Price Increase-Percent)	3.8	3.8	3.8	4.8	3.8	3.8
7. Crude Oil Imports by 2003 (Millions of Tons)	290	290	240	200	Decline of 100 Million Tons per Year During Conflict	290
8. Coal Exports by 2003 (Millions of Tons)[4]	107	156	107	156	156	290[5]
9. Gulf Coast Share of Total Coal Exports in 2003 (Percent)[4]	19	23	11	23	23	35
10. Domestic Coal Consumption by 2003 (Millions of Tons)	1,794	2,360	1,625	1,728	2,360	2,360
11. Synfuel Plants on Water (Coal Consumption in Millions of Tons by 2003)	10 (50)[6]	11 (61)	6 (30)[6]	15 (81)	11 (61)	11 (61)
12. Coal Slurry Pipelines	None	None	None	7[7]	None	None
13. Eastern Coal Use (Lake Erie Loadings of Coal by 2003 in Millions of Tons)	Present Technology and Regulations (20)	Present Technology and Regulations (22)	Increased Use in Great Lakes Area (24)	Present Technology and Regulations (20)	Present Technology and Regulations (22)	Present Technology and Regulations (22)

1. The Miscellaneous scenario incorporates all the assumptions of the High Use scenario. The adjustments are made to account for data base errors (Ohio and Gulf Coast-East reaches) or to introduce alternative regional forecasts (Arkansas and Columbia-Snake Waterway reaches).
2. Based on Federal Emergency Management Agency forecast.
3. Great Lakes share drops 10 percent.
4. Overseas and Canadian destinations.
5. Based on National Coal Association high forecast and modified by Data Resources, Inc. (DRI).
6. An additional demonstration plant (not included in these numbers) on the Monongahela River is assumed in operation from 1983 to 1990 and consumes 3,000,000 to 6,000,000 tons of coal each year. However, after 1990, it is discontinued.
7. One of these seven pipelines (ETSI) will divert 4.5 million tons of coal from the waterways by 2003.

subgroups is summarized on Table 2. All commodities are expected to grow over time except the petroleum commodity group. Petroleum traffic falls in all scenarios due to reduced imports, increased fuel substitution and a continuation of the long term trend of modal shift from water to pipelines.

The scenario concept provides for a broad range of plausible future events which individually, have decisive impacts on waterborne commodity growth nationally and regionally and on the national goals. The scenario output is altered traffic flows by commodity, by region. Probabilities cannot be assigned to the potential external events which so dramatically influence traffic but the decision maker must be able to speak to the possible outcome of these events in terms of his decisions. The scenario approach allows for this--it allows the decision maker to choose one future or set of futures against which his program can be structured.

CAPABILITY

Capability analysis in a systems context involves a wide mix of separate modular analyses, the results of each module input into the network analysis. As found in NWS, locks provide the most frequent physical restraint to traffic. However, channels and many non-constrained locks contribute to inefficient and/or unsafe vessel operations and consequently contribute to a finite economic capacity of segments within the system. Similarly, at ports today's channel dimensions present few physical constraints (nearly all vessels can enter and leave even if they have to carry less than a full load) but these dimensions may present an economic impediment to the vessels and traffic served.

The separate modular analyses which input into the final NWS network model or other modules which in turn provided network input include very detailed efforts. The National Waterways Study, for example, assessed the traffic carrying capacity range of each lock. These results were an input into the broader network analysis model. Similarly, in another separate piece of analysis the impact of channels on vessel operations and tow charateristics was evaluated and became input into the network. In another module the forecast traffic by commodity type was used to determine the expected types of vessels, barges, and tow configurations within a given channel. The network measures of the impacts of constraints, physical and economic, included the increased cost of vessel operations on a segment of the system as well as on a network wide basis. The results of the physical constraint produced a measure of the loss of waterborne traffic (measured in tons) by commodity, by region and for the nation.

The modular network analysis approach allows for measuring consequences of approaching or exceeding capacities at nodes and for evaluating operating condition between nodes or within a region. The significance of a network model for decision making is the ability to trace throughout a system the repercussions of not removing a physical or economic constraint as well as the ability to judge the cost and traffic interferance impact of several unpredictable (or even predictable) external events on that system. For example, the issue most often thought about when dealing with waterway segments which are inseparable parts of a broader national system are the consquences of simultaneously occurring natural disasters. As lock rehabilitation and maintenance is increasingly deferred the likelihood of

Table 2

UNITED STATES WATERBORNE COMMERCE BY COMMODITY GROUP, 1977 AND FORECASTS FOR 2003[1]

(Millions of Tons)

Major Commodity Group Commodity Sub-Group	1977 Base Year	Forecasts: 2003 Baseline	High Use	Low Use	Bad Energy	High Coal Export	Misc.
1. Petroleum	958.2	722.8	722.8	646.8	602.1	622.8	725.9
Crude	488.7	423.6	423.6	369.3	335.6	423.6	423.7
Petroleum and Coal Prod.	469.5	299.2	299.2	277.5	266.5	299.2	302.2
2. Coal	211.8	513.7	642.8	475.9	578.3	805.2	677.4
3. Agricultural Products	202.3	458.6	458.6	418.7	463.0	458.6	461.7
Farm Products	158.1	366.2	366.2	339.3	389.5	366.2	368.8
Food and Kindred Prod.	44.3	92.4	92.4	79.4	73.5	92.4	92.9
4. Metals and Ores	149.6	302.7	302.7	278.5	294.9	302.7	305.0
Metallic Ores	115.3	244.3	244.3	203.5	234.7	244.3	245.4
Primary Metals Prod.	34.3	58.4	58.4	75.0	60.2	58.4	59.6
5. Chemicals/Fertilizers[2]	77.7	139.2	139.2	133.6	136.2	139.2	142.4
6. Forest Products	64.4	70.5	70.5	70.5	70.5	70.5	70.6
Lumber and Wood Prod.	52.6	54.2	54.2	54.2	54.2	54.2	54.2
Pulp, Paper and Allied Prod.	11.8	16.3	16.3	16.3	16.3	16.3	16.4
7. Other	250.8	378.1	390.6	355.9	369.4	390.6	406.2
Nonmetallic Minerals	159.0	197.3	209.8	187.8	194.4	209.8	217.6
Stone, Clay, Glass, Concrete Prod.	16.2	32.8	32.8	27.1	28.8	32.8	33.2
Waste and Scrap	21.8	29.2	29.2	29.1	28.9	29.2	29.3
Other Commodities	53.8	118.8	118.8	111.9	117.3	118.8	126.1
Total	1914.8	2585.6	2727.2	2379.9	2514.3	2889.6	2789.2

1. Foreign and domestic commerce.
2. Phosphate rock and natural fertilizer materials not elsewhere classified are included in the nonmetallic minerals commodity sub-group.

multiple downtimes occurring simultaneously or sequentially increases. The fact that the physical plant is old does increase the probabilities of failure. With half the U.S. lock and dam structures constructed before 1940 (see Figure 1) the increasing likelihood for major downtime and failure in the following decades should be apparent. Just how serious is a lock failure? This question can be tested with the network model. All of the what-ifs for each piece of a system cannot be evaluated. However, with reliance on technical data from engineers regarding the location of potentially serious problems, system impacts of scheduled and unscheduled closures can be assessed. To ignore systemwide consequences of failures because of the low probability of occurrence, or because of the total uncertainty associated with failure, is to ignore reality.

Network capability is restricted by independent as well as jointly occurring reliability and efficiency problems. The growing interdependencies of network traffic--average ton-miles from 1970 to 1980 on the Mississippi-Gulf System increased 53 percent (increase of 103 miles per ton) while tonnage in the same period grew by 23 percent indicating a continuation of a long term trend toward longer hauls--increase the mutual reliance of each structure and channel within the network. Thus network capability became relatively more important in 1980 for decision makers than in 1970, and similarly by 1990 this heavy interdependency will become even more important in decision making as the length of haul increases further.

STRATEGIES

Strategic planning for the navigation network is long term planning, long term anticipatory planning, designed for the top level policy makers who control the development and maintenance of our navigation infrastructure--the executive and legislative branches of government. These bodies are partners in goal focused decision making. The roles of the strategic planning specialist are to monitor the system's use, to measure that performance and to provide an interpretation of the success or failure of the current strategy. These specialists have a responsibility to translate the engineers drawing board level of detail into the systems and national goal context. These strategy specialists aid the decision maker by alerting him of needed mid-course changes to the currently followed program or of the need for a major program revision.

Strategy Development

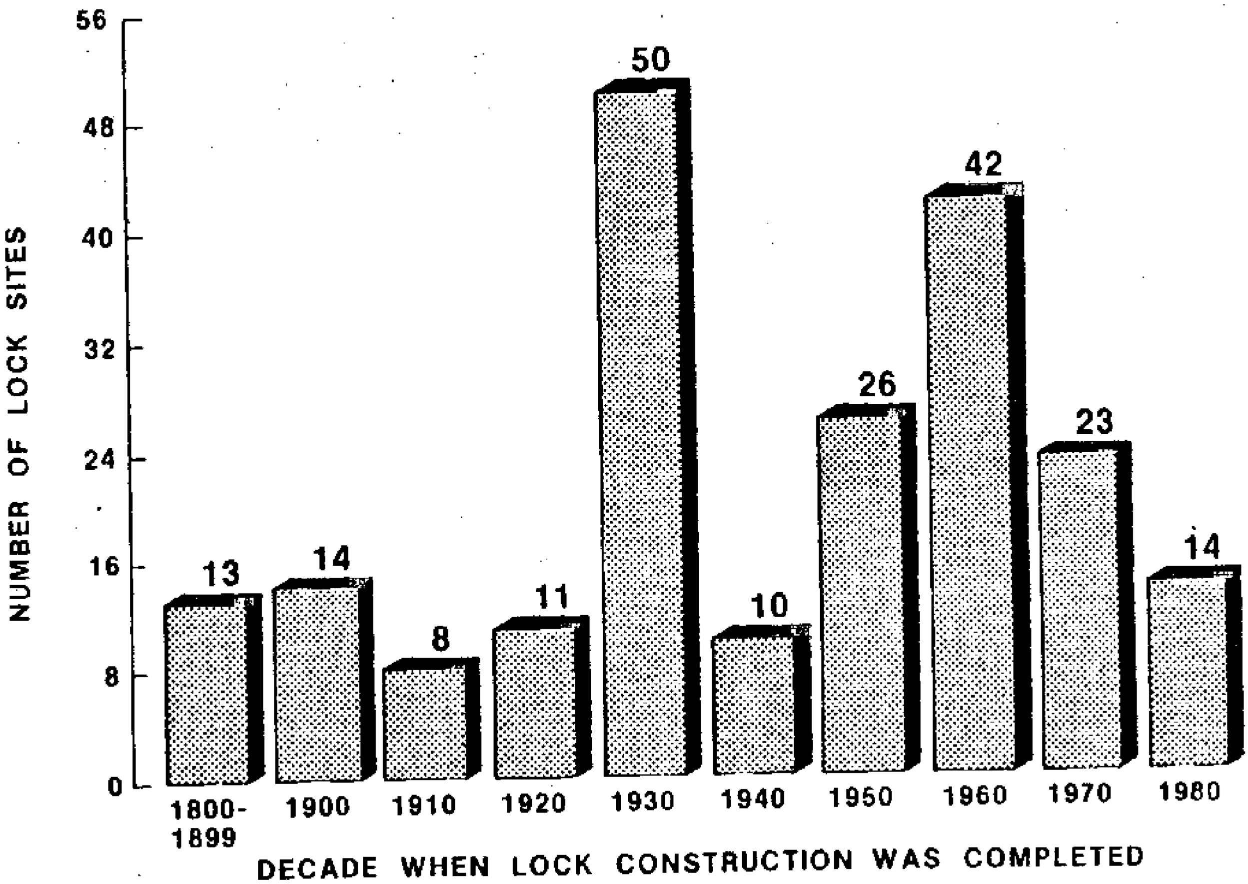
A strategy for network planning is defined as an espoused management philosophy of national level decision makers. The strategy specialist works to determine the national goal achievement value of alternative sets of policies and funding levels. The strategist's aim is not to select any one strategy but to use the network evaluation approach to test several assumptions such as funding levels and fund allocations between navigation activities (O&M, rehabilitation, replacement and new systems).

Four strategies were rigorously tested in the National Waterways Study. These strategies did not, nor could they, replicate complexities and interrelationships of the real world. What they provided to the NWS analysis was a systematic assessment of a few key policy and programming assumptions. The two basic types of controlling assumptions common to all strategies

Figure 1

DISTRIBUTION OF U.S. LOCK CONSTRUCTION BY DECADE

(FOR FEDERAL LOCKS, USED FOR COMMERCIAL PURPOSES)



were: funding availability and the hierarchical ranking of needs--by catagory, by segments and by use (see Table 3). The NWS Evaluation of Alternative Future Strategies for Action[3] shows the details of each strategy and the results of its evaluation.

Strategy I in NWS continued present policies and programs with the historical level of funding. The objective of this strategy was to simulate the possible result of following historical policies for authorization, funding and construction of projects and O&M. Its assumed investment allocation gave priority to operations and maintenance over construction and safety actions. It maintained a 1970s-level of funding and continued the present funding allocation policies. Costs of this strategy averaged about $980 million annually (1982 dollars). Major actions and findings from evaluation of Strategy I are as follows:

1. Improve one constraining lock--the second Lock 26.
2. No deepening of ports and channels.
3. Fails to maintain safe, reliable system.
4. System cannot handle 74 million tons of forecast 2003 traffic, coal traffic is most affected.
5. Some improvement to system efficiency.
6. Fails to accommodate defense scenario traffic surge.

Strategy II: It reprioritized present resources within the existing system. This strategy was intended to serve the greatest level of traffic at the least total cost. High cost, low traffic volume waterways would not be maintained as funds would be freed for construction of needed improvements on high volume waterways. This strategy would maintain 1970s-level of funding ($980 million in 1982 dollars) and alter allocation policies. Major actions and findings were:

1. Adds capacity at six constraining U.S. locks.
2. Terminates maintenance of seven inland waterways and hundreds of small coastal ports and side channels.
3. No port or channel deepening.
4. Fails to maintain reliable system.
5. Safety improvements through minor nonstructural actions.
6. Unable to handle 77 million tons of forecast 2003 traffic.
7. Improve efficiency--linehaul costs compared to Strategy I decrease by $60 million annually.
8. Defense mobilization capability inadequate, but better than Strategy I.

Strategy III: It funded minimum system for needs achievement. Funding does not correct deferred rehabilitation and maintenance. It would add funding to increase lock capacity at 10 U.S. lock sites and increase the maintenance budget. Annual costs in 1982 dollars would be in excess of $1050 million. Major actions and findings from this strategy were:

1. Adds capacity at 10 U.S. locks.
2. No port or channel deepening including.
3. Services all forecast traffic.
4. Improves efficiency--reduces linehaul costs of Strategy I by as much as $200 million annually.

Table 3
COMPARISON OF STRATEGY DECISION CRITERIA[1]

Needs Categories	Strategy I	Strategy II	Strategy III	Strategy IV
Reliability (OM&R)	Meet all O&M needs for Class "A" segments and major ports[2]. If funds are available: 1. Meet O&M needs for Class "B" segments. 2. Meet O&M needs for Class "C" segments, secondary ports, and side channels.	Same as I, except actions for adding lock capacity in Class "A" segments have priority over the needs for operations and maintenance of Class "B" and "C" segments as well as secondary ports.	Funding of channel maintenance needs to maintain 1973–1977 reliability and complete funding of operations and rehabilitation needs.	Same as III, but fund annual deferred maintenance dredging as well.
Lock Capacity	If funds are available: Add lock capacity at 95% utilization of practical capacity. Minor structural and nonstructural actions taken at congested locks.	Same as I, but lock capacity actions for Class "A" segments are made before meeting the O&M needs of Class "B" and "C" segments. Minor structural and nonstructural actions taken at congested locks.	Add lock capacity at 95% utilization wherever it occurs. Minor structural and nonstructural actions are taken at congested locks.	Add lock capacity at 85% utilization wherever it occurs. Replace selected obsolete locks. Minor structural and nonstructural actions are taken at congested locks.
Safety	If funds are available: Take minor and non-structural actions in reaches with traffic growth of no less than 10,000,000 tons by year 2003.	Same as I, but safety actions for reaches with traffic growth of no less than 10,000,000 tons are given priority over the need for operation and maintenance of Class "C" segments.	Take minor and nonstructural actions in reaches with traffic growth of no less than 10,000,000 tons by the year 2003.	Similar to III, but take some major structural actions to alter or replace bridges and widen reaches.
Efficiency: Inland	No actions	No actions	No actions	Deepen heavily used waterways to achieve reduction in linehaul costs.
Efficiency: Coastal	No actions	No actions	No actions	Deepen reaches to 50 feet or more which are forecast to move large amounts of export coal by 2003.

1. It is assumed that the Red River and Tennessee-Tombigbee projects, the single 1200-foot lock replacement project at Lock and Dam 26, the 12-foot channel from Baton Rouge to Cairo, the additional lock at Pickwick Lock and Dam on the Tennessee River, Vermilion Lock on the Gulf Intracoastal Waterway, and replacement of Locks 6 and 8 on the Ouachita River, are completed as part of the "present system." Expenditures for these projects will prevent any new major actions for lock construction and safety from being taken under Strategies I and II until after 1990 due to assumed funding limits of $585 million (1977 dollars).
2. Class A, B, and C inland waterway segments have been grouped in an analysis prepared by A.T. Kearney, Inc. according to projected operations and maintenance costs per ton-mile of projected traffic in 2003. Class "C" inland segments have an O&M cost per ton-mile of 5 mills or more. Class "B" segments have a ratio of 1.5 to 5 mills and Class "A" inland segments have a ratio of 1.5 mills or less. Side channels are short spurs that do not carry through traffic. Minor ports are all those on the Great Lakes or coasts that handled less than 1,000,000 tons in 1977.

