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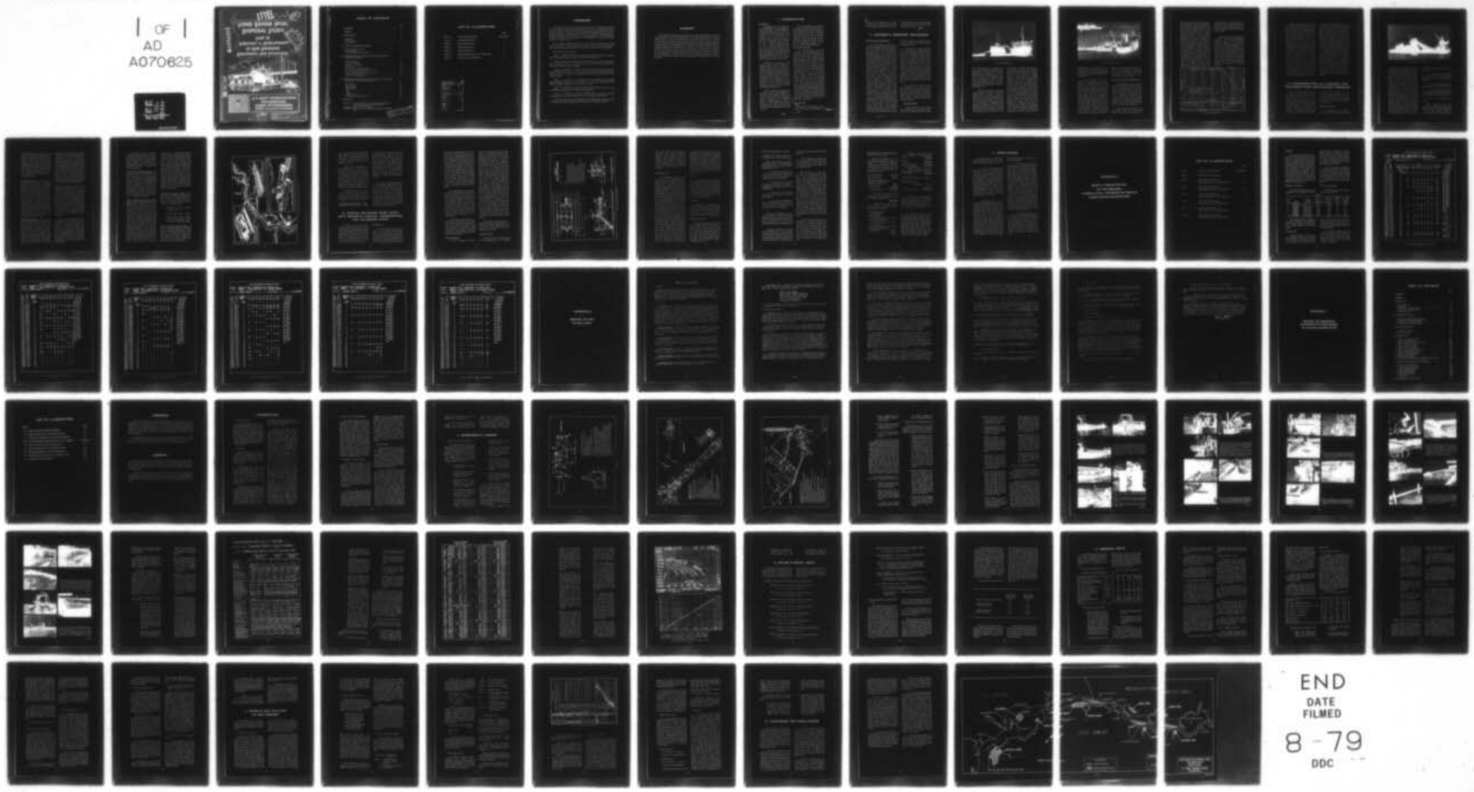

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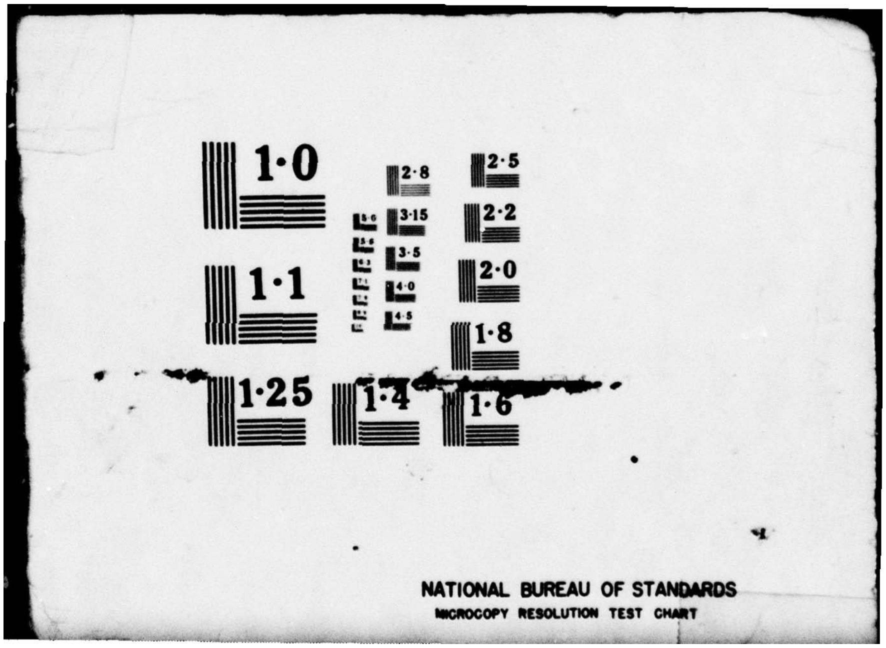
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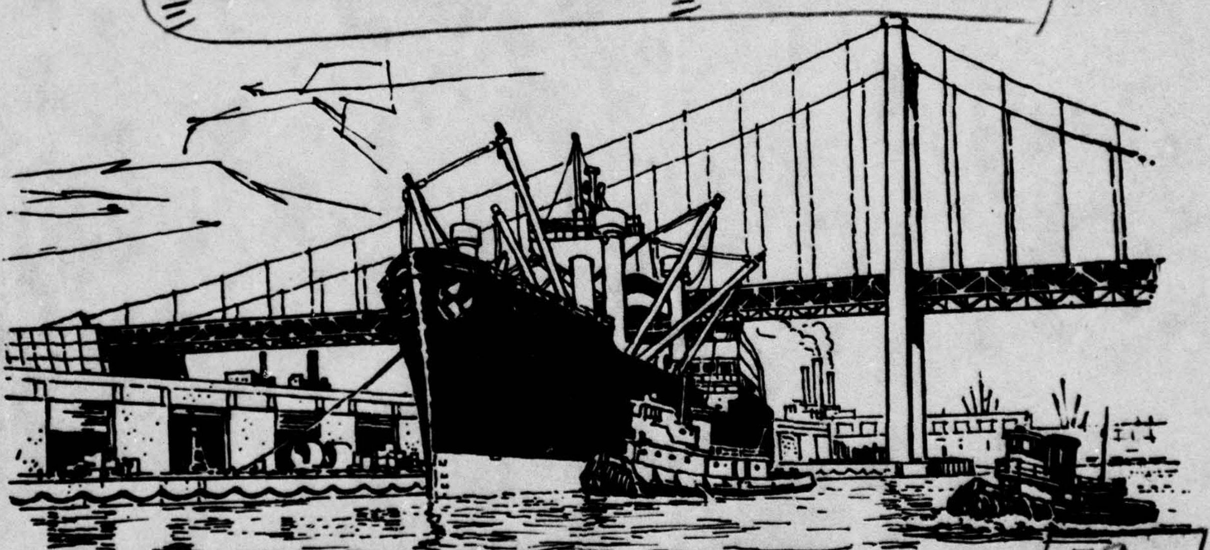
LONG RANGE SPOIL DISPOSAL STUDY

PART IV.

SUBSTUDY 3, DEVELOPMENT OF NEW DREDGING EQUIPMENT AND TECHNIQUE.



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PHILADELPHIA
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NORTH ATLANTIC DIVISION

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FOREWORD

This study was conducted as one of the sub-studies to the Long Range Spoil Study. This investigation centers on the development of a more effective dredging plant that will be able to operate at acceptable costs when employed over long haul distance. The overall study was conceived and initiated by the former Philadelphia District Engineer, Brig. General W. W. Watkin, who had been directed to such an effort by the Chief of Engineers. The Project Manager for the Sub-Study was Mr. Adolph Mohr, P.E. who had assistance from Mr. Lewis Caccese, P.E.

The "Long Range Spoil Disposal Study" consists of seven parts which are listed below. Part I which is "General Data on the Delaware River" contains detailed background data which is pertinent to this report. This report is Part IV of the overall study.

The study is divided as follows:

PART I - GENERAL DATA ON THE DELAWARE RIVER furnishes the information and data on the Delaware River which is pertinent to the entire study.

PART II - SUB-STUDY 1, SHORT RANGE SOLUTION evaluates the remaining disposal area capacity in terms of its remaining life, and to recommend any further desirable and acceptable disposal area developments.

PART III - SUB-STUDY 2, NATURE, SOURCE, AND CAUSE OF THE SHOAL develops in depth the basic data as to the nature of the Delaware River shoals, their sources, and their causes. It is hoped that this knowledge may reveal new concepts for the better control of shoals.

PART IV - SUB-STUDY 3, DEVELOPMENT OF NEW DREDGING EQUIPMENT AND TECHNIQUE identifies the best in dredging plan and dredging technique for Delaware River dredging maintenance tasks now and in the future.

PART V - SUB-STUDY 4, PUMPING THROUGH LONG LINES examines the merits of transporting dredged materials many miles through pipelines.

PART VI - SUB-STUDY 5, IN-RIVER TRAINING WORK determines the potential of training works for control of shoaling. It involves considerable model testing.

PART VII - SUB-STUDY 6, DELAWARE RIVER ANCHORAGES considers the effect of man-made anchorage on shoaling problems and the merits of alternate solutions.

SUMMARY

This report has looked at the evolution of the existing dredging practice employed on the Delaware River by the Philadelphia District of the Corps of Engineers. The existing dredging practice is based on finding disposal areas within about 5 miles of the shoal areas. The need for modification on the present method is foreseen because the availability of such disposal areas is disappearing. With the apparent requirement of longhaul distances, the hopper dredge system, presently used, would become very costly. This report suggests dredging equipment to cope with the future problems. The conclusions drawn in the report are not to be interpreted as the optimum system. However, the scheme that is presented does represent the best system for long hauls on the Delaware River within present knowledge and experience. It is the District's intention to continue experiments, investigate new ideas and methods, and improve both existing dredging techniques as well as those of the future.

I. INTRODUCTION

BACKGROUND

The Delaware River, and particularly the Philadelphia Port Area, supports a major port complex. Over 100,000,000 tons of waterborne commerce move each year through the Port of Philadelphia. This commerce relies, in large part, on the man-made 40 foot channel from the natural deep water in Delaware Bay to Fairless, Pa. The U.S. Steel Plant located at Fairless, Pa. is dependent upon waterborne ore and is 133 miles upstream of the point at which the Delaware River joins the Atlantic Ocean. It is interesting that the man-made 40 foot channel replaces the natural controlling depths of 17 feet to Philadelphia and then 3 feet to Fairless which existed in the early 19th Century.

Maintenance of the 40 foot deep channel requires constant dredging. Over 10,000,000 cubic yards of material are dredged annually out of the Delaware River and its tributaries to support commerce. 7,000,000 to 8,000,000 are dredged from the 40 foot channel and associated anchorage and placed ashore each and every year. A characteristic of the dredging in the Delaware River is that, for the most part, the shoaling and the subsequent dredging takes place in repetitive locations and at reasonably predictable rates.

The most significant shoaling areas are: Marcus Hook, Pa.; Philadelphia, Pa.; and New Castle, Delaware. These areas represent the majority of the dredging required to maintain the Port of Philadelphia. It is apparent that any better approaches to the dredging and spoil disposal problems in these areas will have relevance to the dredging work in the entire river.

Since the shoaling occurs primarily at specific locations, disposal areas for the dredged spoil in these vicinities are of key importance. The supply of disposal areas in these critical areas is severely limited because of past use of the most desirable areas and the physical development of the remaining areas. Plate 1 shows the most significant shoaling areas of the river and the related disposal areas.

REASON FOR THIS STUDY

Since shoaling occurs at specific locations the available disposal areas within the range of economical dredge haul have been, or are being, consumed. In the Delaware River, where hopper dredges pump to overflow only, the limit of economical hopper dredge haul generally is 5 to 7 miles. It can be noted that this 5 to 7 mile limit exceeds by far the normal capability of a pipe line dredge. Accepting that all disposal areas within a 5 to 7 mile radius from the repetitive shoal areas will one day be consumed, it then follows that the dredged material must be transported greater distances to arrive at areas where disposal area capacity may be developed. It is evident that the closest location where a practically limitless potential for the disposal of dredged material exists is the low land areas which surround Delaware Bay and in disposal areas which may be created in the waters of Delaware Bay itself. This indicates that dredged material may have to be hauled up to 50 miles at some date in the future.

GOAL OF STUDY

The object of this study is to examine present dredging technology for the

over

purpose of selecting, improving, or conceiving better equipment and technique for maintaining the Delaware River Channel under the future situation where dredged material will need to be transported long distances (25-50 miles).

II. CHANGES IN DREDGING TECHNIQUES

RECENT DREDGING EXPERIENCE

In 1954 the Corps of Engineers became more stringent in dredging techniques. Since that time there has been a particularly steady increase in the consumption of disposal areas. It was in 1954 that the Sump Rehandling system, seen in Fig. 1, of channel dredging was instituted. This system emphasized the positive retention and disposal ashore of all particles which were picked up in the dredging process. Hopper dredges unloaded their haul into the Sump Rehandler which was a vessel designed to store and pump the mixture ashore. Similar emphasis to prevent the loss of fines was placed on contractor and private dredging operation in the river. For example, enclosed rehandling basins became obligatory for rehandling. The stringent practices were instituted because the prior dredging practice, which permitted hopper dredges to pump beyond overflow, rehandling of dredged material in open waters and free dumping, were compounding the maintenance dredging problem. The fine grained materials which form the shoals were frequently being returned as a colloidal suspension for subsequent floccing, shoaling and redredging. In addition, the fine agitated particles were creating massive clouds of light weight material which was suspended along the river bottom as a layer of "fluff". This material was detrimental and dangerous to navigation and frustrating to dredge or capture because of its fluid nature. Also, it created deceptive double bottoms on fathometer rolls.

In March 1963 the Sump Rehandler system of dredging was supplanted by the direct pump out hopper dredge. (Fig. 2) In the latter technique the hopper dredge obtains its load while pumping only to overflow. The dredge then transports the load to an appropriate location where it pumps its material into a pipe line which terminates in the disposal area.. By this method each particle that has been dredged reaches the disposal area. This technique is an improvement over the Sump Rehandler technique in that the intermediate Sump Rehandler has been eliminated while the characteristic of retention of all fines and other easily suspended particles is sustained.

The efficacy of a dredging system which emphasizes the positive retention and disposal of all dredged particles is presented in the publication "The Direct Pump Out System", issued by the Philadelphia District of the North Atlantic Division in March of 1964. Pertinent quotations therefrom are:

BOTTOM DUMPING

"Prior to December 1954, removal was accomplished by hydraulically dredging material into hoppers, hauling it to deep

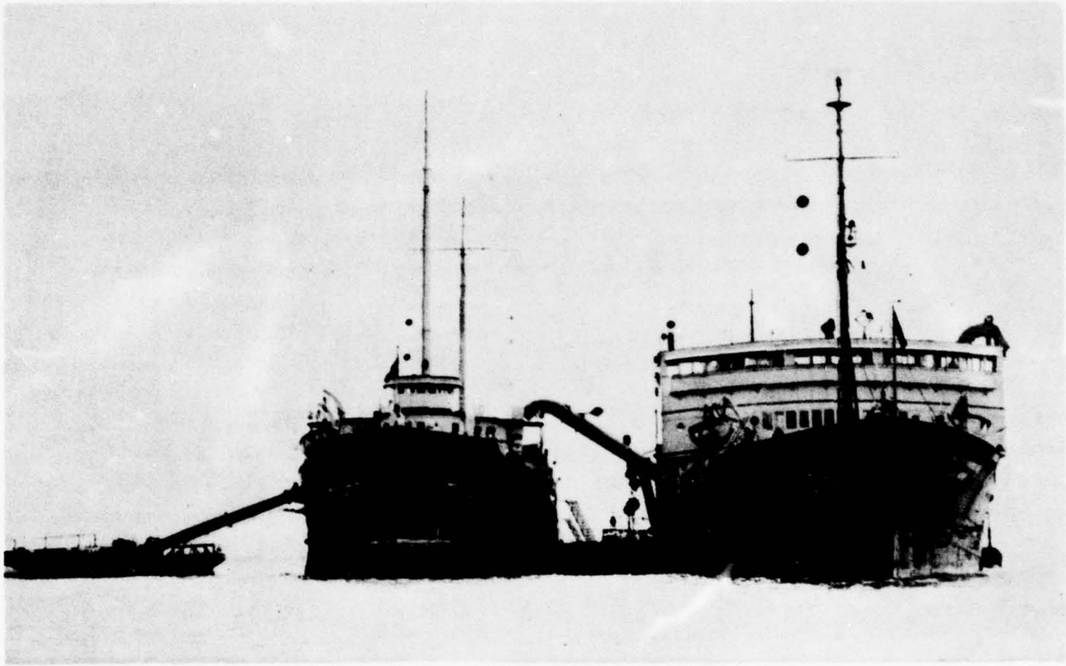


Fig. 1. Sump Rehandling System.

water either adjacent to the channel, or to the sea, or previously excavated rehandling basins close to disposal areas and then dumping the spoil through doors in the bottom of the hoppers. The rehandling basins were 150 feet long and 500 feet in width and were excavated to a depth of 35 feet. From these rehandling basins, a pipeline dredge pumped the material into the nearby disposal areas."

"The bottom material comprising recurring shoals in the lower portion of the Delaware River is a light silt, about 1266 grams per liter in density, with approximately 90 per cent by weight of the solid grains finer than .06 mm in diameter. The retention of such material in rehandling basins presented a problem. As much of the finer material was carried away by river currents and thus returned to the channel, only the coarser material was actually removed. The finer materials so returned, plus those resulting from free dumping, formed shifting shoals of light material and caused the recording of a layer of "fluff" or "double bottom" by echo sounders. The shifting shoals were detrimental to navigation and difficult to remove. It was also noted that, on the average, there was dredged each year three times the estimated amount of shoal material entering the estuary without a corresponding improvement in the condition of the channel. The year 1951 may be used as an example of this type of operation. A total of 25,600,000 bin yards were dredged during 1951 by use of hopper dredges. Of this total, 14,300,000 were free dumped in the estuary and the balance was dumped into rehandling basins. Of the 11,300,000 yards dumped for rehandling, only, 5,900,000 yards (52%) actually were placed ashore, 5,400,000 yards (48%) were returned to the estuary as a loss from the

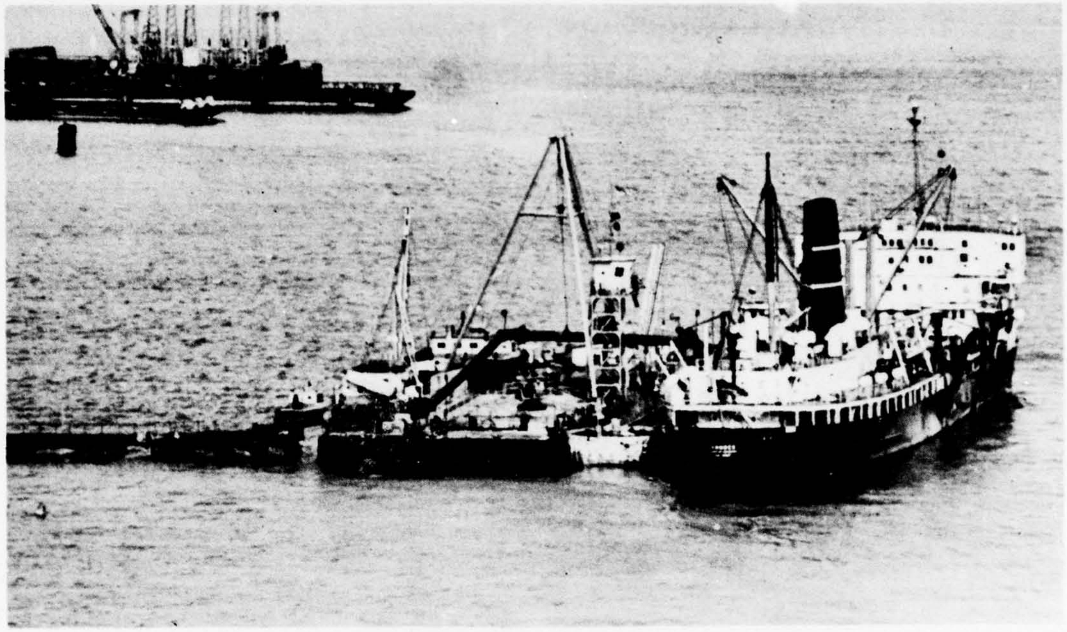


Fig. 2. Direct Pump Out System

rehandling process. In other words, 77% of the total material dredged was permitted to remain in the estuary; 14,300,000 yards by free dumping and 5,400,000 yards by rehandling loss."

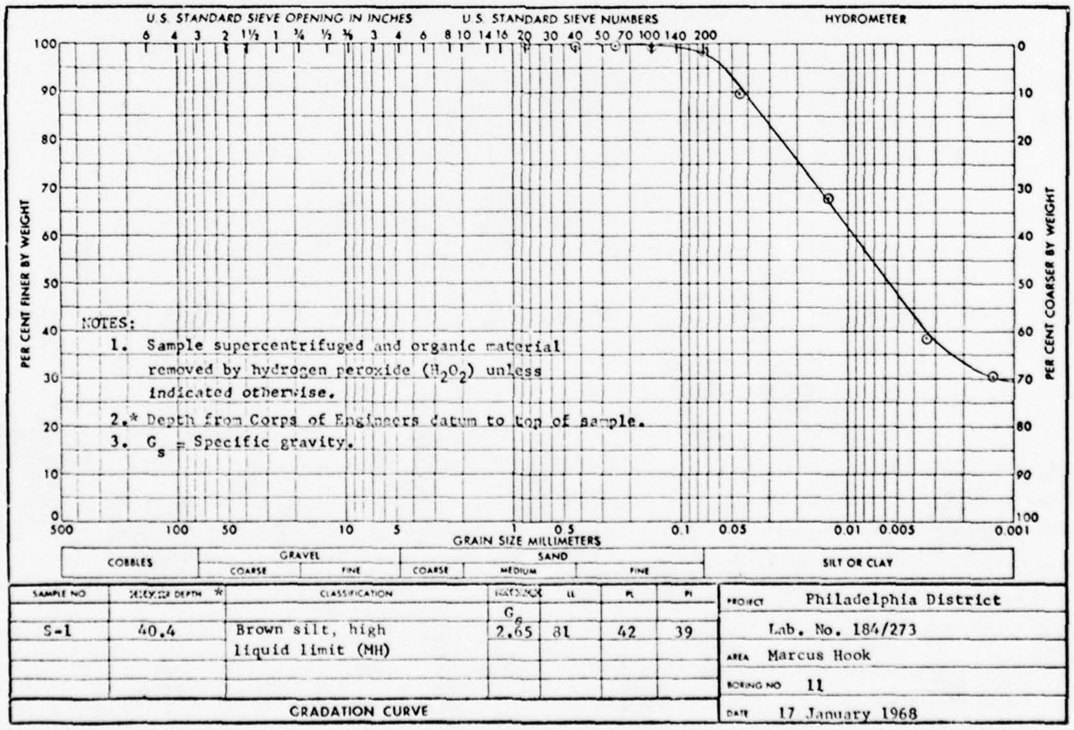
"It was obvious that bottom dumping into rehandling basins was not effecting a permanent removal of dredged material. It must be noted, however, that the method of rehandling spoil by dumping into open water basins has merit when the material is heavy and consists of relatively coarse grains that readily settle after dumping and are not significantly affected by prevailing currents. Prior to sump rehandling, 22 Hopper Dredge months per year together with full time use of several pipeline dredges were necessary to handle nearly 25 million yards being dredged annually. Subsequent to the system's initiation, only 10 hopper dredge months per year were needed to handle 7.5 million yards being dredged annually. Obviously, the Sump Rehandler System, with its positive retention feature, reduced the dredging effort one-half and, at the same time, produced a better channel."