5. Some improvement in reliability.
6. Safety unchanged from Strategy II.
7. Defense mobilization prospects improved, except in Great Lakes.

Strategy IV: It enhanced the navigation system. There would be no funding limits. Rehabilitation and deferred maintenance were added as was replacement for projects judged to be obsolete in 1977. Deepening and widening of channels and ports were added. Policies for improvement actions were liberalized--locks were replaced when traffic levels reached 85 percent of maximum physical capacity rather than 95 percent, as used in all other strategies. It would add funding to maximize potenital savings in linehaul costs and consider coastal needs. Annual costs in 1982 dollars would be as much as $1500 million. Major actions and findings were:

1. Construct 27 U.S. locks.
2. Modify inland channels in five reaches.
3. Deepen five coastal ports.
4. Major safety improvements added.
5. Serves all forecast traffic.
6. Reduces linehaul costs by $600 to $900 million annually over Strategy I.
7. Improves existing system reliability.
8. Serves most of the defense mobilization needs.

Several major findings from the NWS strategy evaluation were influential in subsequent framework formulation. These were:

1. Continuation of historical funding levels will result in a system which cannot physically serve all the forecast traffic, will be more costly, and will be less dependable. Also, the ability to maintain the U.S. share in the world agricultural and coal markets will be hindered.

2. Funding allocation policies need to become responsive to changes in national goals and project use.

3. The impact of alternative traffic scenarios on project replacement or supplementation assumed for Strategy IV was a 5 to 10 year delay beyond year 2003.

4. Strategies considered modification actions to only locks and channels. Programs must incorporate actions on other navigation structures such as wiers, jetties, and breakwaters as well.

5. Major flaw of NWS strategy analysis was the assumption that a corrective action would be on-line as needed. The consequence of imposing the historic lapse times would place many of the needed actions outside of the planning period ending in 2003 and hence the average annual costs would be reduced.

6. The optimun replacement of each lock is lock specific. Strategies I-II assumed replacement at 95 percent use and for Strategy IV at 85 percent use. For long term strategic planning an early identification of potential lock constraints is needed. Therefore, incorporation of locks into a framework program when the predicted use level reaches 70-75 percent within a 20 year period would be advisable.

7. No priority was given to actions at the less dependable aging components of the system over actions at the more recent structures. Given the large number of depression-era structures this was an oversight.

8. No clear prioritization by discrete goals--energy self-sufficiency, agricultural flows, economic development, national defense--was apparent.

Framework

Unlike the initial four strategies the NWS concluding program proposal was a summary framework derived from four other goal-oriented frameworks. These frameworks displayed inland and intracoastal waterway projects by their relative importance in achieving four national goals. Knowing that no one future would be realized exactly as predicted, the frameworks were developed for the maximum predicted system use. The framework displays an ordering of systems and projects by goal achievement, by structural reliability and by the level of uncertainty of capacity exceedance. The concept embodied in the framework is, as the future unfolds, the unneeded or lower priority systems and their improvements are postponable and actions can be taken accordingly.

The investment costs for major navigation projects estimated by NWS for the complete framework, for port deepening and for completion of projects currently under construction are $13.6 billion (1982 dollars). If spread evenly over the 21 year planning period the annual investment expenditure would be $650 million per year. This compares to the average annual rate during the 1970 decade of $375 million. However, unless the length of time from authorization (see Figure 2) through construction is shortened (currently 15-24 years), only a small number of the necessary rehabilitization, replacement or supplementation projects will be constructed as needed. If, for example, the highest level of coal exports is realized (not highest level for inland waterways) as few as four seriously congested locks out of 36 U.S. locks forecast to be congested by 2003 could be supplemented as needed and only 2 rehabilitations could be completed. The problem becomes processing first, money second.

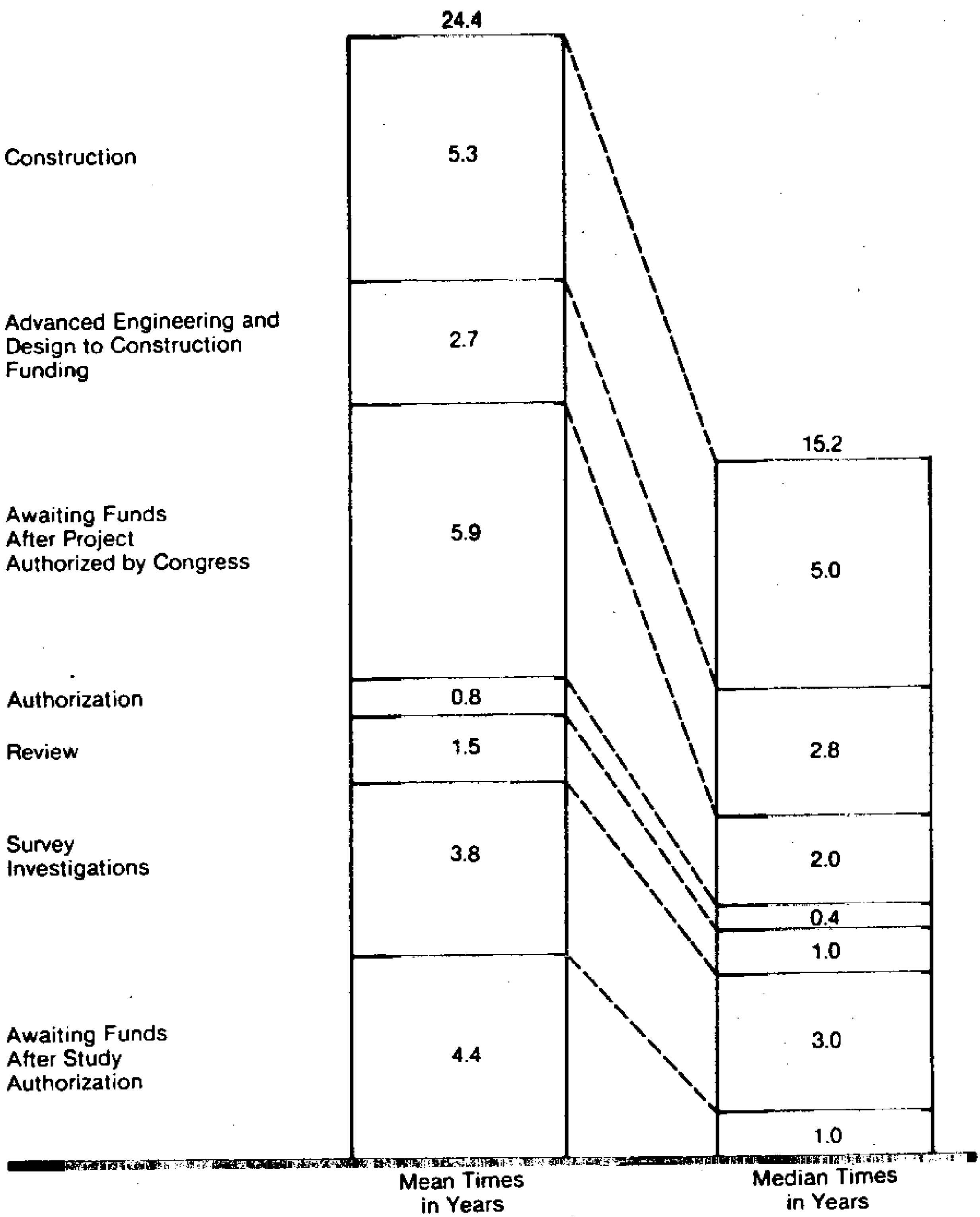
The year 2003 O&M costs estimated within NWS are $690 million, a $100 million increase over the 1970's decade level. This increase is associated almost wholly with current deep draft port studies.

MONITORING FOR STRATEGIC PLANNING - SYSTEM USE, PERFORMANCE AND STRATEGIES

Occurrence of the unforeseen circumstances is the only certainty the strategic planning specialist can trust will happen. Therefore, the changing influence of world and national events and their influence on the demand for and the supply of navigation must be continuously monitored and new casual relationships recorded. How well will the existing program, if extended into the future, perform under newly evolving future conditions? To answer this, a program's performance requires periodic assessment and possibly, revision. To these ends it becomes necessary to monitor defense use, national and international developments (political and economic) historically recognized to influence waterborne demand, and to monitor system conditions by means of reviewing the key performance measures--delays at locks, frequencies of groundings and other accidents, linehaul costs, and downtime.

Figure 2

MEAN AND COMPOSITE MEDIAN COMPLETION TIMES FOR MAJOR COMPONENTS IN THE PLANNING, DESIGN AND CONSTRUCTION OF CIVIL WORKS PROJECTS (YEARS)[1]



1. Times are based on 36 projects completed in Fiscal Years 1973, 1974 and 1975.

The job of the Corps' strategic navigation planner is not to update the NWS, but to take those lessons learned from NWS and direct energies to the necessary periodic monitoring and to the preparation of options for program modifications.

SYSTEM USE

The system use monitoring requires the planner to relate, on an annual basis, the national, regional and specific waterway traffic by major commodity group to past trends and to the current world and domestic determinants. The monitoring and assessment of the major determinants of demand for transportation, and for water transportation in particular, require the planner be on the alert for events which will affect them, such as a single legislative act (e.g. Staggers Act which essentially deregulated railroads). The institutional and legislative developments become a major component of the monitor's task. The monitors for traffic draw together information on the changes in commodity growth, the causal economic and political factors of this change and provide discussion of the deviation from the expected trends.

SYSTEM PERFORMANCE

The navigation network is increasingly susceptable to the ripple effect as the average ton of waterborne traffic moves greater distances. This ripple does not stop on the inland system but continues to the coastal ports and our export programs as well. The growth of system downtime, vessel delays, and growth in linehaul costs (three measures of performance) at nodes and on system segments must continually be tracked in order to flag new problems, reprioritize projects in the current program framework and generally provide feedback to the national level decision maker regarding the appropriateness of his funding, scheduling and allocation policies. Over the long run, on-going system monitoring will provide data on the "cascading consequences" of the larger and technologically modern replacement projects coming on-line.

Monitoring of key measures should be done annually. However, the full impact on the network structure, new and in the future, will require periodic--more frequent than each decade but less frequent than annually--network analysis against a current set of scenario forecasts. System capability of the national system should be reviewed as a whole once or twice in a decade in order to verify or help modify the navigation program established by decision makers.

NAVIGATION STRATEGIES

The full-blown redevelopment of navigation strategies, like the capability reassessment, would require something less than another NWS. A great deal has been learned during NWS. For example, even though water availability is a potential problem on the Missouri and Middle Mississippi rivers, the the impact of water shortages on navigation need not be reestablished by another nationwide research effort. Future strategy development and testing will involve the use of system models but absent the development, research and lengthy calibration associated with the NWS.

Much of the navigation strategy development will involve review and analysis of the current decision process and its performance. Similarly, the significance of major funding, allocation and other policies on the performance of the navigation network will need to receive periodic analysis for purposes of assisting decision makers in maintaining or altering those policies. The entire system's analysis effort is major and should be conducted at most, on a bidecadal basis. The monitoring of the performance measures of the decision process however should be part of an annual monitoring program.

CONCLUSION

National level strategic planning in navigation is not a substitute for either project planning and the essential engineering drawing board level of detail or for executive policy making at the national board room level. What it offers is a systematic approach to evaluating long term policy and program decisions by displaying the potential national level impacts (expressed in terms of national goal contributions) of pursuing alternative policy and programming decisions. The planner's role is one of first understanding and expressing which strategy is currently followed and then translating the consequences of continuing that strategy in broad national, goal-oriented terms. The proposed steps involved in this are as follows:

1. Established national goals supported by navigation.

2. Assess existing and potential system use under a broad mix of plausible scenarios made up of external events which have major impacts on commodity transport growth.

3. Evaluate the capability of the system in terms of physical and economic capacity, efficiency, and system dependability under each scenario.

4. Assess, in terms of national goal achievement optional investment strategies developed to meet the potential problems and needs.

"New developments" in use and system performance require an annual monitoring with feedback relating to the current strategy. This annual monitoring of use, physical conditions, and problem development should be input into the decision to continue the on-going programs and policies or to revise them. Revised forecasting, capabilities and ultimately, strategies should be in the strategic planning program for a five-year update, if warrented.

This proposal for strategic planning capability attempts to respond in part, to the conviction held by the Chief of Engineers that "... we have to look at them [navigation projects] as part of the whole, part of the series, a body of interrelated investments" and to the opinion expressed by the Assistant Secretary of the Army, William R. Giannelli who closed his August 18, 1983 speech with these words "Indeed without developing a new systematic basis for project implementation, few projects will be financed and those that are may not be responsive to the most pressing demands throughout the nation."[3]

FOOTNOTES

1. Magnanti, Thomas, "Planning for An Uncertain Future" transportation, Massachusetts Institute of Technology Center for Transportation Studies, Spring 1983.

2. Bratton, LTG Joseph K., "National Waterways Study," Speech presented at International Inland Waterways Conference and Trade Show, Louisville, KY, August 28, 1983.

3. Egan, John, David Reitz and Edwin Isely, National Waterways Study Evaluation of Alternative Future Strategies for Action, May 1982.

4. Gianelli, William R., Assistant Secretary of the Army for Civil Works, "Federal Water Project Cost Sharing and Financing Policies," Speech delivered to the California Water Resources Association, August 18, 1983.

BIOGRAPHICAL SKETCH

Arlene L. Dietz

Mrs. Dietz is manager of the National Waterways Study and is employed by the U.S. Army Corps of Engineers Institute for Water Resources. The Institute is a Corps organization responsible for water resources policy and planning research. Increasingly, much of this research is becoming navigation oriented.

Mrs. Dietz began her professional career in 1967, teaching economics at the University of Wisconsin. She joined the Corps' North Central Division Office in 1968 and became Chief Economist and Economics Branch Chief for the Corps' Chicago District in 1969. In addition to her economics duties in Chicago, she served as project manager on several Great Lakes and inland waterway navigation projects. She transferred to the Institute in 1977, where she was assigned the management of the National Waterways Study. She also is responsible for managing ongoing navigation research projects for the Institute.

Mrs. Dietz has prepared papers and published broadly in both transportation and water resource areas and is active in several professional societies. Most recently she completed terms as President of the American Water Resources Association, Washington Chapter, President of a local Virginia toastmistress club and is presently serving as General Chairman of the 1984 American Water Resources Association Annual Conference and Symposium. She serves on a committee for the National Academy of Science Transportation Research Board and is active in the Permanent International Association of Navigation Congresses (PIANC), where she currently is a reviewer for the Inland Waterway Session of the 1985 meeting to be held in Brussels, Belgium.

Her most recent honor is election to the 1983-84 Who's Who of American Women.

BUILD UP OF SABLE ISLAND

by

Marie C. Rockwell[1]

ABSTRACT

Sable Island is the only visible part of the Sable Island Bank. Until 1971 this island was of little significance except perhaps for its unique environment. In that year significant quantities of oil and natural gas were discovered. Since 1971 several other significant hydrocarbon deposits have been located; the largest to date of which is the Venture structure located just offshore Sable Island and in water depths of less than 20 meters.

The Venture Structure is the first scheduled for production and engineering is currently underway addressed to providing necessary facilities to recover the gas and move it to the mainland. Two proposals have been put forward for Venture gas production. The first by Mobil Oil utilizes an offshore production platform method with emergency back- up facilities on Sable Island. More recently a proposal has been put forward by Beaver Dredging Company to construct an artificial island on the Venture site. This island would contain all the necessary support facilities for gas production.

A third proposal which I am advocating for study is the selective build-up of Sable Island, resulting in a larger land mass. Enlarging of Sable Island will have two major benefits. It will permit the recovery of gas utilizing on shore technology at lower costs and less hazard to the environment and, secondly, it will stabilize the Island and reduce the effects of erosion. Sable Island has been eroding during the centuries,as is shown since discovery and use by man, and may disappear if this trend is not reversed.

INTRODUCTION

The shelf off Nova Scotia is characterized by the existence of several banks; the largest and most easterly of which is the Sable Island Bank approximately 250 km long, 100 km wide and with water depths of up to 100 meters. Since the discovery of America, these banks have proved to be rich in fish and have provided a stable income to fishermen during several centuries.

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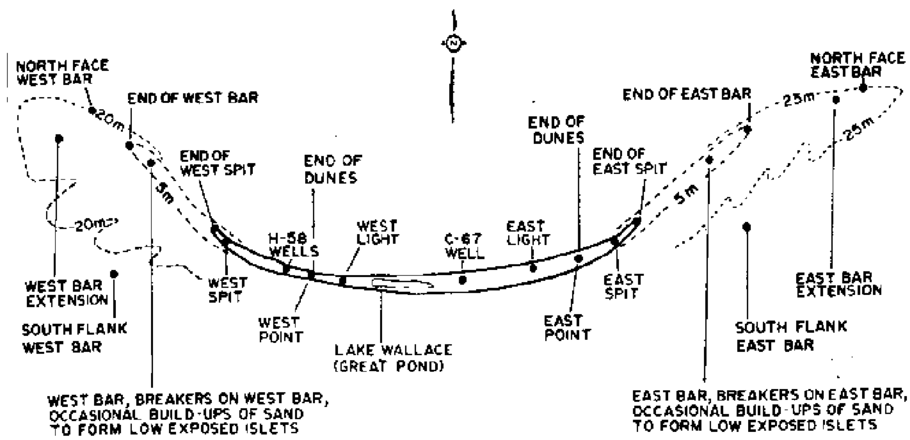
Sable Island is the eroding remnant of a one-time land mass of now Sable Island Bank. The island is located 190 km off shore, is nearly 43 km long and 1.4 km wide. It is surrounded by shoals which are particularly hazardous to navigation. These shoals and bars extend nearly 5 km southwest of the island and 13 km northeast of it as shown in Figure 1. (Mobil Oil Canada Ltd., 1983).



DIAGRAMMATIC INDEX MAP TO MAIN GEOMORPHIC FEATURES OF SABLE ISLAND AND RELATED IMMEDIATE OFFSHORE AREAS

Figure 1: Diagrammatic Map to Main Geomorphic Features of Sable Island. (Mobil Oil Canada Ltd., 1983)

Until 1971 Sable Island was relatively unknown and ignored except for its reputation as a hazard to navigation. More than 200 shipwrecks are listed in known and recorded history. However, in 1971, a combination of the impending "Oil Crisis" and the announced discovery of hydrocarbons by Mobil Oil sparked a new interest in the island and its banks.

Extensive drilling has been carried out, on and near Sable Island, since 1967 with several wells showing significant quantities of hydrocarbons, mainly natural gas.

RECENT HISTORY OF SABLE ISLAND

The ultimate fate of Sable Island is still under some debate. However, records during the past 500 years indicate that the island is not only diminishing in size, but is also moving north-eastward. Early records, going back to 1505, indicate that Sable

Island was once much larger than at present. At that time the island was also heavily vegetated. Various domesticated animals were introduced to Sable Island in the 16th century and thereafter.

In 1775 charts compiled from French records indicated that Sable Island was approximately 64 km long, 3.6 km wide with sand hills over 60 meters high. By 1799 the island had not only been reduced to a length of 50 km and a width of 3.3 km, but it had also migrated eastward by 21 km.

By 1815 Sable Island was only 46.4 km in length. At present the island is 42.5 km long, 1.4 km wide and has sand hills of less than 20 metres. During a period of 200 years the island has been reduced in length by 33 % and has an area of less than 59 sq. km. One also observes that Sable Island is only 22 km south west of a deep seabed canyon. This canyon, known as "The Gully", has water depths of over 200 metres. As Sable Island moves eastward, sand is irreversibly lost to this deep canyon. Should this erosion continue Sable Island may cease to exist as anything other than a shoal and hazard to shipping. It is also readily apparent that Sable Island is very fragile.

PHYSICAL DESCRIPTION OF SABLE ISLAND

Sable Island is structured from sand dunes, of which less than 39 % are vegetated as shown in Figure 2. (Martec, Ltd., 1980). The sand grains are fine with 84% of the particles between .25 mm and .5 mm. The soil is of poor quality lacking in both organic matter and nutrients.

There are still over 150 species of plants on Sable Island. In past centuries crops were raised successfully; however, the attempt to grow trees on the island in 1901 failed. At that time some 80,000 trees were planted on the island, most of which disappeared by 1913.

Mammals on Sable Island were quite extensive at one time and included horses, cattle, pigs, sheep, rats, mice, cats, dogs, foxes and rabbits. All have disappeared excepting the unique Sable Island ponies that have adapted to the environment. The introduction of animals probably speeded the erosion of the island. Over-grazing of land and the reduction in vegetation cover left exposed sand vulnerable to the forces of erosion, thus leading to a degenerating situation which has not been halted.

Other life on Sable Island includes several hundred species of birds which are routinely sighted, or nest, on the island, herds of seals, various types of fish, insects, etc. All of these will be lost should the island continue to eroded.

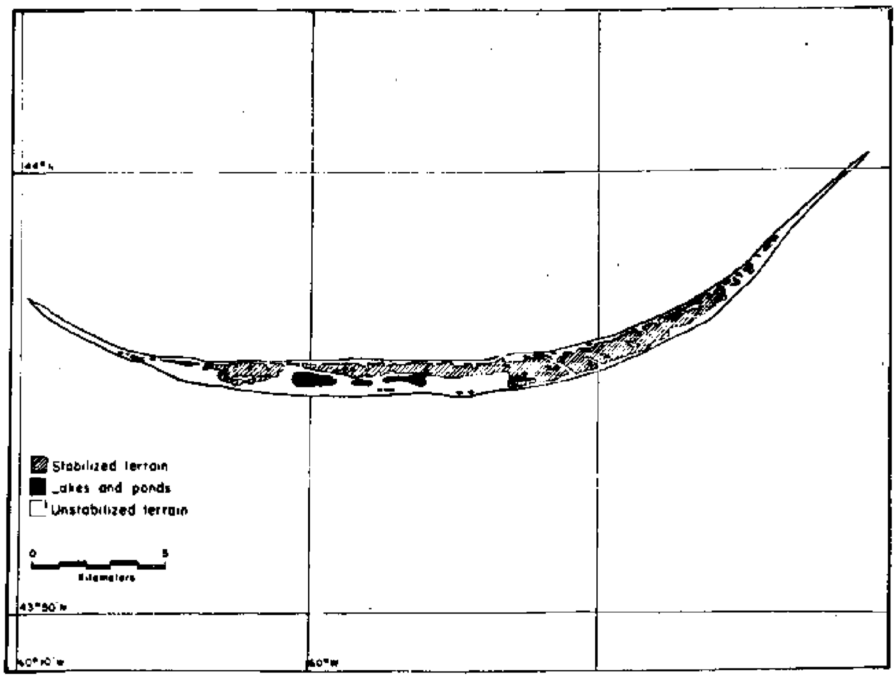


Figure 2: Stabilized Terrain on Sable Island
(Martec Ltd., 1980)

GEOLOGY OF SABLE ISLAND

The geology of the Scotian Shelf has been well studied, particularly since 1967. The Sable Island Bank near Sable Island has been the focus of much of this attention, especially since the advent of the extensive drilling program for hydrocarbons.

The Scotian Shelf consists of unconsolidated quarternary sediments overlying older bedrock strata as summarized by King & MacLean (1974,1976). 50 km off the coast of Nova Scotia the rocks which form the acoustical basement are overlain by sediments. These mesozoic and cenozoic sediments thicken seaward and reach a thickness of 8 km in the Venture Gas Field near Sable Island. The strata then dips seaward.

Figure 3 (Jansa and Wade, 1975) shows a cross section of the Scotian Shelf stratigraphy.

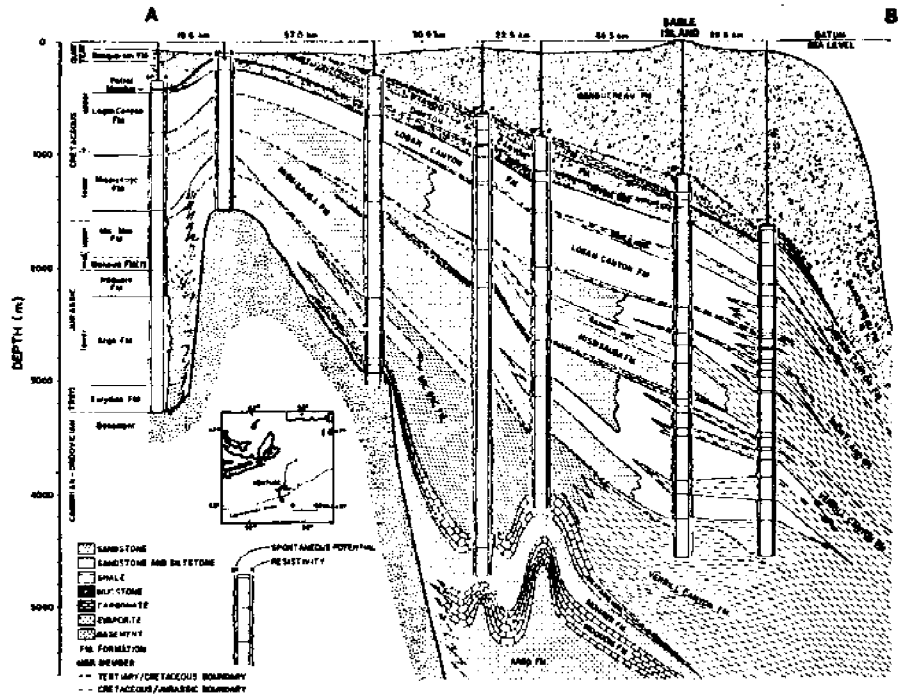


Figure 3: Diagramatic Cross Section of Scotian Shelf Stratigraphy. (Jansa and Wade, 1975)

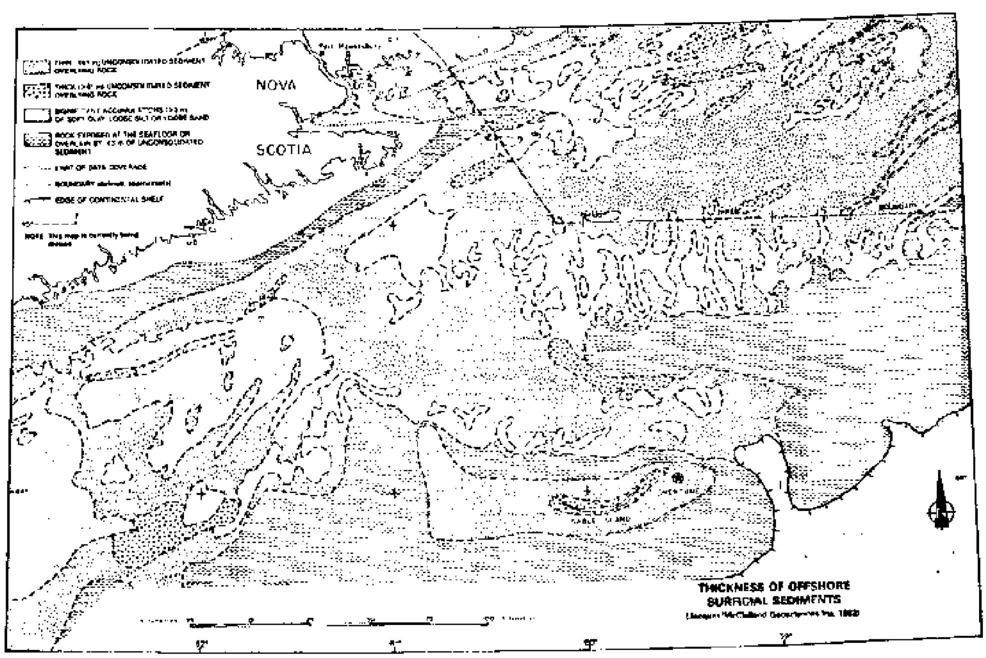


Figure 4: Thickness of Offshore Surficial Sediments (Jacques/McClelland Geosciences Inc., 1982)

The thickness of the surficial sediments is shown in Figure 4 (Jacques/McClelland Geosciences Inc. 1982). The sediments near Sable Island have been worked and reworked over the years by ocean currents.

CURRENTS AND SEDIMENT TRANSPORT

Sable Island is located in an area under the influence of two major and several minor ocean currents as shown in Figure 5. (McLellan, 1957; Sutcliffe et al., 1976; Smith, 1978; Houghton et al,1978).

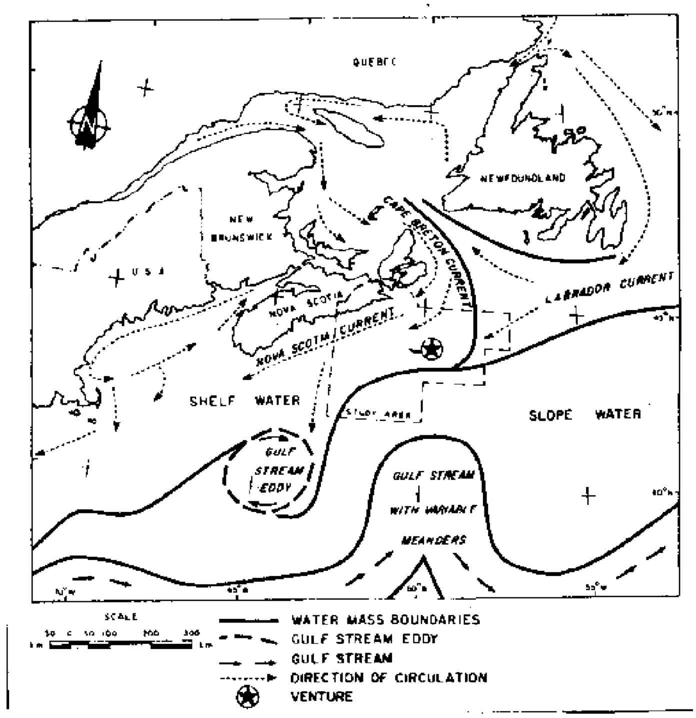


Figure 5: Scotian Shelf Currents
(McLellan, 1957: Sutcliffe et al., 1976; Smith, 1978; Houghton et al., 1978)

The major current flows are the north-east flowing warm Gulf Stream and the southeast flowing cold Labrador current. In addition there are several minor currents, particularly the Cape Breton current. These currents influence the Sable Island Banks and generally affect both water and air temperatures and cause extensive fog over the region. The interaction of these currents place Sable Island in an area where current velocity and direction vary considerably.

Within the immediate vicinity of Sable Island, the local currents are determined by waves, tides, wind and major ocean currents which flow over the Scotian Shelf, James and Stanley, 1968; Evans-Hamilton Inc., 1975, 1978; and Martec Ltd., 1980.

The direction of waves on Sable Island is from the open ocean approaching the island from the south west. Little investigation has been carried out to determine the volume of sediment transported by this mechanism acting alone.

Tides generate significant current flow on the banks of Sable Island. The ebb tide flows south toward the island at magnitudes of approximately 75 to 100 cm/sec. This tidal current changes direction as it approaches the island flowing eastward along the northside of Sable Island. The flood tide flows northward at approximately 50 to 75 cm/sec and as it nears Sable Island flows toward the northwest over the west bars.

Winds also induce current flow near Sable Island. Although it is difficult to separate wind driven currents from other sources, the direction of the winter wind is toward the southeast while the summer wind is toward the northeast. The net effect of these winds is eastward; however, the influence of other current sources make this difficult to identify.

Although there has not been extensive studies of the sources, magnitudes and direction of the currents near Sable Island, the limited information available (Evans-Hamilton, 1977-1978 & others) supported by past observations of drift bottles and other objects, indicate that there is a net clockwise current around the island of approximately 5 to 8 cm/sec. These result in a net sediment transport toward the east as shown in Figure 6. The magnitude and direction of this sediment transport requires confirmation by much needed additional measured data.

Sable Island is structured from sand dunes. There are several small freshwater and brackish ponds and various types of vegetation on the island; however, the majority of the island is exposed sand. These open sand dunes form a ridge of sand on each side of the island contribute to the erosion of the island from the wind forces. These winds, particularly during storms, result in significant sand transport as shown in Figure 7, (Owens, 1973). During the winter months the wind tends to blow toward Sable Island from the north-west transporting sand toward the southeast part of the island. In contrast, during the summer months, the wind tends to come from southwest transporting sand toward the northeast. The net effect of these wind forces over the long term is to transport sand toward the eastern end of the island; the same direction as current induced sediment transport. The combined effect of all forces, as records for the past several centuries confirm, is to move Sable Island eastward.

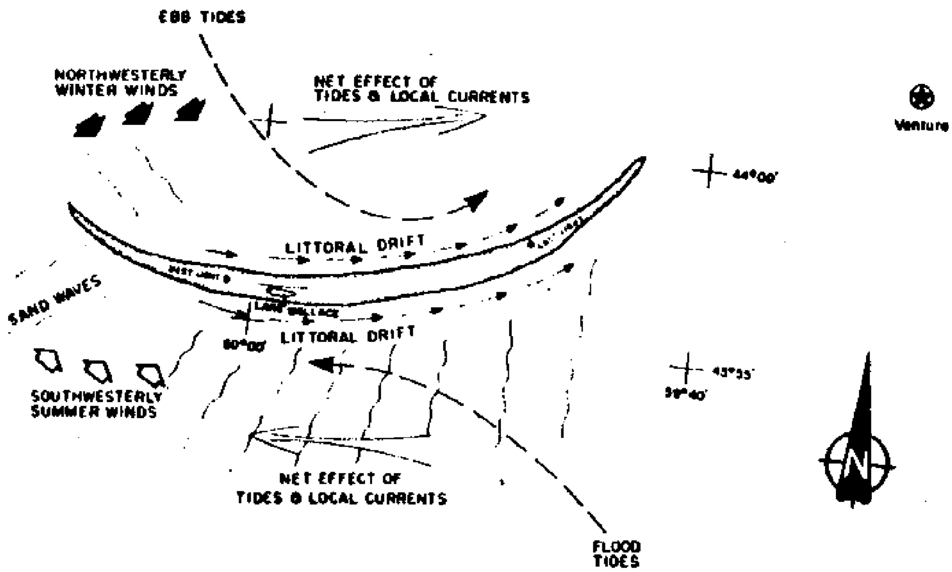


Figure 6: Current Induced Sediment Transport. (James and Stanley, 1968; Evans-Hamilton, Inc. 1975; Martec Ltd., 1980).