NATURE OF DELAWARE RIVER SHOALING

An understanding of the nature of the material dredged in the Delaware River and the local shoaling process is of value in conceiving dredging plants and dredging techniques. Almost one half of the maintenance dredging in the Delaware River is done at Marcus Hook Range. Detailed sampling of this shoal was done by Philadelphia District in 1967. The samples were analyzed in the South Atlantic Division Laboratory of the Corps of Engineers.

This testing program revealed that approximately 10% of the solids in the shoal were organic when measured by weight. The 90% of inert matter remaining was composed of particles which had a size where 99% of them passed the 200 mesh screen and approximately 30% were finer than .001 millimeters in size. The gradation curve of one of these samples is shown in Figure 3. These analyses manifest the nature of the material to be dredged. The 10% of organic materials contribute more than 10% of the volume of each shoal because the organics have a lesser specific gravity than the inert matter. The settling rates of the organic materials and of the inert matters, because of their fineness, are obviously extremely slow. This fine material is generally readily transported by the moving water until it arrives at a location where the river has environmental characteristics of pH, current, etc. supporting flocculation which causes the settling for shoaling. These characteristics explain why the shoals occur repetitively at specific locations in the Delaware River. The bulk of the maintenance dredging material encountered in the Delaware River exhibits the same characteristics.

In the foregoing lies the explanation as to why it has been found beneficial to emphasize positive retention of particles which are dredged; to avoid agitation dredging; to limit hopper dredging to overflow only; to enclose rehandling basins; and to insist on enclosed disposal areas with firm waste weir controls. It is believed that the dredging process will, by agitation, break down the floc or aggregation of particles and will resuspend the fine particles to renew the cycle of suspension, floccing, and shoaling whenever particles are permitted to re-enter the waterway.



NOTES:

1. Sample supercentrifuged and organic material removed by hydrogen peroxide (H_2O_2) unless indicated otherwise.
2.* Depth from Corps of Engineers datum to top of sample.
3. G_s = Specific gravity.

SAMPLE NO	[illegible] DEPTH *	CLASSIFICATION	[illegible]	LL	PL	PI
			G_s			
S-1	40.4	Brown silt, high liquid limit (MH)	2.65	81	42	39

GRADATION CURVE

PROJECT Philadelphia District
Lab. No. 184/273
AREA Marcus Hook
BORING NO 11
DATE 17 January 1968

Fig. 3. Sample Gradation Curve.

Another significant characteristic of shoaling in the Delaware River is that there is a null point in the Delaware River near the lower end of Artificial Island (about 52 miles above the mouth of the river, see plate 1). Below this point for some distance, believed to be at least to mile 41, bottom flood tide currents predominate over ebb tide currents. Since most of material in transport is carried along the bottom, this area between mile 52 and mile 41 forms an effective barrier to the transport of solids to Delaware Bay or the Sea. Consequently, agitation of shoal material results in merely a redistribution of particles in the waterway (probably depositing in a repetitive shoal area) and is not an effective method for removing material and for maintaining the waterway. The effectiveness of this natural flow barrier in eliminating the transport of particles downstream to below Artificial Island, and the fact that dredging methods which agitate but do not positively capture and dispose of dredged material, are significant factors in dredging in the Delaware River. This is substantiated by the Delaware Dredging history. In the years prior to Sump Rehandler an average of 3,000,000 cubic yards of material were being dredged annually from this barrier area which is known as Liston Range. Since the Sump Rehandler, or positive retention has been in vogue, no shoaling takes place in this area and no dredging is required. A more detailed description of the nature of the shoal material and the shoaling processes is contained in the report on Sub Study No. 2 which discusses these matters in more detail. The foregoing discussion on the character and nature of the shoaling material, the shoaling process, and the dredging technique is to establish the desirability and need for insisting that future dredging plant for the Delaware River be conceived on the basis that first, no agitation dredging such as pumping into hoppers beyond overflow will be permitted and, second, that material once dredged shall be disposed of in a positive manner.

III. CONSIDERATIONS IN A CONCEPT FOR DELAWARE RIVER MAINTENANCE DREDGING

In view of the foregoing, this study is designed to produce the best concept for dredging the shoal materials in the Delaware River when nearby (5 to 10 miles) shore disposal areas are no longer available and dredged material may have to be transported 25 to 50 miles prior to disposal. Obviously, a condition of any dredging scheme is that pumping beyond overflow, as is frequently done to increase the quantity of solids in a load, will not be permitted. This prohibition exists to avoid the turbidity, pollution, the creation of new scattered shoals, and the degradation of the river caused by the fine grained materials which are pumped overboard in the overflow.

INITIAL EVALUATION

In approaching this development the most knowledgeable dredging personnel

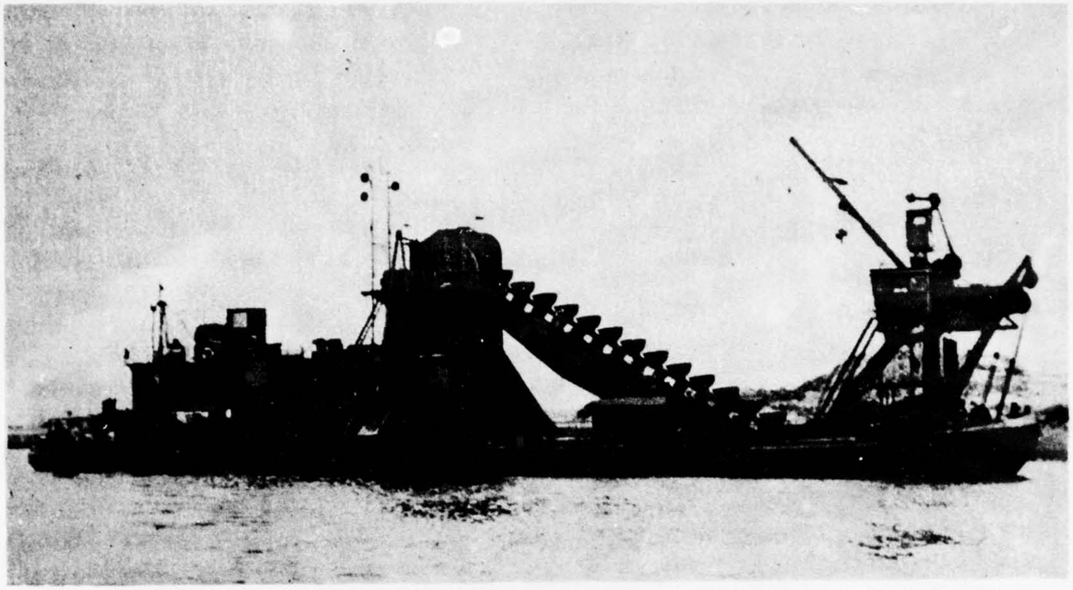


Fig. 4. Endless Chain Bucket Dredge.

in the District were assembled to suggest and appraise the possibilities of all suggested schemes. The endless chain bucket as a machine to obtain undiluted shoal material was extensively considered. (Figure 4) Propulsion of an endless chain bucket over the long (5,000 ft.) shallow shoals (2-4 feet) which are encountered in maintenance dredging was the major consideration. It was anticipated that the working buckets would develop a high horizontal force on the self propelled dredge making such operation unrealistic. There was a general concern that pulling the endless chain dredge on a system of anchors would be unwieldy since there would be many movements of anchors as shallow shoals are to be removed rather than deep banks to be cut. Other concerns were that the channel would be blocked by anchors, and there would be a tendency for the dredge to get displaced in the cut by its own digging or by currents, winds, etc. The following approaches also were considered:

(1) A scheme whereby the bucket would bite into the cut and pull itself along such as exists in trench digging machines.

(2) Use of walking spuds or something similar to the tracks on a bull dozer.

(3) Use of spud barges ahead and aft of the dredge so that the dredge would move by pulling against the spud barge.

(4) Use of a clamshell bucket dredge.

After consideration, the above schemes were largely discarded and the opinion prevailed that the development of a self propelled hydraulic dredge designed especially for the Delaware River problem offered the most promise at the time. The efficiency of such a dredge, despite the projected long haul distances, would be related almost directly to the density of mixtures to be hauled. It was recognized that current hopper dredging techniques when pumping to overflow only provide mixtures which are about one half shoal material and one half water. With this in mind many methods and devices were considered for improving densities of dredged effluent.

Gravity Precipitation - Studies were made to determine the efficacy of improving densities of dredged loads by permitting materials to settle. It was found for the fine materials encountered in the Delaware River that in some instances the top 1/3 of a hopper load of material would clear up due to settling of solids in an 8-hour period while in most instances little if any *settlement occurred. Settling of* dredged material usually encountered in maintenance dredging only occurred when it had a density of about 1060 grams/liter or less. Efficiently dredged material should customarily exceed this density. Appendix A covers the details of this study. It was concluded that this concept offers no promise for improving bin densities.

Chemical Precipitation - A series of field trips to dredges and investigations were made by Dow Chemical Co., Rohm and Haas Company, Drew Chemical Co. and Rutgers University with a view towards accelerating the sedimentation of dredged mixtures by chemical precipitants, flocculating agents or ion exchange. The subject was approached with considerable enthusiasm by each of these participants since they recognized the great benefits resulting from improvement in dredging programs which spend millions of dollars annually. In each instance interested expert chemists from these chemical firms were involved. Tests were performed on samples in the laboratory and on the dredge itself. The common conclusion of all the aforementioned was that the innate density of the dredged mixture exceeded that density at which chemical agents or catalysts could be effective. In other words the conclusion was that chemical precipitants, flocculating agents, or ion exchange did not offer any expectation of success. This confirms similar investigations performed by the Philadelphia District in 1958.

Hydroclone - Engineers associated with hydraulic dredging operations have always sought a means to separate the solids from the water in a dredged mixture. Consideration has frequently been given to the capability of a centrifuge in accomplishing this. Such considerations have always concluded that the masses of material handled in a dredging process (30,000 gallons/per min. from one 30" pump) make such a separation impracticable. The size of equipment and amount of energy required to attain the separation of a fine grained suspended mud from the water-mud mixture becomes intolerable.

The office of Engineering Research at Oklahoma State University has done considerable work with Hydroclone Separators. The Hydroclone employs high acceleration forces to achieve separation of heterogeneous mixtures as happens in *centrifuges*. High efficiencies are claimed for the Hydroclone Separator. In view of this, correspondence was conducted with Oklahoma State University to determine the applicability of the Hydroclone to the dredging process.

Consideration of their information confirmed that the Hydroclone Separator did not offer a practical device for separating solids from water in dredged mixture aboard a dredge. It was evident that, as in the centrifuge, the mass of material to be handled is so great as to make such an approach impractical.

Consideration of European Methods - Several discussions were held with BOS EN KALIS, and a visit to Europe was made by Mr. Adolph Mohr of the Philadelphia District to determine what techniques and knowledge was existing elsewhere which might be applicable to our problems. In general, knowledge was obtained but no techniques or equipment specifically directed towards a problem similar to the Delaware River Problem was uncovered. A more detailed report on the European visit is contained in Appendix B.

Effect of Submerged Pump and Related Matters - Hopper Dredges working in the Delaware River, and Pumping to overflow only, produce dredged mixtures between 1150 and 1200 grams/liter density. From work done by Lehigh University and Franklin Institute in their laboratory testing with a 6'' model pump it was concluded that densities as high as 1400 grams/liter should be attainable. The reasons for the disparity have never been adequately identified. In the large hopper dredges, working in mud, a characteristic event is that the large dredge pump cannot sustain the continuous pumping of a heavy mixture. The pump will "choke" and a raising of the drags is required to allow more water to enter. In other instances material just cannot be pulled from the bottom at "densities", which approach the "in situ" density. There have been various conjectural reasons to explain the limitation of the modern large and high powered dredge pump when working in mud. Among them are cavitation, limited effectiveness of gas ejectors, excess pump size and power which overwhelm available mud supply and therefore demand mixing water, drag size and configuration, the general geometry of the assemblage, and the efficiency of the dragtender. In order to evaluate these matters an experimental dredge (Figure 13) was assembled. Details of this dredge and the testing therewith are contained in Appendix C. This experimental dredge demonstrated that 1200 gram/liter mixtures were reliably pumped from the Delaware River with a submerged 12'' pump mounted on a draghead.

Evaluation of Dredging Schemes - The most probable schemes by which Delaware River maintenance dredging might be performed with material disposal 25 miles away were identified and evaluated. These schemes are considered to be:

1. Contractor Operated Bucket Dredge & Scow
2. Conventional Hopper Dredge
3. Special Delaware River Plant with separate Loading, Transporting, and Unloading Plant.

Contractor Operated Bucket Dredge and Scow - A frequent method of removal and disposal of material which requires a long haul is for dredging contractors to load the material into scows by clamshell or dipper dredge and to then transport the material to the disposal location. The limitations on these operations are:

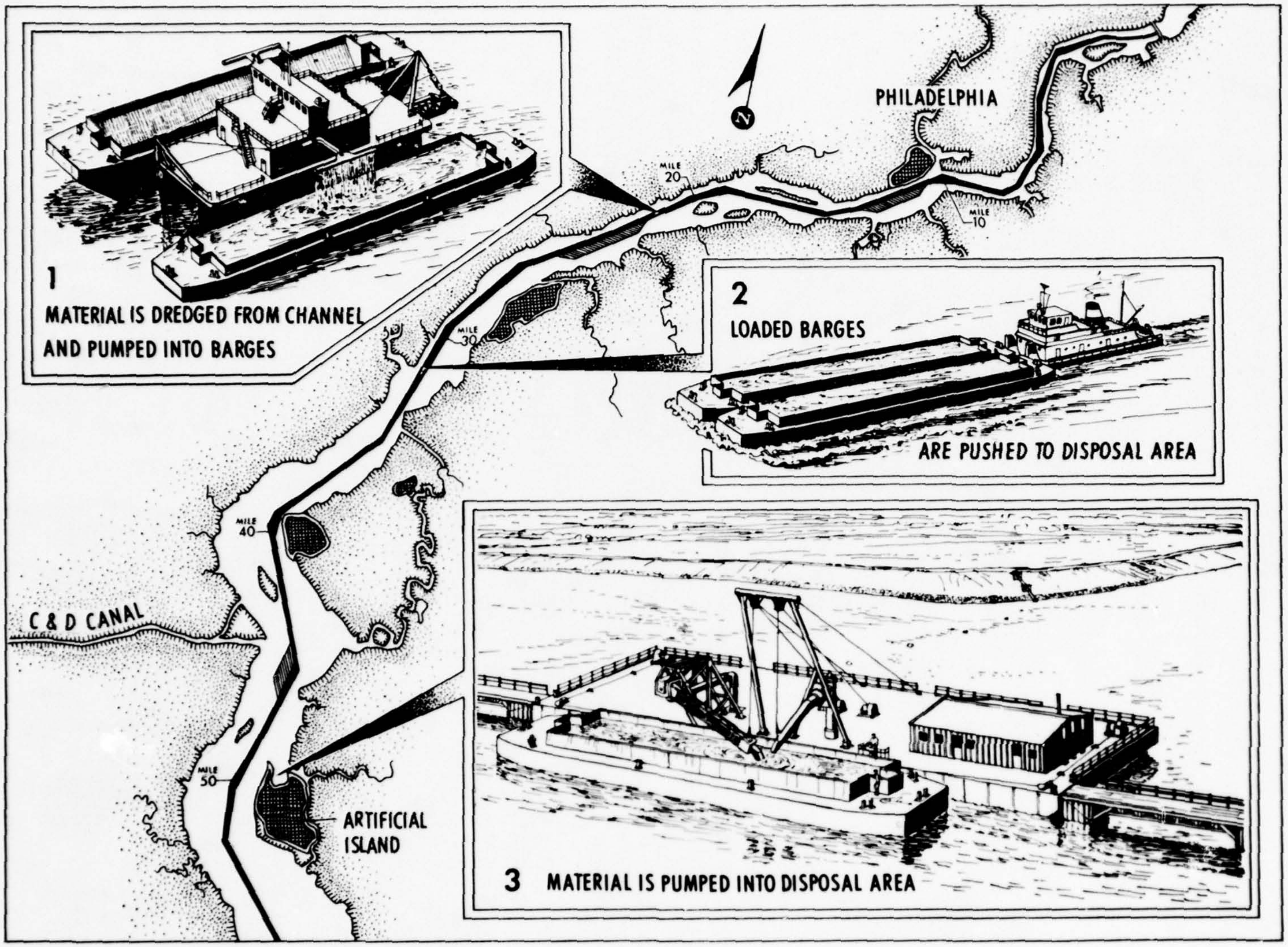


Fig. 5. Proposed Special Delaware River Plant System

1. It is a high cost method. Currently (1968) the work to remove 200,000 cubic yards from the Schuylkill River and to dispose of it 7 miles away costs $1.06 per cubic yard bin measurement. Longer hauls will cost more.

2. There are also significant losses in the dumping process, as done by contractors. The dredged material is usually dumped on the river bottom for rehandling by pumping into a disposal area with a pipeline dredge. However, the effects of such losses are related to the location of the dumping area. This would be an element of importance in dumping in the Delaware Bay or Delaware River. It would be of little consequence in dumping at sea.

3. Reliance on this type of operation is of concern because of the lack of competition. All bucket and scow dredging in the Delaware River is done by one dredging company without competition.

Conventional Hopper Dredges - Hopper dredging in the Delaware River pumping to overflow only with direct pump out dredges, transports and places the material behind banks ashore at a cost of $0.34 per cubic yard of bottom density material. This was the average cost for 6,245,000 cubic yards in Calendar Year 1968 in which the average one way haul distance was 3 miles. This was a typical year. This cost must be increased by $.09 per cubic yard for disposal area maintenance, which includes costs of banking, real estate, pipe line installations, etc.

The above costs are impressively low for performing dredging work. However, it can be noted that the key to those low costs is the ability to maintain disposal areas relatively close to the shoals so that an average 3 mile one way haul was achieved. Foreseeing that a 3 mile haul will soon no longer be possible and a 25 mile one way haul becomes necessary the $0.34 unit cost per cubic yard will exceed $1.00 per cubic yard because of the additional hauling distance.

IV. SPECIAL DELAWARE RIVER PLANT WITH SEPARATE LOADING, TRANSPORTING, AND UNLOADING PLANT

This plant is envisioned as incorporating all the knowledge gained from the experimental dredge and would be designed and sized particularly for Delaware River maintenance. This scheme is discussed below in considerable detail since it is believed to be promising for development for the Delaware River. Figure 5 is an artist's concept of the entire operation.

DESCRIPTION

This scheme utilizes one new type dredge, a fleet of barges pushed by tugs, one special unloading unit at a distant disposal area, and two motor tenders. The self-propelled dredge would operate in the dredging area and pump material from the shoal into hopper barges along its sides.

The barges would be pushed by tugs to a disposal area in the Delaware Bay where they would be hydraulically unloaded and then returned. This operating cycle consists of dredging, unloading and two hauling phases, or a total of four phases. To assure maximum continuity of operations, all components should be sized to result in 100 percent operating time when the mean one way hauling distance of 25 miles anticipated for the future between dredging area and disposal site exists. Assuming that a tug-barge team proceeds at a mean speed of eight statute miles per hour (seven knots), this distance would require a travel time of three hours. This time interval constitutes the duration of one phase.

Since this scheme is designed solely for the Delaware River, there are simplifications which can be of benefit. For instance, all plant would be designed to a one compartment standard. There would be three eight-hour shifts for seven-day operation. Because it will be limited to river operations, this dredge would not require personnel licensed for ocean navigation and it would not be equipped with quarters or mess facilities. This plant would be designed to the same standards as contractor's plant.

All equipment would be industry or manufacturer's standard as far as possible. This would include material handling and jetting water pumps, all dredge piping (which should be specified by outside diameter), and tugs required. The design of the dredge, the unloading unit, and the barges would be special.

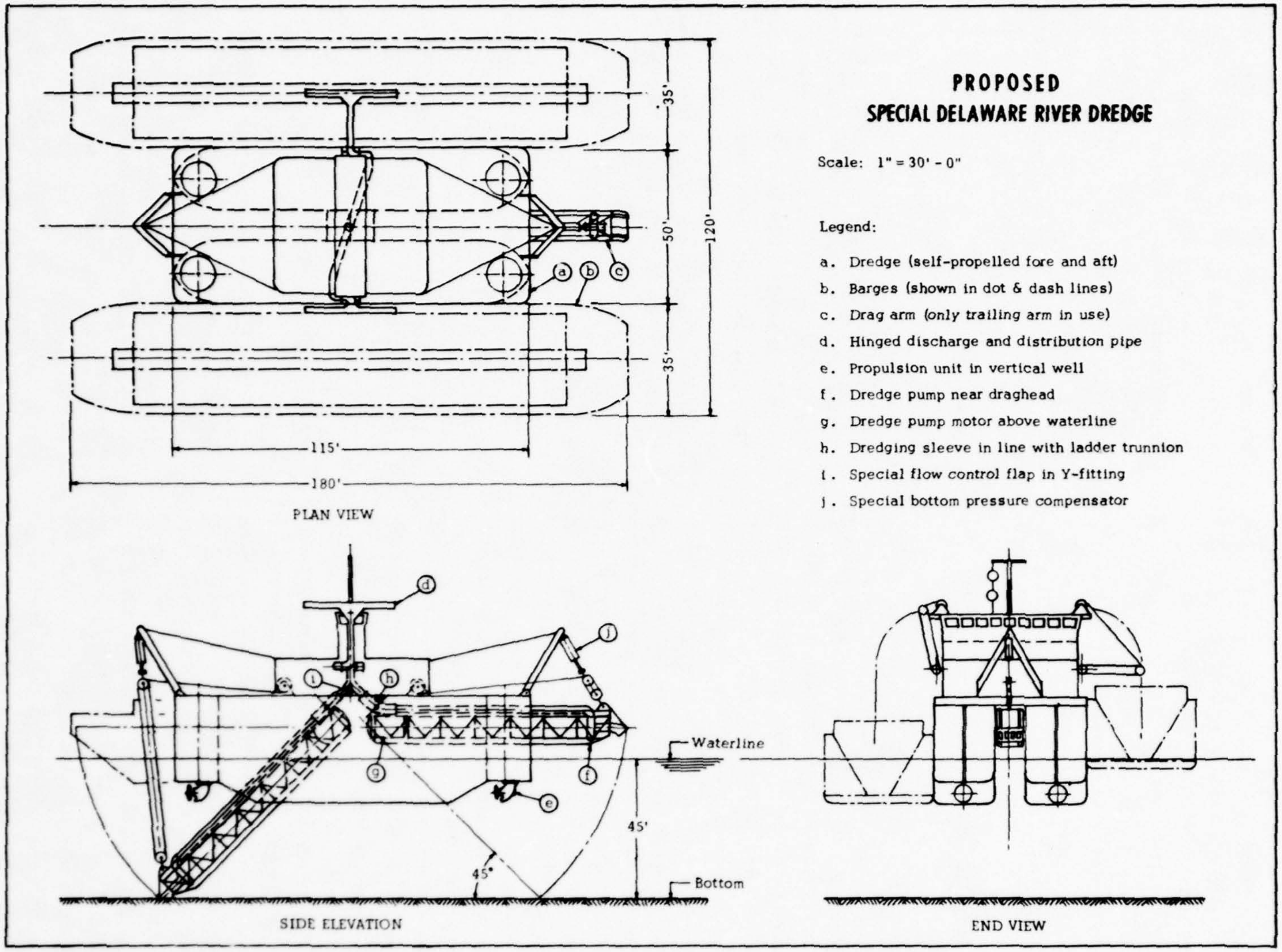
SPECIAL DREDGE

A sketch, outlining the special dredge is shown in Figure 6. This dredge would be of catamaran design with a propulsion system similar to that installed in modern ferries or four vertical shaft Voith-Schneider propellers or four outboard motor type (in wells) propellers. Two dragarms would be installed at the centerline of the dredge, one pointing fore, the other aft. The trailing dragarm would be used for dredging, while the forward dragarm would be in the raised position. This arrangement avoids turning at the end of each cut. The design and size of the two dredging assemblages would reflect on the best configuration found in the testing program described in Appendix C. Each dragarm is to be rigid throughout its length with the dredge pump adjacent to the draghead with the driving motor at the upper end of the ladder. Both dredge pumps would discharge into a common short piece of vertical pipe and branch from there to the distribution pipe on each side of the barge. It is envisioned that the system will work without any valves, by installing a control flap in the "Y" connection into the vertical pipe. The flow into the barges would be controlled by raising or lowering the distribution pipes. That is, if flow into one barge is desired, the distribution pipe on the other side will be raised until its outflow ceases.