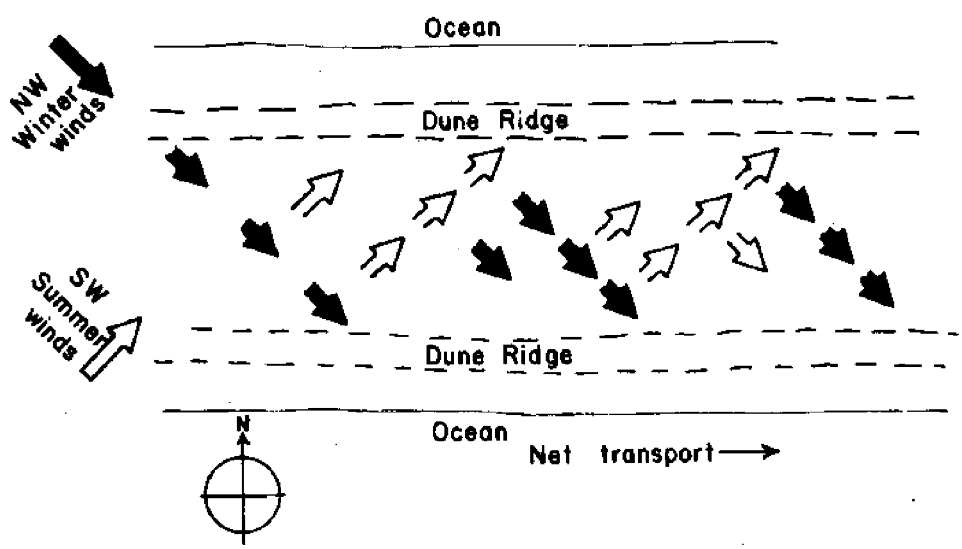


Figure 7: Subaerial Sand Transport on Sable Island (Owens, 1973)

HYDROCARBONS EXPLORATION ON THE SABLE ISLAND BANK

The hydrocarbon drilling program commenced in the Sable Island area in 1962 with the first well drilled by Mobil Oil in 1967. A gas show came in 1967 and an oil show in 1970. In 1971 significant oil and gas appeared from a well drilled on the western end of Sable Island. By August of 1983 a total of 88 wells had been drilled on or near the island, of which 12 showed significant gas and 6 significant oil. Most are on or near Sable Island and in water depths of less than 20 meters. Figure 8 (Nova Scotia Department of Mines and Energy) shows the location of these wells.

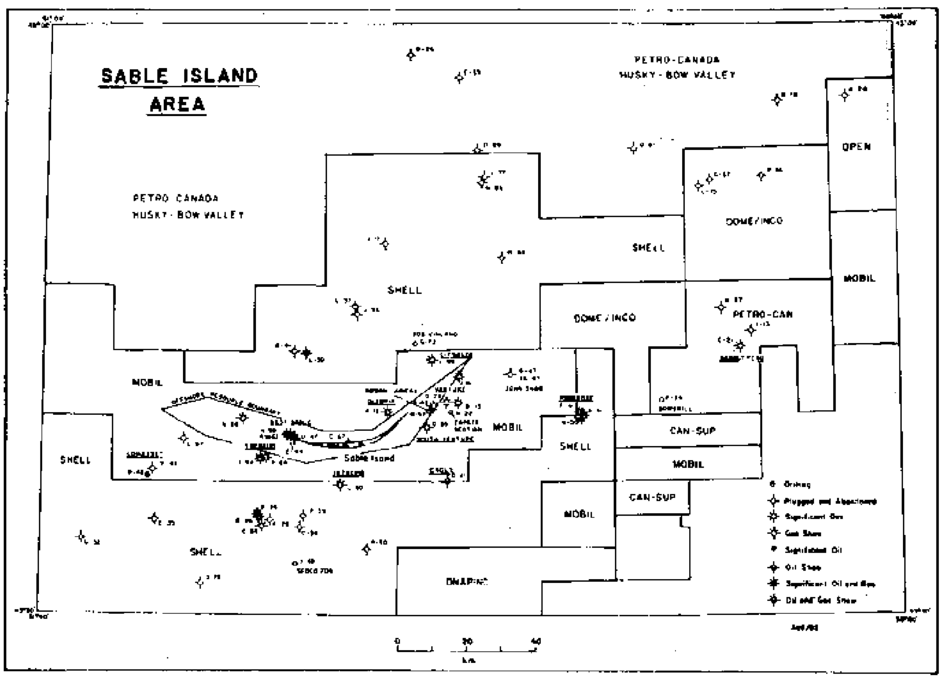


Figure 8: Hydrocarbon Structures on Sable Island Banks
(Nova Scotia Dept. of Mines and Energy)

There are twelve major structures in this area:

- The Venture structure located just off the east bar of Sable Island has had four wells drilled on it, the deepest being 5960 meters. This structure is estimated to have 72 billion cubic meters of natural gas and is scheduled for production in 1988.

- The South Venture Structure is 5 km southwest of the Venture field. One well drilled to 6176 meters tested 2,645,000 cubic meters/day of gas.

- The Olympic Structure is located 13 km west of the Venture Field. One well at a depth of 6064 meters tested at 1,598,000 cubic meters/day of gas.

- Citnalta is located 16 km northeast of the eastern tip of Sable Island. One well drilled to 4575 meters tested a flow rate of 555,000 cubic meters/day of gas.

- Intrepid located 12 km south of Sable Island has one well at 4162 meters which showed a flow rate of 513,000 cubic meters/day of gas.

- Cohasset is located 48 km west of the western tip of Sable Island. Of two wells drilled, one was dry and the second tested at 2719 cubic meters/day of gas and 249 cubic meters/day of oil at a depth of 4427 meters.

- Thebaud Structure is 7 km southwest of the western tip of the island. Two wells drilled to 4115 meters and 3962 meters tested at 849,800 cubic meters/day of oil and 387,984 cubic meters/day of gas.

- Eagle is located 20 km southeast of the eastern tip of Sable Island. One well at 4660 meters tested at 4248 cubic meters/day of gas.

- Primrose is 80 km east of the eastern tip of Sable Island. Three wells were drilled, two were dry and one tested at 1,430,000 cubic meters/day of gas at 1714 meters.

- West Sable E 48 is located on the western tip of Sable Island. The well was drilled to 3603 meters and tested at 1,812,000 cubic meters/day of gas and 649 cubic meters/day of oil. Seven delineation wells have been drilled on this structure.

- West Sable 0-47 well was drilled to 4199 meters. It tested at 172,752 cubic meters/day of gas and insignificant oil.

- Petro Canada Banquereau C21 is 96 km east northeast of Sable Island. Of two wells, one was dry and one drilled to 4991 meters tested 642,864 cubic meters/day of gas.

The Venture field, off the east spit of Sable Island, is expected to be developed with a production rate of 11 million cubic meters/day.

The exploration and development of oil and gas near Sable Island may have a severe impact on the environment of the island. Much of the data presented has indicated a fragile environment which may be seriously affected by both the exploration and production of hydrocarbons. Some of the common concerns are:

- destruction of dunes by traffic and roads.
- erosion of the land base from wind and water.
- spoiling of fish spawning and feeding grounds by drill cuttings, drilling fluids and muds, debris and garbage.
- damage to fishing equipment by drill and supply ships and debris.
- disruption of fishermen's traffic and routes with limited access to traditional fishing areas.
- mechanical damage to sea bottoms by anchoring and drilling.
- destruction of habitats of fish, birds, and mammals by oil leakage, spills, sewage, deck drainage, wash waters, producing formation water and well treatment materials.
- pollution from spills and blow-outs, leading to loss of flora and fauna, and irreparable damage to the island.
- concern for appropriate cleanup facilities in case of spills.
- social disruptions on the mainland because of influx of oilfield workers and support people.
- competition with fisheries for crews.
- competitions with fishery for wharf space and services.
- lack of compensation fund for damage to fish nets and for fishing time lost during accidents or spills.
- localized inflation caused by the petroleum industry demands on goods, services, amenities and people.

GOVERNMENT LEGISLATION

To help reduce the possible negative aspects of hydrocarbon exploration and development, legislation has been enacted at both the federal and provincial levels of government to protect the environment and residents of the area. The significant federal legislation includes:

- Fisheries Act, 1970. This defines Canadian fisheries waters, deleterious substances, and provides for penalties for violations.

- Canada Shipping Act. Defines pollutants in all-embrasive terms, prohibits the discharge of pollutants from ships and provides for ship inspections.

- Canada Water Act. Provides for the Federal Government to enter into agreements with Provincial Governments to establish bodies to undertake comprehensive water resource management programs.

- Migratory Birds Convention Act, 1970. Prohibits the killing or injuring of migratory birds and the destruction of their eggs or nest.

- Navigable Water Protection Act, 1970. Provides that no work shall be placed in, upon, over, under, through or across any navigable water unless the plans have Ministerial approval. It prohibits the depositing of any stone, earth, or substance that is liable to sink to the bottom of any navigable water less than 20 fathoms deep.

- Ocean Dumping Control Act. 1974-75. Prohibits the dumping of any substance at sea, from aircraft, ships, platforms, or other man made structures. The Act exempts disposal of material incidental to normal operations, explorations, exploitations and processing of seabed mineral resources. Permits may be issued for discharges considered harmless to human and animal health.

- Canada Oil and Gas Act (Bill C-48, March 1982). this act establishes a resource management regime for the "Canada Lands" which include the East Coast of Canada. Companies must actively explore the land they hold and all activities must be environmentally sound.

- The Canada - Nova Scotia Agreement 1982. This agreement establishes an organization that could manage the offshore oil and gas resources. The agreement is for 42 years and guarantees petroleum revenues to the Province of Nova Scotia.

Provincial legistlation covering offshore development includes:

- Nova Scotia Environmental Protection Act. Defines various terms and provides for a permit for any plant or facility that affects the environment.

- Nova Scotia Water Act. Regulates exploration, development and production of petroleum and provides for exploration agreements, drilling permits, producttion leases, etc.

- Nova Scotia Energy and Mineral Resources Conservation Act. Establishes a board to regulate the conservation of and to prevent the waste of energy and mineral resources.

- Nova Scotia Pipeline Act. Regulates the transmission of oil and gas from the wellhead to the consumer. It also selects routes for pipelines with due regard for the environment and the safety and convenience of the public.

- Nova Scotia Utilities Act. Regulates and establishes fair prices for gas to be charged by a gas utility in Nova Scotia.

- Nova Scotia Beaches Protection Act. Prohibits the removal of any sand, gravel, stone or any other material without a permit from the Minister of Lands and Forests.

- Petroleum and Natural Gas Act. Provides for notification to the Minister of intention to drill and provides for granting of a licence or lease and for payment of fees, rentals, royalties, etc. It also makes the licensee or leasee responsible for ensuring the proper disposal of wastes.

These Federal and Provincial Acts are intended to encourage the timely and effective development of resources with the greatest benefit to the public while reducing the environmental risks to a minimum.

PROPOSED HYDROCARBONS PRODUCTION

The hydrocarbon exploration phase at Venture near Sable Island is almost complete in that sufficient gas has been discovered to warrant planning of production facilities. These production facilities are undergoing the required engineering and other studies directed to delivery of gas via pipeline to the mainland for distribution to customers in Nova Scotia and elsewhere. Although production will be complicated by the weather, sea, and bottom conditions, the area is free of ice and does enjoy a fairly moderate climate with minimum temperatures seldom falling below freezing.

The production of gas from Sable Island will centre in early years on the Venture Field located from 6 to 16 km east of the island and in places less than 3 km from the east bar. The water depths range from 14 to 28 meters.

Mobil Oil is proposing to develop the Venture gas field utilizing two offshore production facilities. Each will consist of two wellhead platforms, one accomodation platform and one production platform. Gas will be shipped to the mainland by undersea pipeline.

This production method will necessitate the use of Sable Island for some facilities such as an emergency base for personnel employed on the offshore, including housing, storage of supplies, water, and other necessary support facilities. Additional helicopter handling and navigational installations will be required. Although the use of Sable Island will be limited, some environmental damage may occur and steps must be taken to minimize or eliminate these.

A second alternative has recently been proposed by Beaver Dredging Company for the Venture field. This proposes the construction of an artificial island at the Venture site. This island would be approximately 700 meters long and 350 meters wide at the surface. The base of the island would be nearly 1200 meters by 900 meters. This island would contain an airstrip for fixed wing aircraft, storage facilities for such aircraft, a harbor for service vessels, production facilities for gas, and all required support installations for staff. This island would be completely self sufficient and not dependent on the use of Sable Island.

The construction of this island would be mainly from rock and sand fill. The rock would be shipped to the island site from the mainland while sand would be dredged from the nearby bottom. The construction time is estimated at 5 years with a cost approaching $300,000,000.

Although this island approach may have merits, it may also present several problems other than cost. This artificial island would be located in 15 meters of water and within 3 to 4 km of the shallow east bar of Sable Island. With a base of 1.2 km by .9 km, this artificial island could significantly influence the current flow and sediment transport around Sable Island. The result of this change in sediment transport patterns could possibly lead to a change in the island and its associated bars. The end result may be beneficial, harmful, or effect no change. There must be extensive study prior to the construction of such an island. Should accelerated erosion of Sable Island occur after construction of an artificial island, additional costs may be incurred in stabilizing Sable Island.

The third alternative to gas production on Sable Island is to induce sedimentation on the Sable Island Bank; building up the banks and effectively enlarging Sable Island itself. The stabilizing of Sable Island has been a problem and although some limited success has been realized by land management under the Sable Island Environmental Advisory Committee established in 1975, its activities have been relatively small compared with the magnitude of the problem. Land management to date has had limited success, partially stabilizing some of the sand blowouts which have threatened to erode the island at further locations.

In spite of these land management efforts, the fragility of Sable Island has not been reduced and the island is certainly not environmentally or physically stable.

The concept of building up the Sable Island Banks may be the least expensive and best long term solution to guaranteeing the future of the island. These banks would be built-up through utilizing natural sediment transport mechanisms combined with structures or devices which will cause this sediment to be selectively deposited and stabilized in the desired locations. The first step in this process is to obtain and correlate additional information on the currents flowing around Sable Island along with the volume and direction of sediments transported by the currents.

More aggressive methods of stabilization and vegetation must be exercised on Sable Island. This may include more extensive use of fencing, nets or other stabilizing devices placed on the island. Additional planting and upkeep, including fertilization, must be undertaken. This will reduce the sand drift and erosion caused by winds.

Sediment is probably being transported via currents to Sable Island from all directions; however, the net transport of this material is eastward. Figure 1 shows the extensions of the west and east bars and the 20 - 25 meter water depth boundary representing the area of Sable Island which could potentially be built up.

The actual build up of the Sable Island banks may be accomplished in several ways. These include the construction of groynes along the coast, the construction of headlands near the coast and the selective placing of nets or other sediment trap devices along or near the coast.

The construction of groynes along the coast of Sable Island would be relatively inexpensive. Material would be transported from the mainland; however, the volume would be small in comparison to an artificial island. The effectiveness of groynes would require further investigation; however, work published by Silvester, R. M. and S. K. Ho indicates this may not be the most effective approach and might prove counter productive in this environment.

The second approach, found effective by Silvester and Ho in Singapore, is to construct artificial headlands along the coast of Sable Island. These headlands could be constructed from rock fill, structures or possibly, sand trapping devices constructed from nets or metal webbs. These would be spaced at intervals of several hundred meters along the coast and perhaps 50 to 200 meters offshore. Their size would be in the order of 50 meters long and 10 meters wide. Sand would accumulate between these headlands and the shore effectively moving the shoreline south and east. Extending these headlands along the west and east bars may possibly lengthen the island. Once sand has been built up along the east shore of Sable Island, stabilization techniques would be applied to this sand and new headlands constructed further offshore.

Several cycles of the above techniques could eventually lead to building up the Sable Island bank to cover the Venture gas field. Once this gas field has been covered by built up banks, its development into production would be simplified and relatively inexpensive through utilizing onshore technology.

The potential benefits of a built up Sable Island are many, the major being:

- The larger island would be inherently more stable and easier to protect from further errosion.

- The island would provide a more stable home for its unique plant and animal life.

- Sable Island would become a base for offshore operations providing space for the construction of workers' accomodations, storage, recreation, production and communication facilities, an airstrip for fixed wing aircraft, etc.

- The larger island would provide for easier access to oil and gas fields from onshore sites on Sable Island rather than utilizing offshore facilities. This would make the recovery of hydrocarbons from Sable Island more economical and would provide access to some of the smaller fields through the use of onshore technology.

- There may also be a change in the relationship between federal and provincial roles in the Sable Island area by making gas production an onshore rather than an offshore program.

CONCLUSIONS

The production of gas from Sable Island has not yet reached the stage where it will definitely proceed to full possible production in the near future. Substantial gas has been found; however, the difficulties in bringing this gas to market are extensive. The building up of the Sable Island Banks will make the development of production facilities more attractive and will also ensure the continued existence of this island with its uniqueness. Research is continuing into the technology which can lead to the build up of these banks. Much work remains in this field and more data must be gathered.

The cost benefits of this approach are potentially large and financial and technical investment into this project could provide a substantial return. Should the demand for gas in eastern North America decline or the technical diffficulties in bringing the gas ashore increase, the build up of the Sable Island Banks may prove to be the only viable solution to the development and production of east coast natural gas.

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BRIEF PERSONAL HISTORY

Marie C. Rockwell

Education:	Ph.D. in Mineral Engineering from the Technical University of Nova Scotia, 1981. M.Eng. in Metallurgy from the Technical University of Nova Scotia, 1972. B.Eng. in Mining from the Technical University of Nova Scotia, 1965.
Experience:	Presently, Associate Professor in the Department of Mining and Metallurgical Engineering of the Technical University of Nova Scotia, Halifax, N.S., Canada, teaching undergraduate and graduate courses in mining, petroleum and mineral economics. Also, supervising several graduate student research projects. Prior to joining the teaching staff in 1979, I spent over ten years in industrial research, the last five with the Atlantic Industrial Research Institute as a senior research associate. Contributed to engineering profession with several papers on R&D and as a TV guest speaker on various occasions on issues of advanced technology in engineering. The research topics undertaken vary in nature from new creative ideas to applied research in mineral handling and processing, mining and petroleum technology, offshore drilling and production engineering and electronic ceramics.
Professional Affiliations:	Member of the Association of Professional Engineers of Nova Scotia; SPE & SME; Canadian Mining and Metallurgical Society; Canadian Petroleum Society; American Ceramic Society; NICE & CEC.
Personal:	Married to a biomedical engineer and have two teenage children.

FABRIC-REINFORCED DIKES FLOATED ON SOFT DREDGED MATERIAL FOUNDATION

by

Jack Fowler[1]

QUANDARY: How do you build a dike over a dredged material foundation that must have prompted the quote "too thin to walk on and too thick to swim in"? An innovative technique to do just that, tested at the Craney Island Disposal Area in the Corps' Norfolk District, is described in the following article.

The Craney Island Disposal Area, a 2500-acre confined dredged material disposal site, is one of the largest such sites in the United States (Figure 1). The Corps' Norfolk District constructed the site in the mid-50's for long-term disposal of material dredged from ports and channels in the Hampton Roads area near Norfolk, Virginia. Almost continuous use for disposal from direct pipeline discharge and hopper dredge pumpout has deposited over 147 million cubic yards of material within the containment.

In the early 70's, an attempt was made to construct two interior dikes using woody debris and end-dumped or hydraulically placed sand. The dikes were designed to create subcontainment areas that would improve sedimentation in the containment area being used and allow the other two containment areas to dry out. Construction was halted when very soft dredged material, encountered about midway between the perimeter dikes, prevented the progress of end-dumping.

Public Law 94-587, enacted in 1976, authorizes use of containment-area management practices that will increase the capacity and extend the useful life of dredged material disposal areas. In 1980, the Norfolk District, assisted by the U. S. Army Engineer Waterways Experiment Station, developed a plan to ensure good management of the remaining resources of the Craney Island Disposal Area (see Information Exchange Bulletin 1980 and Palermo, Shields, and Hayes 1981).

The 1980 management plan identified early completion of the two interior dikes as a key element. Dike closure would form three subcontainment areas that would improve the sedimentation process, improve weir performance, and increase the storage capacity of the disposal area. Overall benefit would be to postpone the need to acquire scarce, expensive real estate for another disposal area.

SITE DESCRIPTION

Extremely poor foundation conditions existed along the interior dike alignments for about 5000 ft for closure of the north dike and 3500 ft for the south dike. Soft dredged material, which extended to depths of 30 to 40 ft, had undrained shear strengths that ranged from 25 to 100 psf. The predominant underlying in situ material was very soft marine clay (CH and OH). The land surface enclosed by the completion of the perimeter dike in 1957 was at el -10 ft mean sea level (msl) with the

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very soft marine clay extending to el -90 ft msl.

Approximately 40 percent of the alignment area had a dried 3- to 4-in. crust. The other 60 percent was covered by recent deposits of dredged material, and there was surface water near the weirs.

DESIGN CONSIDERATIONS

Site conditions dictated a wide shallow-sloped dike (1 vertical: 10 horizontal) to be raised incrementally as filling of the containment area progressed. Previous experience indicated that the magnitude of dike displacements would be 8 to 10 volumes down for one volume above the surface of the dredged material. To provide the necessary initial containment area capacity, the dikes were to be 11 ft above present surface at the embankment center line.

CONSTRUCTION ALTERNATIVES

End-dumping of displacement sections is an accepted method of dike construction where marginal foundation conditions exist. Clean sand dredged material was available near by, but the large quantities required to construct an unreinforced displacement section were not economically feasible. Also, engineering judgment led to the conclusion that it would be difficult if not impossible to control displacement dike sections to achieve the desired width and stable base for future dike raising anticipated at the Craney Island facility.

Analysis of the use of conventional dike construction without any reinforcement indicated that the factor of safety in bearing would be less than 1.0. Unreinforced dikes constructed on the soft foundation in the disposal area could exceed the foundation bearing capacity and result in one of three types of failure:

- Localized foundation failure with propagation of a rotational failure through the dike.
- Lateral splitting and outward spreading and sliding of the dike.
- Bearing failure caused by excessive subsidence caused by excessive consolidation and displacement.

A design concept developed by Dr. Fowler and the late Dr. T. Allan Haliburton of Haliburton Associates, Stillwater, Oklahoma, supported by the Dredged Material Research Program (DMRP) and the Dredging Operations Technical Support (DOTS) Program, was considered: floating a dike on the soft foundation by using a civil engineering fabric (also called geofabric, geotechnical fabric, and filter cloth) for tensile reinforcement (Fowler 1981). The fabric would be placed on the soft foundation transverse to the dike alignment, followed by placement of a sand layer for a working table with a wide-base shallow-sloped dike to be raised as soon as pore water pressure dissipated and the dredged material foundation consolidated.

The design considerations and construction techniques are described by Fowler (1981). Test Sections 1 and 2 were designed by the late Dr. Haliburton and Dr. Fowler, author of this article. Test Section 3 was built as a worst-case exercise.

Design analyses indicated that the fabric would provide the reinforcement necessary to prevent rotational foundation failure or embankment spreading and splitting until the soft foundation consolidated sufficiently to support the embankment. A similar system was used successfully to construct a multi-purpose dike at Pinto Pass in the Mobile District (see Information Exchange Bulletin 1979).

Experience from prior end-dumped dike construction at Craney Island and from fabric-reinforced dike construction at Pinto Pass indicated that the latter could be accomplished for about 40 percent of the cost of end-dumping and that better control of the desired section could be maintained with the fabric-reinforced dike. Based on these two factors, the fabric-reinforced construction was selected for installation of three dike sections to determine the feasibility of using floating dikes at Craney Island. Construction began in mid-July 1982 and was completed in mid-November 1982.

CONSTRUCTION TECHNIQUES

The planned construction sequence was essentially the same as that used for the dike at Pinto Pass (Fowler 1981). Fabric was laid on the dredged material surface in 16-ft-wide panels placed transverse to the longitudinal axis of the dike (Figure 2), and the panels were sewn together (Figure 3) with very strong polyester thread (breaking strength approximately 80 lb).

As the fabric placement progressed, sand was end-dumped and then spread with small wide-track dozers with 2.3-psi contact pressure (Figure 4). The sand layer was 2.0 to 2.5 ft thick. Where the dredged material was very soft, the weight of the sand caused a small surface mud wave that launched the fabric forward. Laborers used 16-ft-long poles to assist in launching and spreading the fabric (Figure 5). The low ground pressure dozers pushed sand onto the in-place fabric, creating a wave in the underlying mud that stretched the wrinkles from the newly placed panels.

Initially, all dump truck traffic was confined to the outside edges along the toe of the test section to provide lateral spreading that would pretension the fabric. After the fabric was placed and the sand was spread for the working table, the dikes were raised in increments to a height of 11 ft for Test Sections 1 and 2 and 8 ft for Test Section 3.

On-site construction was directed by Dr. Fowler assisted by personnel of the Norfolk District: Mr. Matthew Byrne, geotechnical engineer; Mr. Rivers Westcott, manager of the Craney Island Disposal Area; and Mr. T. J. Szelest, Project Manager for implementation of Craney Island Management Plan. The project was under the general supervision of

COL Ronald E. Hudson, Norfolk District Engineer, and Mr. Ronn Vann, Chief of Norfolk District's Dredging Management Branch.

FIELD TEST SECTIONS

Test Section 1

Test Section 1 was a 750-ft-long dike designed to begin at the west end of the existing north interior dike. There had been very little disposal into the area since April 1982, and a 3- to 4-in.-thick crust of dried material covered the alignment of the dike. The in situ undrained shear strength of the foundation was about 100 psf.

The crust provided a good working surface that supported the laborers as they spread the fabric across the center line of the dike and sewed the panels together. The spreading of the sand working table closely followed the fabric-laying operation. This sequence progressed rapidly for 600 ft with no evidence of the anticipated mud wave, and the decision was made to construct the remaining 150-ft dike section without the fabric reinforcement.

The embankment was raised incrementally. There was complete failure of the unreinforced section when the dike approached a height of 6 ft. The fabric-reinforced section was raised to 11 ft without failure. Figure 6 shows the completed dike section.

Test Section 2

A 400-ft-long dike section was to begin at the west perimeter dike and be constructed eastward on the same alignment as Test Section 1. Foundation materials were very soft on the west side of the containment area; the in situ undrained shear strength was about 50 psf. No crust had formed in the area because dredged material had recently been deposited. Disposal operations continued in the northwest corner during the construction of Test Section 2.

Construction proceeded as planned (Figure 7). A very shallow mud wave was created and was used to advance the fabric. The dike was completed without any major construction problems and a stable embankment was built.

Test Section 3

A 300-ft-long dike was projected eastward from the west perimeter dike on the same alignment as the south interior dike. The elevation was the lowest of the entire disposal area. Records showed that water had ponded there continuously since construction of the perimeter dikes was completed in 1957. Needless to say, no crust had developed. In situ tests showed the undrained shear strength of the foundation dredged material in the area was 25 psf. Construction in the area would be under worst-case foundation conditions.

The planned construction sequence was used for laying the fabric and raising the dike (Figure 8); however, the dike did not float on the soft material, but displaced downward about two volumes for each volume of sand raised above the surface. (This was a vast improvement over the previous experiences of site personnel, who had consistently observed downward displacements of 8 to 10 volumes below the surface for one volume above.) The embankment was successfully raised to a height of 8 ft.

General

An equipment rental contract was used by the Norfolk District rather than a performance contract because specific items in the construction process, such as construction sequence, fabric placement, and sewing techniques, were considered critical to satisfactory performance of the test sections. The low construction bid for the three dikes was about $280,000 and the 92 rolls of fabric used for reinforcement cost approximately $141,000.

SUMMARY

The reinforced embankments at Test Sections 1 and 2 were finished to design width and grade without excessive lateral spreading or rotational bearing failure in the foundation despite excessive pore water pressure of about 20 ft that developed above the dredged material surface. The embankment of Test Section 3 experienced a downward displacement of about two volumes for one volume raised above the surface during construction, but no embankment failure occurred.

The fabric performed satisfactorily when the fabric warp fibers were oriented perpendicular to the long axis of the dike, but failure occurred in the fabric fill fibers which were oriented in the longitudinal direction at Test Section 3 (which is the inherently weaker orientation of the fabric fibers). Nonetheless, the fabric provided sufficient reinforcement to support rapid dike construction to the desired height and to maintain the structural integrity of the embankment.

Foundation pore pressures are dissipating gradually. After the excess pore pressures have been reduced, the height of the dikes can be increased to provide additional storage area.

Long-term settlement and pore pressure data are being collected and evaluated to determine the performance of the dikes and to refine the design and construction procedures and criteria. Results of the long-term study will be published in a technical report.

LESSONS LEARNED

When time constraints will permit, construction of a floating dike will progress with a minimum of difficulty if construction is delayed until a crust is formed that will support the fabric-laying activities. Crust formation can be accelerated by drainage/dewatering techniques such as progressive trenching with the RUC (Riverine Utility Craft, see Skjei 1976). The crust along the alignment of Test Section 1 was 3 to 4 in. thick and supported fabric laying and construction of the initial sand layer, eliminated the mud wave construction technique, and reduced the fabric fill fiber strength requirements.

For detailed information concerning the Craney Island project or the construction technique, contact Dr. Fowler (Commercial 601 634-2703 or FTS 542-2703); Mr. Charles C. Calhoun, Jr., Program Manager for the DOTS Program (Commercial 601 634-3428 or FTS 542-3428); or Mr. Szelest, Norfolk District (Commercial 804 441-3503 or FTS 827-3503).

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8 Test Section 3 during construction (viewed from east to west)

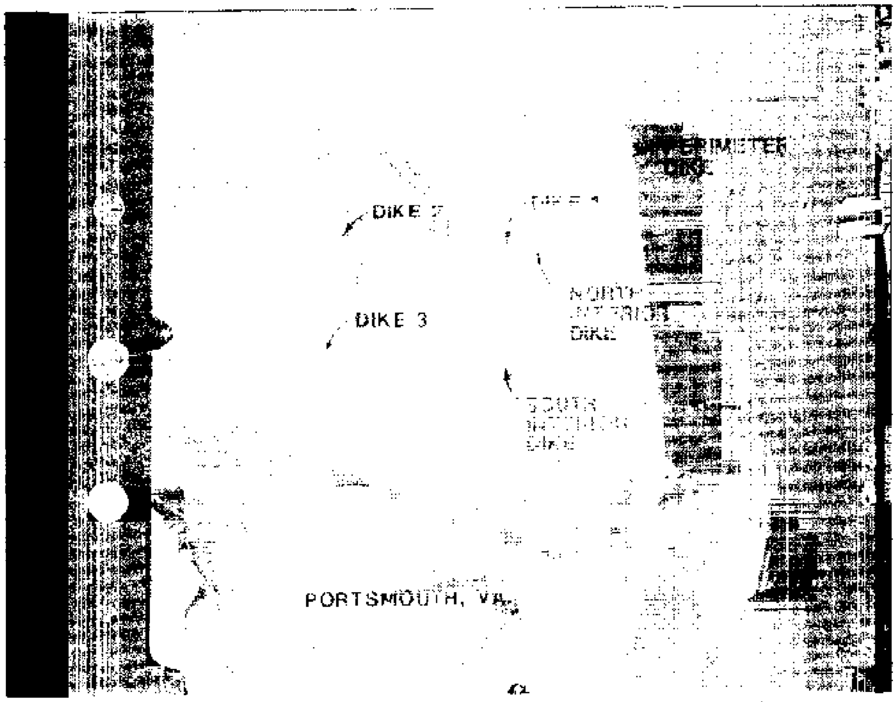

Figure 1. Aerial view showing December 1982 configuration of Craney Island Disposal Area, looking north

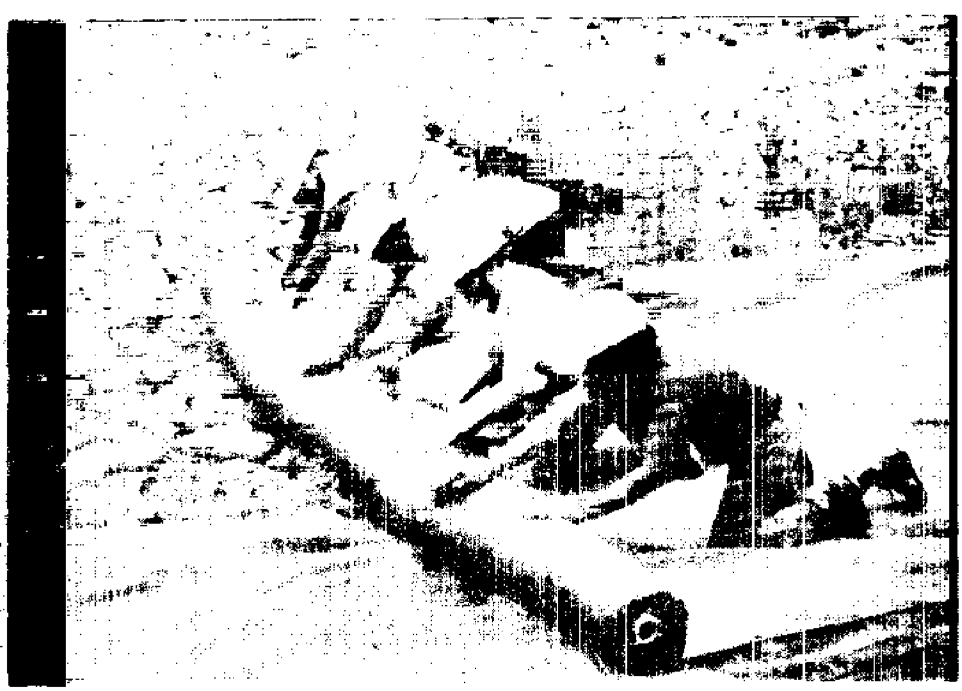

Figure 2. Unrolling fabric across the center line of the dike

Figure 3. Sewing fabric panels together

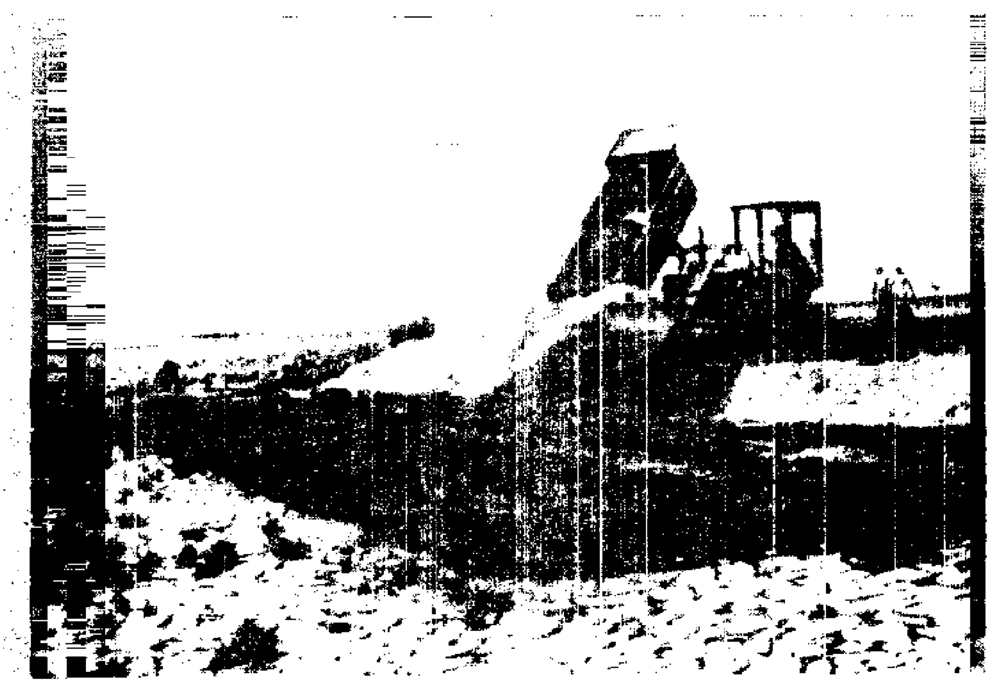

Figure 4. Dumping and spreading sand on in-place fabric

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BRIEF PERSONAL HISTORY

Jack Fowler

Education: B.S., Civil Engineering from the University of Mississippi 1961
M.S., Civil Engineering from Mississippi State University, 1972
Ph.D., Civil Engineering from Oklahoma State University, 1979.
Major field of study: Soil Mechanics

Experience: Mr. Fowler worked for the Soils Conservation Service for one year while attending the University of Mississippi. After receiving his BS degree in 1961, Mr. Fowler was employed by the Corps of Engineers Ballistic Missile Construction Office, Inglewood, California, as a construction inspector at the Jacksonville, Arkansas, Field Office. This work involved construction of 18 Titan II Missile Bases. Mr. Fowler was on Military leave of absence for 3 months in 1962 at Fort Polk, Louisiana, during the Berlin Crisis. Since 1962, Mr. Fowler has been employed at the U.S. Army Engineer Waterways Experiment Station as a Research Civil Engineer, participating in the Dredge Material Research Program as a Senior Project Engineer on numerous projects involving dewatering of dredged materials and design and construction of fabric reinforced containment levees and construction haul roads. He has also participated on a streambank erosion inspection team that is responsible for providing new guidelines for streambank protection. He is currently a principal assistant to the Chief, Engineering Studies Branch, and is responsible for planning, executing, and analyzing the results from research and development studies and preparation of engineer manuals on construction control for earth and rock-fill dams and levee design.