Each dragarm hoist should be equipped with a drag controller. The controller would hold the draghead in the position in or on the shoal at which best production is attained.

HOPPER BARGES

The hopper barges would be alike and have neither power nor an assigned



PROPOSED
SPECIAL DELAWARE RIVER DREDGE

Scale: 1" = 30' - 0"

Legend:

a. Dredge (self-propelled fore and aft)
b. Barges (shown in dot & dash lines)
c. Drag arm (only trailing arm in use)
d. Hinged discharge and distribution pipe
e. Propulsion unit in vertical well
f. Dredge pump near draghead
g. Dredge pump motor above waterline
h. Dredging sleeve in line with ladder trunnion
i. Special flow control flap in Y-fitting
j. Special bottom pressure compensator

Fig. 6. Proposed Special Dredge Design.

crew. They would have one hopper of trapezpodal cross section without distribution, bottom dumping or overflow systems. (The distribution pipes suspended from the dredge are believed to suffice.) Barges which are standing by the dredge, would be secured to anchored buoys to avoid the handling of anchors on the barges.

UNLOADING UNIT

The unloading unit would consist of a barge (existing Mooring Barge #1 could be utilized for this purpose) permanently moored in a sheltered area off the disposal area. It would be equipped with a hydraulic hopper unloading facility. This facility would consist of a single material handling pump, plus a standby pump, which will pump the spoil from the barges through the unloading arm (reaching into the hopper barges) through submerged and shore piping into the disposal area. A water jetting system would be installed to aid in dislodging the material in the hopper barges. It would consist of a jetting pump furnishing water to a single jetting nozzle mounted on the unloading arm. This nozzle would be so installed that its stream could be directed sideways and fore and aft. The discharge from the jetting pump would also be used to prime the unloading pump. The hopper barges would be moored to the sheltered side of the larger unloading barge. Their handling would be facilitated by a series of dolphins (in line with the side of the unloading barge) connected with a walkway and a cable hauling system. The latter would pull the hopper barges alongside the unloading barge and control the advance of the hopper barges under the unloading arms. Equipment of this type was observed at a Bos en Kalis installation in Holland. However, one significant difference between the proposed installation and that observed in Holland would be the absence of a concentrating hopper on the unloading barge. Because of the fineness of the material encountered in Delaware River Maintenance and the relatively short discharge line it is considered that this hopper is unnecessary and the material may be pumped directly into the disposal area.

TUGS

The tugs would best be of the pusher type. They would pick up the loaded barges from the dredge and/or a nearby anchorage, and deliver them to one side of the unloading barge. Thereafter, they would pick up empty barges and return them to the dredge or a nearby anchorage. It is believed that the tug service of hauling the barges can best be obtained by contract.

TENDERS

The motor tenders would bring personnel to and from the dredge and the unloading barge and handle the hopper barges in the vicinity of these units. These are envisioned as craft of about 60 feet in length with several hundred horsepower.

COMPONENT SIZING

The dredge pump size can be arrived at by assuming 7,000,000 cubic yards of material which averages 1290 grams/liter will be removed annually, and that it will be dredged with an average mixture density of 1175 grams/liter flowing at 10 feet/sec. The dredge will operate 7,000 hours per year. Then, the annual effluent volume = 7,000,000 x (1290 - 1000)/(1175 - 1000) = 11,600,000 cubic yards

The required dredge pump size becomes

(11,600,000 x 27)/(7,000 x 3,600 x 10) = 1.24 square feet or 16 inches in diameter.

There exists no precise method to determine the size of the unloading pumps. They should, however, be larger than the dredge pumps because:

a. The material in the barges has settled out, requiring some dilution water for the heavier part of the load, thus increasing the volume to be handled.

b. The barges have to be cleaned with water, thus increasing the volume to be handled and decreasing the effective pumping time.

c. Barges have to be shifted one at a time, thus reducing the effective pumping time.

d. The material handling pumps have to be primed with water, thus increasing the volume to be handled and decreasing the effective pumping time.

Because of the foregoing, it is believed advisable to make the unloading pumps one size larger than the dredge pumps and size the jetting pump somewhat larger than the difference in capacity between the dredge pumps and the unloading pumps.

The size and number of the hopper barges depends on the quantity dredged per hour, the hauling time, the largest barge size the dredge can effectively propel, and the maximum permissible width of the barge. The latter depends on the maximum hopper width and the maximum width of the dredge-barge team.

Several combinations of barge numbers, sizes and shapes indicate that twelve identical barges of 2,500 cubic yards capacity each, operating in pairs, seems to be the optimum solution.

With this barge size, it would take the dredge and the unloading unit three hours to load and unload a barge pair respectively. The mean running time was also assumed with three hours in the foregoing. If this running time was never exceeded, only four barge pairs or eight barges would be required. However, since running times vary with the loading condition of the barges, the direction of the current and the weather, two more barge pairs are added to provide a "buffer," increasing the total number of barge pairs to six, that is twelve barges. This arrangement would also permit a third hired tug to join operations when hauling distances appreciably exceed the 25-mile mean distance between dredging area and disposal site discussed in the Introduction. Conversely, one tug and fewer barges would be used when hauling distances become appreciably shorter.

It is believed that the barge size established in the foregoing is the maximum the dredge can effectively handle. This implies that an average barge traveling speed lower than the eight statute miles per hour assumed in the foregoing, or a six or five-day work week would require more and smaller barges of larger total capacity. In this case, the dredge would load two barge pairs for each tug to transport.

EQUIPMENT AND UNIT MATERIAL COST
(Based on 1968 cost levels)

Assume the procurement costs for the equipment described in the foregoing as follows: (It is assumed that barging of loaded tugs will be obtained by contract arrangement. The cost of this service has been estimated in consultation with commercial tug operators)

Twelve hopper barges	$4,800,000
One Special Dredge	3,500,000
One special Unloading unit and piping (Assume modified Mooring Barge MB-1)	500,000
Two motor tenders	400,000
Total Procurement Cost	$9,200,000

Based on an economic life of thirty years for this equipment, the yearly (straight line) amortization cost is $ 307,000

Assume these personnel requirements (The factor 1.6 accounts for seven-day operation and vacation):

Twelve hopper barges No personnel	
One special dredge 1 x 3 shifts x 6 men x 1.6 =	29 men
One special unloading unit 1 x 3 shifts x 3 men x 1.6 =	15 men
Two motor tenders 2 x 3 shifts x 2 men x 1.6 =	20 men
Supervision, administration, and repair crew	9 men
	73 men

Based on an average yearly salary of $8,000, the yearly personnel cost is $584,000

Fuel Cost	$ 100,000
Tug Rental 330 days (2 tugs x $1300 each)	$ 858,000

Assume all other yearly costs such as repair, maintenance, small tools, etc. to amount to 500,000

The net total yearly cost is	$2,349,000
Allowing 10 per cent contingencies	235,000
Total yearly cost is	$2,584,000

Based on a yearly production of 7,000,000 cubic yards of in situ material, the unit cost with this scheme amounts to $2,584,000/7,000,000 cubic yards, or $0.37 per cubic yard without disposal area costs and based on a 25 mile haul.

It is of interest to note, that this unit cost approximately equals that for the COMBER rehandling Delaware River material on an average 3 mile haul. The new system outlined above would obviously result in a lesser unit cost if permanently employed on such short hauls. It is assumed that only 8 barges and one tug would be required in this case. This would reduce the unit cost to $0.29 per cubic yard without disposal area costs.

V. CONCLUSIONS

From examination of all work done on this Sub-Study through 31 December 1968 the following conclusions are made:

1. If there is any decision in the near future to produce a new dredging plant for Delaware River the plant should be of the nature described in this report, namely, the plant should be of the self propelled hydraulic dredge type; it should have submerged pumps; the digging, transporting, and unloading units should be separate; and facilities for furnishing of subsistence and quarters will not be required. Such plant should produce dredging and disposal, even with 20-25 mile hauls, at a unit price in the general area of what is done with present plant for a 3 mile haul.

2. Significant benefits can be achieved from dredging plant specially designed for the Delaware River. From this it follows that when requirements exist for another hopper dredge in the Corps of Engineers, that it will be advantageous to make the Comber available for those requirements; and a new special plant be constructed for maintenance dredging in the Delaware River. This should provide benefits of approximately $560,000 per year in maintenance dredging cost on the Delaware River; it also will make another hopper dredge available for work for an approximate investment of $9,200,000 for new Delaware River dredging plant, whereas, the approximate cost of a new hopper dredge is $15,000,000; a saving in investment of $5,800,000.

3. This investigation has concluded that the best present conception of improved plant for Delaware River maintenance work is a self-propelled hydraulic dredge with separate loading, transporting and unloading units. It is not contended that this conception can not be improved upon through further knowledge, experience, and imagination. For example, the advantages of loading with an endless chain bucket, or a clamshell bucket, are significant. Such machines can best gather material at its "in situ" density. The problem of advancing such machines over a cut of relatively shallow depth at a sufficient rate to attain required dredging rates has not been resolved. Although the studies in connection with this report did not find a solution to this problem it nevertheless is believed such an inquiry should be continued as the advantages of a self propelled mechanical dredge for dredging mud shoals might be significant.

4. A conclusion of this study was that the limitation on hydraulic dredging of mud at "in situ" density frequently is the rheological properties of the mud. The mud will only arrive at the drag at a rate which depends on its viscosity. Recognition of this factor suggests that further inquiry into means of affecting the rheological properties of mud are warranted and should be investigated in the future.

APPENDIX A

GRAVITY PRECIPITATION OF FINE GRAINED HYDRAULICALLY DREDGED MATERIALS FROM THE DELAWARE RIVER

LIST OF ILLUSTRATIONS

		Page
Plate 1	Delaware River, Major Shoals	Back of Book
Figure 3	Gradation Curve, Marcus Hook	5
Figure 7	Consolidation of Hopper Load, Range: Cherry Island, Sta: 169+000-174+000	2-a
Figure 8	Consolidation of Hopper Load, Range: Marcus Hook, Sta: 126+000-130+000	3-a
Figure 9	Consolidation of Hopper Load, Range: Deepwater Point, Sta: 190+000-197+000	4-a
Figure 10	Consolidation of Hopper Load, Range: New Castle, Sta: 226+000-233+000	5-a
Figure 11	Consolidation of Hopper Load, Range: New Castle, Sta: 226+000-233+000	6-a
Figure 12	Consolidation of Hopper Load, Range: Marcus Hook, Sta: 120+000-124+000	7-a

PURPOSE

The purpose of this study was to determine the settling characteristics of the fine grain and light weight shoal material which is dredged in the Delaware River hydraulically and pumped into the hoppers of hopper dredges or scows. Such information is required to determine whether settling in hoppers is a technique which will produce significant amount of effluent reasonably free from fines in a reasonable amount of time. Such a characteristic would permit draining of the innocuous supernatant liquid so that it need not be hauled to a disposal location.

METHOD OF TESTING

In an effort to determine the rate of consolidation of dredged material pumped hydraulically into a hopper bin, a loaded hopper dredge was allowed to hold the load for about seven to ten hours while it lay idle to take on fuel, water, supplies, etc. These tests began on 2 February 1967 and ended on 26 April 1967 after several separate loads were sampled.

The tests consisted of sampling of the hopper load throughout its vertical each hour that it lay idle, and determining the depth in the hopper at which the density matched that of the river water. The rate of consolidation of the hopper load was determined for the seven to ten-hour period.

RESULTS OF TESTING

The following table shows the pertinent details of the tests:

TABLE

Load No.	Dredge	Location of Shoal	In situ Density of Shoal G/L	Average Density of Load G/L	Pumping Time to Load	c.y. Slurry per pump minute
1	GOETHALS	Cherry Is.	1290	1048	18	279
2.	COMBER	Marcus Hook	1270	1059	12	272
3.	COMBER	Deepwt. Pt.	1300	1110	16	211
4.	COMBER	New Castle	1300	1123	14	236
5.	COMBER	New Castle	1300	1104	13	255
6.	COMBER	Marcus Hook	1270	1134	25	135

The attached Figures 7 through 12 show the testing data for each hopper load tested. Figure 3, Page 5 of the main text, shows a sample gradation curve of shoal material.

CONCLUSIONS

Significant amount of free water was only released in periods up to 8-hours when the loads in the hoppers consisted of low densities; that is where the densities were 1060 grams or less. This occurred in loads Nos. 1 & 2. Loads 3, 4, 5 & 6 which were better loads did not release any significant amount of free water in an 8-hour period.

This testing confirmed results of similar testing made in 1947 from which it was concluded that gravitational settling of hydraulically dredged fine grained material in dredge bins or scows is not economically feasible.

CORPS OF ENGINEERS PHILADELPHIA DISTRICT

SUBJECT DELAWARE RIVER - CONSOLIDATION OF HOPPER LOAD
Dredge GOETHALS Range CHERRY ISLAND STA. 169+000 to 174+000

Tested by: ____________ Analysed by: ____________ Date 2 Feb 67

HOPPER DATA

DATUM DEPTH	HOPPER CAPACITY
1	
2	6361
3	6156
4	5970
5	5782
6	5584
7	5388
8	5164
9	4940
10	4714
11	4488
12	4262
13	4048
14	3828
15	3612
16	3392
17	3174
18	2960
19	2740
20	2524
21	2308
22	2096
23	1876
24	1660
25	1444
26	1228
27	1028
28	844
29	676
30	524
31	400
32	292
33	200
34	136
35	76
36	36
37	8

ELAPSED TIME (HOURS) 0 1 2 3 4 5 6 7 8 9

ACTUAL TIME	0700 0715	0900	1000	1100	1200	1300	1400	1530
HOPPER DEPTH								
OVERFLOW								
1								
2								
3								
4	1033	1004	1003	1003	1003	1003	1003	1003
5								
6		1012	1009	1016	1005	1003		1005
7								
8	1043	1028	1025	1022	1015	1002	1002	1004
9						1018	1015	1005
10			1025	1025	1015	1024	1026	1024
11								
12						1027		1030
13								
14	1045	1037	1036	1034	1032	1032	1030	1036
15								
16						1033		1037
17								
18	1046	1041	1040	1038	1037	1037	1035	1040
19								
20			1040	1040		1038		1040
21								
22						1040		1040
23								
24	1046	1044	1044	1043	1042	1041	1041	1045
25								
26								1050
27								
28	1046	1052	1050	1055	1065	1055	1060	1054
29								
30								
31								
32								
33								
34	1197	1176	1190	1220	1220	1248	1250	1230
35								

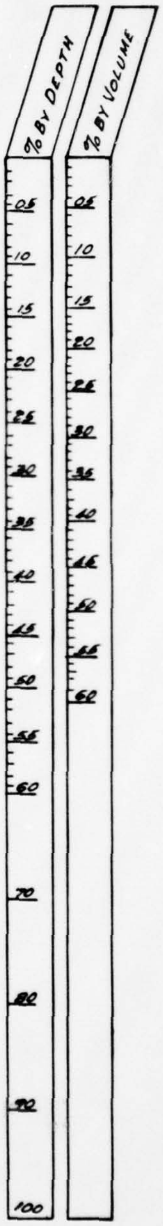


Fig. 7. Consolidation of Hopper Load, Marcus Hook.

CORPS OF ENGINEERS PHILADELPHIA DISTRICT

SUBJECT: DELAWARE RIVER — CONSOLIDATION OF HOPPER LOAD

Dredge: COMBER **Range:** Marcus Hook **STA:** 126+000 - 130+000

Tested by: Walter Snyder **Analysed by:** **Date** 15 Feb. 67

Datum Depth	Hopper Capacity	Elapsed Time	0	1	2	3	4	5	6	7	8	10
		Actual Time	0615	0700	0800	0900	1000	1100	1200	1300	1400	1600
1		Hopper Depth										
2	3524	0										
3	3394	1		1010	1007	1004	1004	1004	1004	1004	1003	1003
4	3284	2	1021	1015	1004	1004	1004				1004	
5	3174	3										
6	3064	4	1021		1020	1010		1004	1004	1004	1004	1003
7	2956	5										
8	2846	6	1021				1005			1004		
9	2730	7										
10	2604	8	1024		1020	1015	1005	1005	1004		1004	1003
11	2478	9										
12	2362	10	1025				1005	1006		1004	1010	
13	2232	11										
14	2106	12	1025		1020	1015	1008	1006	1005	1010	1015	1005
15	1980	13										
16	1860	14	1026				1015	1008	1005	1015		
17	1734	15										
18	1614	16					1020	1015	1020	1030	1020	1003
19	1485	17										
20	1362	18	1025		1025	1015	1026	1030	1035		1026	1005
21	1236	19										1012
22	1104	20						1045	1045	1030		1040
23	872	21										
24	846	22	1027		1025	1030	1030				1045	1050
25	714	23										
26	594	24	1030		1030	1035	1035	1082	1070	1015	1080	1137
27	486	25										
28	380	26	1067									
29	300	27	1360				1180	1180	1195			
30	228	28										
31	168	29										
32	144	30										
33	72	31										
34	42	32										
35	36	33										
36	6	34										

% By Depth: 05, 10, 15, 20, 25, 30, 35, 40, 45, 50, 55, 60

% By Volume: 05, 10, 15, 20, 25, 30, 35, 40, 45, 50, 55, 60, 65

Fig. 8. Consolidation of Hopper Load, Marcus Hook.

CORPS OF ENGINEERS PHILADELPHIA DISTRICT

SUBJECT: DELAWARE RIVER – CONSOLIDATION OF HOPPER LOAD

Dredge: COMBER Range: Deepwater Point STA: 190+000 – 197+000

Tested by: Walter Snyder **Analysed by:** ____________ **Date** 21 Feb 67

Datum Depth	Hopper Capacity	Elapsed Time	0	1	2	3	4	5	6	7	8
		Actual Time	0705	0800	0900	1000	1100	1200	1300	1400	1500
1		Hopper Depth									
2	3526	0	1052	1003							
3	3396	1			1003	1003 1050	1003	1003	1003	1003	
4	3284	2	1084	1055	1054	1054	1050	1048	1046	1045	
5	3174	3									
6	3064	4	1084								
7	2956	5									
8	2846	6				1060	1060		1045		
9	2730	7									
10	2604	8	1095					1050		1050	
11	2478	9									
12	2352	10				1065	1060		1045		Load Disturbed
13	2232	11									
14	2106	12	1092								
15	1880	13									
16	1860	14				1070	1065	1050	1046	1055	
17	1734	15									
18	1614	16	1096								
19	1488	17									
20	1362	18				1070	1065		1060	1055	
21	1236	19									
22	1104	20	1096								
23	978	21									
24	846	22	1101			1100	1083	1085	1090	1090	
25	714	23									
26	597	24	1155								
27	586	25									
28	390	26									1271
29	300	27									
30	228	28									
31	168	29									
32	144	30									
33	72	31									
34	42	32									
35	36	33									
36	6	34									

% By Depth	% By Volume
05	05
10	10
15	15
20	20
25	25
30	30
35	35
40	40
45	45
50	50
55	55
60	60
	65

Fig. 9. Consolidation of Hopper Load, Deepwater Point.

CORPS OF ENGINEERS PHILADELPHIA DISTRICT

SUBJECT: DELAWARE RIVER – CONSOLIDATION OF HOPPER LOAD
Dredge: COMBER **Range:** New Castle **STA:** 226+000 – 233+000
Tested by: Walter Snyder **Analysed by:** **Date** 8 May 67

Datum Depth	Hopper Capacity	Elapsed Time	0	1	2	3	4	5	6	7	8
		Actual Time	0700	0800	0900	1000	1100	1200	1300	1400	1500
1		Hopper Depth									
2	3524	0	1005	1005	1003	1003	1003	1003	1003	1003	1003
3	3394	1			1070			1060	10.50	1050	1052
4	3284	2	1074	1070		1091	1070	1070	1068	1070	1078
5	3174	3									
6	3064	4		1090	1090			1090	1085		1077
7	2956	5									
8	2846	6	1114		1100	1090	1080			1085	
9	2730	7									
10	2604	8						1091	1090	1085	1085
11	2478	9									
12	2358	10	1121		1120	1118	1118				
13	2232	11									
14	2106	12						1090	1091.	1096	1094
15	1980	13									
16	1860	14	1124		1125	1124	1100		1100		
17	1734	15									
18	1614	16						1095		1095	1094
19	1488	17									
20	1362	18	1128		1130	1131	1125				
21	1236	19									
22	1104	20						1100	1110	1100	1115
23	972	21									
24	846	22	1124		1140	1170					
25	714	23									
26	594	24	1126					1131	1130	1125	1128
27	486	25									
28	390	26	1126		1142	1177			1170		1160
29	300	27									
30	228	28	1135			1334		1336			1340
31	168	29									
32	144	30	1146								
33	72	31									
34	42	32									
35	36	33									
36	6	34									

% By Depth	% By Volume
05	05
10	10
15	15
20	20
25	25
30	30
35	35
40	40
45	45
50	50
55	55
60	60
	65

Fig. 10. Consolidation of Hopper Load, New Castle.

CORPS OF ENGINEERS PHILADELPHIA DISTRICT

SUBJECT: DELAWARE RIVER – CONSOLIDATION OF HOPPER LOAD

Dredge: COMBER **Range:** New Castle **STA:** 226+000 – 233+000

Tested by: Walter Snyder **Analysed by:** **Date** 22 Mar. 67

Datum Depth	Hopper Capacity	Elapsed Time / Actual Time / Hopper Depth	0 0700	1 0800	2 0900	3 1000	4 1100	5 1200	6 1300	7 1400	8 1500
1											
2	3524	0	1070	1003	1003	1003	1003	1003	1003	1003 1050	1003 1051
3	3394	1									
4	3284	2	1080	1090	1065	1058	1000	1060	1060	1065	1056
5	3174	3									
6	3064	4									
7	2956	5									
8	2546	6	1098	1100	1070	1060	1060	1060	1060	1059	1060
9	2730	7									
10	2604	8									
11	2478	9									
12	2362	10	1101		1090	1090	1080	1060	1060	1059	1000
13	2232	11									
14	2106	12									
15	1980	13									
16	1860	14	1101		1090	1075	1070	1060	1062	1061	1062
17	1734	15									
18	1614	16									
19	1488	17									
20	1362	18	1110		1100	1100	1080	1066	1064	1065	1065
21	1236	19									
22	1104	20									
23	922	21									
24	846	22	1113		1100	1110	1076	1066	1065	1065	1063
25	714	23									
26	594	24								1080	1085
27	486	25									
28	390	26	1121		1132	1140	1160	1180	1183	1225	1287
29	300	27									
30	288	28						1410			1260
31	168	29									
32	144	30									
33	72	31									
34	42	32									
35	36	33									
36	6	34									

% By Depth
05
10
15
20
25
30
35
40
45
50
55
60

% By Volume
05
10
15
20
25
30
35
40
45
50
55
60
65

Fig. 11. Consolidation of Hopper Load, New Castle.