Professional Licenses: Registered Professional Engineer in the State of Mississippi

Professional Memberships: ASCE, NSPE, ASTM, MES, Vicksburg Engineers Club and Chi Epsilon

Publications: Mr. Fowler has authored or co-authored 25 technical publications, 5 unpublished technical publications, and 7 papers. He has also been technical contributor to 16 technical publications. These publications were in the field of geophysics, dynamics, soil mechanics, soil and structural interaction and pile supported foundations, and seismic wave propagation phenomena.

EFFECT OF A LADDER PUMP ON THE CAVITATION CHARACTERISTICS OF A CUTTERHEAD DREDGE

by
Giulio Venezian[1]

INTRODUCTION

A cutterhead dredge system of fixed geometry is analyzed to determine the head required to achieve a given discharge of mixture for various concentrations. These relationships determine the characteristics of the pumping system needed for the operation of the dredge in the given configuration.

Other parameters calculated are the power required, the weight of solids delivered per unit time, and the net positive suction head available at the pump.

The optimal design would have the best efficiency of the pump coinciding with the highest weight of delivered solids per unit of energy expended. There are various limitations on this optimization: the maximum power available, the minimum permissible suction head for the pump, the maximum concentration of solids that can be carried, and the characteristics of the cutterhead and seafloor which combine to give a relationship between discharge rate and concentration of sand.

Of these four limitations, only the suction head limitation can be avoided easily. The power limitation will be taken as an absolute one, limited by capital cost, size and weight. The maximum permissible concentration of solids that can be pumped is unknown, but in the context of this paper it will be assumed to be 35 percent which is the approximate limit of validity of the Durand-Gibert relations used in the analysis. While higher concentrations can undoubtedly be pumped, the head requirements increase rapidly so that this limitation becomes similar to the power limitation. Finally, the characteristics which determine the concentration for a given flow rate are not known at this time. This is an area where further studies are needed if a rational design of a dredging system is ever going to be carried out.

DESCRIPTION OF THE SYSTEM

An idealized dredging system is shown in Figure 1. It consists of a suction pipe, one or more pumps, and a discharge line. The system is basically the one analyzed by Basco (1973) except that the system geometry is kept fixed, and some details of the analysis have been changed.

In the configuration shown, l_s is the length of the suction line, l_d is the length of the discharge line, d is the water depth and e is the elevation of the pump and discharge above the water surface. An alternative configuration is also considered, in which an auxiliary pump is placed on the ladder at a distance l_a from the inlet.

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In analyzing the system, it is assumed that the fluid in the lines is a slurry containing a concentration C of solids (volume of solids/volume of mixture) while the fluid surrounding the pipe is clear fluid of specific weight γ_1.

The pressure at a point P having the same elevation as the inlet is thus γd, and if it is assumed that slurry is drawn into the inlet starting from rest at point P, the Bernoulli equation between P and the discharge point 0, where the pressure is atmospheric is

$$\gamma_1 d + \Delta p_p = \frac{1}{2} \rho_m V_D{}^2 + \Delta p_s + \Delta p_d + \gamma_m(d+e) \quad (1)$$

where Δp_p is the pressure increase across the pump, Δp_s and Δp_d are the pressure drops due to frictional losses in the suction and discharge lines, and V_D is the velocity of the fluid at the discharge.

If the flow rate is given, the velocities in the suction and discharge lines can be found, and hence the pressure drops can be calculated for any given concentration. The Bernoulli equation then gives the pressure rise required across the pump to achieve the desired flow rate, and the power can then be calculated.

The stagnation pressure at the suction inlet of the pump is given by

$$p_{ss} = \gamma_e d - \gamma_m(d+e) - \Delta p_s$$

The available positive suction head relative to the vapor pressure of the liquid (expressed in feet of mixture) is

$$h_s = (p_{ss} + p_a - p_v)/\gamma_m \quad (2)$$

where p_a is the local atmospheric pressure and p_v the vapor pressure of the liquid.

LOSSES

The literature on losses in a pipe when slurry is flowing traditionally expresses the losses as a head of clear liquid, so that $\Delta p = \gamma_1 h_L$.

The formulation used here will follow the results of Durand (1953) and Gibert (1960). The head loss in a horizontal pipe carrying mixture $(h_L)_m$ is expressed in terms of the corresponding head loss for the same conditions carrying clear fluid $(h_L)_f$ as follows:

$$(h_L)_m = (1 + C\phi)(h_L)_f \quad (3)$$

where C is the concentration and ϕ is a function which does not involve the concentration and is given by

$$\phi = 121\left(\sqrt{\frac{g(s-1)}{d}}\ \frac{DV_s}{V^2}\right)^{3/2} \qquad (4)$$

Here D is the pipe diameter, d the median particle diameter, s the specific gravity of the sediment (relative to the conveying fluid), and v_s is the settling velocity of the particles.

This equation applies only when there is no settling of the sediment to the bottom of the pipe, a condition which holds only when the velocity is larger than a critical velocity V_c which Durand expressed as

$$V_c = F_L(2gD(s-1))^{\frac{1}{2}} \qquad (5)$$

where F_L depends on the concentration and median sediment diameter.

Gibert found that the relation could be applied to a partially blocked pipe by assuming that the blockage would decrease the effective diameter of the pipe and thus the critical velocity until the point would be reached when the velocity became equal to the critical velocity for that blockage and no further blockage would then occur. Expressing the effective diameter as 4 times the hydraulic radius, this equilibrium blockage would be reached when

$$\frac{V^2}{4R_h} = \frac{V_c{}^2}{D} \qquad (6)$$

For inclined pipes, Gibert found that ϕ should be replaced by $\phi (\cos\theta)^{3/2}$ in Equation (3). Worster and Denny (1955) proposed that ϕ should be replaced by $\phi\cos\theta$, and this relation was used in the calculations presented here.

It should be noted that in the case of an inclined pipe the question of partial blockage does not arise, unless the slope is very small.

CALCULATIONS AND RESULTS

Calculations were performed for a system described as follows:

length of suction line: 100 feet
length of discharge line: 2000 feet
suction pipe diameter: 33 inches
discharge line diameter: 30 inches
median particle diameter: 0.5 mm
settling velocity: 0.21 ft/sec

Concentrations were varied from 0.02 to 0.25, and digging depths of 40 and 70 feet were considered.

Figures 2(a) and 2(b) show the head versus discharge curves for different concentrations for digging depths of 40 and 70 feet respectively. The horsepower requirement is also indicated on the curves. There is no significant variation of the curves with digging depths, indicating that the frictional loss is dominant for this geometry. The head loss increases with concentration and the power requirements increase both with flow rate and concentration. There is thus a limitation on the system imposed by the maximum power available.

Figure 3(a) shows curves of available NPSH at the pump superposed on the head versus discharge curves for a digging depth of 70 feet. These curves are nearly parallel to the concentration curves, indicating that there is a maximum concentration that can be conveyed by the system.

Of course the NPSH alone is not a suitable criterion, since the NPSH required by a pump to avoid cavitation varies with flow rate and rotational speed. Nevertheless, the curves do indicate that the available NPSH decreases with concentration.

The efficiency of the system in terms of energy cost per unit weight of solids delivered increases with concentration, so that if the NPSH limitation can be removed, the efficiency of the system can be improved.

Figure 3(b) shows the effect of a ladder pump on available NPSH. The calculations were done with an auxiliary pump halfway up the ladder, assuming that the pressure increase across the auxiliary pump is 20% of the total head. As it can be seen from the resulting curves, the available NPSH at the main pump is virtually constant over the range of values computed. The auxiliary pump thus eliminates the NPSH limitation.

It must be pointed out, however, that the Durand-Gibert formulation does not hold for large concentrations, so that the increase in efficiency with concentration has a limit also. Moreover, the concentration itself is not a controllable variable since it depends on the inlet conditions and the characteristics of the sediment. Optimization of the process is still an operator function, although calculations of the type described here can be of value in the design of the dredging system and in indicating desirable operating conditions.

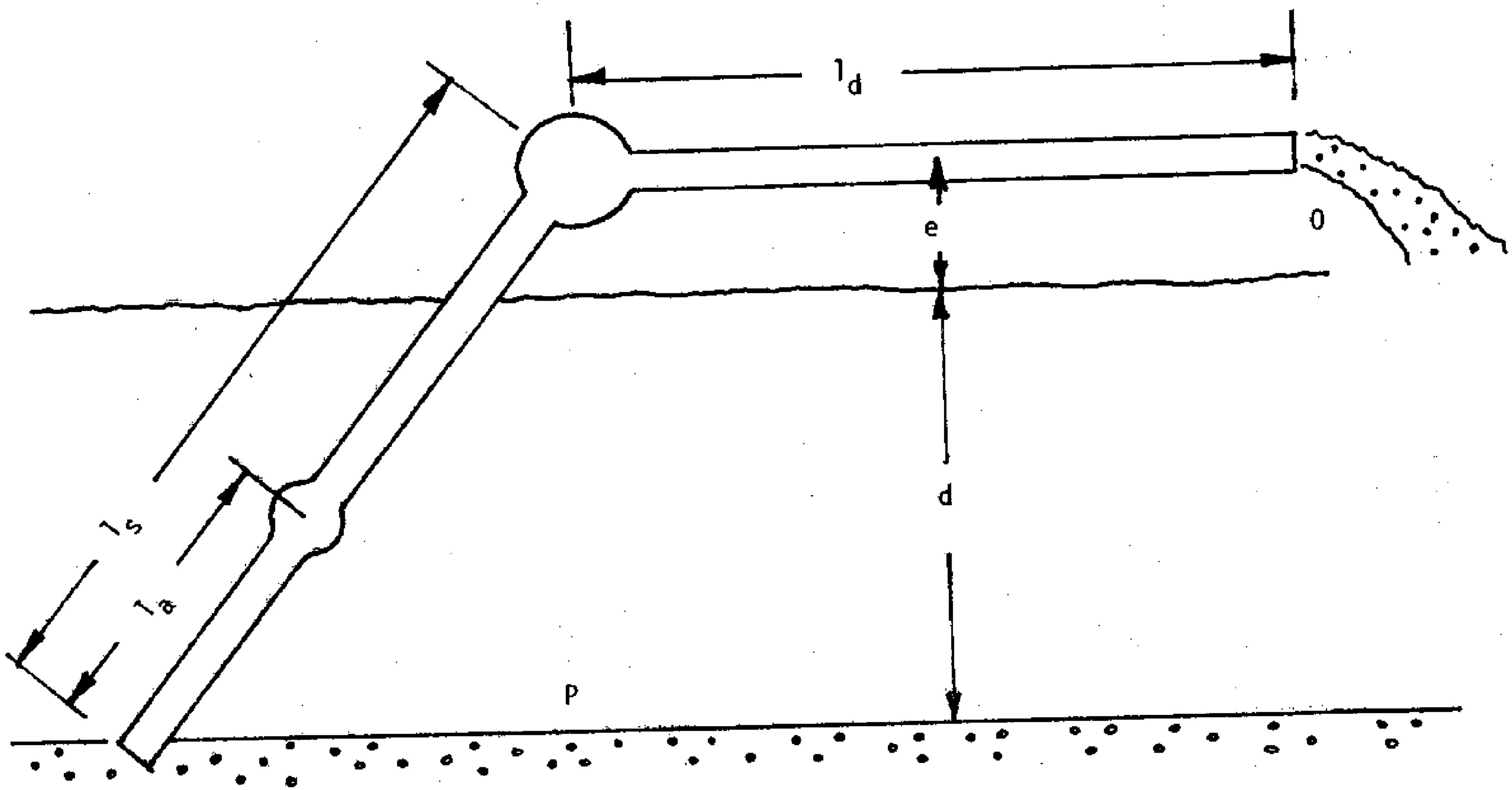
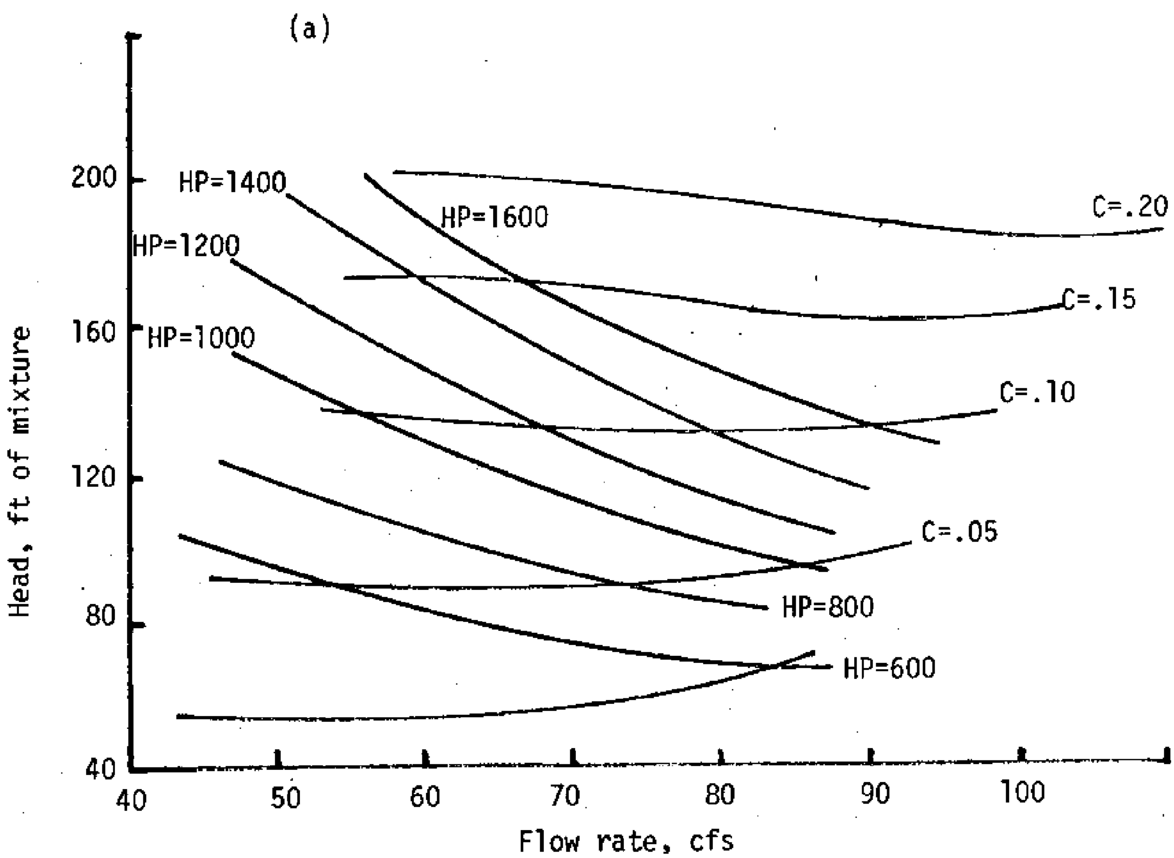


Figure 1. Schematic diagram of dredging system.



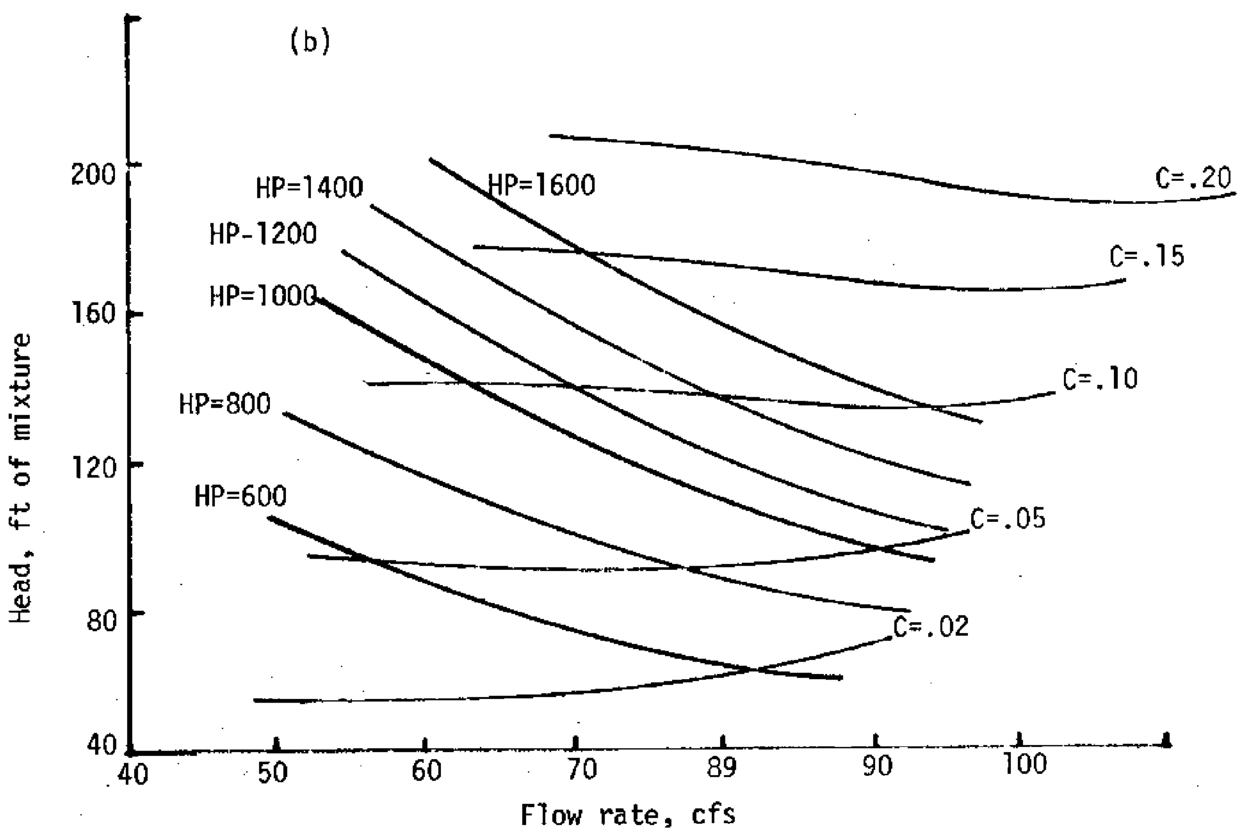
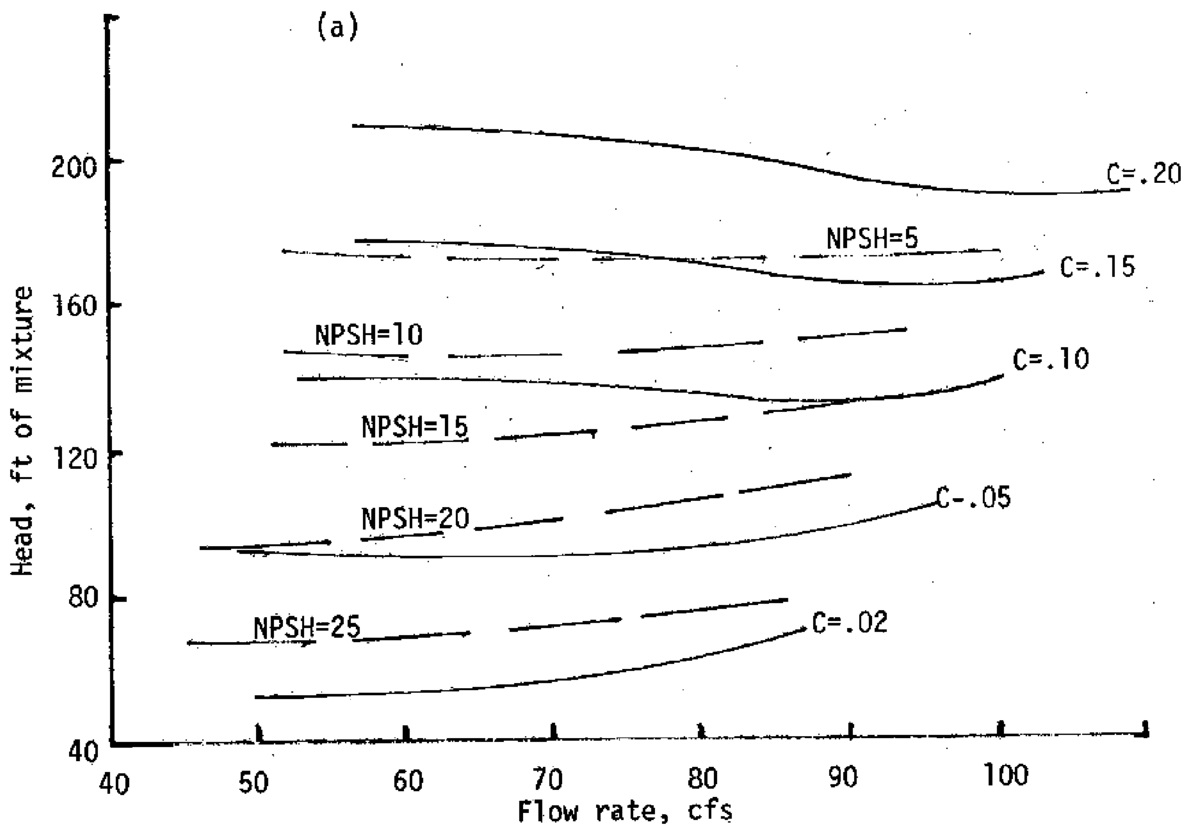


Figure 2. Head vs. discharge curves for different concentrations (a) digging depth = 40 ft; (b) digging depth = 70 ft.



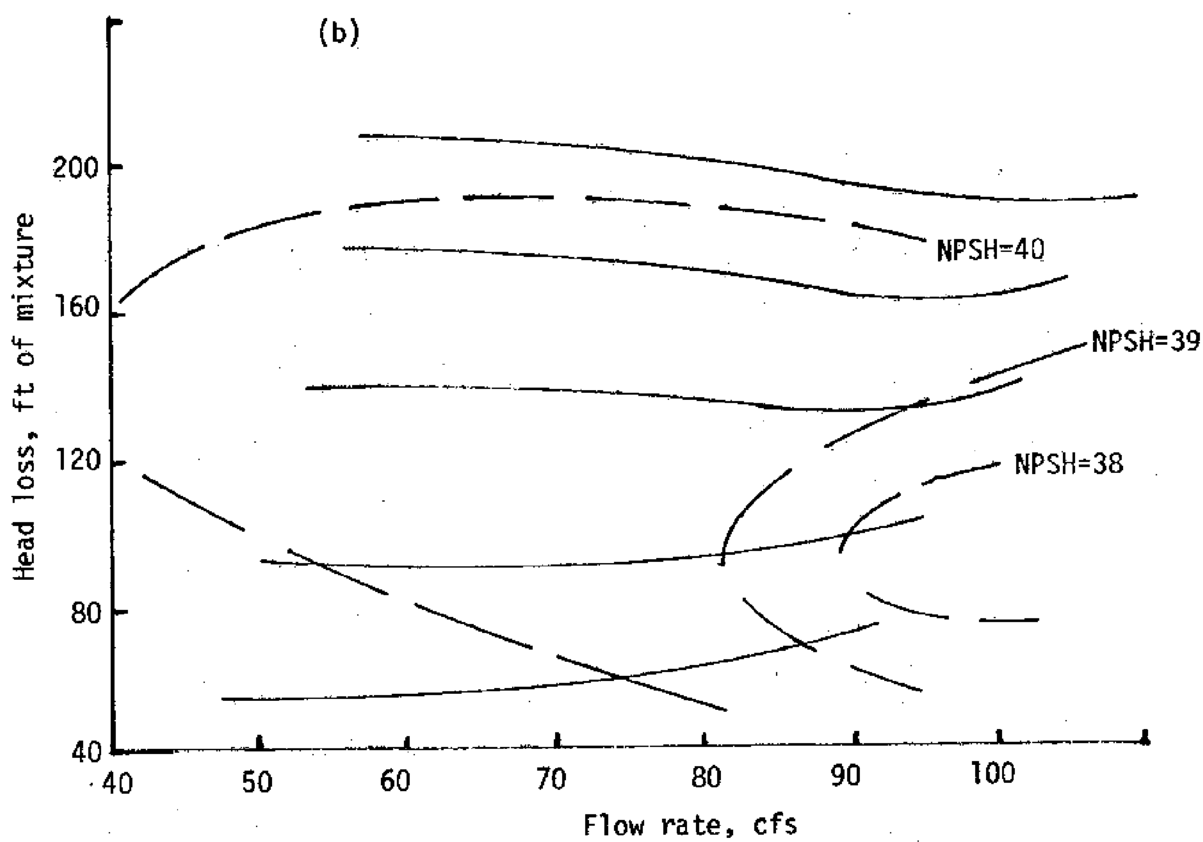


Figure 3. Available NPSH at a digging depth of 70 feet.
(a) single pump; (b) with auxiliary pump on ladder.

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BRIEF PERSONAL HISTORY

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Personal:	Birthdate: 12-9-38 Birthplace: Torino, Italy S.S. No.: 569-60-0236 Marital Status: Married Security Clearance: None Children: Two Citizenship: Italy: Permanent Resident of U.S.
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Professional Interests:	Ocean Engineering; Fluid Mechanics; Numerical Modelling in Fluid Mechanics; Perturbation Methods
Selected Publications:	"Magnetohydrodynamics of the earth's magnetic field," International Shipbuilding Progress, Vol. 14, No. 151, March 1967. "Effect of modulation on the onset of thermal convection," J. Fluid Mech. 35, 243 (1969). "Non-linear dispersive waves in shallow water," Proceedings of the XVI Congress of the IAHR, Sao Paulo, Vol. 1 A-40, pp. 322-329, 1975. "Further notes on a dispersive theory for waves in shallow water," Look Lab/Hawaii, Vol. 6, No. 2, pp. 35-37, July 1976. "Wave energy as a resource for wave power in Hawaii," Preprints, Symposium on Chemistry and Economics of Ocean Resources, 177th Meeting of the American Chemical Society, Division of Chemical Marketing and Economics, pp. 280-291, 1979. "Current-wave coupling and hydrodynamcis," Proceedings of the 6th OTEC Conference, Washington, D.C., 6.10-1-6.10-6, June 1979. "Direct solution of wave dispersion equation," (discussion), J. of Waterways and Harbors, ASCE, 106, 501-502, 1980.

ENGINEERING ASPECTS OF CAPPING DREDGED MATERIAL

by
Raymond L. Montgomery[1]

ABSTRACT

A technique known as capping has been used in the Long Island Sound and the New York Bight during recent years to contain contaminated dredged material in subaqueous disposal sites. This technique involves placing contaminated material in the disposal site and then covering it with clean sediments to prevent spread of the contaminated material in the aquatic environment. The capping technique is attractive as a means of controlling the potential harm of contaminated sediments. The convention on the Prevention of Marine Pollution by Dumping of Waste and Other Matter (known as the London Dumping Convention) has accepted capping of contaminated sediments in open water disposal sites, subject to careful monitoring and research.

There has been a significant amount of research performed on stability of cap materials and biological activity in cap materials. However, there has been little research devoted to the equipment and operational aspects of capping. This paper provides information on past capping practices, capping materials, placement techniques and research and development needs for improved capping techniques.

INTRODUCTION

Great strides have been made in recent years in determining the effects of open-water disposal of dredged material. Research performed under the Corps' Dredged Material Research Program (DMRP) and by others have indicated that disposal of clean dredged material in open water is not of major concern. A major concern, however, is the disposal of highly contaminated sediments that are found in many of our harbors and waterways. The contamination of these sediments is a result of man's activities including industrial expansion, widespread use of pesticides in agriculture, and intentional or inadvertent dumping of pollutants. Disposal alternatives for material dredged during the maintenance of these harbors and waterways are often quite limited. The traditional method of disposing of contaminated sediments is confinement in upland disposal areas. However, a new disposal alternative is emerging in the Long Island Sound and New York Bight areas. This disposal alternative involves placing the contaminated dredged material in open water and capping it with a clean sediment to prevent the spread of contaminated sediments at the subaqueous disposal site and isolating them from benthic organisms. The cap material is thick enough to protect the underlying contaminated material from disturbances by waves and currents and keep the contaminated

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particles buried beyond the reach of burrowing organisms.

A significant amount of research has been performed on stability of cap materials and biological activity in cap materials (Bokuniewiez, et al, 1981) (Freeland, et al, 1983) (Morton, 1983). However, there has been little research devoted to the engineering design, construction, and management of capping activities. This paper provides information on past capping practices, capping materials, placement techniques, and research and development needs for improved capping techniques.

EXISTING CAPPING PRACTICES

Capping is currently being carried out as a means of controlling the potential harm of contaminated or otherwise unacceptable sediments. The London Dumping Convention has accepted capping, subject to careful monitoring and research, as a means of rapidly rendering harmless by physical means, contaminated material dumped into the ocean. The physical means are essentially to seal the unacceptable material from the biosphere by a covering of acceptable material. In the United States, the capping techniques have only been used in the Long Island Sound and the New York Bight. The contaminated sediments have been dredged by mechanical dredges (bucket dredges) and transported to the designated disposal site by scows or barges (Figure 1). The contaminated sediments are dumped at points marked by taut-wire moored buoys. Towboat operators are instructed to hold each scow at a complete halt before and during the dumping operation. Precision disposal of the contaminated sediments is necessary so that discrete mounds can be created prior to capping.

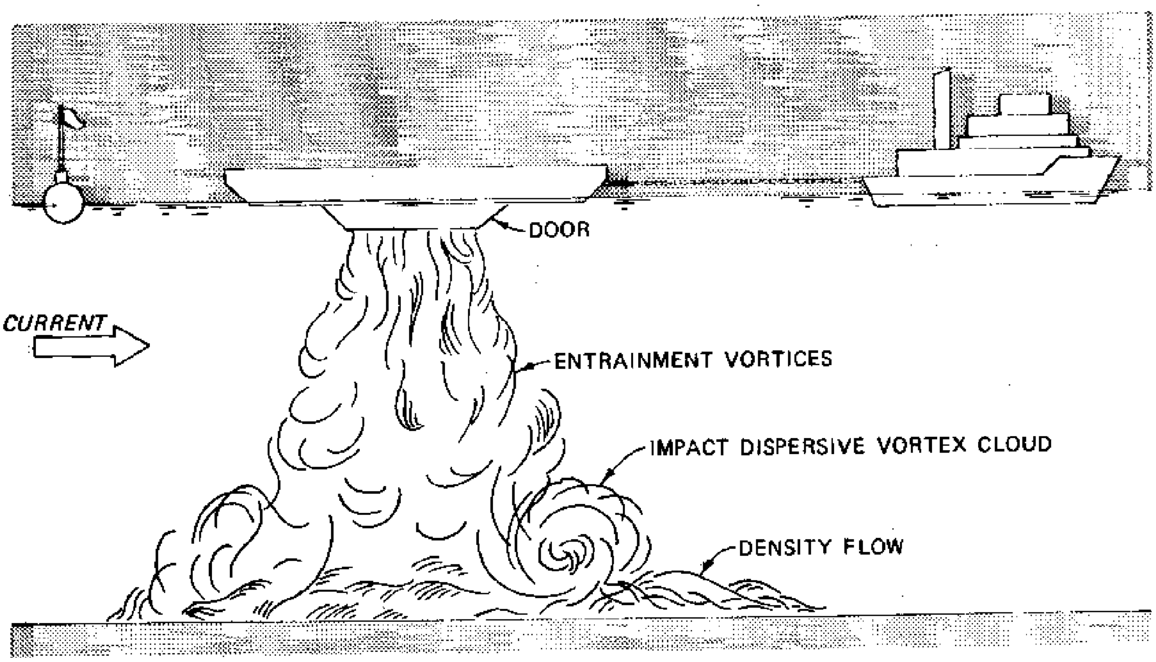

Figure 1. Dredged material discharged from a barge/scow.

It is important that a taut-wire bouy be used to mark the discharge point. In cases where regular bouys have been used, the scows were positioned only within a circle of about a 200 yd radius of bouys. The method of placement of contaminated dredged material on the bottom should be chosen to minimize the surface area of the mound of deposited material. In the future, disposing of contaminated dredged material may require the use of electronic positioning equipment by each transport scow with the data being recorded and later provided to the contracting agency. This would allow verification of accurate placement of each scow load of contaminated sediments.

The sediment discharged from a scow decends to the bottom in a downward directed jet and upon impact spreads radically outward in a density surge. Bokuniewiez, et al (1977) reported that 99 percent of the material discharged from scows containing more than 1000 cu yds would be transported to the bottom in the jet. Gordon (1974) reported that during one disposal activity in Long Island Sound, all of the material in the density surge settled within 170 yds of the impact.

Capping activities in Long Island Sound and the New York Bight have been carried out in about 60 ft of water. The contaminated sediments include fine-grained materials such as silts and clays. Both sand and clean fine-grained sediments have been used to cap the contaminated sediments. Generally the capping material has been obtained from clean sediments removed from nearby navigation projects. In most cases the capping material has been obtained using bucket dredges and transported in scows to the capping site. However, some experience was gained using hopper dredges to dredge the cap material and to transport it to the site. There appears to be an advantage in using the hopper dredge to place the cap material (Figure 2). The advantage involves the spreading characteristics of the cap material dredged hydraulically by the hopper dredge. This material flows over the contaminated sediments resulting in a more uniform coverage. There has been no special-purpose equipment used in past capping activities. These activities have been carried out using conventional dredging equipment developed for and used on routine dredging projects. Many researchers feel that there are improvements needed in equipment and capping techniques to ensure accurate placement of the cap material.

CAPPING MATERIALS

There has been a significant amount of research devoted to cover materials for burial of hazardous spills in lakes and waterways. This research has been summarized by Hand, et al (1978). This work also applies to capping contaminated dredged material. Materials, both naturally occurring and man-made, that can be used to cover contaminated dredged material are divided into three categories: inert, chemically active, and sealing agents.