CORPS OF ENGINEERS PHILADELPHIA DISTRICT

SUBJECT: DELAWARE RIVER – CONSOLIDATION OF HOPPER LOAD

Dredge : COMBER   Range: Marcus Hook   STA: 120+000 – 124+000

Tested by: Walter Snyder   Analysed by: ______   Date 26 Apr. 67

Datum Depth	Hopper Capacity											
		Elapsed Time	0	1	2	3	4	5	6	7	8
		Actual Time	0715	0800	0900	1000	1100	1200	1300	1400	
1		Hopper Depth									
2	3526	0	1099	1090	1040	1000	1000	1000	1000	1000	
3	3394	1								1081	
4	3284	2	1102	1090	1090	1091	1085	1083	1080	1081	
5	3174	3									
6	3064	4									
7	2956	5									
8	2846	6	1105	1100		1100	1080	1088	1088	1087	
9	2730	7									
10	2604	8									
11	2478	9									
12	2352	10	1108			1100	1100	1090	1087	1085	
13	2232	11									
14	2106	12									
15	1980	13									
16	1860	14	1115			1100	1090	1087	1090	1093	
17	1734	15									
18	1614	16									
19	1488	17									
20	1362	18	1118		1100	1100	1090	1092	1090	1095	
21	1236	19									
22	1104	20									
23	972	21									
24	846	22	1118			1100	1095	1094	1100	1110	
25	714	23									
26	599	24									
27	486	25									
28	390	26	1140			1180	1210	1407	1410	1450	
29	300	27							1600	1626	
30	228	28	1415			1230					
31	168	29									
32	144	30									
33	72	31									
34	42	32									
35	36	33									
36	6	34									

% By Depth	% By Volume
05	05
10	10
15	15
20	20
25	25
30	30
35	35
40	40
45	45
50	50
55	55
60	60
	65

Fig. 12. Consolidation of Hopper Load, Marcus Hook.

APPENDIX B

REPORT ON TRIP TO HOLLAND

REPORT ON TRIP TO HOLLAND

1. General:

During a recent vacation in Europe, I visited Bos En Kalis, a Dutch dredging concern, for one week to learn about their operations with a view to further the "Long Range Disposal Study" presently under way in this District. I was met by Mr. Pastoors, Manager Dredge Technical Department, who stayed with me daily. Several inclosures depicting dredging plant and equipment are attached.

2. Itinerary:

12 September 1967 - Arrived in Amsterdam (Holland) by plane and was met by Mr. Pastoors at 1600 hours. We proceeded to my hotel in Rotterdam in his car. Prior to his leaving, I outlined the "Long Range Disposal Study" in general and the new equipment and techniques envisioned in this study in particular. I also gave him one copy each of our drafts on "New Dredging Concepts," "Operation OPPO," and "Optimum Density." We then established an itinerary for a seven-day period which we believed would aid me most. Mr. Pastoors thought it best to have the chiefs of their design and their research departments review our drafts and give me their first impressions of them prior to my leaving. I asked him to keep the contents of the drafts confidential.

13 September 1967 - Met Messrs. Andreae, Teyema, and Waard in the office of Bos En Kalis to discuss several problem areas on the new equipment and techniques envisioned. Saw research facilities at Bos En Kalis. Visited their new dredge being constructed at IHC (Gusto plant) in late afternoon.

14 September 1967 - Visited Bos En Kalis' dredging and pumping facilities at Vinkeveen. (This is the plant shown in the literature we have from them. However, latest dredge able to dig to 100 feet is not shown.) Inspected their experimental dragheads and other components near their office in evening.

15 September 1967 - Visited the hydraulic laboratory "De Voorst" at Emmeloord in North Holland. (This laboratory is similar to WES, works on similar assignments but is more dredge orientated.)

16 September 1967 - Visited office of Bos En Kalis to obtain comments from Messrs. Hartog and Andreae on our three drafts given to them on first day of visit.

17 September 1967 - Participated in boat tour through harbor to see plant in general and small barge unloader in particular.

18 September 1967 - Visited various plant, employed to dig sand in North Sea, transport and rehandle it and unload it hydraulically near Amsterdan. In this connection was aboard:

Hopper Dredge SEAWAY
Plain Suction Dredge SLOTERDIJK
Endless Chain Bucket Dredge ASIF
Hydraulic Unloading Plant ZAAN
Cutterhead Dredge MARK
Unloading Plant Ammerstol

19 September 1967 - Had summary discussion at office of Box En Kalis. Left at noon to board plan for Germany.

3. Results and Comments:

a. Personnel at Bos En Kalis maintain that our contemplated tests with a smaller suction assemblage, larger suction pipes and lower dredge pumps will result in a denser effluent. However, the gain will be nominal. The only way to dredge maintenance silt at near insitu density is with a mechanical dredge. Because of the quantities involved, this dredge should be of the endless chain bucket type.

b. They believe that our objections to a bucket dredge; namely, pollution, anchor wires in channel and poor maneuverability are used by us as convenient excuses to dismiss this type of plant because we know so little about it.

c. According to them, a properly operated bucket dredge (buckets just filled) is not "dirtier" than a suction dredge. Furthermore, a modern dredge has its six mooring wires led off the vessel through vertical, adjustable wells with fairleaders top and bottom. This arrangement permits the passing of vessels in the immediate vicinity of the dredge. As to maneuverability, they feel that with proper operation (moving away from passing vessel to have slack wires under it), work in busy waterways is possible. As proof they cite the 300 meter wide waterway between Rotterdam and the sea which has been dredged with a bucket dredge at an average frequency of passing vessels of one in seven minutes.

d. I pointed out that their vessels are frequently shallow draft or their channels overdredged to gain material, which permits the foregoing mode of operation. However, the Delaware River with a nominal 40-foot channel handles vessels with nearly this draft. Therefore, wires on the bottom, although slack, are dangerous. They acknowledge this fact, but believe its seriousness should be evaluated because of the expected gain, which is dredging material at 1300 grams per liter in lieu of 1150 and thus transporting roughly half the amount of material.

e. Their material handling pumps develop heads up to 150 psi, however, 120 psi is considered a better figure to reduce wear. They don't have pumps close together. In "OPPO" we assumed 100 psi as practical maximum to utilize standard pumps of good efficiency. However, we combined two pumps each in one station to increase station spacing.

f. Bos En Kalis maintains elaborate research facilities for a private concern. Research on dredge instrumentation alone is presently performed (full time) by one engineer, two technicians and two helpers. Instrument maintenance is performed by a separate department. This observation (especially the degree of success attained) leads to the conclusion that we should review our requirements and resources. As a result, we should either eliminate formal research studies (as a sideline for one or two personnel) or establish a department exclusively charged with this task.

g. I noted that they design their plant for only one purpose, that the design is very detailed and emphasis is on simplicity. The resulting equipment is very functional and efficient but not necessarily "beautiful." However, this term is relative. I found beauty in the efficiency of this plant, the fact that all equipment worked and their ability to load a 5300 cubic yard hopper in a hull slightly smaller than that of the COMBER. (Dredge SEAWAY, designed to a one compartment standard.)

h. In regard to maintenance, their standards differ from ours. While operating rooms are so clean that personnel take their shoes off prior to entering, the hull and decks had one initial gray coating which is, in part, corroded or covered with sand. The maintenance of their engine rooms and machinery is on a par with ours. By avoiding anything in operation and maintenance that is not absolutely necessary, they manage to operate with a minimum of personnel. For instance, the Hopper Dredge SEAWAY operates five or six days a week with a crew of 28 men working 12-hour shifts a day (with four hours overtime).

i. Their sand handling operation, Vinkeveen to Rotterdam, is of particular interest to us, since it has all the features of our two most likely schemes for the future. Here they dig sand with two special dredges into barges, pull them to a hydraulic unloading plant and transport the sand through a pipeline containing several booster stations. The installation operates beyond the capacity for which it was designed ten years ago and is being changed. For this reason, one or the other component is acting as a "bottleneck" on the operation. (Example: After a second dredge was added, there is now a shortage of barges.) They also, like we, labor under the necessity of having to use existing equipment. (Example: Booster pumps differ and some are electrically and some diesel driven.) However, the operation of each system component works surprisingly smooth and efficient.

The following particulars apply for the installation:

Over 2,000 cubic yards per hour capacity - 120 psi pressure increase at each single booster pump - Booster stations of 2,000 2,500 and 2,700 HP - Above 20 per cent average absolute solid conncentration - 18 foot per second average effluent velocity - 0 to 45 psi at suction side of booster pumps - Newer of two plain suction dredges (WEESPERKASPEL) dredges to 100 feet below waterline with two pumps partially down dredging ladder.

j. They do more in draghead research than we do. Their thinking agrees with ours in many respects, but differs at least in these two:

They maintain that good draghead research has to consist of a combination of model and prototype tests. This view was confirmed by personnel at their laboratory, "De Voorst." We shun model tests, based on our experience at WES, where model and prototype results did not agree. Perhaps a laboratory more familiar with dredging may have given better results.

They maintain that light maintenance silt (say 1270 grams per liter) is dredged by "sucking" it into the draghead over the whole area like a heavy liquid. Although this opinion is intuitively clear, one of our prototype tests gave reason to believe that light material is dredged like heavy material by depending on a high velocity water stream around the draghead perimeter scouring bottom material in its path. Perhaps we have to review our thinking.

k. In regard to our three drafts, they had these comments after a three-day review. Additional comments may be forwarded by mail.

New Dredging Concepts:

(1) Larger barges (especially in length) in Scheme 1 would be advantageous.

(2) Special dredge in Scheme 1 is too short for good maneuverability. Application calls for four Voith-Schneider propellers.

Operation OPPO:

(1) Hopper of rehandling unit in disposal area should be at least 300 cubic yards to reduce the amount of air entering the pipeline with the material.

(2) Long discharge line should be provided with water inlets at several places to clear line in sections in case of plugging.

(3) The largest particle size for long line discharge, assumed by us as 2-1/2 inches, should be reduced to about 1 inch.

(4) The power supply to rehandling unit should be through a floating cable (made in U.S.A.) in lieu of the overhead supply shown.

Optimum Density:

(1) See Paragraph a.

(2) They would appreciate our test results.

l. Mr. Pastoors pointed out that they have a long range, long hauling dredging assignment, which led them to perform an investigation very similar to our "New Dredging Concepts" draft. Besides other means, they ruled out hopper dredges, since their complexity renders them too expensive for long hauls. In evaluating long line pumping (OPPO) versus barge transport (Scheme 1), they established that the latter is cheaper (also technically less complex) wherever suitable waterways exist. These findings fully agree with our views.

m. Our hopper dredges are built as general purpose tools to a two compartment standard. They are, therefore, more complex and expensive than the Dutch dredges. This leads to the thought that our hopper dredges are frequently not the most economical tool in their present assignments. (Example: COMBER in Delaware River utilizes two 28-inch dredging assemblies approximately 10 per cent of the cycle time.) It also tends to explain why Scheme 1 (each system component performs its function nearly 100 per cent of the time) does not result in a higher cost per cubic yard handled than the present scheme (Hopper Dredges).

n. Mr. Pastoors explained that they would like to help us for these reasons:

(1) As a repayment for their visit to us two years ago.

(2) Their association with us is a status symbol.

(3) They consider us a potential customer, since they intend to handle consulting and design work in the future, in addition to dredging work.

They feel that the expansion into design comes as a natural development, since customers see the size, diversity and efficiency of their plant. At present, they operate approximately 200 dredges, including 12 hopper dredges.

o. Mr. Pastoors does not understand why we have to grow crops on samples of dredged material to determine its agricultural value. He maintains that a chemical analysis of this material should completely suffice to determine this value and also the type and amount of additives necessary to enhance it. As proof, he cites the Dutch land reclamation works. In these projects, soil samples are analyzed as outlined above, while there is still sea water over them. The results have been satisfactory

A. W. Mohr

A. W. MOHR P.E.

APPENDIX C

REPORT ON DREDGING EXPERIMENTS PERFORMED IN THE DELAWARE RIVER

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FOREWORD

The dredging experiments discussed in this appendix were performed as part of an investigation to determine the best dredging method after close-in disposal areas in the Delaware River are depleted. This investigation was made in connection with the third sub study of a total of six, which comprise the overall "Long Range Spoil Disposal Study" in the Delaware River. The overall study was conceived and initiated by the former District Engineer, Brigadier General W. W. Watkin, who had been directed to such an effort by the Chief of Engineers.

The Project Manager for Sub Study III and these dredging experiments was Mr. Adolph Mohr, P.E., who conceived the experiments, designed the equipment, supervised the tests, and wrote this report. He was assisted with the report by Mr. Lewis Caccese, P.E.

SUMMARY

This report discusses a series of prototype dredging experiments performed essentially in the maintenance mud of the Delaware River in 1967-68. In particular, it evaluates the effects of dredge pump location, draghead configurations, ground speed, gas removal systems, and dredge pump size. In the evaluation, major emphasis was placed on high effluent density.

The report concludes that the production of conventional dredges is limited by the suction lift of their dredge pumps. When the dredge pump was placed near the draghead in the experiment, the suction limitation was overcome and performance improved. The experiments showed that a dredge pump adjacent to its draghead is practical and advantageous.

I. INTRODUCTION

1. Purpose and Scope:

The purpose of this study is to determine the arrangement of dredge components and mode of operation that will result in the highest effluent density on dredging assignments in the Delaware River. The study is limited to hydraulic dredging and arrangements employing one dredge pump of conventional design. It is essentially empirical, and places major emphasis on practical solutions rather than theoretical considerations.

2. Background

Dredging requirements in the Delaware River are undoubtedly similar to many other waterways requiring repetitive maintenance. Therefore, new dredging developments described here are believed to be of general interest.

The Delaware River supports the Port of Philadelphia, which is a 40-foot draft port 100 miles inland. This is one of the foremost deep draft ports in the United States. The natural depth in this port is 17 feet. The channel has a consistent shoaling rate, particularly in the intensely developed area about 75 miles from the ocean.

Approximately 7,800,000 cubic yards of in situ material are removed from the Delaware River annually between Philadelphia and the Sea. More than 90% of this material is gaseous maintenance silt with average in situ and particle densities of 1290 gr/1 and 2650 gr/1 respectively. It is so fine that almost all of it will pass through a No. 200 sieve (0.0029" openings). The remainder of the dredging material is fine and medium grained sand, with occasional boulders and debris.

The bulk of the required maintenance dredging work has been and is presently accomplished by U.S. Army Corps of Engineers' hopper dredges. Prior to 1954, a procedure was followed in which the hopper dredges hauled the dredged material to areas adjacent to shore disposal areas and dumped the spoil on the bottom of rehandling basins. A pipeline dredge then rehandled the material, pumping it into nearby disposal areas. Since a high percentage of "fines" escaped the rehandling and returned to the channel, much of the material was repetitively redredged and the bottom of the river deteriorated through the formation of larger shoals of very fine material, which were dense enough to interfere with navigation but too light to be economically dredged. To alleviate this condition, the hopper dredging technique in the Delaware River was changed. Bottom dumping was discontinued and instead, the material was pumped from the hopper dredges into the hoppers of a "rehandler vessel" (a converted hopper dredge), which in turn pumped the material through long pipelines to confined disposal areas ashore. This procedure was effective in getting all dredged particles ashore and was instrumental in appreciably reducing maintenance dredging requirements. In 1963, the "rehandler vessel" was eliminated and the hopper dredges were provided with the capability to pump directly into confined disposal areas on shore through pipelines. This system is in operation today and is satisfactory.

3. Need to Change Dredging Method:

Increasingly intensive land use along portions of the Delaware River where shoaling is most prevalent, has made it very difficult to procure new nearby disposal areas. It is, therefore, expected that when these disposal areas are depleted, dredged material will have to be hauled to the Delaware Bay, a distance of 25 to 50 miles, where disposal areas are obtainable for many years to come. As a result, a study was initiated in the Philadelphia District of the U.S. Army Corps of Engineers to develop a concept for the best dredging equipment for use in the future when nearby (5 to 10 miles) shore disposal areas are no longer available. This investigation is in progress and is considering various dredging and disposal schemes.

4. Significance of Material Density:

The economy of hydraulic material handling is largely determined by solid flow rate or density. In hopper dredging, solid flow rate is the more important criterion when the material transport is short, while density is the over-riding criterion when the transport distance is long. This is obvious when considering that a hopper load of 1150 gr/l density material contains only half a load of 1300 gr/l bottom density material, the other half consisting of added water.

In hopper dredging operations, the density of the hopper mixture is frequently increased over the dredge pump effluent density by pumping beyond overflow. This method of increasing the quantity of solids in a load is effective, but causes turbidity and pollution and creates new and scattered shoals composed of fine grained materials. As a result, pumping beyond overflow is limited in the Delaware River and will probably not be permitted in the future. Other attempts to increase the hopper density, such as gravity, centrifuge, or chemical precipitation, have proved impractical. Therefore, the highest attainable dredge pump effluent density is of paramount importance. In view of this, it is important to dredge a high density initially, for efficiency will be related directly to the density delivered into the dredge.

5. Testing Program:

Because of the importance of dredge pump effluent density, a testing program was conducted to determine the dredge component arrangement and mode of operation that will result in the highest practical effluent density. Testing was performed in mud and sand, with emphasis primarily on mud, since this material is most frequently encountered in maintenance dredging in the Delaware River.

Theoretical analyses indicate that dredge pumps should be able to handle most maintenance muds in their in situ state of approximately 1300 gr/l density. However, despite all efforts, the average dredge pump effluent density of hopper and pipeline dredges seldom exceeds 1150 gr/l. There may be numerous explanations for this difference but none are proved because prototype dredging and model testing cannot be adequately related. Prototype testing on board a dredge would be most expensive and could not obtain the accuracy required for test purposes. Model testing suffers from the inability to test in undisturbed prototype material and to scale down the atmosphere, the particle size, and other variables. For this reason, model results are at best qualitative, but not quantitative.

In view of this it was decided to conduct a series of experiments in the Delaware River utilizing Corps owned equipment. The test assemblage is referred to as the "Experimental Dredge". In the tests that followed, the effluent densities obtained were compared with each other and with those obtained by the Hopper Dredge COMBER in the same area.

II. EXPERIMENTAL DREDGE

1. Components of Experimental Dredge:

The components of the Experimental Dredge consisted of the large Mooring Barge (MB-1), the 1200 HP Tug SAN LUIS, and the small Cargo Barge 40. Their arrangement is outlined on Figure 13. The MB-1 was used because it constituted a large working platform and is equipped with 3 - 150 KW diesel generators. It was modified as follows for the tests.

a. A dredging ladder was added to its port side.

b. A ladder hoist davit was designed, utilizing existing equipment, and installed.

c. The controls and cable arrangement of an existing mooring winch were altered to serve as a drag hoist.

d. The controls and power leads of one of the 150 KW diesel generators were altered to drive the dredge pump.

e. A discharge flume across the deck of the MB-1 was constructed from existing 20" piping to lead the dredge spoil from the dredging ladder to the Cargo Barge.

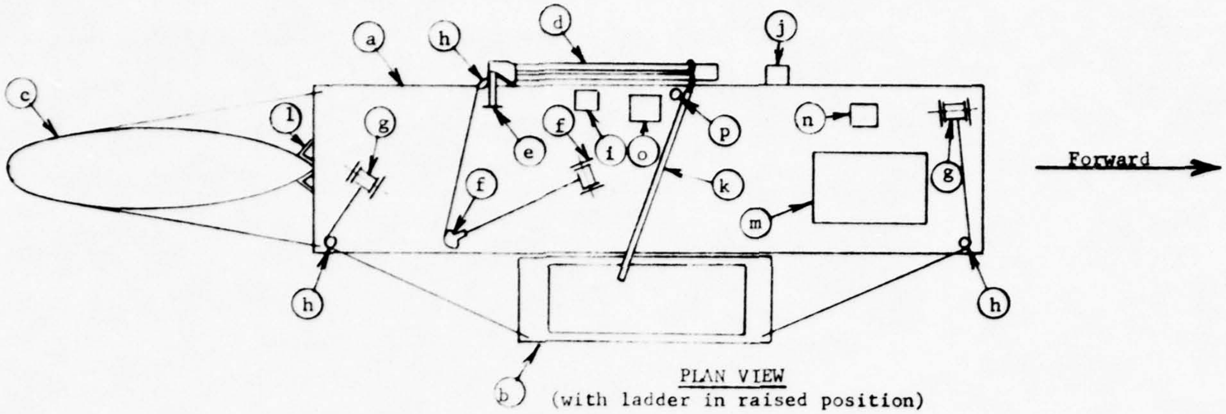
f. A fender was constructed from available material and installed at the stern of the MB-1 to accommodate the bow of the SAN LUIS.

g. The cable run of two mooring winches was altered and fairleaders installed to permit shifting of the Cargo Barge along the starboard side of the MB-1.

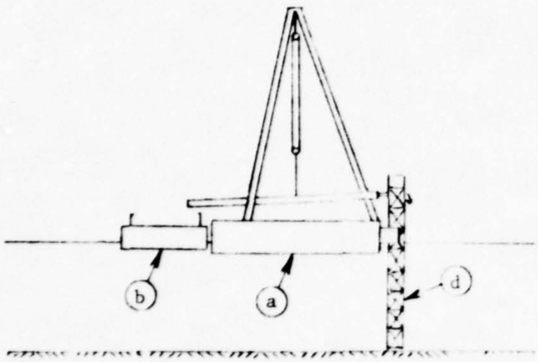
h. A platform was added to the side of the MB-1 ahead of the dredging ladder and an echo sounder installed.

The dredging ladder was designed as a truss, consisting of three 12" pipes with cross bracing. It was hinge connected at its forward end on the port side of the MB-1 to permit raising and lowering and sideways drifts of its after end. A used COMBER's Ambrose draghead was installed at its after end, since it was available and suitable for the planned changes. A Morris Machine, Type 12 CK pump was purchased because:

a. It could eventually be util-



PLAN VIEW
(with ladder in raised position)



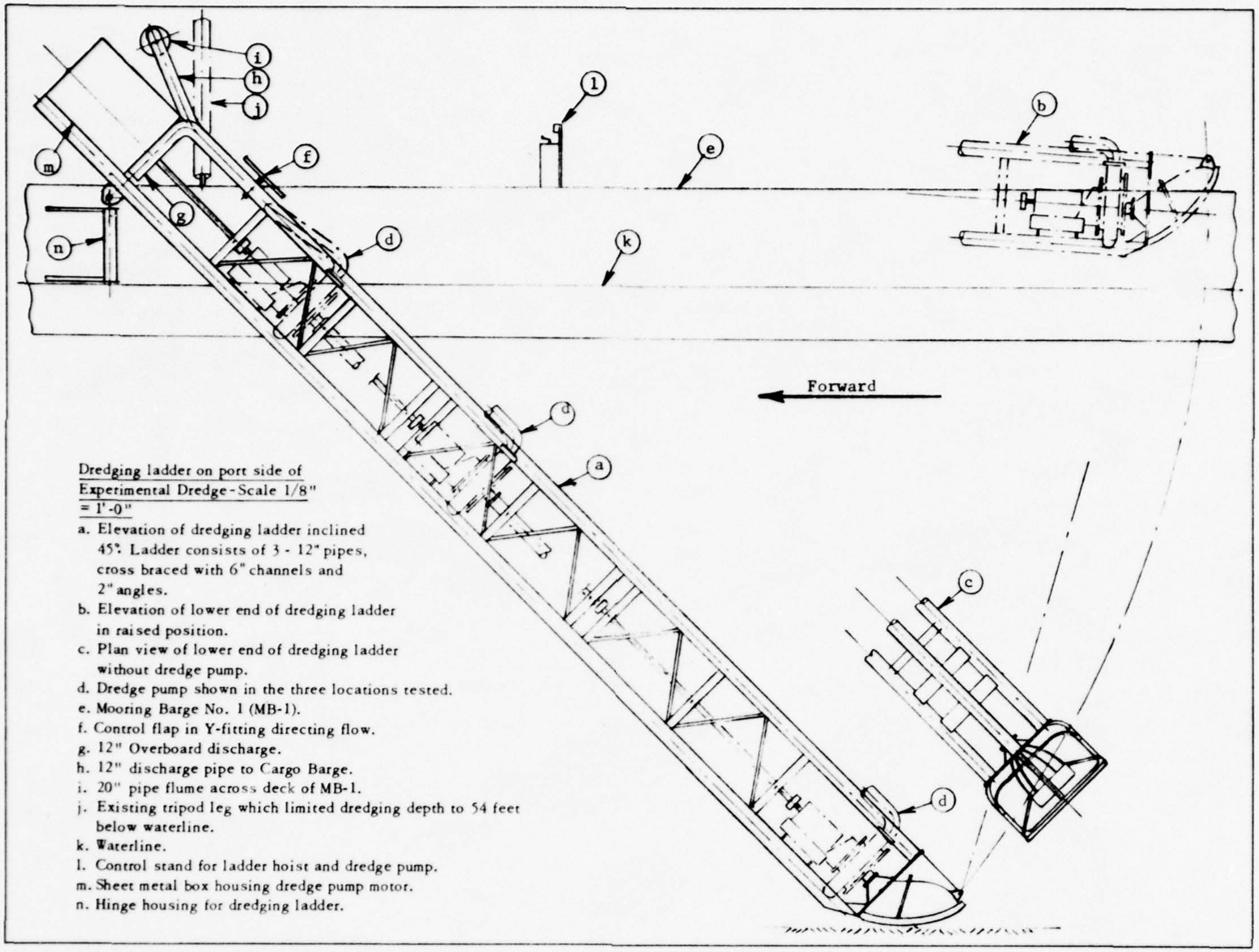
FRONT VIEW
(with ladder in lowered position)

General arrangement of Experimental Dredge

Only equipment required for experiment is shown.
Arrangement is not scale.

a. Mooring Barge No. 1 (MB-1), 250'x60'.
b. Cargo Barge No. 40, 90'x30'.
c. Tug SAN LUIS, 114'x25', 1200 HP.
d. 81' long, special dredging ladder, hinge connected to MB-1.
e. Special ladder hoist davit with drag tension indicator.
f. Existing winch and fairleader used for ladder hoist.
g. Existing winches used to hold and move Cargo Barge.
h. Used fairleaders installed here for experiment.
i. Control stand for ladder hoist and dredge pump.
j. New platform for existing echo depth finder.
k. Existing 20" pipe used as discharge flume to Cargo Barge.
l. Wood lined pushing fender (installed for experiment).
m. Existing deckhouse with 3-150 KW AC diesel generators.
n. Existing shed used to shelter dredge pump motor controls.
o. Existing shed used to shelter dredge pump motor resistors.
p. Existing tripod leg (interferes with 20" flume at 54' dredging depth).

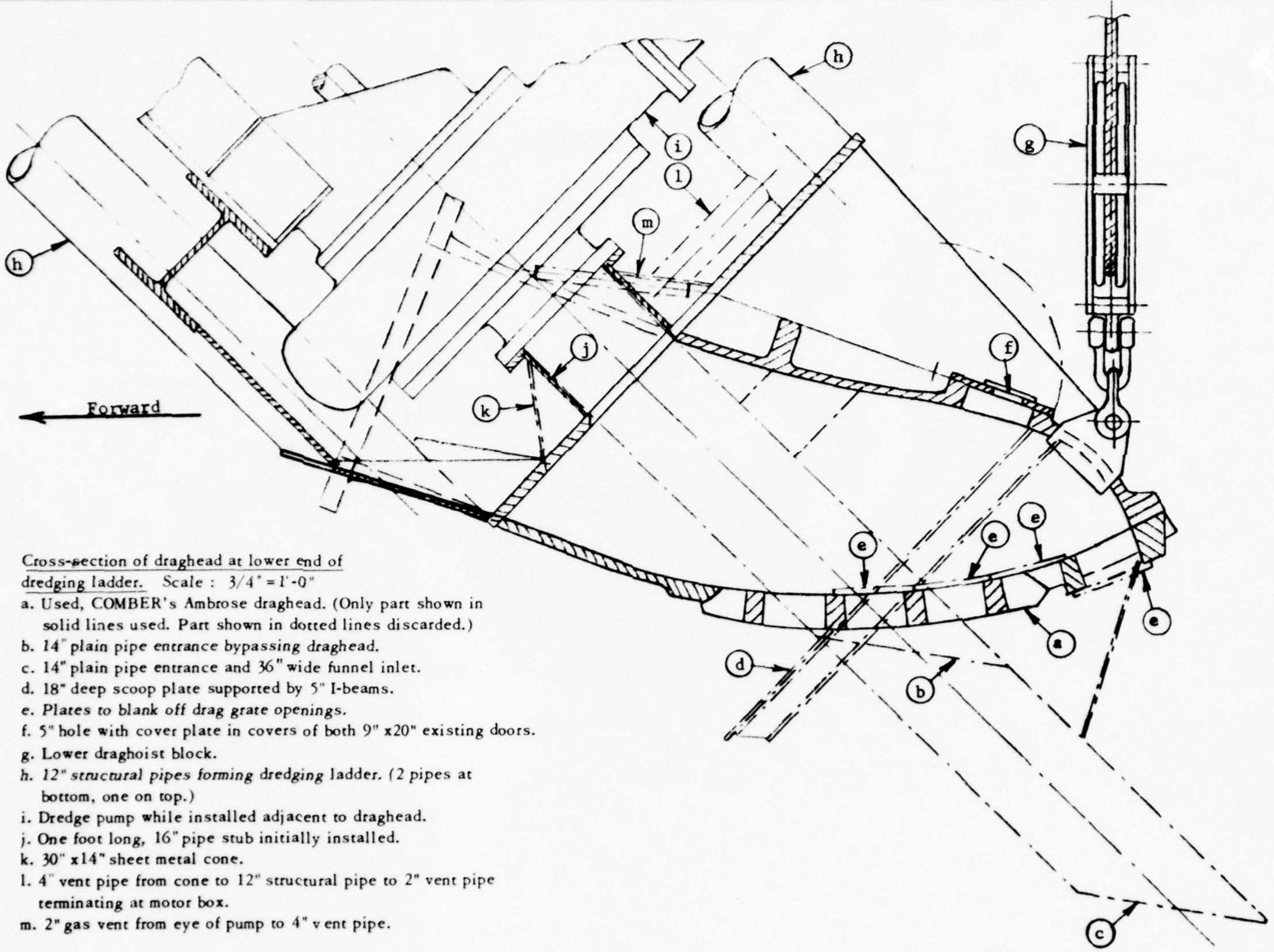
Figure 13



Dredging ladder on port side of Experimental Dredge-Scale 1/8" = 1'-0"

a. Elevation of dredging ladder inclined 45°. Ladder consists of 3 - 12" pipes, cross braced with 6" channels and 2" angles.
b. Elevation of lower end of dredging ladder in raised position.
c. Plan view of lower end of dredging ladder without dredge pump.
d. Dredge pump shown in the three locations tested.
e. Mooring Barge No. 1 (MB-1).
f. Control flap in Y-fitting directing flow.
g. 12" Overboard discharge.
h. 12" discharge pipe to Cargo Barge.
i. 20" pipe flume across deck of MB-1.
j. Existing tripod leg which limited dredging depth to 54 feet below waterline.
k. Waterline.
l. Control stand for ladder hoist and dredge pump.
m. Sheet metal box housing dredge pump motor.
n. Hinge housing for dredging ladder.

Figure 14



Cross-section of draghead at lower end of dredging ladder. Scale : 3/4" = 1'-0"

- a. Used, COMBER's Ambrose draghead. (Only part shown in solid lines used. Part shown in dotted lines discarded.)
- b. 14" plain pipe entrance bypassing draghead.
- c. 14" plain pipe entrance and 36" wide funnel inlet.
- d. 18" deep scoop plate supported by 5" I-beams.
- e. Plates to blank off drag grate openings.
- f. 5" hole with cover plate in covers of both 9" x20" existing doors.
- g. Lower draghoist block.
- h. 12" *structural pipes forming dredging* ladder. (2 pipes at bottom, one on top.)
- i. Dredge pump while installed adjacent to draghead.
- j. One foot long, 16" pipe stub initially installed.
- k. 30" x14" sheet metal cone.
- l. 4" vent pipe from cone to 12" structural pipe to 2" vent pipe terminating at motor box.
- m. 2" gas vent from eye of pump to 4" vent pipe.

Figure 15

ized as a replacement on the Dredge MERRITT should it become surplus.

b. Its power requirement matched the power output of the existing diesel generators.

c. Its size is only slightly smaller than that of projected conceptions.

A used pump motor and controls were purchased and overhauled. The motor matched the existing generator electrically (150 HP, 440 Volts, AC) and provided the design speed range for the dredge pump (350-450 rpm) but was of open construction. It was mounted on the forward end of the ladder and enclosed in a sheet metal box. A Y-connection with a control flap was installed near the motor box to direct the dredge spoil overboard or into the Cargo Barge. The ladder with hinge housing, draghead, and installed dredge pump and pump motor was procured by contract. After delivery, it was mounted on the MB-1 by Government force. All other work was also performed by Government labor.

The following modifications were made to the Cargo Barge 40 for the tests:

a. The fore and aft sides of the cargo box, which had been removed, were restored.

b. Three sluice gates were installed in both sides of the cargo box to permit draining and flushing of the dredged spoil.

c. A walkway was installed across the cargo box to facilitate effluent sampling and material volume measurements.

2. Instrumentation on Experimental Dredge:

The following lists the test data collected and the method and components employed to obtain them. It can be seen that major emphasis is placed on density.

a. Dredge Pump effluent density from displacement and volume: A small sea connection was installed in the bottom of the Cargo Barge near its center, and provided with a stop cock, a transparent vertical pipe and a scale to read the barge draft (See Figure 22, Bottom). An 18'' piece of 3'' pipe was installed vertically on three legs at the center of the cargo box to read the elevation of the "bin water", and the loaded cargo box. (See Figure 22, Top)

b. Dredge Pumps effluent density from sampling: An approximate one-pint metal container was hinge-connected to a 5' handle to permit sampling from the effluent discharge. (See Figure 23, Top Left) A sample was taken every 15 seconds. These were combined in a bucket and the average dredge pump effluent density was determined.

c. Dredge pump motor amperage: An amp. meter was installed at the control stand on deck of the MB-1. (See Figure 17, Bottom)

d. Dredge Pump motor voltage: The generator voltage was obtained from an existing gage at the diesel generator.

e. Dredge pump and motor speed: A mechanical tachometer was connected to the line shaft near the driving motor.

f. Discharge pressure: A 6" pressure gage was installed at the control stand and connected to the discharge elbow of the dredge pump (See Figure 17, Bottom). The tubing was purged with gas from an oxygen bottle.

g. Intake pressure: A mercury manometer was installed at the control stand and connected to the intake side of the dredge pump (See Figure 17, Bottom). The tubing was purged with oxygen.

h. Drag tension: The supporting beam for the upper drag hoist block was hinge connected to the davit and balanced against a spring. Its inboard end was extended by an indicator arm which moved over a tide gage board, thus displaying drag tension in terms of relative numbers. The indicator arm was later extended. (See Figure 17, Top)

i. Bottom sounder: An echo sounder was installed on a platform immediately ahead of the dredging ladder to determine the water depth.

j. Drag depth indicator: Boards were installed on one side of the cable leading to the drag hoist. They were painted white and provided with red stenciled depth figures. A white paint mark on the wire rope indicated the drag depth.

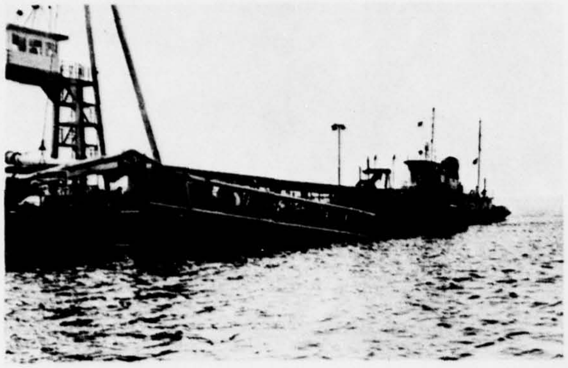
k. Dredging stations: The starting and stopping points of the test runs were determined by means of a sextant and sextant charts. These points coincided with the starting and ending of the material discharge into the cargo box.

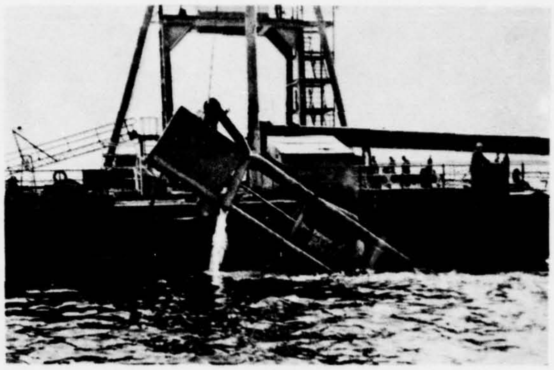
l. Pumping time: This time was determined with a stop watch. It started and stopped with the material discharge into the cargo box.

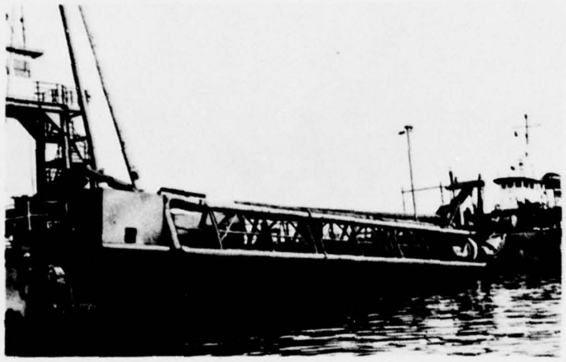
3. Operation of Experimental Dredge:

The Experimental Dredge was first used in October 1967. It was operated in three subsequent test periods: 20 Nov 67 to 4 Jan 68, 6 May 68 to 17 May 68, and 19 Aug 68 to 6 Sep 68.

A primary purpose of the testing was to determine the significance of the elements of the dredging process over which there is a control. This was done by altering only that variable which was being tested while other controllable variables remained constant. The variables tested were dredge pump location, suction pipe size, draghead bottom opening size, top inlet doors on dragheads, shape of pump inlet, dredging speed over bottom, dredge pump speed, gas removal system, force feeding draghead, draghead width, and

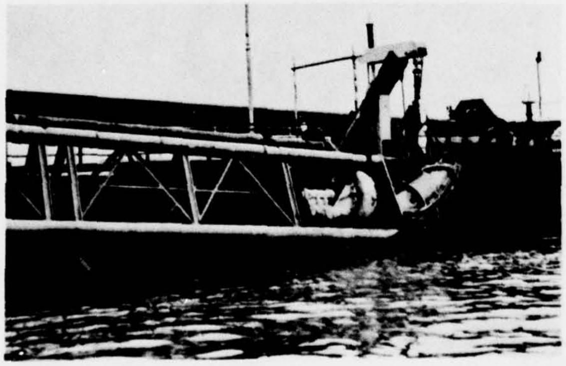


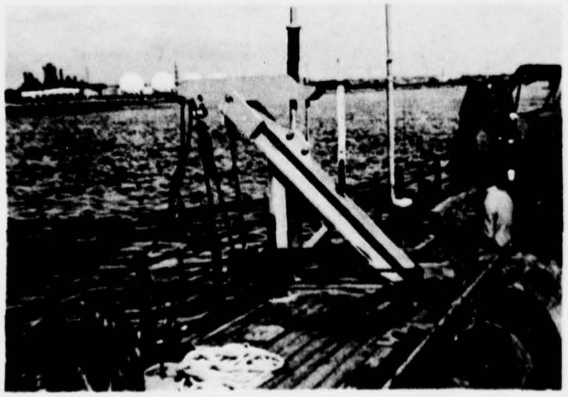


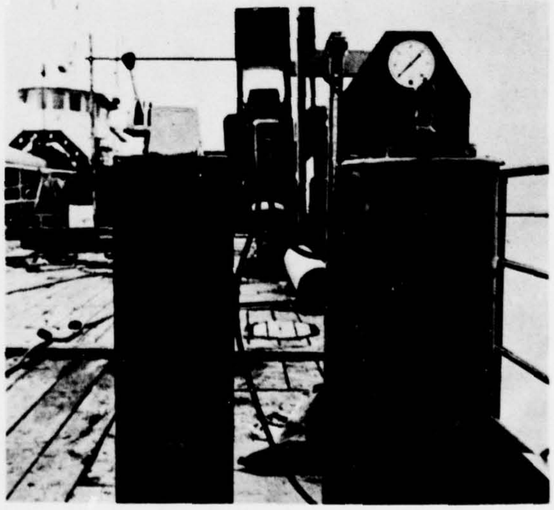


Three views of port side of barge showing dredging ladder. Note dredge pump installed alternately near the motor and the draghead. The tripod, raised control house and 30" discharge pipe are required for the barge's normal function and were not used in the experiment. Picture at top right shows dredging ladder partially lowered and pumping water through overboard discharge.

Figure 16





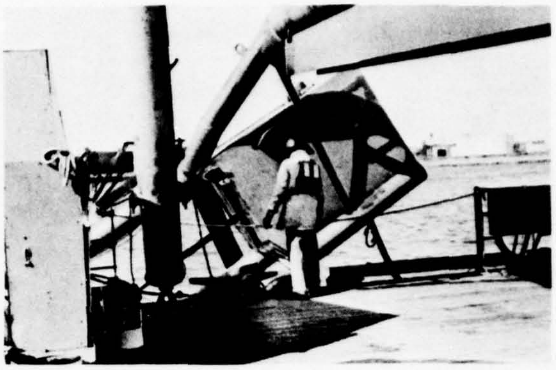


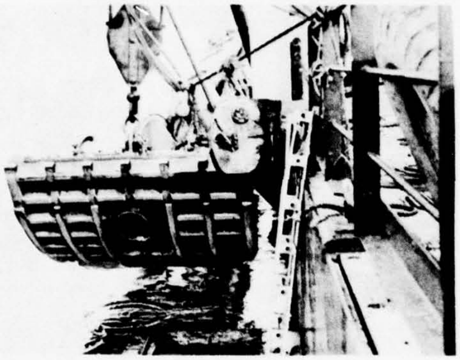
Top left - View of lower end of dredging ladder showing dredge pump, draghead, and forward side of dragarm hoist.

Bottom left - View of dragarm hoist support. Note hinged horizontal support beam on top with drag tension indicating rod. Length of indicating rod was later extended.

Top right - Forward view of control stand, consisting of dredge pump and dragarm hoist controls and some instrumentation.

Figure 17



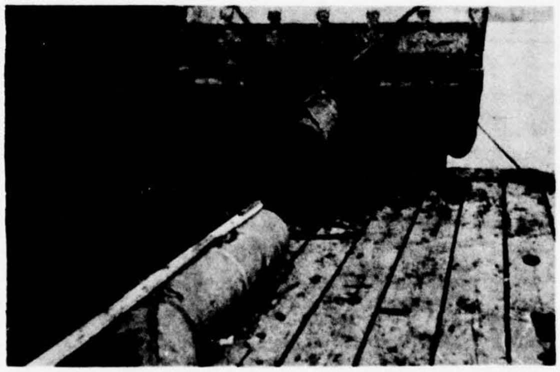


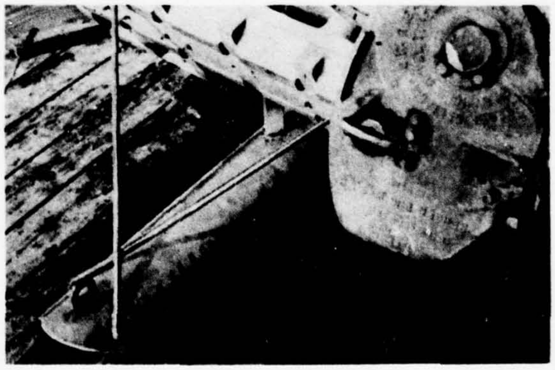
Top left - Aft view of partially lowered dredging ladder and control stand. Note: 1. Y-fitting with control flap to overboard (left) and cargo barge (right); 2. Rope hoists to actuate control flap lever; 3. Five gallon oil drum on top of motor box. 4. Connection between 12" discharge pipe and 20" flume.

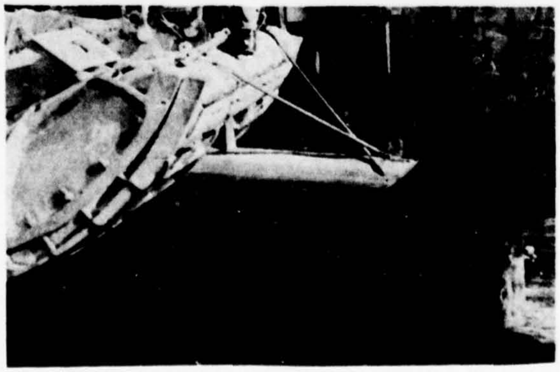
Top right - Inboard view of dredge pump motor box. Ladder swivel and hinge are below man and 20" discharge flume starts over man.

Bottom - Aft view of raised draghead with pipe installed to simulate performance without draghead. Forward pipe end connects directly to dredge pump.

Figure 18

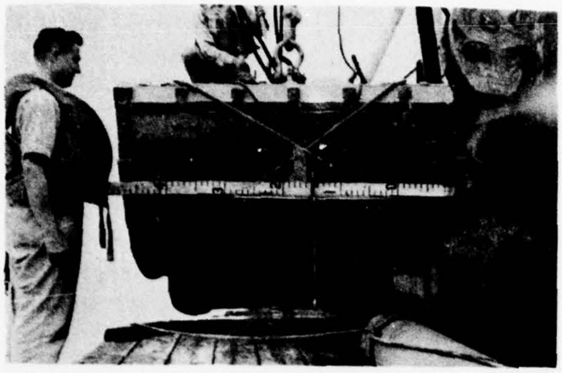


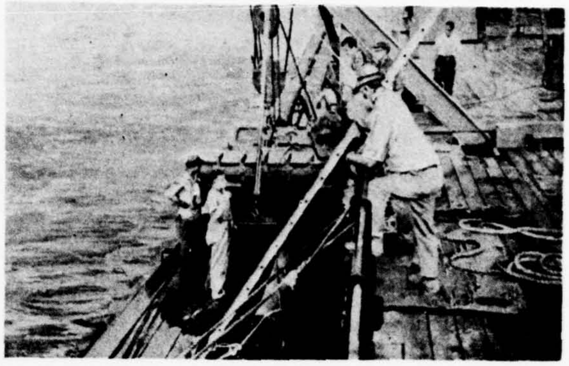


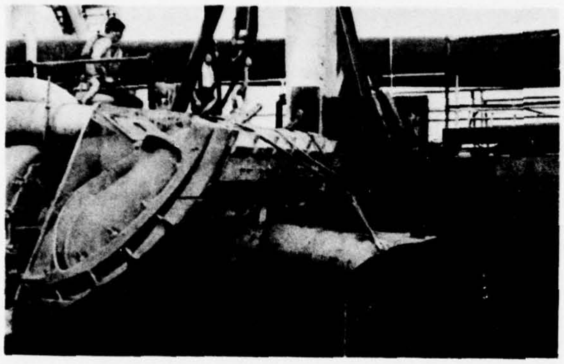


Three views of draghead with plain pipe installed. Pipe is similar to, but longer than pipe shown on bottom of Figure 18, to avoid possible effect of draghead while dredging. The purpose of this attachment was to evaluate the effect of draghead area and width.

Figure 19

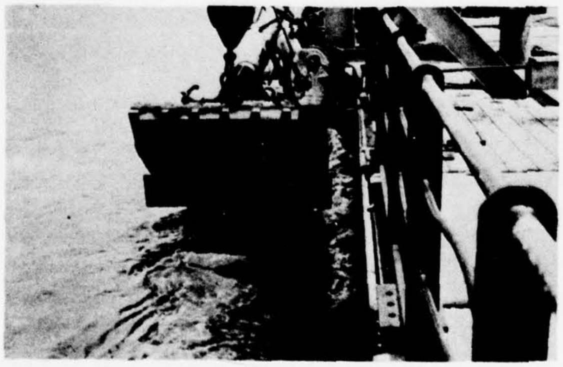


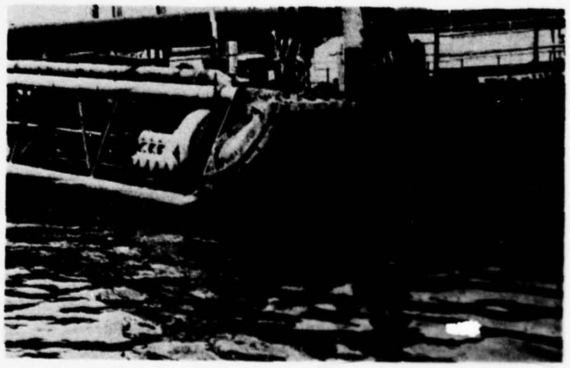


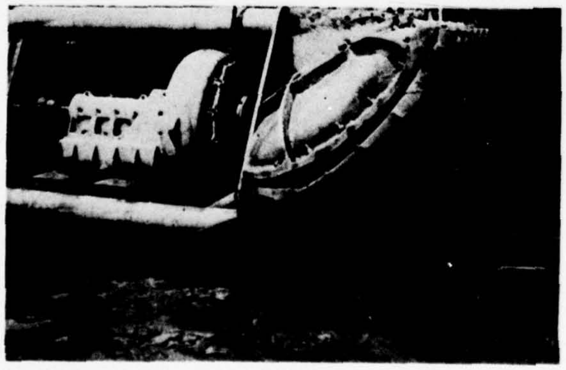


Three views of draghead with funnel inlet installed. This attachment has the same length as that shown in preceding inclosure. Its main purpose was to evaluate the effect of draghead width. Attachment connects directly to dredge pump.