Inert materials include coarse- and fine-grained soils. Research is being performed at the Waterways Experiment Station (WES) to determine covering depths required to inhibit biological activity in the contaminated materials and to retard leaching of contaminants into the water column. When natural soils are used as capping materials they should be thick

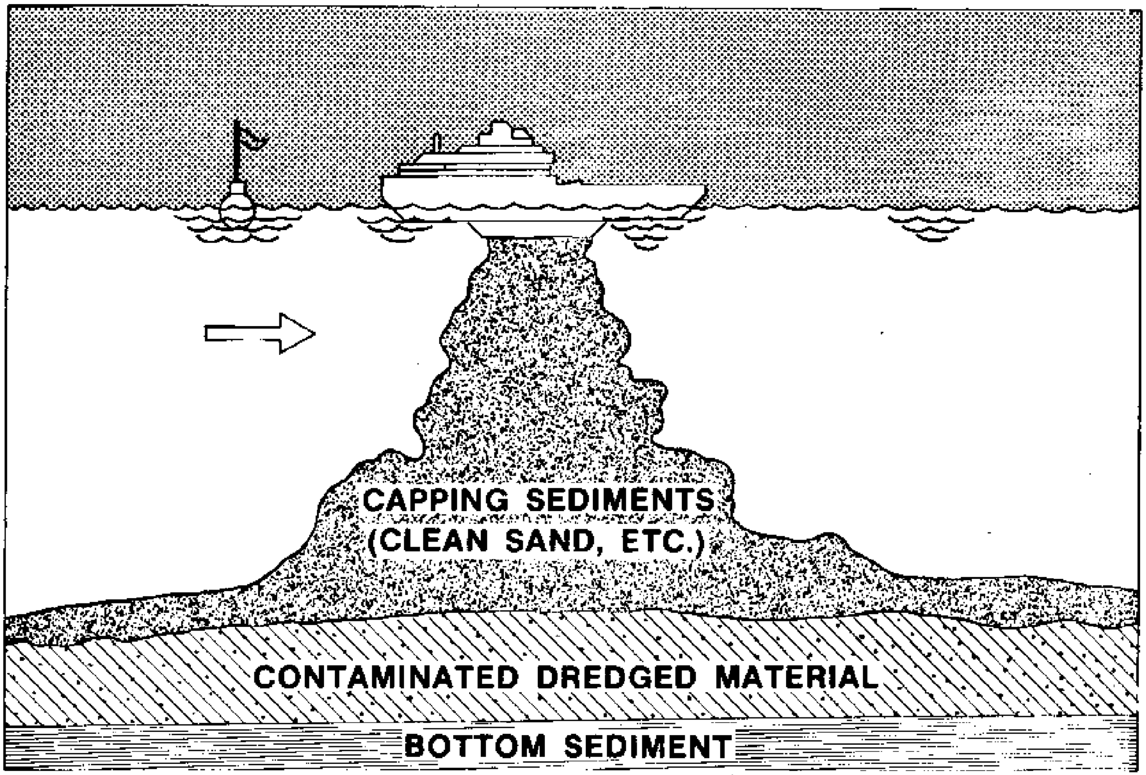

Figure 2. Hopper dredge placing cap material.

enough to protect the underlying deposit from disturbances caused by storm-generated waves and to bury the contaminated sediments out of the reach of benthic organisms. The nature of the capping material will influence the depth and character of burrowing. Myers (1979) reported that a sand cap will attract suspension feeding organisms that should not be expected to be deep burrowers, while deep burrowing deposit feeders will colonize a fine-grained cap. Therefore, site-specific biological populations are important in designing the cap thickness. Bokunieweiz (1981) reported that for disposal sites in relatively protected near shore waters a cap thickness of less than a meter should be sufficient, but site-specific studies should be done to evaluate biological populations and erosion potential.

Stability of the capping material is a major concern in the design of capping projects. Factors influencing cap erosion include: (1) the particles (size, uniformity, shape, size distribution, texture, etc); (2) the hydrodynamics of the system; (3) slope of the mound; and, (4) the degree of cap material cohesiveness. Therefore, the prediction of erosion potential of a capping material should be made on the basis of site specific data. The inert materials used for capping can be classified as cohesive or noncohesive. For given erosive forces, movement of noncohesive particles depends on shape, size, and density of discrete particles and on the relative position of the particle with respect to surrounding particles. The movement of cohesive particles depends on those factors cited above for noncohesive particles as well as on the strength of the cohesive bond between particles. This latter resisting force can be much more important than the influence of the characteristics of the individual particles. Cohesive capping materials excavated by mechanical dredges will be more resistant to erosion than those excavated by hydraulic dredges. Once the cohesive bond has been broken during the hydraulic dredging process, the individual particles and flocs behave essentially as noncohesive particles until they gain strength through the consolidation process. The degree of consolidation, which is inversly proportional to the interstitial water content, has a significant effect on the ease at which the fine-grained particles will erode. The time required for the complete consolidation of fine-grained capping material will take many years if the material is predominantly clay.

Chemically active materials involves the placement of a chemical compound over the contaminated dredged material that would react with the contaminants to neutralize or otherwise decrease toxicity. The active covering strategy differs from the inactive covering strategy using inert materials because each contaminated dredged material must be dealt with on a case-by-case basis. In the capping of dredged material, the active material should be combined with an inert stabilizer to provide stability to the cap. Another approach would be to cover the active covering layer with an erosion-resistant inert layer. The inert layer would also provide protection for the benthic organisms. While the inert covers have little or no chemically related impact on the organisms, the chemically active covering agents could be harmful to some organisms. Also greater accuracy would be required for placement of the chemically active materials.

Sealing agents include grout, cements, and polymer films. The unique feature of the grouts and cements is that, when placed on top of contaminanted sediments, they will harden and form a crust, preventing erosion and resuspension of the contaminated material. A Japanese firm (Takenaka Komuten, 1976) has done work in dredged material stabilization and deep-mixing of sediments using grouting compounds. Also, grouting is often used in the off-shore oil industry for stabilization of oil producing facilities. The technology for using grout in the salt water environment is well developed and it could be adapted for use in capping contaminated dredged material. However, there are some disadvantages associated with the use of grout in capping dredged material. The thin layer of grout placed over the contaminated dredged material cannot be considered as the permanent cap material. It should be used with a covering of inert material to provide additional stability and habitat for benthic organisms. There could also be problems with the grout cracking as the contaminated dredged material consolidates with time.

Polymer film systems have been the subject of a report by Widman and Epstein (1972). They proposed barge-mounted deployment systems for either hot or cold application of polymer film overlays. The application systems included those for placing coagulable polymers, hot melt materials, and performed commercially available films. The application system for the performed overlay limited its application to water depths of 25 to 30 ft. Roe, et al (1970) reported on a chemical overlay system which included 2000-sq ft/hr coverage and availability for water depths up to 120 ft.

Concepts for the use of polymer film overlays for cover of contaminated dredged material were developed from early erosion control efforts related to marine salvage work. None of the concepts have been field tested for dredged material. The major limitation to these concepts involves the capital equipment requirement to place them.

PLACEMENT TECHNIQUES

Several methods for placement of capping materials have been identified as having potential in further improving the capping technique. The first effort was to identify existing methods of dredged material placement. These methods included point dumping from scows/barges and hopper dredges, and open-pipe discharges from hydraulic dredges. Although, these methods are readily available and capable of placing a cap, they were found to have some drawbacks requiring further research and development (uneven cover, turbulent impact on bottom, etc). Several alternatives to these techniques, such as hopper dredge pump-down or sand spray systems, and submerged diffuser system for hydraulic dredges, have potential for both placement of the contaminated sediments and inert capping materials. These methods, however, will result in an increased cost for new equipment. Borrow pits and submerged dikes have been mentioned in the literature as possible methods for confining the contaminated sediments and could be capped using the methods outlined above.

Accurate placement of both contaminated sediments and capping materials are concerns from two points of view. First, the materials may tend to disperse during placement. This concern would apply to the fine-grained materials, which may flow in the form of fluid mud capable of traveling great distances underwater. Second, resuspension caused by placement could result in contaminated sediments spreading outside the capping area.

Point dumping both by hopper dredge and barge/scow is a straightforward application of traditional dredging disposal operations to the capping operation. One important problem associated with this technique is precision in material placement. The taut-wire bouy procedure has improved the precision of dumping but additional work is needed to control the operational aspects. Complete coverage of the contaminated material by point dumping is often not achieved. Figure 3 shows the results of three surveys made along a transect over a disposal site produced from the point dumping method. The first survey was made prior to disposing of the contaminanted dredged material and the second survey was made immediately after point dumping of the contaminated material. The third survey shows the mound of silt cap material. In this case the point dumping method did not produce a complete cover over the contaminated material. A technique used in the New York Bight is to point dump the contaminated dredged material and to cap it with material dumped at a number of discrete points. This method of placing the cap improves the coverage of cap material over the contaminated sediments.

The JBF Scientific Corporation (1975) performed tank evaluations of point dumping of silts and clays. These observations of simulated dumps

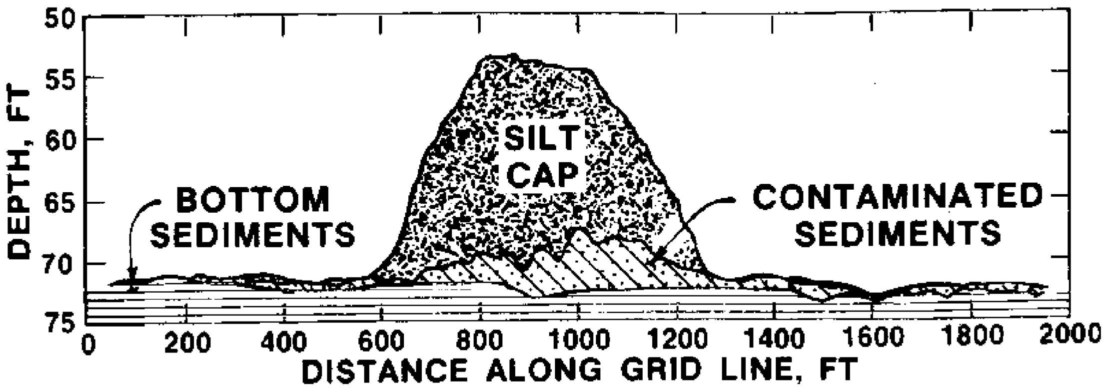

Figure 3. Surveys of a transect across disposal site. (From Morton 1983)

showed that low moisture content silt and clay materials would tend to mound on the bottom, the dumping being characterized by a rapid descent phase, little dispersion in the water column, and little spreading of the material on impact. High moisture content materials were characterized by a slow descent phase, dispersion in the water column, and a rapid flow of material across the bottom after impact. Little or no mounding was evident in the tests on high moisture content material. The low moisture content materials would represent sediments excavated by mechanical dredges and the high moisture content materials represent sediments excavated by hydraulic dredges.

Sustar and Ecker (1972) performed a comprehensive study of point dumping of hydraulically dredged sands. Using a variety of techniques including divers, they found that on bottom contact sand surged radically outward so rapidly that a thin layer was produced over a large area. Scouring of the bottom was observed at the point of contact.

It appears that point dumping of mechanically dredged contaminated sediments is an attractive option because the material tends to mound. However, point dumping of cap materials may not be the best practice. Improved techniques are needed to ensure that the cap material is placed uniformly over the contaminated material with a minimum of disturbance.

The pump-down concept may be a means of avoiding the potential scouring and turbulence associated with point dumping. This is a concept for use with hopper dredges where the dragarms could be used to place the material near the bottom. Sand or other cover material could be pumped out of the hoppers, down the dragarms, and deposited in thin layers over the contaminated material. Discharge of the cover material could be accomplished while the hopper dredge is sailing at a low speed. The material would settle in layers reducing turbulence on the bottom. This technique would ensure good coverage and reduce the potential for displacement of the soft fine-grained contaminated sediments under the heavy load of the cap material. There is some speculation that point dumping of sands on the soft contaminated materials results in displacement of the soft materials and poor coverage of cap material.

The most promising equipment development related to placement of both contaminated sediments and cap material is the submerged diffuser system (Figure 4). This system was designed under the DMRP (Neal, et al, 1978) and it has recently been built by a Dutch dredging form and is presently being used in a capping project in Rotterdam harbor (1983). The diffuser system operates on the principle of radial divergence of flow to slow discharge velocity to acceptable levels. Diffuser systems like this are well tested and present few technological problems to development for use in capping projects. The diffuser system could be used with existing hopper dredges, hydraulic pipeline dredges and barges with hydraulic pump out capability. In these cases the barge mounted diffuser (Figure 4) would be to the discharge pipe. Sediment flow characteristics during placement will vary with the nature of sediment and current, as well as slurry discharge rate and height of diffuser above the bottom. In all cases, however, the use of the submerged diffuser system will increase control over placement of capping material, as well as reduce turbidity and scouring during placement. Complete cover of the contaminated material can be ensured by repositioning the discharge barge throughout the area as necessary. It is expected that the need for repositioning will be greater when sand is being used as the capping material because of its tendency to mound. The submerged diffuser could also be used to place the contaminated sediments. It would minimize the release of contaminated sediments in the water column during placement and provide better control of the placement operation. However, the hydraulically placed contaminated sediments would likely spread over a larger area than mechanically dredged and point dumped sediments. The use of the submerged diffuser in conjunction with subaqueous confinement such as borrow pits, depressions, and dikes is an attractive option. Advantages of the submerged diffuser system include increased control over location of both capping and contaminated sediments, decreased scouring of the bottom upon impact, and less release of contaminated materials into the water column.

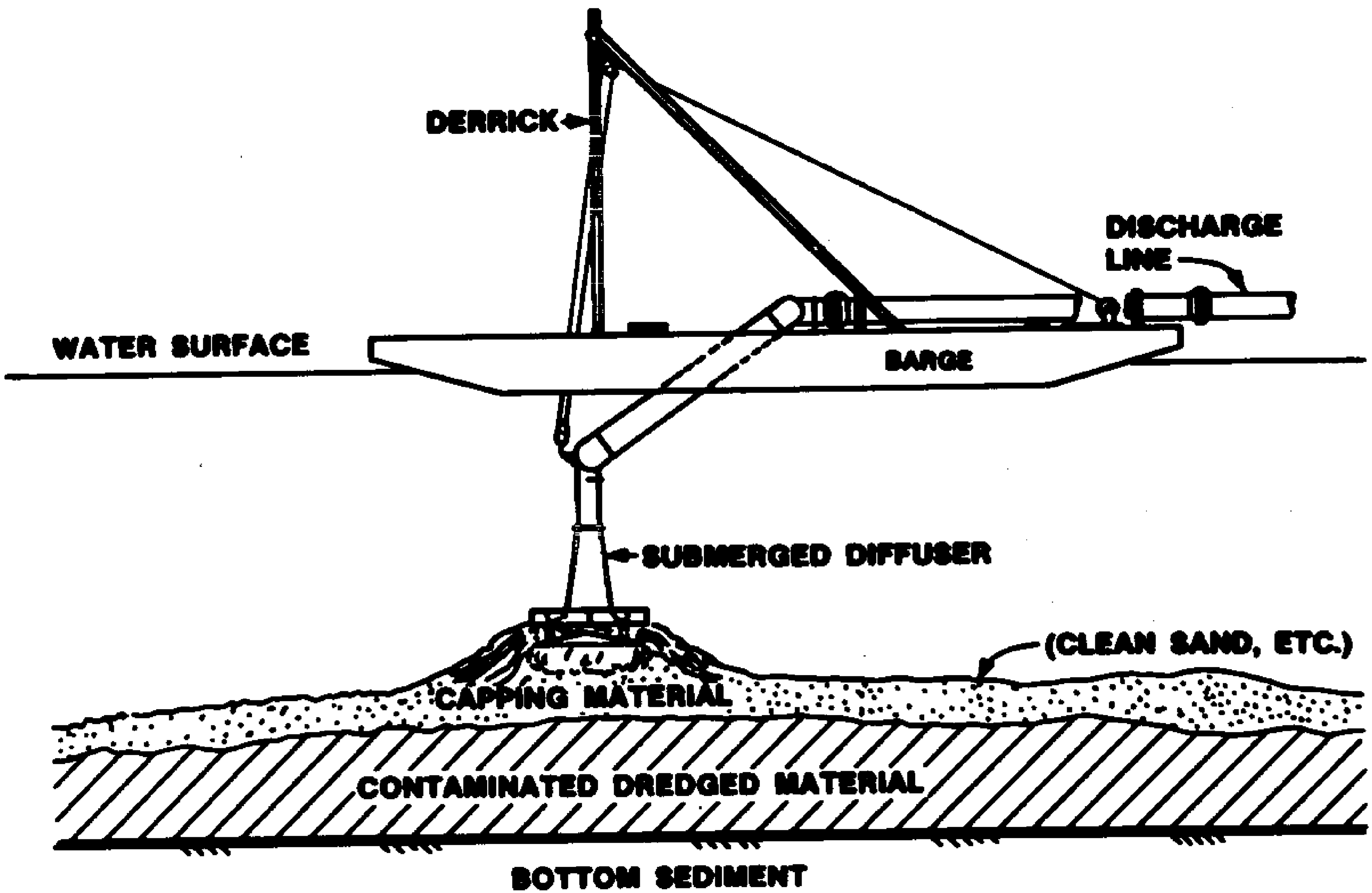

Figure 4. Submerged diffuser system.

SUMMARY

Dredged material capping practices have evolved from existing dredging and disposal practices. Little research effort has been devoted to the operational aspects of placing the contaminated sediments in a controlled manner to minimize spread of contaminated sediments into the water column. Techniques and equipment for placing capping materials have not been developed to the point that accurate placement can always be assured.

There has been some research devoted to evaluating the types and thicknesses of capping materials required to protect the underlying contaminated sediments from wave disturbances and to bury the sediments out of the reach of benthic organisms. However, the results of these studies and others being performed at the WES have not been presented in the form of specific guidance. This guidance should be forthcoming in the near future.

There is equipment available now that would improve the accuracy of both cap and contaminated sediment placement. Such equipment includes automated systems for positioning during placement and the submerged diffuser for control of cap and contaminated material placement. Research is underway at the WES to evaluate equipment, capping materials, and operational procedures required to improve the capping technique. Guidelines will be produced from this work for designing, constructing, and managing capped dredged material disposal areas.

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