Figure 20

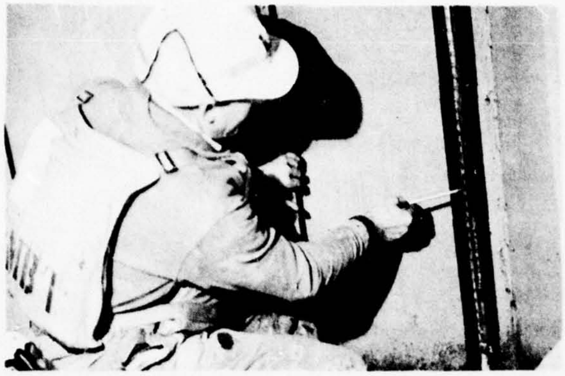


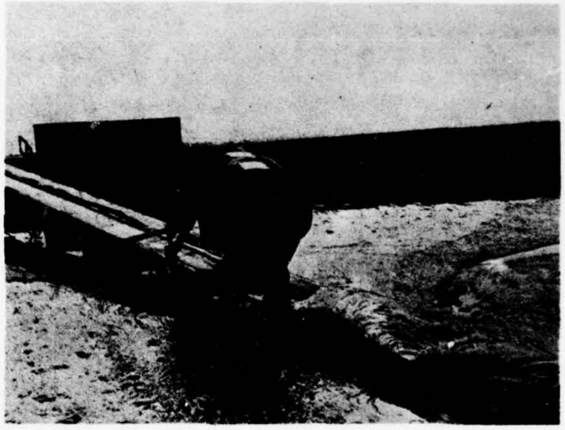




Three views of draghead with "scoop plate" installed. The three athwartship rows of grate openings aft of the scoop were blanked off. The purpose of this attachment was to evaluate the "front entrance principle."

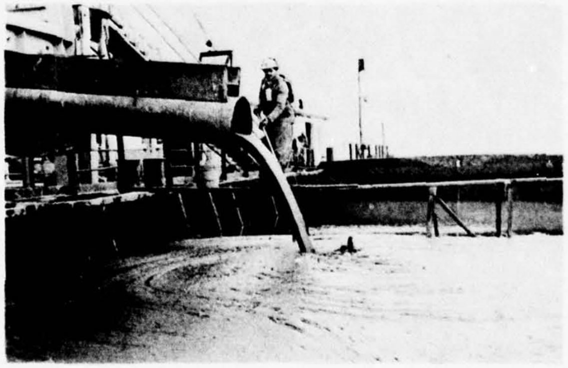
Figure 21

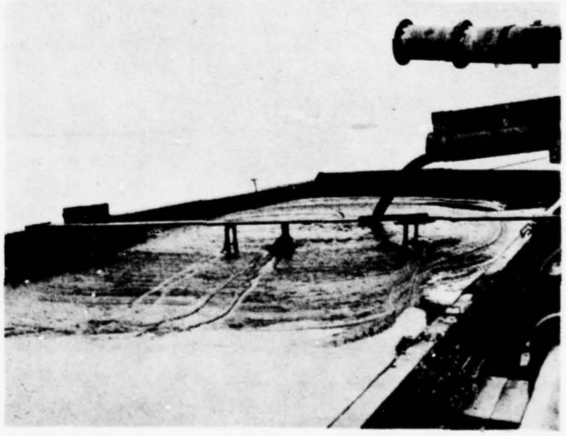


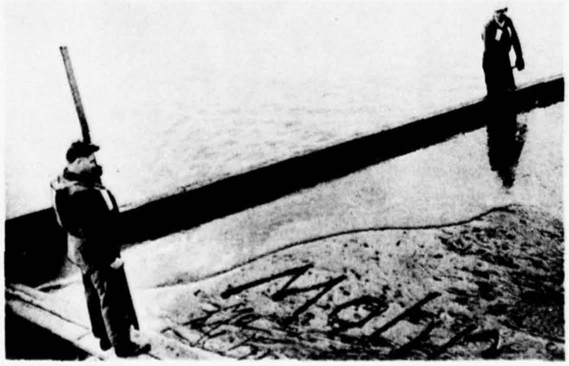


Top left - View of Cargo Barge center showing method of measuring the unfilled capacity prior to loading. Water seen is ¼" deep at center and 3½" deep at sides.
Bottom left - View of Cargo Barge center showing method of measuring the mud volume after loading. Note consistency of 1200 gr/l mud that fell on walkway while Cargo Barge was moved under discharge flume to equalize surface of load.
Top right - View of plastic tube connected to center of barge bottom to show light and loaded drafts.

Figure 22





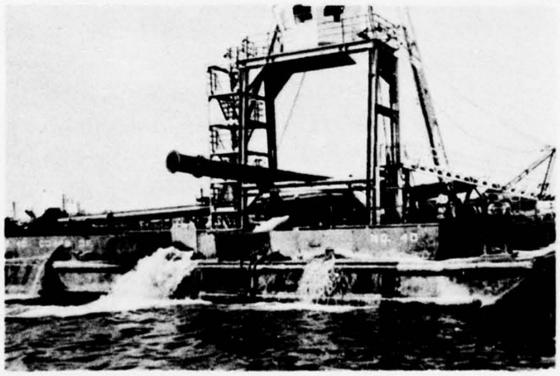


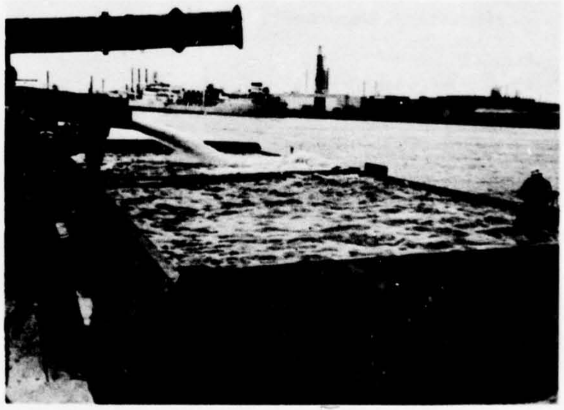
Three views of Cargo Barge being filled with mud of 1200 gr/l density while pump was near draghead. Note: 1. Person in picture obtaining material samples to determine density; 2. Laminar flow of discharge from 20" diameter flume; 3. Piling up of mud under discharge pipe; 4. Initial "bin water" near corners of cargo box; 5. Stiffness of mud.

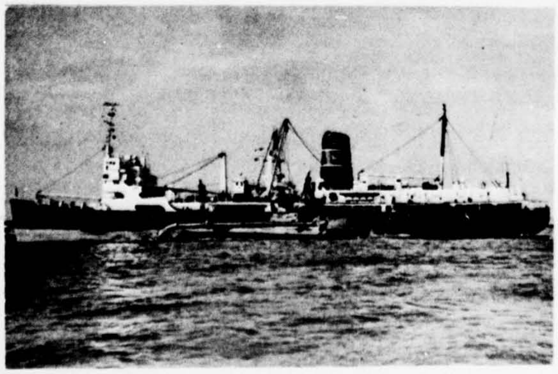
Figure 23

Three views of Cargo Barge after it was filled (without overflow) with spoil containing a high percentage of sand and the light mixture on top of the settled solids was drained off. Cargo Barge listed to starboard because sand predominantly deposited on this side. Note waterline on forward bulkhead and level of settled solids. Latter amount to approximately 40% of effluent pumped. Settled solids could be walked on immediately.

Figure 24







Top left - View of starboard side showing Cargo Barge being emptied of material by pumping water on top and hoisting it fore and aft.

Top right - View of Cargo Barge from Mooring Barge. Cargo Barge is being filled with water to determine flow rate and velocity during water tests.

Bottom - View of 3,710 cubic yard Hopper Dredge COMBER.

Figure 25

pump impeller size. The primary measure of effectiveness of each change was the density pumped.

A water pumping test was performed immediately after each test change to verify the stability of the test equipment. A 200-hour water pumping test was also performed to ascertain the practicability of the test equipment.

It customarily required a day to ascertain the effects of a variable. A typical test day started by discussing the contemplated tests with the tug captain. The equipment was lubricated while in transit from the anchorage to the test area. There, a series of approximately seven test runs was performed. Most tests were made at various speeds over the bottom because of the significance of speed. On the return journey to the anchorage, plans and preparations were made for the next day.

A typical test run consisted of the following tasks in chronological order:

a. Readying the equipment for the test, including closing the sluice gates in the sides of the cargo box and pumping some water into it; then draining the water off to 36'' below the overflow which was the datum elevation. The remaining water in the cargo box eliminated the effects of the deck camber and small amounts of material left from the previous load.

b. Slowing down to read the light draft of the Cargo Barge, adjusting the control flap to discharge overboard, starting the dredge pump and commencing the lowering of the dredging ladder.

c. Resuming the desired dredging speed, obtaining bottom echo soundings at 30-second intervals, lowering the draghead to the bottom and dredging overboard until conditions were stabilized.

d. Stopping the dredge pump momentarily to adjust the control flap to discharge spoil across the deck of the MB-1 into the Cargo Barge, obtaining two sextant readings to determine the starting point of the test run, and starting a stop watch to determine the pumping time.

e. Dredging material into the cargo box until near overflow. Overflow was normally reached between four and sixteen minutes. During dredging, the drag tender observed the material discharge and the instruments and controlled the drag hoist. The recorder, observed the instruments and recorded their readings on a data sheet identical to Figure 26. The lines of the dredge pump intake and discharge instrumentation were purged with oxygen prior to each reading. An effort was made to read these data and the echo and mechanical depth soundings at the same time. The material sampler collected

TEST DATA OBTAINED WITH EXPERIMENTAL DREDGE ON 22 Aug.

Parameter to be tested: Draghead Width (Funnel installed)

Test conditions: Same as day before except for drag pipe inlet.

	Cherry Island Range			Christina River		Cherry Island Range	
Test number							
Recorder Dragtender	Mac Connel Beck	—— ——	—— ——	—— ——	—— ——	—— ——	→ →
Dredging stations Distance	170+440 171+280 = 840	170+960 172+340 = 1380	171+100 173+360 = 2260	5+220 2+870 = 2350	1+500 2+900 = 1400	171+390 74+500 = 3110	170+200 172+700 = 2500
Tide direction (Ebb, Flood, Slack)	FLOOD	FLOOD	FLOOD	SLACK	SLACK	SLACK	EBB
Pumping time (min)	4.35 0.0	4.32 0.0	6.56 0.0	9.50 2.25	8.0 0.0 Time choked	15.10	4.40
Ground speed (ft/sec)	3.05	5.08	5.44	3.98	2.91	3.42	8.92
Water depth from echo sounder (ft)	48 47	48 48	48 48 48 49	39 39 37 38	46 45 41 43	48 47 47 50	47 47
Drag depth from mech. indicator (ft)	48.5 49	49 49	51 51 51 51	45 38 38 39	48 46 42 44	49 50 48 51 52 52 52 52	48 48½
Drag tension from mech. indicator (ft)	7.4 7.5	7.7	7.6 6.5 65 6.5	6.5 7.5 7.5 7.6	7.5 7.5 7.5 7.5	7.4 7.3 7.3 7.4	6.9 6.5
Pressure (lbs) Outlet Pressure (Hg) Inlet	41 41 27.5 24½	38 28	35 35 44 28 30 28	23 25 25 26 19 14.5 24.5 26	39 27 32 30 26 29½ 24 23	35 35 32 21.5 33½ 34.5	40 39 28 26
Current (Amp)	225 210	225	175 150 210	160 210 175 140	160 125 225	150 140 200 120	210 225
Voltage (volt)	450						
Pump speed (rpm)	400 400	410 405	415 420 410	400 425 440 415	425 430 410	425 430 425 425	110 410
Cargo barge draft light (")	22 7/8	22 5/8	22 1/2	22 3/4	22 3/4	22 1/2	22 3/4
Cargo barge draft loaded (")	46 3/4	44 3/4	47	46 1/4	45	46 3/4	44 1/4
Cargo barge weight loaded (LT)	247.1	236.1	248.5	244.4	237.5	247.1	233.4
Cargo barge weight light (LT)	111.0	109.7	109.0	110.3	110.3	109.0	110.3
Weight dredged (LT)	136.1	126.4	139.5	134.1	127.2	138.1	123.1
Depth of load = 36" - measurement (")	36 - 8 1/8 = 27 7/8	36 - 9 7/8 = 26 1/8	36 - 7 5/8 = 28 3/8	36 - 5 3/8 = 30 5/8	36 - 6 1/8 = 29 7/8	36 - 7 3/4 = 28 1/4	36 - 10 5/8 = 25 3/8
Volume of load (cy)	150.5	141.1	153.3	165.4	161.4	152.6	137.1
Pressure at bin bottom (water)	Not used, because the densities (in last row) determined from these measurements were consistently too light.						
Effluent density from displacement (gr/lt)	1205	1190	1210	1080	1050. ?	1204	1195
Effluent density from sampling (gr/lt)	1176	1187	1200	1070	1104	1220	1194
Effluent density from hydrost. head (gr/lt)							

Figure 26

discharge samples at 15-second intervals during this same period. They were combined in a bucket.

f. Stopping the dredge pump and the stop watch when the material level in the cargo box came near the top of the box and obtaining two sextant readings to determine the finishing point of the test run.

g. Raising the dragarm and slowing the tug to read the loaded draft of the Cargo Barge and the elevation of the material level in the cargo box.

h. Emptying the cargo box by opening the three sluice gates in each side of it and pumping water on top of the material. During this time the column representing this test run on the data sheet for this day was completed. That is, the densities were determined by weighing the samples and from load computations and were entered together with the computed ground speed. Figure 27 was prepared to aid in the density determination based on the displacement method. Also all observations and thoughts that occurred during the test run were marked on the back of the data sheet.

The first and second set of tests were performed essentially at Marcus Hook because:

a. The material in this range is most representative of the dredging in the Delaware River.

b. Almost one-half of the dredging which is done in the Delaware River is performed in this vicinity.

c. This range had not been dredged for several months and, therefore, had a shoal several feet thick.

d. The Hopper Dredge COMBER was scheduled to dredge at Marcus Hook, so a ready comparison between test dredging and production dredging could be made.

The third set of tests was started at Marcus Hook. It was not possible to reach the bottom at all times, since the COMBER had previously removed the shoal material within reach of the Experimental Dredge. For this reason, and to determine the effect of changes in bottom materials, test dredging was conducted in Wilmington Harbor, Cherry Island and Tinicum Ranges in the Delaware River and in the Schuylkill River. Subsequently, the COMBER dredged two and three test loads in these areas to obtain a ready comparison.

4. Performance of Experimental Dredge:

The following lists some of the observations made in regard to the test equipment.

a. It would have been desirable to have a longer dredging ladder. It frequently was not possible to dredge the channel bottom effectively near

Conversion Table for Density Determination on Cargo Barge - Experimental Dredge

This table is an expansion of the displacement curve shown on Drg 106-C-20624. It was checked by pumping water into the cargo box and found correct between 1c.y. and 3c.y. in three water pumping tests

A. W. Mohr

Light Draft Reading Versus Load

20	"	95.7 L.T.
	1/8	96.3
	1/4	97.0
	3/8	97.7
	1/2	98.3
	5/8	99.0
	3/4	99.7
	7/8	100.3
21		101.0
	1/8	101.7
	1/4	102.3
	3/8	103.0
	1/2	103.7
	5/8	104.3
	3/4	105.0
	7/8	105.7
22		106.3
	1/8	107.0
	1/4	107.7
	3/8	108.3
	1/2	109.0
	5/8	109.7
	3/4	110.3
	7/8	111.0
23		111.7
	1/8	112.3
	1/4	113.0
	3/8	113.7
	1/2	114.3
	5/8	115.0
	3/4	116.7

Loaded Draft Reading versus Load

45		237.5 L.T.
	1/8	238.2
	1/4	238.9
	3/8	239.6
	1/2	240.3
	5/8	240.9
	3/4	241.6
	7/8	242.3
46		243.0
	1/8	243.7
	1/4	244.4
	3/8	245.1
	1/2	245.8
	5/8	246.4
	3/4	247.1
	7/8	247.8
47	"	248.5 L.T.
	1/8	249.2
	1/4	249.9
	3/8	250.6
	1/2	251.3
	5/8	251.9
	3/4	252.6
	7/8	253.3
48		254.0
	1/8	254.7
	1/4	255.4
	3/8	256.0
	1/2	256.8
	5/8	257.4
	3/4	258.1
	7/8	258.8
49		259.5
	1/8	260.2
	1/4	260.9
	3/8	261.6
	1/2	262.3
	5/8	262.9
	3/4	263.6
	7/8	264.3
50		265.0
	1/8	265.7
	1/4	266.4
	3/8	267.0
	1/2	267.8
	5/8	268.4
	3/4	269.1
	7/8	269.8
51		270.5
	1/8	271.2
	1/4	271.9
	3/8	272.6
	1/2	273.3
	5/8	273.9
	3/4	274.6
	7/8	275.3
52		276.0
	1/8	276.7
	1/4	277.4
	3/8	278.1
	1/2	278.8
	5/8	279.4
	3/4	280.1
	7/8	280.8
53		281.5

Hopper Fill Height Versus Volume

28	"	151.2
	1/8	151.9
	1/4	152.6
	3/8	153.3
	1/2	153.9
	5/8	154.6
	3/4	155.3
	7/8	156.0
29		156.6
	1/8	157.3
	1/4	158.0
	3/8	158.7
	1/2	159.3
	5/8	160.0
	3/4	160.7
	7/8	161.4
30		162.0
	1/8	162.7
	1/4	163.4
	3/8	164.1
	1/2	164.7
	5/8	165.4
	3/4	166.1
	7/8	166.8
31		167.4
	1/8	168.1
	1/4	168.8
	3/8	169.5
	1/2	170.1
	5/8	170.8
	3/4	171.5
	7/8	172.2
32		172.8
	1/8	173.5
	1/4	174.2
	3/8	174.9
	1/2	175.5
	5/8	176.2
	3/4	176.9
	7/8	177.6
33		178.2
	1/8	178.9
	1/4	179.6
	3/8	180.3
	1/2	180.9
	5/8	181.6
	3/4	182.3
	7/8	183.0
34		183.6

Figure 27

high tide. The existing ladder reaches to 44'-2" below the waterline (with Ambrose draghead) when inclined to 45°. The absolute maximum depth was 54 feet below the waterline, because then the 20" flume across the deck of the MB-1 came in contact with the port tripod leg. (See Figure 18, Top)

b. The control flap in the 12" Y-fitting near the motor box leaked material through the overboard discharge line when it was adjusted to discharge into the Cargo Barge. This fitting could have been avoided and all spoil discharged through the 20" flume. The discharge into the Cargo Barge could still have been selective by moving this barge with the winches under the end of the discharge flume when desired. Fore and aft movement of this barge was standard procedure during washout.

c. When the dredge pump was choked and no discharge into the Cargo Barge occurred the overboard discharge kept leaking. This implies that a lower static discharge lift would have maintained the flow and thus given better results. There was six feet vertical distance between the overboard and the barge discharge (See Figure 18, Top left). However, an improvement achieved in this manner may have been misleading since the 16 feet vertical discharge height above the waterline might also be required on a prototype dredge.

d. When a choked condition occurred, the following three steps were taken to relieve it. First the draghead was raised about one foot. If this did not restore flow, the draghead was raised about four feet to have it surrounded by water. The last alternative was to stop the dredge pump to permit the mud column in the discharge pipe to flow backwards and thereby clear the system.

e. The "sampling-weighing" and "displacement-computation" methods were in reasonable agreement when the surface of the loaded spoil was level. In 1200 G/L mud this was often not the case, causing the "displacement-computation" method to read too light. Attempts to determine the unfilled capacity from the barge corners were only partially successful.

f. The performance of the Experimental Dredge is considered so successful that it was decided to retain all components for possible future testing. That is, it will only be dismantled as far as necessary to allow the various com-

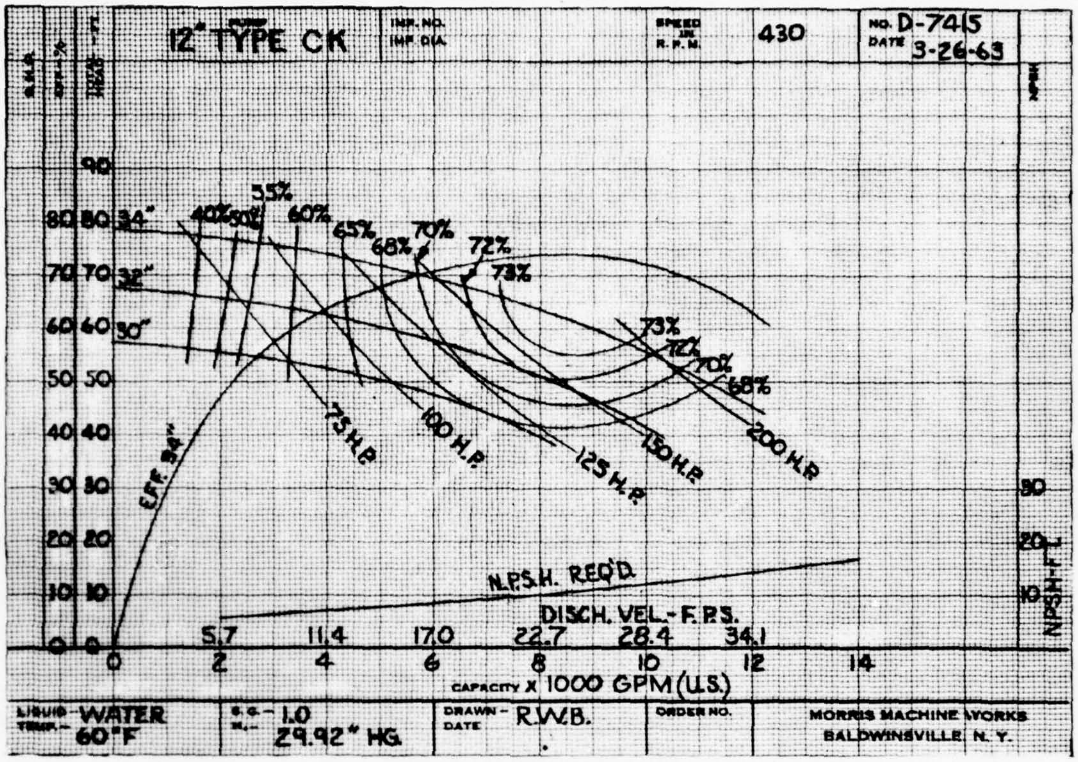
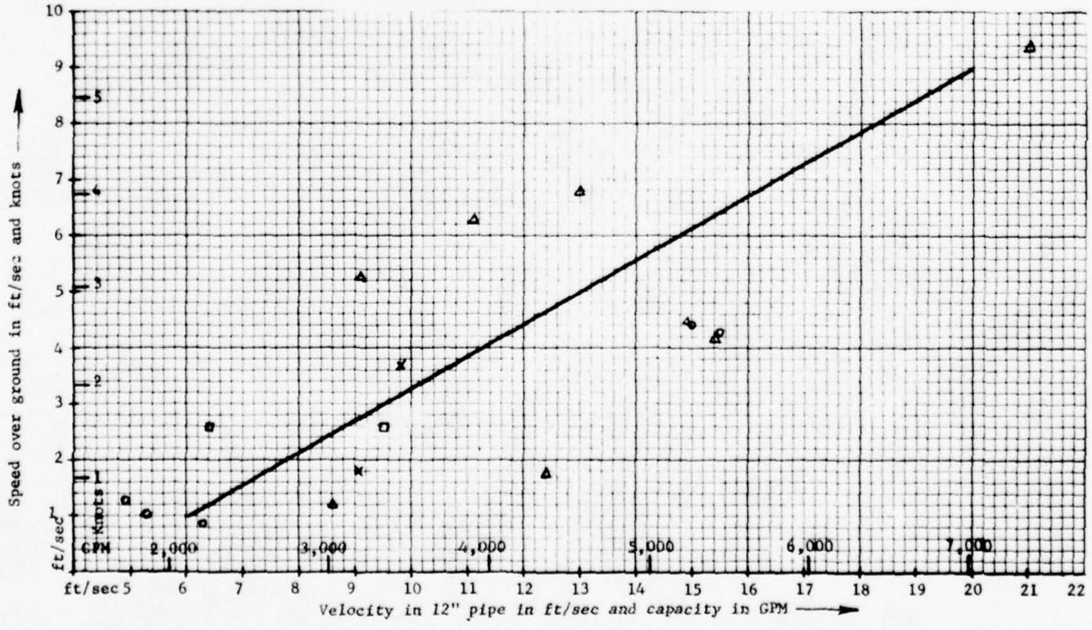


Fig. 28. Dredge pump performance curve while handling water.



Points shown thus ▢ are from data sheet of 8 May (west side of Marcus Hook Range)
Points shown thus ○ are from data sheet of 9 May (west side of Marcus Hook Range)
Points shown thus x are from data sheet of 16 May(west side of Marcus Hook Range)
Points shown thus △ are from data sheet of 21 Aug(west side of Cherry Isl. Range)
All data taken under identical conditions.

Fig. 29. Graph showing speed over bottom versus effluent velocity.

ponents to perform their normal functions. By far the largest single item is the dredging ladder, which will be permanently stowed in its raised position on the MB-1.

III. WATER PUMPING TESTS

These tests were performed to document the hydraulic characteristics of the components and to establish the sufficiency of the type and lubrication method of the dredge pump and line shaft bearings selected. All water tests listed were run with the Ambrose draghead, the 34" impeller running at 375 rpm, and the Experimental Dredge secured to the dock unless otherwise stated.

1. Hydraulic Characteristics: (Pump immersed up to discharge flange)

Pump near motor, 14" suction pipe, pumping into cargo box

9.5" Hg vacuum - 205 amps - 11/13/67

Pump near center, 12" suction pipe, pumping into cargo box

9.3" Hg vacuum - 202 amps - 11/21/67

Pump near center, 14" suction pipe, pumping into cargo box

7.5" Hg vacuum - 205 amps - 11/20/67

Pump near center, 16" suction pipe, pumping into cargo box

4.5" Hg vacuum - 210 amps - 11/27/67

Pump near center, 12" suction pipe, pumping overboard

12.0" Hg vacuum - 215 amps - 11/21/67

Pump near center, 16" suction pipe, pumping overboard

7.0" Hg vacuum - 218 amps - 11/27/67

Pump near draghead, 16" suction pipe fully open, pumping overboard

4.0" Hg vacuum - 218 amps - 12/4/67 *

Pump near draghead, 16" suction pipe 3/4 open, pumping overboard

8.0" Hg vacuum - 216 amps - 12/4/67 *

Pump near draghead, 16'' suction pipe 1/2 open, pumping overboard

16.0'' Hg vacuum - 207 amps - 12/4/67 *

Pump near draghead, 16'' suction pipe 1/3 open, pumping overboard

24.0'' Hg vacuum - 185 amps - 12/4/67 *

(* This 16'' pipe was one foot long and extended from end of draghead to 14'' pump flange. Its draghead end was partially blanked to achieve a partially open pipe. This pipe stub was replaced by a 30'' to 14'' cone at the end of December 1967)

Pump near draghead, 14'' suction pipe 7' long with funnel end installed at pump flange, pumping into cargo box

4.5'' Hg vacuum - 200 amps - 15.0 psi discharge pressure - 18 c.ft/sec flow rate - Experimental Dredge in transit - 8/22/68

Same as previous entry, except 32'' impeller

4.4'' Hg vacuum - 180 amps - 13.5 psi discharge pressure - 16 c.ft/sec flow rate - Experimental Dredge in transit - 9/3/68

(Vacuum changed to 3.7'' Hg when Experimental dredge was stopped in water)

2. Bearing performance: (Pump immersed 28 feet)

The dredge pump shaft is in a horizontal plane in the usual installation. It is supported in the bearing housing by two radial and one thrust bearing, which are designed to dip into a shallow oil sump while operating. The dredge pump and the bearings are inclined up to 50° and are under water in this installation. In view of this the bearing housing was filled completely with oil under a hydrostatic head higher than the outside water pressure. This was accomplished by mounting a five-gallon oil drum on top of the motor box and connecting it to the pump bearing with a 3/8'' tubing. The shaft seals consisted of pairs of rubber closures, mounted back to back to seal against leakage from the inside and the outside. The space between the two seals was filled with grease.

The dredge pump stuffing box was filled with a spring loaded grease cup in lieu of the conventional water purge to simplify the installation.

Babbitted pillow blocks were chosen for the line shaft bearings. They were provided with individual 3/8'' tubings leading to a central lubricating station at the motor box. A steel thrust collar was installed adjacent to and on the upper side of the uppermost pillow block to carry the thrust component of the shaft weight when the ladder is in the lowered position.

By May of 1968 it had been ascertained that the foregoing features were satisfactory on the test installation. However, the approximate 70 hours total running time up to this time had consisted of short dredging and washout cycles. It was therefore decided to perform a 200-hour water pumping test, consisting of essentially 8-hour running periods, to evaluate the practicability of these features for a production installation. This water pumping test was performed during May, June and July 1968. The dredge pump was adjusted to absorb 200 amps at 450 volts, which resulted in 375 to 380 rpm.

The bearings were checked for overheating during the test. It was found that the dredge pump bearing housing (in the water) did not become more than hand-warm. The level in the 5-gallon expansion tank indicated that the oil in the bearing housing did not foam and that the seals were tight. The oil in the housing remained clean. The dredge pump stuffing box and line shaft bearings also did not overheat, even when lubricated only once a day. The uppermost and lowermost line shaft bearings were removed and inspected for wear after 100 and 200 hours of pumping water with the following results. The diameters of the new shaft (without paint) and bearings were 3.434" O.D. and 3.445" I.D. respectively.

	After 100 hrs. Pumping Time	After 200 hrs. Pumping Time
Diameter of shaft in way of bearings	3.432"	3.432"
Diameter of uppermost bearing (out of water)	3.445" to 3.448"	3.445" to 3.460"
Diameter of lowermost bearing (in water)	3.447" to 3.453"	3.447" to 3.460"

The lubricating arrangement for the dredge pump bearing is the first such installation to our knowledge. It performed satisfactorily during the test and is also believed satisfactory, for a permanent installation.

The babbitted pillow blocks used as line shaft and thrust bearings have proven satisfactory for the test. They are also believed satisfactory for a permanent installation, provided they are automatically and continually greased.

IV. DREDGING TESTS

The following outlines: The type of tests made in essentially chronological order. - The structural modifications required and the mode of operations to perform these tests. - The immediate test results.

1. Effect of Dredge Pump Elevation:

For these tests, the dredge pump was installed in three locations on the dredging ladder where shown on Figure 2. All tests were made at Marcus Hook Range, dredging against the current with steady propulsion power, with the pump controller set at the same medium speed setting and without a gas removal system.

These are the more important test data:

Dredge pump located near -	Units	Motor	Center	Draghead
Av. dredge pump effluent density	(gr/l)	1115	1130	1190
Av. dredge pump effluent velocity in 12" pipe	(ft/sec)	15	13	8
Av. 1270 gr/l in situ flow rate	(ft/sec)	5.0	4.9	4.4
Av. speed over bottom	(ft/sec)	2.2	2.3	2.3
Av. pressure at pump inlet	("Hg)	10 vac.	Atmospheric	32 press.
Av. pressure at pump outlet	(psi)	?	?	35
Av. motor current	(amps)	185	185	175
Av. pump speed	(rpm)	375	385	400
Tendency for pump to choke		Frequently	Infrequently	none
Date of test		11/13/67	11/20/67	12/6/67

These observations were made:

a. When the pump was mounted near the motor and the center, there was either a high flow rate or a choked pump. When the pump was mounted near the draghead, the density and flow rate were rather easily controlled by the degree of immersion of the draghead into the bottom. However, the high flow densities were only achieved with low flow rates.

b. The material was appreciably denser with the pump near the draghead.

c. The dragtender could control the dredging process better when the pump was near the draghead.

2. Effect of suction pipe size:

These tests were made while the dredge pump was installed near the center of the ladder. 12", 14" and 16" suction lines were separately installed between the draghead and the 14" pump suction flange. All tests were performed under the same conditions outlined in the previous test.

The results for the 14'' line are shown in the center column of the table in the foregoing test. The test results with the 12'' and 16'' lines were so close that they are not separately listed.

This test demonstrated that a near 100% change in the suction pipe area in this installation had no measureable effect on the dredge pump effluent density and flow rate while dredging mud.

3. Effect of draghead bottom opening size:

These tests were made while the dredge pump was installed near the center of the ladder and near the draghead. The size of the bottom opening was changed by blanking off up to five of the six athwartship rows of grate openings. That is, the draghead width always remained the same while its length was altered. All other test conditions were identical to those outlined for the first set of tests.

Test data collected for the fully open draghead at the two pump locations tested are listed in the second and third column of the table shown in Para. IV, 1. The test results with the partially open grate areas were the same. In view of this, a plain pipe entrance was tested. This was accomplished by extending an approximate 7-foot long 14'' pipe from the pump flange aft, thus by-passing the draghead (See Figure 6, Bottom). Results were again the same; however, somewhat more frequent draghoist adjustments were required.

This test demonstrated that changes in draghead bottom openings in this installation have little effect while dredging mud.

4. Effect of water inlet doors:

The value of water inlet openings was tested while the dredge pump was installed near the center of the ladder. Hopper dredges customarily operate with some openings on top of their dragheads open. Since the existing two 9''x20'' openings in the Ambrose draghead were considered too large for the test installation, a 5'' diameter hole was burned in the door of each opening (See Figure 3). All test conditions were the same as those outlined for the first set of tests.

Opening or closing these holes did not make a measurable difference in the dredge pump effluent density and other data collected. For this reason, these openings were kept closed for all subsequent tests.

Water inlet doors have little justification in theory, since they oppose attempts to seal the dragheads against the entry of diluting water. In practice, they ''steady'' the dredging process by reducing the tendency to choke at the expense of a somewhat more diluted load.

This test demonstrated that water inlet openings on drags had no appreciable affect on production in this installation when working in mud.

5. Effect of shape of pump inlet:

Figure 3 shows the burned off forward part of the Ambrose draghead, which had been replaced by a plate. The dredge pump intake pipe led from this plate to the pump. Since this pipe inlet was hydraulically poor, it was decided to alter it while the pump was near the draghead and determine the effect of these alterations. This was accomplished by substituting the initial one foot long 16" pipe with a 30"x14" cone and then installing two-foot and one-foot long 14" pipe sections in the cone. (See Figure 3) All test conditions were the same as those outlined for the first set of tests.

Neither of these alterations caused a measurable change in performance. The cone entrance was used for all subsequent tests except as noted.

Obviously, the cone inlet was hydraulically better than the other inlet connections. The fact that this inlet did not result in a higher dredge pump effluent density or flow rate indicates that it was not a controlling factor for this assemblage in mud.

6. Effect of speed over bottom:

No changes to the equipment were required for this test. Speed change was obtained by changing the power output of the tug and by utilizing the river current. In this manner average speeds over the bottom from about 1 to 10 ft/sec were achieved. This range covers most practical dredging applications. During the slowest speeds the dredging assembly moved against the current with just enough propulsion power to retain steerage. The highest speeds were attained by moving with the current at full propulsion power. Tests were conducted at Marcus Hook Range on 9 and 16 May 1968 and Cherry Island Range on 21 August 1968, with the pump controller set for full speed and without a gas removal system.

These are the more important test data:

Speed over bottom	(ft/sec)	1	5	9
Av. Dredge pump effluent density	(gr/l)	1190	1200	1200
Av. Dredge pump effluent velocity in 12' pipe	(ft/sec)	6	13	20
Av. 1270 gr/l in situ flow rate	(ft/sec)	3.3	7.6	11.6
Av. Pressure at pump inlet	("Hg)	35	33	30
Av. Pressure at pump outlet	(psi)	35	40	40
Av. Motor current	(amps)	180	200	220
Av. Pump speed	(rpm)	410	410	410

Observing these tests indicates that:

a. Dredge pump effluent flow rates are approximately linearly related to the speed over the bottom. This is shown on Figure 17.

b. Increases in flow rate achieved in this manner are significant.

They do not reduce the flow density; in fact, the density tends to increase with higher speed over the bottom. Because of this finding, all subsequent tests were performed at high and low speeds over the bottom.

c. The pressures, amps, and rpms listed above were difficult to ascertain because the relatively small differences between them were often outweighed by the data scatter.

d. Laminar flow prevailed from the discharge flume even at the highest flow rate as long as the density remained near 1200 gr/l.

e. The dredging process was easier to control at higher speeds over the bottom.

f. The "drag tension" decreased with increased speed over the bottom to the point where the hoist cable became slack at about 9 ft/sec. This is attributed to the planing effect of the dredging ladder in the water.

7. Effect of dredge pump speed and power:

No changes to the equipment were required for this test. It was accomplished by keeping the dredge pump controller on the lowest setting (325 rpm, 165 amps) and then the highest setting (410 rpm, 200 amps) in consecutive test runs. Tests were conducted with the dredge pump near the draghead at Marcus Hook Range at different speeds over the bottom.

The resulting test data was essentially the same as that listed in the preceding paragraph. However, the flow rate, density, and ease of control appeared somewhat improved at the higher pump speed.

It had been expected that the flow rate would be approximately linearly related to the power output of the dredging installation. This was not the case. It indicates that pump speed and power was not a controlling factor for the assemblage being tested when pumping mud.

8. Effect of gas removal system:

A simple gas removal system consisted of venting the dredge pump intake to the atmosphere. This was possible since the pressure at this point was at all times more than atmospheric (See Figure 26). It was accomplished by connecting the top of the cone at the dredge pump inlet to the 12" structural pipe above it with a 4" pipe as shown on Figure 15. The 12" pipe had a blind flange installed at the middle of the dredging ladder. The vent was completed by connecting a 2" line to the 12" line from below the blind flange to a point near the motor box.

This gas vent was tried at least once at Marcus Hook, Cherry Island and Tinicum Ranges, in Wilmington Harbor, and in the Schuylkill River. A 2" pipe connection from the eye of the dredge pump to the 4" pipe connection at the cone was also tried while at Marcus Hook. A "try" consisted of pressing a hand over the end of the 2" pipe for about two minutes to see if gas under pressure would accumulate below the hand while dredging. This gas accumulation was only significant in the Schuylkill River. It occurred in gushes and burned with a red flame about 3 feet long. The flame died out after a few seconds because either the flow of gas stopped momentarily or became great enough to drive water ahead of it and extinguish the flame. Performance in the Schuylkill River improved somewhat when this simple gas removal system was in use.

Poor dredge pump effluent densities were achieved in the Schuylkill River (1075 gr/l). It is believed that a significant limiting factor was the presence of gas, as the gas removal system in use only released a portion of the entrapped gas.

For details on gas in mud, see Para. V, 7.

9. Effect of force feeding draghead:

Force feeding of the draghead was attempted by using the forward motion of the dredge to scoop material into the draghead. An 18" deep scoop plate extending over the whole width of the 7 feet 5 inches wide draghead was installed vertically below the ladder in the horizontal position (See Figures 15 and 21). The three rows of grate openings aft of the scoop plate were blanked off. Tests were made principally at Marcus Hook, at various speeds over the bottom and with the dredge pump installed near the draghead operating at full speed.

Test results were practically the same as those recorded in Paragraph IV, 6, except that the average flow density was slightly lower and averaged 1185 gr/l. When the doors on top of the draghead were opened after the test, it was found that the aft end of the draghead was packed full of stiff mud.

This test is one of several tests performed on other dredges, all of which were designed to force material into the draghead by virtue of the forward motion of the vessel. None of these tests were successful.

10. Effect of draghead width:

Two draghead attachments were made for this test. They are shown on Figures 15, 19 and 20. The plain pipe inlet shown on Figure 19 differs from the plain pipe tried earlier in that it protruded approximately four feet out of the draghead. This was done to avoid (or, at least minimize) any effect of the relatively large draghead. Both attachments were made of 14" pipe and connected directly to the pump flange. The draghead (with two athwartship rows of grate openings open) together with these attachments constituted three draghead widths of 7'-5", 3'-0" and 1'-2". Tests were conducted in mud at Cherry Island Range at various speeds over the bottom, with the dredge pump installed near the draghead and operating at full speed.

Test results were essentially the same as those recorded in Paragraph IV, 6. However, the 3 feet wide funnel shaped intake pipe was somewhat easier to control than the other two widths. After each of the three widths tested it was found that the aft end of the Ambrose draghead was packed full of stiff mud.

These tests demonstrate that altering the width of the drag did not significally alter production in this assemblage when working in mud.

11. Effect of dredge pump size:

The dredge pump used was about the smallest commercially available pump for its size. The 34-inch impeller being used was the largest that would fit in this pump. The purpose of this test was to ascertain the performance of a smaller pump by testing a smaller impeller. A smaller pump has several obvious advantages in the exposed location near the draghead and should be possible because a pressure head exists at all times at its intake side.

The foregoing was discussed with the pump manufacturer and a 32" impeller was chosen for the test. To install this impeller, it was necessary to burn the intake cone off the 1½" plate at the draghead and weld it up again after the impeller change was made (Figure 15). Tests were made in mud at Cherry Island Range at various speeds over the bottom, while the pump was installed near the draghead and operating at full speed.

Test results showed no noticeable change in flow density between the two impellers tested. The results with the 34" impeller are listed in Paragraph IV, 6. The results with the 32" impeller are similar; however, the pump speed was 15 rpm higher, the current 20 amps lower, the discharge pressure 5 psi lower and the dredge pump velocity 3.5 ft/sec lower.

Essentially the same dredge pump density was obtained with both impellers. This is not considered conclusive because of the low dredge pump efficiency of the smaller impeller computed in Paragraph V, 4.

12. Comparison with Hopper Dredge COMBER in several areas:

Test loads were dredged by the COMBER in several areas where the Experimental Dredge had worked to obtain comparative production data. The Experimental Dredge was operated at various speeds over the bottom, with the dredge pump installed near the draghead and operating at full speed. The test data collected are similar to those listed in the table of Paragraph IV, 6, with the exception of the dredge pump effluent densities which are listed below. The test runs with the COMBER were performed under the strict control of the Dredge Master to achieve the best result. The COMBER did not retain all dredge pump effluent pumped since a by-pass exists which overflows 10% to 15% of the lighter part of the dredge pump effluent and some overflow is unavoidable after the hoppers are filled.

The following are the results obtained:

a. Marcus Hook Range, west side: This was the COMBER's regular assignment from December 1967 to August 1968 (except for two months). The area was chosen for a comparison test because it is the most prevelant shoal in the Delaware River. Like most silt shoals, it deteriorates while being dredged, that is, progressively lower dredge pump effluent densities are obtained. Toward the end of the assignment, the Experimental Dredge achieved an average flow density of 1150 gr/l and the COMBER 1130 gr/l.

b. Wilmington Harbor, centerline: This area was chosen for a test, because dredging in this area results in light density dredge pump effluent. The Experimental Dredge and the COMBER both achieved a dredge pump effluent density of approximately 1100 gr/l.

c. Schuylkill River, centerline: This area was chosen, because its shoal is known to contain a large amount of gas. The Experimental Dredge and the COMBER both achieved effluent density of approximately 1075 gr/l.

d. Tinicum Island, inside Buoy 4T: This area was chosen for a test because it was known that the bottom material had a high percentage of fine sand. The Experimental Dredge achieved a dredge pump effluent density of 1400 gr/l while the COMBER attained 1100 gr/l. The Experimental Dredge had the 3 foot wide funnel shaped inlet pipe installed in the draghead for this test.

V. EFFECTS AND ANALYSES OF MUD DREDGED

The following computes and discusses the more important engineering data resulting from dredging viscous mud. It explains some of the phenomena experienced.

1. Type of flow while dredging:

The flow pattern during dredging is normally turbulent. It was also turbulent during the experiments when handling a light density effluent. However, laminar flow was evident in this installation when handling approximately 1200 gr/l mud from Marcus Hook and Cherry Island ranges. The following analysis verifies that this flow pattern prevailed throughout the system with the pump near the draghead. A comparison of the Reynolds numbers for the flow from the 20" flume and the flow in the 12" piping verifies this. The Reynolds number is a criterion for the type of flow in a conduit. Flow is laminar below a value of 2100. The Reynolds number is frequently expressed as Velocity x Diameter/kinematic viscosity. For open flumes a value of four times the hydraulic radius is substituted for the diameter. The hydraulic radius is the cross-section of the area of the flow stream/the wetted perimeter.

It was observed that the flow pattern of the spoil issuing from the 20" flume into the cargo box was laminar. This is shown on Figure 23. Since the discharge area at this point is approximately equal to the area of the 12" pipe, the velocity must also be the same. The viscosity of the spoil is not known, but obviously it is the same throughout the system. Then, the Reynolds numbers for the two cross-sections considered differs only by the value "4 x hydraulic radius". In case of the 20" flume, this value is $4 \times 0.785/2 =$ approx. 1.6 feet. In this equation 0.785 is the cross-section of the flow stream and 2 its wetted perimeter. In case of the 12" pipe, the term "4 x hydraulic radius" equals its diameter or 1.0 foot. Since this value is smaller than the 1.6 feet above, the Reynolds number of the 12'' pipe is also smaller than the Reynolds number for the flow in the flume. This proves that the flow pattern in the 12'' pipe was laminar.

2. Friction head and pipe size.

The following average values were attained while dredging with the pump near the draghead at full pump speed (near 410 rpm) and average speeds over the bottom (near 5 ft/sec) at the west side of Marcus Hook and Cherry Island Ranges:

Flow velocity in 12'' pipe
13 ft/sec (from Fig. 29)
Pressure at pump discharge
40 psi (from data sheets)
Statis discharge head
56 feet (from measurement)
Specific gravity of mud
1.2 (from data sheets)

Then: The static discharge head = 56 x 1.2/2.31 = 29 psi and, based on a length of discharge line of 75 feet (actual length used because of laminar flow), the friction head in 100 feet of pipe = (40-29) x 2.31 x 100/75 = 34 feet of water, or 34/1.2 = 28.3 feet of mud. This friction head is unusually high for work in the Delaware River for the flow velocity involved. It is attributed to the extremely high viscosity of the 1200 gr/l mixture handled and the relatively small pipe size used in the experiment.

This significance of the pipe size becomes obvious when considering the Hagen-Poiseville formula cited in Paragraph V, 3. It indicates that, everything else being equal, a larger system must result in a lower friction head, since the term "pipe diameter squared" appears in the denominator. Conversely, assuming equal heads and velocities in the two pumping systems which differ only in pipe size the larger system will result in a higher dredge pump effluent density because of the reduced head loss provided a supply of mud remains available.

Turbulent flow prevailed while dredging sand with the Experimental Dredge. With this type flow, the Darcy-Weisbach formula is applicable in determining the friction head. This formula has the pipe diameter (to the first power) in the denominator. It is of interest to note that under these conditions the total head was slightly less and the dredge pump effluent density averaged 1400 gr/l. This is attributed to the relatively low viscosity of the sand-water mixture handled.

3. Viscosity and Reynolds number:

The well known Darcy-Weisbach formula is only applicable for turbulent flow. However, substituting 64/Reynolds number for the friction factor converts this formula to a form of the Hagen-Poiseville formula which is applicable for laminar flow and reads:

$$\text{Friction head} = \frac{32 \times L \times \nu \times V}{g \times D^2}$$

Where: L = Equivalent length
ν = Kinematic viscosity
V = Velocity
g = Gravitational acceleration
D = Pipe diameter

Since Paragraph V, 1 established that laminar flow prevailed while dredging mud, this formula can be rearranged and solved for kinematic viscosity using the dredge pump effluent velocity and friction head stated in Paragraph V, 2.

Then: Kinematic viscosity

= 28.3 x 32.16 x 1 x 1/32 x 100 x 13

= 0.0218 ft. squared/sec

= 20.3 cm squared/sec

Although it is realized that the mud dredged is a non-Newtonian fluid with its viscosity changing with shear rate, this kinematic viscosity is many times that normally encountered by hopper dredges dredging mud in the Delaware River. This can be used to determine the Reynolds number, which is

= Velocity x Pipe diameter/kinematic viscosity

= 13 x 1/0.0218

= 596

It is generally accepted that flow is laminar below a Reynolds number of 2,100. This confirms the finding in the foregoing that flow throughout the experiment was laminar when a mud mixture of 1200 gr/l density was pumped.

4. Dredge pump efficiency:

The following is based on the performance of the 32" impeller, since its operating speed agrees with that of Figure 28. Then, the following test data applies while dredging 1200 gr/l mud with the dredge pump near the draghead:

35 psi = Measured discharge head

30"Hg = Measured intake head

450 volts = Measured voltage (3-phase A.C.)

180 amps = Measured current

40 ft. = Measured pump discharge below waterline

44 ft. = Measured pump intake below waterline

1.2 = Computed dredge pump effluent specific gravity

9.5 ft/sec = Computed dredge pump effluent velocity

Based on these data:

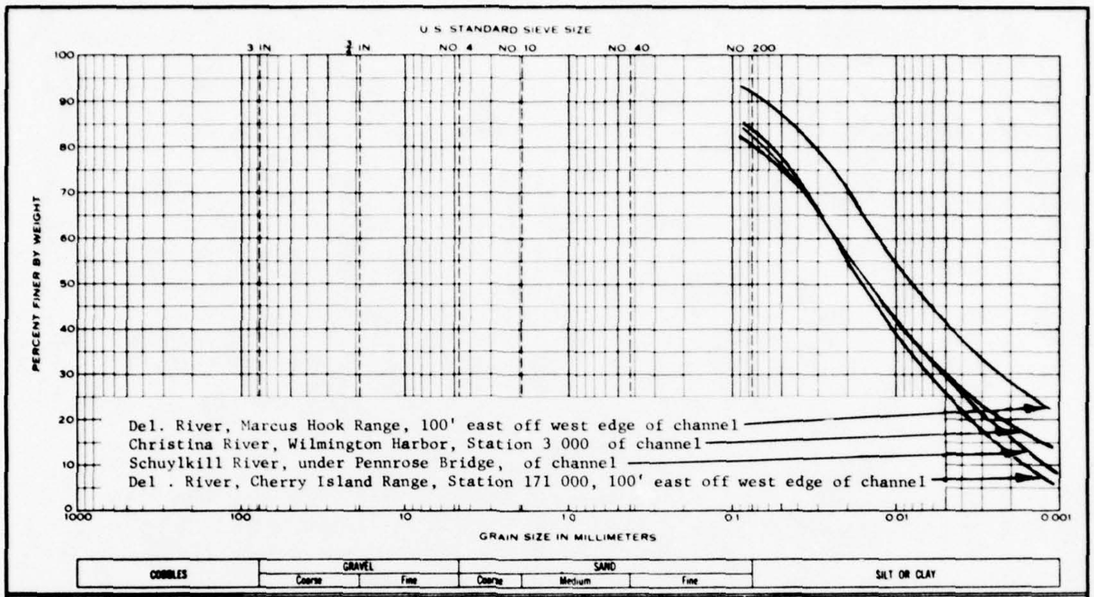
The total pump head = (Discharge head - Outside head of water) + (Entrance loss) + (Static head between measuring points) = (35 x 2.31 - 40) + (44 - 30 x 1.13) + (4 x 1.2 - 4) = 52 ft. of water, or 52/1.2 = 43.3 ft. of mud (neglecting velocity head due to velocity increase in dredge pump)

The pump output power = 9.5 x 0.785 x 62.4 x 1.2 x 43.3/550 = 44 HP (water horsepower)

Where: 0.785 = Pipe area in feet squared, 62.4 = Density of water in lbs/ft cubed, 43.3 = total pump head, and 550 = Constant.

The pump input power equals essentially the output power of the driving motor = 1.73 x 450 x 180 x 0.9 x 0.8/746 = 135 HP (Motor horsepower)

Where: 0.9 = Motor efficiency, 0.8 = Power factor, and 1.73 and 746 are constants.



Del. River, Marcus Hook Range, 100' east off west edge of channel
Christina River, Wilmington Harbor, Station 3 000 of channel
Schuylkill River, under Pennrose Bridge, of channel
Del . River, Cherry Island Range, Station 171 000, 100' east off west edge of channel

Sample No.	Elev or Depth	Classification	NatWC	LL	PL	PI	
		Maintenance Mud					

Project	Test Dredging
Area	See above
Boring No.	
Date	Nov. 68

GRADATION CURVES

ENG FORM 2087 (Translucent) (EM 1110-2-1803)

Fig. 30. Gradation Curves for Mud Handled.

The dredge pump efficiency in per cent = 100 x Power output/Power input = 100 x 44/135 = 33%.

Based on the 34'' impeller and the data in the center column of the table in Paragraph IV, 6, the total pump head = 50.0 ft. of mud, the water horsepower = 69.4 HP, the motor horsepower = 150 HP, and the efficiency 46%.

The total pump heads computed above are near the shut-off heads, since any attempt to increase them by lowering the draghead would stop the flow. These heads are appreciably lower than the shut-off heads established by the pump manufacturer for water.

5. In situ density gradient:

The dredging areas in Wilmington Harbor and Cherry Island Range are within 1,000 feet of each other and contain essentially the same type of mud (See Figure 30). Yet, an appreciable difference in dredge pump effluent density was noted in these two areas. To investigate the cause for the difference, and to obtain a typical in situ density gradient for the mud dredged, bottle and harpoon samples were obtained by a survey launch from both areas and also from Marcus Hook. The samples were taken at, above, and below the bounce-back depths of the echo sounder. The sampling locations were determined by sextant readings and the samples were secured by experienced personnel near low slack water. Subsequently, the densities of these samples were determined.

Analyzing the results, it was found that the vertical distance between samples of 1020 and 1280 gr/1 density was 3.0 feet in Wilmington Harbor and 4.5 feet at Cherry Island Range. From this it was concluded that with an average draghead immersion of two feet (See drag depth minus water depth on Figure 26) dredge pump effluent density of 1200 gr/1 may be considered in situ density. That is, essentially no dilution water was added to the mud dredged.

6. Material pick-up depth:

If it is assumed that the 3-feet wide draghead attachment discussed in Paragraph IV, 10 is the effective draghead width and 1200 gr/1 mud was dredged without dilution water, an acerage thickness of the mud layer picked up by the Experimental Dredge can be computed. This thickness = Quantity of material dredged/ Length of cut x Draghead width. Then, for very slow and high speeds over the ground with cut lengths of 800 feet and 4000 feet respectively, the relative limits of the cut depth range in mud seem to be approxiately as follows:

For 800 feet travel:

155 x 27/800 x 3 = 1.75 feet or

21 inches max. cut depth (approx.)

For 4000 feet travel:

155 x 27/4000 x 3 = 0.35 feet or

4 inches min. cut depth (approx.)

Assuming the in situ density of the sand bottom dredged with the Experimental Dredge with 2000 gr/l, the volume of the in situ density solids pumped = 120 (1400 - 1000) / (2000 - 1000) = 48 c.y.

This quantity can be used to compute the average cut depth, which is

48 x 27/600 x 3 = 0.72 feet or 9 inches.

Although any combination of mud and sand is possible, experience indicates that maintenance shoals are usually muds of 1200 to 1300 gr/1 and sands of 1900 to 2000 gr/1 density respectively.

7. Gas in mud:

It is customary to look at dredge spoil as a solid-water mixture. Although this is realistic for sand-water mixtures, it leads to errors in dredging mud. Here gas is present in varying amounts, which may appreciably affect the process. In other words, mud must be treated as a solid-water-gas mixture. Paragraph IV, 8 indicates that Schuylkill River mud contained appreciably more gas than the muds encountered in the other areas. But, even in those areas where gas was not liberated it was present and affected the operation adversely when the pump was not adjacent to the draghead. This becomes obvious when it is realized that the volume of gas in a conventional dredge pump installation has expanded about six times from what it was at the bottom. This figure is based on the fact that dredging is an isothermal process and therefore changes in gas volumes are inversely proportional to changes in absolute pressure. The latter are about (45/1.13) + 30 = 70 inches Hg at the river bottom and 30 - 18 = 12 inches Hg at the inlet of the dredge pump when the pump is located near the waterline. The significance of this gas expansion is confirmed by the fact that the Experimental Dredge could perform well at Marcus Hook without a gas removal system, while the COMBER's dredge pump effluent density dropped 100 gr/1 when its gas removal system was shut off in the same area.

The following was done to determine the amount and type of gas present in the mud:

a. An instrument used to measure entrained air in concrete known as "Press-Ur-Meter" and made by Concrete Specialties Co., Spokane, Wash., was filled with effluent from the Experimental Dredge at Marcus Hook and the gas content of a 1200 gr/1 sample was determined as being 4.5% by volume and at atmospheric pressure.

b. Mud samples from the Schuylkill River, Marcus Hook, Cherry Island and Wilmington Harbor were analyzed by "infrared spectroscopy" to determine the type of gases they contain. It was determined that the gases from all samples were mixtures of carbon dioxide and methane. No other gases were detected.

VI. DISCUSSION AND CONCLUSIONS

The main objective of the tests discussed in the foregoing was to determine the effects of dredge pump effluent density and flow rate by changes to, and rearrangements of, the major components of a conventional hydraulic dredging system and its mode of operation. The following summarizes and briefly discusses the more important conclusions reached while dredging maintenance mud.

1. From all the variables tested lowering of the dredge pump was the only alteration of equipment which caused a pronounced increase in dredge pump effluent densities. With the pump adjacent to the draghead, a maximum average dredge pump effluent density of 1200 gr/1 was attained. This increase in dredge pump effluent density is attributed to the smaller volume the gas in the mud occupies near the bottom.

2. Increasing the speed over the bottom up to 10 ft/sec caused a pronounced increase in flow rate without any adverse effect on dredge pump effluent density. The effluent velocities were 20 and 13 ft/sec at 10 and 6 ft/sec ground speeds, respectively, 6 ft/sec ground speed is averaged by the COMBER in the Delaware River and is the practical limit because of the available propulsion power and length of the shoals. The increase in effluent rate achieved in this manner is attributed to the greater supply of mud for the drag at the higher speed.

3. All other variables tested were largely ineffective on the test installation. This differed from conventional installations (dredge pump near the waterline) where the suction lift alone usually limits the dredging process. This latter limit is

extended by using a gas removal system. Lowering the dredge pump to the draghead further extends this limit with a resulting increase in flow density until the dredging process is restricted by other limits. These new limits are the total pump head, and/or the inability of the in situ material to flow to the drag without dilution water.

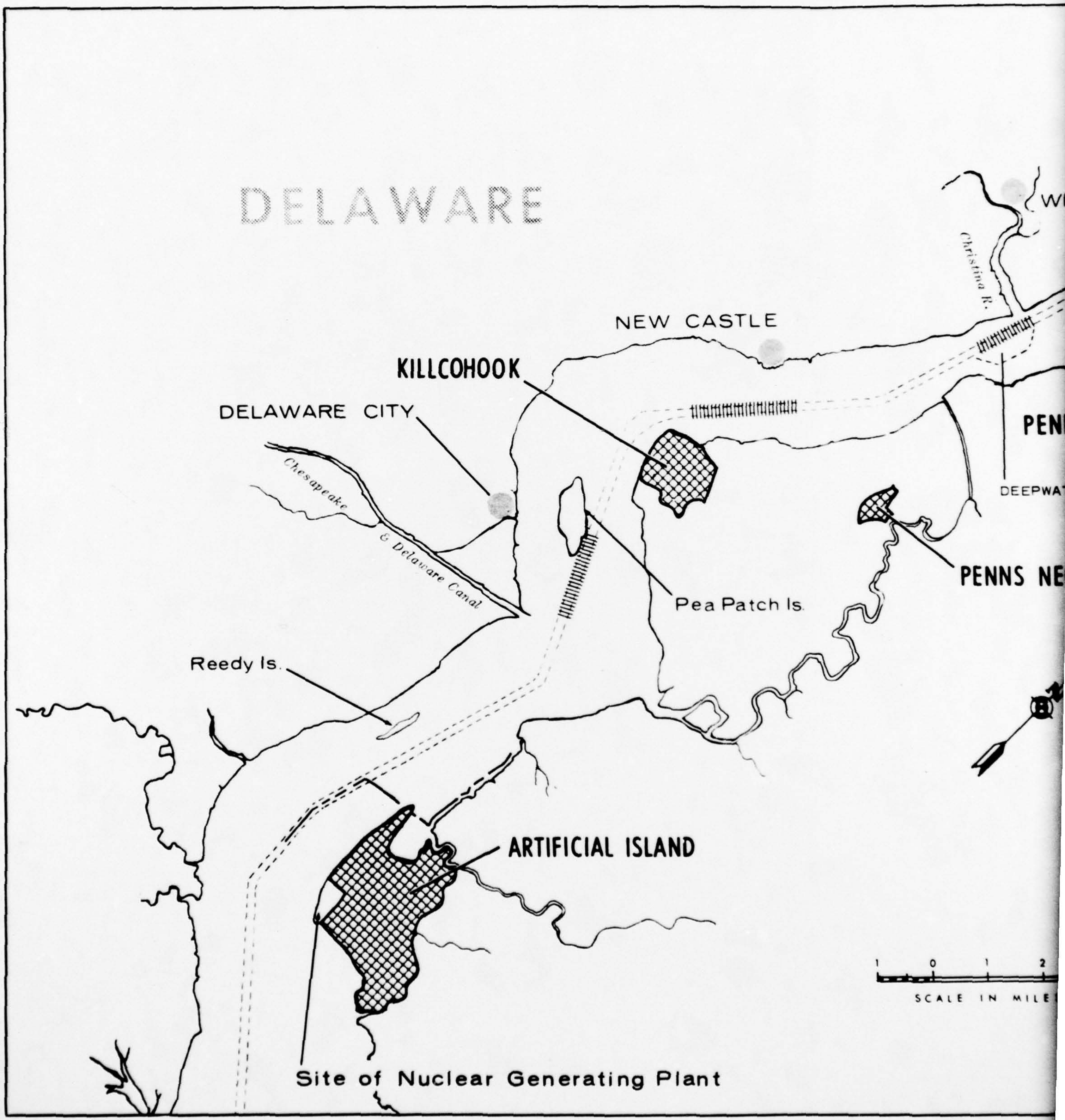
4. From the foregoing, it is concluded that it is advantageous to have the dredge pump adjacent to the draghead, since under this condition, the effluent densities attained were always equivalent to, or better than, those being produced by hopper dredge in the Delaware River. This is especially significant when considering that the latter have larger pumping installations and are equipped with gas removal systems, both of which tend to produce a denser effluent. In addition, the dredge pump near the draghead produced a steadier and more easily controlled flow when compared with pumps mounted in conventional fashion.

5. The dredging ladder of the Experimental Dredge, with the dredge pump near the draghead and the lubricating arrangement chosen for the dredge pump and line shaft bearings performed satisfactorily in all respects. A similar installation should perform well on an actual dredge, even when working continuously.

6. From all the draghead configurations tried, it was concluded that the shape of dragheads, while dredging mud, is of little consequence, as long as no part of its perimeter extends upward into the diluting water.

7. It is believed this study exhausts the dredging system. That is, the best densities and flow rates possible from the components of a hydraulic dredging system was obtained. Changes in equipment beyond pump location caused no variation. The densities attained agreed with the upper and lighter part of the shoal material and so consequently no dilution water was added. To dredge the lower and denser part of the shoal material without, or with less dilution water than now required, will only be achieved by deviation from the present conventional system. These deviations may consist of changing major components of the conventional system, such as placing two dredge pumps in series, or of abandoning the hydraulic system altogether in favor of a mechanical system such as a bucket chain.

8. The Experimental Dredge performed exceptionally well while dredging sand. (1400 gr/1 versus 1100 gr/1 customarily attained). However, the purpose of the study limited the evaluation essentially to the performance in mud.


DELAWARE
WI
Christina R.
NEW CASTLE
KILLCOHOOK
DELAWARE CITY
Chesapeake & Delaware Canal
PEN
DEEPWAT
Pea Patch Is.
PENNS NE
Reedy Is.
ARTIFICIAL ISLAND
Site of Nuclear Generating Plant
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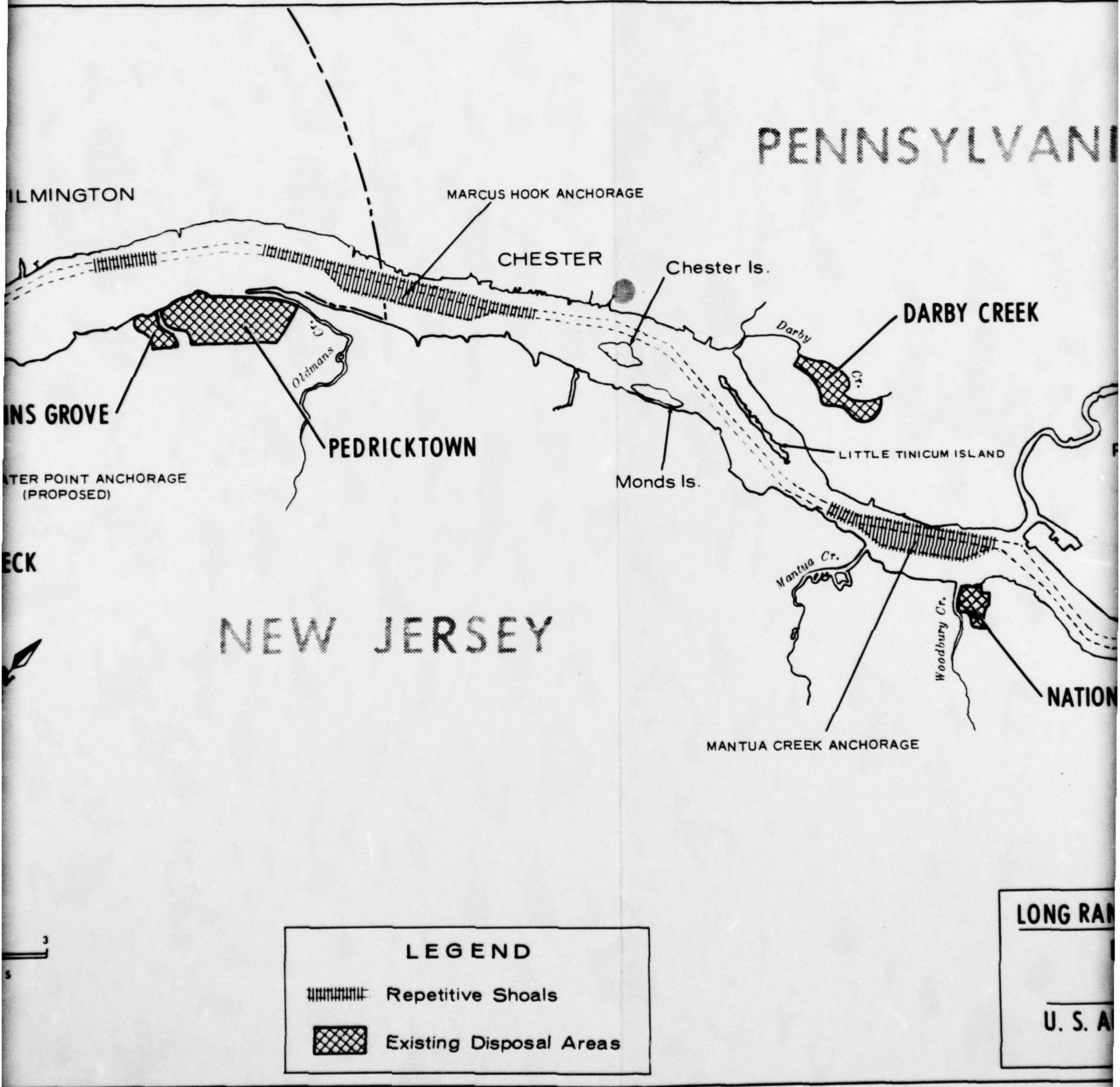
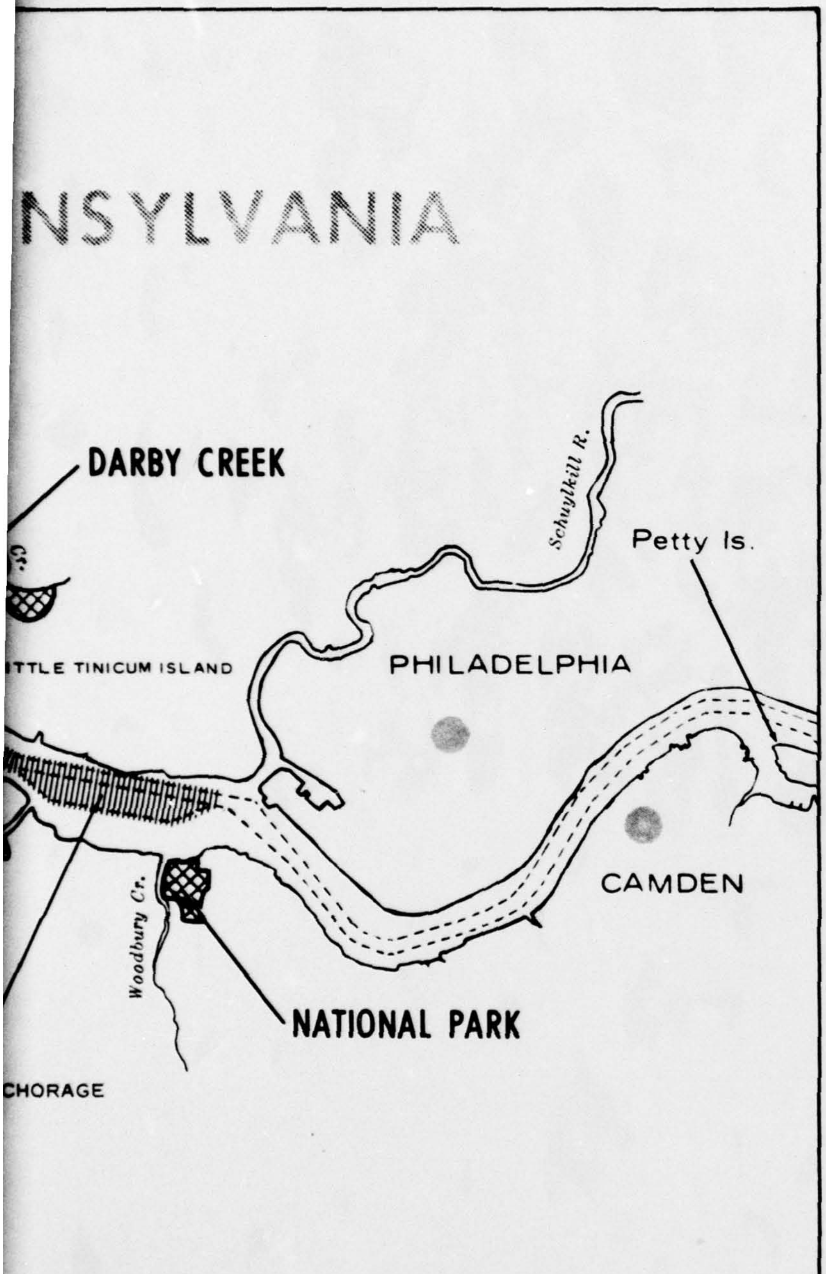
SCALE IN MILE


PENNSYLVANI
ILMINGTON
MARCUS HOOK ANCHORAGE
CHESTER
Chester Is.
DARBY CREEK
Darby Cr.
Oldmans Cr.
INS GROVE
PEDRICKTOWN
ATER POINT ANCHORAGE (PROPOSED)
LITTLE TINICUM ISLAND
Monds Is.
ECK
Mantua Cr.
Woodbury Cr.
NATION
MANTUA CREEK ANCHORAGE
NEW JERSEY
3
LEGEND
Repetitive Shoals
Existing Disposal Areas
LONG RAN
U. S. A

2

1



LONG RANGE SPOIL DISPOSAL STUDY

DELAWARE RIVER
MAJOR SHOALS

U. S. ARMY ENGINEER DISTRICT
PHILADELPHIA

PLATE 1